NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

Monostatic Radar

Graduation Project

EE-400

Student: Amer Abdul Rahim (20032941)

Supervisor: Assoc. Prof. Dr. Sameer Ikhdair

Nicosia – 2007

ACKNOWLEDGMENTS

My utmost thanks to my God Allah that I could complete my graduation project. I could not have prepared this project without the generous help of my supervisor, colleaques, friends, and family.

First, I would like to thank my supervisor Assoc. Prof. Dr. Sameer Ikhdair for his invaluable advice, and belief in my work and myself over all the courses of this Degree. Assoc. Prof. Dr. Sameer Ikhdair supplied the warmth, enthusiasm, and clarity of judgement that every student hopes for. Going beyond the limited role of literary agent, he provided valuable advice at each stage of the preparation of this project.

I would like to express my gratitude to Assist. Prof. Dr.Özgur Özerdem because he provided valuable advice at each stage of the preparation of this project also.

I will never forget the help that I got from this university for continueing my education especially from Dr.Tayseer Al Shanableh, so my regards and my love to him.

My deepest thanks are to my family I could never have prepared this project without the encouragement and support of my parents, brothers, and sisters.
The root of this success lies under the most affectionate wish of my loving FATHER. I am grateful to him to assist me to grow in knowledge. I salute you, my father. And I need really to express how much I am proud of being your son,and I didnt forget my mother and what she did for me I dont think I could do this without her

Special big thanks to my friends HATEM MELHEM,OMAR ABU IRGIE ,ALI ALQAM for their encouragement, constant support, and for their patience.I would also like to thank all my friends for their help and for their patience also for their support.

ABSTRACT

This project is about monostatic radar which is the most commonly used type nowadays in our life, Due to its low cost beside the high quality of receiving and sending electromagnetic waves. Further, this subject is considered as a good introduction to all communication knowledges.

Additionlly, this work is helpful to our knowledge while studying the system of communication while we are talking about the radars commonly. So, We investigate the monostatic radar.

The most important properties of monostatic radar is how to receive and send from the same antenna. In the past, The radars were having two antennas, One is for receiving and the other is for sending the signals, and actually in some old radars we can find more than two antennas and every antenna has its special work without doing any other work. That is why we had alot of errors in many subjects from those radars, but by developing those types of radars we would get better results.

The world's technology always tries to get from any technical machines the best results besides the least errors, That is why we got nowadays the monostatic radar which one can find in it mostly the advanced technology conditions. These informations and more can be exist in this project which we hope that it might be useful for all readers

CONTENTS

INTRODUCTION

In modern times, radar is used in a wide variety of applications including air traffic control, defense, meteorology, and even mapping, Radar is "radio detecting and ranging", an electromagnetic sensor used for detecting, locating, tracking, and identifying objects of various kinds at considerable distances.

It operates by transmitting electromagnetic energy toward object, commonly referred to as targets, and observing the echoes returned from them. The targets may be aircraft, ships spacecraft, automotive vehicles, and astronomical bodies, or even birds, insects, and raindrops. Radar can not only determine the presence, location, and velocity of each object but also can sometimes obtain their size and shape as well. What distinguishes radar from optical and infrared sensing devices is its ability to detect far objects under all weather conditions and to determine their range with precision. Here in this project we shall investigate one of these radars that perform all these functions, which is the monostatic radar. Further, the monostatic radar has one antenna for transmitting and receiving.

Chapter 1 describes the fundamentals of radar system, radar pulse, components, target information, target recognition, also its components, transmitters, receivers, and its antennas. And this chapter also describes Radar types; the radar transmits a pulse of RF energy and then receives returns (reflections) from desired and undesired targets. Desired targets may include space, airborne, and sea- and/or surface-based vehicles. They can also include the earth's surface and the atmosphere, depending on the application.

Chapter 2 in this chapter we will see some applications of radar in our life and we see how much is the radar is important like, radar proximity fuses, police radars, altimeters, Doppler navigators, Millimeter-Wave Seeker for Terminal Guidance Missile,

.

Chapter 3, which is mainly about monostatic radar and how it works, further the main properties of this type of radar, finally all the information's about this special type of radar have been presented.

1. FUNDAMENTALS OF RADAR

1.1 Basic Principle

Typical radar operates by radiating a narrow beam of electromagnetic energy into space from an antenna (Figure 1.1).

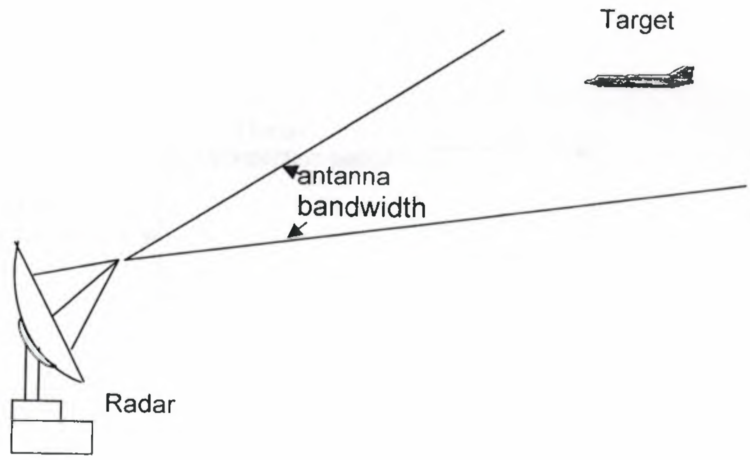

Figure 1.1 Principle of radar operation.

The transmitted pulse which has already passed the target, has reflected a portion of the radiated energy back toward the narrow antenna beam is scanned to search a region where targets are expected.

When a target is illuminated by the beam, it intercepts some of the radiated energy and reflects a portion back toward the radar system. Since most radar systems do not transmit and receive at the same time, a single antenna can be used on a time-shared basis for both transmitting and receiving.

A receiver attached to the output element of the antenna extracts the desired reflected signals and (ideally) rejects those that are of no interest. For example, a signal of interest might be the echo from an aircraft signals that are not of interest might be echoes from the ground or rain, which can mask and interfere with the detection of the desired echo from the aircraft. The radar measures the location of the target in range and angular direction. Range is detennined by measuring the total time it takes for the radar signal to make the round trip to the target and back (Figer 1.2). The angular direction of a target is usually found from the direction in which the antenna points at the time the echo signal is received. Through measurement of the location of a target at successive instants of time, its track can be deteımined. Once this information has been established, the target's location at a time in the future can be predicted, in many surveillance radar a plications, the target is not considered to be "detected" until its track has been established.

1.1.1 Radar Pulse

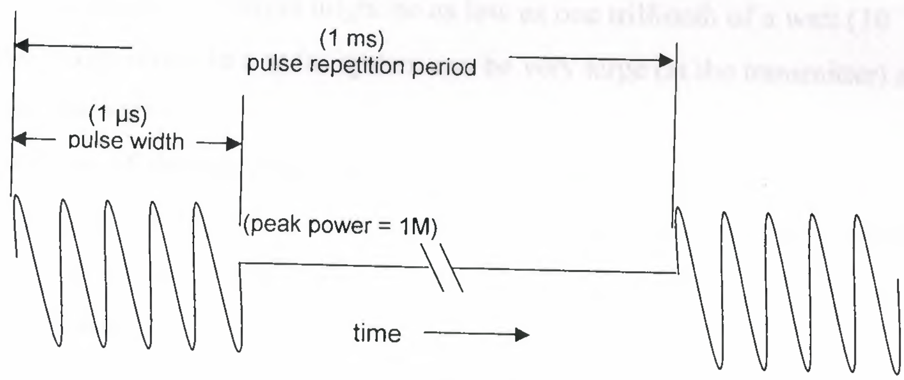

Figure 1.2 *A* typical pulse waveform transmitted by radar.

The most common type of radar signal consists of a repetitive train of short-duration pulses. Figure 1.2 is a simple representation of a sine-wave pulse that might be generated by the transmitter of medium-range radar designed for aircraft detection. This sine wave in the figure represents the variation with time of the output voltage of the transmitter. The numbers given in brackets in the figure are only meant to be illustrative and are not necessarily those of any particular radar. They are anumbers however, similar to what might be expected for a ground-based radar system with a range of about 50 to 60 nautical miles (or 90 to 110 kilometers), such as the kind used for air traffic control at airports. The pulse width is given in the figure as one millionth of a second (one microsecond). it should be noted that the pulse is shown as containing only a few cycles of the sine wave; however, in a radar system.having the values indicated, there would be

1,000 cycles within the pulse. in Figure 1.2 the time between successive pulses is given as one thousandth of a second (one millisecond), which corresponds to a pulse repetition frequency of 1,000 hertz. The power of the pulse, called the peak power, is taken here to be 1,000,000 watts. Since pulse radar does not radiate continually, the average power us much less than the peak power. In this example, the average power is 1,000 watts. The average power, rather than the peak power, is the measure of the capability of a radar system. Radars have average powers from a few milliwatts to as much as one or more megawatts, depending on the application.

A weak echo signal from a target might be as low as one trillionth of a watt (10^{-12} watt). In short, the power levels in a radar system can be very large (at the transmitter) and very small (at the receiver).

Another example of the extremes encountered in a radar system is the timing. An air-surveillance radar one that is used to search for aircraft) might scan its antenna 360 degrees in azimuth in a few seconds, but ,the pulse width might be about one microsecond in duration.

The range to a target is determined by measuring the time that a radar signal takes to travel out to the target and back. The range to the target is equal to cT/2, where *c* is the velocity of propagation of radar energy, and T is the round-trip time as measured by the radar. From this expression, the round-trip travel of the radar signal is at a rate of 150 meters per microsecond. For example, if the time that it takes the signal to travel out to the target and back were measured by the radar to be 600 microseconds, then the range of the target would be 90 kilometers.

1.1.2 Components

Figure 1.3 shows the basic parts of a typical radar system. The transmitter generates the high-power signal that is radiated by the antenna. The antenna is often in the shape of a parabolic reflector, similar in concept to an automobile headlight but much different in construction and size. It also might consist of a collection of individual antennas operating together as a phased-array antenna.

The duplexer permits ultemate transmission and reception with the same antenna, it is a fast-acting switch that protects the sensitive receiver from the high power of the transmitter. The receiver selects and amplifies the weak radar echoes so that they can be displayed on a television-like screen for the human operator or be processed by a computer. The signal processor separates the signals reflected by the target *(e.g.,* echoes from an aircraft) and from unwanted echo signals (the clutter from land, sea, rain, etc).

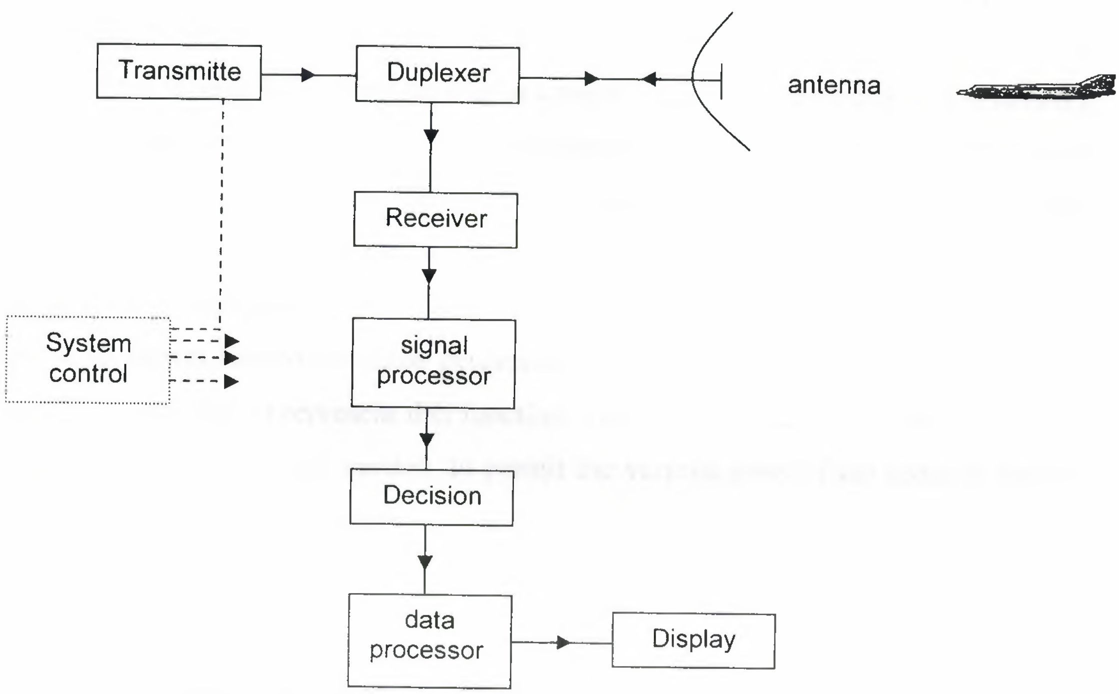

Figure 1.3 Basic parts of a radar system

It is not unusual for these undesired reflections to be much larger than desired target echoes, in some cases more than one miiion times larger. Large clutter echoes from stationary objects can be differentiated from small echoes from a moving target by noting the shift in the observed frequency produced by the moving target. This phenomenon is called the Doppler frequency shift (Figure 1.3) At the output of the receiver a decision is made as to whether or not a target echo is present. If the output of the receiver is larger than a predetermined value, a target is assumed to be present.

Once it has been decided that a target is present and its location has been determined, the track of the target can be obtained by measuring the target location at different times. During the early days of radar, target tracking was performed by an operator marking the location of the target "blip" on the face of a cathode-ray tube (CRT) display with a grease pencil. Manual tracking has been largely replaced by automatic electronic tracking, which can process a much greater number of target tracks than can an operator who can handle only a few simultaneous tracks. Automatic tracking is an example of an operation performed by a data processor The type of signal waveform transmitted and the associated received-signal processing in a radar system might be different depending on the type of target invoived and the environment in which it is located. An operator can select the parameters of the radar to maximize perfomance in a particular environment. Altrnatively, electronic circuitry in the radar system can automatically analyze the.environmet and select the proper transmitted signal, signal processing, and other radar parameters to optimize performance. The box labeled "system control" in Figure1.3 is intended to represent this function. The system control also can provide the timing and reference signals needed .to permit the variolls parts of the radar to operate effectively as an integrated system.

1.1.3 Target Information

The ability to measure the range to a target accurately at long distances and to operate under adverse weather conditions are radar's most distinctive attributes. There are no other devices that can compete with radar in the measurement of range The range accuracy of a simple pulse radar depends on the width of the pulse, the shorter pulse, the better accuracy. Short pulses, require wide bandwidths in the receiver and transmitter. A radar with a pulse width of one microsecond can measure the range to an accuracy of a few tens of meters or better. Some special radars can measure to an accuracy of a few centimeters. The ultimate range accuracy of the best radars is limited not by the radar system itself, but rather by the known accuracy of the velocity at which electromagnetic waves travel.

Almost all radars use a directive antenna-i.e, one that directs its energy in a narrow. The direction of a target can be found from the direction in which the antenna is beam pointing when the received echo is at a maximum. A dedicated tracking radar-one that follows automatically a single target so as determine its trajectory-generally has a narrow symmetrical "pencil" beam. Such a radar system can detennine the location of the target in both azimuth angle and elevation angle. An aircraft-surveillance radar generally employs an antenna that radiates a "fan" beam, one that is narrow in azimuth (about 1 or 2 degrees) and broad in elevation. A fan beam allows only the measurement of the azimuth angle.

Radar can extract the Doppler frequency shift of the echo produced by a moving target .by noting how much the trequency of the received signal diflers from the frequency of the signal that was transmitted. A moving target will cause the frequency of the echo signal to increase if it is approaching the radar or to decrease if it is receding from the radar. For example, if a radar system operates at a frequency of 3,000 megahertz and an aircraft is moving toward it at a speed of 400 knots (740 kilometers per hour), the frequency of the received echo signal will be greater than that of the transmitted signal by about 4.1 kilo hertz. The Doppler frequency shift in hertz is equal to 3.4 $f_0 v_r$, where f_0 is the radar frequency in gigahertz and vr is the radial velocity in knots.

Since the Doppler frequency shift is proportional to radial velocity, a radar system that measures such a shift in frequency can provide the radial velocity of a target. The Dopplei frequency shift also is used to separate moving targets from stationary ones (land or sea clutter) even when the undesired clutter power might be much greater than the power of the echo from the targets. A form of pulse radar that uses the Doppler frequency shift to eliminate stationaiy clutter is called either a moving target indication (MTI) radar or a pulse Doppler radar, depending on the particular parameters of the signal wavefom.

The above measurements of range, angle, and radial velocity assume that the target is like a point. Actual targets, however, are of finite size and can have distinctive shapes. The range profile of a finite-sized target can be deterrnined if the range resolution of the radar is small compared to the target's size in the range dimension. Some radars can have resolutions smaller than one meter, which is quite suitable for deterrnining the radiai. size and profile of many targets of interest.

The resolution in angle that can be obtained with conventional antennas is poor compared to that which can be obtained in range. It is possible, however, to achieve good resolution in angle, or cross range, by resolving in Doppler frequency if the radar is moving relative to the target, the Doppler frequency shift will be different for different parts of the target. Thus the Doppler frequency shift can allow the various parts of the target to be resolved. The resolution in cross range delived from the Doppler frequency shift is far better than that achieved with a narrow-beam antenna. It is not unusual for the cross-range resolution obtained from Doppler frequency to be comparable to that obtained in the range dimension.

Cross-range resolution obtained from Doppler frequency, along with range resolution, is the basİs for synthetİc aperture radar (SAR). SAR produces an image of a scene that is similar to, but not identical with, an optical photograph. One should not expect the image seen by radar "eyes" to be the same as that obseıved by optical ones. Each provides different information. Radar and optical images differ because of the large difference in the frequencies involved, optical frequencies are approximately 100,000 times higher than radar frequencies.

The SAR can operate from long range and through clouds of other atmospheric effects that limit optical and infrared imaging sensors. The resolution of a SAR image can be made independent of range, an advantage over passive optical imaging, where the resolution worsens with increasing range. Synthetic aperture radars that map areas of the Earth's suıface with resolutions of a few meters can provide information about the nature of the terrain and what is on the surface.

A SAR operates on a moving vehicle, such as an aircraft or spacecraft, to image stationary object or planetary surfaces. Since relative motion is the basis for the Doppler resolution, high resolution (in cross range) also can be accomplished if the radar is stationaıy and the target is moving. This is called inverse synthetic aperture radar (ISAR). Both the target and the radar can be in motion with ISAR.

1.1.4 Target Recognition

Radar can distinguish one kind oftarget from another (such as a bird from an aircraft), and some systems are able to recognoze specific classes of targets. Target recognition is accomplished by measuıing the size and speed of the target and by observing the target with high resolution in one or more dimensions. Propeller or jet engines modify the radar echo from aircraft and can assist in target recognition. The flapping of the wings of a bird in flight produces a characteiistic modulation, which can be used to recogize that a bird is present or even to identify one type of bird from another.

1.2 RADAR TYPES

1.2.1 Basic Concepts

The radar transmits a pulse of RF energy and then receives returns (reflections) from desired and undesired targets. Desired targets may include space, airborne, and sea- and/or surface-based vehicles. They can also include the earth's surface and the atmosphere, depending on the application. Undesired targets are termed clutter. Clutter sources include the ground, natural and man-made objects, sea, atmospheric phenomena, and birds. Short-range/low-altitude radar operation is often con-strained by clutter since the multitude of undesired returns masks returns from targets of interest such as aircraft.

The range, azimuth angle, elevation angle, and range rate can be directly measured from a return to estimate target position and velocity. Signature data can be extracted by measuring the amplitude, phase, and polarization of the return.

Pulse radar affords a great deal of design and operational flexibility. Pulse duration and pulse rate can be tailored to specific applications to provide optimal performance. Modern computer-controlled multiple-function radars exploit this capability by choosing the best waveform from a repertoire for a given operational mode and interference environment automatically.

It also predicts the target's flight path to provide range gating and antenna pointing control to the radar system.

Signature measurement applications include remote sensing of the environment as well as the measurement of target characteristics. In some applications, synthetic aperture radar (SAR) imaging is conducted from aircraft or satellites to characterize land usage over broad areas. Moving targets that present changing aspect to the radar can be imaged from airborne or ground-based radars via inverse synthetic aperture radar (ISAR) techniques.

As defined in the subsection "Resolution and Accuracy," cross-range resolution improves with increasing antenna extent. SAR/ISAR effectively substitutes an extended observation interval over which coherent returns are collected from different target aspect angles for a large antenna structure that would not be physically realizable in many instances.

In general, characterization performance improves with increasing frequency because of the associated improvement in range, range rate, and cross-range resolution. However, phenomenological characterization to support environmental remote sensing may require data collected across a broad swath of frequencies.
Multiple-function phased array radar generally integrates these functions to some degree. Its design is usually driven by the track function. Its operational frequency is generally a compromise between the lower frequency of the search radar and the higher frequency desired for the tracking radar.

The degree of signature measurement implemented to support such functions as non cooperative target identification depends on the resolution capability of the radar as well as the operational user requirements. Multiple-function radar design represents a compromise among these different requirements. However, implementation constraints, multiple-target handling requirements, and reaction time requirements often dictate the use of phased array radar systems integrating search, track, and characterization functions.

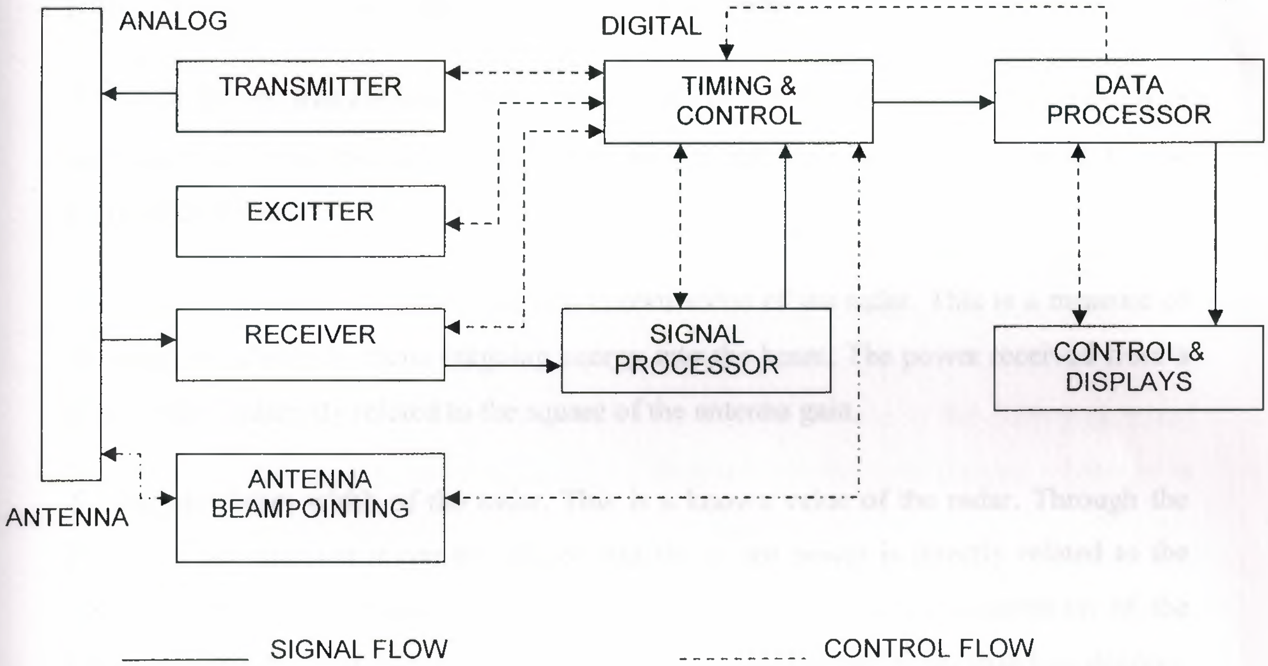

Figure 2.1 Radar System Architecture

1.2.2 Weather Radar

Weather radar has made many improvements in the last 10 years. There are more improvements on the way. All of the radars of the past and present work off the same basic principle: the radar equation below.

$$P_r = \frac{P_t G^2 \theta^2 H \pi^3 K^2 L}{1024(\ln 2)\lambda^2} \times \frac{Z}{R^2} \tag{2.1}$$

Equation (2.1) involves variables that are either known or are directly measured. There is only one value that is missing, but it can be solved for mathematically. Below is the list of variables, what they are, and how they are measured.

P_r : Average power returned to the radar from a target. The radar sends up to 25 pulses and then measures the average power that is received in those returns. The radar uses multiple pulses since the power returned by a meteorological target varies from pulse to pulse. This is an unknown value of the radar, but it is one that is directly calculated.

P_t: Peak power transmitted by the radar. This is a known value of the radar. It is important to know because the average power returned is directly related to the transmitted power.

G: Antenna gain of the radar. This is a known value of the radar. This is a measure of the antenna's ability to focus outgoing energy into the beam. The power received from a given target is directly related to the square of the antenna gain.

θ: Angular beam width of the radar. This is a known value of the radar. Through the Probert-Jones equation it can be learned that the return power is directly related to the square of the angular beam width. The problem becomes that the assumption of the equation is that precipitation fills the beam for radars with beams wider than two degrees. It is also an invalid assumption for any weather radar at long distances. The lower resolution at great distances is called the aspect ratio problem.

H: Pulse Length of the radar. This is a known value of the radar. The power received from a meteorological target is directly related to the pulse length.

K: This is a physical constant. This is a known value of the radar. This constant relies on the dielectric constant of water. This is an assumption that has to be made, but also can cause some problems. The dielectric constant of water is near one, meaning it has a good reflectivity. The problem occurs when you have meteorological targets that do not share that reflectivity. Some examples of this are snow and dry hail since their constants are around 0.2.

L: This is the loss factor of the radar. This is a value that is calculated to compensate for attenuation by precipitation, atmospheric gases, and receiver detection limitations. The attenuation by precipitation is a function of precipitation intensity and wavelength. For atmospheric gases, it is a function of elevation angle, range, and wavelength. Since all of this accounts for a 2dB loss, all signals are strengthened by 2 dB.

λ: This is the wavelength of the transmitted energy. This is a known value of the radar. The amount of power returned from a precipitation target is inversely since the short wavelengths are subject to significant attenuation. The longer the wavelength, the less attenuation caused by precipitate.

Z: This is the reflectivity factor of the precipitate. This is the value that is solved for mathematically by the radar. The number of drops and the size of the drops affect this value. This value can cause problems because the radar cannot determine the size of the precipitate. The size is important since the reflectivity factor of a precipitation target is determined by raising each drop diameter in the sample volume to the sixth power and then summing all those values together. A ¼" drop reflects the same amount of energy as 64 1/8" drops even though there is 729 times more liquid in the 1/8" drops.

R: This is the target range of the precipitate. This value can be calculated by measuring the time it takes the signal to return. The range is important since the average power return from a target is inversely related to the square of its range from the radar. The radar has to normalize the power returned to compensate for the range attenuation.

Using a relationship between Z and R, an estimate of rainfall can be achieved. A base equation that can be used to do this is Z=200*R^1.6. This equation can be modified at the user's request to a better fitting equation for the day or the area.

The basic concept of weather radar works off of the idea of a reflection of energy as shown in figure 3.2. The radar sends out a signal, as seen to the right, and the signal is then reflected back to the radar. The stronger that the reflected signal is, the larger the particle. For more basic information on weather radar

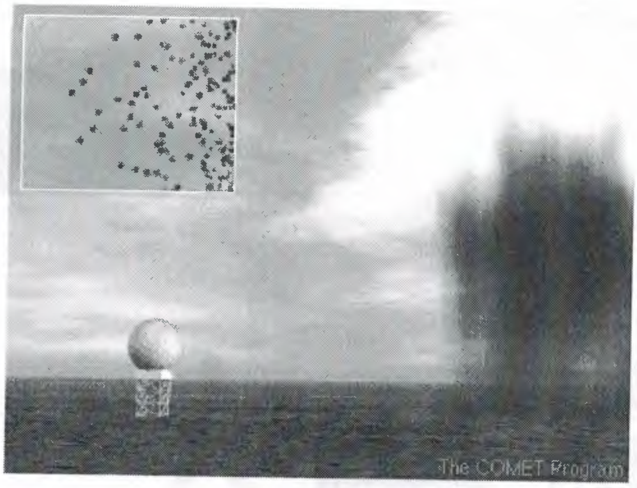

Figure 2.2 Basic Concepts of Weather Radar

1.2.3 Object Classification with Automotive Radar

Automotive radar systems offer the capability to measure simultaneously range, relative speed and azimuth angle of all observed objects inside the observation area. This measurement is processed with high resolution and accuracy in range, Doppler frequency and azimuth angle domain respectively. For all these reasons and excellent technical performances, present driver assistance systems are almost always based on the use of radar sensors.

In addition to the precise measurement results of all targets inside the observation area, the knowledge of target recognition is required. Each individual object (e.g. vehicle, pedestrian, cyclist, tree, traffic sign, etc.) should be classified into an object class. The assignment of detected targets to specified object classes will be called classification. This additional requirement is of increasing interest for future automotive applications (see Figure 2.3). Especially safety related applications like lane departure warning or pre-crash-applications will benefit from this additional information if the classification results are of high performance.

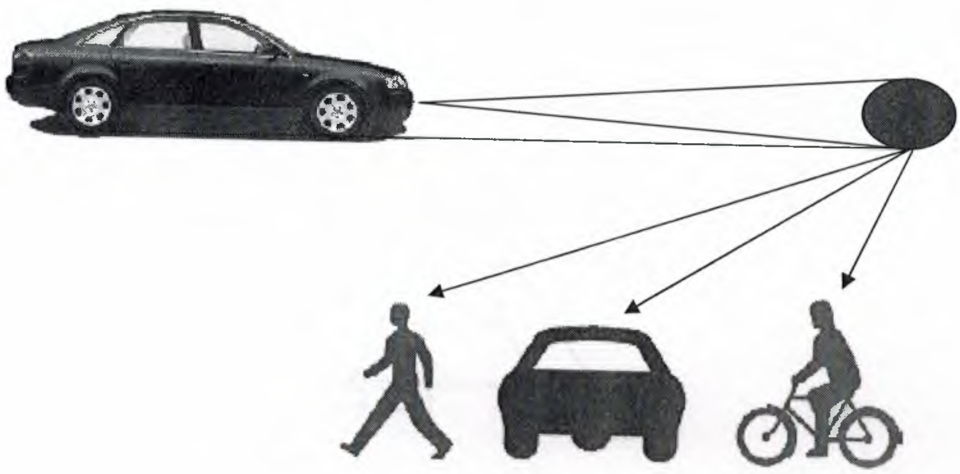

Figure 2.3 Target recognition for automotive radar applications

So far, mainly video systems have been used to perform the object classification in specific automotive applications. These technical solutions need high computation power for image processing and are therefore expensive. There are even strong limitations for video systems in automotive applications due to bad weather conditions in general. Radar systems can overcome all these drawbacks and limitations of video systems, but a radar based target classification system for automotive applications is a pure novelty and technical challenge which has never been realized before.

1.2.4 Radar Network Based on 24 GHz Sensors

A radar sensor network based on four 24 GHz high range resolution (HRR) pulse radars has been integrated into the front bumper of an experimental car. Each sensor is capable of measuring the target range with very high accuracy of ±4 cm and very high resolution over the complete range of up to 20 m. The angular coverage of each sensor in azimuth direction is approximately *±30°. Thus, a system of four distributed sensors in the front* bumper covers a large observation area in front of the vehicle. Figure 2.4 shows the example of a single target situation indicating the measured distances.

The object position is determined by trilateration of the measured distances. This radar network is used as an example for the automotive target recognition system described in this contribution.

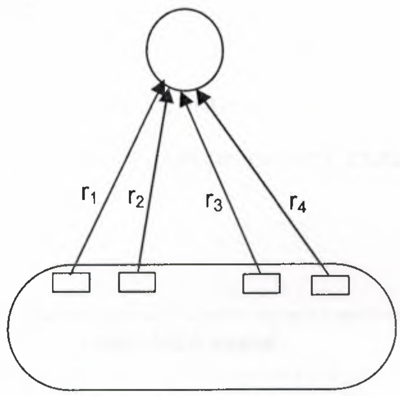

Figure 2.4 Example of a single target situation

1.2.5 Radar Based Object Classification

To distinguish between different object classes, several features are needed which describe the characteristic behavior of the echo signal in a local environment. A single feature is insufficient to solve the target recognition task. Thus, a couple of different, well-chosen features gained from the echo signal are needed to solve this challenging target classification task. The characteristics of the received echo signal depend on the considered radar sensor system. The signal features must be defined in accordance with the implemented radar sensor system. A multi-dimensional feature vector is determined and a classification system is developed, capable of learning the target signal properties and automatically calculating the resulting decision for target recognition. The main objective of a target classification system is to compute a class membership for a given vector of signal features. The set of different target classes is given by the classifier definition. For all classifiers, the application can be split into a learning and a classification phase. Throughout the learning phase, a number of characteristic and individually labeled feature vectors is automatically analyzed by the classifier. During the classification phase, the feature vector is generated for each detected target and the recognition algorithm makes a decision with maximum likelihood to which class the feature vector belongs to.

A polynomial classifier is used for the considered automotive application, because it is well suited for complex classification tasks where several features are considered inside a feature vector. The advantage of the polynomial classifier is the automatic learning procedure, which converges after a single iteration cycle. It evaluates the features' influence on the decision process and eliminates terms automatically which have only a minor impact. Figure 2.5 shows the signal processing chain of the classification system as a block diagram.

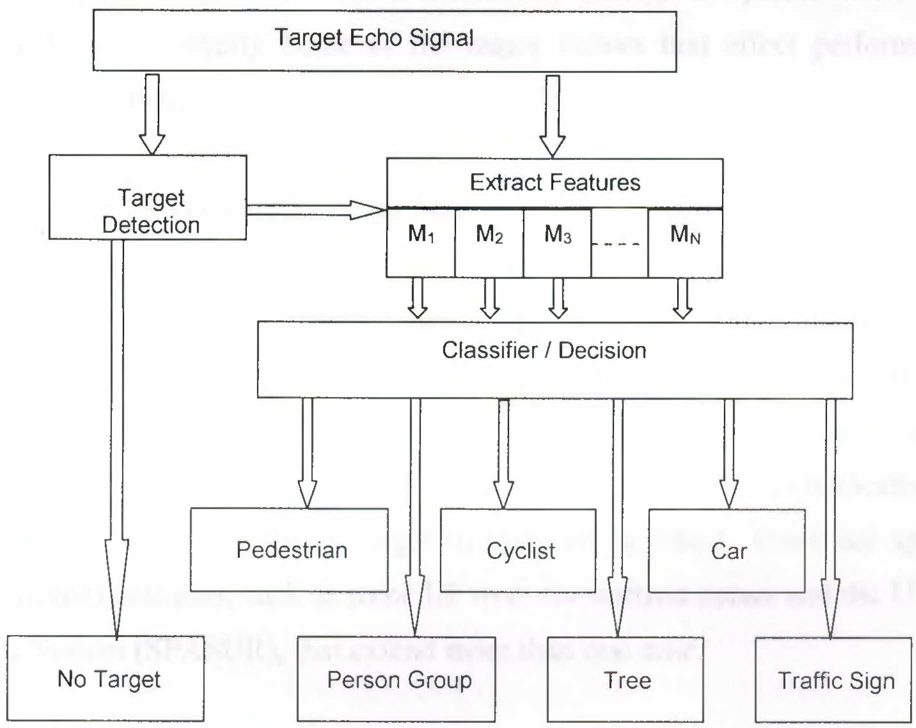

Figure 2.5 Signal processing chain for target recognition

1.3 Factors Affecting Radar Performance

The performance of a radar system can be judged by the following: (1) the maximum range at which it can see a target of a specified size, (2) the accuracy of its measurement of target location in range and angle, (3) its ability to distinguish one target from another, (4) its ability to detect the desired target echo when masked by large clutter echoes, unintentional interfering signals from other "friendly" transmitters, or intentional radiation from hostile jamming (if a military radar), (5) its ability to recognize the type of target, and (6) its availability (ability to operate when needed), reliability, and maintainability Some of the major factors that affect performance are discussed in this section.

1.3.1 Transmitter Power and Antenna Size

The maximum range of a radar system depends in large part on the average power of its transmitter and the physical size of its antenna. (In technical terms, this is the power-aperture product.) There are practical limits to each. As noted before, some radar systems have an average power of roughly one megawatt. Phased-array radars about 100 feet in diameter are not uncommon, some are much larger. Likewise, mechanically scanned reflector antennas about 100 feet or larger in size can be found. There are specialized radars with (fixed) antennas, such as some HF over-the-horizon radars and the U.S. Space Surveillance System (SPASUR), that extend more than one mile.

1.3.2 Receiver Noise

The sensitivity of a radar receiver is detennined by the unavoidable noise that appears at its input. At microwave radar frequencies, the noise that limits detectability is usually generated by the receiver itself *(i.e.* by the random motion of electrons at the input of the receiver) rather than by external noise that enters the receiver via the antenna. The radar engineer often employs a transistor amplifier as the first stage of the receiver even though Iower noise can be obtained with more sophisticated devices. This is an example Of the application of the basic engineering principle that the "best" peıforrnance that can be obtained might not necessarily be the solution that best meets the needs of the user.

The receiver is designed to enhance the desired signals and to reduce the noise and other undesired signals that inteıfere with detection. The designer attempts to maximize the detectability of weak signals by using what radar engineers call a "matched filter which is a filter that maximizes the signal-to-noise ratio at the receiver output. The rnatched filter has a precise rnathernatical torrnulation that depends on the shape of the input signal and the character of the receiver noise. A suitable approximation to the matched filter for the ordinary pulse radar, however, is one whose bandwidth in hertz is the reciprocal of the pulse width in seconds.

1.3.3 Target Size

The size of a target as "seen" by radar is not always related to the physical size of the object. The measure of the target size as observed by radar is called the radar cross section and is given in units of area (square meters). It is possible for two targets with the same physical cross sectional area to differ considerably in radar size, or radar cross section. For example, a flat plate one square meter in area will produce a radar cross section of about 1,000 square meters at a frequency of 3,000 megahertz (S band; see below) when viewed perpendicular to the surface. A cone-sphere (an object resembling an ice-cream cone) when viewed in the direction of the cone rather than the sphere could have a radar cross section one thousandth of a square meter even though its projected area is also one square meter. in theory, thİs value does not depend to a great extent on the size of the cone or the cone angle. Thus the flat plate and the cone-sphere can have radar cross sections that differ by a million to one even though their physical projected areas are the same.

The sphere is an unusual target in that its radar cross section is the same as its physical cross section area (when its circumference is large compared to the radar wavelength). That is to say, a sphere w.ith a projected area of one square meter has a radar cross section of one square meter.

Commercial aircraft might have radar cross sections from about 10 to 100 square meters, except when viewed broadside, where it is much larger. (This is an aspect that is seldom of interest, however.) Most air-traffic-controi radars are required to detect aircraft with a radar cross section as low as two square meters, since some small general-aviation aircraft can be of this value. For comparison, the radar cross section of a man has been measured at microwave frequencies to be about one square meter .A bird can have a cross section of 0.0l square meter. Although this is a small value, a bird can be readily detected at ranges of several tens of miles by long-range radar. In general, many birds can be picked up by radar so that special measures must usually be taken to insure that echoes from birds do not interfere with the detection of desired target:

The radar cross section of an aircraft and most other targets of practical interest is not a constant but, rather, fluctuates rapidly as the aspect of the target changes with respect to the radar unit. It would not be unusual for a slight change in aspect to cause the radar cross section to change by a factor of 10 to 1,000. (Radar engineers have to take this fluctuation in the radar cross section oftargets into account in their design.)

1.3.4 Clutter

Echoes from land, sea, rain, snow, hail, birds, insects, auroras, and meteors are of interest to those who observe and study the environment, but they are a nuisance to those who want to detect and follow aircraft, ships, missiles, or other similar targets. Clutter echoes can seriously limit the capability of a radar system; thus a significant part of radar design is devoted to minimizing the effects of clutter without reducing the echoes from desired targets. The Doppler frequency shift is the usual means by which moving targets are distinguished from the clutter of stationary objects. Detection of targets in rain is less of a problem at the lower frequencies, since the radar echo from rain decreases rapidly with decreasing frequency and the average cross section of aircraft is relatively independent of frequency in the microwave region. Because raindrops are more or less spherical (symmetrical) and aircraft are asymmetrical, the use of circular po1arization can enhance the detection of aircraft in rain. With circular polarization the electric field rotates at the radar frequency. Because of this, the electromagnetic energy reflected by the rain and the aircraft will be affected differently, thereby making it easier to distinguish between the two. (in tair weather, most radars use 1inear polarization-i.e.. the direction of the field is fixed).

1.3.5 Atmospheric Effects

As was mentioned, rain and other forms of precipitation can cause echo signals that mask the desired target echoes There are other atmospheric phenomena that can affect radar pertormance as well. the decrease in density of the Earth's atmosphere with increasing altitude causes radar waves to bend. as they propagate through the atmosphere this usually increases the detection range at iow angles to a slight extent. The atmosphere can torm !'ducts" that trap and guide radar energy around the curvature of the Eanh and allow detection at ranges beyond the normal horizon. Ducting over water is more likely to occur in tropical climates than in coider regions. Ducts can sometimes extend the range of an airborne radar, but on other occasions they may cause the radar energy to be diverted and not illuminate regions below the ducts. This results in the formation of what are called radar holes in the coverage. Since it is not predictable or reliable, ducting can in some instances be more of a nuisance than a help. Loss of radar energy,when propagation is through the clear atmosphere or rain, is usually in significant for systems operating at microwave frequencies.

1.3.6 Interference

Signals from nearby radars and other transmitters can be strong enough to enter a radar when propagation is through the clear atmosphere or rain, is usually insignificant for systems operating at microwave frequencies receiver and produce spurious responses. Well-trained operators are not often deceived by interference, though they may find it a nuisance. Interference is not as easily ignored by automatic detection and tracking systems, however, and so some method is usually needed to recognize and remove interference pulses before they enter the automatic detector and tracker of a radar.

1.3.7 Electronic Countermeasures

The purpose of hostile electronic countenneasures (ECM) is to deliberately degrade the effectiveness of military radar. ECM can consist of (1) noise jamming that enters the receiver via the antenna and increases the noise level at the input of the receiver , (2) false target generation, or repeater jamming, by which hostile jammers introduce additional signals into the radar receiver in an attempt to confuse the receiver into thinking they are real target echoes, (3) chaff, which is an artificial cloud consisting of a large number of tiny metallic retlecting strips that create strong echoes over a large area to mask the presence of real target echoes or to create confusion, and (4) decays, which are small, inexpensive air vehicles or other objects designed to appear to the radar as if they were real targets. Military radars are also subject to direct attack by conventional weapons or by antiradiation missiles (ARMs) that use radar transmissions to find the target and home on it.

Military radar engineers have developed various ways of countering hostile ECM and maintaining the ability of a radar system to perform its mission. It might be noted that a military radar system can often accomplish its mission satistactorily even though its perfonnance in the presence of ECM is not what it would be if such measures were absent.

1.4 Antenna

The radar antenna function is to first provide spatial directivity to the transmitted EM wave and then to intercept the scattering of that wave from a target. Most radar antennas may be categorized as mechanically scanning or electronically scanning. Mechanically scanned reflector antennas are used in applications where rapid beam scanning is not required. Electronic scanning antennas include phased arrays and frequency scanned antennas.

Phased array beams can be steered to any point in their field-of-view, typically within 10 to 100 ms, depending on the latency of the beam steering subsystem and the switching time of the phase shifters. Phased arrays are desirable in multiple function radars since they can interleave search operations with multiple target tracks.

There is a Fourier transform relationship between the antenna illumination function and the far-field antenna pattern. Hence, tapering the illumination to concentrate power near the center of the antenna suppresses side lobes while reducing the effective antenna aperture area. The phase and amplitude control of the antenna illumination determines the achievable side lobe suppression and angle measurement accuracy.

Perturbations in the illumination due to the mechanical and electrical sources distort the illumination function and constrain performance in these areas. Mechanical illumination error sources include antenna shape deformation due to sag and thermal effects as well as manufacturing defects.

Electrical illumination error is of particular concern in phased arrays where sources include beam steering computational error and phase shifter quantization. Control of both the mechanical and electrical perturbation errors is the key to both low side lobes and highly accurate angle measurements. Control denotes that either tolerance are closely held and maintained or that there must be some means for monitoring and correction.

Phased arrays are attractive for low side lobe applications since they can provide element-level phase and amplitude control.

1.4.1 Transmitter

The transmitter function is to amplify waveforms to a power level sufficient for target detection and estimation.

There is a general trend away from tube-based transmitters toward solid-state transmitters. In particular, solid-state transmit/receive modules appear attractive for constructing phased array radar systems. In this case, each radiating element is driven by a module that contains a solid-state transmitter, phase shifter, low-noise amplifier, and associated control components. Active arrays built from such modules appear to offer significant reliability advantages over radar systems driven from a single transmitter. However, microwave tube technology continues to offer substantial advantages in power output over solid-state technology.

1.4.2 Receiver and Exciter

This subsystem contains the precision timing and frequency reference source or sources used to derive the master oscillator and local oscillator reference frequencies. These reference frequencies are used to down convert received signals in a multiple-stage super heterodyne architecture to accommodate signal amplification and interference rejection. The receiver front end is typically protected from overload during transmission through the combination of a circulator and a transmit/receive switch.

The exciter generates the waveforms for subsequent transmission. As in signal processing, the trend is toward programmable digital signal synthesis because of the associated flexibility and performance stability.

1.4.3 Antenna Directivity and Aperture Area

The directivity of the antenna is

$$D = \frac{4\pi A\eta}{\lambda^2} \tag{1.1}$$

where η. is aperture efficiency and λ . is radar carrier wavelength. Aperture inefficiency is due to the antenna illumination factor.

The common form of the radar range equation uses power gain rather than directivity. Antenna gain is equal to the directivity divided by the antenna losses. In the design and analysis of modern radars, directivity is a more convenient measure of performance because it permits designs with distributed active elements, such as solid-state phased arrays, to be assessed to permit direct comparison with passive antenna systems.

Beam-width and directivity are inversely related; a highly directive antenna will have a narrow beam-width. For typical design parameters,

$$D = \frac{10^7}{\theta_{az}\theta cl} \tag{1.2}$$

where θ_{az} and θ_{cl} are the radar azimuth and elevation beam-widths, respectively, in mill radians.

2. Applications Of Radar

Space does not permit giving a full description of the many applications mentioned at the beginning of this chapter, but several will be discussed.

2.1 Radar Proximity Fuses

Projectiles or missiles designed to be aimed at ships or surface land targets often need a height-of-burst (HOB) sensor (or target detection device) to fire or fuse the warhead at a height of a few meters. There are two primary generic methods of sensing or measuring height to generate the warhead fire signal. The most obvious, and potentially the most accurate, is to measure target round trip propagation delay employing conventional radar ranging techniques. The second method employs simple CW Doppler radar or variation thereof, with loop gain calibrated in a manner that permits sensing the desired burst height by measurement of target return signal amplitude and/or rate of change. Often the mission requirements do not justify the complexity and cost of the radar ranging approach. Viable candidates are thus narrowed down to variations on the CW Doppler fuse.

In its simplest form, the CW Doppler fuse consists of a fractional watt RF oscillator, homodyne detector, Doppler amplifier, Doppler envelope detector, and threshold circuit. When the Doppler envelope amplitude derived from the returned signal reaches the preset threshold, a fire signal is generated. The height at which the fire signal occurs depends on the radar loop gain, threshold level, and target reflectivity. Fuse gain is designed to produce the desired height of burst under nominal trajectory angle and target reflectivity conditions, which may have large fluctuations due to glint effects, and deviations from the desired height due to antenna gain variations with angle, target reflectivity, and fuse gain tolerances are accepted. A loop gain change of 6 dB (2 to 1 in voltage), whether due to a change in target reflection coefficient, antenna gain, or whatever, will result in a 2 to 1 HOB change.

HOB sensitivity to loop gain factors can be reduced by utilizing the slope of the increasing return signal, or so-called rate-of-rise. Deriving HOB solely from the rate-of-rise has the disadvantage of rendering the fuse sensitive to fluctuating signal levels such as might result from a scintillating target. The use of logarithmic amplifiers decreases the HOB sensitivity to the reflectivity range. An early (excessively high) fire signal can occur if the slope of the signal fluctuations equals the rate-of-rise threshold of the fuse. In practice a compromise is generally made in which Doppler envelope amplitude and rate-of-rise contribute in some proportion of HOB.

Another method sometimes employed to reduce HOB sensitivity to fuse loop gain factors and angle of fall is the use of FM sinusoidal modulation of suitable deviation to produce a range correlation function comprising the zero order of a Bessel function of the first kind. The subject of sinusoidal modulation is quite complex, but has been treated in detail by Saunders. The most important aspects of fuse design have to do with practical problems such as low cost, small size, ability to stand very high-g accelerations, long life in storage, and countermeasures susceptibility.

2.2 Police Radars

Down-the-road police radars, which are of the CW Doppler type, operate at 10.525, 24.150, or in the 33.4 to 36.0 GHz range, frequencies approved in the United States by the Federal Communications Commission. Half power beam widths are typically in the 0.21 to 0.31-radian range. The sensitivity is usually good enough to provide a range exceeding 800 meters. Target size has a dynamic range of 30 dB (from smallest cars or motorcycles to large trucks). This means that a large target can be seen well outside the antenna 3-dB point at a range exceeding the range of a smaller target near the center of the beam. Thus there can be uncertainty about which vehicle is the target. Fisher has given a discussion of a number of the limitations of these systems, but in spite of these factors probably a hundred thousand have been built.

The designs typically have three amplifier gains for detection of short, medium, or maximum range targets, plus a squelch circuit so that sudden spurious signals will not be counted. The Doppler signal is integrated and this direct current provides speed readout. Provision is made for calibration to assure the accuracy of the readings.

Table 2.1 Parameters for Two Commercial Altimeters

Modulation Frequency	Frequency Deviation	Prime Power	Weight (Pounds)	Radiated Power
Bendix	150 Hz	130 MHz	30 W	11
ALA-52A Collins	100 KHz	100 MHz	8	350 mW
ALT-55	100 KHz	100 KHz	8	350 mW

2.3 Altimeters

A very detailed discussion of FM/CW altimeters has been given by Saunders, in which he has described modern commercial products built by Bendix and Collins. The parameters will be summarized below and if more information is needed, the reader may want to turn to other references. In his material, Saunders gives a general overview of modern altimeters, all of which use wide-deviation FM at a low modulation frequency. He discusses the limitations on narrowing the antenna pattern, which must be wide enough to accommodate attitude changes of the aircraft.

Triangular modulation is used, since for this waveform the Doppler averages out, and dual antennas are employed. There may be a step error or quantization in height (which could be a problem at low altitudes), due to the limitation of counting zero crossings. A difference of one zero crossing (i.e., 1/2 Hz) corresponds to 3/4 meter for a frequency deviation of 100 MHz. Irregularities are not often seen, however, since meter response is slow. Also, if terrain is rough, there will be actual physical altitude fluctuations. Table 2.2 shows some of the altimeters' parameters. These altimeters are not acceptable for military aircraft, because their relatively wide-open front ends make them potentially vulnerable to electronic countermeasures. A French design has some advantages in this respect by using a variable frequency deviation, a difference frequency that is essentially constant with altitude, and a narrowband front-end amplifier.

2.4 Doppler Navigators

These systems are mainly sinusoidally modulated FM/CW radars employing four separate downward looking beams aimed at about 15 degrees off the vertical. Because commercial airlines have shifted to non-radar forms of navigation, these units are designed principally for helicopters. Saunders cites a particular example of a commercial unit operating at 13.3 GHz, employing a Gunn oscillator as the transmitter, with an output power of 50 mW, and utilizing a 30-kHz modulation frequency. A single micro strip antenna is used. A low altitude equipment (below 15,000 feet), the unit weighs less than 12 pounds. A second unit cited has an output power of 300 mW, dual antennas, dual modulating frequencies, and an altitude capability of 40,000 feet.

2.5 Millimeter-Wave Seeker for Terminal Guidance Missile

Terminal guidance for short-range (less than 2 km) air-to-surface missiles has seen extensive development in the last decade. Targets such as tanks are frequently immersed in a clutter background which may give a radar return that is comparable to that of the target. To reduce the clutter return in the antenna footprint, the antenna beam width is reduced by going to millimeter wavelengths. For a variety of reasons the choice is usually a frequency near 35 or 90 GHz. Antenna beam width is inversely proportional to frequency, so in order to get a reduced beam width we would normally choose 90 GHz; however, more deleterious effects at 90 GHz due to atmospheric absorption and scattering can modify that choice. In spite of small beam widths, the clutter is a significant problem, and in most cases signal-to-clutter is a more limiting condition than signal-to noise in determining range performance. Piper has done an excellent job of analyzing the situation for 35- and 90-GHz pulse radar seekers and comparing those with a 90-GHz FM/CW seeker. His FM/CW results will be summarized below.

In his approach to the problem, Piper gives a summary of the advantages and disadvantages of a pulse system compared to the FM/CW approach. Most of these have already been covered in earlier sections, but one difficulty for the FM/CW can be emphasized again. That is the need for a highly linear sweep, and, because of the desire for the wide bandwidth, this requirement is accentuated. The wide bandwidth is desired in order to average the clutter return and to smooth the glint effects. In particular, glint occurs from a complex target because of the vector addition of coherent signals scattered back to the receiver from various reflecting surfaces. At some angles the vectors may add in phase (constructively) and at others they may cancel, and the effect is specifically dependent on wavelength. For a narrowband system, glint may provide a very large signal change over a small variation of angle, but, of course, at another wavelength it would be different. Thus, very wide bandwidth is desirable from this smoothing point of view, and typical numbers used in millimeter-wave radars are in the 450- to 650-MHz range.

Piper chose 480 MHz. Another tradeoff involves the choice of FM waveform. Here the use of a triangular waveform is undesirable because the Doppler frequency averages out and Doppler compensation is then required. Thus the sawtooth version is chosen, but because of the large frequency deviation desired, the difficulty of linearizing the frequency sweep is made greater. In fact many components must be extremely wideband, and this generally increases cost and may adversely affect performance. On the other hand, the difference frequency (F_b) and/or the intermediate frequency (*FIF*) will be higher and thus further from the carrier, so the phase noise will be lower. After discussing the other tradeoffs, Piper chose 60 MHz for the beat frequency.

With a linear FM/CW waveform, the inverse of the frequency deviation provides the theoretical time resolution, which is 1.1 ns for 480 MHz (or range resolution of 0.3 meter). For an RF sweep linearity of 300 kHz, the range resolution is actually 5 meters at the 1000-meter nominal search range. (The system has a mechanically scanned antenna.) An average transmitting power of 25 mW was chosen, which was equal to the average power of the 5W peak IMPATT assumed for the pulse system. The antenna diameter was 15 cm. For a target radar cross section of 20 m2 and assumed weather conditions, the signal-to-clutter and signal-to-noise ratios work calculated and plotted for ranges out to 2 km and for clear weather or 4 mm per hour rainfall. The results show that for 1 km range the target-to-clutter ratios are higher for the FM/CW case than the pulse system in clear weather or in rain, and target-to-clutter is the determining factor.

3. MONOSTATIC RADAR LAYOUT

3.1 Introduction

In monostatic radar, the antenna sharing is made possible by a duplexer, which isolates the sensitive receiver from the high power transmitted pulse. We shall go into more details later as to how this isolation is achieved.

When the target moves radially with respect to the radar antenna, a Doppler shift is introduced to the transmitted frequency f_t. The received signal is therefore $f_t + f_d$ where the Doppler shift is negative if the target is moving away from the antenna, and positive if it is moving towards the antenna. This Doppler shift is an important method of removing unwanted signals in the signal processing part of a radar system as shown in figure 3.1.

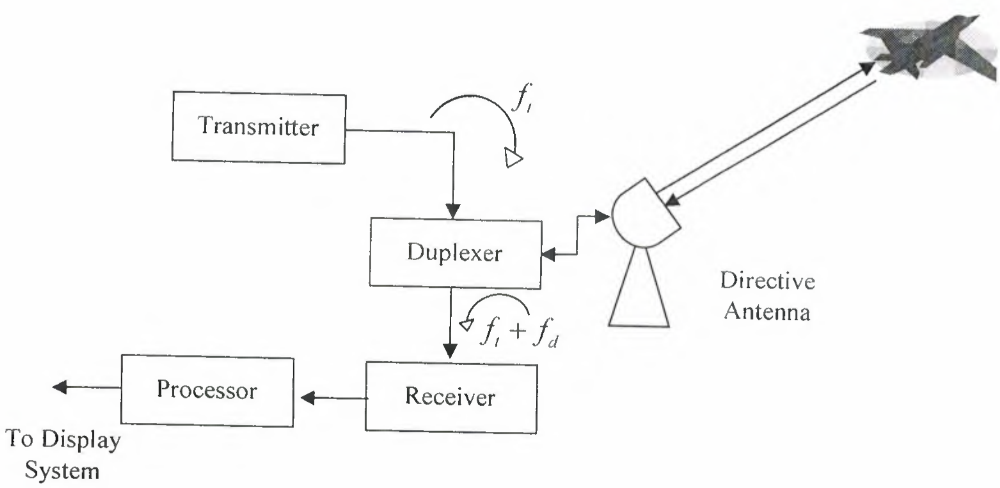

Figure 3.1 Monostatic radar layout

3.2 Co-ordinate System

We have seen how radar can determine the range and azimuth of a target utilising an antenna rotating in the horizontal plane. In a height finding radar, the antenna beam also scans in a vertical plane. Radar is therefore capable of positioning the target in 3-dimensional space and the generalised position in spherical coordinates is shown in the slide.

The origin of the coordinate system has been chosen in the middle of the radar antenna. The y-axis points in the North direction, and the z-axis in the direction of the Zenith. Normally, true North is the reference direction in azimuth (historically magnetic north was used to be compatible with compass navigation). The Zenith is the point in space immediately above the observer. The point P represents the target and P' is the perpendicular projection of P on the xy-plane. In radar, elevation is defined as the elevation above the horizon. The coordinates of the target are: -

- Range (or "slant" range) R.
- Azimuth (Az)angle $_{az.}$
- Elevation (EL) angle $_{el}$.

Most ATC radars only give range and azimuth and are called 2D-radars (2D - two-dimensional). 3D-radars or dedicated height finding radars give additionally the elevation angle.

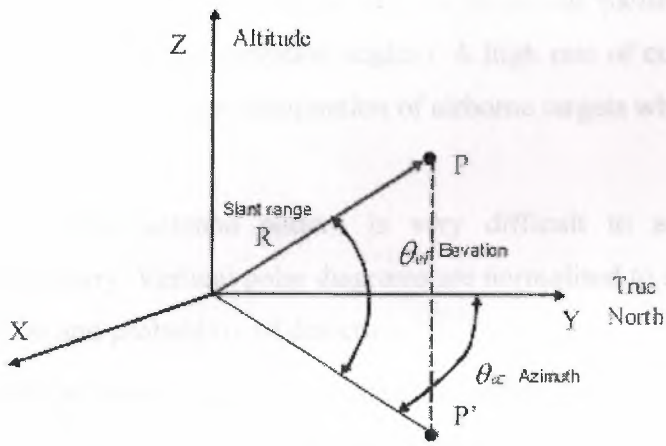

Figure 3.2 The coordinate system

3.3 Antenna Vertical Polar Diagram

In air traffic control radar, targets lie in a thin flat cylinder whose radius is many times its height. This leads to a requirement for a fan shaped beam or vertical polar diagram. The slide shows the coverage diagram for approach/TMA radar. Typically, the range requirement is of the order of 80 *Nm* and the height requirement is about 40,000 feet. The beam must be designed to illuminate targets within the coverage volume without transmitting energy where it is not required. Apart from the basic range and altitude requirements, the antenna must minimise the overhead gap or cone of silence. This gap is the inverted cone mapped out by the rotating antenna as a result of the antenna back angle being less than 90 degrees. Hence, the back angle is an important antenna parameter.

If the back angle is shallow then aircraft will fall outside radar cover as they over-fly the radar site.

A further important parameter relates to the need to avoid too much illumination of the ground. If the antenna transmits too much energy at ground level, then the level of ground returns from physical features such as mountains or buildings may swamp the aircraft returns. A key parameter is therefore the rate of cut off (defined in terms of the rate of cut of antenna gain at low elevation angles). A high rate of cut off on the under edge of the beam permits maximum illumination of airborne targets while minimising the illumination of the ground.

In practice, the idealised antenna pattern is very difficult to achieve and some compromises are necessary. Vertical polar diagrams are normalised to defined parameters such as the target size and probability of detection.

It is also important to remember that the coverage is modified by local obstructions and by interaction with the ground plane immediately surrounding the antenna. These aspects will be covered later in the module.

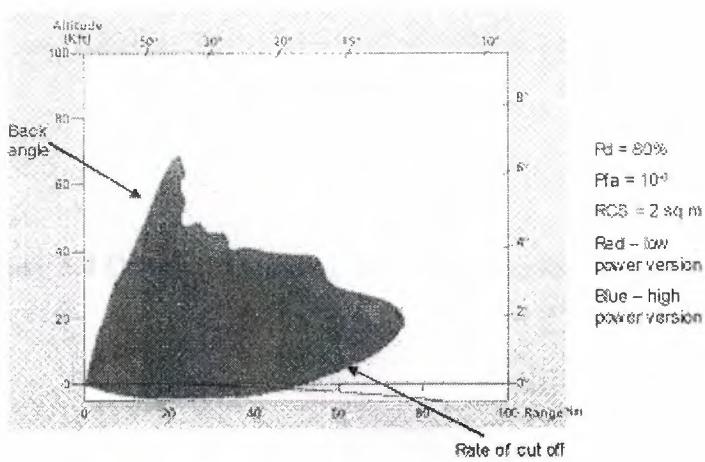

Figure 3.3 Antenna vertical polar diagram

3.3.1 Doppler Shift

Doppler shift is the shift in frequency between the transmitted RF carrier and the echoes reflected from moving objects. The frequency f_l received by an observer on the ground in figure 3.5, predicted by the theory of relativity, is given by

$$f_l = f_t \frac{c + v_R}{\sqrt{c^2 - v_R^2}} \quad (3.1)$$

where f_t is transmitted frequency, v_R is component of aircraft velocity in direction of observer (radial speed), C is speed of light (= 3.108 m/s).

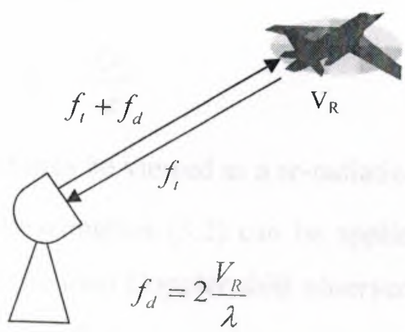

Figure 3.4 Doppler frequency shift is due to radar speed

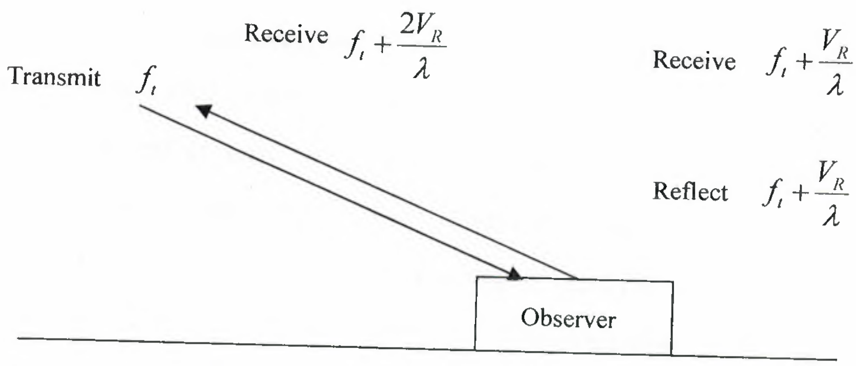

Figure 3.5 Frequency f_t received by an observer on the ground

Defining the Doppler shift as $f_D = f_l - f_t$ and using the fact that the aircraft speed is very small compared to the speed of light $(v_R \langle\langle c)$ equation (3.1) reduces to

$$f_D = \frac{f_t v_R}{c} \tag{3.2}$$

The reflection from the ground may be viewed as a re-radiation at frequency f_l. Equation (3.1) or the very accurate approximation (3.2) can be applied to calculate the Doppler shift observed in the aircraft. The total Doppler shift observed is twice the one way shift and is given by the following formula:

$$f_D = \frac{2 f_t V_R}{c} = \frac{2 v_R}{\lambda} \tag{3.3}$$

Where, $c = f_t \lambda$, λ is wavelength.

The frequency change of the echo will depend upon the radial speed of the target. Note that radial speed is the component of the target velocity relative to the radar site. Radial velocity is often used loosely to mean radial speed.

The Doppler effect can be used to discriminate moving objects from fixed ones (providing there is some component of motion in the radial direction).

However, the Doppler signal processing that is used extensively in primary surveillance radar does not directly measure the Doppler frequency change.

The processing used by pulsed primary surveillance radar is actually measuring the relative phase change from one pulse to the next.

Returns from the same fixed object (such as a building) will produce the same relative phase difference between transmitted and received pulses. Returns from the moving aircraft will produce a relative phase change from pulse to pulse (received whilst the aircraft is still in the antenna beam).

The Doppler shift can be derived in another way which is perhaps more instructive for radar applications. Consider a target at a range R. The round trip distance is $2R$, and the total phase difference between the transmitted and received wave is given by

$$\Phi = -2\pi\left(\frac{2R}{\lambda}\right) \tag{3.4}$$

Where the negative sign indicates a phase delay. Using the definition of frequency:

$$f = \frac{1}{2\pi}\left(\frac{d\Phi}{dt}\right) \tag{3.5}$$

The change in frequency (i.e., the Doppler shift f_D), seen at the radar, resulting from a target with changing range, is given by

$$f_D = -\frac{2}{\lambda}\left(\frac{dR}{dt}\right) = \frac{2v_R}{\lambda} \tag{3.6}$$

Equation (3.6) indicates that the Doppler shift will be positive; that is, at a higher frequency if the target is approaching ($\frac{dR}{dt}$ negative) and negative if the target is receding. The ability to discriminate between closing (approaching) and opening (receding) targets is often a valuable attribute. Most of the radars do not perform the frequency comparison between the transmitted wave and the received wave directly at radio frequency (RF), but down convert the received signal to a convenient intermediate frequency (IF).

Equation (3.4) shows the total phase delay between the transmitted and receives waveforms. The phase change between pulses (i.e., samples) is

$$\Delta\Phi = 2\pi\left(\frac{2\Delta R}{\lambda}\right) \tag{3.7}$$

Where, ΔR is the range change between successive pulses.

The phase change will depend upon the radial velocity of the target, the radar wavelength (Φ) and it's operating PRF.

For example, consider a target with a radial speed of 1 metre/sec, detected by a 10cm (0.1m) radar with PRF=400 Hz (i.e. PRI=0.0025 s).

The motion of the target between pulses (ΔR) = 1 × 0.0025 = 0.0025 metres.

Phase change Φ can be expressed as follows: -

$$\Phi = -2\pi\left(\frac{2R}{\lambda}\right)$$

This equation shows the total phase delay between the transmitted and received waveforms. The negative sign indicates a phase delay. The phase change between pulses (i.e., samples) is: -

$$\Delta\Phi = 2\pi\left(\frac{2\Delta R}{\lambda}\right)$$

Where, ΔR obtain the range change between successive pulses.

Using this equation, the phase change for our target moving at a radial speed of 1 metre per second is $(\Delta\Phi) = 0.314$ radians or 18 degrees [i.e. phase change per metre per second of speed].

The problem with phase measurement is that it will become ambiguous for phase changes beyond 360 degrees. In the above example an aircraft with radial speed of 20 metres/sec will produce the same phase change as a static target. This is known as a blind speed.

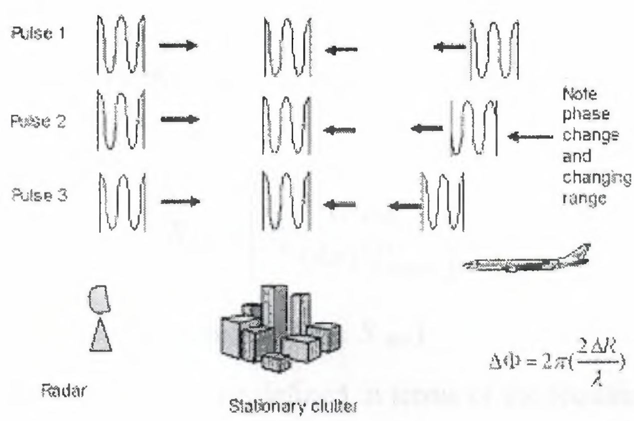

Figure 3.6 Doppler shift

3.3.2 Signal to Noise Ratio

If we rearrange the expression for noise factor given in the previous section in terms of signal input as follows: -

$$S_{in} = \frac{FN_{in}S_{out}}{N_{out}} \tag{3.8}$$

And use the expression for noise power input to the system in terms of standard temperature

$$S_{in} = \frac{FkT_0BS_{out}}{N_{out}} \tag{3.9}$$

Where $KT_{\circ}B$ is the noise into the receiver.

The minimum signal input to the receiver corresponds to the signal to noise ratio that can be detected at the output of the receiver is therefore as follows: -

$$S_{\min} = FkT_0B\left(\frac{S_{out}}{N_{out}}\right)_{\min} \tag{3.10}$$

We had previously derived the basic radar equation in terms of minimum signal input as follows: -

$$R_{\max} = \left[P_p \frac{G^2\sigma\lambda^2}{(4\pi)^3 P_{r(\min)}}\right]^{1/4} \tag{3.11}$$

($P_{r(\min)}$ is equal to the minimum signal input $S_{\min}$)

Then the basic radar equation can be defined in terms of the required signal to noise ratio as follows: -

$$R_{\max} = \left[P_p \frac{G^2\sigma\lambda^2}{(4\pi)^3 FkT_0B\left(\frac{S_{out}}{N_{out}}\right)_{\min}}\right]^{1/4} \tag{3.12}$$

The advantage of this form of the radar equation is that signal to noise ratio can be expressed in terms of probability of false alarms and detection. Next we will examine this approach.

3.3.3 False Alarms

Like signal echoes, the noise passes through the receiver and can then be detected. As we have already discussed, the IF amplifier is usually a high-Q matched filter amplifier, which controls the overall bandwidth of the receiver. So the noise reaching the detector is narrowband. A typical portion of such noise is shown in the upper part of the slide. It looks rather like an amplitude-modulated sine wave, although it in fact contains a range of frequencies and has a random envelope. When the noise waveform is detected, the upper envelope $v_e(t)$ is extracted. It may be shown that the envelope has the so-called Rayleigh pdf: -

$$p(v_e) = \frac{v_e}{\sigma}\exp\left(\frac{-v_e^2}{2\sigma^2}\right), \quad v_e > 0 \tag{3.13}$$

The characteristic of this distribution is that it is mainly centred on the value σ but there are occasional very large peaks as shown in figure 3.7.

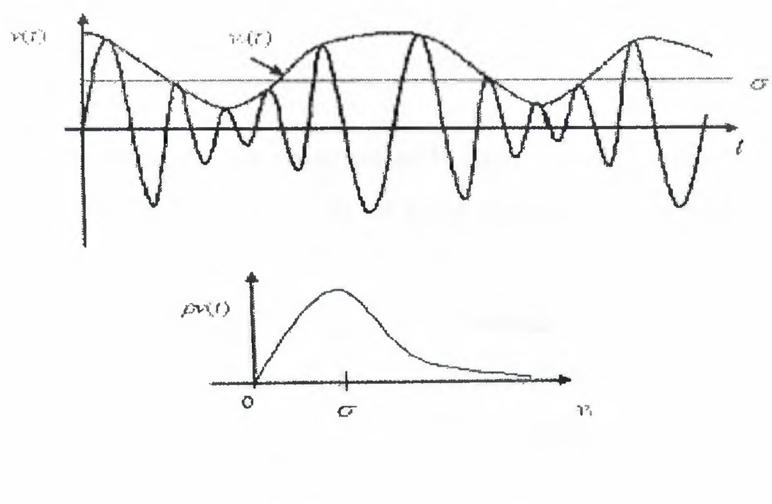

Figure 3.7 False alarms

The output from the detector is compared with a threshold level (threshold detection), to decide whether any target echoes are present. This may be shown to be the statistically optimum approach. Even so, there is unfortunately a danger that the noise will itself exceed the threshold, giving rise to a false alarm. (This leads to the definition of a probability of false alarm p_{fa}.) This is shown by the slide. The time-scale of the envelope $v_e(t)$ has been considerably compressed, compared with the slide in the previous section. But, as before, it fluctuates around the value, with occasional high peaks. One of these peaks exceeds the threshold voltage V_T, causing a false alarm. In other words, a noise peak has been wrongly interpreted as a target echo.

We may, of course, reduce the probability of false alarms by raising the detection threshold. But we are then less likely to detect genuine targets. This calls for a compromise. Too low a value of V_T gives many false alarms; but too high a value causes misses on targets, reducing the probability of successful detection. It now becomes clear that we cannot sensibly talk about target detection without also considering false alarms.

The probability of finding a random waveform above some threshold level V_T equals the area of its pdf between V_T. Hence the probability of obtaining a false alarm due to noise is given by the integral of the Rayleigh distribution: -

$$P_{fa} = \int_{V_T}^{\infty} \frac{V_e}{\sigma} \exp\left(\frac{-v_e^2}{2\sigma^2}\right), \qquad v_e > 0 \tag{3.14}$$

Now the average duration of each noise 'pulse' is approximately equal to the reciprocal of the bandwidth B. So the maximum rate of false alarms (given a very low threshold) is about B per second.

What rate of false alarms can be tolerated in a practical radar system? The answer must depend very much on the application. The acceptable false-alarm rate in strategic early-warning radar may be quite different from that in a system designed to track weather balloons. Note, however, that a wide range of false alarm rates is encompassed by a narrow range of threshold values i.e. the false alarm rate can be significantly modified by a small change in the threshold value. In many practical cases we may expect $v_T^2 / 2\sigma^2$ to be set between about 11 and 14 dB.

The false-alarm probabilities corresponding to acceptable false-alarm rates are very small. For example, an average of one false alarm per minute in a receiver of bandwidth 1 *MHz* corresponds to P_{f_a} = 1.7 x 10^{-8}. This implies that, in practice, the detection threshold must be set well into the extreme 'tail' of the Rayleigh distribution.

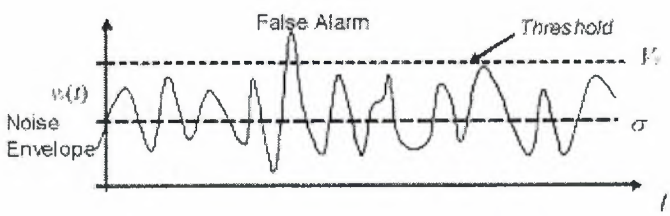

Figure 3.8 False alarm (Rayleigh Distribution)

CONCLUSION

Since radars depend on the measurement of range to create an image in the cross-track direction, they are forced to look to the side to allow the sensor to differentiate between objects to the left and right of the ground track; in the along track direction, platform motion and Doppler frequency shift create the image. Synthetic aperture and matched-filter techniques are used to obtain high resolution in these directions.

This work contributes to assess the feasibility of atmospheric water vapor estimates by means of a wideband CW-FM radar system operating at 19 GHz. In particular, it comes out that it is possible to measure the sensitivity function at 19 GHz by both LEO satellite and airplane platforms. Such measurements allow a direct estimate of the columnar water vapor, certainly with better performances in the airborne case. Further investigation is needed especially to characterize the backscattering cross section behavior to better understand its impact on the sensitivity measurements.

REFERENCES

[1] Sameer Ikhdair, *Lecture Notes*, 2000-2001, Near East University, Lefkoşa.

[2] Frank A. D'Souza., *Design of Control Systems*, Prentice-Hall International Editions.

[3] Vinay K. Ingle, John G. Proakis., *Digital Signal Processing Using MATLAB V.4,* Bookware Companion Series. An International Thomson Publishing Company.

[4] Bellman, R. (1960). *Introduction to Matrix Analysis.* New York: McGraw-Hill.

[5] MATLAB Reference Guide: *High-Performance Numeric Computation and Visualization Software.* The Mathworks, Inc., South Natick, MA, 1984-1994.

[6] IEE PIMRC '96 IEE International Symposium on Personal, Indoor and Mobile Radio Communications Adaptive Algorithms for Asynchronous DS-CDMS Receivers.Graeme Woodward, Predrag Rapajic and Branka Vucetic. http://wwwsyseng.anu.edu.au/~propajic/pap/con/1996/96PIM