NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical & Electronic Engineering

AIRPORT SURVEILLANCE RADAR

Graduation Project
EE – 400

Student: Mohammed Said Abushaban (970615)

Supervisor: Assoc. Prof. Dr. Sameer Ikhdair

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ABSTRACT

Radar is an electromagnetic system for the detection and location of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detects the nature of the echo signal. Radar is used to extend the capability of one's senses for observing the environment, especially the sense of vision. The value of radar lies not in being a substitute for the eye, but in doing what the eye cannot do. Radar cannot resolve detail as well as the eye, nor is it capable of recognizing the "color" of objects to the degree of sophistication of which the eye is capable. However, radar can be designed to see through those conditions impervious to normal human vision, such as darkness, haze, fog, rain, and snow. In addition, radar has the advantage of being able to measure the distance or range to the object. This is probably its most important attribute.

An elementary form of radar consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator of some sort, a receiving antenna, and an energy-detecting device, or receiver. A portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. It is the energy reradiated in the back direction that is of prime interest to the radar. The receiving antenna collects the returned energy and delivers it to a receiver, where it is processed to detect the presence of the target and to extract its location and relative velocity. The distance to the target is determined by measuring the time taken for the radar signal to travel to the target and back. The direction, or angular position, of the target may be determined from the direction of arrival of the reflected wave front. The usual method of measuring the direction of arrival is with narrow antenna beams. If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave (Doppler effect) is a measure of the target's relative (radial) velocity and may he used to distinguish moving targets from stationary objects. In radars, which continuously track the movement of a target, a continuous indication of the rate of change of target position is also available.

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INTRODCTION

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 objects, 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 such objects but can sometimes obtain their size and shape as well. What distinguishes radar from optical and infrared sensing devices is its ability to detect faraway objects under all weather conditions and to determine their range with precision.

Radar is an "active" sensing device in that it has its own source of illumination (a transmitter) for locating targets. In certain respects, it resembles active sonar, which is used chiefly for detecting submarines and other objects underwater; however, the acoustic waves of sonar propagate differently from electromagnetic waves and have different properties. Radar typically operates in the microwave region of the electromagnetic spectrum--namely, at frequencies extending from about 400 MHz to 40 GHz. It has, however, been used at lower frequencies for long-range applications (frequencies as low as several megahertz, which is the HF, or short-wave, band) and at optical and infrared frequencies (those of laser radar). The circuit components and other hardware of radar systems vary with the frequency used, and systems range in size from those small enough to fit in the palm of the hand to those so enormous as to take up several football fields. These differences notwithstanding, the basic principles of operation of all radar systems remain the same.

Radar underwent rapid development during the 1930s and '40s to meet the needs of the military. It is still widely employed by the armed forces, and many advances in radar technology have in fact been subsidized by the military. At the same time, radar has found an increasing number of important civilian applications, notably air traffic control, remote sensing of the environment, aircraft and ship navigation, speed measurement for industrial applications and for law enforcement, space surveillance, and planetary observation.

The project is divided in to six chapters and conclusion; chapter one studies the fundamentals of radar, development of radar, radar equation, subsystems of radar, major application of radar and the factors affecting radar performance.

Chapter two present all the types of radar, by studies example of many difference radar systems such airport surveillance radar, Doppler weather radar and other types which is show the important of radar.

In chapter three, we present radar digital signal processing and Implementation of Radar Signal Processor.

Chapter four, present the airport surveillance radar, primary surveillance radar, secondary surveillance radar and we explain the radar's role in the air traffic control showing the advantages and the disadvantages of the airport radar.

Chapter five, which is radar systems in Ercan Airport, in this chapter we explain the operation and the basic elements of the radar systems used in Ercan Airport then we present some important systems have related with Ercan`s radar to make the operation of the ATC easier.

Chapter six, explain how is radar can be in the future and how it can develop, also we present some new systems which is important for ATC and it can do the radar's work.

Finally, the conclusion section presents the important results obtained within the project.

CHAPTER 1

FUNDAMENTALS OF RADAR

1.1 Fundamentals of Radar

1.1.1 Basic Principle

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

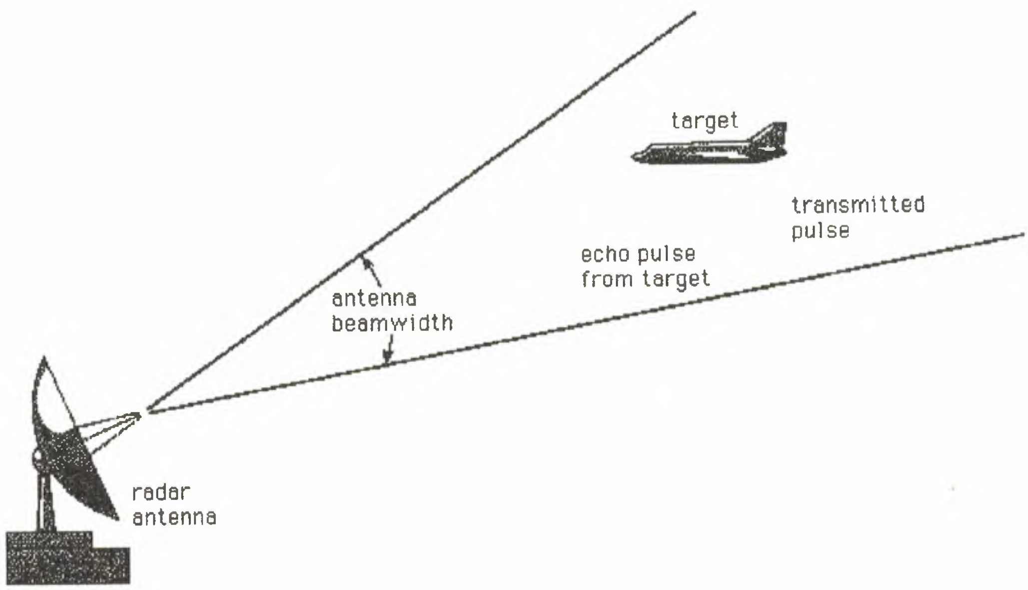


Figure 1.1 Principle of radar operation. The transmitted pulse has already passed the target, which has reflected a portion of the radiated energy back toward the

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 determined by measuring the total time it takes for the radar signal to make the round trip to the target and back (see below). 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 determined. Once this information has been established, the target's location at a time in the future can be predicted. In many surveillance radar applications, the target is not considered to be "detected" until its track has been established.

1.1.2 Pulse Radar

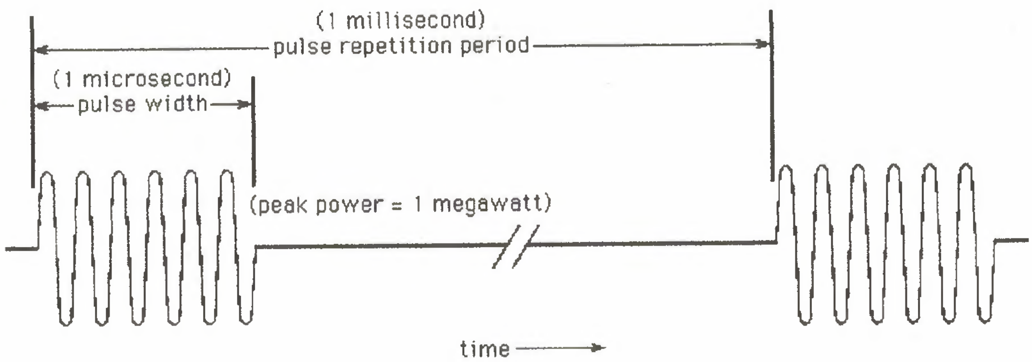


Figure 1.2 *A* typical pulse waveform transmitted by radar

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. The 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, 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 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 (Hz; cycles per second). The power of the pulse, called the peak power, is taken here to be 1,000,000 watts (1 megawatt). Since pulse radar does not radiate continually, the average power is much less than the peak power. In this example, the average power is 1,000 watts (1 kilowatt). 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. (Some radar pulse widths are 1,000 times smaller--*i.e.*, of nanosecond 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. Radar waves travel at the same speed as light--roughly 300,000,000 meters per second (or 186,000 miles per second). The range to the target is equal to $cT/2$, where c = velocity of propagation of radar energy, and T = 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 (0.0006 second), then the range of the target would be 90 kilometers.

1.1.3 Component Parts of a Radar System

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 (see below Radar subsystems: Antennas). In a sense, an antenna acts as a "transducer" to couple electromagnetic energy from the transmission line to radiation in space, and vice versa. The duplexer permits alternate transmission and reception with the same antenna; in effect, 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) from unwanted echo signals (the clutter from land, sea, rain, etc.).

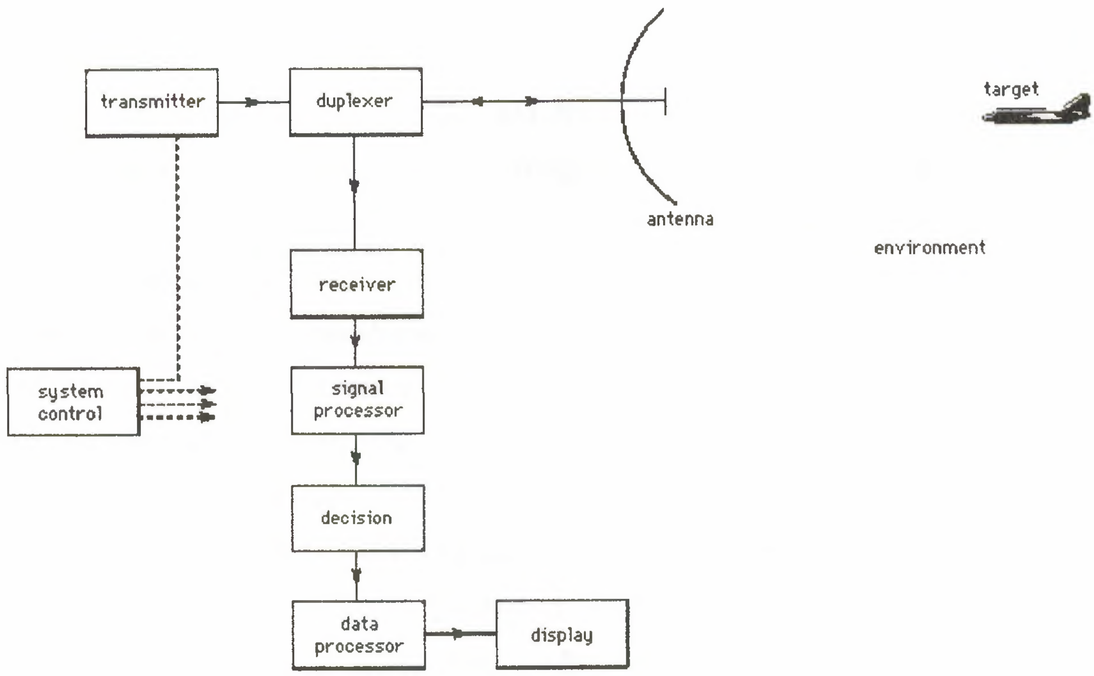


Figure 1.3 Basic parts of a radar system.

It is not unusual for these undesired reflections to be much larger than desired target echoes, in some cases more than one million 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 (see below).

At the output of the receiver a decision is made (either by the human operator or automatically by a computer circuit) 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 (in range and angle) 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 (many hundreds or even thousands) 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 involved and the environment in which it is located. An operator can select the parameters of the radar to maximize performance in a particular environment. Alternatively, electronic circuitry in the radar system can automatically analyze the environment (determine which portions are land, sea, or rain) and select the proper transmitted signal, signal processing, and other radar parameters to optimize performance. The box labeled "system control" in Figure 1.3 is intended to represent this function. The system control also can provide the timing and reference signals needed to permit the various parts of the radar to operate effectively as an integrated system. (Further descriptions of the major parts of a radar system are given below in the section Radar subsystems.)

1.1.4 Target Information Obtained by Radar

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 the pulse, the better the accuracy. Short pulses, however, require wide bandwidths in the receiver and transmitter (since bandwidth is equal to the reciprocal of the pulse width). 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. (The calculation of range involves the velocity of the electromagnetic energy transmitted as well as the round-trip time.)

Almost all radars use a directive antenna--*i.e.*, one that directs its energy in a narrow beam. The direction of a target can be found from the direction in which the antenna is pointing when the received echo is at a maximum. (There are other more precise means for determining the direction of a target, of which the monopulse method is probably the most important.) A dedicated tracking radar--one that follows automatically a single target so as to determine its trajectory--generally has a narrow symmetrical "pencil" beam. (A typical beam width might be about 1 degree.) Such a radar system can determine 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 (elevation beam widths of from 20 to 40 degrees, or more). 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 frequency of the received signal differs from the frequency of the signal that was transmitted. (The Doppler frequency shift in radar is similar to the change in audible pitch experienced when listening to a train whistle or the siren of an emergency vehicle when the train or emergency vehicle is moving either toward or away from the listener.) 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 kilohertz. 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 v_r is the radial velocity (the rate of change of range) 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 Doppler frequency shift also is used to separate moving targets (such as aircraft) 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 stationary clutter is called either a moving-target indication (MTI) radar or a pulse Doppler radar, depending on the particular parameters of the signal waveform.

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 determined if the range resolution of the radar is small compared to the target's size in the range dimension. (The range resolution of a radar, given in units of distance, is a measure of the ability of a radar to separate two closely spaced echoes.) Some radars can have resolutions smaller than one meter, which is quite suitable for determining the radial 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 (*i.e.*, separating one Doppler frequency from another). If the radar is moving relative to the target (as when the radar unit is on an aircraft and the target is the ground), 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 derived 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 basis for synthetic 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 observed 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 or 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 surface 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 objects 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 stationary 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.

1.1.5 Target Recognition

Radar can distinguish one kind of target from another (such as a bird from an aircraft), and some systems are able to recognize specific classes of targets (for example, a commercial airliner as opposed to a military jet fighter). Target recognition is accomplished by measuring 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 characteristic modulation, which can be used to recognize that a bird is present or even to identify one type of bird from another.

1.2 Development of Radar

1.2.1 Early Experiments

Serious developmental work on radar began in the 1930s, but the basic idea of radar had its origins in the classical experiments on electromagnetic radiation conducted by the German physicist Heinrich Hertz during the late 1880s. Hertz set out to verify experimentally the earlier theoretical work of the Scottish physicist James Clerk Maxwell. Maxwell had formulated the general equations of the electromagnetic field, determining that both light and radio waves are examples of electromagnetic waves governed by the same fundamental laws but having widely different frequencies. Maxwell's work led to the conclusion that radio waves can be reflected from metallic objects and refracted by a dielectric medium just like light waves. Hertz demonstrated these properties in 1888, using radio waves at a wavelength of 66 centimeters (which corresponds to a frequency of about 455 MHz).

The potential utility of Hertz's work as the basis for the detection of targets of practical interest did not go unnoticed at the time. In 1904 a patent for "an obstacle detector and ship navigation device," based on the principles demonstrated by Hertz, was issued in several countries to Christian Hülsmeyer, a German engineer. Hülsmeyer built his invention and demonstrated it to the German navy, but failed to arouse any interest. There was simply no economic, societal, or military need for radar until the early 1930s, when a long-range military bomber capable of carrying large payloads was developed. This prompted the major countries of the world to look for a means with which to detect the approach of hostile aircraft.

Most of the countries that developed radar prior to World War II first experimented with other methods of aircraft detection. These included listening for the acoustic noise of aircraft engines and detecting the electrical noise from their ignition. Researchers also experimented with infrared sensors. None of these, however, proved effective.

1.2.2 First Military Radars

During the 1930s, efforts to use radio echo for aircraft detection were initiated independently and almost simultaneously in several countries that were concerned with the prevailing military situation and that already had practical experience with radio technology. The United States, Great Britain, Germany, France, the Soviet Union, Italy, and Japan all began experimenting with radar within about two years of one another and embarked, with varying degrees of motivation and success, on its development for military purposes. Most of these countries had some form of operational radar equipment in military service at the start of World War II in 1939.

The first observation of the radar effect at the U.S. Naval Research Laboratory (NRL) in Washington, D.C., was made in 1922. NRL researchers positioned a radio transmitter on one shore of the Potomac River and a receiver on the other. A ship sailing on the river caused fluctuations in the intensity of the received signals when it passed between the transmitter and receiver. (Today, such a configuration would be called bistatic radar.) In spite of the promising results of this experiment, U.S. Navy officials were unwilling to sponsor further work.

The principle of radar was "rediscovered" at the NRL in 1930 when L.A. Hyland observed that an aircraft flying through the beam of a transmitting antenna caused a fluctuation in the received signal. Although Hyland and his associates at the NRL were enthusiastic about the prospect of detecting targets by radio means and were anxious to pursue its development in earnest, little interest was shown by higher authorities in the navy. Not until it was learned how to use a single antenna for both transmitting and receiving (now termed monostatic radar) was the value of radar for detecting and tracking aircraft and ships fully recognized. Such a system was demonstrated at sea on the battleship USS *New York* in early 1939.

The first radars developed by the U.S. Army were the SCR-268 (at a frequency of 205 MHz) for controlling antiaircraft gunfire and the SCR-270 (at a frequency of 100 MHz) for detecting aircraft. Both of these radars were available at the start of World War II, as was the navy's CXAM shipboard surveillance radar (at a frequency of 200 MHz). It was an SCR-270, one of six available in Hawaii at the time that detected the approach of Japanese warplanes toward Pearl Harbor, near Honolulu, on Dec. 7, 1941; however, the significance of the radar observations was not appreciated until bombs began to fall.

Britain commenced radar research for aircraft detection in 1935. The British government encouraged engineers to proceed rapidly because they were quite concerned about the growing possibility of war. By September 1938, the first British radar system, the Chain Home, went into 24-hour operation and remained operational throughout the war. The Chain Home radars allowed Britain to successfully deploy its limited air defenses against the heavy German air attacks conducted during the early part of the war. They operated at about 30 MHz--in what is called the short-wave, or high-frequency (HF), band--which is actually quite a low frequency for radar. It might not have been the optimum solution, but the inventor of British radar, Sir Robert Watson-Watt, believed that something that worked and was available was better than an ideal solution that was only a promise or might arrive too late.

The Soviet Union also started working on radar during the 1930s. At the time of the German attack on their country in June 1941, the Soviets had developed several different types of radars and had in production an aircraft-detection radar that operated at 75 MHz (in the very-high-frequency [VHF] band). Their development and manufacture of radar equipment was disrupted by the German invasion, and the work had to be relocated.

At the beginning of World War II, Germany had progressed further in the development of radar than any other country. The Germans employed radar on the ground and in the air for defense against Allied bombers. Radar was installed on a German pocket battleship as early as 1936. Radar development was halted by the Germans in late 1940 because they believed the war was almost over. The United States and Britain, however, accelerated their efforts. By the time the Germans realized their mistake, it was too late to catch up.

Except for some German radars that operated at 375 and 560 MHz, all of the successful radar systems developed prior to the start of World War II were in the VHF band, below about 200 MHz. The use of VHF frequencies posed several problems. First, beamwidths are broad. (Narrow beamwidths yield greater accuracy, better resolution, and the exclusion of unwanted echoes from the ground or other clutter.) Second, the VHF portion of the electromagnetic spectrum does not permit the wide bandwidths required for the short pulses that allow for greater accuracy in range determination. Third, VHF frequencies are subject to atmospheric noise, which limits receiver sensitivity. In spite of these drawbacks, VHF represented the frontier of radio technology in the 1930s, and radar development at this frequency range constituted a genuine pioneering accomplishment. It was well understood by the early developers of radar that operation at even higher frequencies was desirable, particularly since narrow beamwidths could be achieved without excessively large antennas. (The beamwidth of an antenna of fixed size is inversely proportional to the radar frequency.)

1.2.3 Advances During World War II

The opening of higher frequencies (those of the microwave region) to radar, with its attendant advantages, came about in late 1939 when the cavity magnetron oscillator was invented by British physicists at the University of Birmingham. In 1940 the British generously disclosed to the United States the concept of the magnetron, which then became the basis for the work undertaken by the newly formed Massachusetts Institute of Technology (MIT) Radiation Laboratory at Cambridge, Mass. It was the magnetron that made microwave radar a reality in World War II. (For a description of the magnetron, see the article electron tube.)

The successful development of innovative and important microwave radars at the MIT Radiation Laboratory has been attributed to the urgency for meeting new military capabilities as well as to the enlightened and effective scientific management of the laboratory and the recruiting of talented, dedicated scientists. Approximately 150 different radar systems were developed as a result of the laboratory's program during the five years of its existence (1940-45).

One of the most notable microwave radars developed by the MIT Radiation Laboratory was the SCR-584, a widely used gunfire-control system. It employed conical scan tracking, and, with its four-degree beam width, it had sufficient angular accuracy to place antiaircraft guns on target without the need for searchlights or optics, as was required with the older VHF SCR-268 gun-laying radar, which had very wide beam widths. The SCR-584 operated in the frequency range from 2.7 to 2.9 GHz (in the S band) and had a parabolic reflector antenna with a diameter of nearly two meters (six feet). It was first used in combat early in 1944 on the Anzio beachhead in Italy. Its introduction was timely, since the Germans by that time had learned how to jam its predecessor, the SCR-268. The introduction of the SCR-584 microwave radar caught the Germans unprepared.

1.2.4 Radar Technology since the mid-1940s

After the war, progress in radar technology slowed considerably. The last half of the 1940s was devoted principally to developments initiated during the war. Two of these were the monopulse tracking radar and the MTI radar (see above). It required many more years of developmental work to bring these two radar techniques to full capability.

New and better radar systems emerged during the 1950s. One of these was a highly accurate monopulse tracking radar designated the AN/FPS-16, which was capable of an angular accuracy of about 0.1 milliradian (roughly 0.006 degree). There also appeared large, high-powered radars designed to operate at 220 MHz (VHF) and 450 MHz (UHF [ultrahigh frequency]). These systems, equipped with large mechanically rotating antennas (more than 120 feet [36 meters] in horizontal dimension), could reliably detect aircraft at very long ranges. Another notable development was the klystron amplifier, which provided a source of stable high power for very long-range radars. Synthetic aperture radar first appeared in the early 1950s, but took almost 30 more years to reach a high state of development with the introduction of digital processing and other advances. The airborne pulse Doppler radar also was introduced in the late 1950s in the Bomarc air-to-air missile.

The decade of the 1950s also saw the publication of important theoretical concepts that helped put radar design on a more quantitative basis. These included the statistical theory of detection of signals in noise; the so-called matched filter theory, which showed how to configure a radar receiver to maximize detection of weak signals; the Woodward ambiguity diagram, which made clear the trade-offs in waveform design for good range and radial velocity measurement and resolution; and the basic methods for Doppler filtering in MTI radars, which later became important when digital technology allowed the theoretical concepts to become a practical reality.

The Doppler frequency shift and its utility for radar were known before World War II, but it took years of developmental work to achieve the technology necessary for wide-scale adoption. Serious application of the Doppler principle to radar began in the 1950s, and today the principle has become vital in the operation of many radar systems. As previously explained, the Doppler frequency shift of the reflected signal results from the relative motion between the target and the radar. Doppler frequency is indispensable in continuous wave, MTI, and pulse Doppler radars, which all must detect moving targets in the presence of large clutter echoes. The detection of the Doppler frequency shift is the basis for the police speed meter. SAR and ISAR imaging radars make use of Doppler frequency to generate high-resolution images of terrain and targets. The Doppler frequency shift also has been used to measure the velocity of the aircraft carrying the radar system. The extraction of the Doppler shift in weather radars, moreover, allows the identification of severe storms not possible by other techniques.

The first large electronically steered phased-array radars were put into operation in the 1960s. Airborne MTI radar for aircraft detection was developed for the U.S. Navy's Grumman E-2A airborne-early-warning (AEW) aircraft at this time. Many of the attributes of HF over-the-horizon radar (see below Examples of radar systems) were demonstrated during the 1960s, as were the first radars designed for detecting ballistic missiles and satellites.

During the 1970s digital technology underwent a tremendous advance, which made practical the signal and data processing required for modern radar. Digital processing allowed radar to achieve what was known to be theoretically possible but difficult to realize by other methods. Significant advances also were made in airborne pulse Doppler radar, greatly enhancing its ability to detect aircraft in the midst of heavy ground clutter. The U.S. Air Force's airborne warning and control system (AWACS) radar and military airborne intercept radar depend on the pulse Doppler principle. It might be noted too that radar began to be used in spacecraft for remote sensing of the environment during the 1970s.

Over the next decade radar methods evolved to a point where they were able to distinguish one type of target from another. Serial production of phased-array radars for air defense (the Patriot and Aegis systems), airborne bomber radar (B-1B aircraft), and ballistic missile detection (Pave Paws) also became feasible during the 1980s. Advances in remote sensing made it possible to measure winds at sea, the geoid (the Earth's figure that corresponds to mean sea level), ocean roughness, ice conditions, and other environmental effects. Solid-state technology, including very large-scale integration (VLSI) and integrated microwave circuitry, permitted new radar capabilities that were only academic curiosities a decade or two earlier.

Continued advances in computer technology in the 1990s allowed increased information about the nature of targets and the environment to be obtained from radar echoes. The introduction of Doppler weather radar systems (as, for example, Nexrad), which measure the radial component of wind speed as well as the rate of precipitation, provided new hazardous weather warning capability. Unattended radar operation with little downtime for repairs was demanded of manufacturers for such applications as air traffic control. HF over-the-horizon radar systems were operated by several countries, primarily for the detection of aircraft at very long ranges over large areas of the oceans. Space-based radars continued to gather information about the Earth's land and sea surfaces on a global basis. Improved imaging radar systems were carried by space probes to obtain higher-resolution pictures of the surface of Venus.

1.3 The Simple Form of the Radar Equation

The radar equation relates the range of radar to the characteristics of the transmitter, receiver, antenna, target, and environment. It is useful not just as a mean for determining the maximum distance from the radar to the target, but it can serve both as a tool for understanding radar operation and as a basis for radar design. In this section, the simple form of the radar equation is derived.

If the power of the radar transmitter is denoted by P_t, and if an isotropic antenna is used (one which radiates uniformly in all directions), the *power density* (watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R, or

$$\text{Power density from isotropic antenna} = \frac{p_t}{4\pi R^2} \tag{1.1}$$

Radar employ directive antennas to channel, or direct, the radiated power P_t into some particular direction. The gain G of an antenna is a measure of the increased power radiated from an isotropic antenna. It may be defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from a loss less, isotropic antenna with the same power input (The radiation intensity is the power radiated per unit solid angle in a given direction.) The power density at the target from an antenna with a transmitting gains G *is*

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2} \tag{1.2}$$

The target intercepts a portion of the incident power and reradiates it in various directions.

The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section σ, and is defined by the relation

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2}\frac{\sigma}{4\pi R^2} \tag{1.3}$$

The radar cross-section σ has units of area. It is a characteristic of the particular target and is a measure of its size .The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is denoted *Ae* the power P_r received by the radar is

$$= \frac{P_t G}{4\pi R^2}\frac{\sigma}{4\pi R^2}A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \qquad (1.4)$$

The maximum radar range R_{max} is distance beyond which the target cannot be detected. It occurs when the received echo signal power P_r just equals the minimum detectable signal S_{min} Therefore

$$R_{\max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{\min}}\right]^{1/4} \qquad (1.5)$$

This is fundamentals form of the radar equation. Note that the important antenna parameters are the transmitting gain and the receiving effective area.

Antenna theory gives the relationship between the transmitting gain and the receiving effective area of an antenna as

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (1.6)$$

Since radar generally use the same antenna for transmission and reception, Eq.(1.6) can be substituted into Eq.(1.5), first for *Ae* then for G, to give two forms of the radar equation

$$R_{\max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{\min}}\right]^{1/4} \qquad (1.7)$$

$$R_{\max} = \left[\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{\min}}\right]^{1/4} \qquad (1.8)$$

These three forms (Eqs1.5,1.7 and 1.8) illustrate the need to be careful in the interpretation of the radar equation .For example, from Eq.(1.7)it might be thought that the range of a radar varies as $\lambda^{1/2}$,but Eq.(1.8) indicates a $\lambda^{-1/2}$ relationship, and Eq.(1.5) shows the range to be independent of λ. The correct relationship depends on whether it is assumed the gain is constant or the effective area is constant with wavelength. Furthermore, the introduction of other constraints, such as the requirement to scan a specified volume in a given time, can yield different wavelength dependence.

These simplified versions of the radar equation do not adequately describe the performance of particular radar. Many important factors that affect range are not explicitly included. In practice, the observed maximum radar ranges are usually much smaller than what would be predicted by the above equations, sometimes by as a factor of two. There are many reasons for the failure of the simple radar equation to correlate with actual performance.

1.4 Radar Subsystems

Figure 1.3 shows the major subsystems that make up a typical radar system. These subsystems are described in greater detail here.

1.4.1 Antennas

A widely used form of radar antenna is the parabolic reflector, the principle of which is shown in cross section in (Figure 1.4-A). A horn antenna or other small antenna is

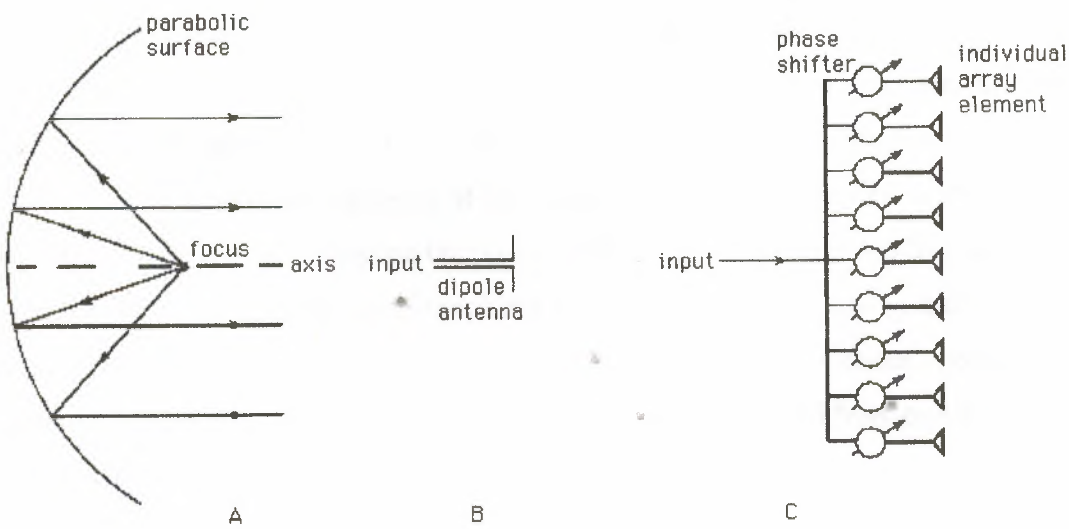


Figure 1.4 *Radar antennas.* (A) A parabolic reflector antenna in which the energy radiated from the focus is reflected from the parabolic surface as a narrow beam. (B) A dipole antenna. (C) A phased-array antenna composed of many individual radiating elements.

placed at the focus of the parabola to illuminate the parabolic surface of the reflector. After being reflected by this surface, the electromagnetic energy is radiated as a narrow beam. A paraboloid, which is generated by rotating a parabola about its axis, forms a symmetrical beam called a pencil beam. A fan beam, one with a narrow beam width in azimuth and a broad beam width in elevation, can be obtained by illuminating an asymmetrical section of the paraboloid. An example of an antenna that produces a fan beam is shown in the photograph.

The half-wave dipole (Figure 1.4-B), whose dimension is one-half of the radar wave length, is the classic type of electromagnetic antenna. A single dipole is not of much use for radar, since it produces a beam width too wide for most applications. Radar requires a narrow beam (a beam width of only a few degrees) in order to concentrate its energy on the target and to determine the target location with accuracy. Combining many individual dipole antennas so that the signals radiated or received by each elemental dipole are in unison, or in step can form such narrow beams. (The radar engineer would say that the signals are "in phase" with one another or that they are coherently added together.) This is called a phased-array antenna, the basic principle of which is shown in (Figure 1.4-C).

The phase shifters at each radiating antenna-element shift the phase of the signal, so that all signals received from a particular direction will be in step with one another. (As a result of this, the power radiated from the elements adds together.) Similarly, all signals radiated by the individual elements of the antenna will be in step with one another in some specific direction. Changing the phase shift at each element alters the direction of the antenna beam. An antenna of this kind is called an electronically steered phased-array. It allows rapid changes in the position of the beam without moving large mechanical structures. In some systems, the beam can be changed from one direction to another within microseconds.

The individual radiating elements of a phased-array antenna need not be dipoles; various other types of antenna elements also can be used. For example, slots cut in the side of a waveguide are common, especially at the higher microwave frequencies. In a radar that requires a one-degree, pencil-beam antenna, there might be about 5,000 individual radiating elements (the actual number depends on the particular design). The phased-array radar is more complex than radar systems that employ reflector antennas, but it provides capabilities not otherwise available.

Since there are many control points (each individual antenna element) in a phased-array, the radiated beam can be shaped to give a desired pattern to the beam. Controlling the shape of the radiated beam is important when the beam has to illuminate the air space where aircraft are found but not illuminate the ground, where clutter echoes are produced. Another example is when the stray radiation (called antenna sidelobes) outside the main beam of the antenna pattern must be minimized.

The electronically steered phased-array is attractive for applications that require large antennas or when the beam must be rapidly changed from one direction to another. Satellite surveillance radars and ballistic missile detection radars are examples that usually require phased-arrays. The U.S. Army's Patriot battlefield air-defense system and the U.S. Navy's Aegis system for ship air-defense also depend on the electronically steered phased-array antenna.

The phased-array antenna is also used without the phase shifters in Figure 1.4 (C). The beam is steered by the mechanical movement of the entire antenna. Antennas of this sort are preferred over the parabolic reflector for airborne applications, in land-based air-surveillance radars requiring multiple beams (as in the so-called 3D radars, which measure elevation angle in addition to azimuth and range), and in applications that require ultralow antenna sidelobe radiation.

1.4.2 Transmitters

The transmitter of a radar system must be efficient, reliable, not too large in size and weight, and easily maintained, as well as have the wide bandwidths and high power that are characteristic of radar applications. In MTI, pulse Doppler, and CW applications, the transmitter must generate noise-free, stable transmissions so that extraneous (unwanted) signals from the transmitter do not interfere with the detection of the small Doppler frequency shift produced by weak moving targets.

It was observed earlier that the invention of the magnetron transmitter in the late 1930s resulted in radar systems that could operate at the higher frequencies known as microwaves. The magnetron transmitter has certain limitations, but it continues to be widely used--generally in low-average-power applications such as ship navigation radar and airborne weather-avoidance radar. The magnetron is a power oscillator in that it self-oscillates (*i.e.*, generates microwave energy) when voltage is applied. Other radar transmitters usually are power amplifiers in that they take low-power signals at the input and amplify them to high power at the output. This provides stable high-power signals, as the signals to be radiated can be generated with precision at low power.

The klystron amplifier is capable of some of the highest power levels used in radar. It has good efficiency and good stability. The disadvantages of the klystron are that it is usually large and it requires high voltages (*e.g.*, about 90 kilovolts for one megawatt of peak power). At low power the instantaneous bandwidth of the klystron is small, but the klystron is capable of large bandwidth at high peak powers of a few megawatts.

The traveling-wave tube (TWT) is related to the klystron. It has very wide bandwidths at low peak power, but, as the peak power levels are increased to those needed for radar, its bandwidth decreases. As peak power increases, the bandwidths of the TWT and the klystron approach one another.

Solid-state transmitters, such as the silicon bipolar transistor, are attractive because of their potential for long life, ease of maintenance, and relatively wide bandwidth. An individual solid-state device generates relatively low power and can be used only when the radar application can be accomplished with low power (as in short-range applications or in the radar altimeter). High power can be achieved, however, by combining the outputs of many individual solid-state devices.

While the solid-state transmitter is easy to maintain and is capable of wide-band operation, it has certain disadvantages. It is much better suited for long pulses (milliseconds) than for the short pulses (microseconds). Long pulses can complicate radar operation because signal processing (such as pulse compression) is needed to achieve the desired range resolution. Furthermore, a long-pulse radar generally requires several different pulse widths: a long pulse for long range and one or more shorter pulses to observe targets at the ranges masked when the long pulse is transmitting. (A one-millisecond pulse, for example, masks echoes from 0 to about 80 nautical miles.)

Every kind of transmitter has its disadvantages as well as advantages. In any particular application, the radar engineer must continually search for compromises that give the results desired without too many negative effects that cannot be adequately accommodated.

1.4.3 Receivers

Like most other receivers, the radar receiver is a classic superheterodyne. It has to filter the desired echo signals from unwanted clutter signals and receiver noise that interfere with detection. It also must amplify the weak received signals to a level where the receiver output is large enough to actuate a display or a computer. The technology of the radar receiver is well established and seldom sets a limit on radar performance.

The receiver must have a large dynamic range in situations where it is necessary to detect weak signals in the presence of very large clutter echoes by recognizing the Doppler frequency shift of the desired moving targets. Dynamic range can be loosely described as the ratio of the largest to the smallest signals that can be handled adequately by a receiver without distortion. A radar receiver might be required to detect signals that vary in power by a million to one--and sometimes much more.

In most cases, the sensitivity of a radar receiver is determined by the noise generated internally at its input. Because it does not generate much noise of its own, a transistor is usually used as the first stage of a receiver.

1.4.4 Signal and Data Processors

The signal processor is the part of the receiver that extracts the desired signal and rejects clutter. Doppler filtering in an MTI radar or in a pulse Doppler system is an example. Most signal processing is performed digitally with computer technology. Digital processing has significant capabilities in signal processing not previously available with analog methods. Without digital methods many of the signal processing techniques found in today's high-performance radars would not be possible. Digital processing also has made practical data processing, such as required for automatic tracking.

Pulse compression (described below in Pulse-compression radar) is sometimes included under signal processing. It too benefits from digital technology, but analog processors (*e.g.*, surface acoustic wave delay-lines) are used rather than digital methods when pulse compression must achieve resolutions of a few meters or less.

1.4.5 Displays

The cathode-ray tube has been the traditional means of displaying the output of a radar system. Although it has its limitations, the CRT has been the preferred technology ever since the early days of radar. The CRT has undergone continual improvement that has made it even more versatile.

Plan position indicator, or PPI is a maplike presentation in polar coordinates of range and angle. The CRT screen is dark (other than for slight noise background) except when echo signals are present. The PPI is called an intensity-modulated display because the intensity of the electron beam of the CRT is increased sufficiently to excite the phosphor of the screen whenever an echo signal is present. The PPI is the most common form of display in use with radar. Another variety, the B-scope, is also an intensity-modulated display that presents the same information and the same coordinates as the PPI but in rectangular rather than polar format. In still another format, the A-scope, the received signal amplitude is displayed as the vertical coordinate and the range as the horizontal coordinate. The A-scope is called an amplitude-modulated display because echo signals are indicated by the increased amplitude (the vertical coordinate) on the CRT. The A-scope is not a suitable display for a surveillance radar that must search 360 degrees in azimuth, but it is used for tracking radars and in experimental radars when examining the nature of the echo signal is important.

All practical radar displays have been two dimensional (*i.e.*, they use a flat screen), yet most radars provide more information than can be displayed on the two coordinates of a flat screen. Colour coding of the intensity-modulated signal on the PPI is sometimes used to provide additional information about the echo signal. Colour has been employed, for example, to indicate the strength of the echo. Doppler weather radars make good use of colour coding to indicate on a two-dimensional display the rain intensity associated with each echo shown. They also utilize colour to indicate the radial speed of the wind, the wind shear, and other information relating to severe storms. The

PPI displays targets as if seen in a horizontal plane. On the other hand, a range-height indicator, or RHI, is an intensity-modulated display that presents the echoes that appear in a vertical plane--*e.g.*, a vertical cut through the cloud of a severe storm.

The radar display has benefited from the availability of digital technology. Digital memory allows the radar to store data from an entire scan period (usually one rotation of the radar antenna) and present the information to the operator all at once (as in the case of a television-type monitor) rather than display targets only when they are actually within the antenna beam. This allows the operator to view the entire scene all the time and to manipulate the output to display the type of target information of most interest.

Modern surveillance radars rarely display the output of a radar receiver without further processing (raw video). When automatic detection of targets is employed in a radar system, the rejection of unwanted echoes such as land or sea clutter, the addition of the radar pulses received from a target, and the decision as to whether a target is present or not are all performed electronically without assistance from a human operator. The display then shows only detected targets without the background noise. This has been called a "cleaned-up" display or processed video. When automatic tracking is performed electronically (in a digital data processor), only processed target tracks are displayed and no individual target detections are indicated. The speed of a target and its direction of travel can be indicated on the CRT by the length of the line defining the track and its orientation. Near each target track on the display, alphanumeric information can be entered automatically to indicate information that is known about the target. For example, when the air-traffic-control radar-beacon system (ATCRBS) is used in conjunction with an air-surveillance radar, the alphanumeric data on the display can indicate the flight number of the aircraft and its altitude.

1.5 Major Applications of Radar

1.5.1 Areas of Application

Over the years, radar has found many and varied uses for both civilian and military purposes. A sampling of some of the more significant applications is given here.

1- Military

Radar originally was developed to meet the needs of the military, and it continues to have significant application for military purposes. It is used to detect aircraft, missiles, artillery and mortar projectiles, ships, land vehicles, and satellites. In addition, radar controls, guides, and fuzes weapons; allows one class of target to be distinguished from another; aids in the navigation of aircraft and ships; performs reconnaissance; and determines the damage caused by weapons to targets. The importance of radar in modern warfare is borne out by the many measures designed to negate its effectiveness (in addition to direct attack, which is an option for any military target of value). Attempts to degrade military radar capability include electronic warfare (jamming, deception, chaff, decoys, and interception of radar signals), antiradiation missiles that home on radar transmissions, reduced radar cross-section targets to make detection more difficult (stealth), and high-power microwave energy transmissions to degrade or burn out sensitive receivers. A major objective of military radar development is to insure that a radar system can continue to perform its mission in spite of the various measures that attempt to degrade it.

2 - Air traffic control

Radar supports air traffic control by providing surveillance of aircraft and weather in the vicinity of airports as well as en route between airports. In the United States and elsewhere, airport surveillance radar (ASR) is employed at most major airports. It is designed to detect both commercial aircraft and general aviation aircraft, as well as precipitation, in the area around an air terminal. A larger system, the air route surveillance radar (ARSR), tracks aircraft en route. It has a range of about 200 nautical miles. Many major airports also employ airport surface detection equipment (ASDE), which is a high-resolution radar that provides the airport controller with the location and movement of ground targets within the airport, including service vehicles and taxiing aircraft. The location of dangerous weather phenomena such as "downbursts" (downward blasts of air associated with storms that have been identified as a major cause of fatal weather-related aircraft accidents) can be pinpointed with a specially configured terminal Doppler weather radar (TDWR) located near airports. Radar also has been used to "talk down" pilots to safe landings in adverse weather conditions. This is called ground-controlled approach (GCA) by the military.

3 - Remote sensing

One of the early applications of remote sensing involved the observation of rainfall. The radar measurement of the radial velocity of precipitation (from the Doppler frequency shift) in conjunction with the strength of the reflected signals (reflectivity) can indicate the severity of storms, as well as provide other important information for reliable weather forecasting (see also weather forecasting: History of weather forecasting: Modern trends and developments: Application of radar).

Astronomers have made radar observations of meteors, auroras, and certain planets. Synthetic aperture radars on orbiting spacecraft have mapped the surface of Venus beneath the ever-present cloud cover that blocks observation at optical wavelengths. Space-based radar systems have measured the Earth's geoid and ocean roughness. An important application of imaging radar from either aircraft or spacecraft is the surveillance of sea ice; information about pack ice distribution and concentration is used to route shipping in cold-weather regions.

Radar has even been used to study the movement of birds and insects at distances and under conditions where visual observation would not be possible.

4 - Aircraft navigation

The radar altimeter measures the height of an airplane above the local terrain, Doppler navigation radar determines the plane's own speed and direction, and high-resolution radar mapping of the ground contributes to its navigation. Radars carried aboard aircraft also provide information about the location of dangerous weather so that it can be avoided. Military aircraft can fly at low altitudes with the aid of terrain-avoidance and terrain-following radars that warn of obstacles.

5 - Ship safety

Small, relatively simple radar systems on board ships aid in piloting and collision avoidance. Similar radars on land provide harbour surveillance.

6 - Space applications

Radars have been used in space for rendezvous, docking, and landing of spacecraft. Since size and weight are important in space, the same equipment is used on a time-shared basis aboard the U.S. Space Shuttle both as radar to allow rendezvous with (and sometimes retrieve) other spacecraft and as a two-way data link to relay satellites that communicate with ground stations. Besides providing remote sensing of the Earth's surface (see above), radar carried by orbiting spacecraft is able to monitor rainfall over the oceans. Large land-based radar systems permit the detection and tracking of satellites and space debris.

7 - Law enforcement

The familiar police radar is a relatively simple, low-power continuous-wave system that measures the speed of vehicles by detecting the Doppler frequency shift introduced in the echo signal by a moving vehicle. The Doppler shift is directly proportional to the radial speed of the vehicle. (A similar kind of CW radar is used to measure the speed of a baseball to determine how fast a pitcher can throw.) Radar also has been used in security systems for intrusion detection; it can "sense" the movement of people attempting to penetrate a protected area.

8 - Instrumentation

Surveyors may make use of special radars to measure distances. CW radars are used to measure speed in certain industrial applications; the sensor does not make contact with the object whose speed is to be determined. Instrumentation radars are employed at missile test ranges for precision tracking of targets.

1.5.2 Radar Applications by Frequency

Each radar application seems to have a particular frequency band to which it is best suited. The various types of application found at the different radar frequency bands are surveyed below. The frequency letter-band nomenclature used here is that approved by the Institute of Electrical and Electronic Engineers (IEEE Standard 521-1984). These letter bands also are recognized by the U.S. Department of Defense and are listed in its Index of Specifications and Standards.

1 - HF (3 to 30 MHz)

Although the first British radar system, Chain Home (see above First military radars), operated in the HF band, it is ordinarily not a good frequency region for radar. Antenna beamwidths are very wide, the available bandwidths are narrow, the spectrum is crowded with other users, and the external noise (both natural noise and noise due to other transmitters) is high. There is, nevertheless, an important application for radar in this band--namely, long-range radar, which takes advantage of refraction by the ionosphere to extend ranges by an order of magnitude greater than can be obtained by ground-based microwave aircraft-detection radars. The ionosphere is a region of ionized gases produced by solar radiation at altitudes from about 80 to 400 kilometers or higher. The ions bend radio waves enough to return to Earth at considerable distances (see below Examples of radar systems: Over-the-horizon radar).

2 - VHF (30 to 300 MHz)

For reasons similar to those cited above, this frequency band is not too popular for radar. However, very long-range radars for either aircraft or satellite detection can be built at the VHF band more economically than at higher frequencies. Radar operations at such frequencies are not bothered by rain clutter or insects, but auroras and meteors produce large echoes that can interfere with target detection.

3 - UHF (300 to 1,000 MHz)

Military airborne early warning (AEW) radars operate in the UHF band to detect aircraft in the midst of clutter. This is a good frequency range for detecting extraterrestrial targets (*e.g.*, satellites and missiles), since large antennas and high power are readily obtained for this application.

4 - L band (1,000 to 2,000 MHz)

This is the preferred frequency band for long-range (200 nautical miles) air surveillance radar, such as the air-traffic control systems used to track aircraft en route between airports. It also is a band of interest for military space surveillance and missile detection because it is not as susceptible to nuclear blackout effects as radar systems that operate at the lower frequencies.

5 - S band (2 to 4 GHz)

Medium-range (50 to 60 nautical miles) airport surveillance radars are well suited for this band. It is the preferred frequency band for long-range weather observation radars. Military 3D radars that determine elevation angle as well as range and azimuth angle are often in S band, but they may also be at L band. Frequencies lower than S band are good for long-range surveillance, since large power, large antennas, and good moving-target detection are better there than at high frequencies. Frequencies greater than S band are preferred for extracting target information, as in tracking radars and weapon-control systems. Therefore, when a single frequency must be used for both surveillance and information extraction (as is necessary when only a single-frequency phased-array antenna is employed), S band can be a compromise.

6 - C band (4 to 8 GHz)

Single-frequency phased-array radars that must perform both surveillance and weapon control for air defense operate at these frequencies as well as at S band. This frequency region is well suited for long-range, precision-tracking radars.

7 - X band (8 to 12 GHz)

This is a band frequently used for shipboard civil marine radar, tracking radar, airborne weather-avoidance radar, systems for detecting mortar and artillery projectiles, and police speed meters. Most synthetic aperture radars operate at X band; the exceptions are some remote-sensing SARs that are designed for lower frequencies.

8 - K band (12 to 40 GHz)

Radars at this frequency band are usually of short range, because it is difficult to obtain the large antennas and large power necessary for long-range applications. This band has been used for airborne radar and for short-range airport surface detection (ASDE).

9 - Millimeter waves (40 to 300 GHz)

Although there has been much interest in exploring the potential of radars at millimeter wavelengths, it has not been practical for most applications because of high attenuation even in the "clear" atmosphere. It is difficult to use millimeter-wave radar for anything other than short range (a few kilometers) within the atmosphere. For deployment in outer space where there is no atmosphere to attenuate these frequencies, millimeter-wave radar, however, can be considered.

10 - Laser Radar

Laser radars, which operate at infrared and optical frequencies, also suffer from attenuation by the atmosphere, especially in bad weather, and therefore are of limited utility. Laser radar systems, however, have been used for precision range-finding in weapon control and for distance measuring in surveying. They also have been considered for use on board spacecraft to probe the nature of the atmosphere.

1.6 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.

1.6.1 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.

1.6.2 Receiver Noise

The sensitivity of a radar receiver is determined 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 lower noise can be obtained with more sophisticated devices. This is an example of the application of the basic engineering principle that the "best" performance 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 interfere 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 matched filter has a precise mathematical formulation 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.

1.6.3 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, this 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 with 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-control 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 0.01 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 targets.

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 of targets into account in their design.)

1.6.4 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 polarization 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 fair weather, most radars use linear polarization--*i.e.*, the direction of the field is fixed.)

1.6.5 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 performance 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 low angles to a slight extent. The atmosphere can form "ducts" that trap and guide radar energy around the curvature of the Earth and allow detection at ranges beyond the normal horizon. Ducting over water is more likely to occur in tropical climates than in colder 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 insignificant for systems operating at microwave frequencies.

1.6.6 Interference

Signals from nearby radars and other transmitters can be strong enough to enter a radar 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.

1.6.7 Electronic Countermeasures

The purpose of hostile electronic countermeasures (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 reflecting strips that create strong echoes over a large area to mask the presence of real target echoes or to create confusion, and (4) decoys, 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.

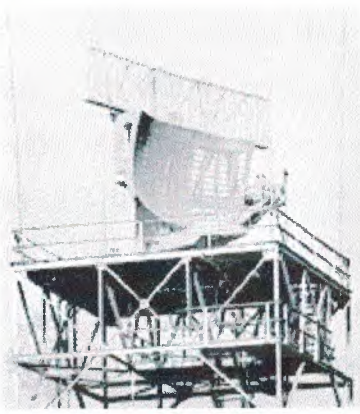
Military radar engineers have developed various ways of countering hostile ECM and maintaining the ability of a radar system to perform its mission. It might be noted that a military radar system can often accomplish its mission satisfactorily even though its performance in the presence of ECM is not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

CHAPTER 2

TYPES OF RADAR

2.1 Examples of Radar Systems

2.1.1 Airport Surveillance Radar



This is a medium-range radar system capable of reliably detecting and tracking aircraft at altitudes below 25,000 feet and within 40 to 60 nautical miles of the airport where it is located. Systems of this type have been installed at more than 100 major airports throughout the United States. The ASR-9 is designed to be operable at least 99.9 percent of the time, which means that the system is down less than 10 hours per year. This high availability is attributable to reliable electronic components, a "built-in test" to search for failures, remote monitoring, and redundancy (*i.e.*, the system has two complete channels except for the antenna; when one channel must be shut down for repair, the other continues to operate). The ASR-9 is designed to operate unattended with no maintenance personnel at the radar site. A number of radar units can be monitored and controlled from a single location. When trouble occurs, the fault is identified and a maintenance person dispatched for repair.

Echoes from rain that mask the detection of aircraft are reduced by the use of Doppler filtering and other techniques devised to separate moving aircraft from undesired clutter. It is important for air-traffic controllers to recognize areas of severe weather so that they can direct aircraft safely around, rather than through, rough or hazardous conditions. The ASR-9 has a separate receiving channel that recognizes weather echoes and provides their location to air traffic controllers. Six different levels of precipitation intensity can be displayed, either with or without the aircraft targets superimposed.

The ASR-9 system operates within S band from 2.7 to 2.9 GHz. Its klystron transmitter has a peak power of 1.3 megawatts, a pulse width of 1 microsecond, and an antenna with a horizontal beamwidth of 1.4 degrees that rotates at 12.5 revolutions per minute (4.8-second rotation period).

The reflector antenna shown in the photograph is a section of a paraboloid. It is 16.5 feet wide and 9 feet high. Atop the radar (riding piggyback) is a lightweight planar-array antenna for the air-traffic-control radar-beacon system. Its dimensions are 26 feet by 5.2 feet. ATCRBS is the primary means for detecting and identifying aircraft equipped with a transponder that can reply to the ATCRBS interrogation. The ATCRBS transmitter, which is independent of the radar system and operates at a different frequency, radiates a coded interrogation signal. Aircraft equipped with a suitable transponder can recognize the interrogation and send a coded reply at a frequency different from the interrogation frequency. The interrogator might then ask the aircraft, by means of other coded signals, to automatically identify itself and to report its altitude. ATCRBS only works with cooperative targets (*i.e.*, those with an operational transponder).

2.1.2 Doppler Weather Radar

For many years radar has been used to provide information about the intensity and extent of rain and other forms of precipitation. This application of radar is well known in the United States from the familiar television weather reports of precipitation observed by the radars of the National Weather Service. A major improvement in the capability of weather radar came about when engineers developed new radars that could measure the Doppler frequency shift in addition to the magnitude of the echo signal reflected from precipitation. The Doppler frequency shift is important because it is related to the radial velocity of the precipitation blown by wind (the component of the wind moving either toward or away from the radar installation). Since tornadoes, mesocyclones (which spawn tornadoes), hurricanes, and other hazardous weather phenomena tend to rotate, the radial wind speed, as a function of angle (as is measured by Doppler radar), will identify rotating weather patterns. (Rotation is indicated when the measurement of the Doppler frequency shift shows that the wind is coming toward the radar at one angle and away from it at a nearby angle.)

The pulse Doppler weather radars employed by the National Weather Service, known as Nexrad, make quantitative measurements of precipitation, warn of potential flooding or dangerous hail, provide wind speed and direction, indicate the presence of wind shear and gust fronts, track storms, predict thunderstorms, and provide other meteorologic information. In addition to measuring precipitation (from the intensity of the echo signal) and radial velocity (from the Doppler frequency shift), Nexrad can also measure the spread in radial speed (difference between the maximum and the minimum speeds) of the precipitation particles within each radar resolution cell. The spread in radial speed is an indication of wind turbulence.

Another improvement in the weather information provided by Nexrad is the digital processing of radar data, a procedure that renders the information in a form that can be interpreted by an observer who is not necessarily a fully trained meteorologist. The computer automatically identifies severe weather effects and indicates their nature on a CRT display viewed by the observer. High-speed communication lines integrated with the Nexrad system allow timely weather information to be transmitted for display to various users.

The Nexrad radar operates at frequencies from 2.7 to 3.0 GHz (S band) and is equipped with a 25-foot-diameter antenna. It takes five minutes to scan its 1 degree beamwidth through 360 degrees in azimuth and from 0 to 20 degrees in elevation. The Nexrad system can measure rainfall up to a distance of 460 kilometres and determine its radial velocity as far as 230 kilometers.

A serious weather hazard to aircraft in the process of landing or taking off from an airport is the downburst, or microburst. This is the above-mentioned strong downdraft that causes wind shear capable of forcing aircraft to the ground. Terminal Doppler weather radar is the name of the type of system at airports that is specially designed to detect dangerous microbursts. It is similar in principle to Nexrad, but is a shorter-range system since it only has to observe dangerous weather phenomena in the vicinity of an airport. It also operates at a higher frequency (C band) to avoid interference with the Nexrad and ASR systems (which operate at S band).

2.1.3 Airborne Combat Radar

A modern combat aircraft is generally required not only to intercept hostile aircraft but also to attack surface targets on the ground or on the sea. The radar that serves such an aircraft must have the capabilities to perform these distinct military missions. This is not easy because each mission has different requirements. The different ranges, accuracies, and rates at which the radar data is required, the effect of the environment (land or sea clutter), and the type of target (land features or moving aircraft) call for different kinds of radar waveforms (different pulse widths and pulse repetition frequencies). In addition, an appropriate form of signal processing is required to extract the particular information needed for each military function. Radar for combat aircraft must therefore be multimode--*i.e.*, operate with different waveforms, signal processing, and antenna scanning. It would not be unusual for an airborne combat radar to have from 8 to 10 air-to-air modes and 6 to 10 air-to-surface modes. Furthermore, the radar system might be required to assist in rendezvous with a companion combat craft or with a refueling aircraft, provide guidance as to air-to-air missiles, and counter hostile electronic jamming. The problem of achieving effectiveness with these many modes is a challenge for the radar designer and is made more difficult by the limited size and weight available on combat aircraft.

The AN/APG-66 radar built for the U.S. F-16 fighter is shown in the photograph. This is a pulse Doppler radar system that operates in the X-band region of the spectrum. The version of this radar for the British Hawk 200 aircraft occupies a volume of less than three cubic feet, weighs less than 237 pounds, and requires an input power of 2.25 kilowatts. It can search 120 degrees in azimuth and elevation and is supposed to have a range of 35 nautical miles in the "look-up" mode and 27.5 nautical miles in the "look-down" mode. The look-up mode is a more or less conventional radar mode with a low pulse-repetition-frequency that is used when the target is at medium or high altitude and no ground clutter echoes are present to mask target detection. The look-down mode uses a medium-prf pulse Doppler waveform and signal processing that provide target detection in the presence of heavy clutter. (A low prf for an X-band combat radar might be from 250 Hz to 5 kHz, a medium prf from 5 to 20 kHz, and a high prf from 100 to 300 kHz.) Radars for larger combat aircraft can have greater capability but are, accordingly, bigger and heavier than the system just described.

2.1.4 Ballistic Missile Detection and Satellite Surveillance Radar

The systems for detecting and tracking ballistic missiles and orbiting satellites are much larger than those for aircraft detection because the ranges are longer. Such radars might be required to have maximum ranges of 2,000 to 3,000 nautical miles, as compared with 200 nautical miles for a typical long-range aircraft detection system. The average power of the transmitter might be from several hundred kilowatts to one megawatt or more, which is about 100 times greater than the average power of radars designed for aircraft detection. Antennas for this application have dimensions on the order of tens of meters to a hundred meters or more and are electronically scanned phased-array antennas capable of steering the radar beam without moving large mechanical structures. Radar systems so equipped are commonly found at the lower frequencies (typically at frequency bands of 420-450 MHz and 1,215-1,400 MHz).

The Pave Paws radar (or AN/FPS-115) is a UHF (420-450 MHz) phased-array system for detecting submarine-launched ballistic missiles. It is supposed to detect targets with a radar cross section of 10 square meters at a range of 3,000 nautical miles. The array antenna contains 1,792 active elements within a diameter of 72.5 feet. It can be expanded to 102 feet. Each active element is a module with its own solid-state transmitter, receiver, duplexer, and phase shifter. The total average power per antenna is about 145 kilowatts. Two antennas make up a system, with each capable of covering a sector 120 degrees in azimuth. Vertical coverage is from 3 to 85 degrees. An upgraded variant of this type of radar is used in the Ballistic Missile Early Warning System (BMEWS) network, with installations in Alaska, Greenland, and England. BMEWS is designed to provide warning of intercontinental ballistic missiles. Each array antenna measures almost 84 feet across and has 2,560 active elements identical to those of the Pave Paws system. Both the BMEWS and Pave Paws radars detect and track satellites and other space objects in addition to warning of the approach of ballistic missiles.

2.1.5 Ground-Probing Radar

Radar waves are usually thought of as being reflected from the surface of the ground. At the lower frequencies (below several hundred megahertz) radar energy, however, can propagate into the ground and be reflected from buried objects. The loss in propagating in the ground is very high at these frequencies, but low enough to permit ranges of about 1 to 10 meters or more. This is sufficient for detecting buried utility pipes and cables, probing the subsurface soil, detecting underground tunnels, and monitoring the subsurface conditions of highways and bridge roadways. (The ranges in ice can be much greater because the propagation loss is less in ice than in most soils.) The short ranges require that the radar system be able to resolve closely spaced objects, which means wide-bandwidth signals must be radiated. Normally, wide bandwidth is not available at the lower frequencies (especially when a 30-centimetre range resolution requires a 500 MHz bandwidth). However, since the energy is directed into the ground rather than radiated into space, the large frequency band needed for high resolution can be obtained without interference to other users of the radio spectrum.

A ground-probing radar might radiate over frequencies ranging from 5 to 500 MHz in order to obtain good penetration (which requires low frequencies) with high resolution (which requires wide bandwidth). The antenna can be placed directly on the ground. The radar unit is small in size and so is portable.

2.1.6 Over-the-Horizon Radar

Radars at frequencies lower than 100 or 200 MHz are not desirable for radar application except in special cases. The ground-probing radar mentioned above is one such special case; here a radar at the lower frequencies can provide a capability not available with other types of radar or other sensors. Another example where lower frequencies can provide a unique and important capability is in the short wave, or HF, portion of the radio band (from 3 to 30 MHz). The advantage of the HF band is that radio waves of these frequencies are refracted (bent) by the ionosphere so that the waves return to the Earth's surface at long distances beyond the horizon, as shown in Figure 5. This permits target detection at distances from about 500 to 2,000 nautical miles. Thus, an HF OTH radar can detect aircraft at distances up to 10 times that of a ground-based microwave air-surveillance radar whose range is limited by the curvature of the Earth. Besides detection and tracking of aircraft at long ranges, an HF OTH radar can be designed to detect ballistic missiles (particularly the disturbance caused by ballistic missiles as they travel through the ionosphere), ships, and weather effects over the ocean. Winds over the ocean generate waves on the water that can be detected by OTH radar. From the Doppler frequency spectrum produced by echoes from the water waves, one can determine the direction of the waves generated by the wind and, hence, the direction of the wind itself. The strength of the waves (which indicates the state of the sea, or roughness) also can be ascertained. Timely information about the winds that drive waves over a wide expanse of the ocean can be valuable for weather prediction because it is difficult to obtain similar information in other ways.

An HF OTH radar might have an average power of one megawatt or more and have phased-array antennas that sometimes extend several thousands of feet. Radar systems of this variety are especially useful for observing large areas that are not easily covered by microwave radar, as, for example, expanses of oceans.

2.2 Types of Radar

Radar systems may be categorized according to the function they perform--*e.g.*, aircraft surveillance, surface (ground or sea) surveillance, space surveillance, tracking, weapon control, missile guidance, instrumentation, remote sensing of the environment, intruder detection, or underground probing. They also may be classified, as in the listing below, on the basis of the particular radar technique they employ. It is difficult to give in only a few words precise and readily understandable descriptions of the many types of radar available. The following survey is necessarily brief and qualitative. Additional information about each radar type can be found in the books listed in the Bibliography.

2.2.1 Simple Pulse Radar

This is by far the most widely used technique and constitutes what might be termed "conventional" radar. (For a discussion of its fundamentals, see above Fundamentals of radar: Pulse radar.) All but the last two techniques outlined below employ a pulse waveform; however, they have additional features that give an enhanced performance as compared to simple pulse radar

2.2.2 Moving-Target Indication (MTI) Radar

This is a form of pulse radar that uses the Doppler frequency shift of the received signal to detect moving targets, such as aircraft, and to reject the large unwanted echoes from stationary clutter that do not have a Doppler shift. Almost all ground-based aircraft surveillance radar systems use some form of MTI.

2.2.3 Airborne Moving-Target Indication (AMTI) Radar

An MTI radar in an aircraft encounters problems not found in a ground-based system of the same kind because the large undesired clutter echoes from the ground and the sea have a Doppler frequency shift introduced by the motion of the aircraft carrying the radar. The AMTI radar, however, compensates for the Doppler frequency shift of the clutter, making it possible to detect moving targets even though the radar unit itself is in motion.

2.2.4 Pulse Doppler Radar (with high pulse-repetition frequency)

As with the MTI system, the pulse Doppler radar is a type of pulse radar that utilizes the Doppler frequency shift of the echo signal to reject clutter and detect moving aircraft. However, it operates with a much higher pulse-repetition frequency (prf) than the MTI radar. (A high-prf pulse Doppler radar, for example, might have a prf of 100 kHz, as compared to an MTI radar with prf of perhaps 300 Hz.) The difference of prfs gives rise to distinctly different behaviour. The MTI radar uses a low prf in order to obtain an unambiguous range measurement. This causes the measurement of the target's radial velocity (as derived from the Doppler frequency shift) to be highly ambiguous and can result in missing some target detections. On the other hand, the pulse Doppler radar operates with a high prf so as to have no ambiguities in the measurement of radial velocity. A high prf, however, causes a highly ambiguous range measurement. The true range is resolved by transmitting multiple waveforms with different prfs.

2.2.5 Pulse Doppler Radar (with medium pulse-repetition frequency)

A modified form of pulse Doppler radar that operates at a lower prf (10 kHz, for example) than the above-mentioned high-prf pulse Doppler system has both range and Doppler shift ambiguities. It is, however, better for detecting aircraft with low closing speeds than high-prf pulse Doppler radar (which is better for detecting aircraft with high closing speeds). An airborne medium-prf pulse Doppler radar might have to use seven or eight different prfs in order to extract the target information without ambiguities.

2.2.6 High-Range-Resolution Radar

This type of radar uses a very short pulse with range resolution from several metres to a fraction of a meter. Such radar can profile a target and measure its projected length in the range dimension.

2.2.7 Pulse-Compression Radar

The ability to generate very short pulses with high peak power (and high energy) is limited for practical reasons by voltage breakdown, or arcing. Thus, conventional high-range-resolution radars with short pulses often are limited in peak power and are not capable of operating at long ranges. Pulse compression overcomes this limitation by obtaining the resolution of a short pulse but with the energy of a long pulse. It does this by modulating either the frequency or the phase of a long, high-energy pulse. The frequency or phase modulation allows the long pulse to be compressed in the receiver by an amount equal to the reciprocal of the signal bandwidth.

2.2.8 Synthetic Aperture Radar (SAR)

The SAR was described above as utilizing resolution in Doppler frequency to provide the equivalent of cross-range (or angle) resolution. More often, it is regarded as a synthetic antenna generated by moving radar. The effect of a large antenna is obtained by storing the echo signals in a storage medium, or memory, and processing a substantial number of the previously received echoes just as if they were received by a large antenna. This kind of radar is primarily used for mapping the Earth's surface. Although it is not obvious, the two different models used for describing a SAR--a synthetic antenna and Doppler-frequency resolution--are equivalent and produce the same results.

2.2.9 Inverse Synthetic Aperture Radar (ISAR)

As previously noted, an ISAR depends on target motion to provide the Doppler frequency shift between various parts of the target and the radar unit so as to obtain high resolution in cross range. A two-dimensional high-resolution image of a target can be obtained by using ISAR for cross-range resolution in conjunction with either a short pulse or pulse-compression radar for resolution in the range dimension.

2.2.10 Side-Looking Airborne Radar (SLAR)

This variety of airborne radar employs a large side-looking antenna (*i.e.*, one whose beam is perpendicular to the aircraft's line of flight) and is capable of high range resolution. (The resolution in cross range is not as good as can be obtained with SAR, but it is simpler than the latter and is acceptable for some applications.) SLAR generates maplike images of the ground and permits detection of ground targets.

2.2.11 Imaging Radar

Synthetic aperture, inverse synthetic aperture, and side-looking airborne radar techniques are sometimes referred to as imaging radars.

2.2.12 Tracking Radar

This kind of radar continuously follows a single target in angle and range to determine its path, or trajectory, and to predict its future position. There are two classes of tracking radars: conical scan and monopulse. The conical scan tracker is simpler but not as accurate as the monopulse variety. Furthermore, monopulse tracking is not as susceptible to some forms of electronic countermeasure as the conical scan. The single-target tracking radar provides target location almost continuously. Typical tracking radar might measure the target location at a rate of 10 times per second.

2.2.13 Track-While-Scan Radar

This form of surveillance radar can provide tracks of all targets within its area of coverage by measuring the location of targets on each rotation of the antenna. Though called track-while-scan radar, it is more often known as automatic detection and tracking, or ADT. The output on a visual display from such a radar usually consists of the tracks of the targets (vectors showing direction and speed) rather than individual detections (blips). This type of tracking is suitable for surveillance radars, while continuous tracking is more appropriate for weapon control and instrumentation-radar applications .

2.2.14 3D Radar

Conventional air-surveillance radar measures the location of a target in two dimensions--range and azimuth. The elevation angle, from which target height can be derived, also can be determined. The so-called 3D radar is an air-surveillance radar that measures range in a conventional manner but that has an antenna which is mechanically rotated about a vertical axis to obtain the azimuth angle of a target and which has either fixed multiple beams in elevation or a scanned pencil beam to measure its elevation angle. There are other types of radar (such as electronically scanned phased arrays and tracking radars) that measure the target location in three dimensions, but a radar that is properly called 3D is an air-surveillance system that measures the azimuth and elevation angles as just described.

2.2.15 Electronically Scanned Phased-Array Radar

An electronically scanned phased-array antenna can position its beam rapidly from one direction to another without mechanical movement of large antenna structures. Agile, rapid beam switching permits the radar to track many targets simultaneously and to perform other functions as required.

2.2.16 Continuous-Wave (CW) Radar

Since a CW radar transmits and receives at the same time, it must depend on the Doppler frequency shift produced by a moving target to separate the weak echo signal from the strong transmitted signal. A simple CW radar can detect targets, measure their radial velocity (from the Doppler frequency shift), and determine the direction of arrival of the received signal. However, a more complicated waveform is required for finding the range of the target.

2.2.17 Frequency-Modulated Continuous-Wave (FM-CW) radar

If the frequency of a CW radar is continually changed with time, the frequency of the echo signal will differ from that transmitted and the difference will be proportional to the range of the target. Accordingly, measuring the difference between the transmitted and received frequencies gives the range to the target. In such a frequency-modulated continuous-wave radar, the frequency is generally changed in a linear fashion, so that there is an up-and-down alternation in frequency. The most common form of FM-CW radar is the radar altimeter used on aircraft to determine height above the ground. Phase modulation, rather than frequency modulation, of the CW signal has also been used to obtain range measurement.

CHAPTER 3

RADAR DIGITAL SIGNAL PROCESSING

3.1 Overview

Radar involves the interpretation of a signal to determine characteristics of targets. With the unavoidable presence of various types of interference, signal processing is naturally an important part of any radar system.

The basic idea behind radar is to send out a signal and analyze the return signal. If the signal hits something, it will be reflected back to the antenna. The delay between the time that the signal was sent out and the time that it is received can be used to determine the object's distance. If the object happens to be moving, the reflected signal will have a different frequency from the one that was sent out. The difference between these frequencies is referred to as a Doppler shift. A common example of Doppler shift is that of a train whistle. As the train approaches, an observer hears a higher pitch than the actual pitch of the whistle. Conversely, as the train moves away, an observer hears a lower pitch than the actual pitch of the whistle. The difference in the pitches heard by the observer is due to the Doppler shift. In radar applications, Doppler shift can be used to determine the velocity of an object. For Range processing, the return signal must first be filtered in order to reduce the effects of clutter and noise that get into the signal due to buildings, mountains, machinery, and other signals. A typical return signal containing a single return burst and white Gaussian noise looks like Figure (3.1).

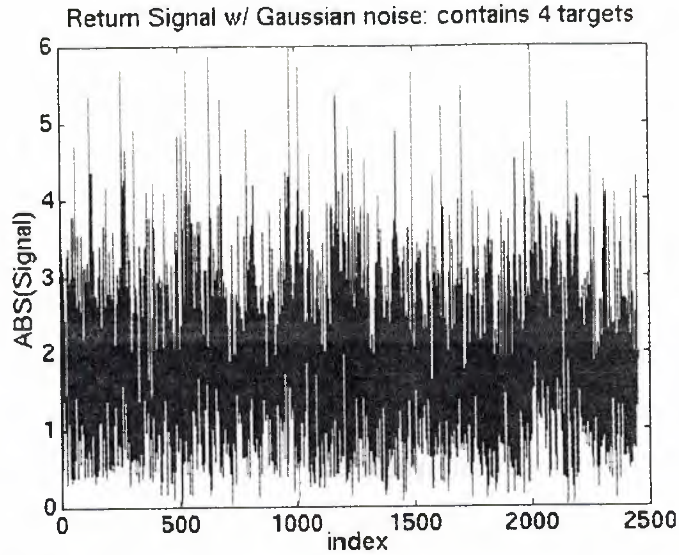


Figure 3.1 Return signals with noise

It turns out that the proper filter to use on the signal is a "matched filter" to the original signal. A matched filter is the original signal flipped about the origin on the time axis and then conjugated. Convolving the return signal with the matched filter like this basically amplifies the bursts in the clutter and noise so that the SNR (signal to noise ratio) is large. Here is an example of a return signal after it has been matched filtered

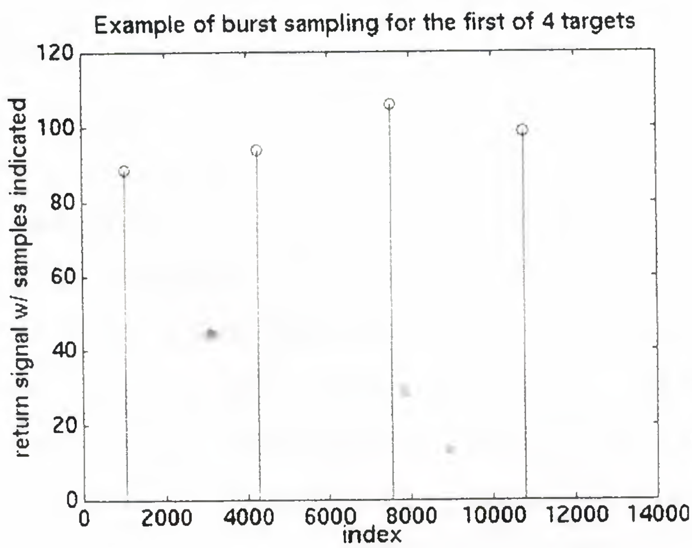


Figure 3.2 Filtered signal with 4 targets

The four peaks in each burst in this example are obvious, and we would want to consider all of these four peaks as targets. To get the ranges, it is necessary to know the time that elapsed between sending the burst and receiving the return burst. It should be clear that it took the signal half of that time to get to the object. With this in mind, the distance to the object can be determined by multiplying the time to get to the object by the speed of the burst (light speed=3x10^8 m/s)

Velocity processing can be even more involved. Velocity is determined by means of measuring the change in frequency of the output signal bursts. This shift in frequency is known as the "Doppler shift". Since the change in frequency within a single burst is virtually impossible to measure unless the object is moving with a velocity that is a substantial fraction of the speed of light, the change in frequency is not determined from one burst but rather the change in the frequency from burst to burst over the entire output signal. From this Doppler shift in frequency, the velocity of each target can be found by multiplying by a scaling factor that is dependent upon the carrier frequency of the radar signal and the inter-pulse period of the bursts.

3.2 Development

Once some knowledge of radar theory had been gained, we began the task of designing a radar signal processor. First, the type of waveform to be used in the system had to be chosen. An impulse would be optimum for range resolution, but, aside from being impractical, it would also fail to yield any range rate resolution. A complex exponential, on the other hand, would yield optimum range rate resolution while leaving a great deal of ambiguity in the range resolution. A compromise between the two was needed. A good test of potential waveforms is to examine the nature of the ambiguity function. The ambiguity function is essentially an autocorrelation of a waveform with a delayed and/or phase-shifted version of itself. Plotting this function versus delay and phase shift yields a convenient visual gauge of a waveform's potential performance in a radar system. It turned out that a linear FM chirp offered acceptable resolution in range and in range rate. The program, was written to generate a discrete LFM chirp for a given time-bandwidth product (TW) and over sampling factor (p). Thus the output was essentially a continuous-time chirp sampled at a rate of p*W. An LFM chirp has a constant magnitude of one, but its phase varies quadratic ally with respect to its displacement from the time origin.

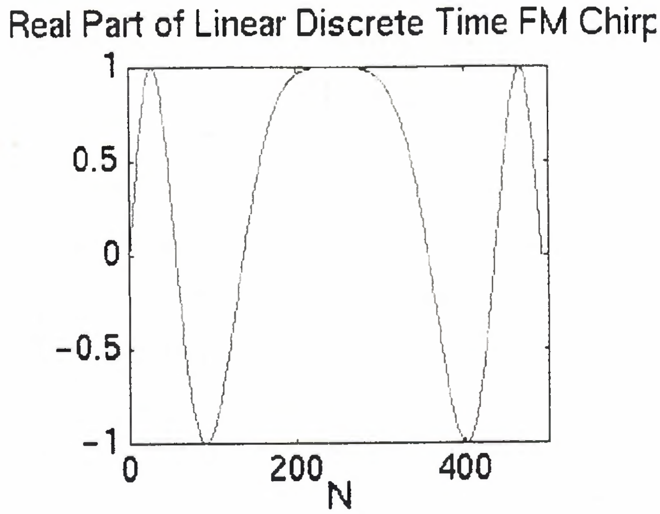


Figure 3.3 LFM chirp (real part)

After becoming familiar with the characteristics of the LFM chirp, we worked on range processing. In order to get good range resolution, a high signal-to-noise ratio is needed. Thus, large time-bandwidth chirps were used to increase the energy initially in the

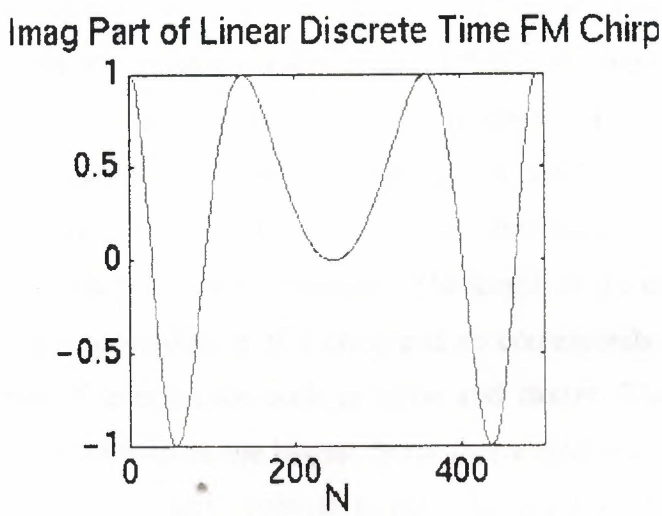


Figure 3.4 LFM chirp (imag part)

signal . This alone is not enough to make target detection possible. Some filtering of the signal must also be done. By examining the equation for the SNR, it is clear that to maximize SNR, the numerator must be maximized. The Cauchy-Schwartz inequality defines the upper bound of the numerator. The equality holds if the filter is the conjugate of the output signal with a reversed time axis. This type of filter is referred to as a matched filter and results in the optimum SNR. Another property of the matched filter is that it compresses the pulse into a narrow peak. As a result, radar systems using matched filtering are often referred to as pulse-compression radar.

Some chirps were generated and white Gaussian noise was added to test our ability to detect and resolve a target in noise. The matched filter results in a large peak in the time domain at the point where the entire pulse has returned. The location of the output peak from the matched filter is used to calculate the range by the following formula:

$$Range = (peak\ location - length\ of\ chirp)*(c / 2) / (p*W)$$

The length of the chirp must be subtracted from the peak location in order to get the delay from the time the signal was sent out until the time the return signal was received since the peak location indicates the time at which the entire signal has been received, not the time at which it first started to arrive.

Once the accuracy of this algorithm was confirmed, modifications were made in order to handle multiple targets. This requires the ability to locate multiple peaks in the filtered signal. For this, the program, taken from CBESP, was used. Given a signal, a threshold, and a maximum number of peaks, the program returns two vectors, one containing the peak values and the other containing the corresponding indexes of the peaks. After experimenting with the threshold, it was determined that a threshold of .6 times the length of the chirp would be adequate. The length of the chirp is equal to the maximum peak in an autocorrelation of a chirp and so corresponds to the energy of a target in the absence of interference such as noise and clutter. The factor of .6 was found through trial and error to be the largest factor that would not result in a failure to detect a target. Experiments with multiple targets also gave us some notion of the degree of resolution that could be obtained with multiple targets (ie, how close could targets be before they could no longer be resolved separately).

Having established an accurate target detection and range finding algorithm, we were ready to attempt range rate processing. Unless the target is moving at an extremely high speed relative to the speed of light, the Doppler shift will be small and very difficult to detect from one pulse. The solution to this problem is to transmit a burst waveform containing repeated pulses. Initially, for simplicity, boxcars were used as the pulse so that some insight into how the parameters of the pulse affect the Doppler shift might be gained. It was determined that the inter pulse period affected the width of the main lobe of the DTFT, the height of the main lobe was related to the number of pulses, and the magnitude of the side lobes depended upon the pulse length. Next, measurement of the Doppler shift from samples of the bursts was attempted. This allows range rate processing with significantly less data and thus faster computation. The sampling was done as follows. Range processing is done with the first burst alone since the additional bursts do not provide any extra range information. For each of the targets detected, each filtered burst is sampled at the location corresponding to the peak location of that target. The Doppler shift for each target is then measured from the peak location of the DTFT of the corresponding sampled waveform. Range rate is then determined by the following formula:

$$(fd / fc)*(c / 2)$$

where fd is the Doppler shift in Hz and fc is the center frequency of the radar in Hz. Range rate calculations will obviously be limited since shifts of the peak that are greater than pi will wrap around, resulting in incorrect calculations. Adjusting the center frequency allows the range of velocities that can be correctly calculated to change. As fc is decreased, larger speeds can be calculated, but accuracy of these velocities suffers somewhat. Conversely, as fc increased, accuracy increased, but high velocities could not be detected due to aliasing.

Next, LFM chirps were used as pulses and our ability to detect Doppler shifts of these waveforms was tested. Finally, a complete range and range rate analysis was performed. Once we were satisfied with the performance of this algorithm, it was time to try and analyze a signal that was not arbitrarily generated.

3.3 Implementation of Radar Signal Processor

The final goal of our project was the implementation of a radar signal processor in Matlab that would take a noisy return signal containing bursts reflected from several targets, and accurately determine the distance and velocity of those targets. The signal waveform used was a series of linear FM chirps. In addition, the radar processor had to take into account several parameters/restrictions that real world radar systems have to deal with. These are the starting time and length of the receive window, the interpulse period, and the center/carrier frequency of the radar.

The radar system that we modeled has a single antenna for sending and receiving the radar signal, and can not transmit and receive at the same time. The system alternates modes, first sending a pulse out, and then waiting for returns to come back. Since there is no simple way of determining when a returning pulse was transmitted, the system assumes that any returning pulse was transmitted just before the start of the current receive window. The receive window's starting and ending points determine how far away detectable targets can be. Furthermore, a pulse that was sent out must return completely before the receive window ends to ensure detection. Thus the range of the system is determined by the pulse duration, start of receive window, and end of receive window. Targets outside of this range will not be detected since the radar system is in transmit mode, or will be seen as a closer target since their signal returns will return in a later receive window, in effect resulting in distance aliasing. The range processing ability of the radar system is given by the following expressions:

$$\textit{distance to target} = (\textit{time when start of pulse returns}) * c / 2$$

$$(\textit{window start time}) * c / 2 = \textit{distance} = (\textit{window end time} - \textit{pulse duration}) * c / 2,$$

where c is the speed of light and times are measured relative to when the pulse was transmitted. The following timing diagram shows how the transmission window and receive window are positioned in time.

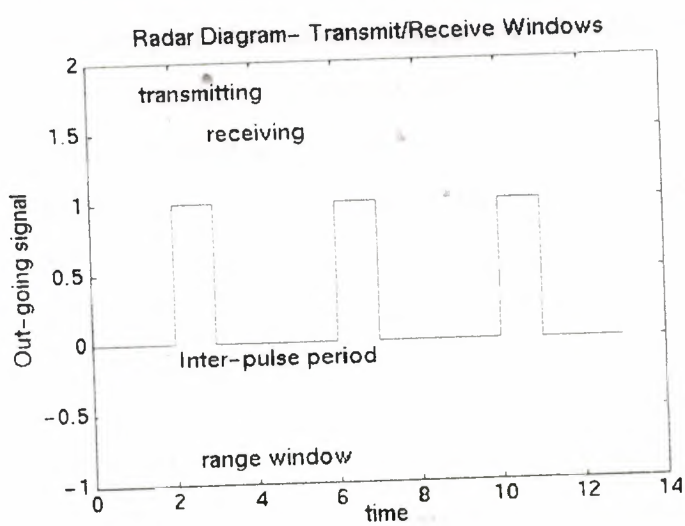


Figure3.5 Graph of timing diagram

The limits on the range of detectable velocities are determined primarily by two factors, the interburst period and the carrier frequency of the radar. In order to determine the velocity of a target, the Doppler shift of its radar return must be calculated. To reduce the amount of computation needed, a single sample is taken from a target's return signal in receive window. such that they are separated in time by the interburst period. The DTFT of the samples is calculated, and from the location of the peak in the DTFT, the Doppler shift is determined. Since velocity determination involves decimating the original signal, velocity aliasing occurs, limiting the range of velocities that are detectable in both the negative and positive directions. Since the Doppler shift is proportional to the carrier frequency of the radar signal, the carrier frequency also effects how large velocities may be before aliasing occurs. The velocity processing ability of the radar system is given by the following expressions:

*velocity of target = (DTFT frequency of peak)*c / (4*pi*interburst period*carrier frequency)*

*| velocity | = c / (4 * interburst period*carrier frequency).*

The routine radar that we used to generate the return radar signals from several targets was provided with the CBESP book. The radar function took several parameters: signal waveform as a vector, sampling rate in microseconds for the waveform, the starting time of each burst in microseconds as a vector (which we kept evenly spaced), the gain factor for each burst as a vector (we kept it as one always), the receive window starting and ending times in microseconds as a vector, the reference time (which we set as 0 always), the carrier frequency of the radar in megahertz, the distances to targets in kilometers as a vector, the signal gains for each target as a vector (which we kept as one always), and the velocities of each target in meters per second as a vector. The function returned a matrix containing all the detected signals during a particular receive window in a particular column. The returns from each target were positioned according to distance and modified according to velocity. Targets outside the receive window were cut off appropriately with no provision for distance aliasing.

On top of the basic radar signal processor we added a small graphical user interface which allows the user to input up to 20 targets on a distance-velocity plane. The radar processor then displays detected targets with X's on the same graph. It also displays numbers next to each target which indicate how high the peak is relative to a isolated target in a noiseless environment. This allows the user to determine which targets are likely to be caused by noise. There was also a provision for keyboard input.

3.4 Results

Analyzing the performance of the radar signal processor in a systematic manner is in general a difficult task. There are multiple variables to deal with even without the addition of the random noise. However, there are certain important performance characteristics that must be discussed. These include accuracy of distance and velocity determination, multiple target resolution, velocity aliasing, and effects of noise level.

We also realized that there are a number of tradeoffs involved in choosing radar parameters. The interburst period determines how long a receive window is possible, so it limits the range of the radar system. However, a large interburst period lowers the range of velocity determination. Also a larger carrier frequency lowers the range of measurement since aliasing will occur at lower velocities. However, it improves the resolution of the system since it maps smaller velocities to larger Doppler shifts. Therefore there is a trade off between velocity resolution and velocity range determination. There is also a tradeoff involved in choosing the duration of the signal pulse. A larger pulse, raises the signal to noise ratio after filtering, but it reduces the ability to resolve close target

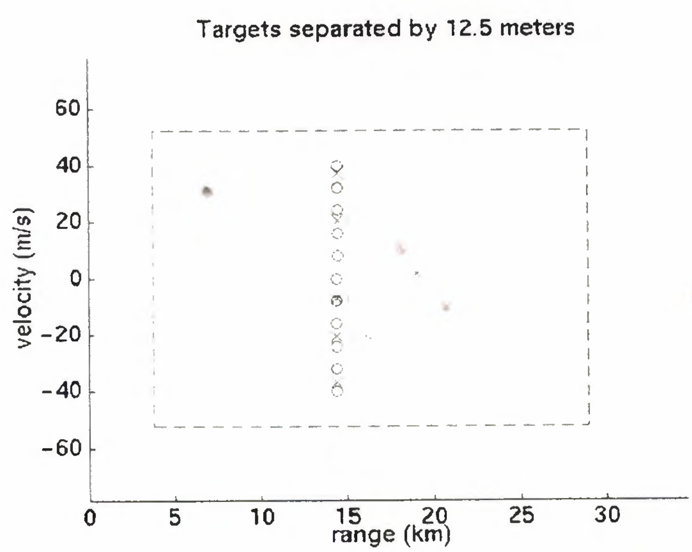


Figure 3.6 Graph of Multiple target resolution (target separated by 12.5m)

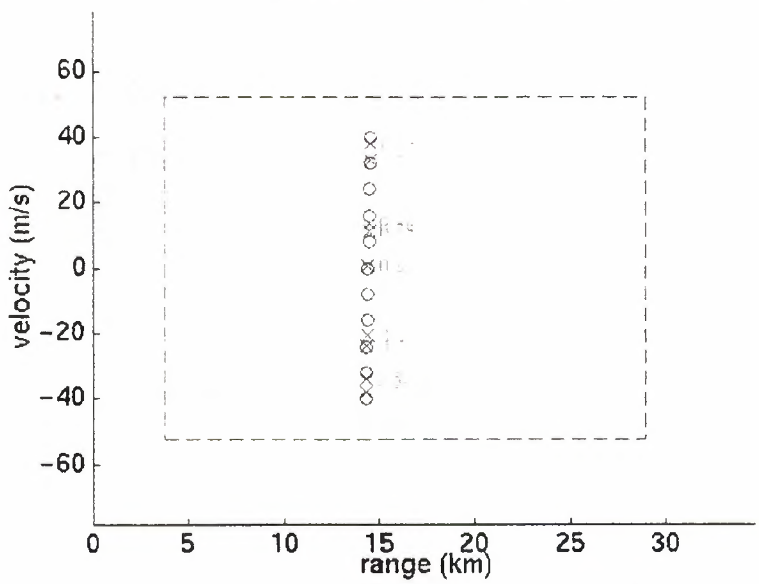


Figure 3.7 Graph of Multiple target resolution (target separated by 25m)

Velocity aliasing occurs when the speed of a target exceeds the maximum detectable velocity. Shown below is a target configuration with velocity aliasing, and the DTFT's used to determine velocity. Note that the peak for one the targets flips to the opposite side.

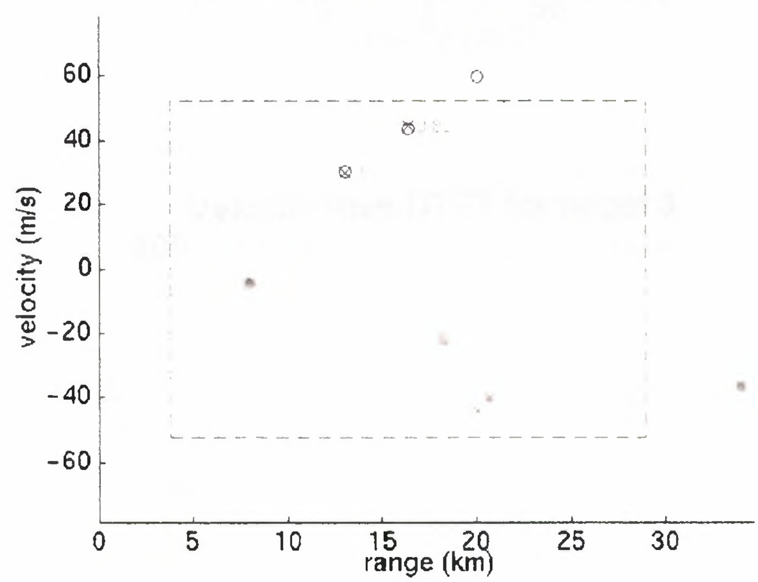


Figure 3.8 Graph of velocity aliasing – detected targets

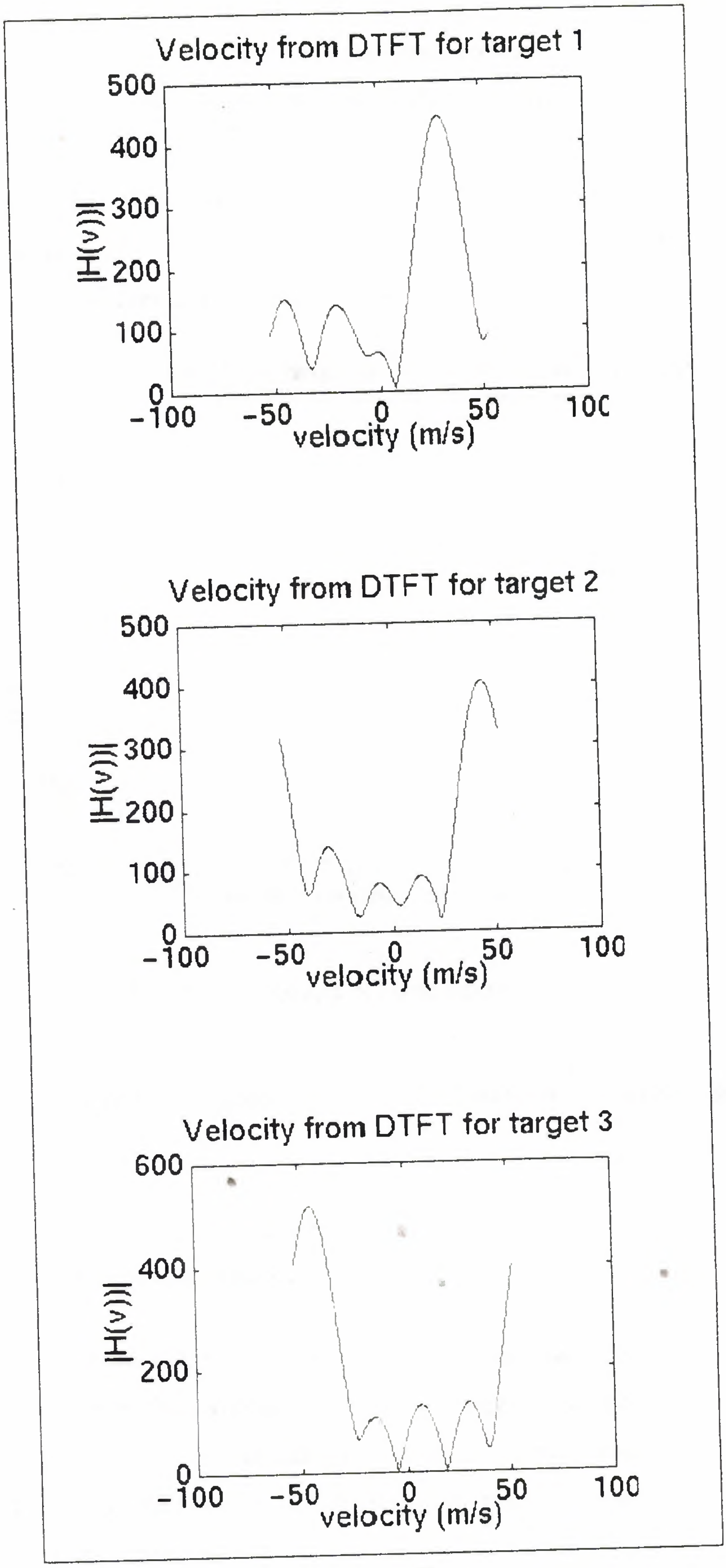


Figure 3.9 Graphs of Velocity from DTFT

When testing the accuracy of the radar, it is important to know the effects that noise will have on the system. The following graph shows what happens as the standard deviation of the noise increases. One single target was input into the system, the noise level was varied, and the number of targets detected was recorded. From this, it is possible to tell that noise begins to have a large negative effect on the performance of the system when the standard deviation of the noise becomes greater than two.

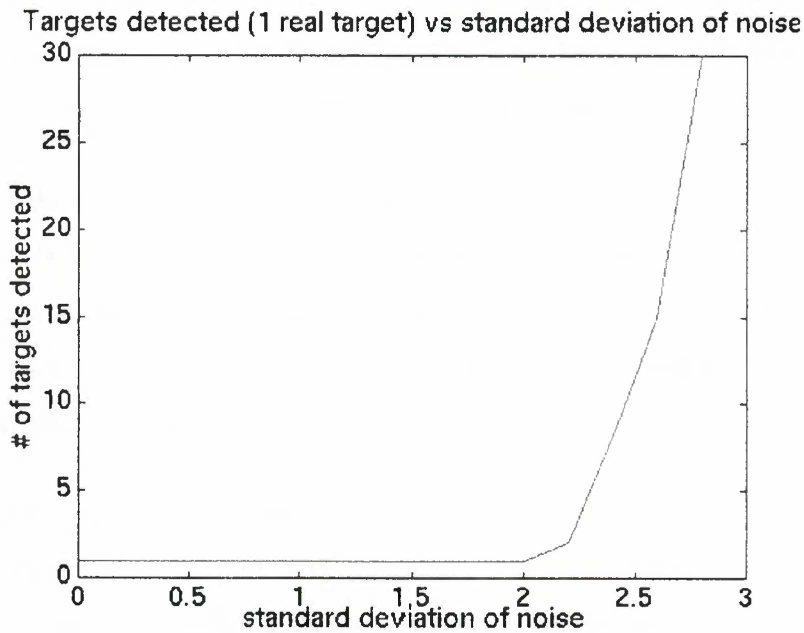


Figure 3.10 Graph of noise interference

To test the accuracy of the program, it was run 40 times with the following ranges and velocities:

ranges = [6.1778 10.8312 17.0892 20.5391 25.8344]
vels = [-20.0016 18.1624 -28.7380 5.2878 41.1528]

The difference between these values and the values calculated by the program were assembled into matrices. The average error of the range calculations was .3506 meters. The average error of velocity calculations was .1509 meters/second. The standard deviation of the range error was 2.6279 meters. The standard deviation of the velocity error was .7266 meters/second.

CHAPTER 4

AIRPORT SURVEILLANCE RADAR

4.1 Surveillance Radar

Surveillance radar a device which, by measuring the time interval between transmission and reception of radio pulses and correlating the angular orientation of the radiated antenna beam or beams in azimuth and/or elevation, provides information on range, azimuth, and/or elevation of objects in the path of the transmitted pulses.

Surveillance radars are divided into two general categories: Airport Surveillance Radar (ASR) and Air Route Surveillance Radar (ARSR). Surveillance radars scan through 360 degrees of azimuth and present target information on a radar display located in a tower (ATCT) or center (ARTCC). This information is used independently or in conjunction with other navigational aids in the control of air traffic.

1. ASR is designed to provide relatively short-range coverage in the general vicinity of an airport and to serve as an expeditious means of handling terminal area traffic through observation of precise aircraft locations on a radarscope. The ASR can also be used as an instrument approach aid. The DFW Terminal Radar Approach Control (TRACON) Facility provides radar coverage with four ASR-9 installations.
2. ARSR is a long-range radar system designed primarily to provide a display of aircraft locations over large areas. The Fort Worth Air Route Traffic Control Center (ZFW ARTCC) provides radar coverage with a total of 9 long range radar installations, 2 radar beacon only sites and one ASR-9 installation.

4.2 Airport surveillance radar (ASR)

Approach control radar used to detect and display an aircraft's position in the terminal area. ASR provides range and azimuth information but does not provide elevation data. Coverage of the ASR can extend up to 60 miles. The DFW terminal area is blanketed with four ASR-9 facilities.

Reliable maintenance and improved equipment have reduced radar system failures to a negligible factor. All of the DFW RADAR facilities have components duplicated-one operating and another, which immediately takes over when a malfunction occurs to the primary component.

The characteristics of radio waves are such that they normally travel in a continuous straight line unless they are:

1. ``Bent" by abnormal atmospheric phenomena such as temperature inversions; The bending of radar pulses, often called anomalous propagation or ducting, may cause many extraneous blips to appear on the radar operator's display if the beam has been bent toward the ground or may decrease the detection range if the wave is bent upward. It is difficult to solve the effects of anomalous propagation, but using beacon radar and electronically eliminating stationary and slow moving targets by a method called moving target indicator (MTI) usually negate the problem
2. Reflected or attenuated by dense objects such as heavy clouds, precipitation, ground obstacles, mountains, etc.; Radar energy that strikes dense objects will be reflected and displayed on the operator's scope thereby blocking out aircraft at the same range and greatly weakening or completely eliminating the display of targets at a greater range. Again, radar beacon and MTI are very effectively used to combat ground clutter and weather phenomena, and a method of circularly polarizing the radar beam will eliminate some weather returns. A negative characteristic of MTI is that an aircraft flying a speed that coincides with the canceling signal of the MTI (tangential or ``blind" speed) may not be displayed to the radar controller.
3. Screened by high terrain features. Relatively low altitude aircraft will not be seen if they are screened by mountains or are below the radar beam due to earth curvature. The only solution to screening is the installation of strategically placed multiple radars which has been done in some areas.
4. There are several other factors which affect radar control. The amount of reflective surface of an aircraft will determine the size of the radar return. Therefore, a small light airplane or a sleek jet fighter will be more difficult to see on radar than a large commercial jet or military bomber. Here again, the use

of radar beacon is invaluable if the aircraft is equipped with an airborne transponder. All radars in the Lone Star SMO have the capability to interrogate MODE C and display altitude information to the controller from appropriately equipped aircraft. Just a quick note here.

The controllers' ability to advise a pilot flying on instruments or in visual conditions of his proximity to another aircraft will be limited if the unknown aircraft is not observed on radar, if no flight plan information is available, or if the volume of traffic and workload prevent his issuing traffic information. The controller's first priority is given to establishing vertical, lateral, or longitudinal separation between aircraft flying IFR under the control of ATC.

4.3 Air traffic control radar beacon system (ATCRBS)

The ATCRBS, sometimes referred to as secondary surveillance radar, consists of three main components:

- Interrogator. Primary radar relies on a signal being transmitted from the radar antenna site and for this signal to be reflected or ``bounced back" from an object (such as an aircraft). This reflected signal is then displayed as a ``target" on the controller's radarscope. In the ATCRBS, the Interrogator, a ground based radar beacon transmitter-receiver, scans in synchronism with the primary radar and transmits discrete radio signals which repetitiously requests all transponders, on the mode being used, to reply. The replies received are then mixed with the primary returns and both are displayed on the same radarscope.
- Transponder. This airborne radar beacon transmitter-receiver automatically receives the signals from the interrogator and selectively replies with a specific pulse group (code) only to those interrogations being received on the mode to which it is set. These replies are independent of, and much stronger than a primary radar return.
- Radarscope. The radarscope used by the controller displays returns from both the primary radar system and the ATCRBS. These returns, called targets, are what the controller refers to in the control and separation of traffic.

The job of identifying and maintaining identification of primary radar targets is a long and tedious task for the controller. Some of the advantages of ATCRBS over primary radar are:

- Reinforcement of radar targets.
- Rapid target identification.
- Unique display of selected codes.

A part of the ATCRBS ground equipment is the decoder. This equipment enables the controller to assign discrete transponder codes to each aircraft under his control. Normally only one code will be assigned for the entire flight. The ARTCC computer on the basis of the National Beacon Code Allocation Plan makes assignments. The equipment is also designed to receive MODE C altitude information from the aircraft.

It should be emphasized that aircraft transponders greatly improve the effectiveness of radar systems.

Center Radar Automated Radar Terminal Systems (ARTS) Processing (CENRAP) was developed to provide an alternative to a non-radar environment at terminal facilities should an Airport Surveillance Radar (ASR) fail or malfunction. CENRAP sends aircraft radar beacon target information to the ASR terminal facility equipped with ARTS. Procedures used for the separation of aircraft may increase under certain conditions when a facility is utilizing CENRAP because radar target information updates at a slower rate than the normal ASR radar. Radar services for VFR aircraft are also limited during CENRAP operations because of the additional workload required to provide services to IFR aircraft.

4.4 What is Primary Surveillance Radar (PSR)?

A primary surveillance radar detects and provides both range and bearing information of an aircraft within its effective coverage. In Hong Kong, depending on the application, the coverage is within 80 nautical miles for approach control and within 200 nautical miles for en-route control purpose.

4.5 What is Secondary Surveillance Radar (SSR)?

A secondary surveillance radar provides, after processing of data transmitted by the aircraft, the range, bearing, altitude and identity (callsign) of an aircraft. The coverage can reach 250 nautical miles. A SSR can provide more useful information than Primary Surveillance Radar (PSR) but is subject to the proper functioning of the aircraft's transponder. To provide the best radar picture with a continuous display of aircraft targets, the SSR is usually paired with a PSR for air traffic control operation.

4.6 Problems with Primary Radar

As you can see from the previous slides:

1. Rain makes targets difficult to see.
2. Birds can show a return that looks like an aircraft.
3. Some aircraft do not show up at all.
4. Clutter from other information makes aircraft difficult to see.

   Secondary Surveillance Radar helps to solve these problems

4.7 SSR Helps us Sort it out

All the transponder equipped aircraft have numbers. Even the ones without primary returns! Birds and alien spacecraft do not have numbers.

The numbers have meaning.

1. 1200 means that the aircraft is navigating on its own under Visual Flight Rules, and not talking to a controller.
2. Other numbers are assigned by controllers, and mean different things in different airspace.

In this example,

- Odd numbers mean arrivals,
- Even numbers mean departures.

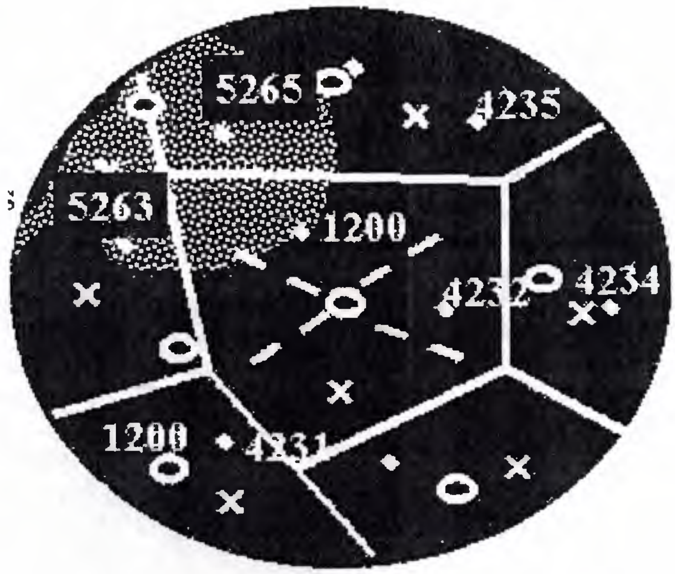


Figure 4.1 Monitor of SSR shows the targets

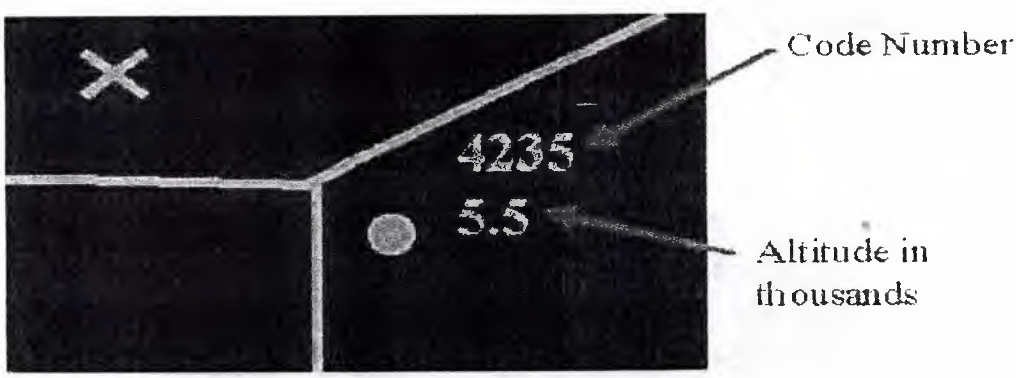


Figure 4.2 Monitor of SSR show the altitude of the plane

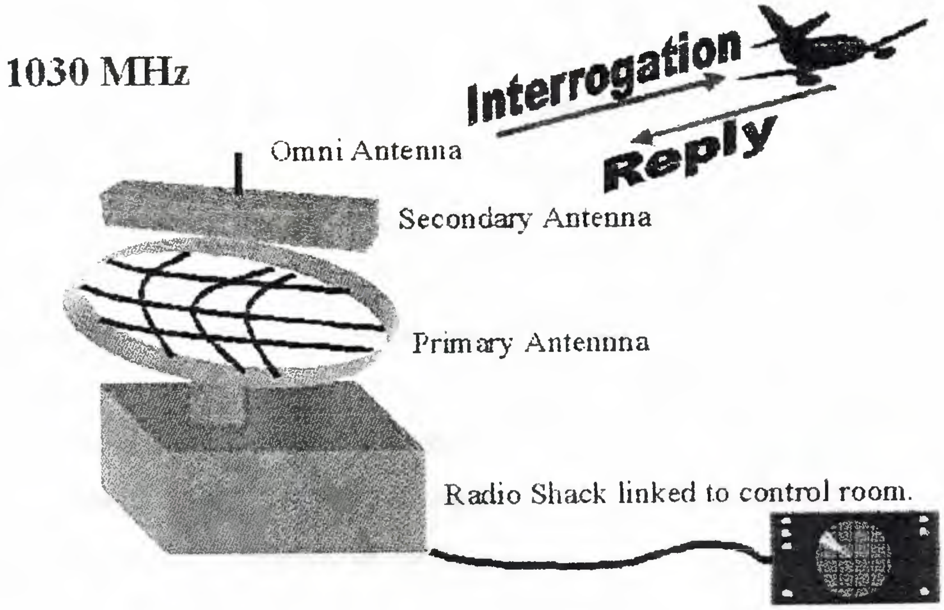


Figure 4.3 The ground system

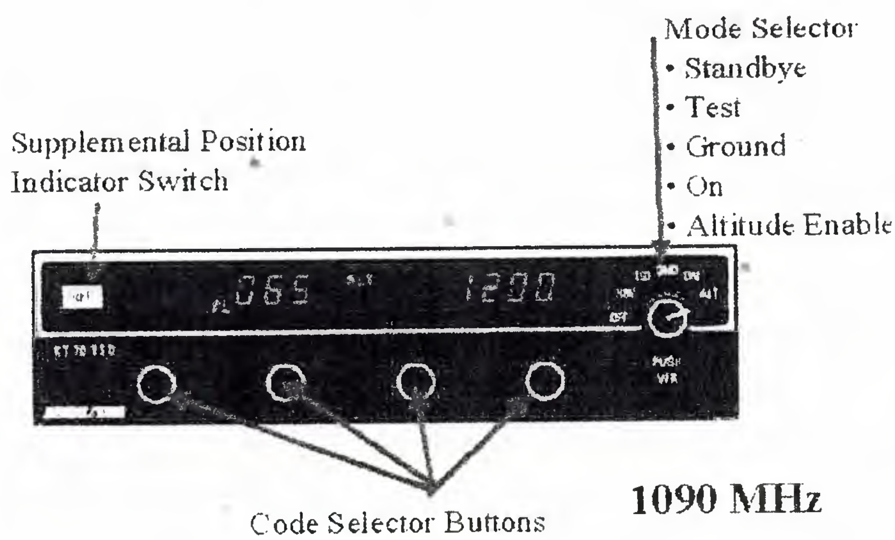


Figure 4.4 The airborne system

4.8 Why it's Difficult to Provide Low-Level Radar Coverage?

Radio waves usually travel in straight line, they cannot detour round obstacles which curtail their line of travel : radar-like all other radio-based systems , therefore a `line-of-sight` instrument and vulnerable to screening by mountains or even – if the aircraft is flying low enough – by the earth's curvature.

An aircraft flying behind a mountain, for example would not be visible to radar, but as soon as it climbed above the mountain or emerged from behind it, the aircraft would once again appear as a target on the radar screen. The higher the aircraft, the greater the radar range. In mountainous regions it is, therefore, difficult to provide low level radar overage which is why airports like Kathmandu in Nepal, which are difficult to fly into even under the best conditions,cannot be made safer with the introduction of radar or indeed other line –of-sight navigational aids.

4.9 What is The Radar's Role in The ATC?

The biggest drawback with primary radar is that it can only highlight targets within its range: it cannot positively identify those targets or their altitude. The controller must paint a three-dimensional picture in his mind so that he knows the identification of each target, its altitude (as reported by the pilot), where it is going, how fast it is going and whether it is likely to conflict with any of the other targets on the screen.

If in doubt about a particular target's identity, the controller can request that aircraft to undertake a specific man oeuvre, such as a turn off course followed by a return to course. By watching which target on his screen makes a momentary detour from course, the controller can pinpoint exactly which aircraft it is .It is a system that works well in areas of low traffic density. In busy skies, however, the controller is faced with a screen crowded with one-dimensional targets for which he is trying to provide a three-dimensional air traffic control service. Under those conditions, identifying man oeuvres becomes more hazardous and some from of positive target identification is essential.

The answer is secondary surveillance radar. Unlike primary radar, which does not require the aircraft to carry any response equipment, secondary radar is an interrogative system: it transmits a signal to the aircraft to which the aircraft replies with coded transmission. The aircraft must therefore be equipped with response equipment, known as a transponder.

In order to identify a particular target, the ground controller will ask that aircraft to transpond or `squawk` an assigned code number which immediately highlights a target on the controller's screen, identifying it as that particular aircraft. If the aircraft is equipped with what is known as a Mode C transponder, the altitude of that aircraft will also be displayed in the identifying label on screen. If the aircraft is not equipped with a transponder, it will not register on the controller's radar screen at all unless a primary radar is also feeding data to that screen in which case , the aircraft will appear as an unidentified target.

These days, most radar data is collected in a computer processing system which extracts the relevant aircraft information and discards the clutter of echoes generated by terrain or weather to create a much cleaner radar display showing all targets and, where relevant, identifying labels.

In busy airspace, or in the vicinity of terminal areas, primary and secondary radar sensors are generally mounted together to ensure that controllers are aware not only of all transponder equipped aircraft in their sector, but also any traffic operating without transponders, For upper level *en route* surveillance, longer range secondary surveillance radar is generally used alone because there is less traffic control density and few, if any, aircraft operate in those sectors without transponders.

Like its primary counterpart, secondary radar is a line of sight tool and range restricted. Where full secondary radar coverage is available, it is possible to reduce the separations required between aircraft and, therefore make more efficient use of the available airspace , thereby increasing the capacity of that controlled airspace. However radar is limited to a range of about 200 nm. On land, it is usually possible to install a sufficient number of radar sites to provide full radar coverage, particularly as aircraft climb away from the earth's surface and obstacle interference. But it is impossible to provide radar cover over the full expanse of the world's oceans and it is rarely viable to provide full cover in the depth of inaccessible terrain such as vast deserts.

4.10 Multi radar tracking

These days, in many busy areas, radar coverage is so comprehensive that several radar returns are generated for each aircraft. In reality, radar bias (the radar signal may be weakened by distance, weather conditions or other interference) or systematic error between radars means that each radar data will give a slightly different position reading. The radar data processor will, therefore, select the reading from the radar providing the strongest signal and translate that into a target on the air traffic control display.

Today, multi radar tracking collate the signal data from all the relevant radars, calculate the strength of each return, and using all this information, define the aircraft's precise position.

4.11 Precision Approach Radar

At airports where it is not possible to install an (Instrument Landing System) or ILS, but it may be necessary to offer a precision approach capability, ICAO recommends the use of (Precision Approach Radar) (PAR).In these circumstances, a local controller literally talks the aircraft down on to the runway. Because it is expensive and rarely used, PAR is not widely applied.

It involves the use of two radar pictures, giving the controller both azimuth and elevation views of the aircraft on approach. The controller will then talk to the pilot giving minute navigation instructions to get the aircraft established on the centerline and glide slope and keep it there for the entire descent. In order for the controller to give accurate instructions, he must have the elevation/height information include in the display. A straightforward azimuth or plan display would provide insufficient data.

4.12 Mode S

`Mode select` , or `Mode S` as it is more commonly known, is a system which enhances existing radar-based surveillance and provides an additional datalink function. It has been developed in order to over come sensitivity of existing systems to synchronous grable and a critical shortage of transponder codes. Existing system are unable to assign unique identity codes to more than 4,096 aircraft in any one region at any given time.

Although all aircraft operating in a specified region have individual codes, those same codes have to be used by other aircraft operating in different region across the globe. An aircraft passing through several regions may therefore have to be assigned a new identity code as it passes from one region into another to avoid an identity conflict with an aircraft already operating in that region with the same code.

Mode S, however, is capable of recognizing up to 16 million unique codes, which means that every aircraft currently in existence could be assigned its own unique code when the Mode S transponder is installed. This code cannot be changed from the cockpit. Mode S codes are derived from the aircraft's registration number or other numbering scheme.

Another key feature of Mode S is that it can selectively interrogate individual aircraft even if several transponder- equipped aircraft are simultaneously within view of the ground sensor. A Mode S transponder. However, in order to pick up unknown aircraft, a sensor periodically broadcasts a Mode S `all-call` interrogation. Any Mode S transponder which has not been specifically commanded to ignore all-call interrogation will reply . Once a transponder has responded to all-call interrogation and been identified, the sensor will then instruct it to ignore all further all-call interrogations. Mode S is claimed to improve overall surveillance accuracy by a factor of up to four.

As it is datalink tool, Mode S uses the basic surveillance interrogation and replies to pass datalink message, taking advantage of the selective address to exchange more comprehensive data. As a result, air traffic controllers can receive on screen more information a bout the status of each aircraft interrogation than is currently possible with Mode A (identity) and Mode C (altitude)

In addition, using the Mode S datalink function, a pilot may access weather and flight information services, flight safety services, Automated Terminal Information Services (ATIS), initial connection services, and automated *en route* air traffic control connection mode services.

ICAO as the Secondary Surveillance Radar (SSR) standard of the future has adopted Mode S.

4.13 Displays

Display technology has made great strides over the last few years, giving controllers a much clearer picture of the aircpace they are controlling.

From the early days of round horizontal monochrome displays, air traffic control authorities are increasingly switching to vertical square colour screens.

Until the advent of SSR, all radar surveillance involved the use of primary sensors. The data generated by these sensors was displayed on round PPI (Plan Position Indicator) screens with a beam making a circular scan of the screen represent each revolution of the radar antenna, updating the echoes with every revolution. But, as well as picking up aircraft, the screen also displayed all other echoes generated by the radar and, as a result, the picture received by the controller was often cluttered.

The advent of SSR and the use of transponders meant that it was at least possible positively to identify a and label targets and, as display technology improved, to select the amount of additional information that was displayed on the screen. It was possible, for example, to screen out terrain and weather echoes , leaving just the active targets and giving controllers a much clearer picture.

4.14 AN/SPS-49 Very Long-Range Air Surveillance Radar

The Radar Set AN/SPS-49 is an L-band, long-range, two-dimensional, air-search radar system that provides automatic detection and reporting of targets within its surveillance volume. The AN/SPS-49 performs accurate centroiding of target range, azimuth, amplitude, ECM level background, and radial velocity with an associated confidence factor to produce contact data for command and control systems. In addition, contact range and bearing information is provided for display on standard plan position indicator consoles. The AN/SPS-49 uses a line-of-sight, horizon-stabilized antenna to provide acquisition of low-altitude targets in all sea states, and also utilizes an upspot feature to provide coverage for high diving threats in the high diver mode. External control of AN/SPS-49 modes and operation by the command and control system, and processing to identify and flag contacts as special alerts are provided for self-defense support. The AN/SPS-49 has several operational features to allow optimum radar performance: an automatic target detection capability with pulse doppler processing and clutter maps, ensuring reliable detection in normal and severe types of clutter; an electronic counter-countermeasures capability for jamming environments; a moving target indicator capability to distinguish moving targets from stationary targets and to improve target detection during the presence of clutter and chaff; the Medium PRF Upgrade (MPU) to increase detection capabilities and reduce false contacts; and a Coherent Sidelobe Cancellation (CSLC) feature.

The AN/SPS-49 long range 2-dimensional air surveillance radar used for early target detection. The long-range AN/SPS-49 radar operates in the presence of clutter, chaff, and electronic counter-measures to detect, identify, and control low-radar-cross-section threats traveling at supersonic speeds. AN/SPS-49 provides the front-end element for successful target identification, designation, and engagement with either long range (SM-1 or SM-2) missiles and/or short range local defense missiles. A key feature of the most recent version of the radar, the SPS-49A(V)1 is single-scan radial velocity estimation of all targets allowing faster promotion to firm track and improved maneuver detection. This is done using unique signal processing techniques originated and tested by the Radar Division of NRL using 6.1 and 6.2 Office of Naval Research (ONR) funds.

The AN/SPS-49(V) radar is a narrow beam, very long range, 2D air search radar that primarily supports the AAW mission in surface ships. The radar is used to provide long range air surveillance regardless of severe clutter and jamming environments. Collateral functions include air traffic control, air intercept control, and antisubmarine aircraft control. It also provides a reliable backup to the three-dimensional (3D) weapon system designation radar.

The AN/SPS-49(V) radar operates in the frequency range of 850 - 942 MHZ. In the long-range mode, the AN/SPS-49 can detect small fighter aircraft at ranges in excess of 225 nautical miles. Its narrow beam width substantially improves resistance to jamming. The addition of coherent side lobe canceller (CSLC) capability in some AN/SPS-49(V) radars also provides additional resistance to jamming/interference by canceling the jamming/interference signals. The moving target indicator (MTI) capability incorporated in the AN/SPS-49 (V) radar enhances target detection of low-flying high speed targets through the cancellation of ground/sea return (clutter), weather and similar stationary targets. In 12-RPM mode operation, this radar is effective for the detection of hostile low flying and "pop-up" targets. Features of this set include:

- Solid state technology with modular construction used throughout the radar, with the exception of the klystron power amplifier and high power modulator tubes
- Digital processing techniques used extensively in the automatic target detection modification
- Performance monitors, automatic fault detectors, and built-in-test equipment, and automatic on line self test features .

Band	L
Frequency Band	850 to 942 MHz ,three selectable 30MHz bands , 48 discrete frequencies
Transmitting Power	360 kW peak, 280 kW specified peak power,12-13 kW average power
Antenna Parameters	Parabolic Reflector stabilized for roll and pitch, 7.3m/24 ft wide, 4.3m/14.2 ft high
Range	250 nm
Minimum Range	0.5 nmi
Frequency Selection	Fixed or frequency agile
Range Accuracy	0.03 nmi
Azimuth Accuracy	0.5 deg
PRF	280, 800, 1000 pps
Pulse width	125 microseconds

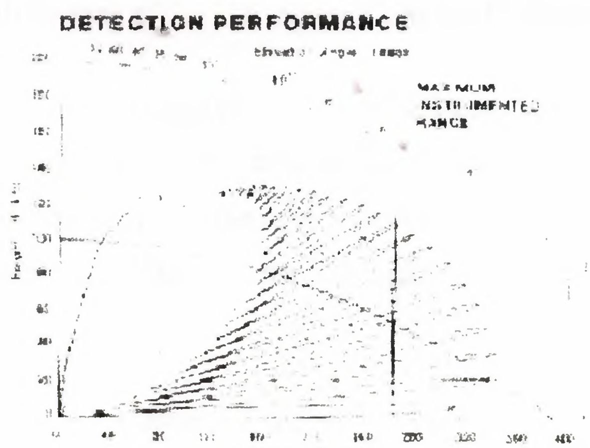


Figure 4.5 Detection performance

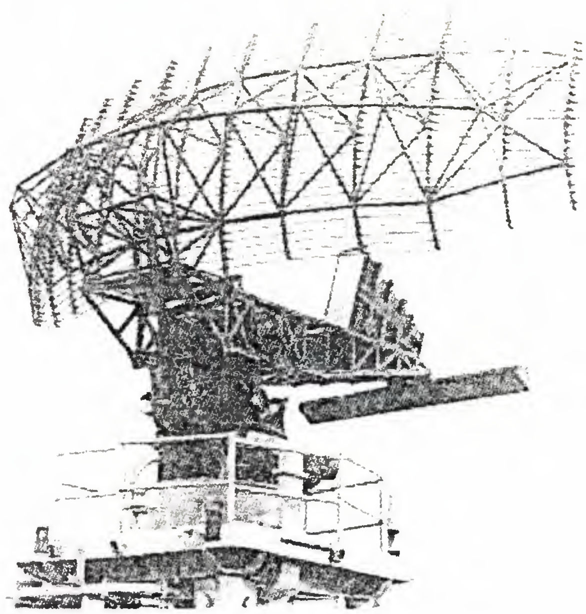


Figure 4.6 SPS-49 antennas on frigate Jack Williams

4.15 Upgrading the Nation's Largest Space Surveillance Radar

Some of the custom electronics assemblies designed at SwRI for the AN/FPS-85 radar transmitter unit upgrade are shown at left. large-quantity production factors were considered during the design phase. For example, a microcontroller (upper left) with highly integrated features were selected to minimize assembly complexity and parts count.

Southwest Research Institute is leading an engineering development effort to upgrade the reliability and performance of the U.S. Space Command's largest surveillance radar.

The world's first large phased-array radar, the AN/FPS-85 was constructed in the 1960s at Eglin Air Force Base, Florida. Other large radars have been introduced since then, but the Grand Old Lady of the South, as the radar installation is known at Eglin, remains the nation's primary space surveillance radar because of its unsurpassed power and coverage.

The AN/FPS-85 is a valued asset to the U.S. Air Force, but one with an aging technology base that must be supported into the future. For example, the on-site maintenance crew repairs an average of 17 radar transmitter units per day at an expense of $2 million annually, a figure that will rise as the vacuum tube market diminishes. Recognizing that maintenance costs could be reduced by reliability improvements, the Air Force contracted with SwRI in 1992 to study ways of improving the installation's transmitter array system.

The AN/FPS-85 Phased Array Radar Facility is located in the Florida panhandle, near the city of Freeport, which is approximately 25 miles east of Eglin Air Force Base. A several mile no-fly zone surrounds the radar installation as a safety concern for the electroexplosive devices, such as ejection seats and munitions, carried on most military aircraft.

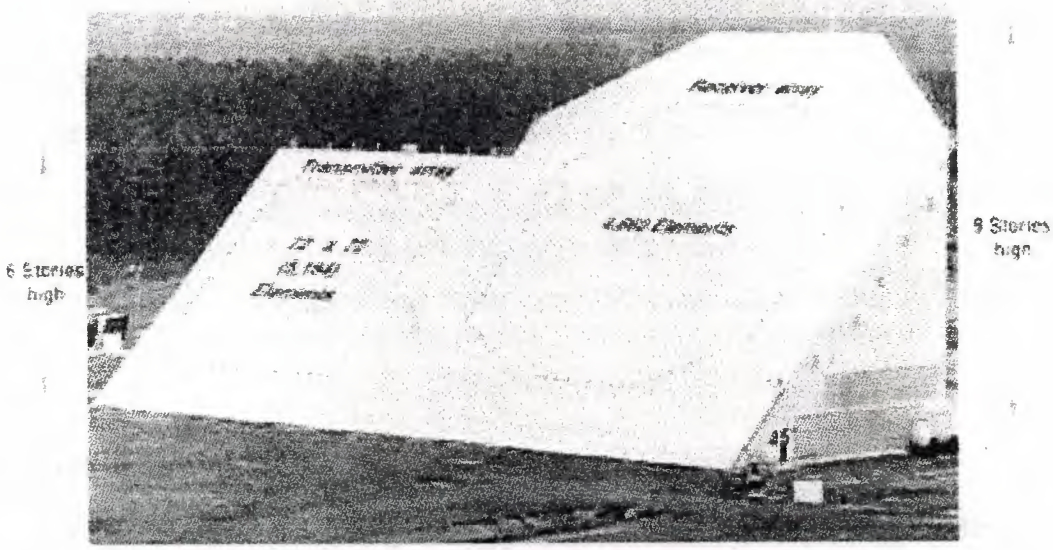


Figure 4.7 The AN/FPS-85 Phased Array Radar Facility in Florida,USA

SwRI engineers determined that reliability, supportability, and reliability gains in the transmitter array system could be realized through modern design approaches that would replace high-power vacuum tubes with RF power transistor and integrated electronic technology. As the project progressed, new transmitter designs were developed, prototyped, and tested by modifying government-furnished radar transmitter units. The basic concept has been successfully demonstrated, and a large four-year production effort to modify the full transmitter array system is planned. The Air Force has endorsed the upgrade plan and is prepared to carry out the modification program with SwRI as the principle-engineering consultant.

CHAPTER 5

RADAR SYSTEMS IN ERCAN AIRPORT

5.1 Introduction

I did my second summer practice at the civil aviation of Northern Cyprus in Ercan Airport (Nicosia). My summer practice was between 07.09.2000, to 04.10.2000.

The main purpose of the summer practice was to improve my theoretical knowledge by particle applications, In the electrical & electronics instruments, by some observation I got many knowledge . I tried to observe the problems, both the technicians and the engineers were faced to.

I gained a lot of data about the most important technique systems in Ercan Airport t by my work with the engineers and technicians.

Also at the first there are some information about the civil aviation in the Turkish Republic of Northern Cyprus (KKTC). And I end the Report with my conclusion; all my book references were from the civil aviation's library also

My report contains some important figures and diagrams witch made my report more clear.

5.2 Civil Aviation Department in Ercan Airport

Name of the Governmental Organization: Civil Aviation Department, Ministry of Communication and Works, Turkish Republic of Northern Cyprus (T R N C).

Number of the engineers employed in the company is four, three are electrical & electronic engineers and one mechanical engineer they are responsible to maintain the available systems for the continuity of airport facilities, they are responsible to manage the technicians, also to make the work plane and they are responsible to prepare new project in order to improve Ercan Airport's facilities.

There are 21 Technicians; 11of whom are Electrical & Electronics Technicians and the rest are mechanical technicians.

The civil aviation in Northern Cyprus is responsible for Geçitkale Airport, which is the second Airport in Northern Cyprus.

Cyprus Turkish Civil Aviation was established in 20 /7 /1974 It's head quarters is in Capital City Lefkosa (Nicosia), 23 km west of Ercan Airport. The Director of the Department is Mr. Orbay Kılıç.

The address is Telephone No 0392 2283666, Civil Aviation Department, Lefkosa, and Mersin10, TURKEY.

5.3 Radar Systems in Ercan Airport

Radar systems in Ercan Airport (The Main Airport in Northern Cyprus) is consisting of Primary Surveillance Radar (PSR), Secondary Surveillance Radar (SSR), Multi Radar Tracking (MRT), Multi Channel Tracking (MCT), Associated modems, Common Display System (CDS) and Digital Display System (DDS) the last two for monitoring.

5.3.1 PSR

Primary Surveillance Radar (PSR) It has 60 nmi

The transmitter of PSR, since a pass of about one Mw for Duration about one micro second through the magnetron this pass travels in the air with speed of light 162 000 nmi/s, when it hits the target i.e. the plane it reflects back and the receiver of our system detect the echo and true the formula of

$$R = C\,t/2 \tag{5.1}$$

Where R is the range, C is the speed of light and t is the time between the transmission of signal and receiving of the echo .It calculates the range of the plane the purpose of PSR is detection and ranging only.

5.3.2 SSR

The principle of secondary surveillance radar is different than the primary surveillance because it needs the assistant of the plane to detect the target.

The transmitter of SSR sends two passes in two different modes mode 3A, and mode C that ask the plane who are you? And what high are you? , The transponder in the plane detects these signals and answers in pre determent model, the receiver of SSR detects and processing this reply. Look at figure 5.1.

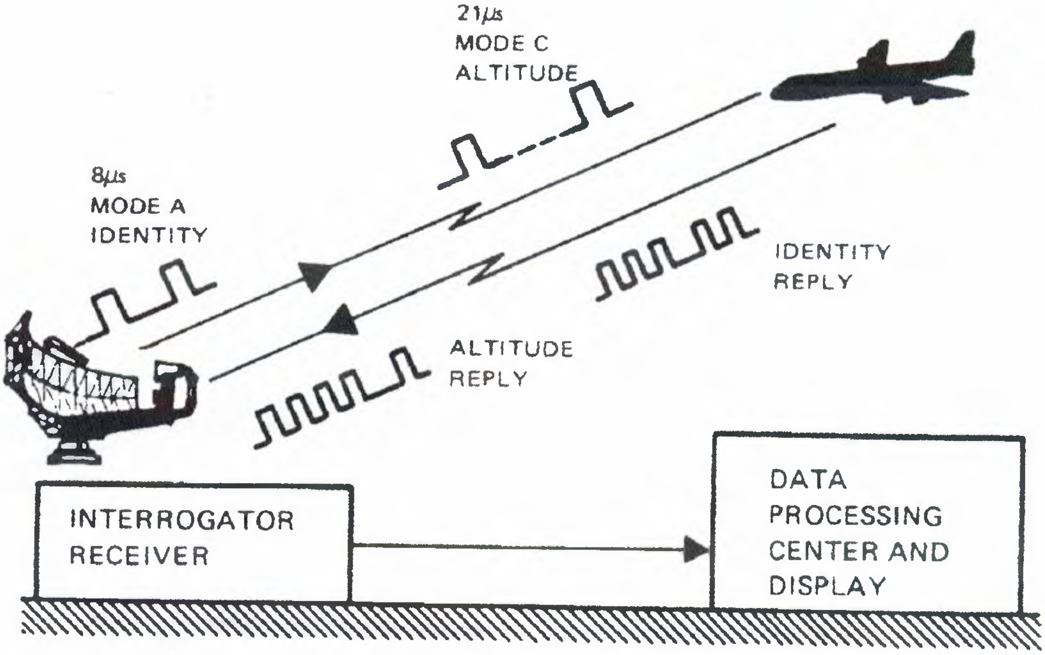
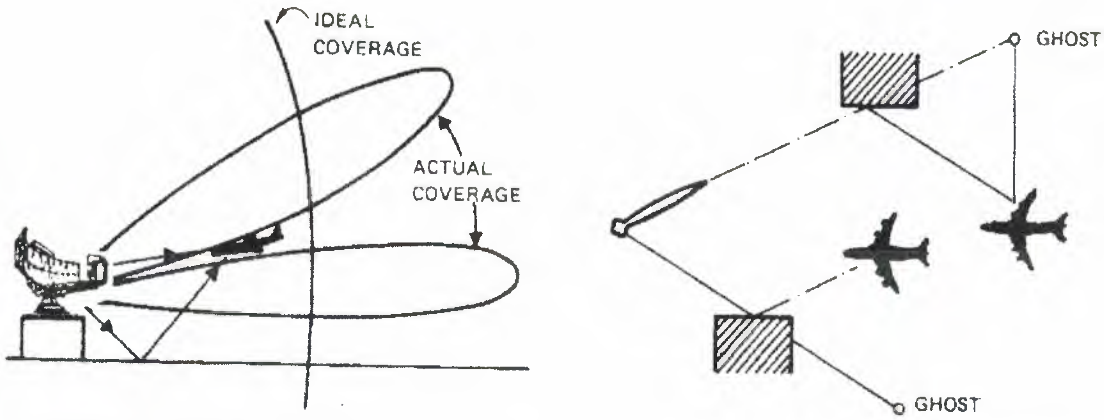


Figure 5.1 The basic principles for the operation of the SSR system in Ercan Airport

5.3.2.1 SSR Performance and Limitations

The attached document contains part of annex 10 of the convention of (I N C A) and it gives specifications and recommendations of for SSR to which the SSR must add here

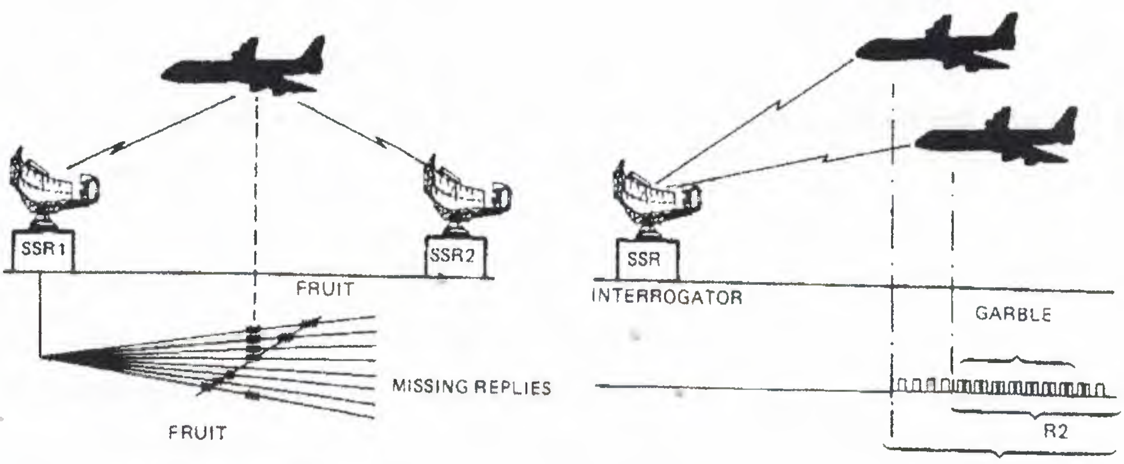
- Detection the aircraft position without to use necessarily the decoding equipment;
- Identification of the aircraft height code; İ
- To identify, when it is requested, a signal aircraft from the reply of special pulse SPI (Special Pulse Identification);
- To indicate, immediatlyian aircraft in an emergency condition or with the radio communication system in trouble such performance must be available, typically with in following limits for all the conditions
- Up to 200 nautical miles ranges
- Up to an altitude of 30.480 meter (100.000) for elevation angles between .5 /45
- For an azimuth angle of 360
- The advantages gamed from an SSR system are off set by the following problems
- Interrogation by antenna side lobes
- Interrogation by means multiple path figure 5.2
- Interrogation by coming from other SSR system figure 5.2
- Replies coming from aircrafts closely spaced figure 5.3 in heaving traffic areas.



a) Lobing of the radar coverage due to ground reflection in the vertical plane.

b) Reflections from large objects, generally ground base structure in the antenna beam (ghosts) in the horizontal plane.

Figure 5.2 Reflection influence on SSR coverage in Ercan Airport



a) Up-link interference (missing replies due to transponder dead time and suppression time).
Down-link interference (fruit) from transponder answering to other interrogators.

b) Overlapped replies due to closely spaced in slant range and azimuth aircrafts (garble).

Figure 5.3 SSR Interferences Ercan Airport

5.3.3 MRT and MCT

MRT means Multi Radar Tracking,

MCT means Multi Channel Tracking

Most of these are for processing and converting the data coming from PSR and SSR in form to send to DDS / CDs for the use of air traffic control.

Also MCT combines the data of SSR coming from Ermenek City (central of Turkey) to Ercan (Northern Cyprus Airport)

Modems:_these are used for transmission of data between Ercan Radar site, Ermenek SSR and the ATC Air Traffic Control center.

5.3.4 CDS and DDS

CDS means Common Display System

DDS means Digital Display System

These are monitoring systems for the air traffic controls rule it has many different access to able an easier control when a controller looks at his displays he sees where the plane is, how high the plane is, what the speed of the plane is, very easily, and in a very clear way.

5.4 Basic Elements of Pulse Radar Systems in Ercan Airport

The basic elements in a typical pulse radar system are:

The timer, modulator, antenna, receiver, indicator, transmitter, duplexer and rotary joint, as is shown in figure 5.4.

5.4.1 Timer

The timer, or synchronizer is the heart of all pulse radar systems, it's function is insure that all circuits connected with radar system operate in a definite time relationship with each other, and that the interval between pulse is of the proper length.

The timer may be a separate unit by it self or it maybe included is the transmitter or receiver.

5.4.2 Modulator

The modulator is usually a source of power for the transmitter it is controlled by the pulse from the timer; it sometimes is called the keyer.

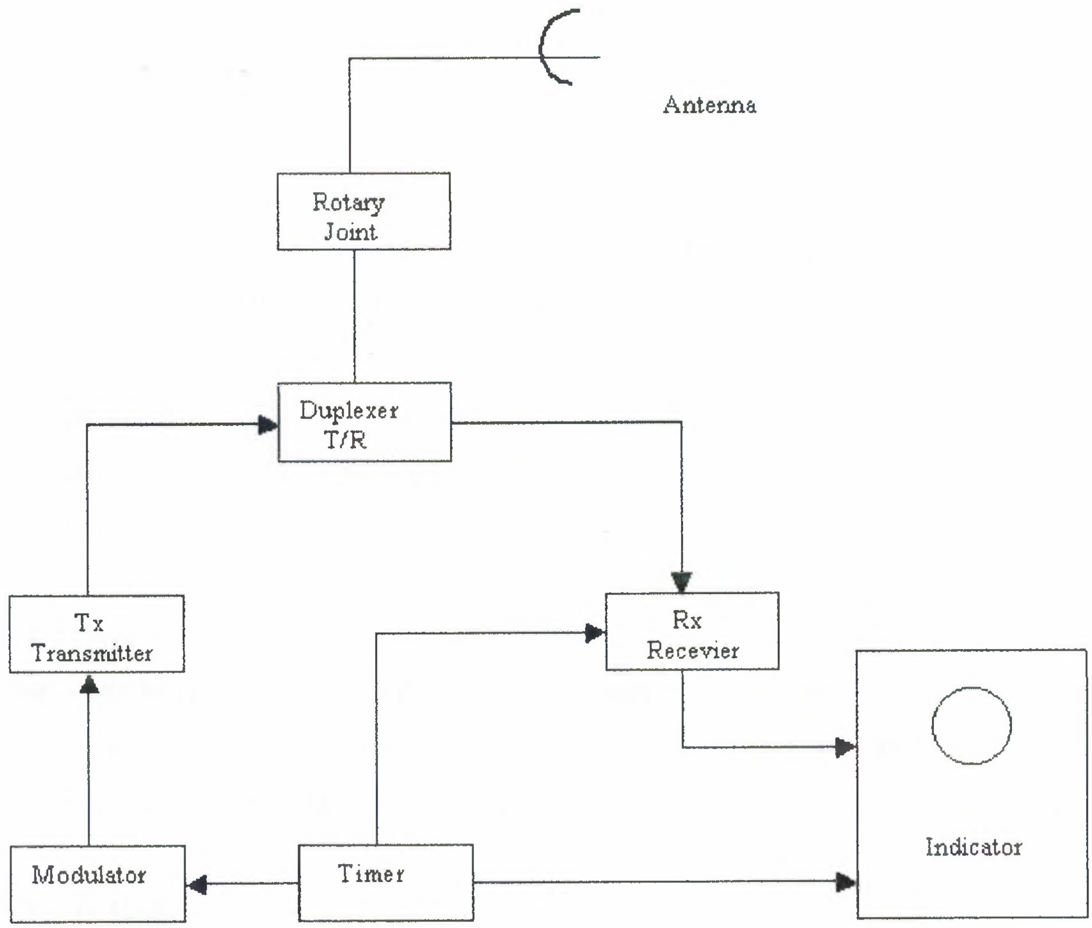


Figure 5.4 Basic elements of pulse systems radar in Ercan Airport

5.4.3 Transmitter

The transmitter provider RF energy at an extremely high power for a very short time. The frequency must to get many cycles in to the short pulse.

5.4.4 Antenna

The antenna is very directional in nature because it must obtain the angles of elevation and bearing of the target to obtain this directivity at centimeter wave lengths ordinary dipole antennas are used in conjunction with parabolic reflectors .usually ,in order to same space and weight the same antenna is used for both transmitting and receiving . when this system is used , some kind of switching device is required for connecting it to the transmitter when a pulse is being radiated ,and to the receiver during the interval between pulse. since the antenna only (sees) in one direction ,it is usually rotated or moved a bout to cover the area around the radar set this is called searching .The presence of targets in the area is established by this searching.

5.4.5 Duplexer

Such a device realized the antenna switching from transmitting phase to receiving phase enabling the path Transmitter – antenna and inhibiting the path Antenna-receiver during radiation; vice versa during reception.

5.4.6 Rotary joint

This device allows the transforming of the RF energy between the fixed part and the turntable one of the RF system.

5.4.7 Receiver

The receiver in radar equipment is primarily a super –hetero dyne receiver .It is usually quite sensitive. When pulsed operation is employed .it must be capable of accepting signals in a bandwidth of one to ten mega cycles.

5.4.8 Indicator

The indicator presents visually all the necessary information to locate the target on the indicator screen. The method of presenting the data depends on the purpose of the radar set.

Since the spot (scans) the indicator screen to present the data, the method of presentation is often reflexes to as the type of scan ,In the following sub paragraphs a brief description on the most common types of scan used will be supplied.

5.5 Important Aviation Systems has Related with Airport Surveillance Radar in Ercan Airport

There are also important aviation systems have related with radar, to make the Air traffic control easier, in this section we are going to present theses systems which used in Eracn Airport .

5.5.1 Navigational Aids Systems in Ercan Airport

The purpose of navigation systems is to ensure the safe, efficient transit of aircraft following established procedures.

The elements which support the basic function of determining the position of aircraft are ground-based navaids, which support en route and approach navigation, and landing at airports.

The surveillance function, needed to provide Air Transit Services, is based on primary and secondary surveillance radar sensors to perform en route and approach air traffic control.

Navigational aids systems in Ercan Airport consist of VOR , NDB and DME .

5.5.1.1 VOR

VOR is (Very High Frequency (VHF) Omni-directional Radio Range), each VOR equipment has a name of three characters and identification in morse code .the VOR station have different frequencies, if two VOR station will use the same frequency they should have 500 miles difference.

What is the job of VOR equipment?

It has a global radio lines transmission, there are 360 radials 0 degree is adjusted to magnetic north.

The frequency of VOR equipment is between 108 MHz – 117.95 MHz, VOR equipment consists of solid state plug in modules, 220 VAC is converted to 40 vdc, 12 vdc and 24 vdc by transformer.

There are mainly six parts in VOR equipment

1 – power supply

2 – transmitter

3 – modulator

4 – electronic goniometer

5 – antenna

6 – monitor

The VOR Frequencies in Ercan Airport (ECN) is 117.00 MHz ,and in Geçitkale Airport (GKE) is 114.3 MHz.

5.5.1.2 NDB

NDB is Non Directional Beacon, it is a radio transmitter NDB frequency range is between (200 – 800 kHz), the frequency of Ercan Airport is 290 kHz. It can be identified by a Morse code signal that it emits at frequent intervals, it offers no tracking guidance and most aircrafts are fitted with an Automatic Direction Finder (ADF) to identify the direction of the beacon from the aircraft.

NDB's are usually used in the vicinity of airports as an aid to locating the airport itself.

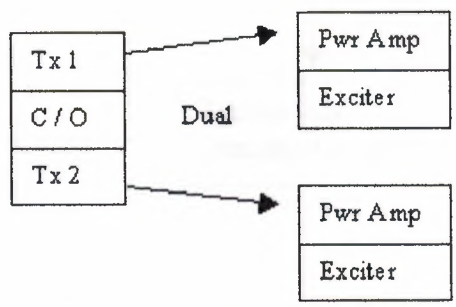


Figure 5.5 The NDB system

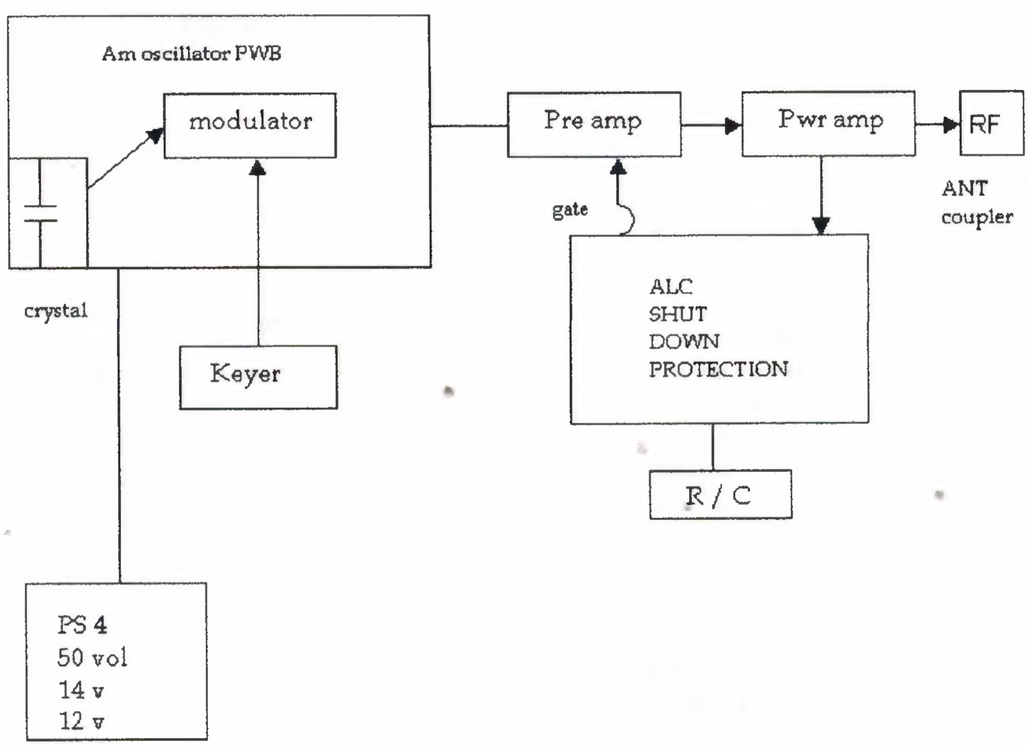


Figure 5.6 Block diagram of NDB in Ercan Airport

5.5.1.3 DME

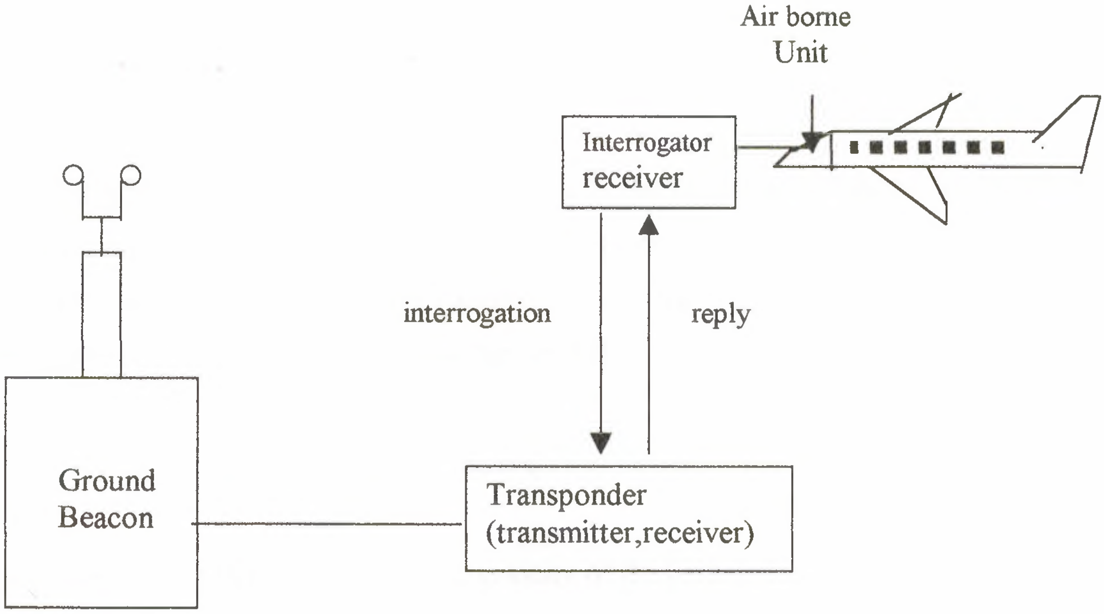


Figure 5.7 The DME system in Ercan Airport

DME is Distance Measuring Equipment, DME is a full-duplex VHF system, full duplex means transmission and reception can be realized at the same time, in DME the frequency is different for every airport, for usage purpose there are two types of DME

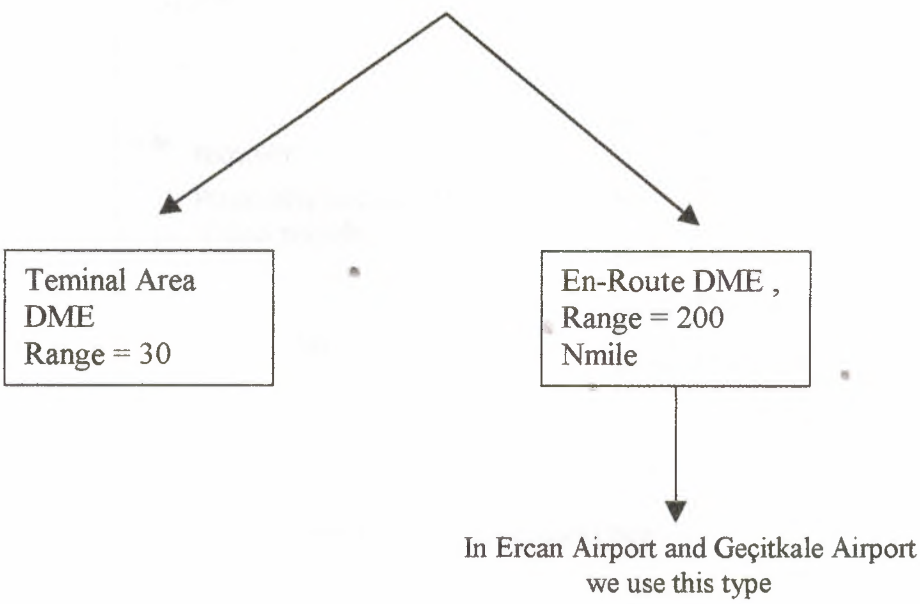


Figure 5.8 Types of DME

Face standard FSD-15 is used in Ercan Airport and the Airsys Navigation FSD-45 is used in Getçitkale Airport,

The working principle of DME:

The interrogator / receiver in airborne unit sends the interrogation signal to the DME ground beacon, then the ground beacon sends a reply signal to the air borne unite, the air borne unit then calculates the distance using the time difference between the interrogation and reply signals by using the formula,

$$M = t.\, c \tag{5.2}$$

M is the distance, t the time and c is the velocity of the light

Parts of DME ground beacon,

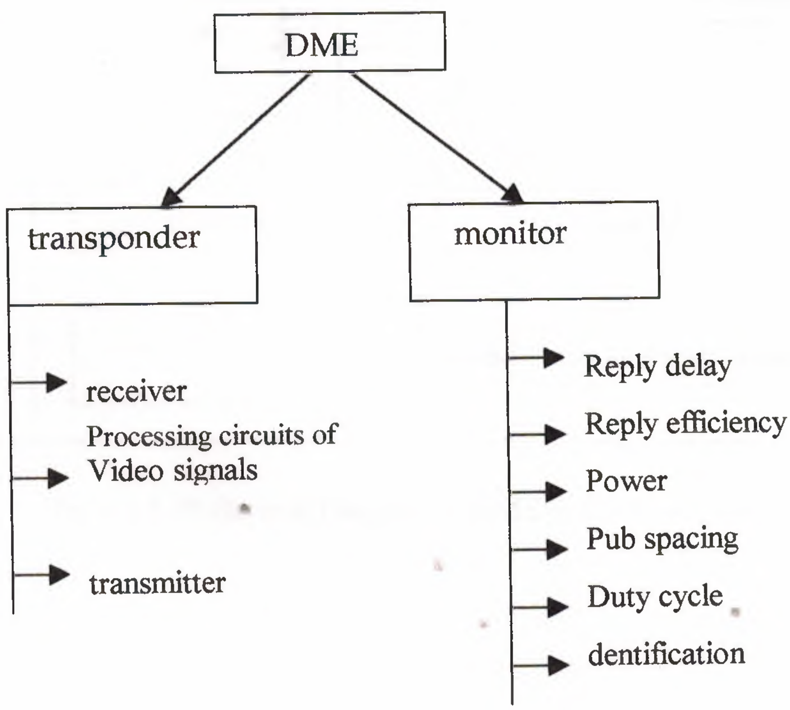


Figure 5.9 Parts of DME ground beacon

The monitor system continuously checks if the pulses and all the transmission properties are correct.

The frequency of Ercan DME is as below,

Airport	Channel	Interrogation frequency	Reply Frequency	Pulse Code	VHF Channel
GKE	90x	1114 MHz	1177 MHz	12 us	114.3 MHz
GKE	90y	1114 MHz	1051 MHz	30 us	114.3 MHz
ECN	117x	1141 MHz	1024 MHz	12 us	117.0 MHz
ECN	117y	1141 MHz	1078 MHz	30 us	117.0 MHz

See figure 5.7 the general diagram of DME

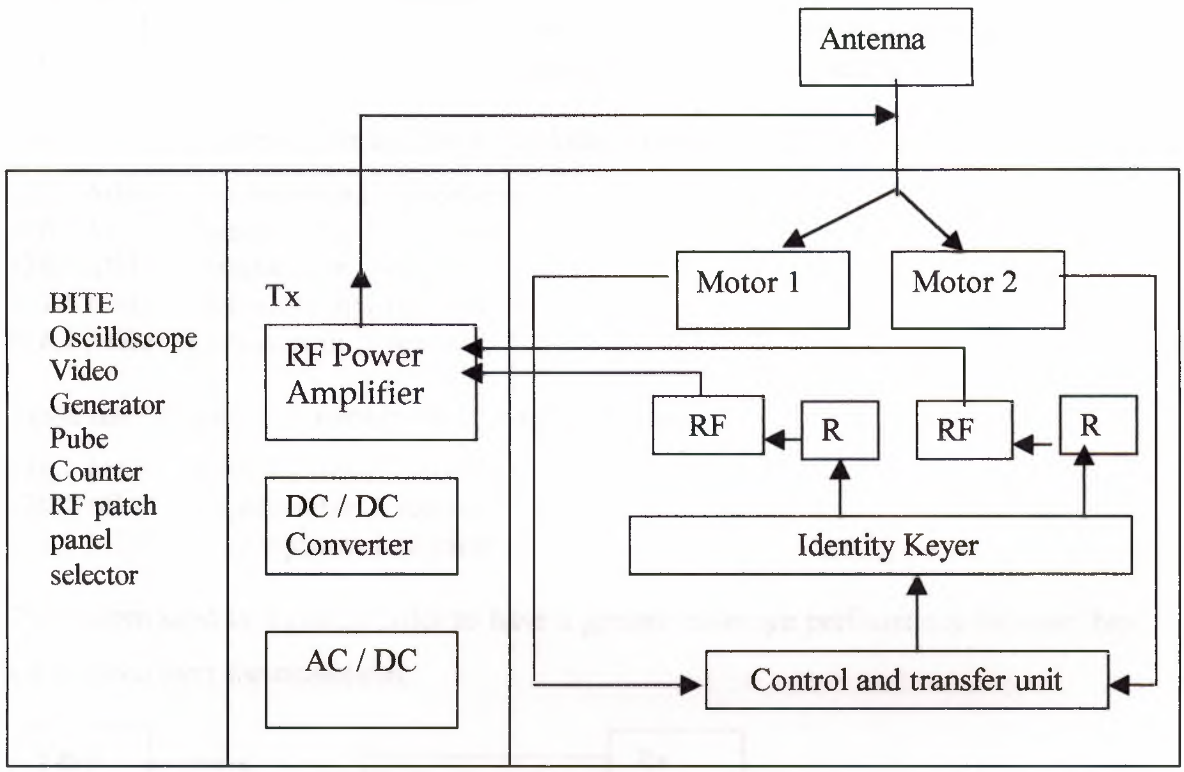


Figure 5.10 General Diagram of DME in Ercan Airport

5.5.2 VHF Voice Communication System in Ercan Airport

VHF frequency in general 30 – 300 MHz in air navigation. 118 MHz – 136 MHz separated for air navigation.

In Ercan Airport, frequencies used (assigned for Ercan), I C A O assigns these frequencies.

Frequency	Function
120. 2 MHz	Tower frequency
126. 7 MHz	Air traffic control frequency
126. 9 MHz	Approach frequency
121. 5 MHz	Emergency frequency, it is same in all the airports of the world
118. 1 MHz	Spare tower frequency (Gecitkale tower frequency)

Local system situated in Ercan Airport for local frequency as,

120.2 MHz	2 transmitters, 2 receivers
126.7 MHz	1 transmitter, 1 receiver
126.9 MHz	1 transmitter, 1 receiver
121.5 MHz	1 transmitter, 1 receiver
118.1 MHz	1 transmitter, 1 receiver

Yayla station system situated in yayla over mountains,

126.7 MHz	2 transmitters, 2 receivers
126.9 MHz	1 transmitter, 1 receiver
121.5 MHz	1 transmitter, 1 receiver

The system used in Yayla in order to have a greater coverage performance because they are situated over the mountains.

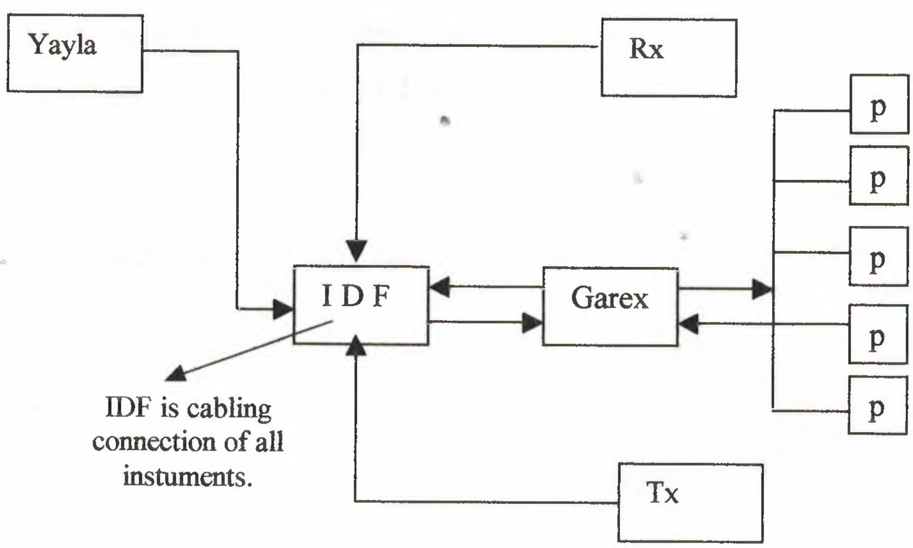


Figure 5.11 Voice communication in Ercan Airport

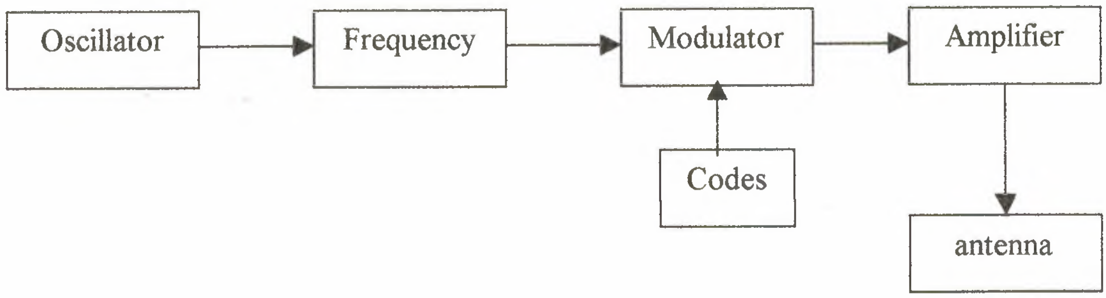


Figure 5.12 Simple block diagram of transmitter in voice communication

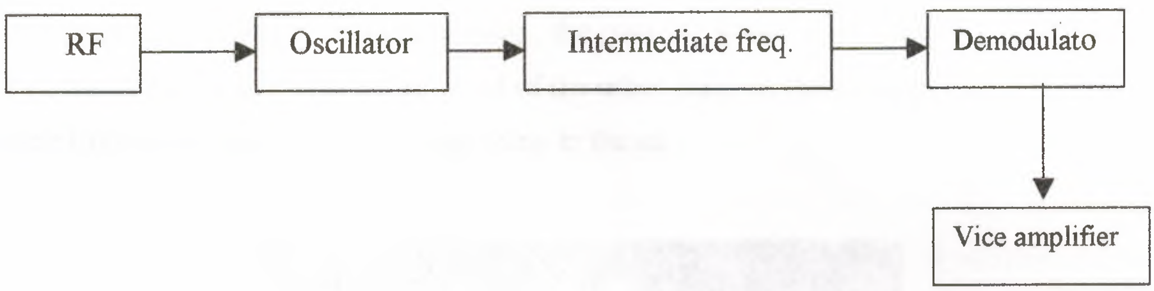


Figure 5.13 Simple block diagram of receiver in voice communication

5.5.2.1 Garex 210

The main controlling and switching instrument for voice communication system.

All the receivers , transmitter ,position intercom telephone lines are all connected and controlled by garex system (Brain of voice communication system), it consist of two functional units , and many position cards and telephone cards and radio cards (7 position cards, 10 telephone cards and 10 radio card) x 2., there is also a diagnostic card which mails the diagnostic of all the system and gives their information to the computer.

5.6 Summary

We can now understand the important of radar systems which include the SSR which inform the ATC room in Ercan about all the civil plans around Cyprus, as we mention that there are transponder in the plan resend the signal and inform Ercan the altitude and the identity of the plan, look at the figure 5.1 .then we know the navigation systems which consist of three main parts DME,VOR and NDB these systems make insurance for the plan ,so the pilot can know the altitude of the plan and its location . here come the VHF voice communication systems , which is very important also , the pilot can contact with the ATC room by this system by the frequencies assigned for Ercan by ICAO , so here the employee in Ercan can tell the pilot what is his altitude as what is written in the radar monitor in the ATC room , the pilot of course will look at the transponder of DME to make insurance , the plan can know what is going on the space by contact Ercan and what is the speed of the other plans so the employee of ATC room here has big responsible to what happening in the air .

Figure 5.14 The new ATC room in Istanbul, and its similar to ATC room in Ercan

CHAPTER 6

THE FUTURE OF RADAR

6.1 Where is Radar Going?

Has radar been developed as far as it is going to go, or does it have a bright future with many further applications and capabilities to be discovered? As with any branch of science or engineering, the way to answer this type of question is to consider whether the system is limited by physical laws, by cost or by technology.

The laws of physics applying to radar are well understood, but do not yet limit our systems. We cannot escape the range resolution being limited by the effective bandwidth of the system, for example, but we can apply processing power to such techniques as super-resolution to extend the effective bandwidth.

Cost is a serious limitation to what can be achieved; there are many cases where phased array radars are desirable but mechanical turning gear is used instead because it is less expensive. However, the influence of large military research programmes has continued radar development, and the failing cost of components, especially computing power, continues to help progress.

Technology is therefore the limiting factor. Faster A/D converters, gallium arsenide transmit and receive modules, better simulation software, more advanced mathematics for data processing algorithms-these are the tools needed to build better radars in the future. As we show below, the overriding need is to increase the bandwidth of radar systems. The other benefits will then follow as a matter of course.

6.2 Developing the Concept of Bandwidth

There are three principal performance requirements for a radar sensor:

sensitivity, resolution and data rate. The fate of radar will be determined by how well these requirements can be fulfilled.

In future, radars will be required to be more sensitive so that smaller targets can be detected in more hostile environments. Microlight aircraft may need tracking near civil airlanes and military radars will be required to detect increasingly Stealthy targets. Meanwhile, the radio environment deteriorates as radio interference and the sophistication of jammers continue to increase.

The sensitivity of radar can be thought of in the following way. If a solid angle of sky Ω is required to be searched in time T, then

$$\frac{T}{t} = \text{time to search the whole sector / dwell time in each beam position}$$

$$= \frac{\Omega}{\Delta\theta\Delta\phi} = \quad \text{whole sector / beamwidth} \tag{6.1}$$

Where t = the dwell time in each position [s]. Rearranging Eq.(6.1) gives

$$t = \frac{(T\Delta\theta\Delta\phi)}{\Omega} \qquad [\mathrm{s}] \tag{6.2}$$

The final radar bandwidth after processing is 1/ t and the noise power in the receiver is therefore

$$N = KT_0F\left(\frac{1}{t}\right) = \frac{FKT_0\Omega}{T\Delta\theta\Delta\phi} \qquad [\mathrm{w}] \tag{6.3}$$

Putting Eq.(6.3) into the radar equation, and replacing G_l by $4\pi / (\Delta\theta\ \Delta\Phi)$ and G_r by $4\pi A_e / \lambda^2$ gives

$$SNR = \frac{P_t A_e \sigma TL}{4\pi R^4 \Omega FKT_0} \tag{6.4}$$

Which is the formula developed by Radford1. Note that the expression is frequency-independent, although some terms, such as the RCS, will vary with frequency. The importance of expressing the radar equation as in Eq(6.4) is that only the power x aperture product P_tA_e is under the control of the radar designer, the others being set by the requirement or the environment.

Survivability and cost mitigate against larger power x aperture products, so where is the improved performance to be found? The answer lies in improved resolution and data rate, and both of these require an increase in the fundamental limiting factor of radar performance, the bandwidth.

Bandwidth can be thought of in terms of the rate of searching radar resolution cells. The total number of beam positions n1 to be searched is

$$n_1 = \frac{\Omega}{\Delta\theta\Delta\phi} \tag{6.5}$$

The number of range bins n_2 is given by

$$n_2 = \frac{\text{interval between pulses}}{\text{pulse duration}} = \frac{1/PRF}{\tau}$$

$$= \frac{1}{(PRF)\tau} \tag{6.6}$$

and the maximum number of doppler filter channels n_3 is set of pulses in the dwell time as

$$n_3 = (\mathrm{PRF})\ \tau \tag{6.7}$$

Combining Eqs (6.5) and (6.7) with Eq. (6.2) gives the total number of resolution cells n to be searched as

$$n = n_1 n_2 n_3 = \mathrm{T}/\ \tau \tag{6.8}$$

Remembering that I /r is the bandwidth B of the receiver, we can rearrange Eq.(6.8) as

$$\mathrm{n} / \mathrm{T} = \mathrm{B} \qquad [\mathrm{Hz}] \tag{6.9}$$

Thus the maximum number of resolution cells that can be searched every second is set by the bandwidth of the system.

The simplest way to increase the bandwidth of a radar system is to use multiple antenna beams and receivers; the effective bandwidth B_{eff} is then

$$B_{eff} = \mathrm{m\,B} \qquad [\mathrm{Hz}] \tag{6.10}$$

where m = number of simultaneous beams and receivers.

Worked example The Marconi Radar System Martello S723 is a long-range L-band surveillance radar using a single transmit beam, but eight receive beams stacked in elevation. If the pulse length (after compression) is 0.25 jis, and the antenna rotation rate is 10 RPM, how many resolution cells could be searched?

SOLUTION If the bandwidth of a single channel is 4 MHz, the effective bandwidth of the system is 32 MHz; if this represents the number of cells inspected every second, and one antenna revolution takes 6 5, the total number of cells to be searched is about 2 x 108.

COMMENT Although 2 x 108 seems a very large number of cells to be inspected, it looks more realistic if you work out the values of n1, n2 and n3 separately. This large number of resolution cells reinforces the point made in Chapter 2 that front-end radar data rates are high.

Increasing the bandwidth of a radar brings several benefits:

- Increasing the receiver bandwidth decreases the range resolution cell size and cuts down the clutter.
- The use of more simultaneous beams implies that longer integration times can be used in each beam position. This increases the radar sensitivity.
- Longer integration times mean that the doppler resolution and clutter rejection can be improved.
- The data processing rate for each target can be increased.

In this way, all our requirements can be met without increasing the power x aperture product and exposing the radar to an increased risk of ECM attack. Generally speaking, the analogue parts of a radar system are not the factor limiting the bandwidth, but the computational power available. This situation is changing with the arrival of parallel processing, very large-scale integration (VLSI) signal processing integrated circuits and optical methods of solving integrated circuit interconnection problems. Soon, large amounts of low-cost computing power will be available, and we must decide how to make best use of it in the design of the next generation of radars. One of our main aims must be to make radars more adaptable to the tasks they have to carry out.

6.3 The Future of Air Traffic Control (ATC)

The future for air traffic control lies in the stars. Satellite-based systems provide the key for ICAO's 'Future Air Navigation Systems' (FANS) concept for global CNS.
Satellite systems use special navigation satellites to establish the whereabouts of each aircraft. At present there are two primary constellations of satellites under development - GPS and GLONASS.

6.3.1 Global Positioning System (GPS)

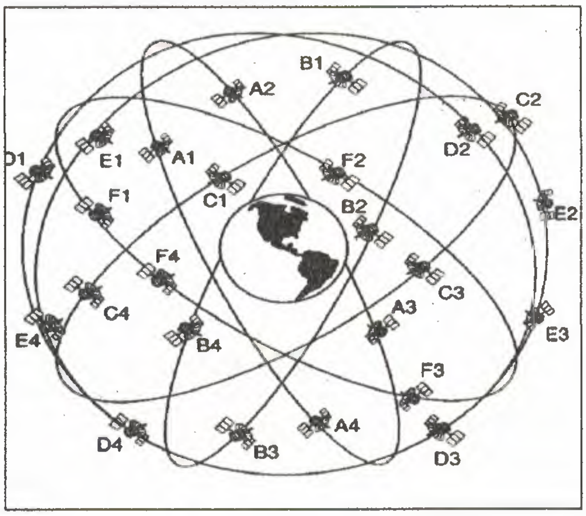


Figure 6.1 The GPS satellite constellation of 21 operational plus three standby satellites

The GPS or 'Global Positioning System' is a network of 24 satellites developed and put into orbit by the US Department of Defense (DoD). It was originally developed for military purposes and provides a highly accurate system of navigation, which was proven during the Gulf conflict in 1991. The entire constellation was due to come on line with an 'Initial Operational Capability' (IOC) in the summer/early autumn of 1993. The last of the 24 satellites was launched in May 1993, and completion of an upgrade of the entire network to new generation satellites is scheduled for complefion in 1995.

Twenty-one of the satellites are operational, with three standbys, and together the network will provide coverage over most of the earth's surface. The US government has promised that the world's civil aviation sector can have access to the satellites free of charge for at least the first 10 years of operation, ie until 2003. In the meantime, the US will retain overall control of the network and provide maintenance and development. Because of the network's military role, the US DoD has insisted that GPS signals are to be deliberately degraded, limiting the accuracy available to civil users to about lOOm. This is known as 'Selective Availability' or SA (see also Chapter 1], Accuracy).

The satellites themselves have an estimated life span of seven years each, but the earliest satellite has now been in orbit for almost 10 years and is still fully operational. Only one satellite has been lost since the launch programme began. The accuracy offered by the satellites is achieved through the incorporation of highly precise and reliable atomic clocks and it is a failure in this unit, more than any other, that is adversely affecting a similar satellite network currently under development in Russia.

6.3.2 Global Orbiting Navigation Satellite System (GLONASS)

The 'Global Orbiting Navigation Satellite System' is a complementary 24-satellite constellation developed initially by the communist regime of the former Soviet Union in response to the US system. Its future remains somewhat uncertain due to the continuing political instability in the region. It is uncertain, for example, whether there are sufficient resources to complete the development programme and sustain essential satellite replacements in the future.

It is understood that a major launch programme was planned for 1993 and Russia remains committed to having the GLONASS constellation completed and fully operational as scheduled by 1995.

At present, the life expectancy of the GLONASS satellites is little more than two years. In total, Russia and the Soviet Union before it have launched more than 60 satellites since launches began in 1982. But there have never been more than 15 or 16 satellites operational at any one time.

Russia has promised that its system will be available to the civil aviation sector free of charge for the first 10 to 15 years of operation. Unlike its US counterpart, the Russian military forces have not insisted that GLONASS signal accuracy be downgraded for civil use: Selective Availability will not be a feature of the GLONASS constellation.

There is no doubt that the redundancy offered by having 48 satellites instead of just the 24 GPS units would significantly improve the reliability and availability of the system and the GLONASS network is therefore a very desirable addition. Alr&ady, research and development work is under way to develop satellite transceivers for aircraft that would be able to work with both GPS and GLONASS satellites. However, integrating the two systems is likely to be an expensive project because they use different time references. Each GLONASS satellite has been allocated its own frequency for purposes of identification, whereas the GPS satellites all use the same frequency, but have been allocated separate identification codes.

6.4 Global Navigation Satellite Systems (GNSS)

Satellite navigation is an airborne tool which involves aircraft and up to four satellites. A transceiver on the aircraft interrogates a satellite and calculates its position by measuring the length of time it takes for the reply to reach the aircraft.

The 24 satellites in the GPS constellation have been put into orbit so that each covers a large region of the earth's surface and overlaps with its neighbouring satellites to provide redundant coverage. At any point in its journey, an aircraft should be able to 'see' at least three and preferably four satellites. By obtaining a position report from each of these, the aircraft's navigation system receives a highly accurate three-dimensional position report giving its precise position, flight level, speed and heading. This report is more accurate than any that could currently be obtained using land-based technology.

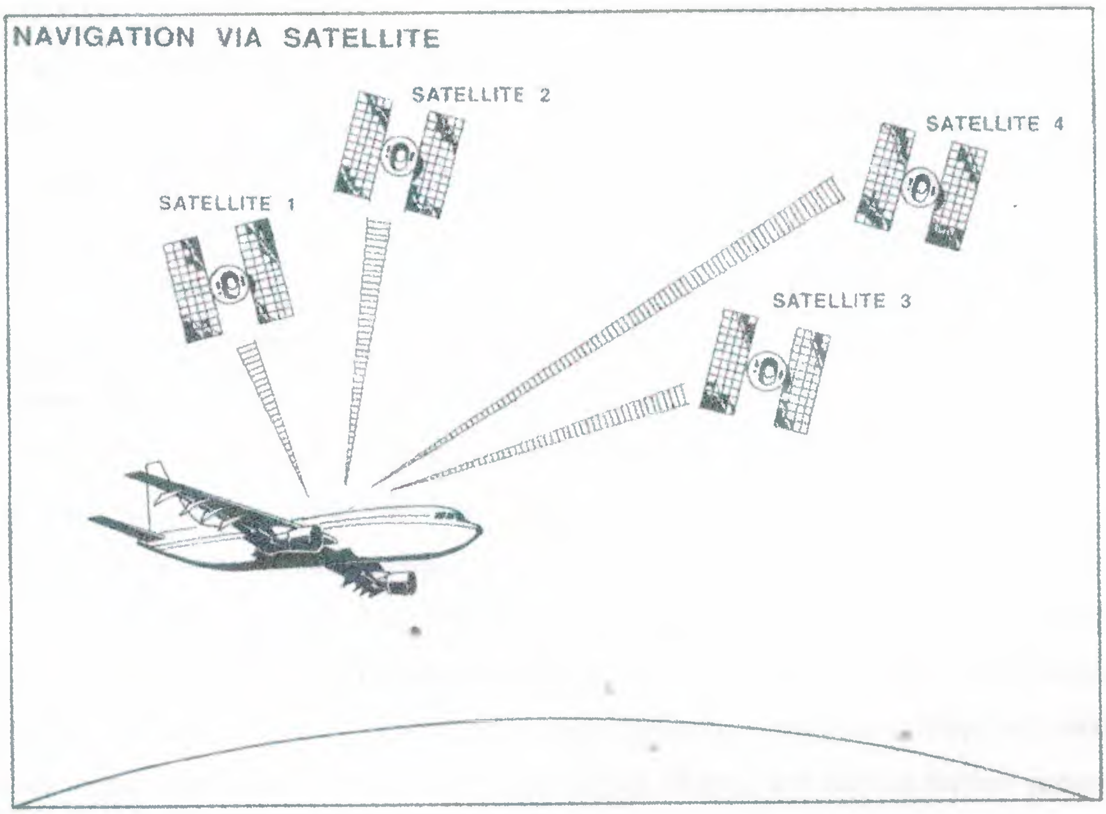


Figure6.2 To obtain the most accurate position fix, an aircraft using (GNSS) should ideally be able to integrate four satellites

At this point, the aircraft has made no communication with the ground; it has transmitted its
own satellite interrogations and received the information independently of any land-based equipment. In order for air traffic control to receive the position data and provide surveillance and control services, the data must be transmitted to earth and this is done either by VHF radio or satellite voice or data links. At present, VHF remains the common communications tool, with satellite links still in the trial stage. But it seems likely that in future an increasing amount of air-to-ground communication will be datalink via satellite.

An automated system of position reporting will be increasingly used worldwide, known as 'Automatic Dependent Surveillance' (ADS). With this system, the aircraft's computer automatically transmits position reports in the form of data in allocated time slots to land-based air traffic control computers. These reports constantly update the aircraft's position on the controller's synthetic picture.

Because the information he is receiving is much more accurate, the controller no longer has to allow margins of error for the data, and can therefore begin to reduce the separations between aircraft on his screen, particularly over oceans and deserts where visual surveillance has not previously been possible.congested routes, like the popular North Atlantic airways, satellite-based systems will generate a significant increase in airspace capacity.

As another safety factor, the pilot can also receive a synthetic picture of the airspace in which he is flying which will detail the whereabouts of other aircraft in his vicinity and alert him of any potential collisions. There is some concern that this will encourage pilots to make their own decisions about safety margins and take corrective action independent of the air traffic controller possibly jeopardising the controller's overall plan. The intention is very clearly that ground-based air traffic controllers will retain control, but it is hoped that an extra airborne pair of eyes will help to further improve safety.

As with secondary surve~lance radar, the one drawback of satellite systems is that they can only detect targets equipped with the appropriate interrogation/response equipment. A controller would be unaware of any aircraft flying within his airspace that were not GNSS transponder-equipped. It seems likely therefore that primary radar will continue to have a role to play.

6.4.1 Precision Approach Systems

Experts believe that satellite-based systems will ultimately be able to replace almost all the ground-based navigation and surveillance tools currently in use, including precision approach systems and this is where the debate hots up and focuses on the potential drawbacks of a system which relies on highly sophisticated pieces of equipment orbiting the earth, miles above its surface.

Precision Approach Systems are necessary when the weather is bad enough to reduce visibility to the point where the pilot may not actually be able to see the runway until late in his approach or possibly even not at all.

ILS (see Tools of ATC) has long been the industry-wide standard precision approach tool. But frequency congestion has forced the search for a replacement and MLS has been selected by ICAO as the most practical alternative. However, only a handful of air traffic control authorities - mainly in the US and Europe -are actively pursuing MLS implementation. For many authorities elsewhere, MLS is seen as a luxury they can ill afford. For many of them, airspace and frequency congestion is not a problem; they may have little need for Cat II/III precision approach aids and the cost of replacing perfectly serviceable equipment is high. As the debate over future precision approach aids continues, many air traffic service providers are pinning their hopes on global navigation satellite systems being able to provide a one-stop replacement for most ground-based navigational aids, including ILS.

6.4.2 GNSS

In theory, there is no reason why GNSS should not be used as a precision approach tool. Indeed, Swedish inventor Hakan Lans - better known perhaps for inventing colour computer graphics and the computer mouse - has been conducting trial precision approaches, using signals from GPS satellites and a transponder he developed himself, since 1988. But there are other schools of through that doubt ,GNSS precision approach capabilities on the grounds of accuracy, integrity, availability and reliability.

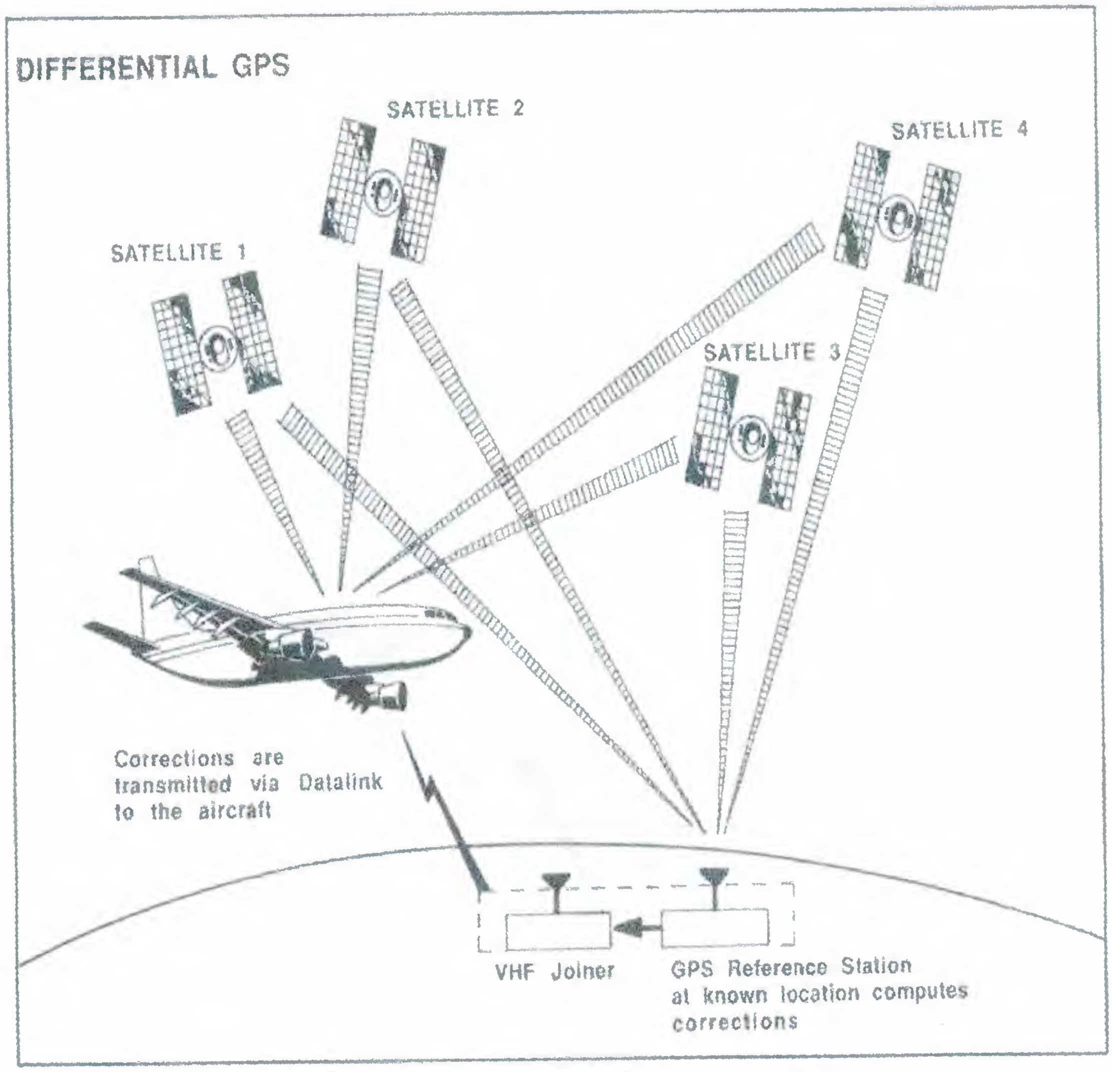


Figure 6.3 Differential GPS can be employed to overcome 'selective availabilit'y', a deliberate degradation of the accuracy available to civil users by the military operators of the US Global Positioning System (GPS). A computer on the ground, which knows its exact position, receives position fixes from aircraft and compares them with readings it is getting from the satellites. Because it knows its own position, it can calculate the amount of error being incorporated by the satellites, calculate the correction and transmit the corrected accurate position data back to the aircraft.

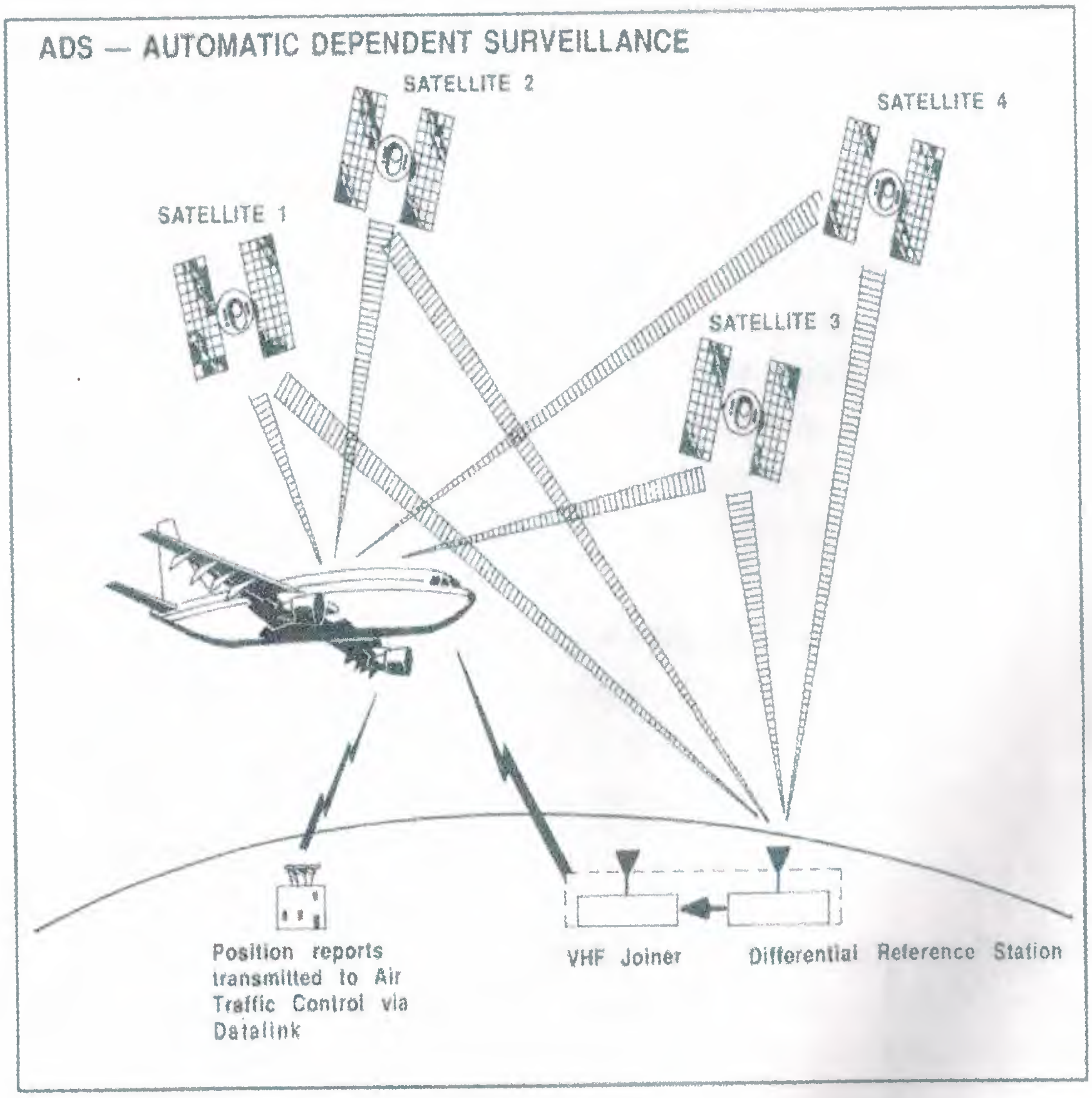


Figure 6.4 For navigation purposes, aircraft talk to satellites without requiring any ground-based communications link. The entire navigational process is entirely airborne and therefore 'independent'. In order to let the air traffic controllers know where they are, aircraft transmit regular and automatic position reports via datalink to provide the ground surveillance link -known as automatic dependent surveillance or ADS.

CONCLUSION

Most of the airports are using the secondary surveillance radar (SSR) to detect the plans and for the air traffic control (ATC), secondary surveillance radar provides, after processing of data transmitted by the aircraft, the range, bearing, altitude and identity (call sign) of an aircraft. The coverage can reach 250 nautical miles. A SSR can provide more useful information than Primary Surveillance Radar (PSR) but is subject to the proper functioning of the aircraft's transponder. To provide the best radar picture with a continuous display of aircraft targets, the SSR is usually paired with a PSR for air traffic control operation.

The future of radar does not lie in larger and more powerful systems, but rather in slightly smaller systems that are more agile, intelligent and difficult to detect because of the larger bandwidths that will be used. The resolution of radars, and the number of targets that can be tracked, can be expected to increase as large amounts of low-cost computer power become available.

We hope that this project has conveyed the main ideas and helped you to understand the underlying principles of the airport surveillance radar. We hope also that you have gained an appreciation of the importance of radar in many diverse areas, and sensed some of the excitement of working in this field.

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