NEAR EAST UNIVERSITY

Faculty of Engineering

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CW DOPPLER RADAR

Graduation Project
EE- 400

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CHAPTER ONE
INTRODUCTION

Radar (Radio Detection and Ranging) is employed in many forms, from complex air defense networks to simple beacons 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 cancroid is 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. Selection of an operating frequency is determined by atmospheric transmission windows and the function of the radar. 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 radar. Advantages, applications and limitations CW Doppler radar is capable of given accurate measurements of relative velocities, using low transmitting powers, simple circuity,low power consumption and equipment whose size is much smaller than 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.

Before the reader begins to wonder why pulsed radar 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 unmodulated. 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 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. 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.

In chapter one, will present introduction to the project. In chapter two, we talk about radar generally and the most important components of it. In chapter three, will be devoted for studying the principles of CW Doppler radar.

In chapter four, will highlight the applications of CW radar as well as Doppler effects.

Finally in chapter five, we give conclusion of the project.

CHAPTER TWO

FUNDAMENTS OF RADAR

2.1 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 2.4.2; note, 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)

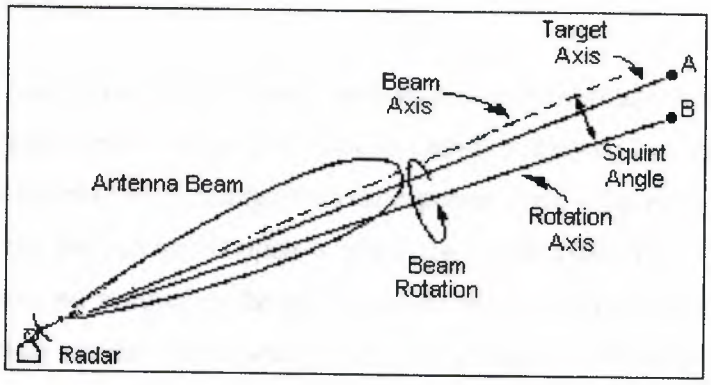

Figure 2.1. Movement of the Radar Beam to Determine Angular Location

2.1.1 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 pulsewidth must locate the target within the accuracy and warhead size of the weapon.

Example: The weapon has a 40 nautical mile maximum intercept range and its kill radius is 300 feet. The pulse travels about 1000 feet per microsecond so that the time to and from the target is 500 microseconds, and the pulse width must be 0.6 microseconds or less. Therefore, the radar cannot pulse faster than about 2,000 times per second with a Pulse Width of 0.6 microseconds.

2.1.1.1 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 pulsewidth 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.

2.1.1.2 Range Jamming

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

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 (PRR) 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). Since 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.

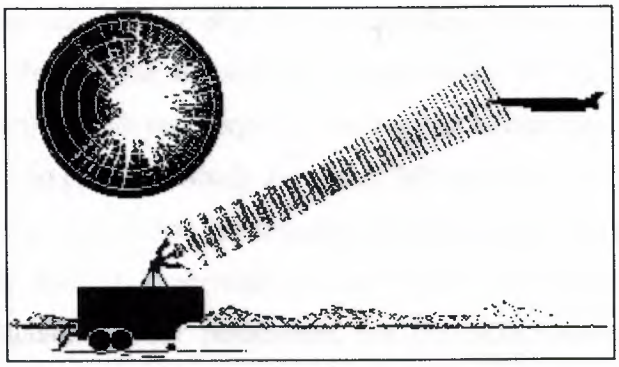

Figure 2.2 Example of Range Jamming

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.

2.1.2 Angle

2.1.2.1 Beamwidth

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

$$\{ (A) (w) \} / s \qquad (2.1)$$

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 falls to 0.707 of the maximum are known as the half-power points and the angular size of the beam between these half-power points is the defined beamwidth of the radar. This definition is always understood when discussing radar parameters, but the difference between the full beamwidth and the defined beamwidth becomes important in EW. Outside the defined beamwidth the power drops very rapidly to the outer edges of the full beamwidth.

2.1.2.2 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 antennae should have the same polarization.

2.1.2.3 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 the power cancroids and align its antenna so that the cancroid is 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 a track-while-scan (TWS) radar. Note that this implies that for best tracking the beamwidth should be larger than the target so that no target exists in adjacent beamwidths.

If the target is bigger than the beamwidth of the radar, the power return will be about equal in several antenna orientations so that the power cancroids will be broad in angle and thus degrade tracking accuracy. If the target is much larger than the beamwidth, 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 .707 of the power cancroids is *assumed* to be from a different beamwidth due to the definition of beamwidth. Therefore, to resolve two targets 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 beamwidth of the radar. The resolution cell of the radar, then, is the solid volume described by one beamwidth 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 systems 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 beamwidth. 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.

2.1.2.4 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 16 dB down from the "main-bang", the jammer must be capable of returning 16 dB more power to the radar than the target normally returns. Side-lobes are spaced about one beamwidth 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".

A second effect caused by large targets is called Effective Beam Broadening. In this case, the portions of the target within the full beamwidth but outside the defined half-power point beamwidth return power to the antenna which equals or exceeds the half-power return. The radar, due to accountability, must credit this to an adjacent orientation of the antenna with the effect being that a defined two-degree beam can actually have a three- or four-degree resolution. Active Deceptive ECM (DECM) also can effectively create angle jamming with ECM transmitters carried on a single aircraft. When a TTR scans a target during track the target return will be modulated at the scan frequency. DECM determines the scan pattern on the target and transmits a stronger signal of opposite modulation.

This will cause the radar to track in the wrong direction for one beamwidth. The radar will then see the target in a second beamwidth, but track has probably been "broken" and must be reacquired. DECM systems are much more complex than simple noise jammers. Angle jamming can also be performed by proper flight tactics. If a formation of aircraft maintains a separation of one beamwidth, then the radar will "see" a large target which appears on the display scope as one target as big as the total beamwidths that the formation occupies. This is particularly effective against systems which use separate Az and El tracking radars and then have computer matched tracking coordinates because the computer must examine every combination of Az and El returns to obtain a match. If the individual aircraft then maneuver *within* their assigned beamwidth, their power centroids will be constantly shifting, merging and separating so that Az-El correlation will be difficult.

When the aircraft are carrying noise jammers, the target cluster becomes two dimensional and automatic target tracking accuracy is degraded. This "cooperative jamming" can be continued to the point that the entire radar display indicator suffers "white-out". For example, in a 2-degree radar with a 16-degree display scope, eight aircraft at 2-degree separations with noise jammers will fill the entire scope with noise (false targets). However, the cancroids of the jamming power are located on the target aircraft so that track, and especially manual track, is still possible.

2.1.2.5 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 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.

2.2 Radar Parameters Used in RWR

2.2.1 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. Selection of an operating frequency is determined by atmospheric transmission windows and the function of the radar. 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 radars operate 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.

2.2.2 Pulse width

Range resolution is at best one-half the distance that the pulse travels in a time equal to the pulsewidth. 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:

Threat radar = short pulsewidth (2.2)

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 pulsewidth. An RWR, then, need normally concentrate on pulsewidth regimes within the range:

$$0.1 \text{ microsecond} < PW < 1 \text{ microsecond}$$

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:

$$0.1 \text{ ms} < PW < 1.5 \text{ ms} = \text{Threat Radar}$$

$$PW > 1.5 \text{ ms} = \text{Non-Threat Radar}$$

Since threat radars are required to have narrow beamwidtns, 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

2.2.3 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 radars are short-range trackers.

(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 pulses 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.

2.2.3.1 Stagger

Several adaptive measures may be assumed by radar to lessen its susceptibility to ECM; one which will make the job of a repeater jammer more difficult is the incorporation of staggered pulse trains. However, the same basic laws of nature apply to exotic pulse train generation (*i.e.*, the elapsed time between any group of pulses cannot be less than the desired maximum range of the radar). The staggered pulse (PRF) repetition frequency also enhances associated radar features such as Moving Target indication by reducing the effects of blind spots in the radar. A staggered pulse train is fundamentally a basic PRF with this same PRF impressed upon it one or more times. Each level of impression (stagger) utilizes a different start time or reference which will preclude the generation of concurrent pulses or pulses shadowing one another. The number of levels (or positions) is the number of times the basic PRF/IPP (inter-pulse period) is integrated in the pulse train.

Figure 2.3 illustrates the time relationship involved in the generation of a 4-level stagger. As mentioned above, each level has the same characteristic PRF and PW, but the Time to First Event (TFE) for each level is different. This has the effect of slewing the masked pulse groups in relation to one another resulting in the desired stagger pattern. The PRF of the radar is the sum of all the pulse trains so that if an RWR operated on PRF, the additional identification inherent in the stagger pattern would not be useful. This problem is overcome by measuring PRI rather than PRF so that the RWR measures the basic PRI a number of times equal to the number of stagger levels.

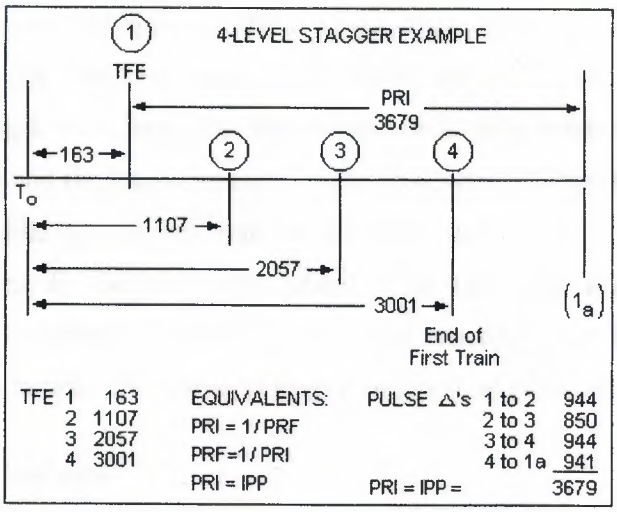

Figure 2.3. Staggered PRF Generation

The example as presented is a 4-level stagger with a basic PRI of 3679. Train number one is initiated at "time-0" +163 and 2, 3, and 4 follow, respectively. The pulse deltas are determined by subtracting the adjacent TFEs.

2.2.3.2 Jitter

The job of the jammer can be made more difficult by the radar's use of a jittered PRI. In Jitter mode, the time between successive pulses, is allowed to vary in a totally random manner over a series of set intervals as long as the maximum range condition is met.

2.2.3.3 Stagger-Jitter Patterns

As long as the maximum range condition is met, an infinite number of PRI patterns can be generated by combining stagger and jitter. The PRI can be modulated by a well-defined function: (a) a sliding PRI very slowly increases/decreases the PRF, (b) a Ramp PRI decreases the interval with a cyclic ramp function, and (c) a modulated PRI varies the intervals in a sinusoidal or triangular manner. Some combinations seemed to be designed to foil processors which use digital analysis.

2.2.4 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.

2.2.4.1 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 a 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-fuzing 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 fuze.

2.2.4.2 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 boresited 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.

2.2.4.3 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 which 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 fuze. 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.

2.2.4.4 Fuse Jamming

Both command guidance and beam riders are susceptible to tracking radar and fuze jamming. The simplest fuze is the radar proximity type which sends out a rather broadbeamed 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 fuze receiver the warhead is detonated when the kill radius is reached.

This system can be jammed by making the target return much larger than normal so that the warhead is detonated prematurely, outside the kill radius. In countermeasures terminology, fuze 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 fuze jammer transmitters can act as fuze homing devices.

2.2.4.5 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 superheterodyne 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 fuze signal is questionable since fuze power is so low that no real warning will be obtained. That is, fuze 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 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 4, 5, 6, 7 and 8.

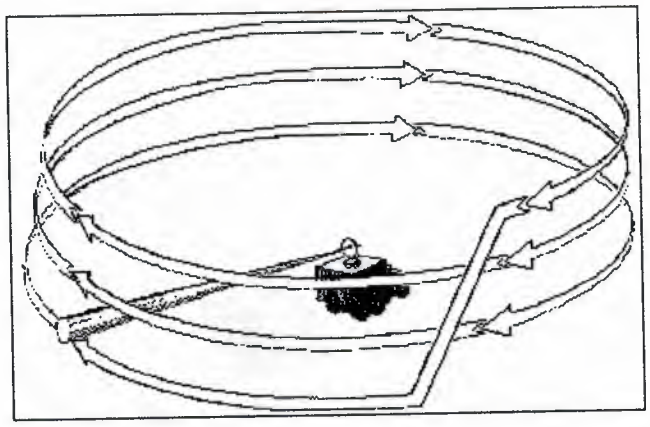

Figure 2.4. Radar System Using Helical Scan with Pencil Beam

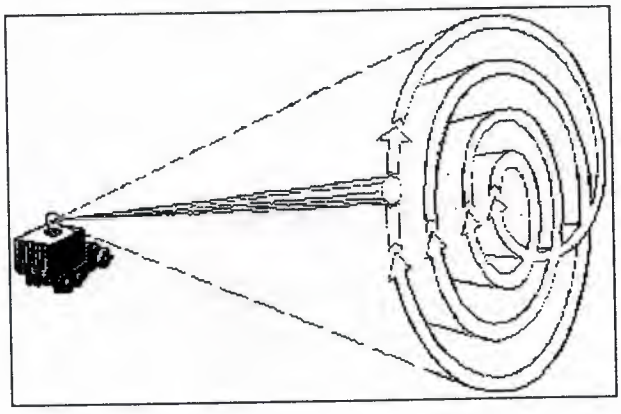

Figure 2. 5. Radar Using Spiral Scan with Pencil Beam

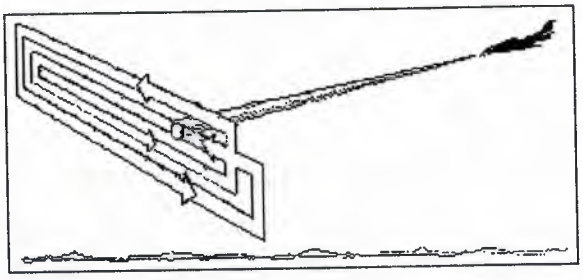

Figure 2.6. Airborne Intercepter Radar with Raster Scan

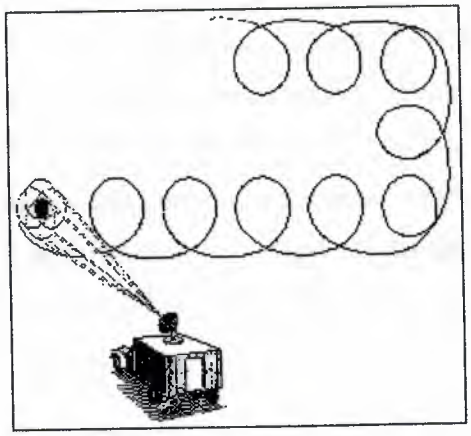

Figure 2.7. Ground Radar with Palmer-Raster Scan

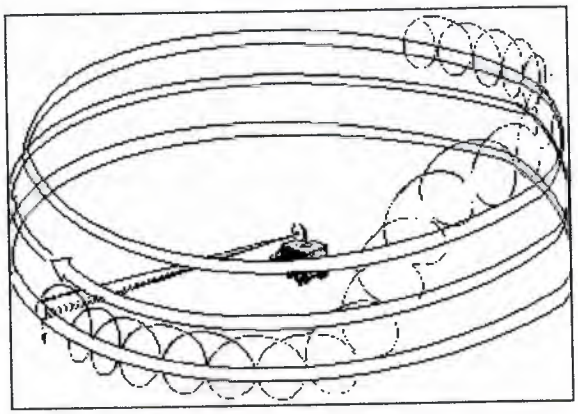

Figure 2.8. Radar using Combination Palmer-Helical Scan

2.2.5 Scan

2.2.5.1 Conical Scan

Radar systems can be categorized by their Scan patterns. The most commonly used today is the Conical Scan, or Con Scan pattern (see Figure 2). In this method, the radar rotates its beam about the circle described by the half-power points of the beam when the beam is boresighted on the target. The beam, when received at the target or at the radar, will be a sinusoidal waveshape whose amplitude is proportional to the distance the target is away from the boresight. 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.

Note that the more accurately the radar tracks the target, the smaller the amplitude of the sine wave, until zero amplitude implies that the radar is exactly boresighted on the target. Con Scan systems require a minimum amount of hardware and therefore are commonly used on inexpensive, mobile systems such as AAA or mobile SAM sites. They suffer the serious disadvantage of not being able to see a target outside their narrow scan patterns. This means that not only is a second radar required to help it find the target (to "acquire the target") but also the tracked aircraft can easily "escape" if it is successful in breaking track since the Con Scan radar cannot see the target, except in the track mode.

2.2.5.2 Track-While-Scan

Con Scan problems can be overcome with Track-While-Scan (TWS) radars. 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 highly vulnerable to ECM jamming. An illustration of TWS radar is shown in Figure2. 9.

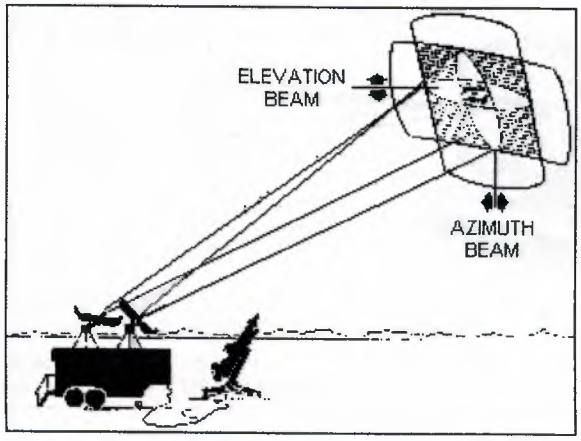

Figure 2. 9. Track-While-Scan Radar

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.

2.2.5.3 Monopulse Scan

Scan can also be accomplished by sequentially pulsing several antennae or sections of a large antenna. This is illustrated in Figure 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.

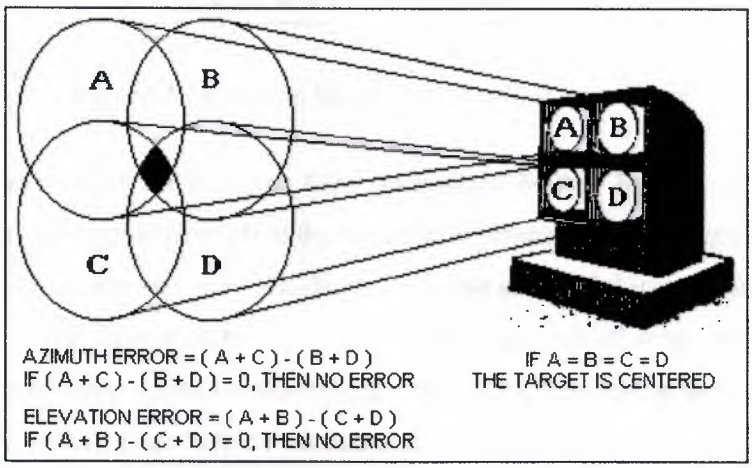

Figure 2.10. Diagram of Monopulse Radar Beam Patterns

2.2.5.4 Received Scan Patterns

Con Scan, TWS, and monopulse radars will cause an RWR to receive pulses with superimposed sinusoidal waveforms. The Con Scan case is shown in Figure 11. The processor identifies these scan patterns by counting the maxima of the sine wave envelope; these maxima are the scan rate of the radar. When a given scan pattern is counted, the Identity Word is updated with this information.

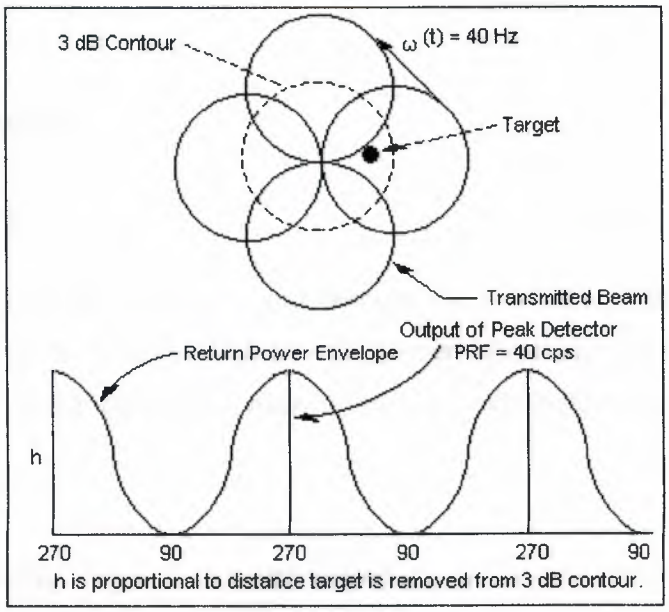

Figure 2.11. Signal Received from Con Scan Radar

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. This lack of scan can be used by the RWR processor 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 boresighted on the target, lack of a scan pattern does not unambiguously identify a radar type.

2.2.5.5 Scan Summary

To summarize, the use of scan by radars to track a target can assist in the identification of a particular radar type. Scan imposes the following considerations on the RWR processor. The scan envelope must be counted to determine scan rate. To ensure the validity of the display, TWS radars must be displayed upon first intercept and must remain displayed for several processor "look cycles" even after the radar appears to be shut down. Lack of scan data can sometimes be used by the processor to identify radar types.

2.3 Types of Radars

2.3.1 Pulse Radars

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 radars, many of the new threat systems are using CW.

2.3.2 CW Radars

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 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 20 kHz.

2.3.3 Radars Other Than SAM Fire Control

Any air defense network will be composed of many radars 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.

2.3.3.1 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.

2.3.3.2 Acquisition Radars

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

2.3.3.3 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 autotrack or associated weapon, it presents no real threat. These radars are primarily used for vectoring airborne interceptors.

2.3.3.4 Ground Controlled Intercept Radars

Ground Controlled Intercept (GCI) systems are usually composed of acquisition and height finder radars. They are used to vector interceptor aircraft to an intruding force.

2.3.3.5 Ground Controlled Approach Radars

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

2.3.3.6 Anti-Aircraft Artillery Radars

Anti-Aircraft Artillery (AAA) fire control radars operate much the same as missile TTRs in that, after target acquisition, auto-track is accomplished by the radar computer and some sort of scanning method. 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 scanning (Con Scan).

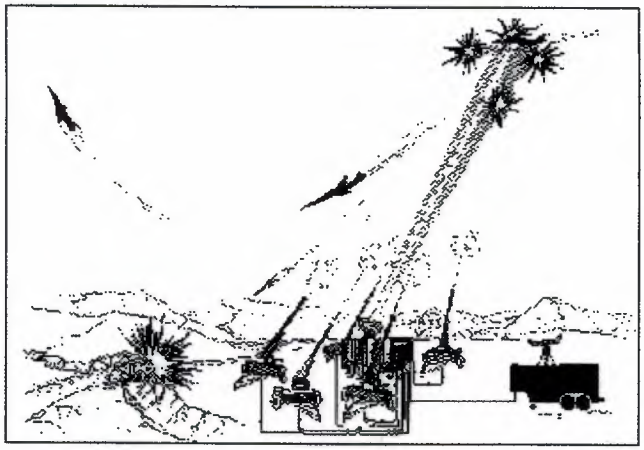

Figure 2.13. Typical AAA Battery in Operation

2.3.3.7 Airborne Interceptor Radars

Airborne Fire Control (AI) systems are used for Airborne Interceptor Missiles (AIM) guidance. The cockpit operator manually acquires the taret by training the antenna; auto-track is then usually accomplished by some scanning method or frequency (Doppler) track.

2.3.3.8 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 headings.

CHAPTER THREE

CW DOPPLER RADAR

3.1 CW Radars

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 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 vary up to 20 kHz.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 20 kHz (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 the 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 slew 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 Figure3. 1.

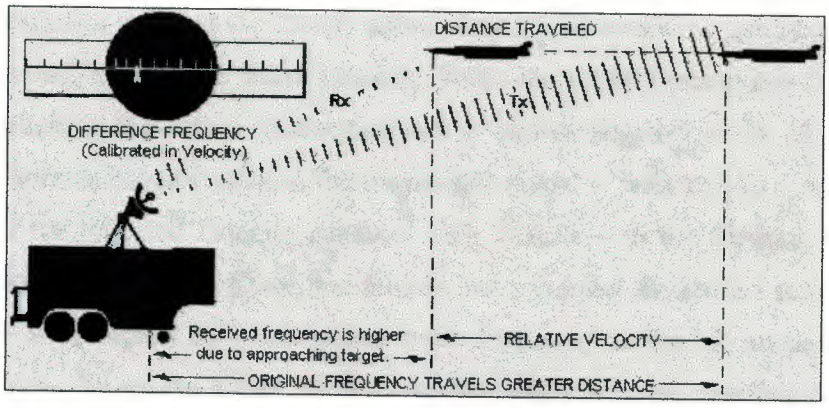

Figure 3.1 CW Doppler Radar Fire Control System

In this case, the ground site CW Illuminator (CWI) radar radiates the target. The missile has both forward- and aft-looking antennae 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 = O, 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 radars 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 two excellent ECCM techniques -- coherency and home on jam. A continuous wave can be modulated by an ultra-low frequency signal. If an 85 Hz modulation is used, the period for one cycle is about 2000 nm. Thus, at normal SAM racking ranges, the phase of the 85 Hz 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 jamming 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 - FM - PM continuous wave. For Pulse Doppler, such as airborne interceptor pulse Dopplers (AIPDs), this same signal would be interrupted periodically for transmission of several ranging pulses or pulse groups (*i.e.*, stagger, jitter or both).

3.1.1 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 -- higher 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)

3.1.2 Frequency-modulated CW Radar

One application of F.M.C.W. Radar is in aircraft altimeters. The normal barometric altimeter is operated by air pressure and has two limitations: If the atmospheric pressure changes while the aircraft is in flight the altimeter reading will change. 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.

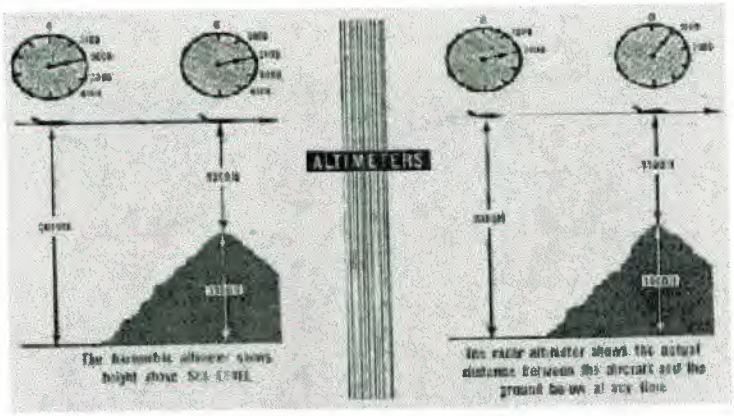

Figure 3.2 Barometric and radar altimeters

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 f.m.c.w. radar altimeter.

3.1.3 Radar Altimeters Using Frequency Modulation

The principles of frequency modulation are considered elsewhere. Basically in a F.M. 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 C.W. output whose frequency is varied by the modulating signal. Let us suppose that the frequency of a F.M. Transmitter is caused to deviate at a constant rate by using a sawtooth waveform as the modulating signal. 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 F.M.C.W. Radar altimeter.

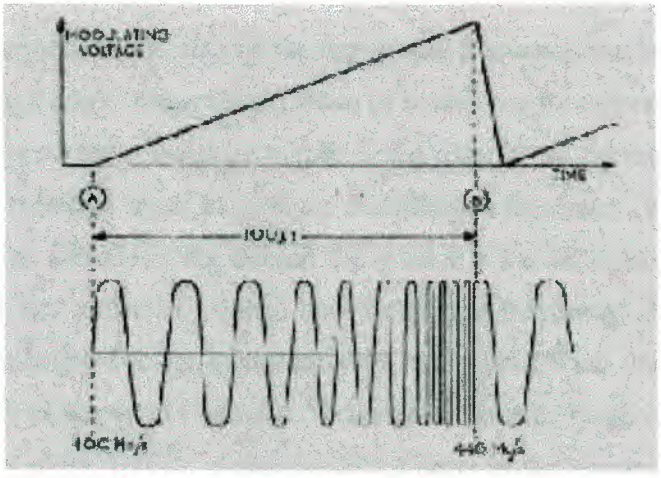

Figure 3.3 Frequency modulation with a sawtooth modulating signal

Figure3.4 illustrates the layout of a typical F.M.C.W. 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

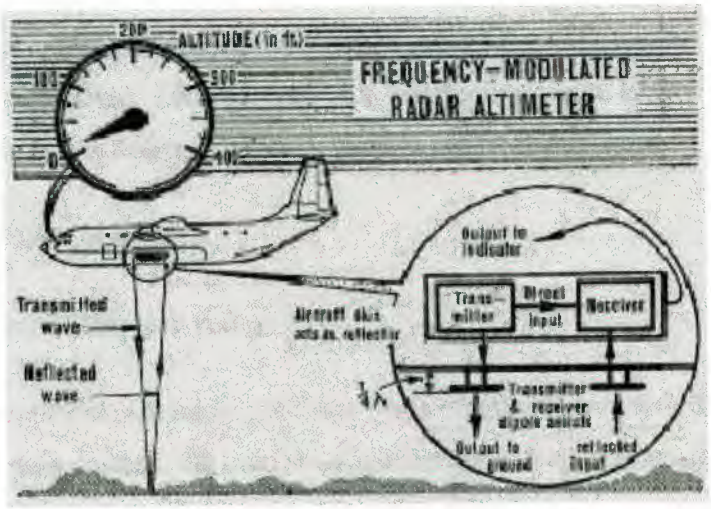

Figure 3.4 typical FMCW radar altimeter layout

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 Figure3.5. 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.

In general we can say that F.M.C.W. 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.

3.2 THE DOPPLER RADARS

3.2.1 Brief 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. Furth 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. 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. The first application of pulsed-Doppler radar principles to meteorological measurements was made by Ian C. Browne and Peter Barratt of the Cavendish Laboratories at Cambridge University in England in the spring of 1953. Barratt 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. 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 sidelobes 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.

Although the PVDF wires do a good job of measuring foot dynamics and position, another system was necessary to complete the impressive sensing by tracking movement of the arms and upper body. A pair of microwave motion sensors, as indicated in Figure 1, was used for this task. The sensor heads are composed of a simple, inexpensive circuit board containing a single-transistor, 2.4 gigaHertz (GHz) CW oscillator, coupled to a 4-element micropatch antenna, which forms a broadside beam roughly 20deg. in width (although with significant sidelobes). As the radiated output is below 10 milliwatts, this system is entirely safe and well within regulation. Since nonconductive material does not significantly absorb this signal, these antennas can be easily hidden behind walls, projection displays, etc.

Doppler-shifted reflections from a performer moving within the beam return to the antenna, where they are mixed with the transmitted signal in a hot carrier diode. This produces beat frequencies in the range of 0-5 kilohertz (kHz) that directly represent the performer's dynamic state (the frequency is a function of velocity, and the beat amplitude is a combined function of the size and distance of the reflecting object). Two such diodes, placed roughly an eighth-wavelength apart, produce a quadrature pair of signals, thus their correlation determines the direction of motion along the antenna boresight. These radars respond to motion within a range of at least 15 feet. Rather than process the Doppler signals in the Fourier domain, a simple analog signal conditioner was designed to minimize real-time computing requirements. This circuit produces three analog signals for each radar head.

One of these is just the low-pass filtered amplitude envelope of the Doppler beats; this corresponds to the amount of general motion that the radar detects. First high-pass filtering the Doppler beats before detecting the envelope derives another; the amplitude of this signal corresponds to the detected velocity. A third signal is derived from an analog correlation between the signals produced by the diode pair; the polarity of this voltage indicates the direction of detected motion. These 3 signals were 8-bit digitized at roughly 50 Hz, and directly used by the music-generating algorithm.

3.2.2 Doppler effect

Many radars use the Doppler Effect to extract information on targets radial velocity (almost all radars designed to detect aerial targets use the Doppler Effect to discriminate moving objects from the undesired fixed echoes). A signal having wavelenght 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. In the case of radar, this effect occurs twice, on the radar-target and target-radar paths: the total Doppler shift is then:

$$\Delta f = 2.v/\lambda \qquad (3.1)$$

At the normal radar frequencies, and for relative speeds in the order of tens or few hundreds m/sec (typical of aircrafts), the Doppler shift is in the kHz range, the same order of magnitude of the PRF, and a period much shorter than the pulse width. This makes impossible to discriminate the frequency shift within the pulse. All radars exploiting the Doppler information use the same reference oscillators (characterized by high short-term frequency stability) in both the transmit and receive chains. The local oscillator LO1 is the same for both chains. The received signal, instead of being demodulated using an envelope detector, is compared (normally using two channel having a 90 deg relative phase shift to extract the sin and cosin components of the signal) with the transmission reference frequency LO2 - the same used to generate the intermediate frequency transmit pulse - in a phase detector (a balanced mixer characterized by low offset voltage).

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).

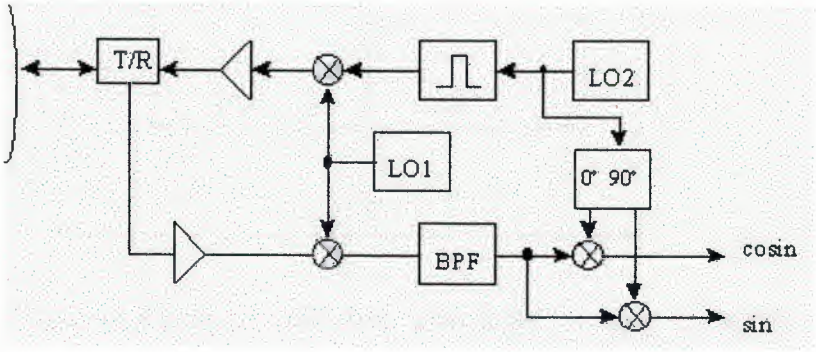

Figure 3.5 two channels, sin-cosin demodulator

A return echo from a fixed target will have a zero Doppler shift, and then a constant phase: all the return pulses from it will have the same amplitude after demodulation. If there is a Doppler shift, the phase will change from pulse to pulse, and the amplitude of the demodulated signal will also change. Using two channels, sin-cosin demodulator, it is possible to unambiguously recover the phase of the return echo. In other words, it is like as the envelope of the Doppler frequency is sampled at the pulse repetition frequency. Which depicts the echoes of the same target in different PRIs at the output of the phase detector, together with the envelope of the Doppler frequency? According to the sampling theorem, to avoid ambiguities in the measurement of the Doppler frequency, the PRF must be, at least, twice the Doppler frequency. This calls for the use of high PRFs, in conflict with the unambiguous range requirement discussed above. Ambiguities resolution techniques using staggered PRFs partially allow conciliating these two requirements.

It must also be noted that, in many cases, the Doppler ambiguity is not of concern, being the Doppler shift used only to discriminate - and to cancel - all targets below a certain Doppler shift, i.e. the fixed targets. For these systems, the only problem related to the Doppler ambiguity occurs when a target has a Doppler shift which is an integer multiple of the PRF: it will be detected as a constant amplitude - zero Doppler - return and then cancelled like a fixed echo.)

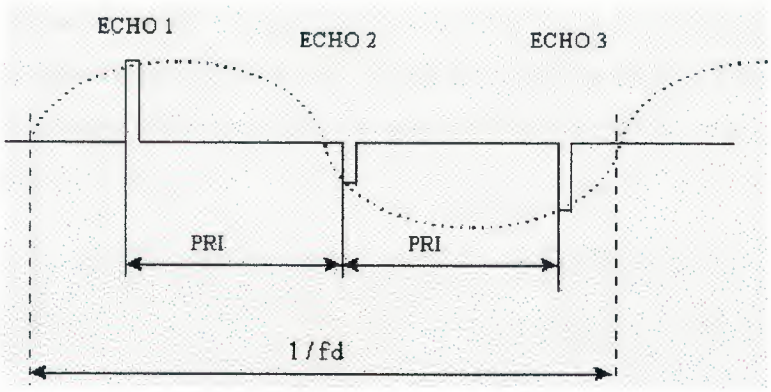

Figure 3.6 Doppler shift which is an integer multiple of the PRF

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. Radars of this class, but with a moderate range resolution capability thanks to a frequency modulation of the signal carrier (FM-CW radars) are used for special applications (illuminating radars for missile guidance). 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 4). 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.

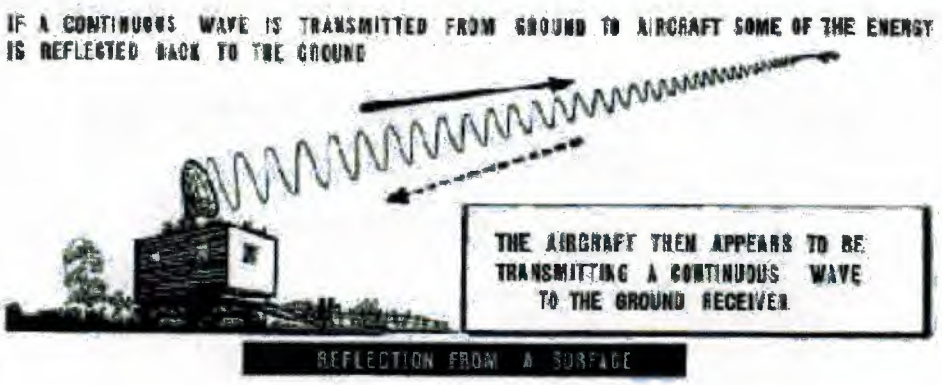

Figure 3.7 reflection of radio waves from a surface

There is however another phenomenon associated with all wave propagation, which is used in unmodulated C.W. radar. If you are watching a motor-cycle race you may notice that the note of the exhaust noise appears to change as the machine passes. This is illustrated in Fig 5.

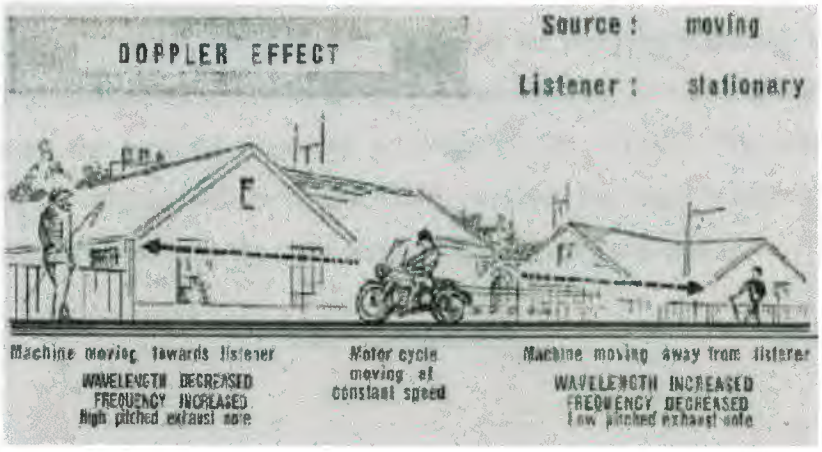

Figure 3.8 Doppler Effect with sound waves

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.

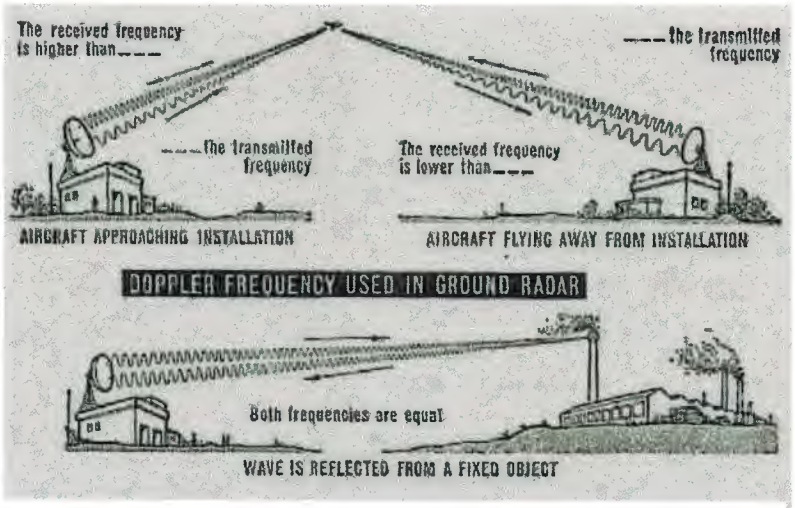

Figure 3.9 Doppler Effect with radio waves

If the transmitted frequency is Ft and the new frequency to which it is changed by the Doppler Effect is Fr, the difference between these two frequencies is known as the Doppler shift Fd = Ft~Fr

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. Fr = Ft+Fd. If the target is moving away the received frequency is lower, i.e. Fr = Ft-Fd. 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:

$$\mathbf{Fd = (2v/c)Ft,} \qquad \mathbf{(3.2)}$$

Where:

Fd = Doppler shift in c/s

Ft = Transmitted frequency in c/s

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

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

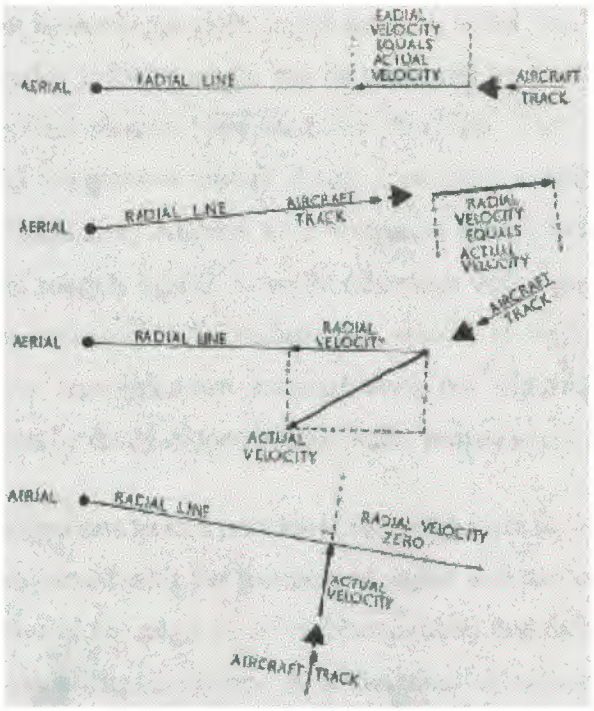

Figure 3.10 Radial Velocity

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 Fd = (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 Fr is Ft + Fd = 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 Fr = Ft - Fd = 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 trans-mitted 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, which Doppler Effect causes, is less. From Figure3.10 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. 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. A pair of microwave motion sensors was used for this task. The sensor heads are composed of a simple, inexpensive circuit board containing a single-transistor, 2.4 gigaHertz (GHz) CW oscillator, coupled to a 4-element micropatch antenna, which forms a broadside beam roughly 20deg. in width (although with significant sidelobes). As the radiated output is below 10 milliwatts, this system is entirely safe and well within regulation. Since nonconductive material does not significantly absorb this signal, these antennas can be easily hidden behind walls, projection displays, etc.

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3.2.3 Use of the Doppler effect in Ground Radar

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

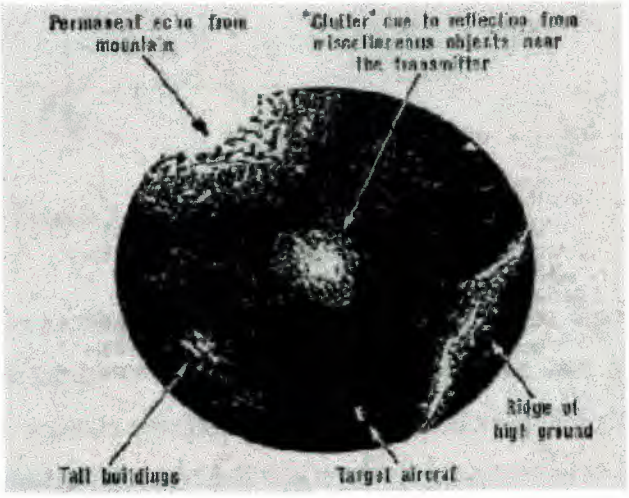

Figure 3.11 Echoes from unwanted objects in pulsed radar

Figure3.12 illustrates a typical arrange-ment for the indication of a moving target. The frequency fr of the reflected signal differs from that of the trans-mitted signal ft by the Doppler shift fd. The reflected signal is mixed with the output of a local oscillator to produce an i.f. signal ($f_{if} \pm fd$) where fd is the Doppler shift. This signal is amplified and fed to a discriminator whose output is either a positive-going or a negative-going d.c. 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.

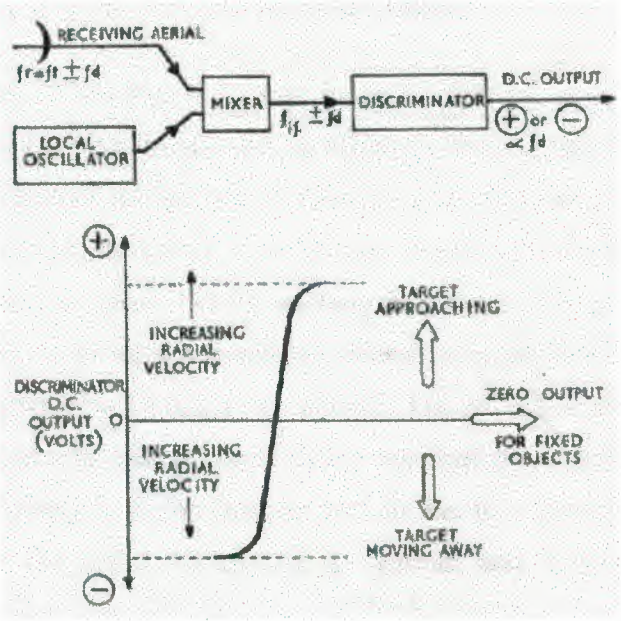

Figure 3.12 Indication of moving targets

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: The presence of a moving target is indicated by the production of a Doppler frequency. Stationary objects provide no change in frequency. The bearing and elevation of the target is determined by using narrow beams. The radial velocity of the target is determined by measuring the Doppler shift in frequency. 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.

3.2.4 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, which 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 fr is higher than the transmitted frequency ft by the Doppler shift fd, i.e. fr = ft + fd. The Doppler shift is deter-mined by the radial velocity of the aircraft and is given as before by the expression

$$fd = (2v/c)\ ft. \qquad (3.3)$$

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. A 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 Figure3.13.

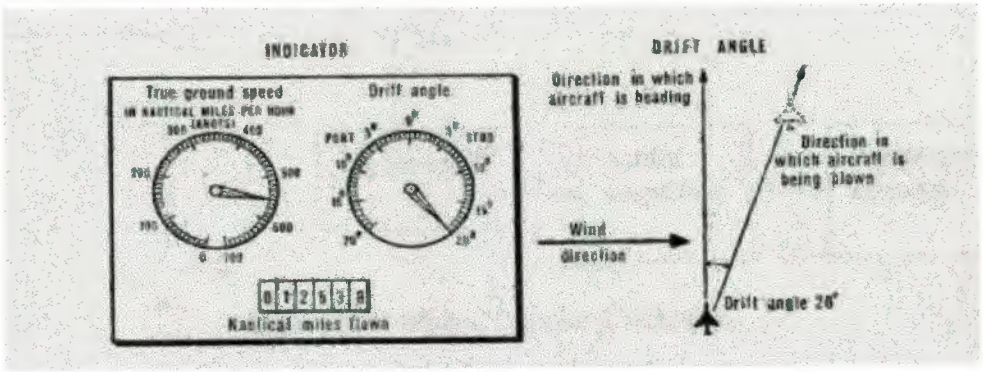

Figure 3.13 Doppler airborne navigation display system

It should be noted that the frequency of received 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 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.

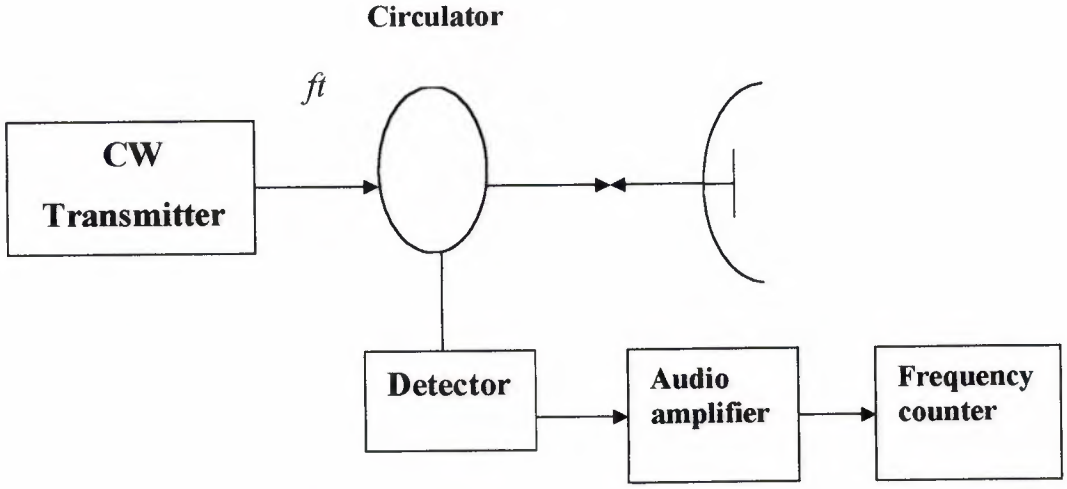

Figure 3.14 Simple Doppler CW Radar

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 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.

NEAR EAST UNIVERSITY

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CW DOPPLER RADAR

Graduation Project
EE- 400

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CHAPTER ONE
INTRODUCTION

Radar (Radio Detection and Ranging) is employed in many forms, from complex air defense networks to simple beacons 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 cancroid is 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. Selection of an operating frequency is determined by atmospheric transmission windows and the function of the radar. 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 radar. Advantages, applications and limitations CW Doppler radar is capable of given accurate measurements of relative velocities, using low transmitting powers, simple circuity,low power consumption and equipment whose size is much smaller than 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.

Before the reader begins to wonder why pulsed radar 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 unmodulated. 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 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. 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.

In chapter one, will present introduction to the project. In chapter two, we talk about radar generally and the most important components of it. In chapter three, will be devoted for studying the principles of CW Doppler radar.

In chapter four, will highlight the applications of CW radar as well as Doppler effects.

Finally in chapter five, we give conclusion of the project.

CHAPTER TWO

FUNDAMENTS OF RADAR

2.1 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 2.4.2; note, 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)

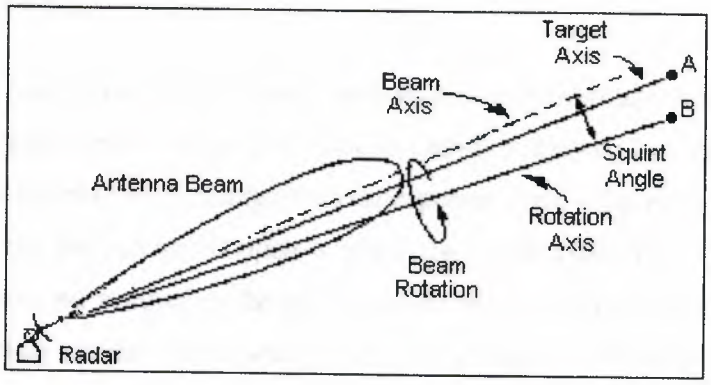

Figure 2.1. Movement of the Radar Beam to Determine Angular Location

2.1.1 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 pulsewidth must locate the target within the accuracy and warhead size of the weapon.

Example: The weapon has a 40 nautical mile maximum intercept range and its kill radius is 300 feet. The pulse travels about 1000 feet per microsecond so that the time to and from the target is 500 microseconds, and the pulse width must be 0.6 microseconds or less. Therefore, the radar cannot pulse faster than about 2,000 times per second with a Pulse Width of 0.6 microseconds.

2.1.1.1 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 pulsewidth 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.

2.1.1.2 Range Jamming

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

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 (PRR) 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). Since 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.

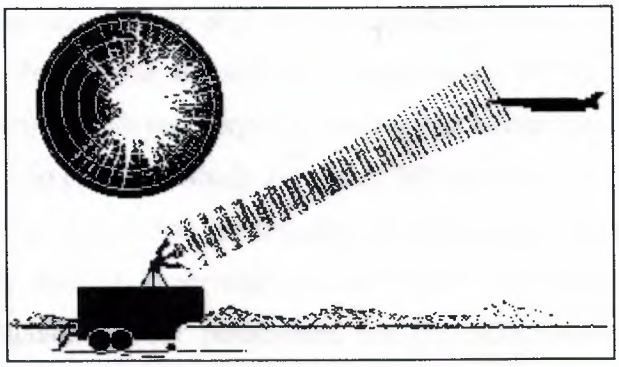

Figure 2.2 Example of Range Jamming

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.

2.1.2 Angle

2.1.2.1 Beamwidth

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

$$\{ (A) (w) \} / s \qquad (2.1)$$

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 falls to 0.707 of the maximum are known as the half-power points and the angular size of the beam between these half-power points is the defined beamwidth of the radar. This definition is always understood when discussing radar parameters, but the difference between the full beamwidth and the defined beamwidth becomes important in EW. Outside the defined beamwidth the power drops very rapidly to the outer edges of the full beamwidth.

2.1.2.2 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 antennae should have the same polarization.

2.1.2.3 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 the power cancroids and align its antenna so that the cancroid is 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 a track-while-scan (TWS) radar. Note that this implies that for best tracking the beamwidth should be larger than the target so that no target exists in adjacent beamwidths.

If the target is bigger than the beamwidth of the radar, the power return will be about equal in several antenna orientations so that the power cancroids will be broad in angle and thus degrade tracking accuracy. If the target is much larger than the beamwidth, 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 .707 of the power cancroids is *assumed* to be from a different beamwidth due to the definition of beamwidth. Therefore, to resolve two targets 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 beamwidth of the radar. The resolution cell of the radar, then, is the solid volume described by one beamwidth 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 systems 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 beamwidth. 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.

2.1.2.4 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 16 dB down from the "main-bang", the jammer must be capable of returning 16 dB more power to the radar than the target normally returns. Side-lobes are spaced about one beamwidth 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".

A second effect caused by large targets is called Effective Beam Broadening. In this case, the portions of the target within the full beamwidth but outside the defined half-power point beamwidth return power to the antenna which equals or exceeds the half-power return. The radar, due to accountability, must credit this to an adjacent orientation of the antenna with the effect being that a defined two-degree beam can actually have a three- or four-degree resolution. Active Deceptive ECM (DECM) also can effectively create angle jamming with ECM transmitters carried on a single aircraft. When a TTR scans a target during track the target return will be modulated at the scan frequency. DECM determines the scan pattern on the target and transmits a stronger signal of opposite modulation.

This will cause the radar to track in the wrong direction for one beamwidth. The radar will then see the target in a second beamwidth, but track has probably been "broken" and must be reacquired. DECM systems are much more complex than simple noise jammers. Angle jamming can also be performed by proper flight tactics. If a formation of aircraft maintains a separation of one beamwidth, then the radar will "see" a large target which appears on the display scope as one target as big as the total beamwidths that the formation occupies. This is particularly effective against systems which use separate Az and El tracking radars and then have computer matched tracking coordinates because the computer must examine every combination of Az and El returns to obtain a match. If the individual aircraft then maneuver *within* their assigned beamwidth, their power centroids will be constantly shifting, merging and separating so that Az-El correlation will be difficult.

When the aircraft are carrying noise jammers, the target cluster becomes two dimensional and automatic target tracking accuracy is degraded. This "cooperative jamming" can be continued to the point that the entire radar display indicator suffers "white-out". For example, in a 2-degree radar with a 16-degree display scope, eight aircraft at 2-degree separations with noise jammers will fill the entire scope with noise (false targets). However, the cancroids of the jamming power are located on the target aircraft so that track, and especially manual track, is still possible.

2.1.2.5 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 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.

2.2 Radar Parameters Used in RWR

2.2.1 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. Selection of an operating frequency is determined by atmospheric transmission windows and the function of the radar. 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 radars operate 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.

2.2.2 Pulse width

Range resolution is at best one-half the distance that the pulse travels in a time equal to the pulsewidth. 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:

Threat radar = short pulsewidth (2.2)

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 pulsewidth. An RWR, then, need normally concentrate on pulsewidth regimes within the range:

$$0.1 \text{ microsecond} < PW < 1 \text{ microsecond}$$

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:

$$0.1 \text{ ms} < PW < 1.5 \text{ ms} = \text{Threat Radar}$$

$$PW > 1.5 \text{ ms} = \text{Non-Threat Radar}$$

Since threat radars are required to have narrow beamwidtns, 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

2.2.3 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 radars are short-range trackers.

(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 pulses 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.

2.2.3.1 Stagger

Several adaptive measures may be assumed by radar to lessen its susceptibility to ECM; one which will make the job of a repeater jammer more difficult is the incorporation of staggered pulse trains. However, the same basic laws of nature apply to exotic pulse train generation (*i.e.*, the elapsed time between any group of pulses cannot be less than the desired maximum range of the radar). The staggered pulse (PRF) repetition frequency also enhances associated radar features such as Moving Target indication by reducing the effects of blind spots in the radar. A staggered pulse train is fundamentally a basic PRF with this same PRF impressed upon it one or more times. Each level of impression (stagger) utilizes a different start time or reference which will preclude the generation of concurrent pulses or pulses shadowing one another. The number of levels (or positions) is the number of times the basic PRF/IPP (inter-pulse period) is integrated in the pulse train.

Figure 2.3 illustrates the time relationship involved in the generation of a 4-level stagger. As mentioned above, each level has the same characteristic PRF and PW, but the Time to First Event (TFE) for each level is different. This has the effect of slewing the masked pulse groups in relation to one another resulting in the desired stagger pattern. The PRF of the radar is the sum of all the pulse trains so that if an RWR operated on PRF, the additional identification inherent in the stagger pattern would not be useful. This problem is overcome by measuring PRI rather than PRF so that the RWR measures the basic PRI a number of times equal to the number of stagger levels.

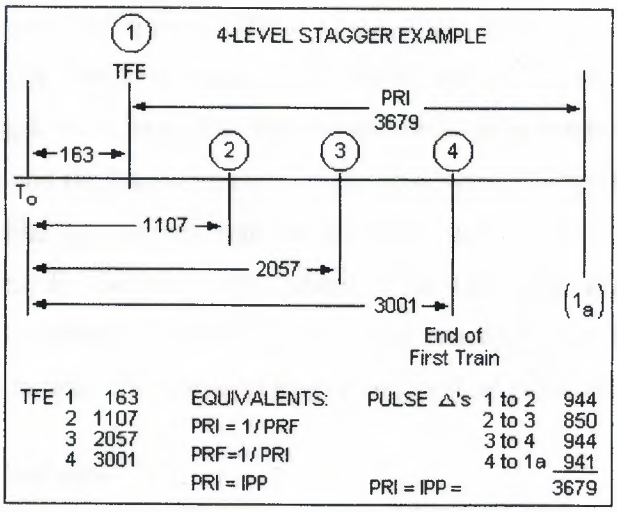

Figure 2.3. Staggered PRF Generation

The example as presented is a 4-level stagger with a basic PRI of 3679. Train number one is initiated at "time-0" +163 and 2, 3, and 4 follow, respectively. The pulse deltas are determined by subtracting the adjacent TFEs.

2.2.3.2 Jitter

The job of the jammer can be made more difficult by the radar's use of a jittered PRI. In Jitter mode, the time between successive pulses, is allowed to vary in a totally random manner over a series of set intervals as long as the maximum range condition is met.

2.2.3.3 Stagger-Jitter Patterns

As long as the maximum range condition is met, an infinite number of PRI patterns can be generated by combining stagger and jitter. The PRI can be modulated by a well-defined function: (a) a sliding PRI very slowly increases/decreases the PRF, (b) a Ramp PRI decreases the interval with a cyclic ramp function, and (c) a modulated PRI varies the intervals in a sinusoidal or triangular manner. Some combinations seemed to be designed to foil processors which use digital analysis.

2.2.4 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.

2.2.4.1 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 a 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-fuzing 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 fuze.

2.2.4.2 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 boresited 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.

2.2.4.3 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 which 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 fuze. 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.

2.2.4.4 Fuse Jamming

Both command guidance and beam riders are susceptible to tracking radar and fuze jamming. The simplest fuze is the radar proximity type which sends out a rather broadbeamed 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 fuze receiver the warhead is detonated when the kill radius is reached.

This system can be jammed by making the target return much larger than normal so that the warhead is detonated prematurely, outside the kill radius. In countermeasures terminology, fuze 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 fuze jammer transmitters can act as fuze homing devices.

2.2.4.5 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 superheterodyne 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 fuze signal is questionable since fuze power is so low that no real warning will be obtained. That is, fuze 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 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 4, 5, 6, 7 and 8.

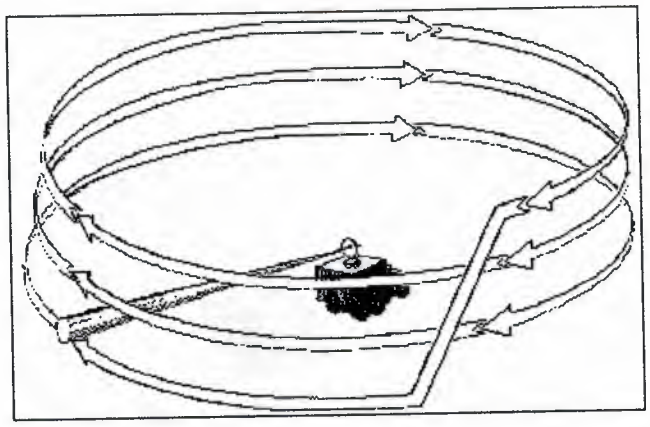

Figure 2.4. Radar System Using Helical Scan with Pencil Beam

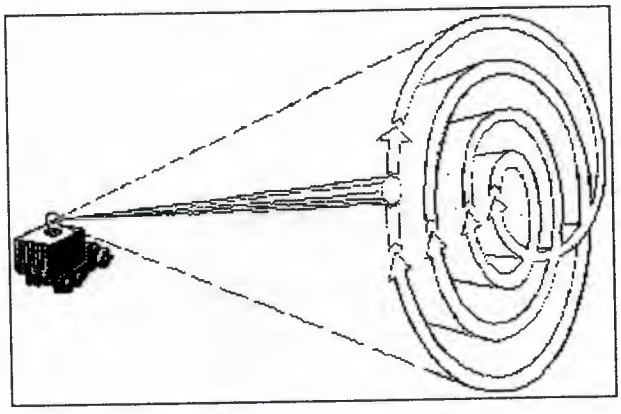

Figure 2. 5. Radar Using Spiral Scan with Pencil Beam

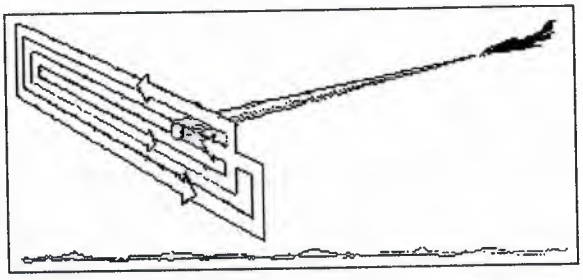

Figure 2.6. Airborne Intercepter Radar with Raster Scan

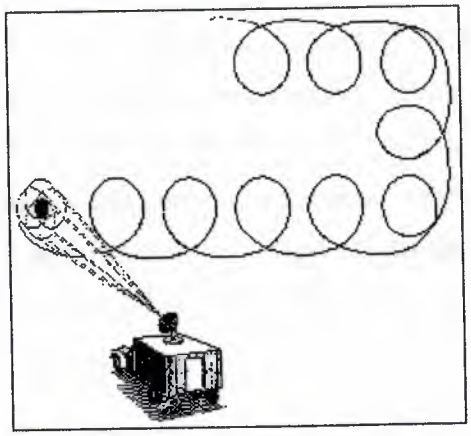

Figure 2.7. Ground Radar with Palmer-Raster Scan

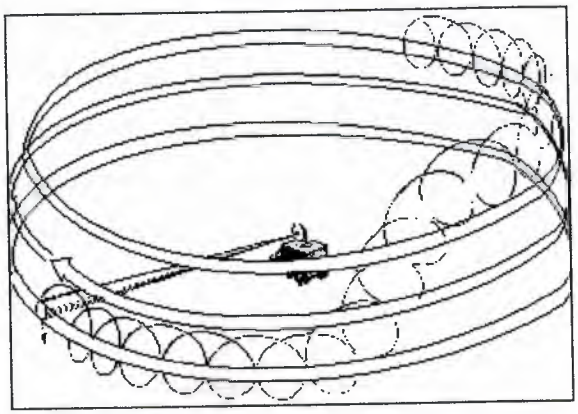

Figure 2.8. Radar using Combination Palmer-Helical Scan

2.2.5 Scan

2.2.5.1 Conical Scan

Radar systems can be categorized by their Scan patterns. The most commonly used today is the Conical Scan, or Con Scan pattern (see Figure 2). In this method, the radar rotates its beam about the circle described by the half-power points of the beam when the beam is boresighted on the target. The beam, when received at the target or at the radar, will be a sinusoidal waveshape whose amplitude is proportional to the distance the target is away from the boresight. 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.

Note that the more accurately the radar tracks the target, the smaller the amplitude of the sine wave, until zero amplitude implies that the radar is exactly boresighted on the target. Con Scan systems require a minimum amount of hardware and therefore are commonly used on inexpensive, mobile systems such as AAA or mobile SAM sites. They suffer the serious disadvantage of not being able to see a target outside their narrow scan patterns. This means that not only is a second radar required to help it find the target (to "acquire the target") but also the tracked aircraft can easily "escape" if it is successful in breaking track since the Con Scan radar cannot see the target, except in the track mode.

2.2.5.2 Track-While-Scan

Con Scan problems can be overcome with Track-While-Scan (TWS) radars. 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 highly vulnerable to ECM jamming. An illustration of TWS radar is shown in Figure2. 9.

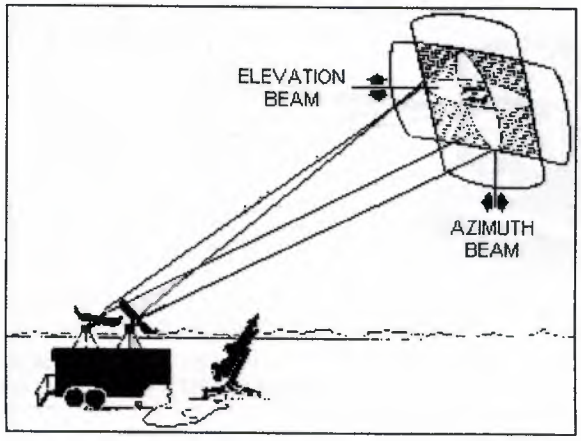

Figure 2. 9. Track-While-Scan Radar

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.

2.2.5.3 Monopulse Scan

Scan can also be accomplished by sequentially pulsing several antennae or sections of a large antenna. This is illustrated in Figure 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.

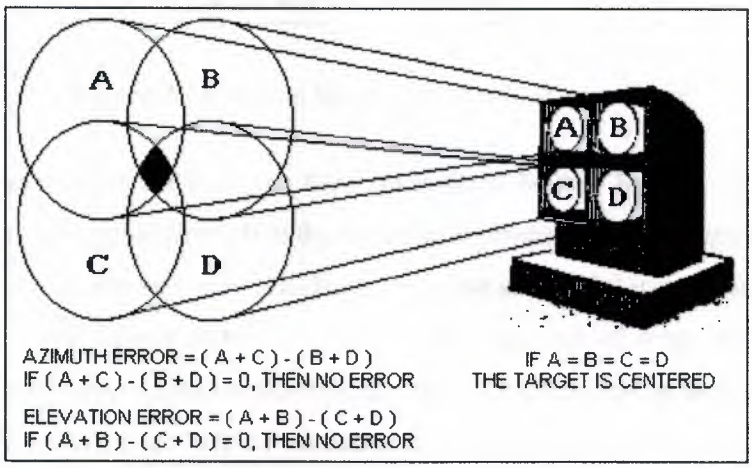

Figure 2.10. Diagram of Monopulse Radar Beam Patterns

2.2.5.4 Received Scan Patterns

Con Scan, TWS, and monopulse radars will cause an RWR to receive pulses with superimposed sinusoidal waveforms. The Con Scan case is shown in Figure 11. The processor identifies these scan patterns by counting the maxima of the sine wave envelope; these maxima are the scan rate of the radar. When a given scan pattern is counted, the Identity Word is updated with this information.

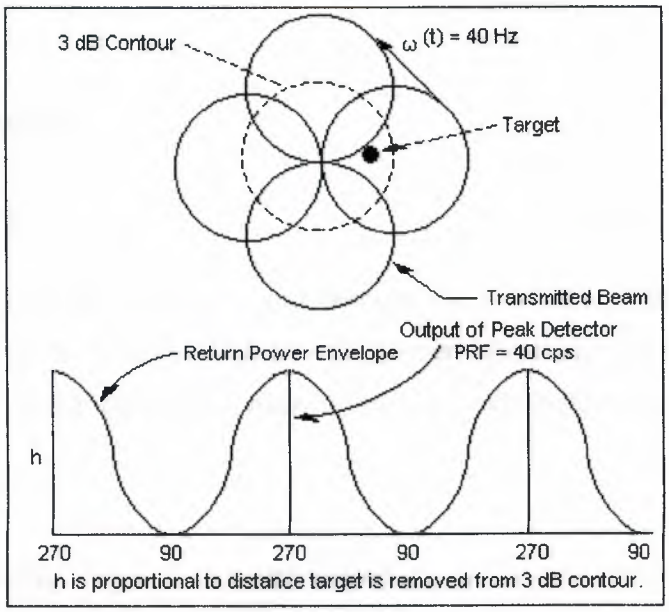

Figure 2.11. Signal Received from Con Scan Radar

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. This lack of scan can be used by the RWR processor 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 boresighted on the target, lack of a scan pattern does not unambiguously identify a radar type.

2.2.5.5 Scan Summary

To summarize, the use of scan by radars to track a target can assist in the identification of a particular radar type. Scan imposes the following considerations on the RWR processor. The scan envelope must be counted to determine scan rate. To ensure the validity of the display, TWS radars must be displayed upon first intercept and must remain displayed for several processor "look cycles" even after the radar appears to be shut down. Lack of scan data can sometimes be used by the processor to identify radar types.

2.3 Types of Radars

2.3.1 Pulse Radars

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 radars, many of the new threat systems are using CW.

2.3.2 CW Radars

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 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 20 kHz.

2.3.3 Radars Other Than SAM Fire Control

Any air defense network will be composed of many radars 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.

2.3.3.1 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.

2.3.3.2 Acquisition Radars

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

2.3.3.3 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 autotrack or associated weapon, it presents no real threat. These radars are primarily used for vectoring airborne interceptors.

2.3.3.4 Ground Controlled Intercept Radars

Ground Controlled Intercept (GCI) systems are usually composed of acquisition and height finder radars. They are used to vector interceptor aircraft to an intruding force.

2.3.3.5 Ground Controlled Approach Radars

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

2.3.3.6 Anti-Aircraft Artillery Radars

Anti-Aircraft Artillery (AAA) fire control radars operate much the same as missile TTRs in that, after target acquisition, auto-track is accomplished by the radar computer and some sort of scanning method. 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 scanning (Con Scan).

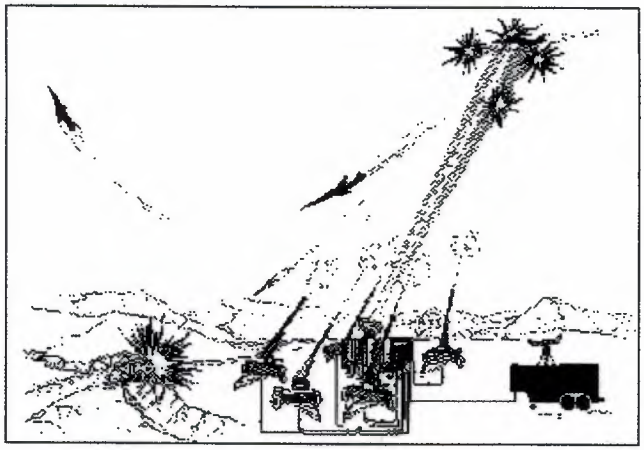

Figure 2.13. Typical AAA Battery in Operation

2.3.3.7 Airborne Interceptor Radars

Airborne Fire Control (AI) systems are used for Airborne Interceptor Missiles (AIM) guidance. The cockpit operator manually acquires the taret by training the antenna; auto-track is then usually accomplished by some scanning method or frequency (Doppler) track.

2.3.3.8 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 headings.

CHAPTER THREE

CW DOPPLER RADAR

3.1 CW Radars

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 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 vary up to 20 kHz.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 20 kHz (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 the 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 slew 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 Figure3. 1.

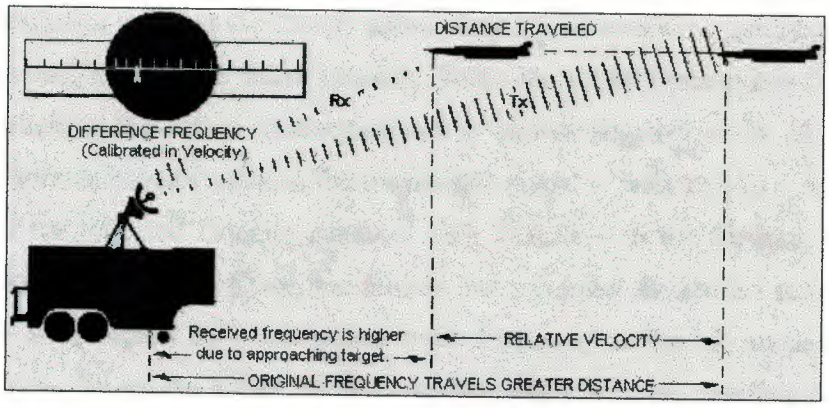

Figure 3.1 CW Doppler Radar Fire Control System

In this case, the ground site CW Illuminator (CWI) radar radiates the target. The missile has both forward- and aft-looking antennae 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 = O, 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 radars 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 two excellent ECCM techniques -- coherency and home on jam. A continuous wave can be modulated by an ultra-low frequency signal. If an 85 Hz modulation is used, the period for one cycle is about 2000 nm. Thus, at normal SAM racking ranges, the phase of the 85 Hz 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 jamming 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 - FM - PM continuous wave. For Pulse Doppler, such as airborne interceptor pulse Dopplers (AIPDs), this same signal would be interrupted periodically for transmission of several ranging pulses or pulse groups (*i.e.*, stagger, jitter or both).

3.1.1 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 -- higher 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)

3.1.2 Frequency-modulated CW Radar

One application of F.M.C.W. Radar is in aircraft altimeters. The normal barometric altimeter is operated by air pressure and has two limitations: If the atmospheric pressure changes while the aircraft is in flight the altimeter reading will change. 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.

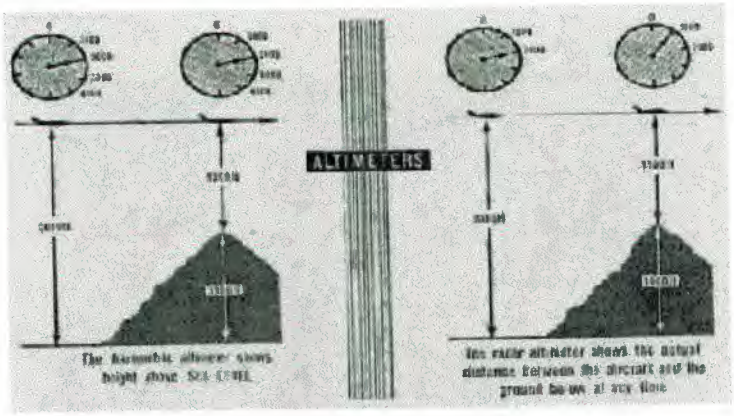

Figure 3.2 Barometric and radar altimeters

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 f.m.c.w. radar altimeter.

3.1.3 Radar Altimeters Using Frequency Modulation

The principles of frequency modulation are considered elsewhere. Basically in a F.M. 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 C.W. output whose frequency is varied by the modulating signal. Let us suppose that the frequency of a F.M. Transmitter is caused to deviate at a constant rate by using a sawtooth waveform as the modulating signal. 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 F.M.C.W. Radar altimeter.

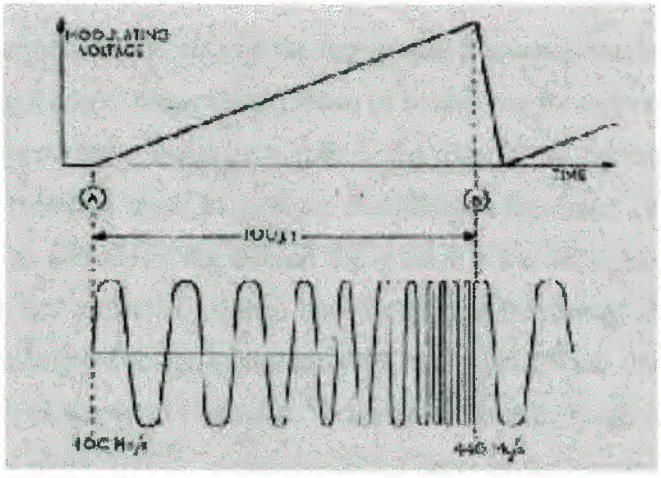

Figure 3.3 Frequency modulation with a sawtooth modulating signal

Figure3.4 illustrates the layout of a typical F.M.C.W. 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

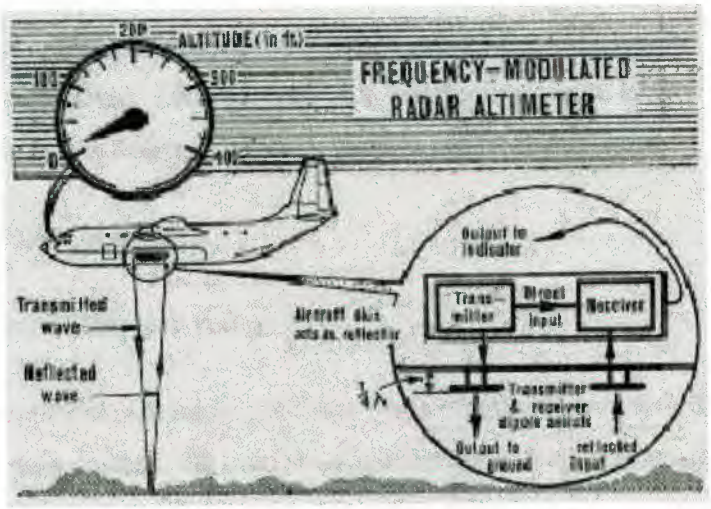

Figure 3.4 typical FMCW radar altimeter layout

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 Figure3.5. 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.

In general we can say that F.M.C.W. 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.

3.2 THE DOPPLER RADARS

3.2.1 Brief 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. Furth 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. 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. The first application of pulsed-Doppler radar principles to meteorological measurements was made by Ian C. Browne and Peter Barratt of the Cavendish Laboratories at Cambridge University in England in the spring of 1953. Barratt 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. 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 sidelobes 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.

Although the PVDF wires do a good job of measuring foot dynamics and position, another system was necessary to complete the impressive sensing by tracking movement of the arms and upper body. A pair of microwave motion sensors, as indicated in Figure 1, was used for this task. The sensor heads are composed of a simple, inexpensive circuit board containing a single-transistor, 2.4 gigaHertz (GHz) CW oscillator, coupled to a 4-element micropatch antenna, which forms a broadside beam roughly 20deg. in width (although with significant sidelobes). As the radiated output is below 10 milliwatts, this system is entirely safe and well within regulation. Since nonconductive material does not significantly absorb this signal, these antennas can be easily hidden behind walls, projection displays, etc.

Doppler-shifted reflections from a performer moving within the beam return to the antenna, where they are mixed with the transmitted signal in a hot carrier diode. This produces beat frequencies in the range of 0-5 kilohertz (kHz) that directly represent the performer's dynamic state (the frequency is a function of velocity, and the beat amplitude is a combined function of the size and distance of the reflecting object). Two such diodes, placed roughly an eighth-wavelength apart, produce a quadrature pair of signals, thus their correlation determines the direction of motion along the antenna boresight. These radars respond to motion within a range of at least 15 feet. Rather than process the Doppler signals in the Fourier domain, a simple analog signal conditioner was designed to minimize real-time computing requirements. This circuit produces three analog signals for each radar head.

One of these is just the low-pass filtered amplitude envelope of the Doppler beats; this corresponds to the amount of general motion that the radar detects. First high-pass filtering the Doppler beats before detecting the envelope derives another; the amplitude of this signal corresponds to the detected velocity. A third signal is derived from an analog correlation between the signals produced by the diode pair; the polarity of this voltage indicates the direction of detected motion. These 3 signals were 8-bit digitized at roughly 50 Hz, and directly used by the music-generating algorithm.

3.2.2 Doppler effect

Many radars use the Doppler Effect to extract information on targets radial velocity (almost all radars designed to detect aerial targets use the Doppler Effect to discriminate moving objects from the undesired fixed echoes). A signal having wavelenght 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. In the case of radar, this effect occurs twice, on the radar-target and target-radar paths: the total Doppler shift is then:

$$\Delta f = 2.v/\lambda \qquad (3.1)$$

At the normal radar frequencies, and for relative speeds in the order of tens or few hundreds m/sec (typical of aircrafts), the Doppler shift is in the kHz range, the same order of magnitude of the PRF, and a period much shorter than the pulse width. This makes impossible to discriminate the frequency shift within the pulse. All radars exploiting the Doppler information use the same reference oscillators (characterized by high short-term frequency stability) in both the transmit and receive chains. The local oscillator LO1 is the same for both chains. The received signal, instead of being demodulated using an envelope detector, is compared (normally using two channel having a 90 deg relative phase shift to extract the sin and cosin components of the signal) with the transmission reference frequency LO2 - the same used to generate the intermediate frequency transmit pulse - in a phase detector (a balanced mixer characterized by low offset voltage).

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).

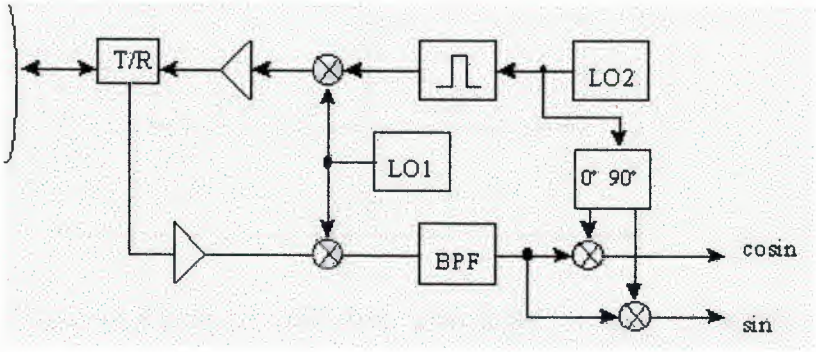

Figure 3.5 two channels, sin-cosin demodulator

A return echo from a fixed target will have a zero Doppler shift, and then a constant phase: all the return pulses from it will have the same amplitude after demodulation. If there is a Doppler shift, the phase will change from pulse to pulse, and the amplitude of the demodulated signal will also change. Using two channels, sin-cosin demodulator, it is possible to unambiguously recover the phase of the return echo. In other words, it is like as the envelope of the Doppler frequency is sampled at the pulse repetition frequency. Which depicts the echoes of the same target in different PRIs at the output of the phase detector, together with the envelope of the Doppler frequency? According to the sampling theorem, to avoid ambiguities in the measurement of the Doppler frequency, the PRF must be, at least, twice the Doppler frequency. This calls for the use of high PRFs, in conflict with the unambiguous range requirement discussed above. Ambiguities resolution techniques using staggered PRFs partially allow conciliating these two requirements.

It must also be noted that, in many cases, the Doppler ambiguity is not of concern, being the Doppler shift used only to discriminate - and to cancel - all targets below a certain Doppler shift, i.e. the fixed targets. For these systems, the only problem related to the Doppler ambiguity occurs when a target has a Doppler shift which is an integer multiple of the PRF: it will be detected as a constant amplitude - zero Doppler - return and then cancelled like a fixed echo.)

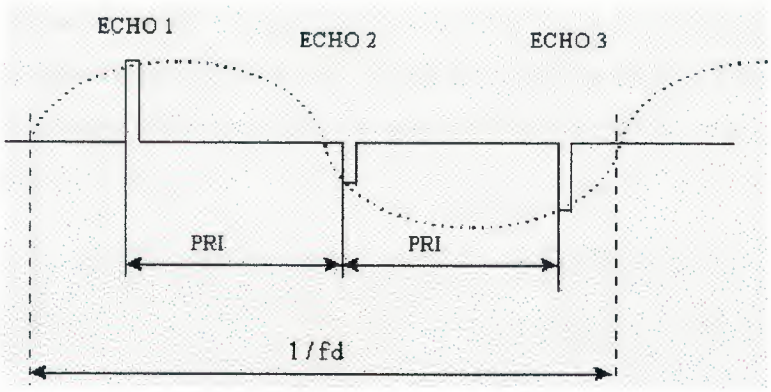

Figure 3.6 Doppler shift which is an integer multiple of the PRF

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. Radars of this class, but with a moderate range resolution capability thanks to a frequency modulation of the signal carrier (FM-CW radars) are used for special applications (illuminating radars for missile guidance). 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 4). 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.

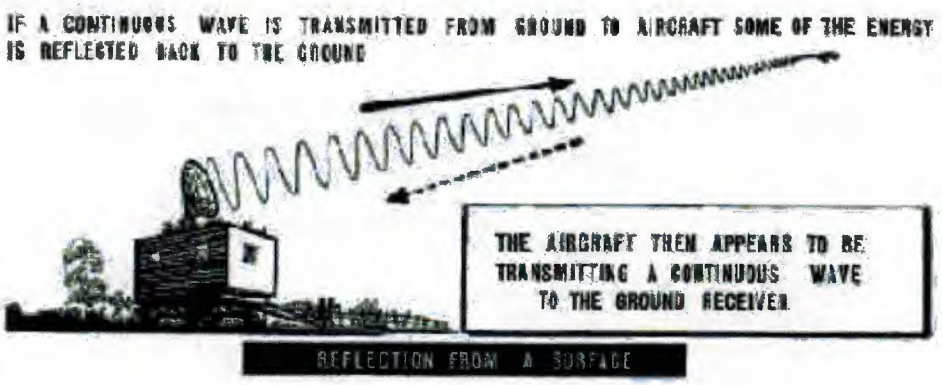

Figure 3.7 reflection of radio waves from a surface

There is however another phenomenon associated with all wave propagation, which is used in unmodulated C.W. radar. If you are watching a motor-cycle race you may notice that the note of the exhaust noise appears to change as the machine passes. This is illustrated in Fig 5.

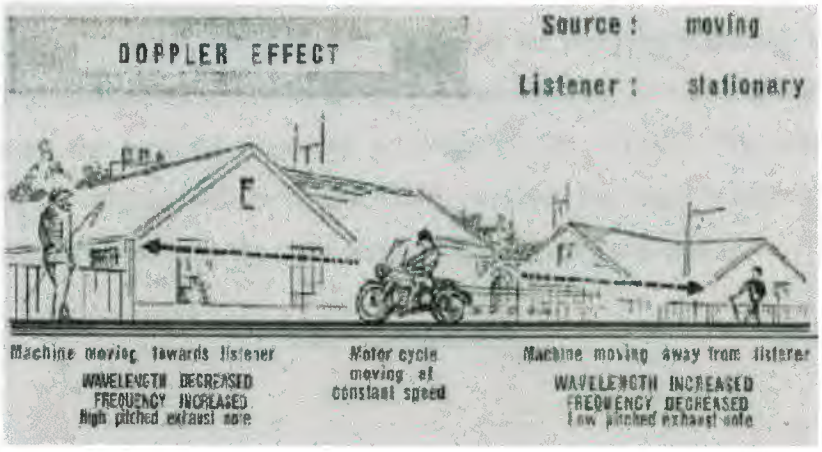

Figure 3.8 Doppler Effect with sound waves

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.

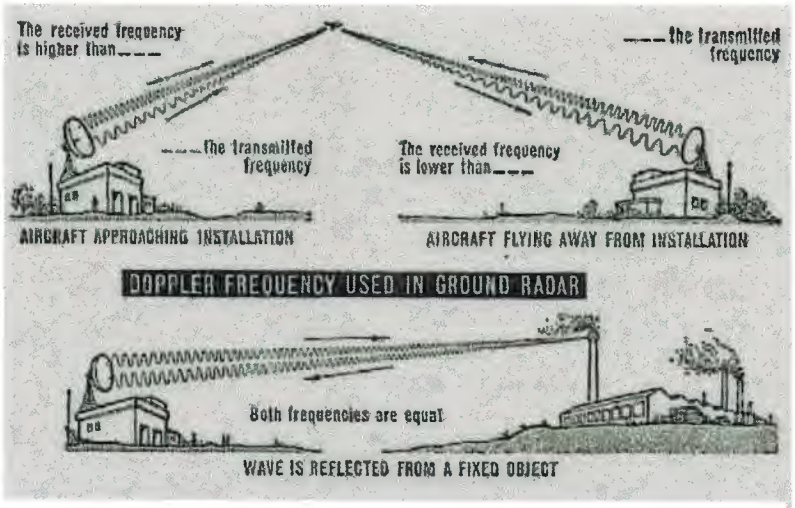

Figure 3.9 Doppler Effect with radio waves

If the transmitted frequency is Ft and the new frequency to which it is changed by the Doppler Effect is Fr, the difference between these two frequencies is known as the Doppler shift Fd = Ft~Fr

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. Fr = Ft+Fd. If the target is moving away the received frequency is lower, i.e. Fr = Ft-Fd. 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:

$$\mathbf{Fd = (2v/c)Ft,} \qquad \mathbf{(3.2)}$$

Where:

Fd = Doppler shift in c/s

Ft = Transmitted frequency in c/s

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

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

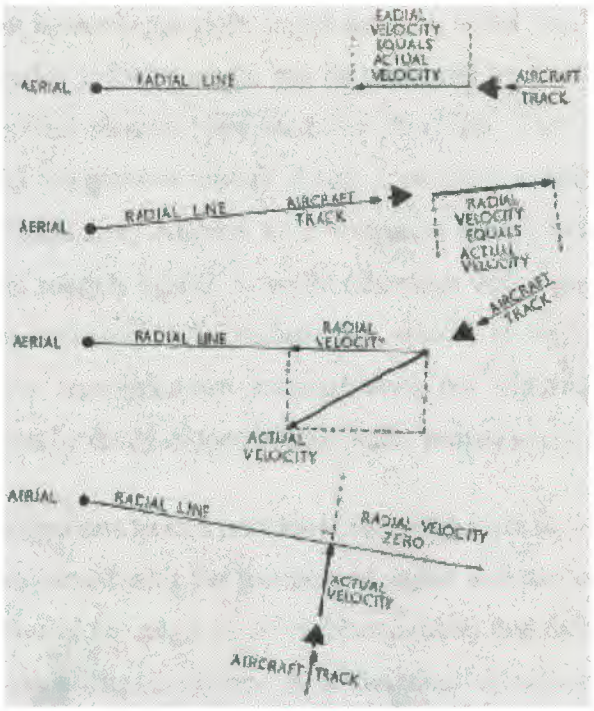

Figure 3.10 Radial Velocity

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 Fd = (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 Fr is Ft + Fd = 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 Fr = Ft - Fd = 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 trans-mitted 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, which Doppler Effect causes, is less. From Figure3.10 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. 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. A pair of microwave motion sensors was used for this task. The sensor heads are composed of a simple, inexpensive circuit board containing a single-transistor, 2.4 gigaHertz (GHz) CW oscillator, coupled to a 4-element micropatch antenna, which forms a broadside beam roughly 20deg. in width (although with significant sidelobes). As the radiated output is below 10 milliwatts, this system is entirely safe and well within regulation. Since nonconductive material does not significantly absorb this signal, these antennas can be easily hidden behind walls, projection displays, etc.

Doppler-shifted reflections from a performer moving within the beam return to the antenna, where they are mixed with the transmitted signal in a hot carrier diode. This produces beat frequencies in the range of 0-5 kilohertz (kHz) that directly represent the performer's dynamic state (the frequency is a function of velocity, and the beat amplitude is a combined function of the size and distance of the reflecting object). Two such diodes, placed roughly an eighth-wavelength apart, produce a quadrature pair of signals, thus their correlation determines the direction of motion along the antenna boresight. These radars respond to motion within a range of at least 15 feet. Rather than process the Doppler signals in the Fourier domain, a simple analog signal conditioner was designed to minimize real-time computing requirements. This circuit produces three analog signals for each radar head. One of these is just the low-pass filtered amplitude envelope of the Doppler beats; this corresponds to the amount of general motion that the radar detects. First high-pass filtering the Doppler beats before detecting the envelope derives another; the amplitude of this signal corresponds to the detected velocity. A third signal is derived from an analog correlation between the signals produced by the diode pair; the polarity of this voltage indicates the direction of detected motion. These 3 signals were 8-bit digitized at roughly 50 Hz, and directly used by the music-generating algorithm.

3.2.3 Use of the Doppler effect in Ground Radar

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

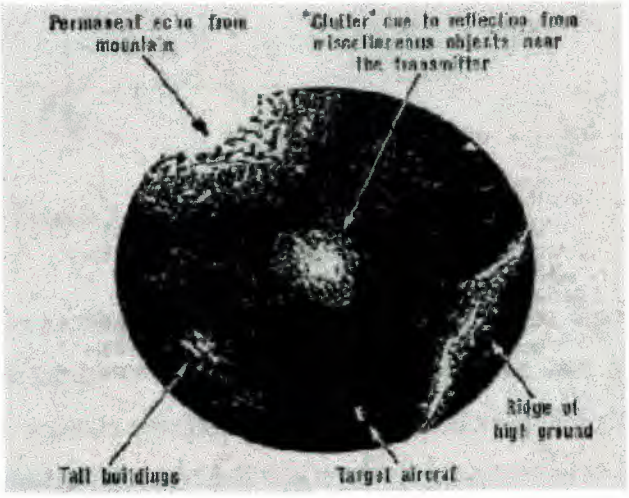

Figure 3.11 Echoes from unwanted objects in pulsed radar

Figure3.12 illustrates a typical arrange-ment for the indication of a moving target. The frequency fr of the reflected signal differs from that of the trans-mitted signal ft by the Doppler shift fd. The reflected signal is mixed with the output of a local oscillator to produce an i.f. signal ($f_{if} \pm fd$) where fd is the Doppler shift. This signal is amplified and fed to a discriminator whose output is either a positive-going or a negative-going d.c. 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.

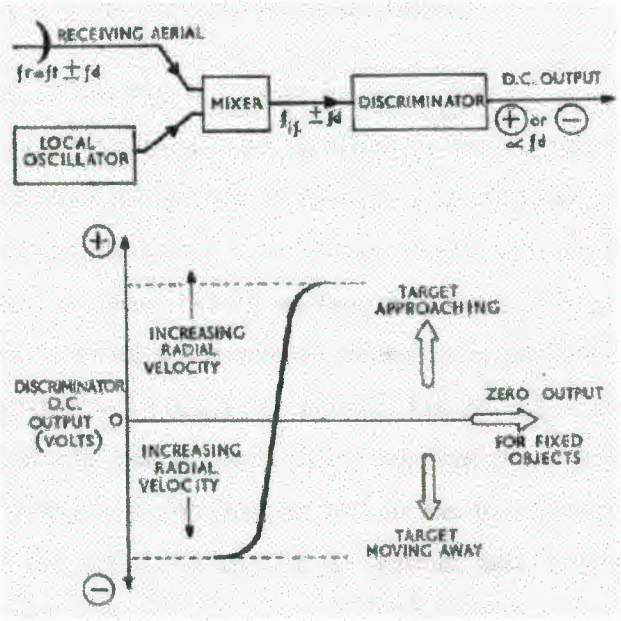

Figure 3.12 Indication of moving targets

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: The presence of a moving target is indicated by the production of a Doppler frequency. Stationary objects provide no change in frequency. The bearing and elevation of the target is determined by using narrow beams. The radial velocity of the target is determined by measuring the Doppler shift in frequency. 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.

3.2.4 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, which 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 fr is higher than the transmitted frequency ft by the Doppler shift fd, i.e. fr = ft + fd. The Doppler shift is deter-mined by the radial velocity of the aircraft and is given as before by the expression

$$fd = (2v/c)\ ft. \qquad (3.3)$$

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. A 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 Figure3.13.

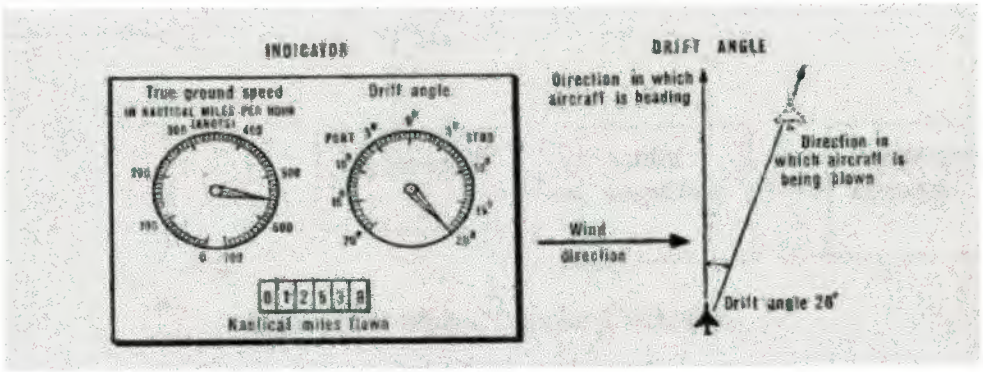

Figure 3.13 Doppler airborne navigation display system

It should be noted that the frequency of received 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 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.

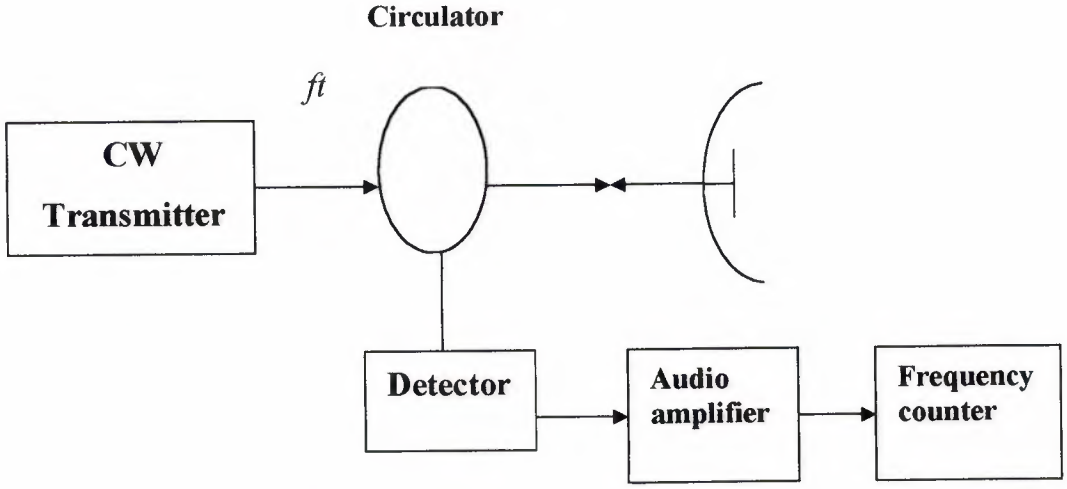

Figure 3.14 Simple Doppler CW Radar

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 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.

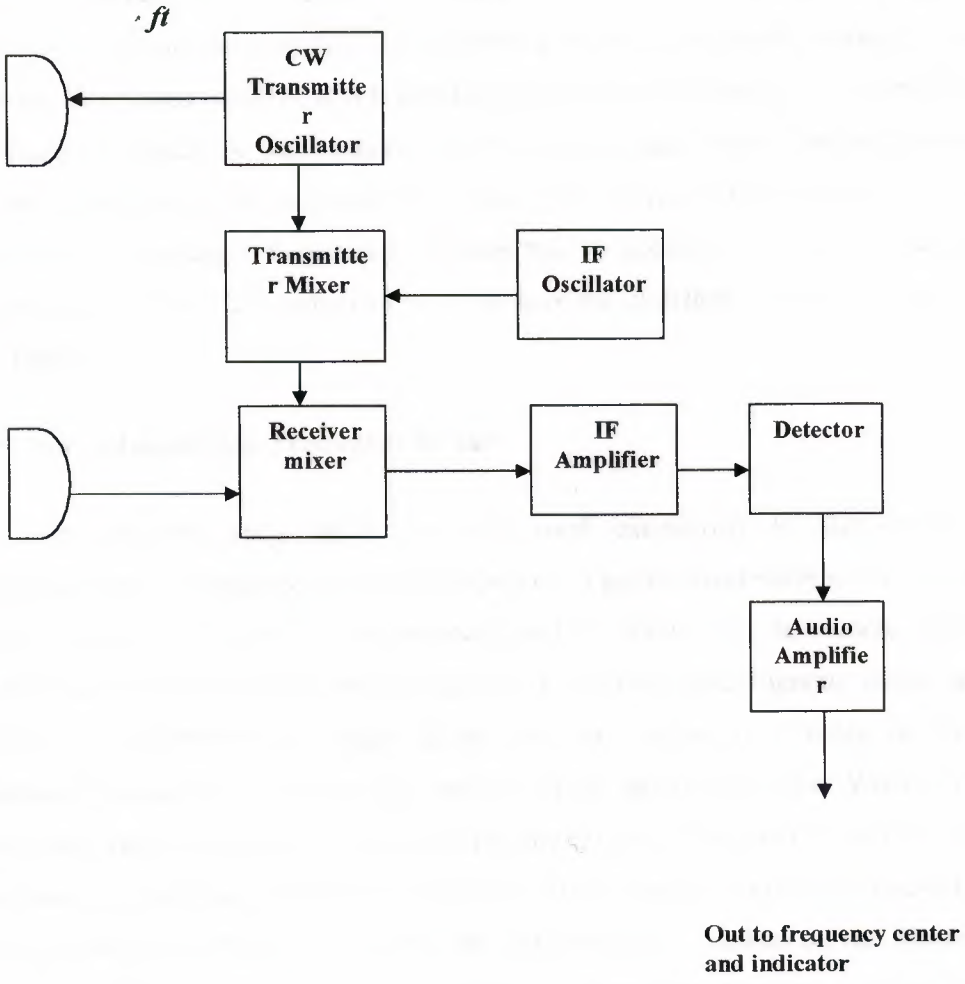

Figure 3.15 CW Doppler radar with IF amplification

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 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 radar.

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

3.3 Range-Gated Step-Frequency Radar

The step-frequency radar has been used extensively in short-range radar measurements to study the 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 step-frequency radar are its limited unambiguous range and the difficulty in implementing range gating for short ranges. The range of the step-frequency radar is limited by the number of its frequency steps. When the step-frequency radar is operated monostatically, the return is corrupted by reflections from the antenna feed, thus affecting the sensitivity of the system. Currently, range-gating for the 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 the 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 than 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.

3.4 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.

3.5 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 milliwatts 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 range only 1.19 times. The power that the transmitter is designed to radiate depends upon the job that the radar has to do.

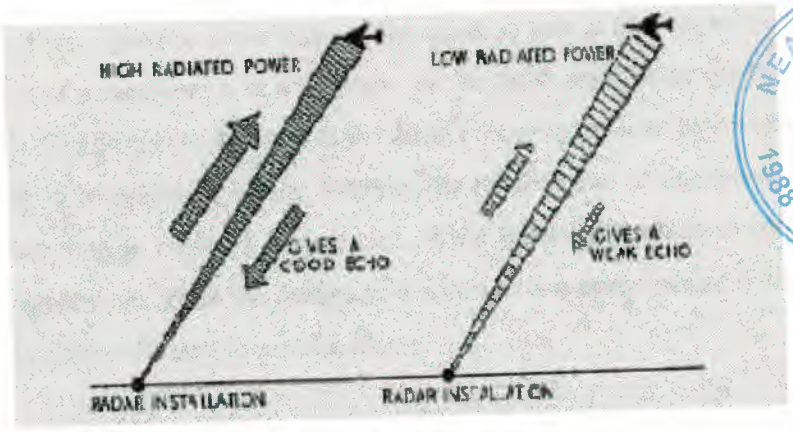

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Figure 3.16 Effect of transmitter power output

3.6 Receiver Sensitivity and Noise Factor

We have already seen that the 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 ratio 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

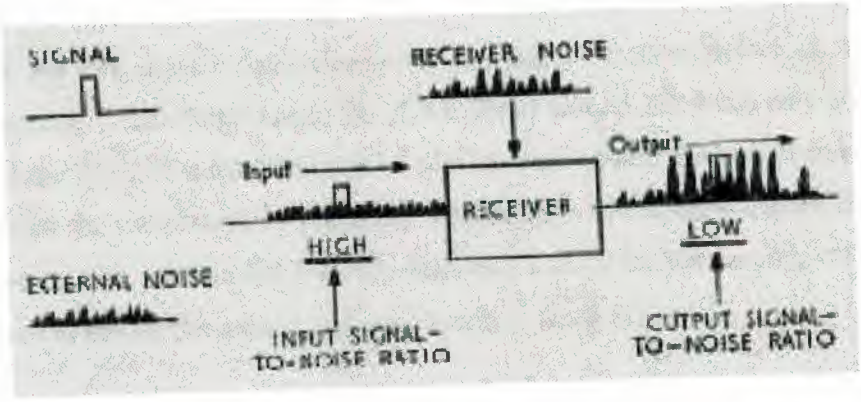

Figure 3.17 Receiver noise factor

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 3.16). 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 low noise factor.

3.7 Frequency of Operation

The frequencies used in radar are high for three main reasons: 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 radars, where early warning is the criterion and accuracy of range and bearing of less importance, the V.H.F. band around 200 Mc/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).

CHAPTER FOUR

APPLICATIONS OF CW DOPPLER RADAR

4.1 Semiactive 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 "semiactive" target illumination is only one of four major methods of missile guidance. These methods are:

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

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 datalink 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). A 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 Barratt 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. Barratt 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, stratiform, 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 modelling 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 sidelobes 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., beated) 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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Barratt 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 *NEX*t 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, mesocyclones, 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 upwards shift in the transmitted frequency, called the Doppler shift.

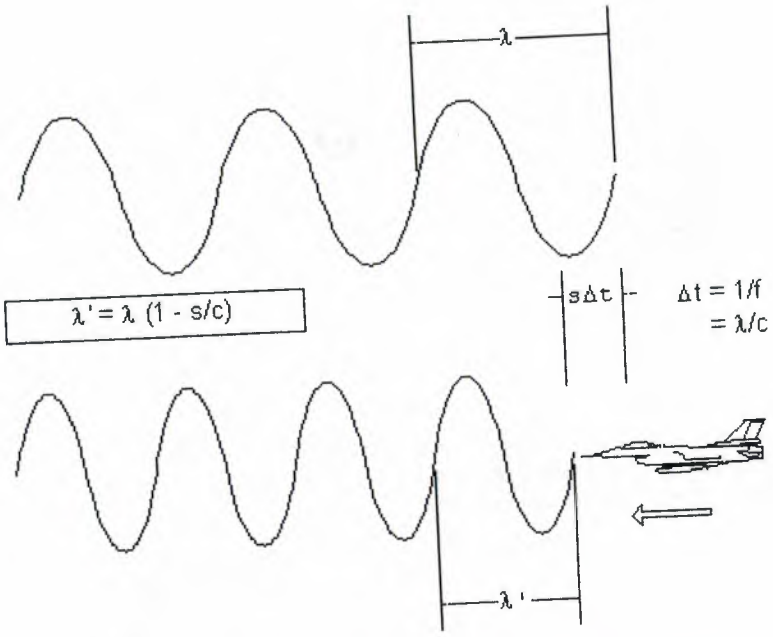


Figure 4.1 Doppler shift from moving transmitter

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).

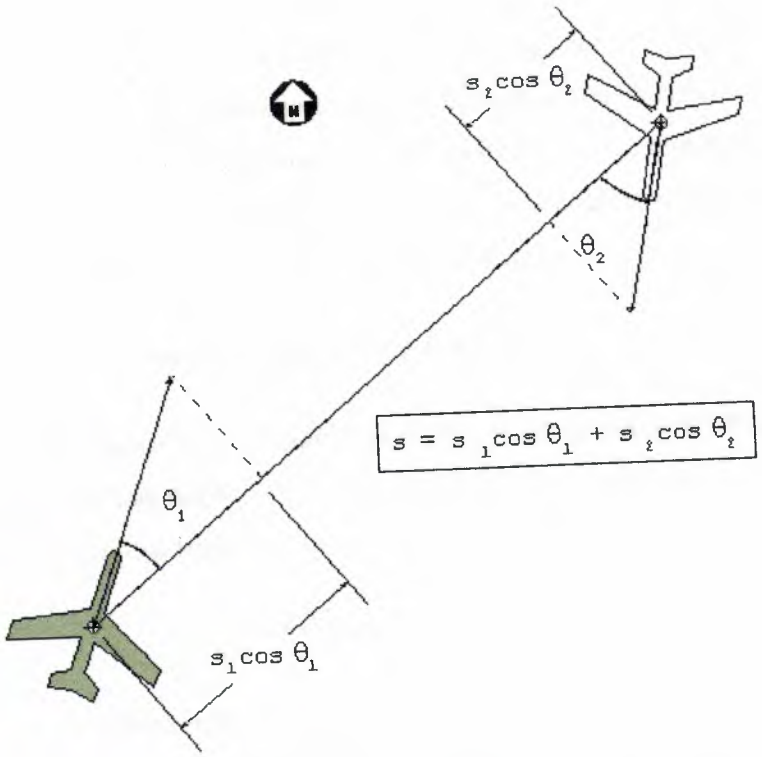


Figure 4.2 Calculating the relative speed in the line-of-sight.

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

$$s = s_1 \cos\theta_1 + s_2 \cos\theta_2. \qquad (4.1)$$

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:

$$\textbf{Relative Bearing} = \textbf{True Bearing} - \textbf{Heading} \qquad (4.2)$$

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:

$$\textbf{Reciprocal Bearing} = \textbf{True Bearing } 180^0 \qquad (4.3)$$

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

$$\Delta f = 2s/\Delta \qquad (4.4)$$

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.

Example: speed gun.

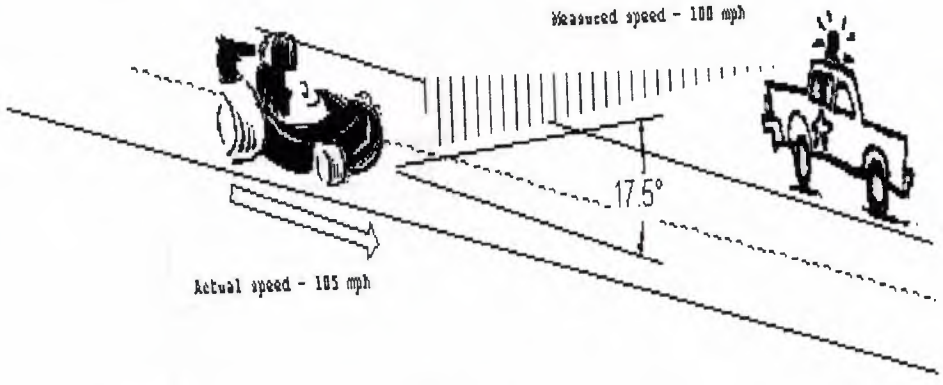


Figure 4.3 CW Doppler radar to measure the speed of cars.

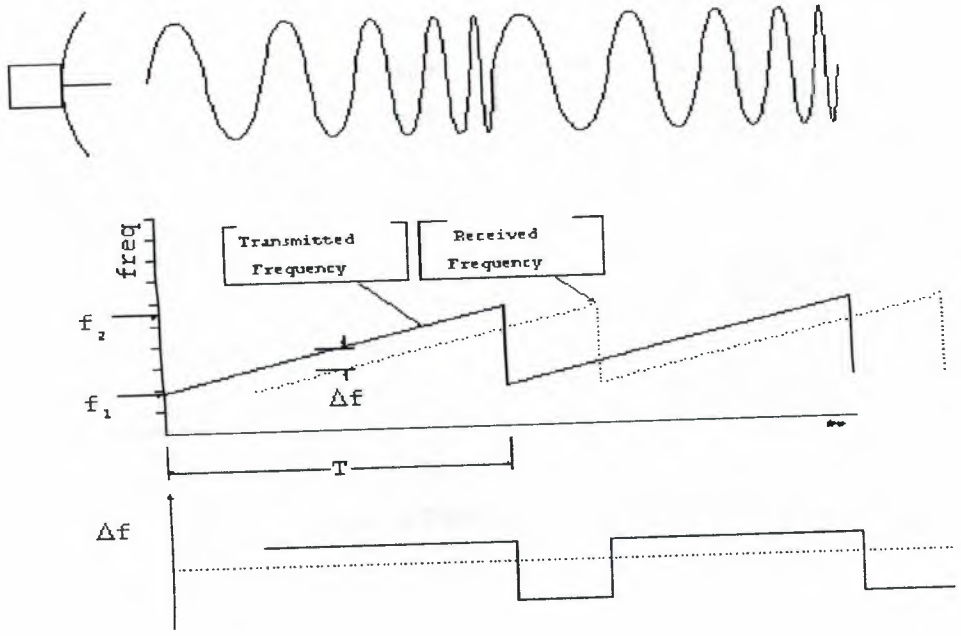
Police often use CW radar to measure the speed of cars. What is actually measured is the fraction of the total speed, which is towards the radar. If there is some difference between the direction of motion and the line-of-sight, there will be error. Fortunately for speeders, the measured speed is always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

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

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

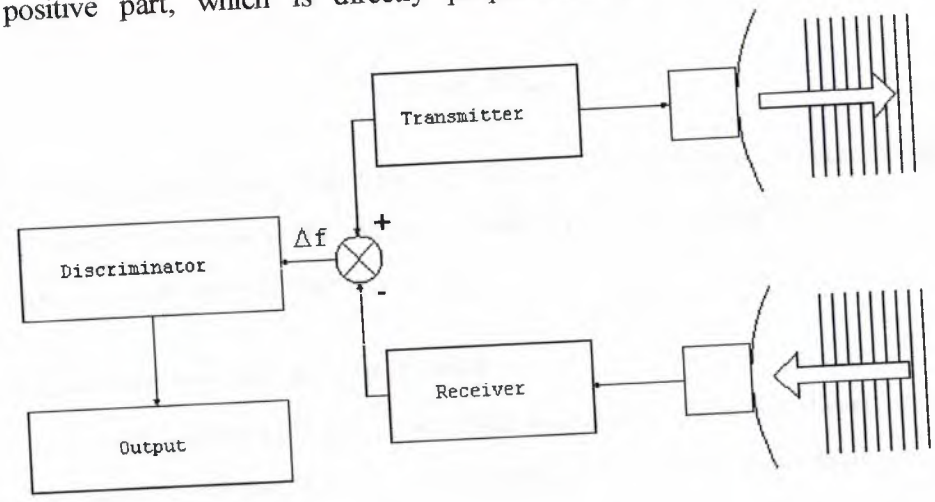


Figure 4.5 FMCW block diagram.

Combining these equations into a single form for the range

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

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

$$R_{unamb} = cT/2 \tag{4.7}$$

FMCW systems are often used for radar altimeters, or in radar proximity fuzes 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,

$$P_{ave} = DC * P_{peak} \tag{4.8}$$

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 beamwidth, and/or shielding). Minimum Detection Range is zero since receiver is never blanked.The *basic* 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 (□f) 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).

$$s = s_1 \cos\theta_1 + s_2 \cos\theta_2 \qquad \textbf{(4.9)}$$

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

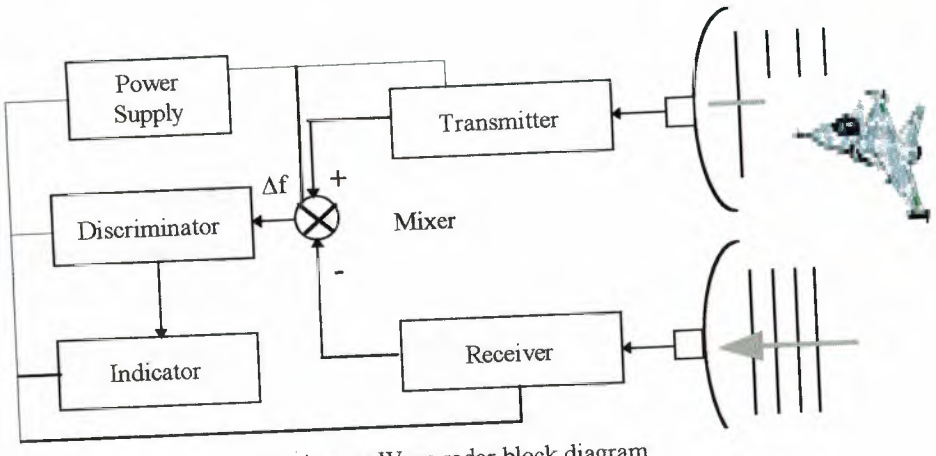


Figure 4.6 continuous wave radar block diagram

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.

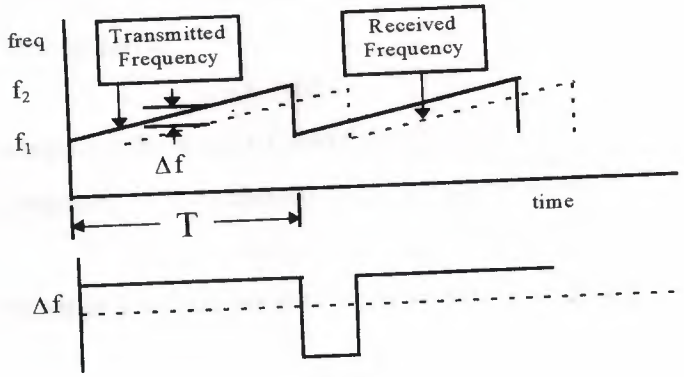


Figure 4.7 FMCW system

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

Where:

f_2= maximum frequency

f_1= minimum frequency

T = period of sweep from f_2 - f_1

Δf = difference between transmitted and received

$$R = \frac{c\Delta t}{2} \qquad (4.11)$$

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

$$\Delta = \mathbf{c / RF} \qquad \mathbf{(4.12)}$$

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

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

$$\mathbf{f_{doppler} = 2 \cdot v / \Delta} \qquad \mathbf{(4.13)}$$

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

$$\Delta = \mathbf{c / RF} \qquad \mathbf{(4.14)}$$

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

$$\mathbf{f_{doppler} = 2 \cdot (v_{Radar} + v_{Target} \cdot \cos\theta) / \Delta} \qquad \mathbf{(4.15)}$$

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

$$\Delta = c / RF \tag{4.16}$$

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

$$f_{doppler} = 2 \cdot v_{Radar} \cdot \cos(Azimuth) \cdot \cos(Elevation) / \Delta \tag{4.17}$$

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.

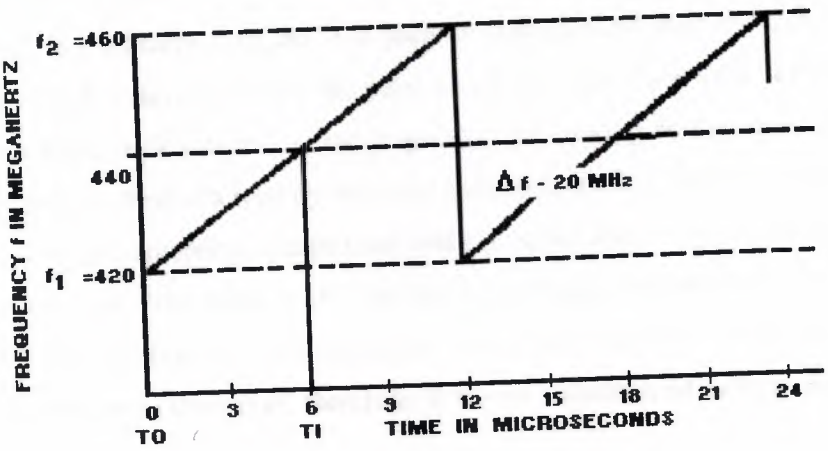


Figure 4.8 Frequency-modulation chart.

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.

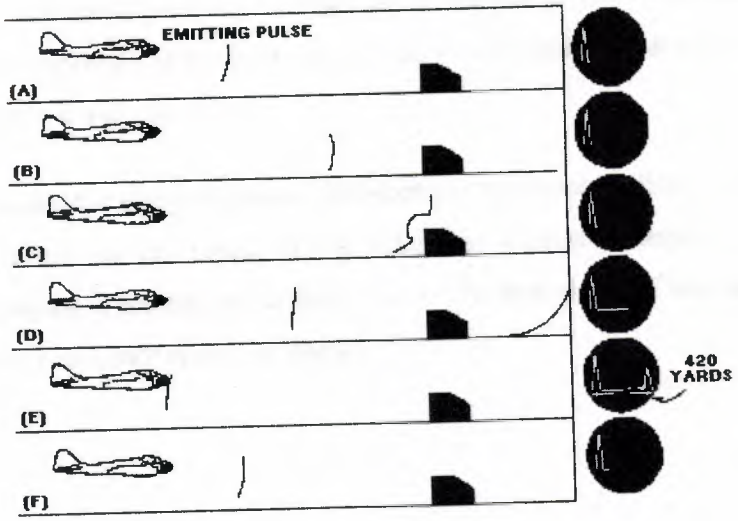


Figure 4.9 Pulse detection

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, generally (but not always) operating in the microwave frequency range (> 1 GHz), and is an active sensor. Here the word active indicates that the sensor radiates energy (electromagnetic waves) toward the surrounding environment and extracts information about it through the analysis of the return echo. Almost all current radars belong to the class called "monostatic", i.e. the transmitter and receiver are located together in single equipment: *bistatic* and *multistatic* radars, on the other side, are those having the transmitter and one (ore more) receivers located in different places.

With transmitter and receiver located several hundreds of meters away: the receiver detected a signal variation when an aircraft was flying above the area between the transmitter and the receiver, thus demonstrating the feasibility of radio detection of flying objects. Common radars are *pulsed*: the transmitted signal is a "short" pulse of radiofrequency, repeated periodically. During the time between two transmit pulses, the radar switches to receive mode to collect the 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 characteristics are accounted for through a parameter called *cross-section.* The signal 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 power must be increased (This applies for a single point target). If the target is a large surface, we shall take into account that the antenna beam becomes wider for increasing ranges, increasing the illuminated area and consequently the reflected power. The two types of modulation most widely used in radar systems are the so-called *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 replica of the transmit signal.

For the chirp, it can be done applying the signal (normally in the Intermediate Frequency section of the receiver) to a *dispersive* delay line in order to concentrate all the pulse energy in a pulse shorter than the original one.

It 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 determine and resolve these important target parameters depends on the characteristics of the transmitted radar signal. The individual components of radar determine the capabilities and limitations of a particular radar system. The characteristics of these components also determine the countermeasures that will be effective against a specific radar system.

The process the radar antenna uses to search airspace for targets is called scanning or sweeping. This chapter will discuss circular, unidirectional, bidirectional, Helical, Raster, Palmer, and conical scans, and track-while-scan (TWS) radar systems. A target tracking radar (TTR) is designed to provide all the necessary information to guide a missile or aim a gun to destroy an aircraft. Once a target has been detected, either by a dedicated search radar or by using an acquisition mode, the TTR is designed to provide accurate target range, azimuth, elevation, or velocity information to a fire control computer.

As the most common radar which has used contineous waves , doppler radar is appeared with adavantages made it, has capability to use the doppler effects which cause around the target and contineous waves 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.

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

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 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 a 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 the 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 target speeds. 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 continous 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.

If the object is moving away from the antenna -- lower frequency. 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. All radars exploiting the Doppler information use the same reference oscillators (characterized by high short-term frequency stability) in both the transmit and receive chains. The local oscillator LO1 is the same for both chains. The received signal, instead of being demodulated using an envelope detector, is compared (normally using two channel having a 90 deg relative phase shift to extract the sin and cosin components of the signal) with the transmission reference frequency LO2 - the same used to generate the intermediate frequency transmit pulse - in a phase detector (a balanced mixer characterized by low offset voltage).

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 unmodulated. 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.