MAWTS-1

ELECTRONIC WARFARE

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INTRODUCTION

The somewhat facetious title of this report is intended to convey a quite serious intent: to present the basics of Electronic Warfare (EW) in so simple and straight-forward a manner that the subject matter may be understood by someone with absolutely no background in the field. While this has been attempted in the past, those writing such works have always been technical experts, and in spite of the best intentions, usually leave the intended reader at a loss by the third page. This may occur because of a concern about "talking down" to the reader, or of dealing in oversimplifications. This report will not be influenced by such considerations. Further, the writer is a dedicated nonspecialist in electronic warfare and deals with the subject matter from the nontechnical aspects only, so over-qualification will not rear its ugly head.

The only assumption that will be made as to the readers technical background is that they have at some time operated a radio, television set, and a telephone. Some information supplied in Appendix A may require knowledge of second-week algebra, but is not required to comprehend the content of this report. Indeed, if a reader who is utterly without a background in electronics feels talked down to, it will merely demonstrate that the desired level of simplicity has been achieved.

It is intended that the reader will, after finishing this report, be able to understand a few basic principles of radio, radar, and electronic warfare, have a broad, general idea of how the major elements of electronic warfare are employed, and have at least a familiarity with the more common acronyms and terms. Any more detailed information is beyond the intended scope of this work, and the reader desiring more should seek it elsewhere.

ELECTRONIC WARFARE

Lesson Purpose

To provide the WTI student with a basic overview of the fundamental principles of Electronic Warfare.

Enabling Learning Objectives

1. Define the following characteristics of pulsed radars: Pulse Width (PW), Pulse Repetition Frequency (PRF), and Pulse Repetition Interval (PRI).

2. State the correlation between frequency and radar range.

3. State the relationship between beam width and angular resolution.

4. Define radar cross section.

5. State the three functional divisions of Electronic Warfare (EW).

6. Define Electronic Warfare Support (ES).

7. Define Electronic Attack (EA).

8. State the two classes of EA.

9. State two forms of noise jamming.

10. State two forms of deception jamming.

11. Define Electronic Protection (EP).

12. Define burn-through range.

13. State three areas of radar design that influence EP capabilities.

14. State seven radar parameters that are used as EP fixes.

15. State two types of IR countermeasures (IRCM).

BASIC TERMINOLOGY

Some terms and abbreviations are so common in the radar field that a basic explanation of them is required. We will begin with those common to the general field of electromagnetic communication.

A. RF

RF is the abbreviation for radio frequency, and is used to differentiate that portion of the electromagnetic spectrum that is not visible light, infrared (IR), ultraviolet (UV) radiation, or x-rays. Stated another way, RF is that form of energy used in radio, television and radar.

B. FREQUENCY

First, the frequency of the transmitted signal is simply the number of times per second the RF energy completes one cycle. Figure 1 shows a frequency of two cycles per second*.

(It is important for the reader to understand that a transmitter and receiver must be on the same frequency for any information transfer to occur. Otherwise, it is just like dialing a wrong number or a disconnected number on the telephone.)

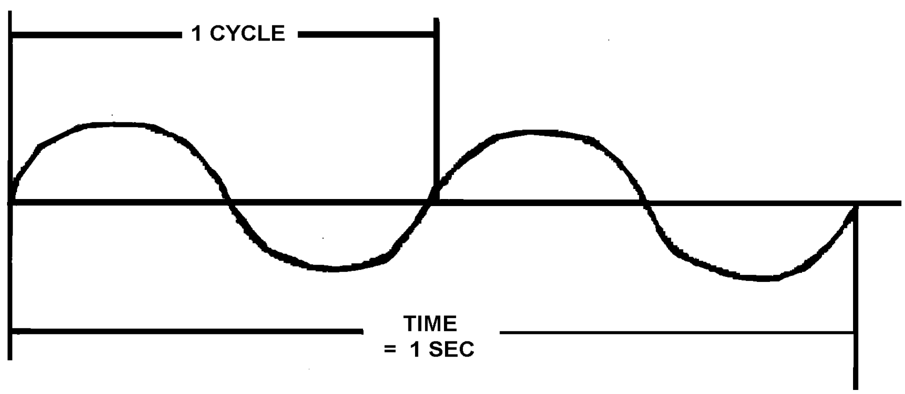

Figure 1: Carrier Wave

*This terminology was apparently so straightforward that the uninitiated could easily comprehend it, so the electronic community changed it to hertz. So 500 kilo (thousand) cycles per second, for example, is now 500 kilohertz (usually written kHz). (The most common prefixes used in this terminology are shown in Table A-1 of Appendix A.) The RF spectrum is generally divided into eight frequency categories shown in Table A-2 of the Appendix. These categories are used primarily with radio and are mentioned here only as a point of information.

This continuous wave (CW), known as the "carrier wave" or simply "carrier" is heard through a receiver as a single tone. By interrupting this tone, using a combination of short and long signals ("dots" and "dashes" - the well known Morse Code), information can be conveyed with only this single tone.

This method of communication is slow, however, and requires trained operators. It is much easier if one can simply talk. The solution to this problem is a technique known as modulation.

C. MODULATION

Modulation is the term used by radio and radar people to describe some change or variation in the transmitted signal. There are two types: FM or frequency modulation and AM or amplitude modulation. In a FM signal, the amplitude stays the same and the frequency varies (see figure 2).

Conversely, in amplitude modulation, the frequency is constant and the amplitude is varied (figure 3). It is these "modulations" on the basic carrier wave that actually convey information such as voices and music.

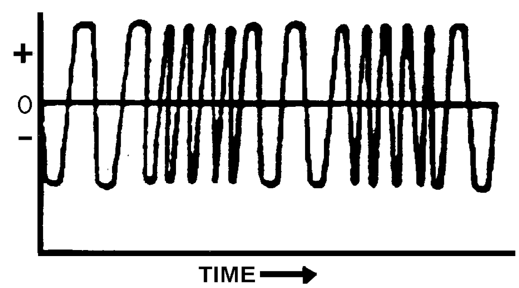

Figure 2: Frequency Modulation

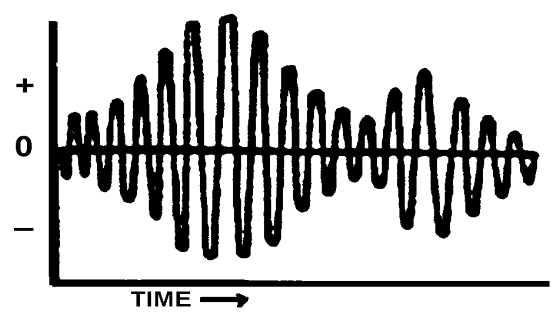

Figure 3: Amplitude Modulation

D. WAVELENGTH

Wavelength is a measure of the physical distance from one end of a complete cycle to the other and is expressed in meters. It is, in effect, the inverse of frequency, i.e., the higher the frequency, the shorter the wavelength. This is the source of the early radio and radar terminology where wavelength was used instead of frequency to describe the operating conditions or the characteristics of the set. Thus, "I broadcast on the 2-meter band" or "That's a 2-centimeter radar".

E. FREQUENCY BAND

While a radio or radar operates at something close to a single frequency, most sets - like your car radio - are capable of being tuned to a number of frequencies within the operating range of the set. This is one example of a band of frequencies. Usually the operating band of a given radio or radar will conform to or fall within the internationally accepted frequency bands, lettered A through M (See Table A-3 of Appendix A). It should be noted that the U.S. Navy and most of the rest of the world use these designations when discussing electronic warfare. However, the radar community still uses the old designations of X-band, C-band , and S-band (Table A-4, Appendix A).

F. BANDWIDTH

Bandwidth is merely the frequency spread of whatever band is under discussion, expressed in Hz (Hertz). For example, if your car radio can tune from 500 to 1500 kHz, the operating bandwidth is 1000 kHz. In the international designations shown in Table A-3, Appendix A, the bandwidth of Band A is 250 MHz; Band C is 500 MHz, and so on.

G. CHANNEL

The term channel is used in electronic warfare in the same manner as your television set. It designates a subset of the operating band. Thus, one may see band designations such a C-3 (Band C, Channel 3). Such designations are not commonly encountered at our level of detail, so they will not be referred to again.

BASIC RADAR CONCEPTS

A. The first operational use of radar in combat was during the Battle of Britain in 1940. The term radar is actually an acronym dating from that time, standing for RAdio Detecting And Ranging. As can be inferred from this, radar is merely a radio which makes use of the fact that electromagnetic energy is reflected by bodies of various composition, those containing metal being the most reflective. The process of locating a target with radar can be likened to locating a cliff in a fog bank by shouting or sounding a horn. The return of an echo reveals the presence of the cliff. Knowing the speed of sound, the sailor can determine the distance of the cliff by noting how long it takes the echo to reach him (Figure 4).

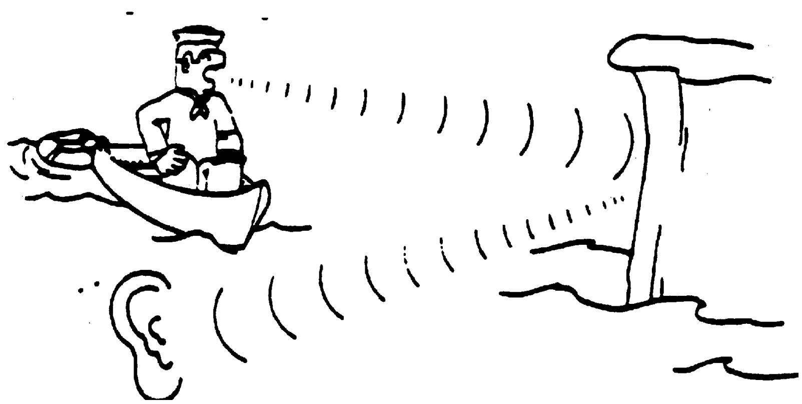

Figure 4: Acoustic Analogy of Radar

B. Radar works on the same principle, using RF energy instead of sound. A radar set consists of two basic elements: the transmitter and the receiver. The transmitter sends out some form of RF energy through its antenna. The presence of the target is revealed when that energy bounces off the target and returns to the radar where it is heard through the antenna of the radar's receiver (Figure 5). Since we know that RF energy travels at the speed of light, the range of the target can be determined by the time it takes the energy to travel from the transmitter to the target and back. One important corollary to this principle is that the radar signal can always be detected at a greater distance than it can "see" a target. This is of some significance in electronic warfare.

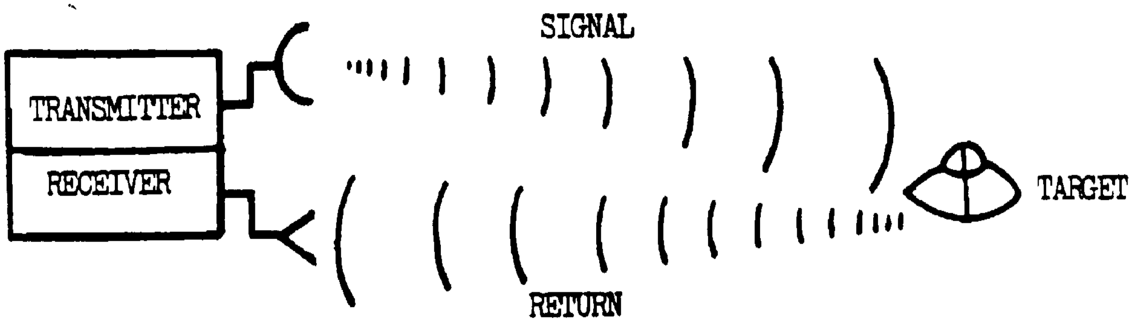

Figure 5: Basic Principle of Radar

C. TERMINOLOGY AND CHARACTERISTICS

The form of the energy of the transmitted pulses is of interest to us, as some of the most frequently used terms in electronic warfare are those describing their form and characteristics. These terms are also used to describe the radars themselves.

1. Transmission Format

We will deal first with the classic type of radar - the pulsed radar - and discuss some other types later.

Since a pulsed radar cannot hear anything but itself when it is transmitting, it must of necessity, cease transmitting if it is to detect anything. (Not unlike the country philosopher who commented "you got to listen - you ain't learning nothing when you're talking.") So the radar sends short pulses of RF energy at its basic operating frequency, and listens for the echo or return, as it is more commonly called.

Note that the ratio of time spent listening to that spent talking is quite high, a characteristic not yet achieved by people. The amount of time the radar transmits is expressed in seconds (usually microseconds) and is called pulse width (PW) (a graphic representation of these terms is shown in Figure 6). The frequency with which the pulses are repeated is called the pulse repetition frequency (PRF), and is expressed as a frequency in the same manner as the operating frequency. The actual time between pulses is called the pulse repetition interval (PRI), again expressed in microseconds.

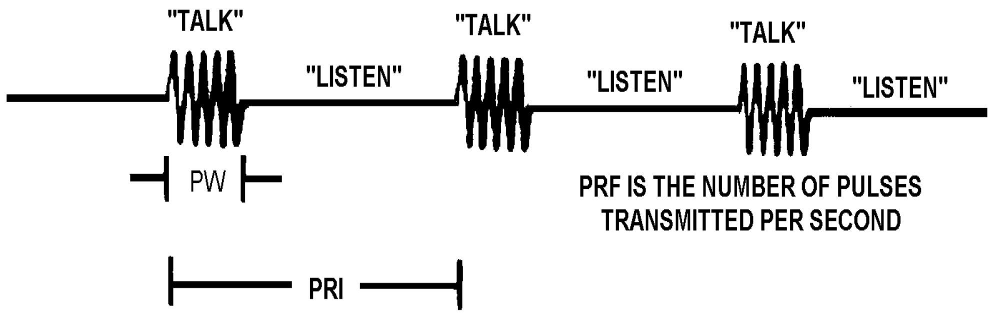

Figure 6: Basic Radar Transmission Format

2. Radar Types Versus Frequency. Frequency being the inverse of wavelength helps determine the function of the radar. Lower frequencies (longer wavelengths) are considerably less precise in determining the actual position of the target than are the higher frequencies (shorter wavelengths). But as in life, it is not all black and white. The other side of the coin is that the lower frequencies deliver greater range. Thus, we find low-frequency search radars, high-frequency fire control radars for weapon direction, and the frequencies in between being used for interim functions such as target acquisition, height finding, etc.

3. Beam Types

   A major characteristic used in distinguishing radars is beam type. The astute reader will have already noted that in our example of the unfortunate sailor trying to find the cliff, detection (presence) and range (distance) were determined. But azimuth (direction) was likely to be uncertain. The same is true with radar. Some means is required to accurately determine direction. The most common way is to broadcast the radar's signal in a narrow beam and rotate it. Thus, when a return is heard, the direction of the target is that in which the antenna is pointing when we hear the return. Note here that if an antenna can transmit a certain shape of beam, the capability of that beam and antenna to receive is exactly the same. Figure 7 shows some typical beam shapes.

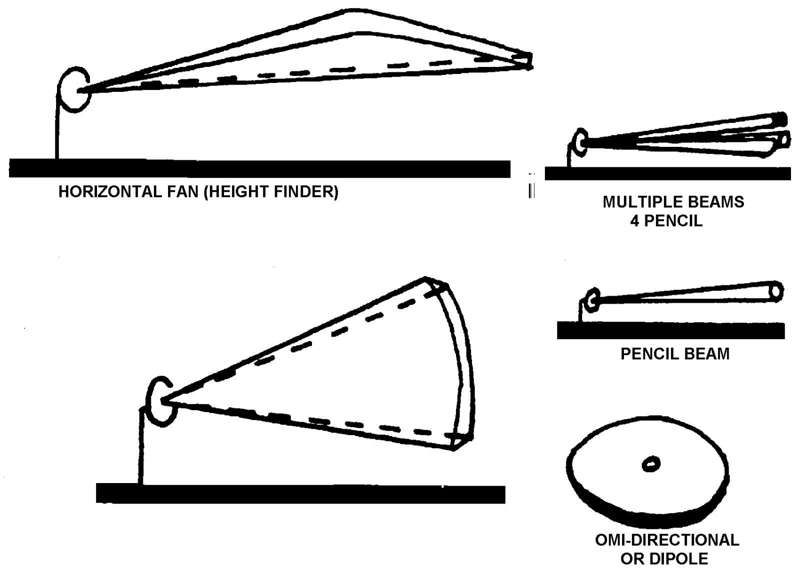

Figure 7: Some Beam Types

4. Beam Width (BW)

The beam types shown in Figure 7 are highly idealized for illustrative purposes. Actually, the beams are more rounded. A vertical fan beam, for example, when viewed from above might be shaped as shown in Figure 8. The width of the beam is measured in degrees. This width is, in essence, the angular resolution of the radar. That is, it describes how far apart in angle two targets must be for the radar to see them as two targets instead of one.

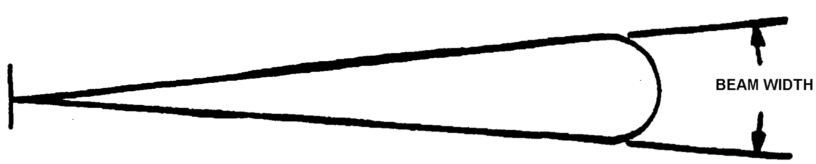

Figure 8: Beam Width

5. Side Lobes

Now that our idealized beam shapes have been demythologized, we can explore one other phenomenon about beams. No beam is ever as good as shown in Figure 8. There is actually what one might think of as "leakage" known as side lobes, shown in Figure 9.

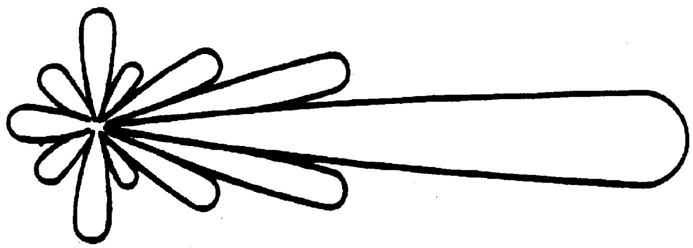

Figure 9: Side Lobes

Sometimes the rearward ones are called back lobes. These side lobes vary from one antenna design to another, and much effort is devoted to making these lobes as small as possible. The reason is that they represent vulnerability to electronic attack, since jamming signals can be received through them as well as through the main beam.

6. Scan

How the beam is employed is called the scan. Some early radars did not move the beam at all - sort of a "steady" scan. In the previous example of rotating the beam, the scan is called a circular or 360° scan. A scan covering less than 360° and swinging back and forth is called a sector scan. To find height, a horizontal fan beam is "nodded" up and down. These and other common scans are shown is Figure 10.

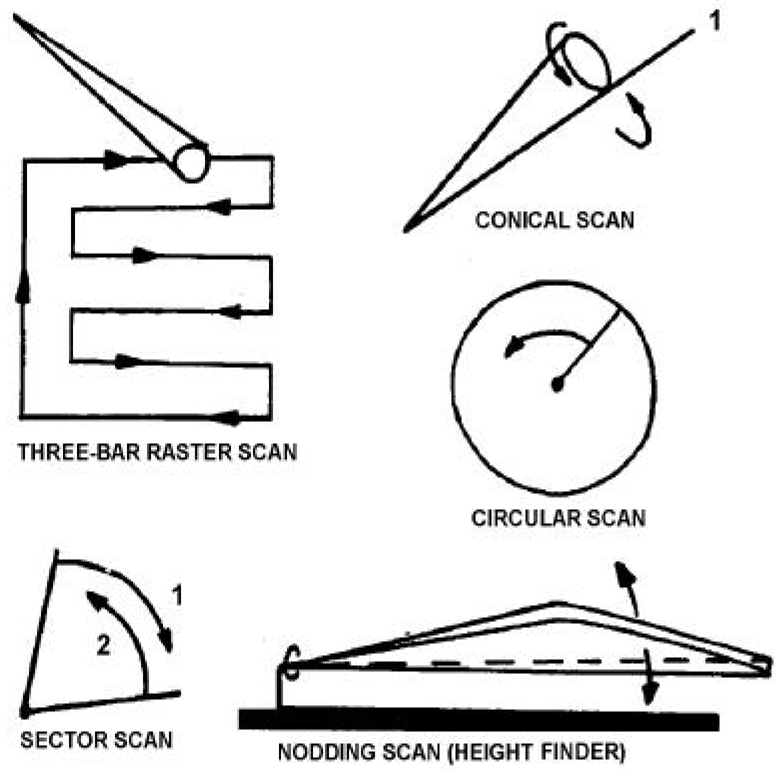

Figure 10: Types of Scan

Another type of scan used with multiple beams is called "lobing" which simply means the transmitter or receiver is switched to each beam in some predetermined sequence.

7. Displays

The most familiar form of radar display is the PPI (Plan Position Indicator). It is simply a map of what the radar sees, with the radar at its center (see Figure 11).

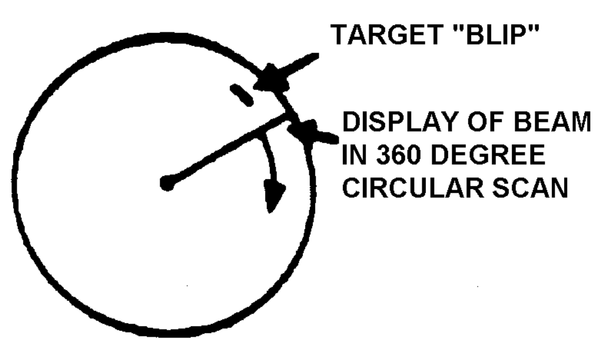

Figure 11: PPI Scope Display

Another type of scope is the "A" scope which shows range only in a linear format. The display shown in Figure 12 shows a target at 15 miles. This type of display is most commonly found in fire control radars. Other types of displays can be used for range, angle, or height, depending on the radar and its function.

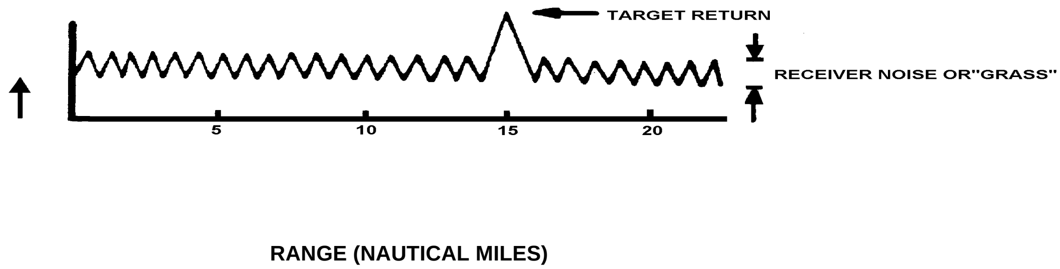

Figure 12: "A"-Scope Display

8. Operating Modes

Search is the operating mode in which the radar is looking for something. Acquisition (detection) is when a return is received from a target. Tracking is when the radar is actually following the target, either mechanically or electronically, usually automatically, keeping the target centered in some sort of electronic box, like a window, peep hole, or as the electronic people refer to it, a "gate". Tracking is also referred to as "lock-on". This mode of operation is usually found only in weapon control radars.

9. Gates

Tracking radars use electronic means to confine the radar's interest to a specific return. A radar can establish a range gate, an angle gate, or a velocity gate. This means that when the target moves enough to approach the edge of such a gate, the radar will move its antenna to keep the target centered in the gate (see Figure 13). This is the essence of tracking.

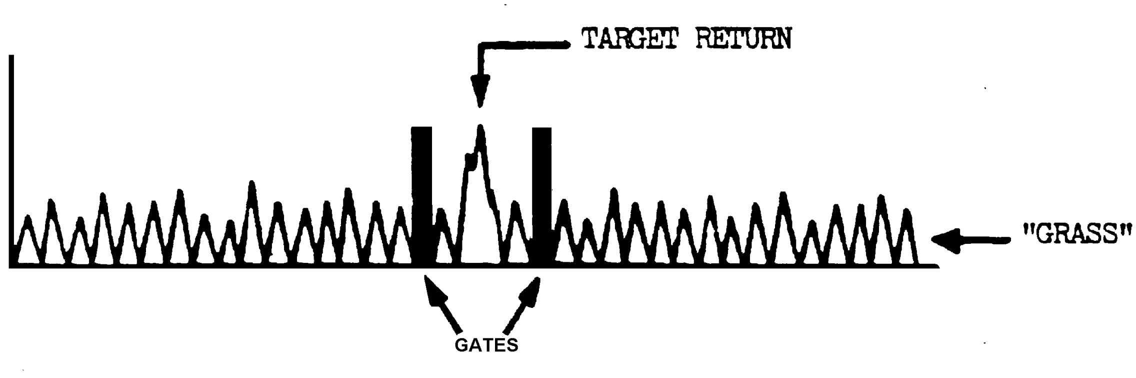

Figure 13: Gates

10. Radar Cross-Section

The radar cross section (RCS) is a measure of the reflectivity of a body to a radar signal of a particular frequency, expressed in square meters. It is not a physical area, although there is a loose correlation between size and RCS. RCS is influenced by frequency, geometry, and aspect. For example, a flat plate will probably have a higher reflectivity, and thus a higher RCS than a sphere of equal physical cross section. Similarly, an object, say an airplane, viewed head on may have a smaller RCS than the same object viewed broadside. Finally, an object will most likely have a different RCS when illuminated at one frequency than it will when illuminated with a different frequency.

11. Probability of Detection

Radar detection is probabilistic in nature, and a probability of detection (Pd) can be estimated or measured for a wide variety of conditions. When a handbook or other source says a radar has a detection range of x miles, it usually means the maximum range at which the probability of detection of a 1-square-meter target is 90% when illuminated with radar energy at a given frequency.

12. Clutter

Clutter is the myriad of spurious and transient returns that occur naturally because of receiver noise, or if the radar is looking down or scanning across a high sea state (Figure 14). It is much like "snow" on a TV screen. The less clutter the better, as it is confusing at best and can mask real targets. Some means is needed to distinguish real targets from clutter. Read on.

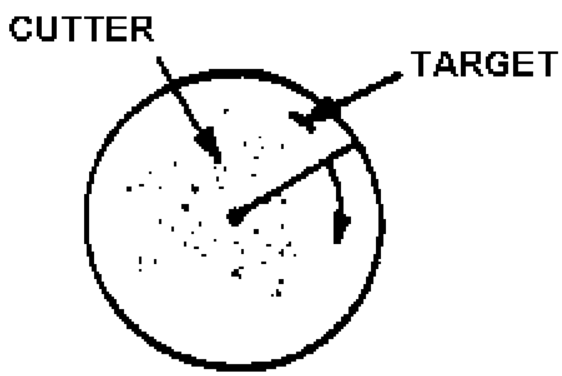

Figure 14: PPI Scope with Clutter

13. Signal Processing

Once a return reaches the radar, it can be processed to display the information relevant to the radar's function, and to eliminate extraneous data such as clutter. A few of these techniques are discussed on the following page.

14. Moving Target Indication

An excellent example is the signal processing technique to eliminate all stationary targets called MTI, or moving target indication. This is done simply by comparing one return with the previous one at that position. If there was a return previously, the return is from a stationary object and is not displayed. If no previous return exists, the object has moved and thus will be displayed.

15. Doppler

Another way of isolating moving target returns, and obtaining velocity information as well, is by making use of the Doppler effect. Almost everyone has experienced, either personally or in a movie, the change in sound as a speeding train passes a fixed point. This is known as the Doppler effect. It arises because as an object emitting a sound moves toward you, its velocity is added to the speed of the sound waves, while that speed is subtracted when the object is moving away from you (see Figure 15).

It is easy to see that by detecting this frequency change, a radar can not only detect a moving target, but also determine its velocity by measuring the frequency change received.

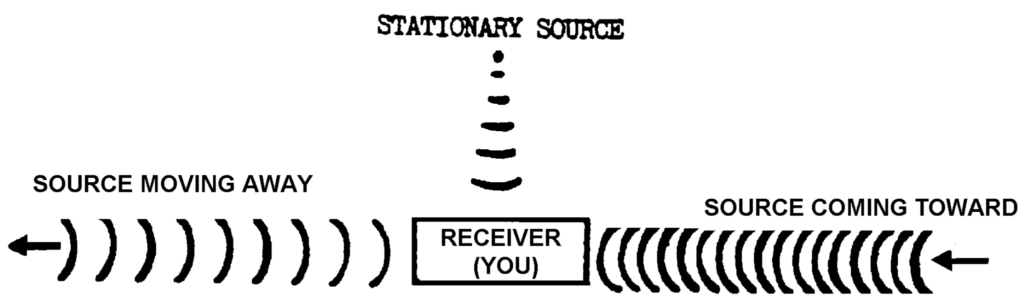

Figure 15: The Doppler Principle

16. Monopulse

Monopulse is a signal processing technique using multiple antennae that can obtain position information on a target from a single return. This is accomplished by examining a combination of the sums and differences in the signals from different pairs of antennas. The monopulse technique is very resistant to electronic attack (EA).

17. AGC

AGC stands for automatic gain control, and is a means of preventing the return from getting too powerful as the range decreases or the signal gets stronger. Without this feature, the return would eventually obliterate the display or "drown" the radar. This feature will figure prominently in the discussion of EA later.

18. Power Density

An important concept in electronic warfare, especially jamming, is power density. This term is merely a way of describing signal strength over a given area. Signal strength decreases as the square of the distance from the source. As the signal is broadcast in a beam, the power of the signal is distributed across a progressively larger area (Figure 16).

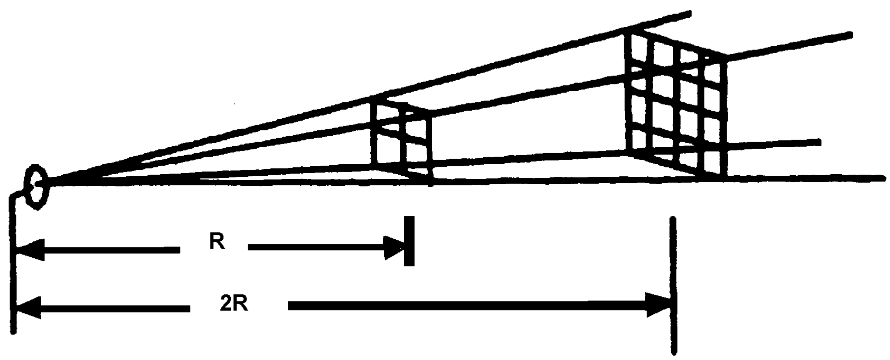

Figure 16: Power Density Versus Range

19. CW Radar

As mentioned earlier, there are types of radar other than the simple pulsed type. There are CW radars, where the transmitted signal is continuous with the receiver well isolated from the transmitted signal. Using a predetermined sequence of frequencies instead of pulses, the radar can then process the return just as if it were a pulse. Doppler processing can be combined with this to produce even more information. It is easy to see that we may also have CW and pulse Doppler radars as well as the simpler type.

D. GUIDANCE TYPES

Since much of electronic warfare is directed at missiles, we must discuss some basic types of missile guidance.

1. Beam Rider

One of the earliest types was where the radar from the firing ship kept the target within its beam, usually a pencil beam. The missile simply listened with its receiver to the radar signal and flew to stay within the beam. This type of guidance is inherently inaccurate because of the divergent beam shape.

2. Command Guidance

In this form of guidance, the target is tracked by the radar on the firing platform; using the information, the missile is actually flown to that point by remote radio signals known as a command link (or up-link, as some call it). It is also common in this type of guidance for the missile to broadcast a beacon signal to make it easier for the operator to bring missile and target together. This is referred to as a down-link.

3. Semiactive Guidance

Semiactive guidance is where the radar transmitter remains with the firing unit, while a receiver in the missile is pointed forward and receives the reflections from the target.

4. Active Guidance

Active guidance is the logical extension of semiactive, wherein the missile carries its own radar transmitter and receiver, and tracks the target entirely with onboard resources.

5. Passive Guidance

Passive guidance is that requiring no transmission or radiation from the firing unit or missile, but homes on some signal produced by the target, such as infrared radiation, RF radiation, visual means, etc.. The only one relevant to electronic warfare at our level of interest is antiradiation guidance. In this technique, the missile guides on the radiation produced by the target, such as a ship's radar.

BASIC EW CONCEPTS

The three basic divisions of Electronic Warfare are Electronic Warfare Support (ES), Electronic Attack (EA), and Electronic Protection (EP). Each area will be discussed briefly.

A. ELECTRONIC WARFARE SUPPORT (ES)

Collection of radar signal parameters (frequency, PRF, PW, etc.) called SIGINT, or signal intelligence, provides the battlefield commander with current EOB (electronic order of battle). ES provides radar type and information to activities engaged in other EW functions, that is EA and EP. Because SAMs and AAA are extremely mobile, ES aircraft are very important in providing updated EOB information that influences tactical decisions. Accuracy of threat radar site location depends on direction finding (DF) capabilities of equipment, operator proficiency, and accurate navigation.

B. ELECTRONIC ATTACK (EA)

If you have understood the previous section, you already have a better grasp of radar than some engineers, many analysts, and most managers. But our subject is really electronic warfare, which is the tactical employment of radar and the various countermeasures that can be employed against it.

EA is action taken to prevent or reduce the enemy's effective use of the electromagnetic spectrum.

The following are five EA concepts used by attacking forces from low threat to high threat.

a. Ignore

b. Avoid

c. Dilute - False Information (Deception and Decoys)

d. Degrade - Jamming

e. Destroy - Damage Sensors and Weapons

1. Passive EA

. EMCON. Passive EA describes those forms of countermeasures which do not involve radiation of a signal. EMCON (emission control) is the management of one's own radiations to minimize the advantage or information given to the enemy. Note that it does not necessarily mean electronic silence, although it is often implemented this way and more often interpreted that way, whether correct or not.

b. Chaff. The most prevalent example of passive EA is chaff. Chaff was first used operationally by the British (who called it "window") in World War II. It consisted of strips of tinfoil which were dropped out of aircraft. The RF reflective strips, especially when cut to a specific length matched to the wavelength of the radar being countered, acted as hundreds or thousands of small antennae and provided so many return echoes to the radar that the reflections obscured large portions of the German radar scopes, thus hiding the real targets. Chaff has now evolved to more sophisticated and complex forms, fall rates, means of dispensing, and effectiveness, but the basic principle remains the same. Chaff can be used for concealment, deception (false target), or self-defense (put out a chaff cloud for the missile to track on). Composition is glass or fibers with a thin metal film on the surface making it fall at a slower rate than all metal chaff. To be effective, the length should be a multiple of one wavelength of the radar signal. Chaff is frequency and orientation sensitive with the strongest reradiated energy obtained when broadside.

Since chaff is small, large quantities can be packaged in a small volume. It is cut to different lengths to be effective against radars of widely different frequencies and has omnidirectional coverage.

Several bundles dropped in a self protection mode create a larger echo than the aircraft and radar tends to lock on the chaff rather than the aircraft. Problems with chaff include target credibility in breadth, width and intensity. Target motion is another problem. With chaff becoming stationary immediately after dispensing, radar systems with MTI (moving target indicator) or CW eliminate chaff altogether.

c. <u>Reflectors</u>. Sometimes it is desirable to make an enemy think there is a target where there is, in fact, nothing. A passive means for accomplishing this is a radar reflector. It is merely a metal box that is very reflective to a radar signal (radar signals are reflected most efficiently by inside corners, and in fact these devices are often called corner reflectors). These reflectors are used in a more benign sense when placed on hills, towers, etc., to provide more visible points of navigation.

2. Active EA

a. <u>Noise Jamming</u>. There are, in general, two types of jamming: noise jamming and deceptive jamming. Noise jamming is basically very simple. The jammer merely transmits continuously at the operating frequency of the victim radar so that the real target return is simply drowned out. If our mythical cliff-seeker was unfortunate enough to have his teenage son playing acid rock music next to him while he was trying to locate the cliff, the effect would be similar. The echo is still there, but it is lost in the louder noise source. The only real differences here are that jamming is done at the same frequency at which the radar is listening, and that radar jamming is not nearly as unpleasant to listen to as acid rock music. Apologies to Black Sabbath and Iron Maiden.

Noise jamming is sometimes referred to as "spot" or "barrage". This merely refers to the frequency coverage of the jamming. If all the jamming is concentrated in a narrow frequency band, say 10 MHz, it is referred to as spot or narrow-band jamming. If, on the other hand, the jamming is spread across a much larger portion of the frequency spectrum, it is referred to as "barrage" or wide-band jamming.

An important aspect of electronic warfare is embodied in these two descriptions, and that is that you generally do not have enough power to jam everything effectively. Obviously, one would prefer to jam the entire band in which a victim radar could operate, but the jamming power is so spread out that it becomes less effective. The spot jamming is generally much more effective over the selected range, but leaves the remainder of the band unaffected. An excellent way to visualize barrage and spot jamming is a garden hose with a nozzle. The wide spray setting, where the force of the water is spread over a wide area, is analogous to barrage jamming. With the nozzle set for a solid stream, the force is concentrated in a narrow area and is analogous to spot jamming. In both cases, the amount of water leaving the hose is the same, and is analogous to jammer power. The strength of the jamming signal is measured in watts/MHz.

b. Deception Jamming. Deception jamming is a complex business, and as such, will not receive detailed treatment here. We will examine a few very basic techniques to give the reader some idea of how these techniques are implemented. The coverage will not be exhaustive, or even complete, merely representative. The reader may wish to consult more detailed references for a more complete list of such terms so that he will be able to recognize them. There are two basic forms of deception jamming: track break and false target. There are several variations to these two basic forms.

(1) Blip Enhancers. The simplest form of deceptive jamming is the blip enhancer. These devices are merely active reflectors or "repeaters" intended to make the radar return appear larger to the victim radar than it really is. Some are merely reflectors, metallic corners that efficiently reflect a signal. They are entirely passive and radiate no signal. Others are responsive and active. Some reradiate on a different frequency and are called "transponders". Blip enhancers are used to make small targets look larger so the enemy cannot determine from his scope picture which are the larger (and generally more valuable) targets.

(2) Range Gate Pull-Off (RGPO). RGPO depends, as do many other EA techniques, on manipulating the radar's AGC circuit. The targets EA device receives the pulse from the radar to be victimized, and repeats it back at a greater strength than received. This is repeated at progressively higher levels of energy. At the victim radar, the AGC circuit is responding by turning its receiver sensitivity down - in effect, saying "That's too loud, I'll turn it down". Once the AGC has turned down the receiver so far that the real radar return from the target is lost in the receiver noise, the repeated pulses (the spurious ones) are then progressively delayed or advanced until the gate, which is now tracking the false returns, is "walked off" the real return. Once track has been broken, the target EA device may stop transmitting the false pulses, and the victim radar now has nothing in its range gate to track. Thus, it must go back into search mode and establish tracking all over again. RGPO is basically a technique to cost the enemy time. It cannot be employed profitably by itself especially against missiles, because the deception usually makes the victim radar think the target is at a different range than it really is. Thus, in some cases, even if the victim missile is totally deceived, it still may fly through the target on its way to where it thinks the target is located, and the target is as effectively hit as if no EA has been employed at all. So

RGPO is a delaying tactic and should be employed in conjunction with some other technique such as angle deception.

(3) Sweep Jammers. Sweep jammers are narrow band or spot transmitters that are swept through a larger frequency range. The advantage of sweep jamming over spot is that power is concentrated in a narrow band covering multiple radar frequencies.

(4) False Target Generators. False target generators are used against Track While Scan (TWS) radars, usually search radars. Multiple targets are generated to saturate the system and hide the true aircraft. Limits on this technique are that false targets are generated on aircraft azimuth only and at ranges equal to or greater than the aircraft. Another limit is that false targets must appear the same as the aircraft return in length, width, and intensity.

(5) Directed Energy. Utilization of weapons such as lasers, RF weapons, or particle beams for the purpose of degrading , neutralizing, or destroying energy combat power.

C. ELECTRONIC PROTECTION (EP)

EP is reducing the effectiveness of an EW threat by making the cost of EA prohibitive for the enemy. EP includes both radar design and operator training. To build and use EP effectively, up to date intelligence on the EA threat needs to be known.

1. Burn-Through

   Burn-through is not an EP technique, but rather an effect - a phenomena that creates an EP condition. It is almost axiomatic that airborne jammers have less power available to them than the surface radars they are trying to jam. This leads to an event known as burn-through. This occurs when the return from the target is stronger than the jamming signal, usually because the range has decreased. Since signal strength decreases with the square of the distance, the weaker jammer can overpower the return of a more powerful victim radar if the distance is great enough. The victim radar's signal suffers R^2 power loss each way (to the target and back to radar) for R4 power loss total, while the jammer signal only travels one way for R^2 power loss total. But as range decreases, the greater power of the radar allows a strong return that overpowers the jammer signal. The electronic people express this as a jamming-to-signal ratio, the signal in this case meaning the reflected signal. Thus if the J/S ratio is great enough, the jamming is effective; if not, the signal will be heard. Burn-through range cannot be accurately predicted or calculated until the characteristics and power of a specific jammer, the radar to be jammed, and the RCS of the target are given.

2. There are many variables that dilute jamming effectiveness to include atmospheric attenuation, tropospheric scatter and other temperature/weather factors that are unpredictable.

3. Radar design is broken down into three areas: radar parameters, signal processing and design philosophy.

a. Radar Parameters. Power, frequency, PRF, pulse width, antenna gain, polarization, and antenna scan are fixed by design and cannot be altered without a major change to the radar. Therefore, EP capabilities are often decided in the early design phase.

(1) Power is the fundamental EP parameter for ground radars which have an advantage over airborne jammers which are limited because of size. The power battle occurs between jammer output and the radar reflected energy from the target aircraft. Two EP techniques dealing with reflected energy are pulse compression and pulse coding. Energy is increased by lengthening the pulse width and filtering the return energy to maintain good range resolution.

(2) Frequency is an EP feature when it is shifted rapidly and automatically to avoid channels being jammed (frequency agility). Another EP frequency technique is CHIRP, which is varying the frequency during a pulse. This adds more power and helps distinguish the target echo from jamming.

Doppler shift is another frequency technique that uses a shift in a very stable frequency, transmitted and received. A shift in frequency indicates target movement towards or away from the radar.

(3) PRF (Pulse Repetition Frequency). False target jamming - the EA platform receives a pulse from a victim radar. A duplicate of this pulse is sent back to the victim radar at regular intervals filling the listening time or PRI. The victim scope is now filled with many false returns as well as the real target.

EP to defeat false target jamming is to stagger the PRF which will cause the ranges of false targets to vary from scan to scan. This causes real targets to stand out from the shifting false targets.

Jittered PRF is similar to staggered PRF causing the same shifting effect of false targets. It is done by randomly sending back a series of pulses to the victim radar. A disadvantage to jittered PRF is that MTI cannot be used.

(4) Pulse width discrimination (PWD) is an EP technique that discards received pulses that do not have the same PW (pulse width) as transmitted. The radar can be programmed to blank pulse widths that are shorter, longer, or both. This blanking, in some instances, can cause loss of a valid target as well.

(5) Antenna design is best as an EP fix when it limits side lobes to a minimum. Those radars with extensive side lobes are vulnerable to jamming from many azimuths, not just the main beam. Side lobes also make radars more vulnerable to anti-radiation missiles.

(6) Antenna polarization is an EP technique that greatly reduces jamming effectiveness if the victim radar has different polarization than the EA platform. The best polarization feature is a radar than can switch polarization. This capability is required for best discrimination with an aspect change of the aircraft and to reduce the affects of jamming, i.e., circular polarization is used by air traffic controllers to discriminate against rain.

(7) Scan pattern determines the amount of energy directed at targets, i.e., height finders are more EA resistant than search radars because its sector scan illuminates an aircraft more frequently. A phased array is even more EA resistant because it rapidly scans in an irregular pattern.

Passive detection and home-on-jam techniques do not transmit, but use EA to determine the jammer's location via triangulation.

b. Processor Design

Signal processing can serve as EP by making the receiver bandwidth match as closely as possible the transmitted frequency. This reduces the amount of barrage jamming or causes narrow spot jammers to be more precise with set ones. Use of long radar pulses provides even more EA resistance as well as increasing energy per pulse.

c. Design Philosophy

As a rule of thumb, EP design is to use unpredictable operating parameters. Jamming becomes more difficult if the victim radar is constantly changing. The most common way of introducing unpredictability is frequency diversity. New radar systems are built so that different radars operate in different bands (A to K) forcing EA operators to cover the entire spectrum. Even with automatic processing of new equipment, a skilled operator is still the most important counter-countermeasure in the presence of deliberate and clever countermeasures.

4. Radar Netting

A single isolated radar rarely exists. There are usually two or three radars feeding information for command and control. Combinations of several radars netted together provide frequency diversity, and spatial separation which dilutes jamming and increases EA operator workload to maintain jammer alignment.

D. ELECTRO-OPTICAL COUNTERMEASURES

Increasing use of EO (electro-optical) systems for target acquisition, fire control, and weapons guidance has necessitated countermeasure development. These countermeasures are optical or infrared.

1. IR Countermeasures

   a. Passive Countermeasures - Engine suppression, IR cross section reduction, IR signature reduction.

      Reducing speed reduces IR signature from the rear quarter of subsonic aircraft. Supersonic aircraft coming out of burner will reduce IR signature greatly not only from the exhaust area, but the aircraft skin as well. Reducing the radiation level is possible in this manner, but it is not tactically sound to slow down in a hostile environment. A more feasible approach is shielding engine exhaust or using by-pass engines. Afterburner engines are still not effectively shielded. Increasing condensation trails or emitting smoke diffuses IR radiation, but increases visual detectability.

   b. Active Countermeasures - Similar to radar jamming by exploiting the electromagnetic spectrum by masking or angular deception.

      Flares counter IR missiles and IR tracking systems. When used properly, flares cause the IR missile to track the false target, allowing the target aircraft to fly out of the seeker's field of view (FOV). Decoys towed behind the aircraft have the same effect. Flying in and out of clouds is also an effective countermeasure.

      IRCM employs a powerful IR source such as a lamp on the aircraft tail, which if blinked at the proper rate, causes angular deception in the missile. The advantage to this method is that supplies do not run out. Maneuvers to evade the seeker FOV by placing it in the sun or terrain masking can also defeat the IR system.

E. OPTICAL COUNTERMEASURES

Optical countermeasures deal with the visual spectrum and countertactics must be directed at the man operating the threat. Because optical systems are passive, their presence is extremely difficult to detect. Effectiveness of countermeasures is usually unknown. The following countermeasures are used against optics:

1. Natural factors such as clouds, rain, smoke, haze, and terrain are effective against optics. Smoke bombs have been successfully used at low altitude to screen aircraft.

2. Electronic jamming is effective against TV optics similar to interference on household TV's. Jamming is not effective against pure optics.

3. Some EO contrast devices are light sensitive and are defeated by high intensity lamps and flashing lights.

4. Aircraft maneuvers can defeat optics by moving out of the seekers FOV or taking the seeker directly into the sun.

F. LASER COUNTERMEASURES

Laser countermeasures include absorptive filters, ablative coatings to protect against high power laser weapons, broadband optical noise against laser communication, home-on-laser missiles, absorptive and non-reflective coatings, laser repeaters, optical decoys and chaff, and atmospheric seeding with laser absorptive materials.

AN OPERATIONAL SCENARIO

Let's follow a hypothetical and very simplified scenario to illustrate some of the aspects of electronic warfare that have been discussed. We will assume that a force of ten Orange tactical bombers and supporting electronic warfare aircraft are enroute to attack a Blue surface force, which includes one aircraft carrier, in a night attack. The Blue force is aware that it is in a battle zone and expects to be attacked, and it has a long range search radar (B-band, vertical fan beam in circular scan) radiating. Orange passively detects this radar well beyond Blue's detection range and homes in on it. Orange chaff-laying aircraft drop a corridor of chaff for the bombers to fly in and remain hidden. Blue sees the chaff layers and turns on the blip enhancers on all ships so that the carrier cannot be identified from blip size. Blue switches to MTI (moving target indication) mode and sees the raid through the chaff. Interceptors are launched from the Blue carrier. Orange jams the long range search radar with its standoff jammers. Blue switches frequency, staying in the MTI mode and reports the position of this raid to the force's air defense system. The target acquisition radars (an E-band radar with a vertical fan beam in sector scan and an D-band height-finder with a horizontal fan beam in noding sector scan) track the bombers and direct ("vector") the interceptors to the bombers. Four bombers are shot down. The target acquisition radars continue to track the raid, changing frequency as required to minimize the effects of the jamming. As the raid closes in, the fire control system - a lobed H-band radar - engages the strike. Burn-through occurs as the range closes. The missile control radar illuminating the bombers fires semiactive surface-to-air missiles at the raid and destroys three bombers. The remaining bombers attack a destroyer which they believe to be the carrier because of his blip enhancer and his central position in the force. The destroyer successfully decoys two bombers using RGPO and angle deception, but a third hits the destroyer and sinks it. The bombers retire, tracked by the air defense radar which vectors fresh interceptors to the bombers and one more is shot down. The two surviving bombers rendezvous with the standoff jammers and return to base. The long-range search radar resumes its vigil.

CONCLUSION

At this point, electronic warfare becomes increasingly complex. The combinations of the principles and techniques become numerous and confusing, and often require technical training to understand. But if you have understood the preceding pages, you will at least understand some of the terminology and some of the principles involved. If that fails, either look owlishly wise and nod a lot, or plead an imminent meeting or an upset stomach and exit the area. Good Luck!

APPENDIX A
SUPPLEMENTAL DATA

TABLE A-1: Common Prefixes

1/1000 - milli	(m)
1/100 – centi	(c)
1/10 – deci	(d)
X1000 – kilo	(k)
X1,000,000-mega	(M)
X1,000,000,000 –giga	(G)

TABLE A-2: RF Spectrum

Frequency Band	Frequency
Very low (VLF)	3-30 kHz
Low (LF)	30-300 kHz
Medium (MF)	300-3000kHz
High (HF)	3-30 MHz
Very High (VHF)	30-300 MHz
Ultra High (UHF)	0.3-3 GHz
Super High (SHF)	3-30 GHz
Extremely High (EHF)	30-300 GHz

TABLE A-3: EW Frequency Band

Band	Frequency, MHz
A	0-250
B	250-500
C	500-1000
D	1,000-2,000
E	2,000-3,000
F	3,000-4,000
G	4,000-6,000
H	6,000-8,000
I	8,000-10,000
J	10,000-20,000
K	20,000-40,000
L	40,000-60,000
M	60,000-100,000

TABLE A-4: Radar Frequency Bands

Band	Frequency
L	1,000-2,000 MHz
S	2,000-4,000 MHz
C	4,000-8,000 MHz
X	8,000-12,000 MHz
K_u	12.0-18 GHz
K	18-27 GHz
K_a	27-40 GHz
mm	40-300 GHz

A few equations:

The relationship between frequency (f) and wavelength (\wvlgth) is described by the equation:

F = c^

where

c is the speed of light
^ is the wavelength in corresponding units

Maximum detection range is expressed as:

$$RD_{max} = \frac{PRI \times c}{2}$$

and minimum detection range is expressed as:

$$RD_{min} = \frac{PW}{2} \times c$$ which also describes range resolution

REVIEW

1. State the three divisions of Electronic Warfare (EW).

    a.

    b.

    c.

2. Define:

    a. Frequency

    b. Modulation

    c. Wavelength

    d. Frequency Band

    e. Band Width

    f. Channel

3. Define:

    a. Pulse Width (PW)

    b. Pulse Width Frequency (PRF)

    c. Pulse Repetition Interval (PRI)

4. In general, radars with low frequency have (longer, shorter) range than those with high frequency.

5. What radar beam feature determines angular resolution?

6. T or F. Radar cross section of an aircraft is dependent solely on size.

7. Define ES.

8. Define EA.

9. What are the 2 classes of EA?

    a.

    b.

10. What are the two forms of noise jamming?

    a.

    b.

11. What are the two forms of decpetion jamming?

    a.

    b.

12. Define Electronic Protection (EP).

13. Define burn-through range.

14. Describe how these radar parameters are changed to be used as EP techniques.

    a. Power

    b. Frequency

    c. PRF

    d. Pulse Width

    e. Antenna Design

    f. Antenna Polarization

    g. Scan Pattern

15. State two types of IR countermeasures.

    a.

    b.

ANSWERS

1. State the three divisions of Electronic Warfare (EW).

   a. ES

   b. EA

   c. EP

2. Define:

a. Frequency -	the number of times per second that RF energy completes one cycle.
b. Modulation -	change or variation in transmitted signal. Two types; frequency modulation (FM) and amplitude modulation (AM).
c. Wavelength -	measure of physical distance from one end of a complete cycle to the other expressed in meters.
d. Frequency Band -	an operating range of frequency capable of being tuned.
e. Band Width -	the frequency spread of a band expressed in Hz (Hertz).
f. Channel -	a term that designates a subset of the operating band (same as TV channel).

3. Define:

a. Pulse Width (PW) -	the amount of time the radar transmits in microseconds (usec).
b. Pulse Repetition Frequency (PRF) -	the frequency with which the pulses are transmitted expressed as frequency.
c. Pulse Repetition Interval (PRI) -	time between pulse expressed in microseconds.

4. In general, radars with low frequency have (**<u>longer</u>**, shorter) range than those with high frequency.

5. What radar beam feature determines angular resolution?

   Beam Width

6. T or F. Radar cross section of an aircraft is not dependent solely on size.

7. Define ES

Collection of radar signal parameters (Freq, PRF, PW, etc.,) called SIGINT, to provide current Electronic Order of Battle.

8. Define EA

   Action taken to prevent or reduce the enemy's effective use of the electromagnetic spectrum.

9. What are the 2 classes of EA?

   a. Active

   b. Passive

10. What are the two forms of noise jamming?

    a. Spot

    b. Barrage

11. What are the two forms of deception jamming?

    a. Track break

    b. False target

12. Define Electronic Protection(EP).

    EP is reducing effectiveness of an EW threat by making the cost prohibitive. Done by radar design and operator training.

13. Define burn-through range.

    When the return from a target is stronger than the jamming signal, usually because range has decreased.

14. Describe how these radar parameters are changed to be used as EP techniques.

    a. Power - because ground based radars are not limited by size, as aircraft jammers are, the power advantage is with ground based systems. Pulse compression and pulse coding also increase power out.

    b. Frequency - frequency agility is rapidly and automatically shifting to avoid channels being jammed. Doppler shift is another frequency EP technique that indicates target movement towards or away.

    c. PRF - jitter or stagger PRF causes shifting of false target jamming causing the real target to stand out from shifting false targets.

    d. Pulse Width - pulse width discrimination discards pulses that do not have the same pulse width as transmitted.

e. Antenna Design - EP fix when side and back lobes which are vulnerable to jamming are reduced to a minimum.

f. Antenna Polarization - switching victim radar polarity reduces the effects of jamming greatly.

g. Scan Pattern - determines the amount of energy directed at a target. More energy directed at a target increases the probability of detection and is EA resistant.

15. State two types include engine of IR countermeasures.

a. Passive to include engine suppression, IR cross section reductions, IR signature reduction.

b. Active countermeasures to include flares or other powerful IR sources.