Air Warfare Centre
Joint Electronic Warfare Operational Support Unit

EW Key Concepts

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Course Textbook

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COURSE OVERVIEW

The Electronic Warfare Key Concepts Course (EWKCC) is designed to provide a basic understanding of Electronic Warfare (EW) at an introductory level, by providing an overview of the fundamentals of EW, Electronic Protection (EP), Electronic Surveillance (ES), Electro Optics (EO), Radar, Weapon Guidance and ADF EW platforms and equipment**.**

The EW Key Concepts Course is provided by JEWOSU. The course can be run at the RESTRICTED or SECRET level, at JEWOSU or externally.

POC for the EWKCC is the JEWOSU EW Training Officer (08) 7389 2832 or at jewosu**.**training@defence.gov.au

JEWOSU

Our Mission
To optimise ADF warfighter effectiveness in an integrated EW environment.

This includes:

- Electronic Warfare (EW) Software Development
- Provision of Expert EW Advice
- Provision of EW Training Services
- Provision of EW Data or data related services

JEWOSU is the ADF centre of expertise for Electronic Warfare. Providing:

- RWR and ESM reprogramming
- RF Jammers reprogramming
- Countermeasures development and trials
- EW threat data research and analysis

JEWOSU - Excellence in Electronic Warfare Operational Support

EW KEY CONCEPTS
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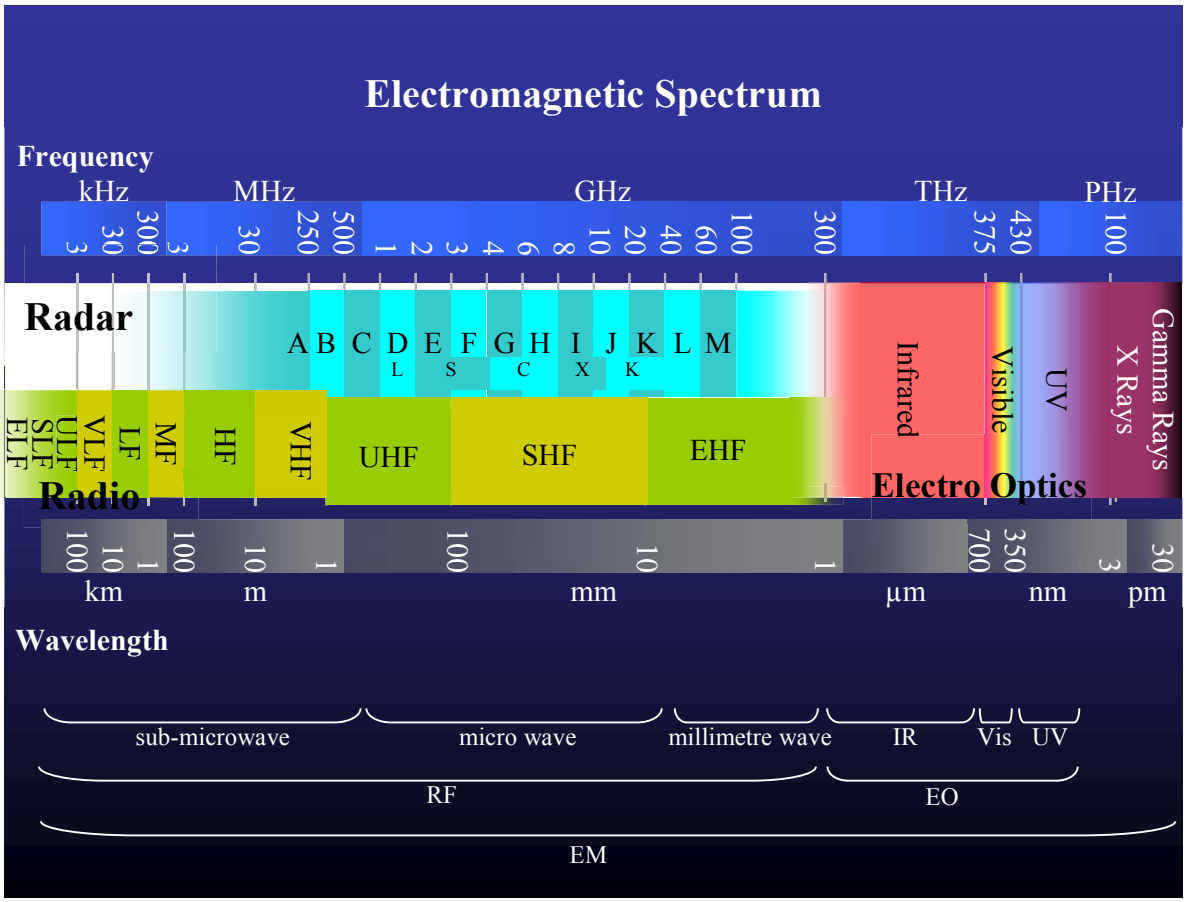
PRELIMINARY PAGES

THE EW SPECTRUM



Units

Hz Hertz (cycles per second)

P	peta	1,000,000,000,000,000	
T	tera	1,000,000,000,000	
G	giga	1,000,000,000	
M	mega	1,000,000	
k	kilo	1,000	
m	milli	1/ 1,000	(0.001)
µ	micro	1/ 1,000,000	(0.000001)
n	nano	1/ 1,000,000,000	(0.000000001)
p	pico	1/ 1,000,000,000,000	(0.000000000001)

GLOSSARY

AAA	Anti-Air Artillery
AAGW	Air to Air Guided Weapons
AAM	Air to Air Missile
ACBS	Automatic Continuous Broadcast System (see IFF)
ADDP	Australian Defence Doctrine Publication
AI	Area of Interest (or Airborne Intercept)
AM	Amplitude Modulation
AO	Area of Operation
AOA	Angle Of Arrival
AOB	Angle Off Boresight
AOT	Angle Only Track
ARM	Anti-Radiation Missile
AS	Air Search (Radar)
ASGW	Air to Surface Guided Weapon
ASM	Air to Surface Missile
BI	Beacon Indicator
BW	Bandwidth
CDM	Code Division Multiplexing
CLOS	Command to Line of Sight
CMDS	Counter Measures Dispensing System
COLOS	Command Off Line Of Sight
COMINT	Communications Intelligence
COSRO	Conical Scan on Receive Only
CPRA	Controlled Radiation Pattern Antenna
CW	Continuous Wave
DC	Duty Cycle
DIRCM	Directional Infra-Red Counter Measures
EA	Electronic Attack
ECM	Electronic Counter Measures (Now EA)
ECCM	Electronic Counter-Counter Measures (Now EP)
ELINT	Electronic Intelligence
EM	Electro-Magnetic (Radiation)
EMCON	Emissions Control
EO	Electro-Optic
EOCM	Electro-optic Counter Measures
EP	Electronic Protection (Formerly ECCM)
ERP	Effective Radiated Power
ES	Electronic Support
ESM	Electronic Surveillance Measures
EW	Electronic Warfare
	Early Warning (Radar)
EWO	Electronic Warfare Officer
FAR	False Alarm Rate
FCR	Fire Control Radar
FDM	Frequency Division Multiplexing
FM	Frequency Modulation
FM-CW	Frequency Modulated Continuous Wave
FMOP	Frequency Modulation on Pulse
FOV	Field of View
GCI	Ground Controlled Intercept
GPS	Global Positioning System
HF	High Frequency
Hz	Hertz (cycles per second)
IFF	Identification Friend or Foe (being replaced by ACBS)
INS	Inertial Navigation System
IR	Infrared
IRCM	Infrared Counter Measures
ISAR	Inverse Synthetic Aperture Radar
JEM	Jet Engine Modulation
JRE	(TADIL) J Range Extension
LED	Light Emitting Diode
LHC	Left Hand Circular (Polarisation)
LORO	Lobe On Receive Only
LOS	Line Of Sight
LOSBR	Line of Sight Beam Riding
LPI	Low Probability Of Intercept
LRR	Long Range Radar
LWR	Laser Warning Receiver
MAWS	Missile Approach Warning System
MG	Missile Guidance
MTI	Moving Target Indicator
MTV	Magnesium Teflon Viton (Flare Ingredient)
MUD	Maximum Unambiguous Doppler
MUR	Maximum Unambiguous Range
NCS	Net Control Station
NCTR	Non Cooperative Target Recognition
OTHR	Over the Horizon Radar
PA	Pulse Amplitude
PAR	Precision Approach Radar
PD	Pulse Doppler
PFM	Pre Flight Message
PMOP	Phase Modulation on Pulse
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PW	Pulse Width
RAM	Radar Absorbing Material
RCS	Radar Cross Section
RF	Radio Frequency
RGPO	Range Gate Pull Off
RGPI	Range Gate Pull In
RHC	Right Hand Circular (Polarisation)
RRC	Radar Resolution Cell
RWR	Radar Warning Receiver
SAG	Seeker Assisted Guidance (formerly TVM)
SAGW	Surface to Air Guided Weapon
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SEAD	Suppression of Enemy Air Defence
SIGINT	Signals Intelligence
SNR	Signal to Noise Ratio
SPECOPS	Special Operations
SSGW	Surface to Surface Guided Weapon
SSM	Surface to Surface Missile
TA	Target Acquisition (Radar)
TADIL	Tactical Digital Information Link
TDM	Time Division Multiplexing
TI	Target Illuminator
TOA	Time Of Arrival
TRD	Towed Radar Decoy
TTR	Target Tracking Radar
TVM	Track Via Missile (now SAG)
TWS	Track While Scan
UAV	Unmanned Airborne Vehicle
UDF	User Data File
UHF	Ultra High Frequency
UV	Ultraviolet
VGPO	Velocity Gate Pull Off
VHF	Very High Frequency

MISSILE AND ELECTRONIC EQUIPMENT DESIGNATIONS

Missiles are designated with three letters from the columns below plus a number (i.e. AIM-7M) Suffixes (M in this case) indicate a modification.

First Letter Launch Environment	**Second Letter** Mission Symbols	**Third Letter** Vehicle Type
A Air B Multiple C Coffin H Silo stored L Silo launched M Mobile P Soft Pad R Ship U Underwater	D Decoy E Special electronic G Surface attack I Intercept, aerial Q Drone T Training U Underwater attack W Weather	M Guided Missile N Probe (non-orbital instruments) R Rocket (without installed or remote control guidance)

U.S. military electronic equipment is assigned an identifying alphanumeric designation that is used to uniquely identify it. This system is commonly called the "AN" designation system, although its formal name is the Joint Electronics Type Designation System (JETDS). The letters AN preceding the equipment indicators formerly meant "Army/Navy," but now are a letter set that can only be used to indicate formally designated DOD equipment. The first three letters following the "AN/" indicate Platform Installation, Equipment Type, and Equipment Function, respectively. The appropriate meaning is selected from the lists below. The letters following the AN designation numbers provide added information about equipment. Suffixes (A, B, C, etc.) indicate a modification. The letter (V) indicates that variable configurations are available. The letter (X) indicates a development status. A parenthesis ( ) without a number within it indicates a generic system that has not yet received a formal designation, e.g., AN/ALQ( ). Quite often the () is pronounced "bow legs" since they look like the shape of cowboy legs.

First Letter Platform Installation	**Second Letter** Equipment Type	**Third Letter** Function or Purpose
A Piloted aircraft B Underwater mobile, submarine D Pilotless carrier F Fixed ground G General ground use K Amphibious M Mobile (ground) P Portable S Water T Ground, transportable U General utility V Vehicular (ground) W Water surface and underwater combination Z Piloted-pilotless airborne vehicle combination	A Invisible light, heat radiation C Carrier D Radiac F Photographic G Telegraph or teletype I Interphone and public address J Electromechanical or inertial wire covered K Telemetering L Countermeasures M Meteorological N Sound in air P Radar Q Sonar and underwater sound R Radio S Special or combinations of types T Telephone (wire) V Visual and visible light W Armament X Facsimile or television Y Data Processing	B Bombing C Communications D Direction finder, reconnaissance and/or surveillance E Ejection and/or release G Fire control or searchlight directing H Recording and/or reproducing K Computing M Maintenance and/or test assemblies N Navigation aids Q Special or combination of purposes R Receiving, passive detecting S Detecting and/or range and bearing, search T Transmitting W Automatic flight or remote control X Identification and recognition Y Surveillance and control

LIST OF ASSESSMENT CRITERIA

INTRODUCTION TO EW

Define Electronic Warfare (EW) and its common terms

1.1 Define EW
1.2 List and describe the elements of the EW Tree
1.3 Describe the role of EW
1.4 List types of Electronic Threats
1.5 List types of Military EW systems or actions that can protect ADF assets

ELECTROMAGNETIC RADIATION

Describe Electro Magnetic (EM) Radiation

2.1 Define EM Radiation
2.2 List and describe basic EM properties
2.3 List and describe factors affecting EM Propagation
2.4 List the two forms of Atmospheric Attenuation
2.5 State the relationship between atmospheric attenuation and frequency (RF)

EW TERMINOLOGY

Define Common Terminology

3.1 Define the following:
3.1.1 Signal bandwidth, and
3.1.2 Noise.
3.2 List the effects of Noise.
3.3 State the relationship between thermal noise, temperature and bandwidth.
3.4 Define the following:
3.4.1 Sensitivity,
3.4.2 Gain, and
3.4.3 Signal to Noise Ratio (SNR).

RF ANTENNAS

Describe the Properties and Operation of Antennas

4.1 Define the following:
4.1.1 Antenna Gain
4.1.2 Antenna Bandwidth
4.1.3 Mainlobe and sidelobes
4.1.4 Effective Radiated Power (ERP)
4.2 Describe the use of Antenna Polarisation
4.3 Describe the relationship between Antenna Gain, Aperture Size, Beamwidth and Frequency
4.4 Describe the Antenna Beam Pattern for the following:
4.4.1 Half-wave dipole antenna
4.4.2 Parabolic antenna
4.4.3 Slotted wave guide
4.4.4 Antenna arrays

RADAR

Describe the operation, use and limitations of Radar

5.1 Describe how a radar determines a target's:
5.1.1 Presence
5.1.2 Range
5.1.3 Position
5.1.4 Closing speed
5.1.5 Identity
5.2 Define Radar Cross Section (RCS)
5.3 List factors affecting RCS
5.4 Define the following:
5.4.1 Radio Frequency (RF)
5.4.2 Pulse Repetition Interval (PRI)
5.4.3 Pulse Repetition Frequency (PRF)
5.4.4 Pulse Width (PW)
5.4.5 Pulse Energy
5.5 List the 2 main radar types
5.6 Describe radar angular resolution
5.7 Describe radar range resolution

5.8 Define Maximum Unambiguous Range
5.9 Define the Radar Resolution Cell (RRC)

RADAR SCAN TYPES AND TRACKING
Describe different scan types, and how radars use them to track targets
6.1 List different radar functions
6.2 Describe basic search patterns
6.3 Describe tracking methods

RADAR IDENTIFICATION
Determine probable radar system applications from antenna features
7.1 Identify antenna features relevant to radar system operation
7.2 Determine probable radar system applications from antenna features

BASIC RADIO THEORY
List the fundamental principles of EM communications
8.1 Define Modulation
8.2 List the differences between Analogue and Digital signals
8.3 List the advantages and disadvantage of Data and Voice communications

ELECTRONIC SUPPORT
Describe Electronic Support (ES) receivers
9.1 State the general purpose of ES receivers
9.2 List the similarities and differences between RWRs and ESMs
9.3 List the steps of RWR/ESM processing between threat transmission and threat display

CHAFF
Describe the characteristics and use of chaff
10.1 Define chaff
10.2 Describe the characteristics of chaff
10.3 Describe the use of chaff to achieve break lock

MISSILE GUIDANCE
Describe various types of missile guidance
11.1 List the key components of a guided missile
11.2 Describe the following types of homing guidance:
11.2.1 Active Homing
11.2.2 Semi-Active Homing
11.2.3 Passive Homing
11.3 Describe the following types of command guidance:
11.3.1 Beam Riding
11.3.2 Command Link
11.3.3 Seeker Assisted Guidance

ELECTRO-OPTICS FUNDAMENTALS
Describe the principles of electromagnetic radiation, relevant to electro optics (EO)
12.1 List the EO radiation spectral bands and state where they reside in the EM spectrum
12.2 State the relationship between temperature and peak wavelength emitted
12.3 State the major effect of the atmosphere on IR frequencies
12.4 State the major effect of the atmosphere on UV frequencies
12.5 List target sources of IR radiation and the bands they radiate in

EO SEEKERS
List Electro-optic (EO) missile seeker types
13.1 List different types of IR/EO seekers

MISSILE APPROACH WARNING SYSTEMS
Describe the principles and limitations of Missile Approach Warning Systems (MAWS)
14.1 Describe when missiles emit IR and UV
14.2 List the MAWS system requirements
14.3 List the limitations of UV MAWS

ELECTRO-OPTIC COUNTERMEASURES
Describe the operation, use and effects of Electro Optic Countermeasures (EOCM)
15.1 List passive IR and Visual Counter Measures
15.2 Describe how an IR jammer deceives an IR missile
15.3 Describe how a flare deceives an IR missile
15.4 List various flare types

15.5 List Missile EP Methods
15.6 List the difference between different generation missiles

RADAR MODULATION AND DOPPLER
Topic Overview - Non-Assessed Presentation
Describe Advanced Radar Concepts
P1.1 Describe interpulse modulation
P1.2 Discuss the use of PRI agility to affect the maximum unambiguous range
P1.3 Describe intrapulse modulation (pulse compression)
P1.4 Describe ground based pulse doppler radar
P1.5 Define Maximum Unambiguous Doppler (MUD)

LOW PROBABILITY OF INTERCEPT
Topic Overview - Non-Assessed Presentation
Describe Low Probability of Intercept (LPI) principles
P2.1 Define LPI
P2.2 Describe LPI principles

GPS AND DATALINK
Topic Overview - Non-Assessed Presentation
Describe GPS and Tactical Data Links
P3.1 Describe GPS navigation principles of operation
P3.2 Discuss GPS jamming
P3.3 State the purpose of a data Link
P3.4 Describe principle differences between Link 11 and Link 16 systems

RF JAMMING
Topic Overview - Non-Assessed Presentation
Describe the techniques and effects of RF jamming
P4.1 Define the J/S Ratio
P4.2 Describe Noise Jamming methods and effects
P4.3 Describe Deception Jamming methods and effects

CHAPTER 1

INTRODUCTION TO EW

Assessment Criteria

Define Electronic Warfare (EW) and its common terms

1.1 Define EW

1.2 List and describe the elements of the EW Tree

1.3 Describe the role of EW

1.4 List types of Electronic Threats

1.5 List types of Military EW systems or actions that can protect ADF assets

ELECTRONIC WARFARE

1. ADF EW is outlined in ADDP3.5 – Electronic Warfare. EW is defined as any military action whose objective is to exploit the Electro-Magnetic spectrum.

2. The scope of EW is quite large and can be divided into three main pillars:

   a. **Weapons.** This includes Radar, Missiles, Infrared detection, radar/IR jamming, lasers, chaff and flares. This is the main focus of this course.

   b. **Communications intelligence.** This involves detection and interception of enemy communications for the purpose of exploitation, locating, or jamming. Enemy communications may be over land lines or wireless (e.g. mobile phones).

   c. **Cyber.** Similar to communications intelligence, this involves the interception of data (either real time or stored) for the purpose of exploiting, decoying (inserting dummy data) or denying. This may involve data over land lines, wireless, or internet.

3. The role of EW in the military environment is the improving of situational awareness and reducing the attrition of own forces while defeating the enemies EW attempts.

THE EW TREE

4. Each of the pillars can be subdivided into 3 broad categories, often called branches of the EW Tree. Electronic Support (ES) provides early detection and classification of enemy emitters and associated platforms or weapon system. Electronic Protection (EP) allows us to protect friendly emitters from enemy actions and Electronic Attack (EA) is used to impede the enemy's use of its own emitters.

Electronic Attack (EA)

5. Previously known as Electronic Counter Measures (ECM), EA involves manipulating the EM spectrum to reduce or prevent the enemy's use of the EM spectrum effectively.

6. 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.

7. Electronic Attack can be conducted against all electromagnetic systems including communications systems. EW systems are operated to detect, acquire and track targets with the ultimate view to engaging and destroying the target. To that end, interfering with 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.

8. EA can be passive or active. Passive measures include signature management and chaff. Both of these alter what the enemy detects through their sensors. Active measures include Radio Frequency (RF) jamming (both noise and deception), flares and Suppression of Enemy Air Defence (SEAD).

Electronic Support (ES)

9. 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 of 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 for threat assessments.

10. Many factors impact on the effectiveness of Electronic Support such as: transmitter characteristics (including transmitted power, operating frequency, polarisation, signal bandwidth and antenna characteristics), atmospheric and meteorological conditions, and the Electronic Support equipment antenna characteristics, receiver capabilities and sensitivity.

11. Electronic Support is a passive activity as the Electronic Support equipment does not transmit any electromagnetic energy. Systems include Radar Warning Receivers (RWRs) and Electronic Support Measures (ESMs).

Electronic Protection (EP)

12. Previously known as Electronic Counter Counter Measures (ECCM), EP ensures 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.

13. 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.

14. 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.

15. Techniques of EP are largely invisible to the operator and are "designed in" to systems. Such techniques may include anti range gate pulloff, passive home on jam, and detection and identification of flares.

ELECTRONIC THREATS

16. There are numerous and varied EW threats within our region, from surveillance radars through to the most complicated of smart bombs. All of which must be dealt with by the command through various methods of identification for avoidance, neutralisation (passive or active techniques) or destruction to ensure mission success. Examples of EW threats are:

a. Search Radars,

b. Radar guided missiles,

c. Radar directed guns,

d. Infrared homing missiles, and

e. Laser guided missiles.

EW EQUIPMENT AND SOLUTIONS

17. To combat the EW threat, many systems and solutions are available including:

a. Radar Warning Receivers (RWRs),

b. Radar Jammers,

c. Chaff,

d. Infrared (IR) Jammers,

e. Flares,

f. Missile Approach Warning Systems (MAWS),

g. Laser Warning Receivers (LWRs),

h. Anti-Radiation Missiles (ARMs),

i. Signature Management, and

j. Tactics, Planning and Manoeuvre.

18. Each EW system protects against a particular threat. There is no single system that offers protection from everything. Also, many systems need to work together to be the most effective.

THE SURVIVABILITY PARADIGM

19. The Survivability Paradigm is a tool to show where our EW protection efforts fit in priority order. The paradigm states:

a. Don't get detected.

b. If detected, don't get tracked.

c. If tracked, don't get engaged.

d. If engaged, don't get penetrated.

e. If penetrated, don't get killed.

20. **Don't get detected.** The ultimate tactic in survival is to not be detected. If we're not detected, then the enemy cannot track or fire at us. This negates the need for any EW systems on our platform. It must be remembered that detection in an EW sense can be visually, on Radar or through Infrared. (Other non-EW detection methods may include acoustically,

magnetically or through vibration). Methods to prevent detection include: camouflage paint, smokeless fuels, IR shielding, low radar cross section and Radar absorption materials.

21. **If detected, don't get tracked.** The enemy may know you're close, but may not know exactly where you are. Noise jamming is effective in this sense. The enemy can see he's being jammed, so he knows you're around somewhere, but cannot pinpoint your location. Again, if your position is unknown, then he cannot fire missiles at you with any real hope of success.

22. **If tracked, don't get engaged.** Pre-emptive flares are an example of a tactic designed to achieve this goal against IR missiles. The firer is able to track your position, and aim the missile at you, however the flares prevent him from 'locking on', and prevent the missile from being launched.

23. **If engaged, don't get penetrated.** Once a missile has been fired at you (you've been engaged) there are still tactics to prevent the missile from hitting you. Flares and DIRCM may be effective at making the missile steer off course. RF jamming may also work against radar threats.

24. **If penetrated, don't get killed**. If all else fails, we can try to build platforms capable of withstanding a hit. For instance, ballistic protection (thick steel plates) on helicopters may be capable of withstanding small arms fire, and may offer some limited protection against larger rounds.

25. As a rule, the earlier in the paradigm that our solution fits, the easier, more effective and lower risk it is, but the higher the cost, and more the integration challenges.

CHAPTER 2

ELECTROMAGNETIC RADIATION

Assessment Criteria

Describe Electro Magnetic (EM) Radiation

2.1 Define EM Radiation

2.2 List and describe basic EM properties

2.3 List and describe factors affecting EM Propagation

2.4 List the two forms of Atmospheric Attenuation

2.5 State the relationship between atmospheric attenuation and frequency (RF)

EM RADIATION

1. Modern warfare is becoming increasingly dependent on high technology weapon systems, the vast majority of which rely on some form of EM radiation. EM Radiation is a self propagating wave of oscillating energy that travels through free space at the speed of light. EM waves do not require a medium to travel in – that is, they can travel both in air or the vacuum of space. They can also travel through solids and liquids, although they will attenuate quickly. EM waves are made of an electric component and a magnetic component that are perpendicular to each other. EM radiation carries energy, which can be manipulated to be information

EM PROPERTIES

2. EM Waves have a number of properties as follows.

Frequency (f)

3. The units of frequency are Hertz (Hz) or cycles/second. The frequency of a wave is simply the number of times the EM cycle repeats itself per second.. Lower frequencies are used for Radio, middle frequencies are used for Radar, and extremely high frequency EM is IR and UV. Even within a particular usage (such as radar), frequency dictates how the EM wave propagates, the distance of propagation, size of equipment, techniques used and types of equipment employed.

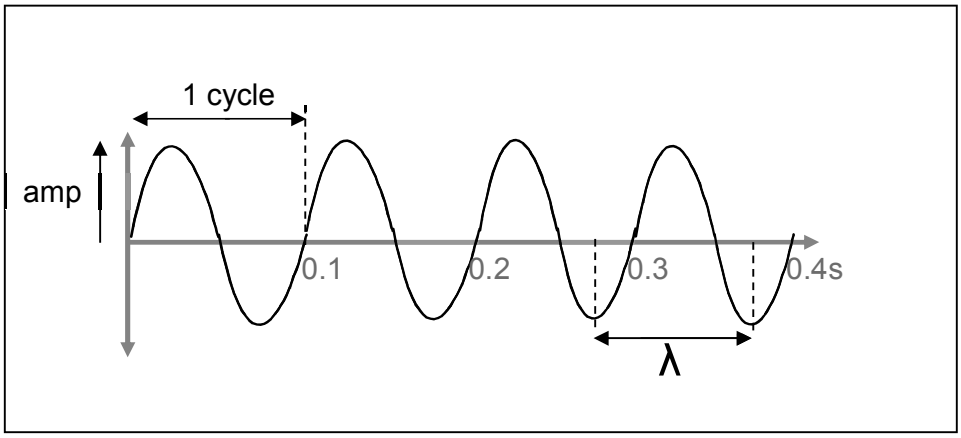


Figure 2-1 – EM Properties

Speed

4. EM waves travel at the speed of light. This speed is about 300,000km/sec in a vacuum, and slightly slower in any other material (air, glass, water). But for most radar calculations, the full speed of light can be used.

Wavelength (λ)

5. The wavelength of EM is the distance between one point on a cycle and the same point on the next cycle (eg the distance from peak to peak). Since an EM wave travels at constant speed, the wavelength is inversely proportional to its frequency. The shorter the wavelength the greater the frequency. The constant of proportionality between frequency and wavelength is the speed of light.

$$\lambda = \frac{c}{freq(Hz)}$$ where c = speed of light (m/s) and λ = wavelength (m)

Amplitude/Power

6. EM waves have an amplitude (power). This is normally measured in Watts (W). Power is the thing we measure to detect the presence of a signal.

Polarisation

7. The term polarisation refers to the physical orientation of radiated waves in space. Types of polarisation are linear (vertical, horizontal), random and circular (right hand, left hand and elliptical). The polarisation of an EM wave is named in the direction of the electric field. When the electric field is vertical, the wave is said to be vertically polarised. When the electric field is horizontal, the wave is said to be horizontally polarised. Circular polarisation is when the polarisation of the transmitted wave rotates through 360 degrees. It can be achieved by transmitting vertically and horizontally polarised waves which are 90 degrees out of phase.

EM SPECTRUM

8. The EM spectrum covers the range of frequencies from zero Hz to infinity. For EW systems, the EM spectrum frequencies range from 1MHz to 10,000THz. Different ranges of frequencies are grouped together and labelled as a band as shown in figure2-2. For example, in Radio, different frequencies are grouped into bands such as UHF or HF. This allows you to discuss general operating ranges of the radios. The same is true for all frequencies in Radar and EO. The radar bands A-M are the NATO designated bands, while the radar bands L, S, C, X and K are the old US military bands.

9. Examples of EM waves are Radio, Radar, Microwaves, TV, visible light, IR and UV.

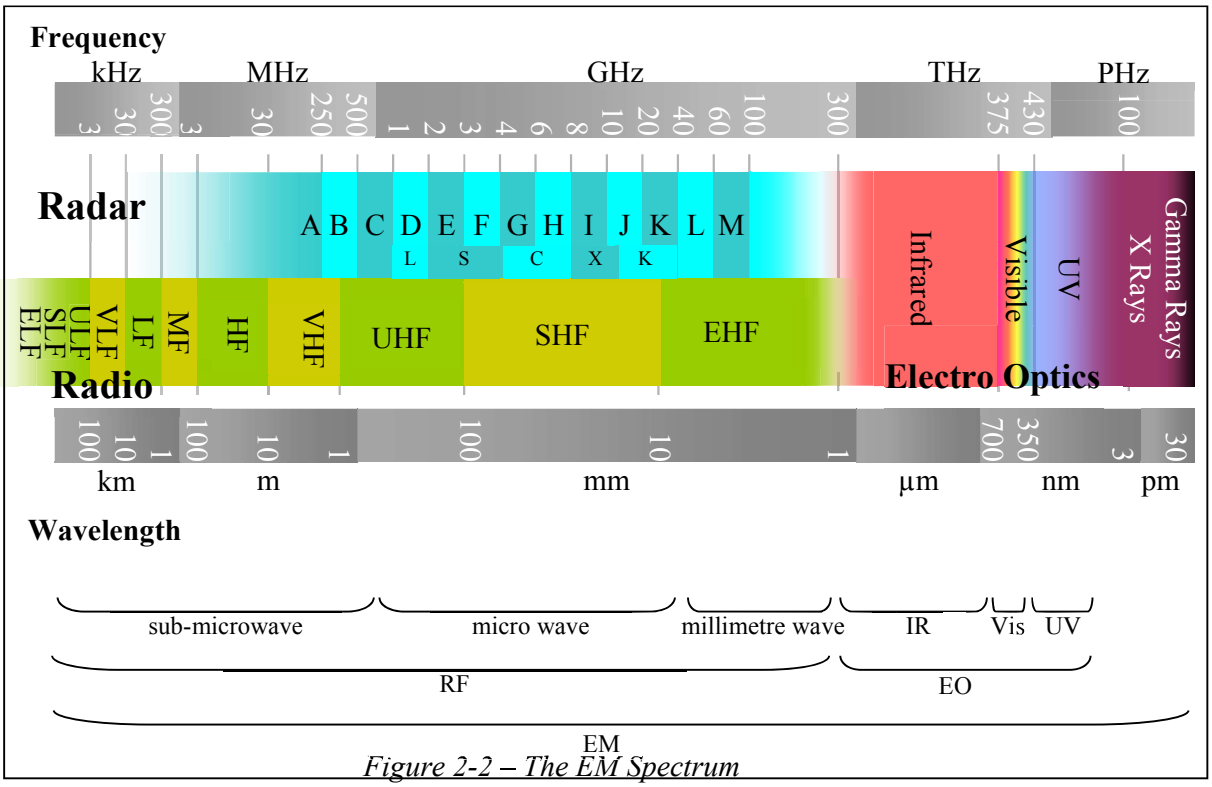


Figure 2-2 – The EM Spectrum

EM PROPAGATION

Spreading

10. An EM wave radiated from a point source in free space will spread uniformly in all directions. The total power output from the source is spread spherically. Power density is defined as the radiated power per unit surface area (i.e. Watts per m^2). If the distance from the source is doubled, then the power density is reduced fourfold. This is the inverse-square law. This can be expressed as:

$$P_r = \frac{P_t}{4 \times \pi \times r^2}$$

where P_r is power density at a distance r from an isotropic source (radiates in all directions equally) and P_t is transmitted power. Another way of looking at this is to say that EM waves are attenuated as they travel outward from the source.

Wavefront

11. EM waves travel in straight lines, and try to radiate spherically from their origin. A line joining all similar points on each EM wave denotes the wavefront. The EM wave propagates perpendicular to the wavefront.

Interactions

12. When EM waves come to a material they can be absorbed, reflected or transmitted (pass through). The actual amount of each of these interactions depends on the material's density, composition and frequency of EM. In general, it is harder for EM to pass through electrically conductive or dense materials (so it's hard to pass through metals, dense concrete or moist

soil) and the higher the frequency, the harder to transmit through a material (eg Radio at 100MHz goes through walls easily whereas WiFi at 2400MHz won't as much).

Absorption

13. Absorption reduces the power or strength of the wave. There is no absorption of EM waves in free space. In the atmosphere however, EM waves can be absorbed, as energy from the EM wave is transferred to the atoms and molecules of the atmosphere. Atmospheric absorption of EM waves below about 10GHz is insignificant. Above that frequency, absorption is variable. If humidity increases or if there is fog, rain or snow, then this form of absorption is increased tremendously, and reflection from rain-water drops may even take place.

14. At all frequencies, the presence of rain, snow, or fog introduces an absorption in the atmosphere which depends on the amount of moisture and the frequency. The more moisture, or the higher the frequency, the more the absorption. During rain, the attenuation at 10GHz may reach 1%/km and at 50GHz it may be in excess of 40%/km. In addition to the effect of rainfall, some selective absorption may result from the oxygen and water vapour in the atmosphere. The first absorption peak due to water vapour occurs at about 22GHz and the first absorption peak for oxygen occurs at about 60GHz.

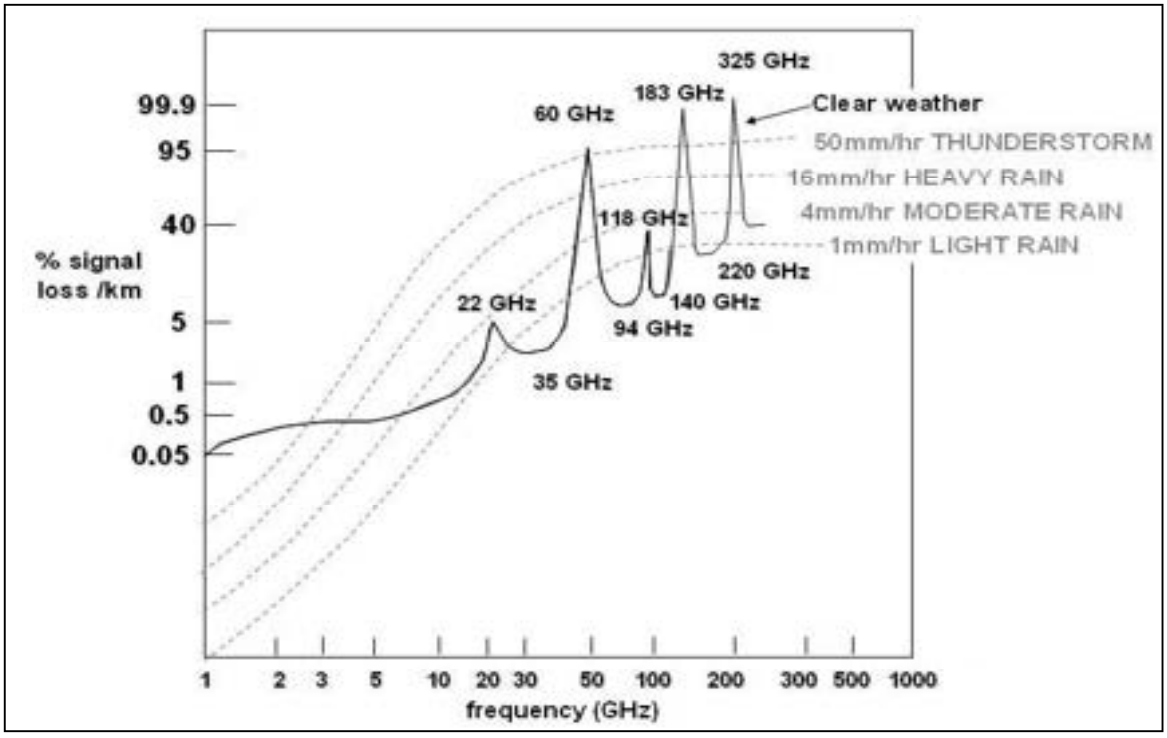


Figure 2-3 – Atmospheric Absorption of EM

15. For example, a radar system operating at 10 GHz may have a range of 75 km in dry air, 68 km in light drizzle, 55 km in light rain, 22 km in moderate rain and 8 km in heavy rain, showing effectively how precipitation causes severe absorption at radar frequencies. It must be repeated that such absorption is insignificant at lower frequencies, except over very long transmission distances, but becomes significant at higher frequencies.

Diffraction

16. In free space, EM waves travel in straight lines. However, when the wave encounters an obstruction, it tends to bend around that obstruction. Thus a straight wavefront can become curved. Refer to Figure 2-5. In the earth's atmosphere, radar waves can be diffracted around the curved earth in the same way.

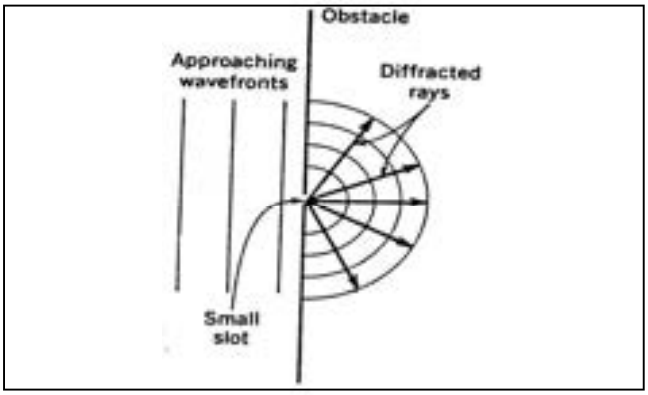


Figure 2-5 - Diffraction

17. Diffraction is of importance in two practical situations. First, signals propagated by means of the space wave may be received behind tall buildings, mountains and similar obstacles as a result of diffraction. Second, in the design of radar antennas, diffraction has a major effect of generating unwanted sidelobes.

Scattering

18. EM waves are also scattered by particles in the atmosphere. Scattering is greatest when the particle size is similar to the wavelength. Scattering doesn't directly change the power of the wave, but it changes the direction of travel. Thus the amount of power being received at the receiver will be less.

19. Radio and Radar wavelengths are generally larger than atmospheric particles sizes, so scattering is negligible for them. However in the EO spectrum, scattering has a major effect. This is discussed further in Chapter 12.

Reflection

20. Reflection of EM waves can be via the ground, mountains and buildings. When a wave strikes a conductive surface, its electric field is short-circuited. The resulting current causes the waves' energy to be re-radiated. Refer to Figure 2-4. From a flat surface, reflection is mirror-like and called specular. From a complex surface, e.g. an aircraft, the reflection is diffuse and called scattering.

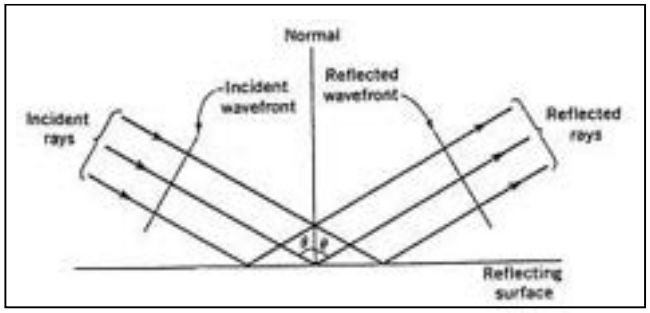


Figure 2-4 - Reflection

The Radar Horizon

21. Given that the Earth is round, there is a limit to how far we can see, as light travels in a straight line. EM all travels in a straight line, however at lower frequencies the curvature of the Earth diffracts the EM, making it "bend" around. Light, Radar and Radio waves are all affected by diffraction, however since light is at a higher frequency the effect on it is the smallest. Radar waves (being at much lower frequencies than light) will be bent more and hence the radar will be able to "see" further than you can visually. Low frequency radio waves bend considerably, and ELF waves (<100Hz) will entirely bend around the surface of the Earth.

22. The equation for the radar horizon is:

$$\text{Range (nm)} = 1.23 \times \left(\sqrt{RadarHeight(ft)} + \sqrt{TargetHeight(ft)} \right)$$

or $$\text{Range (km)} = 4.1 \times \left(\sqrt{RadarHeight(m)} + \sqrt{TargetHeight(m)} \right)$$

Refraction

23. This is the 'bending' of EM waves as they pass from one propagating medium to another, due to the slight change in their speed in different density materials. The effect for EM waves is to bend the ray when changing from one medium to another. The reason is that the portion of the wave entering the new medium first travels briefly at different speeds than the portion entering next.

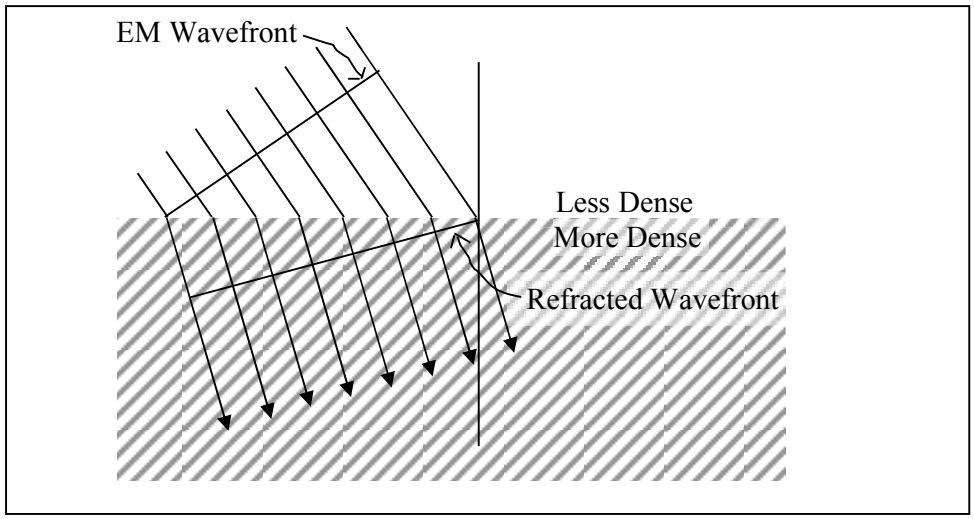


Figure 2-6 - Refraction

24. The ratio of velocities in the two mediums is called the index of refraction. If travelling from a less dense to a more dense medium, the ray is bent toward the 'straight'. This situation can also arise in the atmosphere between different density air layers, and is the principle behind Over the Horizon Radar (OTHR).

Interference

25. Interference occurs when two waves (of the same frequency) overlap. This could occur if two waves leave the one source and travel by different paths, arriving at a point at different times, thus interfering with each other. It can arise when an antenna is located near the

ground, and waves reach the receiving point not only directly but also after being reflected from the ground. Refer to Figure 2-7.

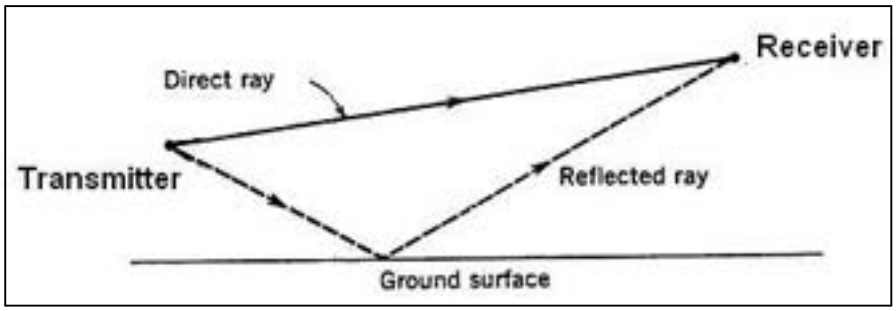


Figure 2-7 – Interference

26. At frequencies right up to the VHF range, this interference will not be significant because of the relatively large wavelengths of such signals. (A 1µs delay at 10MHz is only a 1˚ phase shift, while the same 1µs delay at 10GHz is a 20˚ phase shift.) In the UHF range and above, interference plays an increasing part in the behaviour of propagating waves and must be taken into account.

CHAPTER 3

EW TERMINOLOGY

Assessment Criteria
Define Common Terminology
3.1 Define the following:
3.1.1 Signal bandwidth, and
3.1.2 Noise.
3.2 List the effects of Noise.
3.3 State the relationship between thermal noise, temperature and bandwidth.
3.4 Define the following:
3.4.1 Sensitivity,
3.4.2 Gain, and
3.4.3 Signal to Noise Ratio (SNR).

INTRODUCTION

1. The following is a definition of EW words commonly used throughout this book, and required knowledge for any budding EW user.

FREQUENCY COVERAGE

2. All electronic systems have a range of frequencies over which they are designed to operate. This is their Frequency Coverage. For instance, you car FM radio can listen to any radio station between 87.5 and 108MHz—this is its frequency coverage.

BANDWIDTH

3. Within the frequency coverage range, there is a much smaller range of frequencies called the Bandwidth, which is the range of frequencies that the system is currently using. The Bandwidth is the difference between the upper and lower frequency limits of a band containing the useful components of a signal. For instance, when you try to listen to NOVA (91.9) on your car FM radio, it selects the frequencies from 91.880 to 91.920MHz (a bandwidth of 40kHz) to listen to, and ignores all other frequencies.

4. The term Bandwidth is also used for other applications in Radar. Antennas have a bandwidth—which defines the range of frequencies over which the antenna beam pattern stays constant. And a transmitted pulsed signal has a bandwidth—which defines the range of frequencies used within that signal.

GAIN

5. Gain is the process of making a signal more powerful, or giving it a higher amplitude. Gain is measured as the ratio of the output signal to the input signal. For example if a signal is increased from 5W to 100W then the gain is 100W/5W = 20 times. Gain occurs in many areas with radar including antenna gain, processing gain and conventional power gain.

6. Gain is normally measured in decibels (dB) which will be discussed further in this chapter.

ATTENUATION

7. Attenuation is the opposite of gain—making a signal less powerful. Attenuation happens whenever EM energy is moved around—such as through wires, waveguides and the atmosphere. Attenuation is measured the same way as gain, being the ratio of the output signal to the input signal. If decibels are used, it will be a negative dB number.

NOISE

8. Noise may be defined, in an electrical sense, as any unwanted energy. Noise is undesirable as it interferes with the proper and easy reception and reproduction of wanted signals by:

a. masking weak signals,

b. degrading sensitivity, and

c. possibly causing false targets.

External Noise

9. **Atmospheric Noise** This type of noise is generally called static. Static is caused by lightning discharges in thunderstorms and other electrical disturbances occurring in the atmosphere. Atmospheric noise consists of spurious radio signals with components distributed over a wide range of frequencies. Such noise consists of impulses and these non-sinusoidal waves have harmonics whose amplitude falls off with increase in the harmonic. Atmospheric noise becomes less severe at frequencies above about 30 MHz because of two separate factors:

a. Higher frequencies are limited to line-of-sight propagation (<80 km).

b. The nature of the mechanism generating noise is such that very little of it is created in the Very High Frequency (VHF) range or above.

10. **Industrial Noise.** Between the frequencies of approximately 1 to 600 MHz, in urban, suburban and other industrial areas, the intensity of the noise made by humans easily outdoes that created by other sources, internal or external to the receiver. Sources such as cars and aircraft ignitions, electric motors and switching gears, leakage from high voltage lines and a multitude of other heavy electric machines are included. Fluorescent lights are also a powerful source.

Internal Noise

11. There are many sources of noise internal to all electronics. This noise is caused by the electrons moving around and bumping into one another. Integrated circuits (ICs or chips) are made of many small switches, and each time these switches turn on or off they also create noise. The largest source of internal noise is Thermal Noise.

$$P_n = k\,T\,B$$

where k : Boltzmann's constant = 1.38×10^{-23} J/K
T : Absolute temperature, K = 273 + °C
B : bandwidth of interest (Hz)
P_n : noise power (W)

12. **Thermal Noise.** Noise generated by the resistance or the resistive component of any impedance (i.e. Total opposition to current flow) is random and is referred to variously as thermal, agitation or white noise. It is due to the rapid and random motion of the molecules, atoms and electrons of which any such resistor is made. Noise power generated by a resistor is proportional to its absolute temperature, in addition to being proportional to the bandwidth over which noise is being measured. That is, the higher the temperature, the more noise, and the larger the bandwidth, the more noise.

13. Thermal noise is the most prevalent source of noise in RF and EO systems.

SIGNAL TO NOISE RATIO

14. The Signal to Noise Ratio (SNR) is the ratio of the signal power (or amplitude) to the noise power. A high SNR is more desirable, as it allows the signal of interest to be easily seen above the noise.

SENSITIVITY

15. Sensitivity is the smallest detectable signal power that a receiver needs to receive in order to distinguish the signal from the noise. This is similar to "squelch" in radio. The typical sensitivity of an ESM receiver is around -130dBW, which is around 0.0000000001mW.

AUTOMATIC GAIN CONTROL

16. The gain inside a radar receiver processor is controlled automatically by the receiver to ensure the best performance. When signal levels are strong, the gain is turned down to prevent saturation. When the received signal levels are weak, the gain is turned up to ensure the maximum probability of detection.

17. The Automatic Gain Control (AGC) circuit within the receiver is often the target of jamming. This will be discussed in Chapter P4.

TIME AND FREQUENCY DOMAINS

18. The time domain shows how the strength of a signal varies over time. The frequency domain is a diagrammatic representation of the specific frequencies that exist in a signal (and their relative strengths). All signals (in time) can be broken down into their frequency components. The Time vs Frequency Domain is discussed in more detail in Chapter P1 Radar Modulation and Doppler.

19. EW processing occurs in both the time and frequency domains.

20. In the time domain, we can calculate time delays (for radar ranging). In the frequency domain, it is easy to 'filter out' frequencies that you don't want to reduce interference or to select a specific signal you wish to process.

DECIBELS

Origin

21. The unit originated as a measure of attenuation in telephone cable. The name is derived from Alexander Graham Bell. One decibel equalled the attenuation of one mile of telephone cable. The decibel was originally used to describe attenuation of power, however, it was realised the unit could be used for audio power levels and also in communications and radar.

Advantages

22. The main advantage of the decibel system is that it is logarithmic in nature. Large changes in a power ratio produce a relatively small change in the decibel values. For example a power ratio of 10,000,000,000,000 : 1 is equal to 130 dB. All practical ratios will be able to be expressed as three-digit decibel numbers. Decibels can be used instead of the power ratios

in calculations of gain, loss and to describe output power and sensitivity of electronic equipments.

Ratio to Decibel Conversions

23. To covert a power ratio to decibels we use the following formula:

$$\text{Power ratio in decibels (dB)} = 10\log_{10}\left(\frac{P_2}{P_1}\right)$$

24. To convert a decibel back to a power ratio we divide the dB value by ten then find the antilogarithm of that number.

$$\text{Power Ratio} = 10^{\,dB/10}$$

25. Decibels are normally a dimensionless unit, they simply describe a relationship between one measurement and another. If the ratio is one where a measurement is related to a standard unit then the decibel measure has some value. For example, if we use a reference value of one Watt then 0dBW equals one Watt. 30dBW equals 1000 Watts. So now we have a unit, dBW, that represents a certain power level, we can use dBW units on power meters or in calculations knowing exactly the power level described.

26. Other common units used in EW are the dBm, which is dB relative to 1mW, and dBsm, which is dB related to 1 square meter of radar cross section.

0 dBW = 1 Watt
0 dBm = 1 milliWatt
0 dBsm = 1 square Meter radar cross section

27. Decibels can also be used to represent attenuation. In this instance, the power coming out of a circuit is less than what is going in. For example, if the power into a circuit is 50 watts and the power out is 40 watts, the ratio is 40:50 or 40/50 or 0.8. The logarithm (and therefore the decibel) of a ratio less than one is a negative number (0.8 = -1dB). This does not mean that the number itself is negative, it just shows that the ratio is less than one.

28. Common conversions that are useful are:

Ratio	Decibels
2	3dB
0.5	-3dB
10	10dB

CHAPTER 4

RF ANTENNAS

Assessment Criteria

Describe the Properties and Operation of Antennas

4.1 Define the following:
- *4.1.1 Antenna Gain*
- *4.1.2 Antenna Bandwidth*
- *4.1.3 Mainlobe and sidelobes*
- *4.1.4 Effective Radiated Power (ERP)*

4.2 Describe the use of Antenna Polarisation

4.3 Describe the relationship between Antenna Gain, Aperture Size, Beamwidth and Frequency

4.4 Describe the Antenna Beam Pattern for the following:
- *4.4.1 Half-wave dipole antenna*
- *4.4.2 Parabolic antenna*
- *4.4.3 Slotted wave guide*
- *4.4.4 Antenna arrays*

INTRODUCTION

1. An antenna is a physical device used to transmit and receive EM energy. An antenna can switch between transmitting and receiving very fast (a few microseconds) however it *cannot do both at the same time*.

2. Antennas are used to transmit and receive Radar and Radio frequencies (in the RF part of the spectrum), but are not used for EO frequencies of EM.

OMNIDIRECTIONAL ANTENNAS

3. Omnidirectional antennas, as their name suggests, radiate energy in all directions. The most basic form of an omnidirectional antenna is the Dipole Antenna. This antenna is formed by taking two electrically conductive 'poles' and attaching them to each of the two wires within the cable. Both poles are 'in-line' with each other, however other configurations are also possible. See Figure 4-1.

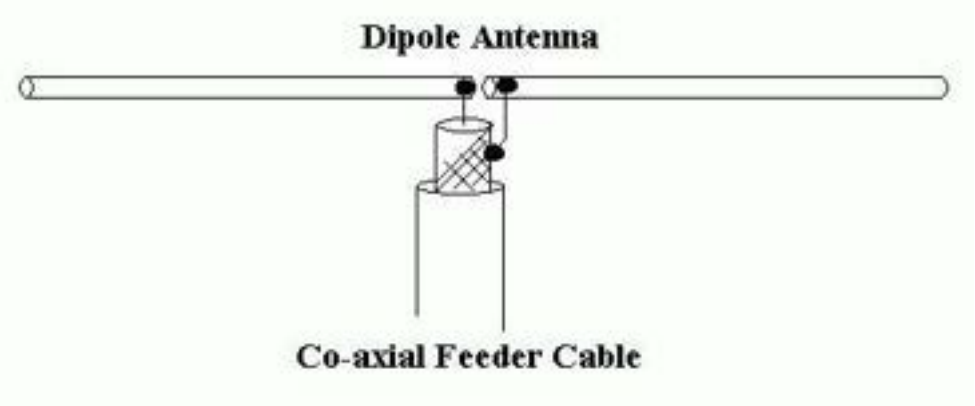


Figure 4-1 – The Basic Dipole Antenna

Antenna Pattern

4. The antenna pattern is a representation of how the antenna both transmits the EM energy into the air, and how sensitive it is to receive energy from different directions. Different antennas have different patterns, which depend on the antenna size, antenna shape, operating frequency and other electrically conductive elements in the antenna beam.

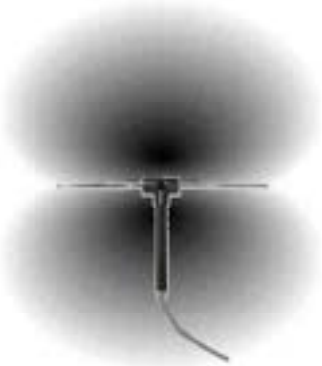


Figure 4-2 - Dipole Beam Diagram

5. When used 'correctly', the dipole antenna radiates energy equally in almost all directions (see Figure 4-2). This is called an omnidirectional radiation pattern.

Bandwidth

6. The bandwidth of an antenna is the range of frequencies over which an antenna is capable of operating whilst maintaining a relatively constant beam pattern – the frequency range over which the antenna is most efficient. Outside of this frequency range the antenna pattern will begin to change and the antenna will become inefficient (see figure 4-3). For a dipole antenna, the normal method is to use an antenna where the length of both poles (total length) is equal to one half of the operational wavelength. If the poles are not the correct length, the antenna will still radiate, but with a different beam shapes and power. HF antennas have electrical or even mechanical couplers to change the physical length of their dipole antennas to ensure its operational frequency is in the bandwidth of the antenna.

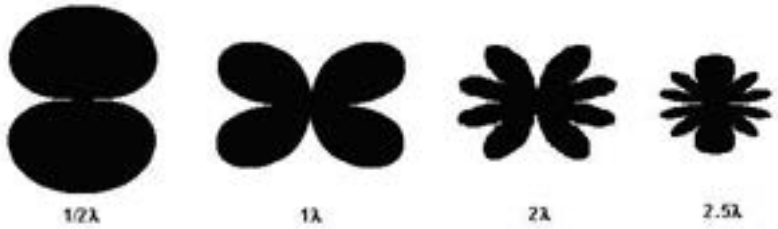


Figure 4-3 – Dipole Antenna Patterns for different Wavelengths

Polarisation

7. The direction of polarisation is defined as the direction of the electric field vector of the EM wave. Most radar antennas are linearly polarised; that is the direction of the electric field vector is either vertical or horizontal. Polarisation may also be elliptical or circular. Elliptical and circular polarisation may be Left Hand Polarised or Right Hand Polarised. For a dipole antenna, the polarisation can be seen by the orientation of the poles – horizontal poles give horizontal polarisation and vertical poles give vertical polarisation.

DIRECTIONAL ANTENNAS

8. While the basic dipole antenna radiates in all directions, other antennas can create a more focussed beam (to radiate in a single direction). In general, there are two main beam types that can be created using directional antennas:

9. Fan Beam (horizontal or vertical); or

10. Pencil Beam.

11. One of the most common Directional Antennas is the Parabolic Antenna which creates a focussed (pencil) beam by using a reflector positioned behind the dipole (see Figure 4-4). Most of the energy being radiated from the dipole is reflected into a single direction, giving a strong beam in one direction.

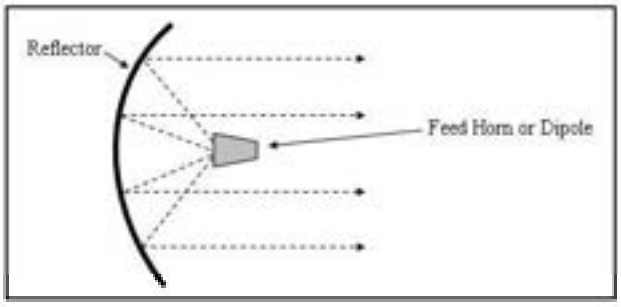


Figure 4-4 – Parabolic Antenna Design

12. Not all energy is focussed in the forward direction. Generally there are a number of beams of differing sizes. The largest beam is the Main lobe, and there will also be sidelobes of lesser strength (see Figure 4-5).

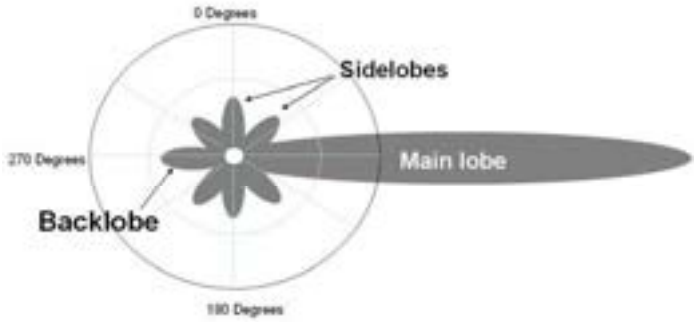


Figure 4-5 – Parabolic Antenna Beam Diagram

Beamwidth

13. The width of the main lobe is called the beamwidth. This is typically measured by checking where the signal strength is half the maximum (this is called the 3dB beam width). The beamwidth (BW) can be predicted by:

$$BW_{3dB} = \frac{k\lambda}{L}$$

Where k = beamwidth constant
- for linear array or rectangular array k = 0.88
- for uniformly illuminated circular aperture k = 1.02
- for a tapered illumination (i.e. fighter aircraft) k = 1.25

BW_{3dB} is in radians (one radian = 57.3°)

λ = wavelength

L = aperture dimension in the plane of the pattern

14. This formula states that the beamwidth become narrower (more focussed) with a larger size reflector, or with a higher frequency of signal. The beam height can also be calculated in the same way.

Sidelobes

15. Sidelobes are where energy is being radiated in undesired directions. Sidelobes result from the diffraction pattern resulting from the main lobe. They are an 'ever present' feature in the design of an antenna system. Sidelobes can cause a number of problems by permitting energy from a non-desired direction to enter the system (i.e. ground returns or jamming).

16. Lowering the sidelobes is possible, but doing so changes the main beam pattern. Array antennas are better suited for achieving low sidelobes. A parabolic reflector with waveguide horn feed typically may have a first sidelobe of 23 to 28 dB below the main beam. An array with proper aperture illumination may realise sidelobes 40 to 50 dB down.

17. Extremely low sidelobes can only be achieved by precise mechanical and electrical tolerances.

Aperture

18. The antenna aperture is the size of the antenna's effective transmitting/receiving area. This size helps determine the beam size and beam shape. For most antennas, the effective aperture is the physical area of the antenna multiplied by the efficiency factor. Different shaped antennas have different efficiency factors.

$$A_e = k * L_h * L_w$$

Where: A_e = the Effective Antenna Aperture
k = beamwidth constant
L_h = Antenna Height
L_w = Antenna Width

Antenna Gain

19. By focussing the transmit power into a directive beam, antennas offer gain (in much the same way that putting a reflector behind a light bulb creates a strong torch beam – even though the power of the light bulb has stayed the same).

$$\text{Gain} = \frac{\text{Maximum radiation intensity in the main beam}}{\text{Radiation intensity from an isotropic source}} = \frac{4 \pi Ae}{\lambda^2}$$

Where A_e = the Effective Antenna Aperture

20. Examining the Beamwidth and Gain formulas show the relationship between the two:

Beamsize	**Gain**
Decreases when **Antenna size** increases	Increases when **Antenna size** increases
Decreases when frequency increases	Increases when frequency increases

Effective Radiated Power (ERP)

21. ERP is a combination of transmitter peak power, transmission line losses (system losses) and antenna gain, and is normally the only measurement of power that an ESM/RWR can measure. In essence, it is the "net amount of power" coming out of the transmit antenna.

22. To look at it another way, if a directional antenna was replaced with an omnidirectional antenna, then the Effective Radiated Power is the power that the omnidirectional antenna would have to transmit for you to receive the same power density at a certain range as what you received from the directional antenna.

RECEIVING

Polarisation

23. An antenna of one polarisation will only receive a very small amount of energy from an antenna of a different polarisation (around 1/400th). For example, a vertically polarised antenna can receive energy from another vertically polarised antenna but an extremely small amount of energy from a horizontally polarised antenna and vice versa. Circular polarised signals are a combination of horizontal and vertical polarisations, so receiving a circular polarised signal with a linear polarised antenna will only result in about a ½ signal strength loss, however receiving Left Hand Circular polarised signals with a Right Hand Circular polarised antenna will still result in large signal losses (only around 1/400th of the signal power will be received).

		Transmit					
		Vertical	Horizontal	RHC	LHC	+45˚	-45˚
Receive	Vertical	0	-26	-3	-3	-3	-3
	Horizontal	-26	0	-3	-3	-3	-3
	RHC	-3	-3	0	-26	-3	-3
	LHC	-3	-3	-26	0	-3	-3
	+45˚	-3	-3	-3	-3	0	-26
	-45˚	-3	-3	-3	-3	-26	0

Table 1 – Polarisation Losses (dB)

Receiver Gain

24. A directional antenna in transmit will also be 'directional' in receive. The transmit beam pattern shows the directions that the antenna will be most sensitive to receive in. Thus the gain of an antenna affects the signal being transmitted as well as **received**.

ANTENNA TYPES

Dipole

25. The dipole is the most basic of antenna types, and essentially consists of two straight wires opposite each other. The cable connecting the dipole to the transmitter and receiver is attached in between the two poles. The relationship between the length of the dipole and the wavelength of EM determines the antenna pattern.

26. If the two poles are vertically orientated, the antenna produces (and receives) vertical polarisation. If they are horizontally orientated, they produce (and receive) horizontal polarisation. Circular polarisation can be achieved by using both a vertical and a horizontal dipole antenna and altering the phase between the two.

27. Both poles of a dipole are not required if a ground plane is used. The ground plane needs to be a large surface that conducts electricity and acts like a mirror of the remaining dipole. Typical ground planes include the wing of an aircraft, or the physical ground, or the surface of the ocean. Using only one pole reduces the size of antenna required, which is useful in aircraft applications (e.g. VHF, HF antennas).

Parabolic

28. Most radar applications require a directive beam, and the parabolic dish in figure 4-4 is a common antenna type in radar for this purpose. The dish can be fed a number of different ways, including waveguides and dipoles, and produces a highly directional beam. The typical antenna beam pattern is shown in figure 4-5. Increasing the size of the reflector will increase the effective aperture size, thus decreasing the beam width.

Slotted Waveguide

29. The slotted wave guide is the first of the antenna arrays. A series of slots in the waveguide each act as individual dipole antennas. The interaction of all the dipoles radiating together create a beam that is narrower in the plane of the waveguide. The more dipoles used, the larger the gain, and the greater the distance between one end dipole and the other end dipole the narrower the beam.

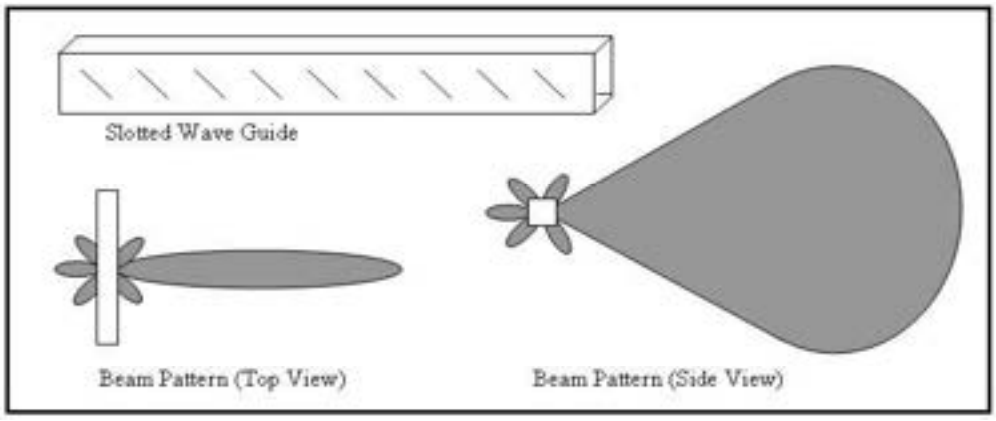


Figure 4-6 – Slotted Wave Guide

Planar Array

30. The planar array extends the slotted waveguide concept. It uses a grid of dipole antennas, all radiating in phase, to create an antenna beam that is narrower in both planes. The antenna array is flat, and the narrow pencil beam comes out perpendicular to the flat array. The planar array is steered mechanically to direct the beam. Again, the more dipoles used, the larger the gain, and the greater the distance between one end dipole and the other end dipole the narrower the beam.

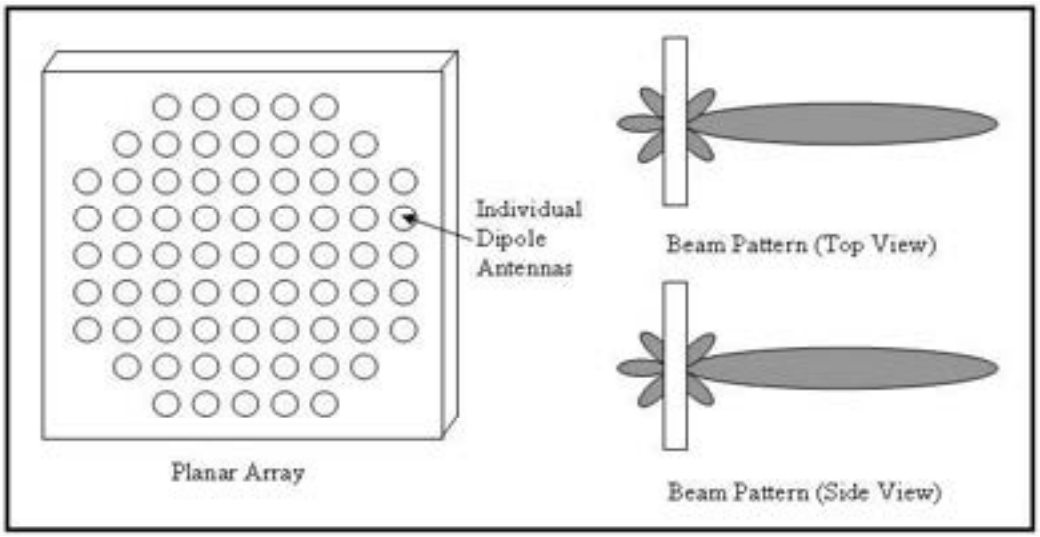


Figure 4-7 – Planar Array

Phased Array

31. In the phased array, the phase to each of the antenna elements can be altered individually. This allows the direction of the beam to be changed rapidly (usually in less than 20 microseconds). Thus, the antenna remains stationary while the beam is moved electronically.

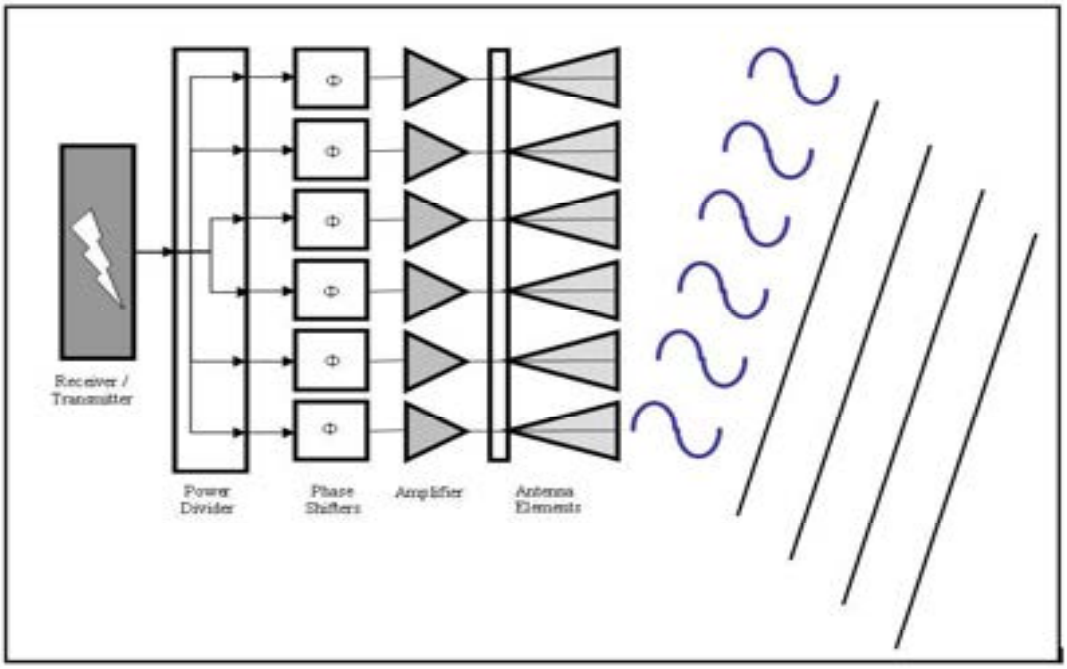


Figure 4-8 – Phased Array

Active Array

32. The active array uses a grid of dipole antennas, with each antenna element powered by its own transmitter and receiver. Thus each antenna element can be transmitting with its own phase shift, or even with its own frequency. This allows the antenna array to be 'split', creating multiple independent beams that are steered electronically.

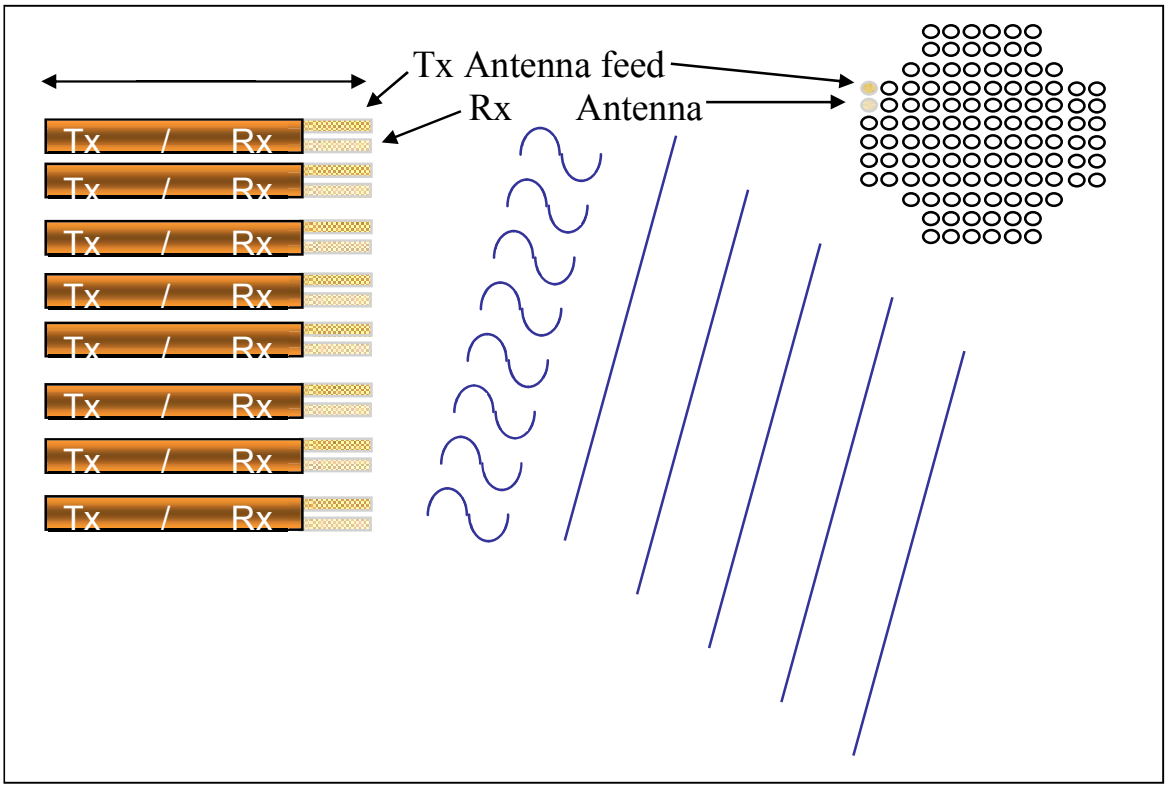


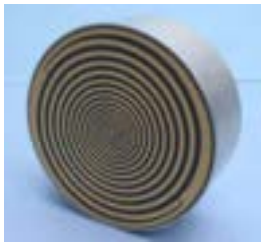
Figure 4-9 – Active Array

Conformal Array

33. Using an antenna array, designers are not constrained to producing flat antenna plates. Conformal arrays are antenna arrays shaped to fit the object they are being attached to, such as the leading edge of a wing. Conforming to the platform's shape reduces the RCS of the antenna, and provides better aerodynamics.

Cavity Backed Spiral

34. Cavity Backed Spiral antennae receive circular and linear polarised signals. These are often seen on ESM receivers. They are normally left hand or right hand circularised polarised, although dual polarity spirals are also available.



CHAPTER 5

RADAR

Assessment Criteria

Describe the operation, use and limitations of Radar

5.1 Describe how a radar determines a target's:
- *5.1.1 Presence*
- *5.1.2 Range*
- *5.1.3 Position*
- *5.1.4 Closing speed*
- *5.1.5 Identity*

5.2 Define Radar Cross Section (RCS)

5.3 List factors affecting RCS

5.4 Define the following:
- *5.4.1 Radio Frequency (RF)*
- *5.4.2 Pulse Repetition Interval (PRI)*
- *5.4.3 Pulse Repetition Frequency (PRF)*
- *5.4.4 Pulse Width (PW)*
- *5.4.5 Pulse Energy*

5.5 List the 2 main radar types

5.6 Describe radar angular resolution

5.7 Describe radar range resolution

5.8 Define Maximum Unambiguous Range

5.9 Define the Radar Resolution Cell (RRC)

INTRODUCTION

1. Radar is an electronic device for the detection and location of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detecting the nature of the returned signal. Radar is used to extend the capability of man's senses for observing his environment, especially that of the sense of vision. The value of Radar lies not in its being a substitute for the eye, but in its doing what the eye cannot do. Radar cannot resolve detail as well as the eye, nor is it yet capable of recognising the colour of objects to the degree of sophistication of which the eye is capable. However, Radar can be designed to see beyond the range of, and through those conditions impervious to normal vision, such as darkness, haze, fog, rain and snow. In addition, Radar has the advantage of being able to measure the range of objects. This is probably its most important attribute.

2. Radar transmission are very similar to Radio transmissions – they both are EW waves and modulated (radar is normally on/off pulse modulation). Radar frequencies are generally higher than Radio frequencies (but not always). In essence, the main difference is that while radio is a one-way signal, radar requires a reflection of energy (called a two-way signal).

RADAR OPERATION

3. A radar system sends out EM energy through a directional antenna. The energy travels through the air at the speed of light, reflects off a target, and some of the energy is returned to the radar antenna and detected.

4. A radar system can tell us the following information about the target:

   a. Target Presence,

   b. Target Range,

   c. Target Position,

d. Target Closing Speed, and

e. Target Identity.

Target Presence

5. The detection of an echo indicates the presence of a target. The strength of the echo is determined by the strength of the pulse sent, and the target's Radar Cross Sectional Area (RCS).

6. **RCS.** The radar cross section of an object is a measurement of its ability to reflect EM energy. RCS is quoted in square metres, being the size that a reference sphere of metal would have to be in order to achieve the same reflected energy.

7. The Radar Cross Section Area (RCS) of a target is dependent upon a variety of factors:

a. **Target surface types.** Smooth surfaces produce less returns than rough surfaces. Radar Absorbing Material (RAM) may also be used to reduce the amount of energy reflected;

b. **Target Material.** Again RAM must be considered but the actual object will exhibit differing amounts of reflection dependent upon its own physical properties;

c. **Target Aspect.** The amount of energy scattered by the object will vary in accordance with the amount of incident area of the object, ie : a ship broadside on, will have more area to reflect energy than the same ship being looked at from a stem or stern aspect;

d. **Target Shape.** A sphere will scatter energy equally in all directions whereas a corner reflector (three planes meeting at right angles) will reflect energy back to its source regardless of what direction the energy strikes the reflector from; and

e. **Source Polarisation and Wavelength.** An object's scattering properties are related to its physical orientation in space, its physical size in comparison to the wavelength of the incident energy and the polarisation of that energy. Selection of polarisation depends on application. Linear polarisation is most often used as it is the easiest to achieve. Horizontal polarisation reflects best off mostly horizontal surfaces (like the wide wing span of an aircraft). Conversely vertical polarisation will reflect well of vertical surfaces like ship's masts. Vertical polarisation is also used for radars used over large expanses of water to minimise the attenuation of the wave by the water. Circular polarisation is used to see through weather. Circularly polarised signals change their direction when reflected (from LHC to RHC). Reflections from rain will be changed once, but reflections from aircraft are likely to be reflected twice, and hence will have a different polarisation to the reflections from the rain (which will then be attenuated by the receive antenna). So a stronger signal will be received from the target aircraft than from rain.

8. **Transmit Strength.** The more energy sent, the more energy there is to receive. Energy sent depends on the maximum power of each pulse, the pulse duration and the number of pulses.

Target Position

9. When using a directional antenna, the target will be in the main lobe of the antenna. So the direction that the antenna is pointing when it receives the echo indicates the direction of the target. For greater target accuracy, a smaller beam is needed.

Target Range

10. EM energy travels at the speed of light. The transmitting radar measures the time between sending the pulse, and receiving the return. This time indicates the distance of the target.

Target Closing Speed

11. When a target is moving towards or away from the transmitter, the frequency of the returned pulse is shifted from the original frequency by an amount dependent on the velocity of the target. The change in frequency is due to the compression of the EM waves, as shown in Figure 5-1. This change in frequency is called the Doppler Frequency Shift, and is determined by the speed of the target (towards or away from the radar) and the RF frequency being transmitted.

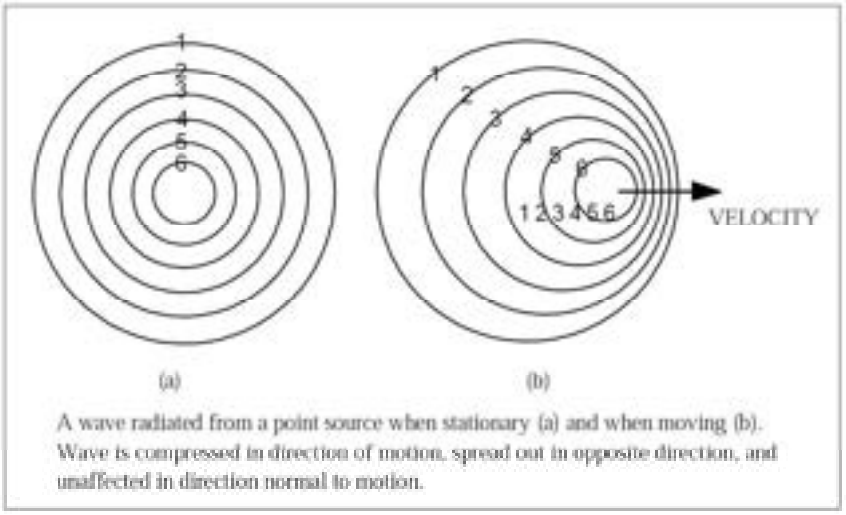


Figure 5-1 – Doppler Effect on Waves

12. As an example, if the transmitted frequency is 10GHz, and the velocity of the target towards the transmitter is 50km/h, the Doppler frequency shift is 927Hz. Thus, the frequency of the returned signal is 927Hz different from the transmitted frequency. If the target was approaching the transmitter, the Doppler would be added so that the returned frequency would be 10,000,000,927 Hz. If the target was moving away, the returned signal would be less than the transmitted frequency by the same amount.

13. If the returned signal is at a different frequency from the transmitted signal, the target must be moving towards or away from the transmitter. The Doppler frequency can be measured, and the velocity of the target can thus be determined. “Velocity” in this case means only the component of velocity towards or away from the transmitter. If the target was flying side-on to the transmitter, the Doppler frequency shift would be 0Hz, because the target is not flying towards or away from the transmitter.

14. The measurement of Doppler frequency as well as range and angle makes it possible to pick out a moving target from larger, stationary masses. For example, the echo of a plane flying close to a mountain may be completely obscured by the echo from the mountain, but

the plane's echo will be changed in frequency. A radar using Doppler can detect the plane easily.

Target Identity

15. There are two methods that a radar may employ to determine target identity.

16. **IFF (Identity Friend of Foe)**. IFF is known either as IFF or SSR depending on whether you are civilian or military. The ground radar has an Interrogator which sends out a coded signal stating the radar's identity and requesting the target's identity. The target receives the signal, checks the code, and if it's valid, transmits back a coded signal stating its identity and often other data such as its own position, altitude and speed. This system does not rely on transmitting a pulse and listening for the echo - one part of the system does transmit a pulse, but a complimentary system on the target receives the pulse and transmits a brand new pulse in reply.

17. **Non Cooperative Target Recognition (NCTR).** This is a feature of some sophisticated radars. If incorporated, NCTR is performed by the primary radar. NCTR identifies a platform by using techniques such as measuring Jet Engine Modulation (JEM) and measuring the length of the target (Range Profiling).

18. In JEM, blade movement complicates the doppler return of a target. For example, the radar returns from a hovering helicopter body will have zero Doppler shift. But the blades and rotor head are spinning and therefore any return off a blade or head component that is moving towards or away from the enemy radar will have a non-zero Doppler shift.

19. Aircraft turbine blades give similar high Doppler shifts. When a radar pulse is reflected from a target the slight Doppler changes can be measured. These changes turn out to be pretty consistent for a given type/make of engine. Thus it becomes possible to ID the engine type and possibly the aircraft type without its co-operation.

RADAR TYPES

Pulsed Radar

20. In a pulsed radar system, the transmitter is turned on and off by the modulator at a fixed repetition rate and for a fixed duration. The antenna transmits the pulse, then listens for echos until the next pulse is to be transmitted. By measuring the time delay between sending a pulse and receiving an echo, the target's range can be calculated.

21. The ability of a Pulsed Radar to detect Doppler shift depends on whether the transmitter is Coherent or not. This will be discussed in Chapter P1.

22. A pulsed radar can detect both moving targets and stationary targets, and can furnish range information for either, by noting the time interval between the transmitted and received signals. Furthermore, if a target is moving, the blip on the radar screen will move as the target position changes, so that the simple pulsed radar can furnish information about the target motion without using Doppler. On the face of it then, it appears that the use of Doppler shift in a pulsed radar is unnecessary complication.

23. It should be remembered that a moving target causes a Doppler shift, whether the radar uses the information or not. If the information can be used profitably, the radar should be equipped to sense the Doppler. In point of fact, sensing the Doppler shift permits the pulsed radar to detect a weak signal from a moving target in the presence of strong signals from

stationary targets. A typical application occurs when an enemy plane is flying close to a hill. The echoes from the plane and the hill arrive at the radar approximately the same time but since the hill has a much larger radar cross section, the echo from the plane is hidden. By looking at the Doppler shift , the echo from the stationary object (the hill) can be ignored and the moving target is easily located. In practice, this method can discern a moving target in the presence of clutter hundreds of times as strong

CW Radar

24. A Continuous Wave (CW) radar does not send pulses, but rather a steady amplitude signal. The CW system cannot detect range. However, it is excellent for detecting the closing speed of a target using Doppler shift.

25. An antenna cannot send and receive the same frequency at the same time, so a single antenna CW system cannot see stationary targets. However, the returns from moving objects (that introduce a doppler shift) can still be measured. Some CW systems use a separate transmit and receive antenna to allow the detection of stationary targets.

26. With a CW system, the transmitted RF energy is radiated, strikes the target and returns to the receiver. The frequency of the returning RF is compared with the frequency of the transmitted energy. If the target is moving relative to the radar, the returning energy is at a different frequency (a Doppler shift). This difference is amplified, processed, and sent to the indicator as a target velocity.

27. Use of the CW radar is limited because of its inability to determine range or to detect targets with zero velocity relative to the radar transmitter. It is also difficult to obtain the high RF power required to produce detectable RF echo's from distant targets because of the closeness of the transmitting and receiving antenna. This is true for all CW systems.

Frequency Modulated CW Radar (FM-CW)

28. The most serious limitation of the simple CW radar is that it cannot determine the range of the target. Since both the transmitter and receiver are working continuously, and every part of the echo from a target looks like every other part, it is impossible to associate a particular instant in the echo signal with a specific part of the transmission.

29. One method of obtaining range information from a CW radar is by using frequency modulation (FM). The transmitter emits a signal continuously, but the frequency is changed in a known fashion (see Figure 5-2). When the echo returns, it is at the frequency of the original transmission (assuming, for the moment, that the target is stationary), while the transmitter is now radiating at a new frequency. The difference in frequency, then, is a measure of the range.

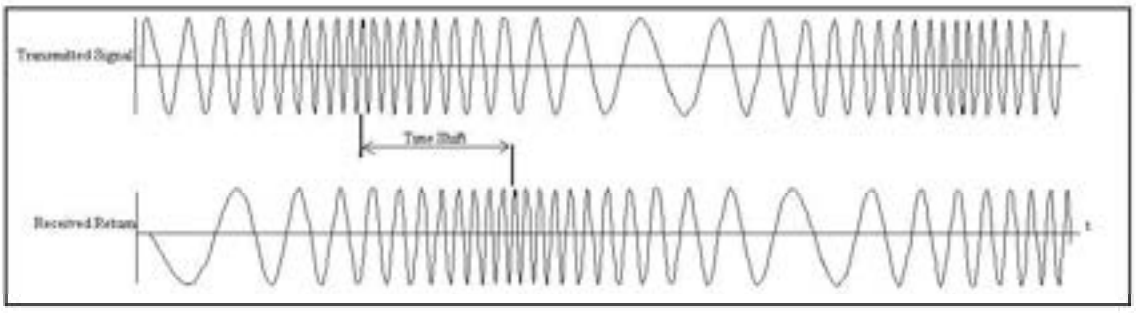


Figure 5-2 – FMCW Wave

30. FM-CW radars can also measure Doppler shift.

RADAR TERMINOLOGY

Radio Frequency (RF)

31. RF is the radio frequency that a radar operates on.

32. As a general rule, antenna size is governed by the RF. The lower the frequency, the larger the antenna. Therefore, large, bulky, fixed sites such as Early Warning / Ground Control Intercept (EW/GCI) radars have low operating frequencies while compact radars, such as Airborne Intercept (AI) radars, have high operating frequencies.

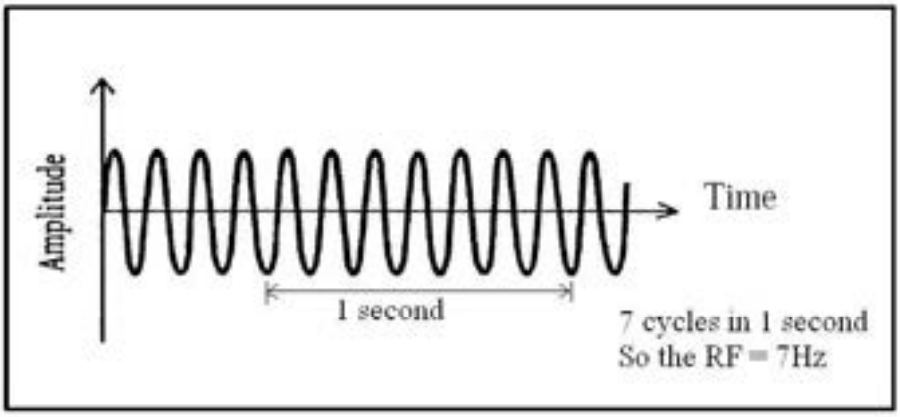


Figure 5-3 - RF Wave

33. The basic unit of RF measurement is the hertz (Hz) (previously called cycles per second). Most radars have a RF in the billions of hertz or gigahertz (GHz).

Pulse Repetition Interval (PRI)

34. The time measured from the leading edge of one pulse to the leading edge of the following pulse is termed the PRI. PRI has an inverse relationship with the PRF:

$$PRI = {}^{1}/_{PRF}$$

Pulse Repetition Frequency (PRF)

35. The number of pulses radiated per second is termed the PRF and is measured in Hertz (Hz). The higher the PRF, the more data returned to the radar per second and therefore, the greater the accuracy of system. However, higher PRFs give worse Maximum Ambiguous Ranges and more eclipsing problems.

Pulse Width (PW)

36. This is the duration of the pulse and is commonly measured in microseconds. Given that a pulse travels the speed of light, we can also measure the Pulse Length (in metres).

37. Normally when a pulse train is drawn, the RF is not shown under the pulse, but it is important to remember that it is there. The normal “pulse” diagram shows when the radar RF is turned on or off, but not the actual RF wave.

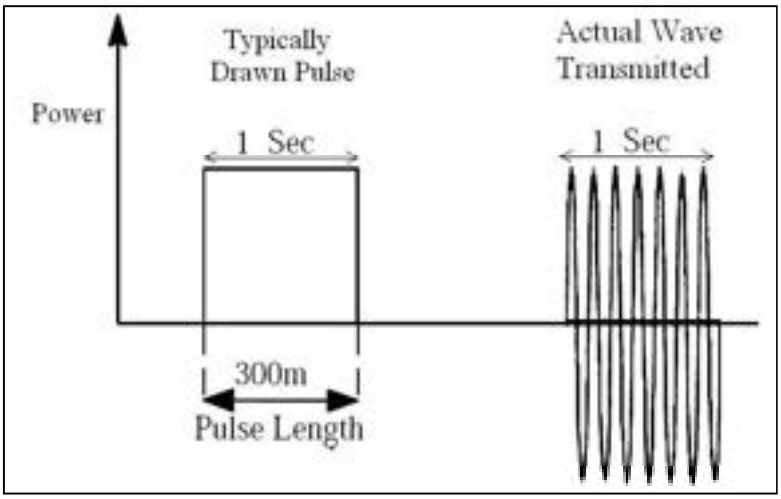


Figure 5-4 - Pulse Width

38. PW is the length of time that the radar is actually transmitting RF energy. A trade-off must be made between desired range and desired precision. A long PW means longer range with less precision, while a short PW yields a shorter range with greater precision. Normally, Early Warning / Acquisition (EW/ACQ) radars have long PWs, while Target Tracking Radars (TT) have shorter PWs.

Pulse Amplitude (Peak Power)

39. Pulse amplitude (or peak power) is a measure of the strength of each pulse. Peak powers in the 1000's of Watts range are normal.

Average Power

40. This is the average of the total power produced by the radar ie the amount of power radiated when the duration of "on" time and the peak power of the system are taken into consideration.

$$P_{av} = P_{peak} \times PW \times PRF$$

41. The average power is a limiting factor in most radars, as the heat generated by a radar is proportional to its average power. Heat produced by the radar needs to be dissipated quickly, or equipment damage will occur.

Pulse Energy (Maximum Detection Range)

42. As expected, stronger radar pulses produce stronger returns, and hence affect the radar's maximum detection range. Less obviously, the radar pulse width also has an affect on maximum range. Although not covered on this course (it's touched on in KCP1), longer pulses have smaller bandwidths. Thus the receiver (detecting the smaller bandwidth) will have less thermal noise, and hence be more sensitive. The overall result is that it is not the *power* of the pulse that determines maximum detection range, but the *energy* of the pulse (energy = peak power × pulse width).

Duty Cycle (DC)

43. The term used to specify the ratio of actual pulse transmission time to total time is called duty cycle.

44. A pulsed radar can only receive pulses when it is not sending them. A high duty cycle indicates that the radar is spending a large amount of time sending pulses, and not much time receiving, so it may miss target returns.

Angular Resolution

45. When an echo is returned from a target, the bearing of the target is assumed to be the direction that the directional antenna is pointing in at the time the echo is received. However, the antenna does not know whether the target echo came from the middle or side of the antenna beam. Additionally, two targets next to each other that are both in the beam will give one combined return. So the angular resolution, or angular precision, is determined by the beam width and beam height of the antenna beam (the narrower the beam the better the angular resolution).

Range Resolution

46. The radar determines target range by timing when pulses are returned. When two targets are very close together, the returns come back overlapping each other. The radar will correctly determine the range of the closer target, but will not see a separate return for the second target. The radar will simply display one target. This is the problem of range resolution, and is determined by the Pulse Width. Short pulse widths give good range resolution while long pulses give poor range resolution. Chapter P1 will discuss ways to improve the resolution.

Radar Resolution Cell

47. Putting the concepts of Angular Resolution and Range Resolution together, we get the Radar Resolution Cell (RRC). This is defined as the smallest volume of space that a radar can see into. The RRC's width and height are determined by the beam width and beam height, and the RRC depth is determined by the pulse width. The radar will receive echos from all targets within the RRC, but cannot determine how many targets there are within the RRC.

Minimum Range

48. Pulsed radar systems generally operate using the same antenna for both transmission and reception. When the antenna is transmitting, it cannot receive. If the reflecting object is close enough to return the energy to the radar system whilst it is still transmitting, this echo signal will not be received. The minimum distance that an object can therefore be detected by a pulsed radar system is dependant upon the PW.

$$R_{min} = \frac{c \times PW(metres)}{2}$$

Maximum Unambiguous Range

49. If a target is sufficiently far away from the radar, then the echo from the distant target may not return to the radar before a second pulse is sent. The echo from the first pulse will then be received by the radar after it sends the second pulse. The radar system can not determine which pulse the echo came from, hence it may produce incorrect range information.

50. The Maximum Unambiguous Range (MUR) is dependent on the time between pulses (PRI). Target echoes that occur after the PRI are termed "second-time-around" returns.

$$\text{MUR} = \frac{c \times PRI}{2}$$

51. Note that the Maximum Unambiguous Range is different to the Maximum Range. A radar still receives echos from targets well beyond its MUR, however the radar will simply display the targets at the wrong range.

RADAR PARAMETER SUMMARY

52. There are a number of tradeoffs to be considered when deciding on the parameters of a radar as described in the following table.

	Long Pulse Width	**Short Pulse Width**
Pulse Width	Poor range resolution	Good range resolution
	Good maximum range	Poor maximum range

	Low PRF	**High PRF**
PRF	Low update rate	High update rate
	Good Max Unambiguous Range	Poor Max Unambiguous Range
	Hard to measure Doppler shift	High average power
		Eclipsing problems

	Lower Frequency	**Higher Frequency**
Frequency	Greater range (less absorption)	Better resolution & Precision
	Better power efficiency	Smaller equipment size

	Wide	**Narrow**
Beamsize	Greater Spatial Coverage	Good Angular Resolution
	Smaller Antenna Reflector	Higher Gain

CHAPTER 6

RADAR SCAN TYPES AND TRACKING

Assessment Criteria

Describe different scan types, and how radars use them to track targets

6.1 List different radar functions

6.2 Describe basic search patterns

6.3 Describe tracking methods

INTRODUCTION

1. Most radar applications require an antenna capable of scanning its beam, either mechanically or electronically or both, to search for targets in a volume of space. A radar's scan pattern is the pattern that the main beam traces out as the radar searches the sky. Scanning techniques for single or multiple beams may be classified as either mechanical or electronic.

2. The early radar antennas developed during and after Word War II relied primarily on mechanical scanning. More recently the development of high power RF phase shifters and frequency-scanning techniques have allowed the beams to be scanned more rapidly by avoiding the inertia associated with moving mechanical components.

3. Accurate pointing is a requirement inherent in all radar applications that measure target location. Radar requirements are generally more demanding than those of communications antennas, especially when precise measurements of target positions are required.

4. Radar applications tend to be divided between two main functions, search and track. The search function requires that the radar examine a volume of space at regular intervals to seek out targets of interest. In this case the volume must be probed at intervals ranging typically from one to ten seconds and every possible target location examined.

5. The radar tracking function operates in a manner quite different from search. Here one or more targets are kept under continuous surveillance so that more accurate and higher data rate measurements may be made of the target's location. Often the interesting targets detected by a search radar will be assigned to and acquired by a tracking radar. Certain radar systems combine search and track functions by time-sharing the agile beam of a phased- array antenna.

RADAR FUNCTIONS

6. Broadly there are four types of functions that radar perform. These are:

   a. Search (Acquisition),

   b. Tracking,

   c. Guidance, and

   d. Imagery.

SEARCH RADAR

7. Search Radar scan one or more beams through a volume in space at regular intervals to locate targets of interest. The search function is sometimes referred to as acquisition, as in a missile-defence system in which detected targets are eventually tracked and intercepted. It is

also called surveillance when targets are being monitored, as in the control of air traffic. But regardless of the term used to describe the search function, the common requirement is to scan a specified region of space at regular intervals.

8. Search radar types include:

   a. Early Warning (EW),

   b. Air Search (AS),

   c. Ground Control Intercept (GCI), and

   d. Target Acquisition (TA).

9. Radars designed to perform only the search function therefore tend to operate at lower frequencies, and just how low is often determined by a trade-off between antenna size and desired angular resolution. The most important parameters determining the size and cost of the search radar are the coverage volume, scan time, and target size.

10. The 2D search systems use a fan beam that is broad in elevation and narrow in azimuth because only the target range and azimuth co-ordinates are required. In the 3D system elevation is also measured to determine target altitude, and in this case the antenna's beam must be relatively narrow in both angular co-ordinates.

11. Good examples of search radars are the old civil air traffic control radars. Search radars normally have slow scan rates and are optimised to detect targets at the maximum possible range.

12. It is desirable for GCI radars to give target height information. A common way of accomplishing this is by transmitting multiple lobes at different angles. The target returns in each lobe can be compared to determine the approximate height of the target.

Height Finders

13. Height Finders can be visualised as a search radar turned on its side. Instead of producing azimuth information, they produce accurate elevation angle and range information. This is then resolved into height information.

14. Height Finders are normally associated with weapon systems. They have antennas that are tall and thin (fine beam in elevation, wide beam in azimuth), and have a characteristic 'nodding' motion.

Target Acquisition

15. Target Acquisition radars are essentially high speed, short range, search radars. Their job is to find targets for a weapon system and to pass the information on as quickly as possible. To achieve this they have high scan rates. As the information will normally be used by another radar which will 'lock-on' or 'track' the target, the information passed on only has to be accurate enough for the target tracking radar to acquire the target for a 'lock'.

TRACKING RADAR

16. In radar applications for which target data with greater accuracy or a higher data rate than can be provided by a search radar are required, a tracking radar is used. The tracking

radar antenna usually has a pencil beam that follows a target in track to provide continuous measurement of the target's position in range, azimuth, and elevation. In some applications target signature data in the form of amplitude and phase variations of the target return are also measured.

17. Targets are usually first detected by a search radar and then designated to the tracker for measurement. To acquire a target, the tracker must search a small volume about the designated point. When the target is detected, range and angle tracking loops close, and the range gate and beam are held centred on the target until target data are no longer required and the track is broken off.

18. Tracking radars tend to operate at higher frequencies than search radars. The equipment designers need to trade off antenna cost, beam size and peak power to achieve the required detection range and accuracy. Fundamental to all tracking-radar antennas is the ability to measure a target's position within the beam so that the beam may be centred on the target.

19. Tracking radar types include:

a. Target Track (TT),

b. Airborne Interceptor (AI), and

c. Multimode.

Target Tracking

20. Target Tracking radars provide very accurate azimuth, elevation and range information so that a weapon may be accurately used against a target. Examples of target tracking radars are those used by Anti-Aircraft and Artillery (AAA) and Surface to Air Missiles (SAM) systems.

Air Intercept

21. The name Air Intercept (AI) radar originally described a simple range only radar (i.e. no azimuth information) that supplied target range to an interceptor aircraft's optical sight. The range information was then used to decide when to fire a gun or rear-hemisphere AAM. As interceptor aircraft radars were upgraded to be used in all-weather and so gained other modes they now come under the umbrella of 'multi-mode' radars, however, the name AI radar is still commonly used to describe radars on interceptor/fighter aircraft regardless of the modes available.

Multi-Mode

22. Multi-Mode radars are exactly that. Whether used to describe ground-, sea- or air-based radars, it will normally cover target search/acquisition, tracking and illuminating functions as well as probable navigation functions. When a radar is described as multi-mode, it is best to read the 'fine print' to find out exactly what it does.

GUIDANCE

23. Radar is also used to aid missile guidance (see chapter 11). The missile engagement is generally short range, so high frequency radar is used with small antennas.

Target Illumination (TI)

24. Target Illuminating radars bathe the target with RF energy so that another part of the weapon system may track, or more usually home to the target. A good example of a target illuminating radar is that of a semi-active radar homing SAM or Air to Air Missile (AAM) system, where the missile has a receiver only and homes to the target by homing to reflected energy supplied by a target illuminating radar. A target illuminating radar is either pointed by a target tracking radar, or has target tracking functions itself. (Semi-active homing is described more in chapter 11).

Missile Guidance (MG)

25. Missile Guidance can be a radio or radar link, providing missile steering commands.

26. When radar is used, it can serve two purposes simultaneously. Radar pulses are emitted, with the returns being used to track the missile position, whilst at the same time the PRI of the pulses constantly changes, and the missile receives these as steering commands.

Beacon Indicator (BI)

27. To aid missile tracking, the missile emits pulses which are used by the ground control radar to determine the missile position and issue steering correction commands.

IMAGING

28. Imaging applications for radar include Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR). Both methods aim to decrease the Radar Resolution Cell (RRC) to such a small size to enable clear, detailed pictures of targets.

Synthetic Aperture Radar (SAR)

29. In SAR, a single antenna is used to view a target area from a number of different viewing points. The data from all viewing points is processed together, giving a result similar to an antenna array. (The antenna array uses multiple viewing points separated in space to create a narrower beam. The SAR method uses multiple viewing points separated in space *and time* to achieve the same result). SAR processing also measures the different doppler shifts from objects in different parts of the beam to effectively sharpen the angular resolution.

Inverse Synthetic Aperture Radar (ISAR)

30. ISAR is especially useful with naval targets. When viewed side on, a rocking-rolling ship produces a large doppler shift from its mast (which is moving the most) and a small doppler shift from its hull. The ISAR radar measures these different doppler shifts to effectively reduce the angular resolution of the beam and give a more detailed picture.

Weather Radar

31. Weather radar is also a kind of radar imaging application. The frequency of the radar is chosen to deliberately correspond to a high atmospheric water absorption peak, to allow the radar to see different water contents in the air.

SEARCH PATTERNS

32. The antenna search pattern describes the path that the main beam traces as the antenna rotates to detect targets. Common scan patterns include:

a. Circular,

b. Sector,

c. Helical,

d. Spiral, and

e. Raster.

33. The scan pattern used depends on the aim of the radar. Circular gives a 360˚ field of view, but normally does not provide height information. A forward looking radar on a fast jet is concerned mostly with what is in front of the jet, and not so much what is beside the jet, and the spiral scan it uses spends most of its time looking forwards.

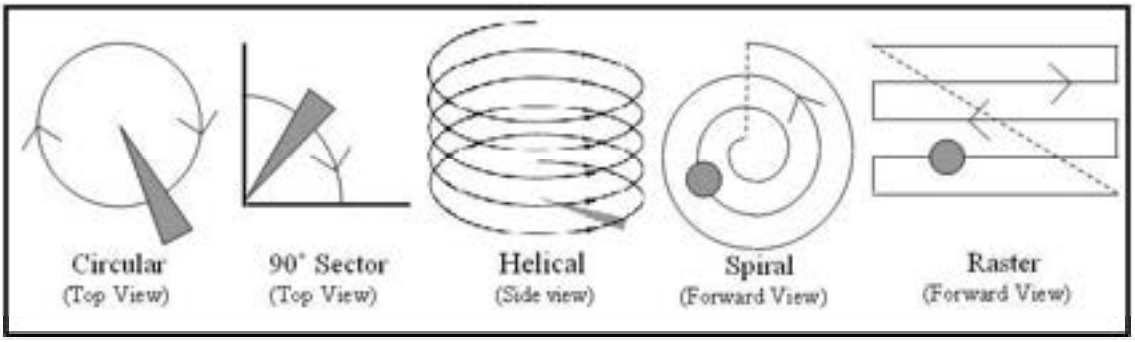


Figure 6-1 – Search Patterns

Time on Target

34. The speed of the beam (slew rate) and the size of the beam, give rise to the Time-On-Target. This is the length of time that the target is being illuminated by the main beam on each sweep. The Time-on-Target needs to be long enough to get enough returns off the target to detect it. If the antenna is sweeping too quickly, or the Pulse Rate Interval is too large, the antenna may sweep the beam over a target and not actually illuminate it.

TRACKING METHODS

35. When a radar return is received through the antenna, the radar does not know where in the antenna's beam the target was located. It could be on the side of the beam, or in the middle (or even in a sidelobe). Also, when the target moves out of the beam (and generates no return) the radar doesn't know which direction the target went. In order to constantly track the target's location, the antenna needs to perform some mechanism to ensure the target is always in the centre of the beam.

Sequential Lobing

36. With sequential lobing radars two or four beams are transmitted sequentially (one after the other) and the amplitude of the returned signals is compared to extract the relevant Angle off Boresight (AOB) data. A two beam system is only capable of resolving the AOB in one

dimension (either Azimuth or Elevation), whereas the four beam system can resolve the AOB in both azimuth and elevation.

37. The two beam sequential lobing radar sequentially transmits two beams aimed to either side of the line of sight (LOS) of the target Figure 6-2. The return power from each of the beams is compared and the strongest return will be from the beam which is pointing in a direction closest to the direction of the target. The antenna LOS is steered in the direction of the strongest return.

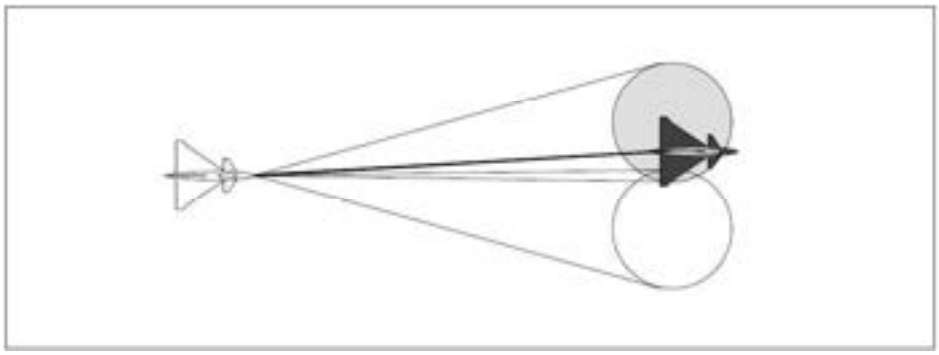


Figure 6-2 – Two beam sequential Lobing

Conical Scan Radar

38. Another type of lobing is the conical scan radar. With this type of radar the boresight of the radar is rotated in a circular pattern around the LOS of the target. Figure 6-3 illustrates the principle of operation in more detail.

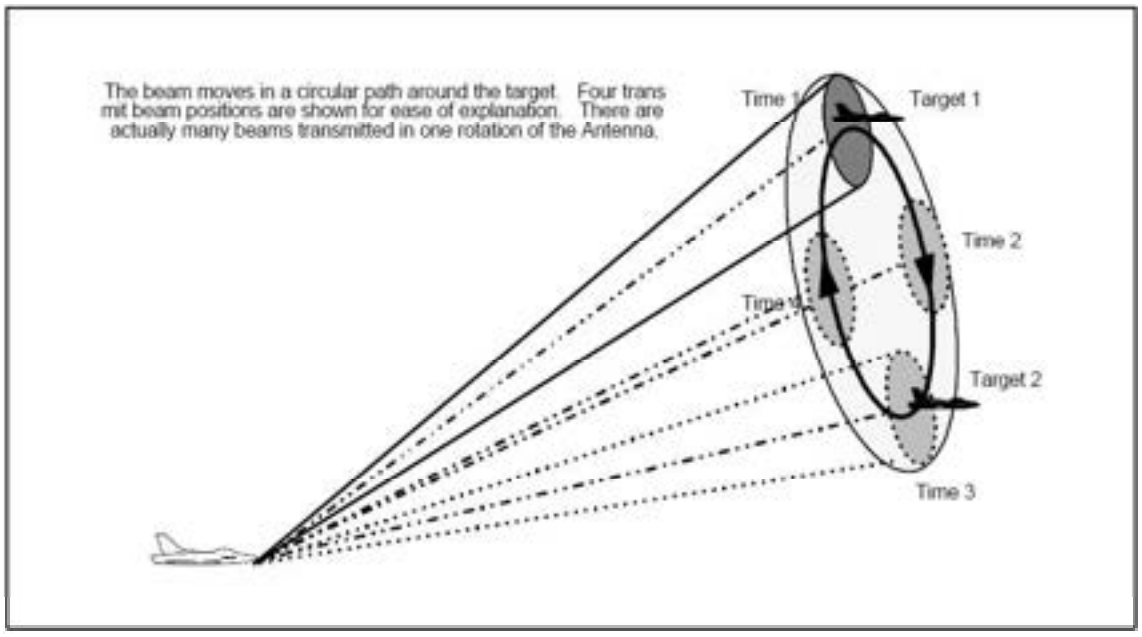


Figure 6-3 – Conical Scan pattern

39. The returns from the conical scan are used to extract antenna drive, angle error and angle rate as with a normal angle tracking loop. The amplitude of the returned echos is directly proportional to the error angle or AOB. If the target was precisely centred in the scanned area it would be illuminated by the same amount of RF energy during the entire scan of the antenna and the returned energy would be constant.

Scan-On-Receive Only Methods

40. With sequential lobing and conical scan radars, the target aircraft can detect where the scan beam is looking at any point in time. This allows a certain type of synchronous jamming to be performed. To deny the target aircraft information about where the beams are looking, scan-on-receive only beams are used. In this method, a wide beamwidth transmit beam is used (which doesn't scan). The receiver antenna or feeds are scanned or sampled in elevation and azimuth to perform target tracking and acquisition. Two common On-Receive-Only methods are Lobing on Receive Only (LORO) and Conscan on Receive Only (COSRO).

Simultaneous Lobing or Monopulse Radars

41. A monopulse radar is a target tracking system that obtains sufficient information from each transmitted pulse to update its computers and reposition its antenna. Instead of scanning a single beam, the radar uses a minimum of four beams which transmit together but receive independently. By comparing the energy returned in the beams, this system can make azimuth and elevation corrections. Comparisons can be made on time of pulse arrival at each receive antenna, signal strength received at each receive antenna, or phase orientation at each receive antenna. Three advantages of this system over conical scan are its speed in gathering data, its ability to track a target even though there is a large amount of pulse-to-pulse fading, and the absence of active scanning that could be vulnerable to countermeasures.

42. Amplitude comparison monopulse radars use beam formation techniques similar to the 2 and 4 beam sequential lobing radars. However all the beams are transmitted and received simultaneously. The transmitted beams point away from the centre of the antenna at a slight angle. The beams are all separated by approximately 90 degrees for better angular definition. The returns from all four beams are of differing amplitudes and the target is assumed to be in the beam having the strongest return.

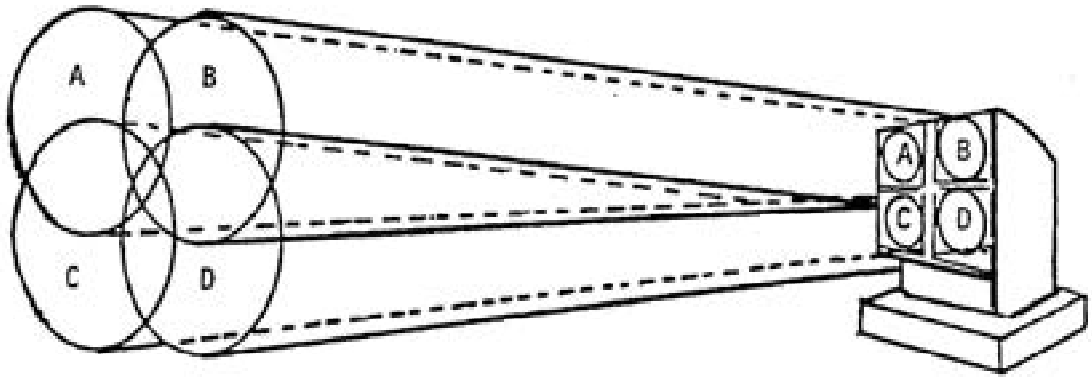


Figure 6-4 – Monopulse Beam pattern

Track-While-Scan Radars

43. The Track While Scan (TWS) Radar performs a combination of search and track functions. Search only radars carry out no target correlation from scan to scan. The TWS radar, however, automatically decides if a target return correlates to a target return from a previous scan, or if the return is that of a new target. TWS radars can track many targets simultaneously. An advantage of TWS is that the target is not aware of being tracked, as the beam does not remain locked on the target.

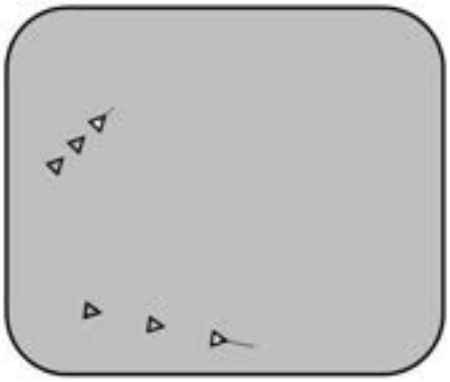


Figure 6-5 Track-While-Scan Display

44. The narrow angle raster scan radar is capable of tracking multiple targets which fall within its scanned area in space. This type of radar employs a narrow pencil beam to improve angle resolution and a short pulse width to improve range resolution. To track the targets the radar first needs to process the incoming data, then correlate this data into existing and new targets.

45. To ensure accurate tracks, a very fast scan rate is required. This may limit the field of view of the radar.

Search-While-Track Radars

46. When using an Active Antenna Array, multiple beams are able to be formed. The main beam of the antenna performs a search scan, and when a target is located, a separate beam is created to track the target. The separate tracking beam performs its own tracking method, while the main antenna beam still performs a search scan.

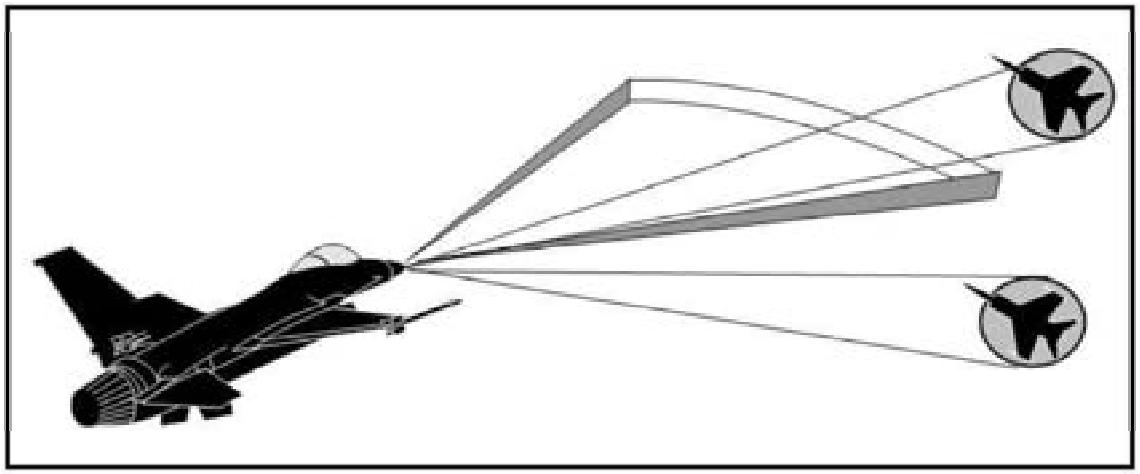


Figure 6-6 Search-While-Track Concept

CHAPTER 7

RADAR IDENTIFICATION

Assessment Criteria

Determine probable radar system applications from antenna features

7.1 Identify antenna features relevant to radar system operation

7.2 Determine probable radar system applications from antenna features

THREAT TYPES

1. Electronic Warfare Officers (EWOs) divide radars into three general categories; those that are an indirect threat to the aircraft, those that pose a direct threat, and those that are of the non-threat variety. The following paragraphs give brief descriptions of the radars found in these groups, and how to identify them.

Indirect Threat

2. Radars in this group are important to an EWO since they may be used to position airborne interceptors and/or pass information to surface-to-air missile sites and anti-aircraft batteries.

3. Examples of radars in this group are:

   a. Early Warning (EW) or Long Range Radar (LRR);

   b. Acquisition Radars;

   c. Height Finder Radars; and

   d. Ground Control Intercept (GCI).

Direct Threat

4. Immediate threat radars are of primary concern to the EWO since they supply information to a weapon system that can destroy his aircraft. These radars detect the aircraft, track it, and continuously update information to a weapon system computer. The computer will automatically fire and alter a missile's trajectory or slew the turret to insure a hit.

5. Examples of radars in this group are:

   a. Airborne Interceptor Radar;

   b. Surface-to-Air Missile Radars;

   c. Monopulse Radars;

   d. Track-While-Scan Radars (TWS); and

   e. AAA Radars.

Non-Threat Radars

6. From the aircraft's standpoint, non-threat radars include navigation, missile detection, and mapping radars.

7. Examples of radars in this group are:

   a. Over-the-Horizon;

   b. Airborne Navigation Radars;

   c. Air Traffic Radars, eg. Precision Approach Radar (PAR);

   d. Surface Search Radars; and

   e. Side Looking Radars.

8. In summary, it is not sufficient to merely understand what a radar is; you must also know how the different types of radar are employed. The way in which different radar sets are used and the information they can gather that is of primary importance to an EWO.

KEY IDENTIFYING FEATURES

9. When identifying a radar type, the only real clue is to examine the antenna. The design and movement of the antenna gives a lot of information about the radar's operation.

Does it Scan?

10. A search antenna needs to search the entire sky, or at least a large portion of it. A tracking antenna will only need to scan a very small piece of sky. An antenna that only rotates, but does not search in elevation is not very useful as a search antenna, unless the beam shape is also fan like. But a fan shape beam is no good for accurate tracking.

11. How fast the antenna scans also gives an indication of the range it is seeing. A long range search antenna needs to rotate slowly, to allow time for the radar pulses to be returned from a large range. A fast rotating antenna will only be looking for returns from short range targets.

Antenna Size/Shape

12. The size and shape tells us about the beam size and beam shape. A circular parabolic antenna has a pencil beam. This is an accurate beam - good for tracking, but cumbersome as a search beam.

13. The larger the antenna the smaller the beam size. A search radar needs to see a long distance, so a low frequency is used. This leads to a wide beam, but to compensate for the wide beam, a large (costly) antenna is used. This then gives a relatively accurate beam (1-10˚).

14. A tracking radar only needs to see a shorter distance, so the antenna size can be smaller (which is cheaper). The smaller antenna has a wide beam (inaccurate) so a higher frequency is used which again gives a relatively accurate beam (<5˚).

Other features

15. There are normally other indicators that help to identify the radar's purpose such as:

   a. Multiple antenna feeds. These give height information to an antenna that normally wouldn't tilt.

b. IFF antenna. IFF antennas are typically wide and short rectangles. The presence of an IFF antenna suggests the radar is looking airborne.

c. Other Sensors (such as a camera). These are typical on a fire control radar as a backup engagement mode should the radar be jammed. Additional antennas may also be present for missile guidance (often a CW signal requiring a separate receive and transmit antenna).

TYPICAL RADAR ANTENNA

Search Radar

16. Search radars generally operate in the low frequency RF to enable large detection ranges. But this creates a wide beam (and hence poor angular resolution). So the antenna is made large to improve the angular resolution, and to improve signal gain.

17. The search antenna will also probably be rotating slowly, to enable pulses time to return from very distant targets. Search radars generally have poor height resolution – a trade-off to be able to scan the entire sky quickly enough – and this can be seen by the relatively short height of the antenna (giving a large beam height).

Figure 7-1 Typical Search Antenna

Tracking Radar

18. A tracking radar needs to track a target accurately in both angle and height – requiring a small beam width and beam height (a pencil beam). The antenna also needs to be agile enough to follow a target's movement. Generally the detection range required is less than that of a search radar, so a higher RF is selected. This decreases the beam size (and hence gives better accuracy) so the antenna dish size can also be reduced.

Figure 7-2 Typical Tracking Antenna

Weapons Guidance

19. The weapons guidance antenna requires accurate tracking ability – so it resembles the tracking radar in appearance. However, a typical weapons guidance antenna will also have multiple other antenna (for separate missile guidance) and possibly cameras (for backup and anti RF jamming capability).

Figure 7-3 Typical Weapons Guidance Antenna

CHAPTER 8

BASIC RADIO THEORY

Assessment Criteria

List the fundamental principles of EM communications

8.1 Define Modulation

8.2 List the differences between Analogue and Digital signals

8.3 List the advantages and disadvantage of Data and Voice communications

INTRODUCTION

1. A widely used application of EW energy is that of Radio communication, and this covers two of the pillars of EW (see Chapter 1). In the Weapons pillar, we are not too concerned with **what** is being transmitted – just the fact that there **is** a transmission. A transmission can be detected and used to aid ES efforts (in locating and identifying the transmitter). The Communication Intelligence pillar is concerned with investigating **what** is being transmitted – but this is not covered in this course.

RADIO TRANSMISSION

2. In Radio, EM energy is generated and sent through an antenna. The antenna converts the EM energy from electrical signals in the wires into EM energy in the air (see Chapter 4). The EM energy radiates from the antenna (travelling the speed of light) and may be detected by another receive antenna.

3. The EM energy being transmitted has a strength that is varying in time (and often frequency). These variations contain Information, which is used by the receiver. A sample of a voice signal is shown in Figure 8-1. The voice signal has been converted from sound to EM energy. The time graph is only a few milli-seconds long and shows how the amplitude (or power) varies. A voice signal also has a range of different frequencies in it, ranging anywhere from 0Hz to 20,000Hz depending on the person.

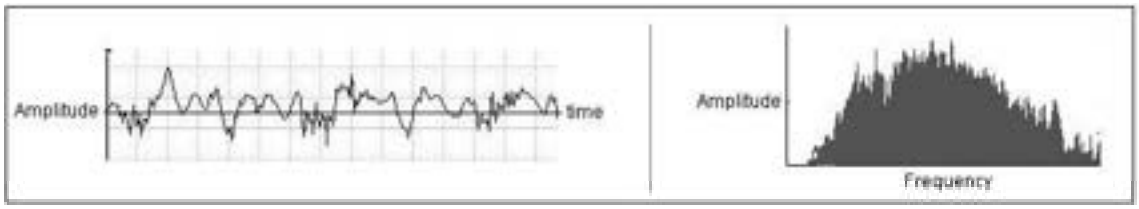


Figure 8-1 Voice Signal in Time and Frequency

4. The range of human hearing is from 0Hz to 20,000Hz, so these are the frequencies we wish to transmit. However, such low frequencies would require using antennas that are ten's of kilometres long – which is impractical. Modulation is used to correct this.

MODULATION

5. Modulation refers to changing an EM wave in some way to send information. One main use for modulation is to take a low frequency signal and "convert" it into a high frequency signal. In actual fact, we are taking a high frequency signal, and changing something about it that reflects the low frequency signal. The high frequency signal is called the carrier. Figure 8-2 shows how a signal is applied to a carrier wave to either frequency or amplitude modulate the carrier wave.

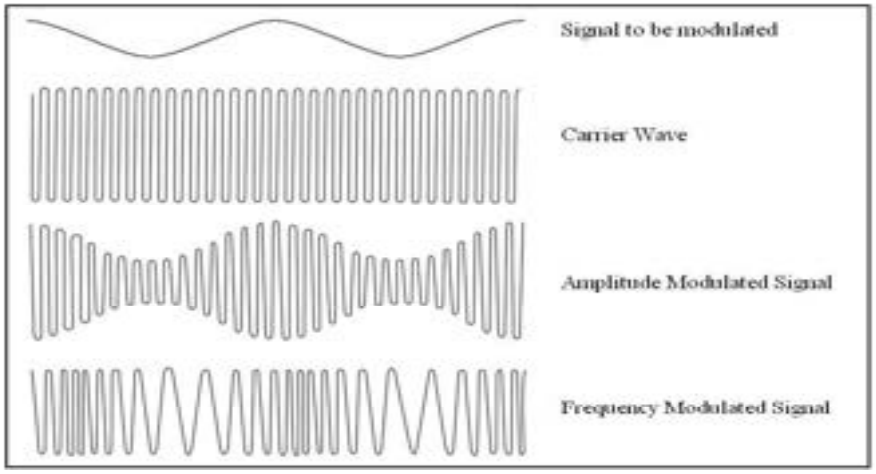


Figure 8-2 Signal Modulation

6. The effect of modulation changes the frequency spectrum of the signal. For example, a voice signal with a bandwidth from 0 to 20kHz when modulated onto a carrier wave at 2MHz will now occupy a bandwidth from 1.98MHz to 2.02MHz.

7. To receive the modulated signal, the receiver needs to know the frequency of the carrier wave. It can then de-modulate the signal (remove the carrier) to extract the original signal.

MULTIPLEXING

8. It is normally desired to be able to send many different radio signals at the same time. If the multiple signals (of the same frequency) were simply all transmitted together, then any receiver would receive all signals merged or overlapping, and be unable to receive the message.

9. Multiplexing refers to being able to send multiple signals at the same time, and have them individually received without the overlapping.

Frequency Division Multiplexing

10. With Frequency Division Multiplexing (FDM), each user is assigned a different bandwidth of frequencies they can transmit on, and can transmit on those frequencies all the time. An example of this is commercial Radio. Each station has its own bandwidth, and constantly transmits.

11. The bandwidth of human hearing only extends from 0Hz to about 20kHz. The bandwidth allocated to a user may be for example from 91.8 to 92.0MHz, so to transmit the signal in the allocated range it must be "shifted" to the higher frequency using modulation (as discussed in the previous section).

Time Division Multiplexing

12. Time Division Multiplexing (TDM) allows all users to send using the same frequencies, but assigns "time slots" for them to transmit in. An example of this is a conference call. Users communicate in turn, with only one transmitting at a time.

13. This method is not normally used for analogue voice communications, as it slows down the rate at which each user can send information. However, it is very common for data communications. Frequency Division Multiplexing is very commonly used for voice

communications, as the bandwidth of voice is relatively small and this technique does not require precise timing as TDM. Data communications has a much higher bandwidth, meaning less frequency channels are available, so high data rate systems would tend to use TDM.

Code Division Multiplexing

14. Code Division Multiplexing (CDM) allows all users to transmit using the same frequencies and at the same time, by mixing the signal to be transmitted with a precise coded signal. The receiver needs to also have the coded signal to mix with what is received to recover the original signal. All of the different signals being transmitted do overlap and jumble together, but the CDM process is able to extract the desired signal (since it has the code), and all other signals appear as noise.

RADIO RECEIVERS

15. The radio signal needs to be received by the end user. The radio receiver has an antenna to collect the signal from the air and convert it to an electrical signal. The receiver itself knows a little about the format of what was sent, so it 'listens' to the range of frequencies that were transmitted and decodes the signal according to the modulation type.

16. Noise is random energy across all frequencies, and adds to the amplitude of what is received. Noise is covered in Chapter 3. For Amplitude Modulated (AM) signals, the information is contained in the amplitude of the signal, so noise will distort the original signal. To ensure a good Signal to Noise ratio (SNR), a strong signal is required.

17. Frequency Modulated (FM) signals do not contain information in the amplitude – rather it contains information in the frequency. So any noise that distorts the amplitude, does not distort the original signal. Additionally, a FM signal is transmitting at 100% power all the time which may increase the range of the signal.

COMMUNICATIONS FREQUENCY SELECTION

18. When choosing an operating frequency for a communications system, there are a number of trade-offs. The final frequency chosen will depend on the intended use of the communications system

19. Low frequencies have much greater range (due to less atmospheric absorption). Low frequencies (in the HF range) are also able to diffract off the ionosphere enabling over-the-horizon ranges. Lower frequencies also exhibit a ground wave component, however this has limited propagation range. But low frequencies are also plagued by external and atmospheric noise. This noise decreases as the frequency increases.

20. Higher frequencies (in the VHF band and above) offer less range due to atmospheric absorption, and are line-of-sight, but have less noise and a greater bandwidth available. The bandwidth required to transmit a signal depends on the signal type. Low quality voice could be transmitted with a bandwidth of 5kHz, high quality voice with 20kHz, while video may require more than 5,000kHz.

VOICE VS DATA

21. In a working environment, communication information can be sent as either voice or data.

22. Voice communication is:

a. **Time intensive**. The information has to be gathered and put into the correct format (e.g. Surpic Report).

b. **Prone to Errors**: Mistakes could be made at any of the steps such as speaking or hearing a wrong position. Many English words sound like other words.

c. **High Workload**: The recipient may be too busy or preoccupied with other tasks to comprehend the information properly. Also the collector/transmitter may be too busy to collect and transmit information properly.

d. **Basic Protocol**: Almost any country will be able to transmit/receive an AM or FM voice signal with no issues.

23. Data communication is:

a. **Fast**: Data can be more quickly sent, received and verified by a computer.

b. **Accurate**: Automatic error checking can be easily added to data communications.

c. **Flexible**: Voice, data, pictures and more can all be sent over a data line.

d. **Organised**: Computers are able to most optimally schedule the communications link, ensuring no down time and maximum information transfer.

e. **Bandwidth Intensive**: Data communication requires more bandwidth than the same amount of information sent via analogue signals.

f. **Protocol Specific**: To transmit data, the transmitter and receiver need to agree on the protocol (e.g. modulation type, bit order, error correction, data rate). There are many different protocols, and it needs to be agreed to prior to communications.

ANALOGUE VS DIGITAL

24. Analogue or digital refers to how a signal is composed. An analogue signal can contain any amplitude (so an infinite number of values). A digital signal is one that only takes one of a small range of values – with the most common being either a 1 or a 0. An analogue and digital signal is shown in Figure 8-3. This signal can then be modulated onto a carrier wave to be transmitted.

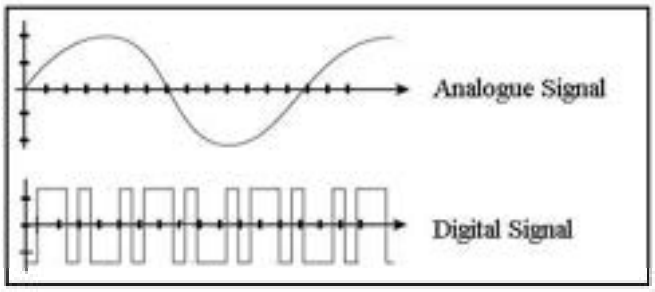


Figure 8-3 Analogue and Digital Signals

25. Common analogue signals are audio and video (voice, music and TV). These have very different bandwidths, so analogue systems tend to be designed for a specific type of signal. (Sending a low bandwidth voice signal over a system designed for high bandwidth TV would be very inefficient – as most of the bandwidth is not being used). Any noise that interferes with an analogue signal is difficult to remove, reducing the SNR.

26. Digital signals offer an amount of noise immunity as the information sent obeys 'rules' (in amplitude and time). A digital "1" may be defined as any amplitude between 50% and 100% of max signal strength, with a "0" being anything less than 50%. If noise alters the amplitude of a "1" signal from 100% down to 60%, it would still be received as a "1". This noise immunity is at the expense of bandwidth. In general, digital signals require more bandwidth than analogue (however, digital signals can be compressed using pattern recognition techniques). Digital bandwidth equals 1/PulseWidth. So the shorter the pulses (and therefore the more information sent) the larger the bandwidth. Digital systems can also handle many different signal types (eg voice, picture, video, text) as they are all just a series of 1's and 0's.

RADIO ELECTRONIC SUPPORT (ES)

27. In normal operation, the radio receiver is held by whoever you wish to transmit to. However, nothing stops an enemy from having their own radio receiver in the area. They would then be able to detect your EM transmission and 'eavesdrop'. This is ES.

28. There are two aspects to ES with radio. The first is the enemy's ability to detect your transmission. This requires the following considerations:

a. Frequency. The enemy must have their radio tuned to the same frequency as your transmission. Since they don't know what frequency you are using, they may need to scan across all frequencies.

b. Signal Strength. The enemy needs to receive a strong enough signal to detect it. This may be more difficult for the enemy due to:

(1) Bandwidth. The wider the bandwidth of the receiver, the more frequencies it will detect, but the less sensitive it is (see Chapter 3). The enemy doesn't know your bandwidth, so their receiver will not be matched to the transmission.

(2) Receiver Power. The enemy may also be further away from the transmitter than the intended recipient. This will reduce their received signal strength. However, they may employ larger antennas to boost the signal strength (see Chapter 4).

c. Time Overlap. Even if the enemy is listening to the right frequency, they need to be listening at the same time that you are transmitting – otherwise they will move on and not detect you.

29. The second aspect of ES is the ability to **decode** the radio transmission and extract intelligence from it. This required the following consideration:

a. Modulation. For analogue signals, the enemy ES receiver needs to know what modulation is being used to be able to demodulate correctly.

b. Protocols. For digital signals, the correct protocol is needed.

30. ES is covered in more depth with radar systems in Chapter 9.

RADIO ELECTRONIC ATTACK (EA)

31. When the enemy has detected your transmission, they are then able to perform Electronic Attack (EA) methods. This may include:

a. Denial (jamming). If the enemy transmits a strong signal at the same frequency of your transmission, any receiver listening on that frequency will receive both signals combined. If the enemy signal is stronger, then the original signal may not be able to be received (this is like yelling over top of someone talking).

b. Spoofing (deception). The enemy can try to transmit information with the same frequency and modulation. The receiver will not know that the transmission has come from the enemy, and believe that the signal is from the original transmitter. (this is like pretending to be someone else on the phone or radio).

32. EA is covered in more depth with radar systems in Chapter P4.

RADIO ELECTRONIC PROTECTION (EP)

33. Electronic Protection (EP) is protecting ourselves against enemy ES and EA. EP techniques will not be discussed in detail, but touched on throughout the course.

EP (Anti-ES)

34. EP methods to prevent enemy detection include:

a. Directional Transmission. Rather than transmitting in all directions, if the radio signal can be directed towards the intended recipient, the enemy will not be able to intercept it. This is covered in Antennas in Chapter 4.

b. Burst Transmission. The enemy has to sweep across all frequencies to find the frequency we are transmitting on. If we only transmit some of the time, there is a greater chance that when he checks the frequency we are using, we may not be transmitting so he'll not detect us.

c. Frequency Hopping. Similar to burst transmission, but rather than intermittently transmitting on one frequency, we continuously jump between transmitting on a number of different frequencies.

d. Spread Spectrum. This technique greatly increases our bandwidth (so we're transmitting over a large number of similar frequencies) but reduces our effective transmit power – thus being harder for an ES receiver to detect.

35. EP methods to prevent enemy decoding of our transmission include:

a. Encryption. The signal is scrambled according to a "code". If the enemy doesn't know the code, they will be unable to reconstruct the transmitted signal.

b. Spread Spectrum. Spread spectrum also employs a "code". If the enemy doesn't know the code, they will be unable to reconstruct the transmitted signal.

EP (Anti-EA)

36. EP methods to prevent enemy jamming (denial) include:

a. Any technique that reduces detection. If the enemy can't detect your transmission, then they don't know to jam you.

b. Increased Power. Jamming relies on being able to generate a jamming signal stronger than the original signal.

37. EP methods to prevent enemy spoofing (deception) include:

a. Encryption. The enemy will be unable to code their own messages with your encryption since they don't know your code. They may be able to record and replay valid messages to create confusion.

b. Frequency Hopping. The order of frequencies being used is in a hard-to-predict sequence (like a code!). The enemy will not know the next frequency to transmit on.

c. Spread Spectrum. Spread spectrum also uses a "code" that the enemy will not know.

d. Challenge/Response. When receiving a suspect signal, a challenge can be issued to the sender to verify who they are. This is a pre-planned question with a pre-planned answer which the enemy will not have.

CHAPTER 9

ELECTRONIC SUPPORT

Assessment Criteria
Describe Electronic Support (ES) receivers
9.1 State the general purpose of ES receivers
9.2 List the similarities and differences between RWRs and ESMs
9.3 List the steps of RWR/ESM processing between threat transmission and threat display

ELECTRONIC SUPPORT (ES)

1. ES is that division of EW which involves actions taken to search for, intercept, locate, record and analyse radiated electromagnetic energy, for the purpose of exploiting such radiations in support of EW operations. The operations may be either pending or immediate. ES is mainly, therefore, the collection, evaluation and dissemination of information about a victim's electronic systems and devices, although it has been found desirable to extend the range of ES activities to include threat detection and warning, and the acquisition of, and homing onto, a target. In short, ES acts as the eyes and the ears of EW and, as such, is the cornerstone of EW.

2. ES is a solely passive operation. The collection devices do not themselves radiate energy to any significant extent and so the victim cannot electronically detect when ES operations are being undertaken. Consequently opportunities for deception or for planting false information are few. Furthermore, not only is interception difficult to detect but it is also difficult to counter. The interception equipment is usually located out of enemy reach, on home territory or in international waters or airspace. It is only when hostilities break out (and when time for remedying any damage is lacking) that the victim can see the result of ES operations against him.

3. ES operations should not, however, be confused with the wider activity of intelligence gathering, which provides information for other than just EW purposes. The long term or strategic gathering of ES information is known as SIGINT (Signals Intelligence) which itself is divided into COMINT (Communications Intelligence) - which concentrates on the gathering of electromagnetic information about communications emitters - and ELINT (Electronic Intelligence) which concentrates on non-communications emitters. The short term or tactical sub-division of ES is warning and is concerned with detecting transmissions which pose a physical threat to the vehicle intercepting those transmissions. The third subdivision of ES is Homing involving the location of emitters for immediate reconnaissance or attack purposes.

THE NEED FOR ES

4. Electronic intelligence information is required both for long and short-term planning and for immediate tactical use in support of forthcoming offensive or defensive EW operations. In a tactical situation the prime function of ES is to support such activities as:

a. **Threat Detection.** Changes in radar activity can act as alarm signals to an aircraft flying in a hostile environment.

b. **Warning.** Indications of impending enemy operations against interdicting aircraft may be obtained.

c. **Avoidance.** By revealing the enemy electronic order-of-battle, the location and density of radiating systems and the types of emitter installed at each defensive

site, accurate and up-to-date information about radars en route to a target and in the vicinity of a target can be obtained. This information is needed before optimum tactics (which may be combinations of manoeuvres and EA) can be planned to aid penetration to the target.

d. **Target Acquisition.** The presence of radar systems can indicate the existence of a hitherto unknown target or assist in the acquisition of a known radar defended target.

e. **Homing.** Bearing information obtained from a threat signal can assist in homing an aircraft or weapon to the source preparatory to acquiring and attacking it. Information of Interest

5. The transmissions of ES interest would be mainly radar or radio signals, but they could also include guidance and navigational signals, laser emissions, infra-red radiations or radiations in the visible part of the electromagnetic spectrum.

6. More specifically, information in the radar field would include the type of radar eg. pulsed, CW, etc, the carrier frequencies employed and their bandwidth, pulse repetition frequencies, pulse durations, transmitted powers, modulation, scan patterns, the function of each radar system eg. AEW, GCI, AI, weapon control, and the locations of ground-based radar equipment.

ES RECEIVERS

7. The main difference between ES receivers and other conventional receivers is that the expected input signals are unknown, and in fact some of these signals may be kept deliberately covert to inhibit detection by the ES receiver. The receiver architectures of radar receivers and ES receivers are the same, however the ES receiver does not know what frequency the intercepted pulses will be, when they will arrive, how they are modulated or what polarity they are. This makes the ES receiver's task much more difficult.

8. Because it is desirable to obtain as much information as possible from the threat radars in a very short period of time, the requirements for an ES receiver are becoming very demanding. The receiver must:

a. have a wide input bandwidth with fine frequency resolution,

b. be highly sensitive (be able to detect very weak signals),

c. have a good dynamic range (to be able to detect very strong and very weak signals),

d. receive all polarisation signals,

e. scan in all directions,

f. be able to process simultaneous signals, and

g. have a high probability of intercept.

9. Processing high frequency (>2GHz) radar signals is very difficult for standard electronics. Therefore, the primary job of the ES receiver is to convert the high frequency RF

to a lower, easy to process frequency signal. Once this is done, the signals can be sent to be deinterleaved and matched.

PROBABILITY OF INTERCEPT

10. The design of an intercept receiver is greatly influenced by the problems and strategies for searching for radar signals. Probability of Intercept is probably the most important performance characteristic of EW surveillance and reconnaissance equipment. It provides a measure of the ES system ability to detect a signal.

11. To detect a target signal the ES system needs to be **on and receiving** while:

a. looking in the right direction as the threat,

b. aligned with the correct signal polarisation, and

c. scanning the matching frequency.

12. The probability of Intercept of an ES system is the sum of all the combinations of the above factors. When discussing the probability of intercept it is assumed that there is an adequate signal level available to the receiver so that the probability of detection is very high and the probability of false alarm rate is very small.

Blanking

13. No practical ES system will have a 100% POI. On an aircraft, there are a number of transmitters including the main radar, radar altimeter, IFF and data-link system. Each of these transmitters can be detected by the aircraft ESM, and falsely identified. To prevent this, the ES system is temporarily turned off when these devices are transmitting – this is called Blanking.

ES PROCESSING

14. Processing of EW information involves analysing, de-interleaving and classifying the pulses detected by the EW receiver sub-system. The steps involved are:

a. receiving signals,

b. analysing (measuring) the parameters,

c. de-interleaving,

d. threat identification, and

e. provision of output for display and/or recording.

Parameter Analysis

15. Probably the most important piece of equipment within the ELINT system is the pulse analyser. The analyser measures elements of the emitter including:

a. Angle of Arrival (AOA),

b. Radio Frequency (RF) and bandwidth (BW),

c. Time of Arrival (TOA),

d. Pulse Amplitude (PA),

e. Pulse Repetition Interval (PRI) / Pulse Repetition Frequency (PRF),

f. Pulse Width (PW),

g. Polarisation,

h. Scan Type and Scan Rate,

i. Intra Pulse and Inter Pulse modulation including:

(1) constant (common search/tracking),

(2) stagger (eliminates MTI blind speeds),

(3) jitter (form of EA),

(4) dwell (resolves range/velocity ambiguities),

(5) sliding (constant altitude coverage during elevation scans),

(6) scheduled (used with electronic scans), and

(7) Pulse compression.

j. Firing order (order in which the PRIs are fired),

k. Beam pattern, and

l. Statistical data.

16. This type of system is the most complex and requires a fair amount of operator processing. Information gained from these systems are used to 'load' the signature libraries of RWR and ESM receivers.

Signal De-Interleaving

17. Signal de-interleaving involves the extraction of a signal of interest from the mix of all signals that may be present. Deinterleaving is multi-dimensional, applying not only de-interleaving in the time and frequency domain but also spatial de-interleaving (angle of arrival).

Threat Identification

18. Threat identification is the process whereby processed data passed by the parameter analysis process is compared with pre-identified parametric data stored in a library of emitters of interest.

19. Construction of an ES library essentially involves formatting the EW System's ELINT database to provide a parametric database on emitters of interest, against which parameters of intercepted signals can be compared. The data file(s) containing the emitters of interest and

their associated parameters is commonly referred to as a Threat Library, Load, User Data File (UDF) or Pre Flight Message (PFM).

RWR VS ESM

20. A Radar Warning Receiver (RWR) and an Electronic Support Measures (ESM) system perform very similar roles but differ slightly.

21. Both systems:

a. Passively detect, classify and ID radar emissions.

b. Direction find the emission.

c. Can trigger countermeasures as required.

22. RWRs:

a. Display simple information for pilot situational awareness.

b. Require very little operator input.

c. Normally used inside the battlezone.

23. ESMs:

a. Provide detailed information for operator analysis.

b. Normally have a dedicated operator.

c. Normally used outside the battlezone so need to be more sensitive.

DIRECTION FINDING

24. ES/RWR systems use four main methods for direction finding. These are described in the following paragraphs.

Directional Antenna

25. The directional antenna will scan the area of interest. The direction that the antenna is pointing when the maximum signal strength is received will indicate the direction of the signal. Directional antennas offer higher antenna gains (than the next three methods), and can therefore allow a much greater detection range, however they significantly lower the ES Probability of Intercept (as the antenna is only 'looking" in a very small portion of the sky at any point in time).

Amplitude Comparison

26. By using multiple omnidirectional antennas, the ES system can detect the minor difference in the signal amplitude (signal strength) between the different antennas. This amplitude difference is due to the spreading and atmospheric attenuation loses caused by the extra distance that the signals must travel to get to each antenna. Measuring the difference allows the ES to calculate the path distance difference, and therefore the angle of arrival (AOA).

Phase Comparison

27. The ES system can measure the phase difference of the incoming signal in a multiple antenna system. If there is a path distance difference between different antennas, then the signal phase being received in each antenna will also be different. Measuring the phase difference allows the AOA to be calculated. When only two antennas are used, there are multiple possible directions of arrival. However, using a third antenna spaced differently to the first two allows the true direction to be calculated. Often, four antennas are used in the ES system, placed as far from each other as possible. This is called an interferometic array.

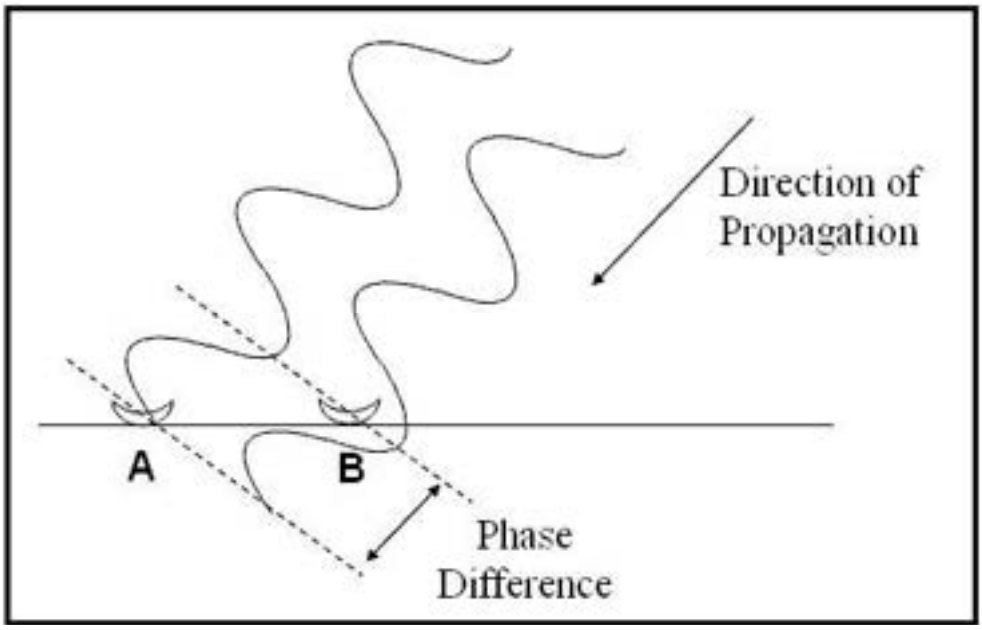


Figure 9-1 – The Interferometric Principle

Time Difference of Arrival

28. Again using multiple omnidirectional antennas, the time that a signal pulse arrives at each ES antenna will be slightly different if the distance from each antenna to the signal source is different. Measuring the time difference, and knowing that radar signals travel the speed of light, allows the path distance difference to be calculated, and hence the AOA.

THREAT LOCATION

29. When a signal is intercepted in the electromagnetic spectrum, it is often important not only to identify the source of the signal and to extract information from it, but also to determine the location of the transmitter. This is normally only performed on an ESM system (not an RWR).

30. Threat location can be determined by measuring the direction to the threat from two separate vantage points. This may be from two separate ES receivers, or two measurements from a single ES receiver as the ES receiver moves between measurements.

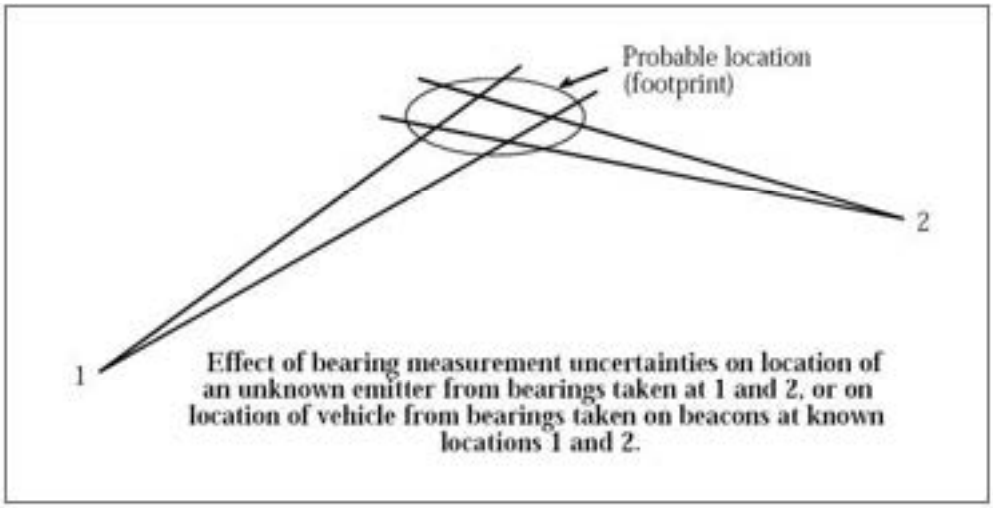


Figure 9-2 – Direction Finding

31. Unfortunately, direction finding cannot locate a source with pin-point accuracy. There is always a degree of uncertainty in measuring the direction of arrival of a signal. Crossed bearings then lead to footprints of probable location areas. Figure 9-2 shows such a footprint. The confidence can be increased (i.e. the footprint reduced in size) if multiple bearings can be obtained, or if each bearing was measured with higher accuracy. When locating by means of two bearings, it is desirable to have the angle between the bearings be approximately 90 degrees.

THREAT AMBIGUITIES

32. Threat ambiguities arise when the received signal matches two or more different signals in the ES library. In this case, the true identity of the threat is not known, so the higher priority threat will be shown.

33. ES equipment designers can minimise ambiguities by making the receiver measure as many parameters as possible (RF, PRI, modulation etc). ES programmers can minimise ambiguities by defining the threat parametrics as finely as possible, and only programming those threats that are likely to be seen in that engagement.

CHAPTER 10

CHAFF

Assessment Criteria
Describe the characteristics and use of chaff
10.1 Define chaff
10.2 Describe the characteristics of chaff
10.3 Describe the use of chaff to achieve break lock

INTRODUCTION

1. In general, chaff refers to large quantities of passive reflecting material deployed in the atmosphere as a countermeasure against enemy radar. First introduced in World War II, chaff has proven to be a very efficient, cost effective EW tool which can:

a. provide radar camouflage or screening for friendly force activities;

b. confuse enemy radar warning, acquisition or control systems with electromagnetic clutter and false targets;

c. create the appearance of military targets or activity to deceive hostile forces; and

d. provide self protection against tracking radars by:

(1) decoying terminal homing systems; or

(2) detonating radar fuses.

CONSTRUCTION

2. Chaff can be made of metal or of non-conducting fibres coated with a conducting material. The most common forms are ribbons of aluminium foil, and glass or nylon fibres coated or striped with aluminium or zinc. Fibreglass chaff is made in diameters ranging from about 0.02 mm to 0.05 mm.

3. It is impractical to produce light-weight chaff having a low rate of fall for frequencies much below 1000 MHz, so for coverage in B and C bands rope is often used. Rope refers to chaff elements, which may be several hundred feet long, usually made from multi-filament aluminiumised-glass fibres or aluminium foil.

APPLICATIONS

4. Chaff can be used to either jam or deceive a victim radar. Jamming usually occurs when a large quantity of chaff is used close to the aircraft boresight position, to saturate the victim's radar receiver. Deception occurs when chaff is dispensed to approximate an aircraft return, therefore, mission requirements dictate the quantity and method of dispersal. For example, Figure 9-1 shows a representative jamming application of chaff with the corresponding victim radar display. Note that the real target position is obscured while the receiver is saturated from the chaff. In fact, chaff can satisfy a variety of broad operational roles such as corridor screening, confusion, deception, signal attenuation and self protection.

5. These are not hard and fast categories, for people differ somewhat in their definition of possible chaff applications. If properly planned and deployed, chaff can satisfy multiple operational requirements simultaneously, for example, a chaff corridor could be deployed as a

deceptive measure for an early strike, however, it could also serve to provide protection for a later strike.

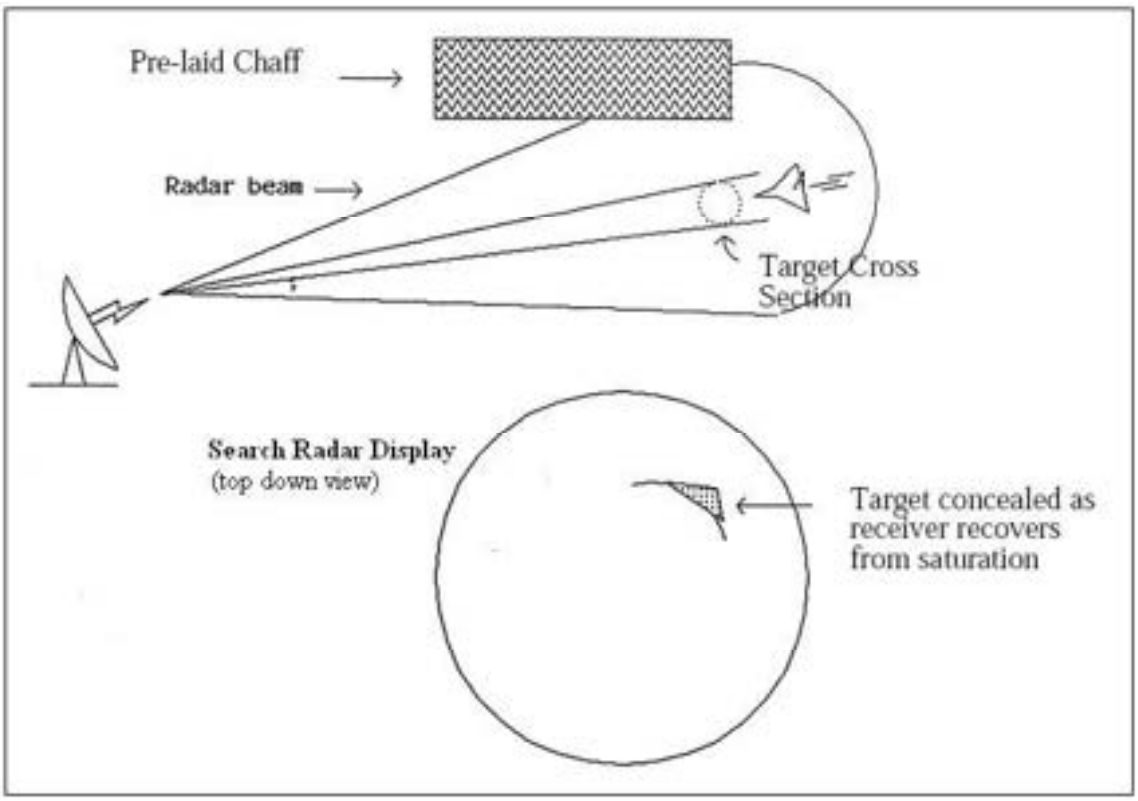


Figure 10-1 - Representative Use of Chaff

Chaff Screening

6. The primary objectives of a chaff corridor screening mission are to deny information to hostile systems regarding presence or absence of strike aircraft within the corridor and to prevent tracking of aircraft entering the corridor. At the time of use by strike aircraft, the chaff RCS per resolution cell throughout the usable volume of the chaff corridor should be greater than the RCS of the strike aircraft within the given resolution cell.

False Target Generation Using Chaff

7. To generate an appearance of targets and air activity on the victim's radar display resulting in a commitment of forces against non-existent strikes, deception can be implemented by using chaff. The radar cross section of individual chaff targets should approximate the returns from aircraft targets. Random, rather than uniform deployment, of chaff targets is required to force radar operators to consider every return. Random appearance of targets at various altitudes using delayed opening chaff can be useful. The use of false target generating chaff is particularly useful when used to simulate slow-moving vessels such as ships. The chaff is fired from conventional naval guns and configured so as to produce a very fast bloom time. Large volumes of chaff are required to produce an RCS greater than the RCS of the ship. Firing of the chaff towards the radar will increase the RCS considerably.

Track Breaking Chaff

8. Chaff, when deployed to prevent or break enemy radar tracking of aircraft, needs to satisfy two rules.

a. The chaff must produce an RCS larger than that of the aircraft.

b. The chaff and aircraft must both remain within the same radar resolution cell until the chaff cloud has a larger RCS than the aircraft.

9. The effectiveness of track breaking chaff is usually increased when co-ordinated with an evasive manoeuvre, provided chaff deployment is not continued into the manoeuvre.

10. **Break-Lock Sequence.** When chaff is deployed, the threat emitter is unable to differentiate between the target and chaff reflections. It therefore tracks the weighted average power (the power centroid) which lies somewhere between the target and the chaff. When the chaff and aircraft separate enough, they will not both be able to be in the same RRC. If the chaff RCS was greater than the aircraft, then the power centroid will be closest to the chaff. Hence the chaff will remain in the RRC, and the aircraft will exit it.

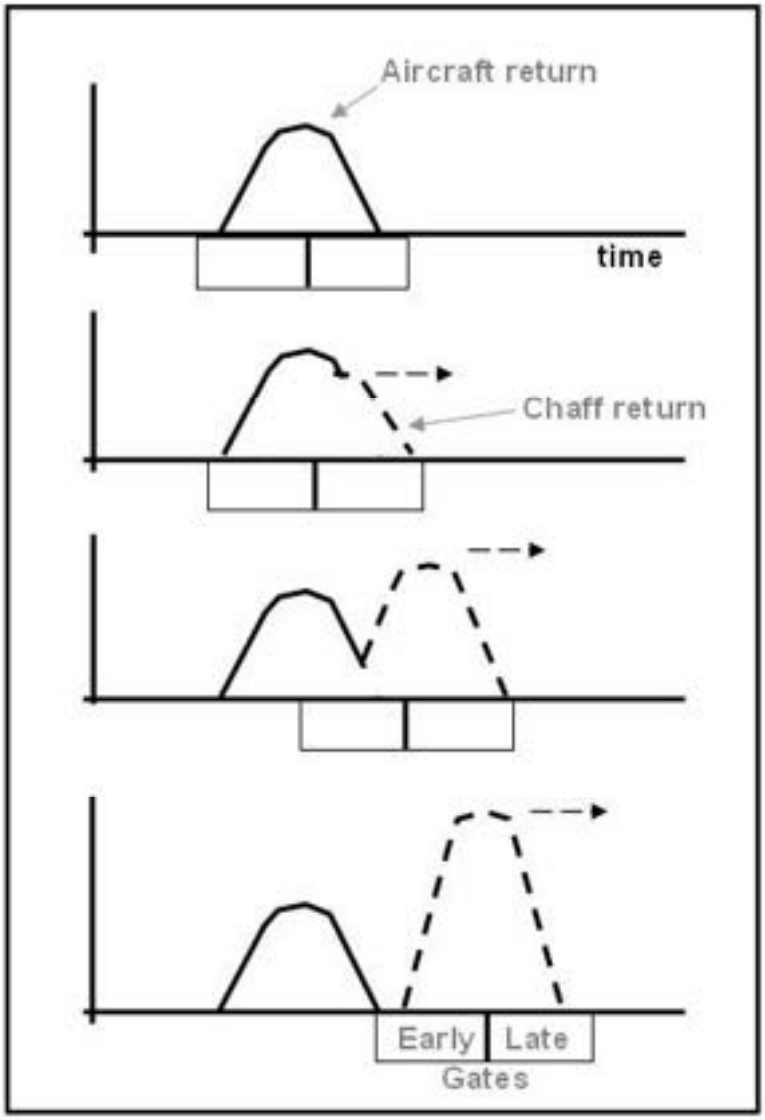


Figure 10-2 – Break Lock

EFFECTIVENESS

11. Chaff can be used to perform varying tasks, however, its effectiveness depends on the radar type to be countered. The concepts of chaff corridors providing a screen against search

radars, and track break chaff being used against a tracking radar have been discussed. Chaff is a very good stand alone Electronic Counter Measure (ECM), but, its effect can be improved when used in conjunction with other EA techniques, such as Velocity Gate Walk Pull Off (VGPO).

12. **Search and Monotracking Radars**. Search and monotracking radars are quite susceptible to chaff deployment, although early deployment of chaff against these radars can produce a beaconing effect, which will only alert the radar operator. Thus, careful consideration has to be given to determine at what time the chaff should released. Radars fitted with a Moving Target Indicator (MTI) capability are less susceptible to chaff as they ignore all stationary or slow moving targets.

13. **Track-While-Scan Radars.** In general, Track-While-Scan radars are not good candidates for self protection chaff deployment as the chaff highlights aircraft position for subsequent manual tracking.

14. **CW and Pulse Doppler Radars**. CW and Pulse Doppler radars can measure target velocity, and can therefore distinguish between chaff and aircraft easily. Against these radars, chaff is used in conjunction with other EA techniques. An example of this is the combination of chaff and VGWO. The VGWO is used to walk the victim's radar velocity gate downward in frequency sufficiently to lock onto chaff packets that have been dispensed from the aircraft.

CHAFF CHARACTERISTICS

15. Understanding the properties and characteristics of individual chaff elements is essential when defining the overall chaff cloud characteristics.

Frequency Response

16. Each chaff element behaves like a ½ wavelength dipole antenna. Thus the chaff reflects radar best when the lengths of chaff elements are about ½ of a wavelength of the RF illuminating it.

Fall Rate

17. The lifetime of chaff is limited to the time taken for the chaff to fall to earth. Fibreglass chaff typically falls at rates from 0.1-0.5 m/s at sea level, depending on the fibre diameter and the thickness of coating. Fall rates vary with atmospheric pressure, hence at 12,000 metres the fall rate is about twice as great as at sea level.

Polarisation

18. When chaff is initially deployed, it is subject to turbulence and vortices in the wake of the aircraft. Dipole orientations relative to each other change rapidly, and at any one instant any dipole orientation is equally likely. As long as dipole orientation in the cloud is random with respect to any illuminating radar, radar polarisation is immaterial.

Bloom Time

19. To be effective, chaff must present a radar cross section larger than the aircraft while the aircraft and chaff are within the same radar resolution cell. The time available for the chaff cloud to expand depends on aircraft speed and the size of the radar resolution cell. Typical bloom times available for defeating tracking radars are around 0.1 – 3 seconds.

20. Chaff can be made to expand very quickly after dispensing by ejecting the chaff in cartridges containing an explosive charge. Each cartridge contains chaff which may be cut for many different frequency bands and there may be more than ten million elements. Aircraft turbulence further dispenses the chaff cloud after which atmospheric turbulence acts on the chaff elements. As the chaff blooms, its physical area enlarges until the radar cross section approaches the value given by the sum of the individual chaff elements.

21. Aluminised glass chaff designed for corridor screening might take 100 seconds to reach its maximum RCS value. The corridor screening is then effective as long as the chaff elements within the cloud lie within a volumetric radar cell. As the chaff cloud continues to expand, the individual chaff elements are dispersed into several radar resolution cells, thereby diminishing the effective overall RCS of the chaff.

CHAFF DISPENSERS

Dispensing Systems

22. Many forms of chaff dispensers have been used operationally and the type of dispenser chosen for employment depends upon the application. The operator of a self screening chaff dispenser needs the capability to very quickly cause a bloom because the chaff may be required as a decoy against a tracking radar, on the other hand, the aircraft EA operator tasked with sowing a long chaff corridor can use a dispenser that has a slower reaction time but with a large capacity.

Dispensing Modes

23. The following modes of chaff dispensing are general modes for Counter Measure Dispensing Sets (CMDS), and also apply to flare dispensing.

24. **Manual Mode.** A manual dispensing mode allows the aircrew to initiate a fire signal to the dispensers. This fire signal may dispense several payloads from one or more dispensers. Any required sequence is controlled by the aircrew who must do all the timing between ejections. This was the first dispensing mode used and is really only suitable for use against 1960's threats and probably only one of them at a time.

25. **Program Mode.** The program mode allows the aircrew to select a suitable sequence program from a library of programs and manually initiate it. This mode overcomes the necessity for the aircrew to do their own timing. The programs are either fixed in hardware at time of manufacture or re-programmable before or during flight. The options available to the programmer are fairly limited. The AN/ALE-40 is an example of such a re-programmable Counter Measure Dispensing Set (CMDS).

26. **Semi-Automatic Mode.** Modern CMDS go one step further and automatically select, from the available options, the most suitable program to meet the threat. The aircrew must still manually initiate the program. This type of mode is available on the ADDS II and AN/ALE-47 CMDS.

27. **Automatic Mode.** The most advanced CMDS have an automatic mode where the CMDS selects the most appropriate program and initiates it. Selection of the most appropriate response is an involved process and uses information from all sensors. The automatic mode will be essential in future combat where advanced and multiple threats will otherwise overload the aircrew. The ADDS II and AN/ALE-47 CMDS have automatic modes.

CHAPTER 11

MISSILE GUIDANCE

Assessment Criteria

Describe various types of missile guidance

11.1 List the key components of a guided missile

11.2 Describe the following types of homing guidance:

11.2.1 Active Homing

11.2.2 Semi-Active Homing

11.2.3 Passive Homing

11.3 Describe the following types of command guidance:

11.3.1 Beam Riding

11.3.2 Command Link

11.3.3 Seeker Assisted Guidance

INTRODUCTION

1. The classification of guided missiles in most general use gives four broad categories:

    a. Air to Air Guided Weapons (AAGW) or Air to Air Missiles (AAM),

    b. Surface to Air Guided Weapons (SAGW) or Surface to Air Missiles (SAM),

    c. Air to Surface Guided Weapons (ASGW) or Air to Surface Missiles (ASM), and

    d. Surface to Surface Guided Weapons (SSGW) or Surface to Surface Missiles (SSM).

MISSILE SYSTEM COMPONENTS

2. The principle components of a typical guided weapon are:

    a. warhead system, which consists of

        (1) warhead. Missile warhead categories include blast, fragmentation, continuous rod, shaped charge and cluster submunitions.

        (2) safety and arming mechanisms, and

        (3) fuse. Common fusing types are radar proximity fusing, active laser proximity fusing, passive IR fusing, crush switch, G switch and command fused.

    b. guidance unit. This is the ‘smarts’ of the system and will be discussed further in this chapter.

    c. control unit. The control system moves the missile and provides roll stabilisation through using aerodynamic controls (moving surfaces) or thrust controls.

    d. propulsion unit. This includes air breathing or non-air breathing engines.

    e. power supplies. Often the power supply is a thermal battery, which once turned on cannot be turned off again.

    f. airframe.

MISSILE GUIDANCE AND CONTROL

GUIDANCE

3. Guidance systems may be categorised as high data rate systems or predetermined data systems. Under each of those categories are sub-categories as shown in Figure 11-1.

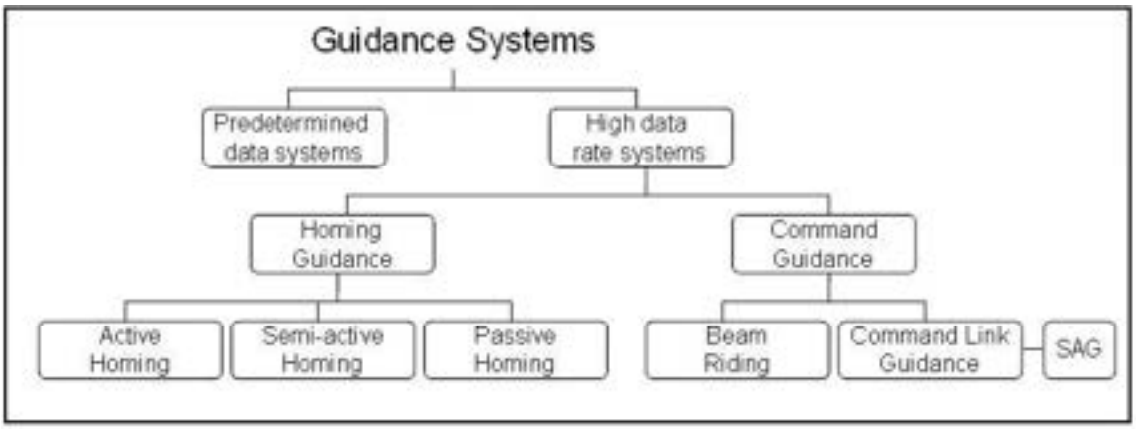


Figure 11-1 Guidance Systems

PREDETERMINED DATA SYSTEMS

4. Predetermined data systems are associated with stationary targets and non-electromagnetic guidance systems. Target coordinates are set into the missile before launch and are not changed during the guidance phase. Corrections to the flight path may be applied by the guidance system as a result of discrepancies noted by navigation sensors (long term corrections) or by short term monitors of the flight path (such as missile autopilot).

5. In sophisticated systems an inertial platform will sense errors from the desired flight path and issue control inputs accordingly to regain the flight path. In less complex guided weapons an auto-pilot may be used.

6. Navigation updates to the missile in flight may be from a number of sources including:

   a. radio navigation aids,

   b. satellite fixes,

   c. star fixes, or

   d. map matching.

HIGH DATA-RATE SYSTEMS

7. High data-rate systems fall into two categories, homing systems where the missile looks forward towards the target, and command systems where the missile looks back for commands, with the commanding agency computing the target position. High data-rate systems may effectively approach continuous data systems.

HOMING SYSTEMS

8. With homing systems, the missile must establish a track towards the target. The method of establishing the track gives rise to the three forms of homing which are:

a. active homing,

b. semi-active homing, and

c. passive homing.

Active Homing

9. The missile transmits some form of energy towards the target and endeavours to receive the reflection of this energy using it to establish the missile-target sight line. Figure 11-2 illustrates active homing.

a. Advantages of active homing are:

(1) accuracy, and

(2) launch and leave capability.

b. Disadvantages of active homing are:

(1) low transmitter power,

(2) complexity,

(3) susceptibility to counter measures,

(4) difficulty in separating targets in formation, and

(5) warning given to target.

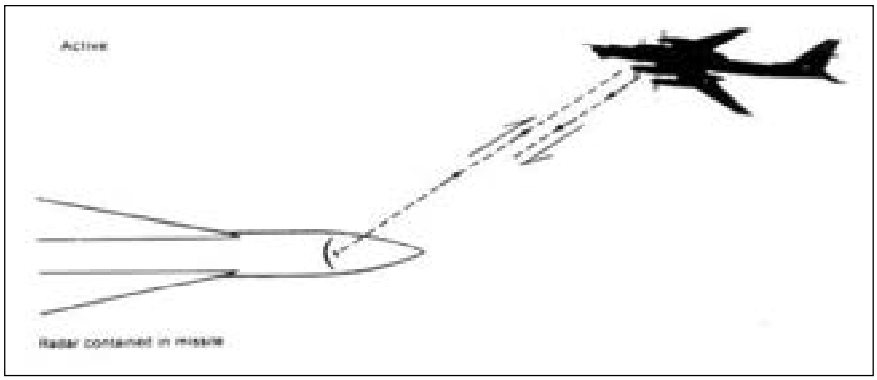


Figure 11-2 – Active Homing

Semi-Active Homing

10. The target is illuminated by energy from a transmitting source remote from the missile. The missile attempts to receive reflections of these signals from the target and thus establish the sight line. Figure 11-3 illustrates semi-active homing.

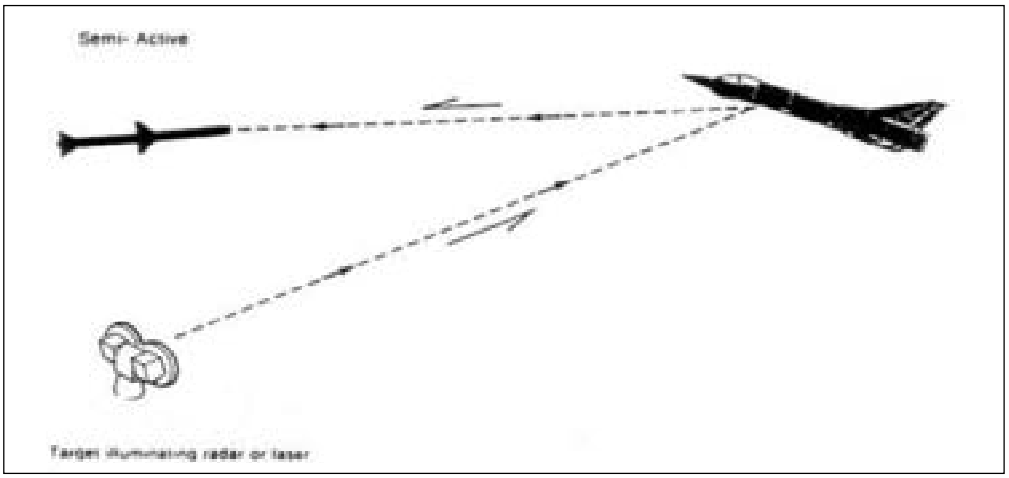


Figure 11-3 - Semi-Active Homing

a. Advantages of semi-active homing are:

(1) accuracy,

(2) long range, and

(3) resistance to counter measures.

b. Disadvantages of semi-active homing are:

(1) not 'launch and leave',

(2) need for extra equipment,

(3) warning given to target, and

(4) difficulty in separating targets in formation.

Passive Homing

11. The missile carries a receiver which endeavours to detect energy radiated by the target itself and thereby establish the missile-target sight line. Figure 11-4 illustrates passive homing.

a. Advantages of passive homing are:

(1) accuracy,

(2) launch and leave capability, and

(3) the target's RWR is not warned of the attack (but the MAWS may detect it).

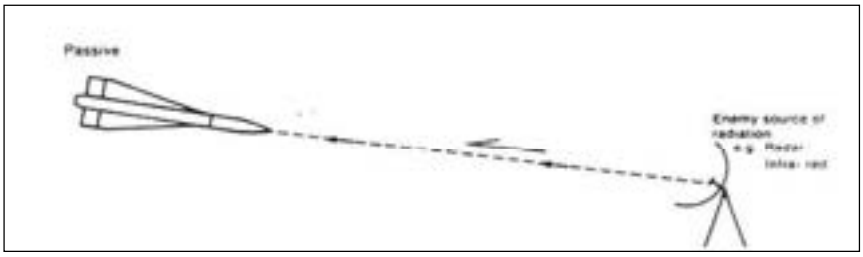


Figure 11-4 - Passive Homing

b. Disadvantages of passive homing are:

(1) short range,

(2) susceptibility to counter measures, and

(3) difficulty in separating targets in formation.

COMMAND GUIDANCE SYSTEMS

12. With Command Guidance Systems the missile, after launch, looks back for steering information from the guidance agency which is tracking the target. There are two subdivisions of command guidance: Command Link and Beam Riding.

Command Link

13. Control commands are issued to the missile in flight by its separate command agency, through the command link. The command agency will track both target and missile in flight and a computer will calculate the control commands to be sent to the missile. The command signal may be a radio link, radar link or wire guidance.

a. Advantages of the command Link System are:

(1) missile simplicity,

(2) versatile trajectory,

(3) ability to differentiate targets in formation, and

(4) difficult to jam the missile.

b. Disadvantages of the Command Link System are:

(1) not ‘launch and leave’,

(2) need for extra equipment,

(3) accuracy falls with range, and

(4) warning to the target.

Seeker Assisted Guidance (SAG)

14. A Seeker Assisted Guided (SAG) missile (previously called Track via Missile – TVM) is a Commanded missile with the addition that the missile contains a receive only seeker that

also tracks the target. The missile relays the target's position back to the ground station, and the ground station uses the extra information to achieve a more accurate track.

Beam Riding

15. The guidance agency projects a beam of energy very accurately towards the target. The missile, in flight, through its rearward facing sensors, detects whether it is off the beam centre and a simple guidance circuit in the missile steers itself to centre the missile in the beam.

a. Advantages of the Beam Riding System are:

(1) missile simplicity,

(2) ability to differentiate targets in formation, and

(3) resistance to counter measures.

b. Disadvantages of the Beam Riding system are:

(1) not 'launch and leave',

(2) the need for extra equipment,

(3) poor accuracy,

(4) poor trajectory, and

(5) warning to the target.

GUIDANCE SUMMARY

16. Missiles can use a combination of guidance types. For example, a missile may be command guided initially, then switch to active homing in the last few kms.

CHAPTER 12

ELECTRO-OPTICS FUNDAMENTALS

Assessment Criteria

Describe the principles of electromagnetic radiation, relevant to electro optics (EO)

12.1 List the EO radiation spectral bands and state where they reside in the EM spectrum
12.2 State the relationship between temperature and peak wavelength emitted
12.3 State the major effect of the atmosphere on IR frequencies
12.4 State the major effect of the atmosphere on UV frequencies
12.5 List target sources of IR radiation and the bands they radiate in

THE EO SPECTRUM

1. In everyday life many different types of radiation are encountered, such as light, heat and radio waves. These radiations are inherently similar in nature, all being examples of the phenomenon of electro-magnetic radiation and they may best be related by their position in the electro-magnetic spectrum. All of the radiations obey similar laws of reflection, refraction, diffraction, and polarisation, and their velocity of propagation is the same. They differ from one another only in their wavelengths and frequencies.

2. As a convention, radio and radar EM are talked about in terms of their frequency, whilst IR, UV and visual EM is talked about in regards to their wavelength. The division between IR and RF is not defined precisely, but a wavelength of 1mm (300GHz) is often taken as the boundary between the two.

3. Since heated objects radiate energy in the infra-red, this is often referred to as the heat region of the spectrum. It is convenient to subdivide the infra-red spectrum into parts as shown in Figure 12-1.

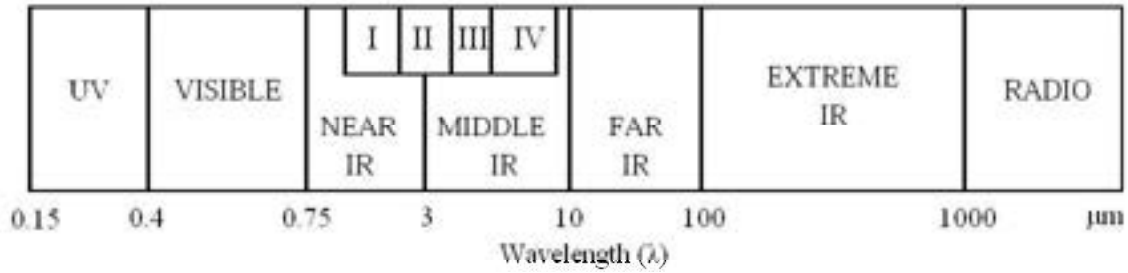


Figure 12-1 – The EO Spectrum

4. Additionally, you may see IR referenced to the bands below:

   a. Band I 1.5 – 2.5μm

   b. Band II 2.5 – 3.5μm

   c. Band III 3.5 – 4.0μm

   d. Band IV 4.0 – 5.0μm

5. This terminology is getting dated, and newer systems simply refer to the wavelength that they can detect.

IR Properties

6. IR radiation displays all the usual properties of EM radiation in that it may be polarized, it propagates in a straight line through a uniform medium, and it can give rise to interference

effects. Most practical applications of IR radiation use radiation in the near and middle bands where the properties are more alike to those of visible light rather than microwave radiation, and IR optical systems usually resemble visible light optical systems.

ELECTRO OPTIC RADIATION

7. Specific EO wavelengths of EM energy can be produced by a number of means; TV remote controls emit in the IR bands; Light Emitting Diodes (LEDs) emit single wavelength light; tanning lamps mostly emit in the UV band. Lasers emit a concentrated beam of a single wavelength of EM energy normally in an IR or visual band.

8. EO energy can be generated, reflected and used just like radar energy. For example, laser range finders (sometime called LIDAR) use reflected EO wavelength energy in a typical radar manner.

9. But in EW, it is the *accidental* production of EO wavelengths that is of interest to us. Most targets are designed to minimise the amount of energy they emit; radars are turned off to prevent ESM detection; lights are turned off to prevent visual detection. But a large amount of EO energy is produced by the process of Thermal Radiation, which is much harder to turn off, and this allows a method of target detection.

THERMAL RADIATION

10. A range of wavelengths of EO radiation are emitted by any object at a temperature greater than absolute zero (-273°C), and the amount emitted and its spectral distribution depend on the temperature and emissivity, ie. Radiation Efficiency of the body. (Thermal emitters emit energy across all EO bands, but IR is the dominant emission).

11. Energy hitting an object can be absorbed by it, reflected off it, or transmitted through it. If all of the energy is absorbed (and none is reflected or transmitted) then the object is a perfect absorber of radiant energy and this is the definition of a *blackbody*. Kirchoff's Law of Radiation in effect states that an absorbing body is an equally good emitter of radiant energy so a blackbody is the perfect absorber and emitter.

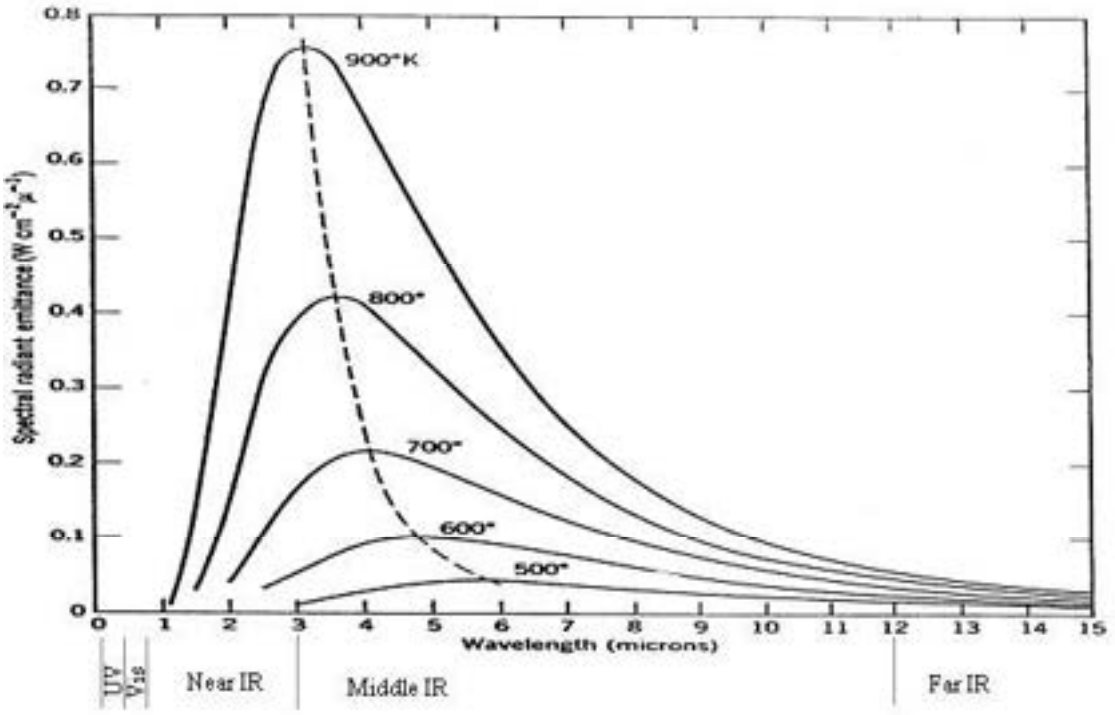


Figure 12-2 - Spectral Radiant Emittance of a Blackbody at Various Temperatures

12. Kirchoff's Law is also known loosely as the *shiny-dull* law. Dull looking objects (like bricks, weathered silver) are great absorbers, hence great emitters. Shiny objects (e.g. polished silver) are poor absorbers, hence not great emitters.

13. The amount of energy radiated by an object, and its spectrum (or wavelengths it radiates over) is given by Planck's Law. The radiated energy of a perfect emitter (a blackbody) is shown in Figure 12-2.

14. It can be seen that the temperature of an object dictates the amount of energy radiated, as well as the shape of the radiated spectrum. In general, as the temperature of an object increases, the peak wavelength of energy it radiates gets smaller. This relationship is called Wien's Displacement law and is formally written as:

$$\lambda_{max} \times T = 2898$$

where λ_{max} = the wavelength of maximum spectral radiant emittance (μm).
T = the temperature in Kelvin (°K = °C + 273)

15. Application of the peak wavelength formula shows that the peak emission wavelength of the sun (at about 6000°K) is at about 0.5μm ie. the wavelength of visible yellow-green light. The sun would also be emitting some energy in the lower wavelength UV spectrum. An object at 1000°K gives peak emission at about 3μm and one at room temperature (say 300°K) at about 10μm. The room temperature object would be radiating very little energy in the visible and UV bands (<1μm).

INFRA-RED TARGET CHARACTERISTICS

Introduction

16. The term target may be used to describe any object that infra-red systems are designed to detect, and thus it is not possible to describe the radiating properties of all potential targets.

These notes describe briefly only the principle sources of infra-red radiation used in military tracking and imaging systems.

Aircraft

17. The principal sources of infra-red radiation associated with aircraft are:

    a. Hot metal surfaces on the engines (especially jet engine tail pipes);

    b. The hot gases in an exhaust trail (plume); and

    c. Kinetically heated surfaces.

    d. Although not a source of radiation, the aircraft could also *reflect* other sources of IR energy (for instance the sun's energy) – called Glint. This will *appear* to be a source of energy coming from the aircraft.

18. **Jet Pipe Emission.** The tail pipe of a jet engine is effectively a cylindrical cavity that is heated by the engine exhaust gases. A cavity is generally an efficient radiator, approximating to a theoretical black body, and thus the radiation depends primarily on the exit area and the temperature of the pipe. An emissivity (radiation efficiency) of about 90% may generally be assumed. Current jet engines generally run with exhaust gas temperatures of the order of 800°K-1000°K, although under some running conditions temperatures may be outside these limits.

19. It can be seen that a hot jet pipe can be quite an intense source of infra-red radiation, with maximum intensity usually in the wavelength band 2µm to 4µm (Band I). The total radiant power emitted is typically in the order of several kilowatts, and thus hot jet pipes can act as good targets.

20. The orifice of a jet engine can usually be seen only from a limited arc to the rear of the aircraft; thus missiles designed to home on to jet pipe emission are limited to rear attack.. Such missiles are capable of homing from a conical zone centred on the jet pipe with an angle of about ±30°. This angle is called the AOT or angle-off-tail. Such a missile approach from the rear would see a point source of IR, radiating from the jet pipe.

21. **Jet Plume Emission.** Two of the main constituents of jet plumes are water vapour and carbon dioxide. Both of these gases emit in the infra-red when heated. Carbon dioxide in particular emits very strongly in the waveband 4.2µm. Unfortunately, but expectedly, carbon dioxide also absorbs strongly in this waveband, so most of the emission should be expected to be absorbed.

22. However, at high altitude the density of carbon dioxide in the atmosphere falls off, in common with the other atmospheric constituents. Thus at high altitude the carbon dioxide in jet plumes provides a fairly intense source whose radiation is concentrated into a narrow waveband. Water vapour radiates in the 2.8µm region but once again this is largely absorbed by the atmosphere. Overall, the plume emits across Bands II-IV.

23. For subsonic aircraft the exhaust plume temperature is likely to be about 600°K, but in many current aircraft, reheat (afterburner) is necessary for supersonic flight. In this case the plume may reach a temperature of over 1000°K and extend over a considerable volume giving a total emissive power of several kilowatts. Normally, a jet plume presents its greatest area when viewed from the side or rear, however with afterburner it becomes clearly visible from

the front. Thus homing missiles designed to home on exhaust plume radiation can have an all-round attack capability in this scenario.

24. **Hot Skin Emission.** In high speed flight the temperature reached by the engine air intakes and the leading edges of wings and control surfaces can be quite high due to friction in the stagnation region. The effective hot area of the whole aircraft is difficult to determine and it appears to be common practice to calculate using the average temperature over the skin area. The engine air intakes are more uniformly heated to stagnation region temperature, thus emit more IR energy.

25. Because the skin approximates to a blackbody and its emission is less attenuated by the atmosphere than jet plume emission, it is detectable at lower temperatures than the jet plume. It would appear that for more modern aircraft, able to fly supersonically without exhaust reheat, the hot skin will be the main source of infra-red radiation at speeds above Mach 1.5, and homing systems must be designed to exploit this. For aircraft which use reheat, the emission from the jet plume is so great that it constitutes the major source at any speed.

26. The IR from the leading edges radiate at wavelengths greater than 4μm (Band IV), and a missile capable for locking to it is capable of a head-on attack.

Surface Targets

27. The mean temperature of the surface of the earth is close to 300°K, and radiation intensity is thus very low compared with, say aircraft as targets. The wavelength of peak radiation is around 10μm, and thus systems suitable for detecting hot point targets, eg. aircraft, which are most sensitive at much shorter wavelengths are generally unsuitable for detection of surface targets. Surface targets are usually detected by imaging systems most sensitive around 10μm and hence to differences in temperature close to earth temperature. Such systems can make detectable temperature differences of less than 0.1°C, and thus enable detection of a wide range of targets.

28. Almost all potential military targets which are visible can also be detected by IR methods, provided that sufficient resolution is available. An advantage of IR detection is that radiation characteristics may be as pronounced at night as during the day and hence it becomes possible to locate targets at night. Such methods can be applied, for example, to the location of:

a. Vehicles and grounded aircraft, by virtue of their shape on IR images and their temperature excess over their surroundings;

b. Personnel, even if visually inconspicuous, may be detectable in IR due to skin temperature difference of some 10°C above that of surroundings; and

c. Fires, power plants, etc. operating above the temperature of surroundings.

29. Some terrain features which may be invisible in normal light become visible when an IR image is formed because they may be at temperatures different from their surroundings. In this way it may be possible to locate, for example:

a. Equipment which is completely camouflaged;

b. Tracks of vehicles and places where vehicles may have been left standing; and

c. The wakes of ships, even of submerged submarines.

30. It can be seen that IR imaging is potentially of great value in surveillance and has a unique ability to indicate hidden targets and to give evidence of recent activity. It is worth noticing, however, that:

a. Heavy rain can equalise the temperature and emissivity of all ground surfaces and hence eliminate the radiation differences on which target detection depends; and

b. IR energy is similar to visible light in its transmission properties and cannot penetrate cloud; there is improved penetration of haze.

Conclusions

31. IR radiation characteristics are of importance in target location and tracking, and offer many unique advantages over alternative techniques. The detectability of an IR target depends principally on:

a. Its temperature;

b. How good an emitter it is (shiny-dull law);

c. Its area;

d. Its spectral emission characteristics, if a liquid or gas; and

e. The nature of the atmosphere between the radiation source and the detector.

ENVIRONMENTAL EFFECTS

EO Propagation

32. IR, Visual and UV radiation propagates at the speed of light and is subject to the normal inverse square spreading loss. Like other EM radiation it may be absorbed, reflected, or refracted as it propagates.

Absorption

33. Absorption by the atmosphere is the most serious impediment to IR radiation. Figure 12-3 shows the transmittance of the atmosphere in ‘normal air’. It shows the existence of “windows” where the transmittance is good, and those where attenuation is excessive. For instance, no equipment would be designed to detect wavelengths between 20 and 1000μm because all the IR in these ranges is completely absorbed by the atmosphere.

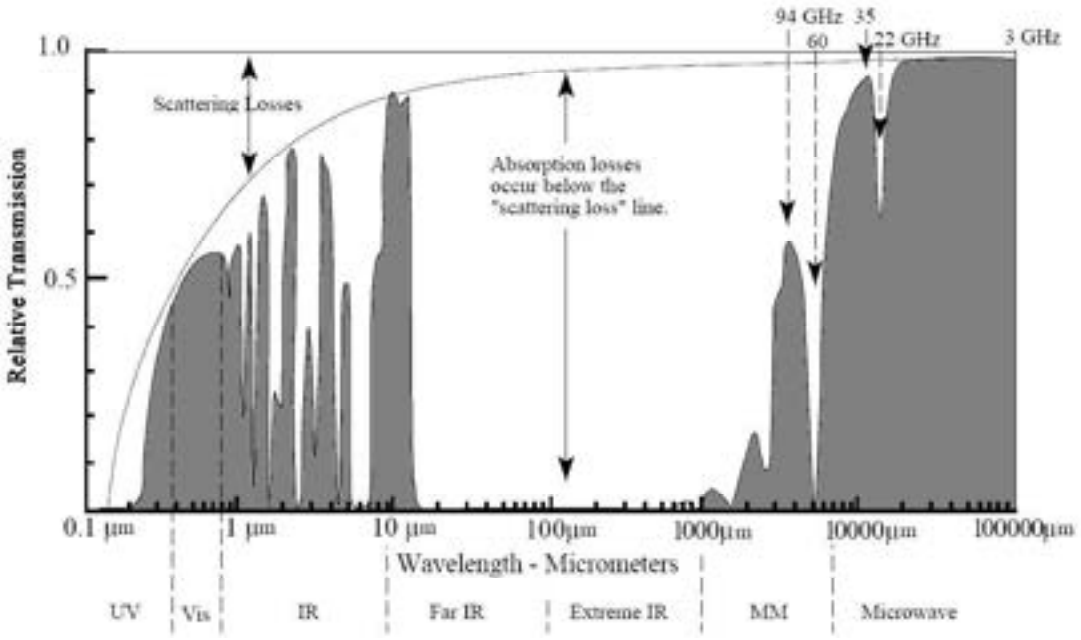


Figure 12-3 – Atmospheric transmission over 1nm at sea level

Scattering

34. Figure 12-3 also shows the effect of EM scattering in 'normal air'. The scattering losses are negligible for large wavelengths (e.g. radar and radio). IR wavelengths start to be affected by scattering (but absorption losses are still dominant) and short UV and visual wavelengths are greatly scattered.

35. The amount of scattering depends on the particle size. Particles will scatter EM if the particle size is 'close' to the wavelength. Particles in the atmosphere are rarely bigger than 0.5µm and thus they have little effect on wavelengths of 3µm or greater. However, once moisture condenses on the particles to form fog, the droplet sizes are comparable to IR wavelengths, and the transmittance becomes very poor. The same reasoning applies to clouds. And as raindrops are so much bigger than the wavelength of IR, there is less scattering from rain in the infrared. Figure 12-4 shows the scattering effect of different particle sizes on different wavelengths.

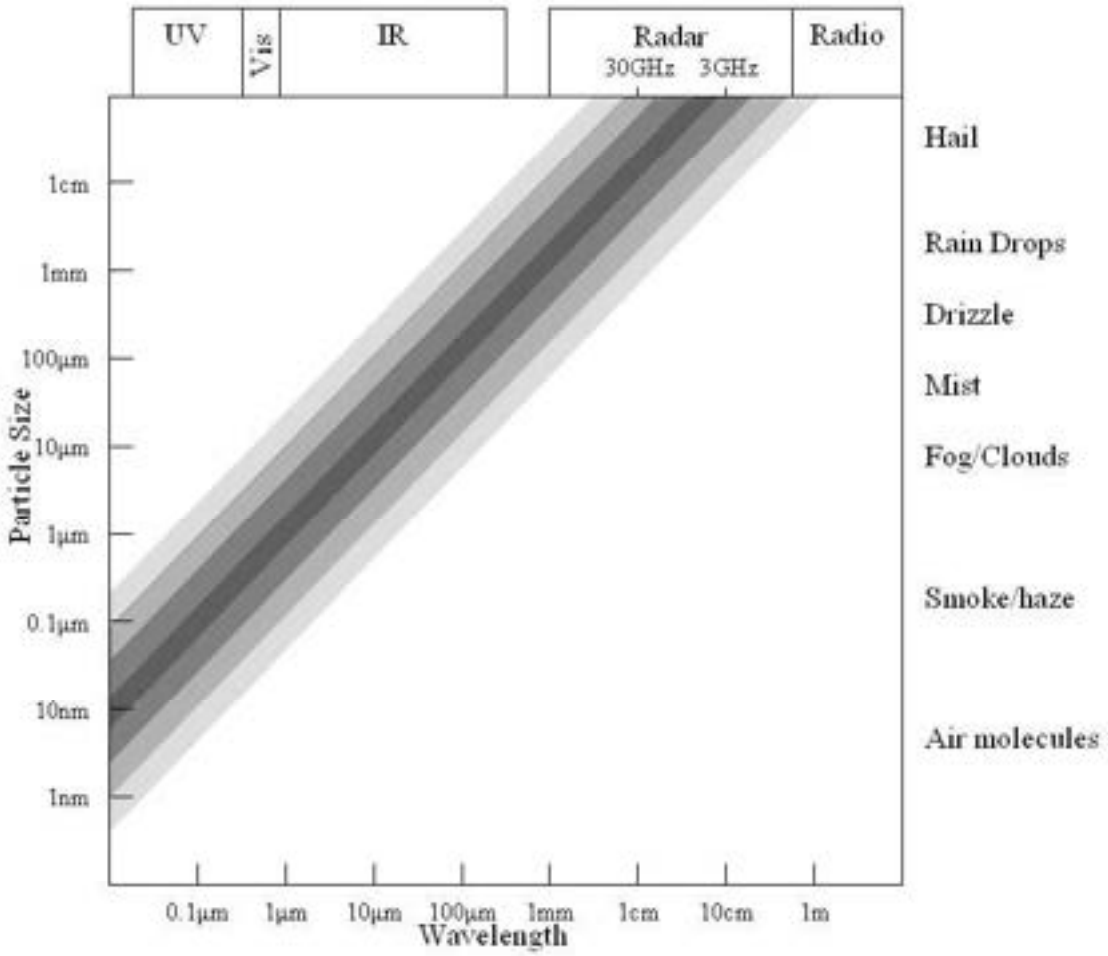


Figure 12-4 – Atmospheric Scattering vs Particle Size

36. From this figure, it can be seen that the effects of scattering by smoke/haze in the atmosphere is mainly of concern in the visible spectrum, and are of minor concern in the IR spectrum. Fog will greatly affect IR, but IR transmission through mist/drizzle is less affected.

CHAPTER 13

EO SEEKERS

Assessment Criteria
List Electro-optic (EO) missile seeker types
13.1 List different types of IR/EO seekers

INTRODUCTION

1. The purpose of a tracking device is to define the direction of a target, and this is usually achieved by aligning the boresight of the tracking device with the direction of radiation from the target. In order to maintain this alignment it is necessary to determine the angular error between the boresight and the incoming target radiation and then turn the tracker to reduce the error to zero. It is thus necessary to measure both the magnitude and direction of the error angle, and a variety of techniques are available to do this.

2. Tracking systems are usually designed so that they can detect and hence track only targets which fall within a relatively small angle around the boresight direction. Fields of view of a few degrees are typical in IR systems. The field of view is determined by the optical arrangement of the tracking head. Although IR lenses do exist and may be used, it is more common to find reflection optics. Only radiation from the field of view can reach the IR detector cell and hence generate an output signal: baffle plates prevent any radiation from reaching the cell surface without prior reflection from the two mirror surfaces.

TARGET DETECTION

3. All bodies above 0°K emit IR radiation, the wavelength of which depends partly on the materials composing the body and partly on the temperature. A typical target to be detected and tracked could be an aircraft engine exhaust located in space against a large background which could be blue sky, a cloud or even the ground itself. The ground in particular gives out radiation in a selective manner due partly to reflection (as the short wavelengths less than 3μm) and partly to emission (at longer wavelengths greater than 5μm). The emissions from aircraft lie in the region 1.8 to 5.2μm (1.9-2.6μm from engines, 2.7μm and 4.2μm from exhaust plumes).

4. The problem may be acute when looking for ground-based targets against the background of ground emissions. Even though the background may have its peak emission at a wavelength remote from that of the target to be detected, the size of the background and the strength of its overall radiation may result in the target and background emissions at a particular wavelength being of the same order.

5. The problem is then to be able to detect the target in the midst of the background clutter and to reject the clutter. There are two possible ways of achieving this:

   a. Spectral filtering; and

   b. Spatial filtering.

Spectral Filtering

6. By choosing detector materials having peak sensitivity at a wavelength where a radiation emission occurs from the target and having a cut-off at a wavelength just above, it is possible, hopefully to reduce the effect of the background by selection or spectral filtering. However, there are two limitations to this:

a. When the temperatures of the target and background are similar, then spectral filtering is of little use in discriminating the target from background; and

b. The target to background contrast ratio obtained by the means of spectral filtering alone is rarely sufficient to make the system operation independent of background. Although some benefit can be obtained normally, the background level is sufficiently large that there must be an additional form of filtering. For example in the 2-2.5μm transmission region the background from clouds may be 104 to 105 times greater than the emission from a distant jet engine. In this case spatial filtering can be used although generally both spectral and spatial filtering are used together.

7. An additional capability to discriminate against unwanted sources can be obtained using two or more separate colour detectors, for example a 'hot' (Band I) detector and a 'cold' (band IV) detector. By comparing the relative magnitude of the pulses in these two bands simultaneously it is possible to separate target signals from background and countermeasure signals.

Spatial Filtering

8. In general all targets have the same characteristic in that they are generally small in angular extent compared with the background in the field of view. Spatial filtering is therefore used to enhance the signal from the target and suppress the signal from the background. By looking at smaller regions within the field of view, the average brightness within the small region changes more dramatically in the presence of the target.

TRACKING METHODS

9. As the target moves away from the optical axis or line of sight (LOS) of the missile, the missile head must be able to measure the displacement and track the target. A number of different methods have been designed to allow this tracking such as:

a. Spin Scan (rotating reticle),

b. Con Scan (stationary reticle),

c. Rosette Scan (pseudo imaging),

d. Pulse Position (pseudo imaging), and

e. Imaging.

Spin Scan

10. The use of a reticle or 'chopper' disk in front of a detector provides the basis for spatial filtering and direction tracking. A rotating disk with segments alternately clear and opaque to target radiation is placed at the focal plane of the objective optics. At long range the target

image is small compared with the disk segments, thus the radiation from the target is interrupted or 'chopped' whilst the general radiation from the background is uninterrupted. The output from the detector is then a direct current signal from the background which can be easily filtered from the target and cloud edges.

11. A simple two-sector reticle is shown in Figure 13-1. This reticle, which has one transparent and one opaque sector, rotates about the optical axis of the system. At Figure 13-1(a) the image of a target is shown slightly to the left of the centre of the reticle. The detector output, shown to the right, is a train of pulses at the chopping frequency, which is identical with the rotational frequency of the reticle. The relative phase shifts δ1 and δ2 of the pulses are seen to be proportional to the angular displacement of the target. It is therefore necessary to provide a phase reference so that the phase shifts can be measured. One of the simplest phase-reference generators is a small magnet fastened to the periphery of a reticle with one or more pickup mounted on a fixed frame near the path of the magnet. Each time the magnet passes the coil, a short pulse or pip is generated that can be used as a stable reference from which phase can be measured.

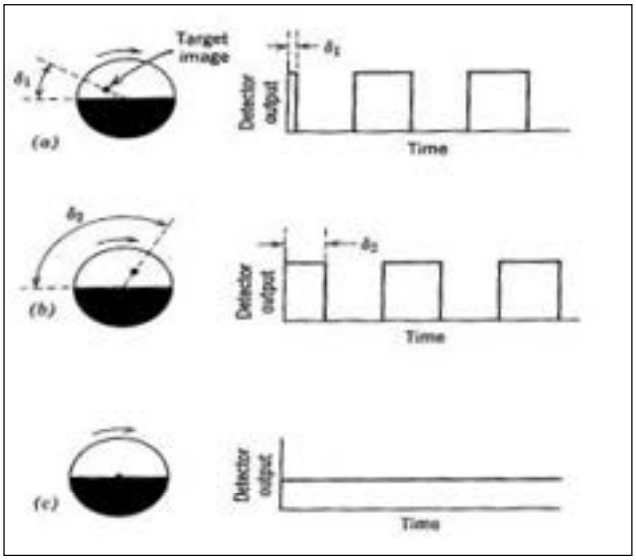


Figure 13-1 - Simple two-segment reticle for generating target directional information

12. When the system of Figure 13-1 is pointed directly at the target, so that there is no point error, the target image lies at the centre of the reticle and there is no chopping action, as shown in Figure 13-1(c). As a result there is no output signal generated with zero pointing error—an unfortunate condition, since it is indistinguishable from that found when there is no target in the field of view.

13. The reticle shown in Figure 13-2 generates ten times more chopping than the reticle in Figure 13-1. This reticle is balanced ie. the average transmittance of the target and phasing sections are equal. The rejection of the background is higher using a phasing section with a transmittance of 0.5 instead of an opaque phasing section by an order of 5 or 6 times. Note that this design, like that shown in Figure 13-1, generates no signal when there is zero pointing error.

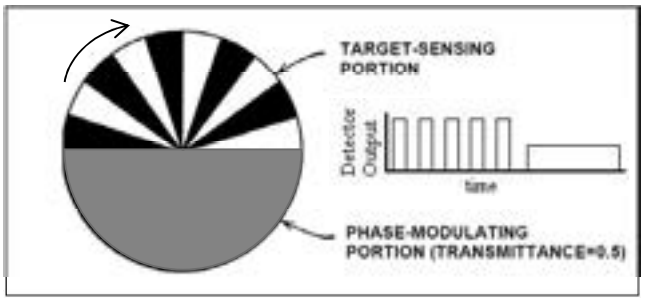


Figure 13-2 – Spinscan reticle with good rejection of sky backgrounds

Con Scan

14. Con Scan systems rotate the image optically with respect to a fixed reticle to provide target information via Frequency Modulation (FM). Such stationary reticle systems offer additional flexibility in the types of modulation that can be produced and they offer the important feature that there is no loss of carrier for zero pointing error.

15. Rotation of the image is called nutation or rotating field; it can be accomplished in several ways. A common method is to mount the lens so that it can be rotated about an axis normal to and passing through the centre of the reticle. The lens, however, is displaced laterally a distance so that the optical and rotational axes are parallel but not coincident. When the lens is rotated, the image follows a circular path called the nutation circle. When the pointing error is zero, the nutation circle is concentric with the rotational axis and with the centre of the reticle.

16. When a pointing error exists, the nutation circle is no longer concentric with the centre of the reticle. A simple reticle with fan-blade segments is shown in Figure 13-3. At Figure 13-3(a) there is no pointing error—the image travels around a nutation circle that is concentric with centre of the reticle. The detector output is a train of identical pulses. With a pointing error, as at Figure 13-3(b), the nutation circle is no longer concentric with the centre of the reticle—the detector output is a series of pulses of varying widths. The difference in width of the narrowest pulse and the widest pulse is proportional to the radial distance of the image from the axis of rotation.

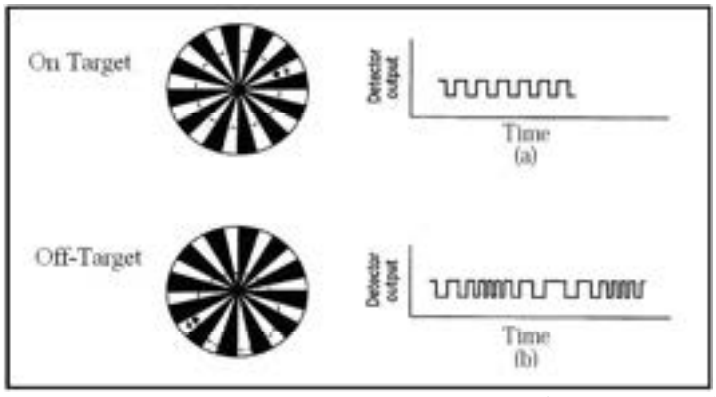


Figure 13-3 – Conscan nutating system generating frequency modulation

Rosette Scan

17. A rosette scan system does not use a reticle. It effectively rotates a small detector over the field of view in a 'flower' pattern as shown in Figure 13-4. (Actually the image is rotated over a fixed detector, but the result is the same).

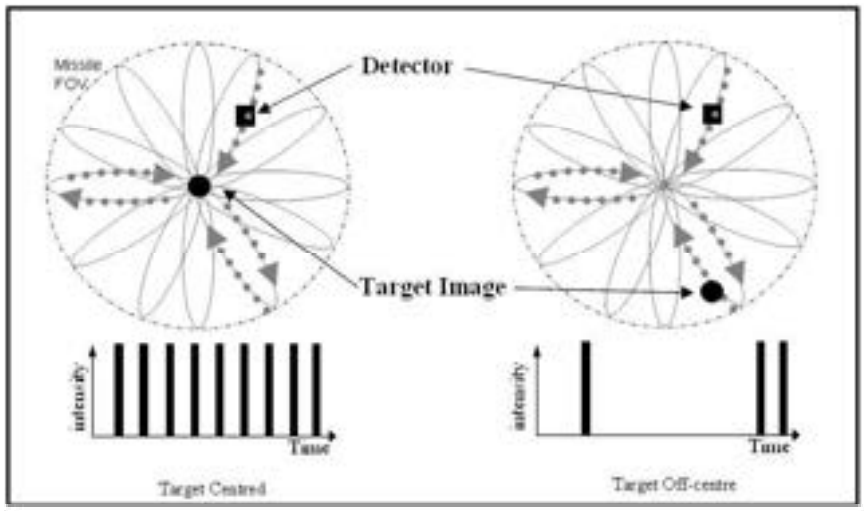


Figure 13-4 Rosette Scan

18. When there is no pointing error, the detector gives a large amount of information, as it passes over the target every sweep. When the missile is off-course, the location and spacing of the detected pulses allows the error offset to be determined.

19. The detector of the rosette scan only has a very small instantaneous Field Of View (FOV) so it is much more sensitive than spinscan or conscan. The rosette scan is also able to resolve multiple targets and choose which one to track. Large targets (such as clouds) tend to produce long pulses while small targets (such as flares) produce narrow pulses.

Pulse Position

20. A pulse position system rotates the image over multiple thin detectors. One such system, using a four-element detector is shown in Figure 13-5.

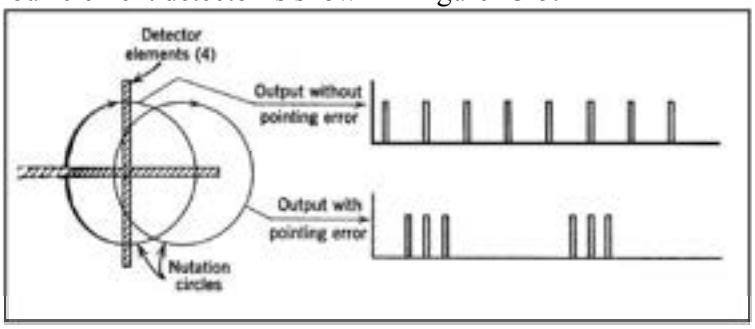


Figure 13-5 – A pulse-modulation system without a reticle

21. Rotating optics are used with a detector consisting of four rectangular elements arranged in a cross-shaped pattern. In the absence of a pointing error, the centre of the nutation circle coincides with that of the detector array. The image crosses the four elements at equal time intervals, and the detector output is a series of pulses occurring at a constant rate. With a pointing error, the nutation circle is not concentric with the centre of the array and the time intervals between crossings of successive detector elements are no longer constant. By comparing these time intervals with reference signals derived from the rotating optics, the rectangular components of the target coordinates can be determined. Thus the combination produces a pulse position modulation in which variations in pulse position indicate the direction of the target. Similar performance can be obtained from a two-element array in which the elements are arranged in an L-shaped pattern.

22. The background rejection characteristics of such pulse systems are excellent. Since the motion of the target image is across the short dimension of the detector elements, this dimension should meet the same criterion used in determining the width of reticle openings; that is, the width of the element should be from one to three times the diameter of the blur circle of the optics. Each pair of detector elements (those lying in the same straight line) can be oppositely biased so as to cancel signals from large straight edges, such as the horizon. Unfortunately, good rejection requires that the edges be accurately parallel to the detector elements, a condition difficult to maintain.

Imaging Systems

23. An image scanning system is another non-reticle technique in which a very small instantaneous FOV is scanned over a wider FOV using either rotating mirrors or rotating prisms. Common types of scan patterns are:

a. Linear Scan. A single detector is scanned over the image plane, line-by-line, much like a TV raster scan;

b. Circular/spiral scan; or

c. Staring Array. If an array of detector cells is used, the seeker will be able to build a 'picture' of the target (like a digital camera).

24. Imaging systems give much better resolution on target location, and can see the difference between sizes of targets. They are able to distinguish target features and can therefore be programmed to guide to a specific part of a target.

CHAPTER 14

MISSILE APPROACH WARNING SYSTEMS

Assessment Criteria

Describe the principles and limitations of Missile Approach Warning Systems (MAWS)

14.1 Describe when missiles emit IR and UV

14.2 List the MAWS system requirements

14.3 List the limitations of UV MAWS

INTRODUCTION

1. Inbound missile threats will generally either be Radar guided or IR homing. Radar guided missiles will trigger an aircraft's RWR, however passive IR missiles will not. Being passive, there is no indication they are targeting you until they have been fired. By the time aircrew visually detect an incoming missile by its smoke trail, there is very little time to react to it. Typical missile flight time for passive IR missiles is around 10-20 seconds duration.

MAWS SYSTEM REQUIREMENTS

2. A Missile Approach Warning System (MAWS) is designed to detect passive missiles, with enough warning time to initiate countermeasures. The MAWS system has the following essential requirements:

a. **Detect the missile early**. The missile is passive, so there is no indicating it is targeting you until it has been fired. Therefore, the MAWS must detect and declare the threat quickly to enable time to employ countermeasures.

b. **Low False Alarm Rate (FAR)**. Given the small amount of time to deploy countermeasures after missile detection, the MAWS will normally connect straight to the Countermeasure Dispensing System (CMDS) and dispense flares automatically. False alarms will quickly deplete the stock of flares.

c. **High Probability of Detection**. Almost opposite to the low FAR problem, the MAWS must declare every time for maximum survivability. A single missile can destroy the aircraft.

3. There are also a number of desirable MAWS characteristics:

a. Automatic handoff to a Counter Measures Dispensing System (CMDS),

b. Detection of the missile at any phase of flight,

c. Estimation of the missile time-to-impact,

d. Identification of the missile type, and

e. Tracking of the missile through its entire flight.

MAWS DISPLAY

4. The MAWS system is normally integrated with the RWR display, such that a MAWS incoming missile alert is displayed on the RWR screen. Normally, it comprises a large red 'wedge' with associated audio alarm.

MISSILE SIGNATURES

5. A missile has three broad stages of flight:

   a. **Launch.** This phase launches the missile from its container into the air. This is normally done using compressed air to prevent the operator from being burnt by hot exhaust gasses. This phase lasts about 0.5 seconds.

   b. **Boost.** The missile then ignites its engines, which burn fuel with a hot flame and hot exhaust. This flame is a good source of IR energy, UV energy and smoke. The boost phase duration depends on the missile.

   c. **Coast.** Once all the fuel in the missile is expended, the missile continues to fly using its own inertia. The missile speed is now quite fast, so there is considerable friction heating of the nose and control surfaces. These continue to emit IR energy. However without the flame, the missile no longer emits UV or smoke.

MAWS ARCHITECTURES

6. Generally there are three detection technologies available for MAWS. These are:

   a. IR,

   b. Pulse Doppler, and

   c. UV.

IR

7. A surface-to-air missile (SAM) sitting in its launch tube is at the same temperature as its surroundings and invisible to IR detectors. Once launched, the missile bursts from its tube and produces a high-intensity spike of mid-range IR and a flare of optical radiation. The booster ignites and burns producing a large, IR rich plume and optical emission at the engine exhaust. As the missile approaches its target the booster rocket may have burned out, but portions of the missile skin surrounding the engine and the leading edges of the missile will continue to emit IR radiation. The IR and optical radiation emitted at launch can be detected to provide the maximum warning time. Similarly the radiation from the fin/wing leading edges of a missile may be detected in flight to provide a warning once the booster has burnt out.

8. The biggest disadvantage of an IR MAWS is the amount of background IR clutter around. The IR MAWS will find it hard to distinguish the small head of the missile from background sources such as rocks, cars and sun-glint. Traditionally IR MAWS has only been used for high level fast jets that operate in a fairly clutter free environment.

Pulse Doppler

9. A Pulse Doppler (PD) MAWS uses an active radar on the protected aircraft. It continuously transmits omnidirectional pulses and listens for high Doppler shifted returns, indicating a high velocity inbound target, i.e. a missile. However, this system has the undesirable property of radiating continually and the radiation may be used to provide a homing signal for the missile, or be detected by any RWR/ESM.

UV

10. The UV MAWS detects the UV being emitted by the missile plume while burning fuel.

11. The sun generates a very large amount of UV energy, which is diffuse due to scattering in the atmosphere. However, all solar UV energy in the 0.23 – 0.28μm region (the Solar Blind Region) is absorbed by the upper atmosphere. UV MAWS detectors are tuned to look in this small band to prevent them being triggered by the sun. However, the UV MAWS still needs to discriminate the missile plume from other background UV clutter such as:

a. forest fires,

b. night illuminating flares,

c. white phosphorous grenades,

d. rockets and mortars,

e. high explosives, and

f. arc welders.

12. UV MAWS have the following limitations:

a. Can only detect UV during the missile launch and boost phases (from the rocket flames). No UV is emitted once the motor has burnt out (the coast phase).

b. Can be triggered by false alarms (both man-made and natural).

c. Are limited to short ranges (approximately 6nm).

MAWS Comparison

13. Table 14-1 compares the three MAWS architectures types.

	IR	Doppler	UV
Range	10-20nm	~ 1nm	4-6nm
Detection	Boost, Coast	Any moving object	Boost (not coast)
False Alarm Sources	Many (sun and hot objects)	Very few	Few (not affected by sun)
Angular Resolution	Fraction of a degree	Quadrant	Fraction of a Degree

Table 14-1 Comparison of MAWS Architectures

14. Most current ADF MAWS systems are UV detectors.

LASER WARNING RECEIVERS (LWR)

15. Lasers produce a highly directional, high intensity, coherent beam of light normally at a single wavelength. These properties make laser technology ideal for applications in fire control and rangefinding. The applications against aircraft create the need for airborne Laser Warning Receivers.

16. Laser radiation can reach a LWR by any of four mechanisms. These four mechanisms, are direct radiation (including sidelobes), reflected (surface scattered) radiation, port scatter (caused by dust and imperfections in the optics) and aerosol (atmospheric particles) scatter.

17. For threats such as laser-beam-rider missiles, which have a large laser beam divergence, the mechanism by which the LWR is illuminated is direct radiation. Other threats, such as laser rangefinders and designators, have such narrow beam divergences that the laser threat may illuminate only a small portion of the target and this portion may not include the LWR. The LWR must therefore have a detection radius larger than the radius of the direct laser beam. This aspect requires serious consideration when selecting locations on the aircraft for mounting the LWR sensors.

18. One of the impediments to the widespread fit of LWRs in aircraft has been the lack of a suitable countermeasure. There are two countermeasures to laser systems: getting under cover and counterfire. Taking cover, or evasive manoeuvre, is a suitable countermeasure for helicopters and fast flying jets but is not so readily available to slower and larger aircraft.

19. Counterfire countermeasures to laser systems are yet to be developed. However, as the threat from laser-beam-rider missile systems becomes more widespread the requirement for LWR will increase. Additionally, there are several companies that offer a LWR module as an enhancement to their MAWS.

CHAPTER 15

ELECTRO-OPTIC COUNTERMEASURES

Assessment Criteria

Describe the operation, use and effects of Electro Optic Countermeasures (EOCM)

15.1 List passive IR and Visual Counter Measures
15.2 Describe how an IR jammer deceives an IR missile
15.3 Describe how a flare deceives an IR missile
15.4 List various flare types
15.5 List Missile EP Methods
15.6 List the difference between different generation missiles

INTRODUCTION

1. There is a fundamental difference between infrared and radar countermeasures in that infrared devices cannot be jammed in the usual sense. Infrared homing weapons are passive, that is, they do not depend on reflected radiation from an active source for their operation. They operate solely on the radiation which originates from their intended target. For this reason almost all Electro-Optic Countermeasures (EOCM) are based on the two basic concepts of **deception** and **suppression** of radiation reaching the detector of the seeker or reconnaissance device.

2. Deception may use one of a number of different forms. It may be a strong source ejected from the aircraft such as a flare, it may consist of modulated beacons on the wingtips, or a source which is towed behind the aircraft. The techniques used to suppress radiation are ideally designed into an aircraft but some reductions can be gained retrospectively.

PASSIVE EOCM

3. Relating back to the survivability paradigm, the best countermeasure is to not be detected. This is the principle behind passive countermeasures. Techniques for passive EOCM include:

a. In the visible spectrum:

(1) Camouflage – role suited paints;

(2) Turn off Aircraft lighting; and

(3) Use of smokeless fuels.

b. In the infrared spectrum:

(1) Shielding of hot engine parts,

(2) Plume shaping,

(3) Fuel additives or bypass air,

(4) Treatment of the surface finish, and

(5) IR absorbing paint.

4. In the cases where passive EOCM cannot prevent detection, tracking or targeting, active EOCM may be required. Active EOCM usually consists of on-board or off-board energy sources operating in the IR spectrum (IRCM).

ON-BOARD INFRARED COUNTERMEASURES

5. Active IR jammers are an alternative method to suppression of radiation, deception (flares) and tactics for overcoming IR seeking missiles. However, IR jammers are often used in conjunction with these other methods.

6. IR jammers overcome the need to carry and replenish flares and also avoid the ground handling hazards associated with flare systems. They have the advantage of being covert when operated, that is, the jammer output is filtered to remove radiation in the visible spectrum. The current versions of IR jammers are operated continuously when in the threat region and can provide a wide field-of-view protection in any direction from which a threat is expected.

7. On-board active IR jammers operate on the principle of projecting energy in the direction of the threat. The jammer energy is generated by one of three methods.

a. An electrically heated or fuel-fired black body source (the so called 'Hot-Brick') is modulated mechanically by external shutters or filters. Typical systems include the AN/ALQ-144 and AN/ALQ-147. These systems have the disadvantage of being relatively inflexible in changing the jamming modulation in real time, and consume very large amounts of power.

b. Electronically modulate an arc plasma source. Systems using this method include the AN/AAQ-4, AN/AAQ-8, AN/ALQ-123 and AN/ALQ-157. These systems are more complex than the 'Hot-Brick' type jammers but they have the advantage of flexible modulation selection and implementation.

c. Directed Infrared Countermeasures (DIRCM) direct a high power narrow beam IR laser into the missile seeker. These systems require accurate threat location and tracking abilities, however they have the advantage of being able to produce flexible modulation and a very large J/S ratio, whilst consuming very little power (<5W).

IR Jammer Requirements

8. A good understanding of how IR seeking missiles work is required in order to understand how active IR jammers work. To disrupt an IR missile, the IR jammer must radiate in the IR seeker's spectral bandpass region and the jammer output is modulated to alter the reticle signal output.

9. The output signal from the IR detector of a spin scan, centre null, rising sun type reticle seeker is shown in the top line of Figure 15-1. Note that each waveform has chopped segments and constant segments. The constant segment is due to the phasing sector of the reticle while the reticle's spokes create the chopped segment in response to a constant intensity target. The segments are smoothed, and the smoothed waveform is processed to provide guidance signals to steer the missile towards the target.

10. Carrier frequency jamming was the first method developed to defeat the first generation IR seekers. The carrier frequency in the IR seeker is the frequency that the target signal is chopped at and is a function of the number of spokes on the reticle and the reticle spin frequency. Typical carrier frequencies for IR missiles are in the range 800-1500 Hz. The output of the IR jammer is produced by modulating, at the IR seeker carrier frequency, the intensity of an IR source. The output from the IR jammer is shown in the middle line of Figure 15-1.

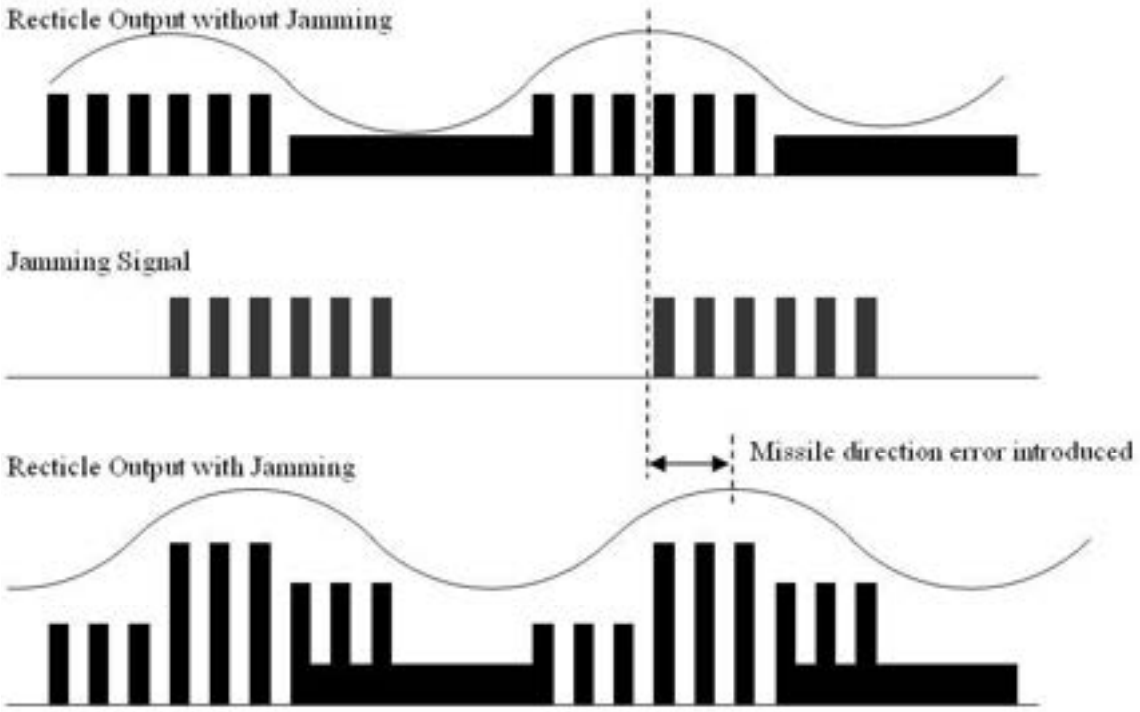


Figure 15-1 - IR Jamming

11. The missile seeker will receive the combined IR from the jammer and the aircraft, as shown in the bottom line of Figure 15-1. These segments are smoothed, and the smoothed waveform differs in phase to the original (unjammed) waveform by a small amount. The small phase shift progressively introduces a small error in the missile steering commands, which steers the missile successively away from the line of the aircraft.

12. For Conscan seekers, which use frequency modulation, this kind of jamming will produce an error offset for the missile, but the missile will still be tracking generally towards the aircraft. The success of jamming relies on the missile's inability to turn hard enough at the end of flight to intercept the aircraft, and creates an effective miss distance.

13. IR Jammers are useful against Spin Scan and Conscan seekers. They have limited effect against Pulse Position and Rosette scans, and are ineffective against imaging seekers.

Future IR Jammers

14. Current IR jammers are 'open loop' – in that they do not know what kind of missile is coming towards them. Thus they output a generic series of pulses to try to deceive the incoming missile.

15. In development are 'closed loop' IR jammers. These use reflections from the missile seeker to determine the missile type, and then send exactly the right jamming signal to control the missile.

16. High power lasers are also being investigated for use as a counter measure to IR guided missiles for hard kill. The process is to direct enough power onto the missile casing to cause it to superheat and explode.

OFF-BOARD INFRARED COUNTERMEASURES

17. Flares are dispensed from aircraft to present alternate sources of IR radiation to the threat missile so that the missile seeks the flares rather than the aircraft. Since missiles are often designed to explode within some fusing distance, the flare must separate a distance that exceeds the fusing range of the missile's warhead (i.e. a miss-distance). Further, realising that IR guided missiles are 'short range' weapons with restricted Fields of View (FOVs), the decoying action must occur quickly.

Conventional Flare Characteristics

18. Conventional flares were developed to quickly establish an intense source of radiation that quickly separates from the aircraft. The pyrotechnic compound Magnesium Teflon Viton (MTV) is used to provide the intense source of radiation and an impulse cartridge (or squib) is used to dispense the burning MTV from the aircraft (25 - 45 m/s typical).

19. The MTV flare characteristics are:

a. rise time (0.2 - 0.5 seconds);

b. burn time (3 - 5 seconds);

c. high energy output (8 - 49 kW/steradian);

d. wide spectral output (UV, visual and near to far infrared); and

e. temperature (2000 - 5000° Celsius).

20. In general the burn time and energy output are determined by the quantity of fuel, the spectral output by the burning temperature and the rise time by the firing mechanism and type of fuel.

Flare Requirements

21. There are two driving forces that determine the flare requirements for protecting aircraft. These are aircraft infrared radiation sources and seeker characteristics. An understanding of both is required to design or select effective flares for operational use.

22. **An Alternate Source (Spectrally).** For a flare to act as an alternate source of IR radiation it must radiate more energy than the aircraft it is to protect within whatever wavelengths the missile seeker is detecting. Some missiles detect radiation from hot metal parts of an aircraft (e.g. tail pipes – band II) while some missiles detect radiation from the aircraft's hot exhaust gasses (i.e. the plume – band IV). 'Dual colour' missiles detect radiation from both sources.

23. **A Separate Source (Spatially).** It is important that the flare separates a sufficient distance from the aircraft for the seduced missile to pass the aircraft beyond the miss-distance. While many IR guided missiles are in fact 'hit-iles', the need for a miss-distance can not be understated.

24. **Temporal Factors.** IR missiles are launched at distances that range between (typically) 500 and 5000 metres, although shorter minimum ranges and greater maximum ranges are common. Surface-to-Air Missiles travel at velocities around 680 metres per second (Mach 2.0). Ignoring the contribution of closing or opening target velocities on an IR missile

engagement, a target aircraft can expect to have as little as one to two seconds to provide an appropriate countermeasure to an IR missile. Therefore, the flare must produce the alternate heat source quickly.

25. **Other Factors.** It is important that the flare reach full intensity while it and the target are still unresolved by the seeker system. This is due to the fact that seeker systems are often designed so that a source far from the centre of the field of view is less effective than a source of the same intensity nearer the centre. Another reason for the flare to reach full intensity while near the centre of the field of view is that a source near the edge of the field may move completely out of the field of view before the seeker can shift over to it.

COUNTERING CONVENTIONAL FLARES (MISSILE EP)

26. Early missiles were easily defeated by flares. But as missile technology developed, missiles became able to distinguish between flares and aircraft (Missile Electronic Protection - EP) using the following techniques.

Missile EP - Flare Rejection Methods

27. **Spectral Ratio.** The most effective EP technique is the 'spectral ratio test' which compares measurements of the target's emissions in two regions of the IR spectrum, Band II (hot metal tail pipe) and Band IV (plume). Aircraft produce different spectral ratios to that of MTV flares; consequently, dual-band (two colour) IR seekers were developed.

28. **Temporal Triggers.** Temporal triggers attempt to sense the rapid increase in intensity when a flare is fired. Aircraft emissions vary with aspect; therefore, a manoeuvring aircraft will produce emissions that vary with time. However, these changes are generally slow. Flares produce a rapid rise in intensity which can be detected as non-aircraft like behaviour.

29. **Kinematic Trigger.** When a flare is deployed, it quickly reaches zero velocity, very unlike an aircraft. This can trigger the kinematic test to enable the missile to ignore the flare. To prevent the missile from being blind to a slow target (e.g. a helicopter) some missiles have a high/low target speed selector on them to disable the kinematic testing.

30. **Spatial Comparison.** When a missile is tracking correctly, the target should be in the centre of the reticle most of the time. If a flare is dispensed, the missile will have two targets in its FOV that start in the same location, but separate. The missile will track the flare, and the aircraft will 'move' to the outer edge of the reticle. The reticles can be designed so targets in the middle of the reticle generate different waves than targets on the outer edge. The missile can then recognise it has two targets in its field of view, separating away from each other, and can decide which to track.

31. **Image Processing.** Aircraft and flares appear different. Aircraft are larger, have wings and tails, whilst flares are small and round. Being able to determine outlines or shapes allows the missile to differentiate between flare and aircraft.

COUNTERING MISSILE EP - ADVANCED FLARES

32. To counter the missile EP, advanced flares have been developed.

33. **Activated Metal Flares.** Activated metal flares have not been developed to counter EP techniques, but should be included in the discussion because of the technology's applicability to Special Operations (SPECOPS). Activated metal flares are cooler than MTV flares and do not radiate energy in the visual region of the electromagnetic spectrum. As such, activated

metal flares are used for operations were the airborne platform is not meant to be detected such as SPECOPS. Since activated metal flares produce less radiation than MTV flares, a greater number of activated metal flares are required to produce an effective J/S ratio.

34. **Spectrally Matched Flares.** Spectrally matched flares are designed to radiate energy that has a similar spectral density to that of the aircraft, ie the ratio of energy radiated in the hot metal parts band to that radiated in the plume band is the same for the flare and aircraft.

35. **Aerodynamic and Thrusted Flares.** These flares have aerodynamic shapes attached to one end and sheaths enclosing the explosive to provide a source of thrust at the other end. When dispensed, the ignited flare will 'fly' with the aircraft, therefore separating slower than non-aerodynamic conventional flares. The purpose of the slow separation is to seduce the missile by not triggering spatial EP. Note that spectrally matched flares may also be made aerodynamic.

36. Aerodynamic flares will fall away behind the aircraft, whilst thrusted flares will fall away in front of the aircraft.

37. It is important to understand the (possible) consequences of slow separation rates. A slowly separating flare must be dispensed at a greater missile/target distance so that the minimum missile/target distance exceeds the miss-distance. Therefore, additional warning time is required. If warning time is inadequate, missiles may be decoyed but by an amount less than the missile's fusing distance. Consequently, the platform/threat/countermeasure (EW engagement) must be well understood and the aircraft must be fitted with a MAWS that complements the aerodynamic flare.

38. **Slow Rise-Time Flares.** The time for the flare to reach peak intensity is reduced by changing the chemical composition to the explosive. The rate of flare separation from the aircraft also plays a large part in the effectiveness of slow rise-time flares. Slow rise-time flares are often made aerodynamic to ensure the flare has adequate time to be effective. The use of slow rise-time flares should be carefully considered.

SUMMARY OF MISSILE TRACKING CHARACTERISTICS BY GENERATION

39. Over time, IR missile performance has improved in both their target accuracy/resolution and tracking frequency band. As new missile capabilities deployed, IR missiles came to be grouped into Generations depending on their capabilities such as:

a. IR Detector Material and cooling (Target frequency band),

b. Ability to track different target IR sources,

c. Guidance method and accuracy, and

d. Missile Electronic Protection (EP) (formerly counter-counter measures).

Generation 1

40. Generation 1 missiles have the following characteristics:

a. Spin Scan reticle,

b. Band I IR detector (tailpipe chasers), and

c. No EP.

41. These missiles are easily defeated by flares. A single MTV flare is normally all that is required to defeat the missile. There are sill a very large number of Generation 1 missiles in our areas of operation.

Generation 2

42. Generation 2 missiles have the following characteristics:

a. Conical Scan reticles,

b. Band IV IR detector (all aspect), and

c. No EP.

43. Generation 2 missiles are also easily defeated by MTV flares. There are sill a very large number of Generation 2 missiles in our areas of operation.

Generation 3

44. Generation 3 missiles are divided into those that have a single detector (S class) or those that have multiple detectors (M class). Generation 3 missiles have the following characteristics:

a. Band IV (all aspect), and

b. Electronic Protection including spectral (Band I), kinematic and temporal triggers.

45. Conventional flares are ineffective in most cases. However specific flares have been developed to counter Gen3 missiles as detailed earlier in the chapter.

Generation 4

46. Some organisations define Gen4 as “pseudo-imaging”, however there is no formal definition as to what this means! Australia has recently started using Gen4 to categorise ‘advanced’ Gen3 missiles. These missiles generally use multiple seeker technologies and are much more complex and harder to defeat than classic Gen3 missiles.

47. Generation 4 missiles have the following characteristics:

a. Band IV (all aspect), and

b. Multiple EP methods (including spectral, kinematic and temporal triggers).

48. The same advanced flares used against Gen3 missiles are used against Gen4 missiles.

Generation 5

49. Generation 5 missiles have the following characteristics:

    a. Imaging,

    b. Band IV (all aspect), and

    c. EP (Image Processing).

50. Flares are ineffective against Gen5 missiles.

CHAPTER P1

RADAR MODULATION AND DOPPLER

Topic Overview - Non-Assessed Presentation
Describe Advanced Radar Concepts
P1.1 Describe interpulse modulation
P1.2 Discuss the use of PRI agility to affect the maximum unambiguous range
P1.3 Describe intrapulse modulation (pulse compression)
P1.4 Describe ground based pulse doppler radar
P1.5 Define Maximum Unambiguous Doppler (MUD)

INTERPULSE MODULATION

1. The term 'interpulse modulation' is applied to those radars that change their pulse characteristics. This is achieved by PRI or RF agility. PRI agility is transmitting pulses at intervals which are varied from the uniform, fixed pulse repetition interval of a conventional radar. RF agility is changing the frequency of successive pulses.

PRI AGILITY

2. PRI agility techniques fall into four broad categories:

   a. Staggered PRI,

   b. Jittered PRI,

   c. Pulse Group Modulation, and

   d. Dwell and Switch.

3. Radars that employ some form of PRI agility have several advantages over conventional radars. The advantages include: reducing range ambiguity; eliminating blind speeds; eliminating "main beam eclipsing" of target returns; and improving anti-jamming characteristics.

Staggered PRI

4. A staggered PRI pulse train is a train of pulses wherein two (or more) precise interpulse intervals are alternated in a fixed sequence. Figure P1-1 illustrates the difference between a staggered train and non-staggered train.

5. Note that in the normal train, the time between each pulse (the PRI) is equal, while in the staggered sequence the PRI varies.

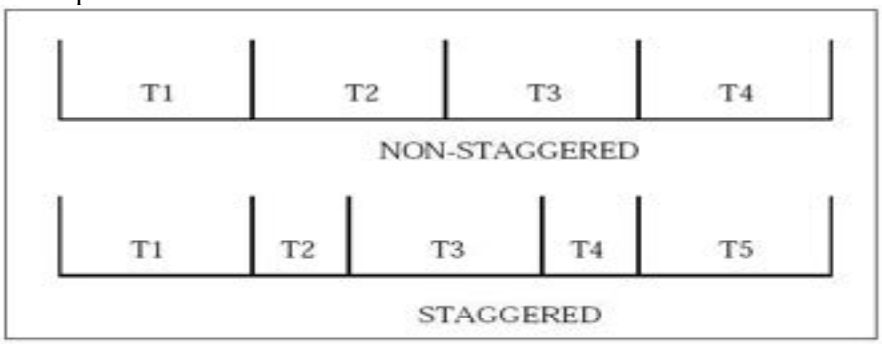


Figure P1-1 – Staggered and Non-Staggered Pulse Trains

Jittered PRI

6. A jittered PRI is defined as a pulse train where there is a change in the starting time of each successive pulse relative to the time it would start if the pulse train were at regular intervals. The PRI of a jittered train is bounded between a maximum and a minimum value but can be any value between these limits. There are two general forms of jitter; programmed (or intentional) and unintentional. The main reason to use jitter is as an EP feature. It will prevent range gate stealers from operating since they have to lock onto the PRI.

7. Pseudo random is a programmed or intentionally jittered train which is seemingly random but actually is not. Analysis of this would require the use of a computer.

8. Pulse Frequency Modulation is a form of jitter where the train varies in a sinewave, sawtooth, or triangular fashion. The most common of these is the sinewave because it is easier to generate.

Pulse Group Modulation

9. A pulse group PRI is defined as a pulse train in which there are groups of closely spaced pulses separated by much longer times between these pulse groups.

10. One of the more common uses of pulse group modulation is missile guidance. Some weapon systems employ one radar which tracks the missile and another radar which tracks the target. A computer is used to calculate the missile trajectory needed to intercept the target. The missile tracking radar is used to convey this trajectory information to the missile. It is usually in the form of pulse groups with pulse position modulation within the pulse group. Thus the tracking radar is used to track the missile (via pulse returns), but also to command the missile (by coding the pulse PRIs).

Dwell and Switch

11. Many radar applications have processing that requires a constant PRI (e.g. Pulse Integration). In these cases, the radar may send a series of pulses at constant PRI (a dwell), then switch to a new PRI and send another series of pulses. This combines the advantages of multiple PRIs with the processing requirements of constant PRI.

Figure P1-2 – A Dwell-Switch Pulse Train

Maximum Unambiguous Range

12. The Maximum Unambiguous Range (MUR) of a radar is related to the Pulse Repetition Interval (PRI). A large PRI is required to give good MUR, however this reduces the Time on Target and total energy being transmitted. To solve this problem, Interpulse Modulation techniques may be used.

13. Firstly, a series of pulses is sent out at certain PRI. The target's range is calculated, however the radar knows that the true range may be any number of multiples of the MUR further.

14. A second set of pulses is then transmitted at a different PRI. This will give a second set of possible ranges that the target may be.

15. If the time between sending the first set of pulses and the second set of pulses is small (less than ½sec) then the target cannot have moved far in that time. So the true range of the target is the range that is common to the first calculated set of ranges and the second.

RF AGILITY

16. RF agility describes a radar that changes the RF of pulses sent. Radars use RF agility as a jamming counter measure, or to impede detection by an ESM or RWR. RF agility can also be used to ensure that a "clear" channel is used, to minimise interference from other radars.

17. RF agility techniques fall into two broad categories:

a. Pulse to Pulse agility, and

b. Dwell to Dwell agility.

Pulse to Pulse RF Agility

18. In a pulse to pulse RF agile radar, the RF of each pulse differs from the last. The RF of each pulse can vary using methods similar to that of PRI agility, the RF may be Staggered, a deliberate pattern (such as sawtooth or sinewave), or Random.

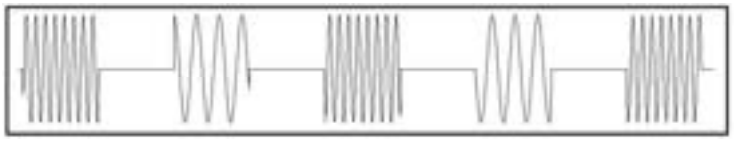


Figure P1-3 – Pulse-to-Pulse RF Agility

Dwell to Dwell RF agility

19. Many radar applications have processing that requires a regular RF to be used (e.g. Doppler processing). The tuning circuits of a radar also require a small amount of time to change RF. In these cases, the radar will send a series of pulses at the same RF (a dwell), then switch to a new RF for the next series of pulses.

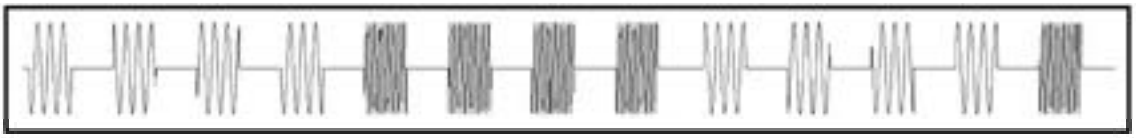


Figure P1-4 – Dwell-to-Dwell RF Agility

DOPPLER RADAR

20. The benefit of doppler processing is that it enables a radar to ignore all the clutter (reflections from stationary objects like the ground, clouds, trees, or buildings) and just show the operator moving objects. Moving objects will produce a doppler shift in the reflected radar return, stationary objects will not.

Coherency

21. Doppler radar requires a coherent signal to work. A coherent signal is one that maintains phase between pulses. A coherent signal reduces the spectral noise generated—allowing the measurement of doppler variations in the radar reflections.

22. A Continuous Wave (CW) radar emits a single frequency RF waveform. In the frequency domain, this is shown as a single line at that frequency as shown in Figure P1-5. A shift in this single frequency line would be easy to determine.

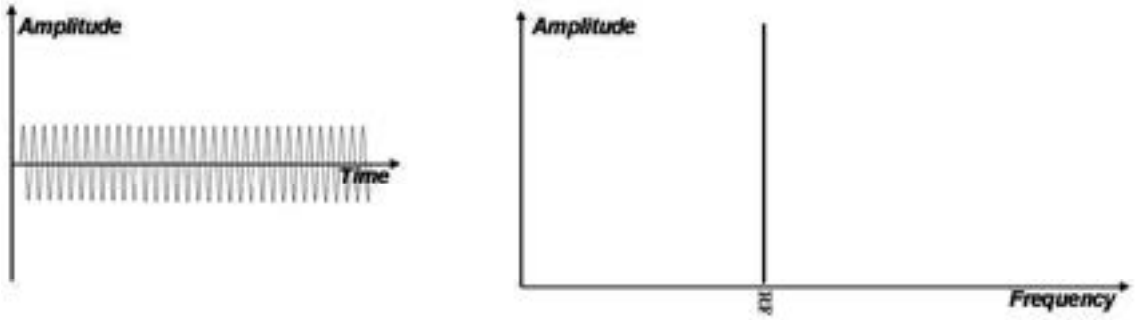


Figure P1-5 Time and Frequency Domain Graphs for a Continuous Wave Signal

23. However, when this CW wave is turned on and off at a high rate (e.g. many thousands of times each second) as for a pulsed radar, other spectral lines appear on the frequency domain graph. Figure P1-6 shows a coherent pulse train in the frequency domain. The spectral lines are centred on the RF of the pulses, and the lines are spaced by the Pulse Repetition Frequency (PRF). The bandwidth of the signal is inversely proportional to the Pulse Width (so the shorter the pulse, the more bandwidth the signal uses).

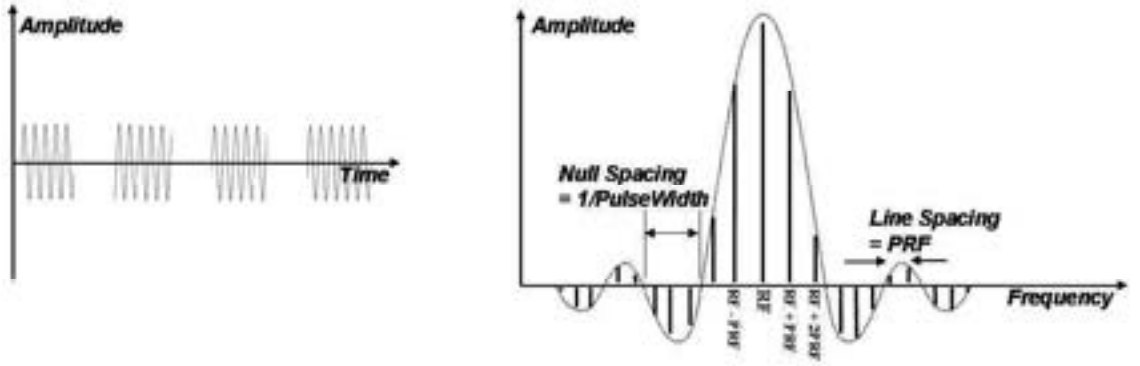


Figure P1-6 Time and Frequency Domain Graphs for a Coherent Pulsed Signal

24. A non-coherent series of pulses has a frequency distribution with the same shape, but instead of a few spectral lines, it has an infinite number of spectral lines. This makes measuring the very small doppler frequency shift impossible.

Doppler Processing

25. When a moving object reflects a coherent pulse train, the entire spectrum is shifted in frequency by the doppler frequency (f_D). The radar measures the doppler shift by looking for a returned signal near the center RF frequency. The difference between the returned frequency and the frequency transmitted is the doppler frequency, and this can be used to calculate the target's speed. Noise will add to the amplitude of spectral lines randomly, so amplitude information is not used when detecting the doppler shift.

Doppler Blind Speeds

26. The spacing of the spectral lines is at the radar's PRF. If a target is travelling the exact speed to introduce a doppler shift equal to the PRF, then the centre of the radar return will be hidden by the first spectral line of the transmitted signal. The radar processor ignores amplitude information; therefore it will see no shift in the spectral lines and report that the target is stationary. This will also occur if the target's speed introduces a doppler shift equal to double the PRF, triple the PRF and so on. These are doppler blind speeds.

27. To prevent doppler blind speeds, doppler radars can alternate between multiple PRFs. Each time the PRF changes, the blind speeds also change. By switching between different PRFs quickly, the target will be unable to adjust its speed to match the blind speed fast enough and will be detected.

Doppler Ambiguity

28. If a target's speed introduces a doppler shift greater than the PRF, then the reading is abiguous. The echo will have spectral lines near to the RF, but the radar has no way of knowing whether these are highly shifted spectral lines or slightly shifted spectral lines. So the radar can only report speeds between zero and the Maximum Unambiguous Doppler (MUD) speed.

29. The Maximum Unambiguous Doppler speed is dictated by the PRF. Increasing the PRF will increase the MUD speed. However, increasing the PRF will decrease the Maximum Unambiguous Range (MUR). Thus the doppler radar needs to trade off MUR for MUD. By switching between multiple PRFs quickly, the radar is able to resolve both the target speed and range.

INTRAPULSE MODULATION (PULSE COMPRESSION)

30. Intrapulse modulation refers to a radar changing the characteristics of a pulse *during* the sending of the pulse. The term Pulse Compression comes from the way this was first achieved, using variable delays which had the effect of making a received pulse shorter.

31. Ideally, if we wanted both long detection range and fine range resolution, we would transmit extremely narrow pulses of exceptionally high peak power. But there are practical limits on the level of peak power one can use. To obtain long detection ranges at PRFs low enough for pulse delay ranging, fairly wide pulses must be transmitted.

32. One means of optimising this problem is to use Pulse Compression. By changing the pulse during the sending of the pulse, it behaves much like a series of short pulses, giving good range resolution, whilst still having a large amount of energy sent, giving good range detection.

Matched Filters

33. As will be seen in the next section, the bandwidth of a pulsed radar is actually infinite. A receiver needs to choose the bandwidth it will listen for echos in. Choosing a wide bandwidth will result in a large amount of signal return, but have lots of thermal noise, and a low Signal to Noise Ratio (SNR). Conversely, choosing too narrow a bandwidth will have low thermal noise, but also low signal return, so still a low SNR.

34. The optimum bandwidth (for greatest SNR) is achieved when the receiver bandwidth is 1/PW. This is commonly achieved using a Matched Filter. The process of the matched filter will not be discussed, but it is based on the mathematical Correlation function.

35. The results of the matched filter process on a non-compressed pulse are shown in Figure P1-7. This shows the results from a single target, and from two targets spaced less than the radar's range resolution – both in a zero noise environment. For the two closely spaced targets, the radar would not be able to distinguish the second target, especially when noise is added in.

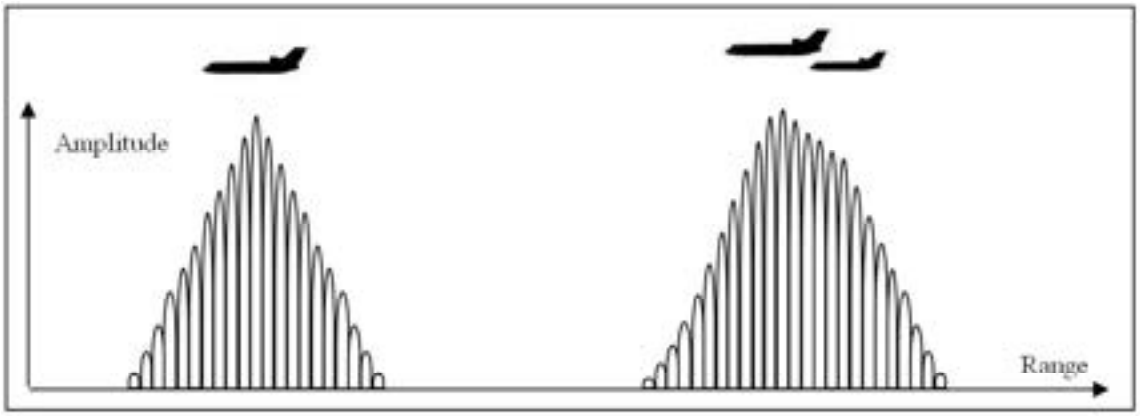


Figure P1-7 – Matched Filter Results (Non-Compressed Pulse)

Frequency Modulation on the Pulse (FMOP)

36. Frequency Modulation on the Pulse (FMOP) was called 'chirp' by its inventors because this method of coding is similar to the chirping of a bird,. Since it was the first pulse compression technique, some people still use the terms chirp and pulse compression synonymously. With chirp, the frequency of each transmitted pulse is increased at a constant rate throughout its length which is graphed in Figure P1-8. Every echo, naturally, has the same linear increase in frequency.

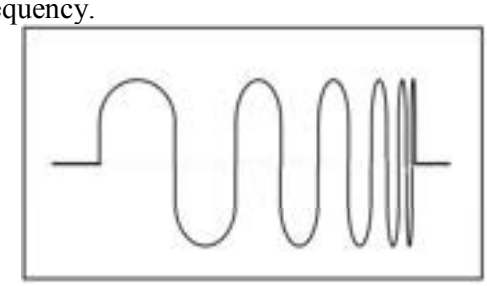


Figure P1-8 – Frequency Modulated Pulse

37. The results of a Matched Filter using FMOP is shown in Figure P1-9. The closely spaced targets are now easily distinguished from each other, due to the low 'sidelobes' of the match. Ideally, the sidelobes would be zero, however this is unachievable.

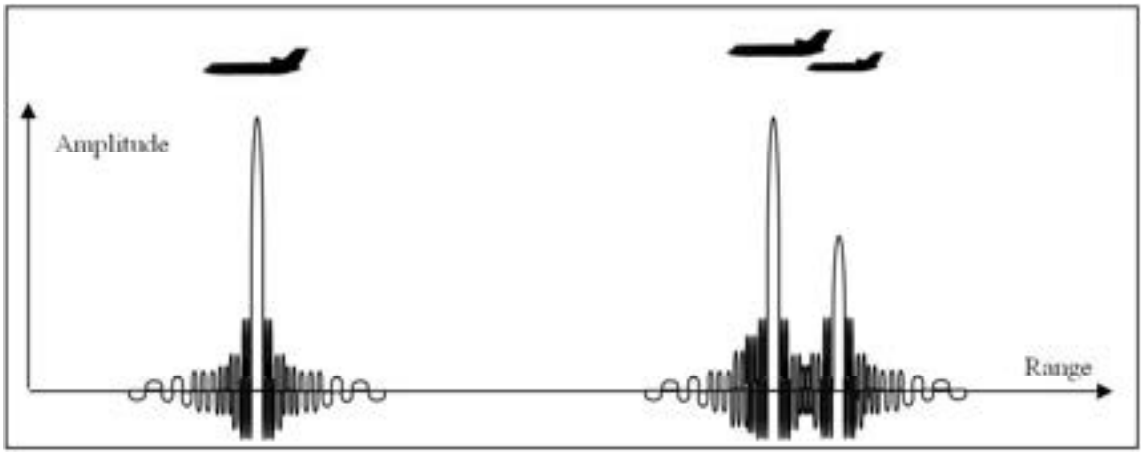


Figure P1-9 – Matched Filter Results (FMOP)

38. Frequency modulation has the advantage of enabling very large compression ratios to be achieved (see below). In addition, it is comparatively simple. The principle disadvantage is a slight ambiguity between range and Doppler frequency. If the frequency of a pulse has been, say, increased by a positive Doppler shift, the radar will have no way of telling whether this difference is due to a Doppler shift or to the echo being reflected from a slightly greater range. However since the Doppler shifts typically encountered are very much less than the range of frequencies over which the transmitted pulses is swept, ambiguity is generally not a problem.

Phase Modulation on the Pulse (PMOP)

39. In Phase Modulation on the Pulse (PMOP) coding the phase of the transmitted pulses is modulated, and the modulation is done in finite increments. For Binary Phase Modulation only two increments are used (0˚ and 180˚). Other methods have multiple phase increments; however those will not be discussed.

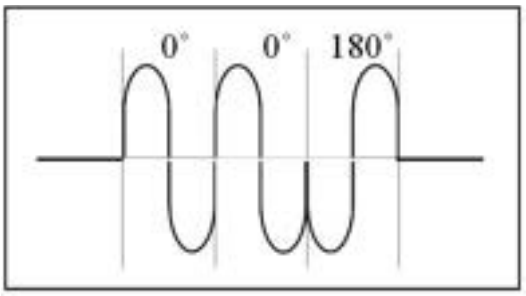


Figure P1-10 – Binary Phase Modulated Pulse

40. Each transmitted pulse is, in effect, marked off into narrow segments of equal length. The radio frequency phase of certain segments is shifted by 180 degrees, according to a predetermined pattern. An example of a PMOP pulse is shown in Figure P1-10. (For ease of explanation, each individual oscillation is shown as coded. In real systems, many oscillations at the same phase would occur in each segment).

41. The results of a Matched Filter using PMOP is shown in Figure P1-11. Again, the closely spaced targets are now easily distinguished from each other. The ‘sidelobes’ are still present, but small in amplitude. One set of PMOP pattern codes, called Barker codes, have the lowest sidelobes possible. Other pattern codes have larger sidelobes.

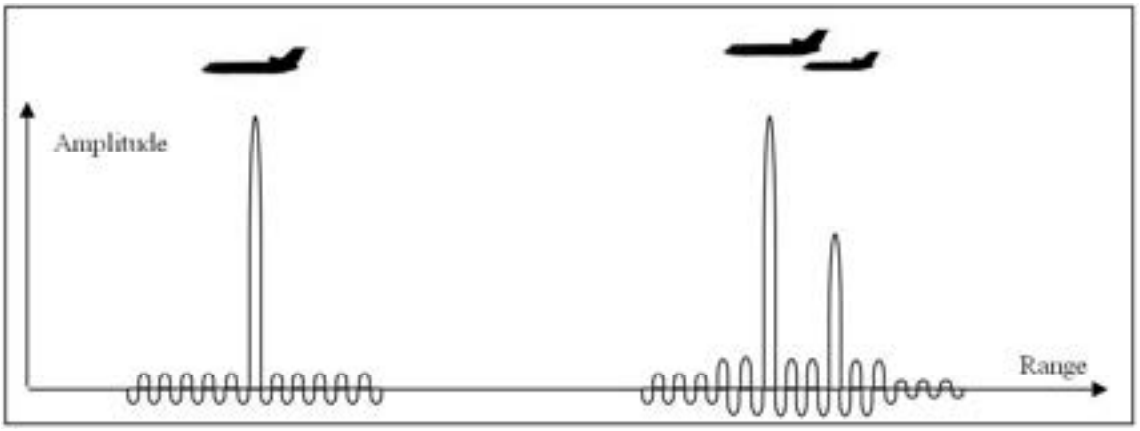


Figure P1-11 – Matched Filter Results (PMOP)

42. The use of FMOP and PMOP greatly increase the range resolution of the radar, however a second target could still be missed if it was hidden in the sidelobes of another target.

Compression Ratio

43. The Compression Ratio is a measure of the increase in range resolution as a result of the pulse compression. For example, if a radar had a range resolution of 50m, and uses pulse compression with a ratio of 10, then the actual range resolution becomes 50m / 10 = 5m.

CHAPTER P2

LOW PROBABILITY OF INTERCEPT

Topic Overview - Non-Assessed Presentation
Describe Low Probability of Intercept (LPI) principles
P2.1 Define LPI
P2.2 Describe LPI principles

INTRODUCTION

1. LPI is the term used for techniques designed to reduce the probability that a radar's emissions will be usefully detected by an intercept receiver. LPI is distinguished from Electronic Protection (EP) in that it is attempting to prevent intercept, not protect against Electronic Attack (EA). It does use some similar techniques to EP.

2. LPI techniques are typically aimed at reducing the amount of detectable energy through distributing energy over time, spreading energy over a range of frequencies, reducing the overall energy output, or selectively radiating.

SPREAD ENERGY IN TIME

3. ES systems tend to have short energy collection times (integration periods) so that precise pulse timing information can be obtained about the intercepted signals. Since the integration time is short (and limited), the ES system requires large peak powers in signals to see them above its noise threshold.

4. By transmitting a longer pulse width with less peak power, we can spread a single transmitted pulse over multiple ES system integration periods, thus the pulse energy is effectively split between integration periods.

5. The maximum range of a radar is determined by the pulse energy (being the peak power multiplied by the pulse width). By reducing the peak power, but increasing the pulse width, the radar is still transmitting the same energy and hence its maximum detection range is unchanged. However, the pulse energy is spread over multiple ES system integration periods, thus the pulse energy in each is greatly reduced.

6. There are two techniques to spread energy in time:

   a. Pulse compression, and

   b. Pulse integration.

Pulse Compression

7. Pulse compression allows a radar to lower its peak power, and lengthen its pulse width, whilst maintaining the same energy per pulse and the same range resolution. Pulse compression (or intrapulse modulation) has been discussed in Chapter P1.

Pulse Integration

8. Normally several pulses are returned from each target. These can be used to improve detection by summing (or stacking) all the returned pulses. Noise energy that accumulates over the integration time may vary widely, however, due to random phase and amplitude, the average level of noise energy is essentially independent of integration time. The integrated target returns, on the other hand increases in proportion to the integration time.

9. Integration requires that the phase of the echo signal remain the same between returns, which means the target cannot have moved much over the integration time.

10. Signal integration effectively increases the sensitivity of the radar, allowing it to see further. Or, if increased range is not required, the power sent per pulse can be reduced.

11. The radar receiver can "stack" returns, because it has timing information (i.e. it knows when pulses are sent). The ES system can't stack, because it doesn't have the timing information. The lower power pulses received by the ES system become lost in the noise.

SPREAD ENERGY IN FREQUENCY

12. The principle of this approach is to make the bandwidth (BW) of the transmitted signal wider than the bandwidth of the collecting ES system.

13. This is more of a communications LPI approach than a radar one because the bandwidths of ES collection systems can be quite wide (GHz for Crystal Video Receivers, 100+MHz for Superheterodynes).

14. It is very difficult to make a pulse width short enough to create an instantaneous BW that is wider than the collection ES system's bandwidth. For example, a short radar Pulse Width (PW) is 0.1 μs (15 metre range resolution) which gives:

$$BW = {}^{1}/_{PW} \text{ (approximately for a matched system)}$$
$$= 1 / 0.1 \times 10^{-6}$$
$$= 10 \text{ MHz}$$

15. Frequency Modulation on the Pulse (FMOP – see Chapter P1) can also be used to spread the pulse energy in frequency; however the maximum practical sweep is still only relatively small.

16. In communications, Code Division Multiplexing (CDM) (or Spread Spectrum) is a technique used to widen the bandwidth and lower the power of a signal. The power level of the signal in some Spread Spectrum techniques can actually be lower than the background noise level. The "code" of frequencies used is required to extract the signal from within the noise.

MINIMISE ENERGY

17. The less energy radiated, the less chance there is of an ES system receiving the signal. However, reducing the transmitted energy means reducing the maximum range of the radar.

18. If a radar design can reduce the system thermal noise, or improve its sensitivity it will reduce the Signal to Noise ratio required for detection. Therefore the radar will detect weaker signals, and hence have a greater detection range for the same output power.

19. By combining the two principles—radiating less energy and increasing the sensitivity—a radar will effectively have the same maximum range, but at a reduced chance of ES detection, or increased range before ES detection.

20. Using a higher gain antenna (instead of adjusting output power alone) will provide a one-sided benefit to the radar system over the ES system's ability to detect it. A radar's antenna offers gain during transmission (which the ES receiver also benefits from) however, during reception it provides additional gain (which the ES receiver doesn't benefit from). For

example, for every 10% additional gain the antenna can offer, the transmit power can be reduced by 17% while maintaining the same maximum range. For the 17% reduction in power, the ES receiver will need to be 5% closer to detect the signal.

OPERATIONAL TECHNIQUES

21. All of the techniques discussed so far have been design techniques. There are operational or procedural techniques to reduce the probability of interception. Ultimately, to prevent detection of radiation, don't radiate. Not radiating eliminates any change of an ES system detecting the radar, however it reduces situational awareness. A number of methods exist to reduce or eliminate emissions, but maintain situational awareness:

a. Limit radar 'on-time' (known as Emissions Control - EMCON) or direction to the minimum required for the task or present threat. Although you are still radiating, you are minimising the amount of time you are radiating.

b. Use passive sensors such as RWR, ESM, or IRSTS. Passive sensors will give you some idea of the disposition of nearby targets, however if everyone is not transmitting, it may be difficult.

c. Use collateral intelligence and reconnaissance information. If there are other friendly platforms collecting information, they can share with you on data-exchange networks such as Link 16. You will still be passive, but will have access to the entire picture of what they see.

CHAPTER P3

GPS AND DATALINK

Topic Overview - Non-Assessed Presentation
Describe GPS and Tactical Data Links
P3.1 Describe GPS navigation principles of operation
P3.2 Discuss GPS jamming
P3.3 State the purpose of a data Link
P3.4 Describe principle differences between Link 11 and Link 16 systems

TACTICAL DATA LINK

1. A Tactical Data Link (TDL) is defined as a communications system which supports the exchange of near-real-time tactical data between participants using a variety of free or fixed format messages, which are characterised by unique transmission characteristics, protocols and standardised message structure.

2. Types of data that can be send on the TDL may include:

    a. Telemetry and Navigation,

    b. Imagery and Reconnaissance,

    c. Target Information,

    d. Weapon Control and Guidance,

    e. Movement of Forces / Assets,

    f. Equipment status, and

    g. Levels of Supplies.

3. To set up a data link, two platforms must agree on parameters like:

    a. the transmission media (Landline, RF, acoustic, fibre optic, laser etc);

    b. the data rate (how fast you will send or receive data);

    c. a specific frequency (how often will you transmit & what RF);

    d. the modulation type (AM, FM);

    e. a standard message format (which bits go where in the message); and

    f. a specific protocol (who sends first and for how long).

4. A TDL standard specifies these protocols. Common defence TDL standards include:

    a. Link 1,

    b. Link 4 / TDL C,

    c. Link 11A / TDL A,

    d. Link 11B/ TDL B,

e. Link 14,

f. Link 16 / TDL J, and

g. Link 22.

5. The most common TDLs in the ADF are Link 11 and Link 16.

Link 11

6. Developed in late 1950s, Link 11 is a netted digital communications system, utilising standard military UHF or HF radios for the exchange of tactical information between participating units.

7. Link 11 can exchange information between airborne, land based, submarine, and ship-borne platforms. It can use a number of mediums including HF radio, UHF radio, satellites and telephone landlines. All data is encrypted using the secure data link (KG 40A).

8. Information must pass through the Net Control Station (NCS) to the other platforms. The NCS can only talk to one platform at a time, and if it stops working, then the network shuts down.

9. Link 11 suffers from the following problems:

a. Limited electronic attack protection,

b. Slow data rate (1.3 / 2.2kbps),

c. Maximum of 62 participants,

d. Critical dependence on single node (NCS), and

e. Doesn't support voice.

Link 16

10. Link 16 is a high data rate TDL which supersedes the functions of Link 11 and Link 4.

11. Link 16 utilises Time Division Multiplexing (TDM). Each participant is assigned one or many of 1536 timeslots in each 12 second block to transmit in. Participants broadcast information omni-directionally during their own time slot. Information can be received by any terminal within range, however it is limited to line of sight (UHF). Each terminal can select or reject messages according to its need for that information. Passive participants can receive without being assigned time slots

12. Link 16 offers many improvements over Link 11 including:

a. High capacity (technically unlimited participants);

b. Near real-time, omni-directional broadcasts;

c. Line of Sight Digital UHF link;

d. Non-nodal, two-way, Half Duplex communications;

e. Multi Net operations (users may belong to one of many sub-nets, and can transfer information between nets);

f. Built in secure voice and TACAN;

g. Jam resistant using Spread Spectrum and Frequency Hopping techniques;

h. Secure (encrypted); and

i. High data speed.

13. Beyond line of sight capabilities compatible with Link 16 are available through the TDL J Range Extension (JRE) protocol using satellite and terrestrial mediums.

14. Link 16 requires a common time reference to ensure all participants are transmitting during their assigned timeslot. The most convenient source of a common time is GPS.

GPS

15. The GPS (Global Positioning System) uses satellites to enable accurate positioning of ground, naval and air users. Many countries have alternate networks that provide a GPS-like function including:

a. America. GPS utilising 24-32 satellites.

b. Russia. GLONASS system of 24 Satellites.

c. Europe. Galileo planned 30 Satellites beginning limited operations in 2014.

d. China. Beidou using 3 satellites, or planned Beidou-2 (Compass) of 35 satellites.

e. Japan. QZSS system of 3 satellites which augments the GPS system to increase accuracy over domestic Japan

GPS Operation

16. Each GPS satellite knows its precise location in space, as well as the precise system time. Each satellite constantly transmits a coded signal broadcasting the satellite position and time that the signal was sent.

17. A GPS user receives the signal from each 'visible' satellite. The time of reception is compared to the time of transmission (by decoding the signal) to determine the time it took the signal to travel from the satellite to the user. The transmission travels at the speed of light, so the distance from the user to each satellite can be calculated.

18. The GPS receiver then calculates the user's position through simple trigonometry (it knows precisely where the other satellites are, and the distance to them, so it can determine its own position).

19. Timing is critical to GPS positional accuracy. If the GPS receiver's clock was perfectly synchronised with the satellite's clock, then only 3 satellites would be required to determine your position. A clock error of 1μs will create a position error of 300m. Perfect synchronisation of clocks is not possible, so the GPS receiver must use a fourth satellite to compensate for clock errors.

GPS Jamming

20. The received GPS signal on Earth is very low power. Typical received signal strength is only -163dBW (0.000 000 000 000 000 05W). As well, GPS antennas are almost omni-directional (half hemisphere) and therefore receive from all directions.

21. These two properties make GPS extremely easy to jam. For less than $20 from your local electronics shop you can make a wideband, non-coherent noise jammer able to jam GPS at a range of many hundreds of metres. Commercial GPS jammers are also available on the open market able to jam GPS to hundreds of kilometres.

22. For this reason, GPS is not trusted as the primary navigation aid in aircraft. Therefore, an Inertial Navigation System (INS) is used for navigation, using GPS as a backup to increase its accuracy.

23. The only 2 proven protection techniques against GPS jammers are terrain masking, and an anti-jamming antenna system integrated with an INS, also known as Controlled Radiation Pattern Antenna (CRPA). The idea behind the CRPA is to not use an omni-directional beam, but to use a series of directional antenna beams. The can be steered in the direction of satellites, and away from the direction of any jamming signal (see Figure P3-1).

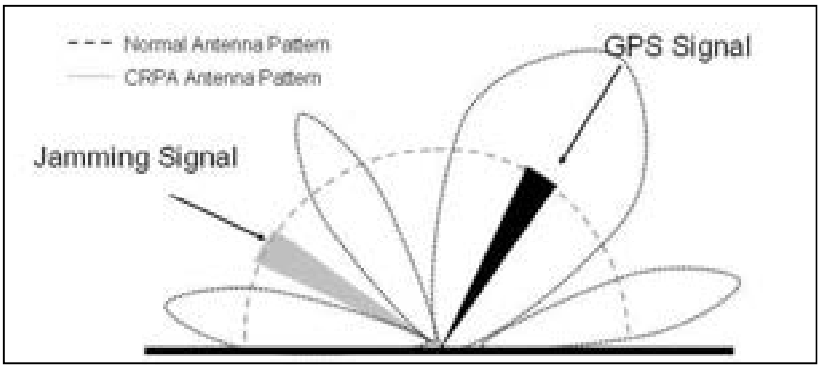


Figure P3-1 CRP Antenna

24. The use of a CRPA antenna will not prevent jamming, but reduces the effective power of the jammer by about 50x, requiring the jammer to be more powerful, or be a lot closer, to be effective.

CHAPTER P4

RF JAMMING

Topic Overview - Non-Assessed Presentation
Describe the techniques and effects of RF jamming
P4.1 Define the J/S Ratio
P4.2 Describe Noise Jamming methods and effects
P4.3 Describe Deception Jamming methods and effects

INTRODUCTION

1. A radar system derives target information by transmitting a pre-defined signal (pulse or CW) and then receiving the same signal displaced in time and/or frequency. Thus, to actively counter the radar, it is necessary that a jammer propagate signals that are electronically matched to the radar to either overload or confuse the radar receiver.

2. Any signal generated to counter the radar must operate at the same frequency and cover at least the same bandwidth as the victim radar, and for maximum effect, the signal should match the polarization of the victim radar signal.

3. Jamming or EA should not be initiated until the enemy radar is considered a threat. The early use of countermeasures could alert the enemy to an otherwise undetected target's presence. The indication that the enemy radar is present and is a direct or indirect threat can be obtained from RWR or ESM equipment, which gives a visual and/or audio signal to the operator. Each type of radar scan system—CW, pulse, conical scan, mechanical track-while-scan etc—has its own recognisable signature which can enable the best choice of EA to be made.

DEFINITIONS

Jamming

4. Jamming is the deliberate radiation or reflection of electromagnetic energy with the object of impairing the use of electronic devices, equipment, or systems being used by the enemy.

Jamming to Signal Ratio

5. The ratio of the power outputted by a jammer (J) to the signal return coming off the target skin (S) is called the Jammer to Signal ratio (or J/S). The power transmitted (J) depends on the jammer power and jammer antenna gain. The target signal power (S) depends on the radar power, radar antenna gain, distance between the radar and the target, and the target Radar Cross Section (RCS). To be effective, the jamming power needs to be greater than the signal power (J/S >1).

Burn Through Range

6. A jamming signal is a one-way path, and hence depends on the inverse square of the jammer range (i.e. spreading loss). Skin echo, on the other hand, is a two-way path, and hence depends on the inverse fourth power of the target range. This difference due to the effect of range means that, at long range, the jammer has the advantage. At closer ranges, however, the skin echo becomes relatively stronger. The distance where the two signals are equal strength (J/S=1) is called the Burn Through Range. At distances less than the Burn Through Range, the jammer is not able to output enough signal strength and jamming is ineffective.

EA POSTURES

7. **Stand-off Jamming.** An aircraft with high power capabilities flies outside enemy detection ranges and emits disruptive signals to jam radar and communications. This is most effective against Surveillance Radars. The jamming radar requires high power (1-2kW) to overcome the large range losses.

8. **Mutual Support Jamming.** Combat elements work in a cooperative manner to negate hostile acquisition and tracking radars. Tracking systems may be lured away from targets using cooperative techniques such as 'Blinking' or artificial glint. Mutual support may also be used to increase active jamming Effective Radiated Power (ERP). Mutual support jamming can be used against Target Track and Missile Guidance Radar.

9. **Escort Jamming.** A specially equipped aircraft accompanies combat elements into areas within the detection and engagement ranges of the enemy. This aircraft may have an EWO on board whose job is to negate all enemy sensors. Special care must be taken to protect this aircraft because if it is destroyed the force will be left unprotected.

10. **Self Protection Jamming.** As the name suggests, this is EA that protects the platform. This form of EA is used against terminal engagement modes of radars. Self Protection deception Jamming is the most used form in the ADF.

11. **Stand-in Jamming.** Future EA will utilise new technology such as micro UAVs (unmanned aerial vehicles). These UAVs will be small and able to be flown right up to the threat radar so their very limited output power is adequate enough to jam the radar.

JAMMING TYPES

12. The use of electronic countermeasures against radar can be divided into two main categories:

a. **Denial Jamming** is the deliberate radiation, re-radiation or reflection of electromagnetic energy with the object of impairing the use of electronic systems, equipments or devices. This is normally Noise jamming.

b. **Deception Jamming** is the deliberate radiation, re-radiation, alteration, absorption or reflection of electro-magnetic energy in a manner intended to mislead an enemy in the interpretation or use of information received by their electronic systems.

The Application of Radar Jamming

13. Within an operational mission, there are two main applications of radar jamming:

a. Jamming Against Surveillance Radars. The main strategy against search and surveillance radars is to avoid detection. The obvious approaches therefore, are noise or confusion jamming. Both of these attempt to prevent target detection.

b. Jamming against Weapon Radars. Should detection have taken place, the next obvious stage for an acquisition/tracking radar is to lock on, and a weapon sent to destroy the target. The priority for the target in this circumstance is to make the weapon miss. The techniques most likely to succeed are deception, (of either the tracking radar or the missile homing radar), the use of chaff, or deployment of

decoys. There is also the possibility of using deception directly against the weapon fuse (if it is a radar fuse) to make it detonate at the wrong time.

14. These notes will emphasise noise/confusion techniques against search radars and deception techniques against tracking radars. It should be noted, however, that the boundaries are not clear-cut. It is perfectly possible, for example, to use noise jamming against a tracking radar in an attempt to deny range information. Also, some radars are not easily categorised. The obvious example is a modern multi mode AI radar, which operates sometimes in search and sometimes in track modes. It should also be noted that jamming against specialist radars, such as Terrain Avoidance, Terrain Following and Synthetic Array may require separate consideration.

DENIAL JAMMING

15. Radar receivers need to be highly sensitive due to the very weak amplitude of returned radar echoes. This sensitivity makes radar receivers vulnerable to jammers which are able to generate sufficient noise in the receiver to swamp the wanted signal.

16. Noise jamming is achieved through the jammer simply generating random noise energy, amplifying it, and radiating it towards the threat. The threat receives the noise energy, as well as the aircraft returns. Because the jamming noise energy is stronger than the aircraft return, the threat radar will not be able to distinguish the real return from the noise.

17. Noise jammers can be divided into three major categories:

a. Spot Jammers,

b. Sweep Jammers, and

c. Barrage Jammers.

Spot Jammers

18. Spot jamming provides the maximum jamming power to the victim radar, but has the limitation of being able to jam only one radar frequency at any one time. To apply a spot jammer, the victim radar's frequency and bandwidth are known from previous intelligence or are found by using an intercept receiver. The jammer is then tuned manually or automatically to centre on the victim radars' frequency with sufficient bandwidth. This is illustrated in Figure P4-1.

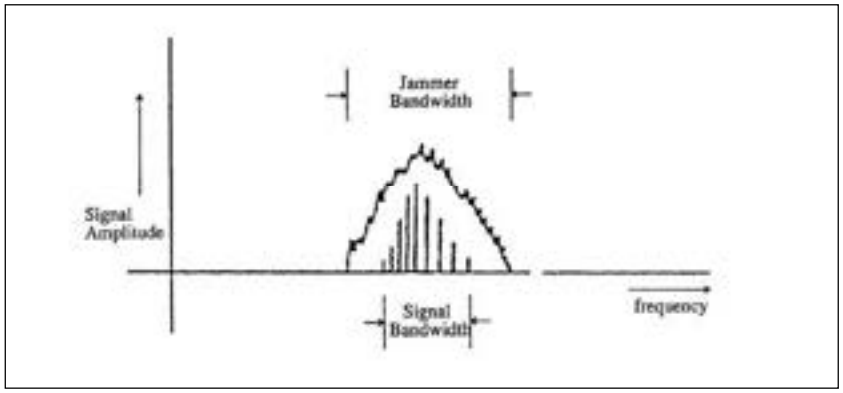


Figure P4-1 Spot Noise Jamming

Barrage Jammers

19. Barrage noise jammers are used when there is a requirement to jam over a wide bandwidth continuously. This type of jammer is attractive because a number of enemy radars, including those which are frequency agile, can be jammed simultaneously and continuously. However, barrage jammers, as seen in Figure P4-2, spread the available power over a wide bandwidth (f_A to f_B). The disadvantage of this is the jamming power at any one particular frequency is much reduced from that available from a spot jammer tuned to that frequency. Barrage jammers also output energy on frequencies in the selected bandwidth range which do not need to be jammed since no radar is using them. For this reason, barrage jammers need to have as high a power output as possible.

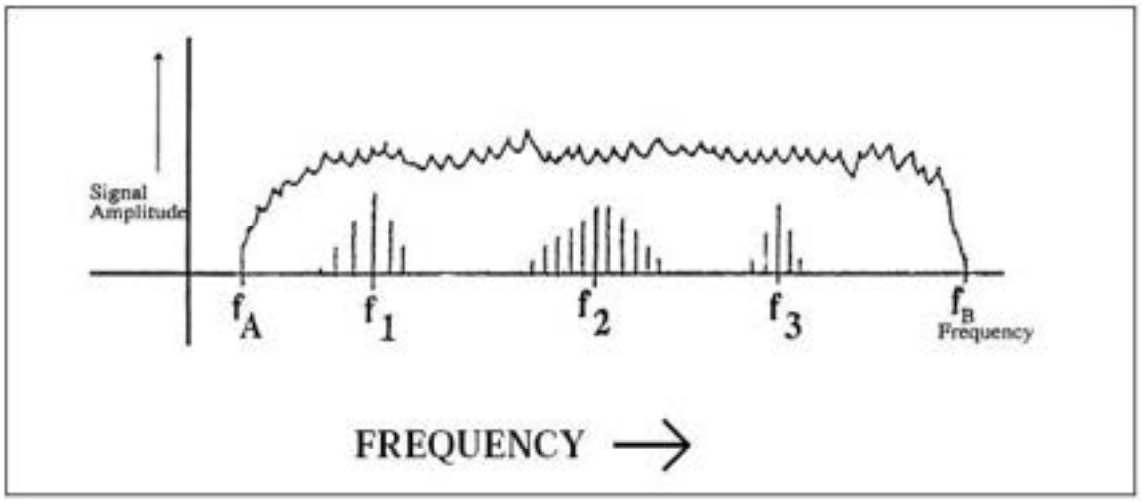


Figure P4-2 Barrage Noise Jamming

The Effects of Noise Jamming

20. On a radar display, such as the plan position indicator (PPI) in Figure P4-3, the effect of a noise jammer masks the range of the jammer, though the target azimuth can be clearly seen.

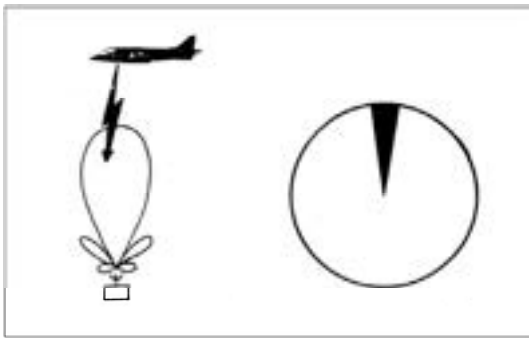


Figure P4-3 Main Lobe Noise Jamming

21. For a powerful airborne jammer, shown in Figure P4-4, the display is affected by the jammers ability to inject energy into the sidelobes of the antenna. When the antenna receives energy in the sidelobes, it assumes the energy came from the direction the main beam and paints the sidelobe jamming on the azimuth of the main beam. The display will then present an ambiguous azimuth to the operator, or jamming will appear from multiple directions.

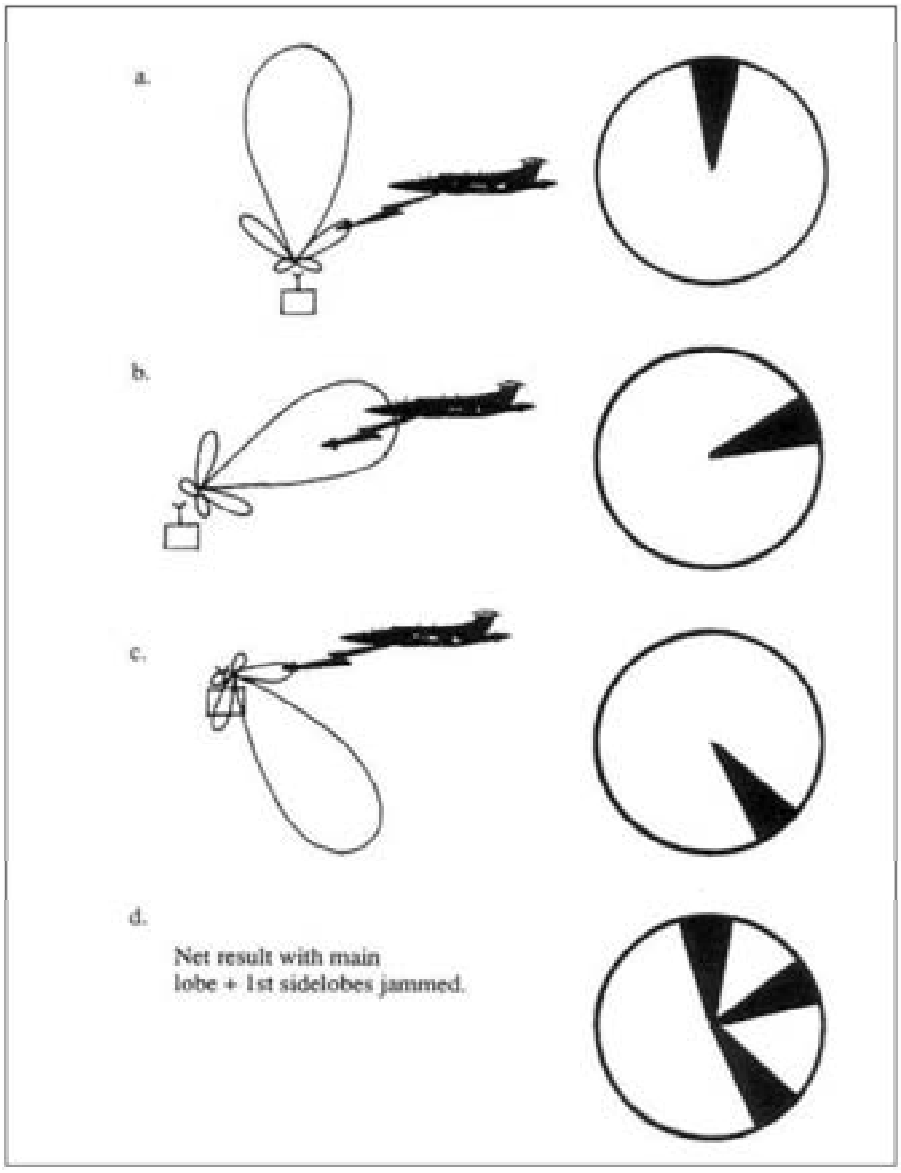


Figure P4-4 Sidelobe Jamming

DECEPTION JAMMING

22. The preceding notes on Noise Jamming dealt with ways in which the detection capabilities of surveillance radars could be degraded. This section deals with the situation where detection has taken place, and the prime objective is then to make the enemy weapon system miss its target. In the world of radar, weapon systems are normally given targeting information from a single-target tracking radar, which has been assigned to its target by information from the surveillance radar. Thus the crucial thing is to deny the tracking radar (also referred to as the fire control radar - FCR) correct target information. At best, this will cause the tracker to lose the real target altogether (a situation known as break-lock). Failing this, any significant increase in the weapon's miss distance will at least give the target a better chance of surviving the encounter. If the weapon is a missile, rather than a gun, it is possible that it can reach its selected target using only target direction.

23. Simple noise jamming, which denies only range information, is not greatly favoured in most cases. Deception in range, velocity or angle (preferably achieving break-lock) is therefore the most desirable approach. The following paragraphs outline the methods

available for achieving this against tracking radars. It should be noted that in most cases the techniques are identical whether the radar is in the weapon itself, or remains at the firing point.

24. A noise jammer is not normally an appropriate system to use against a tracking radar since by tracking the noise strobe in azimuth and elevation a weapon can be directed against the target using 'three-point guidance' or command-to-line-of-sight (CLOS) guidance. If the target is known, or assumed to be in range; the application of a noise jammer against a tracking radar for missile-systems can be likened to putting a beacon on the aircraft. Against gun-laying FCRs, noise jamming may be successful as range data is an integral part of the lead-prediction calculation.

25. In general, deception countermeasures require less power than noise jammers. In some equipment the lower power requirement enables the system to jam more than one threat simultaneously by time-sharing the output of its transmitter. The jamming equipment, by producing signal-like outputs, enjoys another advantage over a noise jammer in that radars are designed to accept the signal-like waveform, whilst rejecting noise-type jamming.

26. To introduce a deceptive jamming signal successfully it is necessary to establish the victims' radar search pattern, its parametric details and, for track-breaking, to have knowledge of the tracking method used by the radar. Deception jammers can cause false targets to appear, range and velocity tracking gates to be pulled off or angle-tracking to be displaced.

RF Decoys

27. A Towed Radar Decoy (TRD) is a small pod that deploys from the target on a tether retaining kinematic properties similar to the target but provides a jamming source a short distance from the main target. The TRD streams out from the aircraft and trails about 100-200m behind it. The TRD is fairly small in size—approx 30cm long—and contains a receiver, processor and transmitter. The TRD simply amplifies any incoming RF signals and retransmits them – effectively looking like a very large RCS target.

28. The towed decoy is considered an "active decoy", in that it uses a power amplifier and antenna within the decoy to generate a large jamming signal. By providing a physical angle separation between target signal and jamming signal, and by providing a stronger signal than the target, a missile seeker will be seduced away from the target aircraft and towards the decoy.

29. The decoy may or may not be hit and destroyed; it depends on the jamming technique, the jamming signal strength, and its effect on the seeker. Ideally the missile should miss both target and decoy—meaning you don't have to worry about deploying another one which takes both time and money.

False Target Generation

30. This form of deception appears on the victims' radar screen as a set of returns which look like targets. This will make it difficult for the operator to decide on a correct course of action or the true location of the real target. On receiving the radar's transmission, the jammer re-transmits the received signal with a slight delay (or in anticipation of the next radar pulse) to result in deceptive returns in range. If the signal is stored, then injected into the sidelobes at a proportionally higher power, the jammer will also be able to deceive in azimuth. By careful programming of the jammer, a variable matrix of echoes can be built up on the victims' radar screen as required by the attacking force.

31. False targets generated by a jammer have a slightly different look than the real target returns due to atmospheric scintillation effects. A well trained operator can discern the difference between them, so in any false target jamming, a false target is also generated on top of the real target return. This cover pulse ensures that all targets (false and real) look identical.

Cover-Pulse Jamming

32. In cover-pulse jamming, the jamming pulse is stretched in time and transmitted on top of the real target return, but starting well before the real pulse and lasting long after it. This denies range information to the victim radar and is also effective against PRI-agile radars.

Range Gate Stealing

33. The technique of range-gate stealing or Range-Gate Pull Off (RGPO) is used as a counter to automatic range gate circuits used by tracking radars. The basis of the technique is illustrated in Figure P4-5. Initially the radar is range-gated to a true target return, as in Figure P4-5a and the automatic gain control (AGC) circuits have set themselves to the desired level for the echo signal strength. The victim radar's signal received by the jamming equipment is then amplified and re-transmitted with minimum delay so as to provide a very strong signal at the radar. This strong signal causes the AGC to adjust as shown in Figure P4-5b and the radar then starts to track the false target. The true target has been suppressed and the range-gate has been captured. The repeated (false) signal is successively delayed or advanced on a pulse-to-pulse basis away from the true target echo (figures P4-5c and P4-5d). After a period, the false target generation is stopped and the tracking is lost (figure P4-5e). The AGC circuits then re-adjust (figure P4-5f) and the radar is now tracking on random noise.

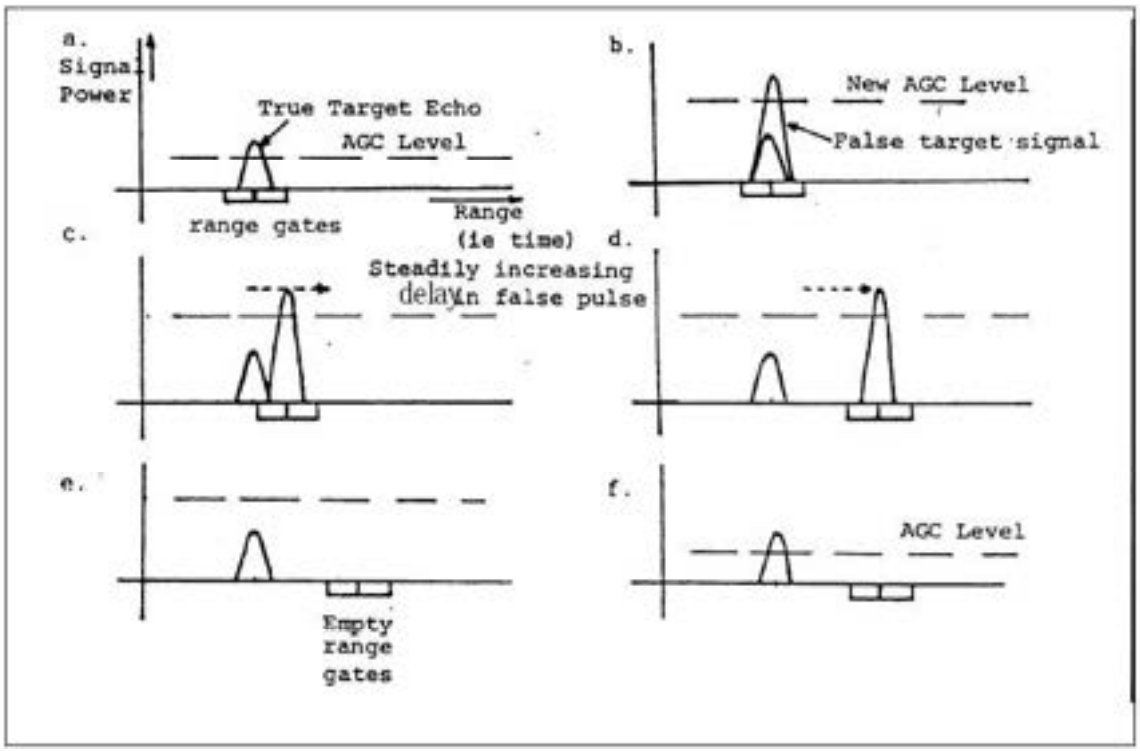


Figure P4-5 Range Gate Pull Off

34. A variant of the RGPO principle is Range-Gate-Pull-In (RGPI). In RGPI the range gate is pulled toward the threat radar (a decrease in false target range) in the same way that the gate is pulled away from the radar. To do this, each false pulse needs to be sent *prior* to the

next received radar pulse. This requires the jammer to be able to predict the arrival of the next pulse, so it requires a knowledge of the radar's PRI to be able to do so.

Velocity-Gate Stealing

35. Doppler-type radars primarily detect targets through velocity differences and use a velocity-gate when locked to a target. This velocity gate is analogous to the range-gate of a pulsed tracking radar and the countermeasure is similar in conception to that described in paragraph 33. Whereas the pulsed system works in relation to range (i.e. Time) the doppler system works in relation to frequency so that to steal the locking gate the deception signal has to be shifted in frequency. The shift can be up or down the spectrum, but, as with range-gate stealing, the rate of change must not be higher than that which the threat radar is designed to accept (i.e. acceleration limits can be imposed upon the target-tracking gates).

Angle Deception - Track-While-Scan Systems

36. To counter TWS systems, the noise technique of sidelobe jamming can be utilised. In this technique, the jamming signals are introduced into the sidelobes as well as the main lobe. The power of the jamming signal injected into each sidelobe is proportional to the ratio of main lobe to sidelobe power levels. The effect that this jamming will have on the TWS scopes is to provide many spokes of noise, effecting masking the targets true azimuth.

Angle Deception - Overlapping Lobe Radars

37. Conical scan and sequential lobing radars obtain tracking information by correlating angular error signals with lobe position to keep the antenna centred on the target. If those error signals could be modified, then deception would be possible. One method for use against conical scan radars is known as 'Inverse Square Wave' jamming. This is achieved by the EA equipment receiving the scan-modulated pulses, inverting the modulation and retransmitting them. This will cause a false error signal at the radar which will drive the antenna away from the target. Figure P4-6 illustrates the basis of the technique.

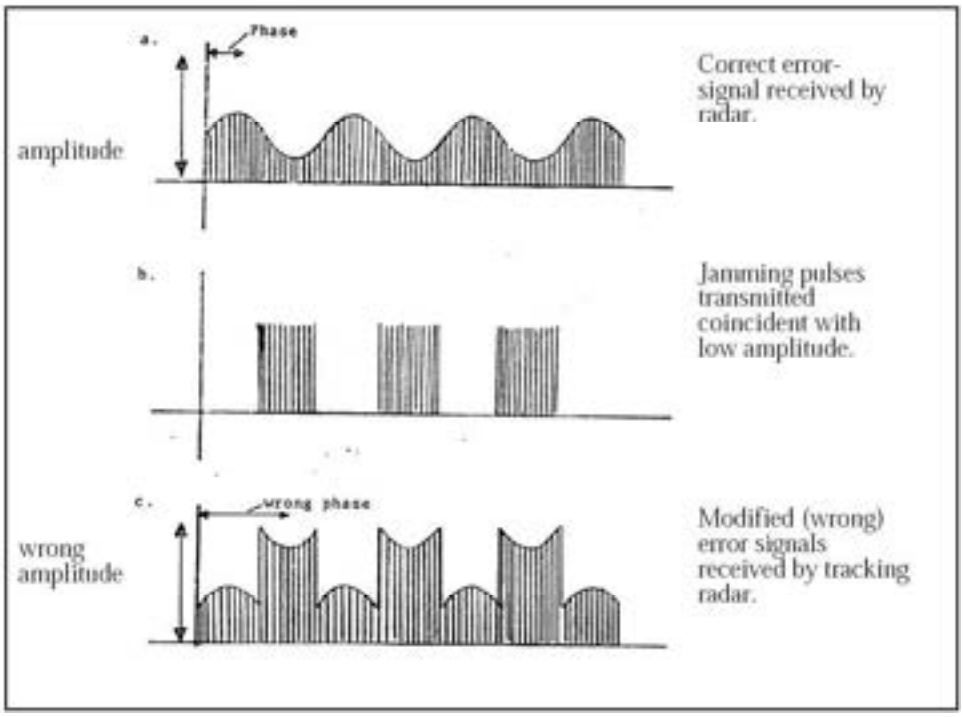


Figure P4-6 Inverse Square Wave Jamming

Lobe-on-Receive Only Techniques

38. Both mechanical TWS and conical scan tracking radars are made vulnerable to jamming because their scan patterns are obvious to the jammer and can be replicated. Many radars therefore hide their scanning rates by transmitting a single wide beam and determining the angle-error amplitude modulation on the receiving beams or beam. This technique is known as Lobe-On-Receive Only (LORO) or Conical Scan On Receive Only (COSRO). Unintentional scanning modulations are often induced onto the transmitted beam by the lobing action of the receiver beams and this can allow the jammer an opportunity to attack.

Angle Deception of Monopulse Radars

39. Monopulse radars are, by their very nature, difficult threats to deceive electronically. Although electronic deception is difficult it is not impossible and some methods include:

a. **Towed Decoys.** When the towed decoy separates from the aircraft, the monopulse radar will track the strongest return—which should be the decoy.

b. **Terrain Bounce Jamming.** Terrain bounce jamming is primarily postulated for use against semi-active missiles. The basic technique is for the jammer to illuminate the Earth's surface in front of and below the target aircraft so that it bounces up to the missile and any associated tracking radar. The jamming signal must be very strong to overcome the losses caused by the Earth's surface and the illuminated spot must be within the missile's main beam. The technique is illustrated in Figure P4-7.

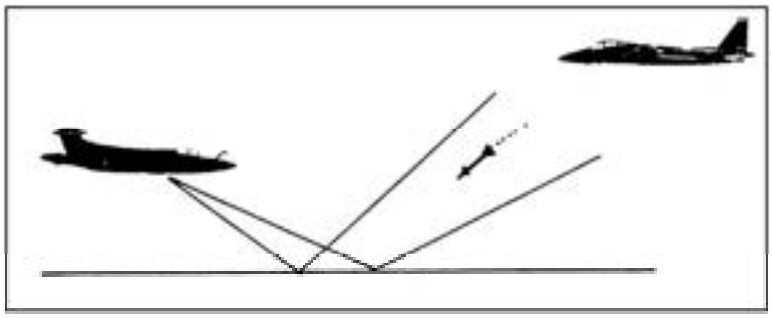


Figure P4-7 Terrain Bounce Jamming

Summary of Deception Techniques

40. As the reader may appreciate, the deception techniques presented thus far in these notes are, by necessity, described at the generic level. However, the vast range of modern countermeasures are derived from, or are variants of, the generic techniques discussed. An understanding of the basics is usually enough to allow an understanding of the more complex techniques.

41. Deception jamming provides the following advantages over noise jamming:

a. Gives false azimuth and elevation;

b. Gives false velocity;

c. Good self protection application;

d. Does not require density, weight, and power of noise jammers; and

e. Does not radiate unnecessarily.

42. Deception jamming exhibits the following disadvantages:

a. Especially vulnerable to changes in signal parameters, e.g. signal power level, scan rate, PRF, frequency;

b. Does not screen real target unless AGC is captured;

c. Does not screen range/velocity unless the gate is captured;

d. Current, accurate intelligence is essential;

e. Usually counters only one threat at a time;

f. Unstable PRF produces unstable false target location; and

g. Strength of radar return varies with RCS, but false targets are constant.