List Of Tables

List Of Figures

List Of Contents

1. INTRODUCTION

RADAR is an acronym for **Radio Detection And Ranging** or **Radio Angle Detection And Ranging**. It is a system used to detect, range (determine the distance of), and map objects such as aircraft and rain. Strong radio waves are transmitted, and a receiver listens for any echoes. By analysing the reflected signal, the reflector can be located, and sometimes identified. Although the amount of signal returned is tiny, radio signals can easily be detected and amplified.

Radar radio waves can be easily generated at any desired strength, detected at even tiny powers, and then amplified many times. Thus radar is suited to detecting objects at very large ranges where other reflections, like sound or visible light, would be too weak to detect.

Electromagnetic waves reflect (scatter) from any large change in the dielectric or diamagnetic constants. This means that a solid object in air or vacuum, or other significant change in atomic density between object and what's surrounding it, will usually scatter radar (radio) waves. This is particularly true of electrically conductive materials such as metal and carbon fiber, making radar particularly well suited to the detection of aircraft and ships. Radar absorbing material, containing resistive and sometimes magnetic substances, is used on military vehicles to reduce radar reflection. This is the radio equivalent of painting something a dark color.

Radar waves scatter in a variety of ways depending on the size (wavelength) of the radio wave and the shape of the target. If the wavelength is much shorter than the target's size, the wave will bounce off in a way similar to the way light bounces from a mirror. If the wavelength is much longer than the size of the target, the target is polarized, like a dipole antenna. This is described by Rayleigh Scattering (like the blue sky). When the two length scales are comparable, there may be resonances. Early radars used very long wavelengths that were larger than the targets and received a vague signal, whereas some modern systems use shorter wavelengths (a few centimeters or shorter) that can image objects as small as a loaf of bread or smaller.

Radio waves always reflect from curves and corners, in a way similar to glint from a rounded piece of glass. The most reflective targets for short wavelengths have

90° angles between the reflective surfaces. A surface consisting of three flat surfaces meeting at a single corner, like the corner on a block, will always reflect directly back at the source. These so-called corner cubes are commonly used as radar reflectors to make otherwise difficult-to-detect objects easier to detect, and are often found on boats in order to improve their detection in a rescue situation and reduce collisions. For generally the same reasons objects attempting to avoid detection will angle their surfaces in a way to eliminate inside corners and avoid surfaces and edges perpendicular to likely detection directions, which leads to "odd" looking stealth aircraft. These precautions do not completely eliminate reflection because of diffraction, especially at longer wavelengths.

Electromagnetic waves do not travel well underwater; thus for underwater applications, sonar, based on sound waves, has to be used instead of radar. RADAR (Radio Detection and Ranging) is basically a means of gathering information about distant objects by transmitting electromagnetic waves at them and analyzing the echoes. Radar has been employed on the ground, in air, on the sea and in space. Radar finds a number of applications such as in airport traffic control, military purposes, coastal navigation, meteorology and mapping etc. The development of the radar technology took place during the World War II in which it was used for detecting the approaching aircraft and then later for many other purposes which finally led to the development of advanced military radars being used these days. Military radars have a highly specialized design to be highly mobile and easily transportable, by air as well as ground. In this paper we will discuss about the advanced features and benefits of military radar, system configuration of a typical military radar, operating the radar, system functions, various terminal equipments used along with their functions and some of the important parts of the radar such as transmitter, receiver, antenna, AFC (Automatic Frequency Control) etc. A military radar can be considered as a searchlight looking for enemy targets. Energy sent out by the radar would be reflected by the target and processed. Military radars, whether land based, ship borne or air borne have acted as a multiplier and sensor par excellence for over 60 years. For example, in the battle in Britain where it enable a small overstretched force to beat off attacks from a larger opponent and in the gulf war where ground surveillance radar enable monitoring of the opponent deployment. However, with the proliferation of stealthy targets, which are difficult to see with radar, sensitive radar homing and warning systems, which allow targets to avoid radar systems, the effectiveness and survivability of military radar have reduced.

Furthermore, there have been rapid development of sophisticated jamming systems and anti-radiation missiles (ARMS) to suppress, identify and destroy radar systems. Like radar itself, counter measures are a two-edged sword. Friend and enemy can use them effectively. However, no matter how sophisticated one s counter-measures are, ways could be found around them and no matter how ingenious the counter-counter – measure are ways can be found to defeat them, and so no and so forth.

Although, little attention has been given to radar development in the Nigerian Armed Forces, this piece of information could be handy for military hardware designer and war planners. This paper will therefore discuss new trends in the use of radar in the battlefield .the concept of low probability of interaction, millimetric wave and laser radar technology will be examined. In addition, the potential application of radar in landmine detection will be highlighted.

2.RADAR

2.1 MILITARY RADAR

Military radar should be an early warning, altering along with weapon control functions. It is specially designed to be highly mobile and should be such that it can be deployed within minutes. Military radar minimizes mutual interference of tasks of both air defenders and friendly air space users. This will result in an increased effectiveness of the combined combat operations. The command and control capabilities of the radar in combination with an effective ground based air defence provide maximum operational effectiveness with a safe, efficient and flexible use of the air space. The increased operational effectiveness is obtained by combining the advantages of centralized air defence management with decentralized air defence control.

There is no radar system that can perform all of the radar functions required by the military. Some newer systems have been developed that can combine several radar functions, but no single system can fulfill all of the requirements of modern warfare. Different types of radars are built for different types of functions. Search radar is designed to continuously scan a volume of space to provide initial detection of all targets. Search radar is generally used to detect and determine the position of new targets for later use by tracking radar. Tracking radar provides continuous range, bearing, and elevation data on one or more targets. Most of the radar systems used by the military are in one of these two categories, although some radar systems are designed for specific functions that do not precisely fit into either of these categories. A surface-search radar system's primary function is the detection and determination of accurate ranges and bearings of surface objects and low flying aircraft. A search pattern in a defined angular sector is maintained to detect all objects within line-of-sight of the radar antenna. GSR systems are a type of surface-search radar that detect and recognize moving targets including personnel, vehicles, watercraft and low flying, rotary wing aircraft. Phased-array radars, based on electronically scanning antennas populated with transmit/receive (T/R) modules that employ GaAs (Gallium Arsenide, an important semiconductor used to make MW frequency integrated circuits) MMIC chips, are on the cutting edge of military radar technology. They provide numerous advantages over conventional radars, particularly for fighter aircraft, including lower radar cross-section, simultaneous multiple-target engagement capabilities, extended target-detection range, higher survivability, greater reliability, and reduced weight and size. By 1990, however, a technology revolution appeared to be under way in the commercial sector regarding microwave and MMW (millimetre wave) technologies. Many defence-critical RF microwave/ MMW technologies directly relevant to military radars, CNI, EW, intelligence gathering, and other sensors appear increasingly likely to be driven by civilian market demands.

2.2 Basics of Radar System

Radar measurement of range, or distance, is made possible because of the following properties of radiated electromagnetic energy:-

(a) Reflection of electromagnetic waves. The electromagnetic waves are reflected if they meet an electrically leading surface. If these reflected waves are received again at the place of their origin, then that means an obstacle is in the propagation direction.

(b) Electromagnetic energy travels through air at a constant speed, at approximately the speed of light.

(c) This energy normally travels through space in a straight line, and will vary only slightly because of atmospheric and weather conditions. By using of special radar antennas this energy can be focused into a desired direction.

Transmitter: The radar transmitter produces the short duration high-power RF pulses of energy that are into space by the antenna.

 Duplexer: The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.

 Receiver: The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.

 Radar Antenna: The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.

 Indicator: The indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets.

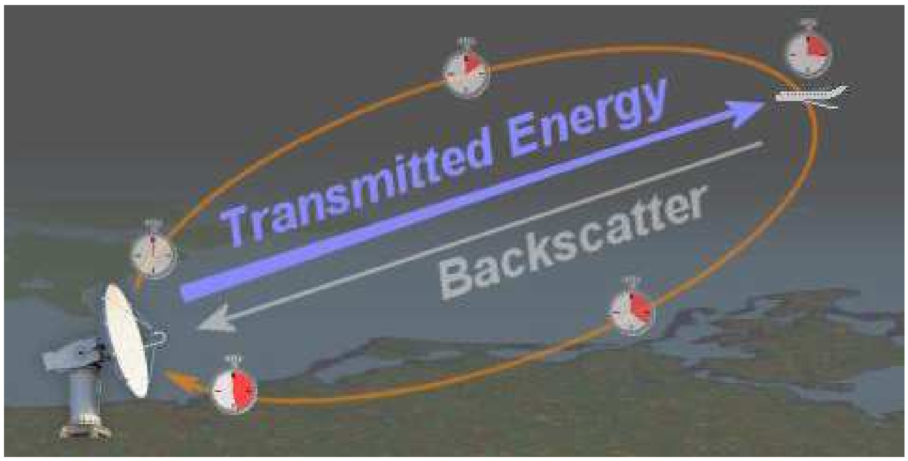

Figure 1 Basic Structure

2.3 Functional Description Of Radar Subsystem:

The detection of air targets is accomplished by the search radar, the video processor and the colour PPI unit. The colour PPI unit provides the presentation of all moving targets down to very low radial speeds on a PPI screen The search radar is pulse Doppler radar (also called MTI radar) i.e. it is capable of distinguishing between the echo from a fixed target and that of a moving target. The echoes from fixed target are eliminated, so that the echoes from the moving targets are presented on the screen.

The great advantage of this is that it is possible to distinguish a moving target among a large number of fixed targets, even when the echoes from these fixed targets are much stronger. To achieve this the search radar makes use of the Doppler effect, if the target having a certain radial speed with respect to the search antenna is hit by a series of transmitter pulses from the search radar antenna, the change in range between this target and antenna is expressed by successive echo pulses in phase shifts with respect to the phase of the transmitter pulses.

For moving targets the phase difference from echo pulse to echo pulse is continually subject to change, whereas for fixed targets this is a constant. The distinction between the echo signals from a fixed target and moving target is obtained by detecting the above phase differences.

Radio waves always reflect from curves and corners, in a way similar to glint from a rounded piece of glass. The most reflective targets for short wavelengths have 90° angles between the reflective surfaces. A surface consisting of three flat surfaces meeting at a single corner, like the corner on a block, will always reflect directly back at the source. These so-called corner cubes are commonly used as radar reflectors to make otherwise difficult-to-detect objects easier to detect, and are often found on boats in order to improve their detection in a rescue situation and reduce collisions. For generally the same reasons objects attempting to avoid detection will angle their surfaces in a way to eliminate inside corners and avoid surfaces and edges perpendicular to likely detection directions, which leads to "odd" looking stealth aircraft. These precautions do not completely eliminate reflection because of diffraction, especially at longer wavelengths.

Electromagnetic waves do not travel well underwater; thus for underwater applications, sonar, based on sound waves, has to be used instead of radar.

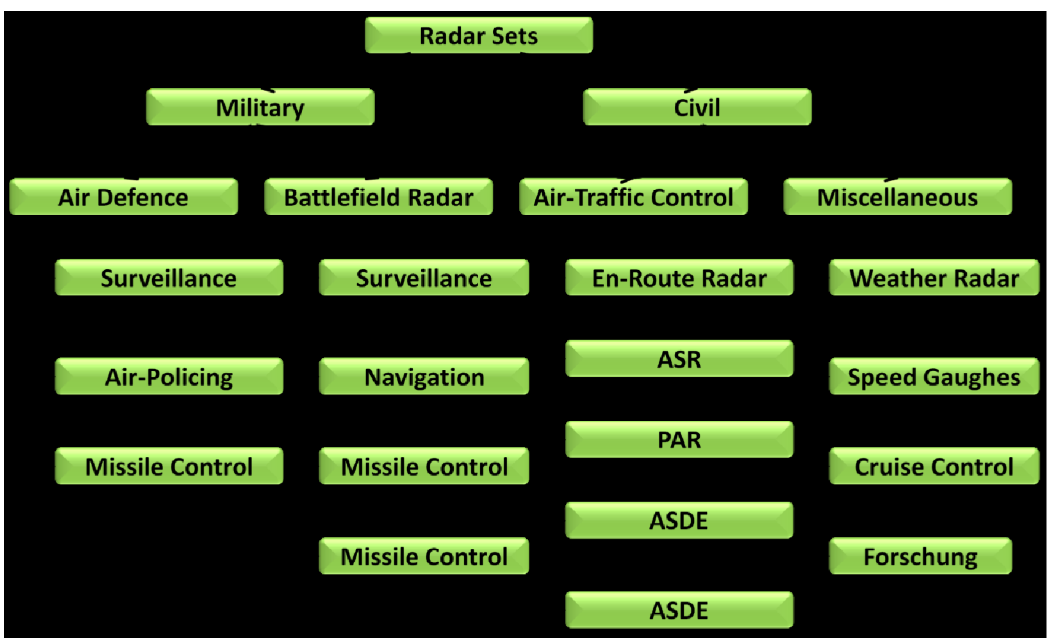

Figure 2 Classification Of Radar

2.4 The System Configuration

A typical military radar system can be split up into three parts:

1) Radargroup

The radargroup consists of antenna, mast unit, remote control, high tension unit, LO/AFC (Local Oscillator/Automatic Frequency Control) unit, radar transmitter, radar receiver, video processor, waveguide drier and IFF interrogator.

The transmitter and receiver forms the active part of the system. The integrated radar/IFF antenna is fitted on the collapsible mast, mounted on the container. The container is connected by cable to the operator/control shelter.

2) Shelter

Shelter contains display unit, processor unit, TV monitor, colour PPI (Plan Position indicator), IFF control unit, air conditioner, battery charger with battery, Radio set with antenna for data link, radio set with antenna for voice transmission i.e. communication, filter box for radios.

3) Motor generator

The motor generator supplies the power to the whole radar system.

Generally, the transmitter and receiver share a common antenna, which is called a monostatic radar system. Bistatic radar consists of separately located (by a considerable distance) transmitting and receiving sites. Therefore, monostatic Doppler radar can be upgraded easily with a bistatic receiver system or (by use of the same frequency) two monostatic radars are working like bistatic radar. Bistatic radar makes use of the forward scattering of the transmitted energy. By receiving the side lobes of the transmitting radars direct beam, the receiving sites radar can be synchronized. If the main lobe is detected, azimuth information can be calculated also. A number of specialized bistatic systems are in use, for example, where multiple receiving sites are used to correlate target position. A tactical idea in Kosovo war was possibly transmitting stations radiated the airplane outside the (technical) weapons range of activity and a second station could command the air defense weapon system only by passive reception. VHF-radars like P-12 or P-18 are particularly suitable for such bistatic arrangement.

3. SETS OF TERMINAL EQUIPMENT

These are the sets of lightweight man portable units, which can be easily be stacked together and consists of: -

1) TDR (Target Data Receiver)

The TDR is either connected to a VHF-FM radio receiver or to a LCA to receive transmitted target data. The TDR itself is intelligent, it performs parallax correction, threat evaluation and it displays the result in a threat sequence, enabling the weapon commander to make the correct decision.

2) Radio Receiver or LCA (Line Connection Adapter)

A radio receiver or LCA (with standard 2 wire telephone line) can be used to receive target data. In principle any VHF-FM radio receiver can be used as a part of the terminal equipment set. In case line connection is applied, no radio receiver is required. An LCA connects the 2-wire telephone line to the TDR cable.

Figure 3 Radar Antenna

4. WHAT IS THE NEED ?

The United States Department of Defense defines intelligence as information and knowledge obtained through observation, investigation, analysis, or understanding. Surveillance and reconnaissance refer to the means by which the information is observed. Surveillance is systematic observation to collect whatever data is available, whereas reconnaissance is a specific mission performed to obtain specific data. The primary function of MI officers is the collection, analysis, production, and dissemination of intelligence at both the tactical and strategic levels.

This is accomplished through the deployment of intelligence collection assets, the combination and preparation of all-source intelligence estimates, preparation of intelligence plans in support of combat operations, and the coordination of aerial and ground surveillance. Information collected about the enemy or potential enemy is passed on to a decision-maker. The decisionmaker could be a top general or a soldier on the ground facing an armed attacker.

Classification of Intelligence

The military services and the intelligence community classify intelligence based on the source. Intelligence that comes from a person observing it is called Human Intelligence (HUMINT). Intelligence derived from photographs and other imagery is called Imagery Intelligence (IMINT). Intelligence obtained from electronic signals such as communications is called Signals Intelligence (SIGINT). Finally, intelligence derived from other technically measurable aspects of the target is named Measurement and Signatures Intelligence (MASINT). *SYRACUSE RESEARCH CORPORATION* MASINT collection and analysis results in intelligence that detects, tracks, identifies, or describes the signatures of fixed or dynamic target sources. It is obtained by quantitative and qualitative analysis of data derived from specific technical sensors for the purpose of identifying distinctive features. Metric data can provide information on the dynamic capabilities of targets and the tactics for their use. Signature data allows the unique identification of targets. MASINT includes many subfields, including Radar Intelligence (RADINT), Acoustic Intelligence

(ACOUSTINT), Radio Frequency/Electromagnetic Pulse Intelligence (RF/EMPINT), and Infrared Intelligence (IRINT).

There is no radar system that can perform all of the radar functions required by the military. Some newer systems have been developed that can combine several radar functions, but no single system can fulfill all of the requirements of modern warfare. Different types of radars are built for different types of functions. Search radar is designed to continuously scan a volume of space to provide initial detection of all targets. Search radar is generally used to detect and determine the position of new targets for later use by tracking radar. Tracking radar provides continuous range, bearing, and elevation data on one or more targets. Most of the radar systems used by the military are in one of these two categories, although some radar systems are designed for specific functions that do not precisely fit into either of these categories.

A surface-search radar system's primary function is the detection and determination of accurate ranges and bearings of surface objects and low flying aircraft. A search pattern in a defined angular sector is maintained to detect all objects within line-of-sight of the radar antenna. GSR systems are a type of surface-search radar that detect and recognize moving targets including personnel, vehicles, watercraft and low flying, rotary wing aircraft. The United States military uses a standardized classification scheme, called the jointservice standardized classification system to identify particular radar systems.

AN/PPS Ground Surveillance Radar Systems

The AN/PPS-5 Ground Surveillance Radar is an American radar system that has been around since the Vietnam War, having been designed with 1950's technology. Despite its old technology, it has been the workhorse of MI Battalions in the U.S. Army since its original production. The radar is a lightweight, man-portable, ground-to-ground surveillance radar set for use by units such as infantry and tank battalions. The PPS-5 radar is a pulsed Doppler radar, and is capable of detecting and locating moving personnel at ranges of 6000 meters and vehicles at ranges of 10000 meters, under virtually all weather conditions. The radar displays targets in a multimodal manner, both aurally and visually. The visual display is a Plan Position Indicator (PPI), and the aural indicator produces tones corresponding to target velocity. The system can operate in an automatic sector scanning mode or in a manual searchlighting mode. The PPS-5 is rugged enough to withstand rough field handling, and when packed in its watertight container, it can be parachute dropped and undergo repeated submersion. The radar can also be mounted in a jeep or humvee. New versions of this radar system are being developed, which make use of modern computer and Digital Signal Processing (DSP) technology.

The AN/PPS-4, the AN/PPS-6, and the AN/PPS-15 Radar systems are additional GSR
systems that are used by the U.S. Army. The AN/PPS-4 system is very small and portable. It is approximately 4 feet high, and can be carried by a single person. This system also has aural and visual indicators. The visual display is not a PPI, but a simple range indicator. The maximum range for target detection of the PPS-4 is much less than the PPS-5. The AN/PPS-6 has a range of approximately 1500 meters for personnel detection, and 3000 meters for vehicle detection. Like the PPS-5, the PPS-6 has automatic and manual searching modes. The AN/PPS-15 is another portable, ground-to-ground battlefield surveillance radar system. This radar is usually operated on the ground, and is usually not mounted on vehicles. The maximum range for personnel detection is 1500 meters, whereas the maximum range for vehicle detection is 3000 meters. All of the AN/PPS series radars can penetrate smoke, haze, fog, light rain, and snow, and are equally effective in day or night.

5. FOREIGN GROUND SURVEILLANCE RADAR SYSTEMS

The Russian military has historically used many different kinds of GSR systems. A couple of examples include the SBR-3 short-range surveillance radar, and the PSNR-5 portable ground surveillance radar. New radar systems have recently been developed which offer greater target detection range and coordinate measuring accuracy; greater capacity due to automation of target detection and coordinate measurement processes; and data transmission over communication channels via standard interfaces. The FARA-1, for example, is lightweight, not bulky, and can be carried by one man. It is multifunctional, and can be used as a radar sight for automatic weapons, or as a reconnaissance tool. The PSNR-6 radar, a new version of the PSNR- 5, features a long operating range, using advanced signal processor technology. It also has a portable computer control console, which presents targets on the background of a topographic map.

The Australian Man-portable Surveillance and Target Acquisition Radar (AMSTAR) system is able to detect and recognize moving targets including personnel, vehicles, watercraft and low flying, rotary wing aircraft. It has target detection and classification capability at ranges up to 35,000 meters. This radar system can also carried by a few men, or can be mounted on Lightly Armed Vehicles (LAVs). A ruggedized laptop computer provides the Human Machine Interface (HMI). There is also an aural indicator.list. Why? Well, consider that the entire list of routes for a 20 city problem could theoretically take 45 million GBytes of memory (18! routes with 7 byte words)! Also for a 100 MIPS computer, it would take two years just to generate all paths (assuming one instruction cycle to generate each city in every path).

Ground Surveillance Radar Applications

GSR systems can be used in a variety of applications, including urban warfare maneuvers, covert stakeout surveillance, counterterrorism, maritime surveillance, border patrol and security, observation and protection of remote areas, airport security, nuclear facility security, and tactical battlefield applications.

A battlefield commander requires much intelligence to command and control his assets proficiently. For ground combat situations, information that is useful includes:

- Enemy Troop Concentrations,
- Enemy Vehicle Concentration,

• Enemy Vehicle Classification,

• Enemy Personnel & Vehicle Movement,

• Movement of a Possible Counterattack Force Conducting a Flanking Attack, and

• Information about Avenues of Approach and Infiltration Routes used by Enemy.

This information can be used as targeting data to support effective attacks, as early warning for force protection, or simply as surveillance to find the enemy. In general, GSRs provide timely surveillance and tactical near-real time data and are very versatile.

GSRs are used to search for enemy activity on critical chokepoints, mobility corridors, and likely infiltration routes. They are used to observe point targets such as bridges, road junctions, or narrow passages to detect movements. GSR systems can extend the surveillance capability of patrols by surveying surrounding areas for enemy movement, and survey target areas immediately after an attack to detect enemy activity and determine the effectiveness of the attack. Radars can assist in visual observation of targets partially hidden by haze, smoke, fog, or bright sunlight, and can confirm targets sensed by other types of sensors. GSR systems have a few weaknesses that must be overcome by using other types of sensors in conjunction with the radar. Radars require line-of-site to the target area, and their performance is degraded by heavy rain, snow, dense foliage, and high winds. Also, they are active emitters, and are subject to enemy detection and electronic countermeasures (ECM).

Finally, radars are unable to distinguish between friend and foe, only able to detect and classify moving targets by type. The dominant U.S. Army ground maneuver in the Vietnam War was the Fire Support Base (FSB), often referred to as firebase. Conceptually, the FSB functioned to provide a secure but mobile artillery position capable of providing fire support to infantry patrols operating in areas beyond the range of main base camp artillery. This concept gave infantry a greater degree of flexibility without sacrificing artillery protection. FSBs were targets for enemy counterattacks and bombardments, so defensive measures were also installed.

The typical cavalry FSB was a defensive area, about 250 meters in diameter, with an 800- meter perimeter. It contained howitzers and enough equipment and supplies to support the infantry with artillery fire around the clock. The firebase also supplied logistics, communications, medical, and rest facilities for the cavalrymen within its area. GSR emplacements were constructed around the FSB to provide surveillance for force protection. Intelligence derived from GSRs was also used to locate enemy positions to direct artillery fire and infantry patrols. The life span of an FSB depended on the tactical situation in its area. Since firebases were normally established to give a battalion and its direct support howitzer battery a pivot of operations to patrol the immediate vicinity, the firebase was closed when the battalion relocated. Finally, radars are unable to distinguish between friend and foe, only able to detect and classify moving targets by type. The dominant U.S. Army ground maneuver in the Vietnam War was the Fire Support Base (FSB), often referred to as firebase. Conceptually, the FSB functioned to provide a secure but mobile artillery position capable of providing fire support to infantry patrols operating in areas beyond the range of main base camp artillery. This concept gave infantry a greater degree of flexibility without sacrificing artillery protection. FSBs were targets for enemy counterattacks and bombardments, so defensive measures were also installed.

The typical cavalry FSB was a defensive area, about 250 meters in diameter, with an 800- meter perimeter. It contained howitzers and enough equipment and supplies to support the infantry with artillery fire around the clock. The firebase also supplied logistics. Radars require line-of-site to the target area, and their performance is degraded by heavy rain, snow, dense foliage, and high winds. Also, they are active emitters, and are subject to enemy detection and electronic countermeasures (ECM).

Finally, radars are unable to distinguish between friend and foe, only able to detect and classify moving targets by type. The dominant U.S. Army ground maneuver in the Vietnam War was the Fire Support Base (FSB), often referred to as firebase. Conceptually, the FSB functioned to provide a secure but mobile artillery position capable of providing fire support to infantry patrols operating in areas beyond the range of main base camp artillery. This concept gave infantry a greater degree of flexibility without sacrificing artillery protection. FSBs were targets for enemy counterattacks and bombardments, so defensive measures were also installed

6.MULTI FUNCTION RADARS

Active array Multifunction Radars (MFRs) enable modern weapon systems to cope with saturation attacks of very small radar cross-section missiles in a concentrated jamming environment. Such MFRs have to provide a large number of fire-control channels, simultaneous tracking of both hostile and defending missiles, and mid-course guidance commands. The active phased-array antenna comprises flat sensor panels consisting of arrays of GaAs modules transmitting variable pulse patterns and building up a detailed picture of the surveillance area. A typical fixed array configuration system could consist of about 2,000 elements per panel, with four fixed panels. Each array panel can cover 90° in both elevation and azimuth to provide complete hemispherical coverage. The operational functions of a Multi Target Tracking Radar (MTTR) include:

- Long-range search;
- Search information with high data rate for low-flying aircraft;
- Search information with high resolution of close in air targets;
- Automatic position and height information;
- Simultaneous tracking of a lot of aircraft targets;
- Target designation facilities for other systems.

Phased Array Antenna

11. A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference. The main beam always points in the direction of the increasing phase shift. If the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is 120° (60° left and 60° right).

Advantages	Disadvantages
High gain width low side lobes.	The coverage is limited to a 120 degree sector in azimuth and

Table 1 Advantage vs disadvantage

The typical cavalry FSB was a defensive area, about 250 meters in diameter, with an 800- meter perimeter. It contained howitzers and enough equipment and supplies to support the infantry with artillery fire around the clock. The firebase also supplied logistics. Radars require line-of-site to the target area, and their performance is degraded by heavy rain, snow, dense foliage, and high winds. Also, they areactive emitters, and are subject to enemy detection and electronic countermeasures (ECM). Finally, radars are unable to distinguish between friend and foe, only able to detect and classify moving targets by type. The dominant U.S. Army ground maneuver in the Vietnam War was the Fire Support Base (FSB), often referred to as firebase. Conceptually, the FSB functioned to provide a secure but mobile artillery position capable of providing fire support to infantry patrols operating in areas beyond the range of main base camp artillery. This concept gave infantry a greater degreeof flexibility without sacrificing artillery protection. FSBs were targets for enemy counterattacks and bombardments, sodefensive measures were also installed

7. ADVANCED FEATURES AND BENEFITS

Typical military radar has the following advanced features and benefits: -

- All-weather day and night capability.
- Multiple target handling and engagement capability.
- Short and fast reaction time between target detection and ready to fire moment.
- Easy to operate and hence low manning requirements and stress reduction under severe conditions.
- Highly mobile system, to be used in all kind of terrain
- Flexible weapon integration, and unlimited number of single air defence weapons can be provided with target data.
- High resolution, which gives excellent target discrimination and accurate tracking.

The identification of the targets as friend or hostile is supported by IFF, which is an integral part of the system. During the short time when the targets are exposed accurate data must be obtained. A high antenna rotational speed assures early target detection and a high data update rate required for track accuracy. The radar can use linear (horizontal) polarization in clear weather. During rains, to improve the suppression of rain clutter, provision exists to change to circular polarization at the touch of the button from the display console. The main advantage of RADAR, is that it provide superior penetration capability through any type of weather condition, and can be used in the day or night time.

Radar uses electromagnetic wave that does not require a medium like Sonar (that uses water) so can be used in space and air. Radar can be long range and the wave propagate at the speed of light rather then sound (like with sonar). It is less susceptible to weather conditions compared with Lasers.And be used at night unlike passive cameras. It does not require target cooperation to emit any signals or emission.

7.2 Operations of radar

The simplest mode of radar operation is range-finding, performed by time-of-flight calculation. The unit transmits a radar signal, i.e., sends radar waves out toward the target. The waves hit the target and are reflected back in the same way that water waves are reflected from the end of a bathtub. The returning wave is received by the radar unit, and the travel time is registered. Basic **physics** tells us that distance is equal to **rate** of travel multiplied by the time of travel. Now all electromagnetic waves travel at the same speed in a vacuum—the speed of light, which is 3.0×10^8 m/s. This speed is reduced by some small amount when the waves are traveling in a medium such as air, but this can be calculated. If the radar system sends a pulse out toward a target and records the amount of time until the return pulse is received, the target distance can be determined by the simple equation $d = vt$, where d is distance, v is velocity, and t is time.

A basic radar unit consists of: a frequency **generator** and timing control unit; a transmitter with a modulator to generate a signal; an **antenna** with a parabolic reflector to transmit the signal; a duplexer to switch between transmission and reception mode; an antenna to gather the reflected signal; a receiver to detect and amplify this return; and signal processing, data processing, and data display units. If the transmitter and receiver are connected to the same antenna or to antennas in the same location, the unit is called monostatic. If the transmitter and receiver antennas are in very different locations, the unit is known as bistatic. The frequency generator/timing unit is the master coordinator of the radar unit. In a monostatic system, the unit must switch between sending out a signal and listening for the return reflected from the target; the timing unit controls the duplexer that performs the switching. The transmitter generates a **radio** signal that is modulated, or varied, to form either a series of pulses or a continuously varying signal. This signal is reflected from the target, gathered by the antenna, and amplified and filtered by the receiver. The signal processing unit further cleans up the signal, and the data processing unit decodes it. Finally, the data is presented to the user on the display. Before target range can be determined, the target must be detected, an operation more complicated than it would seem. Consider radar operation again. A pulse is transmitted in the direction that the antenna is facing. When it encounters a material that is different from the surrounding medium (e.g., **fish** in water or an airplane in the air), a portion of the pulse will be reflected back toward the receiver antenna. This antenna in turn collects only part of the reflected pulse and sends it to the receiver and the processing units where the most critical operations take place. Because only a small amount of the transmitted pulse is ever detected by the receiving antenna, the signal amplitude is dramatically reduced from its initial value. At the same time, spurious **reflections** from non-target surfaces or electronic noise from the radar system itself act to clutter up the signal, making it difficult to isolate. Various filtering and amplification operations help to increase the signal-to-noise **ratio** (SNR), making it easier to **lock** on to the actual signal. If the noise is too high, the processing parameters incorrect, or the reflected signal amplitude too small, it is difficult for the system to determine whether a target exists or not. Real signals of very low amplitude can be swamped by **interference**, or "lost in the noise." In military applications, interference can also be generated by reflections from friendly radar systems, or from enemy electronic countermeasures that make the radar system detect high levels of noise, false targets, or clones of the legitimate target. No matter what the source, interference and signal quality are serious concerns for radar system designers and operators.

8. CIRCUIT STAGES FOR PROCESSING RADAR SIGNALS

Mixers are used to generate an output signal from two signals of different frequencies with the appropriate differential frequency. Multiplying two sine functions together produces sinusoidal signals with the differential and the cumulative frequency. The latter is generally eliminated by frequency filtering. Mixers can be made e.g. with the aid of transistors in various circuit configurations (as multipliers or non-linear amplifiers) or with diodes using their non-linear characteristic.

FMCW systems generally feature two mixers:

one to allow measurement of the VCO transmitted frequency after mixing with the DRO frequency (e.g. VCO = 10 GHz and DRO = 9 GHz, giving a mixture frequency of 1 GHz, which is easier to process metrologically than the considerably higher VCO frequency by the direct method); another to mix the signal received by the antenna with the transmission signal; the differential The information is rather qualitative such as degree of condition, insufficient to calculate the optimal route and hence used mainly for display on the map. To realize the second phase only a one-way communication link from the ground to the vehicle is required. The third phase (Advanced Dynamic Navigation System) is to make the communications link bilateral. The on-board equipment transmits to the ground, traffic information such as travel time measure on each road segment. Roadside equipment provides the vehicle with valuable and quantitative information such as process travel time which is collected and predicted using both onboard and control center data. The on-board equipment calculates an optimal route based on the traffic information and driver's pre-entered route finding criterion, and then carries out route guidance.

8 RECEIVER NOISE

Natural thermal noise is calculated according to: Pnoise = $k \cdot T \cdot B$, where k is the Boltzmann constant, T the absolute temperature, and B the receiving bandwidth. For a receiver, the input-related noise is increased by the noise figure F:

P'noise = $F \cdot k \cdot T \cdot B$.

The signal-to-noise ratio should be as high as possible in order to obtain high detection reliability and a low error rate.

The required transmission power is determined from this, taking into account the total transfer function .With the relatively short ranges (up to some 10s of metres or 100s of feet) that are relevant for level measurements, powers of less than 1 mW to a few mW are sufficient to obtain a sufficiently large signal-to-noise ratio. etc.

Various forms of interference can falsify the received radar signal in relation to the ideal reflection pattern. They need to be given consideration and if necessary included in the signal evaluation in order to avoid misinterpretation.

In regard to level measurement, significant interference factors are :

- Atmospheric effects:

Heavy damping or scattering from particles in the atmosphere (dust, vapour, foam, etc.)

→ If the surface of the medium is no longer detectable, no significant value can be determined for the level; an appropriate (error) message must be available.

- Interference reflections

Various internals (pipes, filling nozzles, agitator blades, other sensors, etc.) or mediuminduced interference (e.g. condensation or deposits on the antenna) can also produce reflection signals. →If reproducible, they may be included in the signal evaluation (“empty-tank spectrum”). However, if the surface of the medium is at times obscured (e.g. level below agitator), measurements must be blanked out for such times.

35

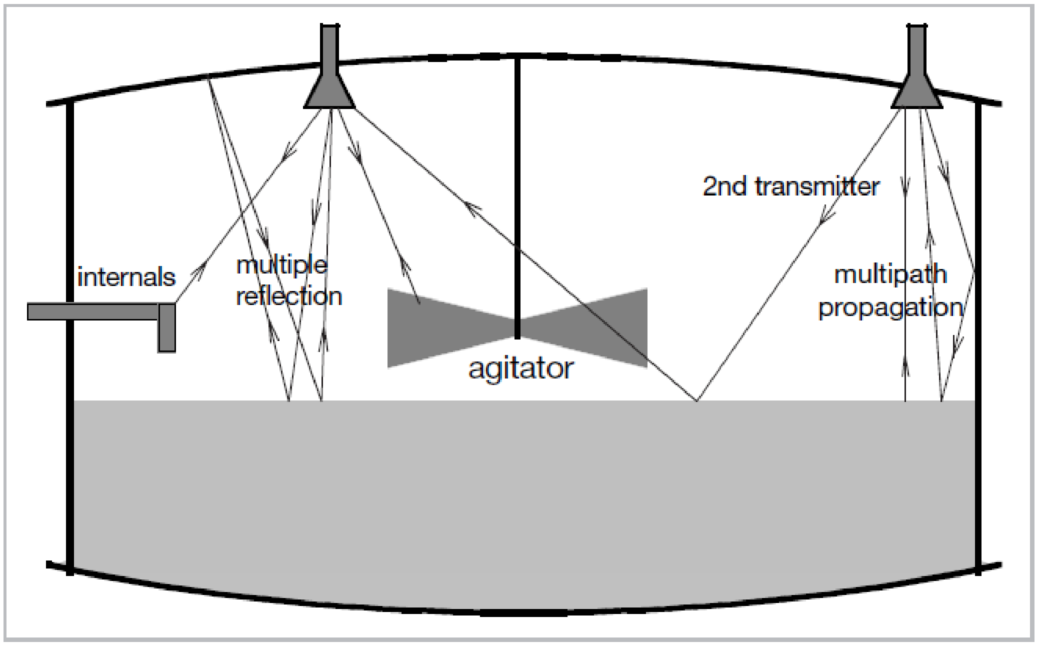

Figure 4 radar interference

Multiple reflections:

These occur, for example, when the signal is reflected from the surface of the medium, then strikes the tank cover or some other “good” reflector, and is again reflected from the medium before being received by the antenna → Since multiple reflections occur at periodic intervals, they can be detected and taken into account in the signal processing. A better solution is to change the mounting position so as to eliminate multiple reflections altogether.

● Multipath propagation:

If, for example, a signal is deflected from the tank wall, its propagation path is lengthened; the reflection signal is thus broadened in time and the measuring accuracy reduced →The antenna should be moved further away from the wall.

● Other microwave transmitters:

Several radar systems that are installed in one tank can mutually influence one other. With FMCW radar, however, this probability is normally very low because the systems would have to operate in synchronism down to fractions of µs in order to generate an additional differential frequency portion within the processing bandwidth of a few kHz. In pulse radar with a high pulse repetition rate, an interference can however easily occur when the signals from several transmitters are interpreted as being the total reflection

Part I: Tracking

The objective of this method is to determine the frequency of a digitized signal. It is carried out in four steps: first the frequency is estimated, for which e.g. the FFT analysis can be used; in the second step, a signal is synthetized from the frequency and, in the third step, compared with the measuring signal. This comparison supplies an error value, from which in the fourth step the deviation of the estimated from the real value is calculated. The corrected frequency can then be used as the starting value for the next measurement. If the frequency value has not changed by too much between two measurements, the change in frequency – and thus the change in level – can be very accurately tracked. Hence the term "tracking". Appropriately, tracking is also carried out by means of digital signal processing, but the computational effort is substantially higher than when using the FFT.

Part II: Signal filtering

Since in FMCW radar the information on the target distance is to be found in the frequency of the down-converted received signal is possible by appropriately filtering the frequency to considerably increase the effective dynamic performance of measurement and thus improve signal quality. Owing to the low signal frequencies involved, such electronic filters are easy to set up and reproduce. shows, by way of example, the circuit arrangement of a second-order high-pass filter with an operational amplifier. A point worth noting for all practical filters is that the signals cannot be completely suppressed in the rejection band, but that a finitely steep filter slope is obtained,

Due to time-discrete analog/digital conversion of the signal and because of Shannon's sampling theorem, the frequency spectrum f has to be limited to half the sampling frequency fA : f < fA / 2. If this is ignored, the higher signal frequencies will be reflected from half the sampling frequency and will produce spurious frequency contents after conversion and Fourier transform : f' = fA – f.

Part III: RADAR RANGE. The non-ambiguous range provides only indication about the maximum range at which the target range information can be extracted unambiguously, and does not give any information about the maximum range at which a target can be detected. To derive the real detection range, the link budget shall be taken into account for the two paths radar-target and target-radar, together with the target characteristics. For the purpose of this introduction, the minimum Signal-to-Noise (S/N) ratio required for proper target detection will be considered as an input, and its determination will not be treated here. NOTE: it is anyway important to remark that the radar detection is always a **statistic** process. The problem is to detect a signal within a gaussian noise: indipendently on how we can decide to position the decision threshold ("everything above the threshold is signal, everything below is noise") there is always a defined probability that: 1) the noise will exceed the threshold or 2) the signal + noise will be below the threshold (even if the signal itself would have been above the threshold). For a given S/N it is possible, changing the threshold, to reduce the probability of false alarm at the expense of the probability of detection. It is therefore uncorrect to say "this radar has a x km range on the target y" without adding "with 90% of probability of detection, and probability of false alarm 10^-6).

We will derive here the basics of the radar equation.

Let's have a transmitting antenna, *isotropic*, i.e. which radiates homogeneously in all directions. The transmitted power Pt, at a range R from the transmitter, is homogeneously spread over the surface of a sphere of radius R, with a power density:

$$Pd = \frac{Pt}{4 \cdot \pi \cdot R^{\wedge}2}$$

Real antennas provide directivity: the antenna *gain* (G) is the measure of the antenna effectiveness in concentrating the radiated energy in the direction of interest. Then:

$$Pd = \frac{G \cdot Pt}{4 \cdot \pi \cdot R^{\wedge}2}$$

For a single-point target (a single-point target is a target having small dimensions compared to the angular and range resolution of the radar. For instance, for a typical search radar, a Boeing 747 is a single-point target), the target characteristics are accounted for through a parameter called *cross-section* (sigma, measured in m^2). A target having 1m^2 cross-section reflects toward the radar a power equivalent to all the power impinging on a surface of 1m^2 radiated isotropically (the physical area of the target may be smaller than its cross-section if it re-radiates preferentially toward the radar).

NOTE: for extended targets (like land or ocean surfaces) the target characteristics are accounted for through the reflectivity (sigma-0), a pure number having as reference a surface of the same area re-radiating isotropically all the impinging energy.

For the target-to-radar path, the same approach of the radar-target applies: the reflected power is spread on a spherical surface. The power density at the radar will then be:

$$Pd = \frac{Pt \cdot G \cdot \sigma}{16 \cdot \pi^2 \cdot R^4}$$

The signal is collected by the receiving antenna proportionally to its *effective area.* If the same antenna is used for both transmit and receive, we can apply the formula relating the effective area to the gain:

$$G = \frac{4 \cdot \pi}{\lambda^2} \cdot Aeff$$

The echo power returning at the receiver will then be:

$$\Pr = \frac{G^2 \cdot Pt \cdot \sigma \cdot \lambda^2}{64 \cdot \pi^3 \cdot R^4}$$

The above formula does not take into account for simplicity the losses due to atmospheric attenuation and to the system non-idealities.

It must be noted that the received power decreases with the fourth power of the range: to double the radar range, the transmitting power must be increased by a factor of 16 ! (This applies for a single point target: if the target is a large surface, we shall take into account that the antenna beam becomes wider for increasing ranges, increasing the illuminated area and consequently the reflected power. Depending on the radar-surface geometry, the echo strength can be proportional to 1/R^3 or to 1/R^2.)

The echo signal shall be compared with the thermal noise. The noise equivalent power at the receiver input is given by:

$Pn = kT\ B\ F$

where :

k = Boltzmann's constant

T = receiver temperature (in degrees Kelvin)

B = Receiver noise bandwidth (can be roughly considered equal to the signal bandwidth)

F = Noise Figure, a term greater than 1, indicating how much the receiver is 'noisy' compared to the ideal case (F=1).

It is then possible to compute the S/N ratio.

It is important to remark that the receiver noise is proportionally to its bandwidth: this is also intuitive, being the thermal noise "white", i.e. homogeneously spread over the whole frequency spectrum. Increasing the receiver bandwidth will then increase the amount of noise energy developed inside the receiver. It is therefore important to keep the receiver bandwidth narrow, at the minimum level allowed by the need to provide proper amplification of the signal. For a simple pulse on a carrier, the optimum bandwidth is about $B = 1/T$ (T = pulse length).

From a range point of view, it is therefore convenient, for the same peak power, to increase the pulse width (and therefore, its energy). Unfortunately, this requirement is in conflict with the range resolution requirement, as discussed later.

As a general rule, applicable to any radar waveform, it is possible to show that the range performance is relate only to the pulse **energy**, i.e. to the P x T product, at the condition that the receiver uses an "optimum" filter (called *matched filter*), having a frequency response complex conjugate of the signal spectrum (i.e., same amplitude response of the signal spectrum, and opposite phase response)

Part IV: **Angular resolution and range resolution**

For a conventional radar, the angular resolution is equal to the aperture of the antenna beam, which, in turn, is related to the antenna linear dimension and to the signal wavelenght. For an antenna having linear dimension l, and for an operating wavelenght lambda, the beam aperture (in radiants) can be approximated by the formula:

$$\theta = \frac{1.2 \cdot \lambda}{l}$$

The use of higher operating frequencies (shorter wavelenght) allows then to use smaller antennas for the same angular resolution.

Concerning the range resolution, it is possible to discriminate between separate echoes only if the difference in their delays is greater than the pulse width T. The range resolution is then T c/2.

The most straightforward way to improve the range resolution is then to use shorter pulses, i.e. larger pulse bandwidths (it can be demonstrated that the information content - the range resolution in our case - is proportional to the signal bandwidth): the drawback is that in this way the pulse energy is also reduced, degrading the performance in range if the other parameters are left unchanged.

The above constraints create severe problems in the design of high resolution radars: the transmitter technological limitations affects more the peak power than the average power or the energy of the single pulse. In other words, it is much easier to develop a transmitter capable of 2kW peak for 10 microsec than one providing 20kW peak for 1 microsec, even if the pulse energy is the same in both cases.

In order to achieve the advantage of both the "wide bandwidth" pulses in term of range resolution, and the use of "long" pulses with limited peak power, a technique called *pulse coding* is often used. In this technique, a form of modulation is superimposed to the long pulse, increasing its bandwidth. This modulation allows to discriminate between two pulses even if they are partially overlapped.

The range resolution of such a system can be approximated as T'=1/B (for an unmodulated pulse of duration T and bandwidth 1/T, it reduces to T'=T).

The two types of modulation most widely used in radar systems are the so-called *chirp* and the *Barker Code*: the former is a linear frequency modulation, the latter is a discrete (bi-phase) phase modulation.

In the receiver, the return signal is correlated with a stored replica of the transmit signal. For the chirp, it can be done applying the signal (normally in the Intermediate Frequency section of the receiver) to a *dispersive* delay line (i.e., having a delay which is linear function of the frequency), in order to concentrate all the pulse energy in a pulse shorter than the original one. It is also possible, taking advantage of the modern digital signal processing techniques, to perform, after analog-to-digital conversion, the convolution of the echo with a ideal single-point-target response (this is normally performed in the frequency domain, following a Fast Furier Transform of the signal, to improve the computational efficiency).

For the Barker Code, tapped delay lines with a summing/weigthing network are generally used. They can be implemented both in digital or in analog form (at intermediate frequency) using a (non-dispersive) delay line. Many radars use the Doppler effect to extract information on targets radial velocity (almost all radars designed to detect aerial targets use the doppler effect to discriminate moving objects from the undesired fixed echoes). A signal having wavelenght lambda is received by an observer in relative motion at radial velocity v with respect to the source as having a frequency shifted by an amount v/lambda from the transmitted frequency. In the case of a radar, this effect occurs twice, on the radar-target and target-radar paths: the total Doppler shift is then:

$$\Delta f = \frac{2 \cdot v}{\lambda}$$

At the normal radar frequencies, and for relative speeds in the order of tens or few hundreds m/sec (typical of aircrafts), the doppler shift is in the kHz range, the same order of magnitude of the PRF, and a period much shorter than the pulse width. This makes impossible to discriminate the frequency shift within the pulse.

All radars exploiting the doppler information use the same reference oscillators (characterised by high short-term frequency stability) in both the transmit and receive chains (see fig. 2). The local oscillator LO1 is the same for both chains. The received signal, instead of being demodulated using an envelope detector, is compared (normally using two channel having a 90 deg relative phase shift to extract the sin and cosin components of the signal) with the transmission reference frequency LO2 - the same used to generate the intermediate frequency transmit pulse - in a phase detector (a balanced mixer characterised by low offset voltage). The amplitude of the detected signal is proportional not only to the input signal amplitude, but also to the relative phase between the received signal and the reference (having used the same oscillators for both transmit and receive, the remaining frequency at the output is just the one due to the doppler shift).

A return echo from a fixed target will have a zero doppler shift, and then a constant phase: all the return pulses from it will have the same amplitude after demodulation. If there is a doppler shift, the phase will change from pulse to pulse, and the amplitude of the demodulated signal will also change.

Using a two channels, sin-cosin demodulator, it is possible to unambiguously recover the phase of the return echo.

In other words, it is like as the envelope of the doppler frequency is sampled at the pulse repetition frequency. This is shown in fig. 3, which depicts the echoes of the same target in different PRIs at the output of the phase detector, together with the envelope of the doppler frequency. According to the sampling theorem, to avoid ambiguities in the measurement of the doppler frequency, the PRF must be, at least, twice the doppler frequency. This calls for the use of high PRFs, in conflict with the unambiguous range requirement discussed above. Ambiguities resolution techniques using staggered PRFs partially allow to conciliate this two requirements. (It must also be noted that, in many cases, the doppler ambiguity is not of concern, being the doppler shift used only to discriminate - and to cancel - all targets below a certain doppler shift, i.e. the fixed targets. For these systems, the only problem related to the doppler ambiguity occours when a target has a doppler shift which is an integer multiple of the PRF: it will be detected as a constant amplitude - zero doppler - return and then cancelled like a fixed echo.)

Where an accurate measurement of the doppler frequency is needed, continuous wave (CW) radars are used. Such radars do not provide any information about target range. Radars of this class, but with a moderate range resolution capability thanks to a frequency modulation of the signal carrier (FM-CW radars) are used for special applications (illuminating radars for missile guidance).

MTI RADAR

In the early years of Radar, the only available microwave power device was the Magnetron (yes, the same used in your microwave oven), which was not an amplifier, but an high power oscillator: in pulsed applications- typical of radar - RF energy is generated for the duration of the high-voltage pulse applied at the cathode. But - as in any self-oscillating device - there is no way to predict the phase of the microwave pulse so generated: the oscillation starts, for each pulse, in an absolutely random way, unrelated from the phase of the other pulses.

While this is not an issue in applications where only amplitude information is of interest (e.g., ground mapping radars) it becomes a serious problem in MTI applications. The typical MTI scheme requires to keep memory of the phase of the transmitted pulse deriving it from the two local oscillators.

How to solve this problem? The solution was found by reverting the approach: instead of transmitting a signal derived from a reference of known phase, the (random) phase of each transmitted pulse is memorised by the system and corrected for in the receiver.

This approach is known as "coherent-on-receive" (as opposed to the "coherent-on-transmit" scheme which uses an amplifier) and its classic implementation is depicted below. Here, the microwave local oscillator (LO1 in classic MTI scheme) is used for the receiver only, and is generally referred to as "STALO" (STAble Local Oscillator). Considering that the oscillation frequency of the magnetron is not quite accurate nor stable, the frequency of the STALO is locked to the magnetron frequency by means of an automatic frequency control circuit (AFC) which uses a frequency discriminator, to ensure that their difference provides the correct Intermediate Frequency.

The Tx pulse is coupled into the Rx chain, and at IF is used to phase-lock the COHO (COHerent Oscillator) which is an oscillator, capable of being initialised to the phase of the coupled pulse, and used as phase detector reference.
The two "classic" ways to implement a COHO are:
- delay line: the coupled IF signal is injected in a loop with a delay line (often, a long cable) with delay equal to the pulse length. The output was fed back to the delay line input (recovering the losses with an amplifier), thus recirculating it for the whole duration of a PRI. - locked oscillator: the oscillator loop gain was reduced below the unit (stopping oscillation), then the oscillation conditions was restored while the reference pulse was applied. In this way, the oscillation started with the same phase of the reference pulse. Another possible approach to coherency recovery makes use of a normal oscillator as COHO. The phase of the Tx pulse is "memorised" by sampling the I and Q components of the coupled pulse, and this information is used to adjust the phase of the COHO signal sent to the phase detector via a phase shifter.

One big limitation of the coherent-on-receive technique is that the memory of transmit phase last only the duration of a PRI. With a new transmit pulse, starting at a random phase, the system locks on this new phase and memory of the former one is lost. As a result, the phase of second-time-around echoes at the output of the receiver remains totally random, preventing their cancellation by MTI filters.
Therefore, MTI doesn't work for multiple-time-around echoes.

Another possible approach to use power-oscillator devices in MTI application is to "prime" them: practically, as done for the COHO in the classic coherent-on-receive, the oscillation of the magnetron (or whatever microwave power oscillator is used) is initialised on the phase of a reference pulse injected in it while it is turned up, allowing to implement a coherent-on-transmit system.

This anyway requires the capability to amplify microwave signals at mediumpower (generally, in the order of some Watts) in order to achieve proper locking, capability which wasn't available in the early times. And when it become possible, also high power amplifier tubes such as klystrons and, later, TWTs started to be available, making all the above phase-locking techniques obsolete for most applications.

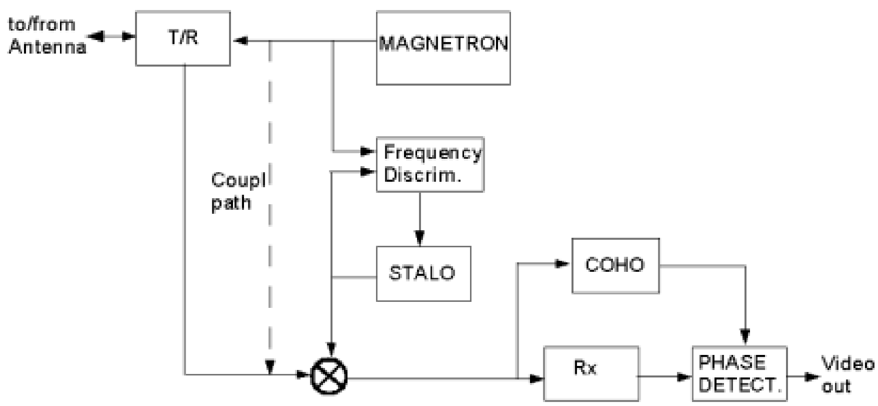

Figure 5 MTI RADAR

9 STAGGERD PRF

Staggered PRF operation is used on many radars (almost all, in different forms). Staggered PRF are mainly used to cope with multiple-time-around echoes. In fact, as explained in radar basics, targets at ranges greater than Ru=c.T/2 (where T is the pulse repetition interval) appear as echoes of the following pulse at shorter range.

Apparent range Ra = Rr-Ru where Rr is the real range.

It is possible to remove this range ambiguity by changing the PRI during the time-on-target. With different PRIs, the target will appear at different ranges. Using a proper logic, it is possible to identify the echo as a second-time-around one, and assign to it the proper range. As a general rule, use of n different PRI allows to solve up to nth-time around echoes (normally, 3 or 4 are used). It is possible to change the PRI at each transmitted pulse, but, generally, in modern radars using "packet" processing, they are changed on a packet basis (some tens of pulses). Note that many modern air-search radars (the so-called "pulse doppler" radars) interntionally work with PRFs so high to have ambiguous range, in order to sample the return at frequency higher than the maximum expected doppler shift (no doppler ambiguity), and cannot work without range ambiguity resolution. [avoiding range ambiguity requires low PRFs, while avoiding doppler ambiguity requires high PRFs. The trade off between these two needs is a big issue in radar design: normally, you have to accept and solve ambiguities in one of these field, or in both] At least 3 PRFs are needed because, for target at range equal to Ru, the radar is blind (the radar is transmitting another pulse, and therefore the receiver is blanked). Having 3 PRIs, this happens only in one packed over 3, allowing a reasonable decision algorithm (e.g., 2 out-of 3) to be implemented. In the times of earlier radars, the only available device capable to produce an high-power output at microwave frequencies, and therefore, suitable for use in radar transmitters, was the *Magnetron* tube. Unfortunately, the magnetron is not an amplifier, but a power oscillator: when a high-voltage pulse is applied to the cathode, it generates at its output a corrensponding pulse of RF energy, with a random initial phase. This is not a problem if coherent operation is not needed: if you don't have to discriminate the phase of echoes, the only thing you need to make this device working is an *Automatic Frequency Control* (AFC) circuit to ensure that the

transmitter and the receiver are working at the same frequency (usually, tuning the STALO - in this case, used only for the downconversion in the receiver - frequency). Things changes if the radar has to exploit the echo phase information, as in MTI radars. In this case, you may either: Force the magnetron to start oscillating at a given phase, or Keep memory of the trasmitted phase and compensate for it in the receiver. The second approach, named "coherent-on-receive", was by far the most widespread used In this approach, the STALO is used for the receiver local oscillator, and it is locked to the magnetron frequency by means of an automatic frequency control circuit (same as for non-coherent systems). The Tx pulse is coupled in the Rx chain, and at IF it is used to phase-lock the COHO (phase detector reference). Two different types of COHO were used:
- delay line: the coupled IF signal was injected in a loop with a delay line (often, a long cable) with delay equal to the pulse lenght. The output was fed back to the delay line imput (recovering the losses with an amplifier) to cover the whole PRI.
- locked oscillator: the oscillator loop gain was reduced below the unit (stopping oscillation), than the oscillation conditions was restored while the reference pulse was applied. In this way, the oscillation started with the same phase of the reference pulse. A third way (I dont know if ever used in practice) is to sample the I/Q component of the reference pulse to detect its phase, than to compensate for it by means of a phase shifter (at IF or in video by cross-multiplying the I/Q components) Note that coherent-on-receive techniques recover the coherence only over a PRI (the system keep memory only of the phase of the last transmitted pulse), i.e. you cannot cancel multiple-time-around clutter. To overcome this limitation while using magnetron or similar devices (such as *EIOs - Extended Interaction Oscillators*) the transmitted oscillator must be forced (or "primed"), by injecting a signal (derived from the COHO + STALO upconverted chain to ensure phase coherency) in the cavity while they are starting oscillating, in order to 'lock' their phase exactly as done for the COHO (but here is much more tricky, due to the high power levels involved). In this way you get a fully 'coherent-on-transmit' system. PRF staggering can also be an ECCM technique. In fact, it makes difficult for the jammer to predict the arrival time of the next pulse, making, for example, uneffective the use of the "range gate pull in" deception technique. Anyway, if only ECCM is of interest, "PRF jittering" (random pulse-to-pulse variation of the PRF) is normally preferred. There are several possible scan techniques for search radars. The "classical" old fashioned search radars

use a "fan beam" antenna, i.e. narrow on the azimuth plane and tall in the elevation plane, to avoid the need to scan in elevation, rotating over 360°. The limitation of this system is that it does not provide information about target elevation, and the target data are limited to azimuth and range (so called *bidimensional*, or 2-D radar). The elevation information, when needed, is achieved by external means: commercial aircraft, for instance, transmit the flight level info via their secondary-radar transponder; in air-defence systems, dedicated "higth-finder" radars, with a so called *nodding beam* (a fan beam rotated by 90°) scanning in elevation only, where used, in association with the main radars, to detect the flight level of the objects to be intercepted. To extract the tridimentional information without rely on external means, capability of scanning the antenna beam in both azimouth and elevation is required. Generally, the scanning speeds required to effectively cover a 360° angle are not compatible with mechanical antenna steering. For this reason, the modern tridimensional (3-D) radars, use the so-called *electronical scanning*, exploiting the Phased Array technique. These systems usually perform the azimuth scan in convenctional way, while using electronical scanning for the elevation. Search radars are systems devoted to the systematic exploration of a large volume of space (for typical air search radars, this is performed over 360° in azimuth and over elevation angles ranging from 20-30° up to almost 90°, processing the echoes over the whole PRI, i.e. over the whole observable range), using different scan techniques. On the other side, tracking radars remains "locked" on a specific target to provide continuos information about its position and motion. Usually, a "pencil beam" (i.e., narrow in both azimuth and elevation) is used. Only a small "range window" correnponding to the target range and its immediate vicinity is processed. External designation systems (such as search radars) are normally employed for target initial location. Tracking radars use "closed loop" (feedback) control systems to keep the target aimed in both angle and range. For angle tracking (azimuth/elevation) different techniques, such as *conical scan* or *monopulse* are employed to detect if the target is off the antenna axis, and the direction and amplitude of this deviation. These *error signals* is used to drive the antenna pointing servomechanism (or the steering control system for electronically-steered antennas) to keep the antenna beam centered on the target. In the same way, range tracking is performed detecting the position of the echo centre of gravity (or, for some applications, the leading edge) with reference to the observed "range window" (using, for instance the *early gate-late gate* technique, in which the amplitudes of two samples collected on the leading and trailing edge of the echo - which, after filtering, is approximately a triangle - are compared to generate the correction signal) to generate an error signal which shift in time the processed range window to keep the target centered. To perform the angular tracking of a target, it shall be measured how much, and in which direction, the target is away from the radar antenna axis. The first technique used for this purpose was the so-called *sequential lobing*. In this technique, normally using multiple antenna feeds, the beam was sequentially pointed slightly away, in the 4 directions, from the antenna axis. Comparing the amplitude or right-left and up-down echoes, it was possible to determine the target off-axis in azimuth and elevation.

The ***conical scan*** is an evolution of this technique, in which the beam is continuosly moved (nutated) around the antenna axis (typically, this is achieved by nutating the feeder, at frequencies in the order of tens of Hz). An echo from an off-axis target will then be amplitude modulated (at the conical scan frequency). The modulation depth provides the error amplitude, while its fase is related to the direction of the deviation. Demodulating the modulation envelope in its sin and cosin component, the azimuth and elevation error are then extracted. Both sequential lobing and conical scan have the disadvantage of being sensitive to errors induced by the echo amplitude fluctuation (glint) during the scanning. To avoid these errors, the measurement must be performed on the basis of a single pulse: this is done with the *simultaneous lobing* or ***monopulse*** technique. In the monopulse technique, 4 different off-axis beams are used simultaneously.

10. Radar Cross Section

Bistatic scattering is the name given to the situation when the scattering direction is not back toward the source of the radiation, thus **forward scattering** occurs when the bistatic angle is 180 degrees. It is called **monostatic scattering** when the receiver and the source are located at the same point, as is the case for a single radar. [19A-1]
Probably as an outgrowth of antenna research and design, this spatial distribution of scattered energy or scattered power is characterized by a **cross section**, a fictitious area property of the target. An antenna is often regarded as having an "aperture of effective area" which extracts energy from a passing radio wave.
The power available at the terminals of the receiving antenna can be represented as the product of the incident power density and an effective area exposed to that power. [19A-2] The power reflected or scattered by a radar target can be expressed as the product of an effective areaand an incident power density. In general, that area is called the **scattering cross section**. For directions other than back toward
the radar, it is called the **bistatic cross section**, and when the direction is back toward the radar, it is called the **back scattering cross section** or the **radar cross section**. In the pioneer days of radar research, the term **echo area** was common and occasionally researchers defined "effective areas" that could be identified with the geometry of a flat plate. [19A-3] In general, the target can be considered to consist of many individual"scatterers". These scatterers can be added vectorially to give the total scattered field. Since the scattered fields depend on the attitude at which the target is presented to the incident wave, the scattering cross section fluctuates. Therefore, it can be seen that the scattering cross section is **not** a constant, but is strongly dependent on the angular properties of the target and the direction from which the target is viewed. The RCS variables often consist of many orders of magnitude; transmitted powers may be in megawatts and received power may be in picowatts. Because of the wide range of variables involved, parameters are conveniently converted to logarithmic values. Typically, transmitted power, antenna gain, and RCS values are provided in dB. (RCS values are often expressed in dBsm - decibels relative to a square meter - where dBsm is a direct function of the logarithm to the base ten of the RCS of a target expressed in square meters.) A comparison of the square meter and dBsm. Wavelength and range are usually given in linear units and must be converted to dB. (Regardless of whether they are dBm, dB, dBsm, "dB"s may

be arithmetically added.) The purpose of an RCS measurement range is to collect radar target scattering data. Usually, the range user requires far-field data, corresponding to the case where the target is located far enough from the instrumentation radar that the incident phase fronts are acceptably flat. Many times this dictates the use o an outdoor range. However, depending on the target and the nature of the research program many tests are conducted indoors in an anechoic chamber. Whether outdoors or indoors, an RCS measurements facility
must have, as a minimum, these five features:

• An instrumentation radar capable of launching and receiving a microwave signal of sufficient intensity,

• Recording instruments, either analog or digital or both, for saving the information,

• A controllable target rotator or turn table,

• A low background signal environment, including "invisible" target support structures, to minimize contamination of the desired signals,

• A test target suitable for the measurements. After the decision has been made to conduct a measurement program, a suitable facility must be found.

Negotiations usually involve the specification of a set of test conditions and a test matrix, and the prospective range will submit a bid. This bid should be carefully evaluated to ensure that the facility can actually produce the data required and to determine if the range is able to offer a differing set of test conditions that could produce the desired data in a more cost effective fashion based upon the experience of the facility personnel. Free-flight measurements of air vehicles are accomplished primarily to ascertain the RCS, determine the
contributions of "dynamic" components such as engines and control surfaces, validate and/or define problems with the ground measurements, and determine RCS under combat conditions such as maneuvering flight and the modification to RCS at the time of chaff release. A complex target, such as an aircraft, contains several dozen significant scattering centers and dozens of other less significant scatterers. Because of this multiplicity of scatterers, the net RCS pattern exhibits a rapid scintillation with aspect angle due to the mutual interference as the various contributors go in and out of phase with each other. The larger the target in terms of wave-length, the more rapid these scintillations become. Major sources of nose-on reflections on a commercial transport are the flat bulkhead on which the weather radar is mounted, the large cockpit cavity, and the interaction between the engine fan faces.

11. INDOOR RANGES

Although a large building is required to house an indoor range, much less ground area is required than for an outdoor range. However, the indoor range does have its problems such as undesired reflected signals

from chamber walls. To a lesser extent facility screen rooms are often required to meet radio frequency interference (RFI) and security requirements which in turn lead to lighting, heating, and cooling complications. Often, even though the convenience, economy, and security of an indoor test range are preferred, most targets are just too big. For example, a target as small as 1.5 meters (5 feet) should be measured at a range of not less than 154.0 meters (about 500 feet) for a test frequency of 10 GHz if the far-field criterion is to be satisfied. Thus, even the largest indoor ranges may fall short of being useful even for small targets. The compact indoor range represents a successful approach to significantly increasing target size for a given chamber size. In fact, compact ranges can now provide some farfield equivalent measurements that even the largest outdoor ranges cannot. The compact range concept is based on the premise that devices can be constructed which will collimate (i.e., make straight) a spherical or cylindrical wave to produce a plane wave. Two different types of collimators are available: lenses and reflectors. Within certain limitations these devices straighten out the incident phase fronts making it possible to conduct

measurements indoors with a fraction of the distance normally required. The EMI Electronics, Limited, has developed a radar modeling capability at the UK National Radio Modeling Facility. Emphasis at this facility is on the development of instrumentation systems and the collection and interpretation of radar scattering data at frequencies up to 2 GHz. Virtually all of the measurements and testing are performed on scale models from missiles and artillery shells to ships and aircraft. The EMI Electronics, Limited, has also developed state of the art components such as RF sources and detection systems. All measurements are conducted indoors. As of 1978, nine different radar systems were operable in conjunction with seven different model support systems. Unlike most indoor facilities, this one makes limited use of radar absorbing material and relies instead on range gating to eliminate background reflections. Once experimenters learned the importance of reducing extraneous reflections, true anechoic chambers were constructed. At first these chambers were rectangular, simply because the room was this shape to start with. Later, the concept of a tapered chamber was introduced to suppress the specular wall reflections. The taper effectively removes the sidewall regions where specular reflections can occur. This tapered concept was first described by Emerson and Sefton, Tapered chambers are superior to rectangular chambers for RCS measurements, especially if the measurements must be made at low frequencies for which high gain antennas (to reduce sidewall illumination) cannot be used. At millimeter wavelengths (one-eighth inch at 93 Ghz), the sharp tips on the pyramidal absorbing material must be maintained, otherwise the effectiveness of the design is degraded. Further, at these frequencies the absorber must not be painted.

12 RADAR BEAM PROPERTIES

The radar antenna consists of a parabolic dish with an microwave feed in its focal point. On transmission the radiation is concentrated in a narrow beam. On reception the echo energy is sampled from the same restricted volume as well. Unfortunately the radar beam may be disturbed by a protecting radome or by a reflecting ground surface. More seriously, the beam may be obstructed completely by man-made or natural obstacles. The useful range of radar for nowcasting as well as the accuracy of precipitation estimates depends strongly on these disturbances. In a densely populated area like The Netherlands “radar horizon pollution” is an increasing threat to radar meteorology applications. The radar position at Schiphol was abandoned for Den Helder in favour of a better coverage to the northwest. In retrospect, KNMI escaped Schiphol just in time to avoid a high rise airport expansion. The future horizon of the radar on top of the central office at De Bilt is by no means secured. The new location in Den Helder is regularly threatened by plans to install tall wind generators. This chapter tries to provide quantitative information on the degree of distortion caused by these effects. Factory specifications are based on measurements (sometimes without radome) on special towers and are usually not representative for the operational site. It is strongly advised to perform a beam pattern measurement on the radar site and to repeat such measurements to check e.g. radome deterioration. A microwave transmitter feedhorn (horizontal polarization!) can be mounted on a nearby mast and the scanning radar will record the power as a function of azimuth for various elevations. The complete beam pattern can be reconstructed by combining these records.. An alternative is to record the radar signal during such multidimensional scans with a nearby receiver. This possibility exists at the Den Helder “collimation tower”. As the measurements are usually relative to the power at the beam axis, it is difficult to use them in measuring the antenna gain. The width of the beam might give a clue whether changes are necessary. A more direct application for KNMI is the beamwidth/sidelobe correction used for the echo top measurements. The correction parameters are derived from simulations 12 with the measured beam pattern (Section 8.6 of the Echo Top Chapter). The relevant part of the beam regarding errors of echo tops lies below the axis. As an example the average pattern over a 2 deg azimuth sector is drawn. A numerical approximation of the normalised (two-way) pattern, up to the second side lobe, is:

$F = \exp[-b0x2] + \exp[-b1(x - a1)2 - 0.23d1]$

$+\exp[-b2(x - a2)2 - 0.23d2]$ (2.1)

where x is the off-axis angle in deg. The side lobes are found at a1 resp. a2 deg and their two-way peak values are d1 resp. d2 dB below the peak of the main lobe. In the example of Figure 2.1 we have a1=2.63, d1=63, a2=4.5 and d2=67. These parameters can be read directly from the graph. The factors b0...b2 determine the width of the main and side lobes: b0=5, b1=16 and b2=5 were found by fitting our example. The measurements in Den Helder on Sep. 7, 1999 can be fitted with a1=2.0, d1=58, a2=3.0, d2=63, b0=6.5, b1=7.8 and b2=4.

13 PROPAGATION AND REFLECTION EFFECTS

If we want to observe precipitation at large range, we have to use a low elevation beam. In the Netherlands the radars are positioned at a height around 50 m, so the radar horizon is at an elevation of about −0.1 deg below horizontal. Because the beam width is 1.0 deg, most of the beam is used if the lowest elevation is 0.3 deg. See also Smith (1995). This has (and can again) been checked by maximizing the return of distant low-altitude precipitation. There are two reasons for non-precipitation radar returns in the 0.3 deg beam:

• In anomalous propagation conditions (see general literature) part of the beam is trapped in a duct, where the power reduction with range is according to an inverse linear rather than the usual inverse squared law. Although this only applies to a part of the beam, the effective antenna gain is increased and scattering cross-sections below 0 dBZ may be detected.

• If the lowest beam is reflected at a flat conducting surface like the sea, interference of the main and reflected beams deform the circular beam pattern into a series of vertically stacked flat sub-beams of which the lowest has a 3 dB larger sensitivity (one way) than the original axial gain (Ma Zhenhua, 1985, p.108).

The targets that become visible in these narrowed beams are: • land surface echoes, luckily removed by clutter cancellation. • the sea surface, for which clutter cancellation is less effective. • (low) clouds, with too small drops to be detected normally. • refractive index fluctuations, normally smaller than 0 dBZ. • possibly insects, etc. In operational practice these confusing echoes occur only over the sea surface. Additional tools to check their non-precipitation character are the radar echo top picture and satellite images for both visible and infrared radiation.

14 RADAR HORIZON

The radar is intentionally located on a high position, to avoid nearby obstacles like hills or buildings. In principle a nearby “ring” of obstacles is advantageous to avoid ground clutter, but this reduces the operating range of the radar. In the project COST-73 the radar range has been defined as the range up to where the lowest usable beam axis would detect precipitation echoes not higher than 1.5 km above the local terrain (Newsome, 1992, p.41-50). Due to the curvature of the earth the lowest possible beam will touch the earth surface at a range Dh, Dh = p 2HrR (2.2) where Hr is the height of the antenna and R = 1.33 · 6367 km, the earth radius corrected for near-surface microwave propagation. For Den Helder Hr=51 m, so Dh=30 km, at least where the radar has a clear view on the sea. For most of the country the horizon consists of trees and buildings, so it is better to increase the height of the earth surface H with about 5 m. It is important to note that nearby obstacles up to 50 m height remain below the radar beam, while a 40 m high row of dunes at 30 km range will rise the lowest beam with 0.08 deg and reduce the radar range with nearly 10%. An 40 m high isolated building with a width of 40 m would hardly have an effect at 30 km range, because 0.08 deg is small for a 1 deg radar beam. From a radar at height Hr above m.s.l., an obstacle at range D and height H will be seen at elevation E = arcsin _ (R + Hr)2 + D2 − (R + H)2 2D(R + Hr) _ This follows from the cosine rule in the triangle: radar, target and the “radar earth” centre. An explicit formula for the connecting line between radar and m.s.l. horizon is H = p 2HrR – D sin(arctan((p 2HrR − D)/R)) − R expressing the height H as a function of range D.

15 RADAR MODULATION

Radio frequency energy in radar is transmitted in short pulses with time durations that may vary from 1 to 50 microseconds or more. If the transmitter is cut off before any reflected energy returns from a target, the receiver can distinguish between the transmitted pulse and the reflected pulse. After all reflections have returned, the transmitter can again be cut on and the process repeated. The receiver output is applied to an indicator which measures the time interval between the transmission of energy and its return as a reflection. Since the energy travels at a constant velocity, the time interval becomes a measure of the distance traveled (RANGE). Since this method does not depend on the relative frequency of the returned signal, or on the motion of the target, difficulties experienced in cw or fm methods are not encountered. The pulse modulation method is used in many military radar applications.

Most radar oscillators operate at pulse voltages between 5 and 20 kilovolts. They require currents of several amperes during the actual pulse which places severe requirements on the modulator. The function of the high-vacuum tube modulator is to act as a switch to turn a pulse ON and OFF at the transmitter in response to a control signal. The best device for this purpose is one which requires the least signal power for control and allows the transfer of power from the transmitter power source to the oscillator with the least loss. The pulse modulator circuits discussed in this section are typical pulse modulators used in radar equipment.

Spark-Gap Modulator The SPARK-GAP MODULATOR consists of a circuit for storing energy, a circuit for rapidly discharging the storage circuit (spark gap), a pulse transformer, and an ac power source. The circuit for storing energy is essentially a short section of artificial transmission line which is known as the PULSE-FORMING NETWORK (pfn). The pulse-forming network is discharged by a spark gap. Two types of spark gaps are used: FIXED GAPS and ROTARY GAPS. The fixed gap, discussed in this section, uses a trigger pulse to ionize the air between the contacts of the spark gap and to initiate the discharge of the pulse-forming network. The rotary gap is similar to a mechanically driven switch. Between trigger pulses the spark gap is an open circuit. Current flows through the pulse transformer (T1), the pulse-forming network (C1, C2, C3, C4, and L2), the diode (V1), and the inductor (L1) to the plate supply voltage (E_{bb}). These components form the charging circuit for the pulse-forming network. The hydrogen thyratron modulator provides improved timing because the synchronized trigger pulse is applied to the control grid of the thyratron (V2) and instantaneous firing is obtained. In addition, only one gas tube is required to discharge the pulse-forming network, and a low amplitude trigger pulse is sufficient to initiate discharge. A damping diode is used to prevent breakdown of the thyratron by reverse-voltage transients. The thyratron requires a sharp leading edge for a trigger pulse and depends on a sudden drop in anode voltage (controlled by the pulse-forming network) to terminate the pulse and cut off the tube.

As shown in figure 2-39, the typical thyratron modulator is very similar to the spark-gap modulator. It consists of a power source (E_{bb}), a circuit for storing energy (L2, C2, C3, C4, and C5), a circuit for discharging the storage circuit (V2), and a pulse transformer (T1). In addition this circuit has a damping diode (V1) to prevent reverse-polarity signals from being applied to the plate of V2 which could cause V2 to breakdown.

With no trigger pulse applied, the pfn charges through T1, the pfn, and the charging coil L1 to the potential of E_{bb}. When a trigger pulse is applied to the grid of V2, the tube ionizes causing the pulse-forming network to discharge through V2 and the primary of T1. As the voltage across the pfn falls below the ionization point of V2, the tube shuts off. Because of the inductive properties of the pfn, the positive discharge voltage has a tendency to swing negative. This negative overshoot is prevented from damaging the thyratron and affecting the output of the circuit by V1, R1, R2, and C1. This is a damping circuit and provides a path for the overshoot transient through V1. It is dissipated by R1 and R2 with C1 acting as a high-frequency bypass to ground, preserving the sharp leading and trailing edges of the pulse. The hydrogen thyratron modulator is the most common radar modulator.

Pulse modulation is also useful in communications systems. The intelligence-carrying capability and power requirements for communications systems differ from those of radar. Therefore, other methods of achieving pulse modulation that are more suitable for communications systems will now be studied.

16. RADAR DEFEATER

The radar speed gun has quite a bit of sophisticated electronics in it. First, there is a transmitter, which creates a signal (called a carrier wave) at a specific frequency (of whichever band the radar is designed for). We will use as an example 1.5 Ghz, which means that one and a half billion sine wave pulses are created every second. This signal is not modulated like a signal from a radio station would be. Some people seem to assume that this frequency is absolutely precise and that it doesn't ever vary. In the real world, variations in component values and dependence on temperature cause continuous slow changes in the carrier frequency. (This will come up again later). To simplify our example, we will assume a frequency of EXACTLY 1,500,000,000 Hertz. Next, a tiny fraction of this signal is taken off and kept in the radar gun, to be used later. Then, most of the signal is amplified and sent out the front of the radar gun. This signal is radiated out toward your car. As the signal spreads out, its strength gets weaker and weaker. It complies with the inverse-square law of physics. Going twice as far away makes the signal 1/4 as strong, and the radiation pattern is twice as wide and twice as high. Various radar guns have different spread patterns, but a block away, the pattern may be about 30 feet in diameter. This means that the signal strength is less than 1/100,000 of its original strength. (By the way, that is why there is no radiation danger to you in your car.) This is the signal that gets to your car. If your car passes through any part of the 30-foot diameter circle (actually, cone), the signal will hit it. Then your car reflects it. Reflection occurs in two ways.

SPECULAR reflection is like your reflection in a mirror. In the situation we're considering, some parts of the curved parts or your chrome bumpers and other curved metal car body parts will be able to reflect a very small but intense reflection back to the source. A similar situation of specular reflection is on a sunny day, where you will see a small, very bright reflection of the Sun from a chrome bumper from almost anywhere you stand.

DIFFUSE reflection is like the reflection of light off of a matte finish aluminum sheet or even a white sheet of paper. Instead of reflecting all the incoming signal or light in one specific direction, a weak reflection occurs in all directions. In the situation of a radar signal, all of the metal surfaces of your car make contributions toward the total signal reflected by your car. A tiny fraction of this energy that is reflected in all directions, happens to be reflected back in the exact direction of the originating radar gun. The total radar signal reflected **exactly** back toward the source radar gun is the sum of these specular and diffuse components. You can probably see from this that on the whole, the signal strength from a huge semi tractor and trailer is likely to be far stronger than that from your little compact car. (That situation is actually due almost entirely to the much larger diffuse reflection. The specular reflection can be of pretty similar strength.) Even though that reflected signal is stronger, it MAY NOT be the one that the radar gun notices. (More about this later.) In any case, the actual total signal strength reflected back FROM your vehicle to the radar gun is even far weaker than when it first got to your vehicle, so it's REALLY miniscule now!

As an experiment in 1987, we started fitting the front of a huge old 1972 Ford van with a sloping flat, mirror shiny, surface, tilted back (upwards) at about a ten degree angle. The whole front of the van was this sloped mirror surface. (It would NOT have been safe to drive since you couldn't see the road!) Such a modified vehicle was ugly as sin, but was INVISIBLE to Police speed radar, because ALL of the signal was reflected (in a specular manner) up and out into space! In order for this approach to work effectively, the mirror surface had to be absolutely clean! We discovered that if it got even a small amount of dust on it, there was enough diffuse reflection to send a signal back to the radar gun, and it was no longer invisible to the radar.

When the US Government was designing the Stealth Bomber and the other Stealth technologies, they faced dealing with both of these types of radar reflections. We heard a story that they had done such an excellent job of making the entire airplane anti- and non- reflectant, that it was totally invisible to radar sitting on the Tarmac. EXCEPT when a pilot sat in it! His glasses and helmet and face were NOT Stealth modified, and therefore reflected a signal back, and therefore made the plane's location known to the radar! (I understand that they solved this later!)

Have you ever noticed the weird angular shapes of a Stealth airplane? That's related to an attempt at reducing specular reflection back toward an enemy radar, much like our experiment with the shiny wedge on that old van. Of course, they combined that basic shape with anti-reflective coatings and other technologies. If you had several billion dollars to spend, you could apply military Stealth to a car and make it invisible to Police RADAR! The reflected signal spreads out from your car and gets weaker again. By the time it gets back to the radar gun, it can be far less than one-billionth of its original strength. Remembering that the gun retained a tiny amount of the radiated signal, we can now electronically compare the retained and reflected signals to learn several things. If we had wanted to, we could have timed the delay until the reflected signal got back, and found how far away the car was, like aircraft radar does. But Police DON'T CARE how far away the car is, so this processing does NOT occur in a Police speed radar gun. There is a phenomenon called the Doppler shift, which causes the frequency of any signal radiated from an object (including a reflected signal) to be shifted by a very specific amount. The size of this frequency shift is dependent on the speed of the moving vehicle, and on almost nothing else. The equation is f(reflected)=f(source) * Sqr.Rt((c+v)/(c-v)), where c is the velocity of light, and v is the velocity of your car. The speed of light is REALLY fast! For a car going 100 mph (toward the radar gun), this only represents a frequency shift (increase) of our original signal to 1.500000150 Ghz, a VERY tiny change. It is SO small a change that it would seem impossible to even recognize it. The ONLY way to even know there was a change is through combining (ADDING) the retained signal with the reflected signal. In the process of this signal addition, several new signals appear, one of which is at the frequency of the difference! This process is called beating the signals together. So we get an resulting output (difference) signal of about 150 Hz for the 100 mph car. Lower speeds give lower (difference) frequency. Every frequency corresponds uniquely with a specific speed, virtually exactly proportional to vehicle speed. An important effect results from this method of getting this difference of frequency. Since the signals being added were created within about one one-millionth of a second, from the same source oscillator, very little accidental frequency change could have occurred. Even though the (carrier) frequency gradually drifts due to temperature and other effects, little change can occur in such a very short time. Five minutes later, that same radar gun might have warmed up and is now oscillating at 1.500001000 (a change much larger than the final measured difference) but it would still be precise because BOTH the retained and reflected signals would have been shifted identically. Since the difference frequency is virtually directly proportional to the target vehicle speed, a simple circuit converts the 150 Hz signal into a readout of 100 mph. A 75 Hz difference signal would show as a 50 mph readout. The radar gun has a circuit that retains the highest previous difference reading, and compares all new readings with it. A higher new difference reading replaces the previous retained/displayed value. The speed determined in this way is the speed difference between the police car and the target vehicle. These comments have described the situation for a stationary police car, the common situation. Some radar guns meant for use in moving Police cars are also connected with the Police car's speedometer, to automatically adjust the output reading to the correct value for the target vehicle. Deficiencies in Speed Radar Operation We felt it necessary to include this fairly full description in order to address several subjects that seem to mystify everyone, such as the 65 mph trees. And to assure you that we know what we are talking about. So, even if you didn't follow all the details above, it's OK. Speed Radar Guns aren't always accurate in rain. A primary reason for this is that gusty winds might blow some raindrops (near the radar gun) toward the radar gun (horizontally) at, say, 60 mph, for an instant. Raindrops aren't particularly good reflectors of microwave signals, so such raindrops need to be fairly near the radar gun to cause a reflected signal strong enough to be recognized by the gun's circuitry. The retain circuit in the radar gun becomes confused by seeing targets moving toward it at 60 mph and therefore it can show a 60 mph reading, even with no target car present. Another effect of rain (and fog) is its interference with the radar beam going both ways and the resultant loss of signal strength. (Remember how tiny the reflected signal is under perfect conditions?) The explanation of this is similar to the rain explanation above. The highly publicized trees were in gusty winds. Their leaves and branches were whipping back and forth, being pushed back and then snapping forward (toward the radar gun) when the wind gust stopped. At some point, a few leaves or branches were moving toward the radar gun at 65 mph. The gun received this (highest) speed value and decided to retain this value because it was higher than any previous value. (This experiment can be reproduced with any sports radar speed gun on a very gusty day. Newer Police radar have additional analysis circuitry to try to minimize this problem, and it is almost unheard of with modern Police radar.) If a speed gun was on a side street and aimed at the side of your car AS YOU PASS across in front of it, a very low reading would be registered, no matter how fast you were going. This is called the PARALLAX effect. An accurate measure of your speed can ONLY be attained from directly in front of or directly behind your car. From any other direction, the reading is actually LOWER than your actual speed (by the cosine of the angle from the path of your car). Personal experience has shown that even some Police don't understand this effect. Generally, when Police wait in their parked car along a highway, they are NEARLY in front of your car, and get NEARLY your full speed. (The cosine of that angle is about 0.99, so the radar gun would record 99% of your actual speed, which is pretty close.) If he was several lanes away from being in front of you when your speed was radar detected, the speed reading could be several MPH LOWER than your actual speed. It can NEVER read HIGHER than your actual speed. Since the circuitry in a radar gun only processes the difference of the frequencies of the retained and reflected signals, the exact same result would be shown whether a target vehicle is moving toward or away from the police radar gun. If a car and a truck are simultaneously in the radar beam, from the discussion above, we know that the truck's reflection is probably much stronger. You might think that this stronger echo might drown out the smaller echo from a faster but smaller compact car. Occasionally, that can actually happen, but usually, the radar will still measure the smaller, faster car, since it is so focused on finding the greatest frequency differential and therefore the fastest possible target. The illegal radar jammers that some people try are just very simple transmitters. Usually, they set the carrier frequency right at or near the center of the specific radar band. (This is EXTREMELY illegal!) Due to variations in components and fluctuations due to temperature, the actual frequency is certain to be just a little off. In our example above, let's say that your (illegal) transmitter is only 1/10 of one percent off, or 1.501500000 Ghz. When that frequency signal was received by a radar gun and compared to the retained signal, it would get a VERY large frequency difference. That result would cause a speed reading of almost 700,000 mph! The radar gun would just blank out because its output usually cannot display speeds of over 140 mph. Such illegal jammers are active transmitters which can (and in this case, are intended to) disable a clear Police band. Long ago, bank robbers would sometimes try to jam Police communications bands to try to have a better chance to get away. The Police and the Government SERIOUSLY frowned on this and quickly got very strong laws passed. Now, even POSSESSION of such a transmitter is a Federal felony. The laws apply to all frequencies that are reserved for Police use, which includes the radar bands. Don't even THINK about it!

The frequency is much higher, being near the optical band rather than in the microwave band, but everything else is similar. The same differencing of retained and reflected signals establishes the target's speed. The other major difference is that the diameter of the target circle is usually much smaller. Where a radar beam might be 30 feet in diameter at a substantial distance away, the laser beam might only be one foot in diameter. The gun must be aimed much more accurately at the target vehicle. A single vehicle, or even a PART of a vehicle can be targeted. Some recent ads show license plate holders which allegedly glow in a color close to the color of the Police laser guns. They hope to defeat the radar by confusing it, as in the illegal transmitters described earlier. We suspect that these occasionally but seldom work. This would be especially true for very narrow beam laser beams where the laser gun was aimed at a part of your car that did NOT include the license plate holderThe Radar Scope, developed by DARPA, is expected to be fielded to troops in Iraq as soon as this spring. The Radar Scope will give warfighters the capability to sense through a foot of concrete and 50 feet beyond that into a room, Baranoski explained. Weighing just a pound and a half, the Radar Scope will be about the size of a telephone handset and cost just about US$1,000, making it light enough for a soldier to carry and inexpensive enough to be fielded widely. The Radar Scope will be waterproof and rugged, and will run on AA batteries. "It may not change how four-man stacks go into a room (during clearing operations)," Baranoski said. "But as they go into a building, it can help them prioritize what rooms they go into. It will give them an extra degree of knowledge so they know if someone is inside." Even as the organization hurries to get the devices to combat forces, DARPA already is laying groundwork for bigger plans that build on this technology. Proposals are expected this week for the new "Visi Building" technology that's more than a motion detector. It will actually "see" through multiple walls, penetrating entire buildings to show floor plans, locations of occupants and placement of materials such as weapons caches, Baranoski said. "It will give (troops) a lot of opportunity to stake out buildings and really see inside," he said. "It will go a long way in extending their surveillance capabilities." The device is expected to take several years to develop. Ultimately, servicemembers will be able to use it simply by driving or flying by the structure under surveillance, Baranoski said.

17 FUTURE SCOPE

Radar—short for radio direction and ranging—has been with us for nearly seven decades, when British systems designers first deployed this technology to give the Royal Air Force early warning of Nazi bombers crossing the channel to attack cities and towns in England. In those days a radar contact was just a blip on the screen; it did not offer information on the size or type of the contact, and provided only rudimentary information on the contact's speed and direction. It is almost impossible to understate the value and importance of radar to the Allied effort during World War II in terms of being a real game changer. Put simply, radar may have been the decisive factor in the British victory in the Battle of Britain in the spring of 1940. Today's radar technology is every bit as decisive as it was during the Battle of Britain, yet it is worlds away from the large, tube-based, mechanically steered, relatively low-frequency systems that once stood as electronic sentinels along the English coast. Modern radar systems often have imaging capability, can yield digitized signals quickly and easily for use with graphical overlays, can be networked together so the total system is greater than the sum of its parts, and can serve several different functions—such as wide-area search, target tracking, fire control, and weather monitoring—where previous generations of radar technology required separate systems to do the same jobs. Once the radio waves have been generated, an antenna, working as a transmitter, hurls them into the air in front of it. The antenna is usually curved so it focuses the waves into a precise, narrow beam, but radar antennas also typically rotate so they can detect movements over a large area. The radio waves travel outward from the antenna at the speed of light (186,000 miles or 300,000 km per second) and keep going until they hit something. Then some of them bounce back toward the antenna in a beam of reflected radio waves also travelling at the speed of light. The speed of the waves is crucially important. If an enemy jet plane is approaching at over 3,000 km/h (2,000 mph), the radar beam needs to travel much faster than this to reach the plane, return to the transmitter, and trigger the alarm in time. That's no problem, because radio waves (and light) travel fast enough to go seven times around the world in a second! If an enemy plane is 160 km (100 miles) away, a radar beam can travel that distance and back in less than a thousandth of a second. The antenna doubles up as a radar receiver as well as a transmitter. In fact, it alternates between the two jobs. Typically it transmits radio waves for a few thousandths of a second, then it listens for the reflections for anything up to several seconds before transmitting again. Any reflected radio waves picked up by the antenna are directed into a piece of electronic equipment that processes and displays them in a meaningful form on a television-like screen, watched all the time by a human operator. The receiving equipment filters out useless reflections from the ground, buildings, and so on, displaying only significant reflections on the screen itself. Using radar, an operator can see any nearby ships or planes, where they are, how quickly they're travelling, and where they're heading. Watching a radar screen is a bit like playing a video game—except that the spots on the screen represent real airplanes and ships and the slightest mistake could cost many people's lives.

There's one more important piece of equipment in the radar apparatus. It's called a duplexer and it makes the antenna swap back and forth between being a transmitter and a receiver. While the antenna is transmitting, it cannot receive—and vice-versa. Take a look at the diagram in the box below to see how all these parts of the radar system fit together.

18 CONCLUSION

Military radars are one of the most important requirements during the wartime, which can be used for early detection of ballistic missile and also for accurate target detection and firing. Radar system discussed here has a built in threat evaluation program which automatically puts the target in a threat sequence, and advises the weapon crew which target can be engaged first. Most essential, the target data is available to the weapon crew in time, so the can prepare themselves to engage the ‘best’ target for their specific weapon location. A magnetron radar system is relatively simple and reliable. As a consequence, minimum maintenance is required and thus the system life cycle costs can be kept low. Ground Surveillance Radar systems are a key military intelligence technology. They are able to provide intelligence that is vital to the success of many military tactics and strategies. When RADINT is combined with other types of intelligence, a battlefield commander can get a clear picture of the battlespace, resulting in well-informed decisions. The versatility of GSR systems makes them useful for a variety of military missions, ranging from war making to peacekeeping.

19 REFERENCES

1) Skolnik ‘Introduction to Radar Systems’ McGraw Hill

2) ‘Electronic Communication Systems’ by Kennedy, Davis Fourth Edition

3) Bharat Electronics Limited website www.bel-india.com

4) Various other internet sites and journals

[1] *AN/PPS-6*, STANO Components. [Online]. Available: http://www.stano.nightvision.
com/html/pps6.html.

[2] *Army Branch Information*, University of Wisconsin Oshkosh, 1997. [Online]. Available:
http://www.uwosh.edu/departments/military_science/spring/ra8.htm.

[3] Chizek, Judy G, *Military Transformation*: *Intelligence, Surveillance and Reconnaissance*,
Report for Congress, 2001. [Online]. Available: http://www.fas.org/irp/crs/RL31425.pdf.

[4] *Fire Support Bases*, Grunt! The Online Vietnam Resource. [Online]. Available:
http://www.soft.net.uk/entrinet/arty9.htm