NEAR EAST UNIVERSITY

Faculty of Engineering

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ELECTRONIC WARFARE

Graduation Project
EE - 400

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I am indebted to my home land, Palestine. We shall do every thing to get it freed.

ABSTRACT

What is the nature of the process of implementing a new technology? How should the dynamics of implementing a new technology be studied? What research methods are best-suited to the study of complex issues of social and organizational impacts arising from the implementation of a new technology? EW is the art and science of denying enemy forces the use of the electromagnetic spectrum while preserving its use for friendly forces. EW is a significant force multiplier because it reduces friendly losses by defeating or reducing the effectiveness of enemy weapons The modern battlespace has become more sophisticated. Military operations are executed in an increasingly complex electromagnetic (EM) environment. Military forces, as well as civilians, depend on electronic equipment operating within the electromagnetic spectrum for communications, navigation, information gathering, processing, and storing; and as a means for detection and identification of enemy forces. Historically, radar has been the primary concern of electronic warfare; today the threat has expanded to include command and control systems, electro-optic systems, electromagnetic dependent munitions, and directed energy systems. The outcome of modern conflict greatly depends on control of the electromagnetic spectrum.

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INTRODUCTION

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

Although the typical radar transmits a simple pulse-modulated waveform, there are a number of other suitable modulations that might be used. The pulse carrier might be frequency- or phase-modulated to permit the echo signals to be compressed in time after option. This achieves the benefits of high range-resolution without the need to resort to a short pulse. The technique of using a long, modulated pulse to obtain the resolution of a short pulse, but with the energy of a long pulse, is known as pulse compression. Continuous waveforms (CW) also can be used by taking advantage of the Doppler frequency shift to separate the received echo from the transmitted signal and the echoes from stationary clutter. UN modulated CW waveforms do not measure range, but a range measurement can be made applying either frequency- or phase-modulation. And we will speak about it more clearly in second chapter.

New developments in communications systems have oscillated between wired and wireless. Early initiatives in Morse telegraphy and the wired telephone subsequently gave way to Marconi's wireless telegraphy and then to voice. After the Second World War fixed wireless systems led the way providing higher capacity terrestrial and satellite radio links. Later networking led to the advent of the Internet and the interconnection of computers. Cellular communication systems were also developed, but these two communities largely stayed apart.

Now, for the first time, networking and radio are getting together to meet the desire for high capacity, mobile and flexible personal communications systems (PCS) - thereby providing communications on the move and enabling new concepts like pervasive computing. This information sheet explores some of these exciting new developments and how they affect the future of military communications. And we will see more about it in chapter three.

Communications via radio, cable or optical fibre pervades all aspects of military operations. Communication systems provide the vital conduit between one computer and another to ensure the distribution of command and control, intelligence and other information. Communications are the glue that cements military operations. Without a functional communications system virtually all modern wartime and peace keeping activities would quickly grind to a halt and knowledge superiority would be impossible. As we will see it in chapter four.

In order to maintain information dominance, military communications must be maintained when and where needed. What makes Military Communications systems different from civil systems is that they have traditionally been designed to resist geo-location, jamming and other this system is electronic warfare (EW) This project introduces communications theory, including bands and their uses, transmitters, receivers, antennas and completes systems. Threats to communications are discussed and the project concludes with communications EW theory and techniques. A there'd chapter is available for those wishing to cover communications developments and further depth on spread spectrum, tactical voice/data systems, tactical data systems, information distribution systems and the EW pertinent to these.

CHAPTER ONE

HISTORY OF RADAR

1.1 Overview

Radar systems (Radio Detection and Ranging) were developed in the 1942s mainly by the armed forces. Radar is an active remote sensing system which means that it provides its own source of energy to produce an image. Thus, it does not require sunlight (as do optical systems) and data can be acquired either by day or by night. Furthermore, due to the specific wavelength of radar cloud cover can be penetrated without any effect on the imagery.

Figuer 1.1. Show An Army Cd Radar At North Head Circa 1942.

using a radio transmitter and a reciever. The transmitter sends out a high frequency radio wave. If the radio wave hits another object (a plane or a ship) it will reflect back to the reciever. By gauging the time it takes for the wave to return and the amount of the radio wave which returns to the reciever, the position and size of the plane or ship can be projected onto a radar screen. If a lot of the signal is bounced back then they are close to the object. If only a little bit of the signal is bounced back then they are far from the object. If only a little bit of the wave returned that means the object is smaller. If a lot of the radio wave returns that means the object is larger.

This process is similar to a bat's use of echo-location to locate insects in the dark. The only difference is that echo-location uses sound waves as opposed to the radio waves sent out by the radar.

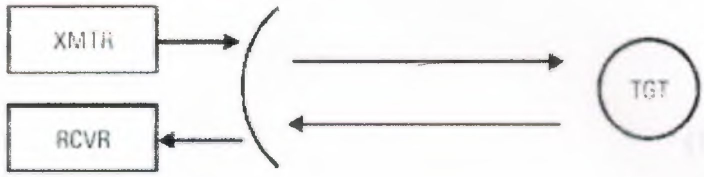


Figure 1.2. Basic Radar Function

An elementary form of radar consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator of some sort, a receiving antenna, and an energy-detecting device, or receiver. A portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. It is the energy reradiated in the back direction that is of prime interest to the radar. The receiving antenna collects the refinanced energy and delivers it to a receiver, where it is processed to detect the presence of the target and to extract its location and relative velocity. The distance to the target is determined by measuring the time taken for the radar signal to travel to the target and back. The direction, or angular position, of the target may be determined from the direction of arrival of the reflected wave-front. The usual method of measuring the direction of arrival is with narrow antenna beams. If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave (Doppler Effect) is a measure of the target's relative (radial) velocity and may be used to distinguish moving targets from stationary objects. In radars which continuously track the movement of a target, a continuous indication of the rate of change of target position is available. The name radar reflects the emphasis placed by the early experimenters on a device to detect the presence of a target and measure its range. Radar is a contraction of the words radio detection and ranging. It was first developed as a detection device to warn of the approach of hostile aircraft and for directing antiaircraft weapons. Although well-designed modem radar can usually extractors information from the target signal than merely range, the measuftment of range is still one of radar's most important functions. There seem to be no other competitive techniques which can measure range as well or as rapidly as can radar. The most common radar waveform is a train of narrow, rectangular-shape pulses modulating a sine wave carrier. The distance, or range, to the target is determined by measuring the time TR taken by the pulse to travel to the target and return.

Since electromagnetic energy propagates at the speed of light c =3 x 10^8 m/s, the range R is

$$R = \frac{cT_R}{2} \tag{1.1}$$

The factor 2 appears in the denominator because of the two-way propagation of radar. With the range in kilometers or nautical miles, and TR in microseconds, Eq. (1.1) becomes

$$R(Km) = 0.15T_R\,(\mu\, s) \text{ or } R(nmi)=0.081T_R\,(\mu\, s) \tag{1.2}$$

Each microsecond of round-trip travel time corresponds to a distance of 0.081 nautical mile, 0.093 statute mile, 150 meters, 164 yards, or 492 feet.

Once the transmitted pulse is emitted by the radar, a sufficient length of time must elapse to allow any echo signals to return and be detected before the next pulse may be transmitted. Therefore the rate at which the pulses may be transmitted is determined by the longest range at which targets are

Expected. If the pulse repetition frequency is too high, echo signals from some targets might arrive after the transmission of the next pulse, and ambiguities in measuring range might result. Echoes that arrive after the transmission of the next pulse are called second-time-around (or multiple-time-around) echoes. Such an echo would appear to be at a much shorter range than the actual and could be misleading if it were not known to be a second-time-around echo. The range beyond which targets appear as second-time-around echoes is called the maximum unambiguous range and is

$$R_{unamb} = \frac{c}{2f_p}\,, \tag{1.3}$$

Where f_p = pulse repetition frequency, in Hz. A plot of the maximum unambiguous range as a function of pulse repetition frequency is

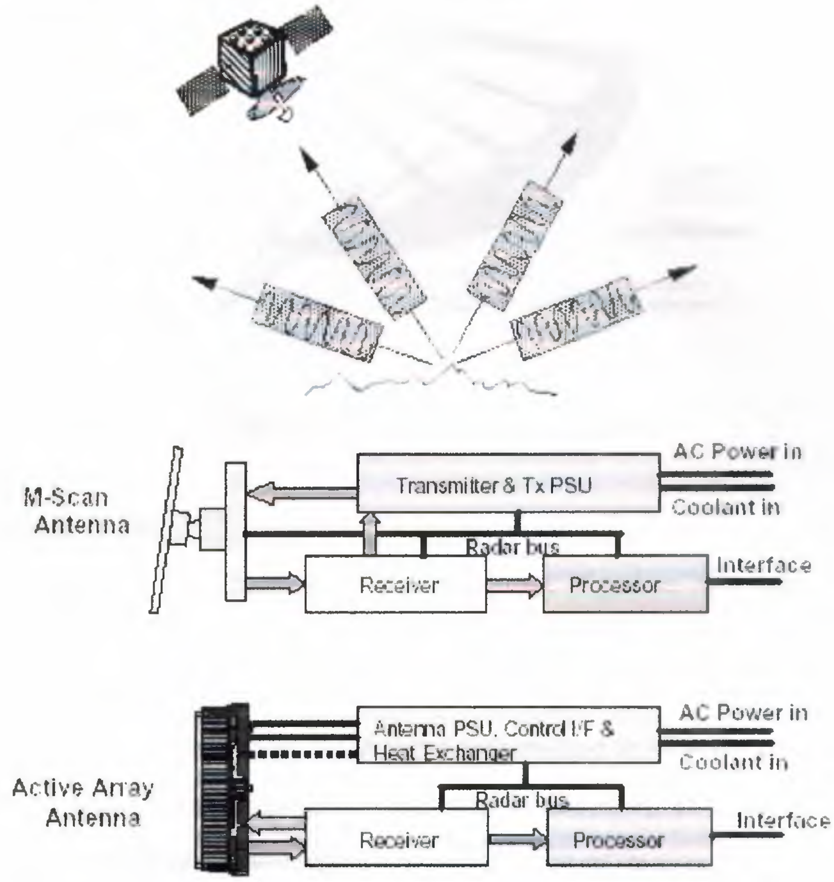


Figure 1.3. Radar concept transformation m Radar concept transformation m-scan to scan to AESA

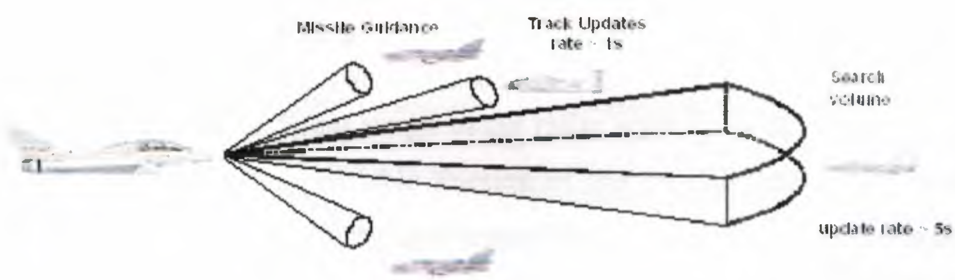


Figure 1.4 (a) AESA Independent Search and Track AESA Independent Search and Track Regime

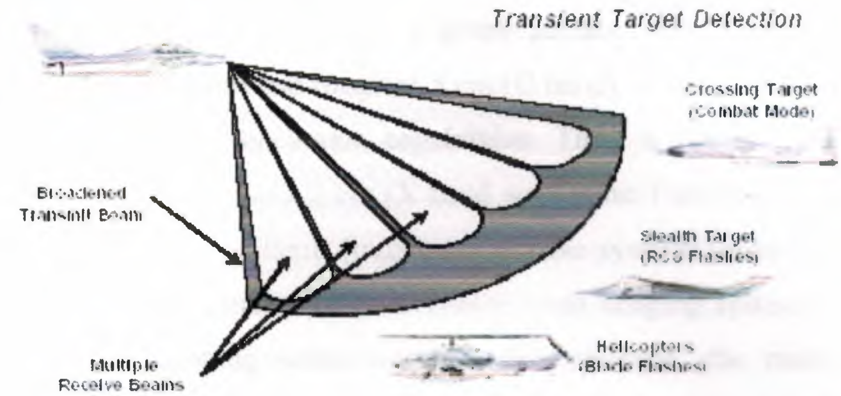


Figure 1.4 (b) Beam shape Control

1.2 Some Basic Radar Principles

Radar is based on the transmission and reception of pulses in a narrow beam in the cm bands of the electromagnetic spectrum; the returning echoes are then recorded, taking into consideration their strength, time interval and phase. The power received by the antenna on board from each radar pulse transmitted is directly connected with the physical characteristics of the target through the backscattering coefficient. The value of this backscatter coefficient (corresponding to grey values in optical images) is basically dependent on three factors:

- the surface roughness,
- the surface humidity,
- the wavelength of the radar.

A surface is considered as being rough in the radar sense if its structure or shape has dimensions which are an appreciable fraction of the incident radar wavelength. For example, gravel surfaces exhibit stronger scatter than smooth clays. Another example of the effect of surface roughness can be observed when looking at the difference between water surfaces with and without waves. Over water surfaces which are not moved by wind effects, almost no energy is scattered back to the antenna, which means that this area appears dark. Land surfaces are usually rougher (higher backscatter) than water surfaces as they contain structures with vertical faces and corners. Moisture content influences the electrical properties of a target (soil, vegetation, etc.) and the backscatter increases with humidity. A wet ground surface is characterised by a stronger backscatter than a dry one having the same roughness. The importance of both factors is also dependent on the chosen wavelength. A given surface may appear smooth at a wavelength of 25 cm (S band) and rough at 5 cm (C band). Furthermore, the longer the wavelength the higher the penetration capabilities. Thus, a 100 cm wave (P band) penetrates vegetation better than a 3 cm (X band wave) one. Furthermore, a distinction can be made between active systems (radar) and passive systems (radiometers), as well as non-imaging systems (scatterometers, altimeters) and imaging systems (synthetic or real aperture radar, scanning scatterometers). For example, the radar instrument mounted on ERS is a SAR (Synthetic Aperture Radar) which means that the antenna is made to appear longer than it really is by exploiting the relative movements between the platform and the Earth with complex processing. Through this, a higher resolution can be achieved. Moreover, both the polarization and the incidence angle play a very important role in the detection of a target with the radar instrument.

1.2.1 Radio Wave Frequency and Wavelength

Radar is a variant of radio technology and shares many of the same basic concepts. It is useful to discuss fundamental concepts of radio operation to provide a basis for discussing fundamental concepts of radar operation.

Late in the 19th century, researchers discovered that if an alternating electric current were run through a wire or rod, it emitted an invisible form of radiation that could generate an alternating electric current in a separate wire or rod. This invisible radiation was quickly realized to be a form of "electromagnetic radiation", a disturbance of electric and magnetic fields that propagated through space. Electromagnetic radiation is in the form of waves, conceptually similar to the waves set up by shaking a rope up and down, and propagating at a speed of 300,000,000 meters per second (186,000 miles per second). The waves could be generated at varying "frequencies", defined by the number of cyclical variations of the wave that passed through a plane every second. Frequencies were once measured in "cycles per second (CPS)", but now are universally defined in terms of "hertz (Hz)", after Heinrich Hertz, a pioneering radio researcher. The frequencies of electromagnetic radiation are usually large numbers, and so it is useful to use "metric prefixes"

The full range of frequencies of electromagnetic radiation is known as the "electromagnetic spectrum". Radio waves only take up part of this spectrum, generally involving kilohertz, megahertz, or gigahertz radio emissions. Above about 300 GHz, electromagnetic radiation moves into a region of the spectrum known as "infrared"; and then with increasingly higher frequencies into the region of visible light that we can see with our eyes; and finally into energetic radiation defined as the "ultraviolet", "X-ray", and (at the very highest frequencies) "gamma ray" regions of the spectrum. Put a little bit more simply, radio waves are the same thing as visible light, both being forms of electromagnetic radiation. The only difference is that radio waves have lower frequencies. Incidentally, electromagnetic waves are entirely different from sound waves, which are mechanical disturbances propagating through the air, water, or a solid medium. The two kinds of waves can be confused because very low frequency electromagnetic waves are sometimes said to be at "audio" frequencies, and of course electromagnetic waves can be used to transmit audio waves, as turning on a household radio shows.

This document focuses only on radio waves. Sometimes it is easier to talk about radio waves in terms of their "wavelength" in meters instead of their frequency. There is a simple relationship between the wavelength and frequency of a wave:

$$wavelenght = \frac{wave\_propagation\_speed}{frequency} \tag{1.4}$$

Since the propagation speed of electromagnetic radiation in free space is 300,000,000 meters per second, then for electromagnetic radiation this is:

wavelength = 300,000,000 / frequency

If frequency is given in megahertz, this simplifies to:

wavelength = 300 / frequency

Various frequency / wavelength ranges, or "bands", have been defined for radars, with general classes of equipment usually operating in one or a few bands. The band names, with the frequency / wavelength corresponding to the low end of each band, The VLF through UHF band definitions were inherited from radio engineering. The bands above UHF don't follow a clear order, which apparently was partly by intent, as a security measure. The K band originally included the Ku and Ka bands, but it turned out that the center portion of the K-band was useless for most military purposes as water vapor in the atmosphere soaked up radio waves in that range. The portion of the K-band "above" the absorption range became the "Ka-band", while the portion "under" the absorption range became the "Ku-band".

Just to make things more confusing, different band definitions are used in other electronic fields. Radio engineers retain the ELF through UHF definitions, but take the UHF band up to 3 GHz, and then cover the higher frequencies with the "Super High Frequency (SHF)" band from 3 to 30 GHz, covering the centimetric / microwave region, and then the "Extremely High Frequency (EHF)" band from 30 to 300 GHz, covering the millimeter wave region.

Electronic countermeasures systems are defined by a band scheme entirely different from the radar and radio scheme, with the bands much more conveniently arranged from "A" to "M" in order of increasing frequency. Oddly, there isn't a one-to-one correspondence between the countermeasures bands and the radar bands, and though there was some interest at one time at applying the more rational countermeasures scheme to radar, it wasn't practical.

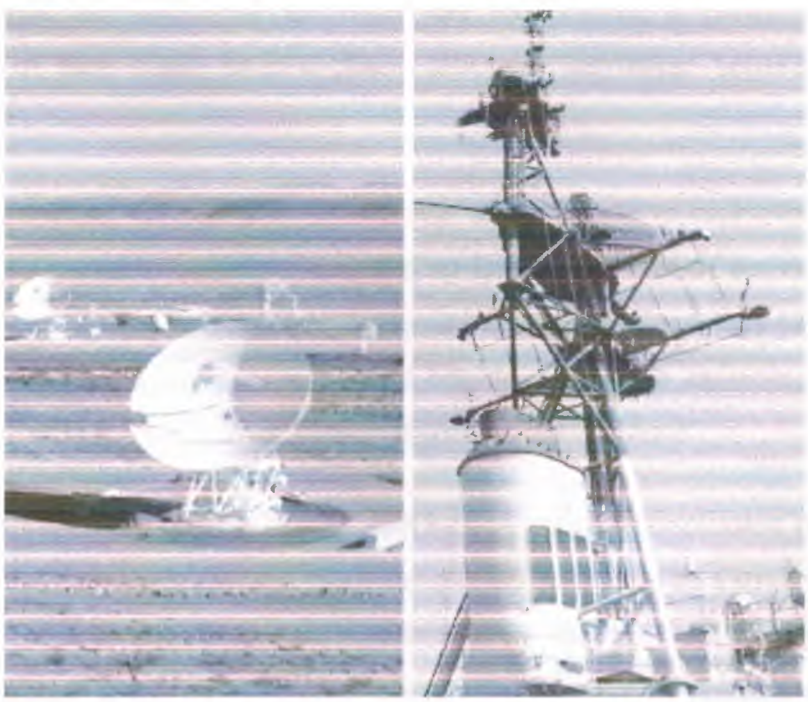


Figure 1.5. Band Scheme Entirely Different From The Radar And Radio Scheme

1.2.2 Radio Wave Polarization, Phase, Interference, and Propagation

As electromagnetic radiation is a wave phenomenon, it has certain characteristics associated with waves, such as "polarization", "phase", and "wave interference".
The oscillations of an electromagnetic wave occur back and forth across the direction of the wave's propagation. This means that the wave has a certain "polarity". If the wave's oscillations are up and down, the wave is said to be "vertically polarized"; if they are back and forth, the wave is said to be "horizontally polarized". Of course, the wave could also be polarized at any angle between those two extremes. The concepts of "phase" and "wave interference" are a bit trickier to explain. Suppose you have a tank of water, and are using some sort of vibrating element to generate waves. If you stick another vibrating element in the water operating at the same vibration rate and same intensity, it will generate waves of the same frequency and height (or "amplitude"), but the peaks and valleys of the waves generated by the second vibrating element will not necessarily coincide with those of the first. In other words, they won't have the same "phase".

The phase of the two sets of waves could be matched up, with the peaks and valleys of both coinciding; or they could be completely out of phase, with the peaks of one coinciding with the valleys of the other and the reverse, a condition known as "antiphase"; or they could have a phase difference anywhere between those two extremes.

The really interesting thing is that the two sets of waves add to each other. If the two sets of waves are exactly in phase, they add up into a single set of waves of twice the amplitude of one of the sets of waves. If they are exactly antiphase, they cancel out, and the water in the tank is smooth. If they are between those two extremes, the additive effect is intermediate. This phenomenon is known as "interference".

Radio waves also have phase and can interfere. A single transmission may go from point A to point B by various paths. For example, one path may be a straight line, while another may be a long path due to a reflection or "bounce" off a mountain. Such "multipath effects" cause the "ghosting" sometimes seen on TV transmissions, with a faint image slightly offset from the main image. They can also cause "phase delays" that seem to alter the direction of the beam by interference. Controlled interference effects can be used to deliberately shift the direction of a radio beam, a scheme known as "electronic steering" and discussed later. One final comment before moving on to radio and radar technology: radio waves generally propagate over a line-of-sight, weakening with distance, as anybody who's driven from town to town in a car with a radio realizes, with the music fading out as one town is left behind, and becoming stronger as another town is approached.

The radio waves can propagate through the sky or over the ground, and as noted can often propagate by multiple paths. At night, radio waves can bounce off the ionospheric layer in the upper atmosphere, allowing them to propagate over the horizon, if in a somewhat unpredictable fashion. Such "ionospheric bounce" tends to work better at lower frequencies. Anybody's who's ever played around with a broadcast radio receiver late at night knows remote stations can be picked up, sometimes over great distances.

Other atmospheric effects can interfere with radio signals. Higher frequencies can be blocked by heavy rainstorms or snowstorms, and lightning can thrown "noise" into radio transmissions. Particle flows from eruptions on the Sun can cause massive disruptions of radio communications. There is also a variable background of radio noise from human sources that can cause unwanted interference.

Radio waves vary in their interactions with solid matter. Radio waves, like light, can be absorbed or reflected by matter. Metals and water, for example, tend to reflect radio waves, while soils tend to absorb them. Also as with light, radio reflections can be "specular", as if bounced off a mirror, or "diffuse", as if bounced off a rough and uneven surface. If radio waves can penetrate a material, the penetration is greater at longer wavelengths. Radio wave can penetrate buildings well enough, and very long wavelength can even penetrate a good depth through the sea or into the ground. Very short wavelengths are strongly attenuated and have limited range.

1.3 Radio System Basics

A radar system is basically an evolution of a radio system, and it is useful to define the basic elements of a radio system first. A radio system consists of a "transmitter" that produces radio waves and one or more "receivers" that pick them up, with both transmitter and receiver(s) fitted with antennas. The very earliest "wireless telegraphy" radio systems used a transmitter that simply generated a burst of radio energy by opening an electric circuit with a telegraph key and causing a spark. The radio waves propagated through space and set up an electric current in a receiving antenna, which in turn closed a relay switch, possibly using an "amplifier" circuit to boost the electrical signal. Messages were sent using Morse code.

The problem with this simple scheme is that the spark generated waves over a wide and indiscriminate range of frequencies, with a single receiver picking up and mixing up transmissions from every transmitter in the line of sight.

The way to get around this problem is to fit each transmitter with a "variable oscillator", an electronic circuit that generates electrical signals at different frequencies, as set by a knob turned by the transmitter operator. Receivers are then fitted with a "variable filter", another electronic circuit that can be set by a knob turned by the receiver operator to block out all frequencies except one. This scheme allows multiple transmitters to operate in a given area without interference. The transmitter operator sets the transmitter oscillator to a given frequency; the receiver operator sets the receiver filter to the same frequency; and the transmitter operator uses a telegraph key to turn the output of an oscillator on and off, with the receiver operator picking up the output over the airwaves. The receiver will usually be fitted with a "detector" circuit to convert high-frequency signals into a direct-current signal to activate the relay switch. This is obviously the same concept that is used in tuning a voice radio to different channels, though a voice radio works somewhat differently from a radio telegraph. A voice radio also uses a variable oscillator. The voice of a user is converted into an electrical waveform which is "mixed" with the output of the oscillator, shifting the voice signal up in frequency to that of the oscillator, and transmitted. The oscillator frequency is known as the "carrier" frequency, since it "carries" the voice signal.

The receiver has its own variable oscillator, tuned to the same carrier frequency, which is mixed with the received signal, a process that somewhat magically obtains the original voice waveform. The voice waveform is converted back into sound through a loudspeaker.

The process of converting a voice (or music or whatever) into an electrical signal is known as "modulation". There are two classic forms of modulation: "amplitude modulation (AM)", in which the electrical signal varies in amplitude along with variations in amplitude of the voice input; and "frequency modulation (FM)", in which the electrical signal varies in frequency along with variations in the amplitude of the voice input. The process of mixing and unmixing frequencies is known as "heterodyning". In many cases, heterodyning is used to translate a voice or other signal up to an "intermediate frequency", which is then heterodyned again to produce an output signal of even higher frequency. This is done because it gets more difficult to handle signals at higher frequencies, and this scheme, known as "superheterodyning", allows most of the handling to be performed at the intermediate frequency.

A traditional analog television signal is conceptually much the same as a voice radio. The TV sound track is transmitted with FM, while the basic visual signal, which is black and white, is transmitted by AM. There are various schemes used in different nations for overlaying color signals, but they are devious and irrelevant to this discussion.

Incidentally, transmitter output power is measured in watts, or (as far as radar is concerned) more usually kilowatts (kW, thousands of watts) and megawatts (MW, millions of watts). Receiver "sensititivity", or the ability of the receiver to amplify received signals, is determined in terms of "decibels", defined as:

$$\text{decibels} = 10_{\text{LOG10}} \left(\frac{ou\_power}{in\_power}\right) \qquad (1.5)$$

The amplification factor is commonly referred to as "gain". Incidentally, a radio doesn't transmit or receive on a single frequency but on a range or band of frequencies. Although the details are beyond the scope of this simple document, the "bandwidth" is roughly proportional to the amount of information carried by the signal. A TV channel needs more bandwidth than a hi-fidelity radio channel, for example, just as a hi-fidelity radio channel needs more bandwidth than a low-fidelity radio channel.

1.4 Antenna Basics

A transmitter needs an antenna to send its radio signal, and a receiver needs an antenna to pick up that radio signal. The design of these antennas is not trivial. The simplest form of antenna is the "dipole". Suppose the electrical output of an oscillator is directed down two conductors, not connected at the ends. This will produce radiate electromagnetic energy from the open-circuit ends. It radiates energy much more effectively if the conductors are bent at the ends to form a right angle, with each bend being a quarter-wavelength long relative to the oscillator frequency. This is a "half-wave" dipole. It is not only effective in generating radio waves at a particular frequency, it is also effective in picking them up. This is true in general of all antennas: they are "reciprocal", working much the same in transmission or reception, just in different directions. By itself, a dipole "broadcasts" in all radial directions evenly, but a directed focus can be obtained, through interference effects, by building an antenna with multiple dipoles, spaced at carefully designed intervals. Such "dipole arrays" were common with early longwave radars, and in a modified form persist today. Another way to create a "directional" antenna with a dipole is to mount it within a row of parallel conductive rods, with the rods of decreasing length to the "front" of the dipole (relative to the direction of focus) and of increasing length to the "back" of the dipole. This type of antenna is known as a "Yagi-Uda" or just "Yagi" antenna. It is recognizable as the modern broadcast TV antenna. A conceptually simpler directional antenna is the parabolic dish. This is configuration familiar with a modern satellite-TV receiver. It's really very much the same as using a parabolic mirror to focus light, only the wavelength of electromagnetic radiation is longer. While parabolic dishes are usually circular, elliptical or cylindrical dishes with parabolic curvature can also be used if the radio beam needs to be focused along one axis but not along the other. An elliptical dish with the long axis vertical is used to create a narrow horizontal beam, useful for height-finding, while one with the long axis horizontal gives a narrow vertical beam, useful for surface targeting.

Incidentally, directional antennas don't always generate all their radio output in a nice neat directional beam. They may generate "sidelobes" that cause unwanted transmissions to the sides of the beam, or a "backlobe" in the reverse direction. The sidelobes and backlobe not only produce signals in undesired directions, they also rob the main lobe of energy.

In addition, as a general rule, the larger the receiver dish, the greater the receiver sensitivity, since it creates a bigger "bucket" or "eye" to collect radio waves. However, the longer the wavelength, the bigger the dish has to be to focus the radio waves. Another little related fact is that the dish doesn't have to be solid. It can be a mesh, just as long as the mesh grid spacing is less than that of the radar operating wavelengths. This makes for a lighter antenna, and also one not so easily disturbed by the wind.

1.5 A simple Pulse Radar System

A discussion of voice radio is useful for background in discussing simple radar systems, but is also somewhat incidental, since a simple radar works more like a wireless telegraphy set.

The best way to explain radar is to imagine that you are standing on one side of a canyon, and shout in the direction of the distant wall of the canyon. After a few moments, you will hear an echo. The length of time it takes an echo to come back is directly related to how far away the distant canyon wall is. Double the distance, and the length of time doubles as well.

If you know that the speed of sound is about 1,200 KPH (745 MPH) at sea level, then if you have a stopwatch you can actually figure out how far away the distant canyon wall is. If it takes four seconds for the echo to come back, then since sound travels about 330 meters (1,080 feet) in a second, the distance is about 660 meters (2,160 feet).

Radar uses exactly the same principle, but it times echoes of radio or microwave pulses and not sound. Like a wireless telegraphy set, a simple radar has a transmitter and a receiver that can usually be tuned to a range of frequencies, with the transmitter sending out pulses, short bursts, of electromagnetic radiation and the receiver picking them up.

In the case of the radar, the receiver is picking up echoes from a distant target, which are then timed to determine the distance to the target. Early radars simply used an oscilloscope to perform the timing. An oscilloscope measures an electrical signal on a beam that moves or "sweeps" from one side of a display to the other at a certain rate. The rate is determined by a "timebase" circuit in the oscilloscope.

For example, the sweep rate might push the sweep from one side of the display to the other in 100 microseconds (millionths of a second). If the display were marked into ten intervals, that would mean the sweep would pass through each interval in ten microseconds. While 100 microseconds would be shorter than the human eye could follow, the sweep is normally generated repeatedly, allowing the eye to see it.

Since electromagnetic radiation propagates at 300,000,000 meters per second, or 300 meters per microsecond, then each 10 microsecond interval would correspond to 3,000 meters, or 3 kilometers. If the sweep on the scope is "triggered" to start when the radar transmitter sends out the radio pulse, and the sweep displays an echo on the eighth interval on the display, then the pulse has traveled a total of 8 kilometers. Since this is the two-way distance, that means that the target is 4 kilometers away.

The display scheme described here is known as an "A scope", and allows the user to determine the range to a target. It would also be nice to know what the direction to the target is, in terms of its "altitude (vertical direction)" and "range (left to right direction".

This is a bit trickier to describe, but no more complicated in the end. Some early radars, like the famous British "Chain Home" sets that helped win the Battle of Britain, simply transmitted radio waves out in a flood over their field of view, and used a directional receiver antenna to determine the direction of the echo. Chain Home actually used a scheme where the power of the echo was compared at separated receiver antennas to give the direction, which astoundingly actually worked reasonably well. Other such "floodlight" radars used directional receiver antennas that could be steered to identify the direction of the echo. Floodlight radars were quickly abandoned. They spread their radio energy over a wide area, meaning that any echo was faint and so range was limited. The next step was to make a radar with steerable antennas. For example, two directional antennas, one for the transmitter and the other for the receiver, could be placed on a steerable mount and pointed like a searchlight.

The transmitter antenna generated a narrow beam that could be steered like a searchlight, and if the beam hit a target, an echo would be picked up by the receiving antenna on the same mount. The direction of the antennas naturally gave the direction to the target, at least to an accuracy limited by the width in degrees of the beam, while the distance to the target was given by the trace on the A-scope. Of course, it would be more economical and easier to use one antenna for both transmit and receive instead of separate antennas, and it was possible because a radar transmits a pulse and then waits for an echo, meaning it doesn't transmit and receive at the same time. The problem is that the receiver is designed to listen for a faint echo, while the transmitter is designed to send out a powerful pulse. If the receiver were directly linked to the transmitter when a pulse is sent out, the receiver would be fried.

The solution to this problem was the "duplexer", a circuit element that protects the receiver, effectively becoming an open connection while the transmit pulse was being sent, and then closing again immediately afterward so that the receiver could pick up the echo. The receiver is also generally fitted with a "limiter" circuit that blocked out any signals above a certain power level. This prevents, say, transmissions from another nearby radar from destroying the receiver.

After this evolution of steps, we have a simple, workable radar. It has a single, steerable antenna that can be pointed like a searchlight. The antenna repeatedly sends out a radio pulse and picks up any echoes reflected from a target. An A-scope display gives the interval from the time the pulse is sent out and the time the echo is received, allowing the operator to determine the distance to the target.

The transmitter emits pulses on a regular interval, typically a few dozen or a few hundred times a second, with the A scope trace triggered each time the transmitter sends out a pulse. The number of pulses sent out each second is known as the "pulse repetition rate" or more generally as the "pulse repetition frequency (PRF)", measured in hertz. The width of a pulse is an important but tricky consideration. The longer the pulse, the more energy sent out, improving sensitivity and range. Unfortunately, the longer the pulse, the harder it is to precisely estimate range. For example, a pulse that last 2 microseconds is 600 meters long, and in that case there is no real way to determine the range to an accuracy of better than 600 meters, and there is also no way to track a target that is closer than 600 meters. In addition, a long pulse makes it hard to pick out two targets that are close together, since they show up as a single echo.

PRF is another tricky consideration. The higher the PRF, the more energy is pumped out, again improving sensitivity and range. The problem is that it makes no sense to send out pulses at a rate faster than echoes come back, since if the radar sends a pulse and then gets back an echo from an earlier pulse, the operator is likely to be confused by the "ghost echo". This is actually not too much of a problem, since a little quick calculation shows that even a PRF of 1,000 gives enough time to get an echo back from 150 kilometers (185 miles) away before the next pulse goes out. However, propagation of radar waves can be freakishly affected by atmospheric conditions, and sometimes radars can get back echoes from well beyond their design range. This is why radars were developed that could be switched between two different PRFs. Switching from one PRF to another would not affect an echo from the current pulse, since the timing would remain the same, but such a switching would cause a ghost return from a current pulse to jump on the display.

Incidentally, the power of the pulse is given as "peak power", usually in kilowatts or megawatts. This may be an impressive value, but it's only the power that goes into the pulse itself. Suppose we have a pulse width of 2 microseconds with a peak power of 150 kilowatts. If we have a PRF of 500, then the time from pulse to pulse, or "pulse period", is 1/500 = 2 milliseconds, or two thousandths of a second. This means that the average power transmitted by our radar is only:

$$150Kw\left(\frac{2\,micro\sec onds}{2\,milli\sec ondes}\right) = 0.15kw = 150\,watts \tag{1.6}$$

which is about as much as the power draw of a bright household light bulb.
Doppler radar can be divided into several different categories according to the wavelength of the radar. The different bands are L,S,C,X,K. The names of the radars originate from the days of WWII.

1.6 Band Radar

1.6.1 L Band Radar

Operate on a wavelength of 15-30 cm and a frequency of 1-2 GHz. L band radars are mostly used for clear air turbulence studies.

1.6.2 S Band Radars

Operate on a wavelength of 8-15 cm and a frequency of 2-4 GHz. Because of the wavelength and frequency, S band radars are not easily attenuated. This makes them useful for near and far range weather observation. The National Weather Service (NWS) uses S band radars on a wavelength of just over 10 cm. The drawback to this band of radar is that it requires a large antenna dish and a large motor to power it. It is not uncommon for a S band dish to exceed 25 feet in size.

1.6.3 C Band Radars

Operate on a wavelength of 4-8 cm and a frequency of 4-8 GHz. Because of the wavelength and frequency, the dish size does not need to be very large. This makes C band radars affordable for TV stations. The signal is more easily attenuated, so this type of radar is best used for short range weather observation. The frequency allows C band radars to create a smaller eam width using a smaller dish. C band radars also do not require as much power as an S band radar. The NWS transmits at 750,000 watts of power for their S band, where as a private TV station such as in Des Moines only broadcasts at 270,000 watts of power with their C band radar.

1.6.4 X Band Radars

Operate on a wavelength of 2.5-4 cm and a frequency of 8-12 GHz. Because of the smaller wavelength, the X band radar is more sensitive and can detect smaller particles. These radars are used for studies on cloud development because they can detect the tiny water particles and also used to detect light precipitation such as snow. X band radars also attenuate very easily, so they are used for only very short range weather observation. Also, due to the small size of the radar, it can therefore be portable like the Doppler on Wheels. (DOW) Most major airplanes are equipped with an X band radar to pick up turbulence and other weather phenom enon. This band is also shared with some police speed radars and some space radars.

1.6.5 K Band Radars

Operate on a wavelength of .75-1.2 cm or 1.7-2.5 cm and a corresponding frequency of 27-40 GHz and 12-18 GHz. This band is split down the middle due to a strong absorption line in water vapor. This band is similar to the X band but is just more sensitive. This band also shares space with police radars.

- **Bands Section**

Especially with S band radars, see the bands section, a large dome is needed. Since this dome can easily be over 30 feet in height and on top of a tower over 100 feet in height, it can be visible from long distances. The dome essentially just houses and protects the radar dish. It is made of a material that allows the signal to leave through it and also return through it. Inside that dome is the dish itself.

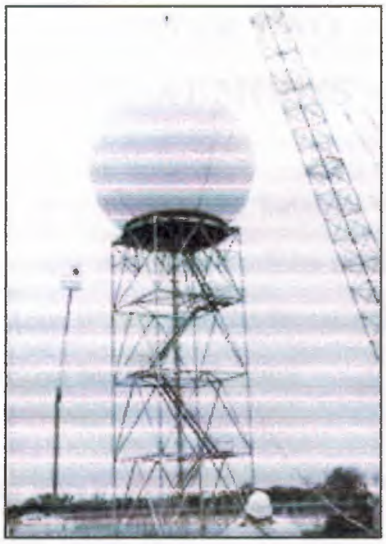


Figure 1.6. Band Radar

The main purpose of the dish is to focus the transmitted power into a small beam and also to listen and collect the returned signal. More information about dish sizes can also be found in the bands section. In a nutshell, that is essentially what a radar's dish does. That visible part is really just a small part of what actually makes the radar work. There are three components in a WSR-88D radar besides the dish and tower. These are the Radar Data Acquisition (RDA), the Radar Product Generator (RPG), and finally the Principal User Processor. (PUP)

* **RDA** – The radar data acquisition unit is what houses the actual transmitter and the receiver. The transmitter sends out multiple pulses every second. Between those pulses, the receiver receives the reflected energy from the pulse. Since precipitation is moving and every return signal is different, it reads over 20 pulses per second and sends that data on to the RPG.

* **RPG** - The radar product generator receives the information from the receiver. It takes the 20 or more pulses that the receiver received in one second and averages them together. After the RPG gets the information from one volume scan, or one rotation of the radar, it creates the products that we see on TV or the Internet. Some of these products are the reflectivity of the precipitation and also the velocities of the precipitation calculated using the Doppler Effect.

* **PUP** - The principal user processor is the unit that allows for the interface with the radar. This has been in the past the only workstation that allowed a user to access the radar data and control the radar. Now, the NWS is installing AWIPS in all of their offices. This allows anyone in the building to access the radar data. This will aid in monitoring multiple storms and help get warnings issued more quickly.

CHAPTER TWO

THREAT MODES

2.1 Modes of Operation

One of the characteristics of a threat is its location. We also need to make some assumptions about how the threat reacts to various tactical situations. Normally, the proximity of a friendly asset (our friend, not the threat's friend) will cause the threat to change modes. Generally, a threat has the following

Types of operating modes:

• Search, in which threat radar tries to determine the presence of potential targets;

• Acquisition, in which threat radar detects the presence of a potential target and establishes a track (or lock) on the target;

•Tracking in which threat radar continues to update its tracking information while preparing to fire a weapon and while it guides a weapon to the target;

• Launch, in which an enemy weapon is fired;

• Guidance in which the enemy sends guidance commands to a weapon in flight;

• Fusing, in which a short-range radar or other sensor determines exactly when to fire the warhead.

These steps often employ different radars, but many systems use the same radars (in different modes) to perform multiple functions.

2.1.1 Ground-Based Weapons

Missile systems on ships and at fixed or mobile ground sites will typically have the following important activities, each characterized by some range to the potential target. The actual ranges for each activity are derived from intelligence data; they will be a function of RCS of the target and some geometrical considerations (altitude, terrain, etc.). Figure 2.1 shows a typical set of mode division contours.

- **Search**

  Search is performed by long-range radars that operate continuously. Since their purpose is to detect new targets, they can be expected to be up and Working when the EW system arrives over the horizon. They will continue their transmissions through the entire engagement.

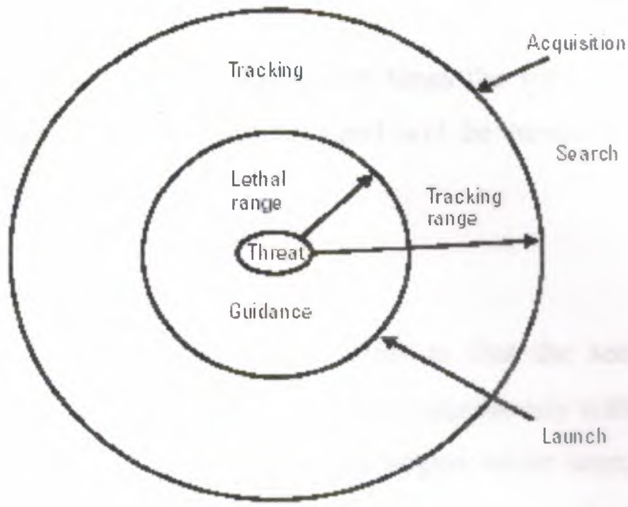


Figure 2.1. Zones for Threat Modes.

- **Acquisition**

Acquisition is the event at which the mode of the radar relative to a given Potential target changes from search to tracking. Sensors on that target will then observe that the tracking radar is tracking it.

- **Tracking**

Tracking is performed by radars that have an effective range slightly beyond The lethal range of the weapons they support. Thus, when a friendly aircraft Comes within the circular area of radius equal to a little over the lethal range (Perhaps 10%), this radar can be expected to come on in a mode appropriate For tracking the target. Note that tracking radar may be up when the potential Target is beyond its lethal range, but the radar will be tracking another Target that is within its tracking range.

- **Launch**

Launch will occur at a range that is established in the model. You may choose to have launch occur when the target first comes within lethal range, or you May chose to launch at some proportion of lethal range (e.g., half of lethal Range). You can run the model with different launch criteria to evaluate the Relative weapon performance.

- **Guidance**

Guidance signals will be present when a command-guided missile is in flight. There may be subtle differences in the guidance signal as seen from the actual Target of the missileas opposed to sensors on another friendly platform (Not the target) that can receive the guidance signal associated with a missile Attacking the target.

- **Fusing**

Fusing radars are very short range a few times the burst radius of the Weapon. They are independent of the other radars, and will be turned on at a Distance that depends on the type of missile.

2.1.2 Track-While-Scan Threats

Track-while-scan (TWS) threats are different in that the search and acquisition Processes are performed by the same radar, and simultaneously with the Tracking of the threat. This allows the radar to track multiple targets while searching for more. The target being tracked will not detect any change in the tracking Radar when it has been selected as a target.

2.1.3 Antiship Missiles

Antiship missiles are normally fired from a great distance. They can be launched from ships on targeting information from some remote observation Asset (aircraft, satellite, etc.). They can also be launched from aircraft that Acquire targets with their own search radars. Figure 2.2 shows the phases of a typical antis' hip-missile attack. Once launched, the missile guides itself inert ally to the target location Designated before launch. The missile skims the surface during its approach and does not radiate. Common missiles are either slightly subsonic or supersonic at about mach 2.5. From a surface-skimming altitude, the ship breaks Horizon at about 10 km. When the ship is expected to break horizon, the anti ship missile turns on its radar and tries to acquire the ship. When it detects the ship, the radar Locks on and guides the missile toward the center of the ship.

During the terminal phase of the attack, the missile either dives to Strike the ship at the waterline or climbs for an almost vertical attack straight down through the deck.

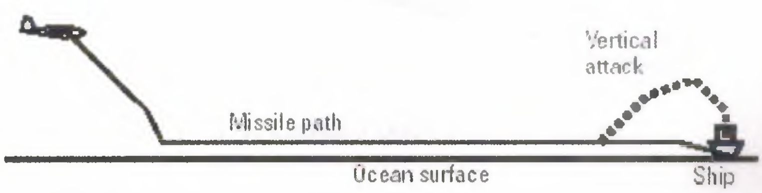


Figure 2.2. Antiship Missile Flight Path.

2.1.4 Air-to-Air Threats

Tactical aircraft are normally vectored into attack position by combat controllers Based on information from airborne or ground-based radars, as Shown in Figure 2.3 Long-range ground radars are often called early warning/ Ground-control intercepts (EW/GCI) radars for this reason. The airborne Radars used to detect and establish tracks upon target aircraft are very similar. Neither the airborne nor ground-based acquisition radars will change modes when they detect targets, since they handle multiple airborne targets and Continue to search for more targets. When a fighter with AI radar is being vectored toward a target, a digital control signal may be present. This is particularly true in situations in which there are only narrow corridors through which aircraft can fly to avoid Shoot-down by ground-based ant air defenses. Once it is within range, the fighter will turn on its fire control radar, this has several modes. Usually, the fire control radar will cover a large Angular area to acquire its target. Once locked to a target, it will change to a Tracking mode in which it covers a much narrower area and uses a different Modulation. The fire-control radar transmits over a limited angular segment from the nose of the aircraft, as shown in Figure 2.4. This signal can be received at full power only when the target aircraft is within the lethal zone, but may be

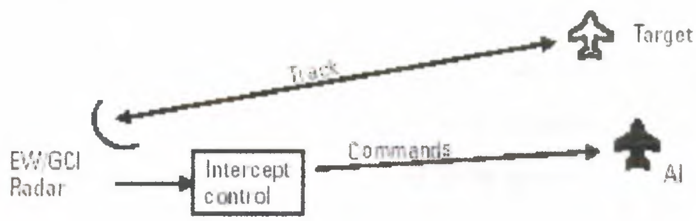


Figure 2.3. Radar-Controlled Aerial İntercept.

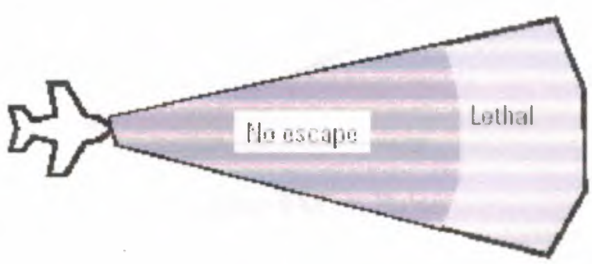


Figure 2.4. Lethal Zones For Aı Radars.

Received at side-lobe level from other angles. There are generally two lethal zones: one would allow a launch to take place and the second, smaller area would typically not allow the target to escape. In general, a launch can be expected to occur when a target comes into the edge of the no escape zone.

2.2 Modulations

There are two basic types of signal modulations of concern to EW systems and operations. One is pulsed and the second is continuous. Pulse signals are associated with radars, while continuous signals can be associated with either radar or communication.

2.2.1 Pulsed Signals

Pulsed signals are 100% amplitude modulated, and are characterized by RF frequency, pulse width, duty factor, pulse pattern, and modulation on the pulses. In general, the longer the range, the lower the frequency, the longer the pulse width, and the longer the pulse interval. Search radars typically have pulse widths of several microseconds. The long pulses allow the radar to get more energy onto the target—which enhances the detection range. However, this degrades their range resolution. Frequency or binary modulation is often added to reduce the range resolution cell. Frequency modulation on pulse is called chirp. Its implementation is shown in Figure 2.5. The binary modulation
is often referred to as Barker code (because the digital modulation often forms that kind of code). Figure 2.6 shows a typical, but short, binary sequence on a pulse. The pulse repetition interval of search radars can be expected to be several milliseconds.

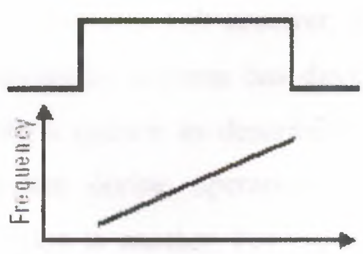


Figure 2.5. Linear FM on Pulse.

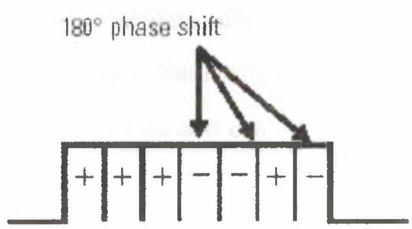


Figure 2.6. Binary codes on Pulse.

Tracking radars have much shorter pulse widths and higher pulse repetition frequencies. The pulse widths are from a very few microseconds down to sub-microsecond. The pulse repetition intervals are from a very few milliseconds to sub milliseconds. Except for high PRF pulse Doppler radars, the duty cycle will be very low. Airborne fire control radars often have a pulse Doppler mode in which the pulse repetition frequency may be about 300,000 pulses per second, and the duty cycle can be of the order of 30%. Because receivers limit the bandwidth of signals they receive, the pulses are seen to be rounded on their leading and trailing edges. In general, transmitters are wider in bandwidth than the associated receivers, so transmitted pulses are usually considered to be nice square pulses.

2.3 Antenna Characteristics

2.3.1 Communication Threat Antennas

The antennas for most communication antennas transmit 360 in azimuth, and are received near the horizontal plane, so it is sufficient to just consider the ERP as the transmitter power increased by the gain. When received from straight overhead, the communication antenna will typically have a pattern null that may be as much as 20-dB deep. While this reduces the ERP considerably, it is not an important characteristic. A receiver directly overhead will not usually remain there very long (aircraft pass over quickly) and the receiver will be very close to the transmitter (unless it is in a satellite), so it will receive plenty of signals to do its job. The challenge usually comes because the receiver, particularly a no cooperative EW receiver, is far away near the horizon. When a VHF or UHF communication antenna has directivity, it is normally a log-periodic or similar antenna with a pattern as described a directional communication antenna typically does not rotate during operation. It is set to optimally carry information from one fixed position to another. For microwave links, the antennas are narrow-beam horns or dishes.

They have gain patterns like radar antennas and are discussed they are different from radar antennas in that they do not change their orientation during operation. If you are in the beam, you get lots of signal and if you are out of it you receive only side-lobe level signals.

2.3.2 Radar Antennas

Radar antennas are more interesting; not only do they have narrow beams, but the beams move in ways that tell us a lot about the type of radar and its operating mode. The movement of the antenna is called the antenna scan. The real interest is how the threat antenna looks to an EW receiver as it is moved.

- Threat Antenna Patterns As Seen by a Receiver

The gain pattern of an antenna is a plot of its gain as a function of the angle from its bore sight to the observation point. For a transmitting antenna, this causes an angular variation in its effective radiated power. If the transmitting antenna is scanning, a time-varying signal level will be observed by a receiver in a fixed location, as shown in Figure 2.7. The main beam of the transmit antenna causes a peak signal to be received as it passes through the receiver location. Each of the transmitter antenna side lobes causes a smaller peak signal as it passes the receiver location. Assuming that the transmit antenna is

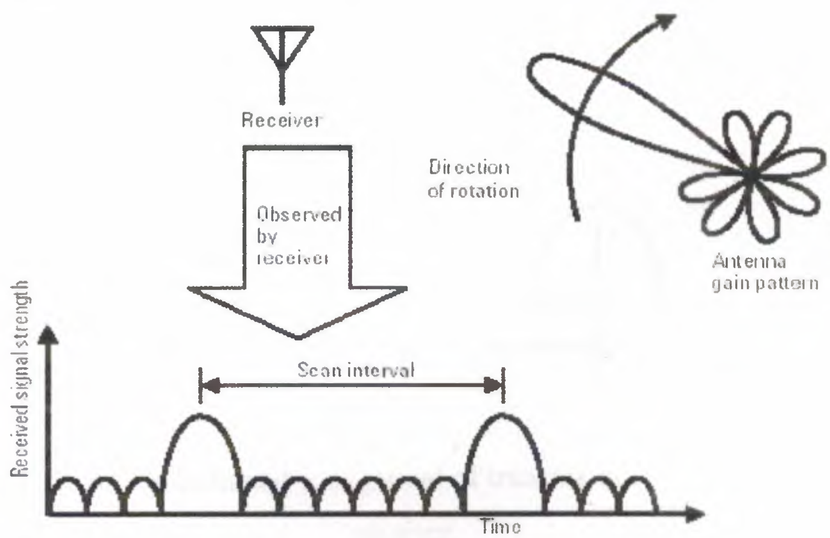


Figure 2.7. Antenna Pattern As Observed By A Receiver.

Rotating at a constant rate, each of these peak signals will be received at a fixed interval. As shown in the figure, the scan interval is the time between receipts of the main lobe peak by the receiver (i.e., a 5-second interval means the antenna is rotating once per 5 seconds). As shown in Figure 2.8, the time between the 3-dB points on the received main beam signal strength curve is related to the 3-dB beam width of the transmitting antenna. The relationship is

Beam width = (beam duration / scan period) × 360 degrees

There are a number of types of radar antenna scans, depending on the type of radar, its mission, and its operating mode. Analysis of the antenna pattern is one of the tools used by EW receivers to identify enemy radars. Also, the pattern will determine the amount and periodicity of the time during which a receiver can receive the threat signal. Thus, it is important for a simulator to accurately represent the received antenna patterns of simulated threats. In the balance of this section, we will discuss a number of types of antenna scans. For each, we will consider what the threat antenna is doing (i.e., its angular movement history), the general mission of a radar using this scan pattern, and what it looks like to a receiver in a fixed location.

2.3.3 Circular Scan

As shown in Figure 2.8, the circularly scanned antenna rotates in a full circle. This type of scan is associated with search radars. It typically monitors a large area to detect targets, which are handed off to tracking radars if appropriate. The received pattern is characterized by even time intervals between observations of the main lobe, as shown in Figure 2.8.

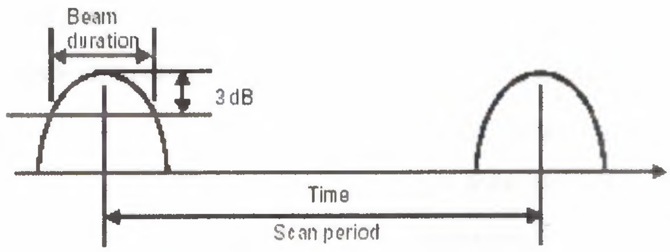


Figure 2.8. Beam duration and scan period of transmit antenna as observed by a receiver.

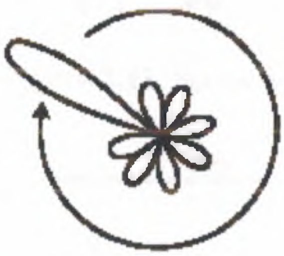


Figure 2.9. Circular Scan.

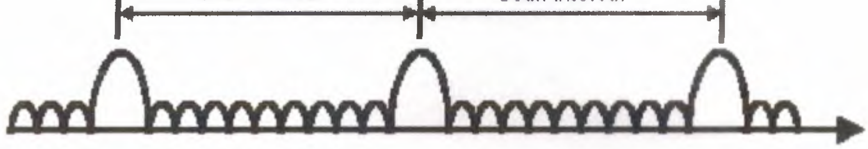


Figure 2.10. Received Power Versus Time for Circularly Scanned Antenna.

2.3.4 Sector Scan

The sector scan differs from the circular scan in that the antenna moves back and forth across a segment of angle. This scan concentrates its attention in a smaller angular segment, increasing the probability that it will intercept a short duration signal. It is used during the acquisition phase by anti ship missile radars. The time interval between main lobes has two values, except in the case in which the receiver is at the center of the scan segment. Figure 2.11 shows the physical sector scan and Figure 2.14 shows the time power history as this type of scan is observed from a fixed receiving position.

2.3.5 Helical Scan

The helical scan covers 360 degrees of azimuth and changes its elevation from scan to scan. This scan covers a volume of space, providing elevation and azimuth information—as well as range about detected objects. It is observed with constant main lobe time intervals, but the amplitude of the main lobe decreases as the threat antenna elevation moves away from the elevation of the receiver location. Figure 2.13 shows the physical scan, and Figure 2.14 shows the observed power history.

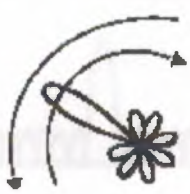


Figure 2.11. Sector Scan.

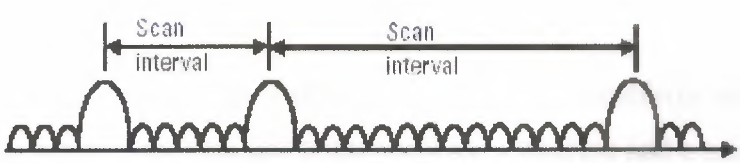


Figure 2.12. Sector-Scan Observed Power History.

Figure 2.13. Helical Scan.

Figure 2.14. Helical-Scan Observed Power History.

2.3.6 Raster Scan

The raster scan covers an angular area in parallel lines. This scan covers an angular volume, and is often used as the acquisition scan for airborne firecontrol radars. It is observed as a sector scan, but with the amplitudes of the main lobe intercepts reduced as the threat antenna covers raster lines that do not pass through the receiver's location. Figure 2.15 shows the physical scan and Figure 2.16 shows the observed power history.

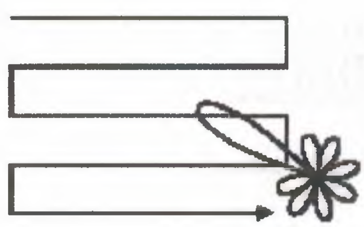


Figure 2.15. Raster Scan.

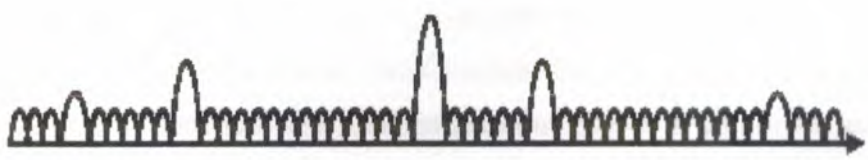


Figure 2.16. Raster-Scan Observed Power History.

2.3.7 Conical Scan

The conical scan is observed as a sinusoid ally varying waveform with a maximum when the antenna beam comes closest to the receiver's location and a minimum when it is pointed maximally away from the receiver. It is an excellent example of a target-tracking scan as the receiver location (T in the figure) moves toward the center of the cone formed by the scanning antenna, the amplitude of the sine wave reduces. When the receiver is centered in the cone, there is no variation in the signal amplitude, since the antenna remains equally offset from the receiver. Figure 2.17 shows the conical scan with three target positions (A, B, and C) moving from the outside to the center. Figure 2.18 shows the corresponding power history observed by a receiver located on the target.

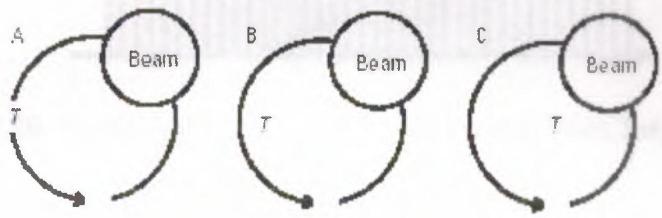


Figure 2.17. Conical Scan As Target Moves Toward Center

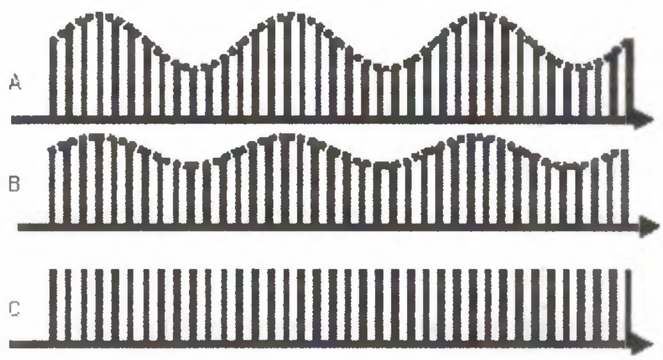


Figure 2.18. Conical-Scan Power History Observed By Target İn Three Positions.

2.3.8 Spiral Scan

The spiral scan is like a conical scan, except that the angle of the cone increases or decreases. The observed pattern looks like a conical scan for the rotation, which passes through the receiver's location. The antenna gain diminishes in amplitude as the spiral path moves away from the receiver location, but still retains a generally sinusoidal shape. The irregularity of this pattern comes from the time history of the angle between the antenna beam and the receiver location. Figure 2.19 shows the physical scan and Figure 2.20 shows the observed power history.

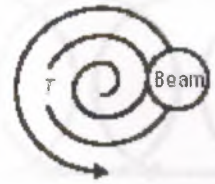


Figure 2.19. Spiral Scan.

Figure 2.20. Spiral-Scan Power History Observed From Target Position.

2.3.9 Palmer Scan

The Palmer scan is a circular scan that is moved linearly. The name comes from the old Palmer method of teaching handwriting, in which students started by drawing looping circles like those shown in the scan motion diagram (Figure 2.21). Its advantage is that it provides high-density coverage of an area with a small vertical angle and a larger horizontal angular segment. The observed threat antenna gain pattern history (Figure 2.22) is a very strange waveform. If the receiver were right in the middle of one of the circles, the amplitude would be constant for that rotation. In the figure, it is assumed that the receiver is close to the center, but not exactly centered. Therefore, the third cycle shown is a low-amplitude sine wave. As the cone moves away from the receiver location, the sine wave becomes full size, but the amplitude of the signal diminishes.

2.3.10 Palmer Raster Scan

If the conical scan is moved in a raster pattern, the received threat gain history will look like the Palmer scan for the line of the raster that moves through the receiver location. Otherwise, the pattern becomes almost sinusoidal, with diminishing amplitude as the raster lines move farther from the angle of the receiver location. Figure 2.23 shows the physical movement of the antenna and Figure 2.24 shows the observed power history.

Figure 2.21. Palmer Scan.

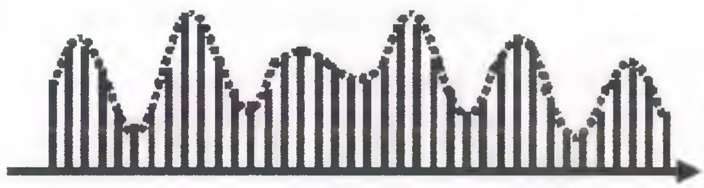


Figure 2.22. Palmer-Scan Observed Power History.

Figure 2.23. Palmer Raster Scan.

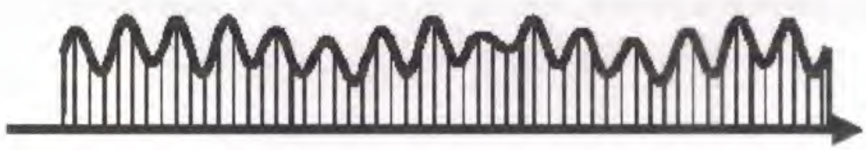


Figure 2.24. Palmer-Raster-Scan Observed Power History.

2.3.11 Lobe Switching

The antenna snaps between four pointing angles forming a square (in this case) to provide the information required to track its target. Like the other patterns, the received threat antenna gain history is a function of the angle between the threat antenna and the receiver's location. Figure 2.25 shows the four antenna beam lobe positions with the target in one position. Figure 2.26 shows the observed power history at the target in the position shown.

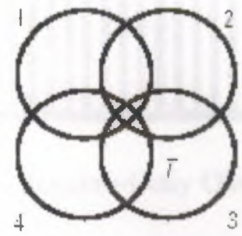


Figure 2.25. Lobe Switching.

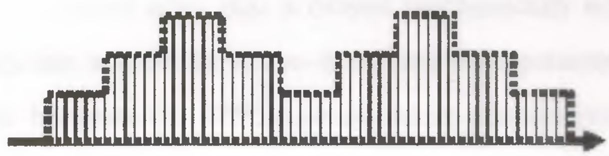


Figure 2.26. Lobe-Switching Power History Observed From Target.

2.3.12 Lobe on Receive Only

In this case, the threat radar tracks the target (the receiver location) and keeps its transmitting antenna pointed at the target if it has a directional antenna. The receiving antenna has lobe switching to provide tracking information. The receiver sees a constant signal level, since the transmit antenna is always pointed at it. Figure 2.27 shows the separate transmit and receive antennas. Figure 2.28 shows the observed power history. Note that monopoles radars in tracking mode are also observed as constant amplitude at the target.

2.3.13 Phased Array

This assumes that the phased array is electronically steered, so it can randomly move from any pointing angle to any other pointing angle instantly

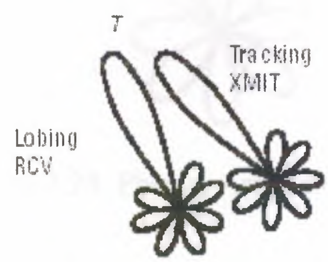


Figure 2.27. Lobe On Receive-Only Antennas.

Figure 2.28. Lobe On Receive-Only Observed Power History.

(See Figure 2.29). Thus, there will be no logical amplitude history observed by the receiver. A fixed-beam phased array that is moved mechanically would, of course, look much like the appropriate one of the above-described scan patterns. The received gain depends on the angle between the instantaneous-threat-antenna pointing angle and the receiver location. Figure 2.30 shows the observed power history (i.e., completely random).

2.3.14 Electronic-Elevation Scan with Mechanical-Azimuth Scan

In this case, the threat antenna is assumed to have a circular scan with the elevation arbitrarily moved by a vertical phased array. Thus, there is a constant time interval between main lobes, but their amplitude can vary without any logical sequence. The azimuth scan can also be a sector scan, or it can be commanded to fixed azimuths. Figure 6.31shows the physical movement of the scan and Figure 2.32 shows its observed power history.

Figure 2.29. Phased-Array Beam.

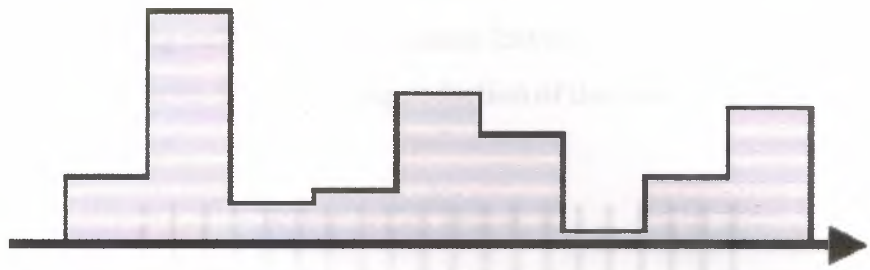


Figure 2.30. Random Observed Power History Of Electronically Controlled Phased Array.

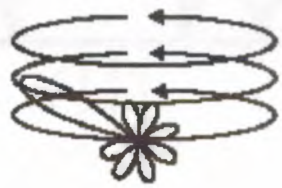


Figure 2.31. Electronic-Elevation Mechanical-Azimuth Phased Array.

Figure 2.32. Observed Power History Of Electronic-Elevation Mechanical-Azimuth Phased Array Radar.

2.4 Signals Leaving Transmitter Site

The signals leaving the transmitter site have the applied modulation, and have an effective radiated power (ERP) that is the sum (in dB) of the transmitter power and the antenna gain. The antenna gain pattern causes signals to be radiated in all directions. The ERP is, of course, a function of the angle from the antenna bore sight. The modulation is not changed by the off-bore-sight antenna gain reduction. It is only the radiated RF signal level that is reduced.

2.5 Signals Arriving at Receiving Site

Signals leaving the transmission site in the direction of the receiver have an ERP that is the product of the transmitter power and the antenna gain in the direction of the receiver. Taking the peak ERP at the transmit antenna bore sight as the standard; the effective ERP of a scanning threat is reduced by appropriate attenuation versus time to reproduce the antenna scans For no scanning threats, the ERP remains constant at the transmitter power plus the antenna gain in the direction of the receiver. Figure 2.32 shows a typical scanning radar signal as it looks leaving the transmitting site. Note that the scanning pattern causes a time-varying reduction of the transmitted pulses.

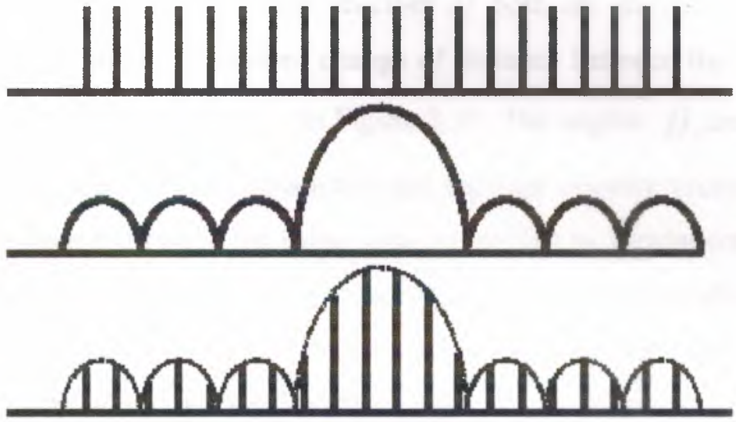


Figure 2.33. Scanning Pulse Radar Signal Leaving Transmitter Site İn Direction Of Receiver.

Once the signal leaves the transmit site, it is reduced by the link losses Described in if there is line of sight between the transmitter and the receiver. If the signal path is at any time interrupted by terrain, it is common practice to assume that the signal strength drops to zero. In Figure 2.34, receiver R2 can receive the signal, but receiver R1 does not have line of sight to the transmitter, and thus will receive no signal. Another consideration is the horizon. Signals at VHF frequencies and above are normally assumed to be limited to the radio horizon, which is determined by the following formula:

$$D_{max} = 4.123(\sqrt{h_T} + \sqrt{h_R}) \quad , \qquad (2.1)$$

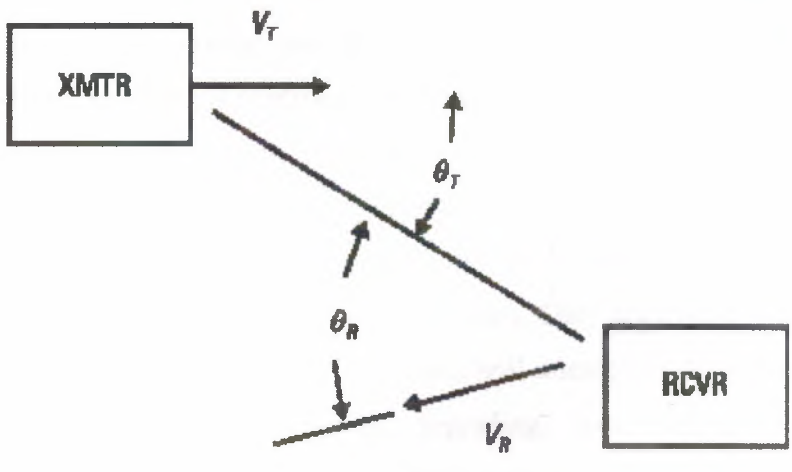
Where D_{max} = the maximum RF line-of-sight distance from transmitter to Receiver (or radar to target) (km);

Figure 2.34. Terrain-Masking Of Signals To Receiver.

h_T = height of transmitter above sea level (m);

h_R = height of receiver above sea level (m).

This formula uses the common four-thirds Earth assumption with smooth Earth surface at sea level. The formula works reasonably well if the transmitter and receiver heights are above local level terrain. The equation also works with the two heights being radar and a target. The frequency of the signal arriving at the receiving site is altered by a Doppler shift if the transmitter or the receiver or both are moving. The change in frequency is proportional to the rate of change of distance between the transmitter and receiver. This is determined as shown in Figure 2.35. The angles θ_T *and* θ_R are the true spherical angles between the transmitter and receiver velocity vectors and the line-of-sight path between the two. This same concept applies to a radar-tracking a target, except that there is a factor of two on the right side of the equation to allow for two-way transmission of the radar signal. It should be noted that the PRF and PW of pulsed signals are also modified by the Doppler shift.



$$\Delta F = \frac{F_T}{c}\left(V_T\cos(\theta_T) + V_R\cos(\theta_R)\right)$$

Figure 2.35. Doppler Effect For Arbitrary Velocity Vectors.

CHAPTER THREE

THE THEORY OF ELECTRONIC WARFARE

3.1 Overview

EW is the art and science of denying enemy forces the use of the electromagnetic spectrum while preserving its use for friendly forces. EW is a significant force multiplier because it reduces friendly losses by defeating or reducing the effectiveness of enemy weapons ;

The modern battlespace has become more sophisticated. Military operations are executed in an increasingly complex electromagnetic (EM) environment. Military forces, as well as civilians, depend on electronic equipment operating within the electromagnetic spectrum for communications, navigation, information gathering, processing, and storing; and as a means for detection and identification of enemy forces. Historically, radar has been the primary concern of electronic warfare; today the threat has expanded to include command and control systems, electro-optic systems, electromagnetic dependent munitions, and directed energy systems. The outcome of modern conflict greatly depends on control of the electromagnetic spectrum. The force that selectively deprives the enemy of the use of the electromagnetic spectrum, or exploits its use by the enemy to obtain information, has an important advantage. Adversaries possess the full range of modern communications, surveillance, and weapon systems that operate throughout the EM spectrum. They are aware of the threat posed by our own EW resources. In general, all sides will attempt to dominate the EM spectrum by targeting, exploiting, disrupting, degrading, deceiving, damaging, or destroying their opponents electronic systems which support military operations will retaining their ability to make use of the same systems. Modern warfare demands that each echelon of command effectively use the electromagnetic (EM) spectrum for their purposes while preventing its effective use by the enemy. In this context, EW is an important part of the arsenal of responses available to military commanders. However, the effective use of EW can only be achieved through close coordination with other resources deployed in support of military operations. EW doctrine provides a basis for: Effective integration of EW within the MAGTF , Coordination and cooperation between joint force components, particularly for the effective employment of EW resources. Operational, procedural, and technical interoperability at operational and tactical levels. The exchange of EW related information and intelligence between US forces and allied nations or coalition partners EW systems provide a first line of defence, interception, analysis and classification of emissions from airborne, land-based, surface and missile radars. Integrated Electronic Counter Measures (ECM) systems also afford the capability to provide self-protection jamming of incoming missiles and to deny an enemy's use of radar to detect or target ships or battle groups. EW is the art and science of denying enemy forces the use of the electromagnetic spectrum while preserving its use for friendly forces. EW is a significant force multiplier because it reduces friendly losses by defeating or reducing the effectiveness of enemy weapons. This chapter deals with the signals, equipment, deployment, and tactics associated with all aspects of EW. As indicated by the chapter title, this discussion provides an overview of EW. It is limited to providing enough information to support our later discussion of EW modeling and simulation, and focuses primarily on the aspects important to modeling and simulation. The following books are recommended to provide the reader with more depth and breadth in the field: We turn now to a discussion of the signals associated with EW (radar and communication) and the three major subfields

3.1.2 Electronic Warfare Definitions

Electronic warfare (EW) describes techniques that exploit an adversary's use of the electromagnetic spectrum or defend friendly use of the electromagnetic spectrum. There are three subdivisions of EW The concepts and doctrine for EW are derived from a series of definitions that, in general terms, explain the boundaries of EW activities. The central definition for EW, from which subordinate definitions are derived, is defined as: Any military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. The definition of EW can be broken down into three key components: exploitation, disruption, and denial. These three components give rise to the following activities:

a. Electronic Warfare Support (ES)

b. Electronic Attack (EA)

c. Electronic Protection (EP)

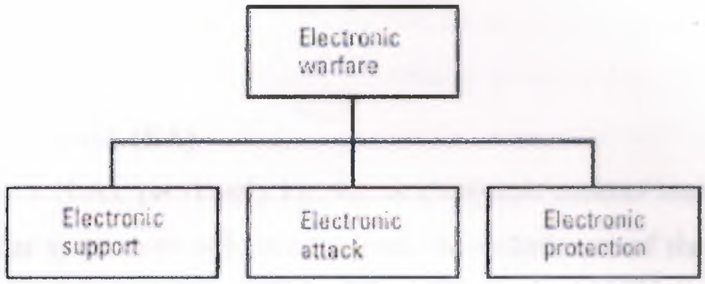


Figure 3.1. Structure of EW

3.1.2.1 Electronic Warfare Support (ES)

Electronic support (ES), previously known as electronic support measures (ESM), is considered the eyes and ears of the EW effort, in that Electronic Support is responsible for the detection, processing, recording and identification of electromagnetic energy transmitted by hostile, friendly and neutral radar systems. The main aim of Electronic Support is to gain sufficient information about radar sensors to allow an understanding of the radar's characteristics including its role, its method of operation, and its strengths and weaknesses. With this information, the Electronic Support system can identify the radar, assess its relative threat and provide information to the operator on how best to manage the radar's presence. Many factors impact on the effectiveness of Electronic Support, but all factors can be grouped into one of the following categories: Electronic Support is a passive activity as the Electronic Support equipment does not transmit any electromagnetic energy in the performance of its roles. It is important that the adversary remains unaware of the ES activity, because there are many tactics an adversary radar system can employ to make the Electronic Support role even more difficult than it is normally. Additionally, remaining passive lessens the opportunity for the adversary radar to plant false information into the transmissions in an attempt to corrupt or confuse the Electronic Support effort.

- Search for, intercept, identify, and locate sources of radiated electromagnetic energy
- Provide near real-time (NRT) threat recognition in support of immediate operational decisions involving EA, EP, avoidance, targeting, or other tactical employment of forces

3.1.2.2 Electronic Attack (EA)

Electronic attack (EA), previously known as electronic counter measures (ECM), is conducted on radar systems to reduce or prevent the radar's use of the electromagnetic spectrum effectively. This chapter investigates the process of performing Electronic Attack, reviews the major Electronic Attack tactics that can be employed and then reviews the major Electronic Attack tools available to the operator. Enemy sensors are the main focus of Electronic Attack action. Active sensors are particularly vulnerable as these sensors are designed to transmit and receive electromagnetic energy. Electronic *Attack tactics and tools look to exploit active sensors by analysing the transmission* (ES) and then attacking the receiver. Electronic Attack can be conducted against all electromagnetic systems including communications systems. The coverage of Electronic Attack in this text is limited to radar Electronic Attack. Radar systems are operated to detect, acquire and track targets with the ultimate view to engaging and destroying the target. To that end, interfering and degrading the performance of radar systems is often of critical value to the targeted platform's survival and ability to carry out its intended role,

- Focus on offensive use of electromagnetic spectrum to directly attack enemy combat capability
- Coordinate EW with military deception plans (timing, message, feedback mechanism
- Use of directed energy and anti-radiation missiles

3.1.2.3 Electronic Protection (EP)

The main aim of electronic protection (EP), previously known as electronic counter counter measures (ECCM), is to ensure continued friendly use of the electromagnetic spectrum despite adversary EA and ES. Countering EA efforts is the main focus of electronic protection although some electronic protection techniques are also designed to make adversary ES more challenging. EP and EA fields tend to be complimentary and reactive fields of endeavour in that an advance in technology and techniques in one field necessarily results in research, development and advancement in the other. The designers of military radar systems must assume that their systems operate in the most hostile of electronic environments and must, therefore design the radar with EA and electronic protection in mind. Electronic protection is not solely a military concern, however. Civilian radar systems also have to operate in hostile electronic environments and must therefore have EP built in. The civilian environment is often hostile due to the operation of other radar and electromagnetic systems in the same physical location as the radar system. Electronic protection techniques developed for the military domain can allow civilian radars to operate in the presence of other sources of potentially disruptive electromagnetic energy.

Electronic warfare (EW) simulation is a serious game of make-believe. A situation is artificially created so that equipment can be tested and operators can be trained under realistic conditions without both the expense and danger associated with training in the real world. EW engagements are typically complex, with many threat emitters seen in constantly changing relationships as either the threat platforms or the EW-protected platform maneuver. The operation of equipment and the performance required of operators cannot be adequately tested under static conditions with only one threat emitter present. This has led to the development of simulators that can simulate many threats grouped and maneuvered in realistic ways.

- Protect personnel, facilities, equipment from effects of friendly or enemy EW

Employ communication security (COMSEC) measures

- Employ emission control (EMCON) measures
- Employ war reserve modes (WARM)
- Reassess operational and tactical measures and countermeasures
- Coordinate EW Reprogramming

3.2 Simulation

Any of several levels of simulation can be applied to any kind of stimulus. For example, in a flight-simulator computer program, the computer screen shows what a pilot would see through the windshield and on the instrument panel of a particular type of aircraft. The view and the instrument readouts change in response to the manipulation of simulated controls. In a more elaborate flight simulator, the pilot sits in a fully simulated cockpit, which tilts and moves to simulate the g forces created by aircraft movement. The visual cues may include a full hemispherical view from the cockpit (including attacking enemy aircraft), and the cockpit sounds will also be provided. All of these displays are interactive, changing in response to control manipulation by the pilot and to selected external events (for example, engine failure).

These are only two examples of the many kinds of simulators that are used for training in many fields. Simulators can also be used to develop and evaluate tactics to deal with almost any kind of external event affecting almost any kind of equipment in almost any field

3.2.1 Simulation in the EW Field

Through simulation, an operator or piece of EW equipment can be caused to react as though one or more threat signals were present and doing what they would be doing during a military encounter. Typically, the simulation involves interactive changing of the threat situation or the way it is processed as a function of what the operator or equipment does in response to the perceived presence of the threat signals.

On the other hand, a simulator may simply supply electronic inputs to a receiver system, subsystem, or individual chassis. The inputs provide the equipment with what it would "see" in the situation in which it is designed to operate.

3.2.2 Modeling

Modeling is typically performed in computers, but can also be performed with pencil and paper. The big advantage of computer modeling is that the details of the model are captured and the process can be run multiple times with controlled granularity and dependable repeatability

Computer simulation (or modeling) is done in a computer using mathematical representations of friendly and enemy assets and sometimes operator responses—evaluating how they interact with each other. In modeling, neither signals nor representations of tactical operator controls and displays are generated. The purpose is simply to evaluate the interaction of equipment and tactics that can be mathematically defined. Modeling is extremely useful for the evaluation of strategies and tactics. A situation is defined, and each of several approaches is implemented. The outcomes are then compared. It is important to note that any simulation or emulation must be based on a model of the interaction between an EW system and a threat environment, as shown in Figure 3.2.

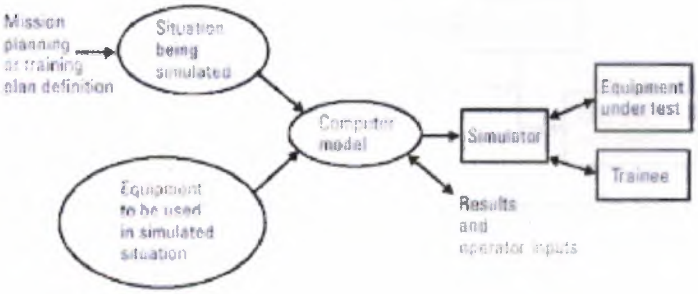


Figure 3.2. Ew System And Threat Environment Model Interaction.

3.2.3 Simulation

In some applications, operator-interface simulation is achieved by driving the actual system displays from a simulation computer. Switches are read as binary inputs, and analog controls (for example, a rotated volume control) are usually attached to shaft encoders to provide a computer-readable knob position.

3.2.4 Emulation

Where any part of the actual system is present (except, perhaps, computerdriven controls and displays), the emulation approach is used. Emulation involves the generation of signals in the form that they would have at the point where they are injected into the system. Although the emulation approach can be used for training, it must almost always be used for the T&E of systems or subsystems.

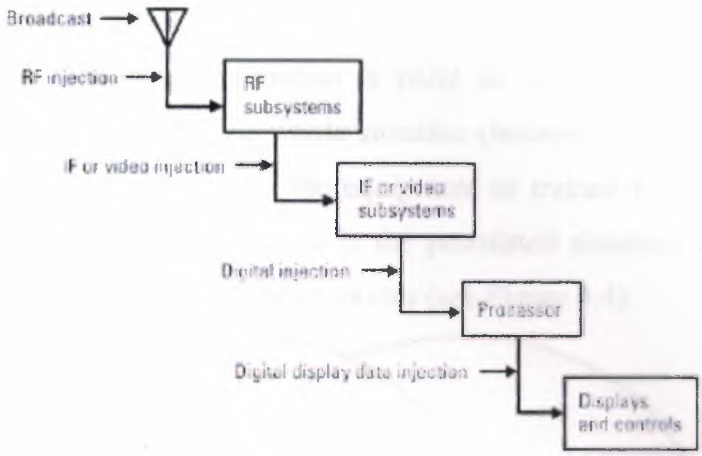


Figure 3.3. Points Of İnjection Of Emulated Signals İn Ew System.

3.3 Simulation for Training

Simulation for training exposes students to experiences (in a safe and controlled way) that allow them to learn or practice various types of skills. In EW training, this most often involves the experiencing of enemy signals in the way they would be encountered if the trainee were at an operating position in a military situation. EW simulation is often combined with other types of simulation to provide a full training experience. For example, a cockpit simulator for a particular aircraft may include EW displays that react as though the aircraft were flying through a hostile electronic environment. Training simulation usually allows an instructor to observe what the student sees and how he or she responds. Sometimes, the instructor can play back the situation and responses as part of the debriefing after a training exercise—a powerful learning experience.

3.4 Simulation for T&E

Simulation for equipment T&E involves making a piece of equipment think it is doing the job for which it was designed. This can be as simple as generating a signal with the characteristics a sensor is designed to detect. It can be as complex as generating a realistic signal environment containing all of the signals a full system will experience as it moves through a lengthy engagement scenario. Further, that environment may vary in response to a preprogrammed or operator-selected sequence of control and movement actions by the system being tested. It is distinguished from training simulation in that its purpose is to determine how well the equipment works rather than to impart skills to operators.

3.5 Electronic Point of View

An important concept in simulation is point of view. While the planner and designer of a simulation know the whole situation (because they have postulated it), the simulation must represent what the equipment or trainee for whose benefit the simulation is created would experience in the postulated situation. This depends on the sensors available and their operating modes (see Figure 3.4).

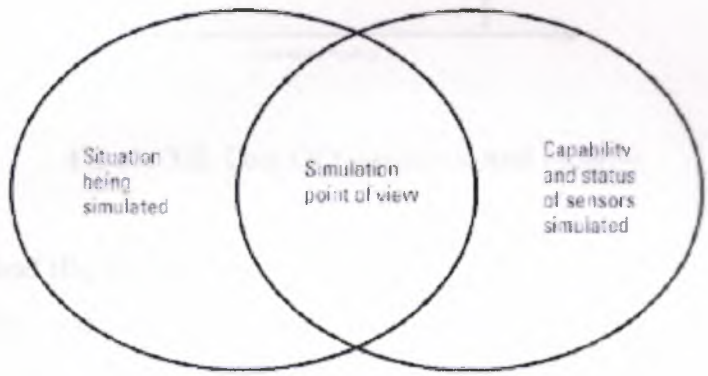


Figure 3.4. Simulation Point Of View.

3.6 Fidelity in EW Simulation

Fidelity is an important consideration in the design or selection of an EW simulator. The fidelity of the model and of the data presented to systems and operators must be adequate to the task. In training simulation, the fidelity must be adequate to prevent the operator from noticing any inaccuracies caused by the simulation (or at least to avoid distortions that will interfere with the training objectives). In T&E simulation, the fidelity must be adequate to provide injected signal accuracy better than the perception threshold of the tested equipment. Both of these issues will be discussed in detail in later chapters. As shown in Figure 3.5, the cost of a simulation rises—often exponentially as a function of the fidelity provided. The curve in the figure shows a sharp cutoff of value versus cost to illustrate the point that the value of the fidelity does not increase once the perception level of the trainee or tested equipment is reached. Any additional fidelity is a waste of money or of equipment complexity (which typically reduces its reliability or increases its requirement for maintenance). However, it must be clarified that the cutoff is not always this sharp; judgment and the consideration of many factors in the design of the tested equipment and the employment of the simulator are required.

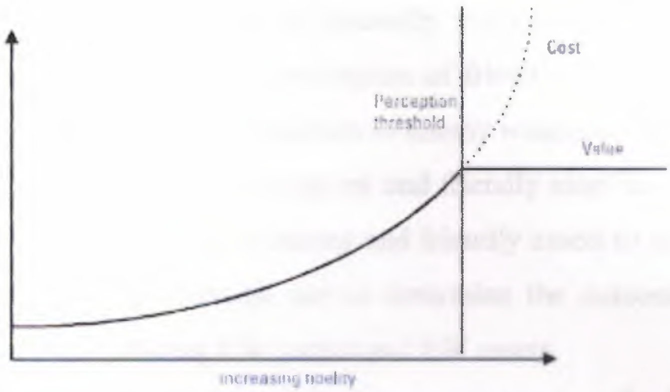


Figure 3.5. Cost Of Simulation And Fidelity.

3.7 **The Tactical Big Picture**

EW modeling and simulation starts with a military situation with EW implications that must be modeled or simulated. As shown in Figure 3.6, the big picture of what is happening typically involves enemy weapons. There are electronic signals associated with the deployment and employment of these weapons. The signals include those generated by communications and radar transmitters. The combination of all of these signals comprises the threat signal environment.

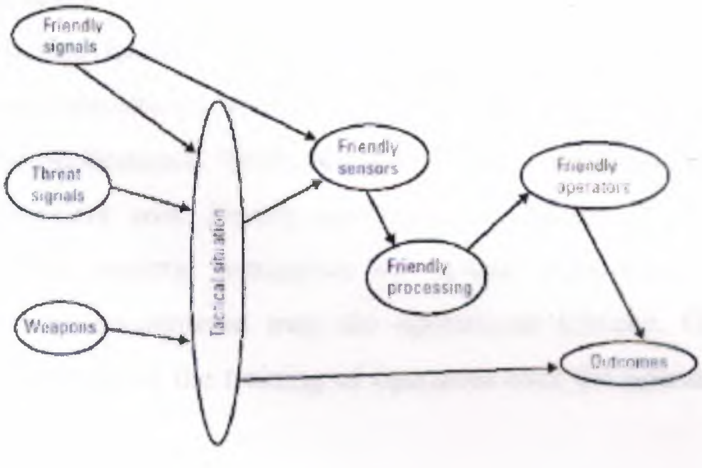


Figure 3.6. Tactical Big Picture.

Taken together, the combined enemy and friendly transmissions reflect the tactical situation. Receivers associated with friendly EW systems collect and analyze enemy signals to derive necessary information about enemy weapons and other assets, and also deal with all of the other signals in the signal environment. As a result of the tactical situation and the automatic or manually invoked EW responses, outcomes occur. These outcomes may be the destruction of friendly assets by the enemy, the defeat of enemy weapons, or the destruction of enemy weapons.

- An EW model might include an enemy and friendly asset laydown along with a set of required responses of both enemy and friendly assets to actions by the other side. Then, the model would be run to determine the outcomes under varying conditions and with different EW tactics and EW assets.
- An EW simulation might also emulate the input signals to the friendly sensors as a function of the tactical environment. Then the sensor or processor outputs can be evaluated, either manually or automatically, to determine how well the sensors (or processors) can be expected to perform under various enemy action scenarios.
- A simulation can include man-in-the-loop features. That is, humans can be involved in the simulation as friendly or expert hostile operators to make the operator training or equipment testing more realistic

3.8 Simulation Versus Life Cycle

Modeling and simulation play a role in many aspects of the development, manufacture, and tactical use of EW systems over their entire life cycle. At the beginning, computer modeling helps establish requirements and concept development. It also assists in tradeoff analysis studies. During the development stages, signal injection into modules, units, subsystems, and the whole system predict later operational performance. Realistic early testing can have a powerful effect on the total development cost. During operational evaluation, high-power radiating simulators provide realistic evaluation of system performance in the actual environments to be encountered over the operational lifetime. Operator-interface simulation is invaluable in the training of operators over the operational lifetime of EW systems.

3.9 Communication

Communication signals are also important to EW considerations. They are intercepted and jammed, and their externals are analyzed to determine an enemy's electronic order of battle. The messages carried by a communication system are called the signal internals, while the modulation, transmitter location, and so forth are called its externals.

As shown in Figure 3.7, communication involves one-way links. Each link includes a transmitter, a transmitting antenna, a receiving antenna, a receiver, and everything that happens to the signal in between. The purpose of the communication link is to get information from the location of the transmitter to the location of the receiver. Equations to predict the performance of one-way links will be covered in

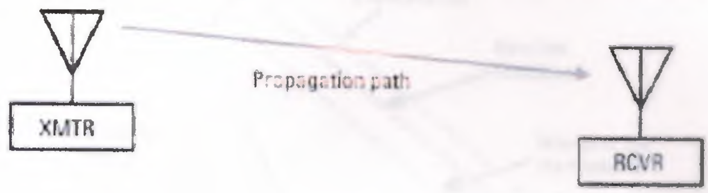


Figure 3.7. Basic Communication Link.

3.10 Tactical communications

3.10.1 Tactical Communications Net

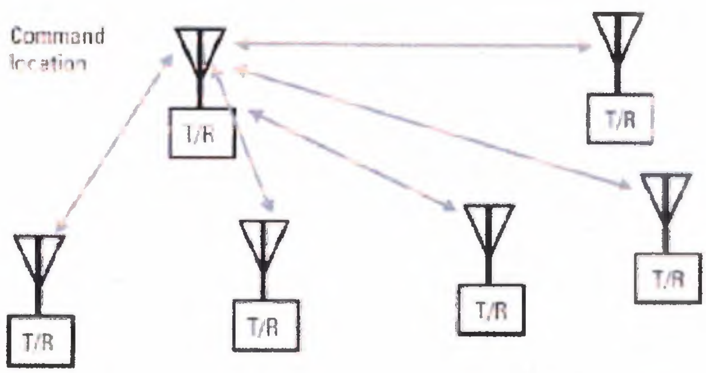


Figure 3.8. Tactical Communications Net.

In any type of modern military situation, a great deal of radio communication is required. Therefore, the available frequency spectrum is heavily used. A common assumption for military communication bands is that 5% to 10% of the spectrum will be occupied at any instant. However, if you observe the spectrum over a few seconds, every available channel will typically be full.

3.10.2 Data Links

Another type of communication signal is the data link. Links are used to pass command and data information between unmanned aerial vehicles (UAV) and their ground stations, between aircraft systems that share information, and between satellites and their ground stations.

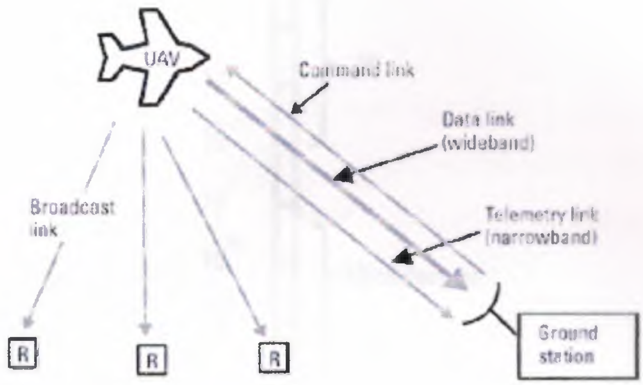


Figure 3.9. Links Supporting a UAV.

Communication satellites (and manned or unmanned aircraft acting as relays) have wideband uplinks and downlinks as shown in Figure 3.10. Both links carry the same information in most cases.

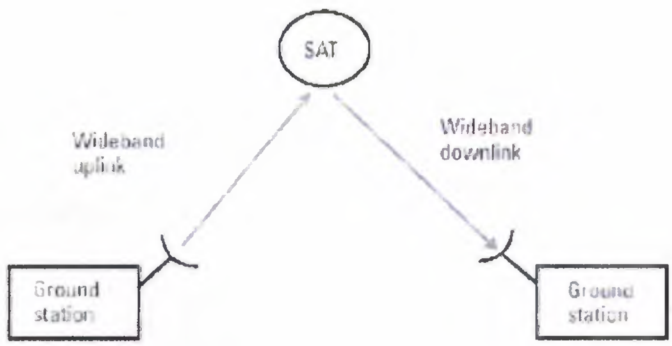


Figure 3.10. Communication Satellite links

3.10.3 Communication Bands

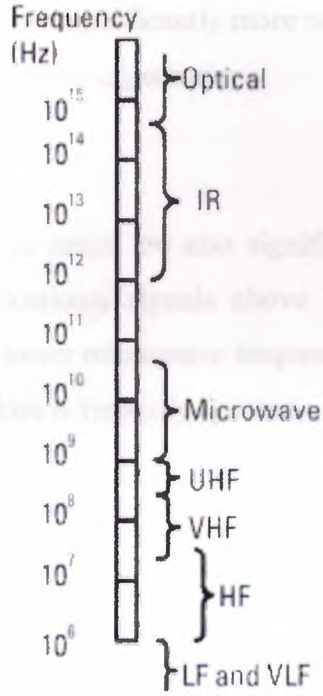


Figure 3.11. Frequency Bands For Communication.

In general, the higher the frequency range, the more information the link can carry. Another generality is the higher the frequency, the more link performance is degraded by non-line-of-sight conditions.

Low-Frequency Ranges

- **HF**

The HF band is 3 to 30 MHz. It supports wide-enough channel bandwidths to carry voice information, and does not require line of sight. HF signals are reflected by the ionosphere, causing hops that can propagate the signals clear around the Earth. HF signals also have significant ground-wave propagation well beyond the line-of-sight horizon

- **UHF**

Although the UHF band is 300 to 3,000 MHz, UHF receivers and transceivers most often operate from about 250 MHz to 1 GHz. They carry voice, video, and digital data. These signals are also considered line of sight— extended by the same non-line-of-sight modes as VHF signals. However, since these modes are all frequency dependent, the UHF signals have significantly more non-line-of-sight attenuation than VHF signals in the same transmission geometry.

- **Microwave**

Signals in the high microwave range are also significantly affected by atmospheric attenuation. In normal applications, signals above 10 GHz are also significantly attenuated by heavy rain. At lower microwave frequencies there is moderate rain loss, and at UHF and below, rain loss is typically ignored

- **IR and Optical Ranges**

Communication in the IR and optical frequency ranges allows the transmission of vast amounts of information, but is restricted to the optical line of sight. It is severely degraded by fog or smoke.

- **Radio Line of Sight**

Figure 3.12. Maximum-Length Transmission Path.

The radio horizon is farther away than the geometric horizon because radio waves are refracted in the Earth's atmosphere. While this refraction can vary widely, there is an approximation that is almost universally accepted.

3.10.4 Communication Modulations

The most common modulations used for communication are amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and single sideband (SSB). Modulations for digital signals and new LPI modulations, although they use these basic modulations, warrant special discussion.

- **AM**

Amplitude modulation changes the amplitude of the carrier signal in accordance with the information that the signal communicates. A radar pulse is a special case of AM. Video signals for broadcast television are amplitude modulated. The bandwidth of AM signals is directly proportional to the amount of information they carry. In general, the transmission bandwidth is twice the bandwidth of the information carried. Figure 3.13 shows the AM spectrum (i.e., power versus frequency). Note that the upper and lower modulation sidebands are mirror image, with each carrying all of the information transmitted.

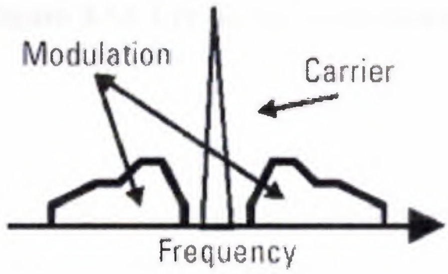


Figure 3.13. AM Signal Spectrum.

- **SSB**

Single sideband signals are basically AM signals with the carrier and one of the sidebands filtered off. This makes the SSB transceivers more complex than AM transceivers, but allows for more efficient use of frequency spectrum. SSB signals can be either upper sideband (USB) or lower sideband (LSB), depending on which AM sideband is transmitted.

- **LPI Communications**

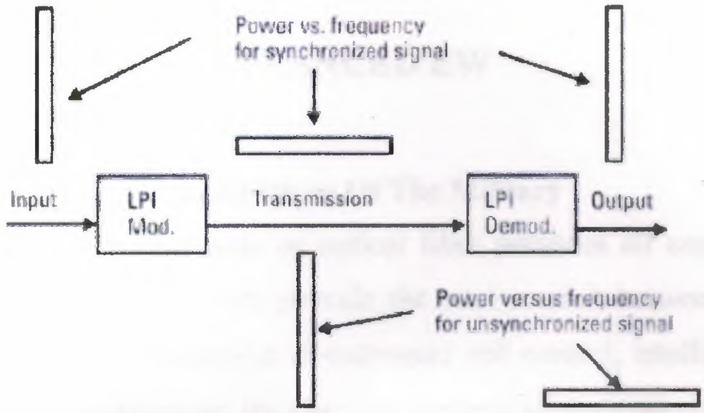


Figure 3.14. LPI Signal Performance.

Frequency hop involves changing the transmission frequency 100 or more times per second. The transmitter hops randomly over a frequency range of many times the transmission bandwidth. A synchronization scheme allows receivers in the same net to hop along with the transmitter. Hostile receivers have no way to synchronize with the transmitter, so they are at a great disadvantage when trying to detect or copy the signal. Since the signal moves quickly over a wide frequency range, a jammer must either cover the whole range or find some way to measure the frequency each time the signal hops to tune a jammer.

Direct-sequence signals have a second modulation applied to spread the frequency of the transmitted signal. This modulation is a high-rate, pseudorandom bit stream that usually PSK modulates the information signal. The receiver is synchronized to the same bit stream, so it can remove the spreading modulation. However, a hostile receiver cannot despread the signal and cannot typically even detect the signal's presence. Jamming signals are spread by the same demodulation that despreads the desired signal, making jamming very difficult

CHAPTER FOUR

ADVANCED EW

4.1 The Importance Of Communications Of The Military

Communications via radio, cable or optical fiber pervades all aspects of military operations. Communication systems provide the vital conduit between one computer and another to ensure the distribution of command and control, intelligence and other information. Communications are the glue that cements military operations. Without a functional communications system virtually all modern wartime and peace keeping activities would quickly grind to a halt and knowledge superiority would be impossible.

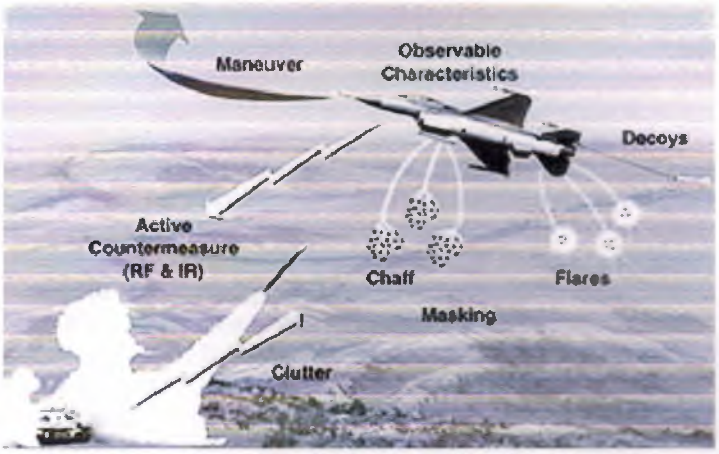
In order to maintain information dominance, military communications must be maintained when and where needed. What makes Military Communications systems different from civil systems is that they have traditionally been designed to resist geo-location, jamming and other electronic warfare (EW) threats As a separate issue they must provide end-to-end message security in order to maintain confidentiality. The network must also be robust to physical disruption; architectures employing a single critical communications node, such as a computer or radio station, have to be avoided if possible. Also many military communications have to be maintained on the move, perhaps between fast moving vehicles such as aircraft or perhaps between command posts and moving troops. Meeting these latter requirements significantly complicates radio system architectures and information flow rates compared to those that are achieved in civilian systems. Against this background of military requirements are the products offered by civilian telecommunications companies and their research and development (R&D). It is estimated that the UK civilian telecommunications research investment in 2001 was around £700M, Can civilian communication systems meet the military requirements directly, or should new military communications systems try to harness the underlying civilian technology rather than the systems, Where are the military communications niche markets which will not be supported by civilian ones? Where the military communications R&D should be focused.

4.1.1 Electronic Warfare - Air

BAE Systems offers a range of EW systems, including advanced onboard radar warning and laser warning receivers, airborne towed decoys, fully automated jamming systems, and directed infrared countermeasures systems. Equipment can be supplied separately or as a fully integrated defensive aids suite.

4.1.2 Air Force Electronic Warfare Evaluation Simulator

The Air Force Electronic Warfare Evaluation Simulator (AFEWES) is a hardware-in-the-loop laboratory facility located at Air Force Plant 4 in Fort Worth, Texas, that develops, validates, and operates high fidelity simulations for testing electronic combat (EC) effectiveness against threat systems The AFEWES provides secure, technical evaluations of radar/infrared-guided terminal threat systems such as surface-to-air missiles, airborne interceptors, and air-to-air missiles. The AFEWES incorporates both hardware and software to stimulate and interact with U.S. and allied EC systems. Testing is conducted at actual frequencies, in real-time, and incorporates hostile effects in a dense radar and infrared environment. This provides an effectiveness evaluation of radar warning receivers, radio frequency and infrared jammers, chaff, flares, towed decoys, evasive maneuvers and combinations of these EC systems and techniques



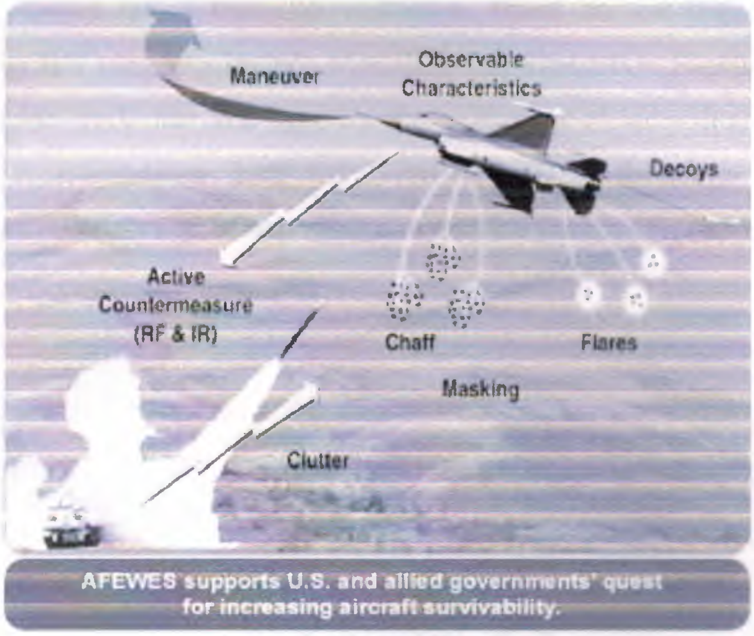
Air Force Electronic Warfare Evaluation Simulator Mission Overview

4.1.3 Electronic Warfare Directorate

The Electronic Warfare Directorate is the Air Force focal point for electronic warfare (EW) test and evaluation. It provides the world's preeminent test and evaluation capabilities, resources and expertise for EW and avionic systems.

The capability exists to develop facilities, equipment, and software to meet current and future test and evaluation mission needs to seamlessly implement the Department of Defense EW and avionics test and evaluation process. Personnel plan, provide for and conduct tests of electronic warfare systems and equipment – then analyze, evaluate and report the results of those tests. The Electronic Warfare Directorate has full electronic warfare test and evaluation capabilities to meet mission-specific requirements. Extensive test facilities include the Test and Evaluation Modeling and Simulation facility, systems integration laboratories for software test and integration, hardware-in-the-loop facilities to evaluate the effectiveness of EW systems and tactics, and installed systems test facilities, such as the Benefield Anechoic Facility. Open air ranges, flight test and measurement facilities provide antenna performance and aircraft radio frequency and infrared signature test and evaluation capabilities. These test facilities provide operator-in-the-loop and hardware-in-the-loop laboratories to evaluate hardware and software interactions, piloted real-time and non-real time simulations of air vehicle performance, flying qualities and flight control systems. Installed systems testing is performed in the Benefield Anechoic Facility, the world's largest known anechoic chamber Perform effectiveness and/or integration testing of electronic warfare systems and techniques in a simulated Infrared (IR) and Radio Frequency (RF) threat environment

The testing of Electronic Warfare systems



AFEWES simulation resources are validated using the 412 Test Wing Verification and Validation (V&V) process, which requires that all models and components contained within the simulation be validated for their intended uses. AFEWES simulations typically include

1) simulator hardware,

2) a missile flyout model,

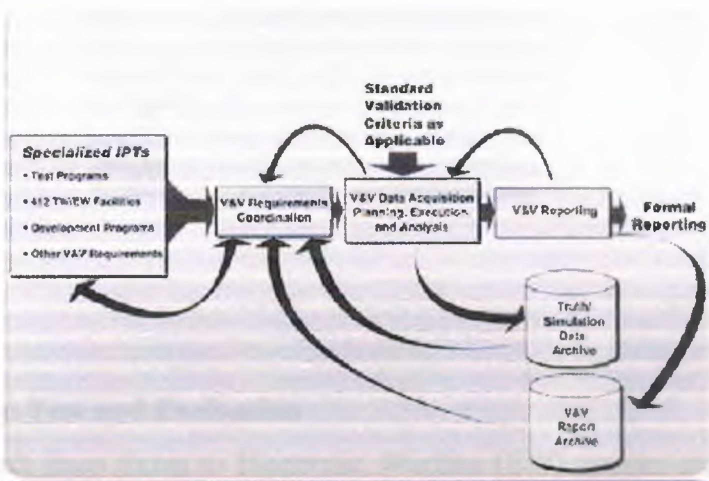
3) a signal propagation model,

4) a victim aircraft signature model,

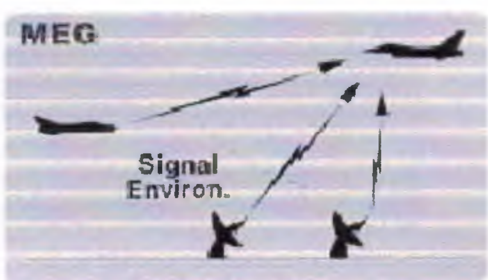
5) aircraft dynamics, and

6) antenna pattern data bases which represent the system under test,

the threat radar, and the hostile missileThe process uses an Office of the Secretary of Defense (OSD)-endorsed, Integrated Product Team (IPT) approach that allows the test customer to be intimately involved in all aspects of validation, which expedites accreditation and ensures that a thorough validation, based on test requirements, is accomplished. Other IPT members include Modeling and Simulation Executive Agents (MSEAs) that provide truth data and approve the validation of individual simulation components, and representatives from the DTSE&E Threat Simulator Validation Review Committee (TSVRC) that is empowered to provide formal OSD approval of the validation effort.



412 Test Wing Electronic Warfare V and V Process

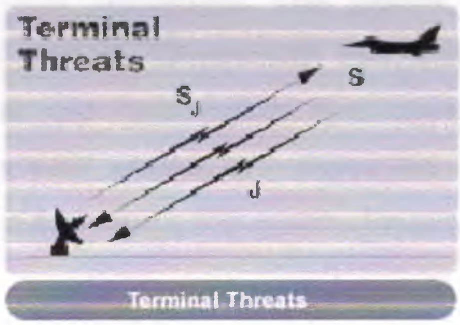


Multiple Emitter Generator (MEG)

4.1.3.1 Open-Loop Test and Evaluation

- One-way path from threat simulation to Electronic Combat (EC) System

Receiver / Processor Testing



4.1.3.2 Closed-Loop Test and Evaluation

- Two-way path from threat to Electronic Warfare (EW) system and EW system to threat

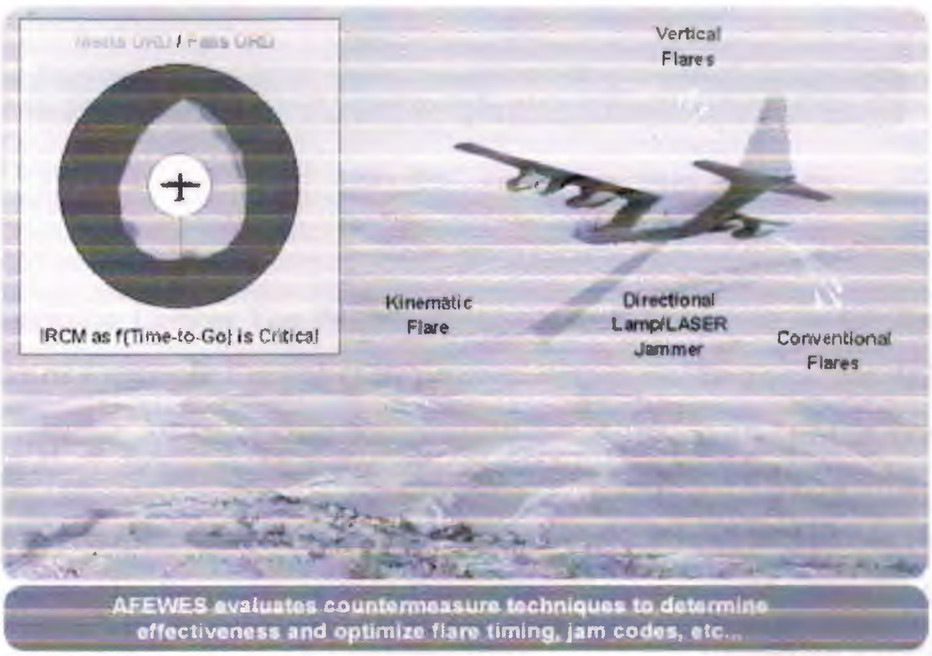
Defensive countermeasures testing

4.1.3.3 Combined Open and Closed-Loop Test and Evaluation

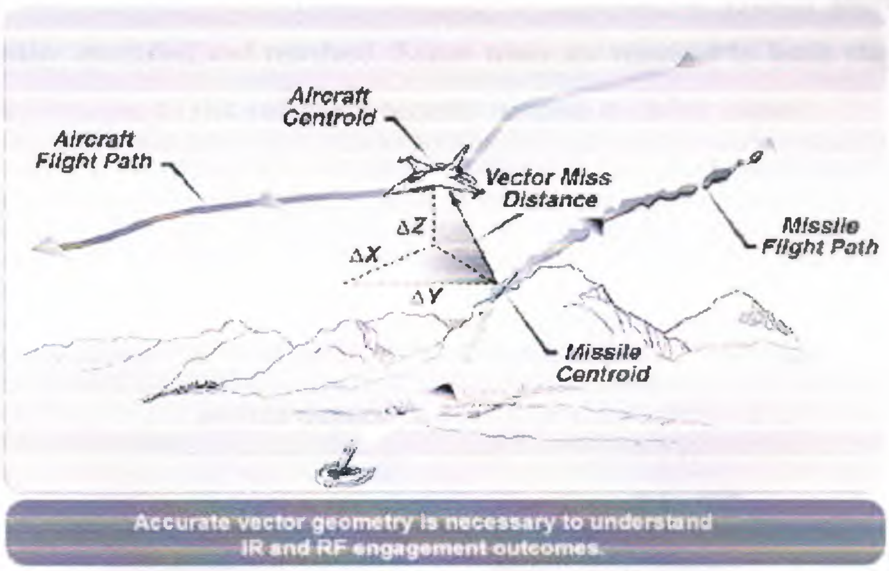
- Individual threats embedded in complex, distributed Radio Frequency (RF) lay downs Dense environment EW system effectiveness

AFEWES develops and operates high-fidelity RF and IR simulations of Surface-to-Air (SAM) and Air-to-Air (AAM) missiles. A vigorous, systematic Verification & Validation (V&V) process is ongoing to quantify the fidelity and accuracy of all AFEWES RF and IR threat simulations. This process is overseen by an IPT representing Intelligence Centers, Government Laboratories, Developmental and Operational Test Agencies, and threat experts from across Department of Defense (DoD). The intent of this V&V process is to ensure that AFEWES simulations are credible and appropriate for determining EW system effectiveness.

Realistic closed-loop simulations of many Infrared (IR) Surface-to-Air and Air-to-Air missiles are available to evaluate the effectiveness of active and expendable IR countermeasures. AFEWES simulations are used to perform optimization and effectiveness testing of conventional and kinematic flares, directed lamp and LASER jammers, and combinations of these techniques

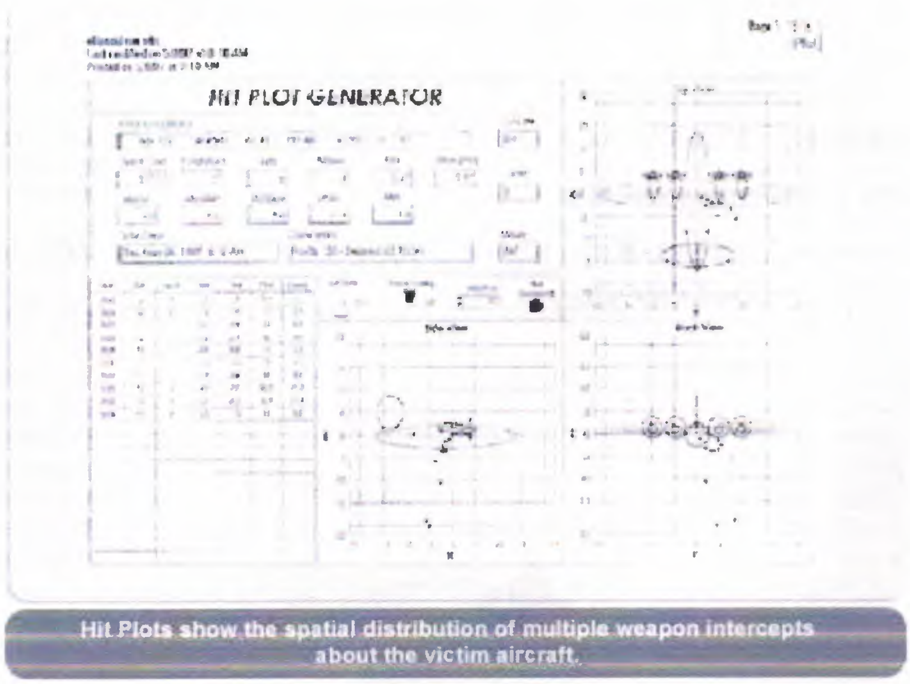


The flight characteristics of each AFEWES threat simulation are represented in a 6 degree-of-freedom (DOF) real time flyout model developed in close coordination with US intelligence agencies. The vector separation between the missile and target as well as the orientation of each are accurately represented throughout the weapon fly out. A primary result of the simulation is the determination of vector missile miss distance. Miss distance is essential to understanding the engagement outcome — a critical part of assessing EW system effectiveness and aircraft survivability



The Electronic Combat Test Process provides a formal structure for the disciplined evaluation of Electronic Combat (EC) systems. Within the Air Force, the 412th Test Wing at Edwards Air Force Base is responsible for implementation of this Process, of which Air Force Electronic Warfare Evaluation Simulator (AFEWES) is an integral part. The Process, depicted in the center of the facing chart, includes six (6) classes of test resources. Air Force Flight Test Center (AFFTC) owns and manages facilities spanning all resource categories. Computer models (Test and Evaluation Modeling and Simulation -TEMS) predict engagement outcomes, structure test trials, and extrapolate data from other facilities to conduct many-on-many combat encounters. Measurement facilities (RATSCAT) quantify the signature and aperture characteristics of EC systems/platforms. Integration laboratories (IFAST) conduct "Systems of Systems" integration tests which establish the non-installed functionality of the EC system prior to its integration on a host platform.

Hardware-In-the-Loop labs (AFEWES) are the first point in the Test Process where EC system hardware is challenged to demonstrate its effectiveness in encounters with hostile threat systems. Installed System Test Facilities (BAF/ECIT) establish installed functionality prior to flight test. Open Air Ranges verify installed EC system functionality and effectiveness in a dynamic, free-space environment other test resource categories cannot provide. As EC systems migrate through this Process, test realism and fidelity is increased and EC system maturity is enhanced as system anomalies are systematically identified and resolved. Fewer trials are required in latter stages of the Test Process because of risk-reduction benefits realized in earlier phases



Hit Plot Generators show the spatial distribution of multiple weapon intercepts about the victim aircraft

4.1.4 Airborne self-protection

In the airborne information gathering domain, Thales supplies off-the-shelf EW systems for SIGINT or multi-sensor wide body and business jet mission aircraft as well as ASTAC - a unique range of ELINT pods, which are qualified on several French and export combat aircraft

Based on its long experience of escort high power jamming equipment, Thales has recently demonstrated operationally the effectiveness of a new generation of digital, solid-state offensive jammers that could be installed in pods for combat aircraft or internally for mission aircraft. New, high-precision, time-critical targeting functions are already available for the latest generation of multi-mission EW Suites for combat aircraft such as SPECTRA and ICMS for the Rafale and the Mirage 2000-5 respectively.

Thales provides all internal EW electromagnetic **self-protection systems** for French Air Force Mirage 2000 and F1, Naval aircraft and transport aircraft, French Army / French Air Force helicopters (Super Puma and Cougar). Thales has also provided CARAPACE, a passive self-protection suite for the F-16 Fighting Falcon of the Belgian Air Force.

The Kestrel ELINT/ESM system is designed for use in patrol, reconnaissance and Airborne Early Warning aircraft. Enhancing EW situation awareness, it can be fully integrated with other airborne sensors, including AEW systems and self-protection countermeasures equipment and is fitted to the UK Royal Navy's Merlin helicopters.

4.1.5 Electronic Warfare For Ground Forces

Thales manufactures a wide range of EW systems for use by land-based forces, each suited to a variety of roles such as electromagnetic intelligence gathering, passive air-defence, coastal/border surveillance. The Thales land-based sensors can be operated alone or can be networked to an Electronic Warfare Operations Centre to provide a complete turnkey solution to the interception, analysis and dissemination of electronic information and intelligence. Thales is prime contractor for the SGEA Valo programme, the improved version of the front-line tactical EW system of the French Army

Figure 4.8. Mobile ESM & Elint System A Tactical Solution Mathched to the Tempo of Modern Warfare

4.1.6 Electronic Warfare – Sea

We produce naval electronic warfare suites, providing ESM or ECM for corvettes, frigates and other naval vessels. The systems provide radar band ESM and deliver target information to the command system. Interfaces and control are available for offboard countermeasures such as chaff, flare and the Siren decoy

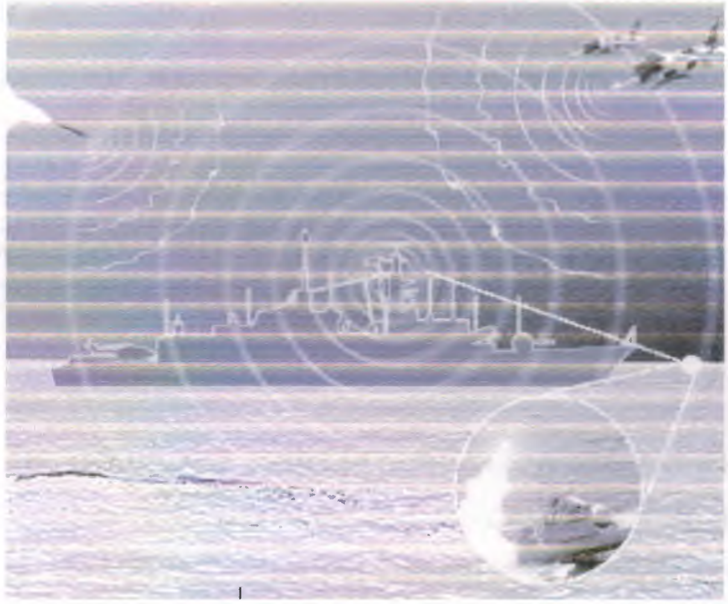


Figure 4.6. Surface Ship ECM

4.2 EW Control Tasks

Control of EW operations is essential to allow optimal friendly use of the electromagnetic spectrum while targeting the enemy in a manner that supports the operational maneuver. However, control may be made difficult in joint operations or operations involving the participation of allied forces. EW is broadly controlled by establishing measures to ensure the coordination of EW activities between forces, establishing procedures to monitor the execution of EW activities, and finally by establishing a means to assess the effectiveness of EW operations and to recommend and implement changes.

4.2.1 Coordinate EW Operations

a. **Within the parameters of designated authority**
b. **Direct action within established timelines and conditions**
c. **Coordinate actions and operations, where lines of authority and responsibility overlap or conflict**

(1) Advises units of adjacent or related actions and operations

(2) Directs supporting operations

(3) Resolves conflicts

d. Coordinate continuing support for EW operations

(1) Coordinate administrative support

(2) Coordinate logistical support

(3) Coordinate communication support

(4) Coordinate external agency support

4.2.2 EW and Joint Operations

Joint operations feature new command relationships and generally increase the complexity of EW operations. This is because coordination is more difficult because more agencies are involved in planning and execution. Although the structure will vary with the situation, the EW organization within the joint force normally centers on the joint force staff, component commands, the Joint commander's electronic warfare staff (JCEWS), and supporting joint agencies. The Joint Force Staff and EW The Joint Force Staff Operations Director (J-3) has primary staff responsibility for EW activity and for planning, coordinating, and integrating joint EW operations with other combat disciplines. To assist the J-3 a JCEWS is normally formed. The Joint Force Staff Intelligence Director (J-2) is responsible for timely collection, processing, tailoring, and dissemination of all-source intelligence for EW. The Joint Force Staff Communications-Electronics Director (J-6) has primary staff responsibility for coordinating use of the entire electromagnetic spectrum for command and control (C2) systems and electronics dependent weapons systems employed by the joint force.

4.2.3 EW and Multi-National Operations

US planners must be prepared to integrate US and allied or coalition EW capabilities into a single, integrated EW plan. They should also be capable of providing allied or coalition nations with information concerning US EW capabilities and provide EW support to allied or coalition nations. A fundamental task for the Electronic Warfare Officer (EWO) of a US-led multi-national force (MNF) is the recognize and resolve terminology and procedural issues. Fortunately, current NATO EW doctrine is largely based on US EW doctrine. Further, each element within a MNF must determine other participant's need to know and determine the releasability of EW related information to other allied or coalition forces

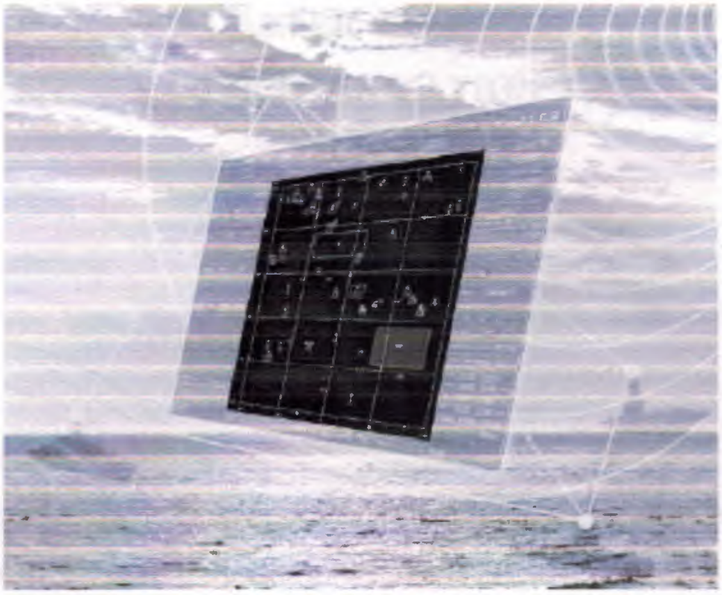
4.3 ADVANCED EW

The advanced of EW controller technology has been developed in its EW laboratories in Adelaide, South Australia. The software-based controller allows diverse EW sensors and countermeasures to be fully integrated and controlled by intelligent and adaptable self-protection programming. SIIDAS has its heritage in the Australian Wedgetail AEW&C EW Self-Protection suite designed for the RAAF by BAE Systems Australia. The company stated that the SIIDAS controller "forms the core of the BAE Systems solution" for the ADF Airborne EWSP Upgrade Program known as Echidna and is fully compatible with the Wedgetail EWSP suite and infrastructure with "more than 80% commonality". The system includes a speech processor and can utilise commercial standard interfaces such as Ethernet (multiple ports), CAN bus and FireWire for connectivity and high speed, cross platform passage of large amounts of data. SIIDAS makes use of COTS hardware that allows for rapid adoption of new IT industry standard technologies over time which means that the military customer will more rapidly benefit from the technology drivers in the global IT sector. "We are thrilled by the prospects that this technology holds for our defence force and for Australia's growing global reputation for excellence in airborne EW," said Patrick Stringer, Deputy Director Marketing - Aerospace Programs, BAE Systems Australia. "SIIDAS now allows us to provide a level of commonality, survivability and affordability, which many experts in the global EW community said were simply not possible. "Australia has access to the Intellectual Property and our customer will be able to adapt quickly to the changing threat environment and growth in technology without the need for re-certification of the entire suite,"

4.3.1 EW Systems: B-1B

The B-1B fleet is the backbone of the U.S. bomber force, responsible for over half of the bomber assigned target base. The B-1B is a high-speed, swing-wing, high or low altitude bomber that can carry large payloads anywhere in the world in a matter of hours. It has a crew of four. The fleet was deployed in the mid-1980 as a low altitude, nuclear armed, lone penetrate of the Soviet Union. However, in the early

1990's, the Air Force established a plan to convert the B-1B into a conventional bomber. This plan is called the Conventional Munitions Upgrade Program (CMUP), and is currently underway. The CMUP will deliver improved lethality, maintainability, and survivability enhancements to the entire B-1B fleet through Block system upgrades approximately every two years. A major portion of the CMUP, the Defensive System Upgrade Program (DSUP) was terminated in December 2002. This paves the way for ALQ-161 hardware upgrades which are already underway.



Advanced multi-platform
Naval Esm/Elint system

CHAPTER FIVE

RADAR MODULATION

5.1 Radar Modulatıon

5.1.1 Radar Modulations

There are three basic types of radar modulation: pulse, continuous wave, and pulse Doppler.

- **Pulse Radar**
  - Because pulses are quite short, the time between transmission and reception of signals can be easily measured.
  - The average power that must be supplied to a radar transmitter is much less than the peak power, which makes both transmission tubes and power supplies smaller and lighter.

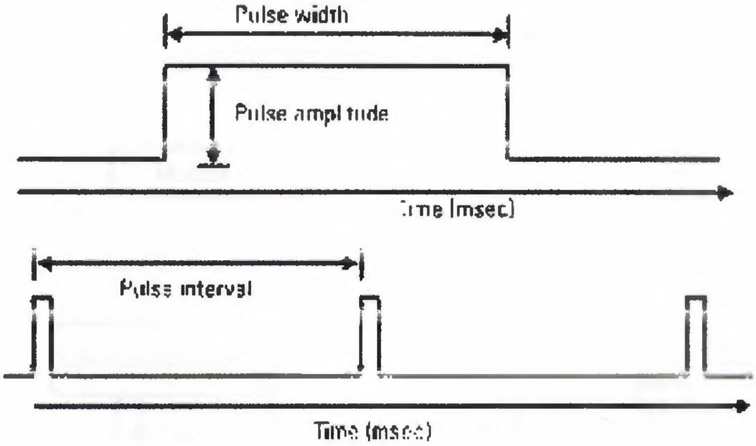


Figure 5.1. Pulse-Modulation Parameters.

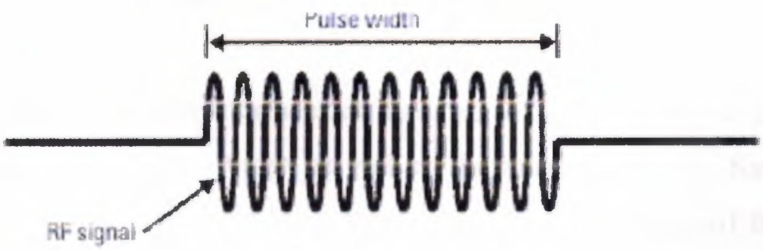


Figure 5.2. Transmitted Pulse Signal.

Figure 5.3 shows the block diagram of a pulsed radar. Note that the transmitter and receiver share a common antenna. Since the pulse has a short duty cycle, the duplexer keeps the antenna connected to the receiver most of the time. Since the transmitter power is usually high enough to damage the receiver, the duplexer must have enough isolation to protect the receiver during the transmitted pulse.

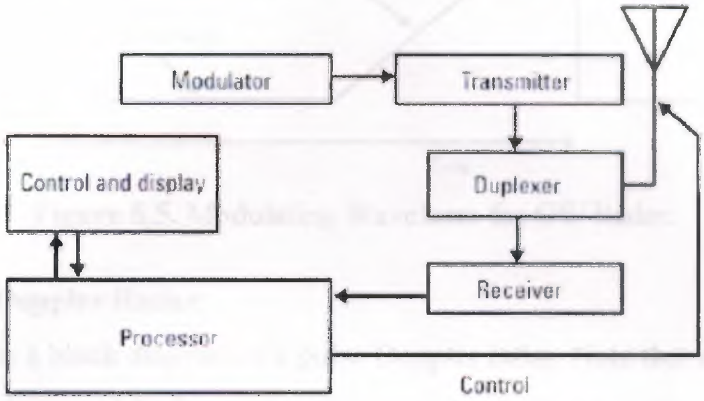


Figure 5.3. Block Diagram of Pulsed Radar.

- **Continuous-Wave Radar**

A continuous-wave (CW) radar requires two antennas, as shown in Figure 5.4, since the transmitter has 100% duty cycle. Isolation between these two antennas must be great enough to prevent the transmitter from saturating the receiver.

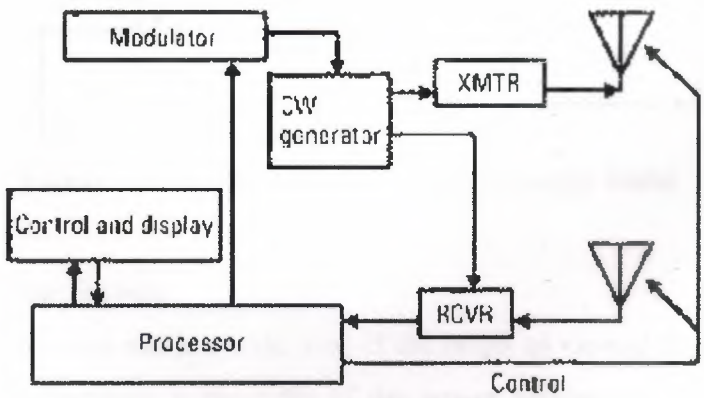


Figure 5.4. Block diagram of CW radar.

Frequency modulation waveforms such as those in Figure 5.5 allow a CW radar to determine the distance to a target as well as the relative velocity. Since the linear ramp portion of the waveform has a known time rate of change of frequency, the frequency difference between the transmitted and received signals is a function of both the Doppler shift and the round-trip distance to the target. The Doppler shift is determined during the flat part of the waveform both to isolate the range component and to provide velocity information.

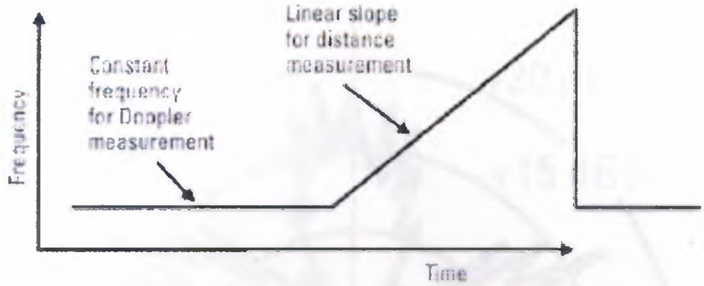


Figure 5.5. Modulating Waveform for CW Radar.

- **Pulse Doppler Radar**

Figure 5.6 is a block diagram of a pulse Doppler radar. Note that a sample of the CW generator is passed to the receiver to support coherent detection. The duplexer allows the use of a single antenna for transmission and reception.

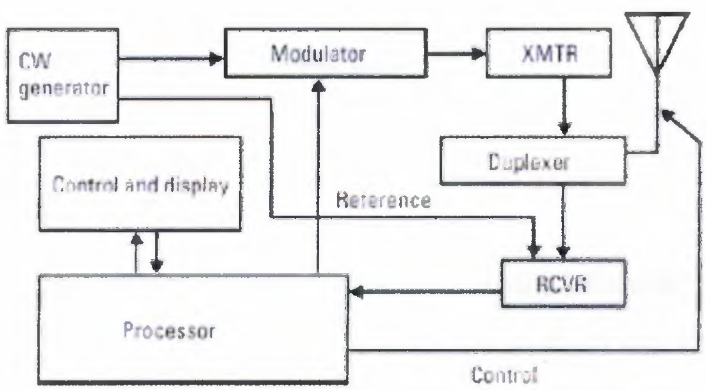


Figure 5.6. Block Diagram of pulse Doppler Radar.

5.1.2 Radar Cross Section

The geometric cross section is the size of the target as viewed from the aspect of the radar. The reflectivity is the ratio of the power leaving the target versus the radar power illuminating the target. The rest of the power is absorbed. Directivity is the ratio of the power scattered in the direction of the radar receiver versus the amount of power that would have been reflected if the total power were scattered equally in all directions. If the radar is monostatic, this is for the power scattered back toward the radar transmitter (also the receiver location). If it is a bistatic radar, this is for the energy scattered from the transmitter location toward the receiver location.

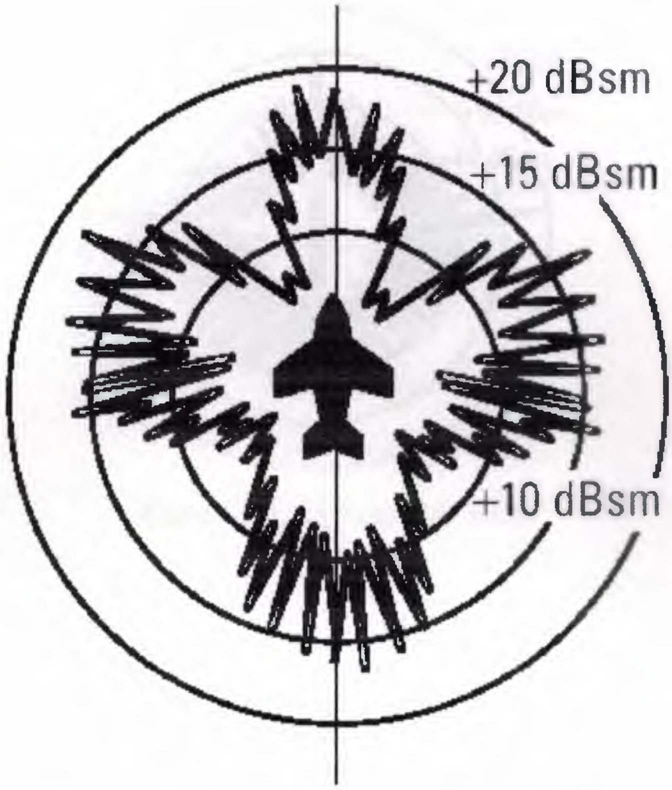


Figure 5.7. Typical Tactical Aircraft RCS.

The RCS for a ship is described in similar charts. Figure 5.8 shows the RCS for an older destroyer. It is for a single radar frequency and assumes that the radar is at an elevation angle above the water at which the RCS is maximum. Note that there are very high peak RCS values 90 degrees from the bow and lesser peaks fore and aft. The RCS at the rest of the angles around the ship have been aptly described as a fuzz ball because of the many narrow peaks caused by individual reflective features of the ship. Modern ships designed for reduced RCS have significantly lower reflections, but large ships still have significant RCS.

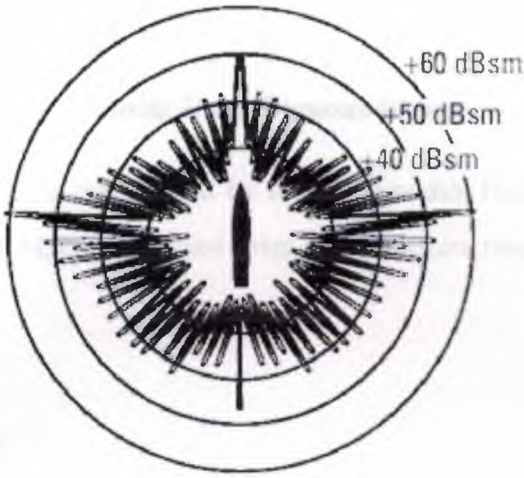


Figure 5.8. Typical Ship RCS.

5.1.3 Radar Performance

- The radar range equation yields the signal level received by a radar receiver as a function of the transmitter power, the antenna gain, the range to the target, the operating frequency, and the RCS of the target.
- The detectability range of the radar is the range at which a hostile receiver can detect the radar's signal. This must be defined in terms of the performance specifications of the receiver.

W=2sin(0.5 beamwidth) x distanc from radar to target (5.1)

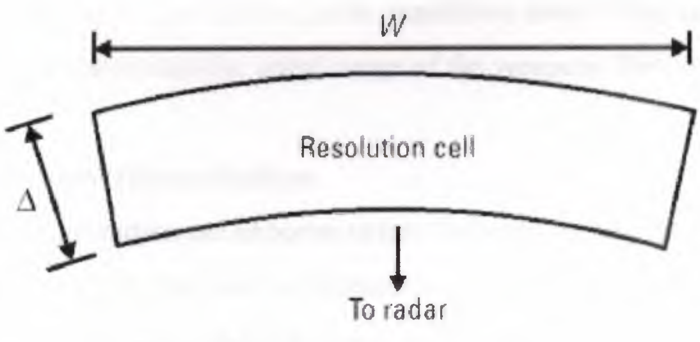


Figure 5.9. Radar Resolution Cell.

The equation for the depth (δ) of the resolution cell is

$$\Delta = 0.5\text{pulse width x speed of light} \quad (5.2)$$

- **Minimum and Maximum Unambiguous Range**

The minimum range is determined by the pulse width. Basically, the pulse must end before its leading edge is reflected from the minimum range target and returned to the receiver.

5.2 Types of Radars

We will classify radars in terms of the tasks that they perform. Each radar type has characteristics that strongly affect the way it interacts with EW systems, and hence the way they are represented in EW modeling and simulation.

5.2.1 Search Radars

When a search radar acquires a target, the radar hands it off to a radar associated with a weapon system or passes information to a fighter aircraft controller who guides a fighter to intercept target aircraft that are detected. Sometimes, specific search radars are associated with specific weapon systems. Also, a single radar can have both acquisition and tracking modes.

5.2.2 Tracking Radars

Tracking radars typically operate at higher frequencies than search radars. They also have shorter pulses and higher pulse repetition rates. They are designed to operate over a little more than the lethal range of the weapons they support.

5.2.3 Battlefield Surveillance Radars

Synthetic aperture radars are airborne radars that map terrain. The term *synthetic* aperture refers to the fact that data is combined over a period of time as the aircraft moves. This creates the effect of a very large antenna and the resulting resolution.

Low-probability-of-intercept (LPI) radars are characterized by detectability range less than detection range. They use complex waveforms and careful parametric trade-offs to achieve this result.

5.3 Multiple Different Types Of Radar

5.3.1 Doppler Radar:

Dopplerizing an existing radar adds the capability of measuring wind direction and speed by measuring the Doppler effect. The radar measures what is called radial velocity. This is the component of the wind going either toward or away from the radar. There are currently two different types of radar that are being experimented with. The first type that is in the final stages of development is dual-polarized radar. The other that is being worked on is bistatic radar.

5.3.2 Bistatic Radar:

This is probably the newest instrument on the horizon for radar since it was created in 1994. In the past, a problem occurred in detecting the wind structure of a thunderstorm with a single Doppler radar. This was a problem because if the winds were flowing perpendicular to the radar beam, it could not resolve which direction they were flowing from. This problem is corrected with bistatic radars. In a bistatic system, there is at least one bistatic receiver and one single traditional monostatic weather radar. In this system, the weather radar transmits a narrow beam and receives the backscattered radiation. At the same time, one or more passive bistatic receivers recover some of the other scattered radiation. Since this gives multiple angles on the wind, many components of the wind can be measured simultaneously. This creates the possibility of directly measuring 3-D winds with a single radar system. There currently is only one bistatic radar network set up in the world. That network is set up around the Montreal airport in Canada. The preliminary results have been very promising, especially in areas like airports that require a good understanding of wind flow. An example of the data is below. One can see below in the data the direction and speed of the winds. This solves the problem that single dopplers have. Single dopplers can only see wind direction toward or away from the radar.There is a lot of hardware that is necessary for a radar to run, here is a brief look at some of the main components required to run a National Weather Service (NWS) WSR-88D NexRad radar.The most seen component of a radar is the actual dome itself.

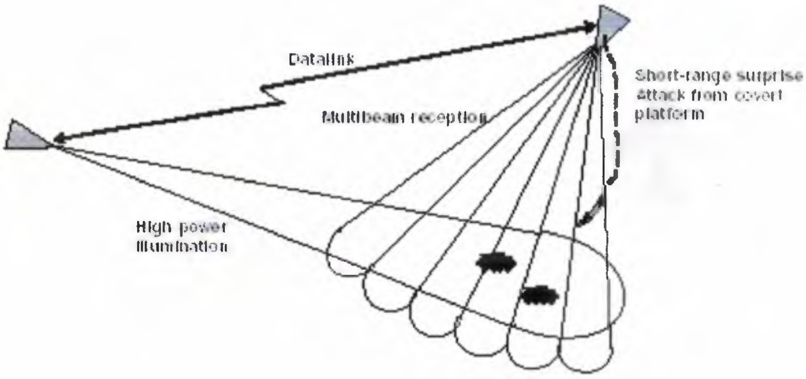


Figure 5.10. Bi-Static Operation–Fighter and UCAV

5.4 Missile Guidance Techniques

5.4.1 Command Guidance

Command guidance is common in surface-to-air missiles. As shown in Figure 5.11, the radar tracks the target and predicts its future locations. Guidance commands argenerated and sent to the missile, taking into consideration moment-to-moment changes in the path of the target during the engagement. With command guidance, the radar has all of the information; the missile simply goes where it is told.

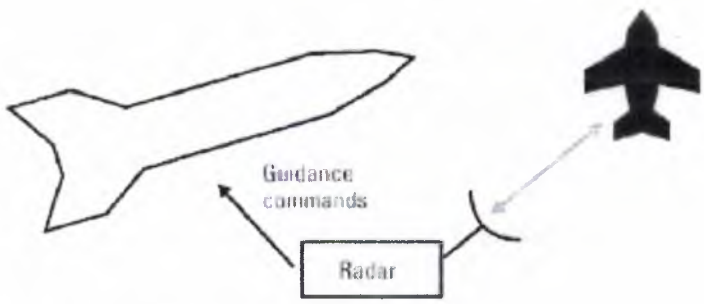


Figure 5.11. Command Guidance.

5.4.2 Active Guidance

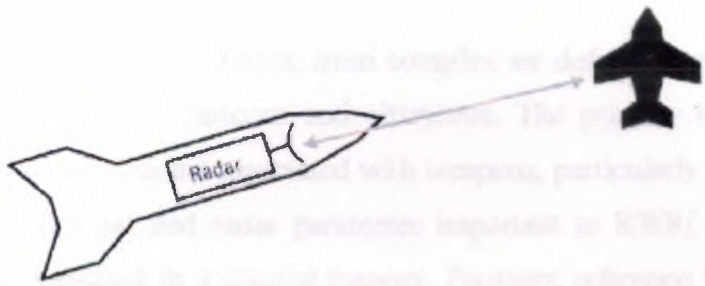


Figure 5.12. Active Guidance

5.4.3 Semiactive Guidance

A semiactively guided missile has only a radar receiver on board (see Figure 5.13). The transmitter is remote from the missile. The transmitter tracks the target to keep its illuminator in place, or uses a very wide transmit antenna beam. The receiver receives the reflected signals from the target illuminator and guides itself to intercept the target. This is an example of a bistatic radar, since the transmitter and receiver are separated. It is commonly used in air-to-air missiles.

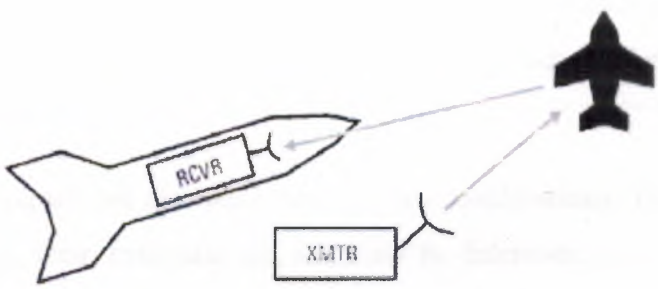


Figure 5.13. Semiactive Guidance

CONCLUSION

Radar is employed in many forms, from complex air defense networks to simple IFF(Intelligent Fire Fighter) beacons and altimeters. The primary threat radars for aircraft are the fire control radars associated with weapons, particularly guided missiles. In this section, each radar and radar parameter important to RWR(Radar Warning Receiver) will be discussed in a general manner. Frequent reference will be made to more detailed sources; the reader should pursue these sources in the library.

EW is the art and science of denying enemy forces the use of the electromagnetic spectrum while preserving its use for friendly forces. EW is a significant force multiplier because it reduces friendly losses by defeating or reducing the effectiveness of enemy weapons. İn 3th chapter deals with the signals, equipment, deployment, and tactics associated with all aspects of EW. As indicated by the chapter title, this discussion provides an overview of EW. It is limited to providing enough information to support our later discussion of EW modeling and simulation, and focuses primarily on the aspects important to modeling and simulation. The following books are recommended to provide the reader with more depth and breadth in the field: We turn now to a discussion of the signals associated with EW (radar and communication) and the three major subfields.

Communication signals are also important to EW considerations. They are intercepted and jammed, and their externals are analyzed to determine an enemy's electronic order of battle. The messages carried by a communication system are called the signal internals, while the modulation, transmitter location, and so forth are called its externals.

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