COMMAND AND STAFF TRAINING INSTITUTE

BANGLADESH AIR FORCE

Individual Staff Studies Programme (ISSP)

PROFESSIONAL-1: AIR DEFENCE WEAPON CONTROL
Part-I, Phase-8

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Part-I, Phase-8

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PART-I, PHASE-8
CONDUCT OF THE PHASE
SUBJ : PROFESSIONAL-1 (AIR DEFENCE WEAPON CONTROL)

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INTRODUCTION TO THE PHASE

Scope of the Phase

1. This phase deals with professional study materials on the subject of Air Defence Weapon Control, which has been divided into two parts Part-I and Part-II. The materials contained in this volume constitute Part-II of the phase. The individual topic has been so presented as to help you to gain theoretical background leading to its practical utilization.

Guidance on Methods of Study

2. In addition to this phase note you should study different manuals and Publications pertaining to this subject to improve your knowledge.

TOPIC- 1
AIR POWER

AIR POWER CHARACTERISTICS AND AIR POWER COMMAND AND CONTROL

"Air power is the most difficult of all forms of military force to measure, or even to express in precise terms."

- Sir Winston Churchill

Defining Air Power

1. It has always been difficult to define the concept of air power. In the early years of military aviation, air arms tended to be seen not as agencies for a distinctive type of military force, but as auxiliaries to the ground and naval forces. By the 1950s perceptions had been revolutionized, and many saw air power as an all-encompassing concept. For example, Marshal of the Royal Air Force Sir John Slessor, argued that air power is a compound of Air Forces and all those things on which Air Forces directly or indirectly depend. Such as a flourishing aircraft industry and civilian aviation, a good meteorological service, secure fuel supplies and so on.

2. Today, most air power thinkers take a middle course and tend to treat air power as a purely military concept. The definition now accepted by the RAF is that air power is the ability to use platforms operating in or passing through the air for military purposes. The means of exercising air power are many and include any system which can be used to wage warfare in the air: for example, manned and unmanned aircraft (fixed and rotary wing), guided missiles, balloons and space vehicles.

Air Power Characteristics

3. The air is a very different environment in which to light than either the land or the sea. Hence, air forces have quite different characteristics, strengths and limitations from land forces and sea forces. That in turn means that air power has different applications at the different levels of war, demands specific skills and types of expertise and — as a result — generates a different type of ethos amongst its practitioners.

4. The Strengths of Air Power. Air power has the unique ability to exploit the third dimension above the surface of the Earth. As a result air vehicles are far faster and have greater reach than naval ships or land vehicles. Thus, height, speed and reach must be considered as the primary strengths of air power. However, height, speed and reach act together synergistically to produce additional strengths which are listed below and which merit examination:

a. **Height**. The ability of aircraft to operate over a spectrum of heights gives them the ability to observe and dominate activities on the surface and below the sea. It allows direct fire to be used against all of the enemy's forces, whether or not they are in the front line, and it permits manoeuvre in three — rather than just two — dimensions, an important factor in survivability.

b. **Speed**. The speed of aircraft allows rapid projection of military power; greater speed allows missions to be completed in shorter times and a larger number of tasks to be completed within a given period. At the tactical level, high speed reduces the time that aircraft are exposed to hostile fire and thus can increase their survivability in battle.

c. **Reach**. 70% of the world is covered by water, 30% by land and 100% by air; as a result air power possesses unrivalled reach, Aircraft can project military power over great distances in any direction unimpeded by surface features such as mountain barriers or water expanses~. Air power reach has been greatly extended in recent years through the use of air-to-air refuelling. Reach is important not only for striking at distant targets and reaching isolated locations, but also for circumventing potential restrictions (eg by routing flights around a country which has refused over flight clearance).

d. **Ubiquity**. Within a given level of resources, air power — thanks to its height, speed and reach -- can counter or pose simultaneous threats across a far wider geographical area than is possible with surface systems.

e. **Flexibility**. Aircraft can perform a wide variety of actions, produce a wide range of effects and be adapted with comparative ease to meet changing circumstances and situations For example; the Tornado GRIA can be used for reconnaissance, air-to-surface attack and air-to-air self defence. It can therefore carry out more than one role during a single mission and be re tasked in the air if necessary. Similarly, larger aircraft such as the Hercules can be used for surveillance and air-to-air refueling as well as its primary role of air transport.

f. **Responsiveness**. Speed and reach make air power uniquely responsive. it can be used to counter or pose simultaneous threats across a far wider geographical area than is possible with surface systems. Air power can be deployed rapidly into distant theatres to provide visible and timely support for an ally or to act as a deterrent to aggression. For closer threats, it can be used to project military power rapidly, direct from its peacetime bases. The responsiveness of air power is as important in crisis management as it is in conflict.

g. **Concentration**. Speed, reach and flexibility allow air power to concentrate military force — in any of its many forms — in time and space, when and where required. The moral and physical effects of such a concentration capability are often crucial to achieving operational success.

5. **Limitations**. Air power has inherent limitations as well as strengths, namely impermanence, limited payloads and fragility. Like the strengths of air power these are relative rather than absolute and need to be understood in that context:

a. **Impermanence**. Aircraft cannot stay airborne indefinitely. Although air-to-air refueling can greatly extend the range and endurance of aircraft, no means have yet been found to re-arm, re-crew or service an aircraft in flight. To that extent, air power is an impermanent form of military force; the effects it creates tend to be transient and to sustain those effects, operations have to be repeated. In certain circumstances, the impermanence of air power can be an advantage. For example, it -can help to avoid the potential military and political liabilities which can arise from an extended presence in a foreign country.

b. **Limited Payloads**. The payloads that can be carried by aircraft are far more limited than those that can be carried by ships or by land vehicles. Thus, aircraft are most cost-effective when they are used for tasks which give high-value pay-offs. This applies equally to combat and combat support tasks, such as, for example, transportation. While relatively small payloads that can be carried are a disadvantage, they can in part be compensated for by the high sortie rate conferred by an aircraft's speed and by the lethality and precision of modern air-to-surface munitions. Moreover, a small payload deployed quickly may be of far more value in stabilizing a critical situation than one many times it size which is deployed later. It is important to note that payload limitations are common to all systems which exploit the third dimension. They are particularly marked in all missiles with small aerofoil lifting sections.

c. **Fragility**. Because air vehicles are by their nature highly stressed and have to be as light as practicable, they carry little or no armour protection. Hence, relatively low levels of battle damage can have catastrophic effects, a fact which tends to limit the extent to which it is sensible to risk exposing aircraft to enemy fire. However, it is important to distinguish between fragility and vulnerability. While aircraft are less robust than land vehicles or ships, this is in large part offset by the ability of aircraft to exploit speed and height which increases the enemy's targeting difficulties.

6. **Other Considerations**. In addition to the strengths and limitations discussed above, air power also possesses certain other important and well-known characteristics which also affect the air power contribution to defence and security. These are as follows:

a. **Cost.** High-technology equipment inevitably costs more than simple equipment, and as military aircraft tend to be at the cutting edge of technology, they can be costly. Similarly, aircrew training can also be very expensive. But these costs are less related to air power per se as a form of military force, than to the level of air power capability desired and the increase in capability they provide over older/obsolete systems often permits a reduction in the numbers of platforms required. A modern highly- capable fighter-bomber aircraft will typically cost in the region of £l5m to £20m. Less capable aircraft can be purchased for the same price as a main battle tank, while micro light aircraft cost about the same as a car, For certain tasks, a highly capable aircraft is essential, but for others a far less costly solution may suffice, Similarly, training costs are closely related to the complexity of the aircraft that the aircrew are required to fly. In every case, cost per se must be balanced against cost-effectiveness.

b. **Dependency on Bases**. All forms of modern military power depend on base support. Armies in the field need depots to support them, and navies need harbor facilities. However, air power is often seen to be more obviously dependent on its bases than are either land power or sea power. Helicopters and some fixed-wing aircraft can take-oil and land vertically, but most aircraft need runways. And all aircraft need a high level of base support if they are to operate at their maximum sortie rate, If this base support is vulnerable to attack, then base-dependency can be a source of potential weakness, However, if the bases are difficult to find or difficult to close, then the converse applies. In these circumstances, the unique ability of air forces to fight directly from their peacetime bases enormously simplifies logistics and expedites the delivery of ordnance from the factory or depot onto the enemy.

Air Power Command and Control

7. Effective command and control is fundamental to the efficient employment of air power. Air power command and control doctrine is the product primarily or experience and has been steadily refined over the years.

Definitions of Command and Control

8. NATO nations take a clear distinction between the respective meanings of the terms ‘command’ and ‘control’. Essentially, command is the authority to direct, coordinate and control military forces, whereas ‘control’ is the responsibility to implement orders or directives.

Key Principles

9. Experience has shown that unified action is essential for the effective use of air power. As Marshal of the Royal Air Force The Lord Tedder pointed out, ‘The old title of the bundle of faggots compared with the individual stick is abundantly true of air power. Its strength lies in unity’ However, the inherent speed, reach and flexibility of air power allow it to be employed in diverse and multiple tasks, and this can lead to fragmentation of forces and thus dissipation of effort. Moreover, there will rarely be sufficient air resources to meet all demands, and tasking priorities will invariably have to be set. To achieve unified air action and to ensure that air power capabilities are used as the overall operational situation demands, certain key principles must be applied:

a. Centralize command and control.

b. Exercise command and control from the highest practicable level.

c. Decentralize execution.

10. **Centralize Command and Control**. Centralized command and control promotes an integrated effort and enables forces to be employed to meet the recognized overall priorities. It also allows air action to be refocused quickly to exploit fleeting opportunities, be responsive to the changing demands of the operational situation and be concentrated at the critical place and time to achieve decisive results. Centralized command and control is essential if air power is to be employed in unified action; it helps to avoid air power being:

a. Divided into fixed ‘penny — packets’ which would inhibit flexibility and hinder speedy concentration of force.

b. Employed in un-coordinated actions or for impractical objectives.

11. **Exercise Command and Control at the Highest Practical Level**. Unity of air effort is best achieved when authority for command and control is exercised from the highest practicable level under a designated air commander. The factors which determine that level include the commander’s operational responsibilities, the combined or joint force objectives, the composition and capabilities of the force involved the control systems available for tasking and controlling air assets, and the functions of the

air resources. Care must be taken not to set the level of centralized control too high, as this will inhibit flexibility and create inefficiency. For example, the most appropriate level hr operational control of the air effort will be that at which the relative priorities of combined/joint demands on air resources can best be assessed. For different types of aircraft, the level at which command and control is best exercised will depend on the reach and capability of the aircraft. In general, the greater the reach and capability, the higher the level at which command and control should be exercised. For example, fighter-bombers are highly capable and can reach targets across a theatre of operations; thus, they are best controlled at theatre level. In comparison small observation helicopters have far less reach and capability and are best controlled at a far lower level, typically at corps or division.

12. **Decentralize Execution**. No single commander can direct personally all of the detailed actions of a large number of air units or individuals. Therefore, decentralized execution is essential, and it is accomplished by delegating appropriate authority to execute tasks and missions. Decentralized execution allows subordinate commanders to use their judgment and initiative within the overall pattern of employment laid down by their superiors. It becomes especially important when command and control systems arc lost through enemy action. Decentralized execution can lead to subordinate commanders taking divergent initiatives which would weaken the cohesion of a campaign. But this effect can be avoided if doctrine and the overall operational objectives are properly understood at all levels of command.

Command and Control Organization

13. **General**. Effective implementation of the key command and control principles depends heavily on organizational arrangements. These consist of two basic elements:

a. A command and control process.

b. An organizational structure.

14. **Command and Control Process**. The process of commanding and controlling air forces normally falls into four main phases (shown graphically in Figure 4.1 below); ie analyze, plan, direct and control:

a. **Analyze**. Effective analysis of the situation is fundamental to the process of commanding and controlling air forces. It involves a continuous effort to collect and evaluate all available information on the location, nature and actions of friendly and hostile forces.

b. **Plan**. The planning phase of the command and control process is based on the situation analysis. It examines the scope for cooperation and coordinated action with other commands, seeks to exploit fully the forces available, develops and assesses alternative options and — as a result — sets out the best course of action. The net result is an outline plan which provides guidance — in terms of space and time — for organizing and coordinating the forces to be employed. This allows a detailed operation plan to be drawn up which selects the required resources, regroups missions, personnel and equipment, assigns responsibilities (usually on a functional or area basis) and delegates authority within the organizational structure.

c. **Direct**. Once the planning phase is complete, operational directives and orders must be promulgated to all participating units and agencies.

d. **Control**. The progress of the operation must be monitored and the results assessed. The effectiveness of friendly force actions should be gauged, deficiencies corrected and any further steps taken that may be needed to achieve the desired objective.

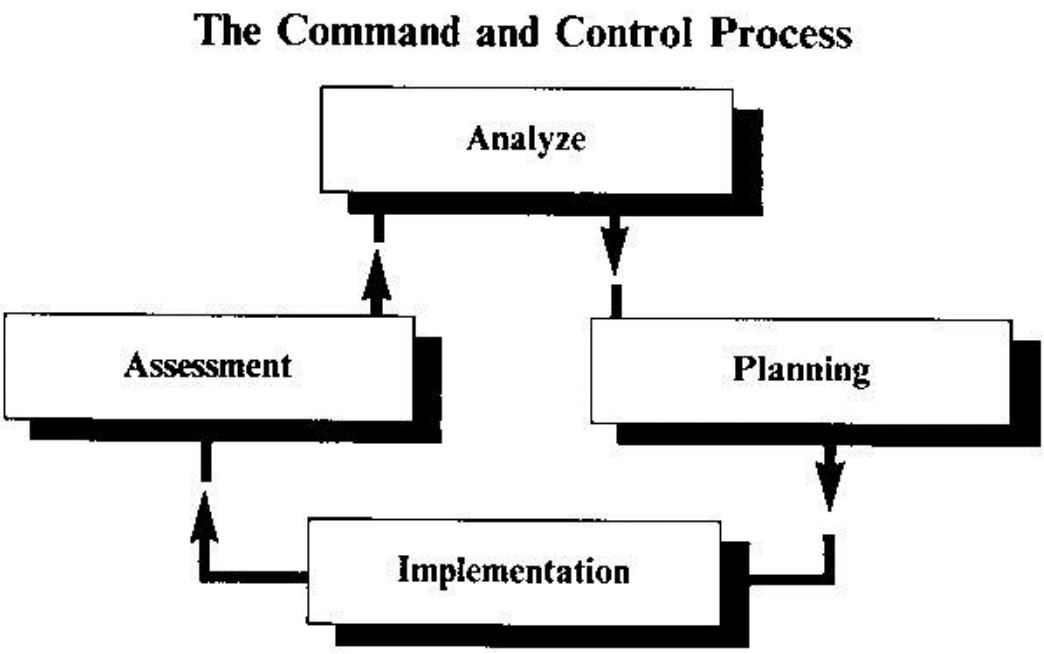


Figure 1.1: The Command and Control Process

15. Structure The successful execution of the planning process depends on establishing a command and control organization composed of a commander, his staff and facilities. This is shown graphically at Figure 4.2 below:

a. **Commander**. At the highest level of a military force there should be only one overall commander. Be alone must be responsible to higher authority for all operational matters. His responsibilities should be defined in terms of duties and areas of responsibility. Unity of command is essential for effective decision making; it not only fosters effective decision making, but also provides single points of contact for lateral and subordinate commanders. Command and control organizations should — at all levels — reflect the principle of unity of command, whether they are functionally or geographically arranged.

b. **Staff**. Each commander should be supported by a staff. The structure of this staff should reflect the composition of the resources under his command.

c. **Facilities**. Commanders and their staffs must have the necessary facilities to execute their command and control functions. These include operations centre and an appropriate range of communications.

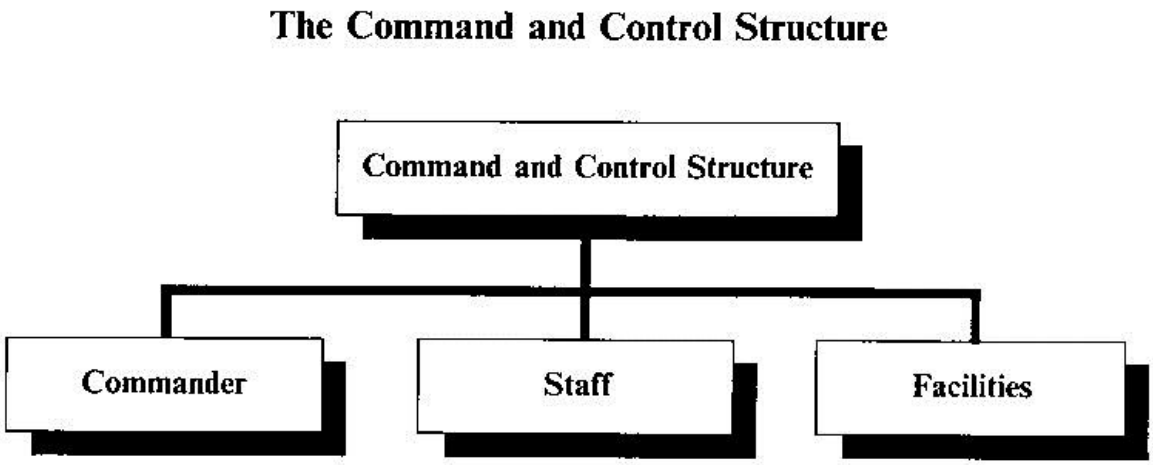


Figure 1.2: The command and Control Structure

16. Levels of Assignment. Air assets can be assigned at one of four levels (shown graphically below in Figure 1.3):

a. **Allotment**. Allotment is the temporary change of assignment of air forces between subordinate commands. The authority to allot is vested in the commander having operational command. The process of allotment is used to provide the balance of forces needed to achieve the objectives stipulated by that command.

b. **Apportionment**. Apportionment is the determination and assignment of the total expected effort by percentage and/or by priority that should be devoted to the various air operations and/or geographic areas for a given period of time.

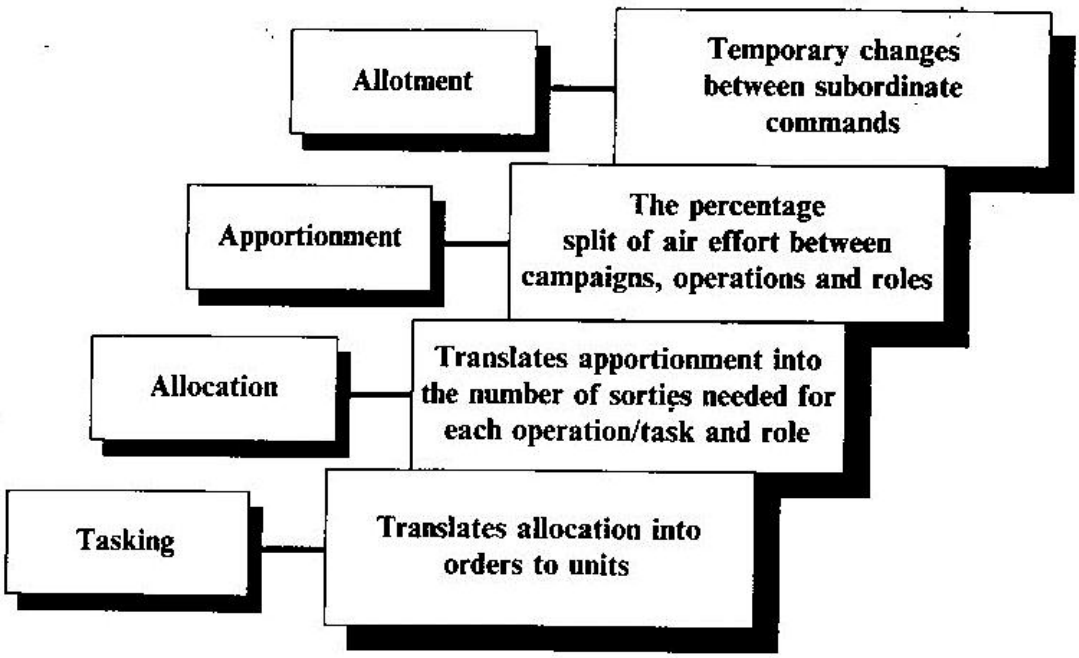


Figure 1.3: Assigning the Available Forces

c. **Allocation**. Allocation is the translation of the apportionment into total numbers of sorties by aircraft type available for each operation/task. When external or other forces become available for use by a NATO commander he will allocate them, by sorties within a given period of time, to a subordinate commander or commanders in much the same way that he would allot assigned forces.

d. **Tasking**. Tasking is the process of translating the allocation into orders, and passing those orders to the units involved. Each order normally contains sufficient detailed instructions to enable the executing agency to accomplish the mission successfully.

17. **The Allotment/Apportionment/Allocation Process**. The disposition of the total air resources to execute air operations should be made by the commander in operational command. It should be made in accordance with priorities established between specific tasks and is normally based on the allotment (if necessary) and apportionment. Factors which have to be taken into consideration during this process include:

a. The objective to be achieved.

b. The nature and intensity of the conflict, the strategy being employed, and particular the threat, the probable types of targets, the likely response times required and the force generation requirements.

c. The operational capabilities, limitations and security of all weapons systems, the terrain and the weather conditions.

d. The availability of logistic support.

e. The political restraints in effect.

18. **Authority and Responsibility of Assisted and Assisting Commanders**. The commander of the assisted force will indicate in detail to the assisting commander the support missions be wishes to have fulfilled. Be will provide the information needed for complete coordination of the supporting action with the action Of Ills own force. The commander of the assisting force will ascertain the requirements of the assisted force and take such actions to fulfill those that are within his capabilities. In the case of supporting naval forces, this control does not include authority to deploy or redeploy assisting air assets, nor does it include authority to deploy or relocate ships of the fleet.

19. **Combined/Joint Operations**. When air operations act in support of land or sea objectives, or when land or naval forces act in support of air objectives, the supporting commander and the supported commander(s) and their staffs must work as a team throughout the period from the creation of joint/combined stir-face/air plans to their final execution. A combined or joint headquarters should be established with separate command centre under the control of that headquarters. When these alternatives are not possible, it is essential that adequate communications and coordinating procedures are established between them.

AEW / AWACS

Introduction

1. An airborne early warning and control (AEW&C) system is an airborne radar system designed to detect aircraft. Used at a high altitude, the radars allow the operators to distinguish between friendly and hostile aircraft hundreds of miles away. AEW&C aircraft are used for defensive and offensive air operations. The system is used offensively to direct fighters to their target locations, and defensively to counter attacks. It can also be used to carry out surveillance, and C2BM (command and control, battle management) functions. AEW&C is also known by the older terms "Airborne Early Warning" (AEW) and "Airborne Warning and Control System".

2. The idea of carrying search radar on an aircraft stemmed from a fundamental geometrical limitation of surface based radar, its inability to see over the horizon. From a warship, subject to the height of the antenna, the radar horizon is of the order of 15 nm away or less with diminishing antenna height. This constraint and the less demanding ocean clutter environment made for a large payoff in the use of AEW at sea, putting the radar antenna onto an aircraft being the simplest way of extending the radar horizon.

3. Modern Airborne Warning and Control/Airborne Early Warning/Airborne Surveillance Warning and Control (AWACS/AEW/ASWAC) aircraft are complex systems integrating a large look-down radar, secondary radar (IFF), Electronic Support Measures (ESM) and a broad array of voice and data communication equipment, all of these carefully traded off to support a specific air defence environment.

History of Development

4. As part of their early use of radar, the British developed a radar set that could be carried on an aircraft for "Air Controlled Interception". The intention was to cover the North West approaches where German long range Fw 200 Condor aircraft were a threat to shipping. A Wellington bomber (serial R1629) was fitted with a rotating antenna array. It was trialled for use against aerial targets and then for possible use against German E boats. Another installation was radar equipped Wellington used to direct Bristol Beau fighters onto Heinkel He 111s, which were air-launching V-1 flying bombs.

5. In February 1944 the U.S. Navy ordered the development of a radar system that could be carried aloft in an aircraft as Project Cadillac. A prototype system was built and flown in August on a modified TBM Avenger torpedo bomber. Tests proved successful, with the system being able to detect low flying formations at a range in excess of 100 miles (161 km). The USN and RN adopted AEW very promptly and deployed AN/APS-20 radar equipped AD-3W, AD-4W and AEW.1 Skyraiders on several carriers, while the USN and USAF fitted the radar to long range land based WV-1/2 and EC/RC-121 C/D derivatives of the Lockheed Constellation. These APS-20 based systems represent the first generation of AEW systems and saw extensive use well into the seventies, when the USAF deployed its C-137(707) based E-3A and the USN phased out the last of its land based AEW in favour of carrier based E-2B/C Hawk eyes. Carrier based AEW has had a colourful history with the USN deploying the AD-3W, AD-4W, E-IB Tracer and finally the very successful E-2B/C family, while the RN transplanted its APS-20s into the Gannet AEW and subsequently passed these radar sets to the RAF where they equipped the long serving Shackle ton AEW.

6. In 1958, the Soviet Tupolev Design Bureau was also ordered to design an AWACS aircraft. After trying to fit the projected radar instrumentation in a Tu-95 and a Tupolev Tu-116, the decision was made to use the Tu-114 fuselage instead. This solved the problems with cooling and operator space that existed with the narrower Tu-95 and Tu-116 fuselage. To meet the flight range requirements, the plane was fitted with an air-to-air refuelling receiver. The resulting plane, the Tu-126, was used by the Soviet Air Forces until it was replaced by the Beriev A-50 in 1984.

7. At this instant in time, AEW has been widely recognised as a key part of a modern air defence system, with the E-2C deployed by the USN, Japan, Israel, Egypt, Singapore and sought by Pakistan, the E-3A/B/C deployed by the USAF, NATO, Saudi Arabia and on order with the RAF and Armee de L'air (French Air Force), the P-3 AEW&C deployed by US Customs, the Il-78 based Mainstay deployed by Russia's IA PVO and the Madcap under development.

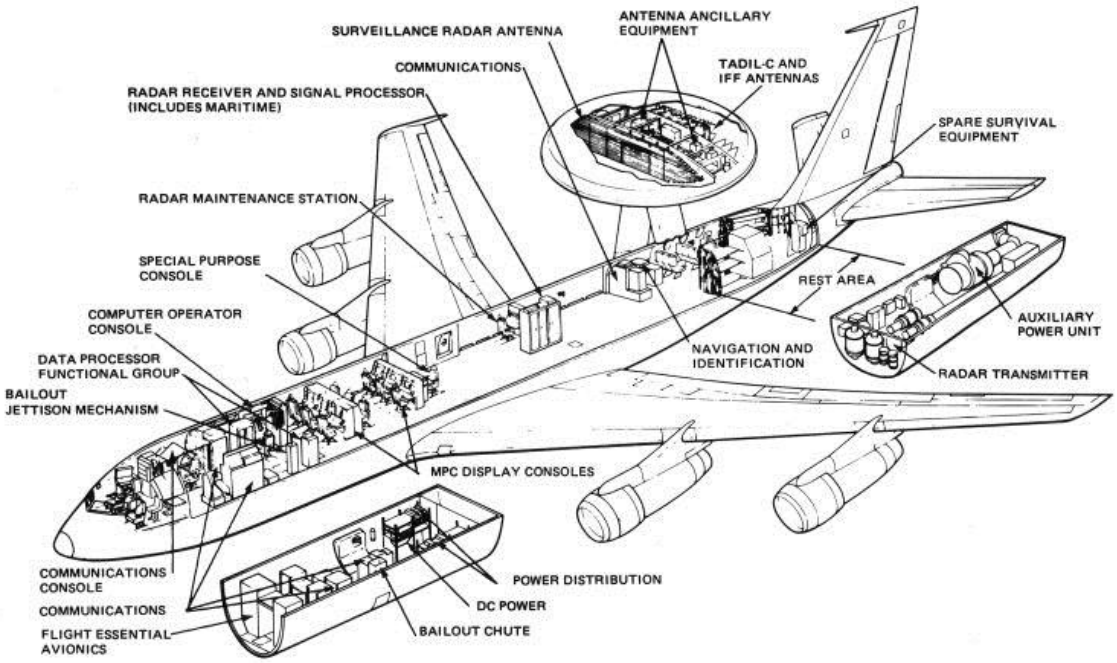


Figure 1.4 : Layout of Boeing E-3A AWACS

AEW - A System Perspective

9. The intensity and pace of the modern air battle with its emphasis upon the disruption of Command, Control and Communications (C) facilities with electronic warfare techniques and exploitation of low level penetration to targets, dictates the use of AEW if a successful air defence umbrella is to be maintained. The ability of an AEW platform's look-down radar to strip away the sanctuary of terrain following flight, removes a key advantage possessed by the attacker, surprise. To fully exploit the high ground held by the AEW platform, it is however, essential that secondary radar (Identification Friend Foe (IFF)) be carried to manage own aircraft and extensive voice and data communication systems be installed to support friendly aircraft and surface based defences. To this must be added ESM, sophisticated radar warning receivers,

which allow passive long range detection of inbound threats and provide the ability to identify non-cooperating tracks (ie those which ignore IFF).

10. With several hundred tracks generated by the radar, IFF and ESM, the task of correlating these tracks and maintaining track histories, demands automation and hence powerful computers must be carried. These will interface to the operators via sophisticated consoles, while considerable mass storage will be required to support operation and log track histories. This hardware alone is complex and demanding of volume, payload, cooling capacity and power, all of which in turn, place demands upon the airframe and power plants. To this complexity, however, must be added the software, some of which carries out specialised tasks such as signal processing and most of which controls the radar, IFF, ESM and C hardware while driving operator consoles and maintaining track histories. AEW is, therefore, expensive to design, build, deploy, support and train aircrew for, this is the price an air force must pay for a priceless tactical advantage.

Airborne Pulse Radar and Clutter

11. The radar system of an AEW platform is the key to much of its capability and in the final analysis, a measure of its worth tactically. The look-down performance of such a radar at long ranges over land mass, is usually seen as the determining performance criterion when judging an AEW platform, weaknesses in this area led to the much publicised demise of the RAF's BAe/GEC Nimrod AEW.3 aircraft three years ago. Modern AEW aircraft carry two forms of radar, Moving Target Indicator (MTI) and Pulse Doppler (PD), both of which are essentially pulse radars with additional signal processing to exploit the Doppler effect in locating targets otherwise hidden by surface clutter.

12. Radar in the general case involves the detection of targets by illuminating them with an electromagnetic wave and then listening for the reflection (echo) of this wave from the target. Because electromagnetic waves travel at a constant speed (of light), numerous techniques can be used to then determine the range of the target (and hence Radio Detection and Ranging). Radar always has three basic components, a transmitter chain, an antenna and a receiver chain. The transmitter chain is a high power source of electromagnetic signal and it can be built as a high power oscillator (typically pulsed Magnetron) or as a MOPA (Master Oscillator Power Amplifier) chain using typically Travelling Wave Tubes. The waves it produces must be focussed into a beam and pointed in some sought of direction, this is one of the functions of the antenna. The beam then propagates through space, hits a target and some of the power in the beam is scattered back in the direction of the illuminating radar antenna.

13. Because the wave weakens with distance covered (inverse square law) and the target reflects only a small fraction of the impinging wave, the return (echo) will be very faint by the time it arrives back at the radar antenna. Here is where the antenna comes into play again, focussing and concentrating the faint return at the input of a sensitive receiver termed a front end. The received return signal is then manipulated in a number of clever ways, amplified substantially and in the simplest case fed to a Cathode Ray Tube which displays an image synchronised to the motion of the antenna.

14. Real surveillance radars are built as Pulse radars. Pulse radar transmits only for a very brief time, a short burst (pulse) usually about a microsecond or so in duration at a time, after which it listens for echoes as the pulse propagates away. Because the Pulse is receding away from the radar at a constant speed, the time elapsed from the

instant the pulse was sent to the time an echo is received, is a clear measure of the line-of-sight distance to the target. The next pulse can only be sent after a time which is equal to the round trip delay of a pulse reflecting from a target at the limit of the radar's detection range (given by transmitter power, antenna gain and receiver sensitivity). If a pulse were sent any earlier, the echo of the first (i.e. preceding) pulse from a distant target could be confused with an echo of the second pulse from a close target (the reader is advised to sketch this).

15. The time gap between pulses is termed Pulse Repetition Interval (PRI), its inverse is an important parameter termed Pulse Repetition Frequency (PRF). Low band long range surveillance radars have PRFs typically of hundreds of pulses per second (or Hertz [Hz]). Needless to say PRF is a distinctive signature betraying the identity and operating mode of radar to any eavesdropping RWR. This generic pulse radar is typical of early systems and performs only when the background beneath the target is clear airspace. If such radar looks at a target flying above eg; a large hill, the return from the hill will be far stronger than the return from the aircraft and the target will be obscured. The term used for these unwanted echoes from Mother Nature's splendour is clutter. Needless to say clutter was a cause of great pain to early radar designers and has only been dealt with adequately in the last two decades. Airborne pulse radars are particularly vulnerable to clutter which most effectively hides low flying targets, these radars are usable only against targets at the same or at a higher altitude.

16. Techniques for dealing with clutter exploit in one or another way, the Doppler Effect (the frequency of a wave reflected off an approaching object is increased, a receding object decreased). The simplest radar which can detect an object in clutter is Moving Target Indicator radar. An MTI is pulse radar which will compare the returns over two or more pulse repetition intervals. Any target which is, moving relative to the radar will register a change in a signal parameter (phase in a coherent MTI), whereas the background clutter is unchanged. Clutter cancellation is then carried out by subtracting the returns from the two successive intervals. In practice cancellation can be accomplished in hardware (delay line cancellers or analogue bucket brigade chips) or by algorithms in software.

17. MTIs operating at a constant PRF suffer a fundamental weakness, they are blind to targets with particular relative velocities (which incur phase shifts of multiples of 180 degrees) and are said to be ambiguous in velocity. Modern MTIs transmit multiple staggered PRFs such that the blind speeds at each PRF are covered by other PRFs. An alternative family of techniques for dealing with clutter fall under the designation of Pulse Doppler radar. PD radars employ substantially more complex processing than MTIs. In a PD radar the returns containing targets and clutter are fed into a bank of Doppler filters, each of which is tuned to a particular frequency (- Doppler -> speed). In this fashion targets with given speeds register as outputs from given filters, which may be implemented in hardware or software. In this basic form, PD radar cannot resolve target range (of MTI) and is said to be ambiguous in range. Further manipulation is thus required to define range, this is usually done by dividing the pulse repetition interval into slices termed range cells, the Doppler filter bank is then selectively fed during a given range cell. This is termed range gating and results in a set of filter outputs indicating the velocity of any targets detected in that range cell. Because typical Pulse Doppler radars operate at medium to high PRFs (usually thousands of Hertz) the above technique becomes ambiguous in range and multiple staggered PRFs are used (of MTI) together with some clever processing to decide which actual range the target is at (it will appear in different range cells at different PRFs).

18. Pulse Doppler radars are usually considered superior to MTI in the detection of low flying targets in heavy ground clutter. In current PD radar most processing is carried out by a dedicated digital computer termed a digital signal processor, usually executing a powerful algorithm termed a Fast Fourier Transform to convert the digitised stream of return samples into something more manageable by other algorithms. DSPs are very flexible in that the algorithms used can usually be rapidly changed by swapping read only memory (ROM) chips, thus rapidly countering an opponent's jamming technique if necessary.

Airborne Doppler Radar

19. The carriage of radar on a aircraft introduces a wide range of problems. The motion of the aircraft dictates that the antenna be stabilised in pitch, roll and yaw, to provide a stable jitter-free picture, this becomes a major effort with increasing antenna size and weight. The other major problem area is of course clutter. A moving aircraft will itself have a Doppler relative to the Earth's surface, hence shifting the nett clutter return in frequency.

20. At first glance this would be a simple problem to tackle, by filtering out all of the return with the expected ground Doppler, which is given by the aircraft's instantaneous ground speed and the direction the antenna is pointed in. Reality isn't so simple though, as antennas are not ideal and will at best try to produce a tight beam, spilling out power in weaker off-axis beams termed side lobes (and receiving unwanted weaker returns from the direction of these beams). As is apparent the different directions the side lobes point in, will result in different Doppler shifts as compared to the antenna main lobe, with the result of course that the clutter produced by the side lobes will be difficult to remove.

21. This is further complicated by the unfortunate reality that the aircraft's airframe itself, interacts with the main lobe and side lobes, reflecting these off in directions very different to the axis of the antenna. Needless to say, this further complicates the rejection of clutter and imposes the need for very careful antenna placement on the airframe. This problem is exacerbated where the radar operating wavelength is large, relative to the antenna size, as the side lobes are larger (in general the larger the antenna relative to the wavelength, the tighter the beam). It is for this reason that PD radars designed specifically for overland look-down performance, use shorter wavelengths (typically E/F band for AEW with 3-8m antennas and I/J band for Air Intercept with 1 m or smaller antennas), even if this incurs a major cost penalty due to more expensive (faster) transmitter chains and receivers (faster, more sensitive).

22. This aspect of performance can be tricky to assess, in that longer wavelengths do tend to provide stronger and more stable returns (resonance region radar cross section, see TE May 1987) with better skin depth penetration of radar absorbent (stealthy) skins, as compared to shorter (microwave) wavelengths where returns scintillate (optics region RCS) with target aspect. The now you see it, now you dont' aspect of a scintillating target imposes the need for a capable data processing system with sophisticated tracking algorithms (Kalman filtering techniques are commonly used). The decision to use a given wavelength and antenna configuration is thus not trivial, with substantial cost and system complexity penalties attached to the use of higher performance microwave band antennas. All of these factors impact upon the physical installation within the aircraft. More sophisticated electronics tend to consume more

power, require more cooling and occupy more space, while costing more and requiring more maintenance by better qualified personnel.

23. While discussing performance tradeoffs, resistance to hostile jamming i.e. ECCM performance must be considered, particularly where one is up against a clever opponent. Antennas with large saddlebows are inherently vulnerable to high power noise jammers and false target generators, while modern AEW radar must have a measure of frequency agility, the ability to quickly tune away from a jammer, preferably automatically. ECM is however, a non lethal threat which can be fought with clever ECCM, the proliferation of high performance Anti-Radiation Missiles will eventually make life quite difficult for conventional AEW platforms. The only real counter to these, is the use of sophisticated Low Probability of Intercept (LPI) techniques (pseudorandom signal formats and scan patterns) requiring phased array antennas and very sophisticated signal processing, scan control and data processing. This will result in further complexity in hardware and particularly software, but with a major pay off in resistance to jamming and an ability to disrupt tracking by an ARM seeker.

IFF, ESM, Data Processing and C3 Systems

24. Given that radar of such capability is successfully fitted to an airframe, it must be integrated with a suitable data processing system, software and operator consoles. The software running on the computer(s) at the core of this system, will command the radar and its dedicated signal processor to given operating modes, while receiving and managing target track information produced by the radar. Tracks are then displayed on operator consoles. Target tracks are usually identified or tagged, depending on their IFF and ESM status, a task termed association which involves matching up radar target tracks with IFF tracks and ESM bearing/type readings. IFF, which relies on coded responses by transponders carried by friendly aircraft, is an essential complement to AEW radar, providing positive identification of responding friendly aircraft. IFF interrogator antennas are usually mounted back to back with radar antennas in rotodomes or on axis with conventional (eg offset parabolic antennas), sharing access ducts and implicitly antenna motion stabilisation.

25. Electronic Support Measures are an often overlooked complement to an AEW platform's primary and secondary radar, but are becoming increasingly important in a modern air battle. ESM equipment comprises sensitive direction finding radar warning receivers, coupled to an extensive software threat library and able to produce bearing and type tracks in a format readable by the data processing software, passively identifying the source of a transmission at ranges of the order of twice that of radar with comparable receive sensitivity. Where a target is not responding to IFF interrogation and is therefore potentially hostile, ESM identification can provide confirmation of, or disprove its status hence avoiding tragedies such as the Persian Gulf Aegis incident, this unfortunate event provides a clear illustration of the pitfalls implicit in air defence operations where decisions are based on the outputs from a single sensor, eg radar.

26. Complete target identity information is today unattainable, given the state of the art in sensors, but well implemented radar/IFF/ESM integration can go a long way in resolving uncertainties. Association of radar, IFF and ESM tracks can take place prior to the radar track information being passed to data processing or be done in software by the data processing system, which will typically create a track file on mass storage (disc or drum in older machines), the file containing target parameters and being maintained as long as the target is tracked. It is worth noting, that any reasonable AEW system will demand considerable mass storage (disc/drum and magnetic tape) to

maintain tracks in a dense signal environment, while logging histories on mag tape drives.

Figure 1.5 : USN Grumman E-2C Hawkeye. Israeli Air Force E-2Cs played a key role in the crushing defeat of Syria's fighter and SAM forces over the Bekaa Valley in 1982. Initially these aircraft employed ESM to pinpoint SAM and radar sites, after these were destroyed in missile and bomb attacks the E-2Cs coordinated and controlled a series of air battles which resulted in the loss of over 80 MiGs for no Israeli losses in air-air combat.

27. The limitation imposed by the data processing is in the number of tracks which can be maintained before the computer runs out of horsepower and the system saturates, resulting in software crashes or tracks disappearing off screens. The failure of GEC's APY-920/Nimrod was due in part to problems in this area, with highway traffic incorrectly tagged as real targets saturating the data processing computer. C3 and its associated management systems are another key component of an AEW system, providing voice communications and digital data links to both fighter aircraft and surface defences, the latter of particular importance, as they can feed target track parameters directly into the fire control systems of interceptors and SAM/AAA systems, thus very tightly coordinating defensive fire. In an environment where inbound bombers can successfully jam smaller AI radars, the superior ECCM performance of a sophisticated AEW radar can allow a successful intercept (the E-2C/F-14/AWG-9 provides for fully automated intercepts).

28. The integration of data Processing and C3 systems is thus of particular importance if a user seeks the full benefit of the AEW system. Deficiencies in this area could bottleneck the flow of vital information to the place it is most needed, the fire control system of a defending interceptor. It is readily apparent the functional utility of an AEW system depends as much upon the performance of its radar as upon the capability of its IFF, ESM, C3, and computers and as upon the capability of the software which ties it all together.

Aerodynamic Performance and the Airframe

29. While the systems carried on an AEW aircraft largely determine the overall system capability, the airframe and its aerodynamic performance must be well matched to the mission electronics. An airframe must have the internal volume to carry substantial fuel, to fit the large radar transmitter chain(s), associated power supplies, the receiver, IFF, ESM electronics racks, the computers and associated mass storage devices and the opera tor consoles, while providing in-flight maintenance access to repairable critical systems, adequate space for active crew stations and relief crew accommodation where applicable.

30. Aircrew accommodation is particularly important, as fatigue will rapidly degrade operator performance. If missions are longer than of two to three hours duration, operators will have to be rotated for breaks. In-flight maintenance access to electronics racks must also be considered under these circumstances, as it could prevent a mission abort in the event of an in-flight repairable failure not covered by redundancy. Accessibility in general helps to reduce down-time and should never be overlooked. Another important aspect is the capacity of the onboard electrical power generators to supply the vast amounts of power required for the transmitters, while the engines are at cruise/endurance thrust settings. Higher thrust settings penalise endurance. Power plant loading must also consider power required for cooling the electronics and transmitter tubes, this can be substantial in itself. The generators are ideally redundant and may have to be separately allocated to the transmitter power supply and remaining electronics supplies, to ensure that the computers and receivers get clean electrical power without interference leaking through (thus preventing software crashes or other problems).

31. Power plant loading thus will affect aerodynamic performance, which alone is a key factor in determining the system's capability. The most important aerodynamic performance parameters are altitude on station and of course endurance. Altitude on station determines the distance to the radar horizon and thus the limit upon the detection range for low level targets, otherwise given by the performance of the radar, in particular its signal processing. Understandably detection range for targets above the horizon is greater and determined much by the performance of the receivers. On station altitude is constrained by flat (skidding) turn performance and minimum power plant fuel consumption (to maximise endurance), for a turbojet/turbofan near the tropopause (cca 35, 0000 ft) and for a turboprop usually between 20,000 to 30,000 ft (props require increasing power with altitude, which counters the improvement in fuel consumption with altitude). Where look-down detection range is a priority a jet powered aircraft has an advantage, as is apparent from a mission profile.

32. A typical mission profile will involve a climb and then cruise (cruise climb if a jet) to station, where the aircraft enters a racetrack pattern which it maintains typically until its allocated fuel load is consumed, after which it will cruise back to its operating base. In-flight refuelling offers a large payoff where the distance to station exceeds a hundred or so nautical miles, as the fixed overheads in fuel and time incurred during a return/refuel/turnaround are reduced, typically by 50% where in-flight refuelling has doubled time on station. This will reduce the number of AEW aircraft required to provide continuous coverage on a given station.

33. An AEW aircraft on station will usually control two or more standing Combat Air Patrols (CAP) in racetrack orbits to the left and right of the threat axis (an imaginary line between the defended target and inbound threat) with the risk to the AEW aircraft determining how far toward the threat the AEW station will be. Where the enemy uses high performance fighters with long range radar and AAM/ARMs, the AEW aircraft will have to be stationed well behind the CAPs which reduce warning time and the width of the interception barrier (an imaginary line perpendicular to the threat axis, through which no hostile should pass). Where AEW detection range is poor, risk must be traded against the need to stop low level penetrations firing standoff Precision Guided Munitions, both of which are the most difficult class of targets to detect and consequently requiring as forward an AEW station position as possible to maximise the warning time.

34. If CAP is unavailable and ground alert interceptors are used, the interceptor's dash to station time delay must be accounted for and the AEW aircraft stationed closer to the defended target, with an inevitable reduction in the interception barrier width (here again tankers prove their worth by allowing extended duration fighter CAP). It is very clear therefore that the choice of AEW radar and airframe will have to be carefully considered against the various operational scenarios likely to be encountered, these factors illustrating the constraints which have led various air forces to develop very different airframes and radars for the role.

Common AEW&C Aircraft

35. **Brazil**.

a. Embraer R-99A Erieye

36. **China**.

a. KJ-1 AEWC
b. KJ-200
c. KJ-2000
d. Y-8 AWACS/Y-8J AEW

Figure 1.6: KJ-2000

37. **India**.

a. DRDO AEW&CS

38. **Iran**.

a. HESA IrAn-140

39. **Israel**.

a. IAI 707 Phalcon
b. IAI Eitam

40. **Russia**.

a. Beriev A-50 Shmel
b. Kamov Ka-31
c. Tupolev Tu-126

41. **Sweden**.

a. Saab 340 Erieye
b. Saab 2000 Erieye

42. **United Kingdom**.

a. Avro Shackleton AEW.2
b. Fairey Gannet AEW.3
c. Hawker Siddely Nimrod AEW3
d. Westland Sea King AEW2/AEW5/ASaC7)
e. Raytheon Sentinel
f. Shadow R1

43. **United States**.

a. Boeing 737 AEW&C
b. Boeing E-3 Sentry
c. Boeing E-767
d. Boeing PB-1W Flying Fortress
e. Douglas AD-3/4/5W Skyraider
f. Grumman AF-2W Guardian
g. Grumman E-1 Tracer
h. Grumman E-2 Hawkeye
j. Grumman TBM-3W Avenger
k. Lockheed EC-121 Warning Star
l. Lockheed EC-130V Hercules
m. Lockheed P-3 AEW&C

Figure 1.7: Boeing E-767 AWACS aircraft

Figure 1.8: Boeing E-3 Sentry.

Figure 1.9: E-2D Hawkeye

TOPIC- 2
TACTICS

DEVELOPMENT OF FIGHTER TECHNOLOGY AND FIGHTER TACTICS

"The only security upon which sound military principles will rely is that you should be master of your own air".

-Winston Spencer Churchill

Training Objectives. At the end of this chapter students should have comprehensive idea about:

a. Control of the air.

b. Current development in fighter technology.

c. Weapons and tactics used in Air Defence.

Introduction

1. The primary mission of a fighter is to intercept and destroy the enemy aircraft. Since early days of air warfare fighters have played a key role in air defence. Gone are the days of rickety bi-planes. Today modern fighters like F-16, F-15, Mirage-2000, Mig-29 and Su-27 etc are technologically masterpieces. They carry advanced electronics equipment and weapon systems on board to defeat the increasingly sophisticated air borne threats. Fighter technology is developing at a fast pace and influencing the tactical employment of fighter in the theatres of war. Although a fighter is employed in a variety of roles. We shall confine our study to its role in air defence.

The Threat

2. The fighter design, its weapons and tactics have evolved to counter the offensive aerial threat. As the bombers, attack aircraft and their weapon system became more powerful, accurate and effective, so also were the fighter's. In a modern air war what are the air borne threats that a fighter is likely to encounter?

3. A fighter aircraft, in air defence role, is likely to encounter attacking bombers that can fly at very high speed either at very low altitude thus avoiding radar detection, or at extremely high altitude where fighter's operational performance may be restricted. Bombers could launch their weapons far away from target thus avoiding interception by fighters. The bombers are also equipped with various electronic devices such as Radar Warning Receiver (RWR) that warn the pilot of a fighter's presence; or jammers that degrade the fighter's weapon performance. The attacking could be escorted by enemy fighters who attack and prevent our fighters from attacking the incoming bombers. It is thus evident that an air defence fighter will have to be a very capable fighting machine over a very wide spectrum of operations. The demands put on a designer are heavy and often conflicting. The fighter must be able to fight very low altitude to very high, fight, launch weapon from very close range to Beyond Visual Range (BVR) and be able to operate at night or in poor weather condition. It must be small and agile, yet be able to carry a wide variety of weapons. It is evident that such a perfect match is difficult to achieve.

The Challenge of Fighter technology

4. The cost, if nothing else, prevents most countries to have different fighters to counter different types of threats. What comes out actually is a multi-role fighter aircraft. It has to have performance envelope from treetop to stratosphere, from low sub-sonic to Mach 2+, and target engagement from close combat to beyond visual range (BVR). It is generally believed in the USAF that, Advanced Tactical Fighter (ATF) may be the last fighter for that service to be designed to remain always within the atmosphere. Obviously, flight beyond the atmosphere into space will complicate fighter designed further, at the very least by demanding altitude-control rockets and possibly a complete space propulsion system with throttle modulation so that the pilot can choice when, where and how he returns to earth. In a fighter of today the pilot's stick and paddles are connected to push/pull rods or cables, new fighters now being built have FBW (Fly By Wire) control in which the input commands are transmitted as small electrical signals alone filing wires. The fighters of 1990s have FBL (Fly By Light) control in which the commands are transmitted by fine optical fibres. Advanced avionics are capable for continuous precision solutions to the problem of navigation, air to air gunnery, air to surface delivery and how best to avoid hostile defence networks. In the subsequent paragraphs current development in fighter technology and its impact on tactics will be briefly discussed.

Improved Air Frame and Engine

5. The next generation of engines will be even more compact, have fewer parts, yet proved similar power by handling generator air flow and running at even higher turbine gas temperatures. FSW (Forward Swept Wing) aircraft like X-29 offers less drag at all speed than ordinary wings, as well as better maneuverability, shorter field length and many other advantages including making the aircraft essentially spin proof. The aim of any designer is to keep the aircraft weight down .To this end, more and light but structurally stronger metal alloys are being used. On the other hand more and more powerful and fuel-efficient engines are being developed. These two factors, together with advanced aerodynamic design have given modern fighters a thrust / weight ratio in excess (Table-1). The result is shorter take-off run, faster rate of climb, quicker acceleration and more reserve power. Short take- off capability means that the fighter will be able to take- off from much larger number of airfields or from a runway even when a certain portion of it is damaged or blocked.

Aircraft	Origin/User	Combat thrust/ Weight ratio
FRS.1 Sea Harrier	UK	1.17:1
F-15A Eagle	USA	1.29:1
F16A Fighting Falcon	USA	1.13:1
F-18A Hornet	USA	0.99:1
Mirage 2000	France	1.01:1
Lavi	Israel	1.05:1
KAS39 Gripen	Sweden	1.09:1
F-15K	USA	1.29:1
Su-27S	Russia	1.26:1

Eurofighter	UK, Germany, Italy, Spain	1.25:1
Mig-29M/M2	Russia	1.19:1
Mig-29B	Russia	1.15:1
Su-30MKI	Russia/India	1.14:1
F-7MB	China/Bangladesh	0.68:1
F-7BG	China/Bangladesh	0.9:1
MiG-23	Russia/India	0.95

Table 2.1: Combat Thrust /Weight Ratio

Advance Cockpit Design

6. The cockpit design is continuously being updated to increase pilot efficiency and reduce work-load. Switches, controls and panels are arranged with ergonomics in mind. Clock-like dials have been replaced by play. The bubble canopy of modern fighter gives a 360 view. It reduces the blind spots; thus there is less chance of being surprised.

Figure 2.1: Cockpit Design of F-16 Aircraft.

Head-Up Display (HUD)

7. This is a system of projecting essential flight and weapon control data on the front wind shield, so that the pilot can monitor the mission without having to look in-side the cockpit. These data can also be displayed on the visor so that the pilot can see the vital flight information irrespective of where he is looking .HUD formats can be designed to meet almost any type of aircraft and weapon combination but they all contain basic flight information and an aiming sight of some kind .A simple system is shown in figure 1-2. The pilot will attempt to keep the target marker and the missiles (MX) aim dot within the MX aiming circle which designates the limit of the missile 's steering capacity he will monitor the target height , speed and heading and look for it to appear (in day light) some where around the target marker, as the rang closes the MX launch zone indicator will tell him that he is in range and the 'shoot' light will come on .He can delay firing down to minimum range or fire at earliest opportunity depending on how he sees the tactical situation.

Figure 2.2: Head Up Display of two Fighter aircraft

Hand on throttle and Stick (HOTAS)

8. The control switches most often used during filing are arranged in the throttle and stick. So that there is minimum movement of hands or need for looking inside. Control of the weapon and radar modes will be by switches on the control column and the engine throttle (HOTAS). This means that the pilot does not have to take his hands off the essential controls in order to make selections imagine trying to reach for a switch to change the missiles in the middle of a combat engagement when the aircraft is in a high 'g' turn and your arms appear to be eight times their normal weight. In the example however there are no such problems. One single press of the trigger mounted on the front of the stick and away goes the missile. You would feel it go with a slight jolt under the aircraft and hear a faint' whoosh as the motor ignited. Then it would accelerate away in front of you with a long plume of white smoke trailing behind it.

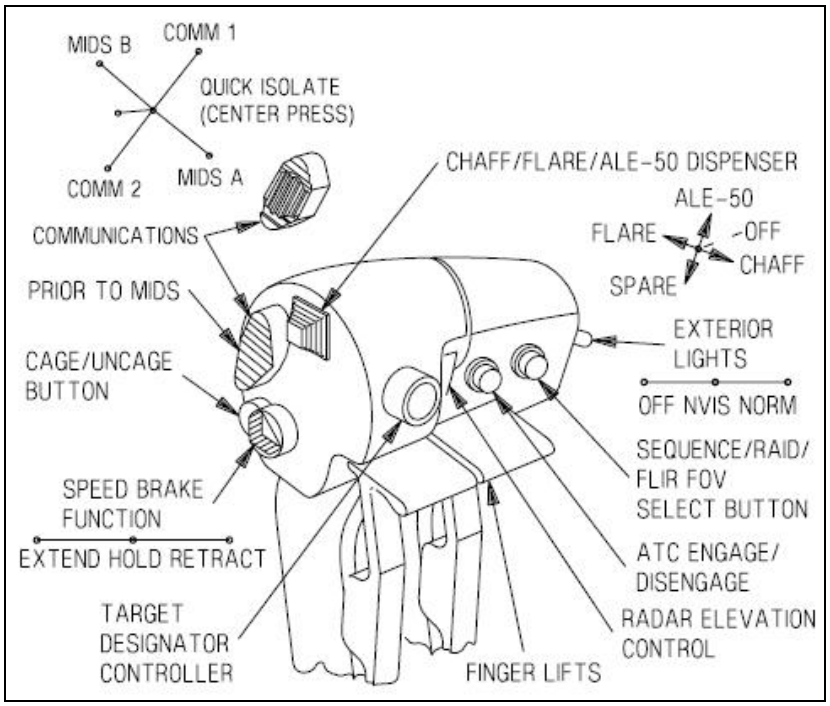


Figure 2.3a: Throttle

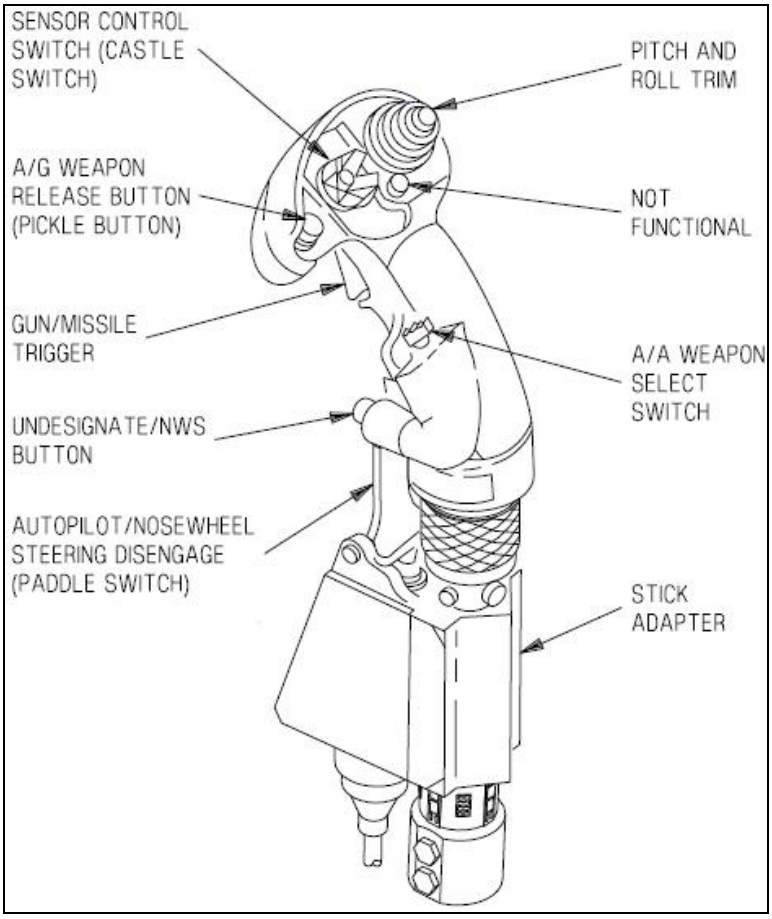


Figure 2.3b: Stick

Figure 2.3: HOTAS Controls of F/A -18 Aircraft

Air to Air Refueling

9. By air-to-air refueling the endurance of fighter can be increased indefinitely. The endurance is now limited by the pilot's human limitation rather that the limitation of the aircraft.

Figure 2.4: Air to Air Refueling

Advance Guideline System

10. Once airborne, a fighter is guided on to the target with the help of Ground Controlled interception (GCI) radars. However, GCI radars are severely limited in detecting low level raids at longer ranges. Therefore, Airborne Early Warning (AEW) aircraft such as E-2C 'Hawk Eye' or E-3A 'Sentry' are being used. The aim of the GCI or AEW is to position the fighter in such a way that the fighter obtains a favorable fighting position and quickly gets a radar or visual contact with the enemy. Once the contact is firmly established, the fighter pilot takes over the control to proceed with the kill. The airborne interception radar (AI) fitted in all modern fighters give a pilot a lot of autonomy to search, track and attack targets; even when GCI or AEW help is not available. It is now possible to pick up the target on the AI when it is many miles away. To intercept a target at high altitude, a fighter can approach at low level to achieve surprise and avoid enemy radar detection. The fighter's AI can look up to track the high flying target and the missile can be fired to destroy it. Similarly, a fighter while loitering at altitude to conserve fuel, on pick up target and fire missile to destroy target trying to sneak through at tree-top. In the AD jargon, these are known respectively as "Look-up/Shoot-up" and "Look-down/Shoot-down" capabilities.

Air -to-Air Missile

11. AAMs (Air-to-Air missiles) were first developed in World War-II. Early types had command guidance with steering command sent to them either by fine wires or via a radio link from the launching aircraft. By the 1950s the technology had moved on to more advanced guidance, which enabled the AAM to home on its target, in other words to steer itself towards its target. There are basically three types of homing guidance of AAM which are given below along with technical characteristics shown in table 2.

a. **Active homing**. In active homing, the missile transmits the illuminating energy itself, which gives the launching platform the launch-and-leave capability. However, since such active homing missiles are constrained to carry smaller antennas, their effective ranges are adversely affected. Yet some of the advanced long range BVR missiles use the active homing guidance system. The pay-off is in the form of complexity, size and cost.

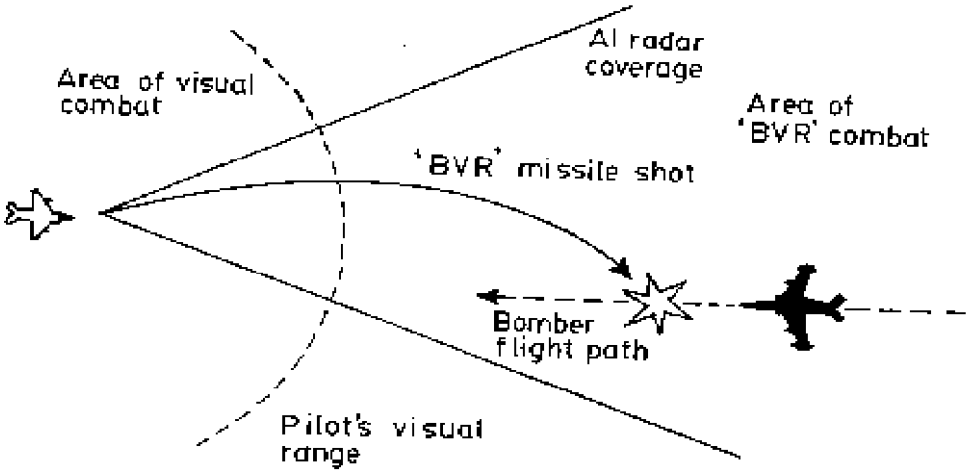


Figure 2.5: Active Homing (BVR Combat)

b. **Semi-active Homing**. Semi-active homing popularly known as semi-active radar homing (SARH), requires the launching fighter to have radar which can lock-on to the hostile aircraft, so that the latter is caught in the radar's beam.

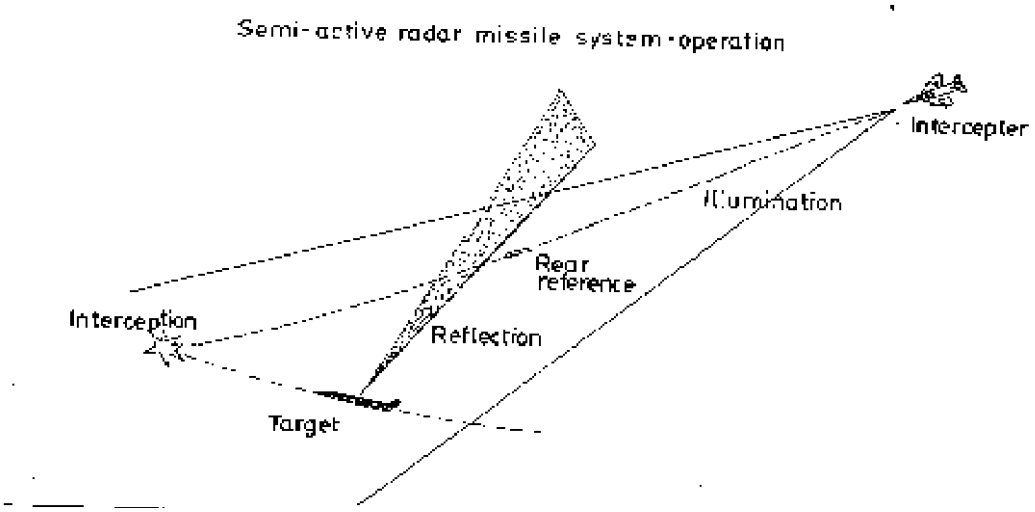


Figure 2.6: Picture of SARH

It is said to be 'illuminated' just as if it were caught in the beam of a searchlight. The AAM is then fired and its sensitive radar receiver in the nose tuned to the fighter's radar signals picks up the radiation which is scattered or deflected from the target and causes the missile continuously to steer towards the source. No matter how the hostile aircraft tries to escape, it is out maneuvered by the AAM until the latter either strikes it or has its warhead triggered by a proximity fuse as it flashes past.

c. **Passive Homing**. In passive homing the missile carries a receiver which detects energy radiated by the target itself; as such no target pre-illumination is required. Infrared guidance (IR) is a typical example of passive homing. IR, or heat radiation, is the same thing as radio or radar waves but with the difference that the wavelength is many times shorter. (almost as short as the visible waves we call light). To some degree this means that the AAM seeker head can be smaller, but the most important difference is that no illumination is needed, the target generates IR radiation itself. Modern IR missiles have seekers of amazing sensitivity which not only lock-on at great distances with the target aircraft but also have much better performance through clouds and rain.

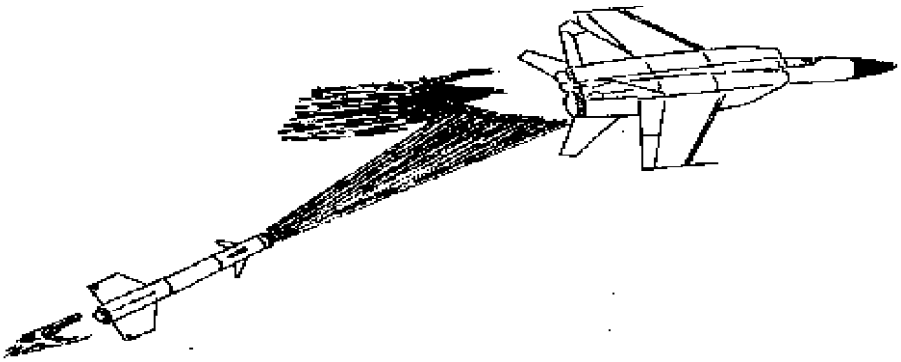


Figure 2.7: IR Missiles

Missile	Origin	Max Speed (Mach)	Range(km)	Type	Users
Phoenix Aim-54C	USA	5	200	SARH/ Active	F-14
Sparrow Aim-7 (E,F,M)	USA	4	44(E), 100(F,M)	SARH	Widely used
Sky Flash	UK	4	50	SARH	F-4j saab JA-37 viggen, JA3, Tornado F.2.
Super 530F	France	4.5	35	SARH	Widely used
AA-7 Apex	USSR	3.5	33(SARH) 15 (IR)	SARH/IR	Mig-23
AIM 120AMR AAM	USA	4.0	55-75	Active	USA,UK & Germany
Sidewinder AIM-9L/M	USA	2.5+	10-18	IR	Widely used
Magic R 550	France	3.0+	0.5-20	IR	Mirage 2000
Shafrir MH-2	Israel	2+	7	IR	Kfir
Falcon Aim 47A	Sweden	6	213 km	Active	Widely used
Kukri	S.Africa	2.0+	0.3-4	IR	Mirage, Cheetah
PL-5B (Like AIM-9L)	China	4.5	16	IR	PLA (Air Force)

AA-8 Aphid	USSR	3	15 (SARH) 7 (IR)	SARH/I R	SU-15, Mig-23 Mig-29
AIM132 ASRAAM	UK/ Germany	3	1-15	IR	NATO Countries
Aspide	Italty	4	50-100	Active/ SAR	Italy

Table -2.2: Air to Air Missiles

Increased Maneuverability.

12. A fighter has to be highly maneuverable in order to fight and survive. Latest fighters use what is termed as “Fly-by-wire” technology. The fly-by-wire aircraft are aerodynamically unstable. The maneuvers are computer controlled. The computer calculates the optimum aerodynamic handling characteristic for a given maneuver. As a result, a modern fighter can pull up to 9G without over-stressing. The limiting factor here is the pilot’s “G” tolerance rather than the aircraft’s. Sustained turn rates have exceeded 20 deg/sec and heading for 30deg/sec. A modern fighter can quickly decelerate to achieve maximum turn rate, get into the firing position and after weapon release break-off and accelerate quickly to get off the debris.

Stealth

13. To help bombers to penetrate AD system undetected, a series of new technologies are being introduced, acronym “Stealth”. ”Stealth” is aimed at making the aircraft less visible optically by camouflage, electronically by reducing radar-section and IR signature, and acoustically by reducing the engine noise. Much of the stealth technology being developed and used with the fighters too. Reduced IR signature, low visual and radar absorbability, use of radar absorbent material (RAM), etc, increase the survivability of a fighter. Radar absorbing materials may be applied to aircraft, with the hope that the defence will before be aware of the presence of an attack. Such materials are intended to have the same effect on the radar return as sound-absorbing materials have in sound proofing a room that is reducing the return-echo to a very weak level. F-117, B-2 are the aircraft having stealth signature.

Figure 2.8: F-117 Stealth Aircraft

The Concept of Operation

14. The concept of operation of fighter in air defence battle has undergone few fundamental changes over the years. The technical development has produced fighters which can fight and destroy the best attackers but at the same time, it has made fighter aircraft very expensive. It is no longer a machine that can be produced in thousands and thrown against the enemy. Atop-of -the-line fighter cost around us S 15m -20m. No country can afford too many of them. The Air Defence Commander has to decide where and against whom he should commit his limited fighter force. Therefore the tactical commitment of fighters is increasingly being controlled from a central agency, like SOC/ADOC. Although defence of national airspace is the responsibility of air force, none can defend all the places at all tines. Air defence weapons will be allotted to protect designated places and installations, which are vital to our war efforts. The fighter should be so committed that they stay and fight under friendly GCI or AEW cover and only then they can hope to win against a numerically superior enemy.

Fighter Tactics

15. Once an air defence mission is "Scrambled", a modern fighter can be airborne less than 2 min. It can take off within 1000-30,000 ft and climb at a rate of 25,000-30,000 ft/min. It quickly reaches supersonic speed and within minutes its AI starts searching the sky ahead. AI and advanced navigation equipment five a modern fighter true all-weather and night capability. Guided by the GCI or AEW the fighter manoeuvres to pick up the target on AI. In case of multiple target the fire control determines target priority and locks the weapon system on the most suitable target the weapon load is generally a mix of long and short range AA missiles and gun for close in combat. This gives a modern fighter target engagement zone from 5km-100km. The tactical doctrine of today's fighter operation is "to kill without being seen, disengage and disappear". Close-in combat is something to be avoided, with multi-mode AI and long range AA missile; it is possible to shoot sown a target without ever seeing it. Surprise can be achieved by using long range weapons and stealth technology. In case of close-in combat such classic maneuvers, like coming from the sun or disappearing into the cloud, remain valid. If air-to-air refueling is available a limited fighter force can remain on station for a long time. This is of particular importance while providing defensive air cover to an important ground or naval operation or escorting an offensive mission.

Conclusion

16. A fighter aircraft is designed to fight and win an air battle. Its adversaries are the bombers, attack aircraft or the enemy fighters. Modern offensive aircraft can penetrate enemy air defence system at very high or low altitude, deliver powerful weapon load from many miles away and guide them accurately over the target in any weather by day or night. To counter this threat, new generation of advanced fighters have been developed.

17. The fighter for air superiority is not a straightforward issue like a naval battle or a land battle it is not even a series of combats between fighters it is frequently a highly complex operation which may involve any or all types of aircraft. It is a campaign rather than a battle, and there is no absolute to it so long as enemy aircraft are operating.

18. A modern fighter, therefore, accelerates faster, climbs faster and turns faster due to powerful and light-weight engines, stronger but lighter air-frame, advance aero dynamics characteristics. It can fight from tree-top to stratosphere. It can destroy its target beyond visual range (BVR) as well as in close combat by powerful weapon and versatile fire control systems. It can effectively deal with multiple threats. It can surprise the enemy but is difficult to be surprised. A modern fighter is truly a multi-role aircraft. Naturally, it costs a lot more. It is costly to procure and maintain, but its versatility and flexibility makes it a major element in air defence. Along with SAMs and AAAs fighters provide an effective deterrent to aggression by air.

AIR INTERCEPTION PLANNING

Training Objective. At the end of this chapter student should know:

a. Points considered for planning of interception.

b. Factors governing tactics selection.

c. Types of attacks and advantages and disadvantages of different types of attacks.

d. Steps of tactics selection.

Introduction

1. During the interception mission the controller manoeuvres the interceptor in such a way that the interceptor pilot achieves visual or radar contact from as far away as possible, closes in without being detected by the target and achieves a favourable position from where he can launch his weapon. To achieve these objectives a number of types of interception and attack procedures have been involved. This précis lays down various attack profiles and factors governing their choice.

Factors Governing Tactics Selection

2. The four elements upon which tactics selection rests are:

a. Air Defence

b. Evolution of Tactics

c. Tactics Design

d. Attack Logic

3. **Air Defence**. The basic concept of air defence system is that it must engage the enemy at maximum range and intensify the defensive pressure with a variety of weapons system as he approaches the defended area. This is the creed of the defender. The strategic goals of a potential offender attacking from the air are:

a. Deliver the weapon undetected.

b. If detected, it must either destroy the detection system or neutralise, disrupt and deceive the system through the use of electronic counter measures and decoy to avoid being attacked.

c. If attacked, it must evade, neutralise or destroy the attacker.

From this brief statement of the enemy's strategy we can state our basic air defence requirements:

a. **Strategic Warning**. An intelligence system which will give us time to prepare both physically and psychologically for an attack.

b. **Tactical Warning**. A detection system capable of detecting all incoming aircraft or missile.

c. **Electronic Counter - Counter Measures**. The men, equipment and procedure to counter all attempts to disrupt, neutralise or deceive our detection system.

d. **Interceptor Performance and Base Location**. Be capable of engaging the enemy at a range greater than the range of his air-to-surface missiles and 'stand-off' jammers, and with sufficient time for re-attacks.

e. **Fire-Control System and Armament**. Have weapons which can effectively destroy or neutralise the enemy, regardless of his counter measures.

f. **Tactics**. Attack in such a manner that the enemy is unable to evade or neutralise our mission.

4. **Evolution of Tactics**. To achieve these requirements, various weapons, detection and communication systems came into being. Interceptors were designed to work within a radar and communication network. Interceptor and missile bases were located both near the defended areas and at the perimeters of radar coverage. Fire control systems and armament were designed specifically for each interceptor. Then, in terms of 'kill probability,' attack logic and tactics were developed. This tactics had to remain flexible, for an advancement occurring at any level (psychological, experimental or technological), can cause a corresponding shift all the way down through tactics. If, for various reasons, this shift does not occur, the unresponsive party is suddenly in a position of weakness, subject to possible exploitation and in war time, destruction. By definition then, flexibility must be the keynote of tactics selection and application, dependent not upon academic theories but in response to a given set of conditions demanding a given response--not always a totally logical one but hopefully, a devastatingly effective one. In land warfare, for example, when the Japanese faced the problems of transporting large number of men quickly over jungle path, they used bicycles, was regarded with humour or by new historians. But for the Japanese, answer to the logistic challenge proved effective, resulting in the capture of Singapore from British.

5. **Tactics Design**. Ideally, tactics selection is a logical step by step process. Each time an interceptor is committed, one specific tactics, considering all factors, is the best and most correct tactic. Our analysis of tactics which follows, is presented for one purpose only; that when the time comes, you will select the correct tactic for your interceptor to meet a given tactical situation. The most skilful controlling of your interceptor would be meaningless if the pilot could not lock on to the target or worse, was destroyed by the invading aircraft because of the selection of the wrong tactic. Let us review the four basic tactics currently used in air defence.

a. **Definition of Tactics.**

(1) **The Front Tactic**. A front tactic is where the difference in interceptor and target heading or the hdg crossing angle (HCA) is from 120° to 180^{0}.

(2) **The Beam Tactic**. A beam tactic is where the HCA is 70^0 to 119^0.

(3) **The Stern Tactic**. A stern tactic is where the HCA is 0^0 to 69^0.

(4) **The Cut-off Tactic**. A cut-off tactic will always result in a front, beam, or stern, but it is considered as a separate tactic because it is a function of time. There is no regard given to positioning the interceptors other than to make an interception in the shortest possible time. The cut off has the advantages and disadvantages of the resulting tactic; i.e. front, beam or stern.

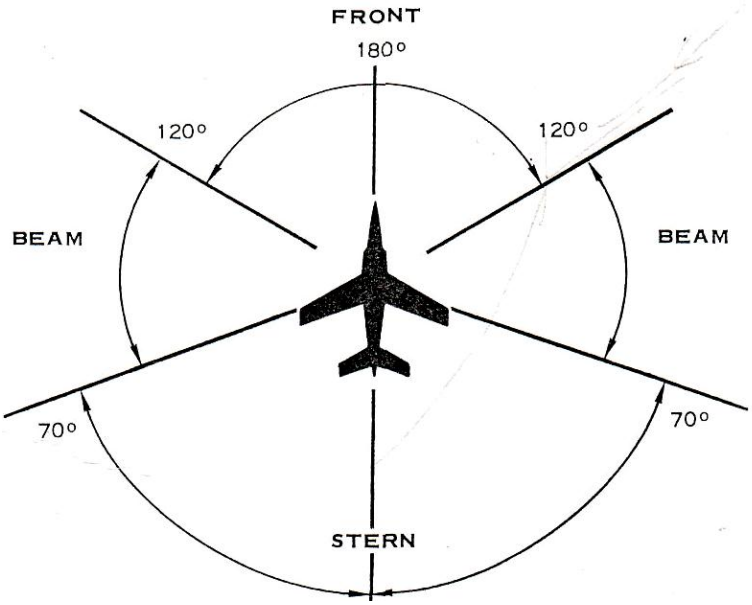


Fig 2.9: Different Approaches of Interceptions

b. **Advantages of Front Tactics**.

(1) **Maximum Range Intercepts**. The intercept takes place at maximum range from the defended area. This allows time for a re-attack and additional commitments of other interceptors and ground-to-air missiles.

(2) **Target Travel Reduced**. The target aircraft's travel is reduced, If the target is jamming our radar and communication frequencies and an early kill is achieved, much pressure is removed from our surveillance and weapons functions, Also, other targets formerly screened by ECM can now be detected and committed against.

(3) **Evasive Turns Away from Defended Are**. The target's evasive turns will be away from the defended area. Some targets will initially head for one defended area but turn toward another when under attack, or at a pre-determined point. Even so, an early engagement will force the target to an early commitment to a specific defended area. The existence of a strong air defense system may force the enemy to use flank-ing manoeuvres for penetration. Since the targets must fly a longer route, we have more time to achieve a kill.

(4) **Maximum Performance Not Required**. Maximum interceptor performance may not be required. Use of a "long" profile may be possible, To make a front attack, the interceptor may set his speed at manoeuvrable cruise rather than at maximum. Since the speed setting is not critical the pilot can concentrate on acquiring the target. This also gives the interceptor more range and time on station before recovering.

(5) **Interceptor Uses Less Fuel**. The interceptor uses less fuel. Because maximum performance may not be required, the interceptor will have sufficient fuel for a high speed re-attack, or it can be committed against another target. If the interceptor is successful in the initial attack, it has sufficient fuel to recover at high speed for a quick turnaround.

(6) **Controller is More Effective**. The weapons controller is more effective. The weapons controller may not have to compute lag, turn radius or other related items. The air mass problem will be solved only to obtain the target's true heading. Making scope corrections is relatively simple. Because the positioning problems have been simplified, the weapons controller can handle more interceptors simultaneously.

(7) **Against Target's Least Defended Area**. The attack is against the least defended area of the target. Practically all bomber aircraft have some defensive armament in their stern areas, Although their range is limited, these defensive weapons, force us to extend our missile launch range when making a stern approach.

(8) **Less Time for Target ECM or Evasive Actions**. The target has less time to determine proper ECM or evasive tactics. Any evasive turn would reduce the closure rate and increase the radar reflectivity. Many missile guidance and fire-control systems have a "home-on-jam" and rapid re-lock capability.

These are eight reasons for favouring the frontal tactics, all valid, some of tremendous tactical importance.

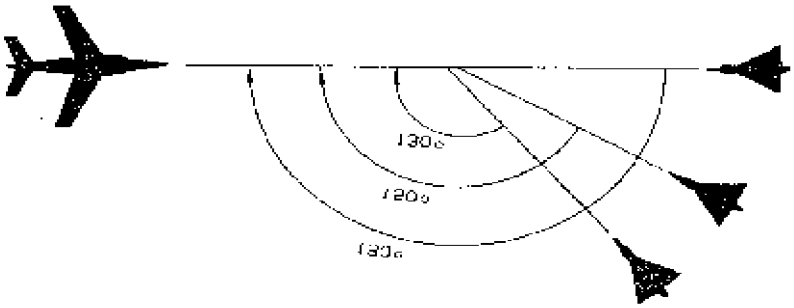


Fig 2.10: Front Tactics

c. **Disadvantages of Front Tactics**. In spite of its advantages, the frontal tactic / is weaker than the stern attack in terms of "kill probability." This is due to the present state-of-the-art of weapons. Frontal attacks have the following disadvantages:

(1) **High Closure Rate**.High closure rate between target and interceptor. For example, the target-to-interceptor speed relationship might be 800 knots to 1,200 knots. This produces a closure rate of 2,000 knots for a 180 degree frontal attack. The net results of the high closure rate are:

(a) Increased contact and lock-on range requirement.

(b) Increased armament launch range.

(c) Limited reaction time for the interceptor pilot; for example, in acquiring the target at low-altitude through ground clutter on the interceptor's radar scope.

(2) **IR Systems Relatively Ineffective**. The radar missile guidance system is normally used, as the IR (Infrared) system is relatively ineffective.

(3) **Lower Kill Probability**. Therefore, for the above reasons, the frontal tactic has a lower kill probability than the stern attack. As weapons and fire-control systems improve, you will see more and more use of the front tactic. Let's look now at the beam tactic.

d. **Advantages of Beam Tactics**

(1) Decreased Target Penetrations.

(2) Interceptor need not have a speed advantage.

(3) Target cannot use defensive armament.

(4) Fuel consumption is lower.

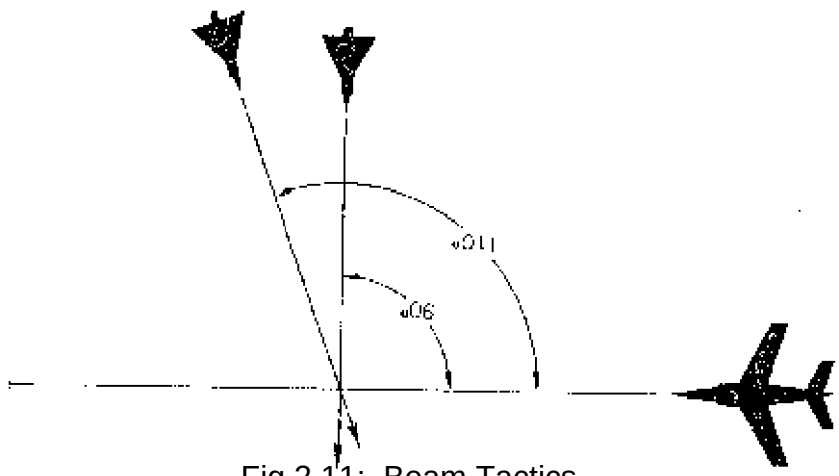


Fig 2.11: Beam Tactics

e. **Disadvantages of Beam Tactics**.

(1) Target ECM may be very effective.

(2) IR systems are relatively ineffective.

f. **Advantages of Stern Tactics**.

(1) A higher kill probability than any other tactic.

(2) More pilot reaction time for ECCM and target acquisition.

(3) The best tactic against a low-level target.

(4) Reduced range requirement for contact and lock on.

(5) Decreased armament launch range.

(6) A low closure rate.

(7) Both the radar and IR fire-control systems can be used simultaneously.

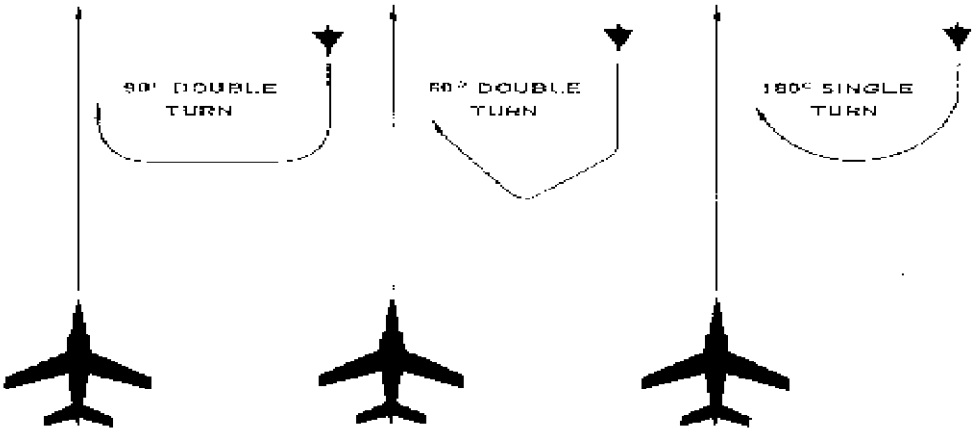


Fig 2.12: Stern Tactics

g. **Disadvantages of Stern Tactics**.

(1) The target's penetration increased.

(2) Less time available for re-attacks.

(3) More fuel is consumed.

(4) The interceptor must have a speed advantage.

(5) The target can employ defensive armament.

(6) Target engagement is limited to one interceptor at a time.

(7) More severe demands may be placed upon the controller.

6. **Attack Logic**. We have discussed tactics design, but this is only a portion of the overall attack. The tactic concerns only a two dimensional view. Since aircraft operate in a three dimensional environment, there must be something else. This 'something else' is the altitude at which the intercept must take place. When altitude considerations are applied to tactics, we have the attack logic, as follows:

a. **The low-level attack**. A low-level attack is when the target altitude is from ground level to 5,000 feet above the terrain.

b. **The co-altitude attack**. A co-altitude attack is when the interceptor is within plus or minus 5,000 feet and the targets altitude and the target is above 5,000 feet. This band width actually encompasses a total of 10,000 feet

c. **The snap-up attack**. A snap-up attack is when the target is more than 5,000 feet alone the interceptor. Although the attack was primarily designed against altitude above the operational limits of the intercepts, it can still be used at any altitude above 5,000 feet if the altitude difference is more than 5,000 feet.

Selection of Proper Tactic

7. We have discussed the air defence concept, evolution of tactics, tactics design, advantages and disadvantages, and attack logic. This information is most valuable when used as a foundation for "tactics selection." Tactics selection can be broken into a step-by-step progression of logic. Even so, it should be noted that a weapons controller will rarely dissect it this way when he/she is at the scope. We will examine each step in order of priority while in reality you should consider them simultaneously. Following are the six steps of tactics selection:

a. Select the proper profile.

b. Select the proper attack.

c. Consider the armament configuration.

d. Determine if a speed advantage exists.

e. Consider the tactical situation,

f. Select the tactic.

8. **Profile**. The reason why the profiles must be considered again, and as a part of tactics selection, is because the profile dictates where the intercept will actually take place. Keep in mind that as a Weapons Controller you may have to change the initial profile due to the target changing direction or speed. There are two deciding factors; first, Engagement at a maximum range with sufficient fuel for a re-attack and recovery and second, the intercept must take place prior to the point of predicted release of weapons on the defended area. For our purposes there are three particular ranges which must be considered. When any of these ranges becomes so short that the target may release its weapons before the intercept takes place, you must select a shorter profile. Remember also that the critical range increases as the Target's speed increases. If any doubt exists, select a shorter profile. The three ranges are:

a. **Range of the target from the interceptor's base**. You should use the following criteria for range of the target from the interceptor's base:

(1) Range 0-125 NM - select a short profile.

(2) Range 126-225 NM - select a medium profile.

(3) Range 226 NM or more- select a long profile.

This distance should be measured at the time the interceptors are airborne. against a very high speed (high Mach) track, a short profile will usually be selected. The basic criteria are shown in Figure 2.13.

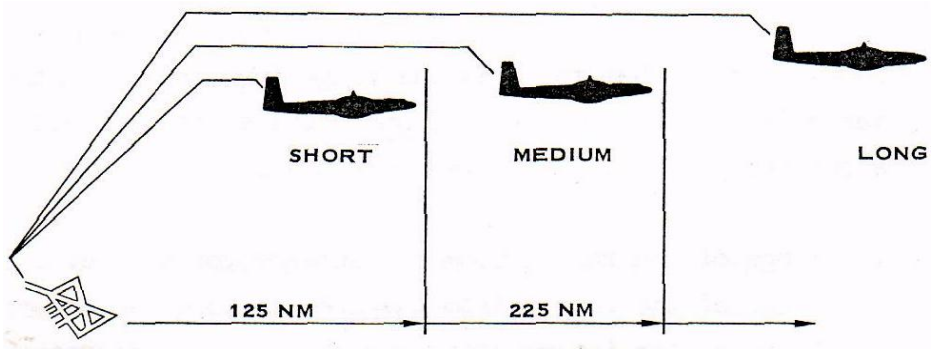


Fig 2.13: Range from Air Base

b. **Range of the target from the area to be defended**. Range of the target from the area to be defended is the primary factor. There may also be times when the interceptors are scrambled from a base which is some distance from the area to be defended. The criteria in such situations is to use the profile which will give you sufficient time to fully engage the target prior to the predicted point of weapons release; that is the BRL (Bomb Release Line) or. MRL (Missile Release Line). These situations are shown in Figure 2.14.

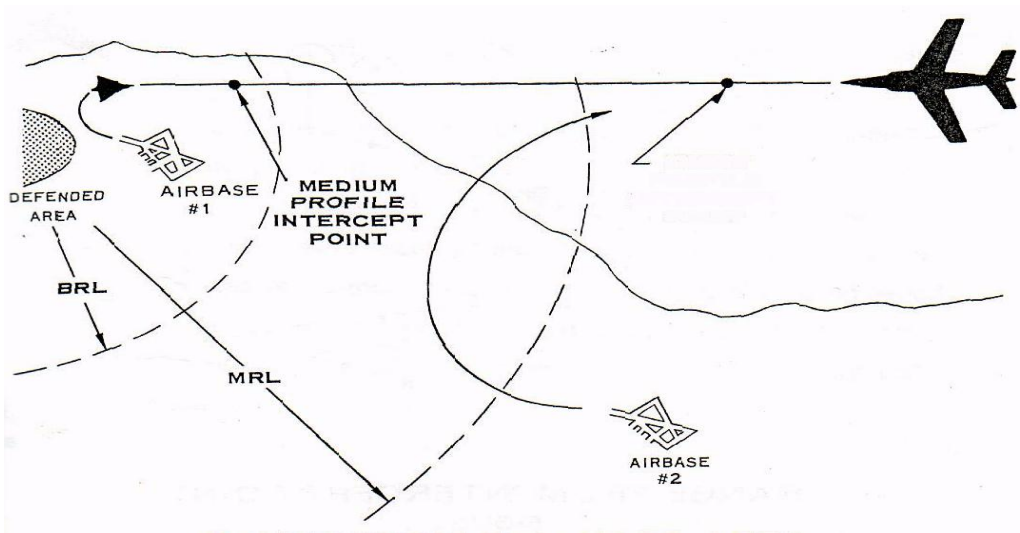


Fig 2.14: Range From Defended Area

c. **Range of the interceptor from the desired intercept point**. At certain times you will be required to make an intercept prior to a certain point or within a specific area. In Figure 2.15 you can see a medium altitude target heading between two defended areas. The target is expected to turn towards one of these areas at point B. Your interceptor has primary attack logic of a co-altitude front. If the target should turn towards one of these areas before the intercept takes place, your interceptor would be out of position for a co-altitude front. In this particular case, a short profile should be selected so that the intercept may

take place at point A, which is prior to the target turn point. Another example would be a low-level target. Assume that maximum radar range at 5,000 feet is 50 nautical miles and if the target continues its present heading, you will be able to maintain surveillance for only another 35 nautical miles. Since the intercept must take place before the target leaves your surveillance, a short profile would be ordered. The selection of profiles must be consistent with economical use of the interceptor and the tactical situation.

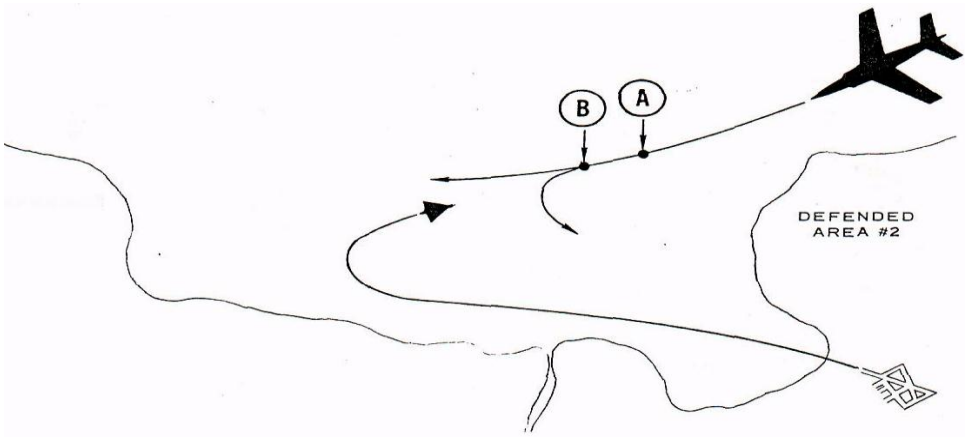


Fig 2.15 : Range From Intercept Point

9. **Attack**. Select the proper attack logic. The attack will vary according to the target's altitude and the performance capabilities of your interceptor. There are three general rules which are a repeat of their definitions.

a. If the target is 5,000 feet or less above the terrain, you will select a low-level attack.

b. Except for the low altitude selection, any time that your interceptor can maintain a 5,000 feet altitude differential with the target, you will select the co-altitude attack.

c. If your interceptor cannot remain within 5,000 feet of the target's altitude, you must select a snap-up attack. If the target is at medium altitude but due to an interceptor malfunction you are unable to get within the required 5,000 feet, you must select the snap-up attack.

Another example would be a "pop-up" target near the interceptor's base. While the interceptor is climbing to the target's altitude, the pilot will attempt to lock-on and fire his weapons. This, again, would be classified as a snap-up attack.

10. **Armament**. Consider the armament configuration. Although the interceptor pilot is responsible for the actual selection of armament, this means only that he will select the best armament for the attack logic he has been positioned for. In effect, the attack and tactic will dictate the armament selection. Since each interceptor carries primary and secondary armament, there are primary and secondary attack logics for each armament configuration. Each type of interceptor has its own armament

configuration and each must be memorized. You must also memorize which armament is used for each primary tactic.

11. **Speed Relationship**. Determine if a speed advantage exists. To have a speed advantage you must have and maintain at least a 1.14:1 speed ratio and, in some cases, a 1:2,1 ratio. This requires that you make an accurate speed check of your target immediately and monitor the target's speed throughout the intercept.

12. **Tactical Situation**. Consider the tactical situation. There is no limit to the number of situations which could force a change in the final selection of the tactic. You may find interceptors with only secondary armament, malfunctions in fire-control systems, or troubles with your own radar. Your interceptors may be committed against targets when out of position for a primary tactic and the cut-off tactic must be used. You must remain flexible and constantly evaluate the developing air situation. This will be discussed again in the Advanced Course.

13. **Select the Tactic**. Now that we have covered the entire process of tactics selection, you can see that circumstances usually select the tactic for you. In any situation where you are given an interceptor with a known armament configuration and you know the target's speed, altitude and heading, you do not select the tactic, but rather, the circumstances select the tactic for you. But and this is of the utmost importance since every air situation is fluid and constantly changing, there must be a knowledgeable weapons controller at the scope, with the ability to recognize and analyze changes in the situation as they occur, who can then select the tactic best suited to the circumstances.

14. Your job is not an easy one, but knowing the enemy's capabilities is the first step. A complete knowledge of the capabilities and limitations of your equipment and interceptors, and how to effectively utilize them, is the second and most decisive step of a successful defense. Study intelligence reports, even aviation publications, as well as tech orders to gain the information about your aircraft and the enemy's aircraft which will add materially to your capabilities as a weapons controllers.

Conclusion

15. An interception in the modern days requires efficient planning and precise execution. The controller today has to cope with high speeds and sophisticated offensive and defensive armament. To achieve a successful attack, he will have to exploit the vulnerabilities of the enemy and derive the best out of his own interceptors.

EMPLOYMENT OF FIGHTER

Training Objective. At The end of this chapter the student should know:

a. Importance of surprise and how to obtain surprise in the air battle.

b. Importance of height and wx in air battle.

c. Tactics of fighter formation against large raids.

d. Employment of fighter in AD role.

e. Tactics for deployment of fighter for AD by night.

Introduction

1. The task of day fighters in the defensive role is to intercept and shoot down enemy aircraft picked up by the C&R system. Since the guns of the day fighter are fixed and can fire only in the approximate direction of i.e. aircraft's line of fight, the effectiveness of tactics will depend on accurate shooting.

2. The design of the armament of future fighters is likely to be dictated by factors such as decreased maneuverability at high speed and high altitude, limited degree of early warning and the limited time available to the fighters to engage the enemy. Therefore, the days of the fixed gun in future are limited.

3. Whatever armament, fighters may carry in future, the first aim of air tactics is to reach to a position from which the enemy can be destroyed with minimum risk. In achieving this object combine effort of the controller on the ground and the pilot in the air necessary.

Importance of Surprise

4. Surprise is a most important factor in air fighting. The chance of achieving surprise always exists. Superiority in armament or in performance will not save a pilot if he allows himself to be surprised; it is easier to surprise single aircraft and small formation than formation in which the "blind spots" are fewer.

5. Obtaining Surprise. Observance of the following points will assist in obtaining Surprise:

a. An aircraft diving from the direction of the sun on a bright day is hidden in its glare. Anti-glare goggles assist in searching the sky towards the sun.

b. A decoy aircraft at low altitude supported by fighters well above may be a trap for an unwary attacking formation. A thorough inspection of the sky above should always be made carrying out an attack.

c. In summer a bank of haze, its top level with the eyes, appears to enshroud the horizon. On the other side, of the sun, the top of this bank is usually dark in colour and constitutes a background against which an aircraft approaching from the same level is difficult to see.

d. In the evening or early morning, it is easier to see an aircraft silhouetted against the bright part of the sky than the dark parts. A special watch should therefore, be kept on the dark quarter.

e. At a level where there are heavy clouds at intervals, a force pursuing a steady course is liable to be surprised. Because, once seen, its approximate; position at subsequent intervals can be anticipated. When enemy aircraft are in vicinity, it is, therefore, advisable to pursue a somewhat through broken cloud.

f. Full advantage of the colour of the countryside below should be taken climbing to intercept an enemy who is thought to be taken almost directly above For example, if the general colour scheme of an aircraft camouflage is brown then brown sand or water should be exploited as a background for as long as possible during the climb. In far eastern theatres, where aircraft camouflaged green is operating over the jungle, dark areas rather than lighter colored paddy fields or scrub should be exploited to be maximum extent.

g. When attacking single aircraft or small formations, a fighter should try to approach to optimum range towards a "blind spot". Pilots should study the details of hostile aircraft to ascertain these spots.

6. Avoiding Surprise. Nearly all fighter pilots who were shot down and who lived to tell of experience confessed to not having seen the aircraft that attacked them. The only way to avoid being surprised is to search the surrounding sky continuously and systematically for hostile aircraft.

Importance of Height

7. Height is a most important tactical factor. Fighters are designed to have a heavy high rate of climb in order to intercept within the limit of the C&R system, as enemy aircraft approaches at higher altitude and speed. An efficient standard of training organization is essential to the dispatch of fighters from the ground in the shortest possible time after warning.

8. Unnecessary delay, even a few seconds may involve the loss of thousands feet or more of tactical disadvantage in height. In some respects, however, technical developments have altered the tactical significance of height which must be considered in relation to speed. In the past the performance of aircraft was limited by engine power. It is now limited by aerodynamic factors associated with the speed of sound. A height advantage used invariably to enable an attacker to close on his target with the added speed of a dive. In aircraft having equal aerodynamic limitations height no longer confers this tactical advantage on the fighter if the target is flying as faster as its aerodynamic limitations.

Weather

9. In general, there are three types of weather which must be taken into consideration:

a. Thick layers of continuous or nearly continuous cloud.

b. Large separate masses of cloud.

c. Clear or nearly clear air.

10. With the development of blind flying instruments and of wireless aids to navigation, it has become possible for bombers to make their passage, find their objectives and return without emerging from continuous cloud for more than brief intervals and in some cases not at all. In the latter event their interception cannot be effected by the orthodox day fighter which at present is not fitted with radar aids such as Al. In conditions of continuous cloud, fighters may sometimes be used for interceptions by day.

11. If, for any reason such as ice formation or while reconnaissance, it is necessary for raiding aircraft to fly above continuous cloud. The tactical conditions become very similar to those associated with a clear sky, except that either the upper or the lower region will be denied to the fighter for any tactical purposes except surprise approaches from range fire and quick withdrawal.

12. Large separate masses of cloud confer certain opportunities of evasion, but at the same time they give the attacker opportunities of surprise. It is probable that, once seen, an enemy formation will try to emerge into the open from regions of broken cloud in order to give their gunners warning of attack.

Tactics of Fighter Formations

13. Defending fighters may be called upon to meet enemy on unequal terms both as regards numbers and initial tactical advantages such as height. To overcome or reduce these disadvantages fighters should be separated in tactical units large enough to deal effectively with the reported strength of the enemy.

14. In order to example the circumstances in which a defensive fighter force of more than in a single squadron should be operated, and to evolve general principles, it is desirable first to summarize the disadvantages under which our fighters have, in some instances, been called upon to operate in time of war. These are briefly as follows:

a. Numerical Inferiority. Squadron has been sent up single or in pairs to meet larger formations of enemy aircraft.

b. There have been insufficient opportunities for fighter formation leaders to discuss or concert plans with the leaders of other fighter formations.

Tactical Implications of Turn

15. The tactical implications of the turn factors affecting maneuverability at high speed and high altitude are best explained by reference to two main types of turn necessary in combat, namely, the initial turn into a curve of pursuit, and the turn necessary to follow evasive action.

16. The Initial Turn. Of the two turns that of the initial turn into the curve of pursuit is the more complex. The ideal condition is assumed to be where the turn ends with the target in firing range of the fighter, and on such a heading that a steady deflection shot is possible. With the use of orthodox gun sights and armament and where the fighter and target speeds are, say 480 knots and 440 knots, it is calculated that the turn could be carried out from angles wider than 20 degrees. At high altitudes the maximum permissible initial angle off would be less, because of the lowered stalling threshold.

17. Best Turning Speed. There is a best speed for turning at any altitude. Because of the limitations affecting the rate in high speed fighting, and because of the importance of approaching the target from small angles off, the fighter pursuit path to firing range will follow more conveniently a comparatively shallow curve, or ideally a straight line, maneuvering between attacks may, in some circumstances, be best achieved by losing speed to the optimum turning speed and accelerating afterwards. Even at the best turning speed the turning circle at high altitude is very large, being in the order of two or three miles in radius at 45,000 feet.

Size of Fighter Formations for Interception

18. The size of formation of defensive fighters is decided by the ground control organization which passes order to intercept. The following factors should be taken into account in estimating the size of fighter forces necessary to intercept a given enemy raid

a. The aim of intercepting fighters is the complete annihilation of an attacking force

b. Squadrons are vectored towards enemy formations in such a way that by the time they reach over the planned position of the enemy" they were at a disadvantage as regards height, and consequently at a great tactical disadvantage when an attempt is made to engage the enemy.

19. An examination or these disadvantages has resulted in the evaluation of the following principles:

a. Wherever possible the minimum defensive formation that should be sent up to meet a large enemy formation should be a wing of two or more squadrons.

b. Ideally, all squadrons of a wing should operate from the same airfield, or from airfields situated close to each other.

c. A high standard of training is required by squadrons before they can efficiently take their place in a wing and it is important that there should be the closest possible co-operation between the leader of the wing and the operation controllers. The difficulties of operating a force of fighters larger than a squadron is that the section will take more time to take-off and to achieve height. This difficulty can be minimized by careful training in take-off drill.

Employment of Fighter In Air Defence Role

20. The task of a defending force of fighters is to find and destroy enemy raiding aircraft before they reach their target. If this is impossible, the aid must be to inflict such heavy losses on the raiding forces that future raids become unprofitable.

21. Our peacetime policy is to deny us the initiative at the outset of a war and the enemy must be expected to exploit to the full the advantages of surprise. Moreover, since the enemy is likely to be the aggressor it is probable that initially, at least she will be armed with forces that are quantitatively, if not qualitatively, superior. The areas vital to our defence will be known to the enemy and they will be relatively few. On the other hand the bases when the enemy may attack us must be assumed numerous, not all known to us, and widely dispersed. By seeking him out, therefore, we risk using our forces uneconomically.

22. The outstanding advantage of an efficient and reporting system is that, within its coverage, the position of every attacking and defending aircraft is known. This system is deployed to give the maximum amount of early warning and coverage around those areas vital to our defence. We can, therefore, make the maximum use of our defending forces by attacking the enemy within the coverage of our control and reporting system. Thus, with comparatively limited forces at our disposal at the outset of a war, we stand the chance of hitting the enemy hardest by using our fighters in the role of interception.

Method of Employing Fighters

23. The manner in which fighter aircraft can best be employed as part of the air defence of a particular area will depend on what other means of air defence are available in the same area. Some of the more important methods of employing fighters are:

a. Interception from the ground. .

b. Standing Patrol.

Interception from the Ground

24. Interception from the ground is the normal method of operating fighter. Aircrafts are held in readiness and sent up to engage the enemy only when information is received from the reporting organization that an attack is approaching. This method has the advantage that the force dispatched can be suited to the requirements of the particular situation, and can take off with full operational endurance available. It should, however, be backed by rapid rearming and refueling, as a quick aircraft turn-round will increase the potential of the fighters force. The effectiveness in carrying out interception from the ground relies, however, on the ability of fighters to destroy the enemy before the point of weapon release. This ability is governed by the following factors:

a. The performance of the enemy aircraft.

b. The performance of the defensive fighters.

c. The range, accuracy and discrimination of the control and reporting system.

d. The distance the enemy has to penetrate before reaching his objective.

e. The sitting of the fighter bases.

f. The length of time between initial detection of an approaching raid and the defensive fighters becoming airborne.

g. The time taken to destroy the enemy after contact has been gained.

Standing Patrols

25. By this method of employing patrols, fighters covering a particular area are kept continuously in the air by means of successive relief's. The patrols are maintained at a height judged to give the best chance of tactical advantage. This method may be used either with or without a C&R system. In neither case are standing patrols economical. The tactical situation may demand their employment for limited periods, but the cost in aircraft is high and they should not be regarded as a normal method of employing fighters. Standing patrols may be used either with or without a control system, though reporting system, even if it is only the 'MOU' service, is essential.

a. Standing Patrols in Conjunction with a C&R System. Standing patrols may sometimes have to be resorted to even if a C&R system is available. The forward range of the C&R system may be such that it cannot give sufficient warning for fighters to climb from the ground end intercept a raid. In these circumstances it may be necessary to keep standing patrols in the air at high altitude and to direct them from the ground, to the probable point of interception, on the strength of information provided by the C&R system. This method of employing day fighters is uneconomical. It will be found tiring, especially for pilots who have to spend long periods in the air at higher altitude without sighting the enemy. It is, therefore, to be considered that employment of fighter on CAP in conjunction with C&R system must be decisive to deal with the target force of enemy aircraft that is likely to be intercepted.

b. Standing Patrols Working Without the Help of C&R System. This method of employing fighters may have to be resorted to as being the only practicable means of affording protection to an area where no C&R system is available, it has all the disadvantages inherent in the standing patrol method with additional weakness that its success depends entirely on the chance of the pilot spotting an enemy approaching him from an unknown direction and height. It should only be employed in desperate circumstances such as might arise on an advance airfield in a special operation.

Tactical Deployment and Organization

26. Below the level of command and groups, fighters are deployed in tactical units within sector area. The shape and size of the sector depends on a number of factors, the most important of which are related to the needs of operations rather than to organization. These factors include the following:

a. The number of the vulnerable points (VPs) to be defended and their position in relation to those of enemy bases.

b. The disposition and number of airfields available to the defence

c. The handling capacity of the operations centre.

27. From a consideration of number and disposition of VPs may be reduced the probable direction and scale of attack and where there is a choice of sites; airfields should be located between vulnerable points and the enemy bases. Where the enemy bases are sufficiently close and our warning is so short as to make it difficult to predict the direction of the enemy's approach, airfields for defence should be located around the VPs. Because no form of air defence is absolute, there will always be the possibility of the vulnerable points being bombed in spite of our defence. Airfields for the defence of a VP should therefore not be established at the VP itself.

28. The factors of communication facilities and handling capability of the operations centre are closely associated either jointly or singly, may be more important than the factors of the number of VPs to be defended and the number of airfields available. This will apply especially in overseas theatres where there are few opportunities of adapting existing civilian means of communications, such as landlines, to the needs of war.

29. **Sector Organization**. Sectors are areas of air defence. Their boundaries are determined primarily to suit the needs of the C&R system as a whole, but may be modified to suit the needs of administration. Each sector is commanded by a group captain who has a wing commander as his deputy to help him to maintain the fighting efficiency of the wings and squadrons within the sector, and a wing commander senior controller who is responsible for the supervision of the C&R system within the sector.

Tactics for Deployment of Fighters for Air Defence by Night

30. There are many factors peculiar to operations by night to make night fighting a specialized form of defensive air warfare. Night operation involves the use of special weapons and tactics. Although it is possible to use day fighters for night defensive operations, the results achieved are comparatively ineffective. The most effective methods of interception by night involve the use of airborne radar (Al). Al involves a high degree of co-operation with ground control, and the tactics of the night fighter vary accordingly to the method and degree of ground control available. Because the problem of control in night defensive operations is to a large extent inseparable from tactics and strategy.

Factors Peculiar to Defensive Night Fighter Operations

31. As long as the limitations of human eye sight in darkness or in restricted visibility factors which cannot be overcome who!!/ by radar, the problem of defensive fighter operations in these conditions will be complex by comparison with day operations in good visibility.

32. By night, the problem of the economical use of fighters complicated the ability of the enemy to operate in raids of single aircraft. An enemy force, therefore, can only be destroyed piecemeal and night fighter operations, unlike defensive operations by day, usually consist of separate combat between one fighter and one enemy aircraft at a time, rather than a clash of aircraft in force.

Methods of Deploying Fighters for Defence by Night

33. The employment of standing patrols controlled by the C&R system is an effective method of conducting night interceptions as a part of the night fighter force is immediately able for interception duties. However, standing patrols are uneconomical and are unnecessary if warning of attack is not available or enemy activity is sporadic. Interception from "standby on the ground" is the preferable method, especially if the night fighter aircraft in use have a short endurance.

34. Which of the two methods is best in given circumstances depends on variable factors which may be conflicting but which are nearly always interrelated. These factors include.

a. The efficiency of the C&R system.

b. The type and performance of the fighter.

c. Strain on the pilots caused by frequent take-off and landing.

d. Strain on the crew caused by their remaining for periods longer than these necessary to effect interception of specific targets.

35. Other factors which cause strain on night fighter crews are:

a. Their standard of proficiency.

b. The intensity of the enemy effort

c. The weather.

d. The efficiency of ground control and the availability of navigational aids.

e. The layout of airfield.

Interception Procedures

36. For interception with AI equipped night fighters operating in conjunction with a C&R system, aircraft are ordered off by SOC or Master GCI station and are allotted to GCI control. All types of control seek to guide fighters to a position when they complete the interception by the more precise assistance afforded.

The Night Interception Using AI

37. Night interception is normally effected in two stages, namely: first, preliminary control by sector or GCI, second by the AI.

a. **The Preliminary to the AI Chase**. If the fighter is not under GCI control, the AI operation may expect only limited information from the sector controller or searchlight. He must be prepared for any type of initial contact, ranging from head on to one which will entail a course and height, relative to the fighter and a correspondingly quick reaction are essential if a continuous contact is to be held under AI control. Once the navigator is satisfied that contact can be firmly held that he will be able to keep it within the coverage of his AI equipment the interception continues under his control. A code word is given over the R/T to ground control to signify that this stage has been reached.

b. **The AI Chase**. The AI chase may be said to consist of three stages, as follows:

(1) Getting roughly behind the target and approximately the same course.

(2) Approaching to visual contact.

(3) Identification and combat.

A normal AI chase takes on an average between 3 and 10 minutes from the time of initial contact to combat. During this time, and in the approach to visual contact and

the final stage, the target will probably take evasive action; consequently the AI technique adopted must be able to deal with this. However, in the first stage no advantage is to be gained in closely following the weaves that the target may be doing. The main object during this stage is to reduce the range of the target from the fighter.

The Night Interception

38. **Stage One**. In stage one the AI operator ignores as far as possible any evasive action the enemy may be taking and concentrates on reducing the range between fighter and the target. Although a stern chase normally develops, the AI operate should ensure that when the fighter settles down on roughly the range by means of a cutting of vector. During the first stage, the all operator must determine the elevation of the bomber relative to the fighter, and order the pilot to climb or drive accordingly. Thus the three things which the AI operator must watch constantly are azimuth, elevation and range.

39. **Stage Two**. The later stages of the approach, closing in from approximately 11/2 miles to visual range, calls for the utmost skill on the part of the night fighter crew if they are to avoid detection. The pilot must decide early in the chase from what position he wishes to approach the target in order to obtain a "visual" as early as possible. The usual approach is from behind and below, but choice is influenced by considerations such as:

a. The target may have a tail warning device. In this case the method of approach would be based on what is known of the performance of the device, the area of most effective coverage usually being dead astern and below.

b. If the night is so dark that the pilot finds difficulty in obtaining a visual silhouette, he should search for the exhausts of the target aircraft. Again, in most type of aircraft these are best seen from below and astern.

c. Even on a very dark night there is always one portion of the sky slightly lighter than the rest. The fighter should attempt to silhouette the bomber against this light patch.

d. In moonlight conditions, with low cloud, an early visual is more likely to be obtained with the target below the fighter and silhouette against the cloud, with high cloud the reverse applies.

e. Snow on the ground gives the same effect as low cloud under moonlight conditions.

In the last three silhouettes the fighter, by maneuvering so that the bomber is against a light background, automatically places himself against a dark background.

40. Speed control is very important. The fighter must still close in on the target but with a much slower overtaking speed that before. Violent throttling back on the part of the fighter may cause exhaust flames that would reveal his presence. The AI operator should contrive not only to follow any evasive action that the target may be taken, but to keep the target constantly in the position that the pilot has asked for, and at the same time gradually close the range.

41. Range is closed until the pilot has visual contact, the Al operator carrying on his commentary until the pilot satisfied that able to hold the contact. Ranges are still given by the Al operator even after visual contract has been established, because distance and speed are difficult to assess visually at night.

42. **Stage Three**. Once the pilot of the fighter has a good visual contact, the problem of closely following the target's evasive action becomes much simpler, as the pilot knows the aspect of the target and is able to anticipate its evasive action.

43. The importance of careful identification cannot be too strongly emphasized. Valuable assistance in identification can be given by special binocular for night use. These should be used by the Al operator. Some cases of fighters shooting down friendly aircraft owing to incorrect recognition occurred during the late war. If the night is light enough for positive identification, the fighter pilot should maneuver into a good firing position as quickly as possible. Having decided to open fire, the pilot lifts the nose of the aircraft until the target appears in his sight at a range of about 150-200 yards for slightly less. He then gives a fairly long burst, say 2-3 seconds, trying to ensure that this burst either destroys the enemy aircraft or damages it so badly that it will not be able take violent evasive action

44. The Al operator should resist the temptation to look out and watch results should continue watching his Al screen in case the first burst is not lethal, and the should takes evasive action.

45. Should the target have warning of the fighters approach interception and combat will become much more difficult because of the targets subsequent evasive action. Eventually, however, the fighter has an opportunity to deliver his attack.

INTERCEPTION PROCEDURE

Training Objective. At the end of this chapter the student should know about phases of interceptions and be conversant with the responsibilities of concern pers during different phases.

Introduction

1. Interception techniques and procedures depend upon types of weapons in use and the available ground environments. Irrespective of the type of weapons all interception techniques have some common principles.

Phases of Interceptions

2. A typical interception mission, using fighter aircraft from ground alert, will have the following phases:

a. **Scramble Phases**. The scramble phase will start from the time the scramble order has been given and will terminate when the wheels of the interceptor are off the ground after its take-off run.

b. **Manoeuvre Phase**. The manoeuvre phase will start from the time the wheels of the interceptor are off the ground and will terminate when the interceptor is given the final turn before it is committed for combat. Before that, immediately after the interceptor is airborne for a mission, the controller establishes radio and radar contact, it is necessary for the controller to positively identify the interceptor before he can proceed with the vectoring instructions. Identification is done by means of IFF, authentication, identification turns etc.

c. **Combat Phase**. Combat phase will start from the time the interceptor is given the final turn and will terminate when the aircraft breaks off.

d. **Recovery Phase**. The recovery phase will start from the time the interceptor breaks off after combat phase and will terminate when the interceptor has been released.

Responsibilities during Scramble Phase

3. a. **The Base Commander**. The Base Commander of the fighter base will be responsible for ensuring that interceptor aircraft takes-off within the period specified from time to time.

b. **ATC**. ATC is to ensure that full scramble order is passed on to the interceptor before it takes off.

c. **Chief Controller**. The Chief Controller is to allocate targets to be intercepted to the senior controller passing scramble information, immediately when scramble is ordered.

d. **Senior Controller**. The senior Controller is to assign interception to appropriate GCI controllers, immediately after the target for interception is allotted to him.

e. **GCI Controller**. The GCI Controller is to take the following action:

(1) Set scope for intercepting the target allotted and establish target track on the scope.

(2) Complete tactical planning and prepare the mechanical positioning aid.

(3) Draw the displacement line on the scope.

Responsibilities during Manoeuvre Phase

4. During the manoeuvre phase the GCI controller will be responsible for planning the interceptor manoeuvre in a manner so as to place the aircraft in the most advantageous position appropriate to the types of weapon in use. To achieve correct positioning the GCI controller is to take the following actions:

a. On establishing R/T contact, assign angels and speed to the interceptor.

b. Establish positive identification of the interceptors by using IFF where practicable, otherwise by giving ID turns or from the ground position.

c. Pass targets information and position to the interceptor at proper displacement by giving appropriate vectors.

d. Continue to keep interceptors along the displacement line till the point of final turn has been reached; pass target information at regular intervals.

e. Prior to final turn pass pigeons at point of intercept and also the break-away information.

f. Give final turn at the appropriate point on the displacement line.

Responsibilities during Combat Phase

5. **GCI Controllers**. During the combat phase the GCI controller will be responsible for correct positioning till the interceptor pilot gives 'Tally Ho' or 'Judy whichever is appropriate. To redirect the interceptor, if and when the pilot loses contact with his target, the controller will continue to observe the manoeuvre even after the pilot has given 'Tally Ho' or 'Judy'.

6. **Interceptor Pilot**. The interceptor pilot will be responsible for accomplishing the mission after he has given 'Tally Ho' or 'Judy'.

Responsibilities during Recovery Phase

7. The GCI controller will be responsible for safe and expeditious recovery of his interceptors. His responsibilities will terminate when the interceptor has been released from his R/T channel. This responsibility is borne by the Fighter Marshal, if the position is manned.

MAINTAINING CONTROL

Training Objective. At the end of this chapter student should know:

a. How to handle situation during loss of radar contact.

b. How to handle ac during R/T failure.

c How to handle ac during emergencies.

Introduction

1. It is the intent of this chapter, to cover in a general way, a number of problems you may face that are outside of the immediate area of tactics. attack techniques and problems directly related to the air defence mission of GCI controlling. This is often the true test of a GCI controller; his ability to maintain control of an in-air mishap, be it a mechanical or human failure, and respond to the challenge in a way that will maximize safety to the aircrew and perhaps allow completion of the mission.

2. As a controller, you are responsible for the safe conduct of the mission just as the aircrew is responsible for flying safety. To outline all unsafe practices would be impossible. What might be unsafe for on skill level or in a given operating environment might be completely safe for another. Often, safety is directly dependent upon the proficiency of the individuals involved. This chapter will emphasize then, several of the unexpected challenges that you may find yourself facing.

Loss of Radar Contact

3. During certain periods you may encounter conditions which reduce or completely block out the radar returns from your aircraft. When an interruption in signal occurs you can normally attribute the cause to one or more of the following:

a. **Ground Clutter**. Regardless of the physical location of the radar site ground clutter will be present. Some stations have more than others because of the terrain but you will always fond ground clutter an operational problem to some degree. When your aircraft enters the ground clutter patterns, the radar return is obscured by the clutter and tracking becomes difficult in some cases, impossible in others. Through the use of your MTI (Moving Target Indicator) circuit, ground clutter can be eliminated somewhat. However, MTI should be used only when absolutely necessary, for MTI can eliminate all finding your aircraft. DO NOT use IFF alone for any extended period of tracking. Dead reckon, rather than use IFF/SIF alone for extended periods of time. Of course, hostile aircraft will not be “squawking”, but friendlies as well may not be squawking and you will not be able to protect your pilot by calling out “strangers” when and where necessary. Procedures for dead reckoning are therefore very important.

b. **Aircraft Flight Path**. It is not uncommon to lose radar contact with aircraft in a turn. This loss usually occurs when a small reflective surface is presented to the antenna, e.g. the nose or tail of the aircraft. Again, your instructor-controller should show you how to dead reckon (DR) ie, how to mark

the track of the aircraft with a grease pencil in order to estimate where the aircraft will be when it reappears. Only practice will perfect this skill.

c. **Height and Topography**. Aircraft height (altitude) and surrounding terrain (topography) may not be a negative factor at your radar site. In some cases however, a complete fade might occur in areas where mountains and broken terrain are common or where your interceptors are at low altitude.

d. **Individual Radar Characteristics**. Only through careful observation, can you determine what areas of your radar coverage are regularly erratic or weak. In addition to PEs (Permanent Echoes), some radars develop performance characteristics which can and should be discovered and learned, e.g. along a certain azimuth at a given range, one radar van be depended on to paint ships at sea. They have been scrambled upon by controllers who did not check out such a radar contact with adjoining sites. Learn the individual characteristics of your radar. That knowledge can save many an intercept. Aircraft flying directly over your station will usually “ring” the radar set i.e. the blip, as it enters the radar “cone of silence” at five miles (more or less), will appear as a small ring around your station. After some time, the aircraft will break out of this ring and again resemble a normal blip. During this period, when the aircraft is in the cone of silence, you can only guess its true position. The solution then is to know where to anticipate this effect and never attempt to complete a practice intercept over your station. Again, careful observation is necessary to achieve this knowledge of your radar’s true capabilities.

Loss of Communication

4. Perhaps one of the most frustrating events in controlling is the loss of radio communications. However, this does not necessarily prevent you or the aircrew from continuing the mission. Communication loss is usually attributed to one or more of the following:

a. **Aircraft Flight Path.** It is not unusual to lose communications with aircraft heading directly to or from the station. Simply change aircraft heading to avoid this “blind spot”.

b. **Shielded Antenna.** This is usually encountered when the aircraft is in a banked attitude. The skin covering of the aircraft shields the transmitting or receiving antenna during the turn. Communications are usually restored as soon as the wings are level.

c. **Topography** You will sometimes have communications problems in mountains terrain. UHF radios transmit and receive only on a line-of-sight basis; therefore, anytime an object interferes with the radio signal, contact will be lost.

d. **Distance** Radio contact is also dependent on transmitting power. The pilot in many cases can read you. However, since his transmitting power is not as treat as yours, you may lose contact. You may experience a fade in communications when working aircraft below 10,000 feet or at more than 200 miles distance.

e. **Equipment** If the cause of communication failure is determined to be aircraft equipment malfunctions, the mission may still be salvaged. To determine the extent of radio failure, advise the pilot to squawk “standby” if he is receiving

your messages. Then, if the IFF return indicates a “standby” squawk, you know he can receive your voice messages. The pilot may use the aircraft transponder to answer questions, as long as they are phrased to allow a “yes” or “no” answer. If your request for a SIF or IFF response fails to indicate that your message was received, request a change in heading. If you still receive no response, continue to make attempts to communicate as the aircraft flies closer to your station. If the pilot’s radio receiver is operating, but not his transmitter, you may expect (or request) him to fly a triangular pattern to the RIGHT, as shown is Figure 5-1.He should complete a minimum of two such patterns before resuming his original course, repeating the pattern at 2 minute intervals.

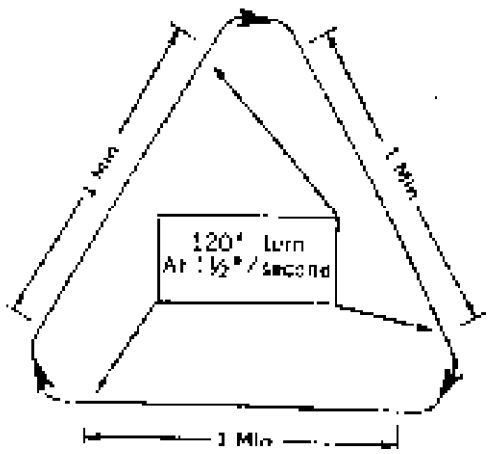


Figure 2.16: Receiver Operating But Not Transmitter

If both his receiver and transmitter are inoperative, he may attempt to alert all ground control stations by flying a triangular pattern to the LEFT as shown in Figure 5-2.

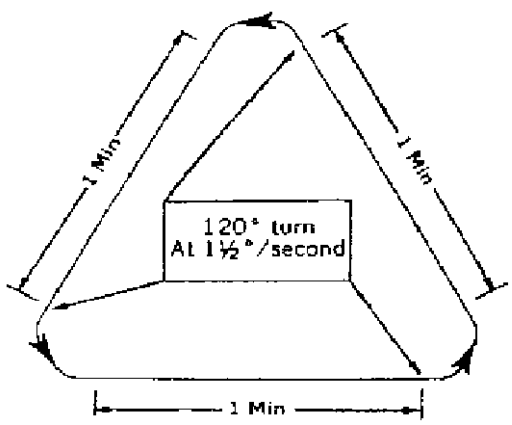


Figure 2.17: Receiver And Transmitter Both Inoperative

Along with radio failure, these patterns may indicate that the pilot has lost his flight or navigation instruments, or both. Jet aircraft use one-minute legs in the triangles, while conventional (piston-powered) aircraft use two-minute legs. If BOTH his receiver and transmitter are inoperative, it may become necessary to vector another aircraft into position to render assistance, particularly in bad weather. In such a case, the airbase approach control radar station should be notified that an aircraft in the returning flight has no radio communications and that another aircraft is joined-up to lead him to a recovery.

Interference

5. “Zipper” control procedures are a means of continuing the intercept during periods of unusual communications interference of any kind. It is normally used when two or more controllers are working on the same frequency or when communications fail due to electrical interference. “Zipper” procedures are imposed by transmitting the work “Zipper” e.g. “Nugget 1, Zipper”. From this point in the intercept until termination of “zipper” you may expect the pilot to transmit only “contact”, “Judy” and mission results. All other transmissions will be acknowledged by two clicks of the pilot’s microphone button. To terminate these procedures, you transmit “Nugget 1, negative zipper’ or “Negative zipper”.

Emergencies

6. The Weapons Controller must be prepared to handle airborne emergencies. The action you take can mean the difference between life and death for an aircrew. Emergencies can occur with any type of aircraft and in varying degrees of severity. Our discussion will consider emergencies from the point of view of supervisory positions, such as Senior Controller, as well as from your perspective as a duty controller. Emergencies are normally declared by the pilot in one or more of the following ways:

a. **By voice, declaring “MAYDAY”**. When you hear a “MAYDAY” call, listen to what the pilot is saying. In most cases he will state what is wrong and what aid he is requesting.

b. **By IFF/SIF**, squawking Emergency mode.

c. **By flying a triangle pattern**. This was discussed earlier in this chapter as an indication of airborne radio transmitter/receiver outage. The pilot may also be lost, due to the concurrent outage of navigational or flight control instruments.

7. If you are at the scope, the instant you hear “MAYDAY” or see an EMERGENCY squawk, mark the position with your grease pencil, note the time of appearance and its range and azimuth from your station. If the EMERGENCY squawk is from a pilot who has parachuted from low altitude, you may only see it for a sweep or two.

8. Once marked be sure that the emergency is reported first to the Senior Controller. He will insure that the information is passed on to the appropriate rescue/ recovery agency. If a radio monitor operator first receives the “MAYDAY” he should answer with “standby for control” and immediately provide the duty controller with pertinent information.

9. Simultaneously, you must determine who is in trouble. Is it an aircraft under the control of your site or a site within your air defense sector? If it is not a supervising controller should direct his assistant to ask Fighter Operations, the Control Center, and airbase Approach Control if they have an aircraft reported in trouble.

10. If you know the outstanding topographical features of your area, much can be accomplished quickly. If the pilot tells you, he is five miles north of Eagle Rock and you know exactly where Eagle Rock is, you can identify his blip immediately. If the EMERGENCY squawk appears over an airbase, there is always the possibility that a maintenance man has accidentally triggered the transponder of an aircraft sitting on the ground. In any case, the appearance of the squawk over the airbase limits the usual assistance that a GCI site can offer. In almost all cases, where the aircraft in distress is over the base, GCA has already taken the aircraft into its control net.

11. If you still cannot determine the identity of the aircraft in distress, attempt to contact the pilot on Guard Channel. This call could be, “MAYDAY” aircraft, do you read Gold coast? “Assuming that you make contact with the pilot, the next question should be “What is your emergency?” When voice transmissions are possible in an emergency, always conduct them on Guard Channel or any other channel set aside specifically for emergency use. There should never be a necessity to have another aircraft or controller speaking on the same channel, unless it is desirable to have them hear your transmissions.

12. Once on Guard Channel, immediately give the pilot “pigeons to home plate”. If the aircraft is closer to an alternate landing field than to his home base, give “pigeons” to this field. In some cases, an instant vector to home base is all that is required to allow the pilot to bring his aircraft safely back to base. In the case of a “flame-out” at high altitude, some pilots have successfully “dead-sticked” their aircraft in. Others, with smoke and a fire light blinking; have requested to be steered away from populated areas, or to the ocean to “ditch” their plane safely. They may ask you to tell them the instant their aircraft is clear of the land mass.

13. As mentioned in the section on communication outages, you can still work with an aircraft, whose transmitter is out. As long as he can receive your questions, communication is possible by means of IFF/SIF responses or identification turns. If a distressed pilot needs to follow another aircraft home because of receiver outage, bad weather or a “bent weapon” go to GCI Common and inquire whether there may be a T-33 or other suitable aircraft available to escort the stricken pilot to base. If necessary, you may even have to scramble interceptors if the range is great or the aircraft’s directional devices are inoperative.

14. There is a limit to what any outside agent can do to assist an aircraft seriously disabled and a pilot in trouble. Your goal is to do all the right things necessary to help the pilot get his aircraft or himself to safety, the real emergencies, the fire warning lights, necessitate that the pilot act so quickly that he may just have time to report he is “Punching out” (leaving the aircraft). The next thing you see may be the chaff dispensing from the pilot’s parachute when it opens. Mark this point of vector a search and rescue aircraft to it, if one is not already on its way.

15. The rule in controlling all emergencies is the same. Be responsive to the needs of the pilot. Nothing is more important than this. If you have established radio and radar contact with an aircraft in distress, you are and should be in control until you release

him to another control agency, such as airbase GCA. Some pilots will request an immediate clearance to land. After your associated technician informs airbase GCA of the location of the aircraft and his situation, you may be requested to conduct a GCI letdown recovery as discussed earlier. Once you have detected the stressed aircraft, it is your responsibility to oversee and direct the resources at your command to assist the pilot.

16. We will next analyze the desirable psychological response on the part of the controller. This response can be summed up in two words : Keep Calm. A MAYDAY or EMERGENCY squawk indicated the pilot believes himself in serious danger. It is his emergency. Logically the pilot should be the more nervous member of the pilot-controller team. Strangely, this is not always the case. Often it is the controller who has difficulty functioning in an efficient manner. The resources at hand, which define the limits of what a controller can actually do to help, may contribute to the combination of frustration and nervousness that some controllers show when assisting a pilot in distress. You should never attempt to legislate the judgment of the pilot. For example, it should be his prerogative to select the radio frequencies to be used in emergency.

17. There was a classic case of a poorly handled emergency with a pilot whose air speed indicator went out. It was winter and he was flying over very rugged, mountainous terrain. He had just completed a pass in a practice intercept pattern, so his partner was some twenty miles away. After calling “MAYDAY” this pilot’s only request was for an altitude check and true air speed reading. Unfortunately when the GCI station called Fighter Operations to notify them of the emergency, the Squadron Commander was present. Since the pilot was new and young, his Commander decided that an inspiring image was more important than the pilot’s request for a true air speed reading.

18. On his UHF radio, the Commander cut the weapons controller off, telling the young pilot not to worry, he was going to make it in and as soon as he did, he and the Squadron Commander were going to go to the officer’s club and have a two-pound steak. By this time, half of the fighter squadron were listening to the transmissions, in addition to the men at the GCI station and early warning sites.

19. The recipient of this sage advice, perhaps surmising that the icy peaks were closer than the warm club, told his Commander : 1 (to get off the horn and let the controller speak and 2) suggested what the commander could do with the two-pound steak in the concise words usually employed by men in peril.

20. There was silence at the other end, finally broken by the voice of the weapons controller who relayed a true airspeed to the pilot. The speed was sufficient to keep the aircraft in the sky at his assigned altitude. Number one aircraft shortly joined-up with the MAYDAY pilot and they were directed home.

21. In summary, as a general guide, the controller should take the following steps for an airborne emergency:

a. Mark the position and time on the scope.

b. Give the pilot the heading and instance to the nearest landmark if he is over water, or to the nearest suitable airbase if he is over land.

c. Have your associated technician report the emergency to the Senior Controller immediately.

d. Ask the pilot to squawk EMERGENCY if he is not already squawking IFF/SIF.

e. Obtain a fuel state.

f. Ask the pilot the nature of the emergency and his intentions. Find out if power or control malfunctions preclude his ability to maintain altitude or heading.

g. Give recovery base weather.

h. Release the aircraft to the recovery agency when requested.

22. All sites should have the aircraft flight manuals (Dash one) for aircraft flying in their area and also abbreviated check lists (aircrew checklists) for each aircraft. Emergency procedures are listed in these checklists. When you find out the nature of emergency, have the appropriate checklist available in case the pilot asks you read the procedure to him.

23. An emergency, except for the time factor, is cut from the same cloth as your other tasks and challenges as a weapons controller. Imagination, versatility, technical knowledge of communication lines, information sources, rescue units, all are necessary for you to know. It all comes under the dictum: “Know Your Area and Its Resources”.

24. If you do, any pilot in distress will be happy to know that the man coming to his assistance is a confident capable weapons controller.

TOPIC- 3
AIR DEFENCE PROCEDURES

AIR SPACE MANAGEMENT

Training Objective. On completion of this chapter, the students will know about the Airspace Management and the utilization of available airspace by dynamic time-sharing and segregation of airspace among various categories of users based on short-term needs.

Introduction

1. Rapid technological advancements in the past few decades have brought about major changes in the aerial warfare. Evolution of fighter aircraft of good low-level capability and high speed, made the aerial warfare complex. Because of low level proliferation, timely detection has become difficult which resulted in delayed Identification and in some cases misidentification of air borne tracks. As such, during a war a ground attack aircraft becomes vulnerable not only to enemy fire but also that of its own force. During Arab-Israel war in 1973, the Egyptians shot down 69 of their own aircraft that accounts for 32% of their total aircraft losses. Israeli Air Defence Force shot down 10% of total aircraft losses of her own. Syria also suffered the same problem in Golan front. Similar things are reported to have occurred in 1965's Indo-Pak war, our Liberation war in 1971, Falkland war and many others. Such fratricidal incidents in different warfare have brought the importance of Airspace Management or Airspace Control to the forefront. ADWC controllers should have an in depth knowledge on 'Airspace Management'.

Definition and Objective of Airspace Management

2. The term Airspace Management is self-explanatory. Still in simple language we can tell that Airspace Management means the optimum and effective utilization of limited airspace. The meaning will be easy to understand if we look at its objective. As per the 'Air Traffic Planning Manual' of 'ICAO' (International Civil Aviation Authority) the objective of Airspace Management is to maximize, within a given airspace structure, the utilization of available airspace by dynamic time- sharing and, at times, segregation of airspace among various categories of users based on short-term needs. Close co-operation between the appropriate authorities on expected and actual utilization of the temporary reserved airspace should result in information being readily available to all parties concerned i.e. commercial air transport, military air traffic and general aviation. The purpose of airspace management is to prevent mutual interference from all users of the airspace, facilitates air defence identification and accommodates the flow of air traffic safely. Air space management in theatres conducting military operations increases combat effectiveness by prompting safe, efficient and flexible use of airspace with a minimum of restraint placed on friendly airspace users. Airspace management requires a set of control measures that facilitates landing or recovery sites, flight routes that includes restricted operating zone and the co-coordinating altitude.

Classification

3. This Airspace Management maybe classified into two discrete types:

a. Peace time Airspace Management
b. Wartime Airspace Management.

Peace Time Airspace Management

4. The Peace Time Airspace Management is a comparatively simple task than that of Wartime. In all countries there are designated airspaces for different types of air space users and standard rules and regulations are laid down for the safe and expeditious use of airspace by all. In most of the countries, though separate air traffic agencies are established for giving service to the civil and military airspace users, there is reasonably enough scope for necessary co-ordination. So, if there are ambiguities or confusions regarding the use of airspace that can very well be settled down on ground keeping sufficient time in hand to relay the decision to all concerns. In any provision of peacetime airspace management, there are designated routes and areas for civil air traffics and 100% 'in flight' and 'on ground'. Service is provided to them by the concerned air traffic and other agencies. Similar is the case for military airspace users. For smooth and flexible operation the airspace allotted for military utilization is exclusively divided for different categories of operation like fighter flying, helicopter flying, practice firing and as such, there is very less room for any confusion, which may result in mid air collision or other in-flight problems. Also there is no chance of any engagement as there is no war. Sufficient preparation is taken for any in-flight emergency and the concerned agencies get reasonably enough time for remedial action. Though there are possibilities of misidentification, crash and other unusual occurrences but it is much lesser than that of wartime.

Wartime Airspace Management

5. Wartime airspace management is a complex and tricky game. During war, the agencies that deal with airspace are to face unforeseen airspace scenarios every now and then. During war the low-level and high-speed flying activities increase, which make 'identification' not only difficult, but also at times impossible. Along with aircraft and other airborne transports, missiles, unmanned air vehicles etc also use airspace during war, which cannot be put in a standard format. All unauthorized airspace use like Air corridor violation, altitude violation, non-scheduled flights and other unauthorized use of airspace by rival countries are the normal phenomenon of a war. Under such cumbersome circumstances it is more than difficult to identify each and every track properly. But, what is the way out? The countries with modern technologies and know how could not yet find a suitable answer to this question. Even NATO is in a perplexing condition in dealing with this problem. For the successful engagement of hostile ac and for ensuring safety of friendly ac, identification of all hostile tracks is an imperative. If that is not possible then at least all friendly tracks should be identified so that fratricidal occurrences do not take place. But till now such a 100% full proof arrangement could be found. IFF and radar were the best possible means so far. But because of their susceptibility to jamming and interference, and absence of means of speedy dissemination of information from radars to gunners in the forward areas, some other solution to this problem was always looked for.

6. A procedural 'Airspace Management' is found to be a significantly effective solution to the problem of dealing with such a cumbersome use of airspace during war or emergency. According to military analysts, this 'Airspace Management' will need to be considered in nearly every aspect of an air warfare, be it a movement of large aircraft formation through friendly air defence, the launch of a missile attack or the forward deployment of Army ground forces with their integrated air defence weapons.

7. However, in spite of its limitations, a procedural means of 'Airspace Management', which we can term as 'Airspace Control', should be in effect for the smooth conduct of a war. Mainly this will be a tool for avoiding the engagement of friendly aircraft, which can be done through the process of identification. But de-confliction of the mission can be achieved by effective airspace management. For reducing the mistakes and other difficulties of identification, the electronic identification means should be supplemented by procedural means, e.g. visual identification. Once errors in identification can be reduced to the minimum, then an effective means of airspace control should be worked out for procedural traffic deconfliction. This should be actually the aim of a procedural airspace management.

Considerations

8. After identifying the need for airspace management, we should move forward to sort out the factors that should be taken into account for producing a system or plan to control airspace effectively and decide when to implement such control. Sufficient care should be taken to ensure that the plan suits the particular theatre or country for which it is prepared. The few points that should be taken into account are; the mission, the threat, own forces capability, depth of the country, identification criteria etc.

9. **The mission**. The mission should be analyzed for preparing an airspace control plan. Is it a peace keeping or peace-enforcing mission? Do we need a plan at all? Is the campaign going to be short with minimum control required or is it going to be of extended duration where full airspace control will be needed? All such points should be studied thoroughly while preparing the airspace control plan.

10. **The Threat**. The threat will also dictate the need of airspace control plan and effect many requirements within the plan. Here we have to consider points like;

a. Does the enemy have an AEW capability?

b. Can the enemy target own AEW aircraft?

c. Does the enemy have Electronic Warfare capability?

d. What are the weapons the enemy is going to use against us?

11. **Own Force Capability**. A thorough study should be made on own force capability, which should cover the points like:

a. Are the communications adequate to produce and disseminate the airspace control efficiently and effectively?

b. What is the depth of own area where control should be exercised?

c. What are our air assets?

d. What is the maximum limit where we can engage an enemy ac?

12. **Identification Criteria**. Another principal consideration should be the identification criteria. These are essential if fratricide is to be avoided and effective airspace management be achieved. Identification must be based on IFF and airspace control means, including the policing of airspace and air corridor if necessary.

13. **Extent of Users**. During peacetime there is a standard operating procedure regarding civil/military flights or national /international flights. So there is least possibility of any conflict between civil and military air operation as both users are allotted with separate airspace that they use for specific purposes. There is specific flight plan or flight schedule for these flights. Routes and training areas are also planned for peacetime flights or exercise. But situation becomes very complex during wartime as because of intensive air operation of various natures. We need to conduct both DCA and OCA operations while there may be special operations like para-trooping, air to air refueling, air support mission, and search and rescue mission. Moreover, various ground based air defence system (SAM and AAA) will also be active. It is also likely that national/international NGO's may require to operate in the same airspace. So, segregation of airspace is highly required in terms of area and altitude. Such separation of airspace is referred to as division of airspace in this chapter. Thus airspace management is very crucial and complex during war. Usually, the airspace is managed through Airspace control plan and control order. Various divisions of airspace are discussed later in this chapter.

Airspace Management Structure

14. For any theatre or country, an airspace doctrine is to be in existence that should be prepared by a high-level consultative body. This Doctrine will be the principal reference for issuing Airspace Control Orders during any emergency. The responsibility of exercising overall airspace control during a war should be vested on an Airspace Control Cell. This Airspace Control Cell will issue airspace control order during a war or emergency and do necessary amendments to this control order as and when required. In a theatre of vast area this controlling authority may be distributed to different Regional Airspace Control Cells with specific area of responsibility. In addition to the above responsibilities The Airspace Control Cell will be responsible for the following tasks:

a. Receiving, coordinating, and approving or denying requites for airspace control means.

b. Coordinating airspace control means requests in adjacent areas with the appropriate airspace control cell.

c. Liaising with Navy, Army and other agencies likely to affect operations.

d. Referring conflicting requests, which cannot be resolved by the airspace control cell to the immediate higher echelon in the chain?

e. Promulgating by the airspace control order the activation, deactivation and modifications of airspace control means.

Types of Air Traffic

15. In time of crisis and war, the air traffic can be categorized into 3 basic types. These are:

a. **Operational Combat Traffic**. Operational combat traffic remains in charge of directly inflicting damage on the enemy or giving support to these missions in the form of air defence, reconnaissance, surveillance, electronic counter-measures, refueling, rescue or special tasks.

b. **Operational Support Traffic.** Operational support traffic is directly engaged in the attainment of national objectives other than Operational Combat Traffic.

c. **Non- operational Traffic**. Non-operational traffic is sub-classified into diplomatic, commercial or neutral military traffic.

Divisions of Airspace

16. Airspace management can be maintained procedurally during peacetime but during wartime due to the peculiarity in the air activities such as, hostile activities and deployment of various friendly forces, non scheduled flights of civil organizations etc. So, the airspace must be divided into different classes and areas. The different airspaces are important to know because different services are provided within them. The four types of airspace are controlled, uncontrolled, special use and others. The type of airspace is dictated by complexity and density of aircraft movements, the nature of operations conducted and the level of safety required. Now different airspace is managed by designated agencies. Success of a battlefield depends on how efficiently the airspace of over that battlefield is used. Airspace management maximizes force effectiveness without inhibiting other the ground effort or the airspace users supporting it. These procedures define the methods used to accomplish the airspace control function, ensure unity and standardize the airspace control effort. They must be sufficiently flexible and responsive to accommodate the rapid changes to planning and ongoing opposition. Divisions of airspace (basing on various users) are described as follows:

a. **Air Corridor**. A restricted air route of travel specified for use by friendly aircraft and established to prevent engagement by friendly forces.

b. **Air Defence Action Area**. An air defence action area and the airspace above it is an area within which friendly aircraft or surface-to-air weapons are normally given preference to conduct air defence operations except under specific conditions.

c. **Air Defence Area**. An air defence area is a specifically defined airspace for which air defense must be planned and provided.

d. **Air Defense Identification Zone (ADIZ)**. An ADIZ is airspace of defined dimensions within which the ready identification, location, and control of airborne vehicles are required.

e. **Air Refueling Area**. An air refueling area is airspace defined by lateral and altitude limits for the purpose of conducting aerial refueling operations. Also known as refueling track, refueling orbit or refueling anchor. Block altitudes are normally required for multiple cell refueling operations.

f. **Airspace Control Area**. Airspace that is laterally defined by the boundaries of the operational area. The airspace control area may be divided into airspace control sectors.

g. **Airspace Control Sector**. An airspace control sector is a sub-element of the airspace control area established to facilitate the control of the overall area. Airspace control sector boundaries normally coincide with air defence organization subdivision boundaries.

h. **Airspace Coordination Area**. An airspace coordination area is a three-dimensional block of airspace of defined dimensions and used as a restrictive fire support coordinating measure.

j. **Amphibious Defence Zone**. An amphibious defense zone is the area encompassing the Amphibious Objective Area and additional adjoining airspace as needed for the accompanying naval force for the purpose of air defence.

k. **Amphibious Objective Area (AOA)**. An AOA is a geographic area delineated in the initiating directive for purposes of command and control, within which is located the objective(s) to be secured by the amphibious task force. This area must be of sufficient size to ensure accomplishment of the amphibious task force's mission and provide sufficient area for conducting necessary sea, air, and land operations. The airspace associated with this area is included in the AOA. When dissolved, airspace control passes to the ACA.

l. **Base Defense Zone (BDZ)**. BDZ is an air defence zone established around an air base and limited to the engagement envelope of short-range air defence weapon systems defending that base. BDZs have specific entry, exit, and IFF procedures established.

m. **Co-ordinating Altitude**. A co-ordinating altitude is a procedural method to separate fixed- and rotary-wing aircraft by determining an altitude below which fixed-wing aircraft normally will not fly and above which rotary-wing aircraft normally will not fly. It may include a buffer zone for small altitude deviations and extend from the forward edge of the communications zone to the Forward Line of Own Troops. The coordinating altitude does not restrict either fixed- or rotary-wing aircraft when operating against or in the immediate vicinity of enemy ground forces. Fixed- or rotary-wing aircraft planning extended penetration of this altitude will notify the appropriate airspace control facility. However, approval acknowledgment is not required prior to fixed wing aircraft operating below the coordinating altitude or rotary-wing aircraft operating above the coordinating altitude. See Figure 8.3 for a graphic representation of a coordinating altitude.

n. **Fighter Engagement Zone (FEZ)**. FEZs normally will be established in those areas where no effective surface-to-air capability is deployed. These operations usually take place in airspace above and beyond the engagement ranges of surface-based (land and sea), short-range air defence systems, and are an alternative type of engagement operation if the detailed control aspects of joint engagement operations cannot be met. FEZ is an air defence control measure.

p. **Firepower Umbrella**. Firepower umbrella is an area of specified dimensions defining the boundaries of the airspace over a naval force at sea within which the fire of a ship's antiaircraft weapons can endanger aircraft, and within which special procedures have been established for the identification and operation of friendly aircraft.

q. **High-Altitude Missile Engagement Zone (HIMEZ)**. Normally applied to long-range surface-to-air missiles, a HIMEZ will limit the volume of airspace within which these weapons may conduct engagements without specific direction of the ADC. HIMEZ is an air defence control measure. See Figure 8.3 for a graphic representation of a HIMEZ.

r. **Minimum Risk Route (MRR)**. An MRR is a temporary corridor of defined dimensions recommended for use by high-speed, fixed-wing aircraft that presents the minimum known hazards to low-flying aircraft transiting the combat zone. MRRs are established considering the threat, friendly operations, known restrictions, known fire support locations, and terrain. See Figure 8.1 for a graphic representation of a MRR.

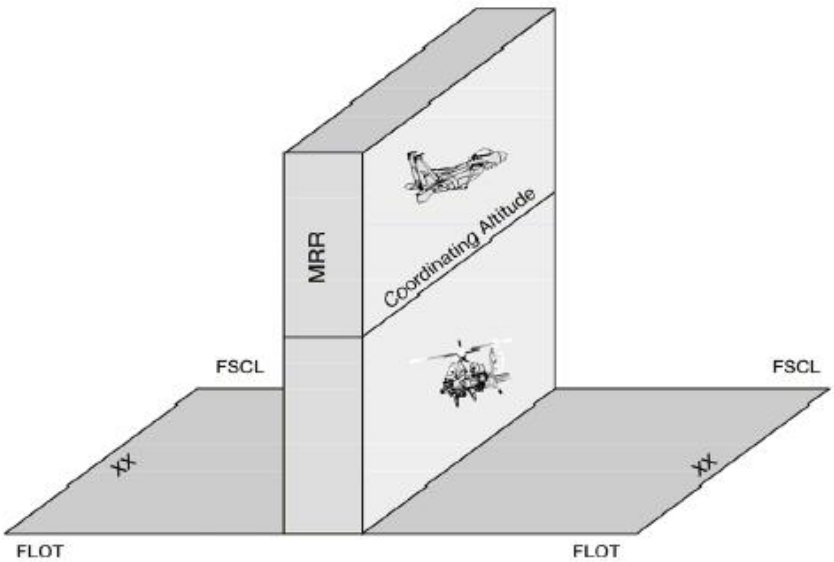


Figure 3.1: Minimum Risk Routes

s. **High-Density Airspace Control Zone (HIDACZ)**. HIDACZ is an area in which there is a concentrated employment of numerous and varied weapons or airspace users. A high-density airspace control zone has defined dimensions that usually coincide with geographical features or navigational aids. Access to a HIDACZ and air defence weapons status within the HIDACZ is normally approved by the appropriate commander. See Figure 8.2 for a graphic representation of a HIDACZ.

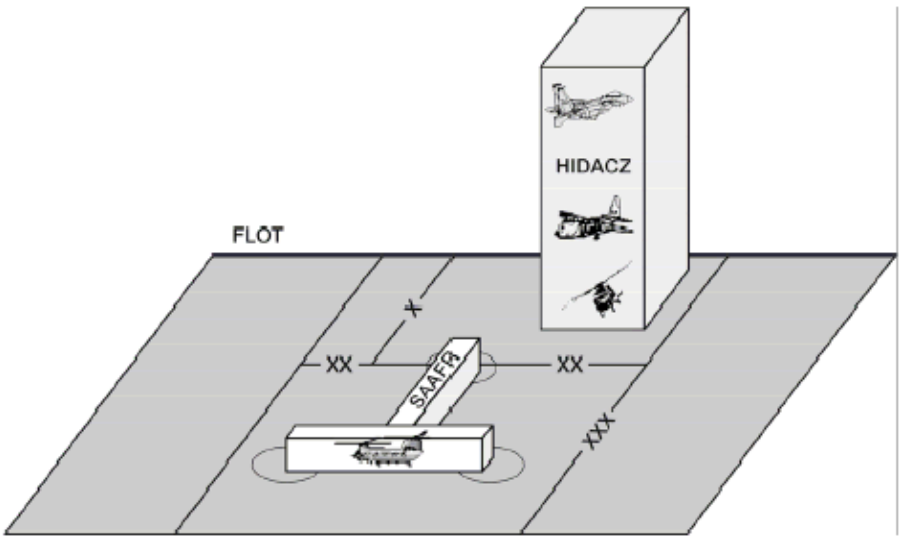


Figure 3.2: HIDACZ and SAAFR

t. **Joint Engagement Zone (JEZ)**. JEZ is airspace of specified dimensions within which multiple air defence weapon systems (surface-to-air missiles and fighters) of one or more Service components are simultaneously employed and operated.

u. **Low-Altitude Missile Engagement Zone (LOMEZ)**. LOMEZ is a volume of airspace established to control engagements of low- to medium-altitude surface-to-air missiles. Subject to weapon system capabilities, the LOMEZ normally will extend beyond the forward edge of the battle area.

v. **Low-Level Transit Route (LLTR)**. LLTR is a temporary bidirectional corridor of defined dimensions that facilitates the low-level passage of friendly aircraft through friendly air defences and controlled or restricted airspace. LLTR currently is used only within the North Atlantic Treaty Organization (NATO).

w. **Restricted Operations Area (ROA)**. ROA is airspace of defined dimensions created in response to specific operational situations or requirements within which the operation of one or more airspace users is restricted. This is also known as a Restricted Operations Zone (ROZ). See Figure 8.3 for a graphic representation of a ROA (ROZ).

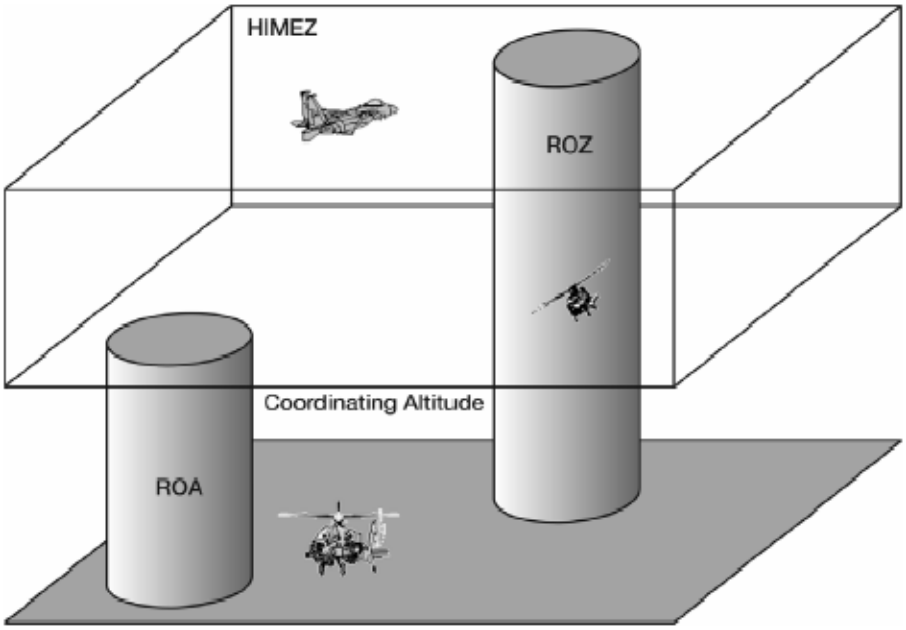


Figure 3.3: Coordinating Altitude, HIMEZ, ROA, and ROZ

x. **Short Range Air Defense Engagement Zone (SHORADEZ)**. Areas of short-range air defence (SHORAD) deployment may fall within a LOMEZ or HIMEZ. It is possible that SHORAD assets may solely defend some areas. A SHORADEZ can be established to define the airspace within which these assets will operate.

y. **Special Use Airspace**. Special use airspace is a term used to define airspace for a specific purpose. It may also designate airspace in which no flight activity is authorized. General subdivisions (regions, sectors, and AOA) are not special use airspace.

z. **Standard Use Army Aircraft Flight Route (SAAFR)**. SAAFR are routes established below the coordinating altitude to facilitate the movement of Army aviation assets and normally located in the corps through brigade rear areas of operation. See Figure 1–2 for a graphic representation of a SAAFR.

aa. **Weapons Engagement Zone (WEZ)**. In air defence, WEZ is airspace of defined dimensions within which the responsibility for engagement normally rests with a particular weapon system. These include FEZ, HIMEZ, LOMEZ, SHORADEZ, and JEZ.

ab. **Weapons Free Zone**. A weapons free zone is an air defence zone established for the protection of key assets or facilities, other than air bases, where weapons systems may be fired at any target not positively recognized as friendly.

Reference:

1. USAF Doctrine Document 2 – 1.7 dt 13 Jul 2005.

MISSILE GUIDANCE SYSTEM

Training Objectives. At the end of this chapter the student shall know about the various guidance systems of missiles.

Introduction

1. This chapter presents a discussion and overview of missile guidance and control laws. Theoretically, the missile-target dynamics are highly non-linear. This is due to the fact that the equations of motion are best described in inertial coordinate systems.

Missiles Types and Classification

2. On the basis of various guidance, the classification of missiles is given in the following diagram:

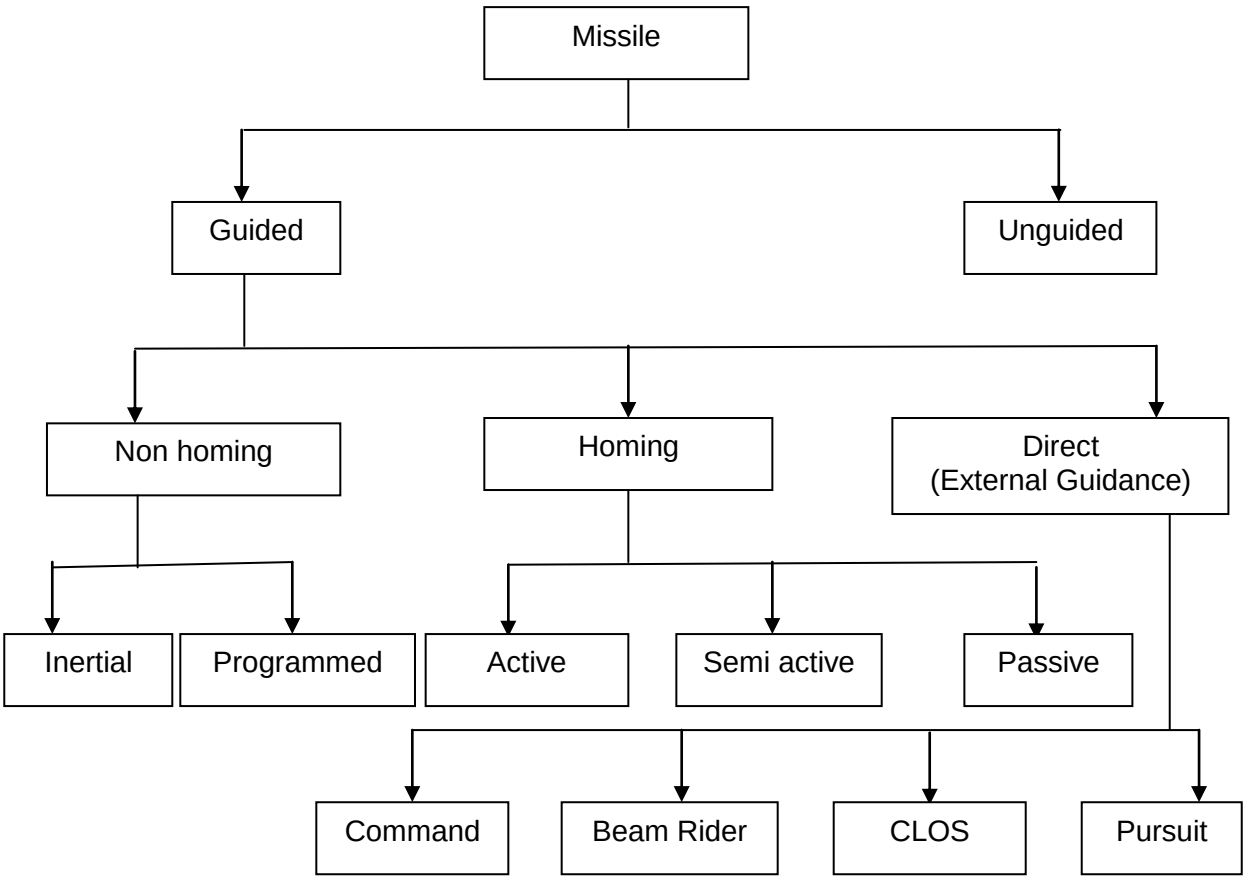


Figure 3.4: Missile types and classification

3. In this chapter two most important basic guidance concepts will be discussed:

a. The homing guidance system- which guides the interceptor missile to the target by means of a target seeker and onboard computer.

b. The direct guidance is that command type guidance which relies on missile guidance command calculated at the ground launching (controlling) site and transmitted to the missile.

4. In addition to these guidance systems, two other forms of missile guidance have been used in the past or being used presently- *Inertial Guidance* (used mostly in ballistic missiles) and *Position Fixing Guidance*.

Homing Guidance

5. The expression *homing guidance* is used to describe a missile system that can sense the target by some means and then guide itself to the target by sending commands to its own control surfaces. Homing is useful in tactical missiles where considerations such as autonomous (or fire-and forget) operation usually require sensing of target motion to be done from the interceptor missile (or pursuer) itself. Consequently, in such cases the sensor limitations generally restrict the sensed target motion parameters to the set consisting of the direction of the line of sight and its rates of carious orders.

6. Homing is used not only for the terminal guidance of missiles, but also for the entire in some cases, particularly for short-range missiles. Homing guidance is a term used to describe a guidance process that can determine the position (or certain position parameters) of the target (e. g. an aircraft, ship or tank) with respect to the pursuer and can formulate its own commands to guide itself to the target. More specifically, a homing system is a specialized form of guidance, which entails selecting, identifying, and following (chasing) a target through some distinguishing characteristic of the target. Such identifying characteristics as heat or sound from a factory, light from a city, or reflections of radar waves from a ship or aircraft are used as the source of intelligence to direct the missile to the target.

7. **Homing Method**. These are where the missile has a homing head or seeker which looks forward towards the target. Homing systems may be classified in three general groups as follows:

a. Passive

b. Semi -active

c. Active

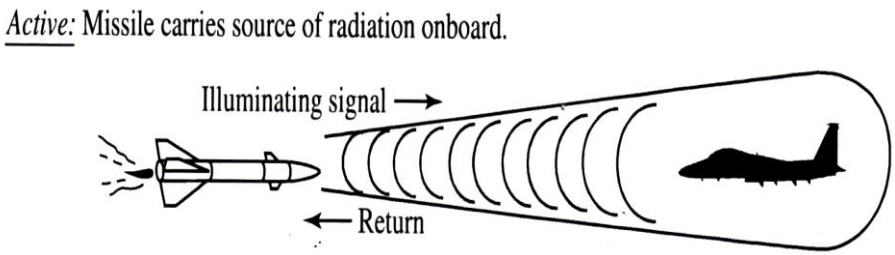


Figure 3.5: Semi-active Homing Guidance

Semi-active: Missile uses external, controlled source of radiation.

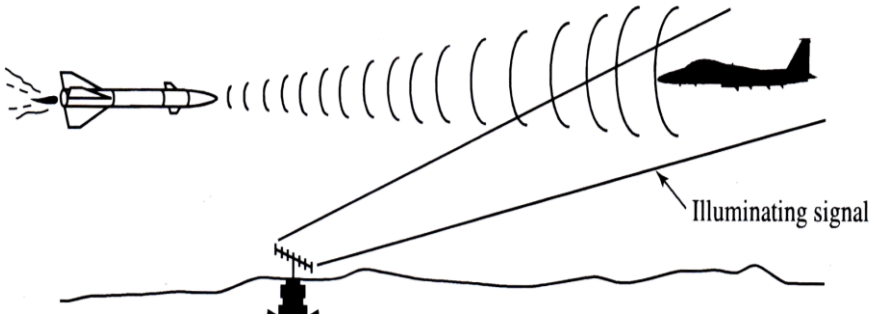


Figure 3.6: Semi-active Homing Guidance

Passive: Missile uses external, uncontrolled source of radiation.

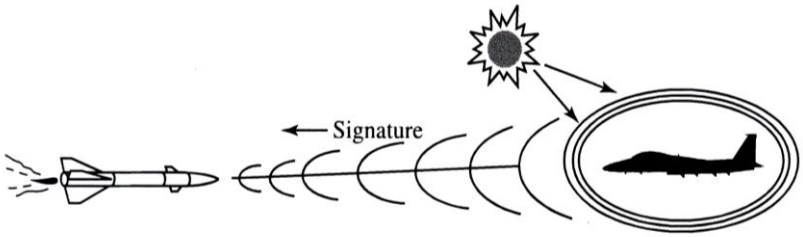


Figure 3.7: Passive Homing Guidance

Passive Homing Missile

8. A passive homing system one that is designed to detect the target by means of natural emanations or radiation such as heat waves, light waves, and sound waves. Thus, passive homing guidance systems are based on the use of the characteristics radiations from the target itself as a means of attracting missile, for example, as in infrared homing systems. In other words, the target acts as a lure. Regardless of the type of intercept guidance technique used, the missile must have sufficient maneuver capability (full sufficient g's) to intercept the target within the lethal distance of the warhead. At lower altitudes, the air frame capability is not a limiting factor because it can generally execute g's in excess of the autopilot limit, say 25 g's. At higher altitude, especially in a snap-up attack, the airframe maneuver limit is usually the parameter that determines the lunch boundary and/or terminal accuracy. Examples are the infra-red Air-to-Air Missile, (IR AAM), anti radar missiles (ARM), passive Torpedoes, and the Home on Jam (HOJ) mode that many missiles possess.

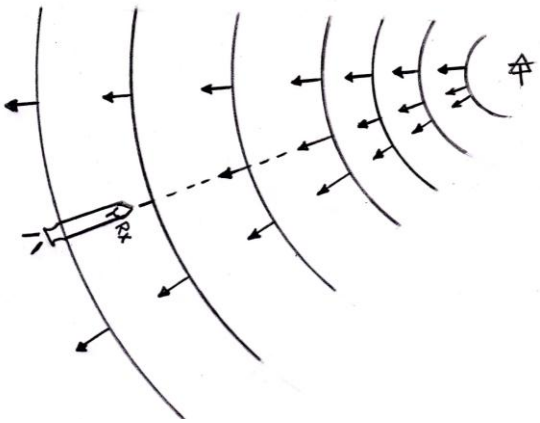


Figure 3.8 Passive Homing Missile

9. **Advantages of Passive Homing**

a. **Accuracy**. As with all of the homing systems, as the target is approached, resolution or discrimination on it gets progressively better. This is because the energy used for homing is coming from the target. In passive homing the energy gets more powerful as the target is approached.

b. **Fire and Forget**. After lunch, the delivery vehicle plays no further part. This is sometimes called ‘shoot and scoot’, but it is not quite the same as ‘lunch and leave’.

c. **Warning to the Target**. The target is not warned of attack because the missile guidance is passive. The target, through other sensors, may know the presence of the lunch vehicle, and may also be able to sense the motor emissions of the passive homer.

10. **Disadvantages of Passive Homing**

a. **Range**. In general, a short range system because it depends on target emissions and these may not be very powerful. But some of the radar systems do not suffer from this (ARM. HOJ etc).

11. **IR Passive Homing Missile.** All targets emit some infrared radiation. As the IR emissions can be detected at some distance, and used to distinguish the target from its environment, it can be used to establish a sight line to the target and hence to guide a weapon.

a. **Advantages of IR Guidance**

(1) **Accuracy**. An IR missile can discriminate between two sources a few yards apart at several miles range, and will generally home on to a particular engine of a multi-engine target. Accuracy improves as the target is approached.

(2) **Lethality**. With its good accuracy, an IR homing missile has high lethality for a given warhead and missile weight.

(3) **Simplicity**. The missile needs only one small and relatively simple receiver; no rear reference signals are required.

(4) **Security**. As it is a passive homing missile, it dose not give away its presence by radiating any type of energy.

(5) **Tactical Freedom**. Once the missile is fired, it is independent of the delivery vehicles.

(6) **Countermeasures**. It is possible to counteract IR missiles by masking the IR source, or simulating it with decoys of the precise radiation characteristics sought bt the missile. However, such countermeasures are difficult to achieve.

b. **Limitations of IR Guidance**

(1) It is degraded by cloud.

(2) Steady target acquisition may be impossible pointing into sun or bright cloud edges.

(3) If the target is sub sonic, most missiles can only attack from the rear, as target skin heating is minimal. However, more sensitive IR receivers now allow homing from any angle, including head on.

(4) An IR homing head dose not indicates target range. An additional range finding system is required.

Semi Active Missile

12. The missile is similar to a passive one in that it homes onto energy which comes from the target, but in the SA case the energy originates in a target illuminator which is part of the missile system. The missile will probably be pre-tuned before lunch to the precise signal required ie the illumination frequency ± target Doppler shift.

13. A semi active homing system is one that selects and chases a target by following the energy from an external source, such as tracking radar, reflecting from the target This illuminating radar may be ground- base, ship-borne, or airborne. Semi active homing requires the target to be continuously illuminated by the external radar at all times during the flight of the missile. The illuminating energy may be supplied by the target- tracking radar itself or by a separate transmitter collimated with it. The radar energy reflected by the target is picked-up by a tracking receiver (the seeker) in the nose of the missile and is used by the missile's guidance system. Equipment used in the semi active homing systems is more complex and bulky than that used in passive systems. It provides homing guidance over much greater ranges and with fewer external limitations in its applications. An example of semi active missile guidance is found in the supersonic Sparrow II *(*model AIM-7F*)* while the Phoenix missile uses both active and semi active homing guidance.

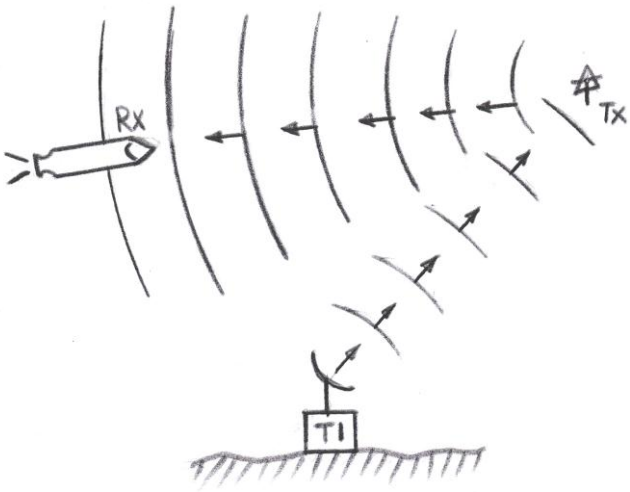


Figure 3.9: Semi Active Missile

14. **Advantages of Semi-Active**

a. **Accuracy**. Target information gets more accurate as the target is approached and signal strength improves.

b. **Long Range**. If the illuminator is of high power, range is limited only by the horizon and atmospheric absorption.

c. **Counter Measures**.

(1) The homing head can be a narrow band device tuned to the illumination frequency ± target Doppler. This makes decoying more difficult.

(2) The illumination beam will have a finite beam width and although it any be distributed by enemy counter measures, if part of the beam still illuminates the target the missile will still succeed.

15. **Disadvantages of Semi-Active Homing**

a. **Not Fire and Forget**. The illuminator is in use during the whole period of target engagement. This also leads to limitations on the target of engaging new targets, although salvoes can be fired at a single target which is being illuminated.

b. **Extra Equipment**. The illuminator is needed, with advice for keeping it pointed at the target (a tracker), and links to the missile to preset the homing frequency.

c. **Warning to Target**. The target is warned by the illumination transmissions that he is under attack. He can jam, but the effect can be reduced by ECCM in the illuminator.

d. **Targets Information**. A formation of targets will all be illuminated. The missile homing head needs very good angular resolution or it may home to the centroid of the return (i.e. the middle of the formation) instead of to an individual targets.

Active Homing Missile

16. In an active homing system, the target is illuminated and tracked by equipment on board the missile itself. That is, the missile carries the source of radiation on board in addition to the radiation sensor. In an active radar homing system, for example, both the radar transmitter and the receiver are contained within the missile. Actively guided missiles have the advantage of *launch-and-leave*, i.e. they can be launched and forgotten. Disadvantages of the active homing system are additional weight, higher cost, and susceptibility to jamming, since the radiation it emits can reveal its presence. An example of an active homing missile system is the European *Meteor* active radar-guided AAM.

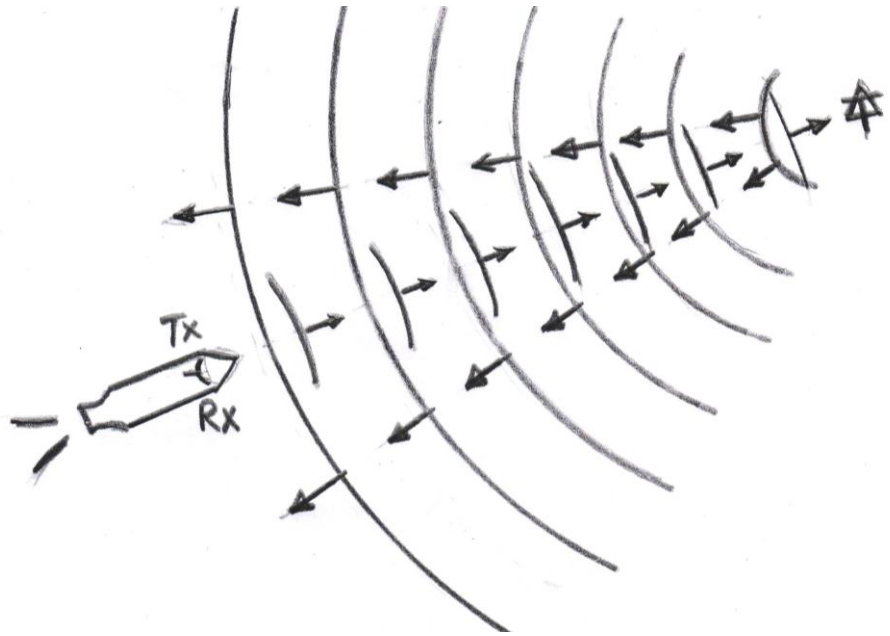


Figure 3.10: Active Homing Missile

17. **Advantages of Active Homing**

a. **Accuracy**. Target information gets more accurate as the target is approached. Signal strength improves markedly as the target gets closer because both the transmitter and receiver are closer.

b. **'Fire and Forget'**. After lunch, the lunch platform plays no further part.

18. **Disadvantages of Active Homing**

a. **Low Transmitter Power**. Within the confines of the missile body it is not possible to have large transmit powers, at least in comparison with the separate illuminator used with SA guidance. Active homing therefore tends to be a medium range system.

b. **Complexity**. The homing head has to have both a transmitter and a receiver. Weight is therefore increased, not only in the homing head but in the internal power source which now has to power the transmitter. Designed compromises may have to be made between the ideals for transmission and reception. The increased complexity will naturally lead to less reliability, particularly as all the transmitter circuits have to have to be stressed for the vibration, 'g' and temperature environment of the missile.

c. **Counter Measures**. The enemy is warned of attack by missile transmissions. He may therefore try and jam the missile. ECCM measures may be difficult to improve to incorporate in an active homing head because of weight, power and size constraints. However, to avoid the effects of decoys and jamming, many active homing head are forced to have range and bearing correlation circuits ('logic circuits' or data processing). Here the return signals are analyzed in the correlation circuits and are rejected for homing purposes if they go out side pre set range and heading changes.

d. **Target in Formation**. A formation of targets will all be irradiated with transmission energy and so the missile receiver needs very good angular resolution in order to home to an individual target. It may home instead to the centroid of the return (ie the middle of the formation).

Various Command Systems

19. Here the missile looks back for commands. The missile itself is ignorant of target position and depends on the commanding agency to direct its trajectory.

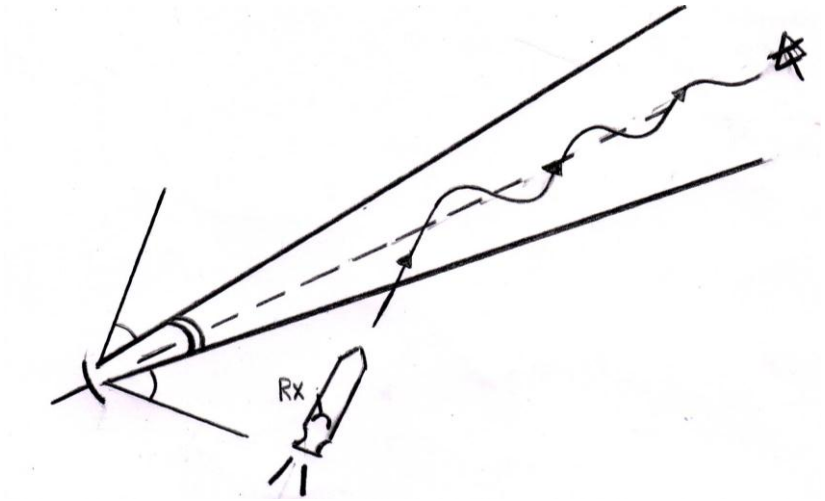


Figure 3.11: Command System

Beam Riding

20. A beam is projected toward the target and the missile in flight (by looking back) senses when it is off the beam centre line. Error signals are then sent to the controls to put the missile back on the centre of the beam. This continuous re-centring process normally results in a spiral flight path and it the designer's job to keep the amplitude of the spiral as small as possible. Some first generation missiles used radar beam riding, and short range Laser Beam Riding is now being used.

21. **Advantages of Beam Riding.**

a. **Missile Simplicity**. The missile construction can be simple. There is no homing head, simply a rearward facing sensor to pick-up the beam and circuit to generate control demands to re-centre the missile in the beam.

b. **Targets in Formation**. The missile itself dose not even know where the target is. The agency directing the beam may be able to discriminate the formation of targets, and Lethality may not be reduced too much, particularly if the missile has a large warhead.

c. **Jamming of Missile**. Since the missile sensor is looking away from the target it will be difficult to the missile itself.

22. **Disadvantages of Beam Riding**

a. **Not 'Fire and Forget'**. The beam has to be accurately aligned during the engagement. Engagement rate (of several targets) is limited, although salvoes of missiles can be sent up the beam to a single target.

b. **Extra Equipment**. A device for producing the beam is required, plus a very accurate target tracker so that the beam is precisely aligned with the target.

c. **Accuracy**. Accuracy falls with range. As the beam widens the amplitude of the missile spiral will increase. This will require a bigger warhead with consequent increase in missile size. Beam riding using divergent radar beams have been discarded as a guidance option.

d. **Poor Trajectory**. In most systems the beam is simply pointed continuously at the target and the missile follows it to impact. The trajectory follows the ground sight line and is analogous to a K = 1 trajectory in a homing missile. It involves a longer flight path and beam more missile 'g' of course a more sophisticated system could aim the beam ahead of the target, lining up with the target for impact ('predicted Beam Riding') but would be the more complex.

e. **Warning to the Target**. The target is warned by the beam transmission that he is under attack. He can jam but the effect can be reduced by ECCM in the beam tracker. However, because very accurate tracking is required for success, a slight disturbance of the beam will defeat the system.

Command Link/ Command Guidance

23. Here the missile is given commands which are relayed to its controls to alter its trajectory as required. The commands are sent through the 'Command Link' from which the system is warned, although frequently the word 'link' is dropped and such a system is simply called 'Command Guidance'. Both the Missile and Target must be accurately tracked so that the system computer can compare their trajectories and work out the commands to be sent to the missile.

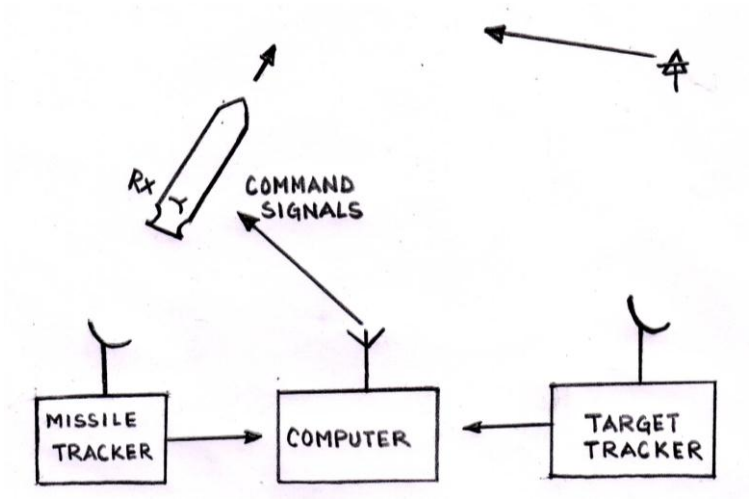


Figure 3.12: Command Link

24. **Advantages of Command Guidance**

a. **Missile Simplicity**. There is no homing head, or indeed any guidance circuitry, in the missile. It simply has its rearward facing sensor which relays commands directly to the controls (normally in Cartesian format).

b. **Versatile Trajectory**. If the computing and tracking system that calculates missile commands is sophisticated enough, the missile can be commanded ahead of the target to a predicted impact point. This “Full- lead Trajectory” is better than ant homing system can produce. Many other flight paths can be followed by simply re-programming the computer and so command guidance can allow a weapon to be uses with more than one trajectory. This can be useful in a jamming environment and also may mean that the weapon can be used in several roles (e.g. surface-to-air and surface- to- surface). It also means that, with a new system, the computer logic can be updated after trials firings to improve the model of missile characteristics and so improve the response to control demands.

c. **Targets in Formation**. The missile itself dose not know where the target is. If the tracker which supplies target information can discriminate between targets in formation then lethality may not suffer too much, particularly if the missile has a large warhead.

d. **Jamming of Missile**. Since the missile sensor is looking away from the target it will difficult to jam the missile itself.

25. **Disadvantages of Command Guidance**

a. **Not ‘Fire and Forget’**. The target and missile have to be accurately tracked during the whole engagement. Engagement rate is therefore limited, and salvoes of missiles against one target are only possible if more than one missile at a time can be both tracked and commanded.

b. **Extra Equipment**. As well as the missile itself, a target tracker, missile tracker, a computer, and the missile command- link itself are required.

c. **Accuracy**. Accuracy decreases with range. The trajectory data fed by the trackers by the computer will thus degrade with range and so missile miss distance will increase as range increases.

d. **Warning to the Target**. The target is warned by the tracking transmissions that he is under attack. He can jam but this effect can be reduced by ECCM in the tracker. However, because very accurate tracking of both target and missile are required for success, a slight disturbance of tracking will defeat the system.

26. **Command Full-Lead**. Here the computer, knowing the target track and the missile characteristics, calculates an intercept point ahead of the target and commands the missile on virtually a straight line to the intercept point. The computer has predicted the correct lead-angle for intercept and the process is similar to that involved in ‘deflection shooting’ where the shooter doses not aim at a moving target but at the correct distance ahead of it. This is the best missile trajectory for the earliest possible

target intercept, which is why it is used in ABM systems (Anti Ballistic Missiles) so that the incoming nuclear warhead can be destroyed before it is closed enough to do any damage. However, depending on target geometry, it may be that 2 separate trackers are required, one for the target, one for the missile. This can be expensive so cheaper trajectories may be used.

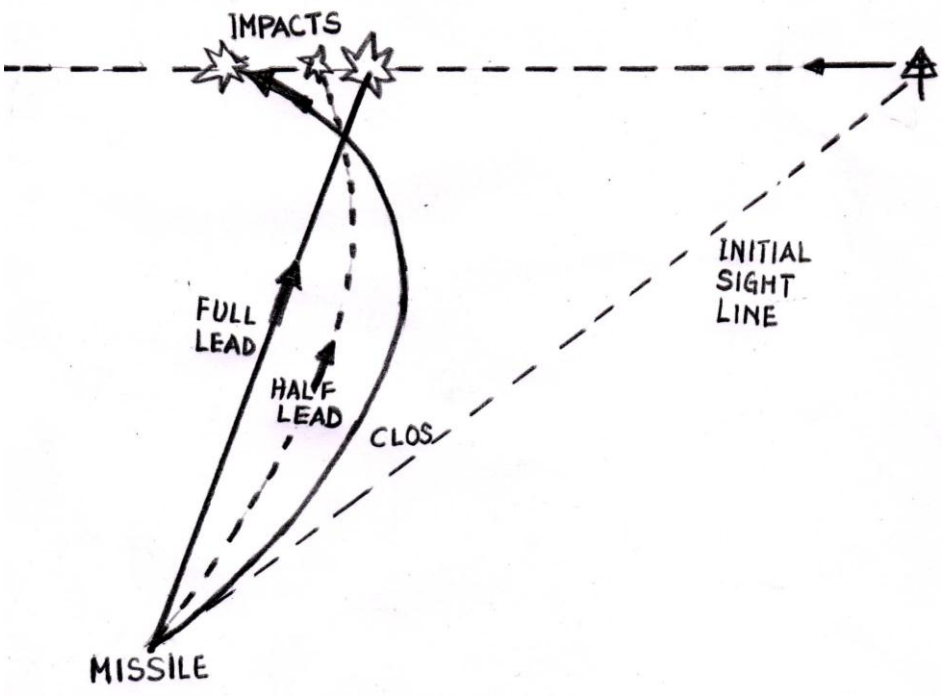


Figure 3.13: Variations of Command Trajectories

27. **Command to Line-of- Sight (CLOS)**. Here the computer generates no lead angle at all on the target but simply commands the missile directly to the target as the target is tracked across the missile engagement zone. This is sometimes also called ‘three point guidance’ because the target, missile and tracker are all in a line until intercept. The tracker is often called a ‘Differential Tracker’ because its function is solely to detect small differentials between missile and target sight line so that the missile can be commanded to reduce the differential to zero.

28. **Partial-Lead Solutions**. Between the extreme cases of full-lead and no-lead (CLOS)predictions, a computer in a command system can generate any other trajectory but if the advantages of full-lead is the earliest intercept, and that of no-lead is having a single simple differential tracker, have partial lead solutions any advantages? If we want to limit ourselves on grounds of cost to a single tracker, but we want to employ a better trajectory than CLOS, we can do this if our tracker is capable of scanning both target and missile. Tracker-while-Scan (TWS) radar is an example. So if we employ one wide-beam tracker, our computer could, for instant generate a ‘Command Half-Lead’ trajectory, as long as this kept missile and target in scan. Sometimes the term COLS is used, meaning ‘Command off the Line-of-Sight’ and this refers to all command system with an element of lead in their trajectories.

Summary of Missile Guidance Systems

29. Various guidance systems are summarized in the following table:

Type	Methods of Navigation	Sensing Devices	Characteristics
Active Homing	1. Proportional Navigation 2. Pure pursuit 3. Deviated pursuit	1. Radar 2. Infrared 3. Imaging Infrared 4. Laser 5. TV	Ground system not committed to single target. Very expensive missile.
Semi-active Homing	1. Proportional Navigation 2. Pure Pursuit 3. Deviated pursuit	1. Radar 2. Infrared 3. Imaging Infrared 4. TV 5. Laser	Ground system committed to single target until Intercept takes place.
Passive Homing	1. Proportional Navigation 2. Pure Pursuit 3. Deviated pursuit	1. Infrared 2. Visible Light 3. Electro Magnetic Energy	Ground system not committed to single target. All sensing devices have limited capability compared with radar.
Command	Any Method	1. Radar 2. Infrared 3. Visible Light	Ground system committed to single target. Missile dynamically linked to ground system. Ground computer required for programmed flight. Low-cost missile.
Beam Rider (or CLOS)	1. Line-of-Sight 2. Programmed 3. Deviated pursuit	1. Radar 2. Infrared 3. Visible Light	Same as Command

Table 3.1: Summary of various Guidance Systems

CHAPTER –X

AIR DEFENCE BATTLE PLAN

Training Objective. On completion of this chapter the student will know about various aspects for Air Defence Operations.

Aspects covered in Typical AD Plan

1. **AD Asset Deployment Plan**.

a. **Fighter Interceptor Deployment Plan**. Fighter interceptors are the most flexible weapons among all the AD weapons. Due to their armament capability, speed and the ability to engage multiple targets, interceptors are the first choice of any Air Defence Commander. Air Defence Commander allocates aircraft to ADOC depending on threat and availability of resources to fight the war. ADOC exercises the operational control over these allotted interceptors.

b. **AD Radar Deployment Plan**. This plan covers all AD radars deployed in different place of a country. It covers detection range, HL and LL pick up. Radars are deployed at suitable locations to detect all airborne objects within the area of responsibility and to conduct interceptions or provide early warning.

c. **AD Arty Deployment Plan**. AD Arty in short AAA are deployed in such a way that it gives optimum deterrence to attackers. It is normally planned around VAs and VPs. After analyzing the likely air threat it is decided what number of VPs/VAs require AD protection. Considering the existing weapon capability and the importance of VAs/VPs the necessity of medium/light AD guns are planned.

d. **SAM Deployment Plan**. SAMs are deployed in such a way that it gives medium and long range deterrence to attackers. For area defence, it requires long and medium range SAMs. For point defence the shoulder launched SAMs are deployed in each VP.

2. **Air Defence Management Plan**. Air Defence Management Plan is made for the total management and control of air defence assets, and control & effective use of Air Space of a country to facilitate smooth conduct of air defence battle. Important aspects of the plan are:

a. **Air Defence Identification Zone (ADIZ)**. The responsibility of exercising overall airspace control during war is vested on Airspace Control Cell located at ADOC. This Control Cell issues airspace control order during war or emergency. It also circulates necessary amendments on the issued order as and when required. *For an example*, if considered, whole airspace or portion of BLUE Land is bounded by enemy country RED Land's international boundary and entire airspace of BLUE Land is declared ADIZ. As such, for entering into Blue Land's airspace, all international flights need to get AD clearance, a specified time like 5 minutes before touching the ADIZ. Air space control cell enforces ADIZ and ensures following actions:

(1) ATCO co-ordinates with civil aviation for promulgating and issuance of instructions on ADIZ.

(2) AD network including radar and ADA will go for round the clock op.

(3) Issue air defence clearance number for any aircraft entering into own airspace.

(4) All allied military aircrafts those need to cross international territory are to be fitted with IFF.

(5) Allied military ac crossing and returning through border during the period of tension switches on IFF 10 nm away from the border.

b. **Identification Criteria**. Identification is based on IFF, intelligence information, available flight plan etc. Effective identification is required to avoid fratricidal attack by AAA or SAM. *For example*, if ac approaching from the RL to BL airspace needs identification by ADOC as Hostile (H) track except recovery of own fighter aircrafts returning from attack mission.

c. **Scramble Procedures**. Scramble is the order to direct the interceptors to take off for intercepting the enemy aircraft. All scramble orders are passed from ADOC or SOC. Interceptors are kept at various alert states on ground. The state of Readiness is directed by:

(1) Current Intelligence

(2) Early warning capability

(3) Number of Hostile ac movements inside the country.

(4) Number of interceptors available.

Various States of Readiness are:

Alertness	Allotted Time	Meaning
Standby-1	2 min	This is cockpit S/By. After scramble order, interceptors are ready to be airborne within 2 minutes
Standby-II	3 min	After scramble order, interceptors are ready to be airborne within 3 minutes
Readiness-I	10 min	After scramble order, interceptors are ready to be airborne within 10 minutes
Readiness-II	30 min	After scramble order, interceptors are ready to be airborne within 30 minutes

After the scramble order from ADOC, GCI controllers at radar unit carry out the interceptions. AD ac can also be diverted from CAP.

d. **CAP Plan/ Procedures**. CAP means Combat Air Patrol. It augments the readiness of interceptor fighter and remains under close control of radar stations. CAP is planned when:

(1) Defence in depth of the country is less.

(2) Early warning of enemy ac is limited.

(3) When intelligence information is received about possible enemy air attack.

(3) When important ground, naval or air operation is taking place which must be protected from enemy air attack.

e. **CAP Position**. CAP positions are pre-planned and normally kept:

(1) Outside the Gun Defended Area.

(2) Close to possible target approach area.

(3) Close to enemy aircraft's exit routes.

f. **Issue of Gun Control Order (GCO)**. During the chase on a raid approaching to VP or Gun Defended Area (GDA), the controlling radar station warns the interceptor about the GDA. If the interceptor pilot is ready to destroy enemy ac, he continues giving a call to the controlling radar. Otherwise, pilot breaks away avoiding GDA. In both the cases, ADOC issues appropriate Gun Control Order.

g. **Combat Actions During Engagement**. ADA ac are fitted with weapons during deployment. Actions during engagement or ROE both by the Interceptors and GCI stations are as per order issued by the authority. *For Example*;

(1). Scramble ac are to approach the target in pairs and take actions as per SOP for ID pass or force land or further action.

(2). Before approaching a target close to the border, the pilot and the radar controllers must be careful about the possible presence of other enemy aircraft within the vicinity.

Airspace Management Plan

3. Having discussed on AD assets deployment and management plan, it is now required to ensure safe, well-coordinated and effective use of air space. In simple language we can say, Airspace Management means the optimum utilization of limited airspace. As per the concept of 'ICAO', the objective of Airspace Management is to maximize, within a given airspace structure, the utilization of available airspace by dynamic time-sharing and, at times, segregation of airspace among various categories of users based on short-term needs. Therefore, to ensure effective management of airspace, Airspace Control Order is promulgated**.**

4. **Airspace Control Order (ACO)**. Airspace Control Order is the measures taken to implement the control of airspace. It is in fact division of airspace to carry out designated operation smoothly. It allows maximum scope for correct identification of each traffic and engaging threat, avoiding fratricidal incidents. *Primary aim* of ACO is to maximize the effectiveness of military operation with minimum mutual interference and undue restriction. Now, before explaining the aspects of Airspace Control Order, it is necessary to explain the classes of AD Artillery.

5. **Classes of AD Arty**. AD Artillery is classified into three groups to indicate restriction on different aircraft to a particular area, like;

a. ADA Class A indicates an area prohibited to friendly ac.

b. ADA class B indicates an area is restricted, which is normally enforced on the move of friendly ac and fire of LAA arty.

c. ADA class C which is completely free area having freedom of action for friendly aircraft movement.

6. **Aspects of Air Space Control Order**.

a. Base Defence Zones (BDZ).

b. Weapons Free Zone (WFZ).

c. High Density Airspace Control Zone (HIDACZ).

d. Special Air Defence Zone (SADZ).

e. Fighter Engagement Zone (FEZ).

f. Air Routes.

g. Low Level Transit Route (LLTR).

h. IFF switch on/off Lines.

j. Restricted Operation Zones (ROZ).

k. Missile Engagement Zones (MEZ).

l. Emission Control (EMCON).

Conclusion

7. Lastly, Air Defence Battle Plan is prepared for judicious and effective use of air assets i.e. Interceptor Fighter, SAM and Artillery Gun etc. Air Defense radar net reports enemy aircraft and guides friendly fighter to intercept enemy. Since attack aircraft, own Ground Based Air Defence weapon and civil traffic operate together, so to make the effective, well-coordinated and controlled use, Airspace Control Order is promulgated.

CHAPTER XI

GENERAL TRAINING

Training Objectives. At the end of this chapter the student should know the requirement of collective and individual training for ADWC officer.

Introduction

1. The introduction of modern air defence system has been achieved. Extended range and supersonic performance is now available to our interceptors. The kill probability of new armament has increased tremendously. To exploit those improved elements of the air defence organization, it is essential that the personnel serving in the system must have the highest level of individual and team skills. To achieve a high standard and to keep abreast of the latest developments, every individual in the air defence system is to work hard all through his career to gain more and more knowledge as he works in the system. Continuation training programme is, therefore, a requirement.

Training Requirement

2. **Collective Training**. To have an effective air defence organization all components of the system are to be equally efficient. Operational training, therefore, is to be oriented towards a collective training of the system so that the team proficiencies, essential to the conduct of the air battle, are maintained at the highest level. In working towards these goals, frequent exercises are to be conducted per quarter. Each problem is designed to exercise all elements of the air defence system and the techniques and procedures associated with them. One exercise per quarter is to be planned to near saturation condition. The degree of saturation is to be measured against the capabilities of the sector concerned and increased as proficiency increases. Exercises are to be planned to represent the threat predicted for the particular sector. All variations of bomber penetration such as multiple targets, high, medium and low altitude penetration are to be included. As proficiency is attained, complexity is to be increased to include, evasive actions and electronic counter measures (ECM). It is realised that internal target and other resources will vary and, at times, it might be difficult to achieve the objectives outlined above. Nevertheless, it is expected that all resources are to be exploited to the fullest to meet the collective training requirements.

3. **Individual Training**. The detailed individual training requirements and guidance contained in AFM355-2 cover three general phases of training, ie continuation training, combat crew training and training for the maintenance of skill and proficiency of qualified combat-ready crews. The first two represent mandatory requirements. These are established and designed for the purpose of standardizing the procedures and methods. The third phase is offered as a guide only.

Reference:

1. AFM 355-2, Vol-I

CHAPTER XII

EXERCISE TRAINING

Training Objectives. At the end of this chapter the student should know the procedure of conducting air defence exercises, different stages of it and its importance.

Introduction

1. In consideration of the fact that air defence exercise is the most valuable means available for training the personnel of air defence system, it has become necessary to advise and set forth a few ideas and ground rules, whereby maximum value may be derived from those exercises. This also necessitates the requirement of a report from which the entire air defence system will benefit.

Stages of Exercise

2. The air defence exercise is divided into three definite stages viz planning, execution and analysis.

3. **Planning**. The planning stage of the exercise is to be well organised to obtain maximum training benefit. This is to be derived only when the aggressor force is complicated and intricate. All efforts are, therefore, to be made to avoid exercise becoming stereo type. In other words, each exercise is to be planned so that the routes and target system are different from the previous. The specific agency to plan the exercise is to be one that is not to be involved in the execution but is thoroughly familiar with the air defence system. Since the training philosophy permits the Air Defence Commander to train according to the situation, it is quite difficult to lay down rules and requirements for the quality and quantity of exercises. Even so, it is quite evident that aggressor forces need to be of such a nature that all components of the system are exercised to get maximum benefit. This will require the following types of targets and tactics:

a. High-altitude target above 40,000 feet to train aircrew and controller in the air mass problem at high altitude.

b. Low level target to train the pilots, controllers and wireless observer units.

c. Force packaging, ie bombers and fighters, bomber escorted by Fighter should be practiced.

d. To conduct effective ECM training, all resources at the disposal of the commander need to be utilised to the fullest extent.

e. Communication jamming such as “Keying the mike” and misdirection should be encouraged.

f. The requirement for high and low target do not preclude staging target at all altitude to exercise the height finding ability of the radar unit.

g. Splitting and merging target to exercise raid assessment and surveillance of the system.

h. In any event, it is necessary for the aggressor forces to think like the enemy pilots.

4. **Execution**. Due to the complexities and differences in the various air defence problems, this subject makes no attempt to lay down hard and fast rules on the conduct of the battle. Decision and weapon assignment are a matter of judgment by the controllers. These take into consideration the raid assessment and available defensive forces. The place, time and tactical action required will depend on many variables.

5. **Analysis**. In order to learn the shortcomings and correct the mistakes, it will be necessary to analyse the result of each exercise, it will be necessary to analyse the results of each exercise. The analysis is to cover the target force, actions taken, results, new procedures or techniques required to better the system andto remove inadequacies with suggested improvements. To give a wider publicity and to provide benefit to the whole of the air defence system a Tactical Training Report (TTR) is to be prepared by the ADOC after every reportable ADEX. This report is to reflect training accomplishments and shortcomings, if any. The report is to be submitted to the Dte of Air Def, Air Headquarters through normal channel, within fifteen days of the end of the ADEX.

Reportable Air Defence Exercise

6. A reportable air defence exercise is to be designed to:

a. Employ at least 50 percent of the assigned tactical units normally available for air defence operations.

b. Last at least 12 hours.

c. Represent the probable threat and be of magnitude to exercise the combat capability of the participating units.

Reference:

1. AFM 355-2, Vol-I

CHAPTER XIII

AIR DEFENCE TACTICAL EVALUATION PROGRAMME

Training Objectives. At the end of the lesson the student should know:

a. The purpose of Tactical Evaluation.

b. Composition of Tactical Evaluation Team.

c. Function of the Evaluation Team and how it is done.

Introduction

1. This chapter will establish the means for assessing the combat capability of operational units and personnel in the air defence organisation. It provides a system for evaluating the validity of the tactics and techniques employed, and in consequence, the validity of the current training programme. The resultant experience will provide the basis for continuous modernisation of the air defence tactics and training directives from which the teaching of up-to-date procedures may be imparted. Directives covering interceptor and ground environment, tactics and training are to be prepared and published only by Air Headquarters. Sub-ordinate commanders, however, are encouraged to develop new tactics and procedures and recommend them, through proper channel, to Air Headquarters for consideration. Recommended changes are not to be implemented until approved for publication by Air Headquarters. This chapter is applicable to the following:

a. Tactical evaluation teams.

b. Interceptor aircrews and controllers assigned to the air defence system.

c. Operational organizations directly affecting the combat capability of the air defence system.

Definitions

2. For the purpose of this directive the following definitions will apply:

a. **Tactical Evaluation**. Tactical evaluation is a periodic and practical assessment by the tactical evaluation team of the selected units and individuals in their capabilities of accomplishing the air defence mission. The object of this evaluation is to:

(1) Assess the overall state of readiness of personnel of the tactical units and the air defence system of Bangladesh.

(2) Assess the proficiency of aircrews and interceptor controllers in the air defence tactics and operational procedures through written examination, check flights and interception control missions.

(3) Demonstrate and teach through discussion and active participation, the current air defence operational tactics and techniques.

(4) Assess the validity of the current tactics and techniques and the adequacy of the air defence training programme.

b. **Tactical Evaluation Team**. A group of experience interception controllers, aircrew and other officers appointed for the purpose of evaluating the air defence system.

Composition of the Tactical Evaluation Team

3. Team is to be appointed by Air Defence Headquarters and is to consist of:

a. ADWC Officer experienced in all levels of air defence organisation.

b. Pilot qualified on the type of interceptor aircraft in use.

c. A C&E Officer experienced in air defence radars in use.

d. Aircraft maintenance officer.

Responsibilities and Functions of the Evaluation Team

4. The tactical evaluation team is to be responsible for:

a. Evaluating the combat capability of operational units and personnel.

b. Evaluating the effectiveness of training and tactics and recommending changes as needed.

c. Standardising and evaluating procedures for tactical operations and inspections.

d. Ensuring that all tactical personnel are capable of employing the tactics effectively for air defence.

e. Improving the efficiency of operations and flying safety.

Procedure for the Conduct of Tactical Evaluations

5. **Air Defence System**. This evaluation is to check the procedures used and efficiency of the air defence system. The current operational capability of the system is to be tested under as realistic conditions as possible. Special emphasis are to be placed on locating strengths and weaknesses and in making constructive recommendations for the improvement.

6. **Fighter Interceptor Squadrons**.

a. **Squadron Operations**. An evaluation is to be made of the overall operations and performance. All functions are to be checked. Reports are to include complete analysis of the organisations, operations, training, maintenance and safety and discipline. An estimate of the combat capability is to be made based on the findings of the team.

b. **Aircrew Flight Check**. The flight check of an aircrew tactical evaluation is to consist of a profile interception mission terminating with a let-down. Success criteria are to be as prescribed for the applicable aircraft in a profile sortie. If safety considerations require break-off, credit for the successful attack would be given if the prior steering shows that the attack would have been successful. An assessment form is to be completed for each tactical evaluation flight accomplished. Scores will be awarded for major headings considering the sub-items listed under each major headings. Minimum scores for different grading are as follows:

(1)	Expert or upgrading to Expert	90%
(2)	Skilled or upgrading to Skilled	75%
(3)	Qualified or upgrading to "Combat Ready"	60%

c. **Aircrew Written Examination**. The written portion of the tactical evaluation is to consist of the 35 questions from the flying regulation and manuals and 15 questions on the aircraft and the fire control system. Minimum scores are:

(1)	Expert or upgrading to Expert	90%
(2)	Skilled or upgrading to Skilled	75%
(3)	Qualified or upgrading to Combat Ready	60%

d. **Grading System**. The final grading of the pilot will depend on the minimum scores secured either in the flight check or in the written examination. Combat Ready or higher crew will be tested once every 6 months

7. **ADWC Units**

a. **Unit Operations**. This evaluation will test the overall combat capability of the Unit. All functions should be monitored. Reports should include complete analysis of organization, operations, training, maintenance, safety and discipline.

b. **Interceptor Controller**. The evaluation of interceptor controller is to cover the following and the result will be recorded on a specified form:

(1) Actual interception using standard tactics.

(2) The evaluator will identify the target but will give no further target information to the controller.

(3) The interceptor controller will advise the evaluator of the type of attack and final attack heading prior to giving final turn to the pilot.

(4) Since the duty interceptor controller does not normally perform scrambles or recoveries, the evaluator will test the controller verbally on these points.

c. **Written Examination**. The written examination includes at least 25 questions on general knowledge of the system, 15 questions on tactics and 15 questions on the performance of interceptor aircraft and fire control system.

d. **Grading System**. The final grading of the controller depends on the minimum score secured either in interception controlling or in written examination. A certificate about the final grading of the controllers is to be signed by the evaluator and pasted in the Fighter Controller's Log Book against the appropriate column on page 5 of the log book. The system of grading for the interception and written examination is as follows:

(1)	Expert or upgrading to Expert	-	80%
(2)	Skilled or upgrading to Skilled	-	70%
(3)	Combat Ready	-	60%

e. **Action in the case of Failure**. If a combat ready intercept controller fails to obtain the score of at least 60% on the written examination, or on the GCI evaluation, he is to revert to training status. A maximum of 90 days additional training is to be provided before his next evaluation. If the controller fails in his second test, the unit commander is to recommend to Air Headquarters within 10 days of his failure, for the retention or reassignment of the officer to other duties.

8. **ADOC/SOC**. The evaluation team is to test the ability of the ADOC/SOC to receive and display information in order that the commander and battle staff is able to take proper and timely decisions. The team will evaluate the performance during ADEX or in periods of intense flying activities. Individual proficiency as well as the ability of the battle-staff to function as a well-drilled team will be the focus of the evaluation.

CHAPTER XIV

INTERCEPTOR CONTROLLER/AIRCREW CROSS TRAINING

Training Objectives. At the end of this chapter the student should know the cross training requirements for the interceptor aircrew and controllers.

Introduction

1. The need for close co-operation and co-ordination between fighter interceptor aircrew and the interception controller cannot be over emphasized. Each is dependent on the other for the successful completion of the air defence mission. A mutual understanding of each other's duties, tactics, procedures and responsibilities is therefore, essential. This chapter, therefore, lays down the cross training requirement for the interceptor aircrew and controllers.

Cross Training Requirements

2. **Interceptor Aircrew**. At least once in every six month, each aircrew is to spend at least two days covering a radar unit, ADOC/FCTU. A definite training programme is to be established to ensure that the visiting aircrew derive maximum benefit from the cross training visit. Training programme is to include, but not be limited, to the following:

a. Capabilities and limitations of radar equipment in control operations, fighter recovery and navigational assistance to aircraft.

b. Air and ground communications network in relation to the air defence units.

c. Interception tactics and techniques, including air mass problems and broadcast control.

d. Actual participation in a minimum of one synthetic and one actual interception. In the event interceptors/or targets are not available a minimum of two synthetic interceptions are to be accomplished.

e. Discussion of training problems and limitation.

3. **Interception Controller**. At least once in every six month, each interception controller is to spend at least two days with a fighter interceptor squadron. The squadron is to explain and provide the following facilities for the visiting interception controller:

a. Briefing on aircrew training requirements established by the Air Headquarters. This is to include the importance of the GCI towards the accomplishment of the squadron training.

b. Requirements necessary for the interceptor pilot to attain “Combat Ready”, “Skilled” and “Expert” grading.

c. Performance data of Interceptor aircraft to include combat radius, combat ceiling, rate of climb and maximum speed under all configurations.

d. Capabilities and limitations of airborne radar (AI) equipment under normal and ECM conditions.

e. General capabilities of pilots to convert poor positioning into a successful interception and the importance of maintaining close control until a pilot has called “Judy”.

f. Procedures employed by fighter interceptor squadron during air defence exercises.

g. A visit to the Operational Readiness Platform and to observe actual or practice scramble.

h. Actual flight in a target aircraft when practicable.

j. Arrange to attend a flight briefing and debriefing conducted for an interception mission.

CHAPTER XV

INTERCEPTION TRAINING

Training Objective. At the end of this chapter the student should know how to execute interception training considering safety.

Introduction

1. The purpose of this section is to outline the requirements for the safe conduct of interception training. In the interest of safety the qualifications and proficiency of aircrews, controllers and target pilots are to be carefully considered. This chapter will apply to all ground environment, fighter units and target crews engaged in radar interception training missions.

Requirements

2. **Interceptor and Target Aircraft**. The following requirements are to be met by the interceptor and target aircraft during all interception training missions.

a. Interceptors are to have fully operational fire control systems and two-way radio communications. Fully operational electronic identification equipment is required only if unable to maintain position by ground contact.

b. Target aircraft are to have fully operational two-way radio communications. Whenever possible comparable size ground attack recee fighter aircraft such as A-5 or L-39 to be used as target. The target aircraft is to be equipped with an artificially augmented radar reflective source.

c. Two-way communication is to be established between attacking interceptor and target aircraft prior to attack. This, however, is not required during an exercise.

3. **Interceptor Controller**.

a. Interceptor controller is to get himself briefed on the following prior to the conduct of interception training:

(1) Weather.

(2) Climb-out.

(3) Interceptor formation.

(4) Communications.

(5) Target information (to include multiple and ECM target conditions).

(6) Tactics.

(7) Break-way.

(8) Re-attack.

(9) Standard and emergency recovery.

(10) Safety responsibilities.

b. Keep aircrew informed of targets that are in close vicinity and could be hazards.

c. Use standard tactics and positioning procedures for the type of aircraft, fire control system and weapons in use, unless briefed otherwise.

d. Break off the AI attack by calling “Skip it” and order to “go visual” when the aircrew has not reported AI contact by:

(1) Four miles during beam to quartering stern attack.

(2) Two miles during quartering stern to stern attack.

e. Conduct a joint debriefing with the aircrew on tactics, techniques and problems encountered at the end of mission, whenever possible.

Special Provisions

4. **Interception of Multiple Targets**. Experience has proved that any time interceptions are conducted against multiple targets, all personnel involved in the operation must be particularly aware of the hazards. All agencies are responsible to minimize the inherent hazards by use of radar and or human “eyes”. During the conduct of the interception the following must be taken into consideration:

a. The interceptor crew must consider all the information available to them, type of targets, position of the sun, restriction to visibility etc.

b. The attack plan that will best assure safe clearance from other aircraft.

c. The target pilot must recognize and avoid unsafe conditions.

d. The interceptor controller must assure that information pertaining to an unsafe condition is disseminated promptly and completely.

e. When an unsafe condition exists, it is incumbent upon all agencies concerned to take positive corrective action.

5. **ECM Interception**. During the conduct of interception training in an ECM condition it must be assumed that the area affected by ECM contains multiple targets. Based on this assumption it is essential that the interceptor crew and/or interception controller attempt to ascertain by means available, the location of targets within the ECM area prior to completing the attack.

CHAPTER XVI

CONTROLLERS' ANNUAL TRAINING PROGRAMME

Training Objectives. At the end of this chapter the student should know:

a. Training programme both academic and interception of a ADWC officer.

b. Fighter controllers' combat status and degree of proficiency.

Introduction

1. This chapter establishes the requirements for the controller's proficiency training programme and incorporates the minimum standards on which these programmes will be based. Training will be established in two stages, viz. academic training and interception training.

Annual Training Programme

2. **Training Responsibility**. A qualified C&R officer who has attained a degree of proficiency of at least "Skilled" and has demonstrated the ability to instruct will be certified as "Instructor Interception Controller" by officer commanding of the unit.

3. **Academic Training**. Each interception controller is to be given 80 hours of academic training each year. This is to be done by group discussion, classroom work or on the job training (OJT). Whenever possible, training is to be programmed to provide 20 hours each quarter. Academic training is to incorporate the following:

a. **Operations**.

(1) Alert and warning.

(2) Operation publication.

(3) Air surveillance procedures.

(4) Future programme.

(5) Movement identification.

(6) Local procedures.

(7) Flight following and emergency procedures.

(8) Scramble and recovery procedures.

b. **Tactics and Techniques**.

(1) Air Mass positioning.

(2) Employment of multiple interceptions.

(3) Control procedures.

(4) Employment of new weapons.

(5) Aircraft performance.

(6) R/T procedures.

c. **Signal**.

(1) Capabilities and limitations.

(2) New equipment.

d. **ECM and ECCM**.

(1) Radar

(2) Radio

e. **Plotting and Display of Information**.

(1) Air surveillance information.

(2) Mission data board.

(3) Status boards.

(4) Plotting board.

f. **Weather**.

(1) Front air mass, thunderstorms, jet streams and winds aloft.

(2) Reporting of scope weather.

(3) Anomalous propagation.

g. **Duties and Responsibilities**.

(1) Air surveillance supervisor.

(2) Floor supervisors.

(3) Scope operators.

(4) Plotters.

(5) Tellers.

(6) Mission data clerk.

(7) Recorders.

(8) Control technician.

4. **Interception Training**. Each interception controller is to complete the number of interceptions, as required below. A certificate indicating the controller's status is to be forwarded to the Air Defence Headquarters at the end of each calendar year:

a. Expert controllers are to conduct at least 110 actual interceptions each year.

b. "Skilled" controllers are to conduct at least 150 actual interceptions each year.

c. "Combat-Ready" controllers are to conduct at least 230 actual interceptions each year.

d. Instructor controllers are to comply with annual interception training requirements as listed in paragraph (a) or (b), as applicable.

5. **Action for Failure**. When an interceptor controller fails to complete his annual academic and interception training, he is to revert to training status, unless otherwise certified by the Officer Commanding of the Unit.

6. **Simulator Training**. This training is intended primarily to familiarise controllers with interception tactics and techniques. It should also be used to develop and maintain proficiency in procedures such as defence against split track, merging track, and evasive action. Each GCI is to establish a simulator training programme as needed to develop proficiency in those aspects which are not normally exercised during actual interception training.

7. **Cross Training**. Cross training is to include but not limited to the following:

a. Air Defence Operations Centre.

b. Associated Radar Station.

c. Associated Fighter Interceptor Squadron as applicable.

Training Records.

8. a. **Interception Training Record**. A monthly record of interception training is to be maintained for each controller in the Fighter Controller's Log Book. When the controller is transferred permanently from the unit, the record is to be brought up-to-date and signed by the OC unit, maintained for each controller in the Fighter Controllers Log Book. A printed Log Book is to be issued to each Fighter Controller, when available. Till such time the GCI stations are to produce copies of pages and maintain the individual record.

b. **Annual Academic Training**. A record of annual academic and cross training is to be kept on a calendar year basis. This is to be reproduced as a chart and displayed in the operations office. The total on the wall chart to be cumulative. Not later than the 10th of each month, a copy of the previous month's record is to be forwarded to the Air Defence Headquarters. This form is to be kept on the file for a minimum of one year.

TOPIC- 4
RADAR TECHNOLOGY

PRINCIPLE AND DESIGN OF RADAR

Training Objectives. At the end of this chapter the student should know the development process of radar and its different characteristics and types.

Introduction

1. Radar is an electromagnetic system for the detection and location of reflecting objects such as aircraft, ships, spacecraft, vehicles, people, and the natural environment. It operates by radiating energy into space and detecting the echo signal reflected from an object, or target. The reflected energy that is returned to the radar not only indicates the presence of a target, but by comparing the received echo signal with the signal that was transmitted, its location can be determined along with other target-related information. Radar can perform its function at long or short distances and under conditions impervious to optical and infrared sensors. It can operate in darkness, haze, fog, rain, and snow. Its ability to measure distance with high accuracy and in all weather is one of its most important attributes.

Principles of Radar

2. The basic principle of radar is illustrated in Figure 17.1. A transmitter (in the upper left portion of the figure) generates an electromagnetic signal (such as a short pulse of sine wave) that is radiated into space by an antenna. A portion of the transmitted energy is intercepted by the target and reradiated in many directions. The re-radiation directed back towards the radar is collected by the radar antenna, which delivers it to a receiver. There it is processed to detect the presence of the target and determine its location. A single antenna is usually used on a time-shared basis for both transmitting and receiving when the radar waveform is a repetitive series of pulses. The range, or distance, to a target is found by measuring the time it takes for the radar signal to travel to the target and return back to the radar. (Radar engineers use the term *range* to mean *distance,* which is not the definition of range found in some dictionaries.) The target's location in angle can be found from the direction the narrow-beam width radar antenna points when the received echo signal is of maximum amplitude. If the target is in motion, there is a shift in the frequency of the echo signal due to the Doppler Effect. This frequency shift is proportional to the velocity of the target relative to the radar (also called the radial velocity). The Doppler frequency shift is widely used in radar as the basis for separating desired moving targets from fixed (unwanted) "clutter" echoes reflected from the natural environment such as land, sea, or rain. Radar can also provide information about the nature of the target being observed.

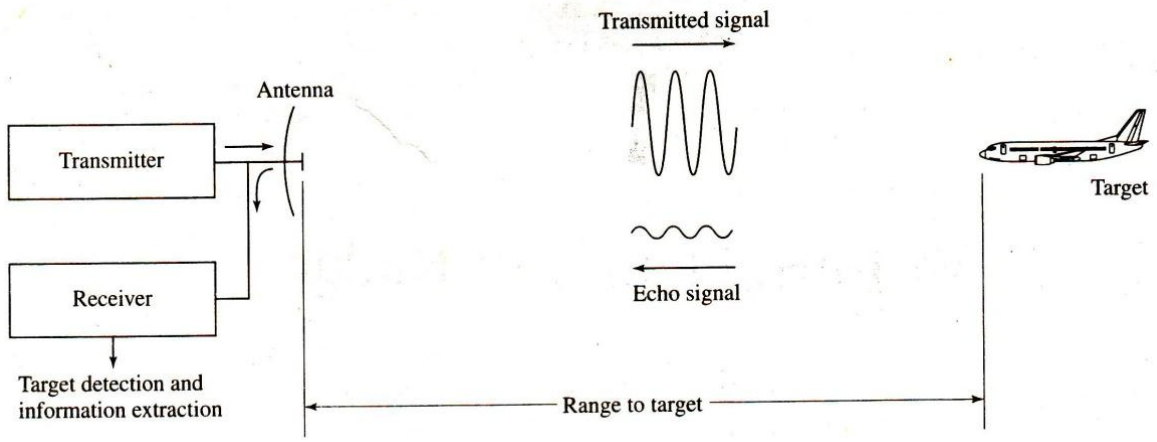


Figure 4.1: Basic Principle of radar

3. The term *radar* is a contraction of the words radio detection and ranging. The name reflects the importance placed by the early workers in this field on the need for a device to detect the presence of a target and to measure its range. Although modern radar can extract more information from a target's echo signal than its range, the measurement of range is still one of its most important functions. There are no competitive techniques that can accurately measure long ranges in both clear and adverse weather as well as can radar.

The Radar Task

4. Radar operation is based on a number of simple principles that have been developed and expanded over the years to produce the sophisticated equipment described in the later chapters. In very basic terms the radar performs the following tasks:

a. Detection of targets by sensing the tiny returning radio echo.

b. Determination of target range by measuring the time taken for radiated pulses of electromagnetic waves to go to and return from the target.

c. Location of the target direction by forming the waves into a narrow beam by use of a suitable antenna so that the direction in which the antenna points gives the target direction.

d. Assessment of target velocity by measuring the change in frequency between the transmitted and received waves, the so-called Doppler Effect.

5. Most modern radars have these features, although the specific application of each technique depends on the intended radar use. In addition, radars can build up further information about the target. For example, techniques exist to examine the target behaviour over a period of time, to create an image of the target, to record the way the target echo changes with time or to measure the echo polarization. Measurement of target characteristics in such ways is an important aspect of current radar systems design. It allows, for example, air defence weapon control radars to possess automatic threat assessment capability, a crucial factor in rapid engagements. As another example, it can allow radar homing seekers in munitions to select optimum aiming points on ground

targets to maximize kill probability. The improvement of existing methods, and the search for new ways to locate and identify targets, occupies an increasing part of today's radar designer's task.

Description of Radar

6. The basic concept of radar is relatively simple even though in many instances its practical implementation is not. Radar operates by radiating electromagnetic energy and detecting the echo returned from reflecting objects (targets). The nature of the echo signal provides information about the target. The range, or distance, to the target is found from the time it takes for the radiated energy to travel to the target and back. The angular location of the target is found with a directive antenna (one with a narrow beam width) to sense the angle of arrival of the echo signal. If the target is moving, radar can derive its track, or trajectory, and predict the future location. The shift in frequency of the received echo signal due to the Doppler effect caused by a moving target allows a radar to separate desired moving targets (such as aircraft) from undesired stationary targets (such as land and sea clutter) even though the stationary echo signal may be many orders of magnitude greater than the moving target. With sufficiently high resolution, radar can discern something about the nature of a target's size and shape. Radar resolution may be obtained in range or angle, or both. Range resolution requires large bandwidth. Angle resolution requires (electrically) large antennas. Resolution in the cross-range dimension is usually not as good as the resolution that can be obtained in range. However, when there is relative motion between the individual parts of a target and the radar, it is possible to use the inherent resolution in Doppler frequency to resolve in the cross-range dimension. The cross-range resolution of a synthetic aperture radar (SAR) for imaging a scene such as terrain can be explained as being due to resolution in Doppler, although a SAR is usually thought of as generating a large "synthetic" antenna by storing received signals in a memory. The two views-Doppler resolution and synthetic antenna-are equivalent. Resolution in the Doppler domain is a natural way to envision the cross-range resolution achieved by the inverse synthetic aperture radar (ISAR) used for the imaging of a target.

7. Radar is an active device in that it carries its own transmitter and does not depend on ambient radiation, as do most optical and infrared sensors. Radar can detect relatively small targets at near or far distances and can measure their range with precision in all weather, which is its chief advantage when compared with other sensors.

8. The principle of radar has been applied from frequencies of a few megahertz (HF, or high-frequency region of the electromagnetic spectrum) to well beyond the optical region (laser radar). This is a frequency extent of about 1 billion to 1. The particular techniques for implementing radar differ greatly over this range of frequencies, but the basic principles remain the same.

9. Radar was originally developed to satisfy the needs of the military for surveillance and weapon control. Military applications have funded much of the development of its technology. However, radar has seen significant civil applications for the safe travel of aircraft, ships, and spacecraft; the remote sensing of the environment, especially the weather; and law enforcement and many other applications.

10. **Radar Block Diagram.** The basic parts of a radar system are illustrated in the simple block diagram of Figure 17.2. The radar signal, usually a repetitive train of short pulses, is generated by the transmitter and radiated into space by the antenna. The duplexer permits a single antenna to be time-shared for both transmission and reception. Reflecting objects (targets) intercept and reradiate a portion of the radar signal, a small amount of which is returned in the direction of the radar. The returned echo signal is collected by the radar antenna and amplified by the receiver. If the output of the radar receiver is sufficiently large, detection of a target is said to occur. Radar generally determines the location of a target in range and angle, but the echo signal also can provide information about the nature of the target. The output of the receiver may be presented on a display to an operator who makes the decision as to whether or not a target is present, or the receiver output can be processed by electronic means to automatically recognize the presence of a target and to establish a track of the target from detections made over a period of time. With automatic detection and track (ADT) the operator usually is presented with the processed target track rather than the raw radar detections. In some applications, the processed radar output might be used to directly control a system (such as a guided missile) without any operator intervention.

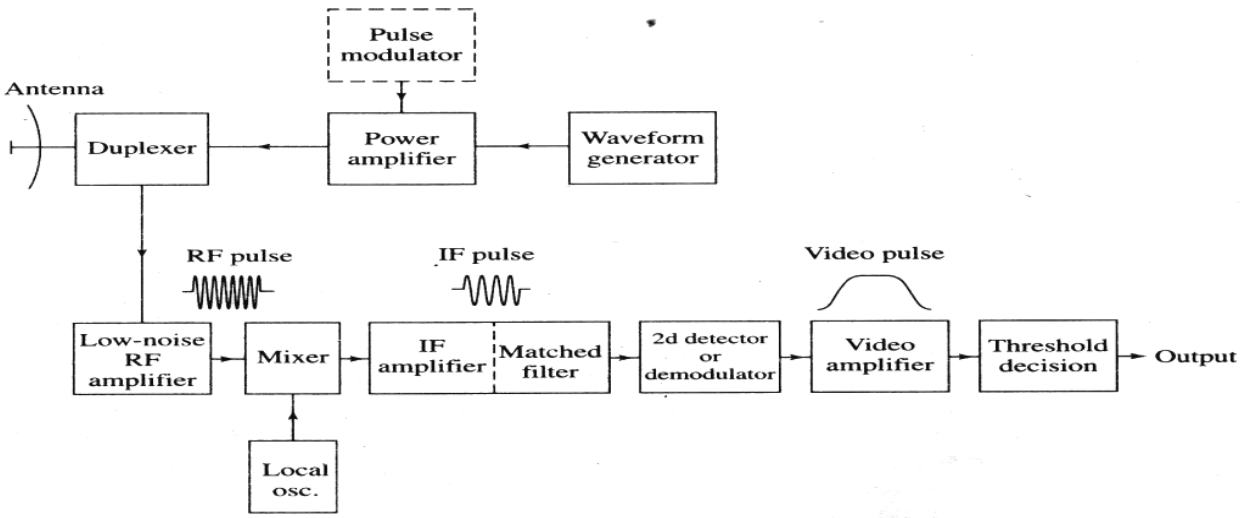


Figure 4.2: Conventional Pulse Radar

11. The operation of Radar is described in more details starting with the transmitter as follows:

a. **Transmitter**.

(1) The transmitter in Figure 17.2 is shown as a power amplifier, such as a klystron, travelling-wave tube, crossed-field amplifier, or solid-state device. A power oscillator such as a magnetron also can be used as the transmitter; but the magnetron usually is of limited average power compared with power amplifiers, especially the klystron, which can produce much larger average power than can a magnetron and is more stable. (It is the *average* power, rather than the *peak* power, which is the measure of the capability of radar.) Since the basic waveform is generated at low power before being delivered to the power amplifier, it is far easier to achieve the special waveforms needed for pulse

compression and for coherent systems such as moving-target indication (MTI) radar and pulse Doppler radar. Although the magnetron oscillator can be used for pulse compression and for MTI, better performance can be obtained with a power amplifier configuration. The magnetron oscillator might be found in systems where simplicity and mobility are important and where high average power, good MTI performance, or pulse compression is not required.

(2) The transmitter of typical ground-based air surveillance radar might have an average power of several kilowatts. Short-range radars might have powers measured in mill watts. Radars for the detection of space objects and HF over-the-horizon radars might have average powers of the order of a megawatt.

(3) The radar equation shows that the range of radar is proportional to the fourth root of the transmitter power. Thus, to double the range requires that the power be increased by 16. This means that there often is a practical, economical limit to the amount of power that should be employed to increase the range of radar.

(4) Transmitters not only must be able to generate high power with stable waveforms, but they must often operate over a wide bandwidth, with high efficiency and with long, trouble-free life.

b. **Duplexer**. The duplexer acts as a rapid switch to protect the receiver from damage when the high-power transmitter is on. On reception, with the transmitter off, the duplexer directs the weak received signal to the receiver rather than to the transmitter. Duplexers generally are some form of gas-discharge device and may be used with solid-state or gas-discharge receiver protectors. A solid-state circulator is sometimes used to provide further isolation between the transmitter and the receiver.

c. **Antenna**.

(1) The transmitter power is radiated into space by a directive antenna which concentrates the energy into a narrow beam. Mechanically steered parabolic reflector antennas and planar phased arrays both find wide application in radar. Electronically steered phased array antennas are also used. The narrow, directive beam that is characteristic of most radar antennas not only concentrates the energy on target but also permits a measurement of the direction to the target. A typical antenna beam width for the detection or tracking of aircraft might be about 1 or 2°. Dedicated tracking radar generally has a symmetrical antenna which radiates a pencil-beam pattern. The usual ground-based air surveillance radar that provides the range and azimuth of a target generally uses a mechanically rotated reflector antenna with a fan-shaped beam, narrow in azimuth and broad in elevation. Airborne radars and surface based 3D air surveillance radars (those that rotate mechanically in azimuth to measure the azimuth angle but use some form of electronic steering or beam forming to obtain the elevation angle) often employ planar array apertures. Mechanical scanning of the radar antenna is usually quite acceptable

for the vast majority of radar applications. When it is necessary to scan the beam more quickly than can be achieved with mechanical scanning and when high cost can be tolerated, the electronically steered phased array antenna can be employed. (Beam steering with electronically steered phased arrays can be accomplished in microseconds or less if necessary.)

(2) The size of a radar antenna depends in part on the frequency, whether the radar is located on the ground or on a moving vehicle, and the environment in which it must operate. The lower the frequency, the easier it is to produce a physically large antenna since the mechanical (and electrical) tolerances are proportional to the wavelength. In the ultrahigh-frequency (UHF) band, *a large* antenna (either reflector or phased array) might have a dimension of 100 ft or more. At the upper microwave frequencies (such as X band), radar antennas greater than 10 or 20 ft in dimension can be considered large. (Larger antennas than the above examples have been built, but they are not the norm.) Although there have been microwave antennas with beam-widths as small as 0.05°, radar antennas rarely have beam-widths less than about 0.2°. This corresponds to an aperture of approximately 300 wavelengths (about 31 ft at X band and about 700 ft at UHF).

d. **Receiver**. The signal collected by the antenna is sent to the receiver, which is almost always of the super-heterodyne type. The receiver serves to (I) separate the desired signal from the ever-present noise and other interfering signals and (2) amplify the signal sufficiently to actuate a display, such as a cathode ray tube, or to allow automatic processing by some form of digital device. At microwave frequencies, the noise at the receiver output is usually that generated by the receiver itself rather than external noise which enters via the antenna. The input stage of the receiver must not introduce excessive noise which would interfere with the signal to be detected. A transistor amplifier as the first stage offers acceptably low noise for many radar applications. A first-stage receiver noise figure might be, typically, I or 2 dB. A low-noise receiver front end (the first stage) is desirable for many civil applications, but in military radars the lowest noise figure attainable might not always be appropriate. In a high-noise environment whether due to unintentional interference or to hostile jamming, radar with a low-noise receiver is more susceptible than one with higher noise figure. Also, a low-noise amplifier as the front end generally will result in the receiver having less dynamic range-something not desirable when faced with hostile electronic countermeasures (ECM) or when the Doppler effect is used to detect small targets in the presence of large clutter. When the disadvantages of a low-noise-figure receiver are to be avoided, the RF amplifier stage is omitted and the mixer stage is employed as the receiver front end. The higher noise figure of the mixer can then be compensated by an equivalent increase in the transmitter power.

e. **Mixer**. The mixer of the super-heterodyne receiver translates the receiver RF signal to an intermediate frequency. The gain of the intermediate frequency (IF) amplifier results in an increase of the receiver signal level.

f. **IF Amplifier**. The IF amplifier also includes the function of the matched filter: one which maximizes the output signal to-noise ratio. Maximizing the signal-to-noise ratio at the output of the IF maximizes the detect ability of the signal. Almost all radars have a receiver which closely approximates the matched filter.

g. **Second Detector**. The second detector in the receiver is an envelope detector which eliminates the IF carrier and passes the modulation envelope. When Doppler processing is employed, as it is in CW (continuous-wave), MTI, and pulse Doppler radars, the envelope detector is replaced by a phase detector which extracts the Doppler frequency by comparison with a reference signal at the transmitted frequency. There must also be included filters for rejecting the stationary clutter and passing the Doppler-frequency-shifted signals from moving targets.

h. **Video Amplifier**. The video amplifier raises the signal power to a level where it is convenient to display the information it contains. As long as the video bandwidth is not less than half of the IF bandwidth, there is no adverse effect on signal detect ability.

j. **Threshold**. A threshold is established at the output of the video amplifier to allow the detection decision to be made. If the receiver output crosses the threshold, a target is said to be present. The decision may be made by an operator, or it might be done with an automatic detector without operator intervention.

k. **Signal Processing**. There has not always been general agreement as to what constitutes the signal-processing portion of the radar, but it is usually considered to be the processing whose purpose is to reject undesired signals (such as clutter) and pass desired signals due to targets. It is performed prior to the threshold detector where the detection decision is made. Signal processing includes the matched filter and the Doppler filters in MTI and pulse Doppler radar. Pulse compression, which is performed before the detection decision is made, is sometimes considered to be signal processing, although it does not fit the definition precisely.

l. **Data Processing**.

(1) This is the processing done after the detection decision has been made. Automatic tracking is the chief example of data processing. Target recognition is another example. It is best to use automatic tracking with good radar that eliminates most of the unwanted signals so that the automatic tracker only has to deal with desired target defections and not undesired clutter. When radar cannot eliminate all nuisance echoes, a means to maintain a constant false-alarm rate (CFAR) at the input to the tracker is necessary.

(2) The CFAR portion of the receiver is usually found just before the detection decision is made. It is required to maintain the false-alarm rate constant as the clutter and/or noise background varies. Its purpose is to prevent the automatic tracker from being overloaded with extraneous echoes. It senses the magnitude of the radar echoes from noise or

clutter in the near vicinity of the target and uses this information to establish a threshold so that the noise or clutter echoes are rejected at the threshold and not confused as targets by the automatic tracker.

(3) Unfortunately, CFAR reduces the probability of detection. It also results in a loss in signal-to-noise ratio, and it degrades the range resolution. CFAR or its equivalent is necessary when automatic tracking computers cannot handle large numbers of echo signals, but it should be avoided if possible. When an operator is used to make the threshold decision, CFAR is not a necessity as in limited capacity automatic systems because the operator can usually recognize echoes due to clutter or to increased noise (such as jamming) and not confuse them with desired targets.

m. **Displays**. The display for surveillance radar is usually a cathode-ray tube with a PPI (plan position indicator) format. A PPI is an intensity-modulated, map like presentation that provides the target's location in polar coordinates (range and angle). Older radars presented the video output of the receiver (called *raw video)* directly to the display, but more modern radars generally display *processed* video, that is, after processing by the automatic detector or the automatic detector and tracker (ADT). These are sometimes called *cleaned-up displays* since the noise and background clutters are removed.

n. **Radar Control**. Modern radar can operate at different frequencies within its band, with different waveforms and different signal processing, and with different polarizations so as to maximize its performance under different environ-mental conditions. These radar parameters might need to be changed according to the local weather, the clutter environment (which is seldom uniform in azimuth and range), interference to or from other electronic equipment, and (if a military radar) the nature of the hostile ECM environment. The different parameters, optimized for each particular situation, can be programmed into the radar ahead of time in anticipation of the environment, or they can be chosen by an operator in real time according to the observed environmental conditions. On the other hand, *a radar control* can be made to automatically recognize when environmental conditions have changed and automatically select, without the aid of an operator, the proper radar operating parameters to maximize performance.

p. **Waveform**. The most common radar waveform is a repetitive train of short pulses. Other waveforms are used in radar when particular objectives need to be achieved that cannot be accomplished with a pulse train. CW (a continuous sine wave) is employed on some specialized radars for the measurement of radial velocity from the Doppler frequency shift. FM/CW (frequency-modulated CW) is used when range is to be measured with a CW waveform. Pulse compression waveforms are used when the resolution of a short pulse but the energy of a long pulse is desired. MTI radars with low pulse repetition frequencies (PRFs) and pulse Doppler radars with high PRFs often use waveforms with multiple pulse repetition intervals in order to avoid range and/or Doppler ambiguities.

Radar Performance Evaluation

12. The key parameters that allow evaluation of radar performance, comparison between radars and comparison between radars and other surveillance devices, re range capability in varying weather conditions and resolution. The factors that determine these include antenna design, detection methods and frequency of operation. All these aspects are now considered.

13. **Antenna Design**. The radar antenna is an important component that features both in the calculation of radar range and resolution. Antenna performance is mainly characterized by its radiation pattern as shown in Figure 17.3. This represents how much power a transmit antenna projects in a given direction; or, if the same antenna is used as a receiver, the receive sensitivity in that direction. Figure 17.3 shows that the antenna has a well defined main beam and many small side lobes in other directions. The function of the antenna is to project as much of the radar energy in this main beam direction whilst minimizing side lobes.

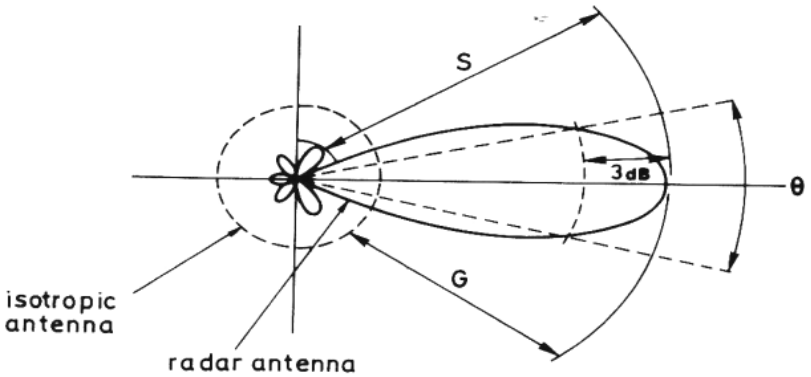


Figure 4.3: Radar Antenna Radiation Pattern
(G is the antenna Gain, θ is the antenna Beam width, S is side lobe level)

14. In practice, antenna may consist of a reflector antenna, an array of small radiators or one of a number of other types occasionally used. The degree to which the antenna concentrates power in a given direction gives rise to the idea of power gain or, more simply, gain. It should be stressed that this is not gain in the sense of amplification as the antenna is a passive device and will always radiate less power than its input due to inherent losses. Gain is defined as the increase in power radiated in the main beam compared to that radiated by a non-directive antenna, fed with the same power. The non-directive radiator is called an isotropic antenna and its radiation pattern, plotted in Figure 17.3 (Radar Antenna Radiation Pattern), is circular. In fact, an isotropic antenna is physically impossible to build but nevertheless forms a useful reference. If gain is given in decibels the unit of gain is dBi, which is dB with respect to isotropic. A decibel is 10 times the logarithm of the quantity considered. In this case if G is the antenna gain with respect to isotropic in numbers the gain in decibels is:

$$G_{db} = 10 \log_{10} (G)$$

Gain for practical radar antennas ranges from a few dBi to 50 to 60 dBi.

15. High gain is advantageous as it increases the amount of power radiated in a

specific direction. High gain also implies large area and this also increases the receive sensitivity in that direction. Both these serve to increase the echo strength and hence enhance the radar range. Power gain, G, is related to antenna size and operating frequency:

$$G = \frac{4\pi A\eta}{\lambda^2}$$

Where *A* is the physical area of the antenna aperture and η is the antenna efficiency. λ is the operating wavelength. The aperture is an imaginary plane at the front face of the antenna. For an array it is the area occupied by the array elements; for a reflector it is the area defined by the reflector rim. This equation is useful for large antennas but is not accurate for dipoles or whips where the aperture cannot be easily defined.

16. Antenna efficiency is determined by a number of factors, including resistive loss, aperture distribution tapering and reflector spill over. Resistive loss occurs when the antenna is made of metal that is not perfectly conducting or contains dielectric material that is not lossless. In general, resistive loss is small, contributing to a few per cent reduction in efficiency. However, in some new printed circuit antennas resistive loss may be significant.

17. **Side lobe**. Aperture distribution tapering is an antenna design technique that allows the side lobes to be reduced so that clutter or jamming outside the main beam can be rejected. Figure 17.3 shows how the side lobe level is defined. In radar antennas it presents the level of the highest side lobe. A highest side lobe level of -40 dB is considered to be good for a large radar antenna. In general, larger antennas will have lower side lobes in the region away from the main beam.

18. To conclude this discussion on antenna gain, Table 17.1 gives an example of an gain calculation.

Antenna diameter	=	1m
Aperture antenna	=	0.78 m^2
Efficiency, η	=	0.6
Wavelength, λ	=	0.03 m
$G = \frac{4\pi A\eta}{\lambda^2}$	=	6580 = 38.2 dBi

Table 4.1: Gain of circular parabolic reflector at 10 GHz

19. **Beam width**. The final antenna parameter, defined in Figure 2-5, is beam width. This is the width of the beam at its half power or -3 dB points. Narrow beam width is an important asset in that it results in good resolution and accuracy. The beam width θ is given by:

$$B = \frac{K\lambda}{a} \text{ radians}$$

Where *a* is the antenna width in the plane in which the beam width is defined, for example, the vertical or horizontal planes. The antenna may have different beam width in these two directions. λ is the wavelength of operation and K is a factor determined by the aperture distribution, given in Table 2.1. It is apparent that as side lobe level is reduced, beam width increases.

20. **Polarisation**. Polarisation of an antenna or electromagnetic wave is another important characteristic. The antenna will radiate or receive electromagnetic waves which are oriented in specific ways. A vertically polarised antenna produces a wave whose electric component vibrates in the vertical plane Figure 17.4. This wave will not be received at all by a horizontally polarised antenna and will only partially be received by a diagonally polarised antenna. For maximum reception antennas should be matched to the incoming wave polarisation. In many radars, linear polarisation, that is horizontal or vertical, is used. In some radar for special roles circular polarisation may be used. Here the wave rotates as it propagates away from the antenna, as in Figure 17.4, and describes a corkscrew motion. As expected, the corkscrew can be left- or right-handed. A left-handed antenna cannot receive right-handed waves and vice-versa. A detail discussion on polarization is made near the end of this chapter.

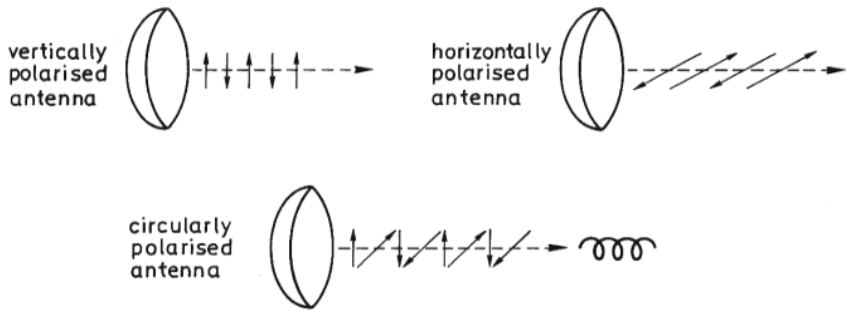


Figure 4.4: Antenna polarization

However, a circularly polarized antenna will receive any orientation of linearly polarised wave but with 3 dB loss of power. Such antennas are especially useful in the electronic warfare field.

21. Some important deductions about antenna design can be drawn from the foregoing:

a. For maximum radar range, gain should be high which implies large antennas.

b. For best resolution, beam width should be small implying large antennas or high frequency operation.

In general a large antenna is contrary to the military requirements for ruggedness, ability and covertness. However, the above performance factors are crucial many of the longer range radars described later have very large antennas.

Radar Equation

22. The radar equation relates the range of radar to the characteristics of the transmitter, receiver, antenna, target, and the environment It is useful not only for determining the maximum range at which a particular radar can detect a target, but it can serve as a means for understanding the factors affecting radar performance. It is also an important tool to aid in radar system design.

23. If the transmitter power P_t, is radiated by an isotropic antenna (one that radiates uniformly in all directions), the *power density* at a distance *R* from the radar is equal to the radiated power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R, or

$$\text{Power density at range } R \text{ from an isotropic antenna} = \frac{P_t}{4\pi R^2} \qquad \ldots\ldots(1)$$

Power density is measured in units of watts per square meter. Radar,, however, employ *directive* antennas (with narrow beam widths) to concentrate the radiated power P_t, in a particular direction. The *gain* of an antenna is a measure of the increased power density radiated in some direction as compared to the power density that would appear in that direction from an isotropic antenna. The maximum gain G of an antenna may be defined as

$$G = \frac{\text{Maximum power density radiated by a directive antenna}}{\text{Power density radiated by a lossless isotropic antenna with the same power input}} \qquad \ldots\ldots(2)$$

The power density at the target from a directive antenna with a transmitting gain G is then

$$\text{Power density at range } R \text{ from a directive antenna} = \frac{P_t.G}{4\pi R^2} \qquad \ldots\ldots\ldots\ (3)$$

24. The target intercepts a portion of the incident energy and reradiates it in various directions. It is only the power density reradiated in the direction of the radar (the echo signal) that is of interest. The *radar cross section of the target* determines the power density returned to the radar for a particular power density incident on the target. It is denoted by σ and is often called, for short, *tar-get cross section, radar cross section,* or simply *cross section.* The radar cross section is defined by the following equation:

$$\text{Reradiated power density back at the radar} = \frac{P_t.G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \qquad \ldots\ldots\ldots(4)$$

The radar cross section has units of area, but it can be misleading to associate the radar cross section directly with the target's physical size. Radar cross section is more dependent on the target's shape than on its physical size.

25. The radar antenna captures a portion of the echo energy incident on it. The power received by the radar is given as the product of the incident power density times the effective area A_e, of the receiving antenna. The effective area is related to the physical area A by the relationship A_e, = $\rho_a A$, where ρ_a= antenna aperture efficiency. The received signal power P_r (watts) is then

$$P_r = \frac{P_t.G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \cdot A_e = \frac{P_t.G A_e \sigma}{(4\pi)^2 R^4} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

26. The maximum range of a radar R_{max} is the distance beyond which the target cannot be detected. It occurs when the received signal power P_r, just equals the minimum detectable signal S_{min}. Substituting S_{min} = P_r and rearranging terms gives

$$R_{max} = \left[\frac{P_t\ G.\ A_e\ \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} \qquad \ldots\ldots\ldots\ldots\ldots\ (6)$$

This is the fundamental form of the *radar range equation.* (It is also called, for simplicity, the *radar equation* or *range equation.)* The important antenna parameters are the transmitting gain and the receiving effective area. The transmitter power P_t, has not been specified as either the average or the peak power. It depends on how S_{min} is defined. In this text, however, P_t, denotes the peak power.

27. If the same antenna is used for both transmitting and receiving, as it usually is in radar, antenna theory gives the relationship between the transmit gain G and the receive effective area A_e as

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \rho_a A}{\lambda^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where λ= wavelength. (Wavelength λ = *c*/f where c = velocity of propagation and, f = frequency.) Equation (7) can be substituted in Equation (6), first for A_e and then for G, to give two other forms of the radar equation

$$R_{max} = \left[\frac{P_t\, G^2 . \lambda^2 . \sigma}{(4\pi)^3 S_{min}}\right]^{1/4} \ldots\ldots\ldots\ldots\ldots(8)$$

$$R_{max} = \left[\frac{P_t\, Ae^2 . \sigma}{(4\pi)^2 . \lambda^2 . S_{min}}\right]^{1/4} \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

These three forms of the radar equations (7), (8), and (9) are basically the same; but there are differences in interpretation. For example, from Equation (8) it might be concluded that the maximum range varies as $\lambda^{\frac{1}{2}}$, but Equation (9) indicates the variation with range as $\lambda^{\frac{-1}{2}}$, which is just the opposite. On the other hand, Equation (7) gives no explicit wavelength dependence for the range. The correct interpretation depends on whether the antenna gain is held constant with change in wavelength, or frequency, as implied by Equation (8); or the effective area is held constant, as implied by Equation (9). For Equation (7) to be independent of frequency, two antennas have to be used. The transmitting antenna has to have a gain independent of wavelength and the receiving antenna has to have an effective aperture independent of wavelength.

28. These simplified versions of the radar equation do not adequately describe the performance of actual radars. Many important factors are not explicitly included. The simple form of the radar range equation predicts too high a value of range, sometimes by a factor of two or more.

Radar Resolution

29. Resolution is defined as the ability to distinguish between two closely spaced targets. The distance between two resolvable targets must be defined in each of the dimensions of measurement, which are typically for a radar, range, azimuth, elevation and velocity.

30. **Range Resolution**. Range resolution is determined by the pulse width. Figure 17.5a shows that if the pulse width is large the returns from the two targets will overlap and hence they will not be resolved. If the pulse were made shorter, as in Figure 17.5b, resolution would take place. The down range distance between targets R_t, is given by:

$$R_t = c\acute{t}/2$$

Where c is the velocity of light. For $\acute{t}$=1 μs, for example, R_t=150 m.

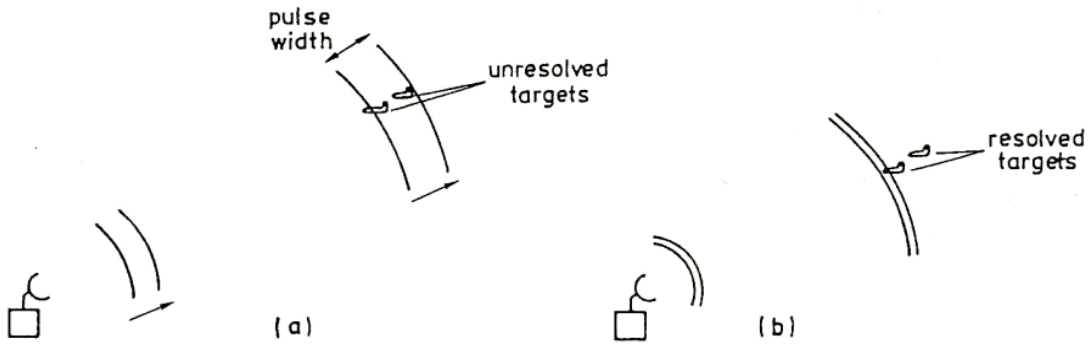


Figure 4.5. (Radar Resolution by pulse width)

31. **Angular Resolution**. The angular resolution in azimuth and elevation is determined by the antenna beam width θ and the range r as shown in Figure 17.6. The targets are just resolved when their cross range distance apart R_θ is given by:

$$R_\theta = r\,\theta$$

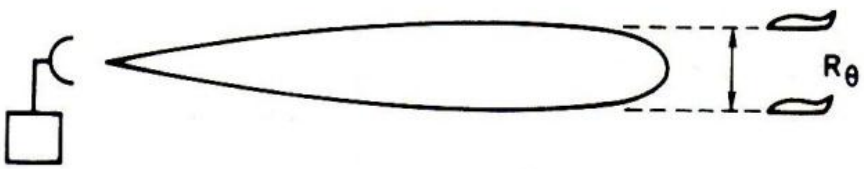


Figure 4.6: Radar resolution by antenna beam width

32. **Velocity Resolution**. The resolution of the velocity measurement is defined as how far apart in speed two targets must be to go into adjacent velocity gates. This is an important method of target discrimination when the targets occupy the same range gate and are not resolved by the antenna beam width. The velocity resolution *R is* dependent on the width of the Doppler filters. The Doppler shift f_D *is* given by $f_D = 2\,v/\lambda$ where λ is the wavelength and v is the radial target velocity. For a Doppler filter of width f Hz, the target velocity difference for resolution R_v is thus given by:

$$R_v = f\lambda/2$$

For $f = 100\ Hz$, R_v = 3 m/s at 10 GHz (λ = 0.03 m).

33. **Radar Accuracy.** Radar accuracy is defined as the difference between a target's actual position or velocity and that indicated by the radar. It is critically dependent

on resolution. It is clear that narrower pulse widths, beam widths and velocity gates can give improved accuracy. As radar measurements are subject to noise-like perturbations, accuracy must be specified statistically. Accuracy is best expressed in terms of the standard deviation, σ_R, of the error in each parameter being measured. Sixty-six per cent of all measurements will be within one standard deviation of the correct result. The accuracy is given by:

$$\sigma_R = CR/\sqrt{S/N}$$

Where C is a constant that depends on the detailed design of the radar. *R* is the resolution in range, angle or velocity. It is thus clear that low errors require mood resolution and a good signal to noise ratio. These two conditions sometimes conflict and require compromise in design. If the above radar has C=1 and S/N = 36, the standard deviation in the range measurement *is 25* m and in angle is 204m.

Choice of Radar Frequency

34. The best radar frequency for any particular application is dependent on a number of factors including both technical and commercial. However, two dominate: atmospheric attenuation and resolution.

35. The radar range equation given earlier includes a loss factor, *L,* to take account of atmospheric loss. It also includes miscellaneous losses in the radar system such as dissipative losses in connecting cables and waveguides and losses due to impedance or polarisation mismatches. In general, radar system losses are kept low by good design and it is atmospheric losses that are most important.

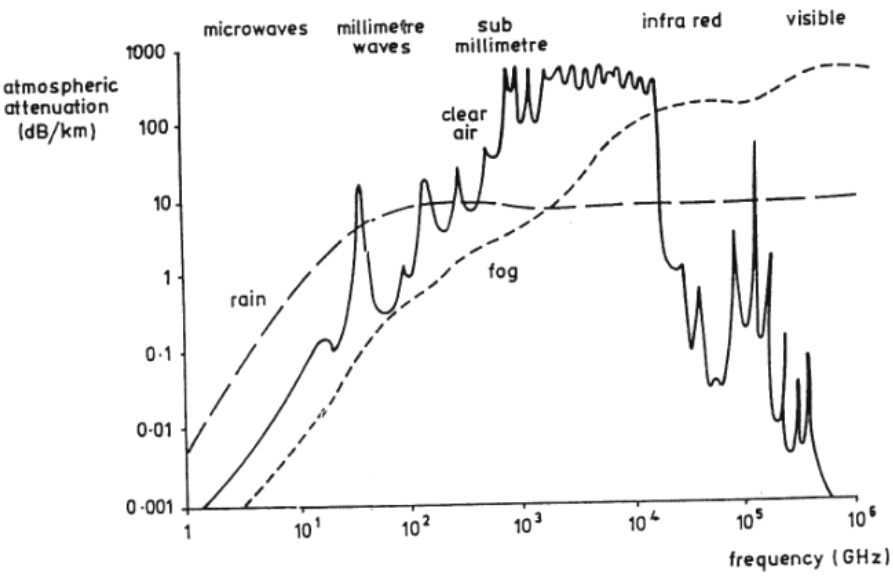


Figure 4.7: Atmospheric attenuation

Figure 1-7 shows how atmospheric attenuation varies with frequency for clear air, rain of 25 mm/hr and fog. The attenuation scale is in decibels per kilometre so that *L* is given by:

$$L = 10^{(2rA/10)}$$

Where r is the radar range in kilometres and A is the atmospheric attenuation in decibels per kilometre.

36. Radar angular resolution, R_θ, is dependent on antenna beam width which is in turn dependent on frequency. The equations given previously can be rearranged to illustrate this:

$$R_\theta = rc/ fa$$

Where r is range, c is the velocity of light, f is frequency and a is antenna size. As frequency increases R_θ, becomes smaller, giving improved resolution and accuracy.

Choice of Frequency	Characteristics
High frequency	• Short range • Good resolution
Low frequency	• Long range • Poor resolution

Table 4.2: Frequency versus Radar Characteristics

Applications of Radar

37. Radar has been employed to detect targets on the ground, on the sea, in the air, in space, and even below ground. The major areas of radar application are briefly described below:

a. **Military**. Radar is an important part of air-defence systems as well as the operation of offensive missiles and other weapons. In air defence it performs the functions of surveillance and weapon control. Surveillance includes target detection, target recognition, target tracking, and designation to a weapon system. Weapon-control radars track targets, direct the weapon to an intercept, and assess the effectiveness of the engagement (called *battle damage assessment). A* missile system might employ radar methods for guidance and fusing of the weapon. High-resolution imaging radars, such as synthetic aperture radar, have been used for reconnaissance purposes and for detecting fixed and moving targets on the battlefield. Many of the civilian applications of radar are also used by the military. The military has been the major user of radar and the major means by which new radar technology has been developed.

b. **Remote Sensing**. All radars are remote sensors; however, this term is used to imply the sensing of the environment. Four important examples of radar remote sensing are (1) weather observation, which is a regular part of TV weather reporting as well as a major input to national weather prediction; (2) planetary observation, such as the mapping of Venus beneath its visually opaque clouds, (3) short-range below-ground probing; and (4) mapping of sea ice to route shipping in an efficient manner.

c. **Air Traffic Control (ATC)**. Radars have been employed around the world to safely control air traffic in the vicinity of airports (Air Surveillance Radar, or ASR), and en route from one airport to another (Air Route Surveillance Radar, or ARSR) as well as ground vehicular traffic and taxiing

aircraft on the ground (Airport Surface Detection Equipment, or ASDE). The ASR also maps regions of rain so that aircraft can be directed around them. There are also radars specifically dedicated to observing weather (including the hazardous downburst) in the vicinity of airports, which are called Terminal Doppler Weather Radar, or TDWR. The Air Traffic Control Radar Beacon System (ATCRBS and Mode-S) widely used for the control of air traffic, although not a radar, originated from military IFF (Identification Friend or Foe) and uses radar-like technology.

d. **Law Enforcement and Highway Safety**. The radar speed meter, familiar to many, is used by police for enforcing speed limits. (A variation is used in sports to measure the speed of a pitched baseball.) Radar has been considered for making vehicles safer by warning of pending collision, actuating the air bag, or warning of obstructions or people behind a vehicle or in the side blind zone. It is also employed for the detection of intruders.

e. **Aircraft Safety and navigation**. The airborne weather-avoidance radar outlines regions of precipitation and dangerous wind shear to allow the pilot to avoid hazardous conditions. Low-flying military aircraft rely on terrain avoidance and terrain following radars to avoid colliding with obstructions or high terrain. Military aircraft employ ground-mapping radars to image a scene. The radio altimeter is also radar used to indicate the height of an aircraft above the terrain and as a part of self-contained guidance systems over land.

f. **Ship Safety**. Radar is found on ships and boats for collision avoidance and to observe navigation buoys, especially when the visibility is poor. Similar shore-based radars are used for surveillance of harbours and river traffic.

g. **Space**. Space vehicles' have used radar for rendezvous and docking, and for landing on the moon. As mentioned, they have been employed for planetary exploration, especially the planet Earth. Large ground-based radars are used for the detection and tracking of satellites and other space objects. The field of radar astronomy using Earth-based systems helped in understanding the nature of meteors, establishing an accurate measurement of the Astronomical Unit (the basic yardstick for measuring distances in the solar system), and observing the moon and nearby planets before adequate space vehicles were available to explore them at close distances.

h. **Other**. Radar has also found application in industry for the no contact measurement of speed and distance. It has been used for oil and gas exploration. Entomologists and ornithologists have applied radar to study the movements of insects and birds, which cannot be easily achieved by other means. Some radar systems are small enough to be held in one's hand. Others are so large that they could occupy several football fields. They have been used at ranges close enough to almost touch the, target and at ranges that reach to the planets.

Polarization

38. Polarization is a property of Electro-magnetic waves that describes the orientation of their oscillations. An Electro-Magnetic wave contains two fields, i.e. electric field and Magnetic field. This Electric field and magnetic field situated in right angle. The electric field or E-plane determines the polarization or orientation of the radio wave. Therefore, the polarization of Electro-Magnetic wave is described by specifying the direction of the wave's electric field.

Types of Polarization

39. The polarizations are classified in to two major categories i.e. Linear and Circular/Elliptical. The linear polarization is again subdivided into vertical and horizontal polarization. The classification of polarization at a glance is shown in figure 17.8.

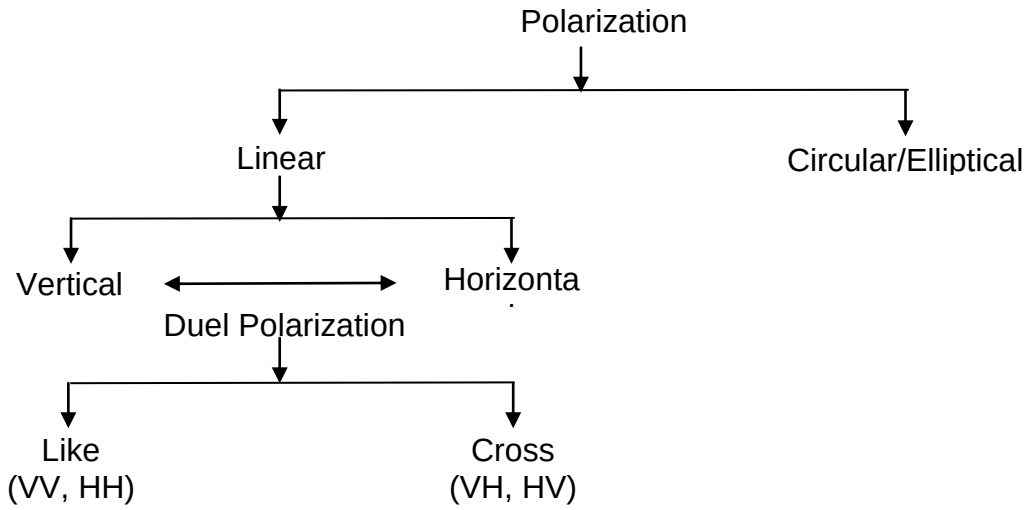


Figure 4.8: Classification of Polarization

a. **Vertical Polarization**. When the Electric field is perpendicular or vertical to the earth surface, the polarization is Vertical Polarization.

b. **Horizontal Polarization**. When the Electric field is parallel or horizontal to the earth surface, the polarization is Horizontal Polarization.

c. **Duel Polarization**. When more than one polarized wave is transmitted and / or received by radar, it is called duel polarization.

d. **Like Polarization**. When same type of polarized wave is transmitted and received, it is called like polarization.

e. **Cross Polarization**. When the polarization of received radiation is the opposite of the transmitted radiation, the image is said to be cross-polarized.

f. **Circular Polarization**. Circular polarization is the polarization where, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. Circular polarized wave radiates energy in both the horizontal, vertical planes and all planes in between. Circular polarized wave is the resultant of two waves superposed upon each other. One is vertical and

another is horizontal. If two vertically and horizontally polarized waves of same amplitude are superposed, but they are not in phase and out of phase by 90 deg, as a resultant circular polarized wave will be created.

g. **Elliptical polarization**. Elliptical polarization is also of same type. If two vertically and horizontally polarized waves are superposed, but they are not in phase and out of phase by any angle other than 90 deg, as a resultant circular polarized wave will be created.

Utility of Different Polarization

40. **Circular polarization**.

a. Circular polarization is used in satellite. Linear polarized wave may be rotated or many other changes may occur in case of linear polarization while crossing the ionosphere.

b. Another reason is that, circular polarization is helpful to keep alignment of the fixed position of the Earth with respect to the satellite.

c. It provides very good long run point to point communication due to a combination of linear noise rejection and high gain.

d. "Circular polarization" is often used mostly in FM radio (87.5 to 108.0 MHz), where a vertical and a horizontal component are propagated simultaneously by a single or a combined array.

e. This has the effect of producing greater penetration into buildings and difficult reception areas than a signal with just one plane of polarization.

41. **Cross polarization**.

a. Cross polarization is used in satellite to carry two separate transmissions on a given frequency, thus doubling the number of customers a single satellite can serve.

b. It is used to transmit signal to very long distance without any unwanted electromagnetic interruption.

c. Indicating the regularity or irregularity of the targets, and by calculating the relative delay between the two waves quantifying rainfall more accurately is also possible.

d. Able to use 3D projection of targets or geography like the satellite picture.

42. **Horizontal Polarization**.

a. In case of VHF and UHF it preferable to use horizontal polarization.

b. In long distance transmission it is less interrupted.

c. Less absorption by buildings.

d. Size of this antenna is convenient.

Despite of having the utility of horizontal polarisation in different aspects, it has few limitations which are as follows:

a. It cannot be used for low frequency for interruption by earth's electro-magnetic Field.

b. If horizontally polarized wave is reflected, some variation will be created.

c. It cannot produce all direction transmission.

Example: television transmission

43. **Vertical Polarization**.

a. Vertical polarization is used to radiate a signal in all directions.

b. It provides Omni directional communication.

c. Generally it is used for low frequency in ground wave propagation

d. After reflected by target any variation does not take place

e. Does not interrupted by earth's electro-magnetic Field

f. AM and FM radio uses vertical polarization.

Despite of having the utility of Vertical Polarization in different aspects, it has few limitations which are as follows:

a. Can not used for a longer distance.

b. Ground interference is more.

c. Limited use in VHF and UHF.

d. Covers less distance.

Polarization for BAF AD Radar

44. **Circular Polarization**.

a. Circular polarization is suitable for use in satellite.

b. This has the effect of producing greater penetration. For its high penetration power it will go through the aircraft also.

c. It is complicated to produce circular polarization, for BAF it will not be cost effective.

d. It produces 3D picture, by using components as HF, we may get Ht. For surveillance 3D picture is not required.

45. **Horizontal Polarization**.

a. In case of VHF and UHF it preferable to use horizontal polarization. But it can not be transmitted in all directions.

b. In long distance transmission it is less interrupted but interruption by Earth's EM interruption is more.

c. Less absorption by buildings and GC, but while being reflected, Phase shift occurs.

46. **Vertical Polarization**.

a. Limited use in long distance due to low power, by using reflector this problem can be over come.

b. Ground interference is more, by using anti interference sys, this problem can be over come.

c. Is not interrupted by earth's electro-magnetic Field.

d. Cost effective.

MTI and Pulse Doppler Radar

47. In the real world, radars have to deal with more than receiver noise when detecting targets since they can also receive echoes from the natural environment such as land, sea, and weather. These echoes are called *clutter* since they can "clutter" the radar display. Clutter echoes can be many orders of magnitude larger than aircraft echoes. When an aircraft echo and a clutter echo appear in the same radar resolution cell, the aircraft might not be detectable.

48. However, the most powerful method for detecting moving targets in the midst of large clutter is by taking advantage of the Doppler Effect, which is the change of frequency of the radar echo signal due to the relative velocity between the radar and the moving target. The use of the Doppler frequency shift with pulse radar for the detection of moving targets in clutter is the subject of this section.

49. A pulse radar that employs the Doppler shift for detecting moving targets is either MTI (moving target indication) radar or a pulse Doppler radar. The MTI radar has a pulse repetition frequency (prf) low enough to not have any range ambiguities. It does, however, have many ambiguities in the Doppler domain. The pulse Doppler radar, on the other hand, is just the opposite. It has a prf large enough to avoid Doppler ambiguities, but it can have numerous range ambiguities.

50. In addition to detect moving targets in the midst of large clutter echoes, the Doppler frequency shift has other important applications in radar; such as allowing CW (continuous wave) radar to detect moving targets and to measure radial velocity, synthetic aperture radar and inverse synthetic aperture radar for producing images of targets, and meteorological radars concerned with measuring wind shear.

51. **Doppler Frequency Shift**. The Doppler Effect used in radar is the same phenomenon that was introduced in high school physics courses to describe the changing pitch of an audible siren from an emergency vehicle as it travels toward or away from the listener. In this chapter we are interested in the Doppler Effect that changes the frequency of the electromagnetic signal that propagates from the radar to a moving target and back to the radar. If the range to the target is *R,* then the total number of wavelengths λ in the two-way path from radar to target and return is *2R/λ.* Each wavelength corresponds to a phase change of 2π radians. The total phase change in the two-way propagation path is then

$$\Phi = 2\pi.\frac{2R}{\lambda} \quad \text{.....(10)}$$

If the target is in motion relative to the radar, *R is* changing aw so will the phases. Differentiating Equation (10) with respect to time gives the rate of change of phase, which is the angular frequency f_d

$$\omega_d = \frac{d\Phi}{dt} = \frac{4\pi}{\lambda}.\frac{dR}{dt} = \frac{4\pi.Vr}{\lambda} = 2\pi f_d \quad \text{.....(11)}$$

Where $v_r = dR/dt$ *is* the radial velocity (meters/second), or rate of change of range with time.

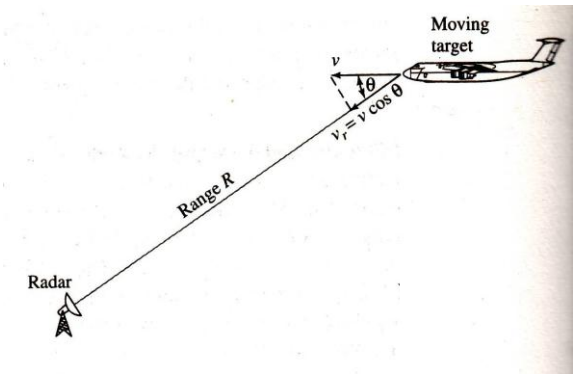


Figure 4.9: Geometry of radar and target in deriving the Doppler frequency shift. (Radar, target, and direction of target travel all lie in the same plane in this illustration.)

If, as in Figure 17.8, the angle between the target's velocity vector and the radar line of sight to the target is θ, then $v_r = v \cos\theta$, where v is the speed, or magnitude of the vector velocity. The rate of change of θ with time is the angular frequency $\omega_d = 2\pi f_d$, where f_d is the *doppler frequency shift.* Thus from Equation. (11),

$$f_d = \frac{2V_r}{\lambda} = \frac{f_t V_r}{c} \quad \text{.....(12)}$$

The radar frequency is $f_t = c/\lambda$, and the velocity of propagation $c = 3 \times 10^8$ m/s. If the doppler frequency is in hertz, the radial velocity in knots (abbreviated kt), and the radar wavelength in meters, we can write

$$f_d\,(\text{Hz}) = \frac{1.03 v_r\,(\text{kt})}{\lambda\,(\text{m})} \approx \frac{v_r\,(\text{kt})}{\lambda\,(\text{m})} \quad \text{.....(13)}$$

The Doppler frequency in hertz can also be approximately expressed as $3.43 v_r f_t$ where f_t is the radar frequency in GHz and v_r is in knots.

52. **MTI Radar Block Diagram**. The local oscillator of MTI radar's super heterodyne receiver must be more stable than the local oscillator for radar that does not employ Doppler. If the phase of the local oscillator were to change significantly between pulses, an un cancelled clutter residue can result at the output of the delay-line canceller which might be mistaken for a moving target even though only clutter were present. To recognize the need for high stability, the local oscillator of an MTI receiver is called the *stalo,* which stands for *stable local oscillator* The IF stage is designed as a matched filter, as is usually the case in radar. Instead of an amplitude detector, there is *a phase detector* following the IF stage. This is a mixer-like device that combines the received signal (at IF) and the reference signal from the *coho* so as to produce the difference between the received signal and the reference signal frequencies. This difference is the Doppler frequency. The name *coho* stands for *coherent oscillator* to signify that it is the reference signal that has the phase of the transmitter signal. Coherency with the transmitted signal is obtained by using the sum of the coho and the stalo signals as the input signal to the power amplifier. Thus the transmitter frequency is the sum of the stalo frequency f_l, and the coho frequency f_c This is accomplished in the mixer shown on the upper right side of Figure 4.9.

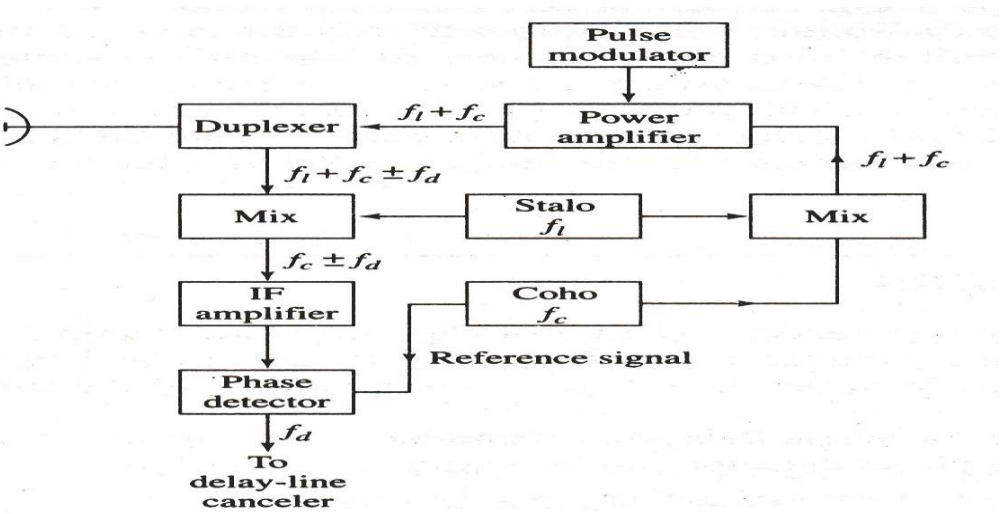


Figure 4.10: Block diagram of MTI Radar.

The combination of the stalo and coho sometimes is called the *receiver-exciter* portion of the MTI radar. Using the receiver stalo and coho to also generate the transmitter signal insures better stability than if the functions were performed with two different sets of oscillators. The output of the phase detector is the input to the delay-line canceller. The delay-line canceller acts as a high-pass filter to separate the Doppler-shifted echo signals of moving targets from the unwanted echoes of stationary clutter. The Doppler filter might be a single delay-line canceller but it is more likely to be one of several other more elaborate filters with greater capability.

53. The power amplifier is a good transmitter for MTI radar since it can have high stability and is capable of high power. The pulse modulator turns the amplifier on and off to generate the radar pulses. The klystron and the traveling wave tube have usually been the preferred type of vacuum-tube amplifier for MTI radar. The crossed-field amplifier has also been used, but it is generally noisier (less stable) than other devices; hence, it might not be capable of canceling large clutter echoes. Triode and tetrode vacuum tubes have also been used with success for radars that operate at UHF and lower frequencies, but they have been largely replaced at these lower radar frequencies by the solid-state transistor. The transistor has the advantage of good stability and it does not need a pulse modulator.

54. Before the development of the high-power klystron amplifier for radar application in the 1950s, the only suitable RF power generator at microwave frequencies was the magnetron oscillator. In an oscillator, the phase at the start of each pulse is random so that the receiver-exciter concept of Fig. 3.7 cannot be used. To obtain a coherent reference in this case, a sample of each transmitter pulse is used to lock the phase of the coho to that of the transmitted pulse until the next pulse is generated. The phase-locking procedure is repeated with each pulse. The RF locking-pulse is converted to IF in a mixer that also uses the stalo as the local oscillator. This method of establishing coherence at the receiver sometimes is called *coherent on receive.*

CHAPTER- XVIII

EVOLUTION AND TYPES OF RADAR

Training Objectives. At the end of this chapter the student should know the development process of radar and its different characteristics and types.

Introduction

1. We have fairly discussed on radar system in previous chapter. The military needs indeed paved the way for development of radar technology in 1930s. The potential of radar system was realized during World War-II, especially during battle of Britain. Since the World War-II, the development process of radar system has been continuing till today. Today we find different kinds of radar system available for different use. Their principles of operation are also different from each other. If we analyze the current trend, we find tube based radars are increasingly replaced by solid-state devices. This has allowed better maintenance provisions, and low power consumptions. A brief discussion is made in this chapter on various types of radar system based on principles and purposes. A comparison between Tube-based and Solid-state radar system is also discussed later in this chapter.

Evolution of Radar

2. **Early Work**. Although British physicist James Clerk Maxwell predicted the existence of radio waves in the 1860s, it wasn't until the 1890s that British-born American inventor Elihu Thomson and German physicist Heinrich Hertz independently confirmed their existence. Scientists soon realized that radio waves could bounce off of objects, and by 1904 Christian Hülsmeyer, a German inventor, had used radio waves in a collision avoidance device for ships. Hülsmeyer's system was only effective for a range of about 1.5 km (about 1 mi). The first long-range radar systems were not developed until the 1920s. In 1922 Italian radio pioneer Guglielmo Marconi demonstrated a low-frequency (60 MHz) radar system. In 1924 English physicist Edward Appleton and his graduate student from New Zealand, Miles Barnett, proved the existence of the ionosphere, an electrically charged upper layer of the atmosphere, by reflecting radio waves off of it. Scientists at the U.S. Naval Research Laboratory in Washington, D.C, became the first to use radar to detect aircraft in 1930.

3. **Radar in World War II**. None of the early demonstrations of radar generated much enthusiasm. The commercial and military value of radar did not become readily apparent until the mid-1930s. Before World War II, the United States, France, and the United Kingdom were all carrying out radar research. Beginning in 1935, the British built a network of ground-based aircraft detection radar, called Chain Home, under the direction of Sir Robert Watson-Watt. Chain Home was fully operational from 1938 until the end of World War II in 1945 and was extremely instrumental in Britain's defense against German bombers. The British recognized the value of radar with frequencies much higher than the radio waves used for most systems. A breakthrough in radar technology came in 1939 when two British scientists, physicist Henry Boot and biophysicist John Randall, developed the resonant-cavity magnetron. This device generates high-frequency radio pulses with a large amount of power, and it made the development of microwave radar possible. Also in 1939, the Massachusetts Institute of Technology (MIT) Radiation Laboratory was formed in Cambridge, Massachusetts, bringing together U.S. and British radar research. In March 1942 scientists

demonstrated the detection of ships from the air. This technology became the basis of anti-ship and antisubmarine radar for the U.S. Navy. The U.S. Army operated air surveillance radar at the start of World War II. The army also used early forms of radar to direct antiaircraft guns. Initially the radar systems were used to aim searchlights so the soldier aiming the gun could see where to fire, but the systems evolved into fire-control radar that aimed the guns automatically.

4. **Radar during the Cold War**. With the end of World War II, interest in radar development declined. Some experiments continued, however; for instance, in 1946 the U.S. Army Signal Corps bounced radar signals off of the Moon, ushering in the field of radar astronomy. The growing hostility between the United States and the Union of Soviet Socialists Republics—the so-called Cold War—renewed military interest in radar improvements. After the Soviets detonated their first atomic bomb in 1949, interest in radar development, especially for air defense, surged. Major programs included the installation of the Distant Early Warning (DEW) network of long-range radar across the northern reaches of North America to warn against bomber attacks. As the potential threat of attack by ICBMs increased, the United Kingdom, Greenland, and Alaska installed the Ballistic Missile Early Warning System (BMEWS).

5. **Modern Radar**. Radar found many applications in civilian and military life and became more sophisticated and specialized for each application. The use of radar in air traffic control grew quickly during the Cold War, especially with the jump in air traffic that occurred in the 1960s. Today almost all commercial and private aircraft have transponders. Transponders send out radar signals encoded with information about an aircraft and its flight that other aircraft and air traffic controllers can use. American traffic engineer John Barker discovered in 1947 that moving automobiles would reflect radar waves, which could be analyzed to determine the car's speed. Police began using traffic radar in the 1950s, and the accuracy of traffic radar has increased markedly since the 1980s. Doppler radar came into use in the 1960s and was first dedicated to weather forecasting in the 1970s. By the early 21st century the United States had a nationwide network of Doppler radar stations to help meteorologists track weather patterns. Earth-observing satellites such as those in the SEASAT program began to use radar to measure the topography of Earth in the late 1970s. The Magellan spacecraft mapped most of the surface of the planet Venus in the 1990s. The Cassini spacecraft, which reached Saturn in 2004, carried radar instruments for studying the surface of Saturn's moon Titan. Space probes orbiting Mars have used radar to map deposits of ice below the planet's surface. As radar continues to improve, so does the technology for evading radar. Stealth aircraft feature radar-absorbing coatings and deceptive shapes to reduce the possibility of radar detection. The U.S. stealth aircraft fleet has included the Lockheed F-117A, first flown in 1981, and the Northrop B-2 bomber, first flown in 1989. In the area of civilian radar avoidance, companies are introducing increasingly sophisticated radar detectors, designed to warn motorists of police using traffic radar.

Types of Radar

6. There is no definite classification of Radar. It can be classified on the basis of purpose, principles and ranges. However, some of general types of radars are:

a. Primary radar.

b. Over-the-horizon radar.

c. Early warning radar.

d. Secondary radar.

e. Target acquisition radar.

f. Target tracking radar.

g. Air intercepts radar.

h. Ground mapping radar.

j. Fire control radar.

7. **Primary Radar**. In primary radar, the detection of a target depends on receiving a direct echo of the transmitted signal. In this type of radar, the transmitted energy travels the path between the radar and target twice. Primary radar is an essential element of Air Defence system, which is used for surveillance, detection and interception of target. Following are the example of primary radar:

a. Long range, Medium range & short range (LRR, MRR, SRR).

b. Low Looking Radar (LRR).

c. High Power Radar (HPR).

d. Early Warning (EW) Radar.

e. Height Finding (HF) Radar.

f. Gap Filler (GF) Radar.

g. Weather Radar.

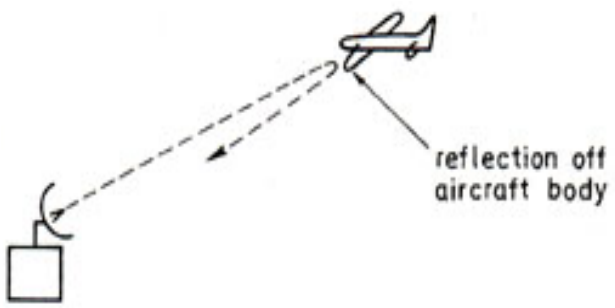


Figure 4.11: Primary Radar

8. **Over-The-Horizon Radars (OTH-R)**. OTH-Rs provide constant detection of airborne and naval targets beyond the normal radar line-of-sight. By using low frequencies typically 3 to 30 MHz, OTH-Rs employ sky-wave propagation that gives minimal atmospheric attenuation. This combination provides a minimum range of around 540 nm and maximum ranges of around 2100 nm. FMCW transmissions are used, giving range accuracy of around 6 to 12nm, but no height information can be determined. OTH-Rs use a bistatic mode of operation, with a physically separated transmitter and receiver.

Frequency Band	**15-30 MHz - A-Band**
Transmission Type	FMCW
Antenna size	Extremely large (1200 m long)

Table 4.3: Typical OTH-R Parameters

9. **Early Warning Radars**. Early warning radars may be ground-based, Airborne (Airborne Early Warning) or ship-borne. These radars use surface wave propagation, which provide maximum ranges of 270 to 320 nm. The first early warning radars used 100 MHz to 500 MHz frequencies, with yagi arrays or mesh antennas to reduce instability in high winds. Later early warning radars were developed using 1 GHz to 2 Hz frequencies.

Frequency Band	**100MHz - 500MHz (A & B Band)** **500MHz - 2 GHz (C & D band)**
Transmission Type	Pulse
Antenna size	Large
PRF	Low (typically 200 to 350 Hz)
Pulse width	Wide (5 to 30 μs)
Power	Very high (100 kW to 10 MW)
Scan rate & pattern	Typically slow, circular

Table 4.3: Typical Early Warning Radar Parameters

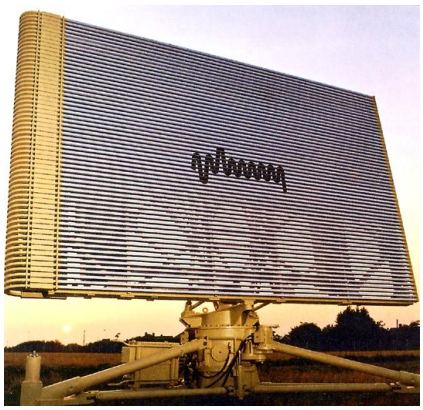


Figure 4.12: AR 325 Early Warning Radar

The radar beam widths are narrow in the horizontal plane and wide in the vertical plan. High power levels are required, which means large Pulse Widths (PW) and low Pulse Repetition Frequencies (PRF). Typically, slow circular scan patterns are used. If the early warning radar has no height-finding capability, a dedicated height finding radar is used. These operate in the same manner as the Early Warning radar but use fan-beams in which the elevation beam width is narrow and the fan beam is swept over a vertical sector in a nodding fashion.

10. **Secondary Radars**. The majority of radars are primary radar. These locate targets by detecting reflected EM energy and no co-operation is required from the target. Secondary radars operate by transmitting a coded message to targets (interrogation), which reply using a separate transmitter (a transponder), on a different frequency. Secondary surveillance radars (SSRs) are used by civilian air traffic control systems to regulate and identify aircraft. SSR is based on a World War II system known as identification friend or foe (IFF). IFF is the primary military method of identifying friendly aircraft from hostile aircraft and is compatible with current SSR.

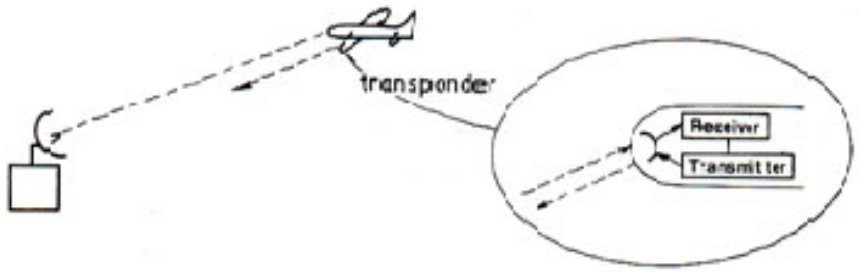


Figure 4.13: Secondary Radar

IFF and SSR can provide warning of equipment failure, emergency or other in flight situations (Hi jack). The interrogation signal consists of pairs of pulses, which are separated by a time equivalent to the required mode of response. The codes can be one of three types and are differentiated by the time difference between the pulses in the interrogation transmission. The fundamental IFF identification modes are 1, 2, 3 and SSR uses Modes A and C. The aircraft response consists of a train of pulses representing the code selected either by the aircrew or provided by equipment in the aircraft. IFF and SSRs use D-band frequencies, 1030 MHz to interrogate and 1090 MHz to respond. Ranges of several hundred miles are possible. Dipole antennas are used for the IFF interrogator and omni-directional blade antennas for the IFF transponder.

Frequency Band	**1 GHz (D Band)**
Transmission Type	Pulse
Antenna size Interrogator	Large - Rotating
Antenna size Aircraft	Small - Omni Directional
Power	Medium (50 - 100 watts)

Table 4.4: SSR/IFF parameters

11. **Target Acquisition Radars (TARs)**. Target Acquisition Radars (TARs) are similar to early warning radars, but are normally associated with a weapon system, such as surface-to-air missile (SAM) system or anti-aircraft artillery (AAA). The detection range for a TAR is dependent upon the capability of the weapon system and can range from 10 nm to 120 nm. TAR frequencies are from 500 MHz to 10 GHz and depending on the frequency the antenna will be large mesh antennas or smaller parabolic dishes. Shorter wavelengths and high PRFs are used with faster scan rates to produce high data rates. Although the majority of TARs use pulse transmissions, CW is used by some systems in order to reduce clutter from terrain and detect targets at low-level.

Frequency Bands	500 MHz -10 GHz (C to I-Band)
Transmission Type	Mainly pulse, exceptionally CW
Antenna size	Medium (1 to 3.5 m)
PRF	Medium (typically 800 to 3000 Hz)
PW	Medium (0.2 to 1 μs)
Power	Medium (2 to 900 KW)
Scan rates & pattern	Medium 40 to 60 RPM, circular or sector

Table 4.5: Typical TAR Parameters

12. **Target Tracking Radars (TTRs)**. Target Tracking Radars (TTRs) provide continuously updated information for weapons systems. Depending on the particular

weapon system, the TTR may have to provide range, azimuth, elevation and velocity data. The differences between TARs and TTRs are in the resolution and data rate. High frequencies 4 GHz to 40 GHz, narrow PWs and narrow beam widths are used to achieve high resolution. The power is lower than TARs and the physical dimensions of the antennas are smaller. High data rates are achieved through the use of very high PRFs and faster and more complicated scan patterns. The majority of modern TTRs use pulse Doppler (PD) waveforms, although some older systems use pulse. A few TTRs use CW.

Frequency Bands	4 GHz to 40 GHz (G/H, I, J and K-Band
Transmission Type	PD, pulse, exceptionally CW
Antenna size	Small (0.6 to 1.5 m)
PRF	High (typically 1500 to 9000 Hz)
PW	Narrow (0.1 to 1 μs)
Power	Medium to low (1 to 50 KW)
Scan rate	Fast/continuous

Table 4.6: Typical TTR Parameters

Figure 4.14: SA-8 TTR

13. **Fire Control Radars (FCRs)**. Fire Control Radars (FCRs) represent the final stage of an engagement with a radar-guided weapon system. They can be used to describe AAA and also SAM missile guidance radars, which issue commands to missiles in-flight. In some radar systems, the TTR and missile guidance radar may be combined, sharing the same parameters of frequency and PRF. However, the PW of a missile guidance signal from an FCR is wider than that of a TTR. FCRs can use pulse, PD or CW transmissions.

Frequency Bands	8 GHz -40 GHz (I, J and K bands)
Transmission Type	PD, pulse, or CW
Antenna size, PRF, Power	Same as TTR
PW	Narrow to medium (0.2 to 0.8μs)

Table 4.7: Typical FCR (Missile Guidance) Parameters

14. **Air Intercept (AI) Radars**. Air Intercept (AI) Radars radar is used by fighter aircraft to search, track and target airborne targets. Due to the lack of space, a single multi-function radar is used, operating on frequencies between 8Ghz and 20Ghz as a compromise between the need for long-range and the need for high resolution. This results in a small antenna size. Another important requirement is the need to reject

unwanted radar echoes caused by the ground. This is achieved by using a PD transmission and filtering radar echoes by velocity. AI radars that can achieve this are termed “look-down-shoot-down” radars. To increase the probability of detecting targets at long range, AI radars use very high PRFs. Unfortunately, high PRFs lead to incorrect range indications, so a mix between low, medium and high PRFs are used. Typically a raster scan is used for search, with computer processing allowing track-while-scan. Some AI radars use command guidance signals to direct air-to-air missiles, with the missiles using their own radars in the final stages of an engagement. Some AI radars use CW illumination of targets, allowing air-to-air missiles to home onto the reflections.

Frequency Bands	8 GHz – 20 GHz (I - J-band)
Transmission Type	Mainly PD, CW for missile guidance
Antenna size	Small (less than a metre)
PRF	High (typically 10 to 30 KHz)
PW	Medium (0.1 to 1 μs)
Power	Medium to low
Scan rate	Medium to fast

Table 4.8: Typical AI Radar Parameters

15. **Ground Mapping Radars (GMRs)**. Ground Mapping Radars (GMRs) are used for navigation and weapon aiming. They are required to detect ground features with minimal distortion and maximum resolution. High frequencies are used, low to medium PRFs, narrow PWs, narrow beam-widths and medium to fast scan rates. Pulse or PD transmissions can be used and there are a variety of complex radar processing techniques that can be used to enhance the overall resolution of the system. These include pulse compression, Doppler beam sharpening and synthetic aperture radar (SAR).

Frequency Bands	8 GHz to 20 GHz (I - J-band)
Transmission Type	Pulse and PD
Antenna size	Small (less than a metre)
PRF	Medium to low
PW	Narrow to Medium
Power	Medium to low
Scan rate	Medium to fast

Table 4.9: Typical Air-to-Ground Mapping Radar Parameters

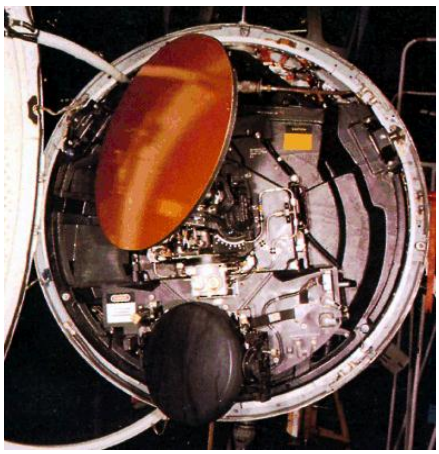


Figure 4.15: GMR Tornado

Simple Pulse Radar

16. Simple pulse radar is the simplest type of radar. In this system, the transmitter sends out short pulses of radio frequency energy. Between pulses, the radar receiver detects echoes of radiation that objects reflect. Most pulse radar antennas rotate to scan a wide area. Simple pulse radar requires precise timing circuits in the duplexer to prevent the transmitter from transmitting while the receiver is acquiring a signal from the antenna, and to keep the receiver from trying to read a signal from the antenna while the transmitter is operating. Pulse radar is good at locating an object, but it is not very accurate at measuring an object's speed.

Continuous Wave Radar

17. Continuous-wave (CW) radar systems transmit a constant radar signal. The transmission is continuous, so, except in systems with very low power, the receiver cannot use the same antenna as the transmitter because the radar emissions would interfere with the echoes that the receiver detects. CW systems can distinguish between stationary clutter and moving targets by analyzing the Doppler shift of the signals, without having to use the precise timing circuits that separate the signal from the return in pulse radar. Continuous wave radar systems are excellent at measuring the speed and direction of an object, but they are not as accurate as pulse radar at measuring an object's position. Some systems combine pulse and CW radar to achieve both good range and velocity resolution. Such systems are called Pulse-Doppler radar systems.

Synthetic Aperture Radar

18. Synthetic aperture radar (SAR) tracks targets on the ground from the air. The name comes from the fact that the system uses the movement of the airplane or satellite carrying it to make the antenna seem much larger than it actually is. The ability of radar to distinguish between two closely spaced objects depends on the width of the beam that the antenna sends out. The narrower the beam is, the better its resolution. Getting a narrow beam requires a big antenna. A SAR system is limited to a relatively small antenna with a wide beam because it must fit on an aircraft or satellite. SAR systems are called synthetic aperture, however, because the antenna appears to be bigger than it really is. This is because the moving aircraft or satellite allows the SAR system to repeatedly take measurements from different positions. The receiver processes these signals to make it seem as though they came from a large stationary antenna instead of a small moving one. Synthetic aperture radar resolution can be high enough to pick out individual objects as small as automobiles. Typically, an aircraft or satellite equipped with SAR flies past the target object. In inverse synthetic aperture radar, the target moves past the radar antenna. Inverse SAR can give results as good as normal SAR.

Phased-Array Radar

19. Most radar systems use a single large antenna that stays in one place, but can rotate on a base to change the direction of the radar beam. A phased-array radar antenna actually comprises many small separate antennas, each of which can be rotated. The system combines the signals gathered from all the small antennas. The receiver can change the way it combines the signals from the antennas to change the

direction of the beam. A huge phased-array radar antenna can change its beam direction electronically many times faster than any mechanical radar system can.

Solid State Radar vs Valve Based Radar

20. In electronics, a vacuum tube, electron tube (in North America), thermionic valve, or valve (elsewhere, especially in Britain) is a device used to amplify, switch, otherwise modify, or create an electrical signal by controlling the movement of electrons in a low-pressure space. Some special function vacuum tubes are filled with low-pressure gas: these are so-called soft valves (or tubes), as distinct from the hard vacuum type which have the internal gas pressure reduced as far as possible.

Figure 4.16: The glow from four KT88 model "Electro Harmonix" brand power tubes lights up the inside of a Traynor YBA-200 guitar amplifier

Almost all depend on the thermal emission of electrons, hence thermionic. Vacuum tubes were critical to the development of electronic technology, which drove the expansion and commercialization of radio broadcasting, television, radar, sound reproduction, large telephone networks, analogue and digital computers, and industrial process control. Some of these applications pre-dated electronics, but it was the vacuum tube that made them widespread and practical. A vacuum tube consists of electrodes in a vacuum in an insulating heat-resistant envelope which are usually tubular. Many tubes have glass envelopes, though some types such as power tubes may have ceramic or metal envelopes.

21. Solid-state devices have largely superseded vacuum tubes in logic and other low-power circuits and even in some very high power applications such as power supplies and power converters below 1 MHz. The only exception seems to be cathode-ray tubes (CRTs), which are less costly than large plasma displays. In radar transmitters, the transition from high-power klystrons, traveling-wave tubes (TWTs), crossed-field amplifiers (CFAs), and magnetrons to solid-state has been more gradual because the power output of individual solid-state devices is quite limited. For most purposes, the vacuum tube has been replaced by solid-state devices such as transistors and solid-state diodes. Solid-state devices last much longer, are smaller, more efficient, more reliable, and cheaper than equivalent vacuum tube devices. However, tubes are still used in specialized applications: for engineering reasons, as in high-power radio frequency transmitters; or for their aesthetic appeal and distinct sound signature, as in audio amplification. Cathode ray tubes are still used as display devices in television sets, video monitors, and oscilloscopes, although they are being replaced by LCDs and other flat-panel displays. A specialized form of the electron tube, the magnetron, is the source of microwave energy in microwave ovens and some radar systems. The klystron, a powerful but narrow-band radio-frequency amplifier, is commonly deployed by broadcasters as a high-power UHF television transmitter. Valves are high voltage/low current devices in comparison with transistors (and

especially MOSFETs). The high working voltage makes them well suited for radio transmitters, for example, and valves remain in use today for very high power radio transmitters, where there is still no other technology available. However, for most applications requiring an appreciable output current, a matching transformer is required. The transformer is a critical component and heavily influences the performance (and cost) of the amplifier. Many power valves have good linearity but modest gain or Tran conductance. Signal amplifiers using tubes are capable of very high frequency response ranges - up to radio frequency. Indeed, many of the Directly Heated Single Ended Triode (DH-SET) audio amplifiers are in fact radio transmitting tubes designed to operate in the megahertz range. In practice, however, tube amplifier designs typically "couple" stages either capacitive, limiting bandwidth at the low end, or inductively with transformers, limiting the band width at high end.

Figure 4.17: AN/TPS-78 Solid State Radar

22. **Advantages of Solid State Device**. However, compared with tubes, solid-state devices offer many advantages:

a. No hot cathodes are required; therefore, there is no warm up delay, no wasted heater power, and virtually no limit on operating life.

b. Device operation occurs at much lower voltages; therefore, power supply voltages are on the order of volts rather than kilovolts. This avoids the need for large spacings, oil filling, or encapsulation, thus saving size and weight and leading to higher reliability of the power supplies as well as of the microwave amplifiers themselves.

c. Transmitters designed with solid-state devices exhibit improved mean time between failures (MTBF) in comparison with tube-type transmitters. Module MTBFs greater than 100,000 h have been measured.

d. No pulse modulator is required. Solid-state microwave devices for radar generally operate Class-C, which is self-pulsing as the RF drive is turned on and off.

e. Graceful degradation of system performance occurs when modules fail. This results because a large number of solid-state devices must be combined to provide the power for a radar transmitter, and they are easily combined in ways that degrade gracefully when individual units fail. Overall power output, in decibels, degrades only as 20 log r, where r is the ratio of operating to total amplifiers.

f. Extremely wide bandwidth can be realized. While high-power microwave radar tubes can achieve 10 to 20 percent bandwidth, solid-state transmitter modules can achieve up to 50 percent bandwidth or more with good efficiency.

g. Flexibility can be realized for phased array applications. For phased array systems, an active transceiver module can be associated with every antenna element. RF distribution losses that normally occur in a tube-powered system between a point-source tube amplifier and the face of the array are thus eliminated. In addition, phase shifting for beam steering can be implemented at low power levels on the input feed side of an active array module; this avoids the high-power losses of the phase shifters at the radiating elements and raises overall efficiency. Also, peak RF power levels at any point are relatively low since the outputs are combined only in space. Furthermore, amplitude tapering can be accomplished by turning off or attenuating individual active array amplifiers.

23. **Advantages of Valve Based devices**.

a. Very linear (especially triodes) making it viable to use them in low distortion linear circuits with little or no negative feedback.

b. Remedy high input impedance (cf bipolar transistors but a characteristic shared by FETs).

c. High voltage devices and thus inherently suitable for very high voltage circuits.

d. Be constructed on a scale that can dissipate large amounts of heat (some extreme devices even being water cooled). For this reason valves remained the only viable technology for very high power, and especially high power/high voltage applications such as Radio & TV transmitters long into the age when transistors had displaced valves in most other applications. However, today these also are becoming obsolete.

e. Electrically very robust, they can tolerate overloads for minutes which would destroy bipolar transistor systems in milliseconds. In the worst case a failed tube can simply be unplugged and replaced by the user.

24. **Disadvantages of Valve Based devices**.

a. Heater supplies are usually required for the cathodes, and dangerously high voltages are usually required for the anodes.

b. They are significantly larger than equivalent solid-state transistors.

c. High impedance / low current output is unsuitable for direct drive of many real world loads, notably various forms of electric motors.

d. Valved audio equipment is normally heavy because of the weight of transformers.

e. Valves may have a shorter working life than solid state parts due to various failure mechanisms (cathode poisoning, breakages (i.e., open circuit) or shorts internally, notably of the heater or grid structures, or in the case of glass valves, physical breakage, although this should not be overstated; many valve types typically have operation lives in the tens of thousands of hours and an indefinite shelf life (many 60 year old tubes are still in regular use).

f. Available in a single polarity only whereas transistors are available in complementary polarities (e.g., NPN/PNP), making possible many circuit configurations that cannot be realized directly with valves.

g. In comparison to the lower impedance environment of transistors special consideration must be made to the physical layout of valve circuits in order to avoid instability and the introduction of noise from radio frequency interference and ac heater supplies.

Types of Radar Basing On Relative Posn of Tx & Rx

25. Types of radar (basing on relative posn of TX & Rx) are as fol:

a. **Monostatic radar**. In a monostatic radar the transmitter and receiver are located in the same place and usually from the same piece of radar equipment

b. **Bistatic radar**. In a Bistatic radar the transmitter and receiver are separated. The receiver is purely passive it is less susceptible to some electronic countermeasures such as jamming and anti radiation missiles.

c. **Multistatic Radar**. The Multistatic Radars are as fol:

(1) Itis an extension of the bistatic system where many widely spaced transmitters and receivers co-operate to form a sensor system that is highly capable and immune to countermeasures.

(2) It is costly.

(3) It is a bit problematical for the synchronization of the many elements.

Technology

26. Advances in technology have allowed considerable improvements in radar capability. Improvements in radar operation, greater ranges, higher resolution and increased data rates have all been achieved through the incorporation of new technology. The minitiarisation of the "Black Boxes" has allowed improved systems to be installed on smaller platforms. Last but by no means is least the adoption of planar and phased array technology. The latter removes the need to rotate aerials to provide bearing information. The details of this technology will be explored in later lessons. The point to note is however that the technology continues to advance but the functions to be performed remain the same.

Summary

27. Radar falls into one of two categories Primary or Secondary, most are Primary radar and within that general category they perform a number of different functions. This

lesson has reviewed the different types of radar, described their functions and identified their generic parameters. As a general rule however long range detection requires low frequencies, large PWs, low PRFs and high power transmissions whilst short-range target tracking requires high frequencies, high PRFs, narrow PWs and narrow beam widths to provide high resolution. PD radar offers accurate range, velocity and bearing information, and therefore is more commonly used for tracking, AI or fire control. CW signals are associated with target illumination and should therefore be considered as a high threat. The introduction of modern technology and the evolution of single function radar into multi-function capability enable commanders to mix search and tracking tasks on a single platform. Multi-beam architecture allows for detection and tracking multifunction capability whilst active arrays provide increased sensitivity and flexibility. This increased technical capability simply reduces the numbers of radar required to perform the tasks required in the battlefield. The functions identified in this lesson still need to be undertaken.

CHAPTER XIX

PASSIVE DETECTION SYSTEM

Training Objective. On completion of this chapter the students will know the historical development, system overview, working principle and functions and main applications of passive detection system.

Introduction

1. It is comprehensively known that radar is the primary detection system in any Air Defence organization. Without radar, the defence system is sightless, just like a person without eyes. But now there are many threats to air defence radar in modern war, such as anti-radiation missile (ARM), anti-radiation unmanned air vehicle (ARUAV), hostile active jamming etc. All of the threats are fatal to active radar. Against the threats, the conventional radar has to switch off or use active decoys to simulate radar emission to confuse/puzzle the ARM or use passive decoys to mislead the ARM in order to protect it. In any case, the effectiveness of the air defence radar is greatly degraded, which is hazardous to the air defence system. Moreover, the stealth aircraft and active jamming are other threats to conventional radar. Because the conventional radar is trouble-free to be located and jammed; and it has exceedingly low detection capability against stealth aircraft.

2. The passive detection system can eliminate/resolve the aforementioned shortcomings of the conventional radar and enhance the ‘eye’ of the national defence system, and can act as an intelligence collection and surveillance facility. One of the outstanding features of passive detection system is passive. Because it does not emit any electromagnetic signal and thereby leaves no possibility to be detected and attacked by enemy. Rather it develops the capability of jamming and anti-jamming and is able to deal with stealth aircraft. It is designed for detection, location, identification and tracking of air, ground and naval targets.

3. This article will draw attention to the features, functions and applications of passive surveillance system after the brief history. But while discussing those, overview and working principle of such system will also be touched upon. Finally the article will try to mention the viability of the system in before making conclusion.

History

4. The concept of passive radar detection—using reflected ambient radio signals emanating from a distant transmitter—is not new. The first radar experiments in the United Kingdom in 1935 by Robert Watson-Watt demonstrated the principle of radar by detecting a Handley Page Heyford bomber at a distance of 12 km using the BBC shortwave transmitter at Daventry. Following the experiments, conventional radar was developed and since then radar was the mainstay in air defence surveillance all over the world. But soon after the development of stealth aircraft, extensive research were undertaken to find out the detection system of stealth aircraft. Czech Republic was the pioneer in this scheme. The first system developed by Czech army in 1963 was known as PRP-1 Kopáč which could track 06 x targets. This was followed by KRTP-81 Ramona (NATO reporting name Soft Ball) in 1979, which could track 20 x targets, and KRTP-86 Tamara (NATO reporting name Trash Can) in 1987, which could simultaneously track 23 x targets and 48 x IFF. Development of Tamara by state-run

company Tesla in Prejudice began in 1981 and continued until 1983. Test of a mobile system began in September 1984 through to 1985. It was finally deployed in 1987 following acceptance tests in October of that year. The system was exported to then USSR, East Germany, USA and Oman. Subsequently more advanced Vera-E passive detection system was developed by Era (Former Tesla) company and believed to be exported to Estonia, Pakistan, USA and China.

5. Consequently Kolchuga passive detection system was developed by Ukrainian Special Radio Device Design Bureau public holding, the Topaz holding, the Donetsk National Technical University, the Ukrspetsexport state company, and the Investment and Technologies Company. It took them eight years (1993 - 2000) to conduct research, develop algorithms, test solutions on experimental specimens, and launch serial production. The new product dramatically changed the balance in the constant competition between offensive and defensive means. The relatively cheap Ukrainian Kolchuga radar station is able to detect and identify practically all known active radio devices mounted on ground, airborne, or marine objects.

6. Later on, China also joined in the fray and developed YLC-20 and DWL002 passive detection system similar to Czech Vera-E system. However, China's breakthrough made USA so concerned that a meeting was summoned immediately to examine the strategic implications of such a breakthrough. It is likely that Serbs were able to shoot down a US F-117 stealth aircraft in 1999 with the help of passive detection system.

System Overview

7. A passive detection system, comprising a receiver having first and second antennas; and processing means; wherein the first antenna is adapted to receive a signal transmitted by a mobile telephone base station and the second antenna is adapted to receive the signal transmitted by the mobile telephone base station after the signal has been reflected off an object. The processing means compares the signal received from the mobile telephone base station with the signal reflected from the object and derives speed or position information relating to the object therefrom; wherein the object is a moving object. The system further comprises a plurality of mobile phone base stations which transmit a signal, such that as the object moves out of range of one base station, it comes into range for another, whereby the distance of the object from a base station being used to determine a position of the object remains substantially constant and distance of the object from the receiver changes, thereby improving the received power and range.

8. Passive detection system is an electromagnetic support measures system that employs two or more sites to locate emitters by Triangulation or Time Difference of Arrival (TDOA) method. The system is mobile and has antenna with receivers. The system typically comprises a central site (containing the signal processing equipment and an ESM receiver) and two or three side sites containing only an ESM receiver. The side sites relay the signals received to the central site over a point-to-point microwave link. Its frequency band is 0.8-18 GHz and provides surveillance over a sector of approximately 100 to 120 degrees. The nominal range of the system is 450 km. The central site uses the known propagation delay from the side sites to estimate the TDOA of the pulses at each site. The TDOA of a pulse between one side site and the central site locates the target on a hyperboloid. A second side site provides a second TDOA and hence a second hyperboloid. The intersection of these two hyperboloids places the

target on a line, providing a 2D measurement of the target's location. A third site provides a third hyperboloid and hence a measurement of height.

9. The detection range of this system is much more than conventional radar, but it is highly dependent on the emitted power of the transmitter being tracked, and requires the line of sight condition at least between two receiving sites for triangulation (technique used by Kolchuga system of Ukraine) and three sites for a multilateration system (technique used by Vera system of Czech Republic and DWL002). Again the detection range will vary depending on the system (sensitivity, deployment height, antenna height etc) and height of the incoming target. However, such system can even give warning of the take of hostile aircraft at ranges that exceed the distance of modern radar system and can provide notification of target numbers and direction of flight. Target identification can be deduced from analysis of the characteristics of the detected emitter.

Working Principle

10. **Multilateration**. It is also known as hyperbolic positioning, is the process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from the object to three or more receivers. When a signal is transmitted from an object, it will be received by two especially separate sensors at different times. The time difference is then used to calculate the objects position. By using three or more sensors, a complete position analysis can be attained. The working principle of Multilateration is described as below:

a. If a pulse is emitted from a platform, it will arrive at slightly different times at two spatially separated receiver sites, the TDOA being due to the different distances of each receiver from the platform. In fact, for given locations of the two receivers, a whole series of emitter locations would give the same measurement of TDOA. Given two receiver locations and a known TDOA, the locus of possible emitter locations is a one half of a two-sheeted hyperboloid (Figure-1).

b. In simple terms, with two receivers at known locations, an emitter can be located onto a hyperboloid. Note that the receivers do not need to know the absolute time at which the pulse was transmitted - only the time difference is needed.

c. Consider now a third receiver at a third location. This would provide a second TDOA measurement and hence locate the emitter on a second hyperboloid. The intersection of these two hyperboloids describes a curve on which the emitter lies.

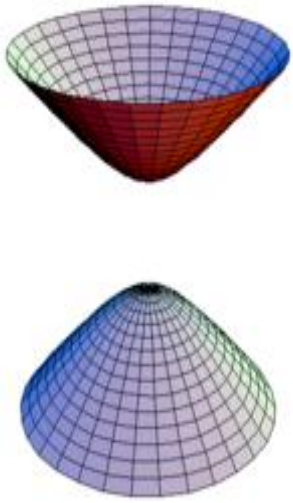


Figure 4.18: Two Sheeted Hyperboloid

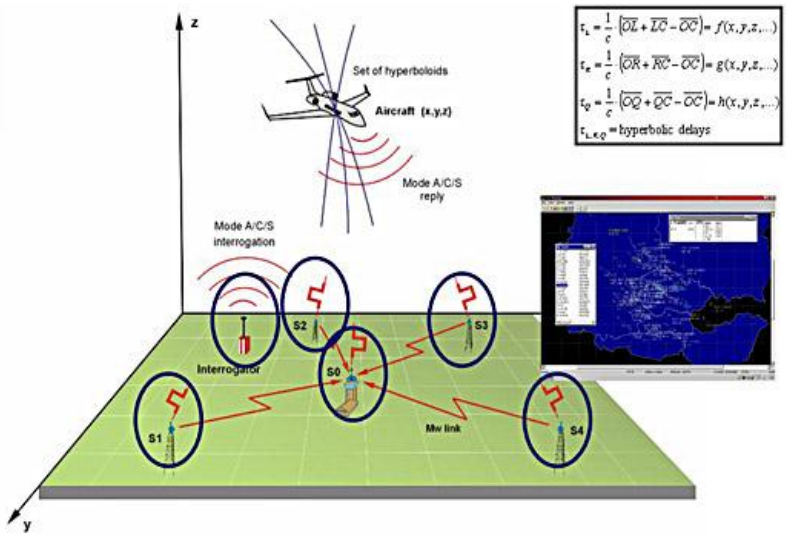


Figure 4.19: Multilateration Technique

d. If a fourth receiver is now introduced, a third TDOA measurement is available and the intersection of the resulting third hyperboloid with the curve already found with the other three receivers defines a unique point in space. The emitter's location is therefore fully determined in 3D. Additionally, the TDOA of multiple transmitted pulses from the emitter can be averaged to improve accuracy.

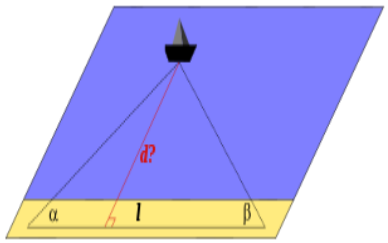
11. **<u>Triangulation</u>**. Triangulation is the process of determining the location of a point by measuring *angles* to it from known points at either end of a fixed baseline, rather than measuring distances to the point directly. The point can then be fixed as the third point of a triangle with one known side and two known angles. The coordinates and distance to a point can be found by calculating the length of one side of a triangle, given measurements of angles and sides of the triangle formed by that point and two other known reference points. There are two formulas to calculate triangulation which are as follows:

a. The following formula applies in flat or Euclidean geometry. They become inaccurate if distances become appreciable compared to the curvature of the Earth, but can be replaced with more complicated results derived using spherical trigonometry.

$$l = \frac{d}{\tan\alpha} + \frac{d}{\tan\beta}$$

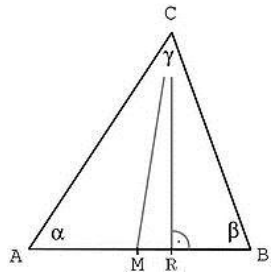
Therefore,

$$d = l \,/\, \left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right)$$



b. Alternatively, the distance RC can be calculated by using the law of sines to calculate the lengths of the sides of the triangle:

$$\frac{\sin\alpha}{BC} = \frac{\sin\beta}{AC} = \frac{\sin\gamma}{AB}$$



The distance AB is known, so we can write the lengths of the other two sides as

$$AC = \frac{AB \cdot \sin\beta}{\sin\gamma} \qquad BC = \frac{AB \cdot \sin\alpha}{\sin\gamma}$$

RC can now be calculated using either the sine of the angle α, or the sine of the angle β:

$$RC = AC \cdot \sin\alpha$$

$$RC = BC \cdot \sin\beta$$

Either way, this gives the result

$$RC = \frac{AB \cdot \sin\alpha \cdot \sin\beta}{\sin\gamma}$$

We know that γ = 180 − α − β, since the sum of the three angles in any triangle is known to be 180 degrees; and since sin(*θ*) = sin(180 - *θ*), we can therefore write sin(γ)=sin(α+β), to give the final formula

$$RC = \frac{AB \cdot \sin\alpha \cdot \sin\beta}{\sin(\alpha+\beta)}$$

Main Features of Passive Detection System

12. **Operational Features**. The main distinguishable operational features of passive detection system are as follows:

a. **Passive**. The system has the important characteristics in comparison to other conventional/traditional radar surveillance system. It is fully passive. The system will not generate and transmit electromagnetic signal. Because of this distinguished feature, the operation of the passive detection system can not be detectable/ observable nor be jammed by the enemy forces. As this system will not transmit high power electromagnetic signal for detection/ recognition, so it can not be positioned or assaulted by the anti-radiation missile.

b. **Real Time**. Passive detection system is featured on the excellent real time characteristics. It can provide the operator and the commander with real time air target moving and flight track scenario, so that the air defence system can be early warned and well prepared. The flight track information of the emitter is refreshed in real time. The system capitalizes on the use of multiple, time-synchronized radio receivers to capture high-frequency radio signals reflected

from a target. The time-lapse between received signals, together with three-dimensional Doppler-shift analysis, permits calculation of a target's location, velocity, acceleration, flight path, and other parameters, possibly to include target size estimation.

c. **Mobility**. Passive detection system has three or more station configuration. However, the whole system ensures the good mobility of the system.

d. **Remote Control**. It can also operate in both in manual and master station remote control mode.

e. **Electronic Protection Measure (EPM) Capability**. It has good EPM and counter ARM capability. The system has also the possibility to detect/ distinguish stealth target and low altitude penetrating target/object.

f. **Continuous Detection**. It detects targets continuously, often, multiple times per second.

h. **Operation at Any Place**. A passive system can be operated in virtually any location.

j. A passive radar system cannot be detected when in operation, since it has no active transmitter as an element of the system.

13. **Technical Features**. The passive detection system employs advance techniques to ensure its stupendous performance:

a. Long base line TDOA and wide-band digitized receiver techniques ensure the system has both sensitivity detection performance and wide band interception performance. It gives wide area coverage to detect target/ object, whose radius often is measured in hundreds, or thousands of kilometres.

b. High speed sampling and parallel digital signal processing ensure that the system has both high accurate parameters measurement and real time processing information.

c. Multi-level co-relation processing ensures good flight track processing, and high stable time base ensures the system accurate synchronization.

d. Automatic setup, chassis levelling and automatic north calibration ensure fast deployment and flexible operation.

Function and Main Application

14. **Function**. The system can perform silence surveillance of hostile air operation and monitor the electromagnetic spectrum of enemy near border area over a long period. It can perform interception, processing, analysis and identification of various radar signals coming from different directions. Followings are the main functions:

a. Real time, accurate location and tracking.

b. Signal analysis and identification.

c. Long range detection.

d. Early warning.

15. **Main application.** Passive detection system is a wide band real time detection system, controlled by high automated computer. Main applications of passive detection system are as follows:

a. In the air defence operation, the system can perform long range detection and location of air targets and enable the commander understand the combat field scenario and assist for correct decision making. In complex signal environment, the system has target identification and multi-target distinguishing capability.

b. In case own active air defence system is jammed, passive detection system can provide the jamming and guidance information.

c. In peace time, passive detection system can act as a part of the early warning intelligence network and radar network to perform detection and location of air target and augment the air situation of target area.

d. Passive detection system can act as an Electronic Signals Intelligence (ELINT) system for intelligence collection.

Viability in Bangladesh Air Defence System

16. At present surveillance system of Bangladesh Air Defence is equipped with only active system i.e. conventional radar. No services have so far acquired any passive system. If the whole airspace of Bangladesh is to be surveilled at low level, then large number of radars would be required. Here the passive detection system could be a viable option to complement the active system. Again the system can also work as ELINT which is yet to be developed by BAF.

17. It has been mentioned before that passive system is almost immune to the enemy attack due to non-emission of any electro-magnetic signal. If Bangladesh air defence system has only active radars which are easy to be located and attacked, then it would be very easy for the enemy to completely blind the surveillance system. Therefore, a passive detection system which is likely to survive enemy onslaught, can also act as redundant in present surveillance system.

Conclusion

18. Passive detection System is an ESM system which is designed for detection, location, identification and tracking of air, ground and naval targets by the Triangulation or Time Difference of Arrival (TDOA) technique. The mobile system typically comprises a central site and two or three side sites containing only an ESM receiver. It can provide 3D information with four sites. It has early warning, attack guidance, anti-stealth and anti- RAM attack capabilities. Some of the system can be remotely controlled and have the ECCM capability. Passive Detection System features wide frequency coverage (0-18GHZ), high automation, powerful capability of parameter measurement and analysis, friendly Man Machine Interface (MMI), flexible operation and maintenance, etc.

Compared with an active detection system such as conventional radar, it has more distinguished advantages: full passive, long detection range, real time, etc.

19. The main function of Passive detection System is to locate the hostile emitter and locate its carrier platform. The system can perform silent surveillance of hostile air operation and monitor the electromagnetic (EM) spectrum of enemy near border area over a long period. It can either act as a complementary to active radar system or itself form a surveillance network. If the whole airspace of Bangladesh is to be survived at low level, then Passive Detection System could be a viable option. The system can also work as ELINT system which is yet to be developed by BAF. Due to its immunity from enemy attack, the system can act as redundant in surveillance system during enemy onslaught.

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CHAPTER- XX

RADAR INTERFERENCE AND ANTI - INTERFERENCE DEVICES

Training Objectives. After the completion of this chapter the students should understand:

a. Various types of interference that degrade radar performance.

b. Anti-interference devices used to nullify the effect of interference.

Introduction

1. Interference in radar may be natural or man-made, intentional or unintentional. Some of the common types of interference are discussed below.

Various Types of Interference

2. a. **Clutter**. One of the most formidable limitations to the use of pulsed radar is of 'Clutters' ie echoes from fixed targets. Often a radar set sees too much rather than too little; unwanted echoes or clutters confuse the picture. This can consist of echoes from surrounding objects on the ground (Ground Clutters), of echoes from the irregular surface of a sea (Sea Clutters) or echoes from the mountains in the radar range (permanent echoes). The clutters can be rid of, to some extent, by using M.T.I technique. M.T.I stands for "Moving Target Indicator" and cancels the echoes from permanent objects and only moving target echoes appear on the scope.

b. **Clouds**. Moving clouds can appear on the scope and be confused with targets. Clouds also absorb EM energy and reduce range. MTI can remedy this interference.

c. **Jamming**. Enemy can jam the radar set. Trained operators should be able to diagnose them and use ECM devices.

d. **Window/Chaff Dropping**. Metal/Nylon pieces of half wavelength, dropped from aircraft create confusion. Partial remedy is MTI and IFF equipment.

e. **Interference from Nearby Radar**. Radar at the same site may produce bent/twisted PPI traces when they are not synchronized. Synchronizing all radar sets at the same site can eliminate this interference. However a radar station 10 to 20 miles away may be a nuisance. Remedial action is to receive the pulse and blank the trace.

f. **Aerial Side Lobes**. As the target comes close, echo strength go on increasing resulting in false target return 180^0 opposite to the actual position of the target. Thus a 747 aircraft at 090/10 nm may also appear at 270/10 nm. It creates confusion, but experienced operators can eliminate the trouble.

g. **Anomalous Propagation**. Anomalous propagations are due to ducting, temperature inversion and other variations in the atmosphere and space. AP results in picking up of tgt beyond the normal pickup ranges. Thus when maximum pickup range of the radar is 200 nm, a target at 250 nm may appear due to AP at 50 nm from the centre.

Anti-Interference Devices

3. **Introduction**. Numerous devices may be incorporated in the design of radar to minimize the effect of clutter. These devices range from such simple circuit refinements as swept gain, which is almost invariably fitted, to more complex systems such as Moving Target Indicator and special receivers capable of dealing with discrete types of jamming. In all these devices the common approach is that of recognizing electronically some characteristic which distinguishes the wanted signals from the unwanted or vice versa. Some of the common anti-clutter features are described below:

a. **Swept Gain Control**. Clutter is worst at short ranges and diminishes along the time base, the swept gain control makes use of this fact and causes the receiver gain to be lowered at the commencement of the time base as each pulse is fired, and thereafter increase the gain exponentially with time. In this way, saturation of the receiver is avoided without the elimination of weaker signals from more distant ranges.

b. **Short Time Constant (STC)**. A differentiating circuit, which comes into operation only when there is increase in the level of incoming signals. STC reduces incoming interference by displaying only the leading edges of long pulses.

c. **Instantaneous Automatic Gain Control (IAGC)**. A fast-acting AGC circuit lowers the receiver gain 2 or 3 pulse lengths after receipt of an incoming signal. Short pulses are, therefore, unaffected and only the leading edges of long pulses are displayed.

d. **Pulse length Discrimination**. Echo signals from wanted aerial targets are mostly of 1 pulse length. Most Clutter signals are, on the other hand, more than 1 pulse length. Pulse Length Discriminator rejects a large proportion of clutter signals by rejecting those signals above 1 pulse length. Certain types of jamming may also be attenuated in this way.

e. **Pulse Interference Suppression**. This device operates on the incoming signals in such a way that only those occurring at the transmitter repetition frequency are passed to the display. It is, therefore, effective against interference from other radars operating at different PRFs and to non-synchronous pulse jamming.

f. **Moving Target Indicator (MTI)**. Any target which moves in relation to a ground radar is likely to be of interest, whereas, those which do not are normally unwanted. As the Doppler effect shifts the frequency of echoes from moving targets, this provides a powerful basis for distinguishing between wanted and unwanted targets. To recognize echoes containing a frequency shift, a coherent frequency reference must be established in the radar. When incoming signals

are mixed with this reference, the components from moving targets vary in amplitude from pulse to pulse at the Doppler frequency corresponding to the relative velocity of the target. The components of the incoming signals returned from fixed targets do not vary in frequency. The radar with the help of MTI suppresses all non-moving targets.

g. **Blind Speed**. A disadvantage of MTI is the existence of blind speed. When the component of a target's velocity towards or away from the radar is equal to either zero, half or any multiple of the blind speed, the signals returned from it will not vary from pulse to pulse with the result that they will cancel when subtracted. The lowest blind speed in an MTI fitted radar is given by:

$$\frac{\text{Wavelength (cm) x PRF (pulses per sec) (kts)}}{2 \times 10^3}$$

For example, if PRF of a radar is 400PPS, then an aircraft flying at 400kph or its multiplication such as 800kph or 1200kph, will not be picked up. If PRF is fixed and is known to the enemy, one could easily calculate all the blind speeds of the radar. An aircraft can easily avoid radar detection by flying any of the blind speeds.

CHAPTER XXI

PRINCIPLES OF SECONDARY RADAR IDENTIFICATION SYSTEM

Training Objectives. At the end of this chapter students should know:

a. Basic principles of IFF.

b. Facilities of IFF.

c. Selective Identification Feature.

d. ATC Secondary surveillance Radar.

e. Combined IFF/ATC SSR Equipment

Introduction

1. A secondary radar system consists of a transmitter/receiver (interrogator) on the ground and a transmitter/receiver (transponder) in the aircraft. The interrogator transmits an interrogation signal to the transponder, which transmits back a reply on a different frequency. Such a system is also used in the airborne for distance measuring equipment. Where rapid identification of aircraft is required either by air defense or air traffic control radars, a transponder in the aircraft is interrogated by a ground transmitter. Such systems are considered in this chapter.

2. Identification systems normally operate in conjunction with a primary radar and the two systems are complementary. Primary radar depends upon the reflection of radio signals from the aircraft whereas identification systems transmit a return signal to the ground which is independent of target size. Greater ranges can be achieved with less power because the signals from ground to air and air to ground have only to survive the one way transmission path.

3. There are two secondary radar identification systems in use; the military Identification Friend or Foe (IFF) system mainly employed with military air defence radars and the civil Secondary Surveillance Radar (SSR) system employed with air traffic control ground radars. Both systems operate in basically the same manner.

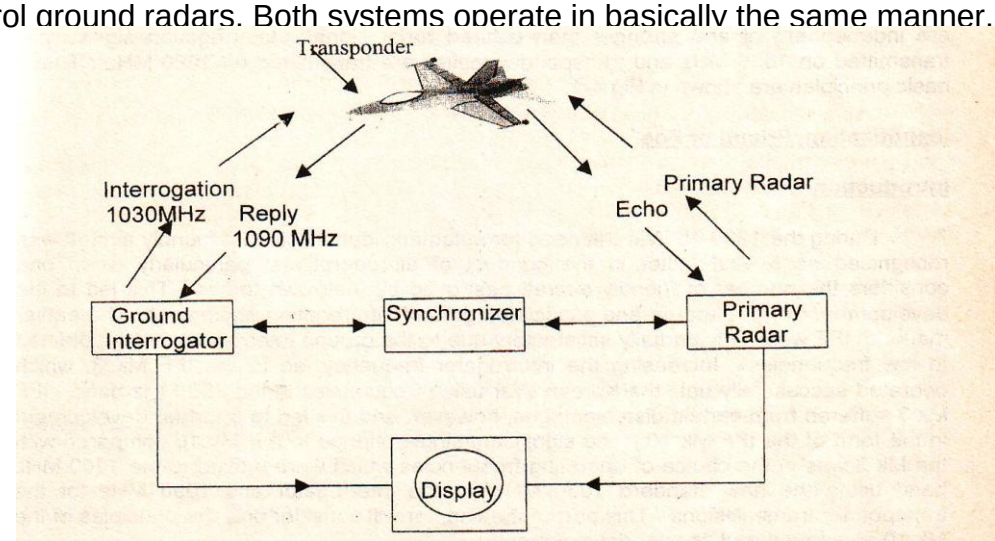

Figure 4.20: Secondary Identification and Primary Radar System

Basic Principles

4 As briefly mentioned in Para 1, ground equipment transmits an interrogation signal to the aircraft. The interrogation, or challenge, signal is received by the aircraft transponder and decoded. If the aircraft transponder is set to respond to the challenge, a signal is sent to the ground station. This signal is processed by the ground equipment and presented on a radar display.

5 **Ground Equipment**. The ground equipment consists of three major components: the interrogator unit, the aerial unit and the decoder. The major function of the interrogator is to generate distinctive RF transmissions in accordance with the type of transmission, or mode, in use. A major requirement of the system is the simultaneous presentation of secondary and primary radar information which means that both system displays must be correlated in range and azimuth. Range correlation is achieved by transmitting the interrogation signal at a preset time before the primary radar pulse to allow for processing time in the transponder and decoder although, depending on the type of ground equipment, an interrogation signal is not necessarily transmitted for every primary radar pulse. Azimuth correlation is achieved by either mounting the secondary radar aerial directly on the primary radar aerial or mounting it on its own turning gear which is servo-synchronized to the primary. The decoder accepts transponder signals and trigger signals from the interrogator. The transponder signals are processed in the decoder and then passed to the radar display either direct or via a video mixer depending on the type of primary radar equipment. In either case, the secondary radar targets and the primary radar targets are displayed close together. In practice, the secondary radar echo appears at a slightly greater range than the primary radar echo.

6. **Airborne Equipment**. The transponder is the airborne unit of the system and consists of a receiver, a signal processing unit and a transmitter. Before the transmitter' portion will reply to an interrogation, specially keyed pulses must have been received and processed. When triggered, the transmitter will emit a series of specific reply pulses which are independent of and stronger than echoed radar signals, interrogation signals are transmitted on 1030 MHz and transponder replies are transmitted on 1090 MHz. These basic principles are shown in Fig 21.1.

Identification. Friend or Foe

7. **Evolution**. During the 1939-45 War the need for automatic identification of friendly aircraft was recognized as a vital factor in the conduct of air operations, particularly when one considers the number of friendly aircraft destroyed by their own forces. This led to the development of IFF airborne and associated ground interrogation equipment. The earlier marks of IFF were only partially satisfactory due to the ground interrogator being confined to low frequencies. Increasing the interrogator frequency led to the IFF Mk 3, which operated successfully until the Korean War using frequencies in the 200 MHz band. IFF Mk 3 suffered from certain disadvantages, however, and this led to a further development in the form of the IFF Mk 10. The significant single change in IFF Mk 10 compared with the Mk 3 was in the choice of operating frequencies which were moved to the 1000 MHz band using the new standard 1030 MHz for the interrogator and 1090 MHz for the transponder transmissions. This part of the chapter will consider only the principles of the Mk 10 equipment and its later developments.

8. **Facilities**. The IFF Mk 10 airborne installation consists of a transponder, a control panel and omni directional aerial(s). (A selective coding feature is afforded by the provision of three modes of interrogation of the transponder to meet different operational requirements. In effect these modes are equivalent to three interrogation codes. By their use, specific aircraft may be identified individually. Ail three modes have corresponding reply signals. In conjunction with the associated ground equipment, the total system has the following facilities.

a. in response to selective modes of interrogation, the transponder decodes the interrogations received and replies only to those interrogators transmitting the appropriate mode.

b. A coded transponder reply referred to as an emergency signal. This is independent of the mode of interrogation and indicates that the aircraft is in distress.

c. A double coded transponder reply referred to as an identification of position (I/P) signal which provides rapid identification of particular aircraft among several operating in the same mode.

9. **Basic IFF Modes**

a. **Mode 1**. This mode is for general use. The interrogating signal consists of a pair of 1 us pulses with 3 µs spacing between the leading edges. The transponder transmits a single pulse reply to all received mode 1 interrogations and this applies even though it may also be replying to interrogators using other modes.

b. **Mode 2**. This mode is intended for detailed recognition. The interrogating signal consists of a pair of 1 µs pulses with 5 us spacing between the leading edges. The transponder replies with a two pulse signal with 16 us spacing between the pulses.

c. **Mode 3**. This mode is also intended for detailed recognition. The interrogating signal consists of a pair of 1 µs pulses with 8 us between the leading edges. The transponder reply is a single pulse, as in mode 1.

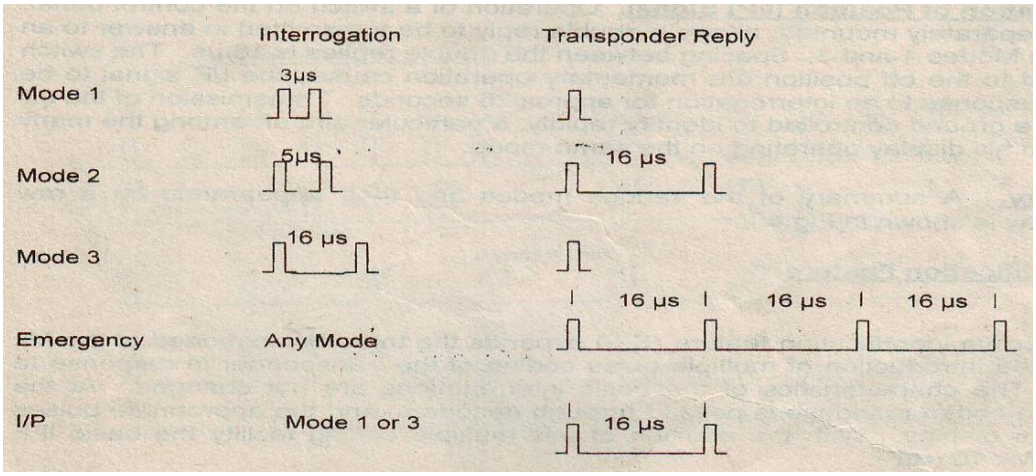

Figure 4.21: Pulse Spacing of IFF Mode

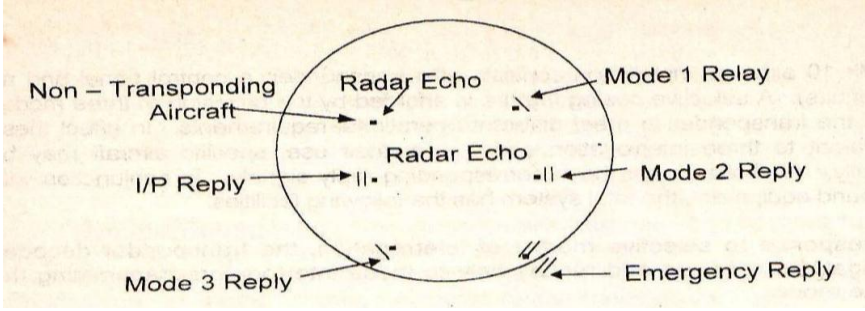

Figure 4.22 : Raw Radar Display of IFF Mode

10. **Mode Combination and Other Facilities**. The transponder can be switched to reply to the following combinations of interrogation modes. The transponder always replies to Mode 1 interrogation.

a. Mode 1.

b. Modes 1 and 2.

c. Modes 1 and 3

d. Modes 1, 2 and 3.

11. **Emergency Signal**. By operation of a switch on the control panel, the transponder can be set to radiate a characteristic four-pulse code irrespective of the mode of interrogation. The pulses are speed at 16 us intervals.

12. **Identification of Position (I/PI Signal**. Operation of a switch on the control panel or sometimes separately mounted, allows a double reply to be transmitted in answer to ar interrogation on Modes 1 and 3. Spacing between the double replies is 16 us. The switch is spring loaded to the off position are momentary operation causes the I/P signal to be transmitted in response to an interrogation for approx 25 seconds. Transmission of the i/p signal allows the ground controlled to identify rapidly, a particular aircraft among the many he may have on his display operating on the same mode.

Selective Identification Feature

13. **General**. The selective identification feature (SIF) expands the three basic modes of the mk 10 system by the introduction of multiple pulse coding of the transponder in response to interrogation, The characteristics of the basic interrogations are' not changed. At the interrogator, the coded response is passed through decoders, and the appropriate pulses are selected for display. With the addition of this multiple coding facility the basic IFF becomes IFF Mk 10 (SIF),

14. When SIF coding is added to an airborne transponder, the normal mode interrogation pulses initiate a pulse train consisting of up to 14 pulses as shown in Fig 4-3. The pulses are divided into two groups of seven, the spacing between pulses of each group being 1.45 µs and between the groups 2.9 µs. In effect, the train consists of fifteen pulses with the eighth pulse missing. The first and last pulses are known as the

frame pulses (F1 and F2) and their heading edges are separated by 20.3 µs. The frame pulses are always transmitted in reply to any mode of interrogation.

15. Between the two frame pulses there are twelve pulses positions but the number of pulses actually transmitted depends upon the code selected in a particular mode. Each of the 12 information pulses is allocated an identifying letter and a numerical value as show in Fig 21.4 so that four groups, each containing three pulses are formed. Thus the maximum unit of any letter group which can be transmitted is 7, represented by three pulses with value of 1, 2 and 4; these values being added. If all pulses of the groups are transmitted, the code 7777 is obtained. When only the frame pulses are transmitted the code becomes 0000.

16. If all 12 information pulses are used it is possible to obtain a maximum of 4096 codes. However, the Mk 10 (SIF) equipment only uses a maximum of 6 information pulses making available the following SIF codes on each interrogation mode:

a . **Mode 1**. 32 codes designated 00 to 73 by use of pulses A1 ,A2, A4,B1 and B2,

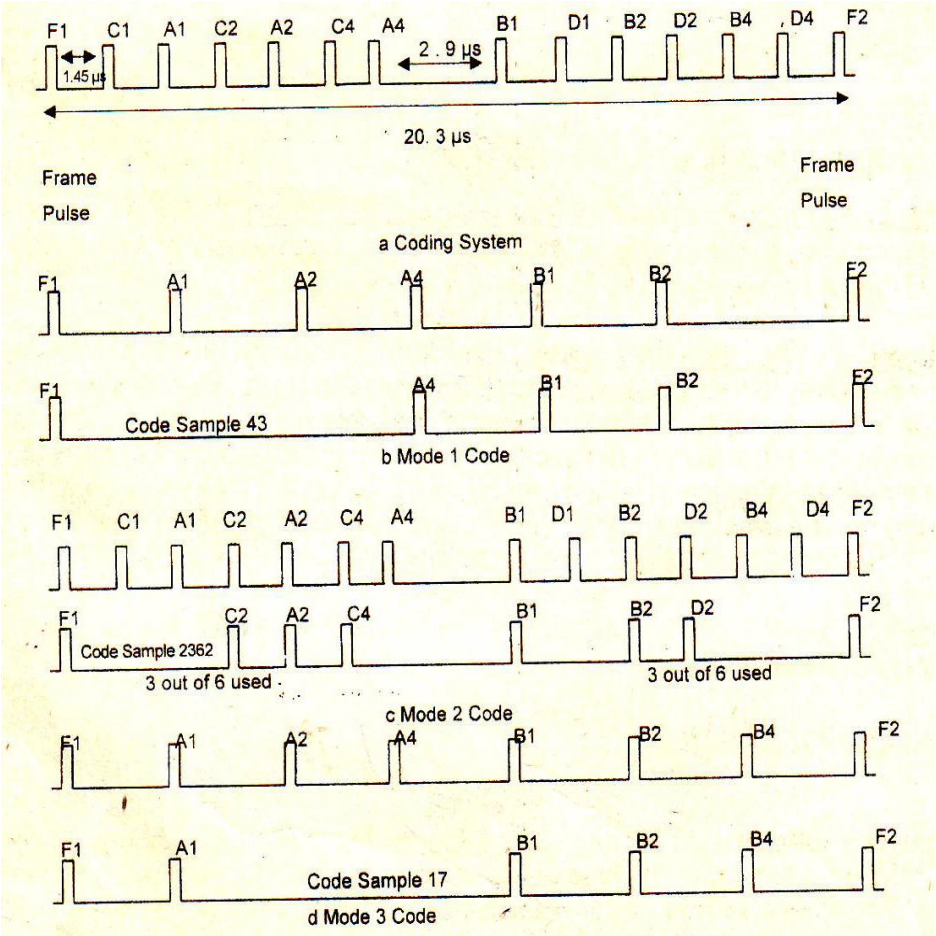

Figure 4.23: SIF Coding System and Mode Responses

b. **Mode 2**. 400 codes from the possible total of 4096 designated 0000 to 7777 by use of 3 pulses from group A and C and 3 pulses from groups B and D.

c. **Mode 3**. 64 codes designated 00 to 77 by use of pulses A1, A2, A4 and B1, B2, B4.

17. **IFF (SIF) Modes**.

a. **Mode 1**. As in the case with basic IFF, Mode 1 is used for general identification. In consequence, it normally employs a common code to be used by all aircraft, the code being changed rarely.

b. **Mode 2**. Mode 2 is the personal identification mode and aircraft are each allotted an individual code which is preset before flight. With most equipment, Mode 2 can not be set on the control panel in the cockpit but has to be set on the transponder or a separate Mode 2 coding unit.

c. **Mode 3**. Mode 3 is used for air traffic control identification i.e. it indicates the classification of an aircraft. It is usually set before fake-off but may or may not be change in flight depending on instructions from the ground.

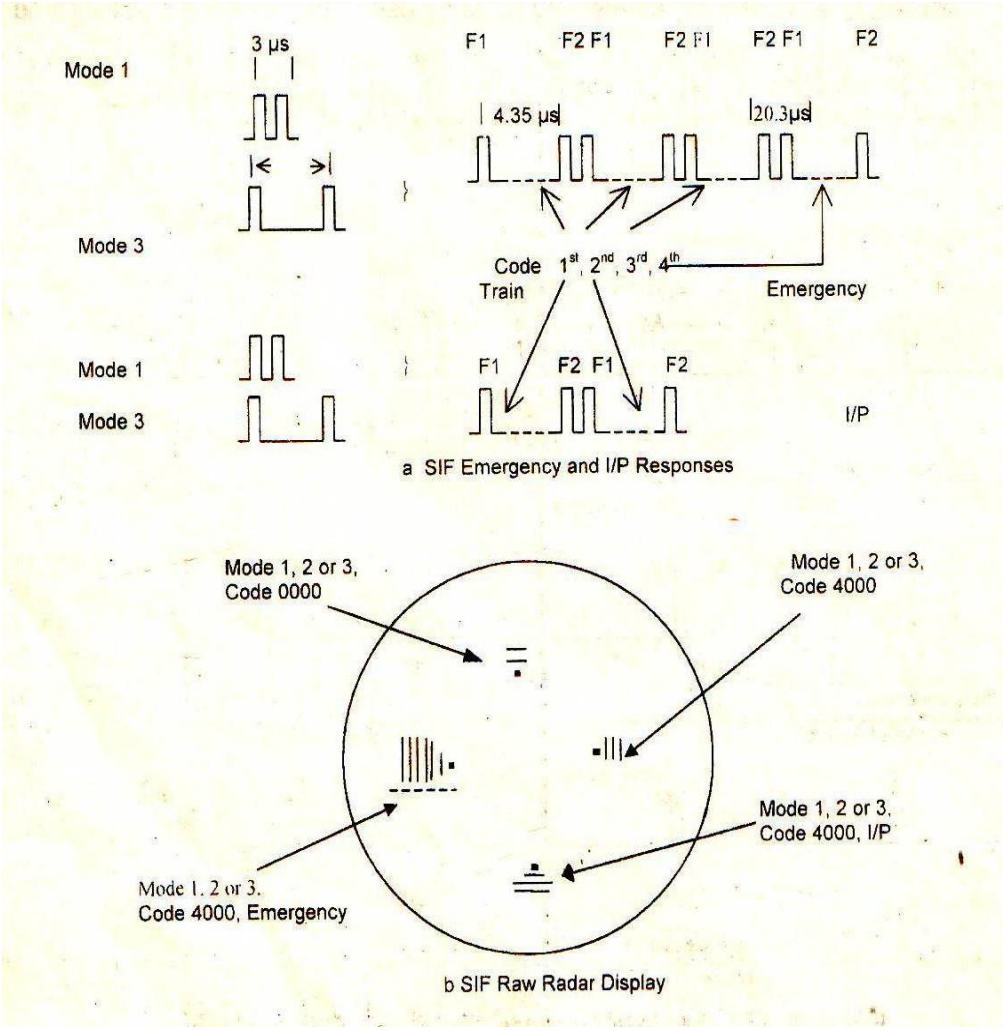

Figure 4.24: IFF (SIF) Responses and Mode Display

d. **Emergency**. The facility whereby an aircraft can transmit readily identifiable distress signal has been retained from the basic IFF system but the

method of achieving the result is different. When set to emergency, the transponder transmits four consecutive code trains for each Mode 1 or Mode 3 interrogation (see Fig-4). The ground system is so arranged that an emergency reply to a Mode 1 interrogation will appear on the display irrespective of the mode in use. Emergency signals in reply to a mode 3 interrogations however, will only be seen when the ground interrogator equipment is selected to the aircraft's Mode 3 code.

e. **I/P**. When the I/P switch is operated, a double Mode 1 or Mode 3 response is transmitted in reply to each Mode 1 or Mode 3 interrogation and will continue for approx 25 seconds after the switch is released (see Fig 4-4). As with the emergency signal the Mode 1 I/P response will appear on any ground display but the Mode 3 I/P response will only appear on the displays where the interrogator is selected to the aircraft's Mode 3 code.

ATC Secondary Surveillance Radar

18. **General**. With the increasing density of civil air transport traffic, ICAO introduced a requirement for a civil secondary radar system that could provide general, individual and functional identification of an aircraft superimposed on the position information obtained by a primary radar system. A system known as Secondary Surveillance Radar (SSR) is now in general use and it is similar to IFF and so far it employs a ground interrogator, an airborne transponder and the same interrogation and transponder frequencies of 1030 MHz and 1090 MHz. There are different interrogation modes and the system has more facilities, particularly automatic altitude reporting. IFF and SSR are only compatible on one mode.

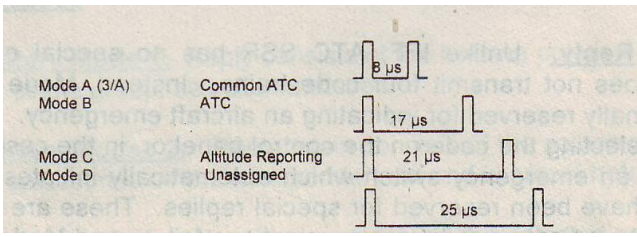

Figure 4.25: ATC SSR Interrogation

18. **SSR interrogation Modes**. SSR has four interrogation modes (see Fig 4-5) as follows:

a. **Mode A**. The interrogating signal consists of a pair of pulse 8 µs apart. This is the same as the interrogation for IFF Mode 3 and is the only mode that is compatible with both IFF and SSR. It is used as a common ATC mode and is generally referred to as Mode 3/A.

b **Mode B**. The interrogating signal consists of a pair of pulses 17 µs apart. This mode is also located for ATC identification but its use will be reviewed when there is a general availability of SS transponders incorporating the full facilities.

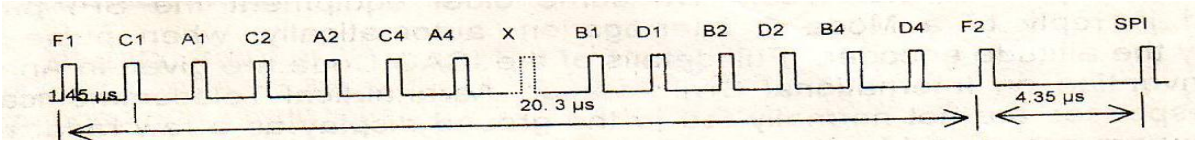

Figure 4.26: ATC SSR Transponder Reply Codes

c. **Mode C**. The interrogating signal consists of a pair of pulses 21 µs apart. This mode is used for automatic altitude reporting from an encoding altimeter.

d. **Mode D**. The interrogating signal consists of a pair of pulses 25 µs apart. This mode has not yet been assigned to any specific identification and is reserved for future expansion of the system.

19. **SSR transponder Codes**.

a. **General**. The transponder response for each ATC SSR mode is similar to the response from IFF (SIF) but all the information pulses are used i.e. the reply consists of two framing pulses F1 and F2 spaced 20.3 µs apart with up to 12 information pulses spaced at 1!45 µs between them (see paras 18, 19 and Fig 4-3a) giving a choice of 4096 codes. In addition ATC SSR has provision for a thirteenth information pulse, situated at 10.15 µs after the first framing pulse known as the X pulse, the use of which has not yet been specified. ATC SSR also has, in addition to the information pulses, a Special Position Identification (SPI) pulse which may be used with any of the modes/codes on request. It is transmitted at 4.35 µs after the last framing pulse and is normally initiated by a switch on the control panel variously labeled SPI, Ident or I/P. The full code train is shown in Fig 4-6. This SPI pulse replaces the I/P modes of IFF (SIF) ie instead of a double code train being transmitted the SPI pulse is transmitted after the code train. In a similar manner to the IFF I/P facility, it is transmitted in response to an interrogation for approx 25 seconds after the switch has been operated.

b. **SSR Emergency Reply**. Unlike IFF, ATC SSR has no special emergency transponder reply ie it does not transmit four code trains. Instead, Mode 3/A code 7700 has been internationally reserved for indicating an aircraft emergency. This code is transmitted either by selecting the code on the control panel or, in the case of some equipment, by operating an emergency switch which automatically initiates the code 7700. Two other codes have been reserved for special replies. These are Mode 3/A code 7600 which is used to indicate a radio communications failure and Mode 3/A code 3100 to indicate that unlawful interference to the flight is taking place ie skyjacking.

c. **Altitude reporting**. Mode C has been internationally agreed as the mode for altitude reporting. When selected at the control panel, the transponder, in conjunction with an encoding altimeter, will automatically reply to a Mode C interrogation with a code train giving the aircraft's height relative to a pressure datum setting of 1013.25 mbs. The altimeter contains a digitizer which, through an encoder, produces an eleven bit digital output in ICAO Gillham code which is suitable for use by the transponder The eleven bits are used to initiate eleven of the twelve information pulses of the transponder (DI is not used). A bit, and thus

a code pulse, change occurs for every 100 ft change in height. The digital code and associated pulses are shown in Fig 4-7 along with examples of their use. On some older equipment the SPI pulse is transmitted in reply to a Mode C interrogation, automatically, when pulse D4 ,s selected by the altitude encoder. Full details of the ICAO Code are given in Annex 10 to the Convention on International Civil Aviation-Aeronautical Telecommunications Mode C responses are not normally fed to the ground display as a raw radar return. Instead they are processed by the ground equipment and shown on digital flight level display or as numeric data adjacent to the primary radar target.

Bit	1	2	3	4	5	6	7	8	9	10	11
Associated Information Pulse	D2	D4	A1	A2	A4	B1	B2	B4	C1	C2	C4
eg 19.750 – 19.850 ft Digital Code	0	0	1	1	1	1	1	1	0	0	1
19.850 – 19.950 ft Digital Code	0	0	1	1	1	1	1	1	0	1	1

(0 or 1 in pulse position denotes absence or presence of pulse respectively).

Figure 4.27: Altitude Reporting Code and Transponder Replies

Combined IFF/ATC SSR Equipment

20. **General**. Because of the increasing mandatory use of ATC SSR in controlled airspace and the requirements of air defence radars for operational flights, it is necessary for some RAF aircraft to have the ability to respond to both civil and military interrogations. To avoid the need for two transponders, the RAF have adopted a combined transponder which will reply to both civil and military systems. Because of the need to combine both civil and military replies to interrogations, the responses of this equipment are slightly different from the single system IFF and SSR equipment.

21. **Normal Replies**.

a. **Military Mode 1**. Reply consists of the framing pulses and the selected information pulse in a single group; selection switches.

b. **Military Mode 2**. Reply again consists of the selected pulses train, in this mode however, selection is on the transponder unit and is preset before flight.

c. **Common Mode 3/A**. Reply consists of the selected train, selected on the control panel by a different set of code selection switches so that replies to Mode 1 and 3/A can be transmitted simultaneously.

c. **Civil Mode B**. As for Mode 3/A but can only be used as an alternative to the latter.

e. **Civil Mode C (Altitude Reporting)**. Automatic transmission of coded altitude if selected on at the control panel.

d. **Civil Mode D**. Not at present in use and would require a separate unit for code selection.

22. **Identification replies**.

a. **Military Ident Reply**. This reply is given on military Mode 1 only when the identification facility is selected. It consists of the selected information pulse train followed by a second pulse train with the second F1 pulse at 4.35 us after the first F2 pulse.

b. **Civil ident Reply**. This reply is given on military Mode 2, common Mode 3/A and civil Mode B and D (when fitted) if the identification facility is selected. It consists of a normal coded pulse train followed by the SPI pulse at 4.35 us after the F2 pulse.

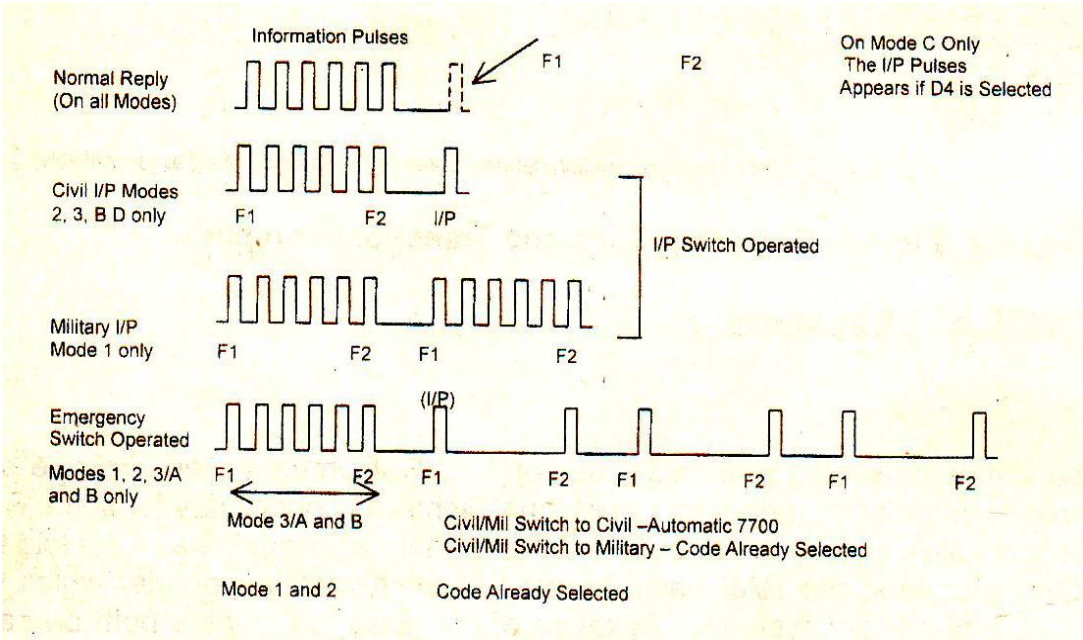

Figure 4.28: Combined IFF/SSR Transponder Replies

Note: The SPI pulse is automatically transmitted in response to a Mode C interrogation if the D4 pulse has been selected in the transponder by the altitude encoder.

23. **Emergency Replies**. Operation of the emergency facility allows an emergency reply to be transmitted on military Modes 1 and 2, common Mode 3/A and civil Mode B. This reply consists of a coded information pulse train followed by three repeats containing the framing pulses only with no information pulses. On common Mode 3/A or civil Mode B the information pulses contained within the first frame depends on the position of a civil/military emergency switch. With the switch set to Civil, the first frame consists of an automatic transmission of Code 7700. With the switch set to Military, the first frame consists of the code which is already selected. In reply to military Modes 1 and 2, the first frame consists of the selected information pulse code. No emergency reply is transmitted on civil Modes C and D. The emergency replies along with the normal and identification replies are summarized in Fig 4.28.

TOPIC- 5
ELECTRONIC WAREFARE

ELECTRONIC WARFARE

Training Objective. This chapter will enable the student Officers to know about:

a. Electromagnetic Environment and its effect on military operations.

b. Division and Role of EW in Military Operations.

c. Effects of Electronic Warfare.

Introduction

1. Military operations are executed in an information environment increasingly complicated by the electromagnetic spectrum (EMS). The EMS portion of the information environment is referred to as the electromagnetic environment (EME). Today, electromagnetic (EM) devices are increasingly used alone and in networks by both civilian and military organizations and individuals for intelligence, communications, navigation, sensing, information storage, and processing, as well as a variety of other purposes. The increasing portability and affordability of sophisticated EM equipment guarantees that the EME in which military forces operate will become more complex in the future. The recognized need for military forces to have unimpeded access to and use of the EME creates vulnerabilities and opportunities for electronic warfare (EW) in support of military operations. In joint operations, EW is one of the five information operations (IO) core capabilities.

Electromagnetic Environment

2. The term “EMS” refers to the range of frequencies of EM radiation from zero to infinity. The spectrum is divided into bands ranging from radio frequencies at the low end to x-ray and gamma frequencies at the high end. Figure 1-1 graphically depicts the EMS. The EME refers to the resulting product of the power and time distribution, in various frequency ranges, of the radiated or conducted EM emission levels that may be encountered by a military force, system, or platform when performing its assigned mission in its intended operational environment. It is the sum of electromagnetic interference (EMI); EM pulse; hazards of EM radiation to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning and precipitation static.

Military Operations and the Electromagnetic Environment

3. The impact of the EME upon the operational capability of military forces, equipment, systems, and platforms is referred to as electromagnetic environmental effects (E3). E3 refers to the impact of the EME upon the operational capability of military forces, equipment, systems, and platforms. It encompasses all EM disciplines, including EM compatibility (EMC) and EM interference; EM vulnerability; EM pulse; electronic protection (EP), hazards of EM radiation to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning and precipitation static. Equipment and systems that operate on the principles of electromagnetism are characterized by EM vulnerability. Once subjected to E3, equipment and systems that

operate within or as part of the EMS, may suffer degradation (incapable of performing the designated mission).

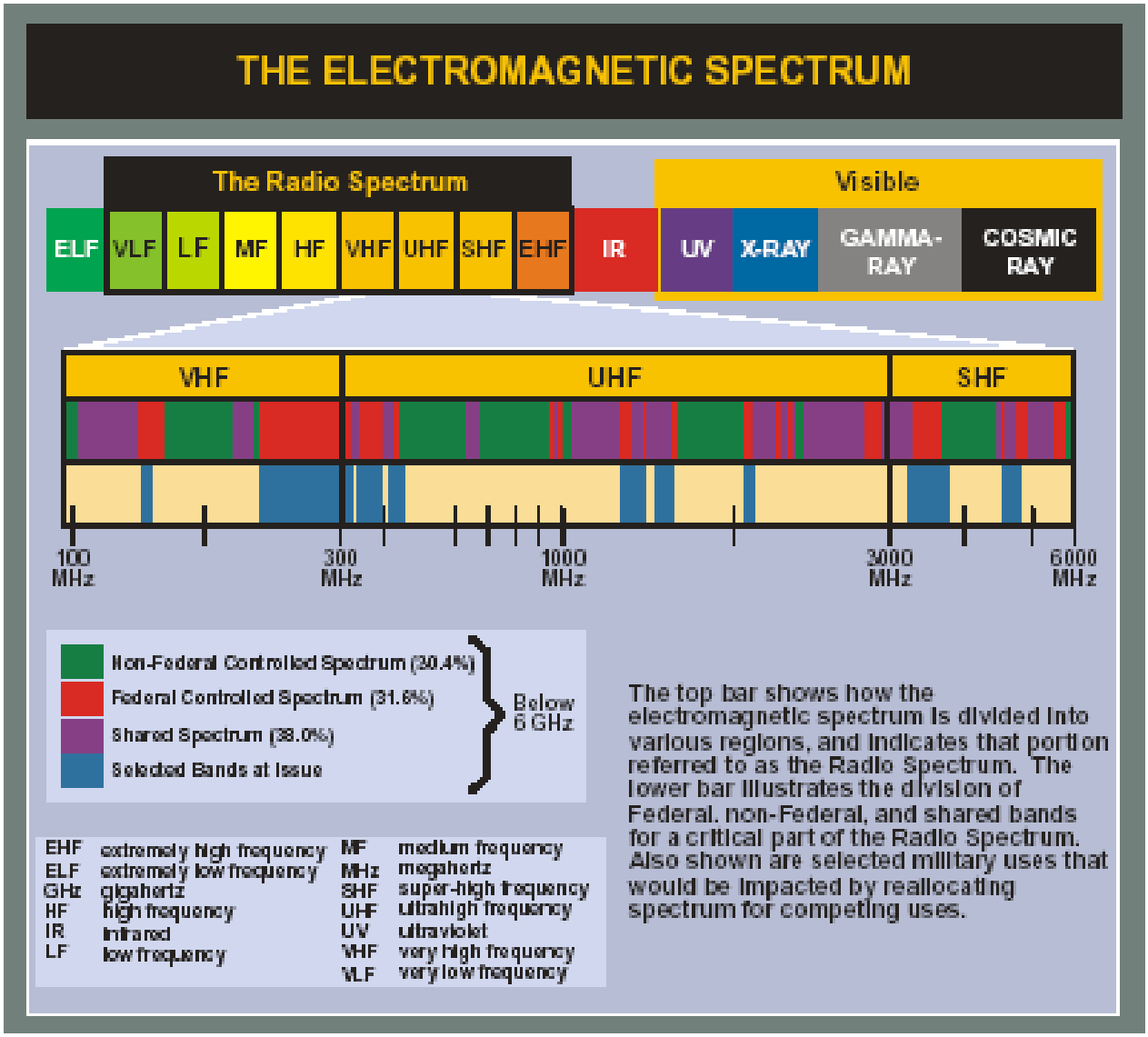

Figure 5.1: The Electromagnetic Spectrum

<u>Role of Electronic Warfare in Military Operations</u>

4. The term EW refers to any action involving the use of EM or directed energy (DE) to control the EMS or to attack the enemy. In general, it means the integration of various EW assets into overall battle plan. To be more specific, EW is the coordinated application of EW resources, each of which has particular capabilities. EW may be defined as military action to exploit the Electromagnetic Spectrum which encompasses the interception, identification and location of electromagnetic emission, to reduce or prevent hostile use of ES and action to ensure effective use by friendly forces. EW includes three major subdivisions: electronic attack (EA), EP, and electronic warfare support (ES). Figure 22.2 depicts an overview of EW, the relationships of the three subdivisions, and the relationship of the subdivisions to principal EW activities. The subsequent paragraphs discuss on them in details.

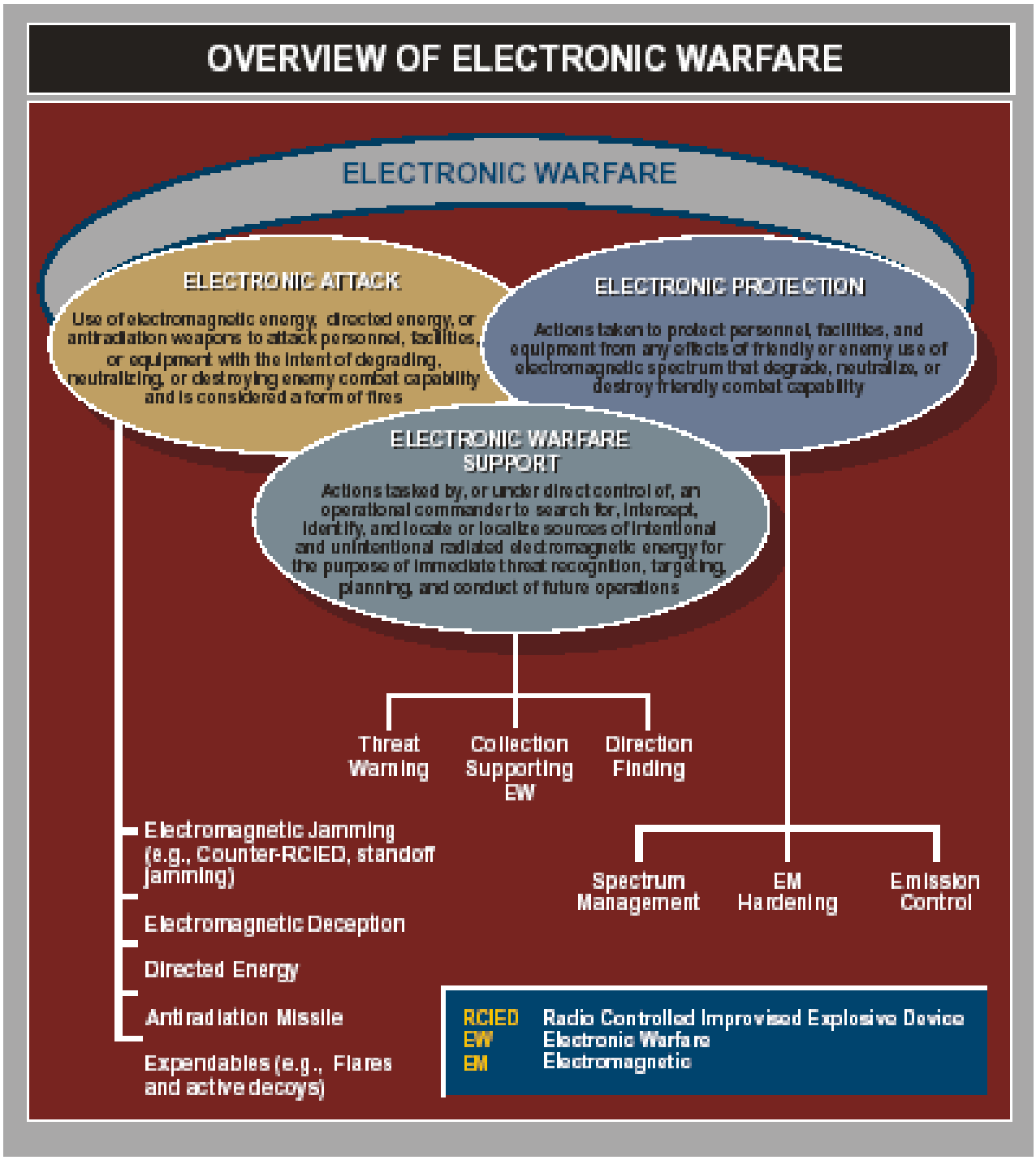

Figure 5.2: Overview of Electronic Warfare

Electronic Attack

5. **Definition and Extent**. EA is the subdivision of EW involving the use of EM energy, DE, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires. EA includes:

a. Actions taken to prevent or reduce an enemy's effective use of the electromagnetic spectrum, such as jamming and electromagnetic deception Wartime Airspace Management,

b. Employment of weapons that use either electromagnetic or directed energy as their primary destructive mechanism (lasers, radio frequency weapons, particle beams).

c. EA includes both offensive and defensive activities to include countermeasures (CMs).

d. Offensive EA activities are generally conducted at the initiative of friendly forces. Examples include jamming an adversary's radar or command and control (C2) systems, using anti-radiation missiles to suppress an adversary's air defenses, using electronic deception techniques to confuse an adversary's intelligence, surveillance, and reconnaissance (ISR) systems, and using DE weapons to disable an adversary's equipment or capability.

e. Defensive EA activities use the EMS to protect personnel, facilities, capabilities and equipment. Examples include self-protection and force protection measures such as use of expendables (e.g., flares, and active decoys), jammers, towed decoys, DE infrared (IR) CM systems, and counter Radio Controlled Improvised Explosive Device (RCIED) systems.

6. **Radar Electronic Attack**. Electronic attack (EA), commonly called jamming, is an attempt to deny an adversary the use of both radar and communications. There are two basic types of EA that radar operators face i.e. mechanical and electronic.

a. **Mechanical**. This type of EA attempts to either create false targets, or increase the amount of clutter, to the point where true targets are masked. Although the name "mechanical" may not sound like a type of EA, it is. Mechanical EA seeks to reflect the RF energy in a manner contrary to the operator's intention. Mechanical EA is accomplished through the use of chaff, rope, decoys, and corner reflectors.

(1) **Chaff**. Chaff is nothing more than thin strips of metal cut to one-half the wavelength of the targeted frequency. It can be employed to create a series of false targets, or to create a wall of clutter that can hide an attacking force. Chaff can be modified in a variety of manners to affect the rate with which it falls, the manner in which it falls, and to prevent it from tangling together. Early chaff fell at a rate of about 300 feet a minute. Modern chaff may fall as slowly as 20 feet a minute. Furthermore, modern chaff dispensers may contain chaff affecting a huge range of frequencies. Because chaff tended to bunch up and become tangled, engineers devised a way of making it more slippery, called slip coating. In slip coating, a thin veneer of lacquer is applied

to the chaff to keep the individual strips from clinging to each other. This further led to the development of ways to allow chaff to target various polarizations. This was accomplished by stream coating. In stream coating, a slightly thicker layer of lacquer to either one end, or one edge of the strip of chaff, is applied. This has the affect of changing the way the chaff falls in the vertical or horizontal plane. Rope is a type of chaff that is, simply stated, a long piece of chaff. Rope is required when the target radar is of unusually low frequency, such as the "Tall King" family of the Former Soviet Union (FSU).

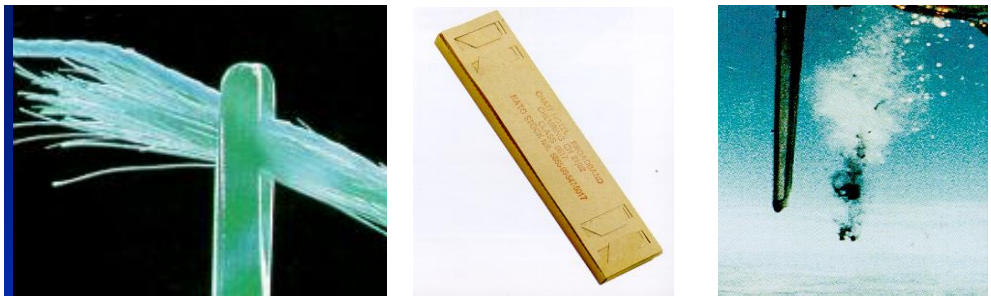

Figure 5.3: Chaff

(2) **Decoys**. The concept of decoys is probably the most obvious form of EA. Sending out false targets that mimic the performance characteristics of a known threat aircraft is a fundamental way of causing an adversary to waste resources or time. A classic example of the decoy is the USAF Quail missile. The Quail originally designated the GAM-72, is an air-launched decoy missile, carried by the B-52 strategic bomber. Designed to produce radar image very similar to that of the B-52, and to fly at approximately the same speed and altitude, the Quail would b;, used during an actual bombing attack to confuse an enemy's defensive radar network. With both and B-52s penetrating the enemy's airspace, it would be difficult for him to distinguish one from the other on his radar. Corner reflectors are a type of decoy, in that they may be used to increase the amount of RF energy reflected by an object. This would allow someone to mimic buildings and other landmarks that a radar navigation system may be programmed to follow, and thus lead the system (such as a cruise missile) off course.

Figure 5.4: Decoy

b. **Electronic**.

(1) **Definition**. The electronic portion of EA attempts to deliberately radiate, reradiate, or alter electromagnetic radiation in a way that would mislead an adversary in the interpretation of information received by his system. This is known as jamming and causes spurious data to saturate the radar's processing capabilities. This results in the loss of true targets, hiding the existence of targets in jamming "noise," or the generation of system displays known as strobes. In most computerized systems where the operator does not have access to "raw" or analog data from the radar receiver, strobes are a type of symbology displayed along the azimuth of the jammer to alert the operator to the presence of jamming. The strobe symbology serves to indicate a signal that has broken the amplitude threshold for the receiver along the displayed azimuth (Figure 22.5). Strobe symbology appears as radial lines emanating from the radar origin down the azimuth occupied by the jamming platform. Jamming can be broadly classified as Noise Jamming and Deception Jamming.

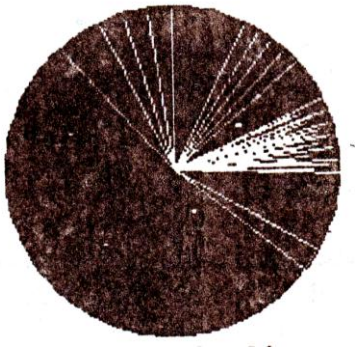

Figure 5.5: Strobing

(2) **Noise Jamming Analysis**. Jamming may even present fake indications resulting in the display of "ghost" targets on a radar console. The aim of noise jamming Aim is to deny position data to threat systems. This is achieved by inserting a strong jamming signal into the victim radar’s receiver. The stronger jamming signal will mask weaker target signals. At low power levels, noise jamming denies or degrades range information. At high power levels, noise jamming can also deny or degrade angle information (Figure 22.6).

(a) (b)

Figure 5.6: Degrading Range (a) and Angle (b) Information

To effectively make noise Jamming following information are required:

(a) Know the victim radar's frequency.

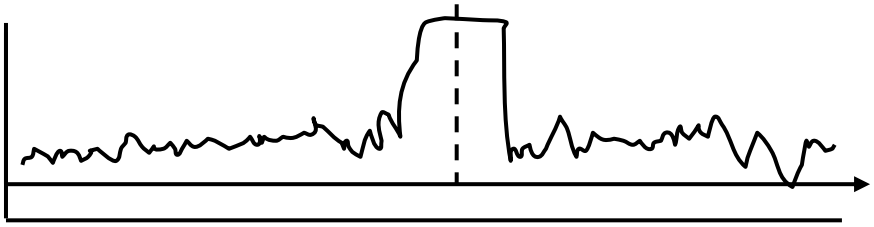

Figure 5.7: Radar Frequency Information

(b) Know the victim radar's bandwidth.

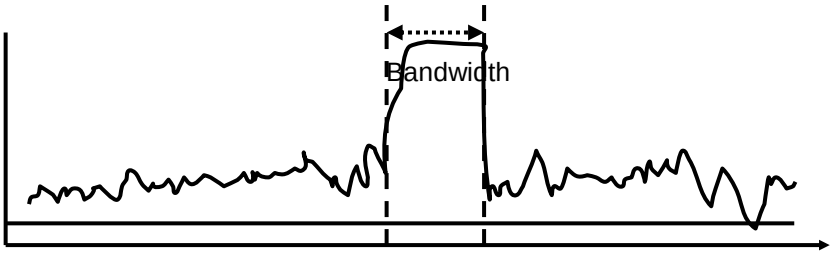

Figure 5.8: Radar Bandwidth Information

(c) Have sufficient jamming power available.

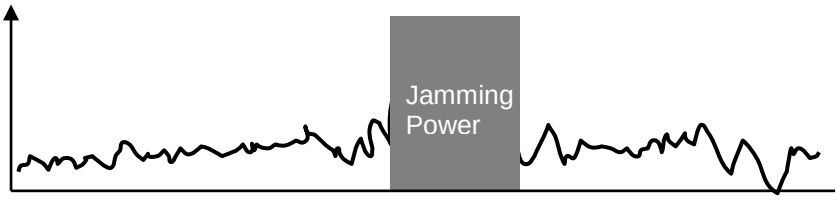

Figure 5.9: Jamming Power Requirement

(3) **<u>Jamming Entry Points</u>**. The noise jamming enters through side lobe and main lobe. If an extremely powerful noise jammer is used noise will enter side lobes as well as the main lobe. This will Increase the unusable sector of the radar display.

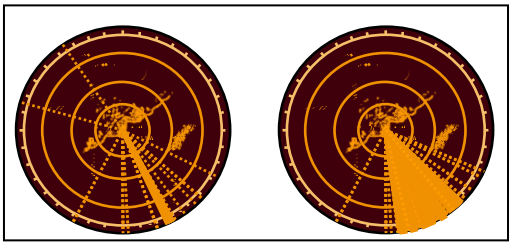

Figure 5.10: Main Lobe Jamming

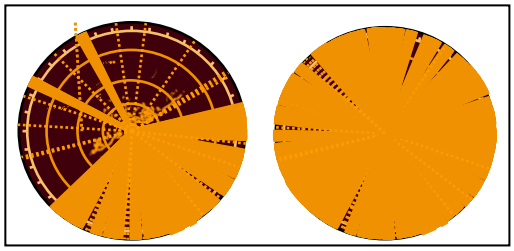

Figure 5.11: Side Lobe Jamming

(4) **Noise Jamming Classification**. The main types of jamming are spot, sweep, and barrage.

(a) **Spot Jamming**. One technique of jamming where the EA aircraft transmits a heavily concentrated beam of RF energy at the enemy radar on the same frequency as the radar (Figure 22.12). Against a particular radar, the jammer can choose to wait until the radar antenna rotates to an azimuth that presents a side lobe, instead of jamming the main lobe of the antenna. After spot jamming into the side lobe, the jammer can then stop transmitting until the antenna again rotates to the same azimuth. The jammer uses this cyclical jamming technique in an attempt to avoid being located by ground radars using triangulation tactics.

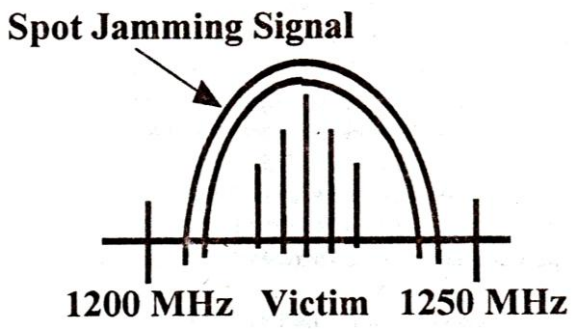

Figure 5.12: Spot Jamming

(b) **Sweep Jamming**. When a jammer broadcasts a high gain signals on one frequency at a time and then rapidly changing the frequency so that the jamming is "swept" across numerous frequencies in rapid succession. Sweep jamming combines the advantages of spot jamming, high power on a single frequency, and barrage jamming, broad coverage, by sweeping a single narrow jamming signal across a range of frequencies. This process results in a high power jamming signal that remains in place for a short time (Figure 22.13). The amount of time spent on each frequency, and the amount of time until the frequency is targeted again, is a factor of the sweep rate of the jammer and the frequency range being targeted. This allows a jammer to use high power and still cover more than one frequency. This type of spot jamming is commonly employed against modern multiple frequency capable radars.

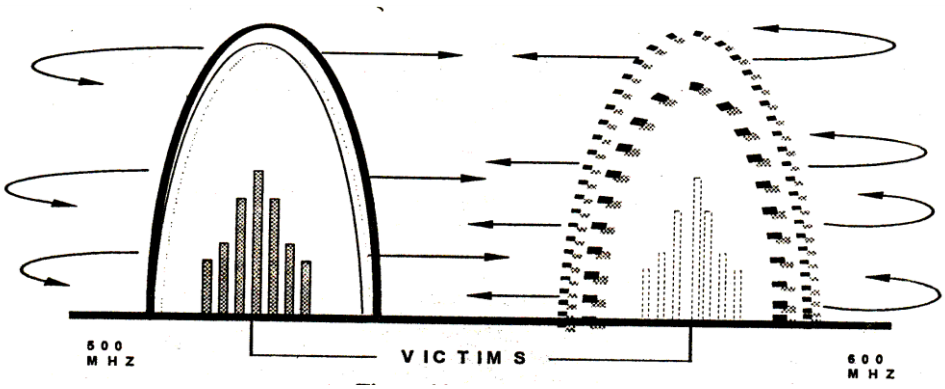

Figure 5.13: Sweep Jamming

(c) **Barrage Jamming**. An attempt to deny the use of a broad portion of the EM spectrum by simultaneously jamming entire frequency range (Figure 22.14). The disadvantage of barrage jamming is the power of the jammer is spread over the entire width of the frequency band, unlike a spot jammer, which focuses all its power on one specific frequency.

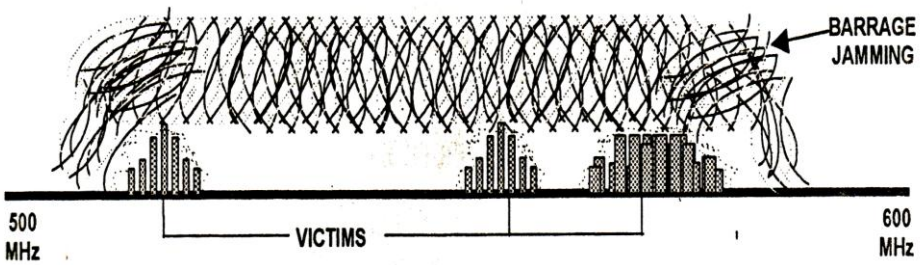

Figure 5.14: Barrage Jamming

(5) **Deception Jamming**.

(a) **Definition**. When a jammner analyzes a potential victims radar signal, so that specific pulses, mimicking those of the victims radar, could be inserted for the purpose of generating false targets, without the victim operator being able to detect that jamming is indeed occurring. This may be done by repeating the received radar pulse exactly as received, with slight time delays, to deny true range information, or by modifying its characteristics to affect azimuth and range of the introduced false targets. Advantages of Deception Jamming are:

i. The radar is not always alerted to the fact that its receiver is being jammed.

ii. This is tactically advantageous.

iii. Less power is needed for deception jamming.

iv. Allows power to be shared between different radar threats on different frequencies.

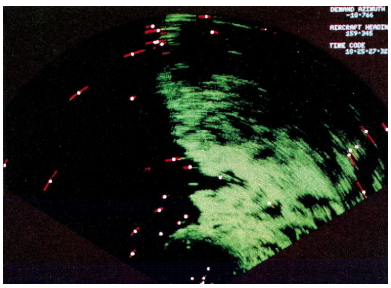

Figure 5.15: Deception

(b) **Types**. Deception jamming is of two types:

i. **False Targets Generators**. It is used against long-range search radars. It injects false targets into the receiver and causes saturation in the radar receiver. Thereby, the operator requires tracking many objects. However, it is Difficult to place false targets at required position within radar's search area. To make false targets appear believable to signal processing is also difficult. Moreover it requires same parameters as radar signal.

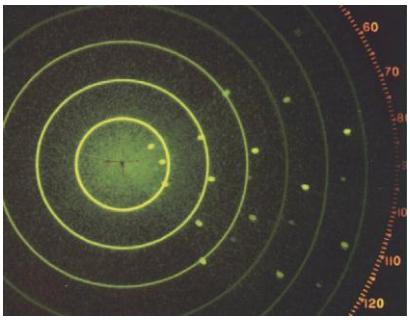

Figure 5.16: False targets

ii. **Track Breakers**. Track breakers pass false parameters to the victim radar. It causes loss of radar lock and the targets need to be reacquired. Thereby, it buys time for aircraft.

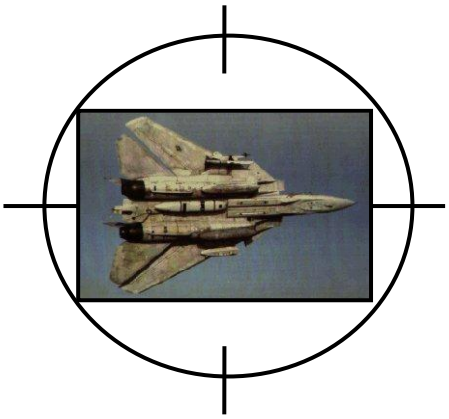

Figure 5.17: Track Breakers

7. **Communication Electronic Attack**. Another important area of EW is communications jamming. It has been used extensively ever since WWII. EA in communications has two varieties: noise and spoofing. Voice communications jamming, done from airborne or ground locations, transmits noise or false information on the victim's voice frequency, with the intent of disrupting an adversary's ability to communicate with their forces. One of the more effective techniques used by the enemy is tape recorder playback.

a. **Noise**. Instead of trying to deceive the enemy, other forms of communications jamming overload voice channels. This type of

communications jamming capitalizes on the sensitivity of the radio receivers used for voice communications. Noise jamming sounds like intense radio static, music, wavering, or solid tones and is extremely difficult to hear through.

b. **Spoofing**. An attempt to deceive the intended victims by interjecting voice communications on the targeted frequency. There are two types of spoofing, live or recorded playback. During the Korean conflict, the North Koreans monitored air-to-ground voice transmissions and tape-recorded directions given by controllers to fighters. As the fighters approached an enemy target, the enemy simply switched on the recorder to a previously taped transmission by the same controller, causing the fighter to turn away from the target at a critical point. Live spoofing attempts to accomplish the same goal by using live controllers, making real time inputs over the frequency.

Electronic Protection

8. **Definition and Extent**. EP is the subdivision of EW involving actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the EMS that degrade, neutralize, or destroy friendly combat capability. Examples include spectrum management, EM hardening, emission control (EMCON), and use of wartime reserve modes (WARM).

a. EP includes actions taken to ensure friendly use of the EMS, such as frequency agility in a radio, or variable pulse repetition frequency in radar.

b. EP should not be confused with self-protection. The use of flare rejection logic on an IR missile to counter an adversary's use of flares is EP. The flare rejection technique ensures friendly use of the EMS to track the intended target despite the adversary self-protection/defensive EA actions (i.e. the flare) to prevent or reduce friendly use of the EMS. While defensive EA actions and EP both protect personnel, facilities, capabilities, and equipment, EP protects from the effects of EA (friendly and/or adversary), while defensive EA is primarily used to protect against lethal attacks by denying adversary use of the EMS to guide and/or trigger weapons.

9. **Radar Electronic Protection**. Electronic protection (EP) is the attempt to retain use of the EM spectrum in an EA or jamming environment. There arc several EP elements that we use to reduce the effects of jamming. The most critical of these is the operator. The operator must be familiar with the EP features of the equipment they are using and the impact that each of these has on operations. The features commonly used to counter radar jamming are often called fixes. Fixes may be applied to either the transmitter fix, the receiver fix or die antenna fix.

a. **Transmitter Fixes**. Transmitter fixes allow for radar transmitter output characteristics to be changed to enhance target detection and tracking despite EA. These changes can be to the frequency, pulse, or the power.

(1) **Frequency Agility**. Frequency agility is the ability of radar set to be tuned rapidly from one frequency to the next. The use of frequency agility can be very effective against a manually tuned spot jammer, or low power barrage jamming, by operating on the "least

jammed" frequency. However, the use of frequency agility initiates a game of cat and mouse between the jammer and the radar operator, in which the radar operator jumps to new frequencies, only to have the jammer follow and begin jamming again. In this game, the faster the frequency changes can be made and the wider the band can be made, the more effective it becomes as an EP technique.

(2) **Power Add**. Increasing the power to the radar's transmitter will obviously result in more powerful echoes that may be easier to "see" through jamming. Operating the transmitter at maximum power has its disadvantages: recover time and pre-trigger time are both increased, reducing actual listening time. Other radar features may also have to be sacrificed. Beam shaping may be dropped... without it, target altitude cannot he determined.

(3) **Pulse Compression**. Pulse compression, similar to pulse coding, is a technique that entails special processing to improve EP capability in a jamming environment. EP pulse compression varies the frequency within the pulse, instead of the phase, as is used to improve range resolution. - Frequency coding also has two types; up-chirp, frequency increases throughout the pulse, and down-chirp, frequency decreases throughout the pulse. Since a jammer cannot duplicate the changes within an individual pulse, the received signal from a jammer will be very different from a radar echo. By comparing the received signals to the transmitted pulses, the jamming signal can be discarded while the echo can be accurately displayed to the operator. The increased average power of such a long pulse will also help increase the burn through range.

(4) **Staggered PRF**. Another method of varying the signal is through staggered PRF. Deception jammers rely on the ability to mimic transmitted pulses in order to introduce false targets. By changing the timing of the pulses transmitted, jammers must attempt to match an ever-changing signal. False targets can then be separated from actual returns by comparing received pulses to transmitted pulses for proper PRF matching.

(5) **Increased Pulse Duration**. By increasing the pulse duration, the average power of the pulse is increased, allowing for increased burn through at the expense of range resolution.

b. **Receiver Fixes**.

(1) **Gain Control**. A receiver's function is to amplify a received signal and present it for processing. This means that the echo must be stronger than the atmospheric noise (signal to noise ratio) in the vicinity of operations. In a jamming environment, the echo must be stronger than the jamming signal (signal to jamming ratio) in order to be received and displayed. When this is the case, the gain of the receiver may be reduced to prevent the jamming signal from being processed as a valid return. This is known as manual gain control. By reducing the gain on the receiver, range may be limited, or system sensitivity may

be reduced, resulting in degradations that may be exploitable by the jamming force. Other methods deal with the side lobes of the radar.

(2) **Side Lobe Cancellation**. Side lobe cancellation has a separate omni directional antenna and receiver system to use for comparison of returns. The reference antenna will have a gain slightly higher than the gain from the strongest side lobe. Returns from the side lobe reference antenna are compared to returns received from the main beam. The canceller works by putting the main and side lobe signals 180 degrees out of phase and adding them together. If the returns are the same amplitude, then the return must have come from the side lobe(s) and is discarded.

(3) **Side Lobe Blanking**. Side lobe blanking uses the same comparison situation as side lobe cancellation, but instead canceling, a blanking gate turns off a main receiver, actually blanking the return. Actual targets in the main lobe can be lost due to blanking. If the interfering signal is of short duration (pulsed), side lobe blanking is effective because it only blanks for a short period of time. Side lobe blanking is intended for use against pulse interference from the side lobes.

10. **Communication Electronic Protection**. Maintaining communications in an EA environment is essential to continuing the mission. In an EA environment, radar may not be the only RF energy targeted. Obviously, our communications may also be jammed. As in radar EP, there are a number of techniques that an operator may employ to defeat communications jamming. Among these techniques are: chatter mark, brevity, simulcast, authenticators, and using anti jam radios. Most communications EP techniques are only temporary fixes to the problem.

a. **Chatter Mark**. Chatter mark procedures are prebriefed steps radio operators will take to overcome the effects of radio communications jamming. A chatter mark plan may include directions to switch frequencies in a specified sequence. Chatter mark often will include directions to employ other communications EP techniques. The point here is that the timing and implementation criteria are spelled out PRIOR to a mission, so that when if jamming is encountered during the mission, everyone knows what to do and when to do it.

b. **Brevity**. The concept of brevity reflects taking radio/telephone (RT) discipline and procedures to their highest level. Obviously in a world with limited communication frequencies, the concept of "get on and get off' is important. In other words, get on the frequency, say what you need to say, and get off the frequency so that someone else can have access to the frequency. Brevity works by shortening standard communications to standard brevity code words. Brevity code words will be introduced in later blocks of training.

c. **Simulcast**. This communications EP technique is designed to prevent the enemy from knowing you are aware of his jamming. In simulcast, at least two separate frequencies are used to broadcast and receive information on. By doing this, when an adversary ceases jamming long enough to see if you are still on the targeted frequency, he may simply continue jamming that frequency without even knowing you are successfully communicating on another frequency.

d. **Authenticators**. Authenticators are based on the challenge/reply concept. Most authenticators are structured on matrix format and the challenges and replies change based on time.

e. **Anti-Jam Radios**. The use of anti-jam systems, such as HAVE QUICK which uses frequency-hopping techniques, can be very effective in an EA environment, but requires pre-planning to ensure everyone is on the same sheet of music.

Electronic Warfare Support (ES)

11. **Definition**. ES refers to that division of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated EM energy for the purpose of immediate threat recognition, targeting, planning and conduct of future operations. ES data can be used to produce signals intelligence, provide targeting for electronic or destructive attack, and produce measurement and signature intelligence (MASINT). ES Measures provide vital electronic warning, Surveillance information to Battle Crews and Commanders. ESM are used for the following purposes:

a. Identifying enemy AD systems for targeting.

b. Provide threat recognition for tactical decisions

c. Provide threat recognition to initiate ECM.

d. Provide programming data for EW systems

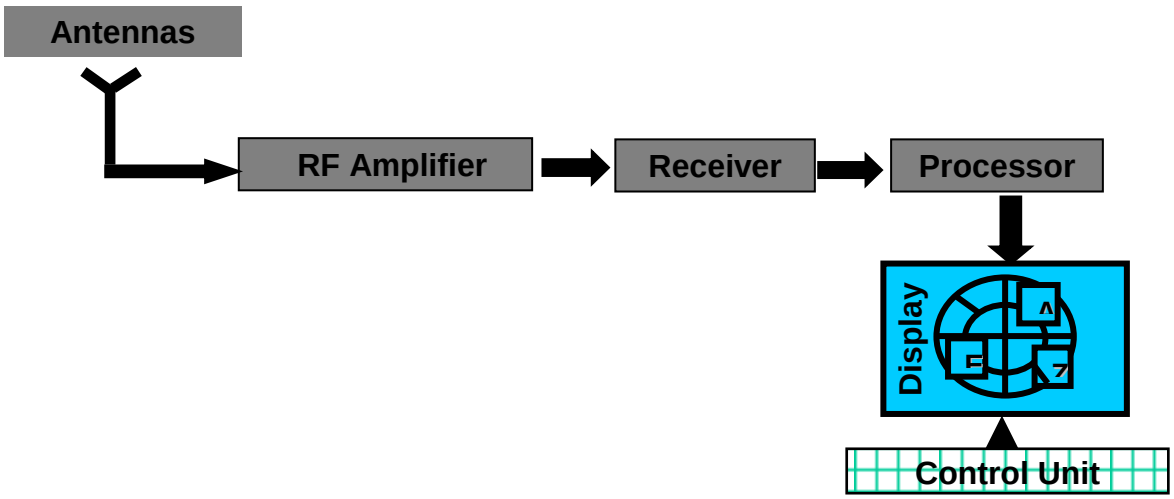

Figure 5.18: ESM System Structure

12. **ESM Process**. ESM devices can be operated from ground and air by receiver through antenna. It enables the operator to find out the enemy's use of electronic spectrum. During this time two types of receiver are being used for effective search. These are: wide open receiver and complex receiver. Complex receiver is further divided into two parts for specifying enemy's actual area of using electronic spectrum. Thus, the operator follows necessary electronic attack profile to mitigate enemy's electronic attack. ESM process can be summarised in following ways:

a. Receives pulses from radars in scenario

b. Measures parameters of these radars.

c. Use the parameters to de-interleave pulses.

d. Identify the emitters.

e. Present information to the operator.

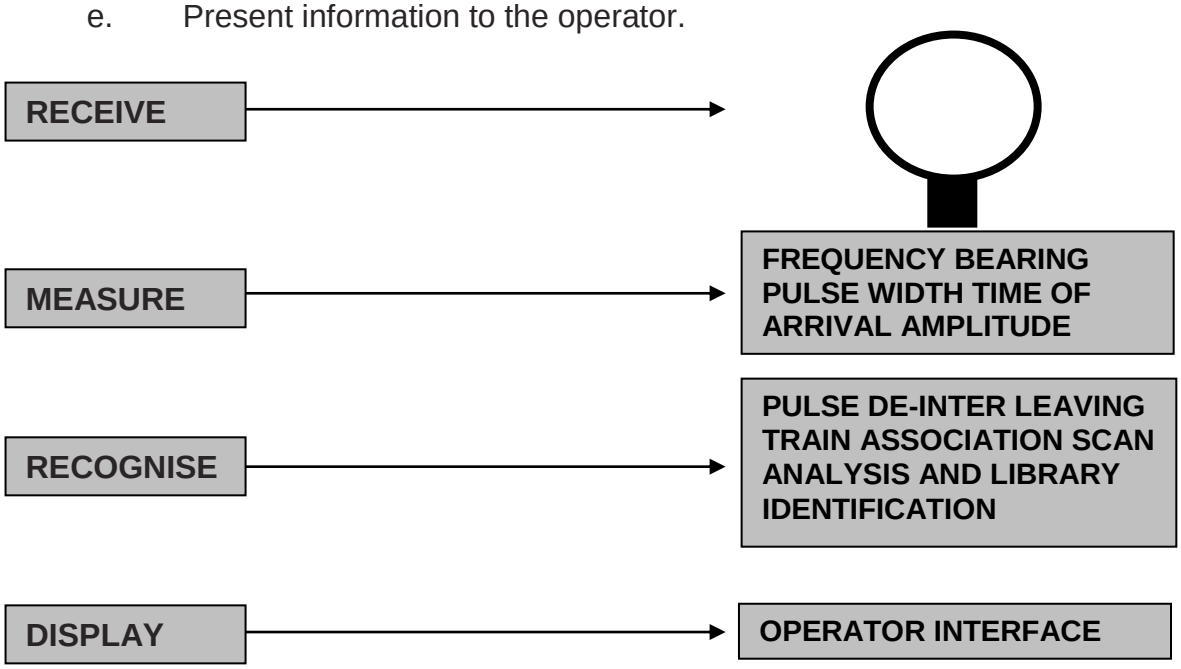

Figure 5.19: ESM Process Diagram

Effects of Electronic Warfare

13. EW is waged to secure and maintain the freedom of action in the EM environment for friendly forces and to deny the same for the adversary. The purpose is to deny the opponent advantage in the EMS and ensure friendly unimpeded access to the EMS portion of the information environment. EW can be applied from air, sea, land, and space by manned and unmanned systems. While control of the EMS through the application of EW is advantageous, when EW is not properly integrated and coordinated, it may adversely affect friendly forces. EW is employed to support military operations involving various levels of control, detection, denial, deception, disruption, degradation, protection, and destruction. EW can further affect the operational environment by influencing the leaders and population.

a. EW is vital throughout the shape, deter, seize initiative, dominate, stabilize, and enable civil authority phases of an operation or campaign. During the shape and deter phases, ES assets contribute to the overall understanding of the battlefield. A judicious commander may employ EW to implement favorable intelligence preparation of the operational environment without prematurely crossing the threshold to conflict. The potential to employ nondestructive and non-lethal capabilities make EW assets vital to the preparation of the operational environment. Using EW, joint forces may set the conditions for combat when imminent, and prosecute the attack once combat is underway. The ability to achieve an objective through nondestructive means may allow a more rapid transition from seizing the initiative and the dominate phase to support operations in the stabilization phase. From stabilization to enabling civil authority, EW can foster restorative operations by offering options such as force protection through ES to monitor subversive elements, EA to counter RCIEDs, or broadcasting selected psychological operations (PSYOP) or civil defense messages to assist civil authorities.

b. EW applications in support of homeland defense are critical to deter, detect, prevent, and defeat external threats such as: ballistic missiles, aircraft (manned and unmanned), maritime vessels, land threats, hostile space systems, and cyber threats. In many cases, ES is the only method of detection and EA can dissuade or even defeat enemy attacks on the homeland.

c. In deterrence, as in other mission areas, the role of EW goes beyond simply being available to support potential combat operations. EW, as a core IO capability, supports shaping adversaries' perceptions, morale, and unit cohesion. EW applications applied toward deterrence can sever lines of communications, logistics, C2, and other key functions while simultaneously protecting friendly capabilities. The physical presence of EW assets (e.g., airborne ES platforms) as well as enabling freedom of navigation activities can reinforce the deterrent message.

d. **Control**. Control of the EMS is achieved by effective management /coordination of friendly systems while countering adversary systems. EA limits adversary use of the EMS; EP secures use of the EMS for friendly forces; and ES enables the commander's accurate estimate of the situation in the operational area. All three must be carefully integrated to be effective. Additionally, commanders should ensure maximum integration among EW, communications, ISR, and other IO capabilities.

e. **Detection**. Detection is the active and passive monitoring of the operational environment for radio frequency, electro-optic, laser, IR and ultraviolet EM threats. It is the essential first step in EW for effective exploitation, targeting, defensive planning, and force protection. Friendly forces must have the capability to detect and characterize interference as hostile jamming or unintentional EMI.

f. **Denial**. Denial is controlling the information an adversary receives via the EMS and preventing the acquisition of accurate information about friendly forces. Degradation can be done by traditional jamming techniques, expendable CMs, destructive measures, or network applications on a limited basis up to complete denial of usage.

g. **Deception**. Deception is confusing or misleading an adversary by using some combination of human produced, mechanical, or electronic means. Through use of the EMS, EW manipulates the adversary's decision loop, making it difficult to establish an accurate perception of objective reality.

h. **Disruption and Degradation**. Disruption and degradation techniques interfere with the enemy's use of the EMS (e.g., counter-C2) to limit their combat capabilities. This is achieved with electronic jamming, electronic deception, and electronic intrusion. These enhance attacks on hostile forces and act as force multipliers by increasing adversary uncertainty, while reducing uncertainty for friendly forces. Advanced EA techniques offer the opportunity to nondestructively disrupt or degrade adversary infrastructure.

j. **Protection**. Protection is the use of physical properties, operational tactics, techniques, and procedures, as well as planning and employment processes to ensure our use of the EMS. This includes ensuring that joint offensive EW activities do not electronically destroy or degrade our intelligence sensors and/or communications systems. Protection is achieved by component hardening, EMCON, frequency management/deconfliction, and employing other means to counterattack and defeat adversary attempts to control the EMS. Frequency management/deconfliction includes the capability to detect, characterize, geolocate, and mitigate EMI that affects operations. Additionally, structures like a joint force commander's (JFC's) electronic warfare staff (JCEWS) or electronic warfare coordination cell (EWCC) enhance EP through deconfliction of EW efforts.

k. **Destruction**. When used in the EW context, destruction is the elimination of targeted adversary's systems. Sensors and C2 nodes are lucrative targets because their destruction strongly influences the enemy's perceptions and ability to coordinate actions. EW, through ES, supports destruction by providing target location and/or information. Adversary systems that use the EMS can be destroyed by a variety of weapons and techniques, ranging from conventional munitions and directed energy weapons to network attacks. While destruction of adversary equipment is an effective means to deny the adversary use of the EMS, the duration of denial will depend on the adversary's ability to reconstitute.

l. **EW and the Levels of War**. EW plays a role at the tactical, operational and strategic levels of war. Jamming an early warning radar, for example, has effects on all of the levels of war. Tactically, it affects cueing of engagement systems. Operationally, it affects the adversary's ability to mass and synchronize forces. Strategically, it prevents senior leadership from maintaining a coherent picture of the national security environment. The value of EW is fully manifested only when commanders consider and employ capabilities across the operational environment.

m. **Effects of EW in Space Control**. Space control is enabled by EW or those efforts to ensure freedom of action in space. EA may be used to deny an enemy freedom of action in space by preventing the C2 of space assets or by preventing or negating the ability to use space systems and services for purposes hostile to national security interests. ES may be used to maintain awareness of the location and status of friendly and adversary space assets. Finally, EP aids in the protection of space capabilities of national interest from adversary interference.

n. **EW Delivery**. EW effects can be generated from a variety of platforms including, but not limited to:

(1) Aircraft (manned and unmanned fixed wing and rotary)
(2) Ground (fixed sites, vehicles, and troops)
(3) Ships (surface and subsurface)
(4) Space

In many cases, techniques and equipment that work in one arena will provide similar success in disparate environments. The same techniques and equipment for isolating the battle space may be applicable regardless of whether the target is on land, at sea, airborne, or in space.

References:

1. United States Joint Publication 3-13.1 dated 25 January 2007
2. USAF Précis of International Air Weapon Controller Course (IAWCC -30104), 2002.