NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

CW Doppler Radar

Graduation Project
EE-400

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Raed Khliefat

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CHAPTER ONE

INTRODUCTION

Radar (Radio Detection and Ranging) is employed in many forms, from complex air defense networks to simple and altimeters. Before one can understand electronic warfare one must first know the principles of radar tracking. The emphasis in this tutorial will be placed on pulsed radars since they are the most commonly used. However, that only the techniques change, and the principles are the same. Basically, a fire control radar system consists of a transmitter, a receiver, an antenna system, a display device, and a computer capable of target tracking (predicting the location of the target at some future time based on its present flight parameters so that the radar can move itself always to point at the target). To perform this function, the radar must measure azimuth, elevation, and range and the rate of change of each. Radar determines angle information by using an antenna array to focus the transmitted signal into a well-defined beam.

When radar attempts to locate a target (scans a small sector of its total tracking envelope) the target receives a large number of pulses, each from a slightly different orientation of the antenna. Radar determines range to an object by the round trip time-of-flight (at the speed of light) of a transmitted pulse. The uncertainty in range is the distance that the transmitted pulse travels in a time equal to one-half the width of the pulse. The radar computer measures each pulse and generates a power plot in which the maximum point is called the power cancroids. The accuracy of the radar is a measure of its ability to locate the power cancroids and align its antenna so that the cancroids are on the antenna axis. Automatic Angle Tracking is accomplished by keeping the power cancroids centered on the antenna axis as the target moves. Radar beams will also be polarized. Polarization is the physical orientation of the E and H fields, which exist, in electromagnetic energy. For best efficiency, the transmitting and receiving antennae should have the same polarization.

The basic radiation source in radar is the high-powered transmitter. These are resonant cavities so that their primary frequency is determined by their physical size. Atmospheric transmission windows and the function of the radar determine selection of an operating frequency. The frequency determines an optimum antenna size, receiver input stages, antenna-receiver-transmitter connections (plumbing), and output power levels. That is, radar normally must operate at its natural resonance for optimum performance.

A simple Doppler radar sends out continuous sine wave rather than pluses. It uses the Doppler effects to detect the frequency change caused by a moving target and displays this as a relative velocity. Since transmission here is continuous, the circulator is used to provide insulation between the transmitter and reviver. Since transmission is continuous, it would be pointless to use duplexer. The insulation of a typical circulator Of the order of 30dB, so that some of transmitted signal leaks into the receiver. The signal can be mixed in the detector with returns from the target, and the differences are the Doppler frequency. Being generally in the audio range in most Doppler application, the detector output can be amplified with an audio amplifier before being applied to a frequency counter. The counter is a normal one, except that its output is shown as kilometers or miles per hour, rather than the actual frequency in hertz.

The main disadvantage of the system as simple as this is its lack of sensitivity. The type of diode detector that used to accommodate the high incoming frequency is not a very good device at the audio output frequency, because of the modulation noise, which it exhibits at low frequencies. A small portion of the transmitter output is mixed with the output at a local oscillator, and the sum is fed to the receiver mixer. This also receives the Doppler-shift signal from its antenna and produces an output differences that is typically 30 MHZ, plus or minus the Doppler frequency. The output of this mixer is amplified and demodulated again, and the signal from the detector is just the Doppler frequency. Its sign is lost, so that it is not possible to tell whether the target is approaching or receding. The overall receiver system is rather similar to the super heterodyne. Extra sensitivity is provided by the lowered noise, because the output of the diode mixer is now in the vicinity of 30MHZ, at which FM noise has disappeared separate receiving and transmitter antennas have been show, although this arrangement is not compulsory. A circulator could be used as in the simpler set.

Separate antennas are used to increase the isolation between the transmitter and receiver sections of the radar, especially since there is no longer any need or a small portion of the transmitter output to leak into the receiver mixer, as there was in the simpler set. To the contrary, such leakage is highly undesirable, because it brings with it the hum and noise from the transmitter and thus degrades the receiver performance .the problem of isolation is the main determine factor, rather than any other single consideration in the limiting of the transmitter output power, as consequences, the CW power from such radar seldom exceeds 100 W and is often very much less. Gunn or IMPATT diodes, or for the largest powers.

CW magnetrons are used as power oscillator in the transmitter. They operate at much the same frequencies as in pulsed. Advantages, applications and limitations CW Doppler Radar is capable of given accurate measurements of relative velocities, using low transmitting powers simple circuitry, low power consumption and equipment whose size is much smaller then that of comparable pulsed equipment. It is unaffected by presence of stationary targets, which it disregards in much the same manner as MTI pulsed radar. It can operate theoretically down to zero range. Because, in pulsed system, the receiver is ON at all times. It is also capable of measuring at large range of target speeds quickly and accurately. With some tradition circuitry. CW radar can even measure the direction of the target, in addition to it speed.

Before the radar begins to wonder why pulsed is still used in the majority of equipment, it must be pointed out that CW Doppler radar has some disadvantages also. In the first place, it is limited in the maximum power it transmits, and this naturally places a limit on its maximum range. Second, it is rather easily confused when, the presence of a large number of targets. Doppler radar is incapable of indicating the range of the target. It can only show its velocity, because the transmitted signal is un-modulated. The receiver can not sense with a particular cycle of oscillations is being received at moment, and therefore cannot tell how long ago this particular cycle was transmitted, so that range cannot be measured.

CW Doppler radar uses the Doppler Effect to extract information on targets radial velocity. The magnitude of the Doppler shift is related to the velocity of target in a straight line between the target and the aerial. A high value for the Doppler shift indicates a high target velocity. In practice it is the velocity of a target we wish to find, so we work the other way round from the measured value for the Doppler shift and the other known factors. A signal having wavelength lambda is received by an observer in relative motion at radial velocity V with respect to the source as having a frequency shifted by an amount V/lambda from the transmitted frequency.

Where an accurate measurement of the Doppler frequency is needed, continuous wave (CW) radars are used. Such radars do not provide any information about target range. If the relative frequency of the radar and target is not zero, another frequency difference, or beat, will superimpose itself on top of the frequency difference just discussed, because of the Doppler frequency shift. However the average frequency difference will be constant and due the time difference between the sending and return of a particular cycle of the signal. Thus correct height measurements can still be made on the basis of the average frequency difference. The beat superimposed on this difference can now be used, as with ordinary Doppler radar to measure velocity (in this case) the aircraft, when due allowance has been made for the slant range.

The main idea of each chapter in my graduation project is as follows:

CH.1- Determine in how many forms can radar be employed specifically the CW Doppler radar.

CH. 2- Goes through radar generally and the most important components of it.

CH.3- Clarifies the basics of CW Doppler radar.

CH. 4- Contains some applications of CW Doppler radar.

CHAPTER TWO

RADAR SYSTEM

2.1 Radar Fundamentals

In most cases, basic radar operates by generating pulses of radio frequency energy and transmitting these pulses via a directional antenna. When a pulse impinges on a object in its path, a small portion of the energy is reflected back to the antenna. The radar is in the receive mode in between the transmitted pulses, and receives the reflected pulse if it is strong enough. The radar indicates the range to the object as a function of the elapsed time of the pulse traveling to the object and returning. The radar indicates the direction of the object by the direction of the antenna at the time the reflected pulse was received.

The "radar equation" mathematically describes the process and may be used to determine maximum range as a function of the pulse width (PW) and the pulse repetition rate (PRR). In most cases, narrow pulses with a high PRR are used for short-range, high-resolution systems, while wide PW's with a low PRR may be used for long-range search.

In general, a higher gain (larger aperture) antenna will give better angular resolution, and a narrower pulse width will give better range resolution. Changing the parameters of radars to satisfy a particular mission requires radar designers to have a variety of frequencies to choose from so that the system can be optimized for the mission and the radar platform.

2.2 Target Tracking Radars (TTR)

Before one can understand electronic warfare one must first know the principles of radar tracking. The emphasis in this tutorial will be placed on pulsed radars since they are the most commonly used. (Continuous wave (CW) radars are described in section 2.7.2; however, that only the techniques change, and the principles are the same). Basically, a fire control radar system consists of a transmitter, a receiver, an antenna system, a display device, and a computer capable of target tracking (predicting the location of the target at some future time based on its present flight parameters so that the radar can move itself always to point at the target). To `perform this function, the radar must measure azimuth, elevation, and range and the rate of change of each. (See figure 2.1).

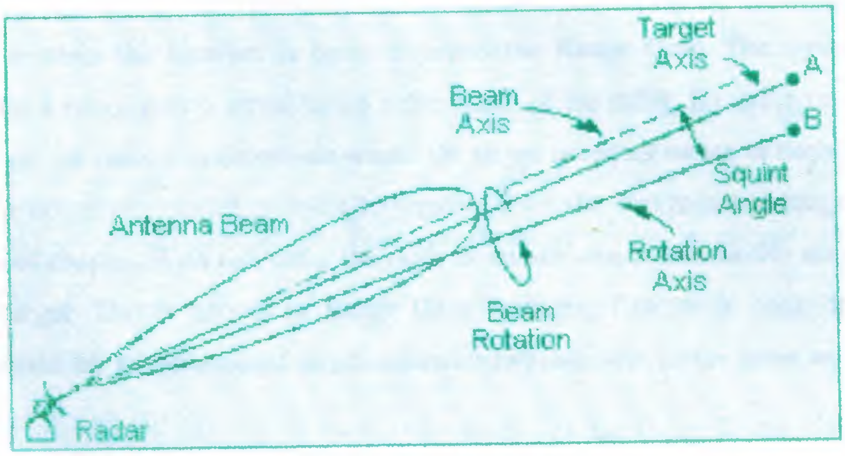

Figure 2.1. Movement of the Radar Beam to Determine Angular Location

2.2.1 Range

The transmitter sends out a high-energy signal, which is reflected, back to the radar whenever it strikes a reflecting object. The amount of energy reflected by an object depends on its physical size and reflectivity, the two parameters which determine the radar cross section (RCS) of an object. When the RCS of the smallest object radar wishes to track and the maximum range to which track is required are known, the receiver sensitivity and required transmitter power can be determined.

Radar determines range to an object by the round trip time-of-flight (at the speed of light) of a transmitted pulse. The uncertainty in range is the distance that the transmitted pulse travels in a time equal to one-half the width of the pulse. Thus, time and range are identical to radar. For a TTR, the weapon associated with that radar determines the maximum range and range resolution. These factors all interact as follows: the transmitter must pulse as often as possible so that the maximum average power is returned to the receiver, but it cannot pulse faster than the round-trip time to a target at the maximum range of the weapon and the pulse-width must locate the target within the accuracy and warhead size of the weapon.

2.2.1.1 Range Tracking

A TTR receives initial range information from assisting radar as discussed later in the tutorial. Receiver signal-to-noise ratio can be greatly improved by only "opening" the receiver input circuitry when a target echo is expected. This is called "range gating" and the period when the receiver is open is called the Range Gate. The optimum time interval for a range gate is equal to the pulse-width of the radar. By using two adjacent range gates, the radar can determine where the target is (equal return in both gates). As the return becomes unequal in these two gates, the radar can measure range rate and direction of change. With this data, the radar computer can automatically range track a moving target. This is known as Range Gate Tracking. Automatic range tracking is accomplished by keeping equal target return in two adjacent range gates as the target moves.

2.2.1.2 Range Jamming

If the radar pulsed at twice the rate of the example above, a target at 40 nautical miles would reflect two pulses 500 microseconds and two targets would appear – one at 20 nm and one at 40 nm – so that range information is un-reliable.

This is the most common form of ECM – for each pulse of the radar, send back one or more pulses from a target carried transmitter to destroy range data. If the ECM pulse repetition rate (PPR) is properly selected, the radar will "see" and display a continuous chain of targets along the radial from the radar to the true target and beyond. A long line of targets generates a continuous chain of undesirable pulses in the receiver (e.g., noise). Time and distance are the same for radar; these noise pulses need not be physically removed from the target but can be generated on board. This is known as noise jamming sending random, high rate false target echoes to the radar. (See figure 2.2). If the radar is multiple frequency (RF) or there are several different radars in the area, noise can be generated at all frequencies by "sweeping" the frequency of the noise pulses through all the known frequencies at a rate at least equal to or faster than the pulse rates of the radars.

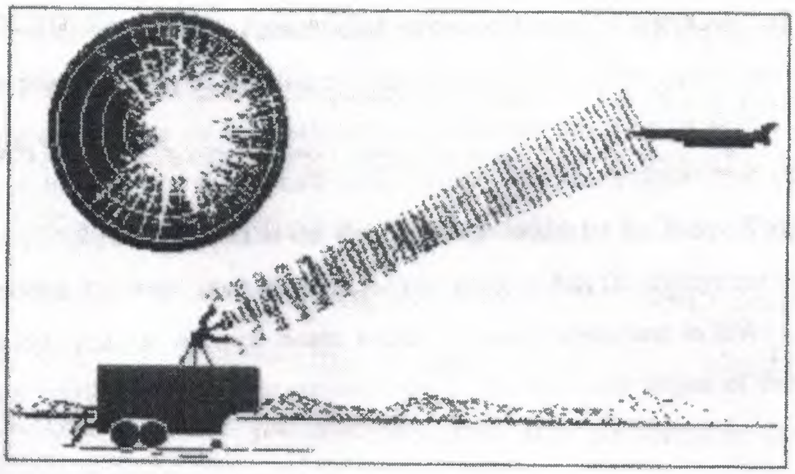

Figure 2.2 Example of Range Jamming

The target is generating a pulse train whose PRF is selected to provide a false target return in every range resolution cell of the radar, thereby denying range information.

2.2.2 Angle

2.2.2.1 Beam width

Radar determines angle information by using an antenna array to focus the transmitted signal into a well-defined beam. Due to the property of antenna reciprocity, signals will be received from the same area defined by the transmitted beam; a directional transmitter is a directional receiver. When an antenna focuses a beam, it produces a main lobe and numerous side lobes; the more directional the antenna, the greater the number of side lobes. In a perfect antenna, the size of the main lobe is

$$Aw/s \tag{2.1}$$

where

A Is the angle (in radians),

w Is the transmitter wavelength and

s Is a geometrical factor determined by the physical size and shape of the antenna.

For a given frequency, the larger the antenna, the smaller the main lobe. This formula defines the entire main lobe (beam) size whose energy distribution has a central maximum and falls to zero at the edges. The points at which the power fall to 0.707 of the maximum are known as the half-power points and the angular size of the beam between these half-known as the half-power points and the angular size of the beam between these half-power points is the defined beam width of the radar. This definition is always understood when discussing radar parameters, but the difference between the full beam width and the defined beam width becomes important in EW. Outside the defined beam width the power drops very rapidly to the outer edges of the full beam width.

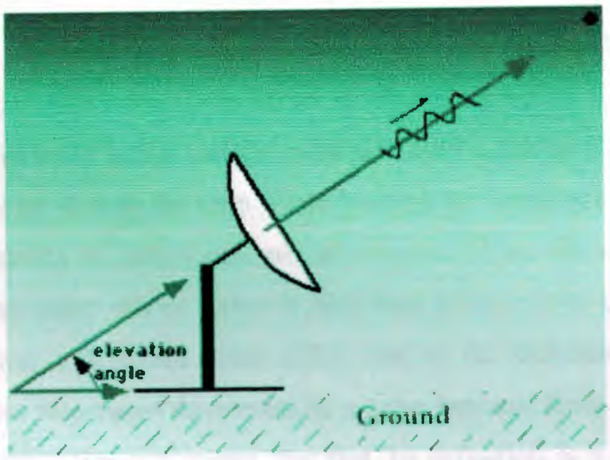

Figure 2.3 The beam with respect to the ground

2.2.2.2 Polarization

Radar beams will also be polarized. Polarization is the physical orientation of the E and H fields, which exist, in electromagnetic energy. For best efficiency, the transmitting and receiving antenna should have the same polarization.

2.2.2.3 Angle Tracking

When radar attempts to locate a target (scans a small sector of its total tracking envelope) the target receives a large number of pulses, each from a slightly different orientation of the antenna. The radar computer measures each pulse and generates a power plot in which the maximum point is called the power cancroids.

The accuracy of the radar is a measure of its ability to locate to locate the power cancroids and align its antenna so that the cancroids are on the antenna axis. Automatic Angle tracking is accomplished by keeping the power cancroids centered on the antenna axis as the target moves. To track the cancroids of power, the radar must "look" at antenna angles where there is no return from the target – it must look where the target is not. This looking is also called scanning and can be the same scan used for acquiring (locating) the target as in track-while-scan (TWS) radar. Note that this implies that for best tracking the beam width should be larger than the target so that no target exists in adjacent beam widths.

If the target is bigger the beam width of the radar, the power return will be about equal in several antenna orientation so that the power cancroids will be broad in angle and thus degrade tracking accuracy. If the target is much larger than the beam width, the power cancroids will be so broad that the radar will not be able to track but instead will "walk" over the target due to the scan while looking for some point of higher return. Resolution is the ability to distinguish multiple targets. When the computer generates the power plot, any pulse whose value is less than 0.707 of the power cancroids is assumed to be from a different beam-width due to the definition of beam-width. Therefore, to resolve two target there must be a point between them where the returned power is down to the half-power points. But that, by definition, is a separation equal to the beam-width of the radar. The resolution cell of the radar, then, is the solid volume described by one beam-width and the range resolution; multiple targets within one cell will appear as one target whose power cancroids will be located somewhere between all the targets to the accuracy of the radar.

Some radar system use separate, large-beamed transmitters for Azimuth (Az) and Elevation (El) tracking. This scheme allows the system to track one-power cancroids while scanning (TWS) its full acquisition sector. The resolution for such a dual beam system is often given as the inter-section of the smallest dimension of each beam, but this is not to be confused with the resolution cell. For a dual beam TWS system, each transmitter has cell in which the power cancroids of the target or targets will be located to within one beam-width. The TWS computer can then locate the two power cancroids to within the size of the intersecting area of the two beams.

This difference between the computed resolution (which is often the published resolution) and the resolution can be important to ECM tactics. The two beams, due to their different physical orientations, may receive differing amounts of jamming. Since every radar requires three coordinates for accurate tracking – Az, El, and range – jamming only one beam can be useful if ECM resources become limited.

2.2.2.4 Angle Jamming

Due to the directional nature of the receiving antenna, angle jamming by target carried noise transmitters is not possible since the jammer will only serve to highlight the target like a microwave beacon. Side-lobe jamming is possible from transmitters not carried on the target if these transmitters have enough power to overcome the side-lobe attenuation designed into the antenna. For example, if the first side- lobe is 16dB down from the "main-bang", the jammer must be capable of returning 16dB more power to the radar than the target normally returns. Side-lobes are spaced about one beam-with apart, but since the computer and display are synchronized to the antenna, side-lobe jamming actually creates a false target in the main lobe of the radar. If side-lobe penetration is successful, range jamming can be performed by noise as already discussed. A highly reflective (large RCS) target can cause side-lobe return in the main beam of the radar. That is, if the return from the target when it is illuminated by the side-lobes can overcome side-lobe attenuation, the radar will "see" false targets due to the synchronization accountability, which radars must use. This effect causes the target to appear larger than its actual physical size. Chaff clouds have been observed to create this "side-lobe jamming".

2.2.2.5 TTR Summary

To summarize to this point, the important concepts for RWR designers are: Determination of unambiguous range places stringent PRF requirements on the radar. Antenna size is inversely proportional at to the radar frequency. Since mobility is a prime consideration for air defense systems, most threat radars will be in the higher frequency bands. High accuracy target location requires small-transmitted beams and narrow pulse widths. These small beams must search an angular segment when first acquiring a target. These beams must also "look where the target is not" in order to track the target. These two effects are called Scan. Determination of angle information/error requires well-defined scan patterns. Best radar reception requires proper antennae polarization.

2.3 Radar Developments

Radar as a means of detection has been around for over 60 years, and although technology has become immensely more sophisticated than it was in the 1930's, the basic requirement remains the same—to measure the range, bearing, and other attributes of a target. Regardless of whether the system is land-based, ship borne, airborne, or space borne, this remains true since whatever the target may be, aircraft, ship, land vehicles, pedestrians, land masses, precipitation, oceans—all provide returns of the transmitted radar energy. What have changed dramatically is the system design, the method and speed of processing the return radar signals, the amount of information which can be obtained, and the way that the information is displayed to the operator. The key to modern radar systems is the digital computer and its data processing capability which can extract a vast amount of information from the raw radar signals and present this information in a variety of graphic and alphanumeric ways on displays as well as feeding it direct to weapon systems. It also enables the systems to carry out many more tasks such as target tracking and identification. In addition, modern signal processors provide adaptive operation by matching the waveform to the environment in which the radar is operating.

Much of the development effort over the past 50 years has been aimed at a number of operational requirements: improvements in the extraction of return signals from the background of noise, provision of more information to the operator, improvement of displays, and increased automation. Other developments have responded to the increasing operational requirements for radars to operate in a hostile electromagnetic environment. It is no longer enough to provide only bearing and range information; to this must be added altitude information, the ability to track a large number of moving targets, including airborne targets at supersonic and hypersonic speeds and to carry out normal surveillance at the same time. The latest ship borne surveillance and tracking radars, and some land-based systems, are designed to allocate the threat priority to incoming targets and guide weapons against them on this basis. Many types of radar are specifically designed for fire control of missiles and guns, and also for use in missile guidance and homing systems, which entails packing the system into a very small space. In the airborne role, systems have to be packaged into a relatively small space with units sometimes scattered around the airborne vehicle.

Radars have seen significant use in the Earth exploration-satellite service (EESS) especially with the deployment of airborne and space borne synthetic aperture radars (SAR's). Significant contributions in the areas of Earth observations, assisting in natural resource monitoring, hazard monitoring, and other global benefits can be attributed in part to the use of radars. The general categories of the active space borne sensors used in the EESS include SAR's, altimeters, scattero-meters, precipitation, and cloud profile radars.

2.4 Radar Propagation Limitations

There are numerous radio frequency bands allocated to support radar operations in the United States. TABLE 1 in page 82 presents the broad categories of the radio frequency spectrum and why geophysical and mechanical limitations make one region of the spectrum more attractive for a particular radar application. These limitations are some of the reasons why operational compromises are necessary for today's multi-role, multi-function radars.

2.5 Radar Parameters Used In RWR

2.5.1 Frequency

The basic radiation source in radar is the high-powered transmitter. These are resonant cavities so that their primary frequency is determined by their physical size. For a given source (usually magnetrons or klystrons), slight variations in their center frequency or operation at harmonics are possible, but these variants reduce the power output of the radar set. The frequency (RF) of radar is that sinusoidal wave chain generated by the transmitter in its "free-running" state. In pulse radar, the output is turned off/on to generate pulse trains; each pulse in the train has the RF of the transmitter. That is, each pulse is a wave packet of a frequency equal to that of the transmitter. Atmospheric transmission windows and the function of the radar determine selection of an operating frequency. The frequency determines an optimum antenna size, receiver input stages, antenna-receiver-transmitter connections (plumbing), and output power levels. That is, radar normally must operate at its natural resonance for optimum performance; so-called frequency agile radar operates within the normal tuning range (about the fundamental) of the transmitter or they switch harmonics. Both techniques require time to accomplish and degrade performance of the radar so that pulse-to-pulse frequency agility is more theoretical than practical. Frequency agility is commonly credited to a radar system, but it normally means that several frequencies are available; once the radar is tracking, the frequency must remain almost fixed. Threat radars can be characterized by their frequencies – threat radar implies high frequency (2-40 GHz) – for the reasons previously discussed. As state-of-the-art improves, the threat frequencies go higher. At the present time, an RWR need only consider the frequency regime of about 2-20 GHz.

2.5.2 pulse width

Range resolution is at best one-half the distance that the pulse travels in a time equal to the pulse-width. This limitation is imposed by nature. Threat radars must be able to resolve multiple targets and targets/jamming. Thus, threat radars can be characterized by short pulse widths:

$$T_r = S_{pw}, \tag{2.2}$$

where

T_r Is Threat radar.

S_{pw} Is short pulse-width

The pulse travels about 1000 feet per microsecond; weapon warhead size reduction requires minimum pulse widths. State-of-the-art and signal-to-noise ratios determine minimum pulse-width. An RWR, then, need normally concentrate on pulse-width regimes within the range:

$0.1 micro\sec ond < PW < 1 micro\sec ond$

Radars whose only functions are initial detection and sector location of a target are called Early Warning, Search, or Acquisition radars. Since range resolution is not a requirement (but high average power is), the pulse widths of these radars are much longer. Theoretical analysis or field surveys will support the generalization:

$0.1ms < PW < 1.5ms = Threat \ \ Radar$

$PW > 1.5ms = Non - Threat \ \ Radar$

Since threat radars are required to have narrow beam-widths, many TTRs have acquisition modes of operation for initial location (acquiring) the target. Though these modes may have pulse widths (and scans), which violate the above rule, they should not be confused with true Acquisition radar.

2.5.3 Pulse Repetition Frequency

Radar computes range to a target by measuring the elapsed time between pulse transmittal and target return reception. For unambiguous range measurements, no more than one pulse should be received from the target for each pulse transmitted by the radar. Thus, the maximum required range of the radar determines the maximum pulse rate of the radar.

Two interesting corollaries to the maximum unambiguous range condition are:

1- High PRF radar is a short-range tracker.
2- Short-range weapons have high PRF radars.

Range jamming of a radar is easily accomplished by repeater jammers onboard the target aircraft. For each pulse received, the repeater sends back one or more pulse to cause the radar computer to calculate incorrect range. Since the target pulses have the same PRF as the transmitted pulses, the radar can use a PRF filter to receive only that rate. This requires the repeater jammer signal processor to measure the incoming PRF so that the proper jamming rate is used.

2.5.4 Missile Guidance

Guided Missiles are not guided after a target; they do not pursue or chase an aircraft. Instead, the fire control computer predicts an intercept point on some future part of the target flight path based on the known flight parameters from the target tracking radar (TTR) and the known maneuverable envelopes of both the target and the missile. Missiles are like guns in that both are fired at a "lead-angle" point. The missile is accelerated (boosted) for the brief initial phase of its flight after which it can never again speed up – it is accelerated toward the predicted intercept point after which it is only capable of slight course corrections to keep it centered on the intercept point.

2.5.4.1 Command Guidance

For a guided missile to intercept its target, it must know at all times where the intercept point is in relation to the missile itself. The simplest method for the missile is a separate transmitter, located at or near the TTR, which sends coded guidance commands (fly left, fly up, etc.) to the missile. That is, the missile is radio controlled just as are model airplanes. This approach has the advantage of cheap expendable (the missile) and a guidance signal (the "up-link") almost immune to target jamming since the missile receiving antenna can be highly directional, aft-looking which allows guidance of the missile by manual mode and optical target tracking when the primary tracker is jammed or otherwise inoperative. It has the serious disadvantage that the ground site must track the missile in order to generate the uplink (error correction) commands; as the missile and target approach the intercept point the missile tracker (the MTR) must point directly at the target and hence is highly susceptible to any jamming source on the target. A second weakness of this system is that since the missile itself never sees the target, some sort of self-fusing device must be carried on the missile to reduce miss distance. Therefore, this system is vulnerable to countermeasures at three points (1) the TTR, (2) the MTR, and (3) the fuse.

2.5.4.2 Homing Guidance

A variation of command guidance is widely deployed. The MTR is replaced by a high power continuous wave illuminator (CWI) radar, which is slaved, and bore-sited to the TTR. The missile homes on the Doppler return from the target. This approach is still vulnerable in three places; the major difference is that no guidance commands are transmitted. Since the CWI is not an MTR, RWR terminology uses Missile Guidance Radar (MGR) to designate all radars used by an RWR to resolve identifications.

2.5.4.3 Beam Rider Guidance

The third method of guidance is the "beam rider" in which the SAM flies up the beam of the TTR. An onboard flight computer keeps the missile centered in the tracking beam by use of aft-looking antennae. Since a target-tracking beam must be quite small to ensure track accuracy, the ground site normally uses broad-beamed, low-power radar to "capture" the missile during the initial flight stage and guide it into the tracking beam. (This system requires the missile to be in a constant turn as it flies up the tracking beam to the target – a maneuver that becomes quite severe during the terminal flight stage and may exceed the physical limitations of the missile, particularly if the target "jinks"). The capture beam is immune to target jamming since it has no receiver and the missile antennae can be highly directional aft. Miss distance improvement of this system also requires an onboard fuzing device. Thus, this approach simplifies the ground site by making the expendable more costly and it has fewer jamming points: (1) the TTR and (2) the fuse. The most serious disadvantage to beam riding is that the TTR must be on the air for missile guidance, even if tracking is accomplished by alternate means—no TTR, no guided missile.

2.5.4.4 Fuse Jamming

Both command guidance and beam riders are susceptible to tracking radar and fuse jamming. The simplest fuse is the radar proximity type, which sends out a rather broad-beamed signal and measures the power in the target echoes. For a given target size and fuse, transmitter power returned from the target when the missile is within the kill radius of the warhead can be well calculated. By using a simple threshold detector in the fuse receiver the warhead is detonated when the kill radius is reached.

Making the target return much larger than normal so that the warhead is detonated prematurely, outside the kill radius can jam this system. In countermeasures terminology, fuse jamming is an "end game reaction" – a last ditch attempt. End game can be avoided in both these guidance systems if the tracking radars can be defeated either completely or by accuracy degradation. Most ECM systems are dedicated to the track radars since target carried fuse jammer transmitters can act as fuse homing devices.

2.5.4.5 Missile Guidance Correlation

Of the guidance methods, command guidance is traditionally the most commonly encountered in a threat scenario. In the case of pulsed TTR and MGR, it should be noted that synchronization of the two radars and the missile correction commands requires that some relationship exist between the PRF of both radars. Thus, it is possible in the case of an all-pulse system to determine if a TTR has entered the missile launch (ML) state by testing time correlation between the TTR and MGR pulse trains. For an RWR to detect the ML state on a homing guidance missile system, the CWI must be received. This detection requires a super-heterodyne receiver input to the RWR. On a pure CW system, microwave detection of an ML state may not be possible. Determining ML from the proximity fuse signal is questionable since fuse power is so low that no real warning will be obtained. That is, fuse power is 100-200 watts broad-beamed. Detection of a Mach 2(2000 feet per second) missile at one-half mile would give a one to two second warning. The aircrew would only be able to "die tense".

One of the most useful features of radar is the ability of radar set to continuously predict the next location of its target from the information being received from the target and to align itself to continuously point at that predicted location. When this is occurring, the radar set is said to be "tracking the target". To make this prediction, the radar measures the returned target power from several positions slightly offset from the target as well as the power returned directly from the target. That is, to track a track a target, the radar must also "look" where the target is not. When the returned power moves into one of these offset locations, the radar can say that the target has moved; the elapsed time between looks tells the radar how fast the target is moving.

This movement of the radar beam around the target location is called the "Scan pattern" or the "Scan" of the radar. Several types are shown in Figures 2.4, 2.5, 2.6, 2.7 and 2.8.

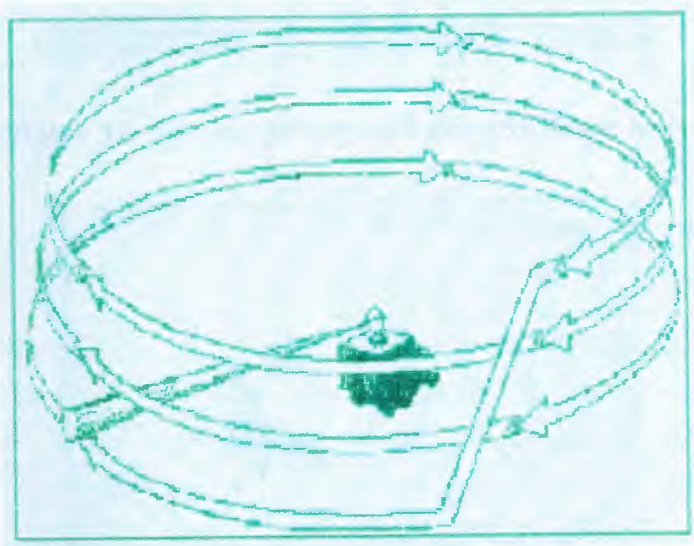

Figure 2.4 Radar System Using Helical Scan with Pencil Beam

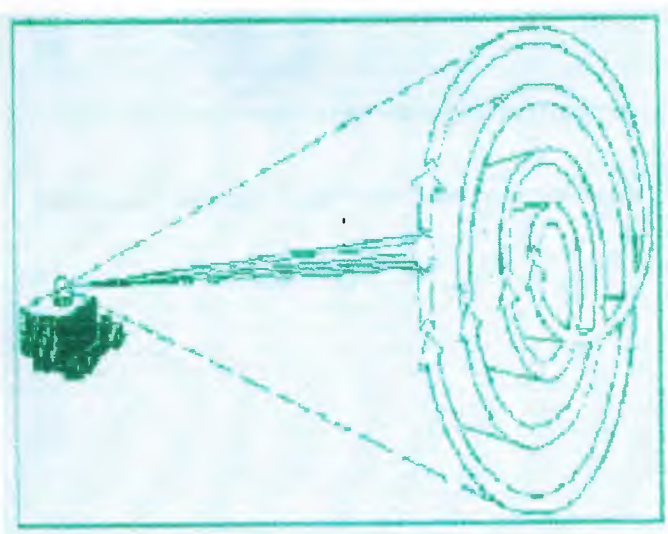

Figure 2.5 Radar Using Spiral Scan with Pencil Beam

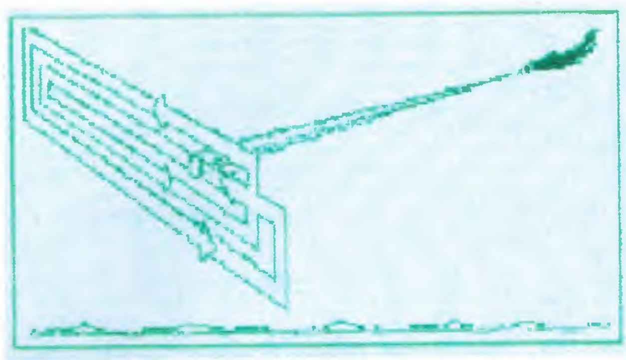

Figure 2.6 Airborne Intercepted Radar with Raster Scan

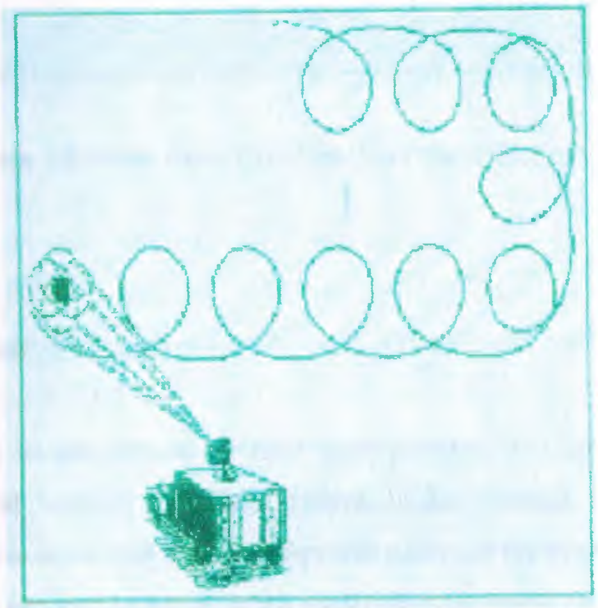

Figure 2.7 Ground Radar with palmer-raster Scan

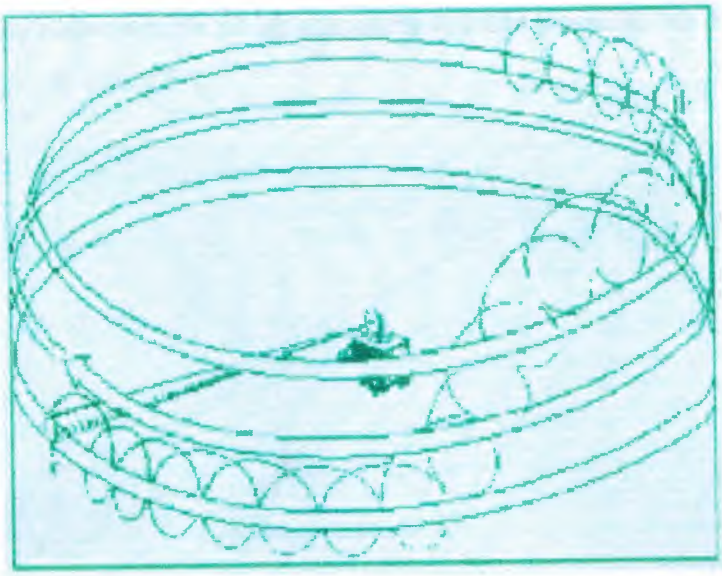

Figure 2.8 Radar using Combination Palmer-Helical Scan

2.5.5 Scan

2.5.5.1 Conical Scan

Radar systems can be categorized by their Scan patterns. The most commonly used today is the Conical Scan, or Con Scan pattern. In this method, the radar rotates its beam about the circle described by the half-power points of the beam when the beam is bore sighted on the target. The beam, when received at the target or at the radar, will be a sinusoidal wave shape whose amplitude is proportional to the distance the target is away from the bore sight. By monitoring the exact location of the scanning beam, the location of the target can be determined from the location of the maximum power received.

2.5.5.2 Track-while-Scan

Con Scan problems can be overcome with Track-While-Scan (TWS) radar. TWS radars scan their beams over relatively large areas. The radar computer still measures returned power as a function of beam location to provide tracking but the large scanning area enables the radar to still see the target even if track has been broken or lost. However, this large scan area makes the TWS high vulnerable to ECM jamming. An illustration of TWS radar is shown in figure 2.9.

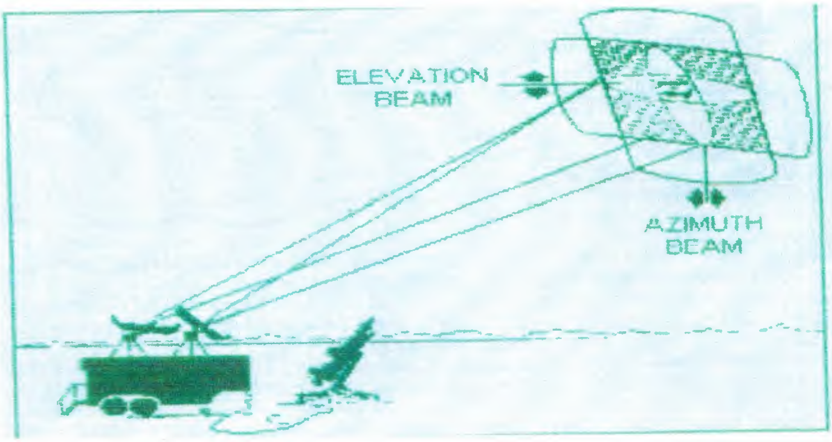

Figure 2.9. Track-While-Scan Radar

TWS radars require special consideration during the design of RWR systems. Since many receivers time-share the frequency bands, it is possible that the receiver may not be "looking" at the TWS frequency band when the TWS is illuminating the aircraft and vice versa. The probability of these missed intercepts increases as range from the TWS increases because scan areas have angular divergence. To overcome this problem, the RWR must be programmed to display the TWS on its first intercept; likewise, it is programmed to not erase the TWS symbol until after a set number of missed intercepts. Of these two factors, missed intercepts is the more troublesome to the aircrew since it requires the symbol to remain on the scope even after the TWS is, in fact, no longer tracking.

2.5.5.3 Mono-pulse Scan

Scan can also be accomplished by sequentially pulsing several antennae or sections of a large antenna. This is illustrated in figure 2.10. While this technique can yield much higher scan rates, the additional hardware requirements normally exclude it from a threat scenario. It will, however, be encountered on shipboard systems.

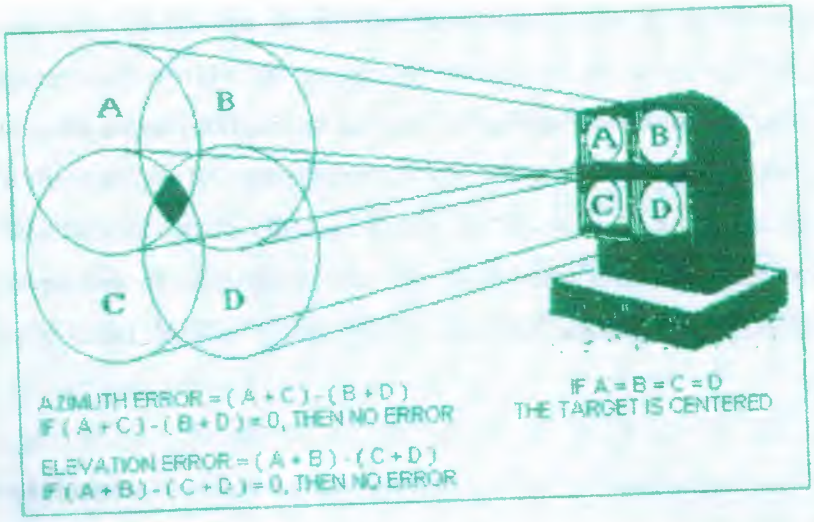

Figure 2.10. Diagram of Mono-pulse Radar Beam Patterns

2.5.5.4 Received Scan Patterns

Con Scan, TWS, and mono-pulse radars will cause an RWR to receive pulses with superimposed sinusoidal waveforms. The Con Scan case is shown in figure 2.11. The processor identifies these scan patterns by counting the maximum of the sine wave envelope; these maximum are the scan rate of the radar. When a given scan pattern is counted, the Identity Word is updated with this information.

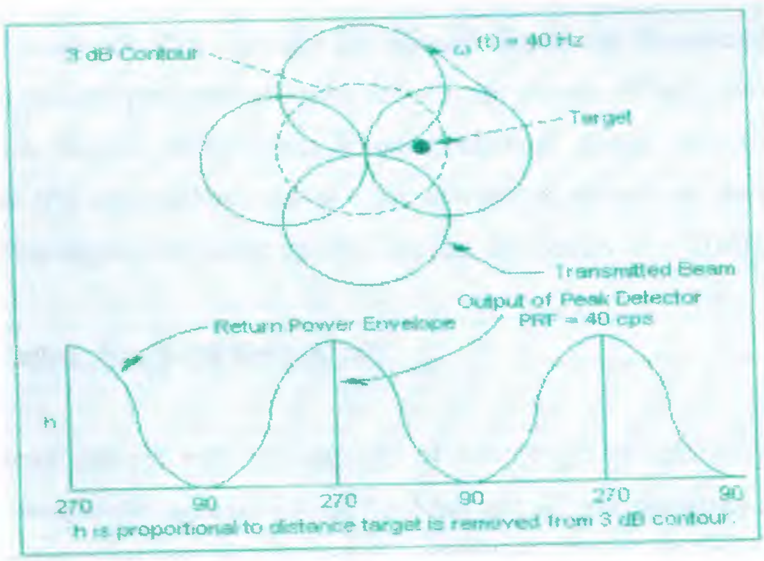

Figure 2.11. Signal Received From Con Scan Radar

Some radar systems do not scan their transmitted beams. Instead, the receiving antennae scan an angular section while the transmitter remains on the target at all times. To the radar receiver, the signal returns have the same sinusoidal waveform as normal scan, but to the RWR there will be NO scan pattern. The RWR processor can use this lack of scan since it characterizes certain types of radars just as well as an actual scan pattern. However, since lack of modulation on a Con Scan beam means that the radar is bore-sighted on the target, lack of a scan pattern does not unambiguously identify a radar type.

2.6 Types of Radars

2.6.1 Simple Pulse Radar

These are the most commonly used because the S/N ratio inherent in pulsed operation minimizes the need for high average power. However, due to the reduced ECM vulnerability of CW type radar, many of the new threat systems are using CW.

2.6.2 CW Radars

When a reflecting target move with respect to the receiver, the returned signal will have a frequency shift proportional to v/c, where v is the target velocity and c is the speed of light. The frequency shift increases for inbound targets and decreases for outbound targets by an amount proportional to the radial range change. That is, crossing targets will have low Doppler shifts while inbound/outbound targets have the maximum Doppler shift. If a target orbits radar at a constant radius, there is no Doppler shift. At microwave frequencies and fighter speeds, Doppler shift varies up to 20KHz.

2.6.3 Radar other than SAM fire control

Any air defense network will be composed of many types of radar other than those designed for weapon fire control. Except for AAA and AI, low frequency, large beams, and no auto-track capability generally characterize these additional radars. Some of the radars in this group are Acquisition, Early Warning, Height Finders, GCI, and GCA.

2.6.3.1 Early Warning Radars

Because fire control radars require very small beams for location accuracy, they must depend on other radars for initial target detection and location. The Early Warning (EW) radar is typically a low frequency (100-1000 Hz), large beam (6-16 degree), long range (200 or more nautical miles) system capable of searching a full 360- degree Az for initial target detection and heading. Therefore, any ECM, which does not make the target disappear, will only assist in the EW mission due to the beaconing effect of jammer transmitters. Although these radars normally employ AGC and MTI, they represent no real threat to aircraft since they cannot accurately direct weapon fire.

2.6.3.2 Acquisition Radars

After the EW radar detects the target, the acquisition (Acq) radar will further localize the position for the small beam tracks. This radar is characterized by medium (3-6degree) beams of medium (800 kHz to 8000khz) frequencies and no auto-track capability. They generally search an Az segment determined by EW radar. Because these radars are very similar to fire control system, the same techniques and tactics as those for fire control can jam them if appropriate frequency device is carried.

Denying Acq radar coordinates to a SAM radar force him into a manual target acquisition mode, which, due to the small beam SAM radar, can greatly increase minimum acquisition time. With some systems, loss of acq results in denial of track.

2.6.3.3 Height Finder Radars

Height finder (HF) systems are used to provide El data on the EW and Acq AZ target data. These radars have characteristics very similar to Acq radars except that the smallest dimension of their beams will be vertical for best El resolution. For maximum El uncertainty, then, the aircraft formation should be "stacked", but since this system also has no auto-track or associated weapon, it presents no real threat. These radars are primarily used for vectoring airborne interceptors.

2.6.3.4 Ground Controlled Intercept Radars

Ground controlled intercept (CGI) systems are usually composed of acquisition and height finder radars. They are used to vector interceptors aircraft to an intruding force.

2.6.3.5 Ground Controlled Approach Radars

Ground controlled approach (CGA) radars have parameters very similar to those of CGI, Acq, and HF. They differ from those systems primarily in their display units; GCA scopes are remarked with the appropriate glide angle for the site. ECM can easily be used against these radars to force interceptor aircraft to use visual approaches.

2.6.3.6 Anti-Aircraft Artillery Radars

Anti-aircraft artillery (AAA) fire control radars operate much the same as missile TTRs in that, after target acquisition, the radar computer and some sort of scanning method accomplish auto-track. Figure 13 shows a typical AAA battery layout. To maintain the high mobility inherent in a simple gun system, the radars have small dishes with medium beams (1-5 degrees) and wide frequency ranges (800 MHz to 20 GHz) with conical (Con Scan).

Figure 2.12. Typical AAA Battery in Operation

2.6.3.7 Airborne Interceptors Radars

Airborne fire control (AI) systems are used for airborne interceptors missiles (AIM) guidance. The cockpit operator manually acquires the target by training the antenna; auto-track is then usually accomplished by some scanning method or frequency (Doppler) track.

2.6.3.8 Terminal Defense Radars

Terminal defense radars are the fire control systems for SAMs and AAAs. As such, they were discussed earlier in this work under those heading

2.7 BASIC RADAR TERMS

The following provides the basic definitions of the characteristics of a PULSE radar wave:

2.7.1 Pulse Duration (PD)

The time a radar set is transmitting radio frequency (RF) energy. It is also referred to as pulse width (PW). Pulse duration is measured in millionths of a second or microseconds (usec).

2.7.2 Pulse Recurrence Time (PRT)

This is the time required to complete one transmission cycle. It is the time from the beginning of one radar pulse to the beginning of the next. It is the reciprocal of our next term, Pulse Recurrence Frequency (*PRF*). This term represents the period for one transmission cycle.

2.7.3 Pulse Recurrence Frequency (PRF)

The PRF equals the number of pulses per second the radar transmits. If you want the radar to look at long ranges, a low PRF is required (this allows time for the radar energy to be reflected by the target and to return to the antenna before the next pulse is transmitted). For shorter ranges, a higher PRF can be used. Of course, if you want both then your radar needs the ability to alternate the PRF.

The relationship between PRF and PRT is

$$PRF = 1/PRT \tag{2.3}$$

2.8 Rest Time

This is the time between the end of one transmission and the start of the next. It is measured in usec. The rest time is divided into two sections, Recovery Time and Listening Time.

2.8.1 Recovery Time (RT)

Represents the time immediately following the transmission of RF energy. Due to the laws of physics, the radar is unable to process the echoes of radar returns during this time.

2.8.2 Listening Time (LT)

Listening time is the part of the Rest Time that the radar can receive and process the echoes of radar returns. It is measured is usec.

2.9 Pulse Radar

Pulse radar transmits a sequence of short pulses of RF energy. By measuring the time for echoes of these pulses scattered off a target to return to the radar, the range to the target can be estimated by the pulse radar. The major components of pulse radar are:

- The transmitter, consisting of an oscillator and a pulse modulator.

- The antenna system, which passes electromagnetic energy from the transmitter to the transmission medium, and receives reflections from the target.
- The receiver, which amplifies the signal received by the pulse radar and detects returns from targets.
- And interfaces, including displays and interfaces to other electronic systems.

2.10 Components of a Radar System

Frequency Generation, timing and control:

Generates the frequency and synchronization signals that are required by the system It determines when the transmitter fires and how other systems functions relate to the time of transmission It controls the system's parameters and passes them to the other modules

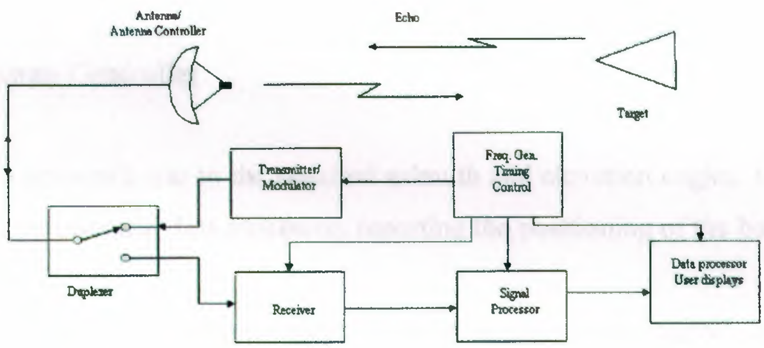

Figure 2.13 Block diagram of a Mono-static Single Antenna Radar System

2.10.1 Transmitter:

The transmitter generates the radio signal, which is used to illuminate the target

Modulator:

- In pulsed systems, Pulsed Radar (PR), the modulator turns the transmitter on and off.
- In continuous systems, Continuous Wave Radar (CWR), it provides the modulation uses to determine target range.

2.10.2 Duplexer:

In a mono-static single antenna system the duplexer switches the antenna between the transmitter and the receiver.

This allows the antenna to be shared between the two functions. The switch is usually electronic, as the switch has to be made within nanoseconds.

2.10.2 Antenna:

The antenna concentrates the signal from the transmitter into a narrow beam radiated in the desired direction

Intercepts the echo from the target in the desired direction. Matches the systems impedances to those of the transmission medium. Is usually steered so that the antenna can search or track in maying directions.

2.10.3 Antenna Controller:

Positions the antenna beam to the required azimuth and elevation angles. Interacts with the system controller and data processor, reporting the positioning of the beam.

Antennas can either be mechanically steered or electronically steered, as is the case with phased arrays.

2.10.4 Receiver:

Amplifies the received echo signal to a level sufficient for the signal processor.

Filters incoming signal removing out-of-band interference. This is called channel selecting filtering.

Signal Processor:

- Processes the target echoes and the interfering signals to increase the target echo signal level and suppress the interference.
- Performs the detection function, i.e. Makes the decision of whether a target is present or not.
- Determines target parameters like range and Doppler shift.

2.10.5 Data Processor

Stores and processes the location of detected targets.
In some radar systems the data processor extrapolates the targets' position in a track while scan function.

In tracking radars the data processor may control the servo for the antenna by processing angular errors into signals that control the antenna's motion.

In some systems the data may be sent to other locations in a process called netting. Target position is converted into coordinates understandable to all systems in the net. At the receiving end the data processor converts the coordinates back to a format understandable by the local system.

2.10.6 Displays

The display puts the information extracted from the echo signal by the data processor into a form that is useable by the radar operator and others such as traffic controllers and weapon system operators and supervisors.

CHAPTER THREE

CONTINUOUS WAVE DOPPLER RADAR

3.1 Continuous Wave Radar (CW Radar)

Continuous wave radar (CW radar) continually transmits energy in the direction of the target and receives back reflection of the continuous wave. Continuous wave radar can provide velocity information by comparing the differences in the transmitted and received waves and making use of the Doppler effect.

When a reflecting target moves with respect to the receiver, the returned signal will have a frequency shift proportional to v/c, where v is the target velocity and c is the speed of light. The frequency shift increases for inbound targets and decreases for outbound targets by an amount proportion to the radial range change. That is, crossing targets will have low Doppler shifts while inbound/outbound targets have the maximum Doppler shift. If a target orbits radar at a constant radius, there is no Doppler shift. At microwave frequencies and fighter speeds, Doppler shift vary up to 20KHz. The radar receiver can recover the Doppler shift by mixing the transmitted and received signals. Because of the low frequency of the shift with respect to the transmitted frequency, the transmitter must operate as a continuous wave (CW) signal source or in a pulse mode with pulses many times longer than the period of 20KHz (pulse Doppler).

In the CW case, range resolution is not possible but in pulse Doppler range can be obtained by transmitting short pulses between the "interrupted CW" pulses. But then change in Doppler shift is directly proportional to range rate (dR) so that the radar can recover dR, a quantity, which not only yields antenna slaw rates but also precisely locates when $R = 0$ is identical to $dR = 0$ and thereby greatly improve missile miss distance. Doppler shift from a target can be used as a homing beacon for any guided missile equipped with a Doppler receiver as seen in Fig 3.1.

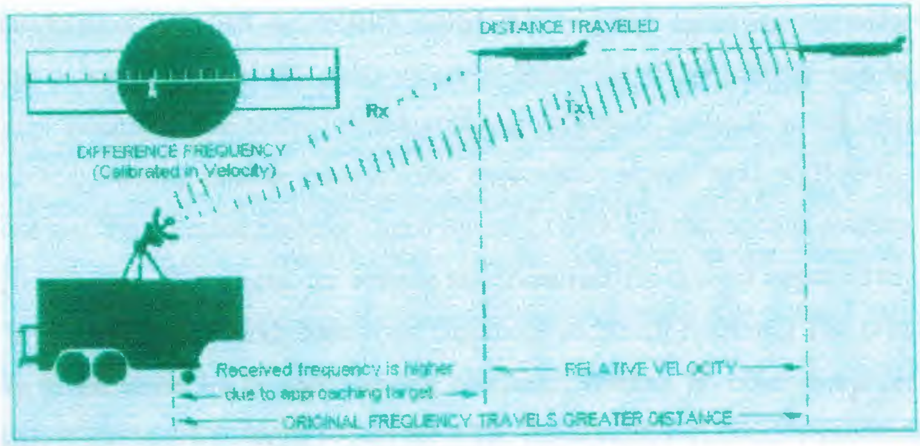

Figure 3.1. CW Doppler Radar Fire Control System

In this case, the ground site CW Illuminator (CWI) radar radiates the target. The missile has both forward-and aft-looking antenna so that Doppler is received. By use of a slotted antenna array (for example) the missile can passively track the target Doppler to an intercept point; when $dR = 0$, the missile is at the target and detonates. Thus, no proximity fuse is required. (This approach so improves the probability of a kill, pk, that direct hits are quite common. Editor's note from actual experience).

Two examples of fire control systems for these homing missiles are;

*Target tracking is accomplished by a non- Doppler pulse TTR. A CWI is slaved to the TTR, often sharing the same parabolic antenna. The missile is launched and homes on the reflected Doppler. The TTR in this case does not receive target Doppler so that ECM techniques applicable to pulse radar will defeat the system by denying acquisition and track to the TTR.

**The TTR itself as well as the missile have a Doppler receiver and track the target in frequency. In this approach, the TTR obtains initial tracking data from pulse radar or from manual operation after which it can auto-track the Doppler. That is, the CWI is the TTR. CWI TTRs are ideally suited for tow excellent ECCM techniques—coherency and home on jam. A continuous wave can be modulated by an ultra- low frequency signal. If an 85Hz modulation is used, the period for one cycle is about 2000nm. Thus, at normal SAM racking ranges, the phase of the 85Hz will be changed very little by the round-trip distance; the transmitted and received signals will be in phase-coherent.

This modulation is called the COHO signal. ANY signal, including jamming signal, must be coherent to pass the radar receiver. Since the COHO phase can be easily randomly switched, the active countermeasure is almost negated as an operational system. The homing missile receives the transmitted signal- with COHO-in the aft antennae and the reflected Doppler signal – with COHO – in the forward antenna. When the two COHOs are in phase, the missile has identified the correct target. (The correct radar is identified by a modulated code frequency at the aft antenna.) The missile can now fly to the target by its own steering computer, needing no other commands from the radar. If the target attempts to jam the TTR, the missile will see this gamming in its forward antenna, which is locked on the target. If the jamming is not coherent, COHO lock will reject it. Alternatively, the missile can divert to a home –on – jam (Hoj) mode and track the jamming signal to the target. That is, due to the COHO capability of a CWI, target- generated ECM can actually be a highly directional homing beacon for the missile.

It should be noted that a pure CW beam conveys very little intelligence to the missile. As already discussed, anti-jamming signals can AM the CW, radar-missile identity codes can FM it, a range approximation can be determined from a ramp function which FMs the signal and phase modulation can also be used as an ECCM device. Thus, a spectrum analyzer display of an actual SAM CW signal would show a complex AM-FM-PM continuous wave. For pulse Doppler, such as airborne interceptor pulse Doppler's (AIPDs), this same signal would be interrupted periodically for transmission of several ranging pulses or pulse groups (i.e., stagger, jitter or both).

3.2 Basic of CW radar

The all pulse-modulated radars have a 'blind' area surrounding the installation within which no targets can be detected. The blind area depends upon the value of pulse duration but even with a pulse of 0.2 us no target within 100 feet of the radar aerial can be detected. Sometimes it is necessary to detect and to measure the distance of targets from the radar aerial down to almost zero feet. Pulsed radar cannot be used for this; frequency-modulated continuous wave radar (FM-CW) can.

The only way to measure the speed of a target in pulsed radar is to try to estimate the distance the echo on the C.R.T. Screen moves in a given time. This is a rather indirect and inefficient method. A better method involves the use of un-modulated CW radar and the 'Doppler effect'.

We are therefore concerned with two different forms of CW radar-FM-CW and C.W. Doppler. In this chapter we shall consider the elementary ideas of both forms, illustrating the application of each with examples.

3.3 Continuous wave (CW) system

If we send a continuous wave, we lose the power to detect constant delay, but instead we can detect changes in frequency due to the Doppler effect. If the object is moving toward the antenna—high frequency. If the object is moving away from the antenna – lower frequency. By sorting return radar by frequency, we can draw another kind of echo power distribution graph. Rotation speed of the planet (though the direction of the rotation cannot be determined by this) Again, an anomalous deviation from the average echo power distribution tells us that there is a rough surface. But, again, the echo power is the sum of the radar returns from regions on the same Doppler shift circle.

This is not very specific. Unlike the moon, Venus is rotating relative to the Earth, and this has helped scientists to identify some of the prominent features on Venus:

1965 Identification of alpha and beta regions (Goldstein).

1966 Identification of more small regions (Carpenter).

3.4 Frequency-modulated CW Radar

A major limitation of continuous wave radar (CW radar) is that it lacks the ability to measure distance to a target. CW radar cannot determine target range because it lacks the timing mark necessary to allow the system to time accurately the transmit and receive cycle and convert this into range. In pulse radar, the pulse itself provided this mark. Pulse radar transmits a form of amplitude-modulated energy. There are other forms of modulation that provide the necessary mark to allow range information to be calculated. Frequency modulation (FM) can also be used. CW radars making use of FM are called frequency modulated continuous wave radar (FM CW radar or sometimes FMCW radar).

In addition to the ranging limitations, the CW radar is unable to detect targets with a zero Doppler shift, including stationary targets and beaming targets. Like pulse radar, frequency modulated continuous wave radar (FM CW radar) overcomes this limitation.

One application of FM-CW Radar is in aircraft altimeters. The normal barometric altimeter is operated by air pressure and has two limitations:

a. If the atmospheric pressure changes while the aircraft is in flight the altimeter reading will change.

b. The barometric altimeter indicates height above sea level, or some other pr-set level. It does not tell the pilot his actual altitude above the ground (Fig 3.2).

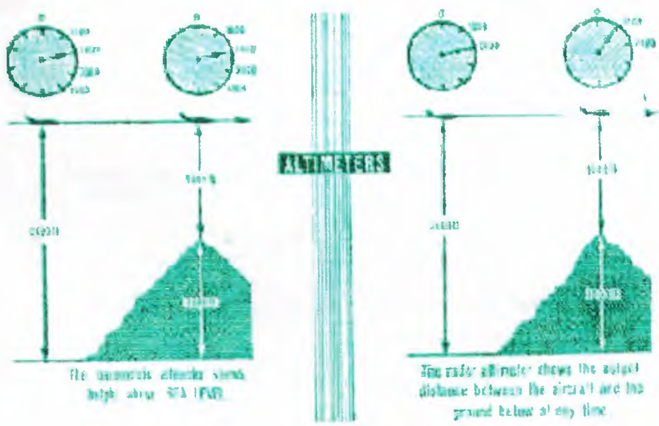

Figure 3.2 Barometric and radar altimeters

These limitations led to the development of the radar altimeter. We have seen how the distance between radar aerial and a reflecting surface can be measured by pulse-modulated radar. If we transmit pulses directly downwards from an aircraft we can measure the actual distance to the ground below.

Altimeters, which work on this principle, give satisfactory results while the aircraft is at a high altitude. However, since all pulsed radars have a certain blind area, altimeters of this type would be useless when the aircraft is flying near the ground, e.g. when it is landing. For this we need a FM-CW Radar altimeter.

3.4.1 Radar Altimeters Using Frequency Modulation

The principles of frequency modulation are considered elsewhere in these notes (see pp 388 and 423 of AP 3302, Part IB). Basically in a FM transmitter the carrier frequency is caused to change at a rate determined by the frequency of the modulating signal and by an amount deter-mined by the amplitude of the modulating signal. The transmitter works continuously and produces a constant-amplitude CW output whose frequency is varied by the modulating signal.

Let us suppose that the frequency of a FM transmitter is caused to deviate at a constant rate by using a saw-tooth waveform as the modulating signal (Fig 3.3). At point A the carrier frequency is, say, 400 Mc/s. At point B, 100 us later, the frequency is, say, 440 Mc/s. Since the change in frequency is linear we can say that the transmitter frequency is changing by 40 Mc/s every 100 us. Let us see how this principle is applied in the FM-CW radar altimeter.

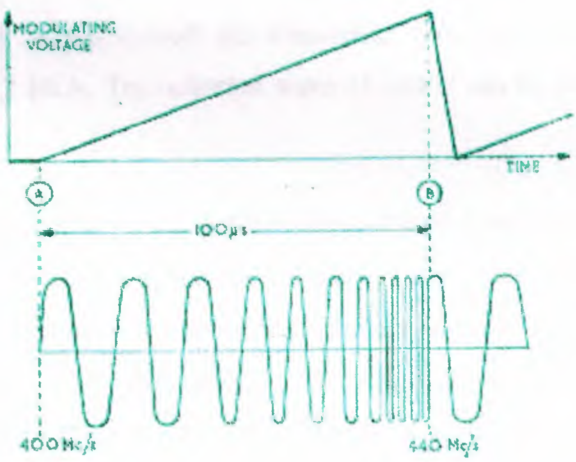

Figure 3.3 Frequency modulation with a saw-tooth modulating signal

Fig 3.4 illustrates the layout of a typical FM-CW radar altimeter in an aircraft. Let us assume that the output frequency is changing as described above and that at a given instant of time it is 410 Mc/s. The wave of this frequency is radiated downwards and reflected from the ground to be picked up by the receiver aerial. The wave takes a definite time to travel over this path so that

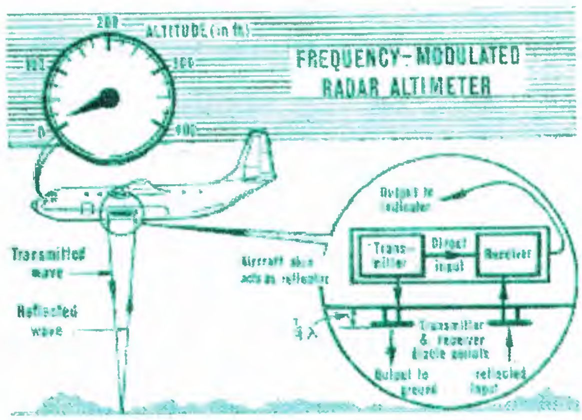

Figure 3.4 Typical FMCW radar altimeter layout

When it arrives back at the aircraft the transmitter frequency has in the meantime changed to, say, 410.2 Mc/s. The reflected wave of course has its original frequency of 410 Mc/s.

A portion of the transmitter output is fed directly to the receiver where it combines with the reflected input to produce a difference frequency, in this case 0.2 Mc/s. The greater the altitude of the aircraft the greater is the difference in frequency between the direct and reflected inputs. This difference frequency is automatically measured in discriminator circuits in the receiver, the output from which operates a simple meter display as shown in Fig. 3.

Since the transmitter frequency is changing linearly by 40 Mc/s every 100 us, a change of 0.2 Mc/s in the transmitter frequency represents a time interval of:

(100 x 0.2)/40 = 0.5 us.

What range, or altitude, does a time interval of 0.5 us represent? We know that one radar mile (5,280 feet) is equivalent in time to 10.75 us. A time interval of 0.5 us therefore represents an altitude of:

(5,280 x 0.5)/10.75 =250 feet approximately.

This is merely one application of FM-CW radar and it will be considered in more detail in Section 7. In general we can say that FM-CW radar can be used to detect an object-indicated by the production of a difference frequency (a beat frequency) in the receiver discriminator circuits; it can measure the range of a target by measuring the beat frequency; and it can provide information on the bearing in azimuth and elevation of the target by using beamed radiation in the same way as pulsed radar.

3.5 CW Radar measure the velocity of the target

By measuring the change in frequency between the transmitted and received signals. The Doppler effect can then be used to calculate the radial velocity of the target.

The Doppler effect:

If radar sends out se (t), then the return signal from a stationary target will be:

$$S_r(t) = A.S_e(t - t_0) \qquad (3.1)$$

A Is the attenuation through transmission through the medium. T_0 Is the delay related to the target's range R.

$$T_0 = 2.R_0 / c \qquad (3.2)$$

If the target is moving the range is given by:

$$R(t) = R_0 \pm V_r(t - t_0) \qquad (3.3)$$

V_r Is the radial velocity of the target

t_0 Is the time at which the target's range was R_0

t_0 Is therefore not constant as it was in the case of a stationary target. Therefore:

$$T = t_0 \pm 2.V_r / c \mp 2.V_r.t_0 / c \qquad (3.4)$$

If we assume that $S_e(t) = S(t)\cos(wc(t))$, then the received echo signal is therefore:

$$S_r(t) = A.S\left[(1 \mp 2.V_r / c)t - t_0 \pm 2.V_r.t_0 / c\right] \qquad (3.5)$$

Let $a = 1 \mp 2.V_r / c$

The signal is therefore compressed, frequency increases, if the target is approaching the radar and is expanded, frequency decreased, if the target is going away from the radar. The frequency change is clearly proportional to the radial velocity, V_r and so by measuring the frequency change we can measure the radial velocity of the target.
It must be noted that this method can only measure that part of the targets velocity that is in the direction directly toward or away from the radar. That is it will not measure any tangential velocity of the target. The tangential velocity can be measured by means of angle tracking.

3.6 Doppler Radar

The most effective tool to detect precipitation is radar. Radar, which stands for **R**adio **D**etection **A**nd **R**anging, has been utilized to detect precipitation, and especially thunderstorms, since the 1940's. Radar enhancements have enabled NWS forecasters to examine storms with more precision.

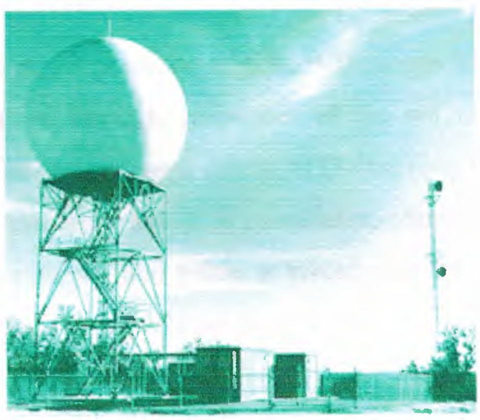

Figure 3.5 Weather Surveillance radar

The NWS's newest radar is called the WSR-88D, which stands for Weather Surveillance Radar - 1988 Doppler (the prototype radar was built in 1988). As its name suggests, the WSR-88D is a Doppler radar, meaning it can detect motions toward or away from the radar as well as the location of precipitation areas.

3.6.1 History of Doppler radar

Christian Doppler explained in 1842 that when one stands near a railroad listening to the sound of a train passing, the train sounds different as it approaches than it does as it recedes. This change is known as the "Doppler effect". It occurs when the sound waves produced by an approaching object are compressed into a higher wave frequency (producing a higher pitch), while those of a receding object are lengthened, producing a lower wave frequency (and lower pitch). The same principle applies to the frequency of radio waves returning to a radar antenna.

The term RADAR was suggested by S. M. Taylor and F. R. Fourth of the U.S. Navy and became in November 1940 the official acronym of equipment built for radio detecting and ranging of objects. The acronym was by agreement adopted in 1943 by the Allied powers of World War II and thereafter received general international acceptance.

Pulsed-Doppler radar was developed during World War II to better detect aircraft and other moving objects in the presence of echoes from sea and land that are illuminated by microwave emissions through side-lobes of the antenna's radiation pattern. The earliest pulsed-Doppler radars were called MTI (moving target indication) radars in which a coherent continuous-wave (CW) oscillator, phase-locked to the random phase of the sinusoid in each transmitted pulse, is mixed with the echoes associated with that pulse. The mixing of the two signals produces a beat or fluctuation of the echo intensity at a frequency equal to the Doppler shift.

In the midst of war, the most significant peacetime application of RADAR was discovered. During the war, RADAR operators continually found precipitation, like rain and snow, appearing in their RADAR fields. Scientists had not known that RADAR would be sensitive enough to detect precipitation. Only during the war did the use of RADAR to study weather become obvious. Ian C. Browne and Peter Barrett of the Cavendish Laboratories at Cambridge University in England made the first application of pulsed-Doppler radar principles to meteorological measurements in the spring of 1953. Barrett and Brown showed that the shape of the Doppler spectrum agreed with the spectrum expected from raindrops of different sizes falling with different speeds. With the advent of computers, Doppler radars have become a widely used tool in forecasting and analysis of many meteorological features. Today, RADAR is an essential tool for analyzing and predicting the weather.

Figure 3.6 Thunderstorm activity and heavy rain to the southwest as detected on Doppler radar

Doppler radar can give a picture of the winds within a storm. If, within a small area, high winds toward the radar are adjacent to high winds away from the radar, a circulation has developed and forecasters prepare to issue a warning. Rainfall is typically estimated from radar data with a Z-R relationship, which converts bulk reflectivity to a rainfall rate. Several "stock" Z-R relationships exist, for different types (convective, Stratford, winter, tropical) of storms. Direct use of the "stock" relationships may give errors of O (50-100%). Use of more sophisticated correction techniques, or local measurement of precipitation drop size spectra, may bring these down to O (30-50%). The real advantage of radar is that it can measure the full extent of the precipitation field over large areas, whereas gauge networks are often widely spaced point measurements. For hydrological applications such as basin modeling and flood prediction, this makes radar data competitive with rain gauges, particularly when integrating over the life of a storm.

3.6.2 Pulse Doppler Radar

CW radar is not the only form of radar able to make use of the Doppler effect. Doppler shifts can be used in pulse radar, as they were in CW radar, to determine the relative velocity of moving targets. Pulse radars designed to make use of the Doppler effect in this way are called *pulse Doppler radar* (PD radar).

Pulse Doppler radars are very useful radar systems as they combine their ability to determine target velocity with the other functionality of standard pulse radar. A pulse Doppler radar can, therefore, determine range, angle and velocity of a target. This makes pulse Doppler radar extremely valuable in situations involving many small moving targets hidden by heavily cluttered environments. A maritime scenario involving low-flying aircraft and anti-ship missiles is an example of such an environment.

It is common for pulse Doppler radars to have a capability to concentrate only on moving targets, removing the sometimes-confusing clutter from the operator's display. This capability is called *moving target indication (MTI)*.

3.7 The Doppler Effect

If we transmit a continuous wave at a fixed frequency, when the beam strikes an aircraft some of the R.F. energy is reflected (Fig 3.7). From the reflected signal, information about the presence of a target and the target's angular position relative to the transmitting aerial can be obtained.

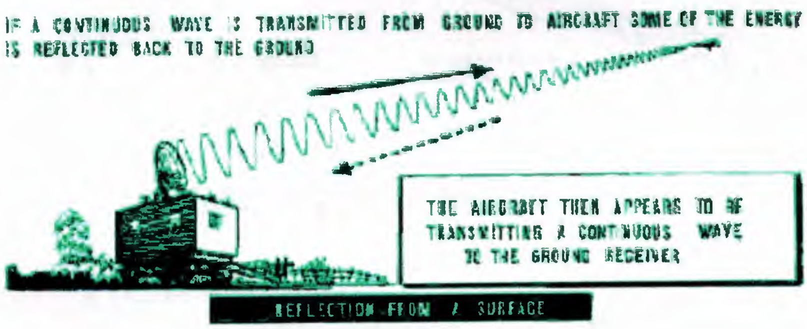

Figure 3.7 Reflections of radio waves from a surface

There is however another phenomenon associated with all wave propagation, which is used in un-modulated C.W. radar.

If you are watching a motorcycle race you may notice that the note of the exhaust noise appears to change as the machine passes. This is illustrated in Fig 3.8.

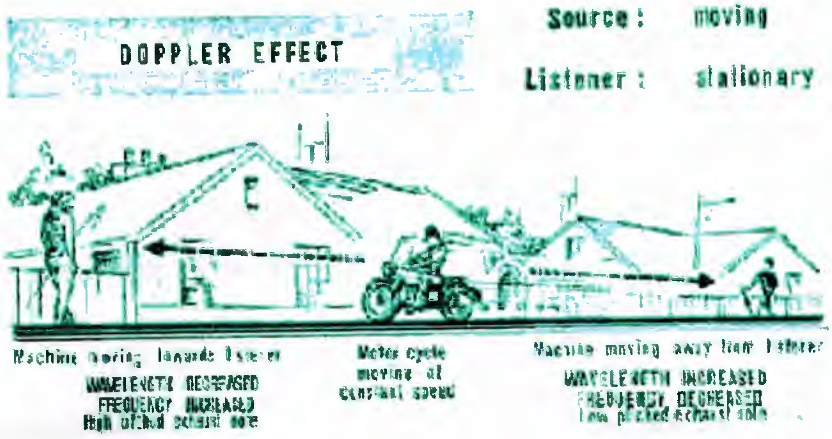

Figure 3.8 Doppler Effect with sound waves

This phenomenon is known as the Doppler effect and it occurs with radio waves as well as with sound waves. As a target approaches a radar aerial the frequency of the signal reflected by the target is higher than that of the transmitted signal. Conversely if a target is moving directly away from the aerial the frequency of the reflected signal is lower than that of the transmitted signal. For stationary targets there is no change in the frequency of the reflected signal (Fig 3.9).

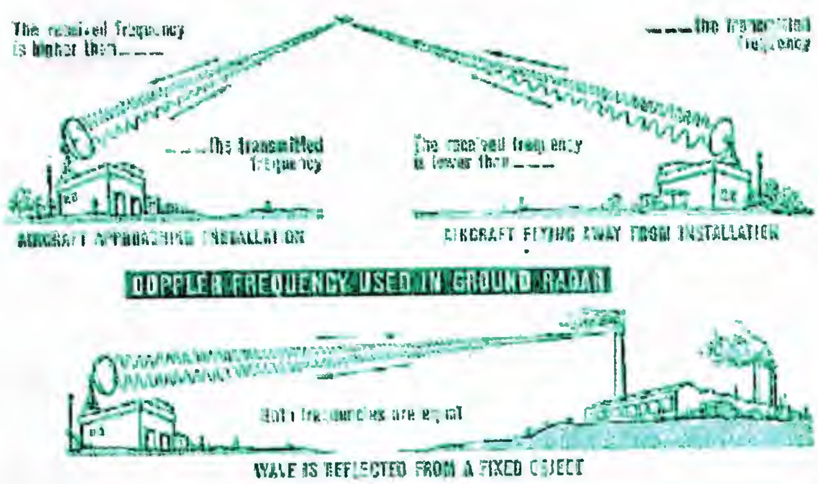

Figure 3.9 Doppler Effect with radio waves

If the transmitted frequency is Ft and the new frequency to which the Doppler effect changes it is Fr, the difference between these two frequencies is known as the Doppler shift $F_d = F_t \sim F_r$

The magnitude of the Doppler shift is related to the velocity of a target in a straight line between the target and the aerial. A high value for the Doppler shift indicates a high target velocity.

If the target is approaching the aerial the received frequency is higher than the original transmitted frequency by the Doppler shift, i.e. $F_r = F_t + F_d$. If the target is moving away the received frequency is lower, i.e. $F_r = F_t - F_d$.

The relationship between a target's velocity and the Doppler shift, provided the target is approaching or receding in a straight line from the radar aerial, is given by the expression:

$$F_d = (2v/c)F_t \tag{3.6}$$

Where:

F_d Is Doppler shift in H_z/s

F_t Is Transmitted frequency in H_z/s

v Is Velocity of target in m.p.h.

c Is Velocity of radio waves in m.p.h.

If the transmitted frequency is 1,860 Mc/s and the velocity of a target directly approaching the aerial is 360 M.P.H. then:

Doppler shift F_d = (2 x 360)/(186,000 x 60 x 60) x 1,860 x 10^6 = 2 Kc/s

This means that the frequency of the received signal F_r is $F_t + F_d$ = 1,860 Mc/s + 2 kc/s. If the target had been moving away in a direct line at 360 m.p.h. the frequency of the received signal would have been $F_r = F_t - F_d$ = 1,860 Mc/s - 2 kc/s.

In practice it is the velocity of a target we wish to find, so we work the other way round from the measured value for the Doppler shift and the other known factors. Knowing the relation-ship it is simple to convert any difference in frequency between the received signal and the transmitted signal into the relative velocity of the target.

So far we have assumed that the target is moving in a direct line either towards or away from the radar aerial. If the target is not moving along such a path, the difference in frequency that Doppler effect causes is less. From Fig 3.10 we can see that the important factor is the radial velocity, i.e. that component of the target's speed, which is in a direct line with the aerial.

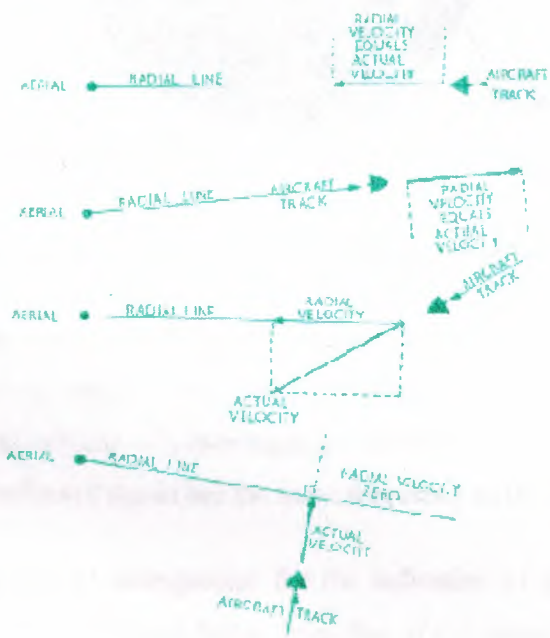

Figure 3.10 Radial Velocity

When the target is not moving along a radial line the radial velocity is less than the actual velocity. In fact if the target is moving at right angles across a radial line its radial velocity is zero. It is only the radial velocity, which can be measured by the Doppler effect.

3.7.1 Use of the Doppler Effect in Ground Radar

With pulse-modulated ground radar equipment reflections from large fixed objects cause permanent echoes on the indicator, and random reflections from small objects close to the radar cause clutter at the center of the p.p.i. (Fig 3.11).

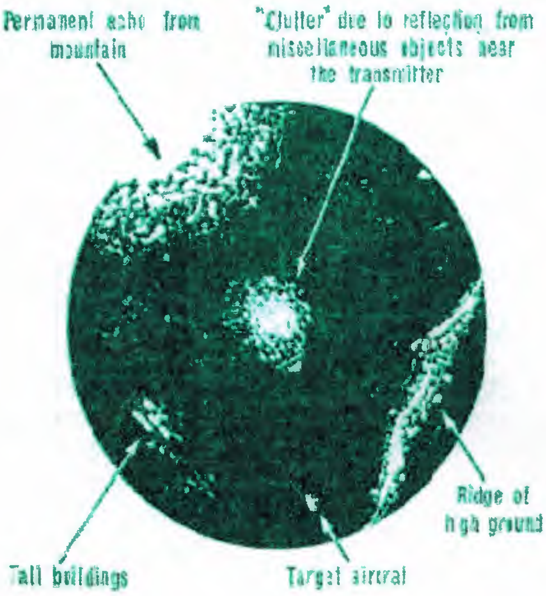

Figure 3.11 Echoes from unwanted objects in pulsed radar

For most applications the receiver should ignore reflections from fixed objects and respond only to moving targets. This can be achieved by using the Doppler effect because only the radial velocity of a moving target produces a Doppler frequency. For a stationary object the reflected signal has the same frequency as the transmitted signal.

Fig 3.12 illustrates a typical arrangement for the indication of a moving target. The frequency F_r of the reflected signal differs from that of the transmitted signal ft by the Doppler shift F_d. The reflected signal is mixed with the output of a local oscillator to produce an i.e. Signal $(F_r \pm F_d)$,

Where

F_d Is the Doppler shift.

This signal is amplified and fed to a discriminator whose output is either a positive going or a negative going dc. Voltage depending upon whether the frequency of the reflected signal is above or below that of the transmitter. Remember that the frequency of the reflected signal increases if the target is approaching and decreases

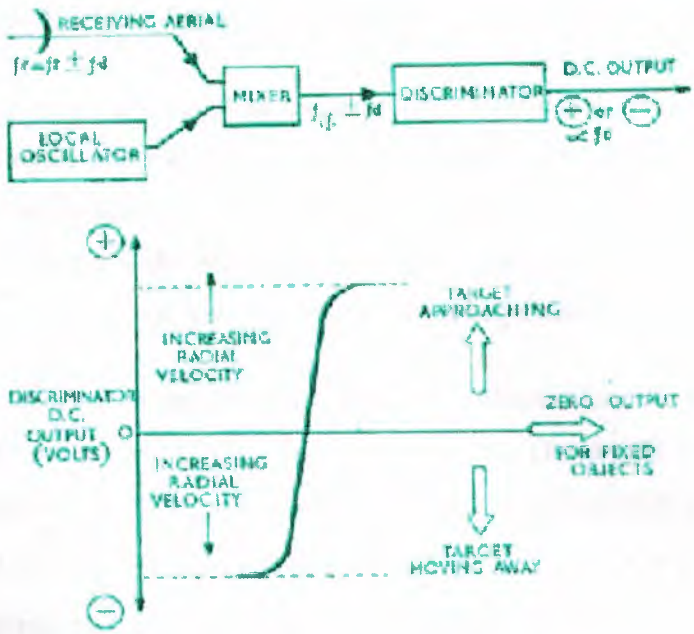

Figure 3.12 Indication of moving targets

If it is flying away from the radar. Thus the sign of the discriminator output indicates whether the target is approaching or moving away. The magnitude of the discriminator output depends upon the frequency deviation of the reflected signal in relation to the transmitter frequency, and this in turn is proportional to the target's radial velocity.

An installation using C.W. Doppler radar will provide the following information about a target:

a. The presence of a moving target is indicated by the production of a Doppler frequency. Stationary objects provide no change in frequency.

b. The bearing and elevation of the target is determined by using narrow beams.

c. The radial velocity of the target is determined by measuring the Doppler shift in frequency.

d. The direction of travel of the target is determined by noting the sign of the Doppler shift.

Note that C.W. Doppler does not measure the range of a target. For this we use either pulse-modulated radar or F.M.C.W. radar.

3.7.2 Use of the Doppler Effect in Airborne Radar

If the radar transmitter is located in an aircraft the signals reflected from the ground ahead of the aircraft will also be subject to the Doppler effect. Use is made of this property in aircraft navigation. To navigate accurately one important factor that must be known by the navigator is the ground speed of the aircraft. This may be quite different from the air speed. Let us see how the Doppler effect helps here.

Since the radar beam from the airborne transmitter is illuminating the ground ahead of the aircraft it will reflect energy back towards the aircraft. The aircraft is always moving towards the apparent source of radiation and so the received frequency f_r is higher than the transmitted frequency ft by the Doppler shift f_d, i.e. $f_r = f_t + f_d$. The Doppler shift is deter-mined by the radial velocity of the aircraft and is given as before by the expression

$$F_t = (2v/c)F_t \qquad (3.7)$$

Special circuits in the receiver automatically measure the Doppler shift and the receiver output can be displayed on a simple meter calibrated in m.p.h. Practical equipment which uses this system transmits not one radar beam but four at different points around the aircraft. The information, which is received from all four points on the ground, is used to eliminate errors, which would otherwise arise when the aircraft is climbing, diving or banking. The four beams also enable the drift of the aircraft to be calculated. A typical meter display is illustrated in Fig 3.13.

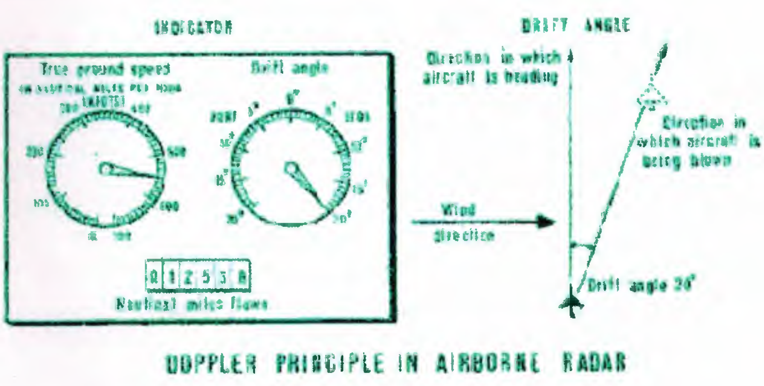

Figure 3.13 Doppler airborne navigation display system

It should be noted that the frequency of receiver pulses in pulsed radar is also altered by Doppler shift. However, the Doppler shift is small and in pulsed radar is accepted within the bandwidth of the receiver circuits. In a Doppler radar the shift frequency is the important factor and to ensure accuracy the frequency stability of a Doppler radar must be high.

A simple Doppler radar sends out continuous sin wave rather than pluses. It uses the Doppler effects to detect the frequency change caused by a moving target and displays this as a relative velocity. Since transmission here is continuous, the circulator is used to provide insulation between the transmitter and reviver. Since transmission is continuous, it would be pointless use duplexer.

The insulation of a typical circulator of the order of 30dB, so that some of transmitted signal leaks into the receiver. The signal can be mixed in the detector with returns from the target, and the differences are the Doppler frequency. Being generally in the audio range in most Doppler application, the detector output can be amplified with an audio amplifier before being applied to a frequency counter. The counter is a normal one, except that its output is shown as kilometers or miles per hour, rather than the actual frequency in hertz.

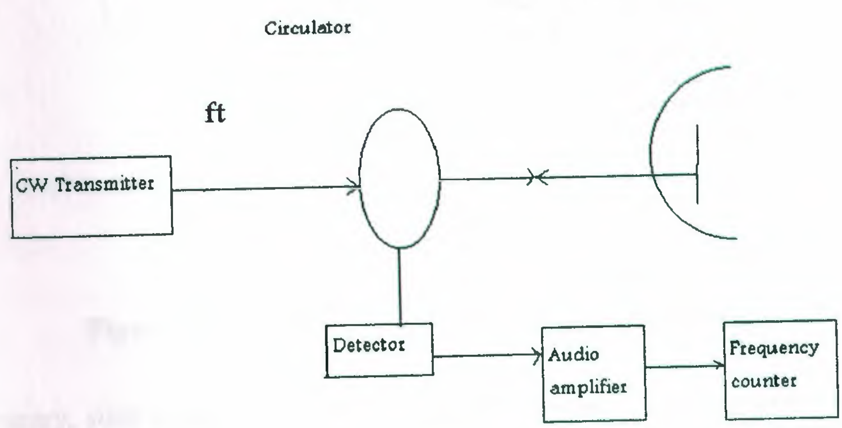

Figure 3.14 Simple Doppler CW Radar

A small portion of the transmitter output is mixed with the output at a local oscillator, and the sum is fed to the receiver mixer. This also receives the Doppler-shift signal from its antenna and produces an output differences that is typically 30MHZ, plus or minus the Doppler frequency. The output of this mixer is amplified and demodulated again, and the signal from the detector is just the Doppler frequency. Its sign is lost, so that it is not possible to tell whether the target is approaching or receding. The overall receiver system is rather similar to the super heterodyne. Extra sensitivity is provided by the lowered noise, because the output of the diode mixer is now in the vicinity of 30MHZ, at which FM noise has disappeared. Separate receiving and transmitter antennas have been show, although this arrangement is not compulsory. A circulator could be used as in the simpler set.

Separate antenna are used to increase the isolation between the transmitter and receiver sections of the radar, especially since there is no longer any need or a small portion of the transmitter output to leak into the receiver mixer, as there was in the simpler set.

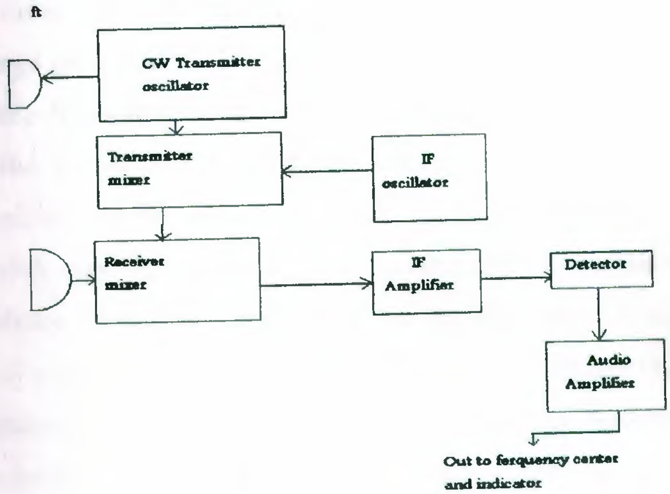

Figure 3.15 CW Doppler radar with IF amplification

To the contrary, such leakage is highly undesirable, because it brings with it the hum and noise from the transmitter and thus degrades the receiver performance. The problem of isolation is the main determine factor, rather then any other single consideration in the limiting of the transmitter output power, as consequences, the CW power from such radar seldom exceeds 100W and is often very much less. Gunn or IMPATT diodes, as for the largest power. CW magnetrons are used as power oscillator in the transmitter. They operate at much the same frequencies as in pulsed radar.

Advantages, applications and limitations CW Doppler radar is capable of given accurate measurements of relative velocities, using low transmitting power, simple circuitry, low power consumption and equipment whose size is much smaller then that of comparable pulsed equipment. It is unaffected by presence of stationary targets, which it disregards in much the same manner as MTI pulsed radar. It can operate theoretically down to zero range. Because in pulsed system, the receiver is ON at all times. It is also capable of measuring at large range of target speeds quickly and accurately. With some traditional circuitry. CW radar can even measure the direction of the target, in addition to it speed.

3.8 Range-Gated Step-Frequency Radar

The step-frequency radar has been used extensively in short-range radar measurements to study scattering properties of geophysical surfaces because of the ease with which it can be implemented and its high-range resolution. The main limitations of the of the step-frequency radar are its limited unambiguous range and the difficulty in implementing range gating for short ranges. The number of its frequency step limits the range of the step-frequency radar. When the step frequency radar is operated monotonically, the return is corrupted by reflection from the antenna feed, thus affecting the sensitivity of the system. Currently, range gating for step-frequency radar is implemented with very fast switches on the transmit and receive sides to gate out the undesired reflections. Switching times must be on the order of nanoseconds, and implementation of such switches is difficult. Some of the problems associated with the step-frequency radar can be overcome by using the frequency-modulated, continuous-wave (FM-CW) radar system. The unambiguous range of the FM-CW radar is usually larger then that of the step-frequency radar, but the resolution is much poorer. The range gating is easily implemented on the FM-CW radar simply by putting a high-pass filter between the output of the mixer and the IF amplifier. The cut-off frequency of this high-pass filter is chosen to eliminate the reflection from the antenna. To overcome the problems associated with these two systems, a new system is proposed. The new system combines the range gating capability of the FM-CW radar and the operation method of the step-frequency radar to obtain a high-resolution range gated spectrum. The system will also have the ranging capability of the FM-CW radar.

3.9 Design Factors Affecting Doppler Radar Performance

The main factors in the design of a radar set, which affect the performance of the CW Doppler radar, are:

- **a.** Transmitter power.
- **b.** Receiver sensitivity and noise factor.
- **c.** Frequency of operation.
- **d.** Shape of radar beam and scanning methods used.
- **e.** Doppler repetition frequency.
- **f.** Doppler duration.

3.10 Transmitter power

Even with the most concentrated radar beam only a fraction of the energy of each radiated Doppler shift strikes the target. At the target this fraction of the original energy is 'scattered' so that, in turn, only fraction of the incident energy returns towards the receiving aerial. To compensate for this very inefficient reflecting process the greatest possible radiated power must be used. This is why we use peak powers of 1MW and more; but even with such high powers the power in the received echo is only of the order of milli-watts or even microwatts. In general the higher the radiated power the greater is the received echo power and hence the greater is the range. However the increase in range obtained by increasing the radiated power is very small. Even doubling the power increases the only 1.19 times. The power that the transmitter is designed to radiate depends upon the job that the radar has to do.

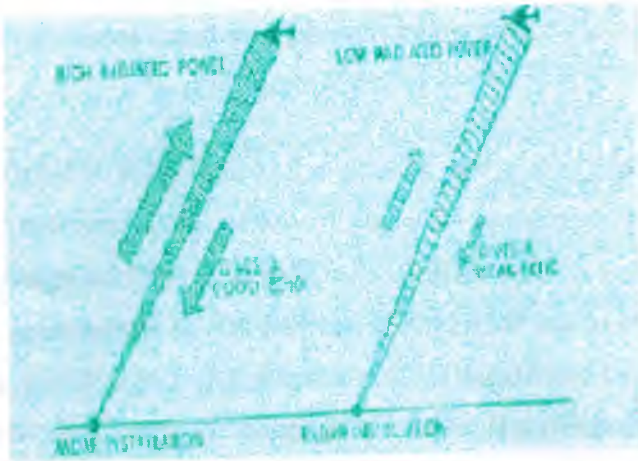

Figure 3.16 Effect of transmitter power output

3.11 Receiver Sensitivity and Noise Factor

We have already seen that main limitation on useful amplification in a radar receiver is the relationship between the amplitude of the wanted signal voltage and that of the noise voltage, i.e. the signal to noise ratio. If the input has a low signal to noise radio the signal echo on the C.R.T. may be 'lost' among the noise indications. The input signal to noise ratio to a receiver is determined by external.

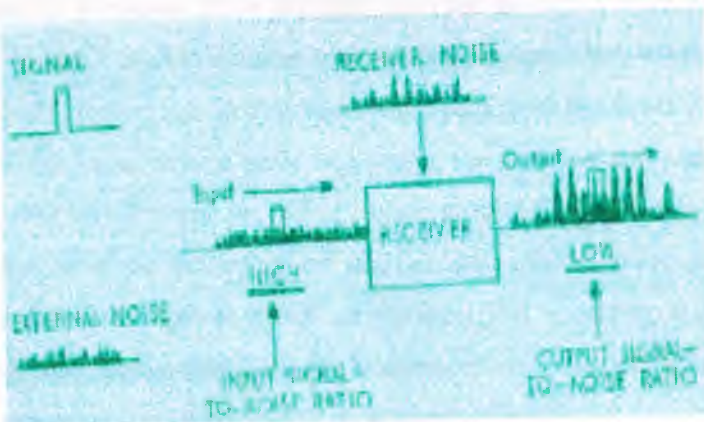

Figure 3.17 Receiver noise factor

Factors as previously noted and it is, at the moment, the ultimate limitation on the reception of very weak echoes. In addition, the receiver itself 'generates' noise (valve noise and thermal agitation) and the receiver noise, when combined with the input noise, means that the output signal to noise ratio is lower than the input signal to noise ratio.

The ratio of the signal to noise ratio at the input to that at the output is known as the 'noise factor' of a receiver. It is a measure of the noise introduced by the receiver itself (Fig 3.17). The design problem is to produce a receiver with as low a noise factor as possible. This is complicated by the fact that the receiver has to accept very narrow pulses and hence a wide band of frequencies. Wide bandwidth tends to increase the noise factor of a receiver. Thus the design of a receiver is a compromise between high sensitivity, wide bandwidth and noise factor.

3.12 Frequency of Operation

The frequencies used in radar are high for three main: To obtain a good echo the radar wavelength must be less than four times the size of the target. For good angular discrimination between adjacent targets, for accurate indication of bearing and for adequate concentration of the radiated energy we use aerials, which can provide a very narrow beam. This can be achieved much more easily at high frequencies. High frequencies are needed to ensure an adequate number of R.F. cycles in each pulse. The frequency chosen for particular radar depends upon the job it has to do. High-resolution radar, which is required to discriminate between targets very close together in bearing, will use super-high frequencies in the microwave region in the band 3,000 to 30,000 Mc/s. for long-range radar, where early warning is the criterion and accuracy of range and bearing of less importance, the V.H.F. band around 200Mc/s may be used. The lower frequencies have the advantage of smaller atmospheric absorption and longer ranges. In radar the wavelength at which the equipment is operating is quoted as often as the frequency. The relationship between frequency f in cycles per second, velocity c of E.M. waves in meters per second and wavelength λ (lambda).

3.13 Doppler Shift

You have probably heard an example of the Doppler shift on many occasions. For example, we have all been at a railroad crossing when a train is approaching the road intersection. The sound of the train's horn starts with a higher pitch as it approaches. As the train enters the intersection, the pitch of the horn levels out (becomes constant). As the train moves beyond the intersection, the pitch again changes -- this time it becomes lower.

What you have heard in this case is referred to as the Doppler effect. The Doppler effect is a shift in the frequency of a wave (a sound wave in this example) reflected by an object in motion. The motion of the train towards the intersection causes the sound wave to be compressed (a higher pitch). As the train enters the intersection, the distance between the train and an individual in the road intersection becomes constant (or a 90 degree angle to the person).

At this point in time, the sound wave is no longer compressed since there is NO RELATIVE movement between the horn and the individual (yes, the train is moving; however, for one brief moment, it is NOT moving toward the individual OR away from the individual).

When the train is in the intersection, its bearing is 90 degrees to the individual. At this point there is no change in the distance between the train and the person and therefore NO Doppler effect. As the train moves beyond the intersection, the distance begins to increase and the Doppler effect returns. This time, the movement of the train away from the person makes the sound of the horn wane as the sound waves are expanded.

3.13.1 DOPPLER SHIFT THEORY.

A Doppler shift allows distinguishing between the target and the transmitter leakage. The radial velocity of the target determines the amount of Doppler shift since the radial velocity is the apparent speed that the target is closing on or going away from the radar.

A target can move in any direction and in a wide range of speed; therefore, the radial velocity can change considerably. If the target is moving at a 900 angle to the radar, then no Doppler shift is produced. However, if the target moves straight at or away from the radar, radial velocity will equal the actual target speed.

The amount of Doppler shift is also dependent on the wavelength resulting from the transmitter frequency. A target radial velocity that produces a specific Doppler shift at 5,000 MHz would produce twice as much at 10,000 MHz.

3.13.2 DOPPLER SHIFT DETECTION

Pulse-Doppler radars can detect moving targets by the Doppler shift. Moving-target indication (MTI) is used primarily to detect moving targets with pulse-Doppler search radars.

Since stationary targets produce no Doppler shifts, the return signal echo has the same frequency and phase as the transmitted pulse. However, moving tar- gets do produce Doppler shifts; therefore, the return signal echo has a different phase from that of the transmitted pulse.

To use this principle, pulse-Doppler radars must be able to compare the echo signal with a reference signal that is in phase (coherent) with the transmitted signal. A means of storing or controlling the transmitted phase is required to provide coherent detection.

One method uses a magnetron for the transmitter. This requires that the local oscillator be stable for a small fraction of a cycle during one pulse period. A sample of the transmitted and stable local oscillator (STALO) signals is fed to the coherent oscillator (COHO). This locks in the phase of the COHO until the next transmitter pulse. Figure 2-2 is a diagram of coherent MTI with a phase-locked COHO oscillator.

3.14 Interpreting Doppler Radar Velocities (speed shear wind patterns).

To understand Doppler radial velocity patterns, one first has to consider the geometry of a radar scan. Normally the radar beam is pointed at an elevation angle greater than zero so that the beam, as it moves away from the radar, moves higher and higher above the surface of the earth. Because of this geometry, radar returns originating from targets near the radar represent the low-level wind field, while returns from distant targets represent the wind field at higher levels.

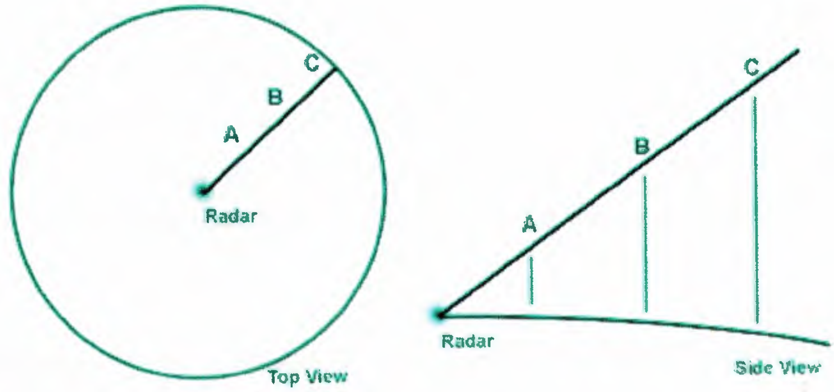

Figure 3.18 Doppler Radar Velocities

On radar PPI display, the distance away from the radar at the center of the display represents both a change in horizontal distance and a change in vertical distance. To determine the wind field at a particular elevation above the radar, one must examine the radial velocities on a ring at a fixed distance from the radar. The exact elevation represented by a particular ring depends upon the elevation angle of the radar beam.

The idealized Doppler radial velocity patterns were constructed with a computer assuming simple vertical wind field patterns. These simplified radial velocity patterns can help us understand the more complicated patterns that are associated with storm motions. Doppler velocity patterns (right) correspond to vertical wind profiles (left), where the wind barbs indicate wind speed and direction from the ground up to 24,000 feet. Negative Doppler velocities (blue-green) are toward the radar and positive (yellow-red) are away. The radar location is at the center of the display.

3.15 Radar Doppler polarimetry applied to precipitation measurements

The differential reflectivity Zdr is sensitive to the shape and orientation of the hydrometeors. The value of this parameter is related to a mean shape, which is not always representative of the measured particles. The differential reflectivity of spherical particles is 0 dB. Even in the case of spheroid droplets, Zdr values of 0 dB can occur. For slant profiles the differential reflectivity corresponds to the mean spheroid shape of raindrops. It indicates the presence of particles with different shapes and orientations in the different meteorological layers of the precipitation: rain, melting layer and precipitating cloud.

A major improvement for understanding the microstructure of precipitation can be achieved by combining simultaneous Doppler and polar-metric information. Two power Doppler spectra, hh and vv must be measured simultaneously in order to obtain the Doppler velocity spectrum of Zdr. The spectral differential reflectivity sZdr is thus defined for each Doppler velocity and provides detailed measures of the microstructure of precipitation.

The Doppler velocity can be related to the fall speed of the hydrometeors in the case of vertical profiles. For slant profiles, there is a Doppler contribution due to the horizontal wind, which differs as a function of height. In case of rain, the Doppler velocity can be related to the size of the hydrometeors. Because sZdr is function of the Doppler velocity and sensitive to the shape of hydrometeors, this enables the study of the shape-size relationship.

Therefore using Doppler polar-metric measurements, linear relations, sZdr versus Doppler velocity, have been measured in rain for slant profiles of light precipitation. These relations, sZdr versus Doppler velocity are the purpose of this paper. The measurement to obtain them and the definition of the spectral differential reflectivity sZdr will be given. The relations are going to be presented and explained. Their possible use for measurement of turbulence will be investigated.

3.16 Radial Velocity (measured by Doppler radars).

Doppler radars can measure the component of the velocity of targets toward or away from the radar. This component is called the "radial velocity".

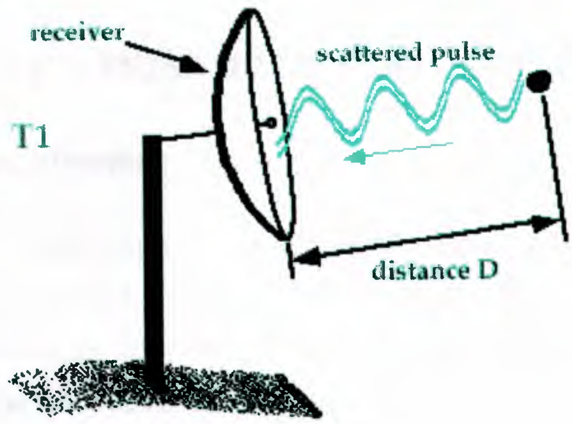

Figure 3.19 For example, at time T1 a pulse is sent towards a target and it returns a target distance "D".

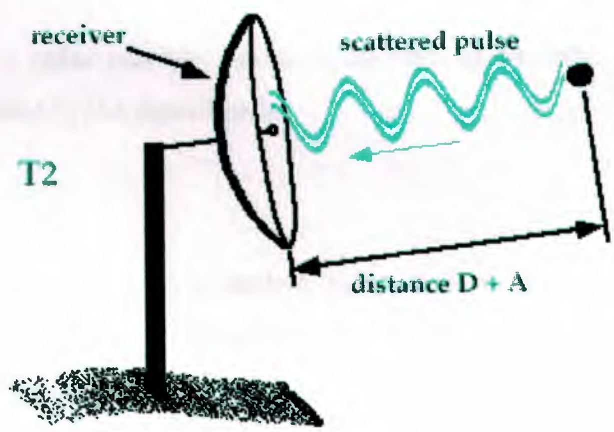

Figure 3.20 at time T2; another pulse is sent towards the same target and returns a target distance "D+A"

The distance to target has changed from times T1 to T2, resulting in a phase shift between the two return signals, which Doppler radars are capable of measuring. By knowing the phase shift, the wavelength and the time interval from T1 to T2, the velocity the target has moved toward or away from the radar can be computed. If the target is moving sideways so that its distance relative to the radar does not change, the radar will record zero radial velocity for that target.

CHAPTER FOUR

APPLICATIONS OF CW DOPPLER RADAR

4.1 Semi active missile Doppler

Beam Rider - The missile maneuvers to stay in the aircraft radar beam, which must remain always pointed toward the target. If the radar beam can stay on the target, the missile will reach the target. This often requires very large missile maneuvers, so it is not commonly used in airborne missile guidance.

4.2 missile guide

The "semi-active" target illumination is only one of four major methods of missile guidance. These methods are:

4.2.1 Semi-active

The missile has a radar receiver, which it operates as biostatic radar, using target illumination provided by the aircraft radar

4.2.2 Active

The missile contains its own complete radar, and is independent of any other equipment. Missile radars are typically small and only operate over the last ten kilometers of the missile attack.

1. Active radar is typically used only for the terminal
2. Command guided - the missile has a data-link receiver.

The aircraft sends inertial coordinates of the target location to the missile. The missile then guides itself toward the location to which it is commanded. This is typically used only in midcourse. The terminal engagement demands a different method, often-active radar guidance.

4.3 Applications of CW Doppler Radar

The Doppler Effect was first recognized and predicted by Doppler (and Fizeau) in the early 1800's, but had never been observed to that date. Why not? Well, the obvious way to test it is with *sound,* which is a periodic effect: a sound wave moves through the air, causing a periodic compression and rarefaction of the density of the particles in the air (like the waves passing through the big `slinky toy' which I used in a classroom demonstration). Before the 1800's, however, motion was too slow to provide any everyday examples of how this would affect our perception of sound. The development of fast-moving trains changed that. Doppler recognized the opportunity this provided, and conducted an experiment using a train moving at about 60 km/h. He had a group of musicians stand in an open rail carriage and play a note on their trumpets - an "A", let us say. Another group of musicians were asked to stand in the ditch beside the train track. They had perfect pitch, and were able to tell what the note sounded like as the train approached. It was indeed raised in pitch (i.e. had a higher apparent frequency) as the train approached - it sounded like an A-sharp.

One job of the APG-70 is to locate aircraft flying close to the ground while the F-15E is flying well above them (20,000 - 30,000 feet above them for example). Pulse radar looking down on the earth would see EVERYTHING -- mountains, buildings, lakes, and the aircraft. This would make it difficult (or impossible) to find an aircraft flying at low altitude. A continuous wave radar (or other radar using Doppler technology) will only "see" objects that are moving (the radar's computer will filter out the speed of the F-15E). Thus, the Doppler shift gives advanced radars like the APG-70 the ability to see aircraft flying at very low altitudes.

Another example of radars using the Doppler shift is in detecting wind shear (a rapid change in the direction and speed of wind, a by-product of thunderstorms that can be deadly to aircraft during takeoff and landings). New radars using computer and Doppler technology are able to see the wind shear and provide warnings to pilots. Older radars were unable to provide this life saving information. In the midst of war, the most significant peacetime application of RADAR was discovered. During the war, RADAR operators continually found precipitation, like rain and snow, appearing in their RADAR fields.

Scientists had not known that RADAR would be sensitive enough to detect precipitation. Only during the war did the use of RADAR to study weather become obvious. Ian C. Browne and Peter Barrett of the Cavendish Laboratories at Cambridge University in England made the first application of pulsed-Doppler radar principles to meteorological measurements in the spring of 1953. Barrett and Brown showed that the shape of the Doppler spectrum agreed with the spectrum expected from raindrops of different sizes falling with different speeds. With the advent of computers, Doppler radars have become a widely used tool in forecasting and analysis of many meteorological features. Today, RADAR is an essential tool for analyzing and predicting the weather. Doppler radar can give a picture of the winds within a storm. If, within a small area, high winds toward the radar are adjacent to high winds away from the radar, a circulation has developed and forecasters prepare to issue a warning. Rainfall is typically estimated from radar data with a Z-R relationship, which converts bulk reflectivity to a rainfall rate. Several "stock" Z-R relationships exist, for different types (convective, Stratford, winter, tropical) of storms. Direct use of the "stock" relationships may give errors of O (50-100%). Use of more sophisticated correction techniques, or local measurement of precipitation drop size spectra, may bring these down to O (30-50%). The real advantage of radar is that it can measure the full extent of the precipitation field over large areas, whereas gauge networks are often widely spaced point measurements. For hydrological applications such as basin modeling and flood prediction, this makes radar data competitive with rain gauges, particularly when integrating over the life of a storm.

Pulsed-Doppler radar was developed during World War II to better detect aircraft and other moving objects in the presence of echoes from sea and land that are illuminated by microwave emissions through side-lobes of the antenna's radiation pattern. Although pulsed-Doppler radar was developed in the early 1940s, Doppler effects were observed in radio receivers when echoes from moving objects were received simultaneously with direct radiation from the transmitter or scattered from fixed objects. The earliest pulsed-Doppler radars were called MTI (moving target indication) radars in which a coherent continuous-wave (CW) oscillator, phase-locked to the random phase of the sinusoid in each transmitted pulse, is mixed (i.e., belated) with the echoes associated with that pulse. The mixing of the two signals produces a beat or fluctuation of the echo intensity at a frequency equal to the Doppler shift.

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Barrett and Brown showed that the shape of the Doppler spectrum agreed with the spectrum expected from raindrops of different sizes falling with different speeds.

With the advent of computers, Doppler radars have become a widely used tool in forecasting and analysis of many meteorological features. Presently, the National Weather Service is deploying a network of 135 Doppler radar units at selected weather stations within the continental United States. The radar network, called NEXRAD (an acronym for *Next* Generation Weather *Rad*ar) is replacing the aging conventional radar units. Here is the current network. The NEXRAD system consists of the WSR-88D Doppler radar and a set of computers that perform on a variety of functions. The computers take in data, display it on a monitor, and run algorithms that, in conjunction with other meteorological data, detect severe weather phenomena, such as storm cells, hail, mesocy-clones, and tornadoes.

4.4 Principle of Operation

As opposed to pulsed radar systems, continuous wave (CW) radar systems emit electromagnetic radiation at all times. Conventional CW radar cannot measure range because there is no basis for the measurement of the time delay. Recall that the basic radar system created pulses and used the time interval between transmission and reception to determine the target's range.

If the energy is transmitted continuously then this will not be possible. CW radar can measure the instantaneous rate-of-change in the target's range. This is accomplished by a direct measurement of the *Doppler shift* of the returned signal. The Doppler shift is a change in the frequency of the electromagnetic wave caused by motion of the transmitter, target or both. For example, if the transmitter is moving, the wavelength is reduced by a fraction proportional to the speed it is moving in the direction of propagation. Since the speed of propagation is a constant, the frequency must increase as the wavelength shortens. The net result is an upward shift in the transmitted frequency, called the Doppler shift.

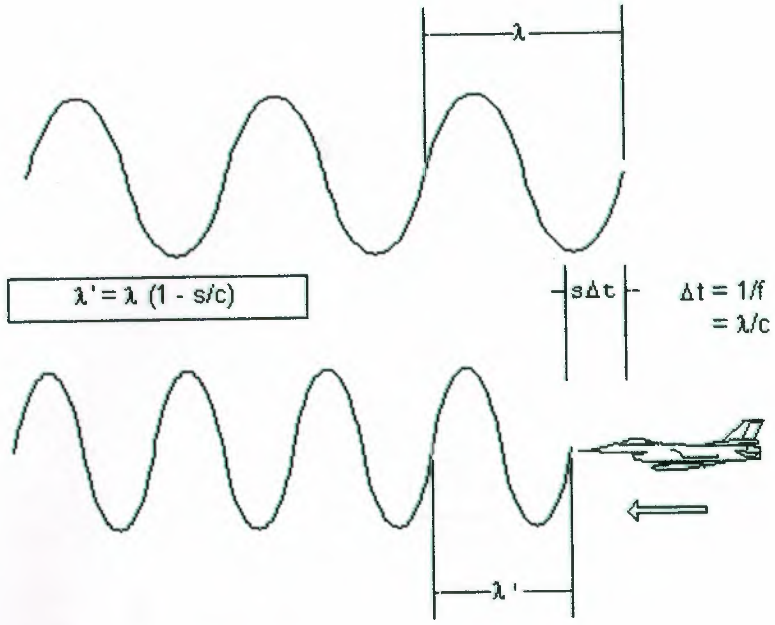


Figure 4.1 Doppler shift from moving transmitter

Likewise, if the receiver is moving opposite to the direction of propagation, there will a increase in the received frequency. Furthermore, a radar target which is moving will act as both a receiver and transmitter, with a resulting Doppler shift for each. The two effects caused by the motion of the transmitter/receiver and target can be combined into a net shift the frequency. The amount of shift will depend of the combined speed of the transmitter/receiver and the target along the line between them, called the *line-of-sight* (LOS).

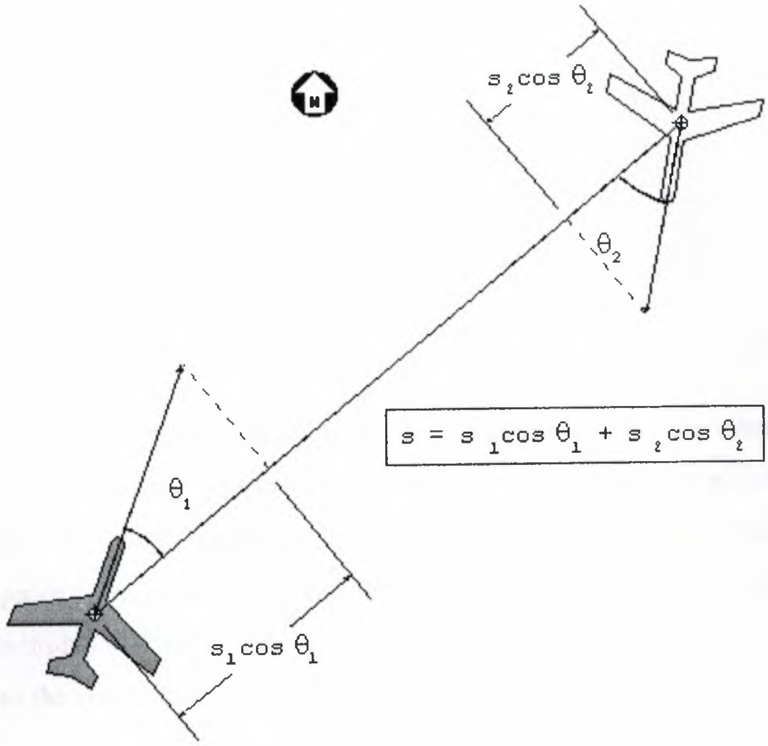


Figure 4.2 Calculating the relative speed in the line-of-sight.

The Doppler shift can be calculated with knowledge of the transmitter/receiver and target speeds, here designated as s_1 and s_2 respectively, and the angles between their direction of motion and the line-if-sight, designated θ_1 and θ_2. The combined speed in the line-of-sight is

$$s = s_1 \ \cos\theta_1 + s_2 \cos\theta_2 \tag{4.1}$$

This speed can also be interpreted as the instantaneous rate of change in the range, or *range rate.* As long as the problem is confined to two-dimensions, the angles also have simple interpretations: θ_1 θ_2 the relative bearing to the target. The difference between the course of the transmitter/receiver and the true bearing to the target. This follows the old nautical rule:

$$R = T - H \tag{4.2}$$

where:

R Is Relative Bearing.

T Is True Bearing.

H Is Heading

Due to the characteristics of the cosine function, it makes no difference whether angle is positive or negative (strictly speaking, relative bearings are always positive and range from 0 to 359^0). θ_2 = the target angle (relative bearing of transmitter/receiver from target). Computed in an identical manner as the relative bearing, except that the target's course is substituted for the heading and the reciprocal bearing is used instead of the true bearing to the target. The reciprocal bearing is found by:

$$R_c = T_B \tag{4.3}$$

Where:

R_c Is Reciprocal Bearing

T_B Is True Bearing 180^0

Again, it does not matter is this result is positive, negative or even beyond 360^0, although the proper result would be in the range of $0\text{-}359^0$. Assuming that the range rate is known the shift in returned frequency is

$$\Delta f = 2s / \Delta \tag{4.4}$$

Where Δ is the wavelength of the original signal. As an example, the Doppler shift in an X-band (10 GHz) CW radar will be about 30 Hz for every 1 mph combined speed in the line-of-sight.

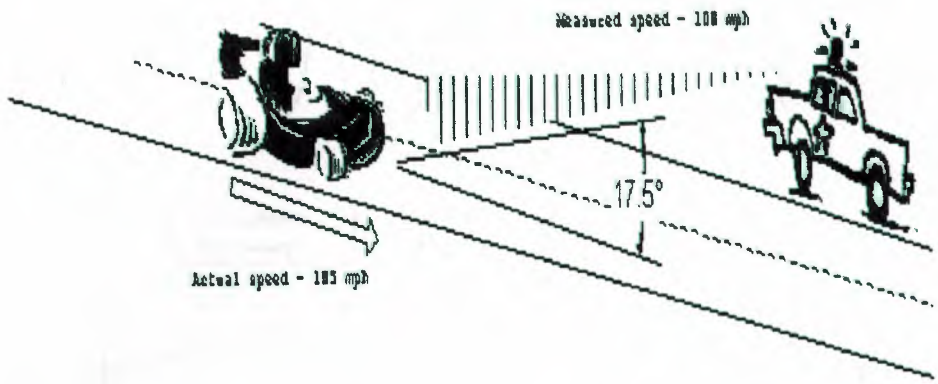


Figure 4.3 CW Doppler radar to measure the speed of cars.

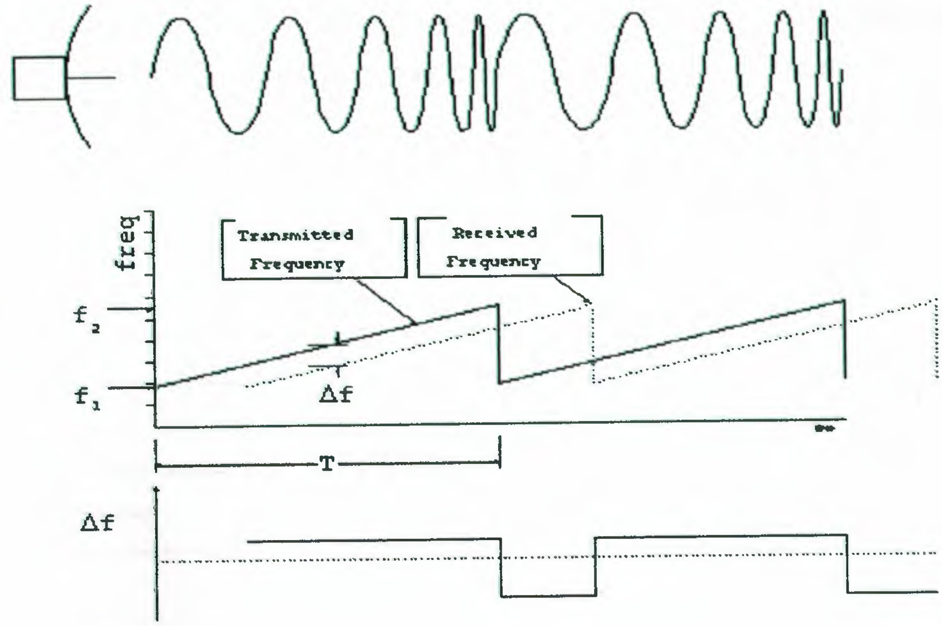
Police often use CW radar to measure the speed of cars. What is actually measured is the fraction of the total speed, which is towards the radar. If there is some difference between the direction of motion and the line-of-sight, there will be error. Fortunately for speeders, the measured speed is always lower than the actual.

CW Doppler radar systems are used in military applications where the measuring the range rate is desired. Of course, range rate can be determined from the basic pulsed radar system by measuring the change in the detected range from pulse to pulse. CW systems measure the instantaneous range rate, and maintain continuous contact with the target.

4.5 Frequency Modulated Continuous Wave (FMCW) Radar

It is also possible to use a CW radar system to measure range instead of range rate by frequency modulation, the systematic variation of the transmitted frequency. What this does in effect is to put a unique "time stamp" on the transmitted wave at every instant. By measuring the frequency of the return signal, the time delay between transmission and reception can be measure and therefore the range determined as before. Of course, the amount of frequency modulation must be significantly greater than the expected Doppler shift or the results will be affected.

The simplest way to modulate the wave is to linearly increase the frequency. In other words, the transmitted frequency will change at a constant rate.



. **Figure 4.4** FMCW theory of operation

The FMCW system measures the instantaneous difference between the transmitted and received frequencies, Δf. This difference is directly proportional to the time delay, Δt, which is takes the radar signal to reach the target and return. From this the range can be found using the usual formula, $R = c\,\Delta t/2$. The time delay can be found as follows:

$$\Delta t = T\,\Delta f/(f_2 - f_1) \qquad \textbf{(4.5)}$$

Where:

f_1 = minimum frequency

f_2 = maximum frequency

T = period of sweep from f_1 to f_2,

and Δf = the difference between transmitted and received.

There is a slight problem, which occurs when the sweep resets the frequency, and the frequency difference becomes negative (as shown in the plot of Δf vs. time).

The system uses a discriminator to clip off the negative signal, leaving only the positive part, which is directly proportional to the range? Here is a system

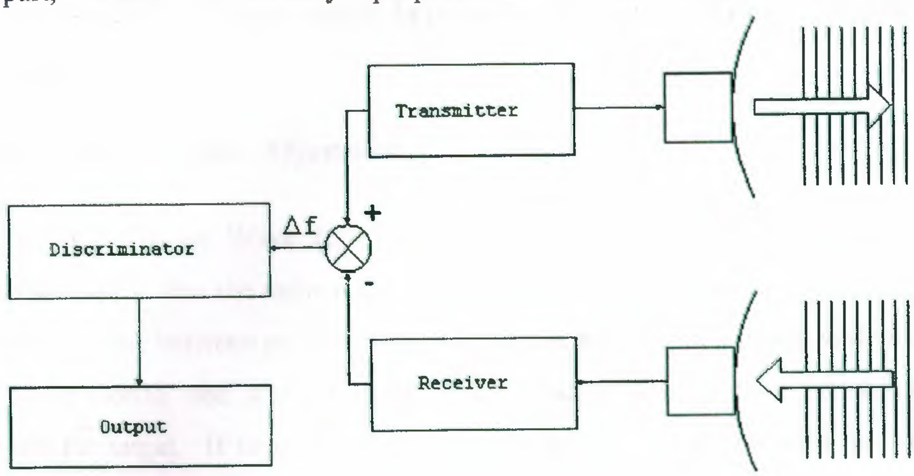


Figure 4.5 FMCW block diagram.

Combining these equations into a single form for the range

$$R = 2cT\Delta f /(f_2 - f_1) \qquad \textbf{(4.6)}$$

Where Δf is the difference between the transmitted and received frequency (when both are from the same sweep, i.e. when it is positive. Another way to construct a FMCW system is to compare the phase difference between the transmitted and received signals after they have been demodulated to receiver the sweep information. This system does not have to discriminate the negative values of Δf. In either case however, the maximum unambiguous range will still be determined by the period, namely

$$R_{\mathbf{unamb}} = cT / 2 \qquad \textbf{(4.7)}$$

FMCW systems are often used for radar altimeters, or in radar proximity fazes for warheads. These systems do not have a minimum range like a pulsed system. However, they are not suitable for long-range detection, because the continuous power level they transmit at must be considerably lower than the peak power of a pulsed system. You may recall that the peak and average power in a pulse system were related by the duty cycle,

$$P_{ave} = DC * P_{peak} \qquad \textbf{(4.8)}$$

For a continuous wave system, the duty cycle is one, or alternatively, the peak power is the same as the average power. In pulsed systems the peak power is many times greater than the average.

4.6 Characteristics / Operation

The Continuous Wave (CW) radar is different from the Pulsed radar previously discussed in that the radar is continuously transmitting a radar signal - meaning there is no rest time between pulses! (Examples: altimeters, weapon fusing systems)

To be able to "see" a target, there must first be "relative motion" between the CW radar and the target. If there is relative motion, the CW radar measures the frequency shift (referred to as Doppler) between the transmitted signal and the returned signal.

If there is no relative motion between the radar and the target, the system is "blind" to the target and will not see it! Here are a few extra "fun facts" about this system.

Duty Cycle = 1 (always transmitting) therefore Peak power = Average power

High SNR (a definite advantage). The CW radar uses two vice one radar antennas - one for transmit the signal and one to receive the return signal. Some means must be employed to protect the receiver (distance, narrow beam-width, and/or shielding). Minimum Detection Range is zero since receiver is never blanked. The <u>*basic*</u> CW radar is unable to determine range since there is no basis for measurement of a time delay between pulses. Determination of the Doppler Shift (Δf) and the Speed *(s)* in the Line of Sight is the most challenging part of this subject (and what you have to demonstrate for me on homework assignments, quizzes and exams).

$$s = s_1 \cos\theta_1 + s_2 \cos\theta_2 \tag{4.9}$$

Always start by drawing a picture! You must also be familiar with relative bearings and target angles.

Reciprocal Bearing = True Bearing + or - 180 degrees (4.10)

4.7 CW Doppler radar components

T - Transmitter: continuous RF oscillator; supplies weak sample signal to mixer

A - Antenna: transmits signal

M - Mixer: determines Doppler shift

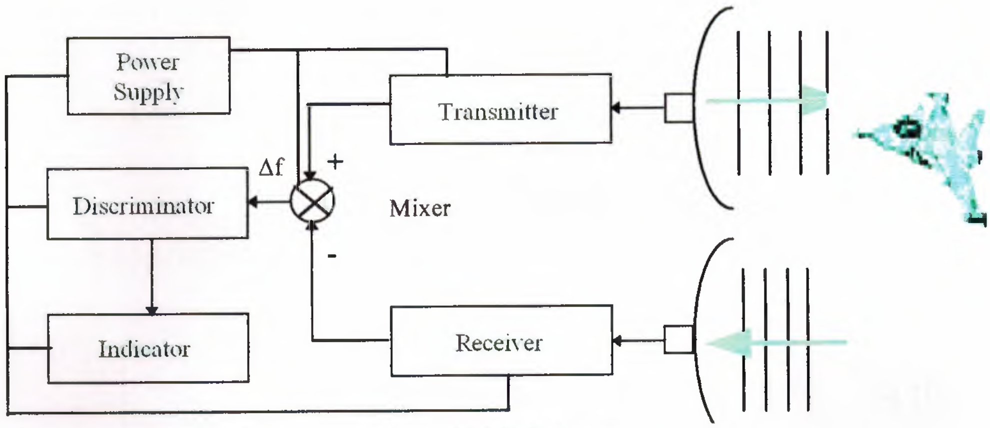
A - Antenna: receives echo

D - Discriminator: amplifies signal and eliminates signal return from stationary targets (noise)

R - Receiver

I - Indicator: scope / display

P - Power Supply



Continuous Wave radar block diagram

Figure 4.6 continuous wave radar block diagrams

Range determination for CW radars. Frequency modulation continuous wave (FMCW) - By linearly increasing (changed at a constant rate) the transmitter output signal frequency over a particular range and then dropping it back to original frequency, this puts a unique "time stamp" on the transmitted signal at every instant. The returned FMCW signal is compared to the transmitted signal and the difference between transmitted and received frequencies is measured. By knowing this frequency difference, time difference can be calculated and subsequently range is determined. An example of the FMCW system is the Altimeter.

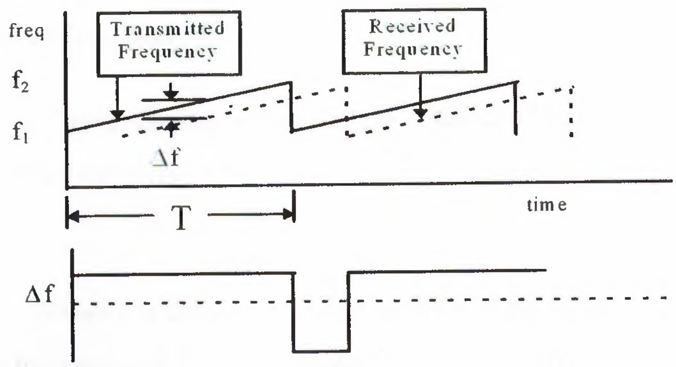


Figure 4.7 FMCW system

$$\Delta t = \frac{T\Delta f}{(f_2 - f_1)} \tag{4.10}$$

where:

f_2= maximum frequency

f_1= minimum frequency

T = period of sweep from f_2 - f_1

Δf = difference between transmitted and received

$$R = \frac{c\Delta t}{2} \tag{4.11}$$

Where R= range and c = speed of propagation.

4.8 Doppler shift Calculations

4.8.1 Determine the Doppler shift

The relationship between radio frequency RF and wavelength is

$$\Delta = c / RF \tag{4.12}$$

Where c is the speed of light and RF is the radio frequency

The Doppler frequency of the reflected wave of radar is given by

$$f_{doppler} = 2v / \Delta \quad \textbf{(4.13)}$$

4.8.1.1 Air-to-air Doppler

An airborne is flying directly radar toward a target. The relationship between radio frequency RF and wavelength is

$$\Delta = c / RF \quad \textbf{(4.14)}$$

Where c is the speed of light and RF is the radio frequency

The Doppler frequency of the reflected wave of radar is given by

$$f_{doppler} = 2(v_{radar} + v_{Target} \cos\theta) / \Delta \quad \textbf{(4.15)}$$

Where θ is the angle from the target velocity vector to the radar's flight path.

4.8.1.2 Air-to-ground azimuth Doppler

The relationship between radio frequency RF and wavelength is

$$\Delta = c / RF\,, \quad \textbf{(4.16)}$$

where c is the speed of light and RF is the radio frequency

The Doppler frequency of the reflected wave of radar from the ground is given by

$$f_{doppler} = 2v_{radar} * \cos(Azimuth) * \cos(Elevation) / \Delta \quad \textbf{(4.17)}$$

4.9 Frequency-modulation method

In the frequency-modulation method, the transmitter radiates radio-frequency waves. The frequency of these RF waves is continually increasing and decreasing from a fixed reference frequency. At any instant, the frequency of the returned signal differs from the frequency of the radiated signal. The amount of the difference frequency is determined by the time it took the signal to travel the distance from the transmitter to the object. An example of a frequency-modulated signal, plotted against time, is shown in figure4.8. As shown, the 420-megahertz frequency increases linearly to 460 megahertz and then quickly drops to 420 megahertz again. When the frequency drops to 420 megahertz the frequency cycle starts over again.

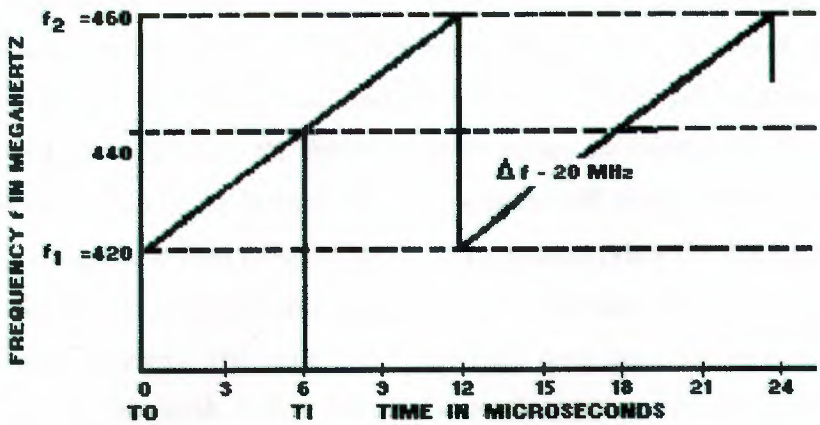


Figure 4.8 Frequency-modulation chart.

The frequency regularly changes 40 megahertz with respect to time; therefore, its value at any time during its cycle can be used as the basis for computing the time elapsed after the start of the frequency cycle.

For example, at T0 the transmitter sends a 420-megahertz signal toward an object. It strikes the object and returns to the receiver at T1, when the transmitter is sending out a new frequency of 440 megahertz. At T1, the 420-megahertz returned signal and the 440-megahertz transmitter signal are fed to the receiver simultaneously. When the two signals are mixed in the receiver, a beat frequency results. The beat frequency varies directly with the distance to the object, increasing as the distance increases. Using this information, you can calibrate a device that measures frequency to indicate range. This system works well when the detected object is stationary. It is used in aircraft altimeters, which give a continuous reading of the height above the earth of the aircraft. The system is not satisfactory for locating moving objects. This is because moving targets produce a frequency shift in the returned signal because of the Doppler effect; this affects the accuracy of the range measurement.

4.10 Pulse-modulation method

The pulse-modulation method of energy transmission was analyzed to some extent earlier in this chapter. As the previous discussions indicated, radio-frequency energy can also be transmitted in very short bursts, called pulses. These pulses are of extremely short time duration, usually on the order of 0.1 microseconds to approximately 50 microseconds. In this method, the transmitter is turned on for a very short time and the pulse of radio-frequency energy is transmitted, as shown in view A of figure 1-22. The transmitter is then turned off, and the pulse travels outward from the transmitter at the velocity of light (view B). When the pulse strikes an object (view C), it is reflected and begins to travel back toward the radar system, still moving at the same velocity (view D). The pulse is then received by the radar system (view E). The time interval between transmission and reception is computed and converted into a visual indication of range in miles or yards. The radar cycle then starts over again by transmitting another pulse (view F). This method does not depend on the relative frequency of the returned signal or on the motion of the target; therefore, it has an important advantage over CW and fm methods.

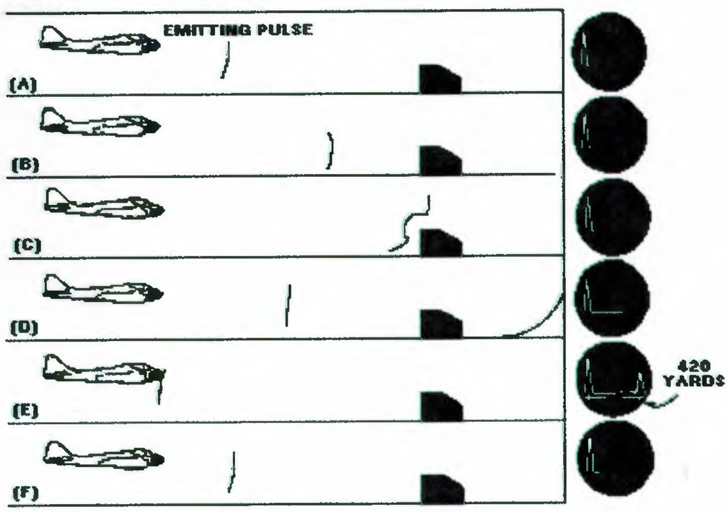


Figure 4.9 Pulse detection

4.11 Pulse-Doppler method

Pulse radar systems may be modified to use the Doppler Effect to detect a moving object. A requirement for any Doppler radar is COHERENCE; that is, some definite phase relationship must exist between the transmitted frequency and the reference frequency, which is used to detect the Doppler shift of the receiver signal. Moving objects are detected by the phase difference between the target signal and background noise components. Phase detection of this type relies on coherence between the transmitter frequency and the receiver reference frequency. In coherent detection, a stable CW reference oscillator signal, which is locked in phase with the transmitter during each transmitted pulse, is mixed with the echo signal to produce a beat or difference signal. Since the reference oscillator and the transmitter are locked in phase, the echoes are effectively compared with the transmitter in frequency and phase.

The phase relationships of the echoes from fixed objects to the transmitter are constant and the amplitude of the beat signal remains constant. A beat signal of varying amplitude indicates a moving object.

This is because the phase difference between the reference oscillator signal and the echo signal changes as the range to the reflecting objects changes. The constant amplitude beat signal is filtered out in the receiver. The beat signal of varying amplitude is sent to the radar indicator scope for display.

CONCLUSION

Radar is a radio sensor general (but not always) operating in the micorwave frequency range (>1 GHz), and is an active sensor. Here the world active indicates that the sensor radiates energy (electromagnatic wave) toward the surrounding environment and extracts information about it through the analysis of the return echo. Almost all current radars belongs to the class call it "monostatic", i.e. the transmitter and reciver are located together in single equipment : bistatic and multistatic radars, on ther other side, are those having the transmitter and one (or more) recivers located in differnet place.

With tranmitter and receiver located several hundreds of meters away: the receiver detected a single variation when an aircraft was flying above the area between the transmitter and the receiver, those demonstrating the feasbility of radio detiction of flying objects. Common radars are pulsed: the transmitted single is a " short " pulse of radio frequency , repeated priodically. During the time between two transmit pulses, the radars switches to receive mode to collect a return echoes (normally , using the same antenna used for the transmission). For a single – point target (a single - point target is a target having small dimensions compared to the angular and range resolution of the radar. The target characterstic are accounted for through parameter call it cross – section. A single is collected by the receiving antenna proportionally to its effective area.

It must be noted that the received power decreases with the fourth power of the range: to double the radar range, the transmitting must be increased (these applies for a single point target). İf the target is a large surface , we shall take into account that the antenna beam becomes wider of increasing range , increasing the illuminated area and consequently the reflected power. The two types of modulation most widely used in radar systems are the so – call it chirp and the barker code: the former is a linear frequency modulation ; the latter is a discrete (bi- phase) phase modulation . in the receiver , the return signal is correlated with a stored replice of the transmit signal.

For the chrip, it can be done applying the signal (normally ine intermediate frequenct section of the receiver) to dispersive delay line in order to concentrated all the pulse energy in apulse shorter than the original one.

İt is also possible ; taking advantage of the modern digital signal processing techniques, to perform, after analog-to-digital conversion, the convolution of the echo with an ideal single-point-target response (this is normally performed in the frequency domain, following a fast furier transform of the signal , to improve the computational efficiency). The primary purpose of radar systems is to determine the range, azimuth, elevation, or velocity of a target. The ability of a radar system to dtermine and resolve these important target parameters depends on the charactersics of the transmitted radar signal. The indvisually components of radar determine the capabilities limitation of a particular radar system. The characterstic of these compnent is also determined the countermeasuers that will be effective against specifc radar system.

The process the radar antenna uses to search airspace for targets is called scanning or swiping. This chapter will discuss circular, unidirectional, biodiractional, helical, raster, palmer, and concial scans, and track-while-scan (TWS) radar systems. A target tracking radar (TTR) is a designed to provide all the necessary information to guide a missile or aim a gun to destroy and aircraft. Once a target has been detected, either by a detected search radar or by using an acqusition mode, the TTR is designed tp provide accurate target range, azimuth, elevation or velocity information to afire control computer.

As the most common radar which has used continous waves, doppler radar is appeared with advantges made it, has capability to use the doppler effects which cause arround the target and continous waves rather than pulses. İt uses the doppler effects to detect the frequency change caused by a moving target and displays this as a relative velocity. Since transmission here is continous, the circulator is used to provide insulation between the transmitter and reciever. Since transmission is continuos, it would be pointless to use duplexer.

Advanteges , applications and limitations CW Doppler radar is capable of given accurate measurments of relative velocities, using low transmitting powers, simple circuity, low power consumption and equipment whose size is much smaller than that of comparable pulse equipment.

It is unaffected by presence of stationary targets, which it disregarads in much the same manner as MTI pulsed radar. It can operate theoretically down to zero range.

CW Doppler uses the Doppler Effect to extract information on targets radial velocity. The magnitude of the Doppler shift is related to the velocity of a target in a straight line between the target and the aerial. A high value for the Doppler shift indicates a high target velocity. In practice it is the velocity of a target we wish to find, so we work the other way round from the measured value for the Doppler shift and the other known factors.

Continuous wave Doppler radars transmit a constant beam of radar energy. When CW radar illuminates a moving object (such as an aircraft or a car) the radar wave returns to a separate antenna with a frequency that is slightly higher (if the object is moving toward the radar) or lower than the frequency of the original radar energy. By measuring this change of the Doppler shift speed of the object can be determined.

The Doppler shift is a change in the frequency of the electromagnetic wave caused by motion of the transmitter, target or both. The Doppler shift can be calculated with knowledge of the transmitter /receiver and targets speed. The radar receiver can recover the Doppler shift by mixing the transmitted and received signals. Because of the low frequency of the shift with respect to transmitted frequency, the transmitter must operate as a continuous wave (CW) signal. If we send a continuous wave, we lose the power to detect constant delay, but instead we can detect changes in frequency due to the Doppler Effect. If the object is moving toward the antenna – higher frequency.

The amplitude of the detected signal is proportional not only to the input signal amplitude, but also to the relative phase between the received signal and the reference (having used the same oscillators for both transmit and receive, the remaining frequency at the output is just the one due to the Doppler shift).

CW Doppler radar has some disadvantages also. In the first place, it is limited in the maximum power it transmits, and this naturally places a limit on its maximum range. Second, it is rather easily confused when, the presence of a large number of targets.

Finally Doppler radar is incapable of indicating the range of the target. It can only show its velocity, because the transmitted signal is un-modulated. The receiver can not sense with a particular cycle of oscillations is being received at moment, and therefore cannot tell how long ago this particular cycle was transmitted, so that range cannot be measured.

TABLE 1

Frequency Bands and Radar OperationalPropagation Limitations	
LF 30-300 kHz	Allocations are provided in the frequency range but no radar usage or applications have been identified.
MF 300-3000 kHz	Used by continuous wave (CW) radar systems for accurate position location. Very high noise levels are characteristic of this band.
HF 3-30 MHz	Refractive properties of the ionosphere make frequencies in this band attractive for long-range radar observations of areas such as over oceans at ranges of approximately 500-2000 nautical miles. Only a few radar applications occur in this frequency range because its limitations frequently outweigh its advantages; very large system antennas are needed, available bandwidths are narrow, the spectrum is extremely congested with other users, and the external noise (both natural noise and noise due to other transmitters) is high.
VHF 30-300 MHz	For reasons similar to those cited above, this frequency band is not too popular for radar. However, long-range surveillance radars for either aircraft or satellite detection can be built in the VHF band more economically than at higher frequencies. Radar operations at such frequencies are not affected by rain clutter, but auroras and meteors produce large echoes that can interfere with target detection. There have not been many applications of radar in this frequency range because its limitations frequently outweigh its advantages.
UHF 300-3000 MHz	Larger antennas are required at the lower end than at the upper end of the UHF band. As compared to the above bands, obtaining larger bandwidths is less difficult, and external natural noise and weather effects are much less of a problem. At the lower end, long-range surveillance of aircraft, spacecraft, and ballistic missiles is particularly useful. The middle range of this band is used by airborne and spaceborne SAR's. The higher UHF end is well suited for short to

	medium-range surveillance radars.
SHF 3 GHz-30 GHz	Smaller antennas are generally used in this band than in the above bands. Because of the effects of atmospheric absorption, the lower SHF band is better for medium-range surveillance than the upper portions. This frequency band is better suited than the lower bands for recognition of individual targets and their attributes. In this band, Earth observation efforts employ radars such as SAR's, altimeters, scatterometers, and precipitation radars .
EHF 30-300 GHz	It is difficult to generate high power in this band. Rain clutter and atmospheric attenuation are the main factors in not using this frequency band. However, Earth observation efforts are made in this band employing radars such as altimeters, scatterometers, and cloud profile radars.

REFERENCE

[1] www.yahoo.com/radar+system.

[2] www.altvista.com/cw+radar.

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