NEAR EAST UNIVERSITY

FACULTY OF ENGINEERING

ELECTRICAL AND ELOECTRONIC ENGINEERING

GENRAL RADAR AND ITS MILITARY USE

GRADUATION PROJECT
EE-400

Student Name: Fahed H.A. ABOUMOUSA

Supervisor : Assoc. Prof. Dr. Sameer IKHDAIR

NICOSIA 2004

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Finally thanks for my university Near East University for every thing.

ABSTRACT

Radar research and development investments are increasingly being directed into dual-use and purely commercial application areas, in addition to the traditional defense-oriented programs. Leveraging the investment of formerly purely military radar applications into civil and commercial applications is increasingly important. One purpose of this conference is to foster the cross-fertilization of developmental successes across the boundaries among military, industrial, and academic researchers. Another is to provide a forum for researchers and system designers to provide visibility for their developments, experimental, and theoretical results that might be of broader interest to the general application developers.

Papers are solicited in the following topical areas related to radar:

Radar Imagery Applications

- synthetic aperture radar
- inverse synthetic aperture radar
- interferometric synthetic aperture radar
- real beam radar imaging
- ground penetration radar

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INTRODUCTION

RADAR is an acronym made from RAdio Detection And Ranging. The name to this electronic system was given during World War II. Its basic principle comprises emitted radio waves which bounce off a target in order to detect its presence and allow locating its position. Like many modern technical achievements military use was the initial spark to radar. The development of the earliest practical radar system is credited to Sir Robert Alexander Watson-Watt, although a large number of scientists contributed numerous technical details. Technical Principle A radio transmitter generates radio waves, which are then radiated from an antenna. A target in this area scatters a small portion of this radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed on a cathode-ray tube (CRT), where it can be studied by a radar operator. By this the presence of a target has been detected, but to determine its position the target's distance (range) and bearing must be measured. Because radio waves travel at a known constant velocity - the speed of light, which is 300,000 km/sec - the range may be found by measuring the time taken for a radio wave to travel from transmitter to target and back to the receiver. It is an old technology that was developed in 1935 by Sir Robert A Watson-Watt (the inventor of stereo). The underlying principal is very simple: objects distances (range) and velocities can be determined from analyzing the echoes that objects reflects. Put simply, electromagnetic waves can be transmitted at an object. The transmitted wave would then be reflected back off the object to the transmitter (or now receiver). The received signal can be analyzed to determine the distance and velocity of the object that reflected the wave. Modern radar transmits radio waves to create these echoes. This is because most objects reflect radio waves as much as they do light, since both are forms of electromagnetic radiation at different frequencies. By detecting reflected radio waves it is now possible to see objects not only in daytime, but at night, through fog, haze, clouds, the following pages contain a detailed description on radar works, considerations when developing a radar system, different types of radar, a Matlab radar toolkit, and additional information.

Aim of a project: is to describe general idea about radar, how it works, theory, application and military radar.

This project contain of four chapter, chapter one about general radar, important of radar, Parts of radar, chapter two about radar theory and equation used, chapter three about application of radar finally chapter four about military radar.

1. INTRODUCTION TO RADAR

1.1 General Radar

Radar is an acronym made from RAdio Detection And Ranging. The name to this electronic system was given during World War II. Its basic principle comprises emitted radio waves which bounce off a target in order to detect its presence and allow locating its position. Like many modern technical achievements military use was the initial spark to radar. The development of the earliest practical radar system is credited to Sir Robert Alexander Watson-Watt, although a large number of scientists contributed numerous technical details. Technical Principle A radio transmitter generates radio waves, which are then radiated from an antenna. A target in this area scatters a small portion of this radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed on a cathode-ray tube (CRT), where it can be studied by a radar operator. By this the presence of a target has been detected, but to determine its position the target's distance (range) and bearing must be measured. Because radio waves travel at a known constant velocity - the speed of light, which is 300,000 km/sec - the range may be found by measuring the time taken for a radio wave to travel from transmitter to target and back to the receiver. For example, if the range were 300 kilometers, the time for the round trip would be (2 X 300 km) 600 km : 300,000 km/sec = two-thousandths of a second, or 2,000 microseconds.

Radar remote sensing, like optical remote sensing, is used to produce an image of the Earth's surface. A radar image is a record of the interaction of energy and objects at the Earth's surface, and its appearance is dependent on such variables as geometric shape, surface roughness and moisture content of the target object, as well as the sensor-target geometry and the transmission direction (look direction) of the radar sensor. There are significant differences, however, between how a radar image is formed and what is represented in that image compared to optical remote sensing imagery. To interpret radar imagery, it is necessary to understand the radar configuration, the energy associated with radar remote sensing, the way in which that energy interacts with objects at the Earth's surface, and the manner in which this interaction is represented as an image. Radar remote sensing utilizes a sensor carried on a platform (aircraft or satellite) which travels along a path transmitting microwave

Pulses towards the Earth's surface (Figure 1-1). Some of this transmitted microwave energy is reflected from the Earth back towards the sensor where it is received as a signal. The signal data is stored on magnetic tape (for airborne platforms), or it may be electronically sent to Earth or stored on an onboard recorder and later sent to Earth (for satellite platforms). The signal data requires computer processing in order to be converted into a conventional image, but once processed the image can be viewed interactively on-screen, plotted or stored as a digital image file.

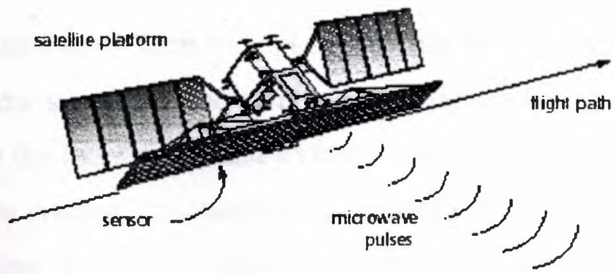

Figure 1.1. Radar remote sensing platform.

Because radar provides its own source of transmitted energy, it is known as an active remote sensing system, and it can acquire imagery day or night because it does not rely upon the sun's energy to illuminate the Earth's surface. In addition, radar's transmitted energy can penetrate through clouds, haze and smoke, although depending on the radio frequency used by the radar, the transmitted energy can be attenuated by rain. Radar is an acronym for Radio Detection and Ranging. A radar system performs three primary operations (Figure 1-2):

- It transmits microwave pulses towards a target.
- It receives a returned portion of the transmitted signal (backscatter) after it has interacted with the target.
- It observes the strength (detection) and the time delay (ranging) of the returned signals.

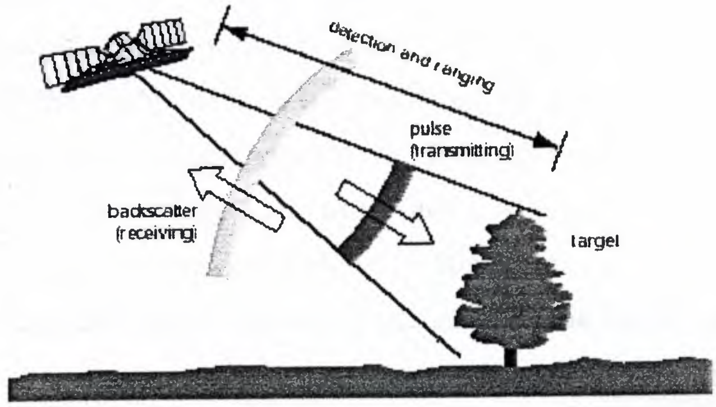

Figure 1.2 Primary operations of a radar system

The returned signal (backscatter) from ground objects (targets) is primarily influenced by the characteristics of the radar signal, the geometry of the radar relative to the Earth's surface, the local geometry between the radar signal and its target, and the characteristics of the target. A radar sensor operates by transmitting microwaves towards the Earth's surface in a direction perpendicular to the flight path of the platform. This perpendicular direction is termed the range direction. The sensor is capable of determining the relative distances of targets in the range direction from the time it takes for the signal to travel from the sensor to the target and return to the sensor; a signal reflected from a target located close to the sensor will take less time to return to the sensor than from one located farther from the sensor. As the radar platform continues in its flight path, the sensor transmits microwave pulses repetitively in the range direction. In doing so, signal data is progressively collected in the flight (or azimuth) direction, in effect resulting in a swath of signal data which is subsequently processed into imagery.

A radar image is a display of grey tones which are proportional to the amount of backscatter that is received from a target. Targets that produce a large amount of backscatter will appear as light grey tones on a radar image. Targets that produce little backscatter will appear as dark grey tones, and targets that reflect intermediate amounts of backscatter will appear as intermediate grey.

1.2 Important Of Radar

Radar (radio detecting and ranging) is often called the weapon that won World War II and the invention that changed the world. While these claims may be a little hyperbolic, there is no question that radar was a major development. It has certainly proven to be one of the most amazingly useful developments of the 20th century and is vital to aviation. It is also a clear example of a military technology that had important civilian uses.

To quote Scottish scientist Robert Watson-Watt, one of the early pioneers of radar technology, radar is "the art of detecting by means of radio echoes the presence of objects, determining their direction and ranges, recognizing their character and employing data thus obtained in the performance of military, naval, or other operations." Radar is used for navigation, targeting, weather tracking, and a host of other purposes. Radio, which was first developed in the late 1800s, allowed people to communicate over long distances without a physical connection such as a wire between the transmitter and the receiver. Radio worked by converting sound into electromagnetic energy that was then transmitted over a distance. When it was received, it could be converted back to sound waves. It did not take those who used radio long to realize that a lot of things could affect its performance. Weather conditions could reduce the transmission of radio waves, as could physical objects such as mountains between the transmitter and receiver. Exactly who gets credit for "inventing" radar is a topic of some disagreement in historical circles, for many people started working on the subject in many places at roughly the same time, and many of their developments influenced each other. In 1934, researchers at the Naval Research Laboratory (NRL) in Washington, D.C., began work on bouncing radio signals off of objects after noticing that ships traveling down the Potomac River interfered with radio signals being transmitted across the river. Robert Watson-Watt had also heard of reports from the government post office, which was responsible for shortwave radio communications, that airplanes flying near post office receivers caused problems with reception of signals. He wrote a lengthy memo on how this phenomenon might be used to detect airplanes. In 1936, the U.S. Army Signal Corps' laboratory for ground equipment at Fort Monmouth, New Jersey, also started a radar project. In 1934, Robert Page developed a pulse radar for the detection of aircraft. The first radar in extensive operational use was the British Home Chain radar (often referred to as the CH radar), which entered service in 1937. The CH and other early radars operated in the "high frequency," or HF portion of the electromagnetic spectrum. But early radar developers recognized that radars that could operate at frequencies higher than HF could perform better. In 1936-37, military radar researchers in the United States developed several devices such as the resonant cavity circuit, the klystron electron tube, and the coaxial and waveguide transmission lines and components that allowed the generation of signals in the microwave region of the electromagnetic spectrum. (Microwaves operate at a higher frequency than "high frequency.") This dramatically improved radar performance and was a major military development. The Americans secretly shared this information with their counterparts in the United Kingdom and this enabled the British to build better radars for detecting planes approaching the British Isles. Radar gave the British warning of approaching German planes during the Battle of Britain in 1940 and was instrumental in the outcome of the battle. Britain also developed airborne radar that helped pilots flying at night to detect aircraft in the darkness and bomber crews to locate targets at night.

The United States Army Air Forces soon established the Radiation Laboratory at the Massachusetts Institute of Technology, in Cambridge, Massachusetts. The "Rad Lab" as it became known, worked to develop numerous radar systems for various uses during the war. These included radar for aiming anti-aircraft guns, general search radars for detecting airplanes, ship borne radar, and airborne radars to be carried in airplanes and used for various purposes, from targeting other airplanes at night to "weather reconnaissance" to navigation. The Germans also made important advances in radar, particularly with the Warburg ground radar which entered service in 1940. They fielded numerous ground-based radars and also developed aerial and ship borne radars as well, although not nearly in as great numbers as the Americans or British. But as the war progressed, German radar research stagnated, which is one reason why some people claim that radar won the war for the Allies. After World War II, the Rad Lab closed and research on radar in the United States and Britain languished for several years. But although radar technology did not advance much in this period, its use certainly did. Many military Radars were transferred to civilian use where they were used for Air Traffic Control (ATC) and Ground Controlled Approach (GCA) to airports. Not until the Korean War did the U.S. Air Force recognize the need for more radar research. It created the Lincoln Laboratory near Boston to research the development of a continental air defense system for protecting the United States from bomber attack. Eventually, this led to the SAGE air defense system developed in the mid-1950s, as well as the Distant Early Warning Line ("DEW-Line") of radars located along the northern boundary of Canada and Alaska. For years after World War II, the Soviet Union used U.S.-built radars it had received during the War. But Soviet engineers began to modify the radars and improve their range and performance. When the first American U-2 reconnaissance aircraft flew over the Soviet Union in the summer of 1956, the Americans expected that the Soviets would not be able to detect the aircraft using the old U.S. radars. But they were surprised when the Soviets tracked the plane for almost its entire flight. This prompted the Americans to seek ways to reduce the radar signature of the U-2. During the 1950s, the quest was for higher and higher frequencies. Most radars used a rotating dish antenna for transmitting and receiving the signals. But by the 1950s and 1960s, researchers were exploring the possibilities of "phased-array" radars that had flat panel antennas. In these systems, the radar beam is pencil-thin and "steered" electronically. This eliminates the wasted time when a radar beam is sweeping across empty space. The most well known of these kinds of radar was the SPY-1 radar used as part of the U.S. Navy's Aegis weapons system on cruisers and destroyers starting in the 1980s. During the 1950s and 1960s, smaller and more robust radars were developed for use in the nosecones of missiles such as the Falcon and Sparrow, allowing them to home in on the reflected energy, or "radar return," from an enemy aircraft. Flat panel antennas were also developed for airborne use. By the 1970s, U.S. military aviation experts became concerned with "low observable" or "stealth" technology that would enable aircraft to evade radar. By designing aircraft with specific shapes and coating them in special materials, they dramatically reduced the amount of electromagnetic energy that the aircraft reflected back to the source. But these techniques do not work equally well against all frequencies, and some low-frequency radars can detect stealth aircraft, although they cannot pinpoint their location. Improvements in electronics, particularly during the 1970s and 1980s, allowed radar systems to become smaller, lighter and more capable, and able to achieve even higher frequencies. But a major improvement in radar capabilities concerned the development of software for better processing of radar signals. One development was "Synthetic Aperture Radar" (SAR), which was first explored in the 1970s and later applied to many different types of radar. SAR electronically stores the radar returns over a period of time as the radar (mounted on an airplane or spacecraft) moves. It then combines them into a detailed image of the ground with picture-like quality. SAR has been used to map the earth from the Space Shuttle, to provide reconnaissance imagery, and to target precision weapons from aircraft such as the Boeing F-15E Strike Eagle. The military has always pushed the boundaries of radar technology, while civilian needs for Air Traffic Control were far less demanding. However, by the 21st century, other technologies were beginning to supplement and in some ways replace radar. In particular, the Global Positioning System (GPS) and satellite communications links allow ground controllers to track aircraft without using radar at all. But radar is such an amazingly useful technology that it will always be used in aviation.

1.3 History of Radar

The roots of radar can be traced back to the year 1886 when Heinrich Hertz, a German, verified Maxwell's electromagnetic theory by showing that shortwave radiation (60 centimeters in length) could be reflected from metallic and dielectric bodies. Nearly two decades later a fellow German, Christian Huelsmeyer, attempted to develop a proximity warning system for ships, so that these maintained knowledge of each other's location during bad weather and night. Still later the the technology generated by these experiments was found to be applicable to weather forecasting by Britain's Sir Robert Alexander Watson-Watt. He discovered that the electro-magnetic acitivity in storms could be detected by basically the same equipment. Heinrich Hertz conceived the idea of a directional loop antenna to take advantage of the phenomenon, and thus permit the relatively precise location of bad weather and its general direction of movement.

Pulse powers of 500 kW in the S band (10 cm) and 150 kW in the X band (3 cm) were quickly made available, and compact radars having beam widths of 1 deg or less were soon deployed for early-warning purposes, for use in aircraft against other aircraft (AI = aircraft interception), or for aircraft patrolling over the sea to detect enemy warships and surfaced submarines (ASV = aircraft to surface vessel). Radar in the S and X bands was also used as an aid in blind bombing missions to delineate the ground beneath the aircraft, functioning as a navigational aid as well as a target identifier. Microwave radars were also important to the anti-aircraft artillery units of the army, providing target detection and automatic firing of the guns. Similarly, radar became an indispensable aid to naval operations. The imaging radar used today had its civilian beginnings in the 1960s, as a tool used for terrain analysis and natural resource surveys. The period from the 1970s to the early 1990s saw the development of experimental synthetic aperture radar (SAR) systems for civilian purposes using aircraft platforms (Canada Centre for Remote Sensing Caviar 580, NASA Jet Propulsion Laboratory AirSAR) and satellite platforms (SEASAT, SIR-A, SIR-B, SIR-C, ERS-1, ERS-2, ALMAZ, JERS-1, RADARSAT). The first airborne radar remote sensing systems used an antenna which was attached to the aircraft and pointed to one side. These systems were called side-looking airborne radars (SLAR). The beam width of the radar signal is inversely proportional to the length of the antenna. This means that in order to obtain the high resolution associated with a small beam width, a long antenna would be required. To ensure constant resolution in the azimuth direction at all ranges of the swath, the SAR system synthesizes effective antennae whose length is proportional to that required to maintain a given (azimuth) resolution at each range interval of the swath, The resulting SAR image therefore has a constant azimuth resolution at all ranges within the swath. SAR systems are the most common sensor used in modern radar remote sensing. In July 2001, the Department of Defense announced an Efficient Facilities Initiative (EFI). This consolidation was projected to save an estimated $3.5 billion annually. EFI will enable the US military to match facilities to forces. EFI ensures the primacy of military value in making decisions on facilities and harnesses the strength and creativity of the private sector by creating partnerships with local communities. All military installations will be reviewed, and recommendations will be based on the military value of the facilities and the structure of the force. The EFI will encourage a cooperative effort between the President, the Congress, and the military and local communities to achieve the most effective and efficient base structure for America's Armed Forces. It will give local communities a significant role in determining the future use of facilities in their area by transferring closed installations to local redevelopers at no cost (provided that proceeds are reinvested) and by creating partnerships with local communities to own, operate, or maintain those installations that remain. In mid-December 2001 House and Senate negotiators authorized a new round of military base closings, but delayed any action until 2005. While the Bush administration and the Senate had wanted the base-closing process to begin in 2003, the House had been opposed. Under the compromise plan, the Secretary of Defense will submit a force structure plan and facility inventory, with a certification that proposed closings were justified by the force structure plan and and that they would produce net savings. The closings would also consider environmental costs and community impact. Seven of the nine commission members could vote to add bases to the Pentagon's proposed closure list, but a simple majority would suffice to drop bases from the closure plan. The Bush administration has estimated that 20 percent to 25 percent of military bases are surplus, and that the Pentagon could save $3 billion a year by eliminating surplus facilities. In August 2002 Phil Grone, principal assistant deputy undersecretary of defense for installations and the environment, estimated the next round of base closures in 2005 could save $6 billion a year, even if it cut only 12 percent of DoD's military infrastructure. One 1998 study suggested that 20 to 25 percent of the military's infrastructure could be considered surplus. Grone indicated that an analysis to "shed excess capacity" would be completed in 2004, before the Pentagon decided how many bases must be closed in the 2005 BRAC round. The Base Realignment and Closure (BRAC) process had its origins in the 1960s. Understanding that the Department of Defense (DOD) had to reduce its base structure that had been created during World War II and the Korean War, President John F. Kennedy directed Secretary of Defense Robert S. McNamara to develop and implement an extensive base realignment and closure program to adjust to the realities of the 1960s. The Office of the Secretary of Defense (OSD) subsequently established the criteria to govern the selection of bases without consulting Congress or the military. Under McNamara's guidance DOD closed sixty bases early in the 1960s without Congress or other government agencies being involved. In view of the political and economic ramifications of the closures, Congress decided that it had to be involved in the process and passed legislation in 1965 that required DOD to report any base closure programs to it. However, President Lyndon B. Johnson vetoed the bill. This permitted DOD to continue realigning and closing bases without congressional oversight throughout the rest of the 1960s. Economic and political pressures eventually forced Congress to intervene in the process of realigning and closing bases and to end DOD's independence on the matter. On 1 August 1977 President Jimmy Carter approved Public Law 95-82. It required DOD to notify Congress when a base was a candidate for reduction or closure; to prepare studies on the strategic, environmental, and local economic consequences of such action; and to wait sixty days for a congressional response. Codified as Section 2687, Title 10, United States Code, the legislation along with the requirements of the National Environmental Policy Act (NEPA) permitted Congress to thwart any DOD proposals to initiate base realignment and closure studies unilaterally by refusing to approve them and gave it an integral role in the process. As economic pressures mounted, the drive to realign and close military installations intensified. After several legislative efforts to break the deadlock failed, Congress introduced a new base closure procedure in P.L. 100-526, enacted October 24, 1988. The original base-closing law was designed to minimize political interference. The statute established a bipartisan commission to make recommendations to Congress and the Secretary of Defense on closures and realignments. Lawmakers had to accept or reject the commission's report in its entirety. On December 28, 1988, the commission issued its report, recommending closure of 86 installations, partial closure of 5, and realignment of 54 others. The Secretary of Defense approved its recommendation on January 5, 1989. Since the commission approach adopted by Congress was successful, new base closure legislation was introduced which also relied on the services of an independent commission. Congress refined the process in 1990 with another law (PL 101-510) that charged the Defense Department with drawing up an initial list of bases for consideration by the commission. This commission, in accordance with a statutory provision, met in 1991, 1993, and 1995. The Defense Base Closure and Realignment of 1990 (1990 Base Closure Act), Public Law 101-510 established the process by which Department of Defense (DOD) installations would be closed and/or realigned. From 1989 to 1997, the Department of Defense reduced total active duty military end strength by 32 percent, and that figure will grow to 36 percent by 2003 as a result of the 1997 Quadrennial Defense Review [QDR]. After four base closing rounds, only 21 percent of the military installations in the continental United States have been reduced. By 1997 the Department of Defense had already reduced its overseas base structure by almost 60 percent. Before the first base closure round, there were approximately 500 domestic military bases. When all of the bases from the first four BRAC rounds are closed, there will be about 400 bases. Ninety-seven major bases have been closed in the United States. The overseas basing structure has been further reduced, ceasing operations at over 960 facilities .Approximately half the savings which DOD assumes will come from BRAC during the implementation are due to assumed savings in operation and maintenance costs. Much of those assumed savings are due to reductions in civilian personnel. Under the BRAC process, the Secretary of Defense makes recommendations to a commission, nominated by the President, confirmed by the Senate. The commission, after being confirmed by the Senate, reviews these recommendations and makes their own recommendations to the President. The President then reviews the recommendation, either sends those back to the commission for additional work or forwards them, without changes, to the Congress, and then the recommendations of the commission go into effect unless disapproved by a joint resolution of the Congress. In 1995 the BRAC commission recommended closing two maintenance depots - McClellan Air Logistics Center near Sacramento, CA, and Kelly Air Logistics Center in San Antonio, TX. As an alternative to shutting the depots in the two politically powerful states, President Bill Clinton proposed having private contractors take over maintenance work at the sites. The 1995 Base Closure Commission did not recommend or authorize `privatization-in-place' at Kelly or McClellan. Concern was raised about the integrity of the BRAC process in light of this attempt to privatize-in-place the work at the Air Logistics Centers at Kelly Air Force Base in Texas and McClellan Air Force Base in California. Republicans charged that Clinton could not be trusted to respect the apolitical nature of the process. Following Clinton´s action, lawmakers did not agree until 2001 to schedule another round of base closings. Before it was resolved, the dispute held up a conference agreement on the fiscal 2002 defense authorization bill (PL 107-107) and led Bush to threaten to veto the bill if it did not allow a new round in 2005. Defense Secretary Donald H. Rumsfeld and Army Gen. Henry H. Shelton, chairman of the Joint Chiefs of Staff, told the House Armed Services Committee in July 2001 that the Pentagon maintained 25 percent more facilities than it needs, even after four rounds of base closings in the 1990s. By some accounts, the excess military bases annually cost taxpayers an estimated $3.5 billion.

1.4 How Does Radar Work

The basic idea behind radar is to transmit a signal with a known spectrum. When the signal strikes an object it will be reflected back toward the transmitter/receiver. The delay time between the signals is transmitted and when the signal is received can be used to determine the distance the transmitter is from the object. Additionally the phase of the received signal can be analyzed to determine if the object is moving and at what speed. The figure below gives a simple demonstration on the radar principle. The time the sound takes to travel from the man, to the water, and back to the man can be used to determine the distance the man is from the water.

Figure 1.3 Showing how we determine the distance

As stated above the velocity of an object can also be determined by the change in phase of the signal. This is called a Doppler shift. For example when a car approaches, a higher pitch is heard than the actual sound of the car. Similarly, when the car is moving away from you, a lower pitch sound is heard. This idea is the same for the phase of the return signal reflected by the object in the radar example. The phase difference can then be used to determine the velocity of the object. The figure below demonstrates the Doppler Shift. Observer 2 hears a higher pitch sound from the car because the sound wave is compressed due to the car's movement. Similarly observer 1 hears a lower pitched sound because the car is moving away from him.

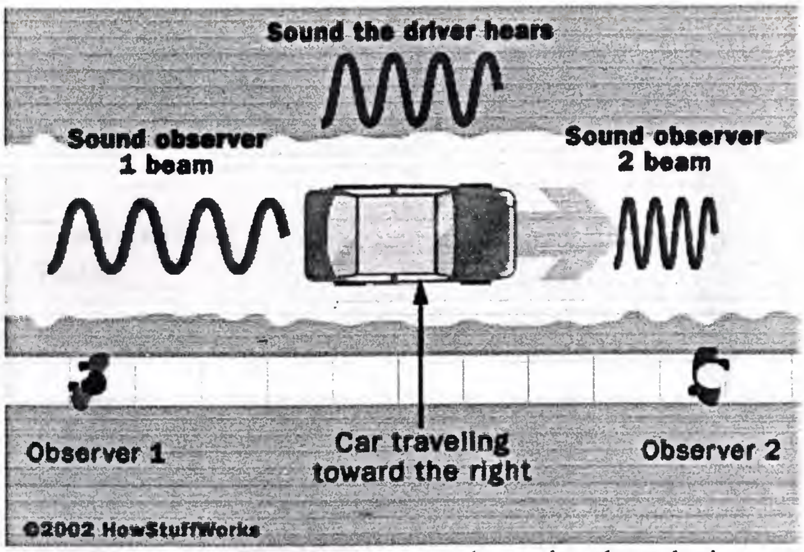

Figure 1.4 Showing how we determine the velocity

The differences in frequencies between the sounds the driver hears and the sounds either observer hears can be used to determine the speed and direction of the cars movement.

1.5 Parts of a Radar System

There are five main parts to a radar system: Transmitter, Receiver, Display, and two ennas. The figure below shows these five main parts.

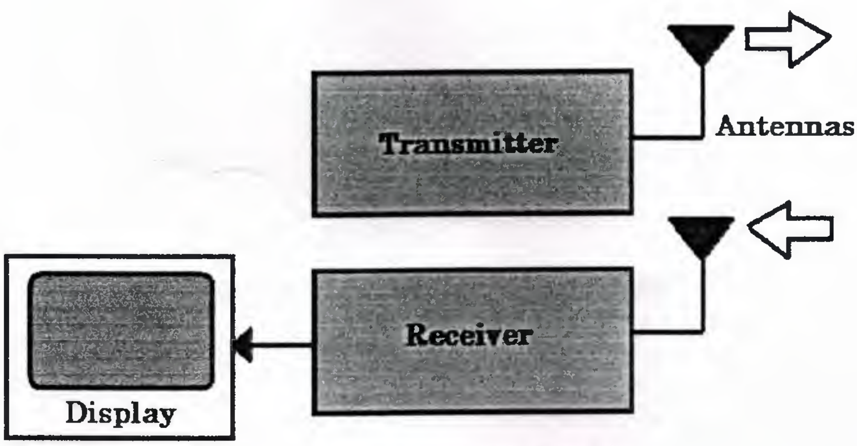

Figure 1.5 Parts of radar

Commonly the transmitter and receiver are combined into one. This is the fundamental difference between continuous wave (CW) radar and pulse radar. When the transmitter and receiver are one object, the transmitter can not continually send signals. It must send a pulse of frequency and then listens

For echoes. Below is a figure of the radar pulse.

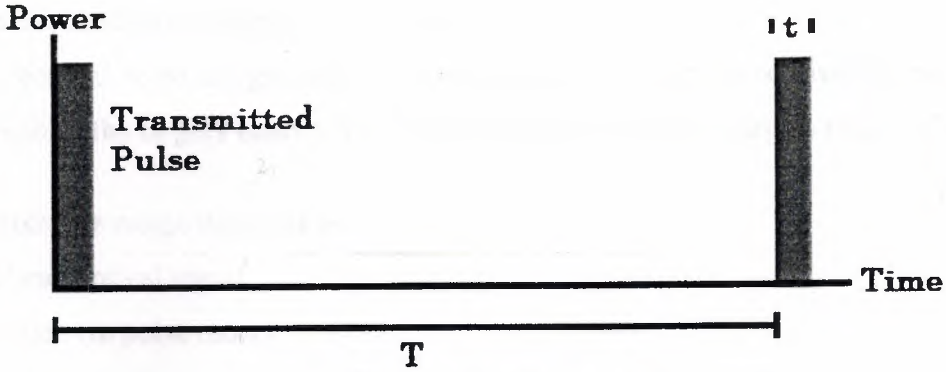

Figure 1.6 Radar pulse

The display of a radar system is also an important element. In airborne radar systems, an aircraft with search an area with its radar system. This search or scan pattern is used to fill a frame in the display in the cockpit. The time it takes to finish one complete scan is called the frame time. The image below shows a fighters scan pattern.

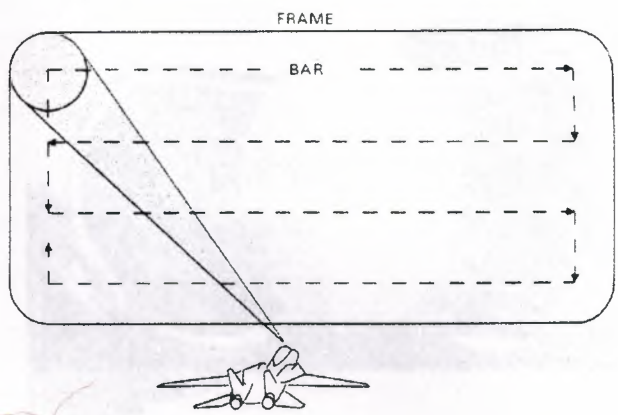

Figure 1.7 Introduction to borne radar

1.7.1 Conditions to determine the range of a target

target must be in line of sight

echoes must be strong enough to be received

ground electrical noise and ground clutter must be smaller than the received signal

The strength of the target's echoes is inversely proportional to the targets range $1/R^4$

1.7.2 Detectable range depends on

power of transmitted signal

pulse duration (in pulse radar)

antenna size

reflecting characteristics of the target

length of time target is in beam scan

strength of ground clutter

Optimizing the above a radar system can fit in the nose of a fighter aircraft and detect of hundreds of miles. This is shown in the figure below.

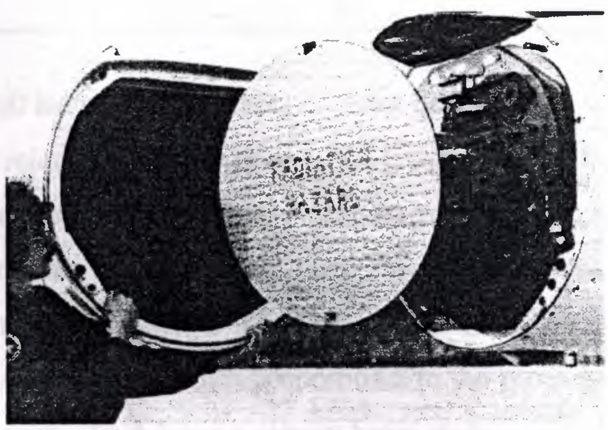

Figure 1.8 Introduction to Airborne Radar

1.7.3 The range of a target can be determined by the following equations

Pulse Radar:

Range = 1/2*(Round Trip Time)*(Speed of Light)

CW Radar:

$$\text{SignalEnergy} = \frac{P_{avg} G \sigma \, A t_{ot}}{R^4} \qquad (1.1)$$

1.6 Radar Frequencies

Most airborne radar operates in the range of 400-40,000 MHz. Within these regions are bands of frequencies for certain types of radar in the table below along with their wavelength in centimeters.

Table 1.1

	GHz	Cm
Ka	38	0.8
Ku	15	2
X	10	3
C	6	5
S	3	10

Different frequencies will have varying effects on radar performance. If smaller hardware is desired then smaller wavelengths must be used. This is due to the fact that dimensions of hardware are proportional to the wavelength. A drawback of using smaller wavelengths (and hardware) is that the hardware cannot transmit large amounts of power, thus there is a loss in the amount of range that can be detected. The reduced size of the hardware also limits the amount of heat dissipation. Beam-width is proportional to the wavelength being transmitted and the width of the antenna. To achieve a narrow beam-width with a large wavelength a large antenna must be used. A narrow beam-width is desirable to achieve a high resolution of the area in interest. Atmospheric attenuation is caused by absorption and scattering of the radio waves. Absorption is mostly caused by oxygen and water vapor in the atmosphere. Scattering of radio waves is mostly done by condensed water vapor (rain drops). Below the frequency of about 0.1 GHz absorption and scattering by the atmosphere can be considered negligible, it starts to become significant around 5 GHz, and starts to become severe around 20 GHz. The choice of radio frequency also has an effect on Doppler shifts. As the frequency

Determining Range

Determining the range of the target is different between continuous wave radar (CW) and pulse radar. There are also several conditions on determining the range of the target.

Where P_{avg} = Average transmitted power; G = Antenna Gain; σ = Radar cross section of target; A = Effective area of antenna; t_{ot} = time on target; R = range.When two targets are close together it is difficult to determine the range of the two distinct targets. Many times the two objects look as if they are one. If a short pulse is used, the receive can better distinguish between the two object. However, if a shorter pulse is used the signal strength is extremely low. One common solution to this problem is transmitting a chirp pulse. A chirp is a signal that linearly increases in frequency with time. The figure below shows the definition of a chirp.

The receive signal is filtered to compress the receive signal. This makes it possible to receive to distinct signals. Below is a figure that depicts the filter used to compress the received signal

1.8 Types of Radar

These are some different types of radar that are currently implemented.

1.8.1 SAR- Synthetic Array (Aperture) Radar

Uses the forward motion of the aircraft implementing pulse radar to produce the equivalent of a long antenna. Ex. If the radar was to synthesize a antenna of 25 feet with a physical antenna of 1 ft. in length it would be accomplish by using superposition. If the aircraft was traveling 1000ft/sec and generating 1000pulses/sec then the antenna would be 1ft further in the flight path after each pulse is transmitted. The returned pulses are then summed (25 of them) to simulate a antenna of 25 ft.

1.8.2 MTI- Moving Target Indication

A radar system can use Doppler frequencies to differentiate between echoes of aircraft and echoes of noise such as ground objects. An aircraft will echo a different Doppler frequency then a rain drop or a vehicle on the ground. Used in search radars.

1.8.3 FM CW Radar- Frequency Modulated Continuous Wave Radar

Pulses of the radar are transmitted too close together to effectively measure the time between them. Instead the frequency transmitted by the radar is varied linearly and the range of an object is determined by the difference of the frequency being transmitted by the radar the frequency of the echo from the object. Used for altimeters in aircraft.

1.8.4 Pulsed Doppler Radar

Same as pulsed radar but is able to measure and use Doppler effects.

2. THEORY OF RADAR

Overview

This chapter describes radar technology, The Antenna, signal, pulse, and Barker Code, One way Radar and its equations.

2.1 Radar Technology

All radars are composed of the items listed below. Their operation is organized in a processing chain and hence it is the weakest part that defines the systems capabilities.

2.1.1 The Transmitter

Transmitters are built around semiconductors (often contained in MMICs, millimeter-wave integrated circuits) or powerful vacuum tubes. The latter are rather complicated and sophisticated devices and often carry weird names ending in '-torn', such as Appleton, Magnetron, Carination, Stabilitron or Klystron. Owners of a microwave oven are also owners of a magnetron. The fact that microwaves can heat up food was discovered by serendipity, when during the 1940s a radar researcher was astonished to see that a chocolate bar was melting in his trouser pocket while he was performing experiments with an unshielded

2.1.2 The Antenna

The radar antenna serves as the coupling element between the wiring in the radar hardware and free space. Radar antennae can be as small as a thumbtack or as big as a 30-storey building, depending on their operating frequency and beam width.

2.1.3 The Receiver

The receiver's task is to pick up the echo that was bounced off a target, filter out unwanted parts outside the radar's bandwidth, amplify the rest and feed it into the signal processor for further analysis. A good receiver is a radar's best defense against *noise*, its toughest enemy. A receiver must be very sensitive in order to pick up weak echoes from far away. But usually it is located near the transmitter which can easily 'blind' or even destroy it by 'spillover' leaking into the receiver's input circuitry. In a pulsed radar, damage can be avoided by using a Transmit/Receive-Switch or *T/R switch* that disconnects the receiver's input from its antenna while the transmitter is operating. In a Continuous Wave Radar, the transmitter operates all the time and receiver protection is only feasible by blocking the frequency that is currently used. Both measures do fulfill their purpose but at the same time they introduce some problems of their own: they produce blind ranges and blind speeds. Until not long ago, traveling wave tubes (TWT) was the mainstay of receiver construction. Like the -torn devices mentioned above, their inner workings are rather complicated as they are built around some chamber or structure where strong magnetic fields or electron beams interact with low power, high frequency signals. During the 1980s, Twits were gradually replaced by semiconductors.

2.2 The Signal

The signal is what the radar transmits into space. A wide variety of types is available, and perhaps more than all the hardware components, the signal is what determines the quality and capabilities of radar. The most powerful radar, equipped with an ultra-low side lobe antenna of incredibly high gain can be *blind* at the most important range or target speed if the signal was chosen wrong. Some signals are likely to produce 'angels' and 'ghosts' on a screen - things that really make a radar operator's life interesting. More often than not, a single type of signal will not meet all the requirements, and fierce discussion about necessary expenditures ensues between manufacturer and customer.

2.2.1 The Signal Processor

The Signal Processor is the central element of radar. It has to decide whether an echo really *is* an echo and whether or not it is worth being reported and displayed. This is not a simple task, as there is much natural noise around, and in the case of military applications there is man-made interference too.

2.2.2 The System

A collection of sophisticated components is a precondition, but not a guarantee, for good radar. The first step during the design phase is to determine which part of the electromagnetic spectrum is to be used, followed by the selection of the signal that is most appropriate for the purpose in question. All this needs to be composed into a system that is more than the sum of its parts. There are only a few things that radar *cannot* do, and the easiest way to find these is to look into the requirement specifications written by the customer

2.2.3 Radar Technology - Signals and Range Resolution

The performance of radar depends on a multitude of things such as antenna pattern, transmitter power, receiver sensitivity and noise level. These quantities mostly define radar's

NEAR EAST UNIVERSITY

FACULTY OF ENGINEERING

ELECTRICAL AND ELOECTRONIC ENGINEERING

GENRAL RADAR AND ITS MILITARY USE

GRADUATION PROJECT
EE-400

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ABSTRACT

Radar research and development investments are increasingly being directed into dual-use and purely commercial application areas, in addition to the traditional defense-oriented programs. Leveraging the investment of formerly purely military radar applications into civil and commercial applications is increasingly important. One purpose of this conference is to foster the cross-fertilization of developmental successes across the boundaries among military, industrial, and academic researchers. Another is to provide a forum for researchers and system designers to provide visibility for their developments, experimental, and theoretical results that might be of broader interest to the general application developers.

Papers are solicited in the following topical areas related to radar:

Radar Imagery Applications

- synthetic aperture radar
- inverse synthetic aperture radar
- interferometric synthetic aperture radar
- real beam radar imaging
- ground penetration radar

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INTRODUCTION

RADAR is an acronym made from RAdio Detection And Ranging. The name to this electronic system was given during World War II. Its basic principle comprises emitted radio waves which bounce off a target in order to detect its presence and allow locating its position. Like many modern technical achievements military use was the initial spark to radar. The development of the earliest practical radar system is credited to Sir Robert Alexander Watson-Watt, although a large number of scientists contributed numerous technical details. Technical Principle A radio transmitter generates radio waves, which are then radiated from an antenna. A target in this area scatters a small portion of this radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed on a cathode-ray tube (CRT), where it can be studied by a radar operator. By this the presence of a target has been detected, but to determine its position the target's distance (range) and bearing must be measured. Because radio waves travel at a known constant velocity - the speed of light, which is 300,000 km/sec - the range may be found by measuring the time taken for a radio wave to travel from transmitter to target and back to the receiver. It is an old technology that was developed in 1935 by Sir Robert A Watson-Watt (the inventor of stereo). The underlying principal is very simple: objects distances (range) and velocities can be determined from analyzing the echoes that objects reflects. Put simply, electromagnetic waves can be transmitted at an object. The transmitted wave would then be reflected back off the object to the transmitter (or now receiver). The received signal can be analyzed to determine the distance and velocity of the object that reflected the wave. Modern radar transmits radio waves to create these echoes. This is because most objects reflect radio waves as much as they do light, since both are forms of electromagnetic radiation at different frequencies. By detecting reflected radio waves it is now possible to see objects not only in daytime, but at night, through fog, haze, clouds, the following pages contain a detailed description on radar works, considerations when developing a radar system, different types of radar, a Matlab radar toolkit, and additional information.

Aim of a project: is to describe general idea about radar, how it works, theory, application and military radar.

This project contain of four chapter, chapter one about general radar, important of radar, Parts of radar, chapter two about radar theory and equation used, chapter three about application of radar finally chapter four about military radar.

1. INTRODUCTION TO RADAR

1.1 General Radar

Radar is an acronym made from RAdio Detection And Ranging. The name to this electronic system was given during World War II. Its basic principle comprises emitted radio waves which bounce off a target in order to detect its presence and allow locating its position. Like many modern technical achievements military use was the initial spark to radar. The development of the earliest practical radar system is credited to Sir Robert Alexander Watson-Watt, although a large number of scientists contributed numerous technical details. Technical Principle A radio transmitter generates radio waves, which are then radiated from an antenna. A target in this area scatters a small portion of this radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed on a cathode-ray tube (CRT), where it can be studied by a radar operator. By this the presence of a target has been detected, but to determine its position the target's distance (range) and bearing must be measured. Because radio waves travel at a known constant velocity - the speed of light, which is 300,000 km/sec - the range may be found by measuring the time taken for a radio wave to travel from transmitter to target and back to the receiver. For example, if the range were 300 kilometers, the time for the round trip would be (2 X 300 km) 600 km : 300,000 km/sec = two-thousandths of a second, or 2,000 microseconds.

Radar remote sensing, like optical remote sensing, is used to produce an image of the Earth's surface. A radar image is a record of the interaction of energy and objects at the Earth's surface, and its appearance is dependent on such variables as geometric shape, surface roughness and moisture content of the target object, as well as the sensor-target geometry and the transmission direction (look direction) of the radar sensor. There are significant differences, however, between how a radar image is formed and what is represented in that image compared to optical remote sensing imagery. To interpret radar imagery, it is necessary to understand the radar configuration, the energy associated with radar remote sensing, the way in which that energy interacts with objects at the Earth's surface, and the manner in which this interaction is represented as an image. Radar remote sensing utilizes a sensor carried on a platform (aircraft or satellite) which travels along a path transmitting microwave

Pulses towards the Earth's surface (Figure 1-1). Some of this transmitted microwave energy is reflected from the Earth back towards the sensor where it is received as a signal. The signal data is stored on magnetic tape (for airborne platforms), or it may be electronically sent to Earth or stored on an onboard recorder and later sent to Earth (for satellite platforms). The signal data requires computer processing in order to be converted into a conventional image, but once processed the image can be viewed interactively on-screen, plotted or stored as a digital image file.

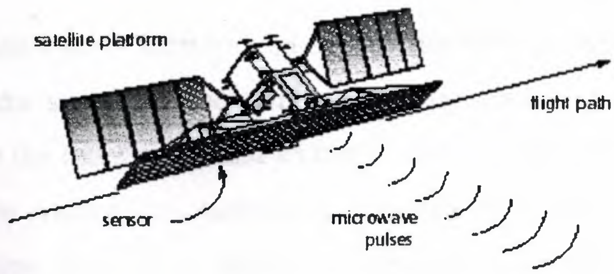

Figure 1.1. Radar remote sensing platform.

Because radar provides its own source of transmitted energy, it is known as an active remote sensing system, and it can acquire imagery day or night because it does not rely upon the sun's energy to illuminate the Earth's surface. In addition, radar's transmitted energy can penetrate through clouds, haze and smoke, although depending on the radio frequency used by the radar, the transmitted energy can be attenuated by rain. Radar is an acronym for Radio Detection and Ranging. A radar system performs three primary operations (Figure 1-2):

- It transmits microwave pulses towards a target.
- It receives a returned portion of the transmitted signal (backscatter) after it has interacted with the target.
- It observes the strength (detection) and the time delay (ranging) of the returned signals.

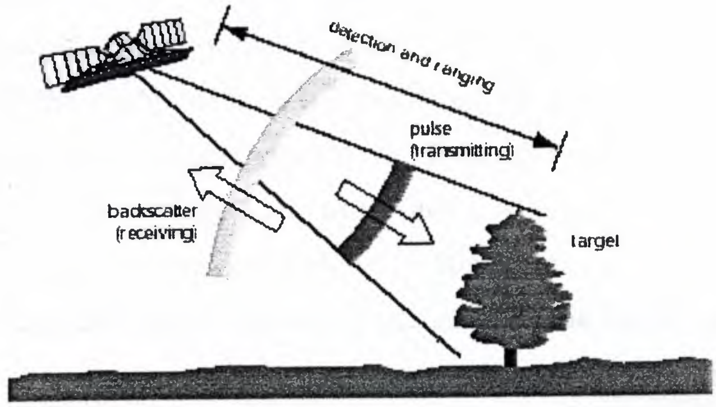

Figure 1.2 Primary operations of a radar system

The returned signal (backscatter) from ground objects (targets) is primarily influenced by the characteristics of the radar signal, the geometry of the radar relative to the Earth's surface, the local geometry between the radar signal and its target, and the characteristics of the target. A radar sensor operates by transmitting microwaves towards the Earth's surface in a direction perpendicular to the flight path of the platform. This perpendicular direction is termed the range direction. The sensor is capable of determining the relative distances of targets in the range direction from the time it takes for the signal to travel from the sensor to the target and return to the sensor; a signal reflected from a target located close to the sensor will take less time to return to the sensor than from one located farther from the sensor. As the radar platform continues in its flight path, the sensor transmits microwave pulses repetitively in the range direction. In doing so, signal data is progressively collected in the flight (or azimuth) direction, in effect resulting in a swath of signal data which is subsequently processed into imagery.

A radar image is a display of grey tones which are proportional to the amount of backscatter that is received from a target. Targets that produce a large amount of backscatter will appear as light grey tones on a radar image. Targets that produce little backscatter will appear as dark grey tones, and targets that reflect intermediate amounts of backscatter will appear as intermediate grey.

1.2 Important Of Radar

Radar (radio detecting and ranging) is often called the weapon that won World War II and the invention that changed the world. While these claims may be a little hyperbolic, there is no question that radar was a major development. It has certainly proven to be one of the most amazingly useful developments of the 20th century and is vital to aviation. It is also a clear example of a military technology that had important civilian uses.

To quote Scottish scientist Robert Watson-Watt, one of the early pioneers of radar technology, radar is "the art of detecting by means of radio echoes the presence of objects, determining their direction and ranges, recognizing their character and employing data thus obtained in the performance of military, naval, or other operations." Radar is used for navigation, targeting, weather tracking, and a host of other purposes. Radio, which was first developed in the late 1800s, allowed people to communicate over long distances without a physical connection such as a wire between the transmitter and the receiver. Radio worked by converting sound into electromagnetic energy that was then transmitted over a distance. When it was received, it could be converted back to sound waves. It did not take those who used radio long to realize that a lot of things could affect its performance. Weather conditions could reduce the transmission of radio waves, as could physical objects such as mountains between the transmitter and receiver. Exactly who gets credit for "inventing" radar is a topic of some disagreement in historical circles, for many people started working on the subject in many places at roughly the same time, and many of their developments influenced each other. In 1934, researchers at the Naval Research Laboratory (NRL) in Washington, D.C., began work on bouncing radio signals off of objects after noticing that ships traveling down the Potomac River interfered with radio signals being transmitted across the river. Robert Watson-Watt had also heard of reports from the government post office, which was responsible for shortwave radio communications, that airplanes flying near post office receivers caused problems with reception of signals. He wrote a lengthy memo on how this phenomenon might be used to detect airplanes. In 1936, the U.S. Army Signal Corps' laboratory for ground equipment at Fort Monmouth, New Jersey, also started a radar project. In 1934, Robert Page developed a pulse radar for the detection of aircraft. The first radar in extensive operational use was the British Home Chain radar (often referred to as the CH radar), which entered service in 1937. The CH and other early radars operated in the "high frequency," or HF portion of the electromagnetic spectrum. But early radar developers recognized that radars that could operate at frequencies higher than HF could perform better. In 1936-37, military radar researchers in the United States developed several devices such as the resonant cavity circuit, the klystron electron tube, and the coaxial and waveguide transmission lines and components that allowed the generation of signals in the microwave region of the electromagnetic spectrum. (Microwaves operate at a higher frequency than "high frequency.") This dramatically improved radar performance and was a major military development. The Americans secretly shared this information with their counterparts in the United Kingdom and this enabled the British to build better radars for detecting planes approaching the British Isles. Radar gave the British warning of approaching German planes during the Battle of Britain in 1940 and was instrumental in the outcome of the battle. Britain also developed airborne radar that helped pilots flying at night to detect aircraft in the darkness and bomber crews to locate targets at night.

The United States Army Air Forces soon established the Radiation Laboratory at the Massachusetts Institute of Technology, in Cambridge, Massachusetts. The "Rad Lab" as it became known, worked to develop numerous radar systems for various uses during the war. These included radar for aiming anti-aircraft guns, general search radars for detecting airplanes, ship borne radar, and airborne radars to be carried in airplanes and used for various purposes, from targeting other airplanes at night to "weather reconnaissance" to navigation. The Germans also made important advances in radar, particularly with the Warburg ground radar which entered service in 1940. They fielded numerous ground-based radars and also developed aerial and ship borne radars as well, although not nearly in as great numbers as the Americans or British. But as the war progressed, German radar research stagnated, which is one reason why some people claim that radar won the war for the Allies. After World War II, the Rad Lab closed and research on radar in the United States and Britain languished for several years. But although radar technology did not advance much in this period, its use certainly did. Many military Radars were transferred to civilian use where they were used for Air Traffic Control (ATC) and Ground Controlled Approach (GCA) to airports. Not until the Korean War did the U.S. Air Force recognize the need for more radar research. It created the Lincoln Laboratory near Boston to research the development of a continental air defense system for protecting the United States from bomber attack. Eventually, this led to the SAGE air defense system developed in the mid-1950s, as well as the Distant Early Warning Line ("DEW-Line") of radars located along the northern boundary of Canada and Alaska. For years after World War II, the Soviet Union used U.S.-built radars it had received during the War. But Soviet engineers began to modify the radars and improve their range and performance. When the first American U-2 reconnaissance aircraft flew over the Soviet Union in the summer of 1956, the Americans expected that the Soviets would not be able to detect the aircraft using the old U.S. radars. But they were surprised when the Soviets tracked the plane for almost its entire flight. This prompted the Americans to seek ways to reduce the radar signature of the U-2. During the 1950s, the quest was for higher and higher frequencies. Most radars used a rotating dish antenna for transmitting and receiving the signals. But by the 1950s and 1960s, researchers were exploring the possibilities of "phased-array" radars that had flat panel antennas. In these systems, the radar beam is pencil-thin and "steered" electronically. This eliminates the wasted time when a radar beam is sweeping across empty space. The most well known of these kinds of radar was the SPY-1 radar used as part of the U.S. Navy's Aegis weapons system on cruisers and destroyers starting in the 1980s. During the 1950s and 1960s, smaller and more robust radars were developed for use in the nosecones of missiles such as the Falcon and Sparrow, allowing them to home in on the reflected energy, or "radar return," from an enemy aircraft. Flat panel antennas were also developed for airborne use. By the 1970s, U.S. military aviation experts became concerned with "low observable" or "stealth" technology that would enable aircraft to evade radar. By designing aircraft with specific shapes and coating them in special materials, they dramatically reduced the amount of electromagnetic energy that the aircraft reflected back to the source. But these techniques do not work equally well against all frequencies, and some low-frequency radars can detect stealth aircraft, although they cannot pinpoint their location. Improvements in electronics, particularly during the 1970s and 1980s, allowed radar systems to become smaller, lighter and more capable, and able to achieve even higher frequencies. But a major improvement in radar capabilities concerned the development of software for better processing of radar signals. One development was "Synthetic Aperture Radar" (SAR), which was first explored in the 1970s and later applied to many different types of radar. SAR electronically stores the radar returns over a period of time as the radar (mounted on an airplane or spacecraft) moves. It then combines them into a detailed image of the ground with picture-like quality. SAR has been used to map the earth from the Space Shuttle, to provide reconnaissance imagery, and to target precision weapons from aircraft such as the Boeing F-15E Strike Eagle. The military has always pushed the boundaries of radar technology, while civilian needs for Air Traffic Control were far less demanding. However, by the 21st century, other technologies were beginning to supplement and in some ways replace radar. In particular, the Global Positioning System (GPS) and satellite communications links allow ground controllers to track aircraft without using radar at all. But radar is such an amazingly useful technology that it will always be used in aviation.

1.3 History of Radar

The roots of radar can be traced back to the year 1886 when Heinrich Hertz, a German, verified Maxwell's electromagnetic theory by showing that shortwave radiation (60 centimeters in length) could be reflected from metallic and dielectric bodies. Nearly two decades later a fellow German, Christian Huelsmeyer, attempted to develop a proximity warning system for ships, so that these maintained knowledge of each other's location during bad weather and night. Still later the the technology generated by these experiments was found to be applicable to weather forecasting by Britain's Sir Robert Alexander Watson-Watt. He discovered that the electro-magnetic acitivity in storms could be detected by basically the same equipment. Heinrich Hertz conceived the idea of a directional loop antenna to take advantage of the phenomenon, and thus permit the relatively precise location of bad weather and its general direction of movement.

Pulse powers of 500 kW in the S band (10 cm) and 150 kW in the X band (3 cm) were quickly made available, and compact radars having beam widths of 1 deg or less were soon deployed for early-warning purposes, for use in aircraft against other aircraft (AI = aircraft interception), or for aircraft patrolling over the sea to detect enemy warships and surfaced submarines (ASV = aircraft to surface vessel). Radar in the S and X bands was also used as an aid in blind bombing missions to delineate the ground beneath the aircraft, functioning as a navigational aid as well as a target identifier. Microwave radars were also important to the anti-aircraft artillery units of the army, providing target detection and automatic firing of the guns. Similarly, radar became an indispensable aid to naval operations. The imaging radar used today had its civilian beginnings in the 1960s, as a tool used for terrain analysis and natural resource surveys. The period from the 1970s to the early 1990s saw the development of experimental synthetic aperture radar (SAR) systems for civilian purposes using aircraft platforms (Canada Centre for Remote Sensing Caviar 580, NASA Jet Propulsion Laboratory AirSAR) and satellite platforms (SEASAT, SIR-A, SIR-B, SIR-C, ERS-1, ERS-2, ALMAZ, JERS-1, RADARSAT). The first airborne radar remote sensing systems used an antenna which was attached to the aircraft and pointed to one side. These systems were called side-looking airborne radars (SLAR). The beam width of the radar signal is inversely proportional to the length of the antenna. This means that in order to obtain the high resolution associated with a small beam width, a long antenna would be required. To ensure constant resolution in the azimuth direction at all ranges of the swath, the SAR system synthesizes effective antennae whose length is proportional to that required to maintain a given (azimuth) resolution at each range interval of the swath, The resulting SAR image therefore has a constant azimuth resolution at all ranges within the swath. SAR systems are the most common sensor used in modern radar remote sensing. In July 2001, the Department of Defense announced an Efficient Facilities Initiative (EFI). This consolidation was projected to save an estimated $3.5 billion annually. EFI will enable the US military to match facilities to forces. EFI ensures the primacy of military value in making decisions on facilities and harnesses the strength and creativity of the private sector by creating partnerships with local communities. All military installations will be reviewed, and recommendations will be based on the military value of the facilities and the structure of the force. The EFI will encourage a cooperative effort between the President, the Congress, and the military and local communities to achieve the most effective and efficient base structure for America's Armed Forces. It will give local communities a significant role in determining the future use of facilities in their area by transferring closed installations to local redevelopers at no cost (provided that proceeds are reinvested) and by creating partnerships with local communities to own, operate, or maintain those installations that remain. In mid-December 2001 House and Senate negotiators authorized a new round of military base closings, but delayed any action until 2005. While the Bush administration and the Senate had wanted the base-closing process to begin in 2003, the House had been opposed. Under the compromise plan, the Secretary of Defense will submit a force structure plan and facility inventory, with a certification that proposed closings were justified by the force structure plan and and that they would produce net savings. The closings would also consider environmental costs and community impact. Seven of the nine commission members could vote to add bases to the Pentagon's proposed closure list, but a simple majority would suffice to drop bases from the closure plan. The Bush administration has estimated that 20 percent to 25 percent of military bases are surplus, and that the Pentagon could save $3 billion a year by eliminating surplus facilities. In August 2002 Phil Grone, principal assistant deputy undersecretary of defense for installations and the environment, estimated the next round of base closures in 2005 could save $6 billion a year, even if it cut only 12 percent of DoD's military infrastructure. One 1998 study suggested that 20 to 25 percent of the military's infrastructure could be considered surplus. Grone indicated that an analysis to "shed excess capacity" would be completed in 2004, before the Pentagon decided how many bases must be closed in the 2005 BRAC round. The Base Realignment and Closure (BRAC) process had its origins in the 1960s. Understanding that the Department of Defense (DOD) had to reduce its base structure that had been created during World War II and the Korean War, President John F. Kennedy directed Secretary of Defense Robert S. McNamara to develop and implement an extensive base realignment and closure program to adjust to the realities of the 1960s. The Office of the Secretary of Defense (OSD) subsequently established the criteria to govern the selection of bases without consulting Congress or the military. Under McNamara's guidance DOD closed sixty bases early in the 1960s without Congress or other government agencies being involved. In view of the political and economic ramifications of the closures, Congress decided that it had to be involved in the process and passed legislation in 1965 that required DOD to report any base closure programs to it. However, President Lyndon B. Johnson vetoed the bill. This permitted DOD to continue realigning and closing bases without congressional oversight throughout the rest of the 1960s. Economic and political pressures eventually forced Congress to intervene in the process of realigning and closing bases and to end DOD's independence on the matter. On 1 August 1977 President Jimmy Carter approved Public Law 95-82. It required DOD to notify Congress when a base was a candidate for reduction or closure; to prepare studies on the strategic, environmental, and local economic consequences of such action; and to wait sixty days for a congressional response. Codified as Section 2687, Title 10, United States Code, the legislation along with the requirements of the National Environmental Policy Act (NEPA) permitted Congress to thwart any DOD proposals to initiate base realignment and closure studies unilaterally by refusing to approve them and gave it an integral role in the process. As economic pressures mounted, the drive to realign and close military installations intensified. After several legislative efforts to break the deadlock failed, Congress introduced a new base closure procedure in P.L. 100-526, enacted October 24, 1988. The original base-closing law was designed to minimize political interference. The statute established a bipartisan commission to make recommendations to Congress and the Secretary of Defense on closures and realignments. Lawmakers had to accept or reject the commission´s report in its entirety. On December 28, 1988, the commission issued its report, recommending closure of 86 installations, partial closure of 5, and realignment of 54 others. The Secretary of Defense approved its recommendation on January 5, 1989. Since the commission approach adopted by Congress was successful, new base closure legislation was introduced which also relied on the services of an independent commission. Congress refined the process in 1990 with another law (PL 101-510) that charged the Defense Department with drawing up an initial list of bases for consideration by the commission. This commission, in accordance with a statutory provision, met in 1991, 1993, and 1995. The Defense Base Closure and Realignment of 1990 (1990 Base Closure Act), Public Law 101-510 established the process by which Department of Defense (DOD) installations would be closed and/or realigned. From 1989 to 1997, the Department of Defense reduced total active duty military end strength by 32 percent, and that figure will grow to 36 percent by 2003 as a result of the 1997 Quadrennial Defense Review [QDR]. After four base closing rounds, only 21 percent of the military installations in the continental United States have been reduced. By 1997 the Department of Defense had already reduced its overseas base structure by almost 60 percent. Before the first base closure round, there were approximately 500 domestic military bases. When all of the bases from the first four BRAC rounds are closed, there will be about 400 bases. Ninety-seven major bases have been closed in the United States. The overseas basing structure has been further reduced, ceasing operations at over 960 facilities .Approximately half the savings which DOD assumes will come from BRAC during the implementation are due to assumed savings in operation and maintenance costs. Much of those assumed savings are due to reductions in civilian personnel. Under the BRAC process, the Secretary of Defense makes recommendations to a commission, nominated by the President, confirmed by the Senate. The commission, after being confirmed by the Senate, reviews these recommendations and makes their own recommendations to the President. The President then reviews the recommendation, either sends those back to the commission for additional work or forwards them, without changes, to the Congress, and then the recommendations of the commission go into effect unless disapproved by a joint resolution of the Congress. In 1995 the BRAC commission recommended closing two maintenance depots - McClellan Air Logistics Center near Sacramento, CA, and Kelly Air Logistics Center in San Antonio, TX. As an alternative to shutting the depots in the two politically powerful states, President Bill Clinton proposed having private contractors take over maintenance work at the sites. The 1995 Base Closure Commission did not recommend or authorize `privatization-in-place' at Kelly or McClellan. Concern was raised about the integrity of the BRAC process in light of this attempt to privatize-in-place the work at the Air Logistics Centers at Kelly Air Force Base in Texas and McClellan Air Force Base in California. Republicans charged that Clinton could not be trusted to respect the apolitical nature of the process. Following Clinton´s action, lawmakers did not agree until 2001 to schedule another round of base closings. Before it was resolved, the dispute held up a conference agreement on the fiscal 2002 defense authorization bill (PL 107-107) and led Bush to threaten to veto the bill if it did not allow a new round in 2005. Defense Secretary Donald H. Rumsfeld and Army Gen. Henry H. Shelton, chairman of the Joint Chiefs of Staff, told the House Armed Services Committee in July 2001 that the Pentagon maintained 25 percent more facilities than it needs, even after four rounds of base closings in the 1990s. By some accounts, the excess military bases annually cost taxpayers an estimated $3.5 billion.

1.4 How Does Radar Work

The basic idea behind radar is to transmit a signal with a known spectrum. When the signal strikes an object it will be reflected back toward the transmitter/receiver. The delay time between the signals is transmitted and when the signal is received can be used to determine the distance the transmitter is from the object. Additionally the phase of the received signal can be analyzed to determine if the object is moving and at what speed. The figure below gives a simple demonstration on the radar principle. The time the sound takes to travel from the man, to the water, and back to the man can be used to determine the distance the man is from the water.

Figure 1.3 Showing how we determine the distance

As stated above the velocity of an object can also be determined by the change in phase of the signal. This is called a Doppler shift. For example when a car approaches, a higher pitch is heard than the actual sound of the car. Similarly, when the car is moving away from you, a lower pitch sound is heard. This idea is the same for the phase of the return signal reflected by the object in the radar example. The phase difference can then be used to determine the velocity of the object. The figure below demonstrates the Doppler Shift. Observer 2 hears a higher pitch sound from the car because the sound wave is compressed due to the car's movement. Similarly observer 1 hears a lower pitched sound because the car is moving away from him.

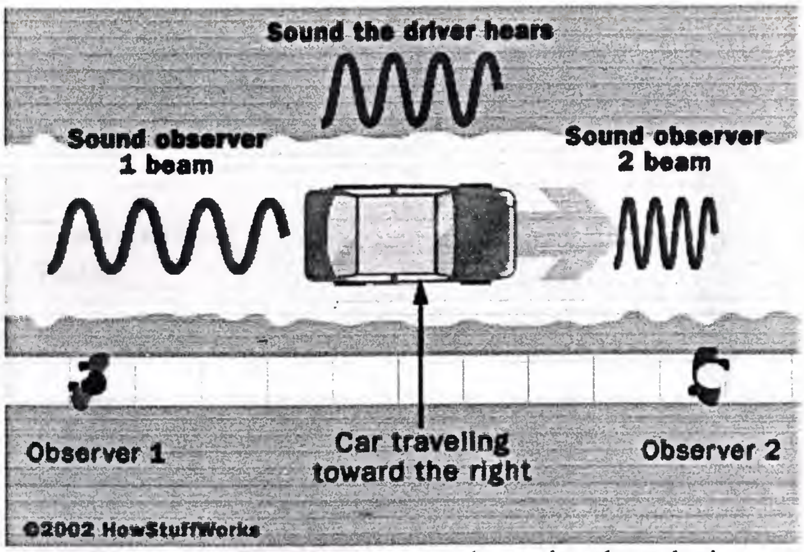

Figure 1.4 Showing how we determine the velocity

The differences in frequencies between the sounds the driver hears and the sounds either observer hears can be used to determine the speed and direction of the cars movement.

1.5 Parts of a Radar System

There are five main parts to a radar system: Transmitter, Receiver, Display, and two ennas. The figure below shows these five main parts.

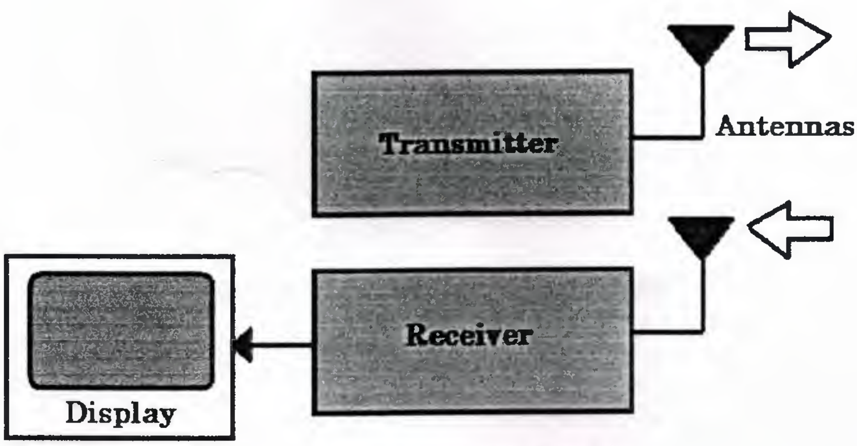

Figure 1.5 Parts of radar

Commonly the transmitter and receiver are combined into one. This is the fundamental difference between continuous wave (CW) radar and pulse radar. When the transmitter and receiver are one object, the transmitter can not continually send signals. It must send a pulse of frequency and then listens

For echoes. Below is a figure of the radar pulse.

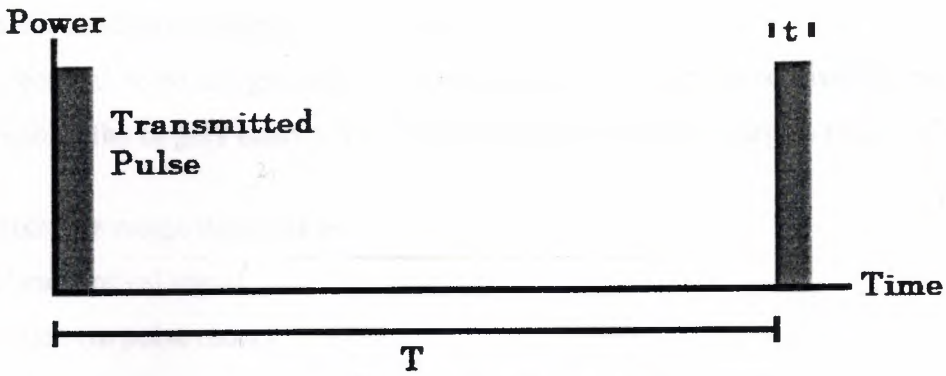

Figure 1.6 Radar pulse

The display of a radar system is also an important element. In airborne radar systems, an aircraft with search an area with its radar system. This search or scan pattern is used to fill a frame in the display in the cockpit. The time it takes to finish one complete scan is called the frame time. The image below shows a fighters scan pattern.

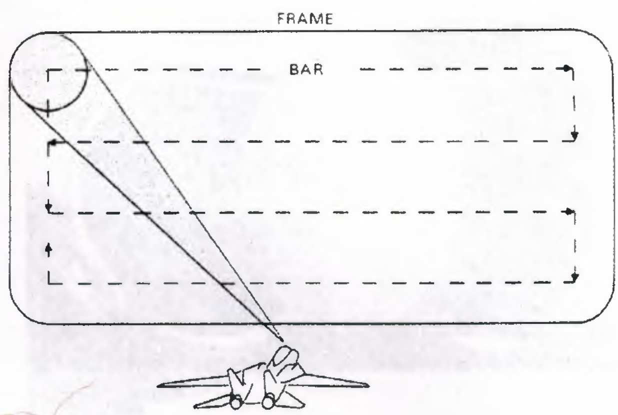

Figure 1.7 Introduction to borne radar

1.7.1 Conditions to determine the range of a target

target must be in line of sight

echoes must be strong enough to be received

ground electrical noise and ground clutter must be smaller than the received signal

The strength of the target's echoes is inversely proportional to the targets range $1/R^4$

1.7.2 Detectable range depends on

power of transmitted signal

pulse duration (in pulse radar)

antenna size

reflecting characteristics of the target

length of time target is in beam scan

strength of ground clutter

Optimizing the above a radar system can fit in the nose of a fighter aircraft and detect of hundreds of miles. This is shown in the figure below.

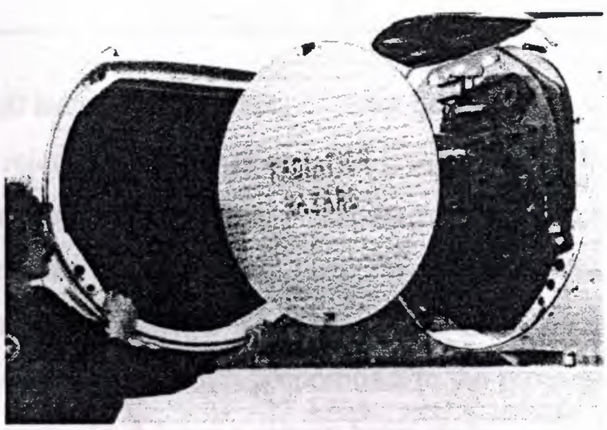

Figure 1.8 Introduction to Airborne Radar

1.7.3 The range of a target can be determined by the following equations

Pulse Radar:

Range = 1/2*(Round Trip Time)*(Speed of Light)

CW Radar:

$$\text{SignalEnergy} = \frac{P_{avg} G \sigma \, \text{At}_{ot}}{R^4} \quad (1.1)$$

1.6 Radar Frequencies

Most airborne radar operates in the range of 400-40,000 MHz. Within these regions are bands of frequencies for certain types of radar in the table below along with their wavelength in centimeters.

Table 1.1

	GHz	Cm
Ka	38	0.8
Ku	15	2
X	10	3
C	6	5
S	3	10

Different frequencies will have varying effects on radar performance. If smaller hardware is desired then smaller wavelengths must be used. This is due to the fact that dimensions of hardware are proportional to the wavelength. A drawback of using smaller wavelengths (and hardware) is that the hardware cannot transmit large amounts of power, thus there is a loss in the amount of range that can be detected. The reduced size of the hardware also limits the amount of heat dissipation. Beam-width is proportional to the wavelength being transmitted and the width of the antenna. To achieve a narrow beam-width with a large wavelength a large antenna must be used. A narrow beam-width is desirable to achieve a high resolution of the area in interest. Atmospheric attenuation is caused by absorption and scattering of the radio waves. Absorption is mostly caused by oxygen and water vapor in the atmosphere. Scattering of radio waves is mostly done by condensed water vapor (rain drops). Below the frequency of about 0.1 GHz absorption and scattering by the atmosphere can be considered negligible, it starts to become significant around 5 GHz, and starts to become severe around 20 GHz. The choice of radio frequency also has an effect on Doppler shifts. As the frequency

Determining Range

Determining the range of the target is different between continuous wave radar (CW) and pulse radar. There are also several conditions on determining the range of the target.

Where P_{avg} = Average transmitted power; G = Antenna Gain; σ = Radar cross section of target; A = Effective area of antenna; t_{ot} = time on target; R = range.When two targets are close together it is difficult to determine the range of the two distinct targets. Many times the two objects look as if they are one. If a short pulse is used, the receive can better distinguish between the two object. However, if a shorter pulse is used the signal strength is extremely low. One common solution to this problem is transmitting a chirp pulse. A chirp is a signal that linearly increases in frequency with time. The figure below shows the definition of a chirp.

The receive signal is filtered to compress the receive signal. This makes it possible to receive to distinct signals. Below is a figure that depicts the filter used to compress the received signal

1.8 Types of Radar

These are some different types of radar that are currently implemented.

1.8.1 SAR- Synthetic Array (Aperture) Radar

Uses the forward motion of the aircraft implementing pulse radar to produce the equivalent of a long antenna. Ex. If the radar was to synthesize a antenna of 25 feet with a physical antenna of 1 ft. in length it would be accomplish by using superposition. If the aircraft was traveling 1000ft/sec and generating 1000pulses/sec then the antenna would be 1ft further in the flight path after each pulse is transmitted. The returned pulses are then summed (25 of them) to simulate a antenna of 25 ft.

1.8.2 MTI- Moving Target Indication

A radar system can use Doppler frequencies to differentiate between echoes of aircraft and echoes of noise such as ground objects. An aircraft will echo a different Doppler frequency then a rain drop or a vehicle on the ground. Used in search radars.

1.8.3 FM CW Radar- Frequency Modulated Continuous Wave Radar

Pulses of the radar are transmitted too close together to effectively measure the time between them. Instead the frequency transmitted by the radar is varied linearly and the range of an object is determined by the difference of the frequency being transmitted by the radar the frequency of the echo from the object. Used for altimeters in aircraft.

1.8.4 Pulsed Doppler Radar

Same as pulsed radar but is able to measure and use Doppler effects.

2. THEORY OF RADAR

Overview

This chapter describes radar technology, The Antenna, signal, pulse, and Barker Code, One way Radar and its equations.

2.1 Radar Technology

All radars are composed of the items listed below. Their operation is organized in a processing chain and hence it is the weakest part that defines the systems capabilities.

2.1.1 The Transmitter

Transmitters are built around semiconductors (often contained in MMICs, millimeter-wave integrated circuits) or powerful vacuum tubes. The latter are rather complicated and sophisticated devices and often carry weird names ending in '-torn', such as Appleton, Magnetron, Carination, Stabilitron or Klystron. Owners of a microwave oven are also owners of a magnetron. The fact that microwaves can heat up food was discovered by serendipity, when during the 1940s a radar researcher was astonished to see that a chocolate bar was melting in his trouser pocket while he was performing experiments with an unshielded

2.1.2 The Antenna

The radar antenna serves as the coupling element between the wiring in the radar hardware and free space. Radar antennae can be as small as a thumbtack or as big as a 30-storey building, depending on their operating frequency and beam width.

2.1.3 The Receiver

The receiver's task is to pick up the echo that was bounced off a target, filter out unwanted parts outside the radar's bandwidth, amplify the rest and feed it into the signal processor for further analysis. A good receiver is a radar's best defense against *noise*, its toughest enemy. A receiver must be very sensitive in order to pick up weak echoes from far away. But usually it is located near the transmitter which can easily 'blind' or even destroy it by 'spillover' leaking into the receiver's input circuitry. In a pulsed radar, damage can be avoided by using a Transmit/Receive-Switch or *T/R switch* that disconnects the receiver's input from its antenna while the transmitter is operating. In a Continuous Wave Radar, the transmitter operates all the time and receiver protection is only feasible by blocking the frequency that is currently used. Both measures do fulfill their purpose but at the same time they introduce some problems of their own: they produce blind ranges and blind speeds. Until not long ago, traveling wave tubes (TWT) was the mainstay of receiver construction. Like the -torn devices mentioned above, their inner workings are rather complicated as they are built around some chamber or structure where strong magnetic fields or electron beams interact with low power, high frequency signals. During the 1980s, Twits were gradually replaced by semiconductors.

2.2 The Signal

The signal is what the radar transmits into space. A wide variety of types is available, and perhaps more than all the hardware components, the signal is what determines the quality and capabilities of radar. The most powerful radar, equipped with an ultra-low side lobe antenna of incredibly high gain can be *blind* at the most important range or target speed if the signal was chosen wrong. Some signals are likely to produce 'angels' and 'ghosts' on a screen - things that really make a radar operator's life interesting. More often than not, a single type of signal will not meet all the requirements, and fierce discussion about necessary expenditures ensues between manufacturer and customer.

2.2.1 The Signal Processor

The Signal Processor is the central element of radar. It has to decide whether an echo really *is* an echo and whether or not it is worth being reported and displayed. This is not a simple task, as there is much natural noise around, and in the case of military applications there is man-made interference too.

2.2.2 The System

A collection of sophisticated components is a precondition, but not a guarantee, for good radar. The first step during the design phase is to determine which part of the electromagnetic spectrum is to be used, followed by the selection of the signal that is most appropriate for the purpose in question. All this needs to be composed into a system that is more than the sum of its parts. There are only a few things that radar *cannot* do, and the easiest way to find these is to look into the requirement specifications written by the customer

2.2.3 Radar Technology - Signals and Range Resolution

The performance of radar depends on a multitude of things such as antenna pattern, transmitter power, receiver sensitivity and noise level. These quantities mostly define radar's *accuracy*. Another important performance figure is *resolution*, the ability to recognize two objects as separate entities, rather than merging them into one (bigger) object. Radar's data sheet features two figures for its resolution because there are two distinct cases: targets can be close to each other in range, and they can be close to each other in angle. Angular resolution depends on the antenna pattern, whereas range resolution is defined by the properties of the radar's signal, which is often referred to as the 'waveform'. A few typical waveforms and their properties are discussed below.

2.2.4 The Simple Pulse

Early radars used a so-called 'simple pulse', that is, the signal could be represented as a slice cut out from a sine wave and typically consists of several thousand cycles. If you were to simulate the signal on a piano then you would simply hit one key .

Let's take pulse duration of 20µs as an example. As with all electromagnetic waves, radar signals travel at the speed of light, c. Thus, when the last portion of the pulse leaves the antenna, the first portion of the pulse has already traveled a distance of 20µs·3·108m which is 6000m. The pulse stretches over 6000m in space and it yields echoes that are also 6000m long.Imagine the situation of two targets being illuminated by the simple pulse depicted above. If they happen to be, say, 10,000m apart then their echoes will be received one after the other. The critical point is when the targets are separated by less than 3000m, because the signal from target 2 must travel an additional distance of 6000m and, after reflection, appears right at the end of the echo from target 1. If the targets are even closer together then the echoes will partially overlap.

There is no way of telling the end of one echo pulse from the beginning of the next, and they get merged into one. Hence the simple pulse can resolve two targets only if they are separated by a minimum distance of 0.5· (pulse duration) · (speed of light). This is a rather poor figure but that's why the signal is called 'simple pulse.'

Obviously, the resolution would be better if the pulse were shorter, but there's a lower limit to pulse duration: a certain amount of signal energy is required to detect an echo in the first place. The energy carried by the pulse is calculated as (transmitter power) · (pulse duration). Therefore, cutting pulse duration in half would necessitate doubling transmitter power in order to keep the signal's energy constant. The problem with that is that transmitter power cannot be increased at will because of cost and other constraints.

But there are other opportunities. If the end of a pulse could be 'painted' in some way so that it was different from the pulse beginning then the problem of overlapping echoes could be solved. Another solution would be to somehow 'compress' the pulse after it has been received. One way of both 'painting' and 'compressing' the pulse is frequency modulation.

2.3 Frequency Modulation and Pulse Compression

Synonyms for this type of signal are:

Chirp - because if you could hear it, it would sound like the 'chirp' of a bird

FMOP, Frequency Modulation on Pulse

LFMOP, Linear Frequency Modulation on Pulse - a special case of FMOP

FMOP is characterized by a constant variation of the pitch of the signal. Think of a trombone-slide performed by Glenn Miller1 and you get the idea. FMOP can be simulated on a piano by 'wiping' a finger over a selected range of keys. Doing so at constant speed produces an LFMOP signal, which is an 'up-chirp' if you're going from left to right or a 'down-chirp if you're going the other way. The difference between the lowest and the highest frequency (or the number of keys on the piano) is the bandwidth of the signal, and bandwidth translates into range resolution.

So, what's the trick?

The propagation speed of a wave depends on the properties of the medium in which the wave travels. Media such as air and water exhibit constant propagation speeds, regardless of the frequency. But there are devices such as Surface Acoustic Wave (SAW) chips that are different. They can be built such that propagation speed is proportional to frequency - in other words, the higher the frequency of a signal, the faster it travels through the chip. Hence, if you pass an up-chirped signal through such a device then the following happens:

The lower frequency part at the beginning of the echo pulse is received first, but travels more slowly than the rest of it.

The higher frequency part of the echo is received last, but travels at the highest speed.

Provided that the device is properly matched to the signal, all signal components arrive at the output at the same time.

Overlapping echoes consist of the high frequency end of the first echo and the low frequency beginning of the second, which are subject to different propagation velocities and get separated. The result is a pulse that is significantly shorter than the signal that was radiated into the air. It is also much stronger because all components are added. The pulse was literally compressed - hence the term 'pulse compression.' Compression factors of a few 100s can be achieved in practical application. Thus, a pulse of 20μs duration yields 3000m range resolution if it is not compressed, and somewhere around 50m using pulse compression. Interestingly, bats have been using this type of signal for millions of years.

2.3.1 Barker Code

It should be possibly to compare a signal with optimum range resolution capability with a time-shifted replica and produce:

A peak output if the 'master' and the copy are identical, and no output if they are identical but there's a time delay between them. Such an ideal signal doesn't exist. However, there are some types that approximate the feature, and the Barker code is one of them. Barker codes yield maximum output if the two copies match precisely, and either zero or a constant minimum value in other cases. The 'comparison' that takes place in the receiver is called *correlation.* A *correlate* compares two signals by:

Looking at one bit of each input line at a time. Multiplying these bits, adding the individual results

The bit streams of the 'master copy' (M) and the echo (E) are encoded as '1' and '-1' as long as the signal is present at all, and '0' if not. Here's an example for the Barker code with length 13, correlated with it at different delay times:

Case 1: No time shift

Master: 1 1 1 -1 -1 1 1 -1 1 -1 1 0 0

Echo: 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 0 0

Products: 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0

Sum: 13

Case 2: Time shifted by 1 bit

Master: 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 0 0

Echo: 0 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 0

Products: 0 1 1 1 1 -1 1 -1 1 -1 -1 -1 -1 0 0

Sum: 0

Case 3: Time shifted by 2 bits:

Master: 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 0 0

Echo: 0 0 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1

Products: 0 0 1 1 1 -1 -1 -1 -1 -1 1 1 1 0 0

Sum: 1

For any amount of delay (zero delay and 12 cases each for positive and negative delay), Barker codes yield either 0, 1, or *N* as the result of correlation. *N* is the length of the code, and there's a limited repertoire of Barker codes: only six codes are known, and the one with 13 bits that was used in the example is the longest of them. The Barker code is usually employed by phase-shift keying: the transmitter is switched onto full power for the duration of the pulse, which is split into *N* segments, one for each bit of the Barker code. For every '-1' in the code sequence, the transmitter signal is inverted, which is equal to a 180° phase shift.

2.3.2 Noise

Random noise is another signal that, if sent through a correlate, can be expected to yield a pronounced peak value for zero delay, and very little response otherwise. The drawback of Barker codes is that the maximum peak value is only 13. Random (or rather, pseudo-random) signals can be made as long as desired, and the peak value after correlation increases by the same amount. Hence, a radar's range resolution capability can be matched to almost any requirement when noise-type signals are employed.

2.4 The Basic Principle

The term 'radar' was coined in the 1930s and is an abbreviation for Radio Detection And Ranging. The initial purposes of detecting objects and range measurements nowadays are only part of a radar's function, as radars also serve for tracking an object's movements and whereabouts, its identification and the

2.4.1 The Principle in A Nutshell

Radars consist of a transmitter, a receiver, one or two antennae and lots of signal-processing circuitry. This is a basic overview of how the principle of radar works:

The transmitter produces a signal which is radiated through the antenna.

The signal is an electromagnetic wave which is capable of propagating through space.

If an object happens to be in the way then part of the signal is reflected and finds its way back to the radar.

The receiver picks up this echo, using the transmit antenna or a dedicated receiving antenna.

The signal processor detects the echoes, sorts them out from among noise and other types of interference, takes measurements with regard to the object's location in space, its speed and perhaps some more characteristics, and prepares them for output to a display or some remote command post. The principle can be compared to finding one's way through a forest at night with the help of a torchlight. The torchlight contains the light bulb (the transmitter) and a reflector (the transmit antenna) which is used to shape the beam and direct it into the area of interest. The 'signal' is the beam of light which is capable of propagating through the atmosphere. Objects like trees and grass reflect the light, and part of it is picked up by the eye (the receiver). Finally, the brain controls the whole process, performs the signal processing and avoids its owner tripping over a fallen tree.

2.4.2General Aspects

Behind the scenes, radars are rather complex devices which bring together scientific areas like mathematics, electronics, optics, mechanics, fluid dynamics and many more. Main application fields for radars include weather forecasting, air surveillance, navigation and collision avoidance, air traffic control, law enforcement and warfare, astronomy, geodesy and ecology. Within a single radar, the units of measure usually stretch over tens of orders of magnitude. The transmitter may operate at megawatts of power for the duration of a microsecond whereas the receiver measures Pico watts. The signal in the air can have a frequency of several hundred Gigahertz while distances in the millimetre range are being measured. The radar principle is also used in optics and acoustics (eg: LIDAR, laser radar) and sonar (acoustic-sounding). Lidar finds its most prominent application in detecting chemical substances in the atmosphere. Sonar[1] is used by navies and commercial fleets all over the world for finding underwater targets and fish. Ultrasonic devices used in medical diagnostics also employ the radar principle in order to produce images of a baby within the mother's womb or a Doppler profile of the bloodstream within a vessel. The signals used in radars are electromagnetic waves just like light. There are only two major distinctions which make it hard for the lay person to gather the similarity:

The wavelengths are different. Light has a wavelength of some minute fraction of a millimetre, whereas radars use wavelengths between 1mm and 100m. Humans don't have sensors for these wavelength bands. Our senses only cover the optical band (which is perceived as light) and the far infrared which is perceived as heat. Radar wavelengths are some 10 orders of magnitude greater than those of infrared radiation. In order to be able to *see* a radar signal, our eyes would have to grow by the same factor. Eyes this big might prove a little cumbersome - even perhaps impractical. Apart from these two points, radar signals share the same properties as light. They propagate through space and Earth's atmosphere, are absorbed by different kinds of matter, get reflected from other kinds of matter and undergo diffraction at objects of particular shapes and dimensions. The entries Over The Horizon Radar, How Stealth Works and Advanced Electronic Countermeasures look into some interesting consequences of this. However, one distinctive difference between light and typical radar signals is that longer wavelengths can easily propagate through precipitation. Hence, radars are able to look through fog, clouds and snow. Some wavelengths do exhibit significantly stronger attenuation in the atmosphere, especially when molecular resonances of oxygen or water molecules are excited. But even these areas of the electromagnetic spectrum are used by radars: weather radars and wind-profiling radars use them in order to look out for

Clouds and to track hurricanes. Radars can also take a look *into* the earth - although not very deep - to detect buried mines.

2.5 One way Radar equations

1. Antenna gain

Device for radiating and reciving electro magnetic energy.

$$G(\varphi,\theta) = 4\pi/\Delta\theta\Delta\varphi \quad (2.1)$$

$\Delta\theta$= width of beam in elevation direction

$\Delta\varphi$= width of beam in azimuth direction

Maximum gain fo antenna= $4\pi A_e/\lambda^2$. (2.2)

The radar equation . shows the ability to detect the presence of target

Power flux = $P_t/(4\pi R^2)$. (2.3)

Power flux at target = $P_tG_t/(4\pi R^2)$. (2.4)

Rrdar cross section . incidant power intercepted by the target and radiated back towards the radar

Power rediated = $P_tG_t\sigma / (4\pi R^2)$. (2.5)

Power density = $P_tG_t\sigma / (4\pi R^2)^2$. (2.6)

Power intercepted by an antenna = $P_tG_t\sigma \lambda^2 G_r L_s / 4\pi (4\pi R^2)^2$. (2.7)

Noise : is always present as internal noise from electronics or external noise from galaxy or man made interference .

SNR= $Pr/N= P_tG_t\sigma \lambda^2 G_r L_s / 4\pi (4\pi R^2)^2 N$ (2.8)

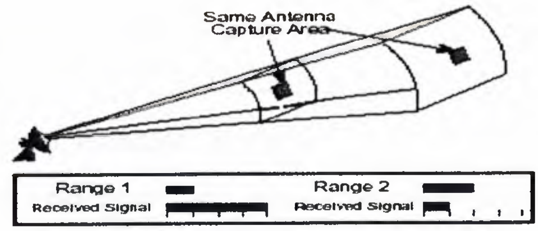

Figure 2.1 Power density vs. range

A receiving antenna captures a portion of this power determined by it's effective capture Area (A_e). The received power available at the antenna terminals is the power density times the effective capture area (A_e) of the receiving antenna. For a given receiver antenna size the capture area is constant no matter how far it is from the transmitter, as illustrated in Figure1

In order to maximize energy transfer between an antenna and transmitter or receiver, the antenna size should correlate with frequency. For reasonable antenna efficiency, the size of an antenna will be greater than 8/4. Control of beam width shape may become a problem when the size of the active element exceeds several wavelengths.

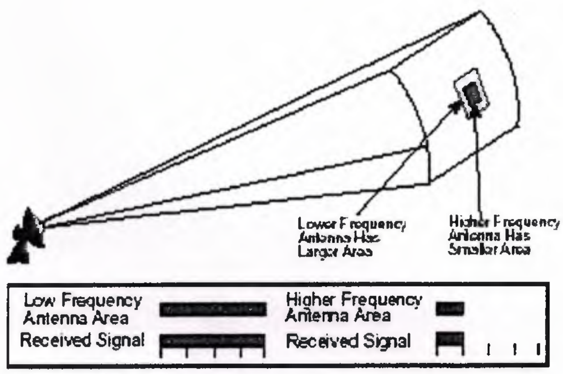

Figure 2.2 Capture Area vs Frequency

The relation between an antenna's effective capture area (A_e) or effective aperture and it's Gain (G) is :

Since the effective aperture is in units of length squared, it is seen that gain is proportional to the effective aperture normalized by the wavelength. This physically means that to maintain the same gain when doubling the frequency, the area is reduced by 1/4. This concept is illustrated in Figure 2.

It is a general purpose equation and could be applied to almost any line-of-sight transmitter to receiver situation if the RF is higher than 100 MHZ. The free space travel of radio waves can, of course, be blocked, reflected, or distorted by objects in their path such as buildings, flocks of birds, chaff, and the earth itself. As illustrated in Figure 1, as the distance is doubled the received signal power decreases by 1/4 (6 dB). This is due to the R^2 .To illustrates this, blow up a round balloon and draw a square on the side of it. If you release air so that the diameter or radius is decreased by 1/2, the square shrinks to 1/4 the size. If you further blow up the balloon, so the diameter or radius is doubled, the square has quadrupled in area.

3. APPLICATION OF RADAR

OVERVIEW

This chapter describes Ground Penetrating Radar, The Application of Radar Sounders to the Investigation of Planets and Small Bodies, Genetic Programming

3.1 Ground Penetrating Radar.

Landmines, buried some centimeters below the surface, are very dangerous weapons not only in wartime but also for decades afterwards. The landscapes of countries like Angola, Cambodia, the former Yugoslavia and even the deserts of Libya are still contaminated with leftovers from wars that are long finished. Ground-penetrating radar can be used to find and subsequently destroy these mines because radar signals are not completely absorbed or reflected at the boundary between air and ground, but can penetrate into soil, provided that the moisture content is not too high.

3.1.1 Area Surveillance or Ground Surveillance.

Most of these radars are small devices (about the size of a business suitcase) mounted on tripods. They serve as a kind of sentry to keep an 'eye' on an area and issue an alert as soon as something is going on. This function is also performed by JSTARS, an airborne MTI (moving target indicator) radar that puts a whole battlefield under surveillance and monitors movements like march columns on the ground. A prototype was successfully used during Desert Storm in 1991.

3.1.2 Air Surveillance. Monitoring the airspace is essential for detecting hostile aircraft and directing defensive measures against them. The first such application was the British Chain Home of World War II. In general, radars cannot look around corners - therefore, these radars are usually located on elevated places in order to achieve maximum coverage area. Better coverage, especially against ground-hugging aircraft, can be obtained if the radar is mounted on an airborne platform such as AWACS (Airborne Warning and Control System). Some radars *can* look around corners: Over The Horizon (OTH) radars exploit certain features of Earth's atmosphere and can detect low-flying objects out to distances of thousands of kilometers.

3.1.3 Shell-tracking.

Radar can detect all kinds of airborne objects, and artillery shells are among them. Shell-tracking radars are used for improving the accuracy of an aircraft's own fire and for measuring the flight trajectory of hostile projectiles, in order to calculate their point of origin.

3.1.4 Ballistic Missile Early Warning (BMEWS) and Ballistic Missile Defiance.

This is where the big ones are. The requirement for high angular resolution at long ranges leads to really huge antennae. The antennae for ABM (anti ballistic missile) phased array radars such as Cobra Dane or Pave Paws can easily take on the dimensions of multi-storey buildings. The latest project in this area is the GBR (Ground Based Radar), which is a part of the American NMD (Nuclear Missile Defiance) incentive. Also called X-band Radar because of the frequency band employed, it is used to find and track incoming long range missiles or individual warheads, preferably before they reach the summit of their trajectory.

3.2 The Application of Radar Sounders to the Investigation of Planets and Small Bodies

So far, the planetary explorations have primarily focused on gathering information about the surface of the planets. Recently, a number of experimental radar sounding instruments have been proposed and are planned to become operational in the near future. The .rest of these radar sounders is MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding). MARSIS (Picardi et al.), is the result of an international collaboration between NASA, the Italian Space Agency (ASI), and European Space Agency (ESA), and will arrive at Mars in early 2004 for a two-year mission. A second radar sounder, termed SHARAD (Shallow RADar) is an Italian instrument (Seu et al.) that will .y on NASA's Mars Reconnaissance orbiter in 2005. MARSIS and SHARAD are in principle very similar. They have more or less complementary objectives. MARSIS has a frequency range between 0.1–5.5MHz and is designed to penetrate the subsurface to a depth of a few kilometers. MARSIS will attempt to map and characterize the subsurface geological structure of Mars, and search for subsurface liquid water reservoirs. In addition to its subsurface exploration goals, MARSIS will study the ionosphere of Mars providing the most extensive amount of data on Martian ionosphere to date. Both MARSIS and SHARAD have the potential of providing answers to a number of questions such as depth of ice-layers in the polar region and recently discovered ice-rich regions in both northern and southern hemispheres of Mars. SHARAD sounder has an instantaneous bandwidth of 10MHz operating between 15–25 MHz. SHARAD is complementary to MARSIS in the sense that it provides higher range resolution. However, it

Will not penetrate as deep as MARSIS. Another area of application for planetary radio sounding is the investigation of small bodies (asteroids and comets). The small size of asteroids and comets provides the opportunity to collect data in a manner that enables topographic reconstruction of the interior of the body. This paper provides an overview of current technical capabilities and challenges and the potential of radio sounders in the investigation of planets and small bodies.

3.3 Multistatic Radar Principles for Automotive Radar Net Applications

3.3.1Current and future Automotive Radar Applications

A current important application that utilizes automotive radar systems is called Adaptive Cruise Control (ACC) which shows an extension in functionality compared to conventional cruise control systems. Each car which is equipped with an ACC system can not only control a reselected cruising speed but is also able to measure surrounding traffic situations by using smart radar sensors and maintains automatically sufficient safety distance to all vehicles ahead. The general objective and the technical challenge of an automotive radar system is to detect all objects inside the observation area and to measure the object parameters range, relative speed and target azimuth angle simultaneously even in multiple target situations. The target azimuth angle can be measured in this case by applying sequential lubing or monopoles techniques. The current technical requirements for a typical ACC system [Roh95] are listed in Table 2.1

Table 2.1 Technical requirements for FDS

Observation area:+-6° in azimuth	Maximum range :180m
Range resolutions:1m	Range accuracy:0.2m
Velocity resolution:1m/s	Velocity accuracy:0.3m/s
Azimuth angle accuracy:0.5⁰	Target acquisition time:100ms

A radar sensor fulfilling these requirements is called in this paper a FDS for automotive applications. The relative narrow observation area in azimuth direction is sufficient for typical ACC functionality but gives serious limitations for additional comfort and safety systems in automotive applications. A huge increase of safety will be accomplished by applications like collision warning, collision avoidance and pre crash detection. These three applications for example have in common that smart radar sensors are needed which cover a wide angular area around each car and that they need angular resolution capability. Therefore an
additional and

alternative type of radar sensors is needed for automotive applications called Near Distance Sensor (NDS). A brief summary of technical requirements for an NDS is shown in the following Table 2:

Table 2.2 Technical requirements for NDS

Observation area:120in azimuth	Maximum range :30m
Range resolutions:0.2m	Range accuracy:0.1m
Velocity resolution:1m/s	Velocity accuracy:0.3m/s
	Target acquisition time:20-100ms

A single NDS does not have any angular resolution and estimation capability at all, while it is required from a network of NDS to have an azimuth angle estimation accuracy of 0.5.

3.3.2 Radar Network

In general, it is possible to extend the FDS system design to be suitable for the aforementioned future automotive applications. This can be accomplished by using narrower antenna beams per sensor and multiple sensors around the car. The drawback of this solution is that the cost of the complete system is growing by the number of sensors and by the number of antenna beams per sensor. A more promising way to achieve the required performance at low cost is therefore the design of a Radar Network. This technique uses a set of low cost NDS distributed for example in the front bumper of a car and a central network node processor. Each NDS will cover a range of up to 30 m and a wide angular area of 120° in azimuth and is connected to the central node processor. Significant to this approach is that each NDS measures very precisely the target range and velocity but does not measure the target azimuth itself. This is one of the technical tasks for the central processing computer calculating the target azimuth by applying multilateration techniques. A conventional FDS can also be linked to this kind of radar network to provide information on targets up to 180m ahead in front of the car. For mathematical convenience the target position will normally be stated in Cartesian (x,y) coordinates rather than in polar (range, azimuth) coordinates.

3.3.3Linear Frequency Modulated Continuous Wave Radar

Pulse radars [Klotz02] can measure and resolve target range unambiguously and there is much experience in building these classical type Radars. Another type of radar waveform is the Linear Frequency Modulated Continuous Wave (LFMCW) radar. An LFMCW radar uses amore complex signal processing but is able to measure the targets range and Doppler frequency simultaneously. Furthermore the high frequency circuitry can be built at low cost, the measurement time is very small, and compared to a pulse Radar synchronization of a group of sensors is easy because of the special system concept: A pulse radar usually uses a reference delay circuitry to measure the signal runtime. Much effort has to be done to trigger the transmit pulse and the delay circuitries of the sensors synchronously and to match the delay times in each sensor.

3.3.4The LFMCW

Radar on the other hand creates the output signal by an oscillator whose instantaneous frequency is changed linearly with time. The signal runtime is measured by the frequency difference between transmit and receive signal so it is sufficient to synchronize the instantaneous frequencies of the local oscillators. The waveform pattern of an LFMCW Radar consists of a set of linearly frequency modulated segments called chirps. The chirps vary on the modulation gradient. For more detail of LFMCW waveform design see [Mei01].

3.4 Applications of the Graph of the Derivative Function

3.4.1 Modeling the Real World: The concept of derivative is utilized in numerous applications. Real-world problems involving instantaneous rates of change of any kind employ derivatives. However, the derivative can also be applied in a geometric or visual manner. In the following two examples we illustrate the use of the graph of the derivative to real-world situations involving volume and traffic. (These examples are taken from Calculus, Single Variable by Hughes-Hallett, Gleason, et al., Wiley, New York, NY, 2000.)

3.4.2The Measurement Principle of the HOCHTIEF Cover meter

The HOCHTIEF cover meter is a device to locate rebase and to measure the concrete cover of rebar. The cover meter creates a low frequency electromagnetic field with a coil. The inductance of this coil changes when metal objects are put near to the coil. The change of inductance depends of the type of steel, the quantity and the distance between the steel and the coil. The influence of magnetic metals (base metals) is much greater than the influence of non magnetic metals (precious metals). The type of steel is known, since in practice mainly base metals are used for armament near to the surface. The mass of steel can be determined by the diameter of the rebars. The diameter of the debars is constant within one object and mostly known. If however, the diameter is unknown, it can be determined by a small opening of the concrete. Since the quantity and the sort of steel are known and constant, the distance between the rebar and the coil, which is equivalent to the concrete cover, can be determined from the change of inductance

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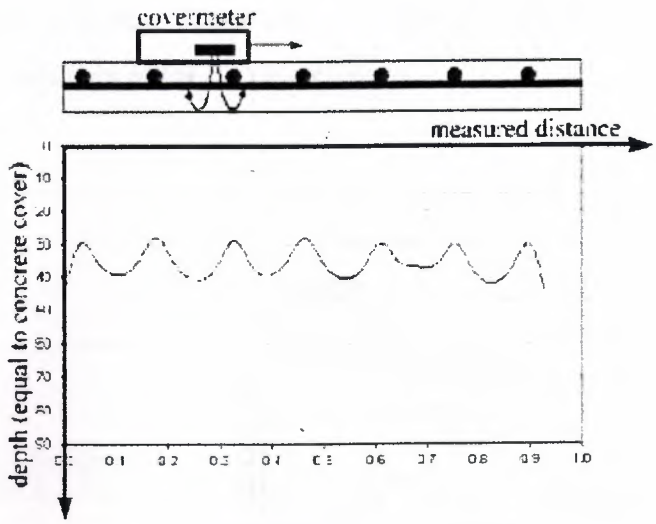

Figure 3.1 Diagram of a cover meter measurement

A measurement is performed by rolling the cover meter across the surface of the concrete. The measured values are transferred to a laptop and displayed in a diagram. Figure 1 shows a concrete specimen with rebase and the corresponding diagram of a measurement. The horizontal axis correlates with the measured distance, while the vertical axis correlates with the measured cover. The highest points of the curve show the positions of debars. These peaks correspond to the minimal distance between the coil and the debars are equal to the amount of concrete cover. In a different mode, with no laptop connected, the built in microcomputer of the HOCHTIEF cover meter detects these peaks on-line during measurement. Every time a peak is detected, the cover meter creates a short audible and visible signal. This function can be used to easily determine the lateral positions of the debars. 3. The Measurement Principle of Radar In civil engineering, radar investigations are used among other things for localization of impurities in concrete structures such as armament or hollow areas. In practice, a pulsed radar system is applied. It consists of a transportable computer, a small monitor with a built-in keyboard and one ore more antennas. The antennas are connected to the computer through special input/output ports. During measurement, the antenna is moved across the surface of the concrete by hand or with a rail system. Figure 2 shows a specimen with a rebar in the middle and the corresponding simplified radar profile underneath. The antenna is moved in direction of the arrow. The antenna emits short impulses of electromagnetic waves (pulse length=1 to 2 ns, frequency approx. 1 GHz) Electromagnetic waves spread spherical in homogeneous materials. Because of the composition of the antenna, the spherical spreading is focused to a shape that can roughly be approximated by the shape of a cone (see figure 2). If the electromagnetic waves hit an interface between two materials, a part of the wave is reflected. The amount of reflection (equation 1) depends on the difference of the dielectric constants of the two materials.

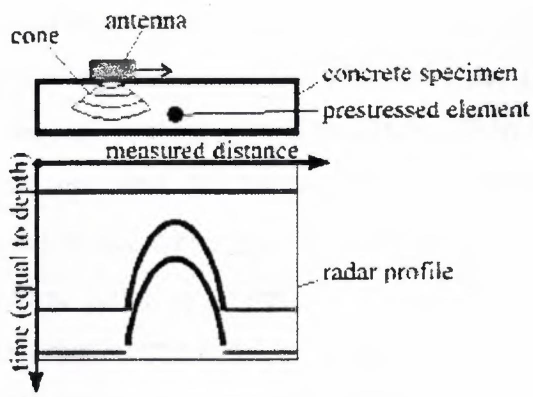

Figure 2.2 Radar of specimen

Reflection coefficient (RC) of an electromagnetic wave hitting the interface between a material with a dielectric constant and a material with a dielectric constant. The reflected parts of the wave are received by the antenna. The intensity of the received reflections of one pulse are recorded in a single line along the vertical axis of the radar profile (figure 3). Waves reflected from interfaces near the antenna are received earlier and therefore displayed higher in the radar profile than waves reflected from interfaces far away (equation 2). The intensity of the reflections is displayed in form of different colors. The recording of all received reflections of one pulse is called a scan. When the antenna is moved, more scans are generated by the survey wheel and displayed next to the previous scan. The sequential scans form the complete radar profile. The horizontal axis of the radar profile corresponds to the measured distance, while the vertical axis corresponds to the depth of the measured object. Because of the cone shaped radiation of the electromagnetic waves, interference patterns like the rebar in the middle of the specimen in figure 2 form a hyperbolic structure in the radar profile. The multiple hyperbolas are caused by multiple reflection of the wave between the rebar and the antenna.

3.4.3 Combination of a Cover meter and Radar

The cover meter is an efficient tool to locate debars near to the surface. The interpretation of the signals is not very difficult, since the cover meter only detects base metals. These advantages, however, limit the range of applications of the cover meter. The gauging depth is 10 cm. A cover meter can only detect the first rebar layer and some parts of a second rebar layer, due to magnetic shielding. Radar has a wide range of applications. It can be used for localization of armament, holes and other objects inside of concrete objects. The gauging range of radar exceeds 50 cm depending on antenna and concrete type. The interpretation of the signals however is difficult, because radar responds to almost all in homogeneities. The area near to the antenna - about 5 cm with the 1 GHz antenna - cannot be seen clearly, because reflected waves are jammed by the emitted pulse. Experience and information about the basic construction of an object are important to interpret the origin of hyperbolas in radar profiles during an investigation In practice, the depth of debars is less then 8 cm and can be localized clearly with a cover meter. Priestesses elements are positioned deeper. They can be localized with radar. By assemblage and synchronization of a cover meter and a radar antenna, HOCHTIEF developed a sensor which combines the advantages of both measurement methods. This CM-Radar sensor marks debars localized by the cover meter graphically in the radar profile.

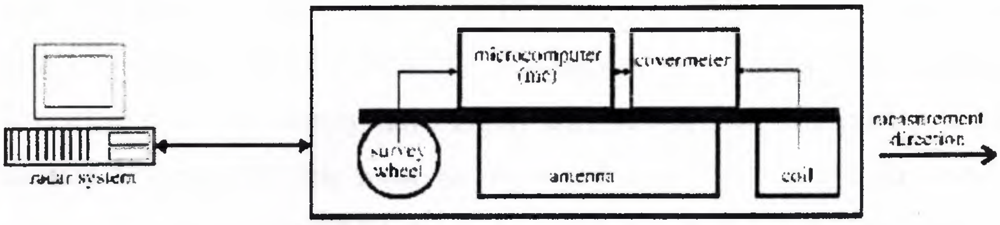

Figure 3.3 CM-Radar sensor

3.5 Applications in the Military

The military and the science of computers has always been incredibly closely tied - in fact, the early development of computing was virtually exclusively limited to military purposes. The very first operational use of a computer was the *gun director* used in the Second World War to aid ground gunners to predict the path of a plane given its radar data. Famous names in AI, such as Alan Turing, were scientists that were heavily involved in the military. Turing, recognized as one of founders of both contempory computer science and artificial intelligence, helped create a machine (called Bombe, based on previous work done by Polish mathematicians) to break any portion of the German Enigma code. As computing power increased and pragmatic programming languages were developed, more complicated algorithms and simulations could be realized. For instance, computers were soon utilized to simulate nuclear escalations and wars or how arms races would be affected by various parameters. The simulations grew powerful enough that the results of many of these 'war games' became classified material, and the 'holes' that were exposed were integrated into national policies. Artificial Intelligence applications in the West started to become extensively researched when the Japanese announced in 1981 that they were going to build a 5th Generation computer, capable of logic deduction and other such capabilities. Inevitably, the 5th Generation project failed, due to the inherent problems that AI is faced with. Nevertheless, research still continued around the globe to integrate more 'intelligent' computer systems into the battlefield. Emphatic generals foresaw battle by hordes of entirely autonomous buggies and aerial vehicles, robots that would have multiple goals and whose mission may last for months, driving deep into enemy territory. The problems in developing such systems are obvious - the lack of functional machine vision systems has lead to problems with object avoidance, friend/foe recognition, target acquisition and much more. Problems also occur trying to get the robot to adapt to its surroundings, the terrain, and other environmental aspects. Nowadays, developers seem to be concentrating on smaller goals, such as voice recognition systems, expert systems and advisory systems. The main military value of such electronic environments - receiving information not only from their own radar, but from many others (principle behind J-STARS). Not only is the information load high, the multi-role aircraft of the 21st century have highly complex atonics, navigation, communications and weapon systems. All this must be organized in a highly accessible way. Through voice-recognition, systems could be checked, modified and altered without the pilot looking down into the cockpit. Expert/advisory systems could predict what the pilot would want in a given scenario and decrease the complexity of a given task automatically. Aside from research in this area, various paradigms in AI have been successfully applied in the military field. For example, using an EA (evolutionary algorithm) to evolve algorithms to detect targets given radar/FLIR data, or neural networks differentiating between mines and rocks given sonar data in a submarine. I will look into these two examples in depth below.

3.6 Genetic Programming

Genetic programming is an excellent way of evolving algorithms that will map data to a given result when no set formula is known. Mathematicians/programmers could normally find algorithms to deal with a problem with 5 or so variables, but when the problem increases to 10, 20, 50 variables the problem becomes close to impossible to solve. Briefly, how an GP-powered program works is that a series of randomly generated expression trees are generated that represent various formulas. These trees are then tested against the data, poor ones discarded, good ones kept and breed. Mutation, crossover, and all of the elements in genetic algorithms are used to breed the 'highest-fitness' tree for the given problem. At best, this will perfectly match the variables to the answer, other times it will generate an answer very close to the wanted answer. (For a more in-depth look at GP, read the case study) A notable example of such a program is SDI's ***e*** evolutionary algorithm designed by Steve Smith. ***e*** has been used by SDI to research algorithms to use in radars in modern helicopters such as the AH-64D Longbow Apache and RAH-66 Comanche. ***e*** is presented with a mass of numbers generated by a radar and perhaps a low-resolution television camera, or FLIR (Forward-looking Infra-red) device. The program then attempts to find (through various evolutionary means) an algorithm to determine the type of vehicle, or to differentiate between a actual target and mere "noisy" data. Basically, the EA is fed with a list of 42 different variables collected from the two sensors, and then a truth value specifying whether the test data was clutter or a target. The EA then generates a series of expression trees (much more complicated than those normally used in GP programs). When new a best program is discovered, the EA uses a hill-climbing technique to get the best possible result out of the new tree. Then, the tree is subjected to a heuristic search to optimize the tree. Once the best possible tree is found, ***e*** will output the program as either pseudo code, C, Fortran or Basic. Once the EA had evolved the training data, it was put to work on some test data. The results were quite impressive: While the algorithms performed well on the training data, the performance decreased a lot when applied to the test data. Nevertheless, the fused detection algorithm (using both radar and FLIR information) still provided a decent error percentage. An additional plus to this technique is that the EA could be actually programmed into the weapon systems (not just the algorithm outputted), so that the system could dynamically adapt to the terrain, and other mission-specific parameters.

3.7 Neural-networks

Neural networks (NN) are another excellent technique of mapping numbers to results. Unlike the EA, though, they will only output certain results. A NN is normally pre-trained with a set of input vectors and a 'teacher' to tell them what the output should be for the given input. A NN can then adapt to a series of patterns. Thus, when feed with information after being trained, the NN will output the result whose trained input most closely resembles the input being tested. This was the method that some scientists took to identify sonar sounds. Their goal was to train a network to differentiate between rocks and mines - a notoriously difficult task for human sonar operators to accomplish. The network architecture was quite simple, it had 60 inputs, one hidden layer with 1-24 inputs, and two output units. The output would be <0,1> for a rock and <1,0> for a mine. The large amount of input units was to incorporate 60 normalized energy levels of frequency bands in the sonar echo. What this means is that a sonar echo would be detected, and subsequently fed into a frequency analyzer, that would break down the echo into 60 frequency bands. The various energy levels of these bands was measured, and converted into a number between 0 and 1. A few simple training method was used (gradient-descent), as the network was fed examples of mine echoes and rock echoes. After the network had made its classifications, it was then told whether it was correct or not. Soon, the network could differentiate as good or better than its equivalent human operator. The network had also beaten standard data classification techniques. Data classification programs could successfully detect mines 50% of the time by using parameters such as the frequency bandwidth, onset time, and rate of decay of the signals. Unfortunately, the remaining 50% of sonar echoes do not always follow the rather strict heuristics that the data classification used. The networks power came in its ability to focus on the more subtle traits of the signal, and use them to differentiate.

3.7.1 Morality: A Quick Thought

All these systems are quite impressive, and perfected models could prove incredible assets on the battlefield. Artificial Intelligence may only get developed to a certain level due to the threat humans feel as computers get more and more intelligent. The concept behind movies such as Terminator where our robotic military technology backfires on us and destroys us are rampant. Are there moral issues that we must confront as artificial military intelligence develops? As Gary Chapman puts it: Autonomous weapons are a revolution in warfare in that they will be the first machines given the responsibility for killing human beings without human direction or supervision.

3.8 Other Applications for Functionally Oriented Targeting Technology

It is important to note that the same enhanced surveillance capabilities MP-RTIP provides will have many other important applications in both war and peace. During war, the ability to precisely track and characterize individual vehicles will be invaluable for supporting counter air operations by making it easier to detect and target missile Tells. In peace, it will provide reliable and early indications and warnings of potential aggression, help verify treaties, and contribute to confidence-building measures. Precise, real-time surveillance of movement will also make crisis management much easier by making it possible to see if diplomatic and military actions are having the desired effect of causing forces to stop movements. Although developments promise to make it technically feasible to apply the functionally oriented air power targeting theory to fielded land forces, realizing the advantages of such targeting is unlikely unless the Department of Defense takes further action. Clearly, the United States must devote the necessary resources to completing the development of the required technologies. For C2ISR systems, this means accelerating the development of the technically low-risk MP-RTIP. Next, it is necessary to field MP-RTIP-equipped C2ISR systems in the appropriate numbers. The current requirement for 19 JSTARS did not consider either the immense advantages provided by the functionally oriented targeting theory or the system's value during peacetime operations.[16] As important as technology can be to success, it is not sufficient by itself. Success requires institutionalizing the targeting theory in joint and service doctrine and training. Clearly, given its ability to guide thinking on key cause-and-effect relationships, the functionally oriented air power targeting theory can and should play a valuable role in helping determine future force structure and training requirements.

4. MILITARY RADAR

Overview

This chapter describe military radar application in more details, Military Theory and Information Warfare, and From Technology to Theory and Doctrine Competing Concepts of Information Warfare

4.1 Introduction

During the Cold War the Soviet Union, western Europe and North America placed great reliance on radar networks to provide early warning of airborne nuclear attack (Dose 1983; Jockel 1987). From the early 1950s isolated stations were constructed in Canada, Alaska and Greenland in order to identify unfriendly aircraft (search or surveillance radars) and to direct the fighters that would intercept them (search and height-finding radars). This article describes the ground-based radar deface lines of northern North America over the past four decades. Though general descriptions of their character and continent-scale maps of their locations have been published (Jockel 1987), little information on individual military stations, including radars, is available for public inspection. There are many, rather dated, non-technical articles dealing with the radars in Arctic Canada and Northern Alaska (for example Moreno's 1957 and La Fay 1958) but very little is known of those elsewhere in North America. Much information on existing and even abandoned stations remains secret. When declassified it usually is difficult to find unless the researcher has access to military libraries such as those of the Department of Defense in Ottawa.

4.2 Military Theory and Information Warfare

The effect of technology on warfare often has colored the predictions of theorists, elevating to eternal truths what we discover in retrospect to have been passing historical epochs. Free of the context of the 1920s, Doucette seems dazzled by the revolutionary possibilities of air power. He cannot be criticized for not anticipating anti-aircraft radar and surface-to-air missiles, nor were he and his contemporaries alert to the continued success of low-tech, ground-based asymmetric strategies of determined, resilient adversaries. But one word--Vietnam--provides a corrective to his assertions. Air power has had a tremendous effect on warfare, but it simply has not lived up to Douhet's prediction that it would be the decisive factor in all future conflicts. Current interest in information warfare and the manifold effects of the information revolution on the conduct of war cause many to proclaim a revolution in warfare. Evangelists of information warfare, like forerunner evangelists of air power, sea power, and artillery, risk losing sight of historical context and the continuities of conflict. We are once again faced with a genuine technological revolution which seems to offer an entirely new mode of warfare, one that advocates insist will supplant existing modes. Thus military theorists and defense planners are once again challenged to use new technologies for the competitive advantages they may offer on the battlefield, while bearing in mind their limitations. This article reviews the effects of information technologies on military theory, tempered by insights into the consequences of previous technological revolutions. Issues emerge that are independent of any technology or international security environment. They include an appraisal of the ability of contemporary analysts and theorists to challenge promises of unprecedented change, and an examination of the theoretical implications of the so-called "revolution in military affairs." Related issues include the need to avoid being dazzled by the new technologies (while not exaggerating their significance) and at the same time appreciating the extraordinary near-term advantages and capabilities they afford. Finally there is the matter of balance. We must use the technologies to advantage, neither misapplying them in haste nor hesitating until we miss the opportunities they represent.

4.3 Technology, Society, and War

The enormous popularity of *The Third Wave* and *War and Anti-War* has given currency to the notion that historical epochs--and the wars that go with them--are characterized by revolutionary technological breakthroughs that cause "waves" of socioeconomic change.[2] According to the authors of those texts, Alvin and Heidi Toffler, the first (agrarian) wave was characterized by animal domestication and agricultural cultivation; the second (industrial) wave by mechanization, mass production, and the division of labor; and the emerging third (information) wave by digitization, computers, and information technologies.

While the Tofflers' thesis is less than perfect,[3] they are generally correct with respect to the goals of warfare imposed by the prevailing socioeconomic frameworks of the various epochs. Successful pre-industrial war was generally predicated on the seizure of territorial assets, control of them, or both. Successful industrial age war was about reducing the means of production and out-manufacturing one's opponent--dubbed schlachtmaterial by the Germans during World War I. If the analogy holds, the advance guard of Pentagon theorists and defense analysts contends, future wars will be waged for control of data, information, and knowledge assets. Weapons of war also reflect the dominant aspects of each era's socioeconomic paradigm. Rifled arms, iron-clad ships, machine guns, tanks, and aircraft depict the evolution of industrial age war. The precision-guided monition, popularly known as the "smart bomb," heralds for some the weaponry of the information age. The deeper expression of any age, however, can generally be found in the organization and culture of the warfighting community. Some propose that hierarchical command structures and ponderous military-industrial bureaucracies, created to fit industrial age needs, must now give way to the decentralized, "flattened" business network of the information age. The success of businesses that have adapted to the new world of networked computing, communications, and data processing--and the failure of those that have not--seem to the Pentagon's reform-minded Young Turks to be compelling arguments in favor of introducing commercial processes and procedures into the military. But there are liabilities associated with moving too rapidly to reengineer the force around new technologies without first considering interests and risks. A view that is too techno-centric risks revisiting such flawed experiments as the Army's Pentomic division of the 1950s, the 280mm atomic cannon, the flying jeep, and the jet-pack-powered infantryman. The appearance of new weapons and new technologies has sometimes caused military leaders and theorists to make errors in judgment, misreading the meaning of the new technology and producing poor returns on the investment, whether on the battlefield or in the view of history.

4.4 Technology and Military Theory

Some attribute current interest in Sun Tzu, the Chinese strategist and philosopher of war, to the advent of the information age and its military subset, "information war." This may seem curious, for Sun Tzu lived some 2500 years before the invention of the computer, the fiber-optic cable, or the orbital satellite. What appeals to many current military writers is Sun Tzu's simple, aphoristic approach to warfare based on the principles of superior intelligence, deception, and knowledge of the mind of one's enemy. Current theorists therefore conclude that the new mode of warfare ushered in by the information revolution will have sweeping effects on the conduct of war in the near future. Precision weapons will be directed at the enemy's decisive point(s) at the critical moment through "information superiority." Superiority, in turn, will occur through space, near-space, and ground-based sensing technologies that will transmit attack instructions in real time via a "system of systems" that links all parts of the battle space. Some even predict that the new technologies will penetrate, if not lift, the fog of war. The more radical of the theorists predict that information warfare will not only provide dominant awareness of the battle space; it will also allow us to manipulate, exploit, or disable enemy information systems electronically. The intent here evidently is to knock an enemy senseless--literally--and leave him at the mercy not only of conventional kinetic attack, but of psychological operations aimed at controlling his perceptions and decision-making abilities. Public opinion is to be shaped, leaders will be cut off from citizens, and the mind of the enemy will be directly penetrated and his strategy defeated. In the ideal case all this will occur bloodlessly, fulfilling Sun Tzu's goal of victory without battle. At least that's the theory. Unlike Sun Tzu, whose timelessness owes much to his lack of tactical or technical advice, most military theorists of the past 500 years have based their work on either specific technologies or scientific assumptions peculiar to the prevailing thinking of their age. This may seem axiomatic, but it is worth considering--given the fact that many of them sought enduring wisdom in their work. Machiavelli, whose insights into military character and the importance of political motives in war prefigures the thinking of Clausewitz, deemphasized the technical aspects of warfare. His exception, however, seems to prove the rule. The theorists that followed him--continuing to this day--demonstrate a predilection for technical fixes.

• The renaissance and the emergence of the scientific revolutions of the 16th and 17th centuries stimulated a fascination with the machine which extended beyond the realm of science and technology proper into the culture and, inevitably, into the making of war. Engineers and mathematicians, among them Galileo and Niccolo Tartaglia, attempted to develop ballistic equations that would refine the blunt and unpredictable force of artillery. Advocates of artillery, which had become progressively more effective starting in the 15th century, believed that it would dominate all wars in the future, sweeping away the age of cavalry and diminishing the importance of the foot soldier.

• The preeminent military theorist of the 17th century was an engineer, Sebastian le Pester de Vauban, the master of siege craft and fortification. Vauban produced no theoretical writings on the nature of war or the integration of new technical innovations into strategy. A technologist, he was concerned only with the creation of plans and formulae for the successful attack of enemy fortresses and the protection of one's own. The study of war in this age of science and reason had become detached from theoretical underpinnings. It used a purely quantitative means of analysis to focus on tools and methods of applying them.

• The tradition of "scientific" war reached its theoretical apogee during the Industrial Revolution in the writing of Baron Antoine Henri de Jomini. Jomini, who served as Chief of Staff to Marshall Ney, analyzed Napoleon's campaigns in a search for the unchanging principles and practices of war. He believed that quasi-mathematical concepts dictated the proper organization of military formations, and the direction and size of attack at the "decisive point." War was, for Jomini, reducible to propositions that were universally true and universally applicable across the spectrum of military conflict, much as any natural compound could be smelted into its elemental nature and thus understood. And despite his embrace of scientific principles, Jomini's decline as an enduring military thinker was due in large measure to his neglect of specific technological innovations. Rifled arms, high-explosive shells, machine guns, and later mobile armor and air power rendered his supposedly immutable rules about "interior lines" and the geometry of the battlefield highly dubious.

• Carl von Clausewitz, Jomini's 19th-century rival, has held up well by comparison. He, like Sun Tzu and Machiavelli, focused less on military technology or contemporary intellectual fads (like Jomini's Newtonianism), and more on war as an eternal human phenomenon, not rational but capricious, not reducible but complex . . . in short, a human activity.[5] He rejected quantitative analysis and scientific formulae in favor of philosophical insights. Clausewitz's concept of "friction" as inherent in war, his belief that in every battle and in every war there is a "culminating point," and his insistence upon recognizing the passionate, violent nature of conflict are not bound to any age. Unlike most of the technical theorists, Clausewitz was mainly concerned with the ultimate goals of conflict. Thus his insistence on the political nature of war and the oft-quoted aphorism that war is "an act of force to compel our enemy to do our will."[6]

• Alfred Thayer Mahan, the prophet of sea power in the late 19th century, was concerned with grand strategy, specifically that of the United States in its development as a world power. Mahan's views on the importance of geography, trading economies, and styles of government are clouded by his obsessive promotion of sea power to the neglect of land power. The new technology of the steam gunship and a selective reading of military history convinced him of the absolute primacy of sea power in ensuring the commercial and military success of nations, and caused him to dismiss the importance of railways and the growing significance of motor transport on land.[7] Nor did he pay much attention to the development of torpedoes and submarines, which promised to make armored capital ships vulnerable to attack.[8] Like his strategic inspiration, Jomini, he continued to insist on permanent scientific principles of naval strategy which would remain unchanged regardless of technical alterations to the equation.

Some may recall that even Clausewitz wrote extensively of tactics and operations. Who has studied his chapters on "Attack of Convoys" or "Defense of Swamps"? These sections of *On War* are seldom read and justifiably so; wed to their particular time and place, they are now of mere historical interest and largely irrelevant to the making of modern war. So we tend to overlook his neglect of sea power, as egregious in a sense as is Mahan's ignoring land power, because of Clausewitz's transcendent insights. Mahan, captured by a long-gone technological moment and the zeitgeist of a forgotten age, does not appeal today because he lacks Clausewitz's reach and depth.

• Air Marshal Giulio Douhet was the last great military techno-prophet before the advent of nuclear weapons (which produced their own generation of influential strategic thinkers) and before the current crop of information warfare theorists. Even before World War I, Douhet saw the potential of aviation as a transformational technology in war. His mature writings, from the 1920s, predicted the emergence of air power as the dominant realm of war and the aerial bomber as the predominant tool: The brutal but inescapable conclusion that we must draw is this: in the face of the technical development of aviation today, in case of war the strongest army we can deploy in the Alps and strongest navy we can dispose on our seas will prove no effective defense against the determined efforts of the enemy to bomb our cities.[9] Douhet anticipated rapid strikes by aerial bombers that would devastate defenseless cities, causing terrified societies and demoralized national governments to capitulate before any counterattack could be mounted. Defenses against air power were bound to fail; they were a waste of resources, he said, based on what he had seen during World War I. Armies and navies, ponderous and surface bound, were virtually useless because wars were likely to be won or lost in the air before fleets could be put to sea or armies mobilized. He tells us unequivocally: If I may be so bold, I have mathematical certainty that the future will confirm my assertion that aerial warfare will be the most important element in future wars, and that in consequence not only will the importance of the Independent Air Force rapidly increase, but the importance of the army and navy will decrease in proportion

4.5 Information Warfare: Prelude to Revolution

The revolution in information technology, from the transistor through widespread digitization toward global socioeconomic revolution via deeply networked communications, has profoundly influenced analysts and planners in and out of uniform. It has also produced a cottage industry in information warfare concepts, studies, and proposals as the military attempts to understand, derive principles and theories for, and apply the new technologies. The frequently confusing nature of these products stems from three principle sources: the rapidity of technological change; the very nature of information and information technology, which blurs distinctions between civil and military use and targets; and uncertainty about the nature of information warfare itself.[11] As with the air power revolution, new and apparently revolutionary information technologies promise an immense effect on the conduct of war.

And as with air power, theorists are emerging to wrestle with the nature of information age war, seeking clues as to how it might change the shape of conflict in general. The Persian Gulf War afforded the average American his first (albeit filtered) glimpse of the future of warfare. Millions were treated to precision-guided bombs annihilating targets in downtown Baghdad, learned of satellite uplinks from the battlefield that provided real-time connectivity, and applauded the ability of stealth aircraft to ensure aerial dominance. These outcomes were enabled by battlefield tracking and targeting systems that allowed American forces to identify and attack targets well beyond the line of sight, by advanced aerial reconnaissance from airborne warning and control systems (AWACS) and from joint surveillance and target attack radar systems (JSTARS), and by space-based satellite sensors. The latter provided highly accurate battlefield information to combatants, tightening decision cycles and dramatically accelerating the tempo of combat. Everyone seemed to understand that something was different about this "videogame war"; there was much more to the spectacle than the immediacy of Vietnam's television war 20 years earlier. Since Desert Storm there have been orders-of-magnitude improvements in technological capabilities. For example, the system used by Gulf War commanders to transmit messages could move 2400 bits of information per second. The current commercially developed and operated Global Broadcast System transmits 23 million bits per second into Bosnia. A message that took more than an hour to send in 1991 can now be sent in less than a second.[12] The challenge for the US military and for political leaders has been to keep up with the pace of change in information technologies generated by innovations in the commercial, not defense, market and driven by consumer, not war fighter, demand. The convergence of digitized information, computers, networks, cellular communications, satellites, precision munitions, and data fusion technologies has translated into quantifiable improvements in volumes of data exchanged, experimental concepts, and testbed programs. The idea of an information-based military technical revolution is reflected in increased understanding of what is happening on the battlefield and improved ability to apply destructive force when and where we want to. These capabilities are built upon specific technologies, such as improvements in sensors carried on advanced AWACS and JSTARS, unoccupied aerial vehicles, or electro-optical satellites with one-foot image resolution and wide-area coverage. Others include intelligent fusion of data products by combining artificial intelligence with "knowledge bases" to process, manipulate, and tailor information for specific user needs; "sensor to shooter" couplings (automatic target recognition capabilities are not far off); and integrated, high-speed, high-capacity battlefield communications capabilities via the aforementioned Global Broadcast System (GBS) and the Global

Command and Control System (GCCS), both of which are designed to provide the right information to the right user at the right time and place. Mastery of information and information processes leads naturally to increases in precision and lethality. The quest for battlespace omniscience can improve tracking and targeting capabilities, aggravating the adversary's problem of finding sanctuary. What can be seen, in the parlance of military analysts, can be hit; with these new information technologies, nearly everything that is not hidden can be seen and is therefore vulnerable. The current revolution in information technologies promises military leaders an extraordinary extension of previous battle space awareness, information dissemination capabilities, and ubiquitous "smart" weapons. Together they offer the ability to know what is happening, what is important, where the points of maximum leverage are, and connection to the means to apply force at those points, all on a vastly compressed time scale.

To appreciate the magnitude of these changes, recall that as recently as the 1970s reconnaissance was conducted by manned aircraft or ground patrols. Both called in data that were plotted on maps for analysis by intelligence experts. Hours at best, more likely days or weeks, could elapse before critical information was sufficiently processed to be forwarded to planes in the air or soldiers in the field. In Panama in 1989 things had still not changed substantially. Today, digital 3-D map representations could provide a complete picture of the battle space to every friendly combatant, updated as events occur. Satellite imagery, or live video from an unoccupied aerial vehicle (UAV) equipped with a digital camera, is potentially available in real-time to a soldier in the field via a buggerized laptop computer and a global positioning system (GPS) receiver. The soldier and his comrades could then synchronize their actions with the flow of battle, unaided by the traditional hierarchical and bureaucratic command and control system. Automatic target recognition systems currently in prototype may eventually remove most of the middlemen in such an environment, directing long-range precision strikes as soon as information is received from the sensor. All this is perceived to occur without human intervention. If these concepts mature, decision cycles for commanders and soldiers would be both compressed and enriched, accelerating the tempo of war fighting, demanding more initiative-based, decentralized decision-making, reducing personnel in the field and on the staff, and eliminating much of the noise, error, and viscosity normally inserted by human links. These communications and intelligence-gathering advantages also would be available during any non-combat operation in which our 21st-century forces might participate: humanitarian, peace enforcement, or support of domestic authorities. Given the seemingly decisive comparative advantage which information technologies offer the possessor, the intrinsic value of data and information would seem to be on the rise. The Gulf War suggested how new awareness and faster targeting capabilities relative to adversary capabilities could translate into a smashingly decisive victory in the field. Therefore, the new technologies--highly sophisticated and integrated, vulnerable to both kinetic and electronic disruption--will themselves become objects of war. Hence the enthusiasm for information warfare. While intelligence and operations security have always been important in wartime, and lines of communications have always been targets, current thinking establishes the preeminence of "information superiority." According to the Joint Chiefs of Staff publication *Joint Vision 2010*: "We must have information superiority: the capability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."[13] So by announcing that the sine qua non for success in future conflicts is "information superiority," we have defined new vulnerabilities and targets for the attack and for the defense. Battlefield employment, exploitation, and targeting, and protection of the means of gaining and maintaining superiority, presently define the conventional range of the information warfare spectrum. The various Pentagon permutations--command and control warfare (C2W); command, control, communications and intelligence (C3I); command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR)--describe the realm of traditional warfare. They are reflected in the addition of new information technologies to units trained for traditional force-on-force combat. The popular image is that of a soldier with a wearable computer and a GPS terminal, calling in long-range precision strikes. But beyond this image, and to many the more revolutionary and important aspect of information warfare, are the vulnerabilities of national and military infrastructures that rely on a host of modern automation and information technologies. The information revolution is driven by the changes that information technologies are creating as they are integrated into the cultural, economic, and civic life of society. Essential national infrastructures such as telecommunications, transportation, electrical power, emergency services, and food, water, and fuel distribution are dependent on digital, software-based systems that are controlled through networked, publicly accessible communications interfaces. International commercial and financial transactions are increasingly dependent on electronic networks. It has been estimated that 62 million Americans now use the Internet to communicate, bank, shop, and do business.Public switched networks on which essential public and commercial infrastructures depend have shown themselves vulnerable to penetration, disruption, and manipulation. Furthermore, a combination of cost concerns and the superiority of established commercial systems has created a situation in which an estimated 95 percent of all military communications travel over commercial systems. With the recent completion of an accord on telecommunications deregulation, these networks become subject to foreign ownership and control. In these changes lie the concerns that America, the most sophisticated, highly networked information age economy and society, has become vulnerable to an "electronic Pearl Harbor."

4.6 From Technology to Theory and Doctrine Competing Concepts

Definitions of information warfare are abundant and protean. The most recent Department of Defense definition describes information warfare (IW) as "information operations (IO) conducted during time of crisis or conflict to achieve or promote specific objectives over a specific adversary or adversaries."[15] According to the Joint Chiefs of Staff, IW can be waged in wartime within and beyond the traditional military battlefield. As a subset of IW, command and control warfare (C2W) is an application of IW in military operations that specifically attacks and defends the C2 target set. However, the capabilities and disciplines employed in C2W (psychological operations [PSYOP], deception, operations security, and electronic warfare) as well as other less traditional ones focused on information systems can be employed to achieve IW objectives that are outside the C2 target set. This attempt to define the information-based revolution for national security policymakers and war fighters is multilayered, a bit confusing, and apparently deliberately vague. Agreeing that IW is a field with the potential for great effect, perhaps the linchpin of a revolution in military affairs, questions still abound about how it will affect military culture and future conflicts. While issues of integration remain problematic, the spectrum of possibilities may be laid out as follows. At the most incremental level of change, there are those who would overlay new and near-future technologies on current military systems. Such an effort can be seen in the "digital battlefield" of the US Army's "Force XXI," and the robust, highly detailed Department of Defense "Advanced Battlespace Information System."[17] These programs perceive information technology as a powerful force multiplier for kinetic warfare that would not in itself be substantially changed from the heyday of industrial age war. Others have suggested that the nascent information-based revolution in military affairs will eventually make possible radical reform of military organizations and tactical doctrines while still operating within the traditional parameters of warfare--dominating an adversary on a physical battlefield. Such approaches can be found in the "Army After Next" project, the Marine Corps' "Sea Dragon" concept, the Navy's "Forward . . . from the Sea," and the Air Force's "New World Vistas." The concept was developed most fully in 1996 through the Defense Science Board's "Summer

Study on Tactics and Technology for 21st Century Military Superiority." The report envisioned restructuring US ground forces into small "distributed combat cells" rather than hefty battalions and divisions, their war fighting power multiplied by sensors, robotic systems, precision logistics, and the ability to call in long-range precision firepower from land, sea, or air. All of these changes were of course predicated on a robust information infrastructure.[18]

Finally, where science fiction meets science fact, there is the emerging concept of "cyber war": conflict in the purely digital realm consisting of remote attacks on critical information nodes, links, and databases to disrupt, exploit, disable, or deny service. Information warfare of this sort would also include deception and psychological operations at a much higher level of subtlety and effectiveness than expected in conventional operations, given the manipulability of digital information. Combinations of all of the foregoing concepts appear in multiple-fence-straddling positions such as the one established above by the Joint Staff.

4.6.1 Theories of Information Warfare

So what do the theorists expect in a future adapted to the emerging information age? The answer presently seems to be faith in the future of information technologies to produce revolutionary changes in military affairs and the conduct of war.

• John Arquilla and David Ronfeldt, two of the first and best, have produced a number of intellectually rich articles, most of them examining the twin concepts of "cyber war" and "net war."[19] In their view, cyber war refers to an information-enriched style of future military conflict in which the struggle for information dominance holds the key to victory. Netwar, the more heady form of future conflict, refers to inter-societal contests of perceptions and national messages. Aquiline and Ronfeldt are well known for their comparison of information warfare to the "decapitation" techniques employed during the 13th century by the Mongols, who used superior speed and lines of communication to control numerically superior enemies located over a wide area. In this context, cyberwar would allow a network of decentralized information warriors to achieve decisive, bloodless victory--a sort of post-industrial blitzkrieg--by directly targeting an adversary's information "nerve centers." Netwar in theory could prevent real wars (or cyberwars) by allowing for deterrent posturing and for control over potential adversaries' perceptions.

• Another group of theorists--George Stein, Richard Szafranski, and Owen Jensen--are associated with the Air University at Maxwell Air Force Base in Alabama. Much of their theoretical work has appeared in *Airpower Journal*, a hotbed of discussion of information

warfare. In general this group maintains that the highest potential of information warfare is as a new realm of conflict in which information (or knowledge) itself is both the center of gravity and the principal weapon. This type of futuristic conflict would occur in a transformed environment; weapon platforms as we now know them would be outmoded. No digitized battlefield, no info-tech applique on existing systems, but something fundamentally different.
To paraphrase their ideas, information warfare would assume an autonomous role in "information campaigns" far beyond its application as a force multiplier in more linear military evolutions. Emerging information technologies might allow us to battle the mind of the enemy via customized propaganda, morphing reality into a fictive universe which we serve up through diversified information networks. These theorists suggest that information warfare, not unlike Arquilla and Ronfeldt's concept of netwar, would be a high-tech, more sophisticated form of psychological operations and propaganda, directed at mass or niche audiences. They conclude that technology will be used to control an opponent through strategic information dominance: tailoring his information content to suit our interests, conditioning his knowledge and understanding of the situation, ideally without his awareness.[20] As defined by the Maxwell school, information warfare seems to be the functional equivalent of conventional concepts of strategic air power.[21]

• Martin Libicki, a standard-setter on the subject of information warfare who has worked harder than most to bridge the gap between ideas and action, has suggested that information may ultimately prove to be a universal deterrent to war because of the global transparency that it will foster. He suggests that a network of satellites, and of air, ground, and sea-based sensors, will ring the earth, affording a God's eye view of the world and all its activities. A global information infrastructure will link users of this information, ensuring a sort of universal awareness of military and other activity. Under such conditions, any border incursions or sudden mobilization would be sensed and could be thwarted immediately, ostensibly by exposing and threatening the would-be aggressor. Were the aggressor to persist, the international community would only have to dam up the aggressor's bit streams and the information flows essential to his war effort, economy, and national infrastructures. Such procedures would (ideally) curb his ambitions without firing a shot. These authors are exploring new ways of thinking about war and warfare in an era of change. They are to be commended for attempting to expand the intellectual horizons of often parochial, hide-bound military and civilian bureaucracies. The assumptions of many of these theorists, however, are highly dependent on the technological innovations of the moment. Even emphasizing as some do, recalling Sun Tzu, that the real object of information warfare is the human mind, the visions they present are unattainable without the array of new and emerging technologies assumed to be part of a fully netted information age world.

Our ability to combat or deter adversaries using cyberspace tools is predicated on their being as reliant on information technologies as we are. Threatening to cut off a hostile neighbor's bit streams will be credible only if two conditions are met. The first is that he is largely dependent upon them for survival; the second is that we have the ability to turn them off. Little of value will be accomplished by niche-casting propaganda at a nation that lacks satellite television or an Internet connection. As recently as 1997, it has been suggested, half the world's population had never even made a telephone call. Similarly, strategic psychological operations, no matter how overwhelming and sophisticated technologically, are likely to be far more effective in a democracy than in the authoritarian states that currently present many of our most significant security threats: Iran, Iraq, Libya, and North Korea. In fact, it is interesting that such a strategy would appeal to an American theorist because it is our highly democratic, media-saturated, and technologically sophisticated society that is most vulnerable to a counterattack. Some information warfare theorists have attempted to shield themselves from accusations of technological determinism by suggesting that we need not follow slavishly the technology wave. Rather, we should use our imaginations to determine what we want it do for us and then develop the technology to fit those needs. This ignores the fact that technology development, much like the formulation of strategy and tactics, is a co evolutionary process. New technologies emerge to either exploit or compensate for weaknesses in existing technologies. Inventing a theory of information warfare risks falling victim to the kinds of fallacies that Douhet encountered. Unable to see the future, he imagined one based on linear projections of extant technologies. Unable or unwilling to imagine counter-air defenses, or the limitations of strategic bombing in the face of a determined foe, he saw only a pristine view of air power, conducting operations with impunity against helpless, terror-stricken citizens.

4.6.2 Technology and the Current Revolution in Military Affairs

Technology-driven changes in military affairs are transient, sometimes eclipsed in less than a generation, and the competitive advantages that they offer are increasingly fleeting. Andrew Krepinevich, one of the leading thinkers in this area, has identified ten technology "revolutions" from the advent of infantry warfare to the birth of nuclear weapons. Steven Metz and James Kiewit of the US Army War College have divided military "revolutions" into major and minor forms. The first are mostly technology driven and malleable; the others ride on broader socioeconomic "waves." It is clear that specific technologies have sometimes had significant effects on the conduct of warfare; gunpowder, internal combustion engines, breech-loading mechanisms, radio, and radar are among the most memorable. But war remains essentially what it has been for centuries: Clausewitz's "act of force to compel our enemy to do our will." In a century that began with active cavalry regiments and ends with nuclear arms, stealth aircraft, and theories of information warfare, progress has been continuous and evolutionary. In Machiavelli's time, improvements in artillery led enthusiasts to predict that it would supplant all other tools of war. Five hundred years later, artillery is still improving, and it still plays a subordinate role in combat operations. So perhaps it is too much to expect truly revolutionary new technologies to lead to fundamental changes in the forms and functions of conflict.

The German blitzkrieg is sometimes offered as a compelling example of creative minds deriving a competitive edge over adversaries by astute application of technology to the problems of land warfare. The Germans combined armor, radio communications, and tactical air support to remarkable effect in Poland, the low countries, and France during 1939-40. But once others had an opportunity to analyze their techniques and methods, the edge was lost. As the Germans later drove into Soviet territory, their logistics train was stretched beyond endurance and the army, in effect, became "de-modernized." The blitzkrieg--material intensive and dependent on frequent resupply to maintain communications, mobility, and combined arms capabilities--fell apart, and the war in the east degenerated into a slow, brutal contest of attrition. The benefits of technological edges can be fleeting indeed. The 1997 "Army After Next" winter war-game, which featured a face-off between the United States and a peer competitor, began with two surprises: a laser attack on US space-based satellite reconnaissance, GPS, and communications capabilities, followed closely by a nuclear electro-magnetic pulse burst in space. The combined effects of these unexpected initiatives reduced by 50 percent the military information infrastructure on which most of our new weapon systems are dependent. Predictions about the effects of technology are almost always erroneous, even when the technology involved justifies the designation "revolutionary." The airplane, an unprecedented technological breakthrough which added a new dimension to the battle space, repeatedly has been shown to be insufficient in and of itself to transform war. Contrary to Douche's assertions, command of the air has certainly not made armies and navies obsolete. And as Michael Howard has pointed out, when the Allies bombed the cities of Germany toward the end of World War II and the conduct of strategic air war most closely approached Douhet's vision, it not only failed to force the enemy to capitulate, but actually hardened resistance. Clausewitz reminds us that the human elements of war are extraordinarily difficult to gauge. If necessity is the mother of invention, asymmetric tactics, strategy, or technological countermeasures will always upset the best laid technology-based plans. Nuclear weapons were supposed to make conventional arms obsolete and totally revolutionize warfare. Massive retaliation, the Eisenhower-era strategy for their deployment, ignored conventional capabilities only to find that the will to use weapons of mass destruction was lacking. Dirty little wars on the periphery continued and guerrillas flourished, despite our fearsome nuclear arsenal and the threat of certain annihilation we wielded. Our bluff was called in Korea and later in Vietnam, and the nukes remained holstered. Soldiers at the dusk of the industrial age faced the same mud and mayhem that had confronted their counterparts during the Napoleonic wars at its dawn. Technological advantages in war have generally proven ephemeral; neither can a technology-driven theory of war or strategy for war hold sway for very long. Nor do old weapons necessarily go out of style--new tools are just added to the box. Technology-driven revolutions in military affairs entail the reorganization of forces and doctrine around those new technologies. Anyone who believes that the nature and rate of change qualify for designation as "revolutionary" should read their mandate carefully and proceed cautiously. It is important to grasp the functional significance of technological innovations; it is equally important that risks and vulnerabilities--the stuff of strategy--remain foremost in assessing their political and military implications. The most durable military theory focuses less on the latest technology and more on the infinite complexity of the user. Military theory provides valuable guidance on how to effectively exploit new technologies through its explanation of cause-and-effect relationships. Given the importance of air power to U.S. military strategy, air power targeting theory should play a key role in transformation decisions. U.S. Air Force leaders are advocating a targeting theory called effects-based operations (EBO) that is very similar to the functionally oriented targeting theory that airmen applied during World War II strategic bombing campaigns.[1] As the name implies, functionally oriented targeting is designed to create effects that make it impossible for a specific system to perform a function that is vital to an enemy's ability or will to continue effective resistance. It calls for achieving systemwide functional effects without destroying a significant part of the entire system. Compared to attrition-oriented targeting that relies on achieving objectives through causing massive destruction, a functional orientation has the potential to provide many important advantages. These advantages are derived from the potential to achieve desired objectives faster and with far fewer casualties, whether those casualties are friendly, civilian, or enemy. Much of the current interest in the functionally oriented targeting theory can be traced to the ability of stealth and precision-guided munitions technologies to overcome the problems of high losses and poor accuracy that handicapped strategic attacks during World War II.[2] Many air power supporters believe these technologies explain the dramatic outcome of Operation Desert Storm.[3] They also assert that using the B-2 bomber and the global positioning system (GPS)-guided joint direct attack monition (JDAM) made a decisive contribution to Operation Allied Force in Kosovo.[4] Although Air Force EBO discussions focus almost exclusively on the advantages associated with strategic targeting, recent developments in technology make it necessary to consider the advantages of a functional, rather than an attrition, orientation when targeting fielded land forces.[5]

4.7 Targeting Requirements

To understand the transformation potential of functionally oriented targeting, it is necessary to apply a perspective to requirements that extends well beyond the survivability of attacking aircraft and the accuracy with which they can deliver their payloads. This wider perspective reveals that the viability of functionally oriented targeting, regardless of whether the target set is a strategic system or fielded land force, depends on meeting a set of five requirements, each of which is essential to success.

1. Target identification. The first step in target identification is identifying the political, economic, and military systems that perform functions that are critical to a specific enemy's ability or will to resist. The next step is to identify critical elements, subsystems, or nodes that define a particular system. Identifying which specific elements make suitable targets requires analyzing how attacks against these elements will contribute to achieving the desired functional effects on the entire system. It also requires determining whether targeting specific elements could be counterproductive to the overall objective. For example, depending on the objective, it may not be acceptable to risk inflicting large numbers of civilian casualties even though targeting a specific element would render an entire vital system functionally ineffective.

2. Target location. Once specific elements are identified as suitable targets, they must be located reliably and precisely; in darkness and adverse weather; despite enemy camouflage, concealment, and deception measures. Precision requires timely information when targets are mobile or releasable. Effectiveness requires the ability to pass target location information directly to attacking weapon systems.

3.Attack system survivability. The theory's feasibility requires that weapon systems, especially manned aircraft and uninhabited combat air vehicles, be able to deliver their munitions at an accept-ably low risk of loss from an enemy's air defenses.

4.Munitions. Munitions must possess sufficient pre-cession in all conditions, including darkness and adverse weather, to deliver enough force to achieve effects that will prevent the targeted system from continuing to function effectively. It is also essential that the same effects that prevent the targeted system from functioning effectively have an acceptably low risk of inflicting large numbers of civilian casualties or significant amounts of collateral damage.

5. Assessment. The fifth requirement is to assess reliably and quickly, regardless of darkness and weather, the magnitude of the contribution specific attacks are making in achieving the desired system wide functional effect.

4.8 Strategic Targeting Challenges

Operations Desert Storm and Allied Force provide evidence that, despite developments in stealth and precision-guided munitions, there are real challenges to meeting the requirements for effective functionally oriented strategic targeting. Identifying a strategic system whose functioning is critical to an adversary's ability or will to continue effective resistance proved to be difficult. For example, some critics are not convinced that strategic attacks in the Gulf war and Operation Allied Force contributed significantly to attaining the desired objectives.

The lack of consensus on effectiveness is evidence of possible soft spots in the capabilities required for strategic targeting. One soft spot results from evidence that an adversary's camouflage, concealment, deception measures, and use of mobility have made it difficult to locate valid targets within command and control systems and the development of weapons of mass destruction. Even when located, hardened targets have made it difficult to achieve desired effects. Ensuring an acceptably low risk of civilian casualties is also an acute problem. The leaders of Serbia and Iraq have demonstrated that they are more than willing to put their own citizens, let alone hostages, at risk by locating them in and around likely targets.

4.8.1 Potential for Functionally Oriented Land Force Targeting

While there are potentially significant challenges remaining to be solved before it is safe to assume that strategic targeting will be effective, developments in surveillance and targeting technologies are providing excellent potential for meeting the requirements for the functionally oriented targeting of fielded land forces. Fielded forces' vulnerability results from

The system of motorized vehicles that almost all land forces now rely on for movement. Movement is vital to their effective operation because it is how they achieve the advantages of surprise, superior force ratios, and favorable positions. Increasingly, the United States is finding that potential adversaries rely on mobility to obtain pro-tuition by making target location information perishable and, thus, unreliable.

When functionally oriented targeting can stop, not merely delay, a land force's militarily significant vehicular movement, it has the potential to keep an adversary from continuing resistance. One way to do this is through denial since both a successful offense and defense depend on the ability of land forces to move effectively in response to or in anticipation of friendly land maneuver. Another way is through coercion since most potential adversaries depend on special police and army forces to remain in power. The prospect of these forces losing their ability to move and function effectively could cause successful coercion because of increased risk of being overthrown by internal revolt.

Within an army's system for movement, an occupied moving vehicle is a potential target. Occupied vehicles are susceptible because of the vital role they play in the effective functioning of armies as well as many paramilitary units. Vehicles not only provide mobility, they also provide heavy firepower, armored protection, supplies, sensors (radar), communications, and engineering support. Other good targets are nodes that support or constrain vehicular movement such as refueling, rearming, repair, and transshipment points, and bridges and tunnels.

Given the key roles movement and vehicles play in the ability of fielded land forces to function, stopping militarily significant vehicular movement can quickly degrade or even destroy the ability to conduct effective offensive or defensive operations. Stopping movement would also reduce the need for friendly land forces to fight close, sustained battles with powerful units. Close battles will almost always still be necessary, but with functionally oriented targeting, these battles would be fought against units weakened by the loss of the important advantages vehicles and their movement can provide. Stopping an enemy's movement would provide U.S. forces with the maneuver dominance necessary to make medium-weight forces sufficient for defeating an enemy army at minimum risk.

4.8.2 The Role of Danger

The key to understanding the ability of functionally oriented targeting to quickly stop an enemy's vehicular movement is to recognize that it does not depend on physically destroying large numbers of vehicles. Widespread vehicular paralysis can be achieved quickly and without destroying excessively large numbers of vehicles, perhaps only hundreds of vehicles.

Such success is possible when targeting decisions are designed to influence the behavior of enemy soldiers by creating and then exploiting fully their perception of an immense danger from air attack if they were to attempt to move.

Theorist Carl von Clausewitz recognizes that many neglect the importance of danger: "they direct their inquiry exclusively toward physical quantities, whereas all military action is intertwined with psychological forces and effects."[8] He also notes that "Danger is part of the friction of war. Without an accurate conception of danger we cannot understand war."[9] The ability of air attacks to quickly create and then maintain a perception of danger that causes militarily significant functional changes in behavior was especially apparent in suppression of enemy air defense (SEAD) operations during Operations Desert Storm and Allied Force. In both conflicts, it took relatively few precision attacks to persuade large numbers of surviving surface-to-air missile system operators to reduce their perceived danger by not letting their radar emit frequently or for very long periods of time.[10]

The perception of immense danger from air attack has had a similar impact on soldiers' behavior. Analyzing air operations in Normandy during World War II, the Gulf war, and Kosovo shows soldiers exhibiting similar behavior. In all three conflicts, soldiers occupying vehicles often stopped moving and even abandoned their vehicles as soon as they perceived that they were likely to be the target of an air attack. In each case, few would risk movement when conditions made air attacks likely. It is important to note that in all of these conflicts this effect was achieved despite the relatively small number of vehicles actually being hit and destroyed by air attack.

4.8.3 The Importance of Technological Developments

Unfortunately, during all of these conflicts, the effect of paralysis achieved by vehicle attacks was not widespread and could not be sustained. During World War II, one reason was the requirement to locate German vehicles through a visual search performed by fighter-bomber pilots flying armed reconnaissance. These pilots' limited field of view made it necessary to fly large numbers of sorties to achieve paralysis even over a relatively shallow area behind the front lines. The low altitudes required to make an effective visual search and a precise attack—often through strafing—increased aircraft exposure to point air defenses, resulting in significant losses of aircraft and pilots. Although the Allies could generate large numbers of sorties and absorb the high losses, their reliance on visual searches made it impossible for them to sustain paralysis during darkness or adverse weather. The German army was quick to exploit this limitation. Although German forces soon confined almost all of their movement to hours of darkness and periods of adverse weather, moving during these times was sufficient for their forces to achieve the force ratios, position, and surprise that made the close battle in Normandy extremely costly for Allied armies.

But, during the Gulf war, there was an important development. Advances in airborne ground surveillance radar technology made it possible for a prototype command, control, intelligence, surveillance, and reconnaissance (C2ISR) system, the Joint Surveillance Target Attack Radar System (JSTARS), to eliminate the need for visual searches. JSTARS could reliably detect, accurately locate, and precisely track vehicles moving throughout a large surface area in all conditions. Equally important for targeting mobile land forces, the system possessed the large onboard crew needed to make timely targeting decisions and the robust communications that could attack aircraft with accurate and timely targeting information. However, since there were only two systems available, they were unable to perform a persistent search over any single portion of the theater. Even when one of the systems was available, its ability to achieve and sustain Iraqi vehicular paralysis was limited to periods of good visibility that U.S. fighter and attack aircraft required to make precision attacks.[12]

During Operation Allied Force, adverse weather seriously handicapped air operations. As for the Gulf war, there were still not enough JSTARS available to maintain a persistent search, even over an area as small as Kosovo. Yet another problem was the failure to learn from the Gulf war. When JSTARS first de-ployed, senior airmen, their staffs, and most fighter pilots were unfamiliar with JSTARS' capabilities and limitations. Gradually, as was the case in the Gulf war, pilots discovered JSTARS' ability to provide them with lucrative moving targets. One F-16 squadron commander stated, "JSTARS became my hero."[13] Because JSTARS detected movers, pilots could be confident that they were not wasting an attack on a previously destroyed vehicle or decoy. One key difference between Operation Allied Force and the Gulf war was the Serb tactic of intermingling military vehicles within refugee traffic.[14] This tactic prevented NATO air forces from relying on JSTARS radar for targeting to the degree that had been possible during the Gulf war. To reduce the risk of targeting civilians, NATO pilots had to deter-mine visually whether a specific vehicle was military or civilian. Even when JSTARS radar information cued pilots on suspected Serb movement, the requirement for visual identification made timely targeting of Serb mobile forces extremely difficult. Often, Serb forces were able to exploit the time required for visual target identification to disperse and hide. But now technology developments are providing the United States with the potential to possess all of the capabilities required for functionally oriented targeting to quickly stop militarily significant movement within a large area while minimizing the risk of civilian casualties. The key enabling development is the radar upgrade known as the Multi Platform-Radar Technology Insertion Program (MP-RTIP). The high-power, multiple-mode radar will make it possible for a C2ISR system to accurately locate, automatically track, reliably characterize, and precisely target air attacks against individual vehicles moving within a large area, even in dense traffic and during adverse weather or darkness. The radar's automatic tracking is the key to minimizing the risk of civilian casualties because it identifies, perhaps from an unmanned aerial vehicle video collected earlier on a track, specific vehicles as military or civilian. An MP-RTIP-equipped C2ISR system's ability to track and characterize vehicles will also make it easy to trace tracks back to their sources to locate and target critical nodal points such as vehicle refueling points. These nodes could be refueling and missile storage points for missile transporter-erector-launcher (TEL) systems. The same ability of the C2ISR system to detect, locate, characterize, and target individual vehicles will make it possible to quickly and reliably assess whether attacks are achieving the desired functional effect. The system can instantly assess an attack's success because it can see whether vehicular movement has stopped. With a functional orientation, it is not necessary to know whether an attack destroyed the vehicle or made its crew too afraid to move and caused them to abandon it. Just as important to effectively targeting land forces is the fact that these enhanced surveillance and targeting capabilities are being complemented by developments in precision weapons technology. JDAM and the Wind-Corrected Munitions Dispenser System are making it possible to target fixed nodal points of a fielded force's movement system precisely in all weather conditions. These munitions can also stop and quickly destroy convoys before the vehicles and their occupants can disperse. Even more important, developments such as the low-cost antiarmor submunition and brilliant antitank submunition provide the potential to counter an army's ability to move in small convoys or with military vehicles intermingled with civilian vehicles. The key to success is the potential of these sub-munitions to use their sophisticated sensors and software to accurately characterize and precisely target individual military vehicles even when they move in adverse weather and darkness. With the ability to precisely target specific military vehicles, it would be possible to avoid causing collateral damage to nearby buildings or civilian vehicles. Further risk reduction could be achieved by waiting to target military vehicles until after they have moved out of areas where large numbers of civilians and buildings are located.The same technologies that make it feasible to target an enemy's military vehicles also provide the advantage of dramatically reducing the risks facing friendly military personnel. On the ground, stopping militarily significant enemy movement would mean that friendly forces would have less need to fight powerful enemy units. Not only would functionally oriented targeting make it difficult for an enemy to achieve the advantages of mass, position, and surprise, but the same real-time information used for targeting would also allow the friendly land forces to use their maneuver to avoid fighting enemy forces except under ideal conditions. Should an enemy's movement present a threat to a friendly unit, this same movement would make the enemy visible to the C2ISR system's sensor and extremely vulnerable to devastating air and artillery attacks. Besides making it likely that the enemy unit would be quickly destroyed, these attacks would also make it impossible for the enemy to match the speed of the friendly unit's maneuver. In the air, the C2ISR system's high-power radar reduces risks by making it possible to see a very large area while flying at a safe standoff distance from an enemy's surface-based air defenses. Also reducing risks are GPS and sensor developments that make it possible for U.S. aircraft to precisely deliver their weapons from medium altitude, well above the reach of the difficult-to-suppress, nonradar-guided air defenses

4.8.4 PULSED RADAR TWT SUMMARY

The VTA-5703 coupled-cavity TWT, shown in Fig. 1 inan SAR application, is a small, lightweight, highefficiency, conduction cooled TWT which produces approximately 1 kilowatt peak output power over 1 GHz bandwidth at 15% duty. The slow wave structure is a staggered double coupling slot cavity that supports a backward wave in the fundamental branch of its omegabeta characteristic. Consequently, the TWT is operated in the first space harmonic branch where the forward wave propagates in a passband where the phase shift between cavities varies from π to 2π over a cold bandwidth of approximately 13 GHz. The phase shift and cavity period define a circuit wave velocity that determines the beam voltage, 19 kV, required for synchronized interaction with the electron beam. The much wider cold bandwidth of the double staggered circuit moves the high interaction impedance ends of the passband, at π and 2π, away from synchronism with the beam, thereby avoiding amplifier oscillations. The reentrant cavities reduce the size of the circuits and enhance efficiency. The reduced cavity size allows a compact PPM focusing circuit and ultimately minimizes the overall size and weight. The TWT is packaged in a two-piece aluminum baseplate that is designed to withstand the stresses of shock and vibration. The final weight of the TWT is less than 5 pounds. The peak output power and body current are shown in Fig. 3 across 1 GHz instantaneous bandwidth. The saturated gain is approximately 42 dB.

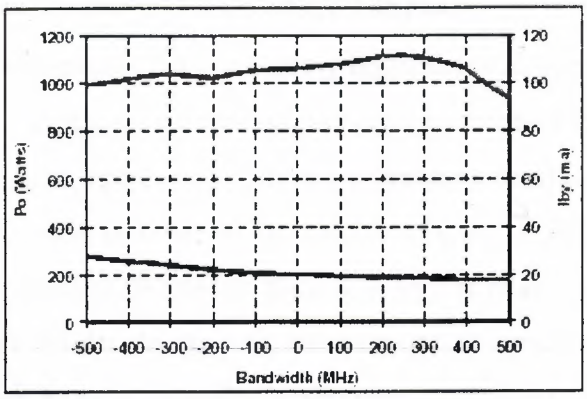

Figure 4.1 input Power and Body Current at 15% Duty

designed to withstand the stresses of shock and vibration. The final weight of the TWT is less than 5 pounds. Fig. 1: VTA-5703 TWT in Airborne SAR Application Courtesy ASE, Inc. Figure 2 illustrates the basic components of the TWT. The assembly of the TWT is based upon a sturdy integral pole piece PPM body into which the rf circuits are inserted. The rf circuits, gun, and collector are rf brazed onto the PPM body to complete the vacuum envelope. The resulting TWT is mechanically strong and the rf brazes may be reversed to remove and replace the gun or collector should repair be necessary. Conduction cooling blocks capture the body of the TWT between the upper and lower halves of the NC machined aluminum base plate. Fig. 2: Basic TWT Components. The electron gun uses CPI's Unigram technology for attaching the shadow grid to the cathode surface. An extensive thermal-mechanical modeling and experimental effort has been made to design thermally compensated cathode and grid supports. The single stage depressed collector yields overall efficiency greater than 20%. Fig. 3 across 1 GHz instantaneous bandwidth. The saturated gain is approximately 42 dB. Fig. 3: Output Power and Body Current at 15% Duty.

CONCLOSION

Possible ImprovementsThere are many improvements that we can make to our system in order to create better results. First of all, we need to increase the range of the detection,not having to limit our input signals as much to get accurate results. We need to adjust with the sampling rate that we use in order to be able to detect smaller velocities as well as more accurate ranges. We could optimize the algorithm for the peak locator in the velocity analysis to give more accurate results. In the end, we managed to create a system that created signals to send out with a RADAR, as well as simulate a returned signal for objects a specific distance away or moving at a certain velocity. We were able to detect the range for objects that were fairly close, and calculate the velocity for objects moving extremely fast. We would like to thank Dr. Courtney Lane and Chris Rozell for all their help.

REFERENCES

[1] "INTRODUCTION TO SYSTEM Radar"
By merrilli . Sholnik MCGRAM-HILL

[2] LECTOMAGNETIC WAVES AND RADEIATING SYSTEM
By Edward c.jordan, Erentice-Hall of India

[3] www.yahoo.com/prenciples+radar

[4] www.google.com/military radar

[5] Characterstic of Military radar with and wiothout single Large Elements and an LE pointing algorithm.

[6] Brain, Marshall. "How Radar Works."
<http://electronics.howstuffworks.com/radar.htm> (2 Dec 2003).

[7] Gruener, W. "System Aspects of Future Airborne Radar Technology" 1998 IEEE

[8] Harkness, Linda L, Bach, Jill K. "Modern Digitatal Simulation Of Airborne Sensor Performance And Vulnerablity", 1991 IEEE

[9] Lu, Alex. "The invention of the radar and its application in World War II."
<http://www.lexcie.zetnet.co.uk/radar.htm> (2 Dec 2003).

[10] Schlachta, Von K. "Digital Radar Recording and Analysis" Dec 1970 IEEE

(11) Stimson, George W. Introduction to Airborne Radar. SciTech Publishing, Inc. 1989