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An illustrated overview of ESM and ECM systems

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An Illustrated Overview of ESM and ECM Systems

by

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13. ABSTRACT *(Maximum 200 words)*

This thesis gives an overview of electronic support measures (ESM) and electronic countermeasures (ECM) systems. The objective is to give the intended reader, students of the EW curriculum new to the subject, an introduction to several different electronic warfare systems. The thesis consists of seven chapters discussing different areas of EW. The first two chapters introduce the reader to the definitions of EW and the threat which EW equipment is designed to counter. The following two chapters are a presentation of typical ESM and ECM systems. The final three chapters cover the integration of ESM and ECM systems as well as two subjects, suppression of enemy air defense and directed energy weapons, which differ from the typical ECM systems. Included with each chapter describing systems is a conclusion section which discusses possible future developments for the group of systems.

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This thesis gives an overview of electronic support measures (ESM) and electronic countermeasures (ECM) systems. The objective is to give the intended reader, students of the EW curriculum new to the subject, an introduction to several different electronic warfare systems. The thesis consists of seven chapters discussing different areas of EW. The first two chapters introduce the reader to the definitions of EW and the threat which EW equipment is designed to counter. The following two chapters are a presentation of typical ESM and ECM systems. The final three chapters cover the integration of ESM and ECM systems as well as two subjects, suppression of enemy air defense and directed energy weapons, which differ from the typical ECM systems. Included with each chapter describing systems is a conclusion section which discusses possible future developments for the group of systems.

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE

This tutorial is written with two main purposes:

- First to be an introduction to ECM and ESM systems for the students of the EW curriculum and among them especially the international students.

- Second to give the author the possibility to investigate a broad spectrum of systems.

B. STRUCTURE

This tutorial categorizes equipment using the traditional definitions, some systems described fall outside the old EW definition but are included by the new, wider definition. For each group of equipment there is a short presentation including a description of the techniques involved. One or more typical systems for the group are discussed. At the end of each chapter are the author's conclusions about the systems described and the trends for the future in that area. These conclusions are based both on discussions with people from the industry but mostly from the facts amassed during the work for this tutorial.

The information for this unclassified tutorial has been collected from three main sources:

- Open literature, books and magazines.

- Visits to conferences and exhibitions.

- Information from the industry.

Because of military and economical considerations many details about the systems configuration and performance are secret and have not been made available to the author for inclusion in this tutorial. Also, because the width of the subject many in-depth details about different systems and technologies have been left out and the reader is recommended to refer to the sources listed in the tutorial for further information.

The written tutorial is accompanied by five videos from manufacturers of different systems and by a bank of computerized pictures which either can be shown using Microsoft Powerpoint or turned into viewgraphs.

II. BACKGROUND

A. ELECTRONIC WARFARE

Electronic warfare (EW) has traditionally been divided into three categories:

- Electronic Support Measures (ESM).
- Electronic Countermeasures (ECM).
- Electronic Counter-Countermeasures (ECCM).

To this group has been added signal intelligence (SIGINT) which in many ways is similar to ESM but has a longer time perspective.

The general definitions have been:

EW - Military action involving the use of electromagnetic energy to determine, exploit, reduce or prevent hostile use of the electromagnetic spectrum and action which retains friendly use of the electromagnetic spectrum.

ESM - Actions taken to search for, intercept, locate and immediately identify radiated electromagnetic energy for the purpose of immediate threat recognition and the tactical employment of forces. Direction finding of radios and radars is an ESM technique.

ECM - Actions taken to prevent or reduce the enemy's effective use of the electromagnetic spectrum. ECM includes jamming and electronic deception.

ECCM - Actions taken to ensure friendly use of the electromagnetic spectrum against electronic warfare. [Ref. 1]

These definitions have been under review and the Joint Chiefs of Staff Operations Directorate has suggested the following new definitions:

- Electronic Combat (EC).

- Electronic Protection (EP).

- Electronic Warfare Support (EWS).

EC includes either electromagnetic or directed energy to attack the entire list of possible targets with the intent of degrading, neutralizing or destroying enemy capabilities. EC is the offensive part of EW and is replacing ECM.

EP replaces ECCM and is the protection of friendly forces against friendly or enemy employment of EW.

EWS replaces ESM and comprises the collection actions primarily geared toward tactical support of the joint force commander. This definition of EWS is more orientated toward collection so combat threat warning systems will probably rather be a part of EC. [Ref. 2]

The difference between the old and the new definitions is mainly that the new ones emphasize the use of EW as an offensive weapon, the old definitions were more reactive. The new definitions also clearly includes directed energy weapons as EW.

B. THE THREAT TO COUNTER

The purpose of this chapter is to give a description of the possible threat to which different platforms could be exposed. This description is expressed in general terms and is not intended to be an operational evaluation but rather a summary of the technical capabilities represented by modern weapon systems. The chapter discusses those parts of the threat arsenal that can be countermeasured by EW-systems at the protected platform. The main threat against the platforms of ground, naval and airborne forces are identified and discussed.

1. Ground Forces

The ground forces main platform is the armored vehicle (AV) which includes both the armored fighting vehicle (AFV) and the main battle tank (MBT). The main threat against the AV is the anti tank guided missile (ATGM); depending on the terrain in which the AV operates the threat from ATGM can come from air launched or surface launched systems. The ATGM guidance system can operate using either IR/EO, radar, TV or laser technologies. The threat against the AV also includes direct fire from tanks using laser range finder and thermal sights. Artillery and mortars firing guided munitions are also an increasing threat with both IR and millimeter wave (MMW) seekers being used (see Figures 2-1 and 2-2).

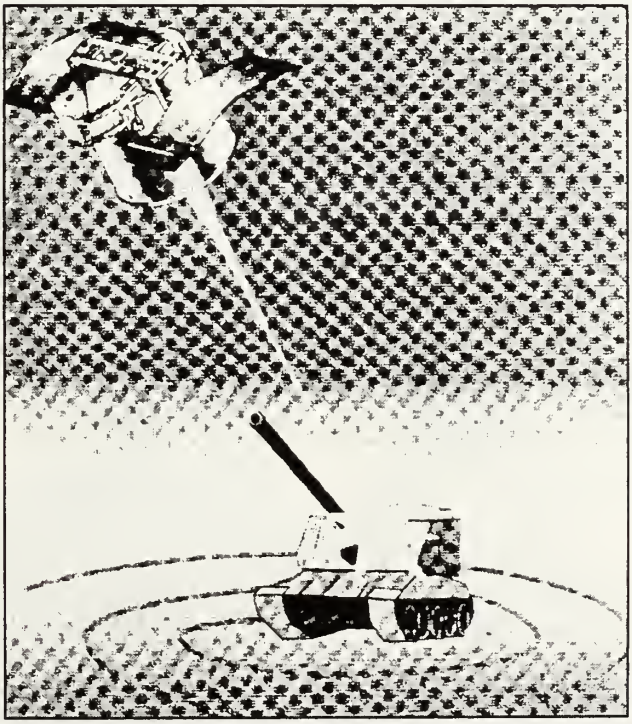


Figure 2-1. BONUS Guided Artillery Sub-Munitions

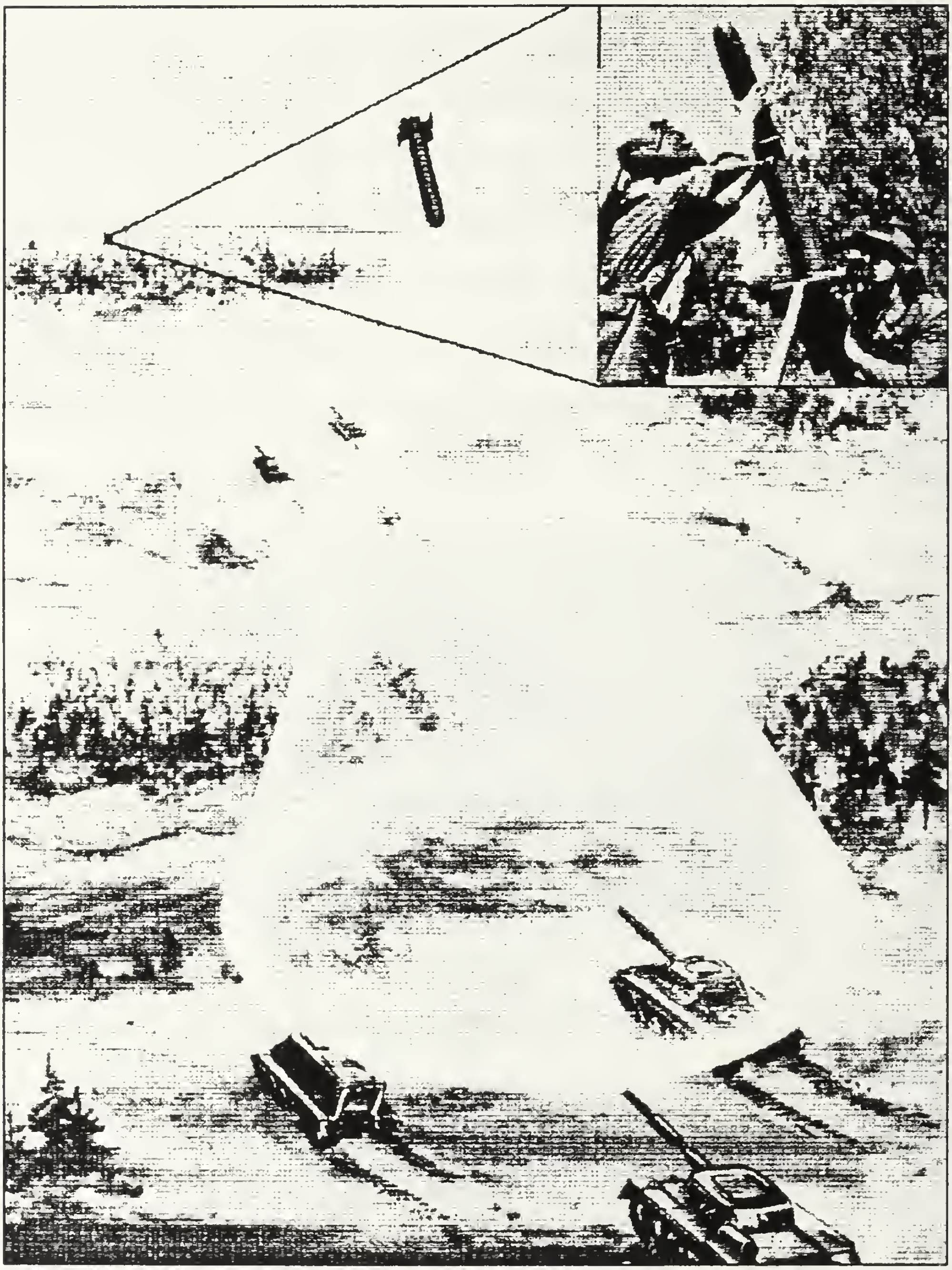


Figure 2-2. STRIX IR Guided Mortar Munitions

2. Naval Forces

The main threat against ships continues to be the anti-ship cruise missile (ASCM). An example of a modern ASCM is the follow-on to the Exocet. The original Exocet is a subsonic sea-skimming missile while the one in development will be capable of Mach 2.0-2.5, with an increase in range from 65 km to 180 km. Some of the larger Russian ASCM's are capable of even higher speeds but then their mode of attack will not be sea-skimming but instead a step dive toward the target. Modern ASCM's will also be equipped with better ECCM and could include multiple sensors such as radar and IR seekers. The times the missiles are transmitting will also decrease which, together with the increased speed, reduces the time for defensive reactions. When a navy operates close to shore there will also be a threat from weapons using laser designators and IR guided missiles as well as from land based ASCM (see Figure 2-3). [Ref. 3, Ref. 4]

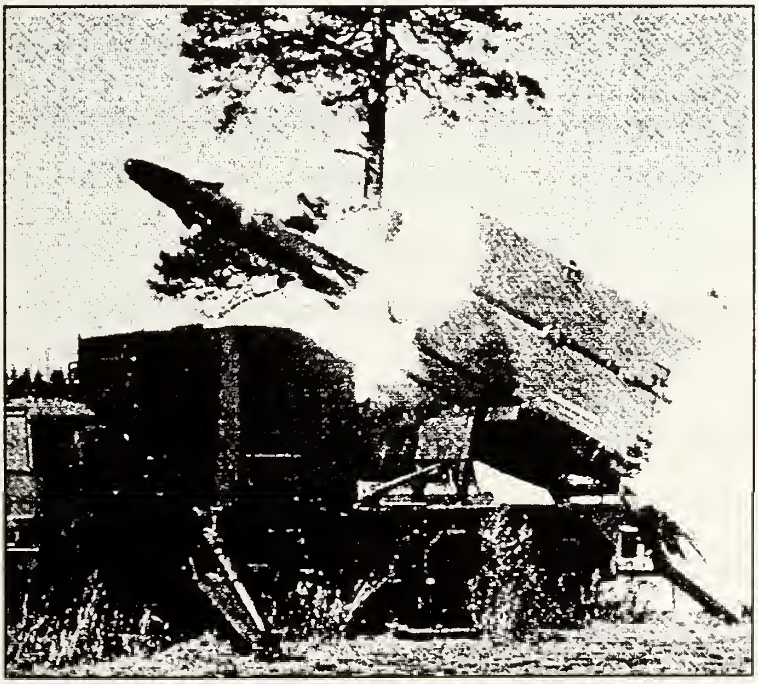


Figure 2-3. Land Based ASCM

3. Air Forces

The main threat against aircraft is missiles, radar or EO/IR guided, air or surface launched. Most aircraft losses in modern conflicts have been caused by IR guided missiles and often the pilot has been unaware of the attack until impact. The IR missiles is being improved by taking advantage of progress in detector and seeker area. Modern IR missiles are not limited to target the aircraft's hot parts, this gives the missiles ability to attack from all aspects. Modern IR-missiles will also have seekers which work in multiple bands which makes deception with flares more complicated. Combinations of RF and IR seekers will also be possible. [Ref. 5]

4. Radar

Radar has been in use since world war II, first for surveillance but later also for guidance of weapon systems. Radar systems have traditionally been the main antagonist for EW systems in a continuous measures - countermeasures race. Some of the latest radar challenges to EW systems are described below:

- Monopulse radar using a single pulse for angle determination which makes deception techniques used against conical scan radars obsolete.
- Low probability of intercept radars, using either spread spectrum, waveform coding or pulse compression, which will challenge the ECM receivers detection sensitivity.
- Pulse repetition frequency and carrier agility which limits the effective generation of noise or false targets.
- High pulse repetition frequency which creates a very dense pulse environment and places high demands on radar warning receivers (RWR) (the largest problem is not necessary pulses from enemy radar but instead friendly emission from adjacent battle areas).

- Phased array antennas which give an opportunity to instantaneously switch the beam, it is also possible to introduce sidelobe blanking. This will make identification by scan rate obsolete and sidelobe blanking will make sidelobe jamming to mask a platform in another direction much more difficult. [Ref. 6]

For further information about radars the reader is referred to specific radar literature.

5. Laser

The threat from weapon systems using lasers has increased rapidly during the last decades. Today lasers are used in several different functions in weapon systems (see Figure 2-4). The most important applications of lasers in weapon systems include:

- Rangefinders: Range information is provided to fire control systems.
- Designators: the target is illuminated by a laser and the missile homes in on the radiation reflected from the target.
- Beamriders: the laser is pointed at the target and the missile uses a rear detector to follow the beam to the target.
- Blinding systems: intense radiation is used to cause temporary blinding of personnel and sensor damage (see Chapter VII. High Energy Beam Weapons).

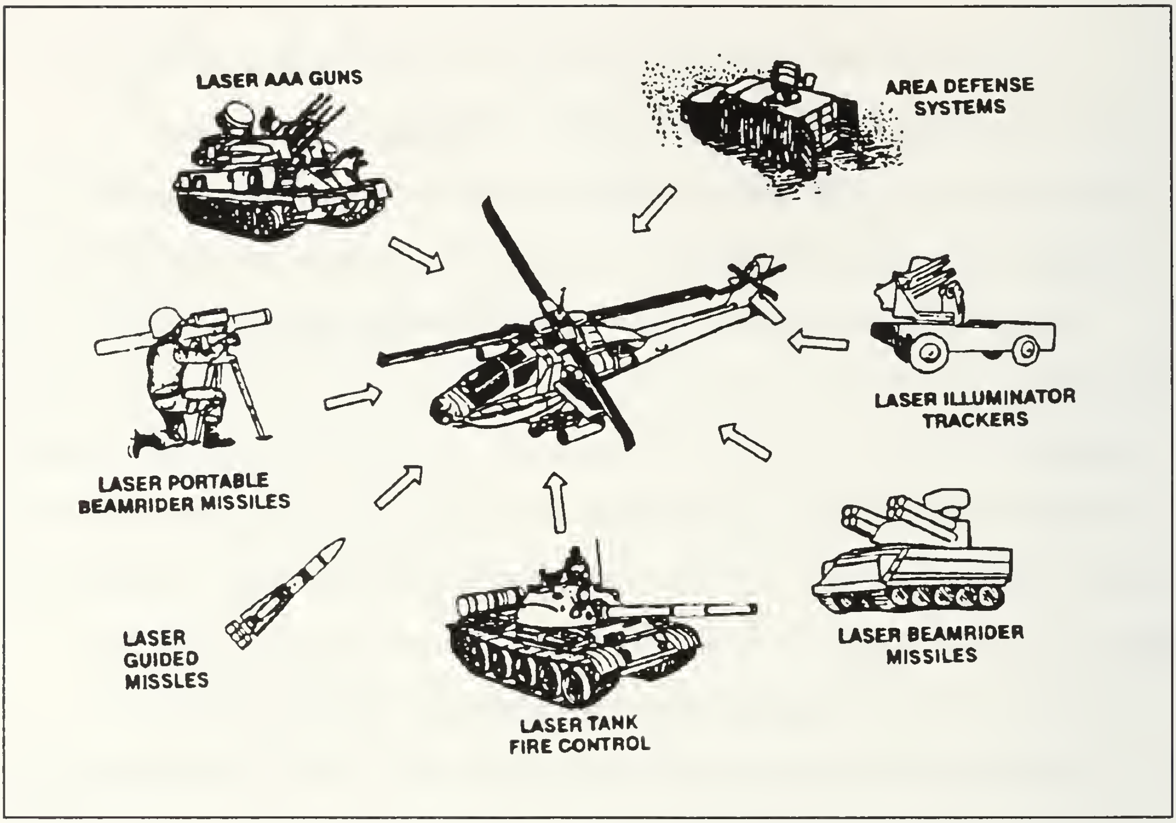


Figure 2-4. Weapon Systems Using Lasers

6. Infrared

Systems utilizing IR radiation are today in use for both detection and guidance purposes. So far IR has had its greatest impact in missile seekers and in sights. With the use of new detector materials today's missile seekers are able to detect longer wavelengths. The effect of this development is that the IR-missiles are not limited to homing in on hot objects such as the engine exhaust but instead can attack from a wider range of engagement angles. There has also been a change in the techniques used by the seekers since the first IR-missiles appeared in the early 60's (Figure 2-5). The first IR-missiles were equipped with a chopping reticle which made it possible to reject the background. The next generation of seekers used a small field of view to scan the area of interest. With the development of the focal plane array (FPA) technology it is today possible to build staring seekers. The modern seekers constructs a image of the target and by using a microprocessor the system is able to discriminate the target from the background. The advanced IR seekers are not susceptible to some of the countermeasures used against reticle based systems. [Ref. 5) For further information about IR-radiation see Appendix B.

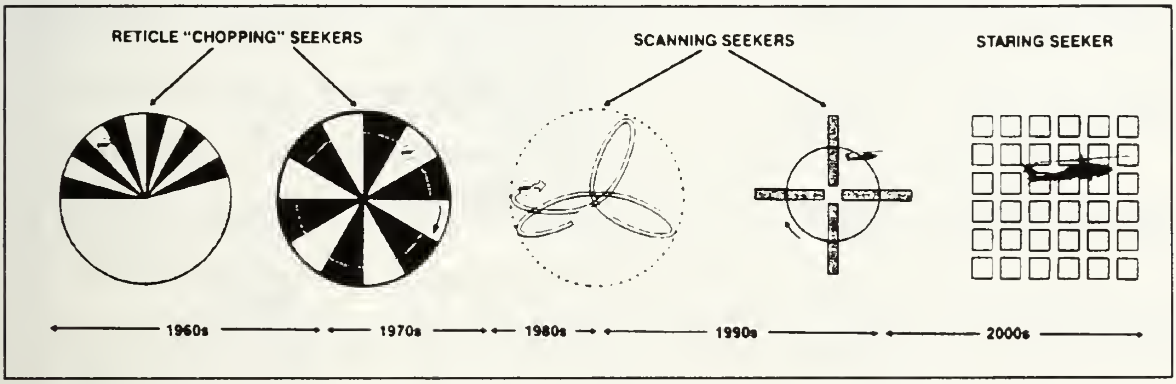


Figure 2-5. Development of IR Seekers

7. Summary

Table 1 gives a summary over the importance of different threats against different platforms.

TABLE 1. SUMMARY OF THREATS AGAINST DIFFERENT PLATFORMS

Threat/Platform	Ground vehicle	Ship	Aircraft
Radar guided missile	Low	High	High
Laser guided missile	High	Low, except at close ranges	Medium
IR guided missile	Medium	Medium, as part of a multi sensor anti-ship missile	High
Laser rangefinder	High	Low	Medium, from anti aircraft artillery (AAA)
IR/EO sights	High	Low	Medium, from short range missile systems and AAA.
Surveillance radar	Low	High	High

III. ELECTRONIC SUPPORT MEASURES

The purpose of ESM is to search, intercept, locate and identify sources of enemy radiation. The information acquired by ESM is used for threat recognition and deployment of countermeasures. ESM differs from electronic intelligence (ELINT) by being limited to systems which react in real-time.

ESM is divided into two broad categories:

- Warning systems operating in real time and used mainly for self protection.
- Reconnaissance/surveillance systems operating in near real time and used to update the local electronic order of battle (EOB), for ECM deployment and in some cases also to give information about target location for launch of missiles. [Ref. 1]

The border between the two categories is not distinct and it is common that the warning systems are called RWR while the reconnaissance/surveillance systems are referred to as ESM systems.

The ESM system normally consists of the following:

- Antennas.
- Receivers.
- Signal processor.
- Computer with emitter library.
- Display unit.

Different approaches regarding the antennas are used to determine the direction to the emitter. By using several antennas, normally four, with separate receivers the direction can be determined by comparing the amplitude from the different receivers or by comparing the time on arrival. The direction can also be found by using a directional antenna which is rotated. There are also special direction finding antenna arrangement like the Rotman lens (see SLQ-32).

A. ELECTRONIC SUPPORT MEASURES RECEIVERS

The receiver is that part of the system which has the largest influence on the characteristics of the ESM system. There are several different receiver approaches to achieve the desired characteristics for the system. Below is a short description of the most important ESM receivers followed by a table describing the different system's characteristics.

1. Crystal Video Receiver (CVR)

The CVR consists of a frequency multiplexer, detectors, log video amplifiers (see Figure 3-1). The multiplexer splits the input signal spectrum into bands where it is detected and amplified.

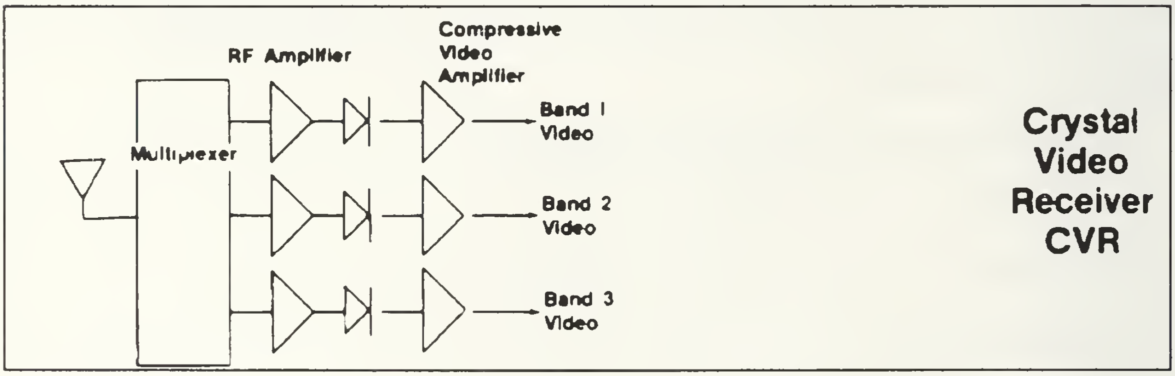


Figure 3-1. Crystal Video Receiver

2. Tuned RF Receiver (TRF)

The TRF is an improved CVR, a computer controlled filter is put in front of the crystal video detector. The filter can be switched in or out and improves the receivers sensitivity by noise bandwidth reduction and limiting of extraneous signals. The TRF is a good receiver in a low density environment due to its narrow bandwidth.

3. Superheterodyne Receiver (SHR)

In the SHR the incoming frequency is translated down to a lower intermediate frequency (IF) before detection (see Figure 3-2). This lower frequency renders possible filtering and amplification which cannot be performed at the higher frequency. This gives the SHR higher sensitivity and better frequency selectivity than the CVR.

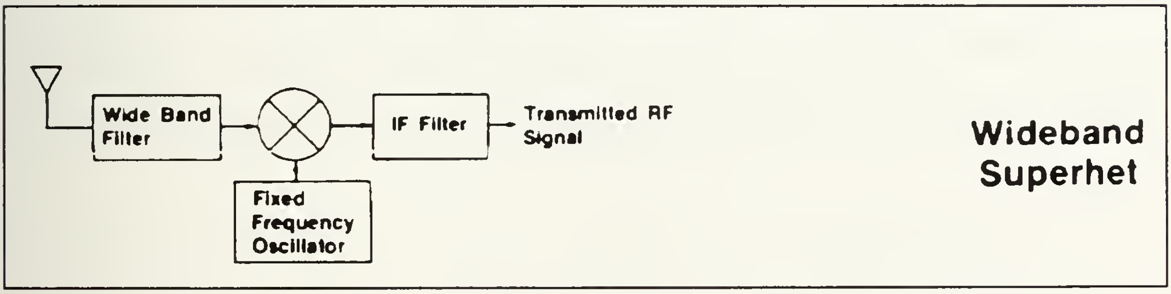


Figure 3-2. Superhetrodyne Receiver

4. Instantaneous Frequency Measurement Receiver (IFM)

The IFM receiver divides the incoming signal into two paths (see Figure 3-3). By delaying one of the signals a phase shift will occur that is a function of the input frequency. The two signals are fed into a phase correlator and an envelope detector which converts the phase difference into frequency information.

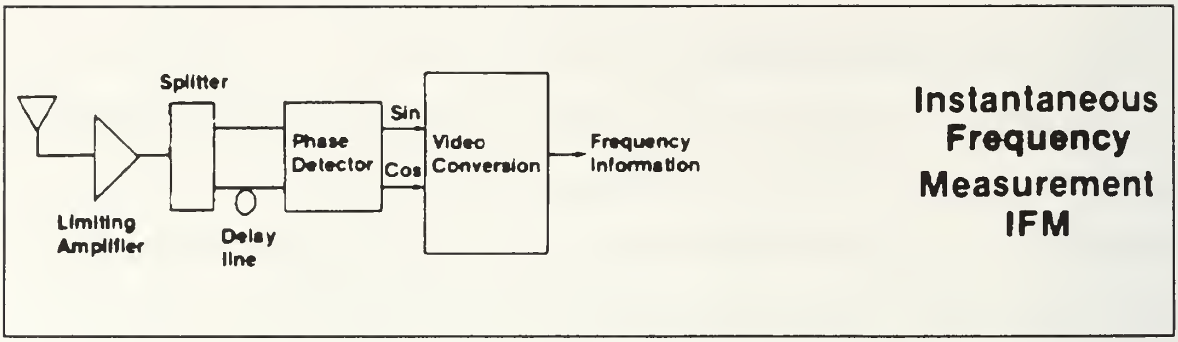


Figure 3-3. Instantaneous Frequency Measurement Receiver

5. Combined Receivers

By combining different types of receiver it is possible to design a system which provides the advantages of both receivers and eliminates the major disadvantages. A combination of the IFM, CVR and SHR gives a system which can handle both pulse Doppler and CW without losing the ability against spread spectrum signals. The system can take advantages of the SHR narrow bandwidth and use the CVR and/or IFM to cue the SHR.

6. Microscan Receiver

The microscan receiver has many similarities with the SHR. By rapidly sweeping the local oscillator, the receiver is caused to sweep the entire RF bandwidth in a pulse width (see Figure 3-4). With increased sweep rate the effective bandwidth becomes wider but at the same time the sensitivity declines. The POI will be excellent but only if the pulse is long enough to be intercepted at least once during the sweep, if not, which is the case for some modern radar, the POI will be dramatically reduced. By applying different scan strategies including parking on a signal and varying filter bandwidth the disadvantages could be overcome.

7. Conventional Channelized Receiver

The channelized receiver is a group of parallel SHRs (see Figure 3-4), this gives a broad bandwidth and at the same time a high sensitivity and high POI. The disadvantage with this approach is that the receiver becomes large and expensive. By use of MMIC (see Appendix A) the cost and size can be reduced and channelized receiver will probably be the norm in high performance ESM systems.

8. Bragg Cell Channelizer

The Bragg cell is an acousto-optic device which converts RF energy into a deflection of a laser beam proportional to the frequency of the RF signal (see Figure 3-4).

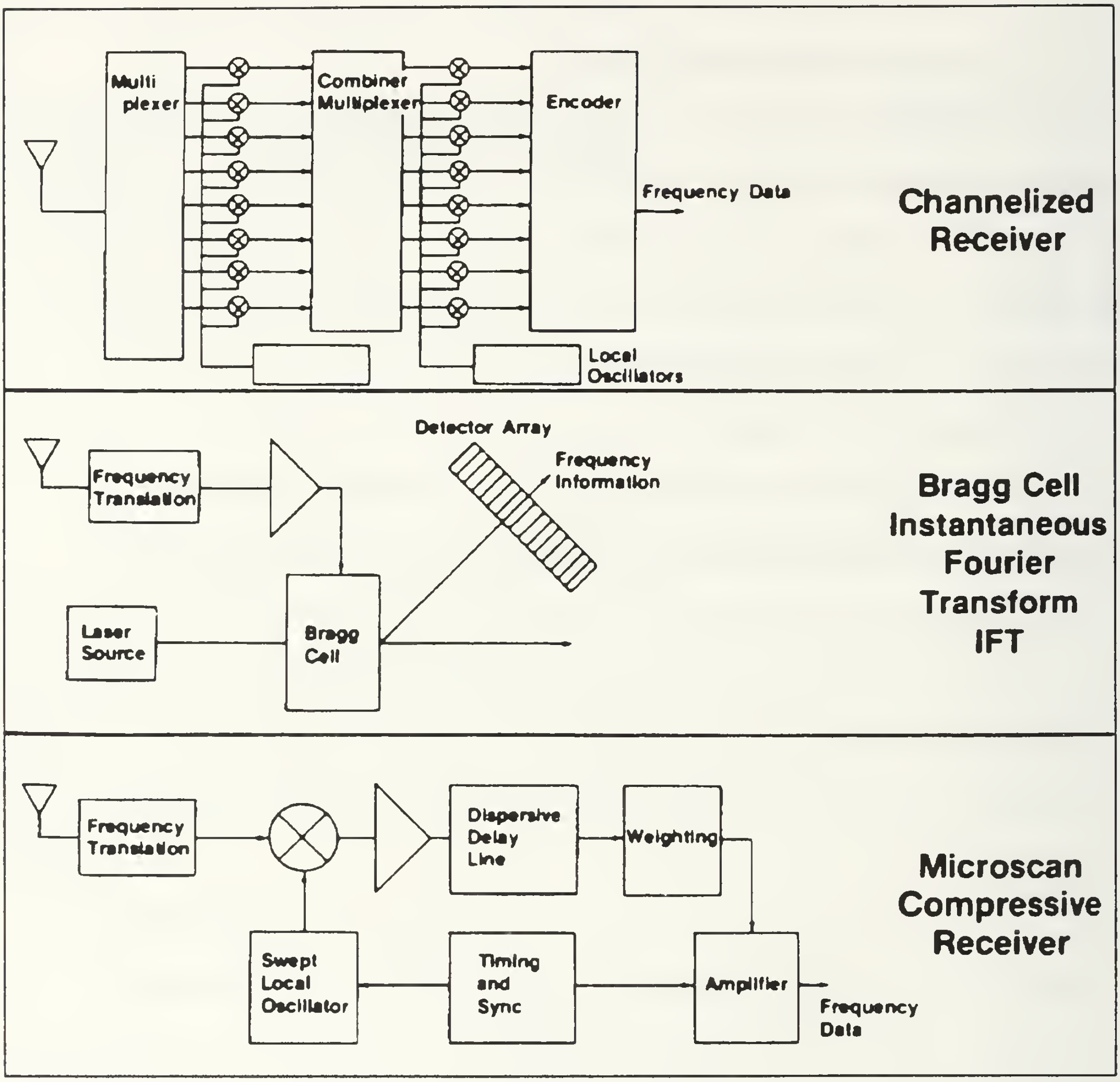


Figure 3-4. Channelized Receiver / Bragg Cell / Microscan Receiver

9. Summary

Table 2 gives a summary of the characteristics for the different receivers, some of the features compared might need to be defined:

- Pulse width, minimum length of pulse required for detection by the receiver.
- CW, PRI agile, Frequency agile and Spread Spectrum, the receiver's ability to detect and measure.

TABLE 2. COMPARISON OF DIFFERENT RECEIVERS [Ref. 7]

Receiver / Features	CVR	IFM	IFM/ CVR/ SHR	SHR	Micro-scan	Bragg-cell	Conven-tional
PW (ns)	40	20	20	50	125	100	35
CW	Fair (if equipped with chopper)	Degradable	Yes	Yes	Yes	Yes	Yes
PRI agile	Good	Good	Good	Good	Fair (Imprecise TOA)	Good	Good
Frequency agile	Fair (does not measure frequency)	Good	Good	Poor	Good	Good	Good
Spread Spectrum	Fair (does not measure frequency)	Fair (does not measure amplitude)	Acceptable	Poor	Fair	Good	Good
In-stantaneous BW	Wide	Wide	Narrow	Wide	Wide	Wide	Wide
Frequency response	Poor	Good	Excellent	Good	Good	Good	Good
Sensitivity	Fair	Fair	Excellent	Fair	Good	Good	Good
POI	High	High	Poor	High	High	High	High
Simul-taneous signals	Poor	Poor	Good	Moderate	Good	Good	Good
Immunity to jamming	Poor	Poor	Good	Fair	Good	Good	Good
Dynamic range	Good	Good	Excellent	Fair	Fair	Fair	Excellent
Power con-sumption	Lowest	Low	Medium	Low	Medium	High	Highest
Size & Weight	Smallest	Small	Medium	Medium	Small	Small	Large
Cost	Lowest	Low	Low	Low	High	Medium	Highest

[Ref. 1, Ref. 7]

B. ELECTRONIC SUPPORT MEASURES SYSTEMS

ESM systems are normally divided into two categories depending on frequency coverage, communication surveillance systems (0.5-500 MHz) and microwave surveillance systems (0.5-20 GHz).

1. Microwave Systems

a. AN/SLQ-32 EW System (Raytheon)

SLQ-32 is a ship-borne threat detection and analysis system (see Figure 3-5). There are several versions of the system, some of which incorporate ECM (see chapter V Integrated Electronic Warfare Systems and chapter IV Electronic Countermeasures. The SLQ-32 is designed to provide warning, identification and direction finding of radar-guided anti-ship missiles and the radar associated with the targeting and launch of the missiles. More than 360 systems have been delivered to the US Navy.

The system consists of two antenna arrays (one for each side of the ship), IFM and direction finding receivers (DFR), a direction frequency correlator/digital tracking unit (DFC/DTU), a computer including threat library and a display unit (see Figure 3-6). The two different receiver types are used to achieve both frequency and direction. The data from the receivers are correlated in the DFC to form a pulse descriptor word (PDW), which is then stored by frequency and angle cell in the emitter file memory. If three or more pulses of this frequency and from this angle are received within a time interval of 32 ms the DTU notifies the computer that a new emitter is present. The computer directs the DTU to store pulses of the emitter to provide sufficient pulses for further analysis. The data is used to calculate pulse repetition interval (PRI), scan period and type of scan. These parameters are used along with frequency to characterize the emitter for identification. The observed signals characteristics are compared with the threat emitter library. The computer sends the emitter information to the display for further actions by the operator. When an ambiguous identification occurs the system will treat the emitter as though it is the most threatening of the possible matches.

Figure 3-5. AN/SLQ-32 Antenna Array

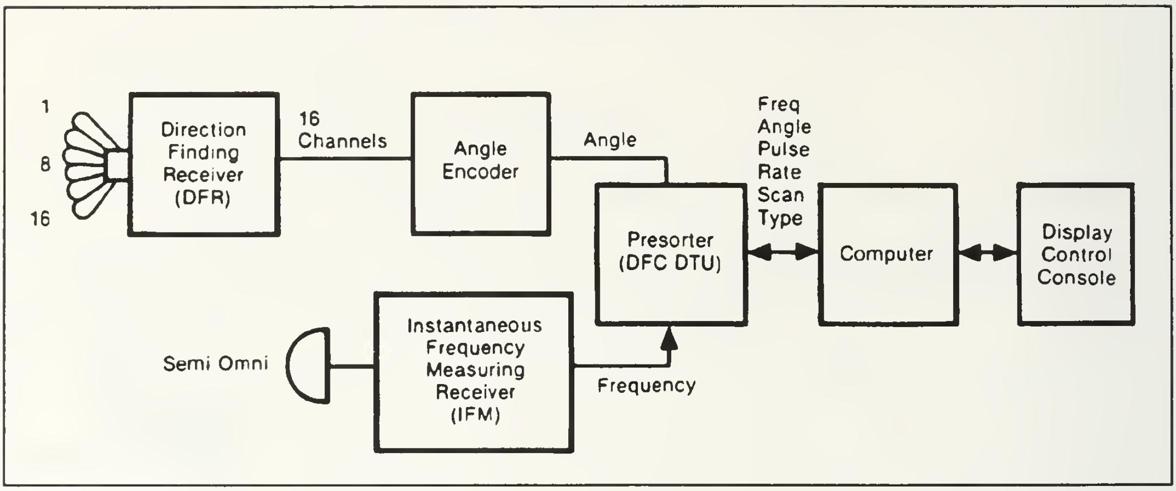


Figure 3-6. Block Diagram for AN/SLQ-32

The IFM receiver determines the frequency of the received energy while the DFR provides the system with angle and amplitude information. The IFR uses semi omni antennas while the DFR uses four multibeam antennas, each covering 90 degrees, to determine the direction to the emitter(see Figure 3-7). The multibeam antenna determines the direction by focusing the incoming signals to a point detector representing the direction of the emitter. The focusing property of the lens is independent of frequency which makes accurate direction finding possible over a wide frequency band.

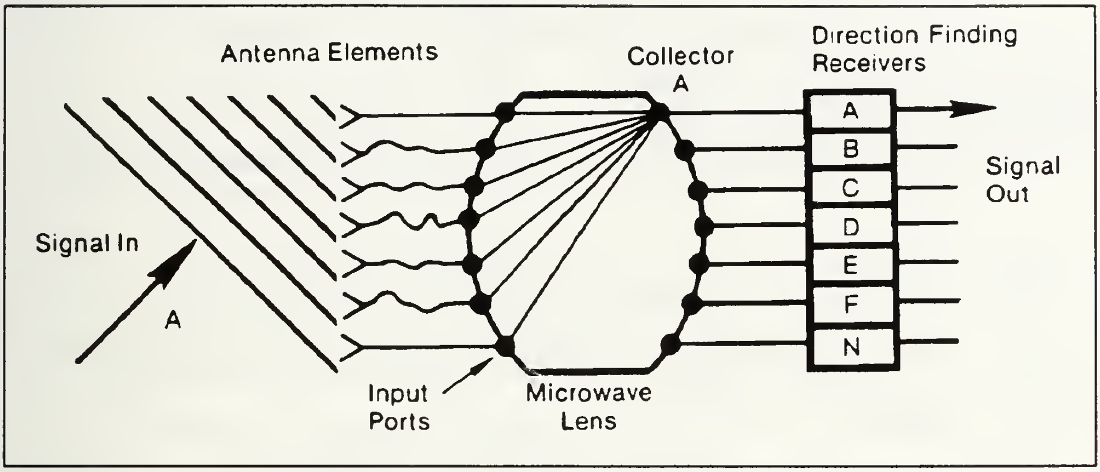


Figure 3-7. Multibeam Lens Antenna

The display unit presents the data on a polar display which is divided into three rings. The receiving ship and friendly emitters are shown in the center, hostile missile emitters are shown in the middle ring while hostile non-missile emitters are shown in the outer ring. [Ref. 8, Ref. 9, Ref. 10]

2. Communications System

a. AN/MLQ-34 TACJAM-A (Lockheed Sanders)

TACJAM-A is a tactical VHF jamming system. The system is deployed on a tracked vehicle. The ESM part of the system consists of multiple receivers to allow the system to monitor many frequencies simultaneously. The monitoring of frequencies is computer controlled and the operator inputs frequency range, signal characteristics and operational characteristics. The receiver automatically scans the desired frequency range and provides the operator with a report over channels which match the given description (see Figure 3-8). Multiple stations may be connected by wire or radio to form a coordinated automatic direction finding and emitter position fixing network. The demodulated audio output from the receivers is available to the operator through a split headset.

The block diagram for the ESM part is shown in Figure 3-9. The system operates as follows:

- The RF distributor interfaces the ESM subsystem to antennas in four bands.

- The tuner down-converts a broad bandwidth for digitization.

- The acquisition units applies digital FFT for detection and direction finding.

- The analysis unit provides automatic signal recognition and demodulation, parallel channels permit high throughput rate.

- The acquisition/analysis (ACQ/ANAL) automatically optimizes the system in response to tasking, it selects and schedules signals for jamming and maintains active and historical data bases.

Frequency range is 20 - 200 MHz. [Ref. 8, Ref. 11, Ref. 12, Ref. 13]

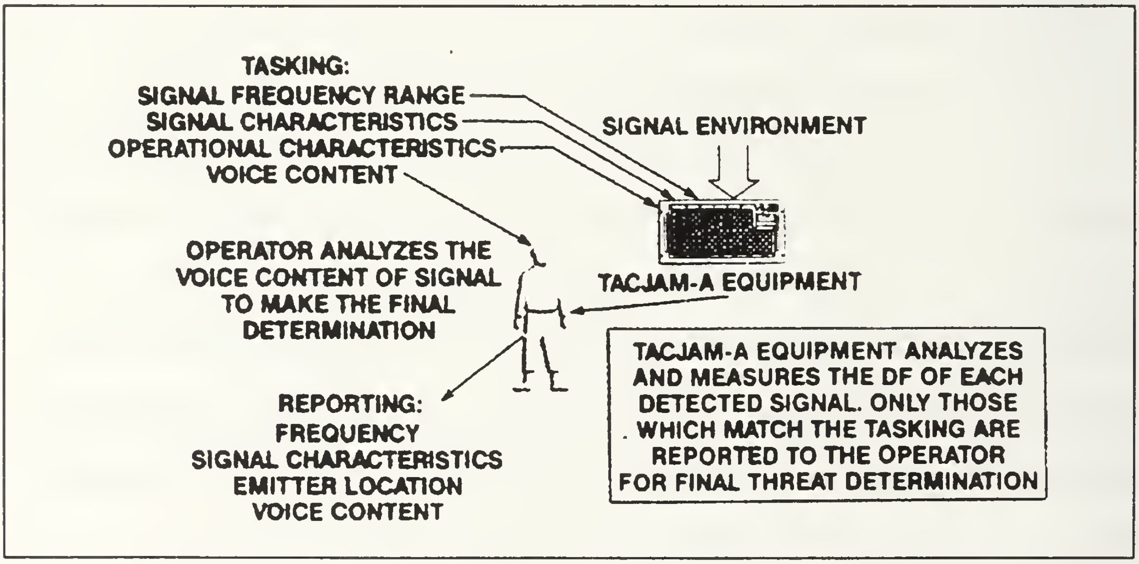
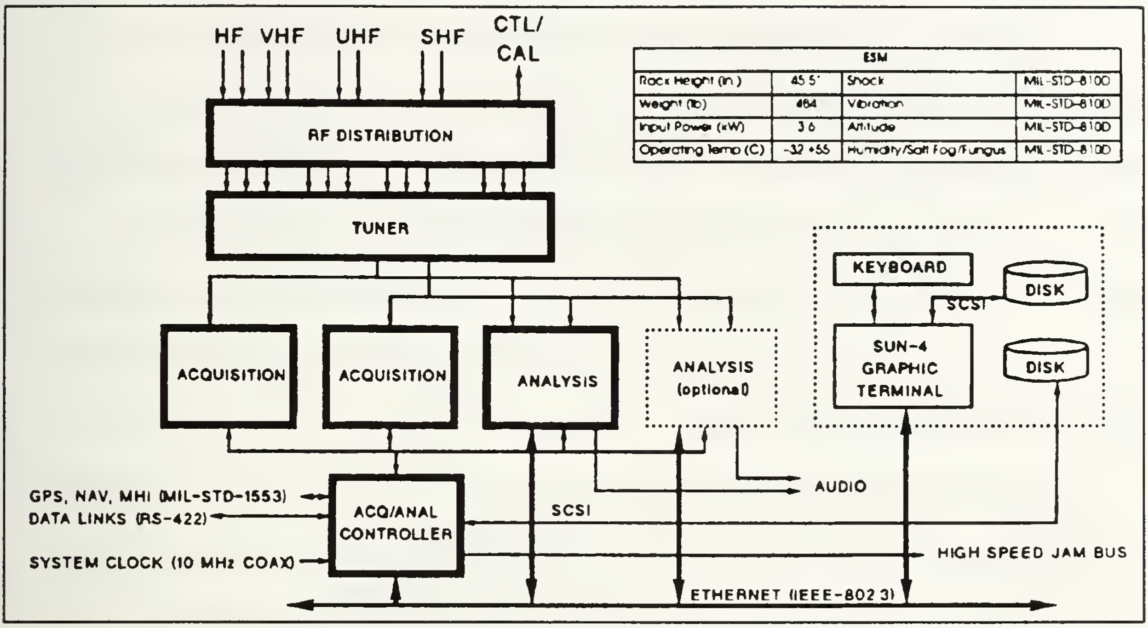


Figure 3-8. TACJAM-As Man-Machine Interface



ESM			
Rack Height (in.)	45.5"	Shock	MIL-STD-810D
Weight (lb)	464	Vibration	MIL-STD-810D
Input Power (kW)	3.6	Altitude	MIL-STD-810D
Operating Temp (C)	-32 +55	Humidity/Salt Fog/Fungus	MIL-STD-810D

Figure 3-9. TACJAM-A Block Diagram

C. WARNING SYSTEMS

1. Radar Warning Receivers (RWR)

The RWR is an ESM system with scaled-back capacity, it was developed to meet the requirement for deployment in aircraft, submarines and armored vehicles. The platforms' limited space puts heavy constraints on volume and weight. The system should further provide sufficient warning against radar and be able to distinguish between different types and modes of operation. To be able to provide sufficient warning the RWR needs to be capable of real time signal processing. The RWR measures the signals frequency, pulse width, amplitude, angle of arrival and time of arrival. The RWR compares the measured parameters against a library over known threat emitters. The amplitude and time/angle of arrival are used to determine the direction and an approximate distance to the emitter.

The RWR can be equipped with a variety of receivers including crystal video, wide and narrow band superhetrodyne and tuned radio-frequency. Combinations of different receivers are also possible to meet the requirement of sensitivity, probability of intercept and ability to operate in a high pulse density environment. For platforms operating at high altitude a RWR which can handle a high pulse density is favorable while a platform operating at low altitude can use a less complex and cheaper RWR with less capability to handle high pulse densities.

The threat emitters are prioritized depending on the detected mode of operation (searching, illuminating, tracking or guidance) and weapon system associated with the identified emitter. The presentation of the threat is normally done both visually by means of a blinking symbol and audibly with different tones representing different types of threats or by a synthetic voice describing the threat emitter.

The RWR can either be used as a stand-alone system or as a part in an integrated EW system (see Chapter V). Two RWRs are described below and they represent two different types depending on requirements. ALR-39A is designed for helicopters and light aircraft operating at low level, ALR-67 is a system designed for frontline carrier-based tactical aircraft. [Ref. 1, Ref. 14, Ref. 15]

a. AN/APR-39A(V)3 Threat Warning System (Litton Applied Technology)

The ALR-39 is a lightweight radar warning system that provides the pilot with both audio warning in form of synthetic speech and a graphical presentation of the threats. The graphical presentation identifies the threat type and the azimuth to the emitter. It also indicates if the threat is searching or locked and tracking, and when the lock is broken.

The system consists of ten units (see Figure 3-10):

- One digital signal processor.

- Two crystal video receivers.

- Four E/J band spiral antennas.

- One C/D band omnidirectional blade antenna.

- One display unit.

- One control unit.

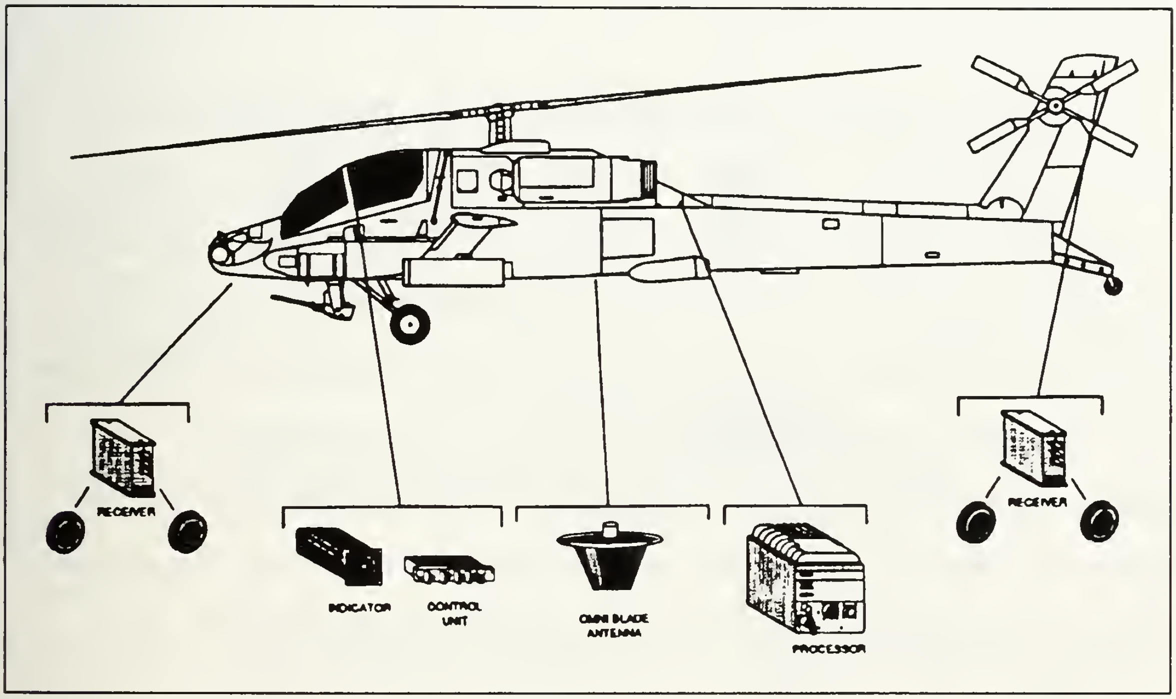


Figure 3-10. AN/APR-39A(V)3

The system is able to identify the threats by pulse repetition interval (PRI), pulse width (PW), pulse frequency modulation (PFM) and scan rate. The system does not measure frequency. The system has the following limitations of detection for different radar types:

- CW: not possible.

- Pulse Doppler (PD): limited.

- Low effective radiated power (ERP): limited.

- Low probability of intercept (LPI): not possible.

The APR-39s library is capable of storing 200 emitters, it is reprogrammable either by change of the user data module or through a memory loader. [Ref. 8, Ref. 16]

b..AN/ALR-67(V)3 Counter Measures Receiving Set (Hughes Aircraft Company)

The ALR-67 is a fourth generation RWR. It is a compact system designed with MMIC (see Appendix A). The system consists of both channelized and superhetrodyne receivers to enhance detection of all relevant radar threats. Thanks to the use of three different types of antennas the ALR-67 can provide coverage of all polarization in the microwave threat band including the millimeter wave (MMW). The system is designed to be able to operate in a very dense pulse environment. The systems different parts and their location at the aircraft are shown in Figure 3-11 and 3-12.

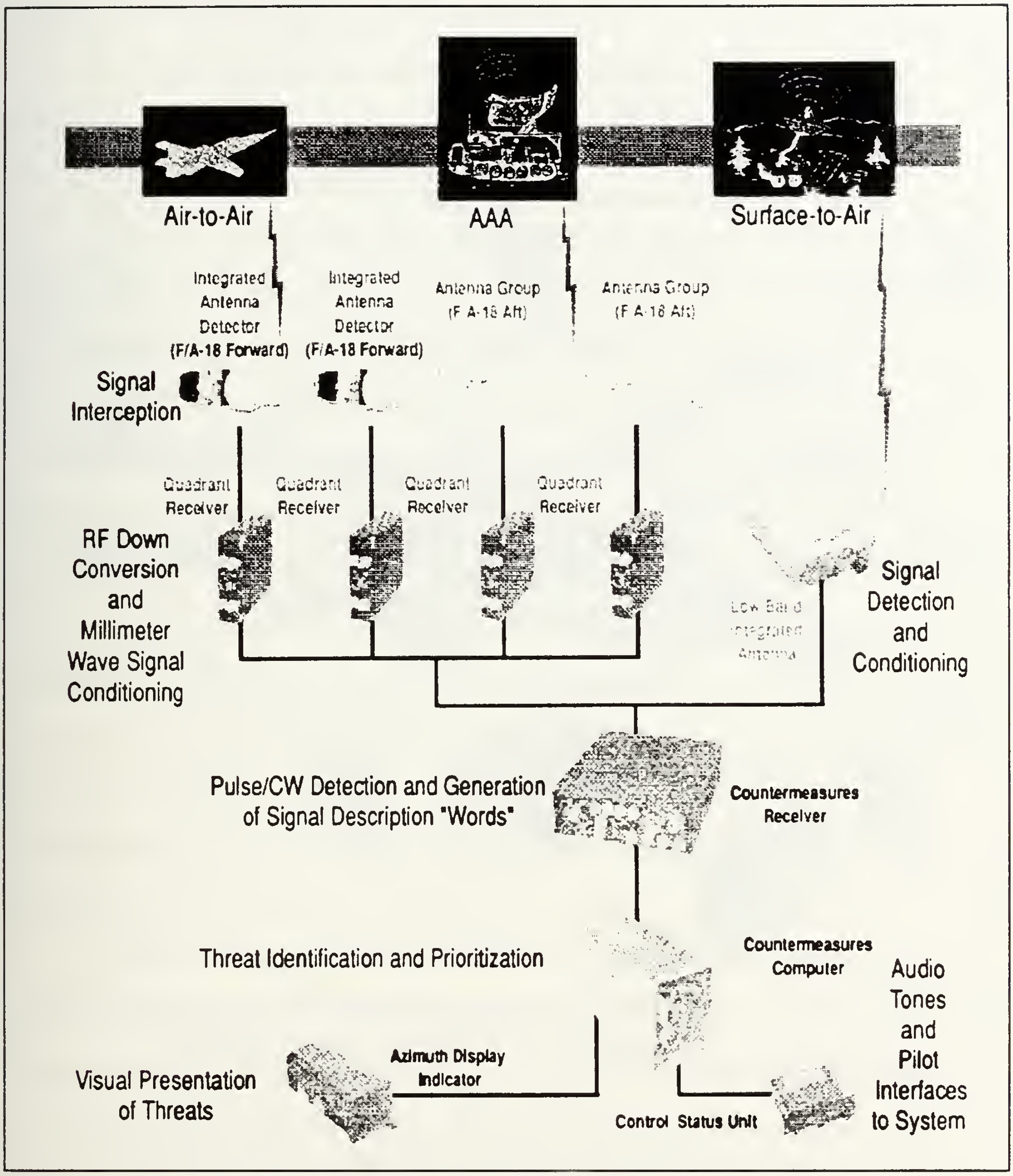


Figure 3-11. AN/ALR-67(V)3 Counter Measures Receiving Set

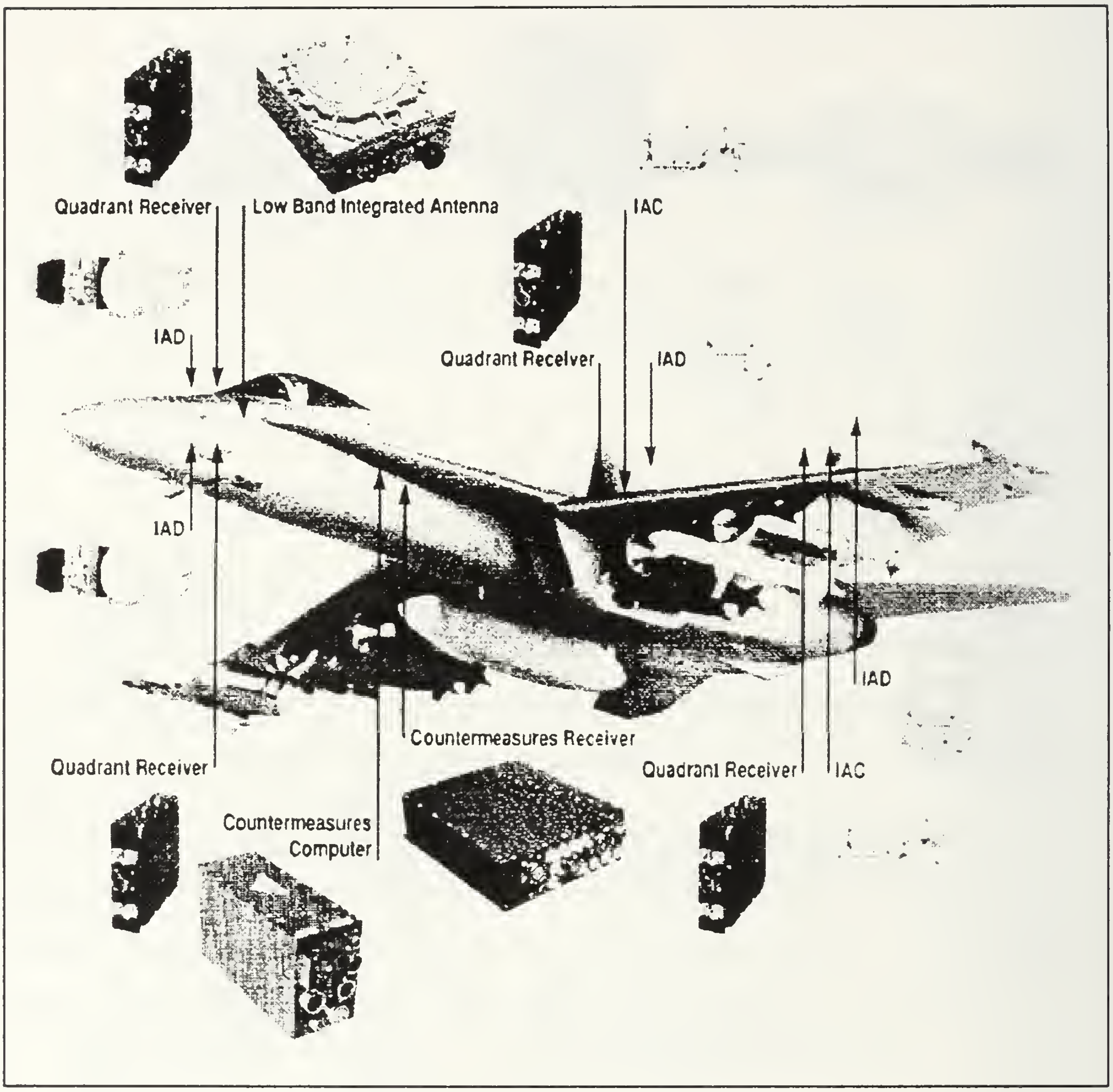


Figure 3-12. AN/ALR-67(V)3 Counter Measures Receiving Set

The countermeasures receiver generates digital words describing the parameters of the pulsed and CW radar waveforms detected. Measured parameters include amplitude, angle of arrival, time of arrival, frequency, pulse width and modulation. By using the rapid tuning superhetrodyne receivers CWs can be detected and measured. The fully channelized receiver has 22 parallel filters to accomplish pulse intercept.

Via the countermeasures computer the ALR-67 interfaces with several CM systems including dispensers and HARM. [Ref. 8, Ref. 17, Ref. 18]

2. Missile Warning Systems (MWS)

The functions of a Missile Warning System is to detect an approaching missile and give a warning to the pilot and to the aircraft defensive systems. The integration of MWS into the Electronic Warfare Suite of the aircraft will be discussed in the Integration section. MWSs have been in use on aircraft since the late 70's. They have gained increased importance because of the proliferation of highly lethal IR and EO missiles. Of the aircraft losses suffered during the conflicts in the last decades a majority have been to IR missiles. Because many IR/EO surface-to-air missiles work independently of a radar, a RWR will not be sufficient to give warning. The increased ECCM capability in modern missiles has decreased the effectiveness of on-board countermeasures and today the trend is toward using more off-board systems. Because of the decoys short operating life the timing of the deployment becomes critical for its effectiveness. The MWS can provide information about the time to intercept and the direction of the approaching missile and trigger launch of off-board countermeasures.

MWS can be divided into two groups: active and passive. The active systems use a pulsed Doppler radar when the passive works with IR or EO. The choice of system depends heavily on the type of platform used. For a stealthy platform a passive MWS is the natural choice so as not to give away the advantage created by the platform. For a platform with large signatures an active MWS could be a good choice. Some of the most important advantages and disadvantages with the different systems are shown in Table 3.

TABLE 3. COMPARISON BETWEEN ACTIVE AND PASSIVE MWS

	Active MWS	Passive MWS
Avoidance of detection	Fair, relatively low compared with other radiating sources on platform	Very good
Weather sensitivity	Almost all weather capability	Poor performance in bad weather
Range estimation	Yes	No
Time-to-intercept estimation	Good	Poor
Ability to detect missile in different phases	Yes, in all phases	Some systems unable to detect missile after rocket-motor burn out

Similar techniques as those used in MWS is used in passive detection systems for air defense surveillance systems. These systems are deployed both in sea and land applications. Normally those systems are not considered EW-systems and are not discussed further here. [Ref. 8, Ref. 14, Ref. 19, Ref. 20]

a. Passive Systems

The passive MWS uses the IR radiation generated from the incoming missiles for detection. The exclusion of detectable energy transmission is the passive systems' greatest advantage compared with active systems. Information about the wavelengths at which the different systems operate has not been released but it can be assumed that they are optimized against the radiation from the rocket-motor, which represents a wavelength of 4.3 μm. It is expected that the propulsion systems of future generations of threat missiles will be cooler than the current systems which will lead to new classes of warning systems operating at longer wavelengths. [Ref. 20]

(1). AN/AAR-44

The system is produced by Cincinnati Electronics Corporation and is fitted to the USAF C-130s. The AN/AAR-44 uses search continually while tracking and verifying missile launches. The system is able to handle multiple missile and has some countermeasure discrimination. To eliminate false alarms the AN/AAR-44 is equipped with multidiscrimination modes against solar radiation and terrain reflections. Different fields of view can be attained by using different sensor unit configurations. [Ref. 8, Ref. 21]

(2). AN/AAR-47

The system is produced by Loral Electro-Optical Systems. AN/AAR-47 is installed on helicopters and slower fixed-wing aircrafts in the US Navy and Marine Corps. The system consists of four sensors, a central processor and a control indicator. To achieve spherical coverage additional sensors can be added. The system uses algorithms and signal processing techniques to achieve a low false alarm rate. The data from the sensors are analyzed by the processor both independently and as a group. Loral also markets the AAR-47 as warning receiver for armored vehicles. The AAR-47 should, according to Loral, be able to detect not only incoming anti-tank missiles but also shells from larger caliber weapons. The latest modification of the AAR-47 sensor includes detectors for laser warning. The four detectors are mounted around the existing optics (see Figure 3-13) and operate in different wavelengths between 0.4 and 1.1 μm. The laser detector gives the AAR-47 a laser warning capability. [Ref. 8, Ref. 21, Ref. 22]

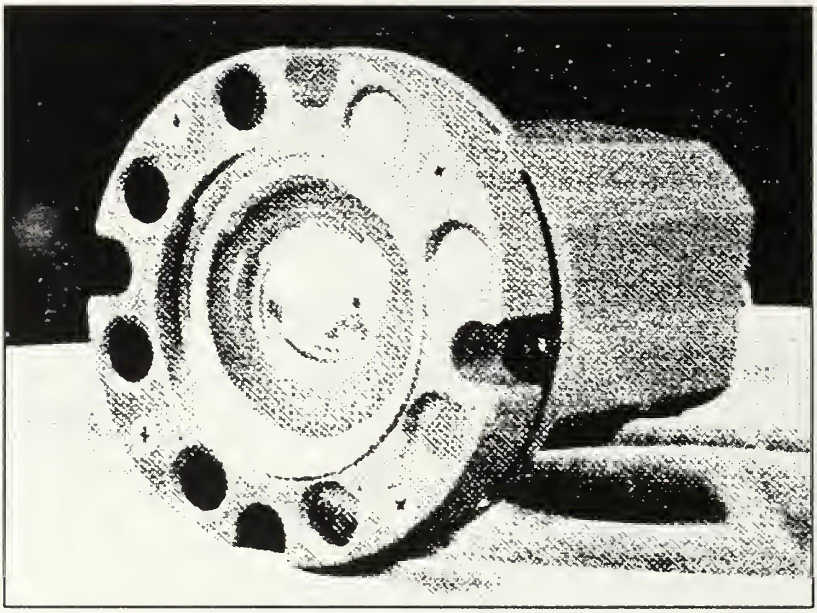


Figure 3-13. AAR-47 Detector Unit

(3). AN/AAR-FX

The system is produced by Cincinnati Electronics Corporation (see Figure 3-14) and is sized for fighter aircraft. The system uses continuous track-while-search processing and has simultaneous multi-threat capability. The AN/AAR-FX uses multi-spectral discriminators to reject backgrounds and countermeasures. [Ref. 23]

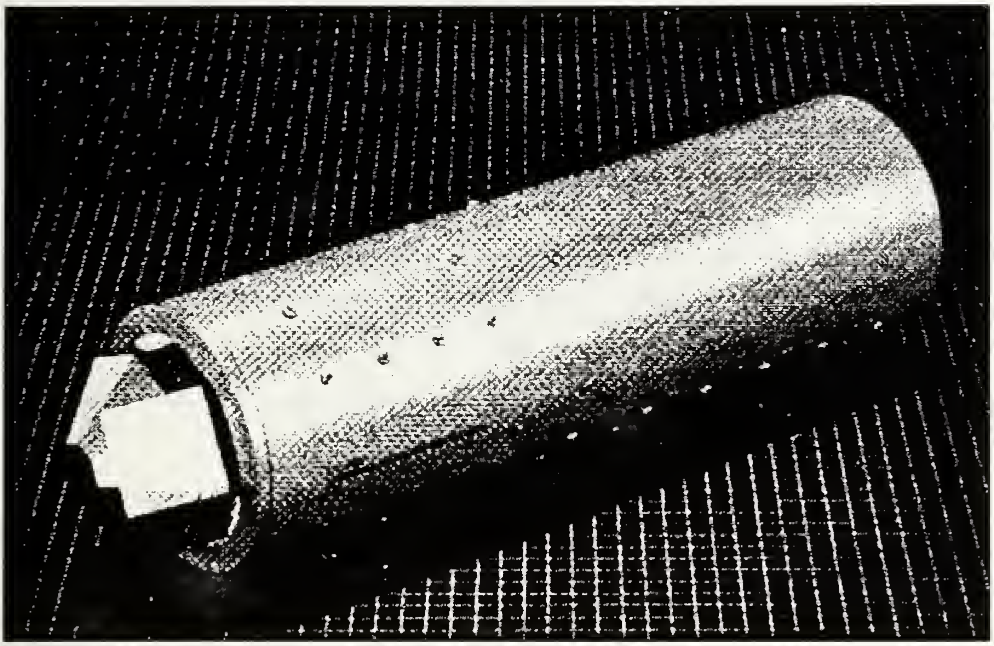


Figure 3-14. AN/AAR-FX

(4). Silent Attack Warning System (SAWS)

The SAWS is a second generation IR warning system being developed under the sponsorship of the US Air Force. SAWS is designed to detect, declare and categorize potential hostile aircraft and missiles. The system uses the scanning array technique which at the start of the project showed much lower false-alarm rates than systems using staring arrays. The system is supposed to be able to differentiate between a missile and an aircraft. It should be able to categorize the missiles in burn or post-burn and the aircraft's in normal or after-burner mode. [Ref. 21]

b. Active Systems

The active MWS systems uses pulse Doppler radar to detect incoming missiles. The radar gives accurate time-to-intercept predictions at all altitudes and during almost all weather conditions. The main challenge for the radar based systems is the effects of clutter. The effects of clutter varies with aircraft speed, altitude and approach angle of the attacking missile (see Figure 3-15). The most demanding case is a tail-chase high speed missile attack at low altitude. The amplitude of the clutter received increases with decreasing altitude and the spectrum of the clutter return signals becomes broader with increasing ground speed. The backlobe of the antenna can produce positive clutter Doppler returns which can compete with the positive Doppler return of the incoming missile (see Figure 3-16). [Ref. 24, Ref. 25]

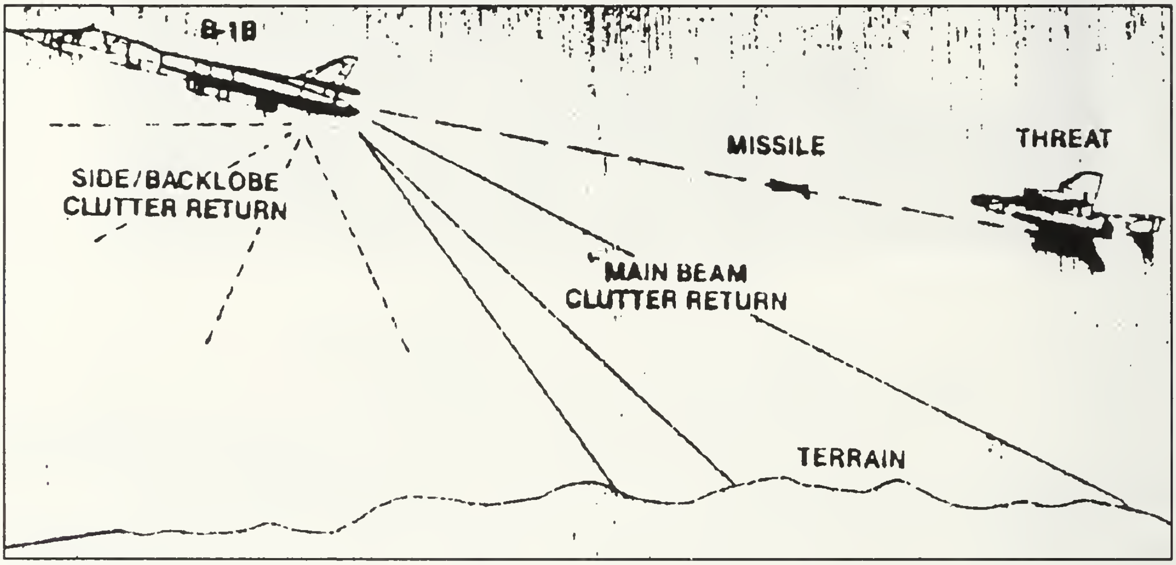


Figure 3-15. Clutter Return for Active MWS

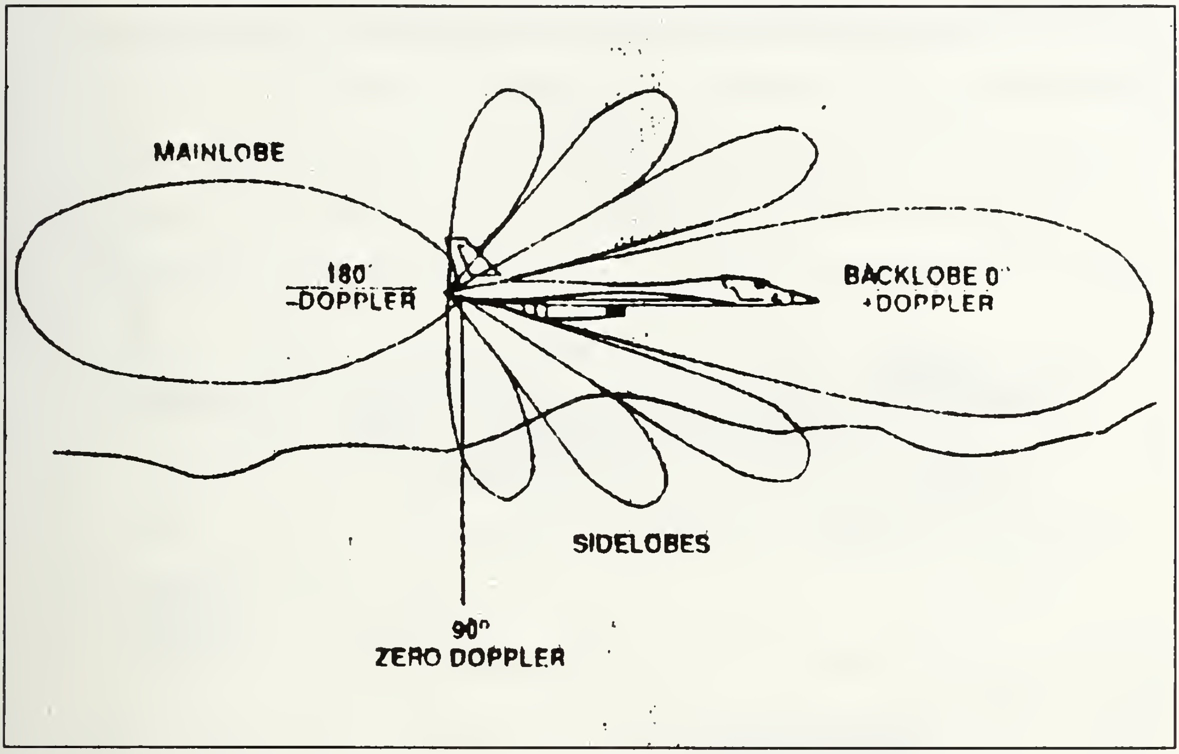


Figure 3-16. Doppler Return from Incoming Missile

(1). AN/ALQ-153 Tail Warning Set (Westinghouse Defense and Electronics Center)

The ALQ-153 is installed in the USAF B-52G/H. It is a range-gated Doppler system and it continuously displays the most imminent threat. The system automatically calculates range and time-to-intercept and transfer the information to automatic countermeasures equipment. [Ref. 8]

(2). AN/ALQ-156(A) Missile Warning System (Lockheed Sanders Inc.)

The ALQ-156 consists of a pulse Doppler radar, probably operating in the C/D-band, which detects incoming missiles and can trigger an automatic ECM dispenser. The system evaluates the threats by comparison of the closing rates. The system is stated to be able to operate close to the ground with good detection probabilities of missiles. Depending on the type of aircraft, the system uses two or four antennas (see Figure 3-17). [Ref. 26]

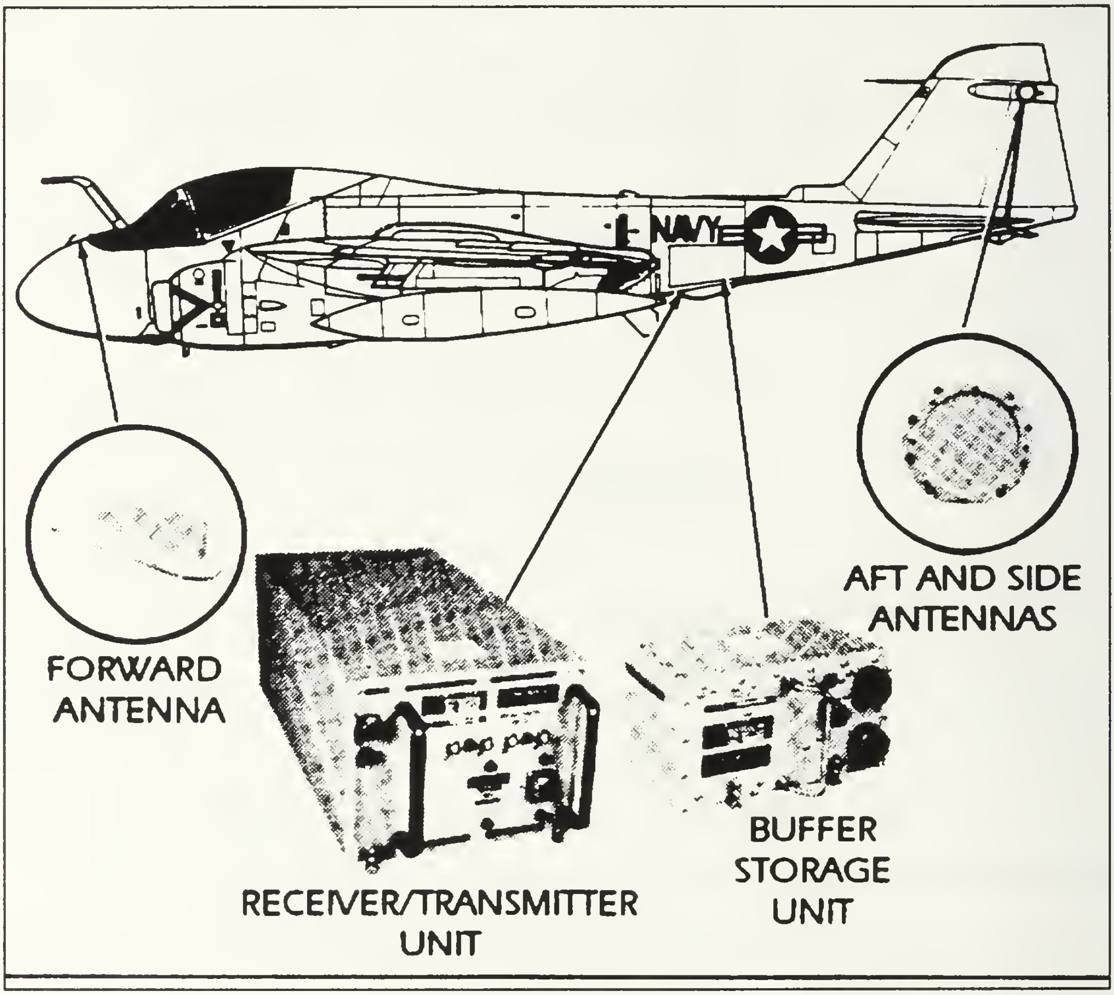


Figure 3-17. AN/ALQ-156(A) Missile Warning System

3. Laser Warning Systems (LWS)

Laser warning systems have become a part of the survivability equipment during the last decade because of the rapid growth in weapons systems utilizing the laser either for missile guidance or for range finding. Because of the properties of the laser radiation, laser systems needs a line of sight between the pointer and the target. For this reason laser warning systems have so far mainly been installed on aircraft and armored vehicles. For ships operating in coastal areas LWS will become an important part of the overall warning equipment. Because of the laser beams' small width, a warning from a LWS means with a high probability that the platform is targeted but the small beam width at the same time means that a large platform like a ship needs several detectors to insure proper warning.

The LWS gives the following information:

- Warning, if the platform is targeted.
- Angle of arrival, direction to the laser threat.
- Pulse repetition interval, which is compared to the emitter library and used to identify the threat emitter.

The LWS takes advantage of the laser radiation's high coherence to filter out the background using a four-stepped etalon. The angle of arrival is achieved by using a slit system together with a detector array (see Figure 3-18). The LWS can be used as one component in an integrated EW system (see Chapter V).

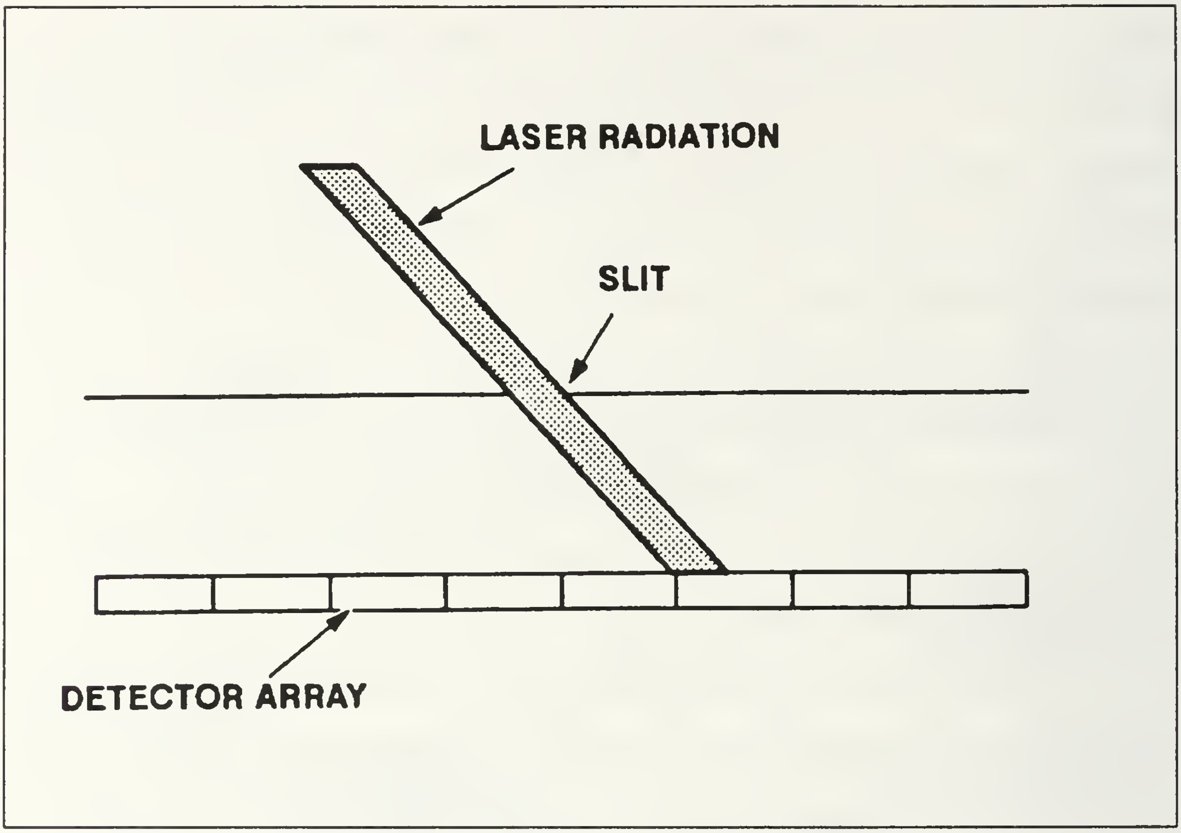


Figure 3-18. Angle of Arrival Determination

a. AN/AVR-2 (Hughes Danbury Optical Systems Inc)

The AN/AVR-2 is a airborne laser detecting set. It detects, identifies and characterizes optical signals. The system consists of four sensor units (see Figure 3-19), one interface unit comparator and one display unit. With the four sensor units mounted the AN/AVR-2 covers 360° around the aircraft. The sensor unit is equipped with three sensor heads one for each band I, II and III, there is space left in the unit for a band IV sensor head. The sensor unit receives the laser signals, validates the signals, identifies threat type, prioritizes the threats and passes the threat message to the interface unit comparator. The pilot gets the warning about the laser threat from the display. The system can also be used as a part of an integrated radar and laser warning receiver system.

The same sensor heads as used in AN/AVR-2 have been used in a laser warning system for the M1 Abrams tank. [Ref. 27, Ref. 28]

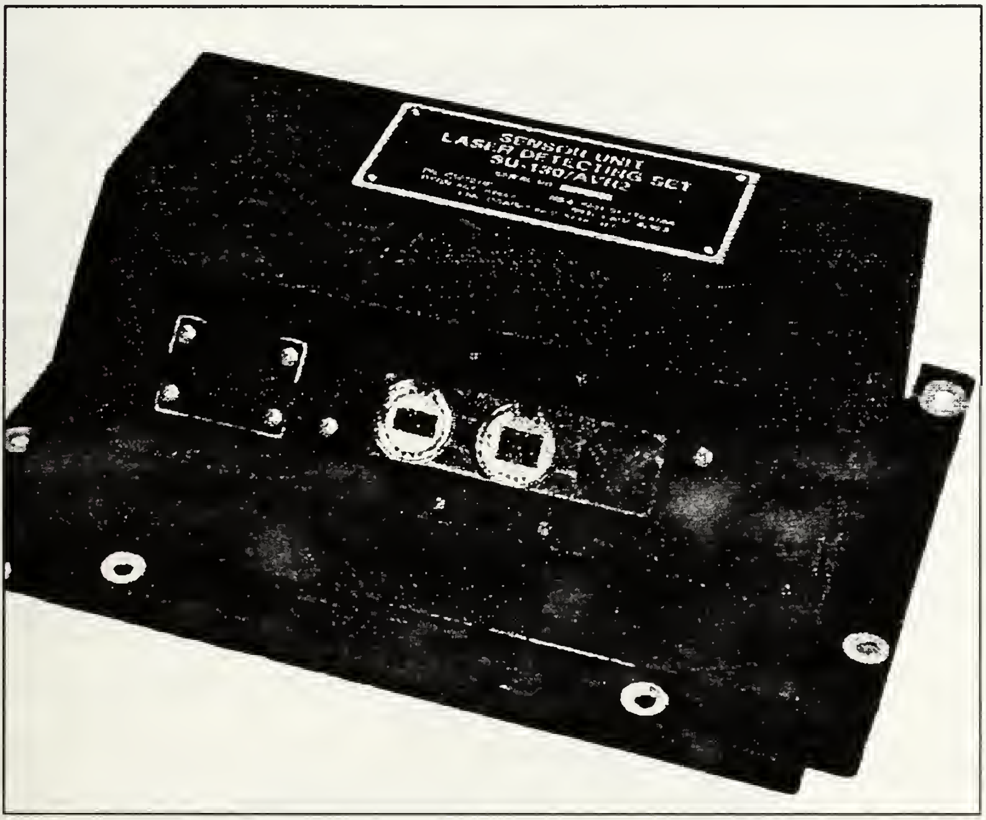


Figure 3-19. AN/AVR-2 Detector Unit

D. CONCLUSIONS

Because todays threat from missiles uses a wide array of techniques for their guidance the warning systems needs to be able to detect not only radar and laser radiation but also IR radiation from passive missile systems. The use of all aspect-attacking IR missiles has further increased the requirements of the warning system by making detection of incoming missiles from all angles a necessity.

The increased pulse density created by the deployment of pulse doppler radar, both enemy and friendly, has created demand for systems with a high signal processing capability. The dense pulse environment and the introduction of frequency and PRI agile signals has lead to a renewed importance of direction finding, in this case as a method to discriminate between different signals. Because the ability to handle a dense signal enivronment is strongly related to the price of the warning system, it has become important to analyse in which kind of threat environment the platform will operate; the pulses present are very different for a low flying helicopter compared to those encountered by a high flying interceptor. Below is a table describing potential countermoves because of the introduction of the systems described in this chapter.

TABLE 4. POTENTIAL COUNTERMEASURES TO ESM SYSTEMS

ESM (microwave)	- The use of special "war modes" could make the system unable to identify the radar. - Low probability of intercept radar will challenge the ESM receivers sensitvity.
ESM (communication)	- Spread spectrum techniques. - Increased capability for coding will make the possibilities for effective decoding for tactical use small.
RWR	- Complex wave forms makes identification harder. - Late switch to active mode makes the reaction times short.
MWS passive	- Reduction of IR signature decreases the MWS detection range.
MWS active	- Decreased radar cross section and use of stealth techniques. - Use of deceptive jamming to create false alarm which causes distraction.
LWS	- Illuminating only during the very last phase of an engagement with semi-active laser weapons gives the platform short time to react to the warning. - Destructive illumination with high energy laser operating in the same band as the detector. - Use of cheap laser illuminators emulates beam riding systems and that way creates false alarms.

IV. ELECTRONIC COUNTERMEASURES

The electronic countermeasures described in this chapter are divided into five categories:

- Radar CM.
- Laser CM.
- Infrared CM.
- Off-board CM.
- Communication CM.

Infrared and laser CM are used mainly for self protection, communications CM is used to support an operation while radar and off-board CM can be used both as self protection and as support for a strike.

A. RADAR COUNTERMEASURES

1. General Description

The radar countermeasures can be divided into two categories: denial and deception. Denial is normally achieved by using noise jamming that masks the echo from the aircraft. Deception is performed by introducing signals designed to fool or confuse the radar by appearing as one or more false targets. [Ref. 14]

a. Noise Jamming

The objective with noise jamming is to introduce a noise like signal into the radar system to mask or obscure the target echo. The operator sees the noise on the PPI as a large area of clutter. Depending on the power of the jammer, the noise will be above the radar's threshold in only the main lobe or both in the main lob and in the side lobes. By changing the radiated power with respect to the radar's antenna gain, the jammer can introduce a constant amount of noise into the radar and thereby deny the radar the direction information.

There are several techniques to introduce noise at the right frequency. If the frequency of the radar is unknown or is changing, or to cover the operating frequency of several radars a technique called barrage can be used. This is a broad band jamming covering a spectrum of frequencies much wider than the operating bandwidth of the radar. The disadvantage with this approach is that most power will be wasted on frequencies not needed to jam which will lead to a high power requirement.

If the radar's frequency is known, spot jamming can be used. The spot jamming technique uses a bandwidth centered at the radar frequency; the jammers bandwidth is normally somewhat larger than the bandwidth of the radar.

Swept jamming is another technique for broad band noise which is achieved by sweeping a narrow band noise signal across the range of frequencies to be jammed.

By utilizing the frequency and direction information from an RWR the noise jamming can be limited in bandwidth and directed thereby substantially increasing the power in the radar receiver. [Ref. 14, Ref. 29]

b. Radar deception

There are several different techniques used for deception of radars and two main approaches:

- Generation of a large number of false targets to overload the system.
- Provision of incorrect target bearing, range and/or velocity information to the radar.

Some of the specific techniques to achieve incorrect targeting are described below.

(1). Range-Gate Pull-Off

This is the most fundamental deception technique used against tracking radars. The deceiver initially repeats the received radar pulse which makes the radar indicate this as a target and because of the strong return adjust its sensitivity. The decption jammer then starts to increase the time delay in the repeated signal, this is done to fool the radar to follow the false target. When the distance between the real and false targets is larger than the range gate of the radar, the deceptive signaling is discontinued. If succesful this will lead to the radar losing its tracking on the actual target.

(2). Angle Deception

To employ a succeful angle deception, the jammer must know which angle-measurment technique the radar is using. Con-scan radar systems can be deceived by transmitting a signal when the radar beam is pointed away from the platform and stopping the transmission when the beam is pointed toward it. The combination of the real echo and the deceiving signal will be interpreted by the radar which will result in incorrect information about the target's angular position.

Range-gate pull-off and angle deception are often used together in deceptive systems.

(3). Cross-Eye

The cross-eye deception technique is effective against tracking radars including mono-pulse. The tracking system has a tendency to align itself in a direction perpendicular to the wave front of the signal being tracked. By using two repeaters located at different ends of the platform it is possible to create a phase-front distortion which causes the radar to misinterpret the position of the target (see Figure 4-1). [Ref. 1, Ref. 14, Ref. 29, Ref. 30, Ref. 31]

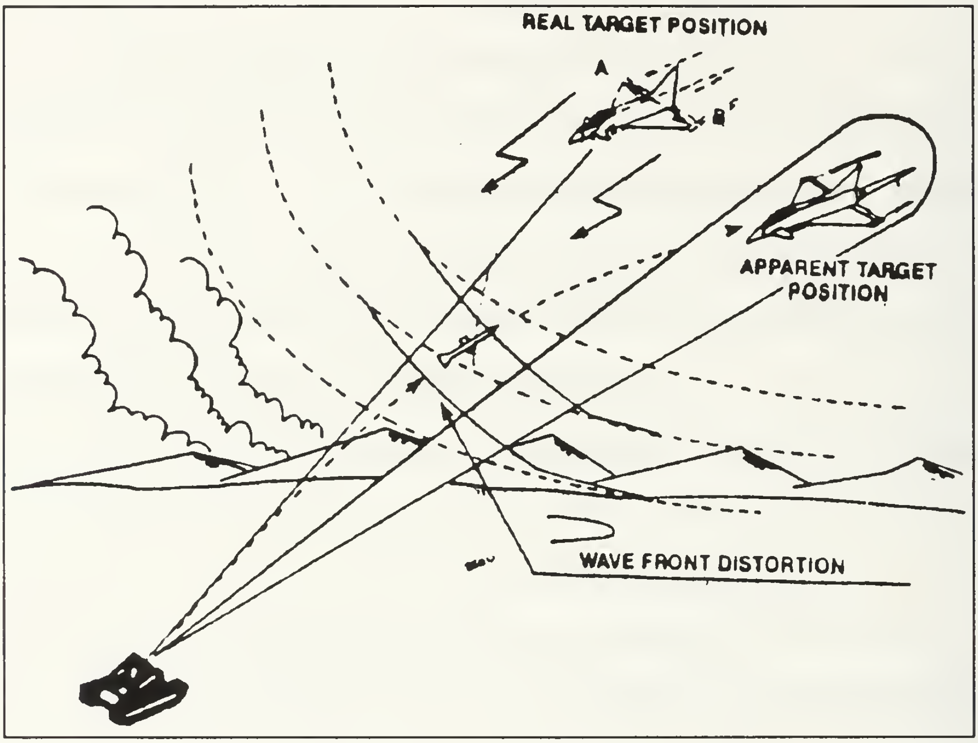


Figure 4-1. Cross-Eye Deception

2. Radar Countermeasures System

a. Sidekick (Raytheon)

Sidekick is an active ECM system for anti-ship defense that works together with SLQ-32. The system is designed for small and midsized ships (900-4500 tons). The transmitter uses a multibeam array antenna which works after the same lens principle as the receiver antenna in SLQ-32. Each array element is fed by an individual low-power miniature travelling wave tube (TWT) (see Figure 4-2). This design improves the system's reliability since an individual TWT failure only cause a slight degradation of the system's performance and not a total failure. The multibeam array antenna also gives the system a high effective radiated power (ERP) and the possibility of instantly-directed jamming beams. The jamming power is said to be sufficient to prevent burn-through of a typical targeting radar until the source is within the hard kill envelope. A typical anti-ship missile radar is said not to burn through the deception jamming power until it can no longer adjust its flight path enough to hit the ship. The Sidekick system can engage radars of different types and in different directions simultaneous. The system selects jamming techniques depending on the identification of the radar done by the SLQ-32. [Ref. 32]

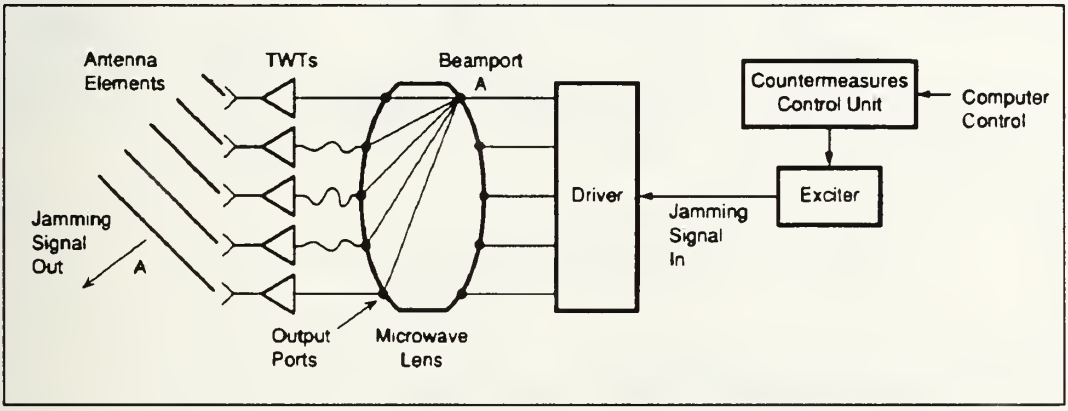


Figure 4-2. AN/SLQ-32 Multibeam Lens Antenna

b. AN/ALQ-184(V) Self Protection Pod (Raytheon)

The ALQ-184 is an active countermeasure system against surface-to-air missiles, radar-directed gun systems and airborne interceptors. The system can function as both repeater, transponder and noise jammer. The different parts of the system are shown in Figure 4-3. The pod uses a multibeam system similar to that used in Sidekick with each lens producing up to 15 beams. The ALQ-184 is equipped with 16 mini-TWTs.

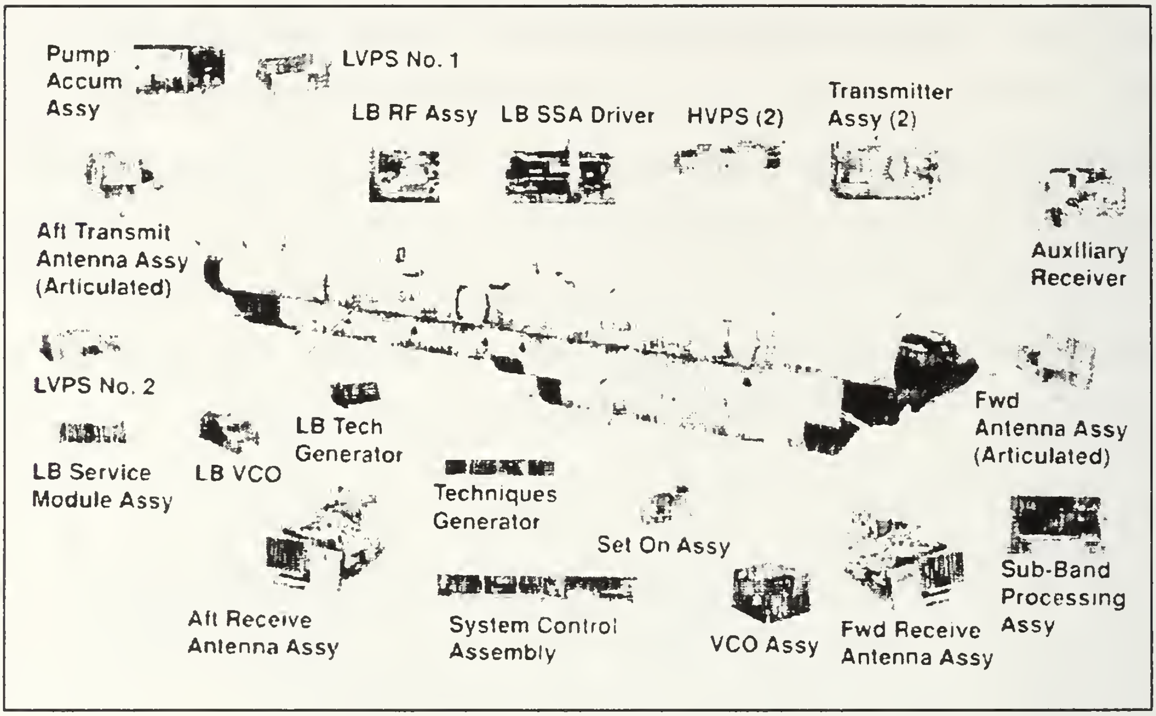


Figure 4-3. AN/ALQ-184(V) Self Protection Pod

The block diagram for ALQ-184 describing the operation is shown in Figure 4-4. An incoming RF signal is focused by the lens to the DF receiver representing the signal direction. The receiver determines signal presence and encodes the signal by angle-of-arrival and frequency subband. The signal is compared against a threat library in the central processor. Once a signal has been classified as a threat, the ECM control determines the ECM mode response and initiates the pod's active countermeasures in real-time operation. The transmit switches select the transmission angle to be transmitted and the Rotman lens provides the correct phasing and feeds the mini TWTs to the antenna array elements.

In the transponder and noise modes, an internally generated signal is selected from the voltage controlled oscillator (VCO) assembly. This signal is modulated by the techniques generator. In the repeater mode, the signal is retransmitted to the threat radar with the selected deceptive modulation. The system has a preset pulse-count threshold which stops it from transmitting until a certain number of pulses have been received. [Ref. 8, Ref. 33]

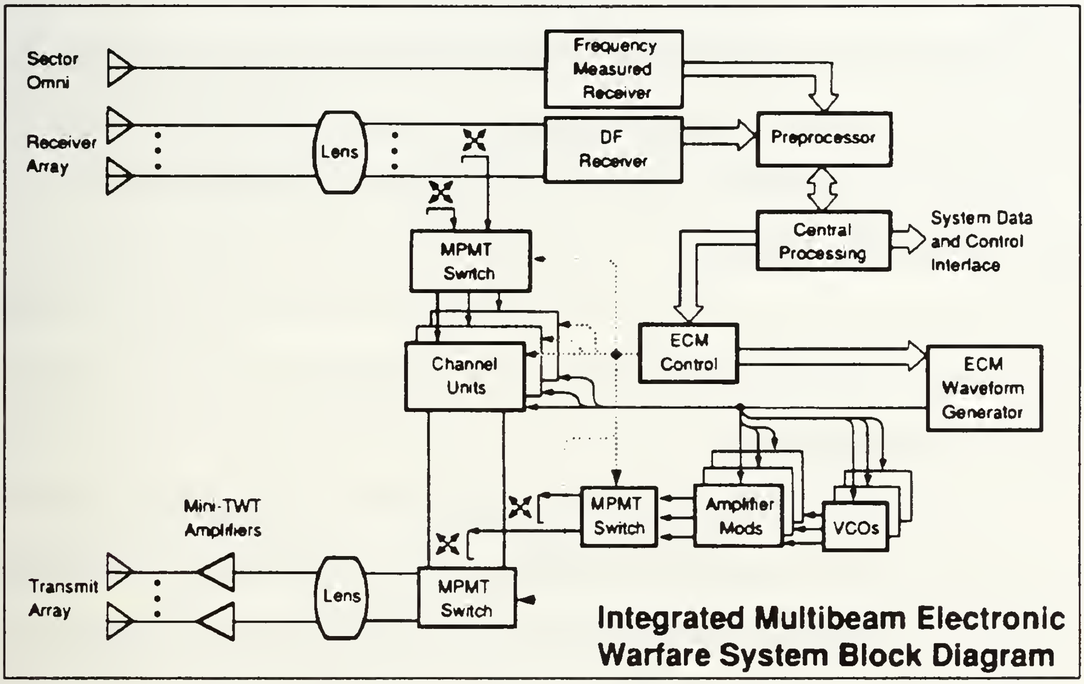


Figure 4-4. AN/ALQ-184(V) Self Protection Pod Block Diagram

B. LASER COUNTERMEASURES

There are today two very different ways to utilize laser for the guidance of missiles: by laser designator or beam riding (see Chapter II Background). The countermeasure against beam riders is to transmit a laser beam toward the sight with the purpose of destroying some of the electronics or optics in the system (see Chapter VII High Energy Beam Weapons). The method against laser designators is more similar to deceptive countermeasures. In systems using laser designators the incoming missile homes on the laser radiation reflected from the target. The target's countermeasure is to use a laser and illuminate another object that will serve as a decoy. The most modern laser designator systems have some resistance against this type of deceptive jamming and are expected to use some form of code in the laser beam. In order to be able to defeat these systems the platform needs to have a receiver that can detect the code and implement modulations to the deceptive laser. More of a brute force approach to counter laser designators is to direct either a high energy laser or direct fire toward the illuminating laser with the purpose of distracting the operator.

C. INFRARED COUNTERMEASURES

1. General Description

Because the threat from IR-guided weapons so far have been mainly from anti aircraft missiles the countermeasure field is dominated by airborne systems. With the fast introduction of both IR sights and IR guided missiles and munition to the battlefield the need for IR-countermeasures for ground forces has increased. To understand the IRCM it is neccessary to have some knowledge about how the threat, mainly the IR-missile, works (see Chapter II Background).

There are two different methods of IR countermeasures, saturation and deception. For the saturation method the IRCM device introduces large amounts of IR noise into the IR seeker. The noise has to be in the bandwidth of the seeker's detector and the purpose is to saturate the detector and if possible damage it. For this type of IRCM some of the systems described in Chapter VII can be used. The deception type of CM uses a modulated IR signal into the seeker. The modulated signal together with the radiation from the target creates false information about the target's real location. For this to be effective the energy of the modulated signal in the detector's band needs to be higher than the same energy from the target. This "blinking" method of CM is effective against reticle based and conical scanning systems. To be able to deceive the missile seeker the CM system needs to know the seeker's reticle modulation frequency, or in the case of a conical scanning system, the conical scan frequency. These frequencies will change from missile to missile, but by observing the energy reflected from the missile's optics the frequency can be measured.

The IR radiation from the IRCM can be produced in several different ways. The most common radiation source in today's system is the arc lamp but there are also systems using electrical and fuel-heated ceramics. For directed systems, lasers are used to produce the radiation. The fuel'heated systems are normally used for aircraft with limited electrical power resources. The modulation of the radiation can be achieved either by pulsing the source as in the case of the arc lamp or by mechanical modulation which is the case with the heated ceramics. To avoid detection of the platform because of radiation from the IR source in the visible region, the device is normally equipped with a filter.

Figure 4-5 gives an approximate expression for the power required. The efficiency of the CM is dependent on:

- The number of different threats operating in the different wavelengths that the system is supposed to counter, this increases the jam-to-signal ratio (J/S).
- The amount of radiation the platform emits.
- The solid angle which must be covered by the system.
- The percentage of the IR radiation from the source that falls in the band of the detector, the arc lamp's maximum occurs at short wavelengths of approximately 1.5μm (see Appendix B). [Ref. 5, Ref. 14]

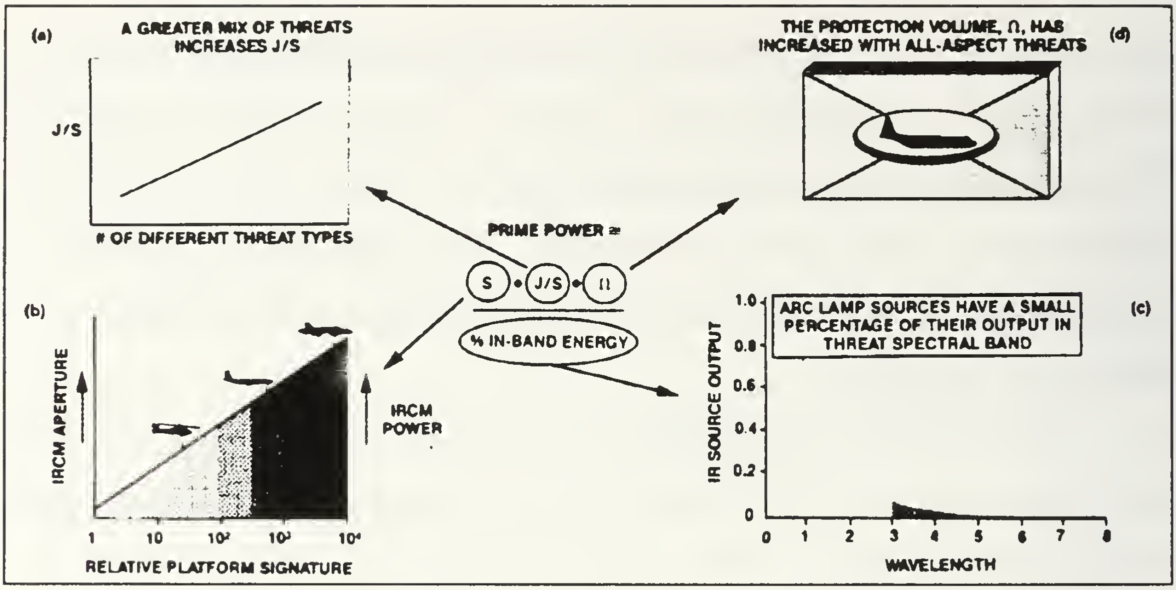


Figure 4-5. Influences on the Power Requirements

2. Infrared Countermeasure Systems

a. Matador (LORAL)

Matador is a powerful IRCM system designed to protect large aircraft and surface vehicles (see Figure 4-6). The system is modular and for large transport aircraft one transmitter per engine is the suggested configuration. The transmitters use arc lamps which are electronically synchronised by the electronics control unit to achieve the desired modulation. The transmitter's IR source has an output between 4 and 12 kW. The system is pre-programmed with a multi-threat jamming code and new codes can be added to cope with new threats. Matador is in operation with the USAF and is deployed on the Air Force One Presidential Transport. [Ref. 8, Ref. 11, Ref. 34]

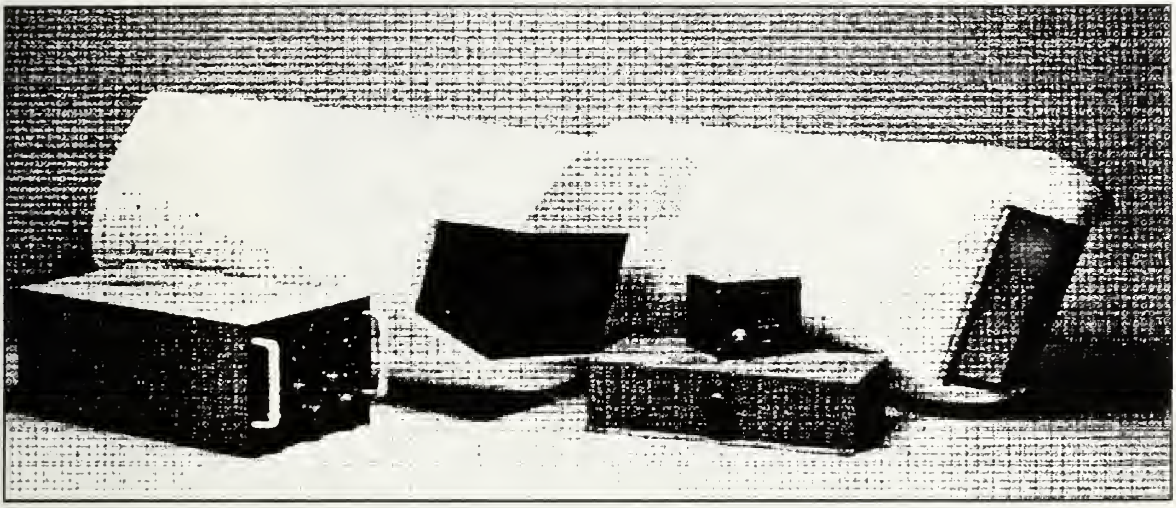


Figure 4-6. Matador

b. AN/ALQ-144 (Lockheed Sanders Inc)

AN/ALQ-144 is IRCM system designed for helicopters (see Figure 4-7). The IR source consists of an electrically heated graphite source. The transmitter is omnidirectional with a cylindrical source. The radiation is modulated, this is achieved by rotating two drums with slots around the source. The transmitter has an output of between 1.2 and 2 kW. [Ref. 8, Ref. 11, Ref. 35]

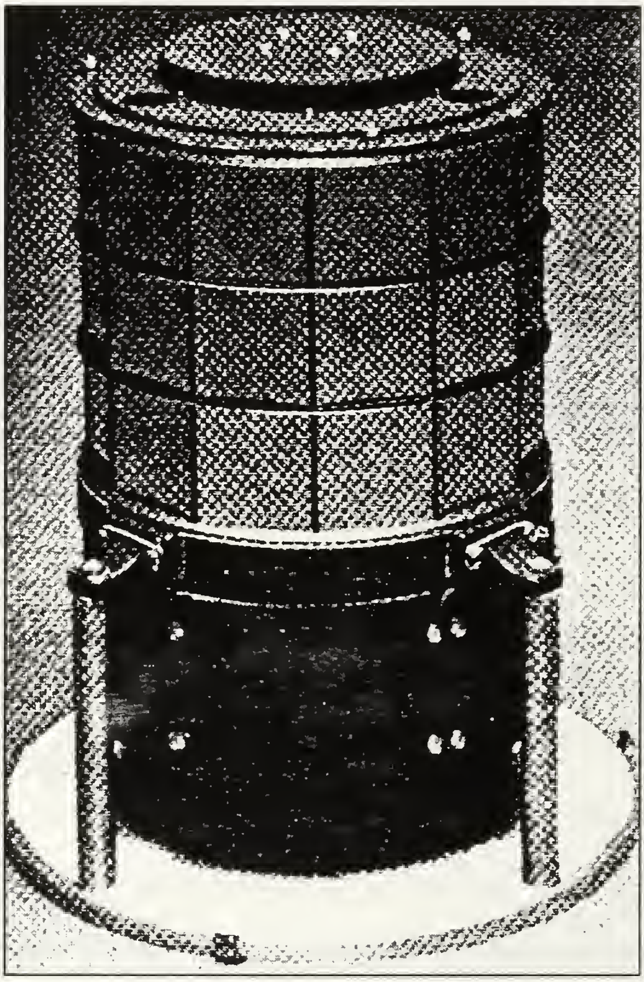


Figure 4-7. AN/ALQ-144

c. Directed Infrared Countermeasures (DIRCM)

DIRCM will probably be neccessary to counter the threat from modern IR missiles. By directing the IR radiation toward the missile the same effect can be achieved as for omnidirectional systems using only a small fraction of the power. This is even more important against missiles operating in the longer wavelength IR band (8-12μm) where it is difficult to find a continuously radiating high power source.

Northrop has developed an DIRCM designed to protect against IR guided missiles including those operating at longer wavelengths (see Figure 4-8). The system is housed in a ball turret which makes it possible to provide a 360-degrees azimuth coverage and -90 to +40 degrees elevation. To find the missile, the DIRCM needs to be directed by a MAWS (see Chapter III. Electronic Support Measures), but when aimed at the missile the DIRCM can take over the tracking using its IR tracking sensor. The DIRCM uses two parallel beams (probably laser) of IR energy to jam the missile. It can be expected that the two beams are of different wavelengths to provide sufficient intensity for both short and long IR wavelengths. [Ref. 5, Ref. 36]

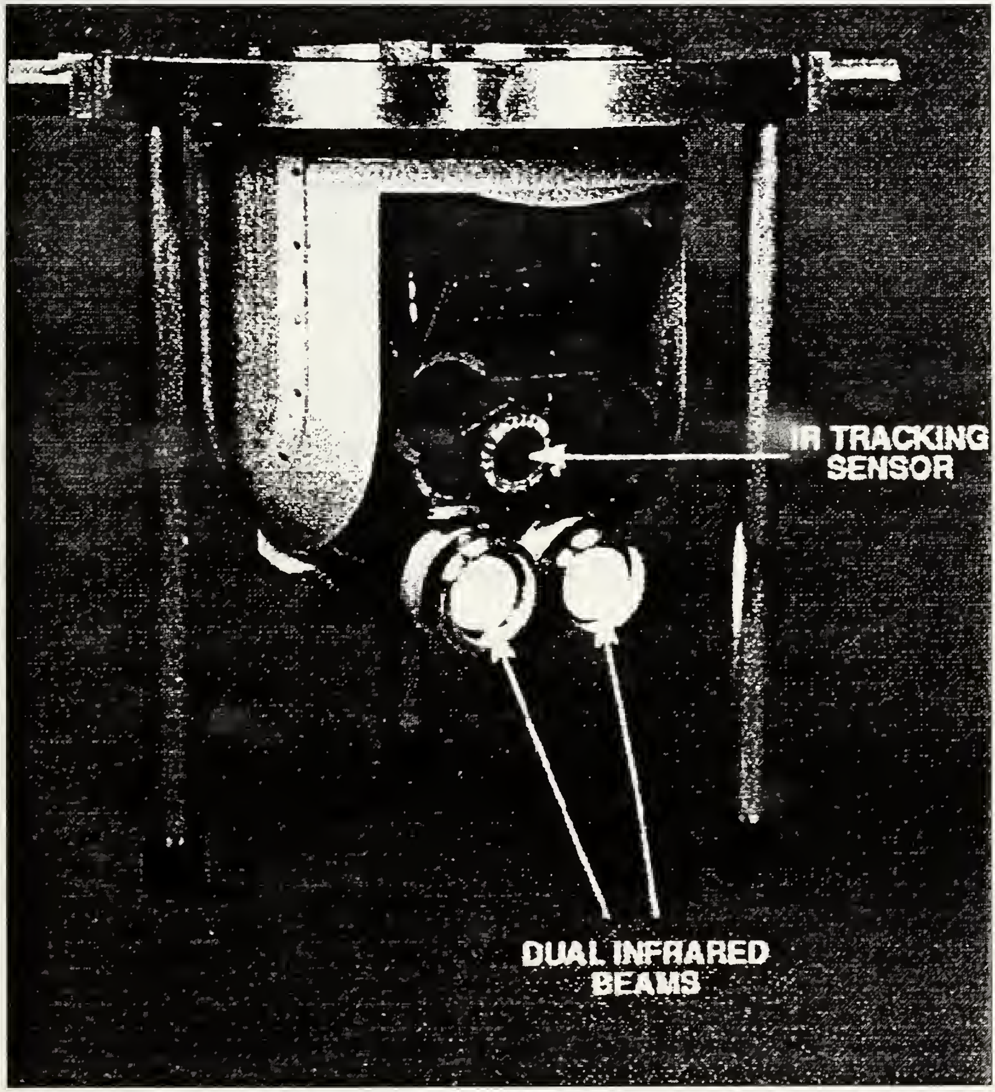


Figure 4-8. DIRCM

D. OFFBOARD COUNTERMEASURES

1. General Description

The offboard countermeasures consist of several different systems representing a wide range of techniques to decrease the susceptibility of the platform they are designed to protect. The systems range from relatively simple chaffs to complex UAV equipped with auto pilot and sophisticated repeater transmitters. There are both active and passive systems in the group as well as expendable and recoverable systems. The common factor for these systems is that they operate outside of the protected platform.

a. Chaff

Chaff was the first countermeasure invented to counter the radar. Even today chaff is widely used to protect aircraft as well as ships against both detection and radar guided missiles. The use of chaff is divided in two different missions, masking and seducing. The masking measure is, as the name indicates, an attempt to hide the platform, normally an aircraft, from detection. This is achieved by having a corridor or barrier pre-laid by a special aircraft, the strike force can then attack through the chaff corridor without being detected by the radars. To avoid the exposure of a chaff-laying aircraft, systems using unmanned vehicles are under development (see TALD). To be effective the chaff barrier has to provide a stronger echo than the target in each of the radar's processing cells.

The seducing measure is today in use in both aircraft and ships. The idea is to throw out chaff in a burst away from the platform in order to create the impression of a target. The radar guided missile is then seduced to target the chaff cloud instead of the platform. In the case of ships, the seduction is often supported by on-board electronic countermeasures.

Todays chaff is normally a dipole made of thin glass fiber coated with aluminum or zinc. The chaff is usually package in cartridges or cassettes (see Figure 4-9) and is ejected by electromechanical, pneumatic or pyrotechnical methods.

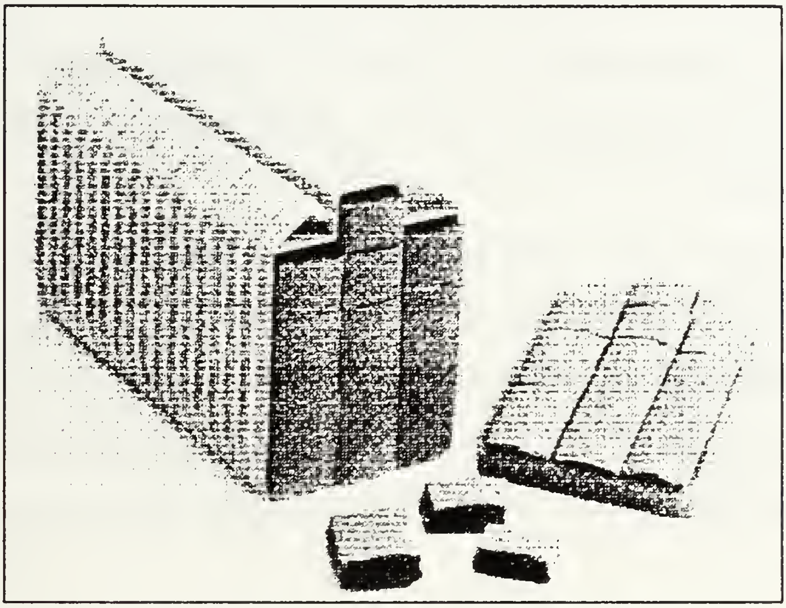


Figure 4-9. Chaff Cassettes

The radar return from each dipole is a function of radar wavelength. The peak return occurs when the radar wavelength is approximately twice the length of the dipole. Resonances also occur at integer multiples of the dipole length but with much lower amplitudes. To achieve good results against radars with different frequencies the chaff in a cartridge is cut to different lengths representing different frequencies. The magnitude on the radar return is also dependent on the orientation of the dipole compared to the orientation of the radar. The maximum return is achieved when illuminated from the side while it is near to zero when illuminated from the end. The maximum radar cross section at the resonant frequency from a single dipole is approximately $0.866\lambda^2$ while the average is approximately $0.15\lambda^2$. As is obvious from the formula the number of dipoles necessary to create a certain radar cross section increases with the square of the frequency.

After being dispensed the chaff forms a cloud. The initial length of the cloud equals the time the dispensing aircraft traveled during the dispensation time. The cloud is spread out because of turbulence caused by the dispensing aircraft. The cloud continues to grow because of differences in fall rates among the chaff, the prevailing wind and the air turbulence.

"Smart chaff" or "Chips Expendables" are under development by the US Air Force. The smart chaff is actually a miniature active RF decoy which consists of a self-powered single chip repeater. The chip uses the MMIC technology (see Appendix A) and has an integrated antenna. The smart chaff will, in contrast to ordinary chaff, not be limited to one frequency, instead it is expected to be effective over a wide range of frequencies.

The effectiveness of chaff is severely reduced by radars using MTI (Moving Target Indicator) and pulse-Doppler. Both systems are able to resolve targets against static clutter backgrounds, to which category a slow moving chaff clouds belongs. Because of the scintillations caused by the continuous movements of the dipoles neither of the radars are capable of totally eliminating the effects of the chaff. [Ref. 1, Ref. 14, Ref. 29, Ref. 37, Ref. 38]

b. Smoke and Aerosol

Smoke has been used since historic time to give cover in the visible wavelength. When not normally considered an electronic warfare component it is a very effective counter measure against several EO and IR systems. Smoke's ability to scatter radiation is a function of the wavelength of the radiation and the particle size in the smoke, the longer the wavelength the larger particles necessary. Generally it is easier to produce smoke with smaller particles and smoke with larger particles also tend to dissipate faster. Aerosols can be used in a similar fashion to smoke. The aerosol cloud will interfere with the radiation because of a reduction in intensity caused by absorption and scattering. Unlike the smoke case, the aerosol also causes scattering because of the different refractive index in the small particles. [Ref. 14]

c. Radar reflectors

Radar reflectors are used to create target-like radar echoes. Because of their form they have a large radar cross section and thereby create an echo normally received from a much larger target. The corner reflector is a simple device which produces a relatively high return over a wide range of angles. An even better coverage is achieved by using a Luneberg lens. The lens has a focal length equal to half the lens thickness. To turn the lens into a reflector the far surface is given a reflective coating. [Ref. 14, Ref. 29]

(1). Replica Naval Decoy (Irvin Great Britain Ltd.)

Replica is a RF passive naval decoy intended to provide a ship-like target to seduce/distract an anti-ship missile (see Figure 4-10). The decoy is a octahedral shaped radar reflector and to achieve better azimuth coverage they are normally deployed in linked pairs. The reflectors inflate and operates with full radar cross section a few seconds after hitting the sea. [Ref. 8]

Figure 4-10. Replica Naval Decoy

d. IR-Flares

IR-Flares are used to seduce missiles with IR-seekers. To be able to attract the missile the flare has to produce intense radiation in the waveband the seeker is using (see Appendix B). The intensity from the flare decreases with increasing altitude and velocity, this complicates the use of flares for fighter aircraft. The flares normally burn for just a few seconds which makes the timing of the launch critical. There are two ways to assure proper timing of the launch; either continuous launch of flares when the aircraft reaches an altitude where it is exposed to IR-missiles (for example take-off and landing in an unsecured area) or automatic launching as a part of an integrated EW-system. The different launcher systems for airborne, land and naval applications are discussed further under dispenser systems. For IR flares to be effective against modern IR-missiles they need to emulate closely the platform; by using sensors sensitive in more than one waveband the missile is able to discriminate a "one-color" flare from the platform. [Ref. 14] *e. RF-Expendables*

(1). GEN-X, Generic Expendable Cartidge (Texas Instruments)

The GEN-X is a active radar decoy which provides endgame protection for tactical aircrafts against radar guided missiles (Figure 4-11). The decoy measures 6 in. in length and 1.3 in. in diameter. Power to the decoy is provided by a lithium battery. The decoy has no propulsion and is stabilized in its free-fall by four small fins which are unfolded after ejection from the dispenser. Both the ALE-39 and ALE-47 dispensers can be used for the GEN-X decoy. The projectile has a forward-facing spiral antenna system located on the nose cone. The receiver and transmitter in the decoy consist of four Microwave Monolithic Integrated Circuits (see Figure 4-12). The MMIC technology is essential for production of a GEN-X sized decoy with high performance and relatively low price. When released from the aircraft the decoy repeats received radar signals to seduce the incoming missile. The GEN-X is said to have three field-programmable bands between which it can switch if it does not pick up any signals in the band it initially searches. [Ref. 8, Ref. 38, Ref. 39, Ref. 40, Ref. 41]

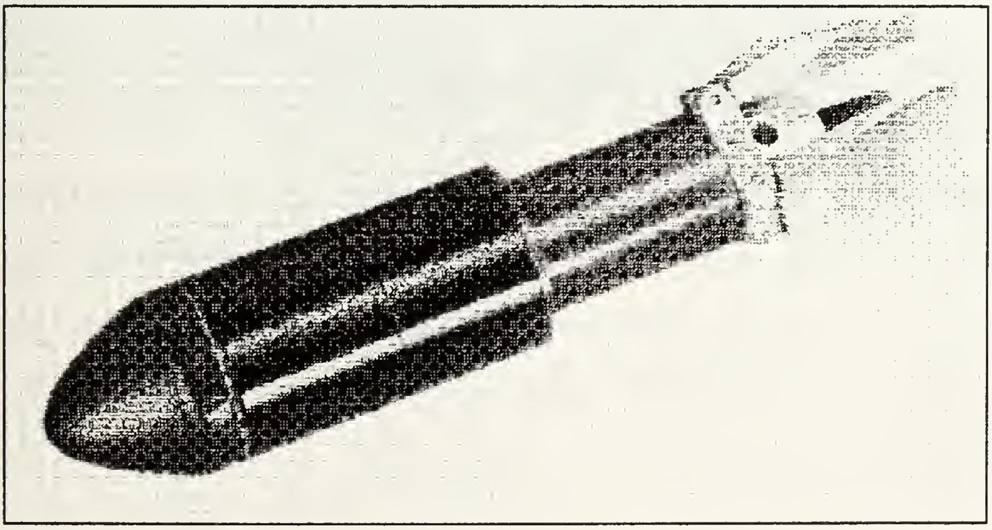


Figure 4-11. GEN-X Decoy

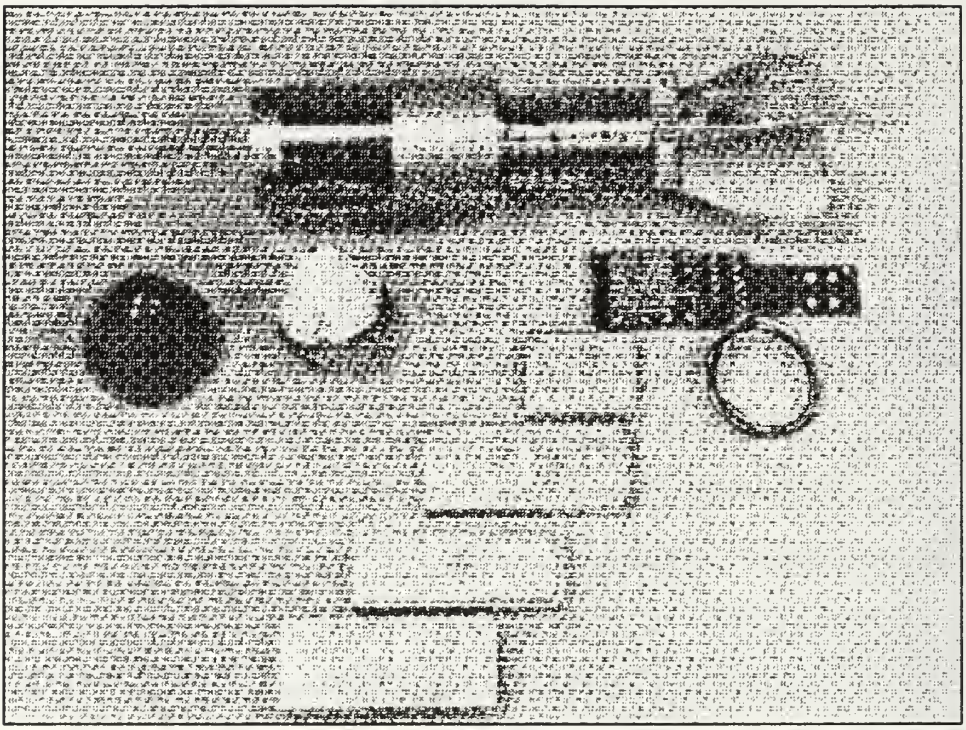


Figure 4-12. GEN-X Decoy

(2). STRAP, Straight Through Repeater Antenna Performance (Tracor)

The STRAP is under development by Tracor for the USN. The Strap differs from GEN-X in two major areas, it uses two antennas, one each for reception and transmission, and it uses Traveling Wave Tube Amplifier (TWTA) instead of solid-state amplifiers. The advantage with using TWTA is that they are more powerful, the disadvantages are the cost and the power requirement. On the STRAP the power requirement has been solved by using a thermally heated cathode for the TWTA. This has been possible because the TWTA is only supposed to work for a short time. [Ref. 11, Ref. 39, Ref. 40]

(3). Carmen (THORN EMI Electronics)

Carmen is an expendable active decoy against radar guided antiship missiles. The decoy purpose is to seduce an incoming missile, thereby achieving a "soft-kill". After detection of the ASM threat by the ship's own sensors (see Figure 4-13), Carmen is launched clear of the ship from a standard 130 mm launcher. The decoy descends slowly by parachute to provide sufficient time for the decoy to seduce the threat away from the protected platform electronically (see Figure 4-14). Carmen uses MMIC technology to achieve low weight and volume and high reliability. Further, the decoy is equipped with TWTA to provide high power (see Figure 4-15). The frequency bands covered are H,I and J. [Ref. 8, Ref. 42)

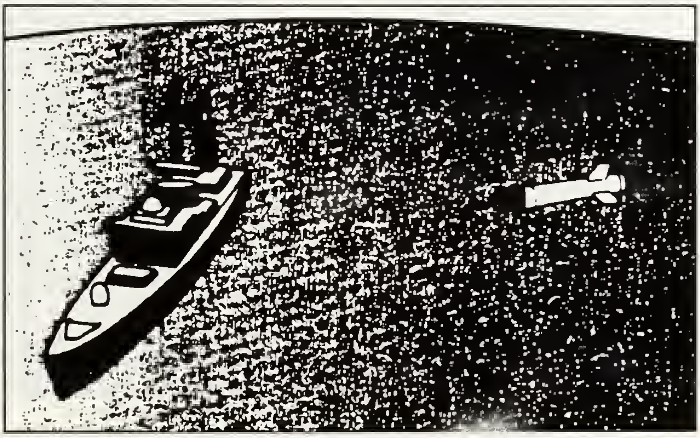


Figure 4-13. ASM Attack on Ship

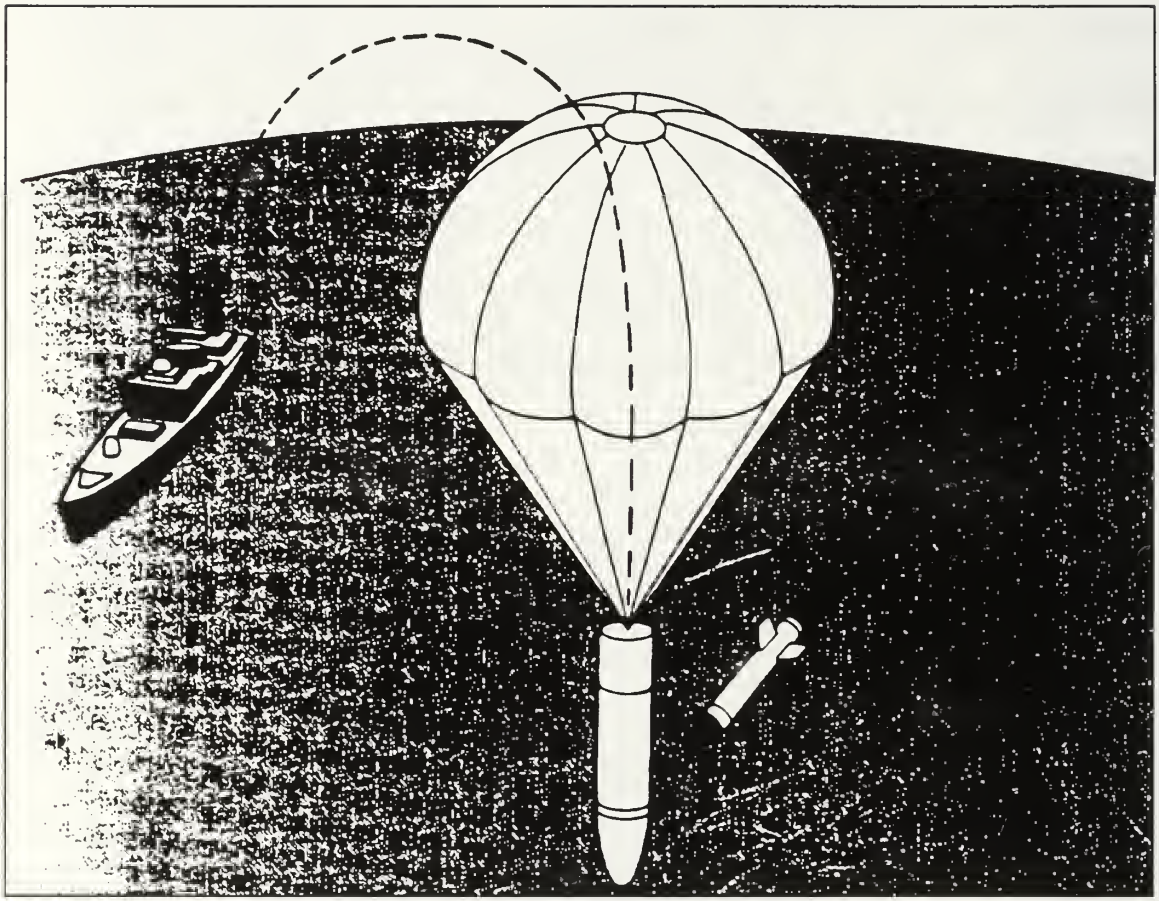


Figure 4-14. Launch of Carmen Decoy

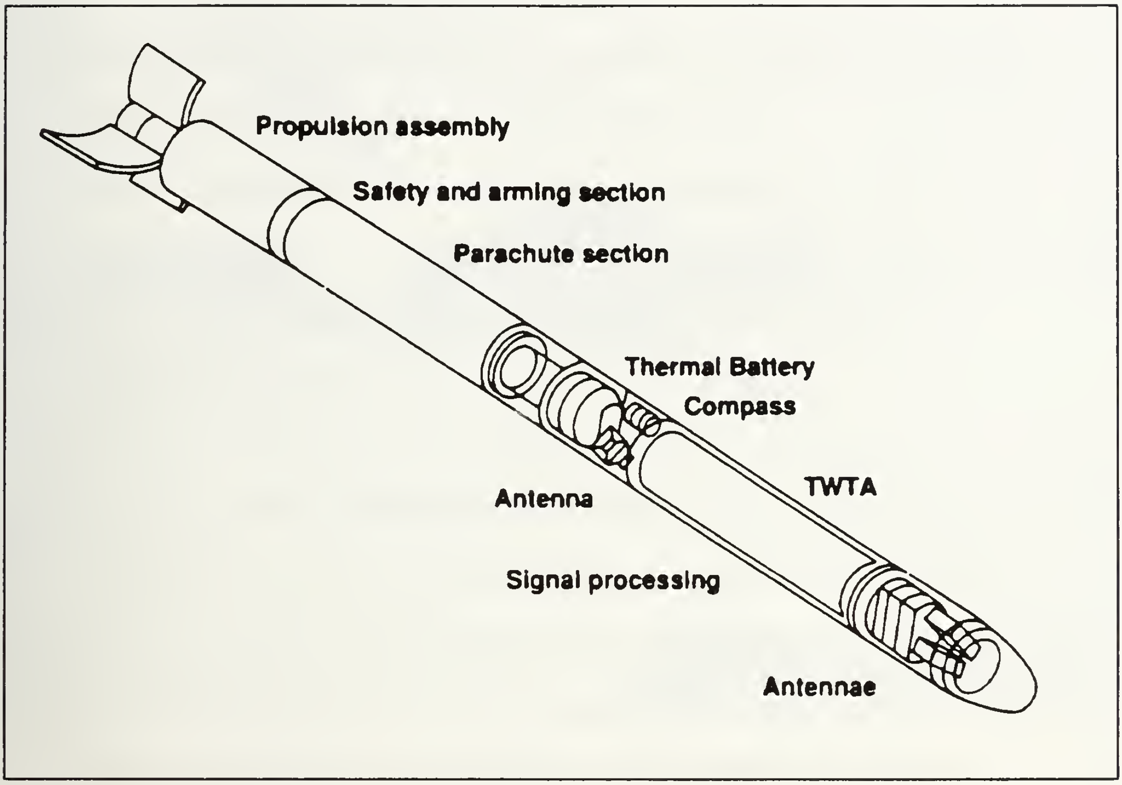


Figure 4-15. Carmen Decoy

f. Flying Decoys

A flying decoy is a drone with its own navigation and possibly propulsion. The main advantage with a free flying decoy is that it is possible to send the decoy in front of the platform it is supposed to protect. This option provides a better ability to counter all-aspect weaponry such as heat-seeking missiles operating in the longer wavelengths. It also improves the possibilities to counter missiles with processors capable of discriminating between the relative velocities of the platform and the gravity-bound decoys.

(1). LORALEI (Loral Electro-Optical)

The Loralei is an expendable decoy which emulates the host aircraft in order to seduce the attacking threat. The decoy simulates the aircraft's flight and spectral signatures. The system is powered by a rocket motor and is able to protect the aircraft from attack in the forward hemisphere. By using a time-delayed ignition the decoy is able to fly close to the host aircraft initially to increase the probability that the threat missile is seduced. Loral states that it is possible to incorporate EO/IR as well RF capabilities into Loralei. [Ref. 34, Ref. 38]

(2). TALD, Tactical Air Launched Decoy (Brunswick Defense)

The TALD is an unpowered decoy which is launched from high altitudes (see Figure 4-16). The decoy's glider flight is controlled by an autopilot. The maximum range of the TALD is stated to be approximately 130 km. The system is equipped with a passive radar reflector in the front as well as with an active repeater system. The repeater system has one antenna, receiving and transmitting, under each wing. The TALD can also have a chaff dispenser. The system is programmable in the field to allow simulation of different flight profiles. Because the TALD is unpowered it gives an opportunity for sophisticated weapon systems to discriminate it from the platform it was supposed to protect.

Brunswick is working on an upgrade of TALD called ITALD (Improved Tactical Air Launched Decoy). The main improvement will be that ITALD will be equipped with a turbojet engine. ITALD will be able to emulate an attacking aircraft more closely with an expected low altitude speed of Mach 0.8. The effective range will be increased to approximately 280 km. ITALD can also be configured as an anti-radiation missile (see Chapter VI Suppression of Enemy Air Defense). [Ref. 8, Ref. 38]

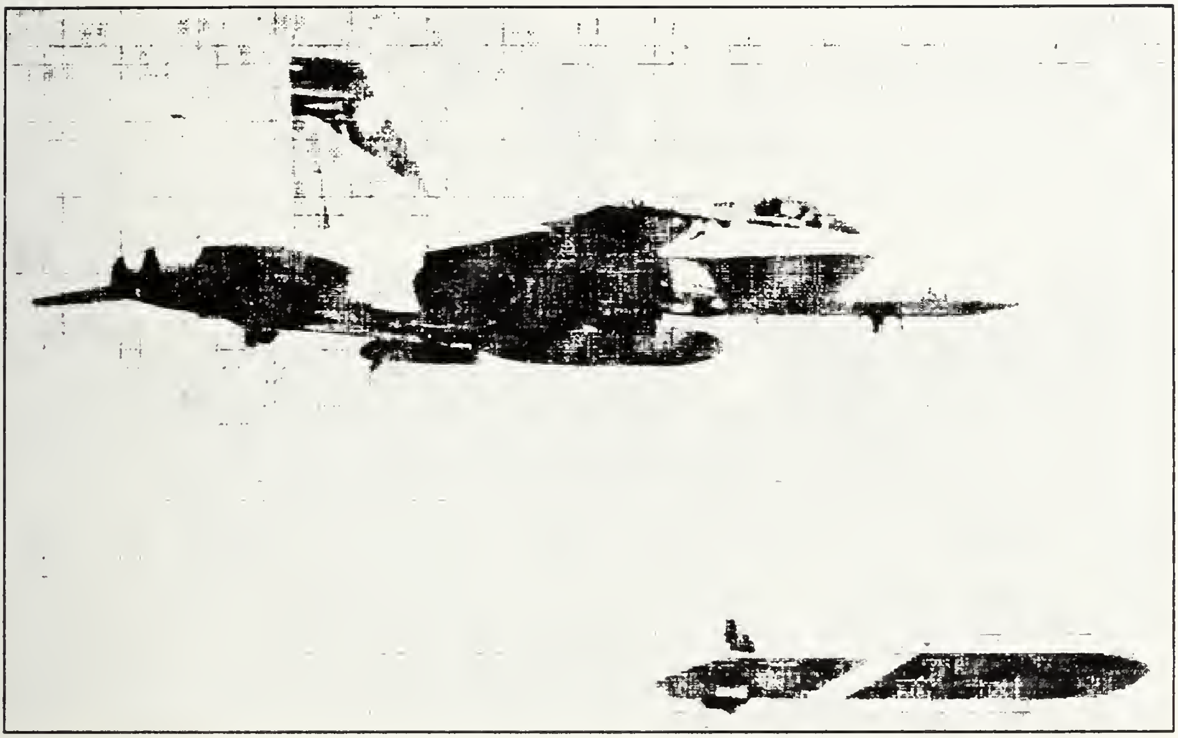


Figure 4-16. TALD, Tactical Air Launched Decoy

(3). Delilah, Tactical Decoy System (Israel Military Industries Ltd.)

Delilah is a development of the TALD. An earlier version called Samson was deployed with great success by the Israeli Air Force against air defense systems in the Bekaa Valley 1982. Delilah is a jet engine powered radar decoy and it can be launched at altitudes between 150 and 30,000 ft. The maximum speed is Mach 0.8 and the range is approximately 400 km. The payload can be either passive, in the form of a Luneberg lens, or active, in the form of RF repeaters. [Ref. 8, Ref. 43]

g. Recoverable Decoys

(1). AN/SSQ-95 Active Electronic Buoy (Litton, ATD/Magnavox)

The SSQ-95 is an antiship missile decoy, it is packaged in a sonobuoy container and can be dropped from an aircraft or helicopter, launched from the deck of the ship or towed behind the ship. The decoy is equipped with a receiver and a TWT transmitter. The power to the decoy is provided by a battery that is activated by sea water. The SSQ-95 is expected to operate in the I/J bands. [Ref. 44]

(2). AN/TLQ-32 Antiradiation missile decoy (ITT)

The system is designed to protect the AN/TPS-75 radar system by seducing incoming antiradiation missiles. Three decoys systems will be deployed with each radar system. The TLQ-32 is said to be capable of protecting the radar site from multiple missile launches simultaneous. The decoy's small size and relatively few exposed parts give the system a good survivability in case of a close detonation (see Figure 4-17). It is not know what radiation patterns the decoy uses but both continuous, in order to attract the missile, or intermittent, in order to confuse it, are possible. [Ref 45]

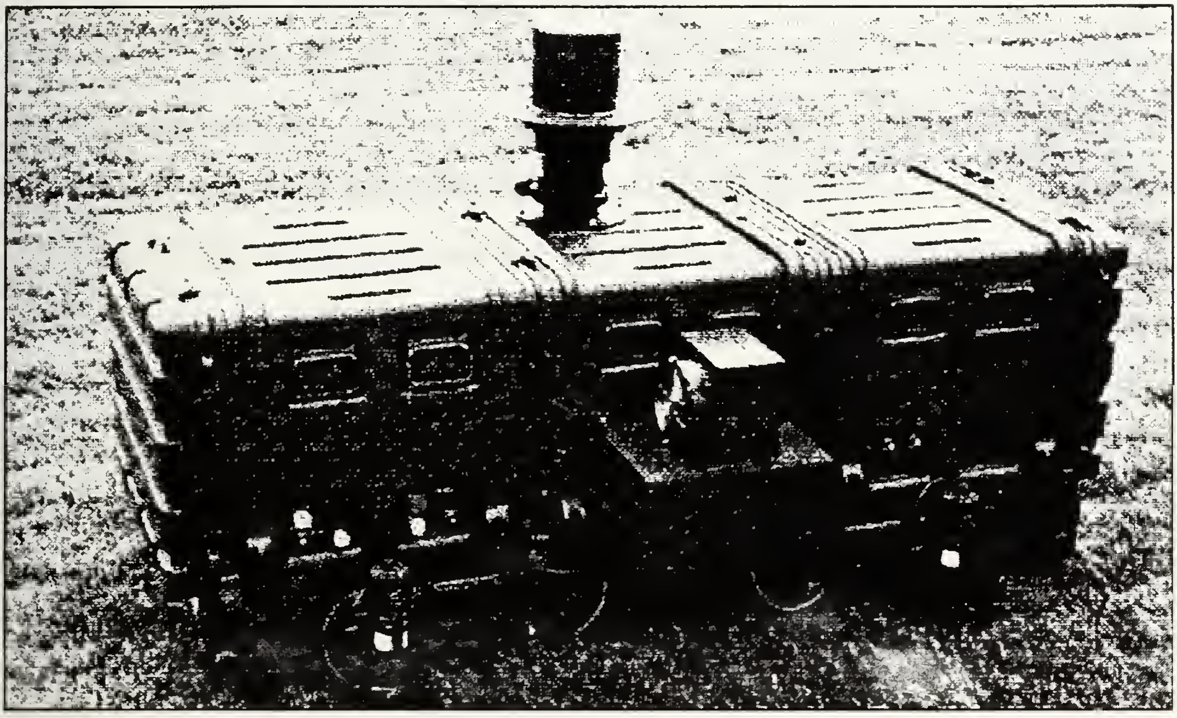


Figure 4-17. AN/TLQ-32 Antiradiation missile decoy

h. Towed Decoy

Towed decoys are used in both naval and airborne applications but the conditions of use are different. In the airborne application the use of a towed decoy has several advantages compared with expendables. Because the decoy is connected to the platform the expensive and power consuming equipment can be inside platform and be used several times, it will also reduce the weight and size constraint on the equipment. In the case of an aircraft the decoy of course needs to be kept on a distance from the platform so the platform is not damaged by a missile hitting the decoy. The towed decoy will be most effective when the attack against the aircraft comes perpendicular to the course of the aircraft and least effective against a forward attack. There are several techniques for using towed decoys in order to protect the platform. One technique is just to produce a stronger return using a repeater jammer. Another method is "blinking" which means that the transmitter in the aircraft and the one in the decoy transmit alternately, this will cause a back-and-forth motion in the threat angle which might stop a missile launch because of the apparent instability in tracking. Figure 4-18 shows different possible configurations for airborne towed decoys, from the most complicated with all components in the decoy to a solution where the decoy actually only is a remote antenna. [Ref. 46, Ref. 47]

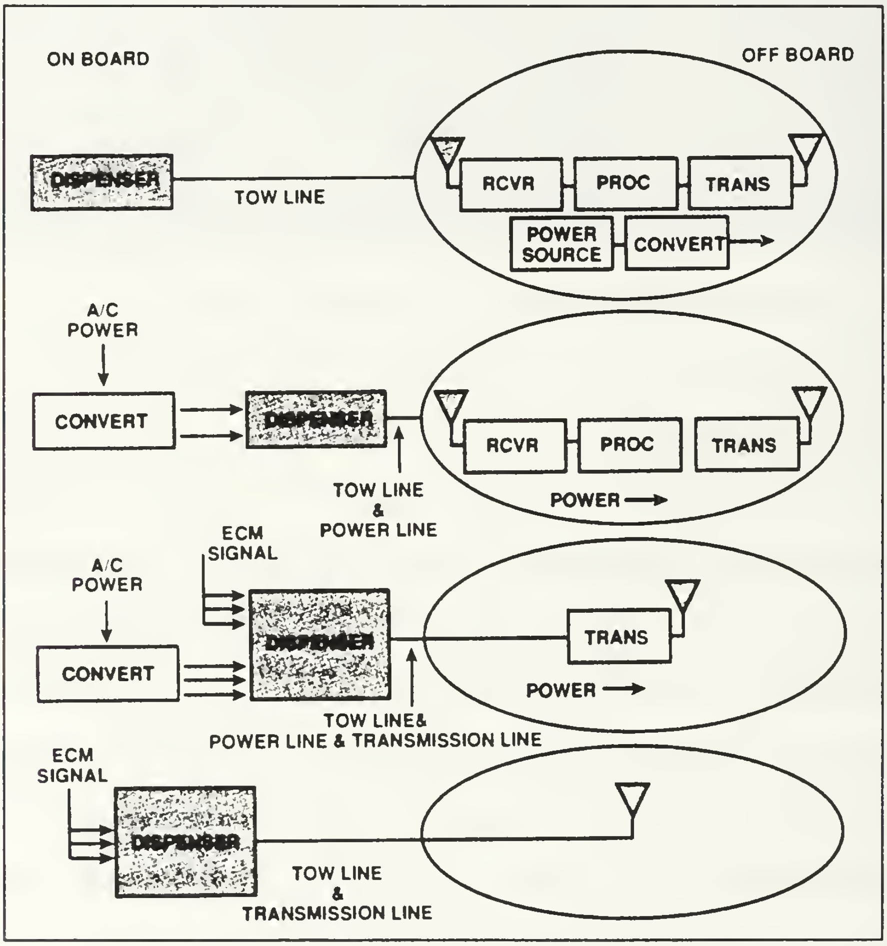


Figure 4-18. Different Possible Configurations for Airborne Decoys

In the ship applications the towed decoy can be a small boat equipped with both radar reflectors and active repeater transmitter. The purpose of the decoy is mainly to break a missile's lock on the ship and seduce it towards the decoy. An example of a towed decoy for naval applications is shown in Figure 4-19. The decoy in the picture is called TOAD (Towed Offboard Active Decoy) and is built by Marconi Defence Systems Ltd. TOAD is equipped with radar reflectors, receiver, signal processor, transmitter and an antenna which is possible to point toward the threat. The system covers the I and J bands. [Ref. 8]

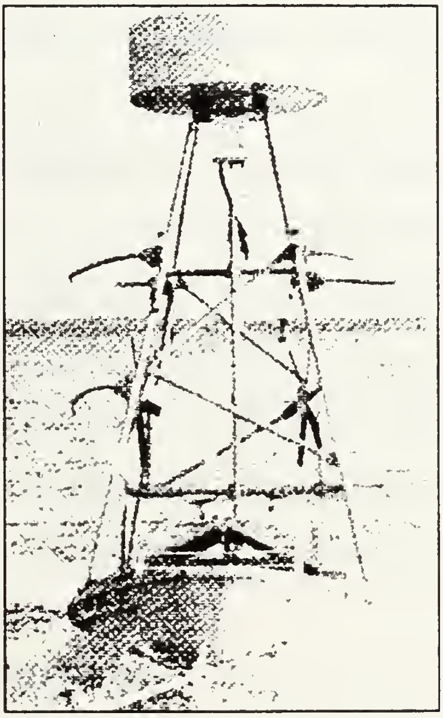


Figure 4-19. Towed Offboard Active Decoy (TOAD)

i. Unmanned Aerial Vehicles

UAV can be used for offboard countermeasures (see Figure 4-20). There are two principal methods in which UAV can be used. One method is to use the UAV as a decoy (compare TALD) equipped with radar reflectors and possible a repeater-transmitter. The purpose of this method would be to distract the air defense. During the Israeli attack in the Beekaa valley in 1982, UAVs were used to seduce the Syrian missile batteries to turn on their radars and thereby give away their EOB (Electronic Order of Battle). The use of UAVs as decoys could also be done with the purpose of removing attention and resources from the striking force, the attack of which would be coordinated with the UAV. The second method to use UAV as an offboard countermeasure could be as a substitute for a jammer aircraft. By equipping a UAV with ECM it would be possible to achieve some advantages compared with a jammer aircraft. The UAV is less expensive, it is also smaller, which makes it easier to avoid detection, and as is apparent from its name, it is unmanned which make it possible to plan missions without considerations for the loss of pilots. For these reasons it is possible to operate closer to the threat radar. This has several advantages, the primary being that the power necessary to achieve the desired effect in the radar is reduced. As can be seen in the equation for ECM (Appendix D) a jammer at half the distance only needs a quarter of the power. Another advantage of operating away from the protected platform is that the effect of the jamming will not interfere with the platform's own weapons to the same degree which makes it possible to use wideband countermeasures without jepordizing the friendly systems. [Ref. 48, Ref. 49]

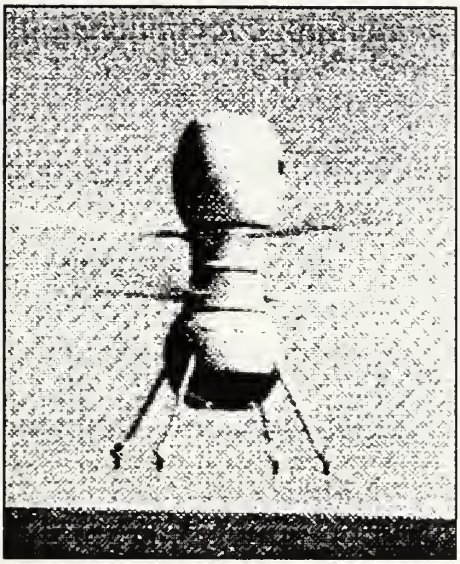


Figure 4-20. Unmanned Aerial Vehicle

j. Dispensing Systems for Chaff, IR-flares and RF-decoys

The requirements for a dispensing system are very different for different applications. Below is a brief description of the application-specific considerations for landbased, naval and airborne dispensing systems.

Because the threats against landbased systems have mainly been IR/EO guided systems, the dispensing systems have been concentrated toward smoke launchers. Smoke is today the most widespread countermeasure system for armoured vehicles. With the increasing threat from anti-tank systems using laser guidance and IR-guided systems, the importance of reliable smoke launchers becomes more important. To get smoke of the right sort in the right place at the right time has become a challenging task. To shorten the response times in order to decrease the susceptibility, the launching systems are becoming integrated with the vehicle's different warning systems (see integrated EW systems). Only one landbased system using both chaff, IR-decoys and smoke for protection of key military installations is known and that is the British system RAMPART.

Dispenser systems for chaff are today the most common countermeasure on naval ships and for many smaller ships chaff is the only countermeasure system. The chaff, IR and RF decoys are normally dispensed by rocket systems. This is done to get the decoys a sufficient distance away from the platform. The dispenser system is usually a part of an integrated EW-system (see Chapter V. Integrated Electronic Warfare Systems) which calculate what countermeasure should be used and in which direction the decoys should be deployed. The British Shield system is described below as an example of naval dispensing systems.

For airborne systems the location of the dispensing system is of great significance for effectivness of chaff and IR flares. For chaff used in a self-protection role it is important that the chaff cloud blooms rapidly to create a sufficient return to the radar when the cloud and the aircraft are in the same range bin. For this reason it is desirable to locate the chaff dispenser so the chaff is dispensed into turbulent flow; this is achieved forward of wing roots and close to the engine exhaust. For IR-flares the considerations are almost opposite. The intensity of the flare decreases with increasing velocity so the flare should be ejected into non-turbulent flow. The velocity with which the flare is ejected has to be balanced so as to be not so slow that the miss distance is insufficient to protect the aircraft, but not so high that the missile seeker does not respond and breaks the lock-on. In many systems IR-flares and chaff use the same dispenser unit so the location of the dispenser has to be a compromise between the different requirements. Typical locations of dispenser units are shown in Figure 4-21. [Ref. 8, Ref. 14, Ref. 37]

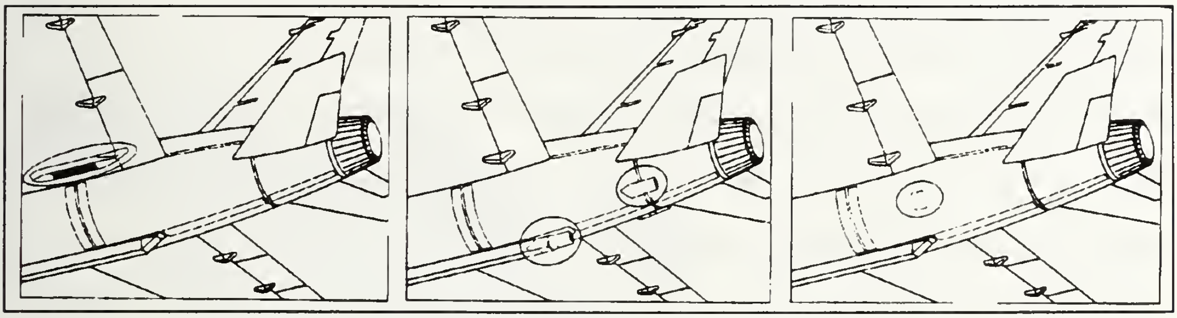


Figure 4-21. Typical Locations of Dispenser Units

(1). RAMPART (ML Aviation Ltd)

RAMPART is a landbased countermeasure system against IR, laser, TV and radar guided missiles. The system also has a feature against low flying aircraft. The system consists of a number of firing units which can be spread out up to 15 km. The firing units are activated by radio

from a central transmitter. The firing units are equipped with rocket decoys for chaff and IR, smoke (both rapid and slow burning) and the Skysnare airborne obstruction. Skysnare is an airborne tethered obstruction that is placed around the target to cause weapon aiming problems for low flying aircraft. The idea behind the obstructions is to force the aircraft to climb to higher altitudes where it will be exposed by active air defense systems. [Ref. 8]

(2). Shield Tactical Decoy System (Marconi Underwater Systems Ltd)

Shield is a chaff and IR decoy system against anti-ship missiles (see Figure 4-22). The system is modular which allows different launcher configurations. Launchers with three, six, nine and twelve barrels are available. The system is equipped with an automaitc response library which takes the input from the ships different sensors and selects the best deployment pattern for the decoys. The launcher system is equipped with rockets with either chaff, IR or a combination of both. The rockets are fitted with a variable fuse which allows the chaff to be dispensed at different positions along the trajectory. The fuse is electronically programmed just prior to launch to take wind changes into account. The submunition IR round deploys each submunition further away from the platform which makes the IR center move away from the ship. The system is also able to fire both active offboard and acoustic decoys.

Shield has four different operational modes to protect the platform:

Confusion - the purpose is to confuse hostile radars by creating multiple false targets.

Distraction - incoming missiles will lock on to chaff clouds before they lock on to the platform, this is achieved by deploying chaff around the ship at a distance of up to 2.5 km.

Seduction/Break lock - seduction of the missile to change targets from the platform to the decoy. The decoys are deployed so they, together with the effect of the wind and the platform's manoeuvre, cause the missile to move with the decoys and break the lock on the ship.

Seduction dump mode - the decoy is deployed outside the missile range gate and an onboard jammer is used to shift the gate position to the decoy. [Ref. 8, Ref. 11]

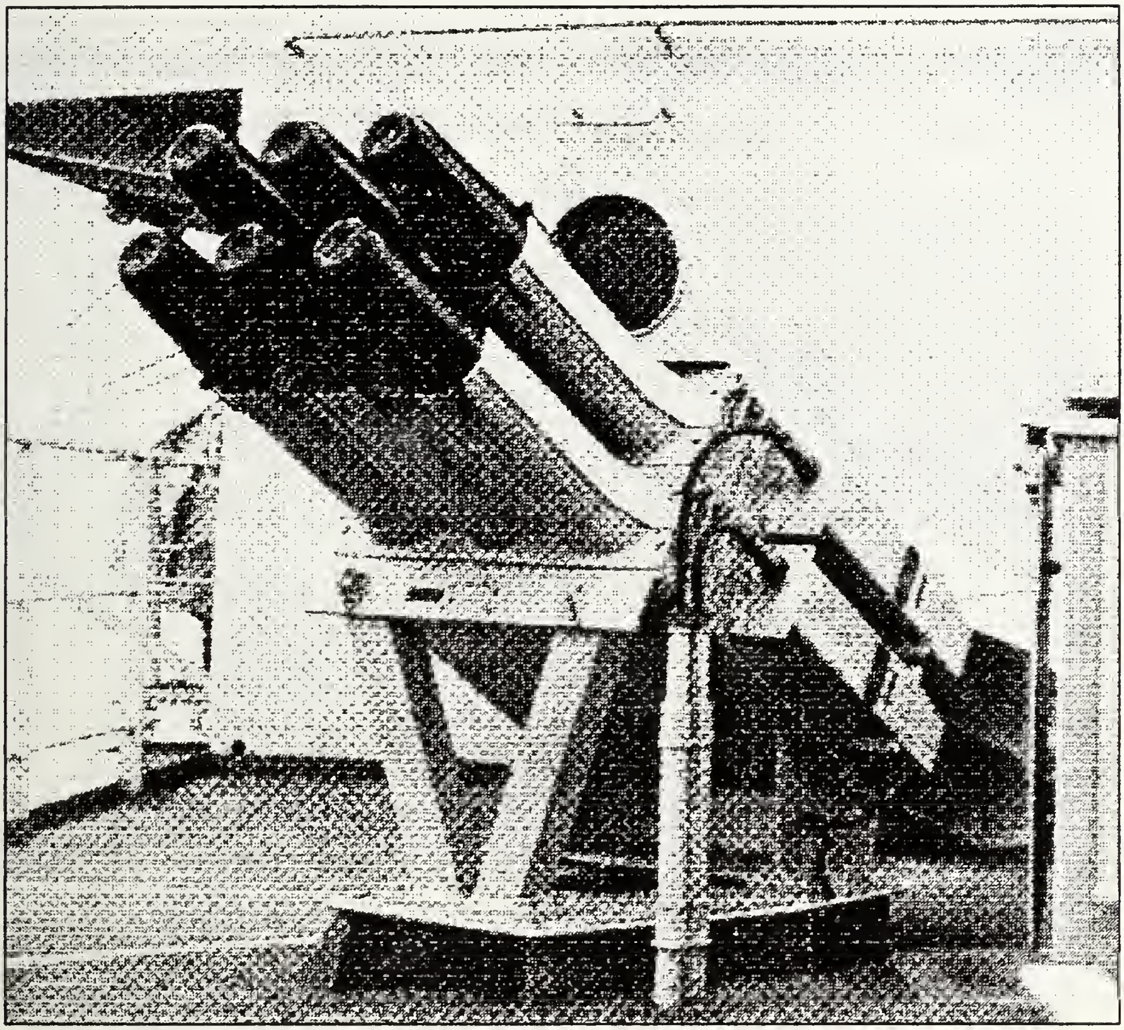


Figure 4-22. Shield Tactical Decoy System

(3). BOL (Celsius Tech)

BOL is an chaff dispenser which lets the aircraft carry chaff for self protection without any reduction in weapon payload capacity. The dispenser is constructed to work with the LAU-7 Sidewinder launcher. By changing some parts in the original missile launcher it turns into a chaff dispenser (see Figure 4-23). The chaff dispenser module consists of a chaff compartment, an electromechanical feed mechanism and an electronics unit. For cooling of the IR missile, a new gas bottle is mounted in the nose of the launcher. Each dispenser holds 160 chaff packages. Chaff cloud dispersion is synchronised by an on-board countermeasures computer. [Ref. 8, Ref. 37]

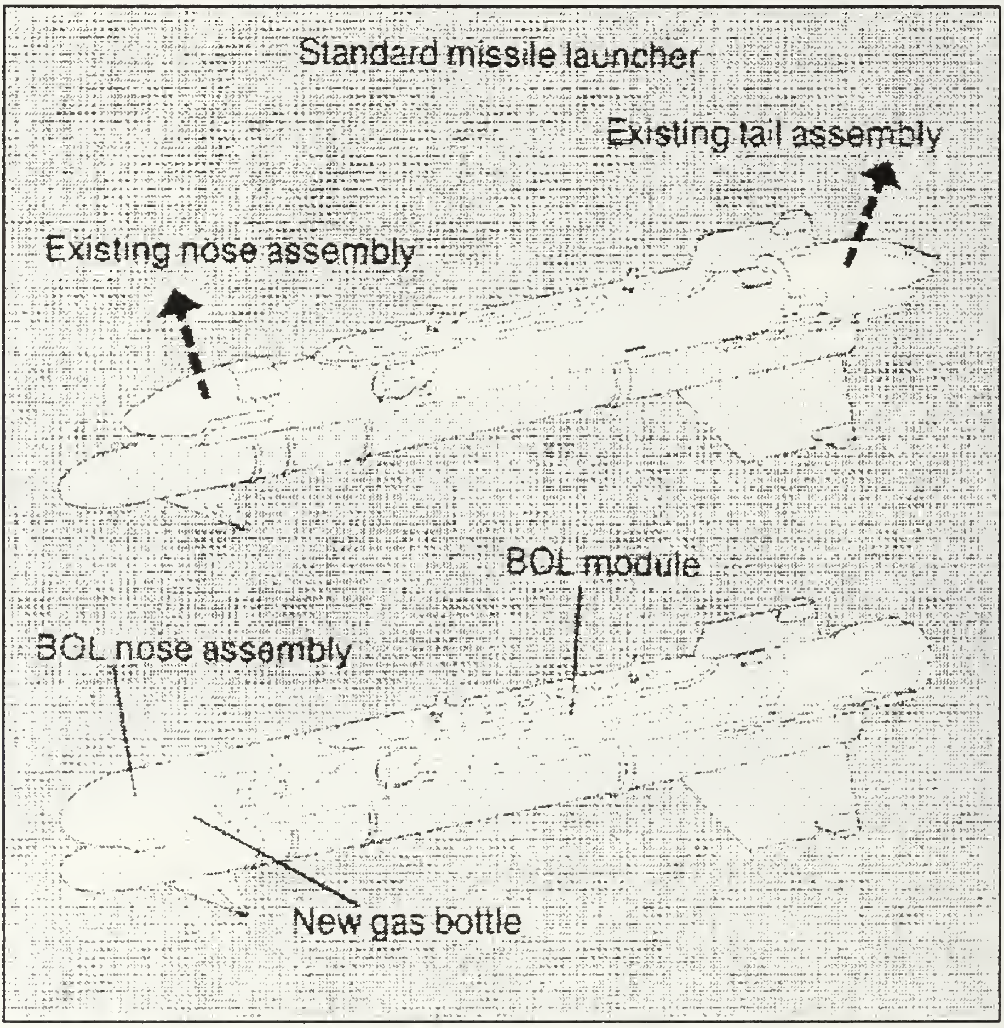


Figure 4-23. BOL Chaff Dispenser

(4). BOP (Celsius Tech)

BOP is a pyrotechnical dispenser which is produced in different versions for compatibility with installation configurations to avoid the risks connected with flares (Figure 4-24). The BOP/B can be loaded with up to six 55 mm diameter standard NATO type flares. The dispenser can be controlled by an automatic EW-system (see integrated EW-system). An optional IR sensor can be mounted at the rear to indicate whether the IR flares have ignited correctly. [Ref. 8, Ref. 37]

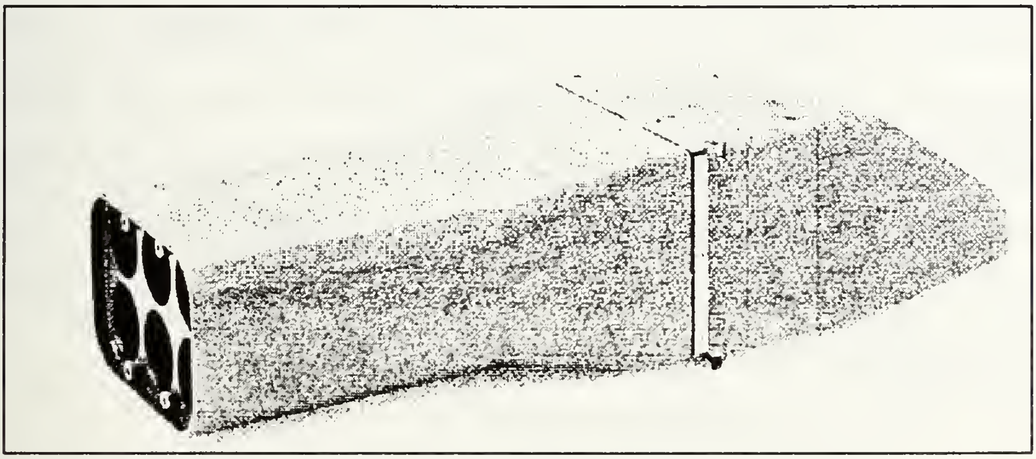


Figure 4-24. BOP Pyrotechnical Dispenser

E. COMMUNICATIONS COUNTERMEASURES

1. General Description

The purpose of communications countermeasures is to deny the enemy the possibility to command his troops by way of radio. The countermeasures can be in form of jamming or deception. Radio deception, which can be in the form of giving false and misleading information, will not be discussed further. Jamming can be either in the form of noise which reduces the signal-to-noise ratio or in the form of psycho-acoustic modulations which distracts and enables the receiving operator. The jammer system normally operates in a responsive mode; the transmitter is connected to a receiver system which activates it when an active channel is detected. To ensure that the channel is still active it uses a process called look-through, which means that the jamming is interupted periodically to provided for the receiver to check. There are different ways to jam several channels. The channels can be preset and the jammer can operate in a time-division multiplex mode, this means that the jammer is moving between the different channels which creates the impression of simultaneous jamming. The different preset channels can be given different priorities which means that the jammer will return to the channels with different intervals. Some systems are using multiple transmitters so some channels with high priority can have true continous jamming. Another method to jam several channels simultaneous is to use wide band jamming. [Ref. 50]

2. Communication Countermeasures System

a. TACJAM-A (Lockheed Sanders/AEL)

TACJAM is a mobile VHF jamming system, the ESM part of the system is described in Chapter III ESM Systems. The system is designed to cover a wide frequency range and compared to older systems lighten the operator's workload. TACJAM has a modular design and if a system component fails the system automatically reconfigures itself to a degraded performance. The system consists of multiple exciter and transmitter sets to allow it to disrupt many frequencies simultaneously. The jamming is computer controlled and has look-through capability. To increase the maximum output power, two amplifier chains can be combined, this is done by a combiner unit which also uses phase control to synchronize the two amplifier chains (see Figure 4-25).

Specifications

Frequency range: 20 - 200 MHz

Power: 3 - 4 kW ERP

Modulation modes: Amplitude modulation (AM), frequency modulation (FM), continous wave (CW), frequency shift key (FSK), Noise and single side band (SSB). [Ref. 8, Ref. 11, Ref. 51]

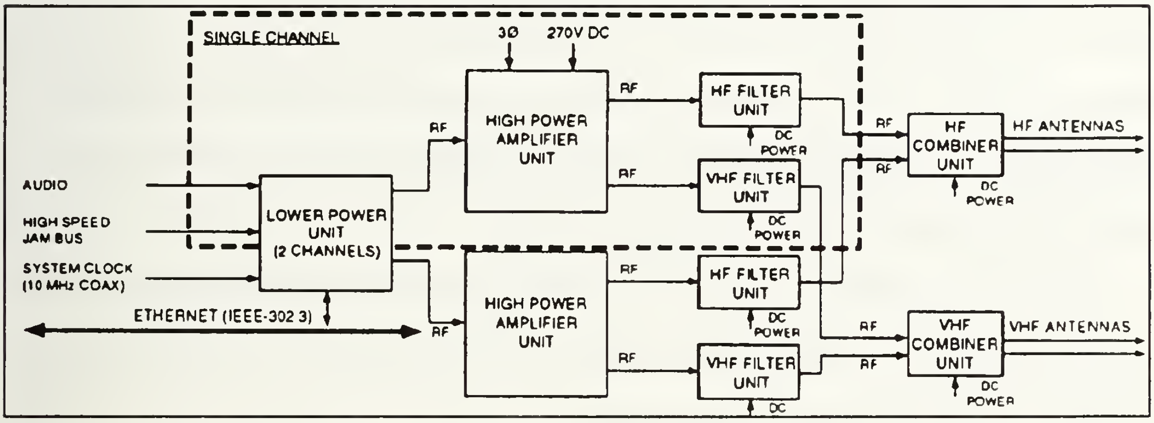


Figure 4-25. TACJAM-A Blockdiagram for ECM section

b. AD/EXJAM (Loral Control Systems)

EXJAM is an artillery (155 mm howitzers) delivered jammer. The sytem consists of five devices stacked within the projectile. The jammer is a broadband barrage transmitter for disrupting enemy communications. The jammers are released in the trajectory by an automatic fuse. The system provides the possiblity of deploying jammers around a command post thereby limiting its ability to receive radio communications. [Ref. 8]

F. CONCLUSIONS

The ECM systems uses many different technologies and methods to achieve their purpose, below is a summary of the expected future for the different types of ECM described in this chapter.

The competition between radar and ECM will, with a high degree of certainty, continue. New ECM systems will no longer only be able to counter the "red" threat but must be able to counter western systems as well. The high cost of developing sophisticated on-board systems will probably lead to a challenge by off-board systems. The use of MMIC will make expendable RF-decoys an attractive alternative. Chaff will probably continue to be a cost-effective self protection against a large part of the radar guided threats. Future systems might well use a combination of on and off board systems to achieve the desired deception at a reasonable cost.

Laser CM will probably become more common because of the latest successes for laser guided weapons. Systems which are able to deceive designator based systems could be deployed in the defense of high value assets.

Infrared CM will, because of the effectivness of IR-missiles, increase in importance. With the deployment of all aspects attacking IR missiles, directed IRCM will be the preferred CM method. New missile seekers with less sensitivity to deception will probably lead to IRCM of the destructive type.

V. INTEGRATED ELECTRONIC WARFARE SYSTEMS

A. GENERAL DESCRIPTION

The introduction of new threats using new techniques for detection and guidance has lead to the development and deployment of new countermeasure systems to counter them. These new CMs have been added to a growing arsenal of EW systems on the platforms. The trend today is to integrate these CMs to achieve a higher efficiency than if the CMs worked without coordination. The EW systems should also be integrated with the other systems on the platform to achieve further synergy effects. The modern threat is also pushing for integrated systems by reducing the reaction time for deployment of CM.

With an integrated system it is possible to produce an interpretation of real-time data from several different sensors and either present a recommendation to the tactical action officer or apply the ECM automatically. For expendables the timing of the deployment is critical for their effectiveness. By using the information achieved from the MWS together with information from the navigation system regarding wind and speed, an optimal automatic launch is possible.

By fusion of the information from different sensors,an integration processor can get a more complete picture of the threat (see Figure 5-1). Fusion of the ESM information with the IR-signature and the targets speed achieved from the radar can give a better probability of identification and thereby a better chance to deploy the best ECM. The information from the ESM can serve as target information for weapon systems.

By integrating the platforms weapon systems with the EW systems it is possible to obtain a better evaluation of the effects of the CM. The platform's radar can track the incoming missile and through the common processor communicate the missile's behavior to the ECM unit. This way it would be possible to determine the effect of the soft kill and, if necessary also be able to decide when to go over to the hard kill method.

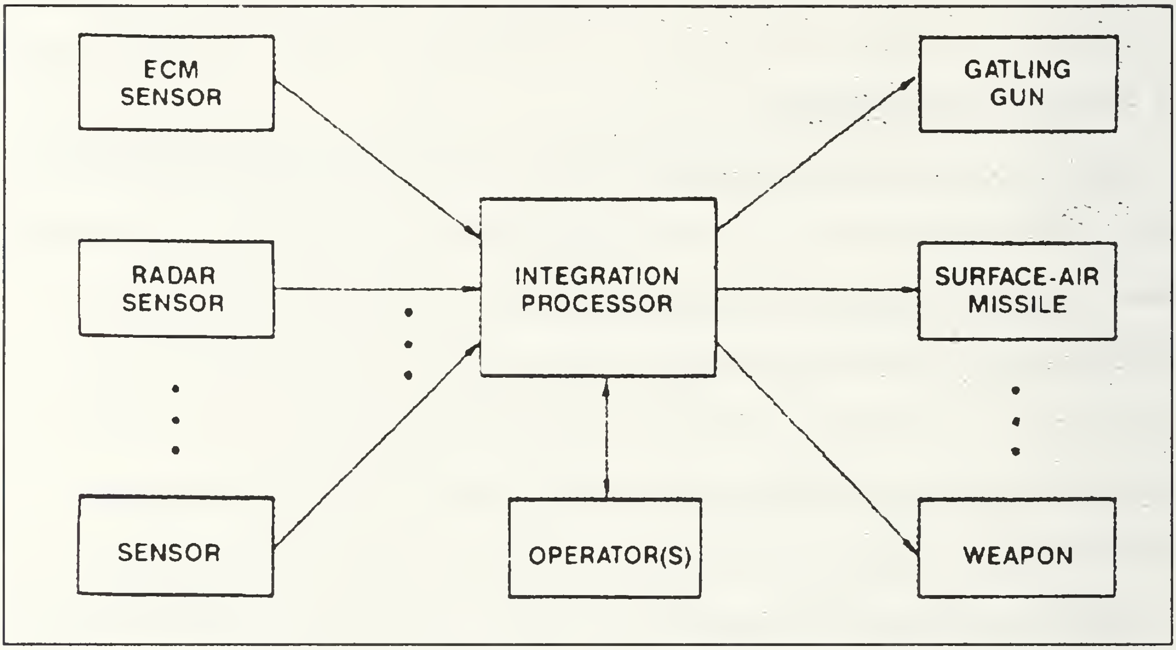


Figure 5-1. Blockdiagram for Integrated EW System

The most important advantage might be a less obvious one: by integrating the systems it would be possible to avoid the systems fighting each other. A central control unit could manage the different components of the system so that no components which would interfere with each other are active at the same time. If the integrated system is designed and specified as a integrated system it will also decrease the risk of interference compared with a merger of independent systems.

Today there are several integrated systems in operation or under development; below is a presentation of a few systems for ground, naval and airborne applications. [Ref. 52, Ref. 53, Ref. 54, Ref.55]

B. GROUND APPLICATIONS

Only recently has EW become a part of the normal equipment for fighting vehicles. The components of the threat against a tank are also different than those for a ship or aircraft. The threat is mainly from anti tank missiles guided by either laser or IR/EO while the threat from radar guided weapons is small.

1. Vehicle Integrated Defense System, VIDS

VIDS is a system under development by the Tank-Automotive Command. The system will combine threat sensor, navigation systems, identification friend or foe (IFF) and countermeasures. The sensors include laser and radar warning. The CM consists of smoke grenade launchers and semi-automatic counterfire. The launcher will be able to carry IR screening, visual as well as millimeter wave smoke. The IFF system is a laser interrogate/RF response system. For navigation the vehicle is equipped with GPS. The central processor interprets the information from the different sensors and provides the commander with a graphic presentation with the threats prioritized. Further development of the VIDS will incorporate the VLQ-6 Hardhat multithreat jammer system into the integrated suite. [Ref. 8]

C. NAVAL APPLICATIONS

1. AN/SLQ-32 (Raytheon)

The SLQ-32 (see Chapter III. ESM and IV. ECM) was originally designed as a stand alone system. Today the system is interfaced with other sensors and on some ships also with the Combat Direction System (CDS) which enable the EW intercepts to be transferred to the ship command where it can be used in the managing of the battle. The Light Airborne Multipurpose Platform (LAMP) using the AN/ALQ-142 ESM system can be integrated with the SLQ-32. Signals detected by the ALQ-142 are transmitted to the

SLQ-32. This integration gives the system a capability to detect threats over the radar horizon it also enables the system to locate threat emitters using cross bearing correlation. [Ref. 9]

2. EW 400 (Celsius Tech)

The EW 400 is an integrated ship-borne warning and self protection system (see Figure 5-2). The system is built around the EW computer which gets information from radar warning receivers, laser warning receivers and the ships weapon and C^3 systems. The EW computer can apply the CM and suggest appropriate steering commands to the steering indicator; this way the ship can coordinate chaff launch and ship maneuver to achieve maximum effect of the CM. [Ref. 8]

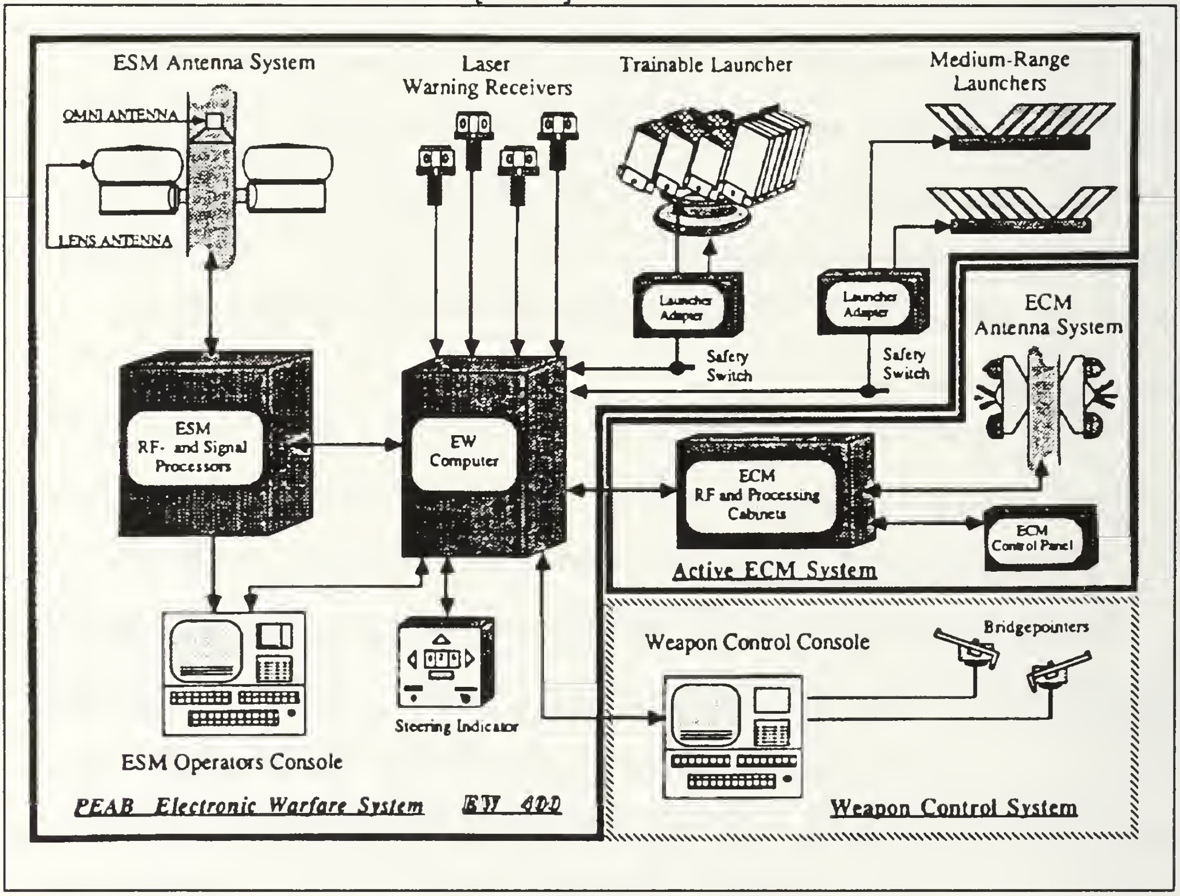


Figure 5-2. Electronic Warfare System EW 400

3. Advanced Integrated Electronic Warfare Suite, AIEWS

AIEWS is the US Navy's name for a program for a future EW system. The objective for the program is a system which integrates active and passive EW equipment with weapons and offboard countermeasures. The systems should be able to handle multiple threats using both hard and soft kill systems. Further, the system should give the option of automatic decision making. To meet the threat from IR attacks the AIEWS will be equipped with laser based IR-jamming system. [Ref. 8, Ref. 9]

D. AIRBORNE APPLICATIONS

1. Integrated Electronic Warfare System, INEWS

INEWS is a USAF project which tries to minimize the use of redundant hardware by integrating all the EW systems. One of the principals in the program is to let the INEWS be one of the fundamental building blocks for the aircraft instead of being looked at as an additional equipment load. By combining an array of different threat warning and countermeasure systems the INEWS will provide an multispectral warning and automatic countermeasures capability for the total electromagnetic threat. The system will share data with the integrated communications, navigation and identification avionics (ICNIA) system. To achieve this performance, it will take advantage of the recent development in monolithic microwave integrated circuits (MMIC) and very high speed integrated circuits (VHSIC). A principal diagram over the system is shown in Figure 5-3. [Ref. 8, Ref. 9, Ref. 56]

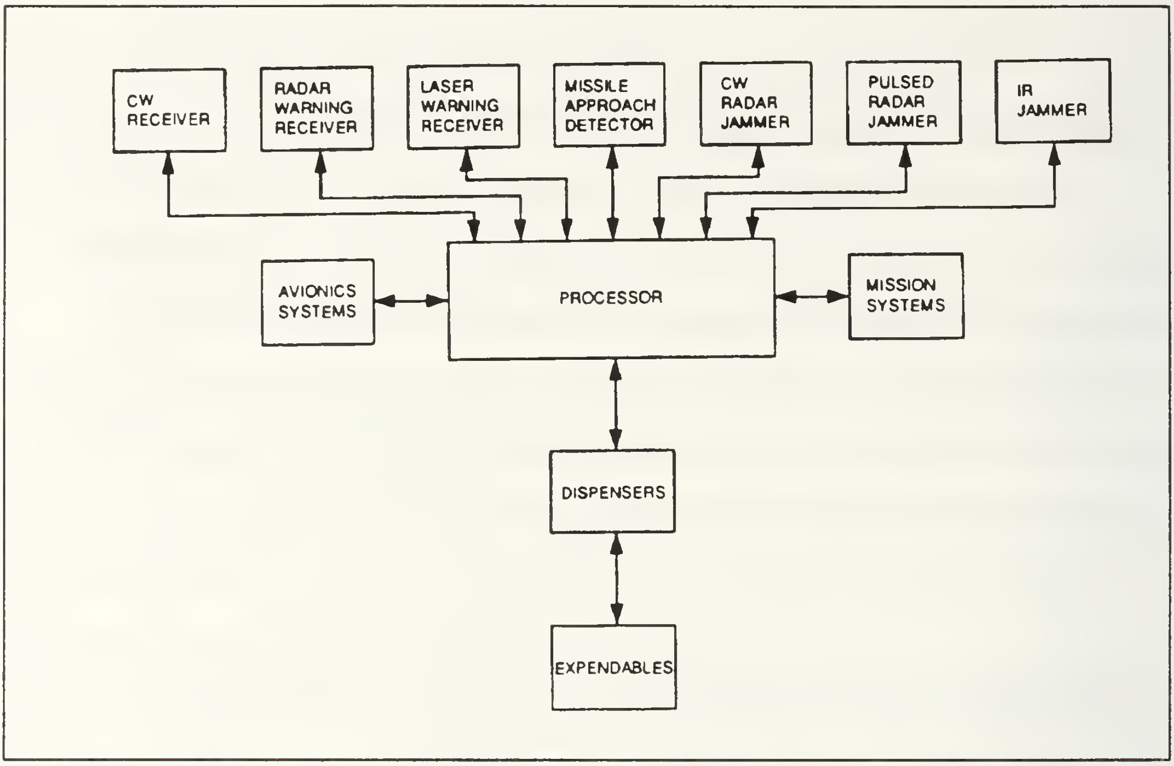


Figure 5-3. Prinicpal Diagram over INEWS

2. APR-39A(V)2 Threat warning system and Electronic Warfare Controller (TWS/EWC)

The TWS/EWC is an integration of different EW systems around the APR-39 RWR (see Figure 5-4). The IEWS interfaces already operational laser and missile warning systems with RF jammers and dispenser systems. The integrated system provides multispectral warning as well as semiautomated and automated countermeasures without being originally designed as an integrated system. [Ref. 8, Ref. 57]

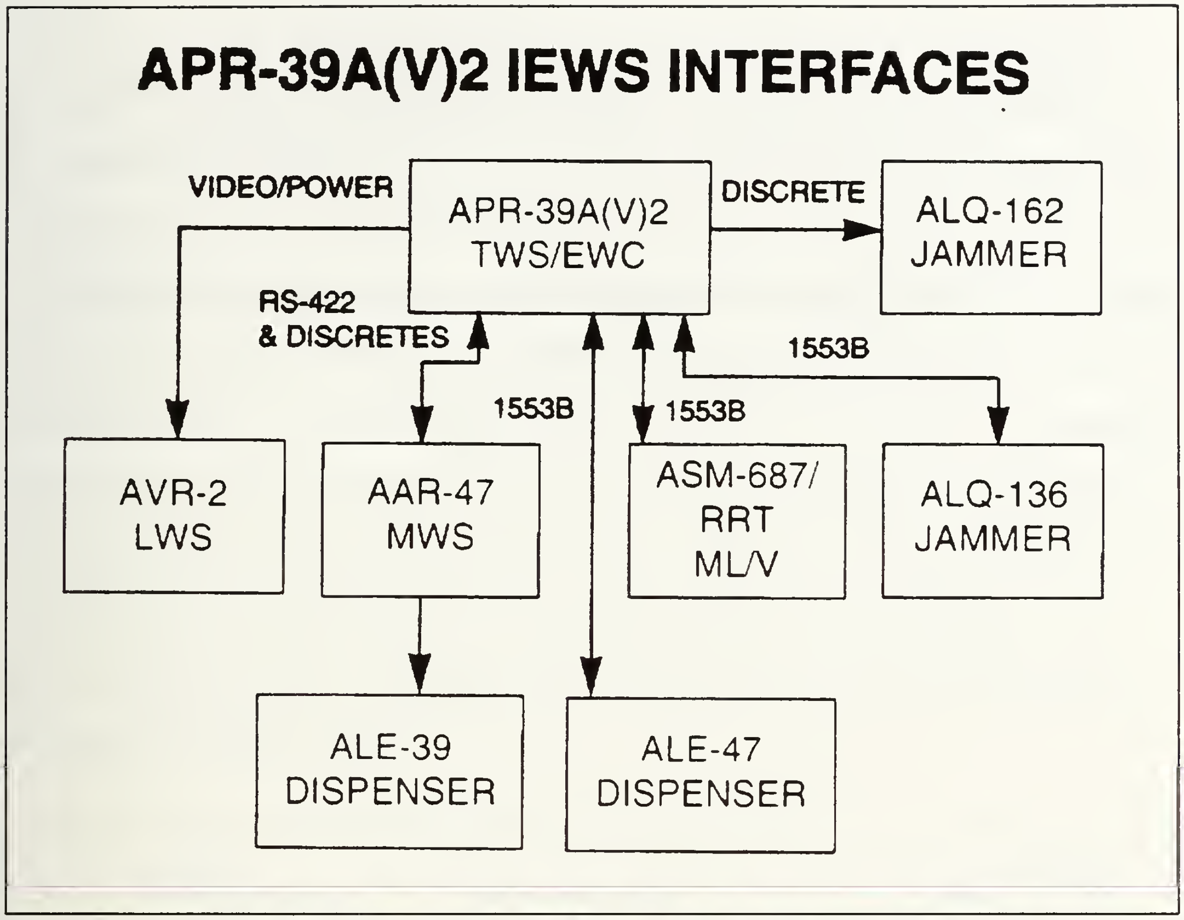


Figure 5-4. Blockdiagram over APR-39A(V)2 as Integrated EW system

E. CONCLUSIONS

Integrated EW systems will be more or less the role model in the future, the reason for this will be:

- Extreme short reaction times requires the option of automatic countermeasures.
- The introduction of threats using several different sensors.
- The fusion of sensors increases the possibilities in evaluating the threats reaction to countermeasures.
- Increased effectiveness by combining different types of countermeasures, such as on and off board.

- Increased ability to avoid different systems jamming each other.

The integrated systems will not only coordinate the different EW functions but will also be integrated with the platform's other systems like navigation and avionics/steering. This will make a truly coordinated response including both ECM and platform maneuvers possible. For platforms utilizing stealth by minimizing their radar cross section, the design of the EW systems antennas will be an important part of the original design of the platform.

VI. SUPPRESSION OF ENEMY AIR DEFENSE (SEAD)

The purpose of SEAD is to render an integrated air defense system (IADS) inoperable through soft and/or hard kill. SEAD is done to allow the follow-on strike aircraft to perform their missions without interference from the air defense. A primary component in the SEAD system is the attack aircraft using anti-radiation missiles (ARM) and emitter locator systems (ELS). The Tornado aircraft shown in Figure 6-1 is equipped for SEAD and electronic combat and reconnaissance (ECR); by using a data link one aircraft with an ELS system can transmit emitter information to another aircraft carrying anti-radiation missiles. [Ref. 58]

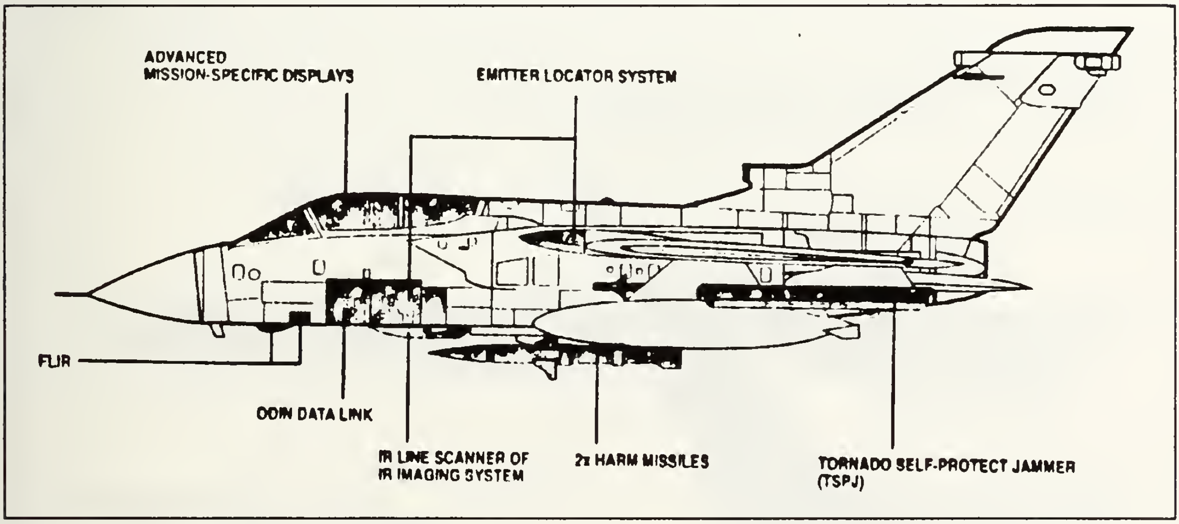


Figure 6-1. Tornado Aircraft Equipped for SEAD

A. RADIATION HOMING SYSTEMS

1. High-Speed Anti-Radiation Missile, HARM (Texas Instruments)

The HARM uses an anti-radiation homing seeker to track the radar emissions (see Figure 6-2). The missile has a maximum speed of Mach 2+. The prefragmentated warhead uses a laser range radar as a proximity fuse to determine time for detonation so as to maximize the damage to the target's antenna. For guidance during the midcourse phase the missile has its own inertial navigation system and auto pilot. The HARM can be launched in two different modes, reactive and preemptive. In the reactive mode the HARM maintains the tracking of the enemy radar from launch to impact. This mode is normally used at shorter distances. A submode of the reactive mode is the self protect launch which is used when the launching aircraft is engaged by an enemy radar guided weapon.

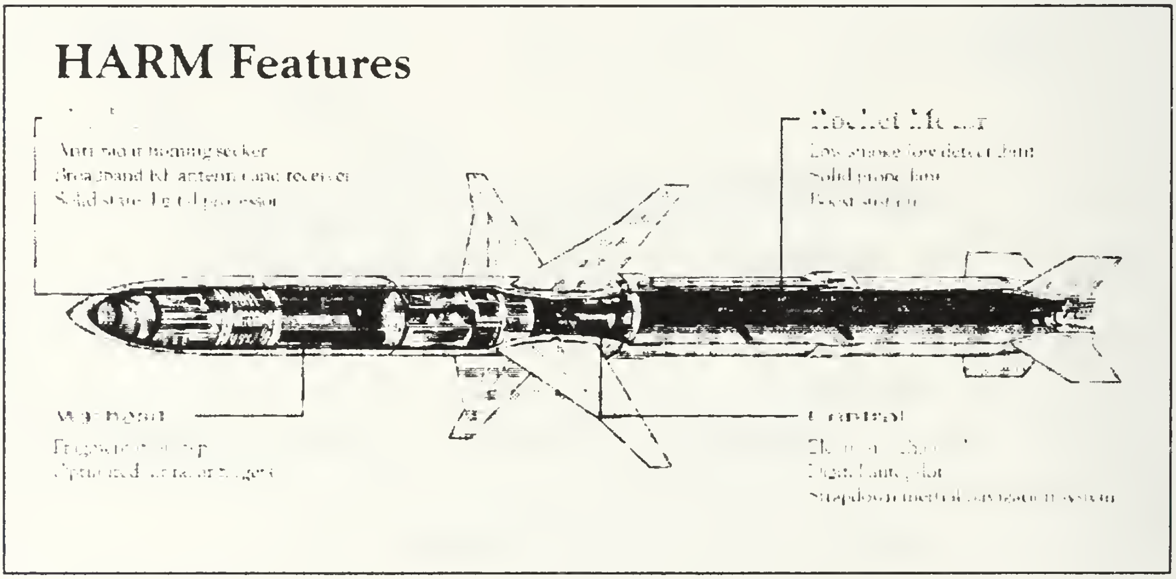


Figure 6-2. High-Speed Anti-Radiation Missile

In the preemptive mode the missile is launched toward a known target location. Before launch, information regarding the target's location and characteristics is passed to the missile, normally from the aircraft's RWR. The aircraft's airspeed and altitude is also passed to the missile prior to launch. Shortly after launch the missile starts its midcourse trajectory during which it is guided by its own inertial navigation system. When the missile reachs the calculated target area it is pointed toward the projected target and the seeker is activated. If the seeker finds the target the missile's guidance system will home in on the radiation until impact. If the missile does not find the target when the seeker becomes active it will continue toward the calculated target position. After a certain time the missile will enter a energy conserving profile with the purpose of increasing its range, during which time it tries to acquire a target. If a target is found the missile enters the guidance mode again. The preemptive mode is illustrated in figure 6-3. [Ref. 43, Ref. 59, Ref. 60, Ref. 61]

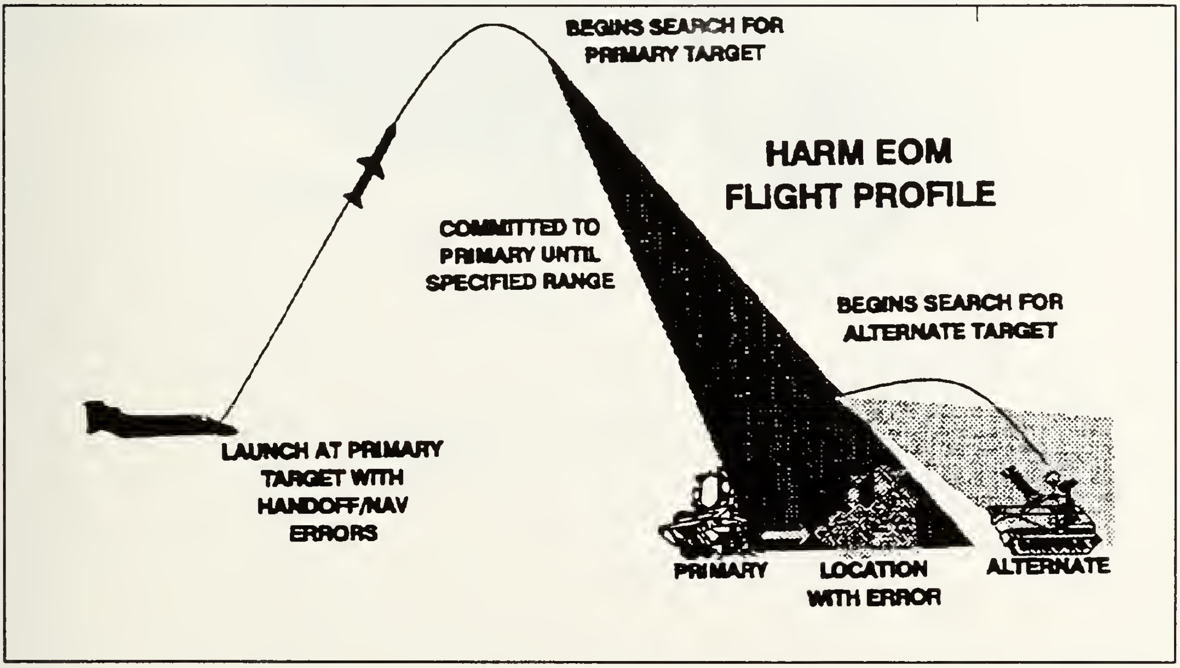


Figure 6-3. HARM in Preemptive Mode

2. Anti Radiation Missile - Unmanned Aerial Vehicle

Another method of achieving SEAD is to use UAVs as ARMs. The UAV equipped with a radar homing seeker can be put into a patrol route to search an area for radar emitters; during this patrol the UAV can be using an energy preserving speed to increase durability. When a radar in the area becomes active the UAV can home in on the radar using a radar homing seeker. A typical radar homing sensor is shown in Figure 6-4. The sensor has a frequency range of 2-18 GHz, a total weight of 12 lb. and a range against typical radar of approximately 10 km. [Ref. 62]

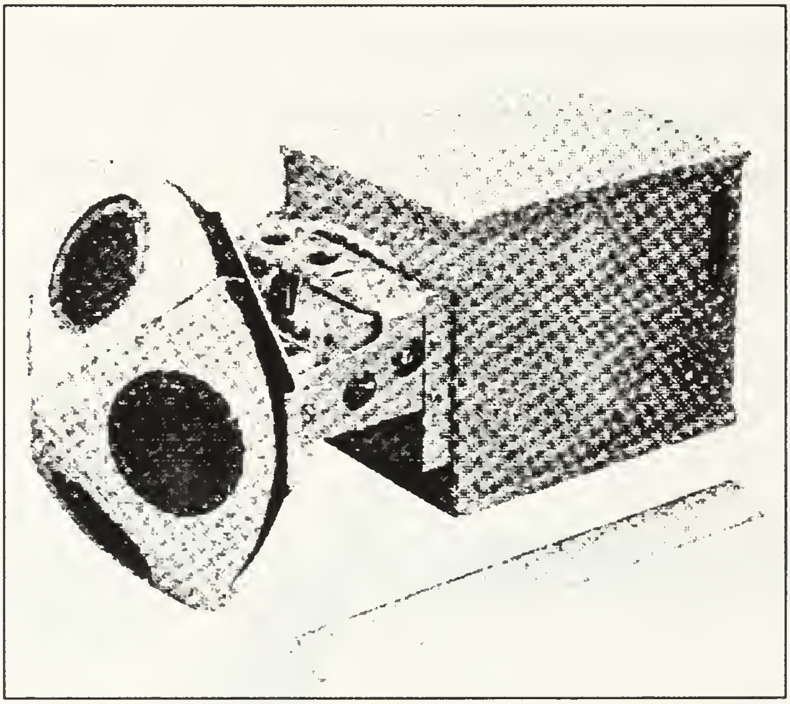


Figure 6-4. Radar Homing Seeker

B. CONCLUSIONS

The importance of SEAD was shown in the Gulf war and ARMs are becoming a part of many nations arsenals. Expected improvements of the ARM will probably come in both the navigation system and in the ability to counter different types of ARM-CM. In the navigation field the inclusion of GPS could lead to improved precision in the midcourse phase, the ARM would become more or less a cruise missile with an anti-radiation seeker. In the case of resistance to CM there are several possible developments:

- Artificial intelligence which could make the missile discriminate between the radar and decoys by way of operation patterns.
- Multiple sensors which makes endgame guidance possible against shut down radar.
- Improved navigation which will make close hit possible even if the radar is turned off during the guidance phase.

Other development in the area might be the inclusion of radar homing seekers to other missile systems both air-to-air and surface-to-surface.

VII. DIRECTED ENERGY WEAPONS

Directed energy weapons (DEW) can be divided into three categories: lasers, high-powered microwave (HPM) weapons and charge particle beam weapons. Of these categories, the lasers seem to have the highest potential in the shorter perspective. HPM and charge particle beam weapons are not predicted to enter the battlefield during the next decade. A general advantage for beam weapons over conventional weapons is that they do not rely on a magazine of explosive shells but instead on an almost unlimited power supply. Beam weapons also have the advantage of a high velocity, literally the speed of light. This makes the time to reach the target negligible, which significantly simplifies weapon guidance; it also gives the systems a potential to engage many targets in a short time (Figure 7-1). [Ref. 63]

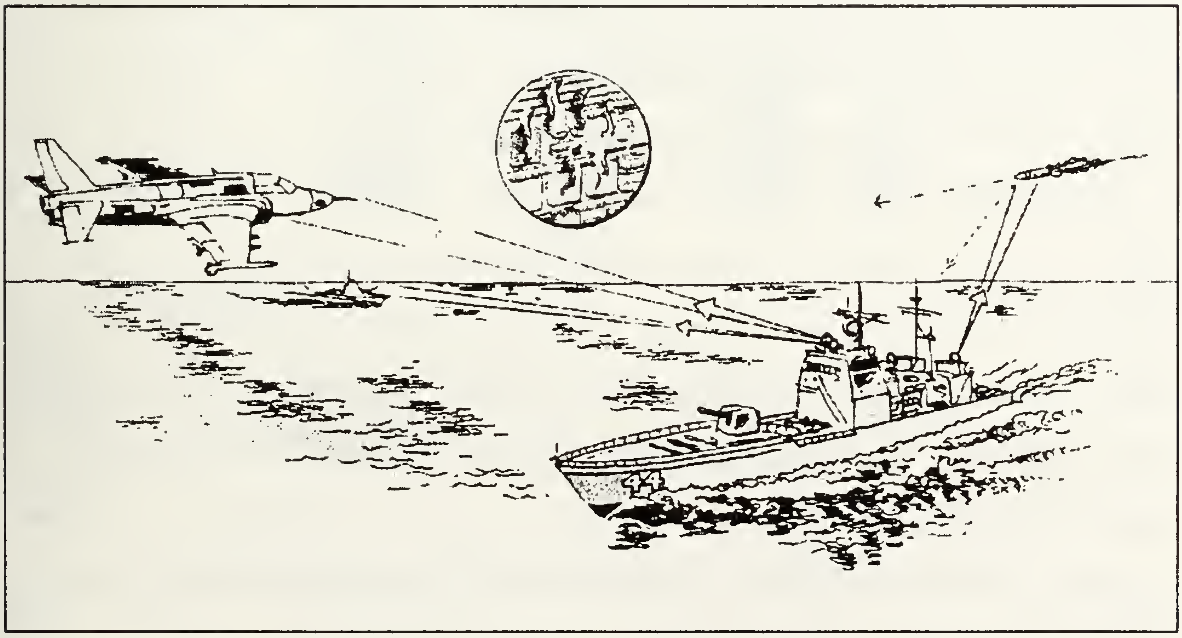


Figure 7-1. Example of possible deployment of beam weapons

A. LASER WEAPONS

Laser weapons can be divided into two categories: jamming and destructive. The jamming systems use the laser beam either to introduce false information into a seeker (see Chapter IV. ECM) or to saturate the detector while the destructive systems use high power in order to destroy components, normally sensors, in the target. The laser could also be used against personnel, especially against the unprotected human eye. Depending on the intensity the radiation can cause:

- Irritation, the illuminated individual is forced to turn the head away.
- Flash blindness, at this energy-level there will also be permanent injuries to the eye.

The destructive laser systems can either be optimized against the detector or be high power systems which by introducing energy to the surface layer of the target creates thermal and mechanical effects which causes breakdowns. If the laser operates in the same wavelength as the sensor, the radiation becomes magnified by the seeker's own optics which can increase the radiation density in the detector by a factor of 100 000. A consequence of this fact is that tuneable lasers would be of great importance as weapons because they could radiate at the sensor's wavelength and thereby use only a small fraction of the power otherwise necessary. Figure 7-2 shows possible weapon lasers against different sensors. There are several methods for frequency conversion which would lead to a laser tuneable in a large part of the optical spectrum. The free electron laser (FEL) with its potential for both high power and tuneablity would be a suitable laser for weapons applications; studies are under way to build a ship-borne weapon system based on the FEL. [Ref. 64, Ref. 65, Ref. 66, Ref. 67]

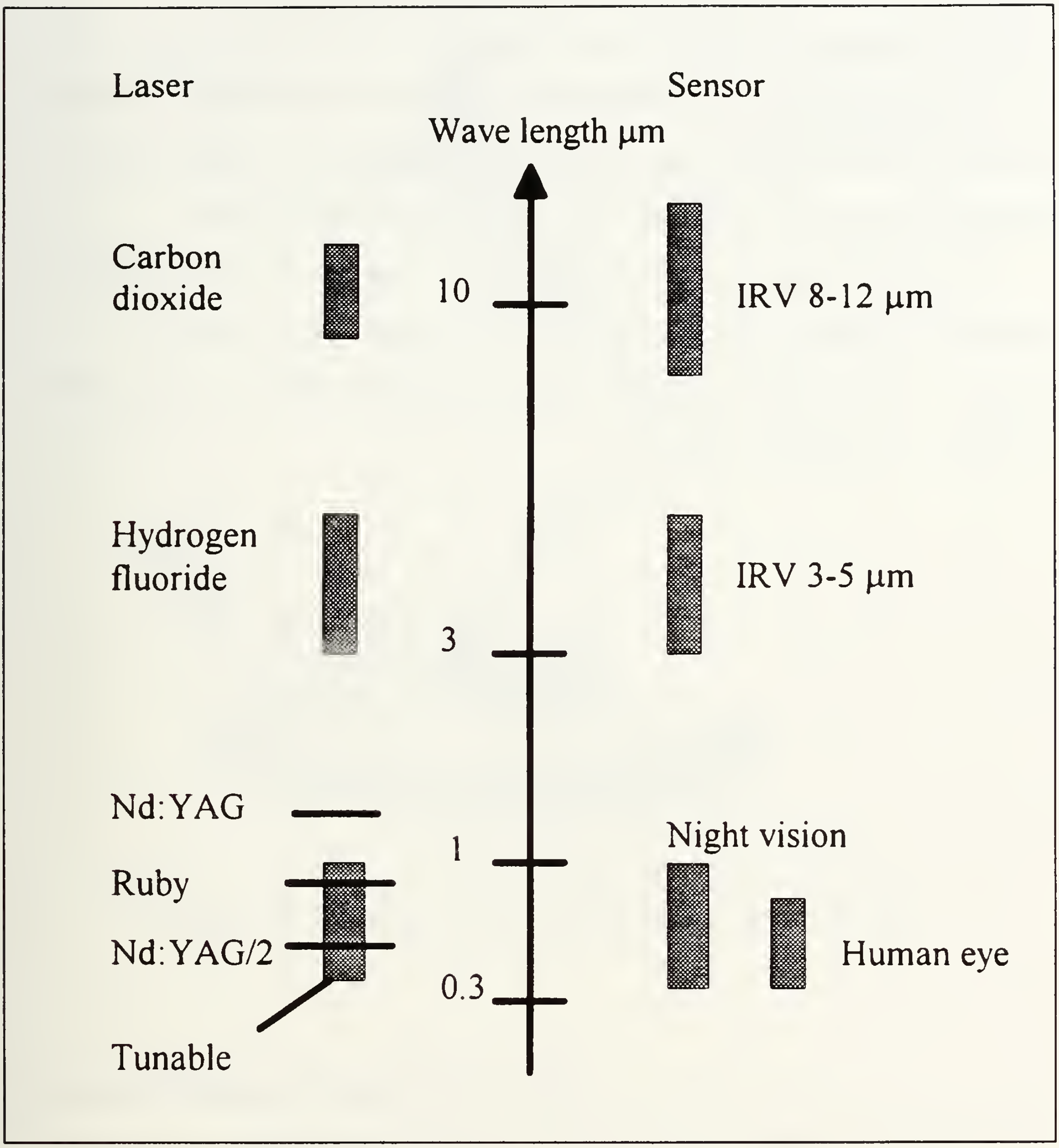


Figure 7-2. Wavelengths for different sensors and potential laser weapons

1. High Energy Laser Air Defense Armoured Vehicle (MBB, Diehl)

The high energy laser (HEL) system is a short-range system for use against low flying aircraft, helicopters and missiles. It has an expected range of 8000 m. The sytem uses a 10.6 μm carbon dioxide laser. The laser is fueled with hydrocarbon fuel and a nitrogenous oxidator, which both are carried by the vehicle. The two components form the carbon dioxide which is used in the stimulated emission. The laser beam is directed at the target by a focusing mirror on an extendable arm (see Figure 7-3). The hot fumes from the gas formation are vented rearwards from the laser generator system.

The HEL achieves its purpose by directing the beam onto a small spot with a very high energy density which causes the material to become heated, melted and vapourised. The HEL system is still in the study phase but a small scale version has been succesfully tested. [Ref. 68]

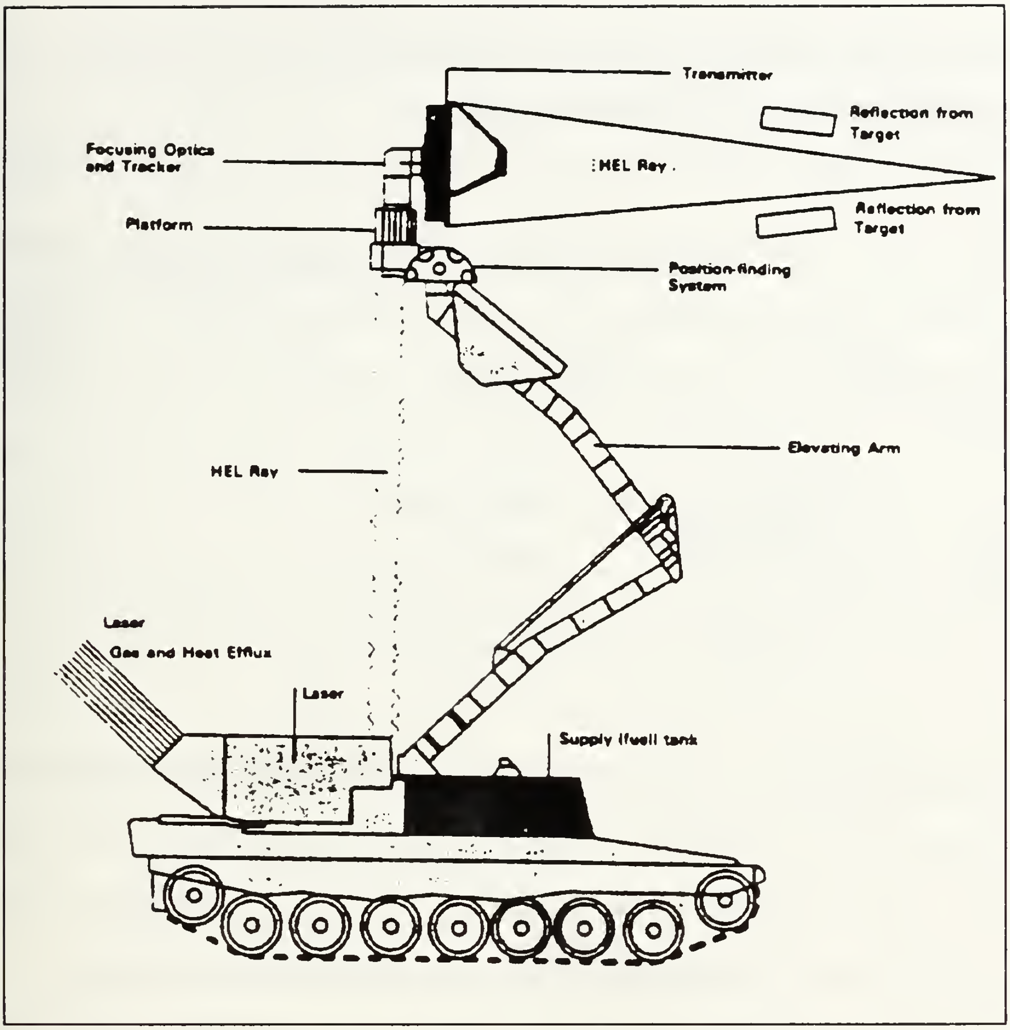


Figure 7-3. High Energy Laser Air Defense Armoured Vehicle

B. HIGH-POWERED MICROWAVE (HPM)

The concept used for HPM is in many ways similar to RF-jammers (see Figure 7-4) but instead of distracting or deceiving the system, the HPMs purpose is to affect and if possible destroy the electronic equipment itself. The HPM systems could potentially be used in three different levels:

- As traditional jammers but with a power that would make it possible to totally dominate the target and decrease the "burn through" distance to almost zero.

- To destroy microcircuits in electronic systems.

- To heat up targets and thereby cause mechanical and thermally induced breakdown.

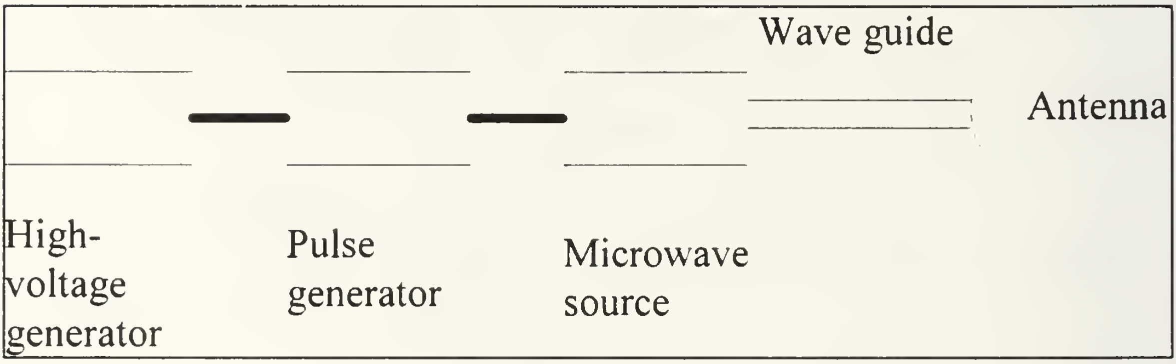


Figure 7-4. Block diagram for HPM system

Because of the high power radiation generated by the HPM it stands a high risk of jamming friendly electronic systems. To be able to operate HPM close to other systems the antennas need to be highly directional and the site would need to be masked by the terrain. A solution to this problem will probably be that HPM systems operate as independent units away from other systems. Another drawback for HPM systems is that modern aircraft normally have protection from electromagnetic pulses which will also be effective against HPM. A trend in aircraft design working in favour of the HPM is that modern stealth aircraft are designed to maximize absorption of microwaves which might make them highly succeptible to microwave thermal effects. [Ref. 69]

C. NON-NUCLEAR ELECTROMAGNETIC PULSE (EMP)

Even though the EMP generated by a high altitude nuclear detonation might by definition be considered an EW weapon it is not discussed further here. The development of a non-nuclear EMP generator has emerged as a possible effective weapon which does not cause severe loss of life. By using an EMP weapon it would be possible to upset electronic components to cause loss of data and other failures which would lead to system collapse.

The EMP generator consists of a helical coil inside a copper cylinder surrounded by high explosives. A bank of capacitors are used to supply the initial current which creates a magnetic field in the gap between the coil and cylinder. The explosion compresses the magnetic field which creates a very short-duration pulse of high power. Los Alamos has conducted tests where the generator has produced a12-16 MA pulse during a rise time of 400 ns. The EMP generator is planned to be fitted into a slightly modified air launched cruise missile (ALCM) (see Figure 7-5). By using a well-tuned antenna the EMP would be focused into a 30 degree beam. The ALCM would be programmed to fly over the target, for example a command center, and at passage detonate its EMP generator. [Ref. 70]

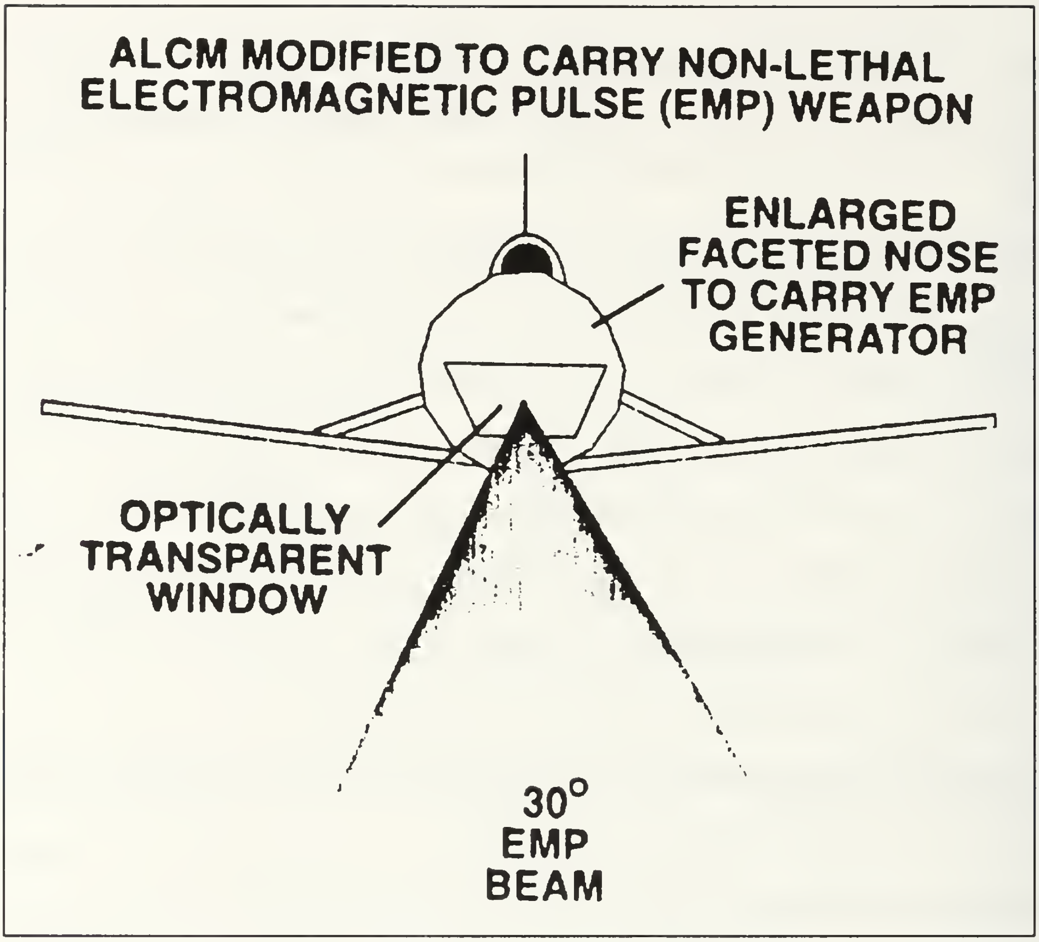


Figure 7-5. Electromagnetic pulse weapon

D. CONCLUSIONS

The use of directed energy weapons will probably be one of the fastest growing branches of EW under the coming decade due to the rapid deployment of EO/IR guided weapon systems. On the battlefield anti-sensor lasers are likely to become a common component in the self protection weaponry of tanks and AFVs and the use of laser in an anti personnel (eye destructive) role might be the role in coming conflicts. If the development of non-nuclear EMP is successful it has the potential to become the weapon of choice in low level conflicts and in retaliation attacks.

APPENDIX A MONOLITHIC MICROWAVE INTEGRATED CIRCUIT TECHNOLOGY

The Defense Advanced Research Projects Agency has sponsored a program to develop the Monolithic Microwave Integrated Circuit (MMIC) Technology. The MMIC can be described as a building block for microwave equipment similar to Integrated Circuits (IC) for electronics. The aim of the program was to develop the MMIC technology to reduce future costs for producing complex microwave subsystems. The result of the program is a series of standard building blocks, such as amplifiers, synthesizers, transmitters and receivers. The introduction of MMIC has made it possible to significantly reduce size, weight and cost for many EW systems. The use of MMIC has also helped to improve the reliability of the systems. These improvements have been achieved without the expected loss in performance compared to hybrid designs where transistors can be selected to optimize the performance. [Ref. 71]

The use of MMIC has made possible products which were earlier not feasible because of cost or size. Among the new products are expendable decoys like GEN-X, lightweight, high performance RWR like ALR-67(V) and smart chaff.

APPENDIX B TRANSMISSION IN THE ATMOSPHERE

The infrared emission from a body is dependent on its temperature and emissivity. As can be seen in Figure B-1 the total radiated power increases with increased temperature while the wavelength for the peak decreases. The tail pipe of a jet engine has a temperature of approximately 800 K, which represents a peak wavelength of 4 μm. The emissivity describes how much power the body radiates. For a perfect emitter, called a black body, the emissivity is equal to one.

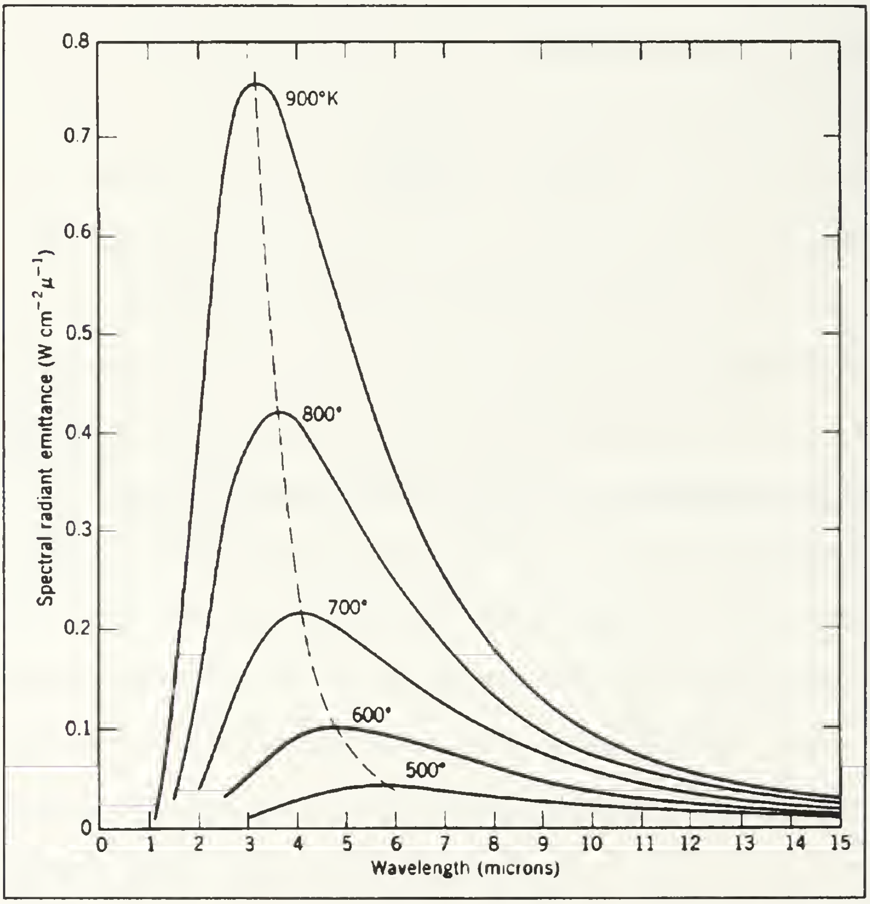


Figure B-1. Spectral Radiant Emittance of a Blackbody

When IR radiation propagates through the atmosphere some of it is reflected, scattered or absorbed. These phenomena are wavelength-dependent which means that the transmission of IR is better for some wavelengths. Figure B-2 shows the percentage of radiation transmission over a 1 nautical mile path for a given sea level atmosphere as a function of wavelength. Because of this phenomenon, the detector technology is concentrated to wavelengths where the atmosphere has a high transmittance, so called windows.

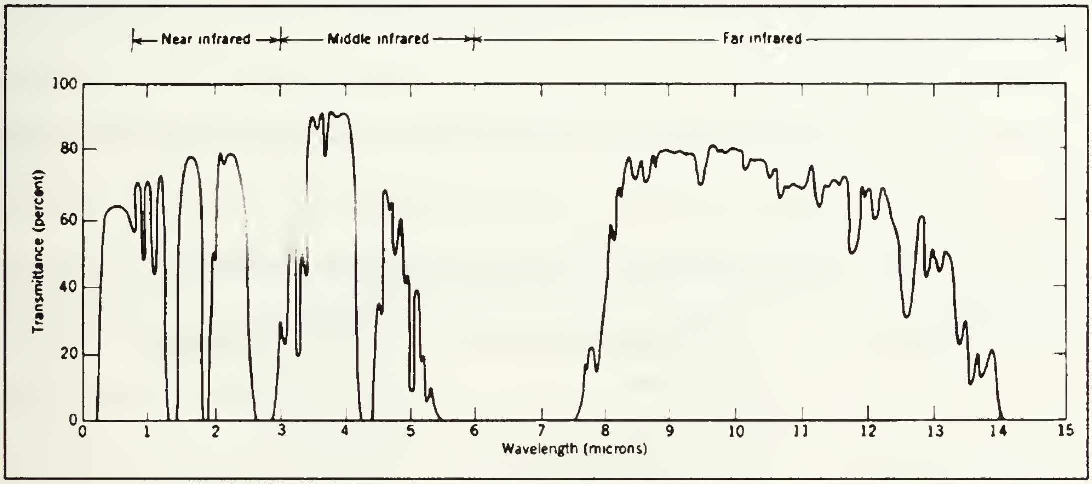


Figure B-2. Atmospheric Attenuation of IR Radiation

APPENDIX C JOINT ELECTRONICS TYPE DESIGNATION SYSTEM (JETDS)

The JETDS is a designation system used by the DoD; which gives a brief classification of equipment. The code consists of the letters AN followed by three letters, a number and, in some cases, another letter. The letters following AN represent, in order, platform installation, equipment type and purpose. The number is the designated number for the piece of equipment and the letter following it provides additional information about the most common modifications.

Below is a list of the most commonly-used designations for EW equipment. [Ref. 73]

TABLE 5. JOINT ELECTRONICS TYPE DESIGNATION SYSTEM

Installation	**Type**	**Purpose**
A: Piloted aircraft	A: Invisible light, heat radiation	D: Direction finder, reconnaissance or surveillance
F: Fixed ground	L: Countermeasures	E: Ejection or release
M: Mobile ground	N: Sound in air	G: Fire control
P: Portable	P: Radar	H: Recording or reproducing
S: Water	R: Radio	Q: Special combination of purposes
T: Ground, transportable	S: Special combination of types	R: Receiving, passive detecting
U: General utility	V: Visual and visible light	T: Transmitting
V: Vehicular ground	W: Armament	Y: Surveillance and control
Z: Piloted-pilotless airborne vehicle combination		

APPENDIX D FORMULAS FOR ECM

This appendix gives the most commonly used formulas regarding ECM systems. The purpose with the calculations is to find either at what range the platform will be visible to the radar or what jamming power is necessary to hide it. It is important to remember that these formulas only give an estimate of the real result and that the real result is dependent, among other things, on attenuation, fluctuations in the radar cross section and ECCM techniques used by the radar.

The most important factor to determine the effectiveness of noise jamming is the jam to signal ratio (J/S). The ratio express the jammer's power intercepted by the radar compared to that intercepted from the target. By setting J/S to the minimum required to conceal the target the burn-through distance, R, can be found. If the jammer is used for self-screening the J/S will be as follows.

$$\frac{J}{S} = \frac{P_j \cdot B_r \cdot G_j \cdot 4 \cdot \pi \cdot R^2}{P_r \cdot G_r \cdot \sigma \cdot B_j}$$

J= Power of the noise

S= Power of the echo

P_r= Power of the radar

P_j= Power of the jammer

B_j= Bandwidth of the jammer

B_r= Bandwidth of the radar overlapping the jammer

G_j= Gain of the jammer antenna in the direction of the radar

G_r= Gain of the radar antenna in the direction of the target

σ= Radar cross section of the target

R= Distance between the jammer and the radar

If the jammer is used as a stand-off jammer, this means that the jammer and the target to be protected are different platforms, the J/S will be as follows.

$$\frac{J}{S} = \frac{P_j \cdot B_r \cdot G_{jr} \cdot G_{rj} \cdot 4 \cdot \pi \cdot \left(R_t\right)^4}{P_r \cdot \left(G_r\right)^2 \cdot \sigma \cdot B_j \cdot \left(R_j\right)^2}$$

G_{jr}= Gain of the jammer antenna in the direction of the radar

G_{rj}= Gain of the radar antenna in the direction of the jammer

R_t= Distance from radar to target

R_j= Distance from radar to jammer

APPENDIX E LIST OF ACRONYMS

AAED	Active Airborne Expendable Decoy
AEB	Active Electronic Buoy
AFV	Armored Fighting Vehicle
AIEWS	Advanced Integrated Electronic Warfare Suite
AO	Acousto-Optic
AOCMS	Airborne Optical Counter-Measures System
ASCM	Anti-Ship Cruise Missile
ASE	Aircraft Survivability Equipment
ASPJ	Airborne Self-Protection Jammer
ATGM	Anti Tank Guided Missile
ATIRCM	Advanced Threat InfraRed Counter-Measures
ATRJ	Advanced Threat Radar Jammer
CM	Counter-Measures
CVR	Crystal Video Receiver
CW	Continuous Wave
DF	Direction Finding
DSP	Digital Signal Processing
EC	Electronic Combat
ECCM	Electronic Counter Counter-Measures
ECM	Electronic Counter-Measures
ECR	Electronic Combat Reconnaissance
EGCM	End Game Counter-Measures

EIDF	Electronic Intercept and Direction Finding
ELINT	ELectronic INTelligence
EME	Electro-Magnetic Environment
EO	Electro-Optic
EOB	Electronic Order of Battle
EP	Electronic Protection
ERP	Effective Radiated Power
ESM	Electronic Support Measures
EW	Electronic Warfare
EWS	Electronic Warfare Support
FFT	Fast Fourier Transform
FPA	Focal-Plane Array
GBCS	Ground Based Common Sensor
HARM	High-Speed Antiradiation Missile
HOJ	Home On Jam
IEWCS	Intelligence and Electronic Warfare Common Sensor
IFM	Instantaneous Frequency Measurement
IFM	Instantaneous Frequency Measurement Receiver
IR	InfraRed
IRCM	InfraRed Counter-Measures
IRMWS	Infrared Missile Warning Subsystem
LOB	Line Of Bearing
LPI	Low Probability of Intercept
LWS	Laser Warning System
MAW	Missile Approach Warning

MMIC	Monolithic Microwave Integrated Circuit
MMW	Milli-Meter-Wave
MSAS	Multifunction Strike Avoidance System
MWS	Missile Warning System
MWS	Missile Warning System
OBCM	Off-Board Counter-Measures
PD	Pulse Doppler
PFM	Pulse Frequency Modulation
PMAWS	Passive Missile Approach Warning System
POI	Probability Of Intercept
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PW	Pulse Width
RF	Radio Frequency
RWR	Radar Warning Receiver
SAWS	Silent Attack Warning System
SEAD	Suppression of Enemy Air Defense
SEW	Surface Electronic Warfare
SHR	Superhetrodyne Receiver
SIGINT	SIGnal INTelligence
SSDS	Ship Self Defense System
TDOA	Time Difference Of Arrival
TOA	Time Of Arrival
TRF	Tuned RF Receiver
TWT	Travelling Wave Tube

TWTA	Travelling Wave Tube Amplifier
UAV	Unmanned Air Vehicles
VCO	Voltage Controlled Oscillator

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