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Military Surveillance Radar

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INTRODUCTION

We had thought to do our work on the radar system, and then we search for the important part on this subject the military radar system is one of the most common and important parts in the same parts in the communication system.

In 1888 Heinrich Hertz showed that the invisible electromagnetic waves radiated by suitable electrical circuits travel with the speed of light, and that they are reflected in a similar way. From time to time in the succeeding decades it was suggested that these properties might be used to detect obstacles to navigation, but the first successful experiment s, that of Tuve and Breit, made use of short repeated pulses ofradiation, and this technique was employed in most of the developments ofradar.

Electromagnetic radiation travels in empty space at a speed of 2.998x 10_8 meters per second, and in air only slightly less rapidly; we can think of its speed as very nearly 300,000 kilometers per second. This speed is denoted by the letter c. Let us suppose that a very short pulse pf radiation is detected towards an object at a distance r, and that a small function of this is reflected back to the starting point, so .that it has traversed the distance 2r. This will take a time t = 2r /c. lfwe can measure this time we can determine an unknown distance to the target: r = 2r/ct. For useful terrestrial distances tis very small; an object 15 km away, for example, will return a signal in one ten-thousandth of a second.

In practice we need to know more about the target than its distance; we must also determine its direction. Arranging an antenna system to project a suitable radiation pattern that can be rotated in azimuth or elevation does this. As may be deduced from what follows, a very great deal of ingenuity and engineering skill has been devoted to the design of radar antennas.

The first successful radar installations in Great Britain in the years 1935 to 1939 used wavelengths in the 6 to 15 m band, and required very large antennas. Other equipment developed later used wavelengths of 3 m and 1.5 m; and in 1940 the ınven.tion of a new from of generator , the cavit-y magnetron, at once made it practicable \~~~~\\)1\\.'!~\~\.\~b..s Qt 1() cm and even less. Nearly, all the radar developed at the "Nationa\Research Cmınci\ 'ın. \91\'l a\.\0. \a\eı ~as ~Ç)\.\I!. ı.\ ~el\\.m.\e\e't~ 'N'o.'1~~'\\.~\.\~.

Universally referred to as microwaves.

In chapter one we are going to talk about the basic principles of the radar. The main components of it, the development. In this chapter we are going to talk also about the maximum unambiguous range. Frequencies and power used in radar. Performance factors, factors influencing maximum range, effect of noise, and target properties.

In chapter two present the Basic pulsed radar, receiver bandwidth requirements, factors governing pulse characteristics. Antennas and scanning, antenna scanning, antenna tracking, display methods, pulsed radar system, moving target indicator (MTI), and radar beacons.

In chapter three we are going to talk about the application of military radar. HAWK system, and the main component of HAWK BATTRY system.

CHAPTER ONE
BASIC PRINCIPLES

A typical radar system consists of the following components:

- A pulse generator that discharges timed pulses of UHF microwave/radio energy
- A transmitter
- A duplexer
- A directional antenna that shapes and focuses each pulse into a stream

Returned pulses that the receive antenna picks up and sends to a receiver that converts (and amplifies) them into video signals

- A recording device which stores them digitally for later processing and/or produces a real time analog display on a cathode ray tube (CRT) or drives a moving light spot to record on film

Each pulse lasts only microseconds (typically there are about 1,500 pulses per second). Pulse length-an important factor along with bandwidth in setting the system resolution-is the distance traveled during the pulse generation. The duplexer separates the outgoing and returned pulses (i.e., eliminates their mutual interferences) by blocking reception during transmission and vice versa. The antenna on a ground system is generally a parabolic dish.

Radar antennas on aircraft are usually mounted on the underside of the platform so as to direct their beam to the side of the airplane in a direction normal to the flight path. For aircraft, this mode of operation is implied in the acronym SLAR for Side Looking Airborne Radar. A real aperture SLAR system operates with a long (about 5.6 m) antenna. usually shaped as a section of a cylinder wall. This type produces a beam of no coherent pulses and uses its length to obtain the desired resolution (related to angular beam width) iç. the azimuthally (flight line) direction. At any instant the transmitted beam propagates outward within a fan-shaped plane, perpendicular to the flight line. A second type of system. Synthetic Aperture Radar (SAR). is exclusive to moving

Platforms. It uses an antenna of much smaller physical dimensions, which sends its pulses from different positions as the platform advances, simulating a real aperture by integrating the pulse echoes into a composite signal. It is possible through appropriate processing to simulate effective antenna lengths up to 100 m or more. This system depends on the Doppler Effect (apparent frequency shift due to the target's or the radar- vehicle's velocity) to determine azimuthally resolution. As coherent pulses transmitted from the radar source reflect from the ground to the advancing platform (aircraft or spacecraft), the target acts as if it were in apparent (relative) motion. This motion results in changing frequencies, which give rise to variations in phase and amplitude in the returned pulses. The radar records these data for later processing by optical (using coherent laser light) or digital correlation methods. The system analyzes the moderated pulses and recombines them to synthesize signals equivalent to those from a narrow- beam, real-aperture system.

1.1 Basic Radar System

The operation of a radar system can be quite complex, but the basic principles are somewhat easy for the reader to comprehend. Covered here are some fundamentals, which will make the follow up material easier to digest. In figure (1.1) and timing diagram (figurel.2). A master timer controls the pulse repetition frequency (PRF). Theses pulses are transmitted by a highly directional parabolic antenna at the target, which can reflect (echo) some of the energy back to the same antenna. This antenna has been switched from a transmit mode to a receiver by a duplexer. The reflected energy is received, and time measurements are made, to determine the distance to the target. The pulse energy travels at 186,000 statute miles per second (162,000 nautical miles per second). For 9.Pnvenience, a radar mile (2000 yd or 6000 ft) is often used, with a little as 1 percent error being introduced by this measurement. The transmitted signal takes 6.16 us to travel 1 radar mile; therefore the round trip for 1 mile is equal to 12.36 us. With this information, the range can be calculated by applying equation (1.1).

$$\text{Range} = \frac{\Delta t}{12.36} \qquad (1.1)$$

t = time from transmitter to receiver in microsecond.

For higher accuracy and shorter range, equation (1.2) can be utilized.

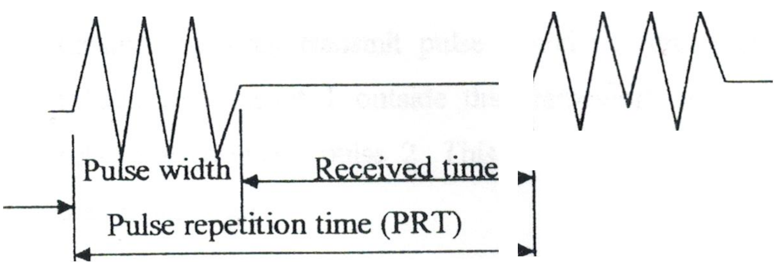
Range (yard)= $\frac{328\Delta t}{2} = 164\Delta t$ (1.2)

Transmitter

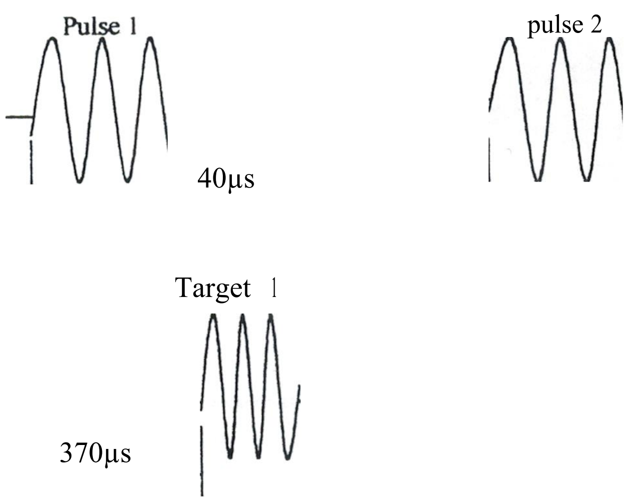
Duplexer Antenna

Receiver

Figure 1.1 block diagram of elementary pulsed radar



(a)



PRR

OrPRF

(b)

Figure 1.2 timing diagram

After the radar pulse has been transmitted, a sufficient rest time (figure 1.2a) (receiver time) must be allowed for the echo to return so as not to interfere the next transmit pulse. This PRT, or pulse repetition time, determines the maximum distance to the target to be measured. Any signal arriving after the transmission of second pulse is called second return echo and would give ambiguous indications. The range beyond which objects appear as second return echo is called the maximum unambiguous range (MUR) and can be calculated as shown in equation (1.3).

$$\text{Mur} = \frac{PRT}{12.2} \qquad (1.3)$$

Range in miles; PRT in us

Refer to the timing diagram (figure 1.2a) by calculation, maximum unambiguous distance between transmit pulse 1 and transmit pulse 2 is 50 mi. Any return pulse related to transmit 1 outside this :framework will appear as weak close-range pulse related to transmit pulse 2. This distance between pulse 1 and pulse 2 is called the maximum range.

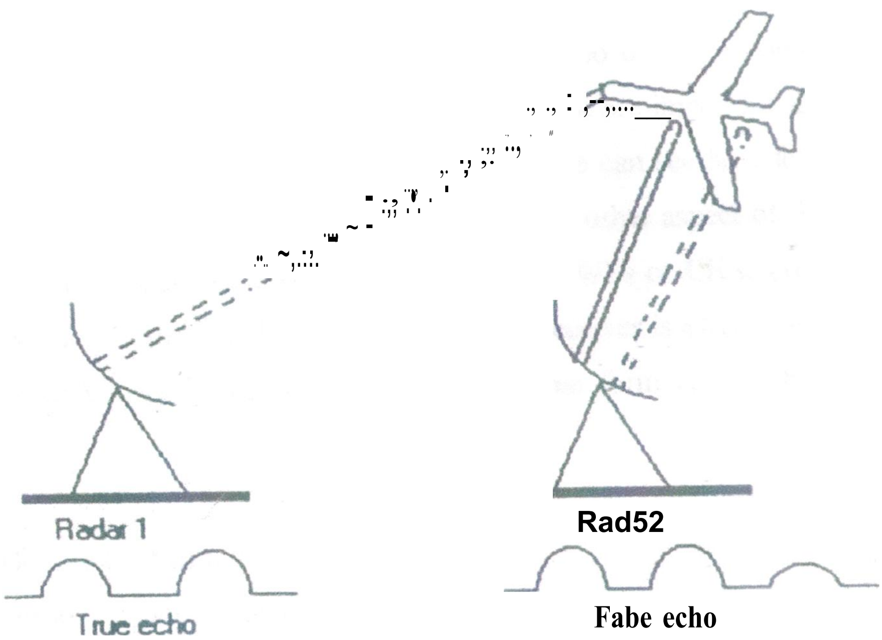


Figure 1.3 Double-range echoes

If a large reflected object is very close, the echo may return before the complete pulse can be transmitted. To eliminate ambiguity, the receiver is blocked, or returned off. Blocking of the receiver during the transmit cycle is common in must radar systems.

A second problem arises with large objects at close range. The transmitted pulse may be reflected by the target for one complete round trip, figure (1 .3). It may then, because of its high energy level, be reflected by the transmitter antenna and bounced back to the target for a second round trip. This condition is called double range echoes. To overcome this from of ambiguity, equation (1.4) is used to determine the minimum effective range.

Minimum range = 164 PW

Range in yards

PW in μs

Other terms sometimes discussed in conjunction with the radar transmitter are duty cycle, peak power, and average power, to calculate the duty cycle Equation (1.5) can be used.

$$\text{Duty cycle} = \frac{PW}{pRT} \cdot \qquad (1.5)$$

We can conclude that in order to produce a strong echo over a maximum range, high peak power is required. In some situation, size and heat are important factors (in radar in aircrafts) and low average power is requirement. We can see how low duty cycle is an important consideration. Commenting briefly on the other aspect of the radar set we find that the pulse-modulated magnetrons, klystrons TWTs or CFAs are normally used as transmitter output tube, and the first stage of the receiver is often a diode mixer. The antenna generally uses a parabolic reflector of some form as will be mentioned in section (2.2).

1.1.1 Development of radar

From its inception, radar has used a system of sending powerful pulses of radio energy and then analyzing the returned echoes to determine the position, distance and possibly velocity of the target. However, the methods of doing so have evolved and become far more refined and sophisticated as time has by. Primary incentive was the imminence of war. Radar was made possible technology, which, at the time war broke out, was just beginning to show promise. This technology itself took great strides forward to meet the new challenges imposed by war.

The first radars worked at much lower frequencies than present systems as 60 MHz for the original British coastal air-warning radar because of sufficiently powerful transmitting tubes at higher frequencies. This was changed in 1940 with the appearance of the cavity magnetron., and the stage was then set for the development of modern radar. One of the prime requirements of a system is that it should have a fair degree of accuracy in its indication of target direction. This is possible only if the antennas used are narrow-beam ones, i.e., have dimensions of several wavelengths. That requirement cannot be fulfilled satisfactorily unless the wavelengths themselves are fairly short, corresponding to the upper UHF or microwave frequencies.

The advent of the magnetron also made possible the next steps in the evolution of radar, namely, airborne radar for the detection of surface vessels and then aircraft interception radar. In each of these, tight beams are necessary to prevent the receiver from being swamped by ground reflections, which would happen if insufficient discrimination between adjacent targets existed. Microwave radar for anti fire control was quickly developed, of which the most successful ground-based was the U.S. Army's SCR-584. It was capable of measuring the position of aircraft to within 0.1 0. And the distance, or range, to within 25 m. Such radars were eventually capable of tracking targets by locking onto them, with the aid of servomechanisms controlling the orientation of the antennas. Anti-surface vessel (ASV) radars became very common and quite accurate toward the end of the war. So did airborne radar for navigation., bombing or bomber protection; electronic navigation systems were also developed. Radar countermeasures were instituted, consisting mainly of jamming (transmission of confusing signals at enemy radar) or the somewhat more effective dropping of aluminum foil, in strips of about a half-wavelength, to cover approaching aircraft by producing false echoes. This "chaff" (American) or "window" (British) proved very effective, but its use in the war was considerably delayed. Each side thought that the other did not know about it and so it was kept secret; however, it eventually came to be used on a very large scale. One of the indications of the enormous growth in the importance of radar in World War II is the increase in the staff of the U.S. Anny's Radiation Laboratory. It started with about 40 people in 1941, and numbers multiplied tenfold by 1945.

The subsequent developments of radar have also been numerous. They have included the use of wavelengths well into the millimeter range, at which atmospheric interference becomes noticeable, but for the presence of radar "windows." We have witnessed the use of greater powers at all wavelengths and the use of computers for a number of applications (especially fire control) to improve accuracy and reduce the time lag of manual operation. Long-range, fixed early-warning radars have been built, including the tv1EWS and Btv1EWS systems. These radars use huge antennas and enormous transmitting powers and are supplemented by radar-carrying high-flying aircraft, which have an extended radar horizon because of their height. Satellites carrying radar have been employed for military purposes, such as early detection of ballistic missiles, and civilian uses, notably in meteorology and mapping. Other important civilian uses of radar have included coastal navigation for shipping, position finding for shipping and aircraft, and air-traffic control at airports. This has extended the use of the landing facilities to. weather conditions, which would have made them unusable without radar and its allied systems. Also, the use of radar by various police forces, for the control of traffic speed and the prosecution of offenders, is becoming commonplace.

Numerous scientific advances have been made with the aid of radar; for instance, as early as in 1945 an error of 900 m was found (by accident) in the map position of the island of Corsica More recent scientific uses of radar on an interplanetary scale have yielded much useful information about the sun and the rest of the solar system, and especially about the distances and rotations of the various planetary bodies. For example, it is now known that the planet Mercury rotates with a speed not equal to its angular orbital velocity, so that it does not always present the same face to the sun.

1.1.2 Frequencies and powers used in radar

The frequencies employed by radar lie in the upper UHF and microwave ranges. As a result of wartime security, names grew up for the various frequency ranges, or bands, and these are still being used. One such term (the X hand), and others will now be identified. Since, there is not a worldwide agreement on radar band nomenclature, the names used in Table 1-1 are the common American designations.

BAND NAME	FREQUENCY RANGE GHZ	MAXIMUM AVAILABLE PEAK POWER MW
UHF	0.3-1.0	5.0
L	1.0-1.5	30.0
S	1.5-3.9	25.0
C	3.9-8.0	15.0
X	8.0-12.5	10.0
KU	12.5-18.0	2.0
K	18.0-26.5	0.6
Ka	26.5-40.0	0.25
V	40.0-80.0	0.12
N	80.0-170.0	0.01
A	Above 170	- -

Table 1.1 radar bands

1.2 Radar Performance Factor

Quite apart from being limited by the curvature of the earth, the maximum range of radar set depends on a number other factors. These can now be discussed, beginning with the classical with classical radar range equation.

To determine the maximum range of radar set, it is necessary to determine the power of the received echoes, and to compare it with the minimum power that the receiver can handle and display satisfactorily. If the transmitted pulsed power is P (Peak value) and the antenna is isotropic, then the power density at a distance r from the antenna will he as given by Equation (1 .6), namely,

$$p = \frac{P_t}{4\pi r^{2}} \quad (1.6)$$

However, antennas used in radar are directional, rather than isotropic. If Ap the maximum power gain of the antenna used for transmission, so the power density at the target will be

$$p = \frac{A_p \; P_t}{4\pi \; r^2} . \qquad (1.7)$$

The power intercepted by the target depends on its radar cross-section, or effective area, will be discussed later on. If this area is S. the power impinging on the target will be

$$p = pS = \frac{A_P P_t S}{4\pi r^2} . \qquad (1.8)$$

The target is not an antenna. It is radiation may be thought of as being omni directional. The power density of its radiation at the receiving antenna will be

$$P' = \frac{P}{4\pi \; r^2} = \frac{A_p p_t S}{\left(4\pi \; r^2\right)^2} . \qquad (1.9)$$

Like the target, the receiving antenna intercepts a portion of the reradiated power, which is proportional to the cross-sectional area of the receiving antenna. However, it is the Capture area of the receiving antenna that is used here. Equation (1.1 0). The received power is

$$P' = P'A_0 = \frac{A_P P_t S A_0}{(4\pi r^2)^2} , \qquad (1.10)$$

where A_0 is the capture area of the receiving antenna.

If (as it is usual the case) the same antenna is used for both reception and transmission, we have equation (1.11) is for the maximum power gain,

$$A_P = \frac{4\pi A_0}{\lambda^2} \qquad (1.11)$$

Substituting equation (1.11) into (1.10) gives

$$P' = \frac{4\pi A_0}{\lambda^2} \frac{P_t S A_0}{16\pi^2 r^4} = \frac{P_t A_0^2 S}{4\pi r^4 \lambda^2} . \qquad (1.12)$$

The maximum range r_{max} will be obtained when the received power is equal to the minimum receivable power of the receiver P_{min}. Substituting this into equation (1.12), and making r subject of the equation, we have

$$r_{max} = \left(\frac{P_t A_0^2 S}{4\pi\lambda^2 P_{min}} \right)^{1/4} \qquad (1.13)$$

Alternatively, if Equation (1.11) is turned so that $A_0 = G\lambda^2 / 4\pi$ is substituted into equation (1.13), we have

$$r_{max} = \left(\frac{P_t G^2 \lambda^2 S}{(4\pi)^3 P_{min}} \right)^{1/4} \qquad (1.13a)$$

Equation (1. 13) and (1.13a) represent two convenient forms of the radar range equation., simplified to the extent that the minimum receivable power P_{min} has not yet been defined. It should also be pointed out that idealized conditions have been employed. Since neither the effects of the ground nor other absorption and interference have been taken into account, the maximum range in practice is often less than that indicated by the radar range equation.

1.2.1 Factors influencing maximum range

A number of very significant and interesting conclusions may be made if the radar range equation examined carefully. The first and most obvious is that the maximum range is proportion to the fourth root of the work transmitted pulse power. The peak power must he increased sixteen fold, all else being constant; if a give maximum range is to he doubled. Eventually, such a power increase obviously becomes uneconomical in any particular radar system.

Equally obviously, a decrease in the minimum receivable power will have the same effect as raising the transmitting power and is thus a very attractive alternative to it. However, a number of other factors are involved h~re. Since P_{min} is governed by the sensitivity of the receiver (which in turn depends on the noise figure), the minimum receivable power may be reduced by a gain increase of the receiver, accompanied by a reduction in the noise at its input. Unfortunately, this may make the receiver more susceptible to jamming and interference, because it now relies more on its ability to amplify weak signals (which could include the interference), and less on the sheer power of the transmitted and received pulses. In practice, some optimum between transmitted power and minimum received power must always be reached.

The reason that the range is inversely proportional to the fourth power of the transmitted peak power is simply that the signals are subjected twice to the operation of the inverse square law, once on the outward journey and once on the return trip. By the same token, any property of the radar system that is used twice, i.e., for both reception and transmission, will show a double benefit if it is improved. Equation (1. 13) shows that the maximum range is proportional to the square root of the capture area of the antenna, and is therefore directly proportional to its diameter if the wavelength remains constant. It is thus apparent that possibly the most effective means of doubling a given maximum radar system range is to double the effective diameter of the antenna. This is equivalent to doubling its real diameter if a parabolic reflector is used. Alternatively, a reduction in the wavelength used, i.e., an increase in the frequency, is almost as effective. There is a limit here also. The beam width of an antenna is proportional to the ratio of the wavelength to the diameter of the antenna. Consequently, any increase in the diameter-to-wavelength ratio will reduce the beam width. This is very useful in some radar applications, in which good discrimination between adjoining targets is required, hut it is a disadvantage in some search radars. It is their function to sweep a certain portion of the sky, which will naturally take longer as the beam width of the antenna is reduced.

Finally, Equation (1.13) shows that the maximum radar range depends on the target area, as might be expected. Also, ground interference will limit this range. The presence of a conducting ground, it will be recalled, has the effect of creating an interference pattern such that the lowest lobe of the antenna is some degrees above the horizontal. A distant target may thus be situated in one of the interference zones, and will therefore not be sighted until it is quite close to the radar· set. This explains the development and emphasis of "ground-hopping" military aircraft, which are able to fly fast and close to the ground and thus remain undetectable for most of their journey.

1.2.2 Effect of noise

The previous section showed that noise affects the maximum radar range insofar as it determines the minimum power that the receiver can handle. The extent of this can now be calculated exactly. It is possible to calculate the equivalent noise power generated.at the input of the receiver. N,. This is the power required at the input of an ideal receiver having the same noise figure as the practical receiver. We then have

$$F = \frac{(S\,IN\};}{(S\,I\,V),} = \frac{S;No}{SONİ} = \frac{S;G(N; + N,)}{GS;N;} = I + \frac{N,.}{Ni}' \qquad (1.14)$$

where, S; is the input signal power

N; is the input noise power

S_0 is output signal power

N_0 is the output noise power

G is the gain of the receiver

We have

$$\frac{N_r}{N_i} = F - 1$$

$$N,. = (F - 1)N; = kT_0ij(F - 1) \qquad (1.15)$$

N,.(F-ONiklo8j(F-J)(16-15)

Where, $kT_0\ddot{o}f$ is the noise input power of receiver

k is the Bolt Mann's constant 1.38*10" J/K

T_0 is the standard ambient temperature I 7°C = 290 K

öf is the bandwidth of receiver

It has been assumed that the antenna temperature is equal to the standard ambient temperature, which may or may not be true; but the actual antenna temperature is of importance only if a very low-noise amplifier is used. Reference may be made for the reasoning behind the substitution for N;.

The minimum receivable signal for the receiver, under so-called threshold detection conditions, is equal to the equivalent noise power at the input of the receiver, as just obtained in Equation (1.15), This may seem a little harsh, especially since much higher ratios of signal to noise are used in continuous modulation systems. However, it must be realized that the echoes from the target are repetitive, whereas noise impulses are random. An integrating procedure thus takes place in the receiver, and meaningful echo pulses may be obtained although their amplitude is no greater than that of the noise impulses. This may be understood by considering briefly the display of the received pulses on the cathode-ray tube screen. The signal pulses will keep recurring at the same spot if the target is stationary, so that the brightness at this point of the screen is maintained (whereas the impulses due to noise are quite random and therefore not additive). If the target itself is in rapid motion, i.e., moves significantly between successive scans, a system of moving-target indication (coming in chapter three) may be used. Substituting these findings into Equation (1.13), we have

$$r_{max} = [\frac{PA_2S}{4.1r_{,,}fK_{,0};(F-l)}]^{};\qquad (1.16)$$

Equation (1-16) is reasonably accurate in predicting maximum range, provided that a number of factors are taken into account when it is sued. Among these are system losses, antenna imperfection, receiver nonlinear ties, anomalous propagation, proximity of other noise sources (including deliberate jamming) and operator errors, and/or fatigue (if there is an operator). It would be safe to call the result obtained with the aid of this equation the maximum theoretical range, and to realize that the maximum practical range varies between 10 and 100 percent of this value. However, range is sometimes, such as super refraction.

It is possible to simplify Equation (1.16), which is rather cumbersome as it stands. Substituting for the capture area in terms of the antepna diameter ($A_0 = 0.65.1rD_2 I4$) and for the various constants, and expressing the maximum range in kilometers, allows simplificationto

$$r_{max} = 48[\frac{P_tD_2S}{\lambda^2 ij(F-1)}]^{\sim}, \qquad (1.17)$$

where r_{max} is the maximum radar range in Km.

P_t = peak pulse power, W

D = antenna diameter, m

S = effective cross-sectional area of target, m

8f = receiver bandwidth, Hz

)ι. = wavelength. M.

F = noise figure (expressed as ratio).

1.2.3 target properties

In connection with the derivation of the radar range equation, a quantity was used hut not defined. This was the radar cross-section, or effective area, the target. For targets whose dimensions are large compared to the wavelength, as aircraft microwave radar is used, the radar cross section may be defined as the objected area of a perfectly conducting sphere which would reflect the same power as e actual target reflects, if it were located at the same spot as the target. The practical nation is far from simple.

First of all, the radar cross section depends on the frequency used. If this is such at the target is small compared to a wavelength. Its cross-sectional area for radar appears much smaller than its real cross section. Such a situation is referred to as the Raleigh region. When the circumference of a spherical target is between 1 and 10 wavelengths, the radar cross section oscillates about the real one. This is the so-called resonance region. Finally. Fey shorter wavelengths (in the optical region) the radar and e cross sections are equal

Quite apart from variations with frequency, the radar cross section of a target will depend on the polarization of the incident wave, the degree of surface roughness (If it is severe), the use of special coatings on 'the target and, most importantly of all. The aspect of the target. For instance, a large jet aircraft, measured at 425 MHz, has found to have a radar cross section varying between 0.2 and 300 m^2 for the fuselage, depending on the angle at which the radar pulses arrived on it. The situation is seen to be complex because of the large number of factors involved, so that a lot of work is empirical.

, CHPTER TWO

PULSED SYSTEMS

Pulse systems can be descried in some details, starting with the block diagram of a typical pulse radar set and its description., followed by discussion of scanning and display method. Pulse radar can be divided broadly into search radars and tracking

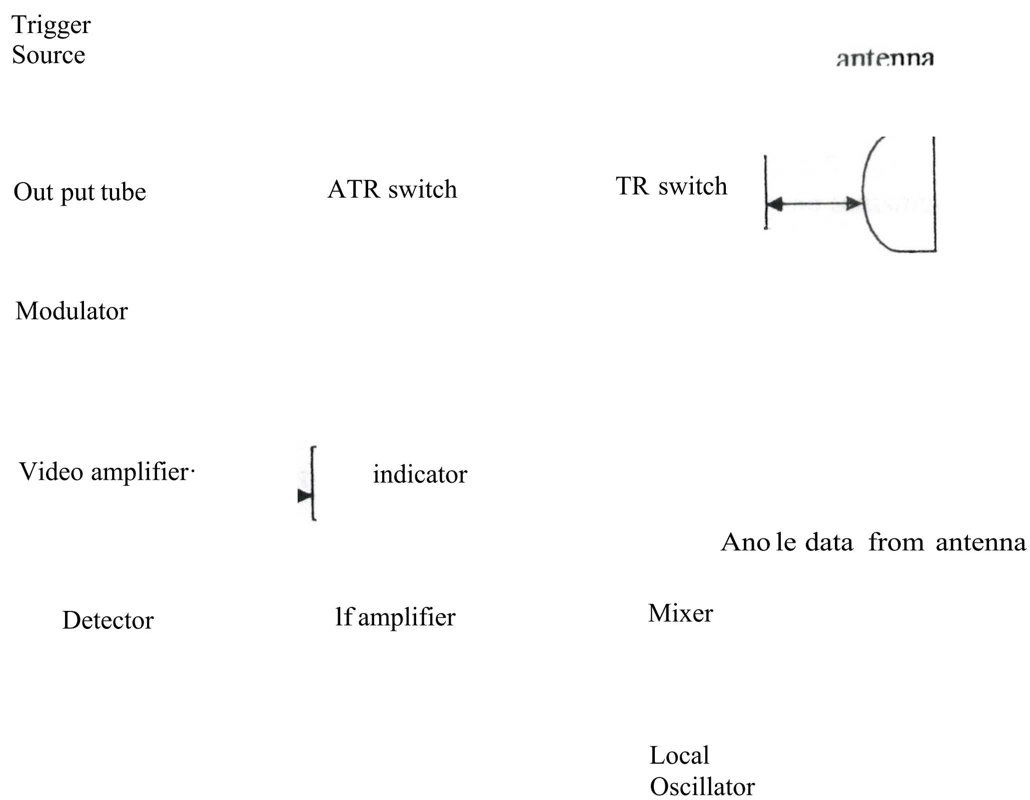


Figure 2.1 pulse radar block diagrams.

and some mention can be made of auxiliary systems such as beacon and transponders.

2.1 Basic Pulse Radar System

A very elementary block diagram of pulsed radar set was shown in figure (1. I) more detailed block diagram is given and it will be possible to talk a bout the pulsed system and the circuits used with those.

The block diagram of figure (2.1) shows the arrangement of atypical high-pulsed radar set. The trigger source provides pulses for the modulator. The modulator provides rectangular voltage pulses used as the supply voltage for the output tube, switching it on and off as required. This tube may be magnetron oscillator or an amplifier such as the Klystron, traveling wave tube or a crossed field amplifier, depending on specific requirements. If an amplifier is used, a source of microwave is required. While an amplifier may be modulated at a special grid, the magnetron cannot. If the radar is small powered one, it may use IMP ATI or gun oscillator, or TRAP ATI amplifiers. Bellow c band power transistor amplifier or oscillator may also be used. The transmitter portion of the radar is terminated with the duplexer, which passes the output pulse to the antenna for transmission.

The receiver is connected to the antenna at suitable times (i.e.. when no transmission is instantaneously taking place). As previously explained, the duplexer also does this. As shown here, a (semiconductor diode) mixer is the most likely first stage in the receiver, since it has a fairly low noise figure, but of course it shows a conversion loss. An RF amplifier can also be used, and this would most likely be a transistor or IC, or perhaps a tunnel diode or par amp. A better noise figure is thus obtained, and the RF amplifier may have the further advantage of saturating for large signals, thus acting as a limiter that prevents mixer diode burnout from strong echoes produced by nearby targets. The main receiver gain is provided at an intermediate frequency that is typically 30 or 60 MHz. However, it may take two or more down conversions to reach that IF from the initial microwave RF, to ensure adequate image frequency suppression.

If diode mixer is the first stage, the (first) IF amplifier must be designed as a low-noise stage to ensure that the overall noise figure of the receiver does not deteriorate. A noisy IF amplifier would play havoc with the overall receiver performance, especially when it is noted that the "gain" of a diode mixer is in fact a conversion loss typically 4 to 7 dB. A cascade connection is quite common for the transistor amplifiers used in the IF stage, because it removes the need for neutralization to avoid the Miller effect.

Another source of noise in the receiver of Figure (1.4) may be the local oscillator, especially for microwave radar receivers. One of the methods of reducing such noise is to use a vector or step-recovery diode multiplier. Another method involves the connection of a narrowband filter between the local oscillator and the mixer to reduce the noise bandwidth of the mixer. However, in receivers employing automatic frequency correction this may be unsatisfactory. The solution of the oscillator noise problem may then lie in using a balanced mixer and/or a cavity-stabilized oscillator. If used, AFC may simply consist of a phase discriminator which takes part of the output from the IF amplifier and produces a de correcting voltage if the intermediate frequency drifts. The voltage may then be applied directly to a vector in a diode oscillator cavity.

The IF amplifier is broadband, to permit the use of fairly narrow pulses. This means that cascaded rather than single-stage amplifiers are used. These can be synchronous that is. All tuned to the same frequency and having identical band pass characteristics. If a really large bandwidth is needed, the individual IF amplifiers may be stagger-nıned the overall response is achieved by overlapping the responses of the individual amplifiers, which are tuned to nearby frequencies on either side of the center frequency. The detector is often a Schottky-barrier diode, whose, output is amplified by a video amplifier having the same bandwidth as the IF amplifier. Its output is then fed to a display unit, directly or via computer processing and enhancing.

Modulators In a radar transmitter, the modulator is a circuit or group of circuits whose function it is to switch the output tube ON and OFF as required. There are two main types in common use: lint -pulsing modulators and active-switch modulators. The latter are also known as driver-power-amplifier modulators and were called hard-tube modulators until the advent of semiconductor devices capable of handling some modulator duties.

Here the anode of the output tube (or its collector, depending on the tube used) is modulated directly by a system that generates and provides large pulses of supply voltage. Slowly charging and then rapidly discharging a transmission line achieve this. Toe charging is made slow to reduce the current requirements and is generally done through an inductance. The transmission line is able to store energy in its distributed inductance and capacitance. If the line is charged to a voltage V from a high-impedance source, this voltage will drop to l/2V when a load is connected (the output tube) whose impedance is equal to the characteristic impedance of the line. However, at the instant of load connection the voltage across the line is l/2V only at the input; it is still V everywhere else. Toe voltage drop now propagates along the line to the far end, from which it is reflected to the input terminals. It is thus seen that a voltage V will be maintained across the load for a time 2t, where t is the time taken by an electromagnetic wave to travel from one end of the line to the other.

If the pulse duration (2t) is to be 1 μs, the line length must be 150 m. This is far too long for convenience, and consequently a pulse-farming network (PFN) is almost always substituted for the transmission line. As shown in Figure (2.2), which illustrates a very basic modulator, the PFN looks just like the equivalent circuit of a transmission line. It also behaves identically to the transmission line for frequencies below f= Vır square root of LC, where L and C are the inductance and capacitance, respectively, per section. In high-power radars, the device most likely for use as a switch is a hydrogen thyratron, because it is capable of switching very high powers and of rapid deionization. *Silicon-controlled rectifiers* (SCRs) may also be used to good advantage.

The advantages of the line modulator are that it is simple, compact, reliable and efficient. However, it has the disadvantage that the PEN must be changed if a different pulse-length is required. Consequently, line modulators are not used at all in radars from which variable pulse widths are required, but they are often used otherwise. The pulses that are produced have adequately steep sides and flat tops.

The active-switch modulator is one that can also provide high-level modulation of the output tube, but this time the pulses are generated at a low power level and then amplified. The driver is often a blocking oscillator, triggered by a timing source and driving an amplifier. Depending on the power level, this may be a transistor amplifier or a powerful tube such as a shielded-grid triode; The amplifier then controls the De power supply for the output RF tube. This type of modulator is less efficient, more complex and bulkier than the line modulator, but it does have the advantage of easily variable pulse length, repetition rate or even shape. It is often used in practice.

Finally, low-level modulation is also sometimes possible. This may be done in UHF radar, which uses orthodox vacuum tubes, or at higher frequencies if a velocity-modulated amplifier is used. Also, in some low-power radars, it becomes possible to apply the output of the blocking oscillator directly to the output tube, simplifying the modulator circuitry.

Receiver bandwidth requirements Based on what we learned in Chapter 1. the bandwidth of the receiver correspond to the bandwidth of the transmitter and its pulse width. The narrower the pulses, the greater is the IF (and video) bandwidth required, whereas the RF bandwidth is normally greater than these, as in other receivers. With a given pulse duration *T,* the receiver bandwidth may still vary, depending on how many harmonics of the pulse repetition frequency are needed to provide a received pulse having a suitable shape. If vertical sides are required for the pulses in order to give a good resolution (as will he seen), a large bandwidth is required. It is seen that the bandwidth must be increased if more information about the target is required, but too large a bandwidth will reduce the maximum range by admitting more noise, as shown by Equation (1.16).

The IF bandwidth of a radar receiver is made n/T, where T is the pulse duration and n is a number whose value ranges from under 1 to over 10, depending on the circumstances. Values of n from I to about 1.4 are the most common; Because pulse widths normally range from 0.1 to 10 μs, it is seen that the radar receiver bandwidth may lie in the range from about 200 kHz to over 10 'MHz. Bandwidths from I to 2 MHz are the most common.

2.1.2 Factors governing pulse characteristics

We may now consider why flat-Lopped rectangular pulses are preferred in radar and what it is that governs their amplitude, duration and repetition rate. These factors are of the greatest importance in specifying and determining the performance of a radar system.

There are several reasons why radar pulses ideally should have vertical sides and flat tops. The leading edge of the transmitted pulse m~ be vertical to ensure that the leading edge of the received pulse is also close to vertical. Otherwise, ambiguity will exist as to the precise instant at which the pulse has been returned, and therefore inaccuracies will creep into the exact measurement of the target range. This requirement is of special importance in fire-control radars. A flat top is required for the voltage pulse applied to the magnetron anode; otherwise its frequency will be altered .It also is needed because the efficiency of the magnetron, multicavity klystron or other amplifier drops significantly if the supply voltage is reduced. Finally, a steep trailing edge is needed for the transmitted pulse, so that the duplexer can switch the receiver over to the antenna as soon as the body of the pulse has passed. is will not happen if the pulse decays slowly, since there will be sufficient pulse power present to keep the TR switch ionized. We see that a pulse trailing edge, which is not steep, has the effect of lengthening the period of time, which the receiver is disconnected from the antenna. Therefore it limits the minimum range of the radar. 1lιis will be discussed in connection with pulse width.

The pulse repetition frequency, or PRF. is governed mainly by two conflicting factors. The first is the maximum range required, since it is necessary not only to be able to detect pulses returning from distant targets but also to allow them time to return before the next pulse is transmitted. If given radar is to have a range of 50 nmi (92.6 kin), at least 620 μs must be allowed between successive pulses; this period is called the pulse interval Ambiguities will result if this is not done. If only 500 μs is used as the pulse interval, an echo received 120 μs after the transmission of a pulse could mean either that the target is 120/12.4 = 9.7 nmi (18 km) away or else that the pulse received is a reflection of the previously sent pulse, so that the target is (120 + 500)/12.4 = 50 nmi away. From this point of view, it is seen that the pulse interval should be as large as possible. The greater the number of pulses reflected from a target, the greater the probability of distinguishing this target from noise. An integrating effect takes place if echoes· repeatedly come from the same target, whereas noise is random, Since the antenna moves at a significant speed in many types of radar, and·yet it is necessary to receive several pulses from a given target, a lower limit on the pulse repetition frequency clearly exists. Values of PRF from 200 to 10,000/s are commonly used in practice, corresponding to pulse intervals of 5000 to 100 μs and therefore to maximum ranges from 400 to 8 nmi (740 to 15 km). When the. targets are very distant (satellites and space probes, for example), lower PRFs may have to be used (as low as 30 pps).

If a short minimum range is required, then short pulses must be transmitted. This is really a continuation of the argument in favor of a vertical trailing edge for the transmitted pulse. Since the receiver is disconnected from the antenna for the duration of the pulse being transmitted (in all radars using duplexers), it follows that echoes returned during this period cannot be received. If the total pulse duration is 2 μs, then no pulses can be received during this period. No echoes can be received from targets closer than 300 m away, and this is the minimum range of the radar. Another argument in favor of short pulses is that they improve the range resolution, which is the ability to separate targets whose distance from the transmitter differs only slightly. Angular resolution, as the name implies, is dictated by the beam width of the antenna. If the beam width is 2°, then two separate targets that are less than 2° apart will appear as one target and will therefore not be resolved. If a pulse duration of 1 μs is used, this means that echoes returning from separate targets that are 1 μs apart in time, (i.e., about 300 m in distance) will merge into one returned pulse and will not be separated. It is seen that the range resolution in this case is no better than 300 m.

It is now necessary to consider some arguments in favor of long pulse durations. The main one is simply that the receiver bandwidths must be increased as pulses are made narrower, and Equation (1.16) shows that this tends to reduce the maximum range by admitting more noise into the system. Increasing the peak pulse power, but only at the expense of cost, size and power consumption may of course, counteract this. A careful look at the situation reveals that the maximum range depends on the pulse energy rather than on its peak power. Since one of the terms of Equation (1.16) is Pı/o J and the bandwidth o /is Inversely proportional to the pulse duration.,we are entitled to say that range depends on the product of PT, and *T,* and this product is equal to the pulse *energy.* We must keep in mind that increasing the pulse width while keeping a constant PRF has the effect of increasing the *duty cycle* of the output tube, and therefore its average power. As the name implies, the duty cycle. is the fraction of time during which the output tube is *ON* If PRF is 1200 and the pulse width is 1.5 μs, the period of time actually occupied by the transmission of pulses is 1200 x 1.5 =1800 *μsis.* or 0.0018 (0.18 percent increasing the duty cycle thus increases the dissipation of the output tube. It may also have the effect of forcing a reduction in the peak power, because the peak and average powers are closely related for any type of tube. If large duty cycles are required, it is worth considering a traveling-wave tube or a crossed-field amplifier as the output tube, since both are capable of duty cycles in excess of 0.02.

2.2 Antennas and Scanning

The majority of radar antennas use dipole or horn-fed paraboloid reflectors, or at least reflectors of a basically paraboloid shape, (the cut paraboloid, parabolic cylinder or pillbox). ln each of the latter, the beam width in the vertical direction (the angular resolution) will be much worse than in the horizontal direction., but this is immaterial in ground-to-ground or even air-to-ground radars. It has the advantages of allowing a significantly reduced antenna size arid weight, reduced wind loading and smaller drive motors.

2.2.1 Antenna scanning

Radar antennas are often made to scan a given area of the surrounding space, but the actual scanning pattern depends on the application. Figure 2.3 shows some typical scanning patterns. The first of these is the simplest but has the disadvantage of scanning in the horizontal plane only. However, there are many applications for this type of scan in searching the horizon, e.g., in ship-to-ship radar, The nodding scan of Figure 2.3b is an extension of this; the antenna is now rocked rapidly in elevation while it rotates more slowly in azimuth, and scanning in both planes is obtained. The system can be used to scan a limited sector or else it can be extended to cover the complete hemisphere. Another system capable of search over the complete hemisphere is the helical scanning system of Figure 2.3c,_ in which the elevation of the antenna is raised slowly while it

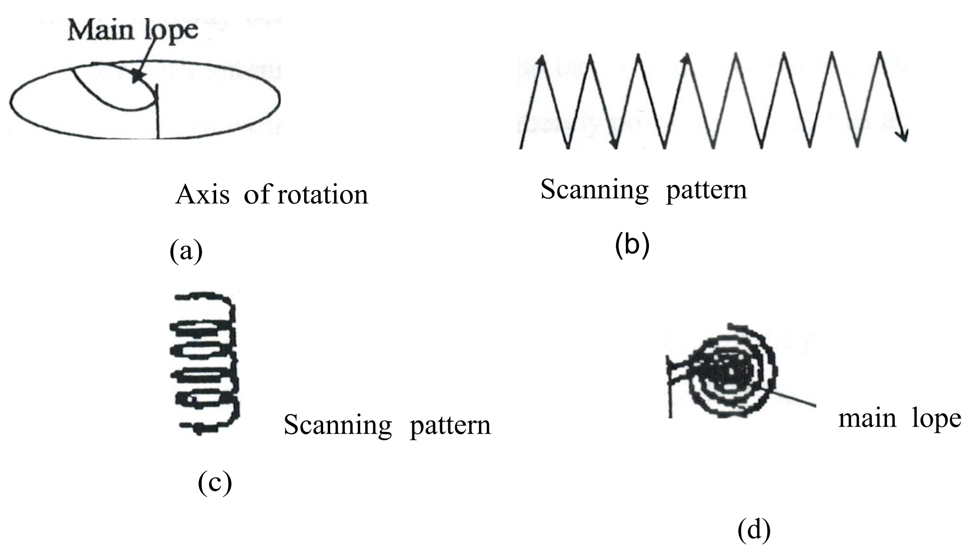


Figure 2.3 representative antenna-scanning patterns. (a) Horizontal; (b) nodding;(c) helical; (d) spiral.

Rotates more rapidly in azimuth. The antenna is returned to its starting point at the completion of the scanning cycle and typical speeds are a rotation of 6 rpm accompanied by a rise rate of20°/minute (World War II SCR-584 radar). Finally, ifa limited area of more or less circular shape is to be covered, spiral scan may be used, as shown in Figure 2.3d.

2.2.2 Antenna tracking

Having acquired a target through a scanning method as just described, it may then be necessary to locate it very accurately, perhaps in order to bring weapons to bear upon it. Having an antenna with a narrow, pencil-shaped. beam helps in this regard, but the accuracy of even this type of antenna is generally insufficient in itself. An error of only 1° seems slight, until one realizes that a weapon so aimed would miss a nearby target, only It 10 km away, by 175 m, (i.e., completely!). Auxiliary methods of tracking or precise location must be employed. The simplest of these is the lobe-switching technique illustrated in Figure 2.4a, which is also called sequential lobing. The direction of the antenna beam is rapidly switched between two positions in this system, as shown, so that the strength of the echo from the target will fluctuate at the switching rate, unless the target is exactly midway between the two directions. In this case, the echo strength will be the same for both antenna positions, and the target will have been tracked with much greater accuracy than would be achieved by merely pointing the antenna at it.

Conical scanning is a logical extension of lo be switching and is shown in Figure 2-4b. It is achieved by mounting the parabolic antenna slightly off center and then rotating it about the axis of the parabola, the rotation is slow compared to the PRF. The name conical scan is derived from the surface described in space by the pencil radiation pattern of the antenna, as the tip of the pattern moves_in a circle. The same argument applies with regard to target positioning as for sequential lobing, except that the conical scanning system is just as accurate in elevation as in azimuth, whereas sequential lobing is accurate in one plane only.

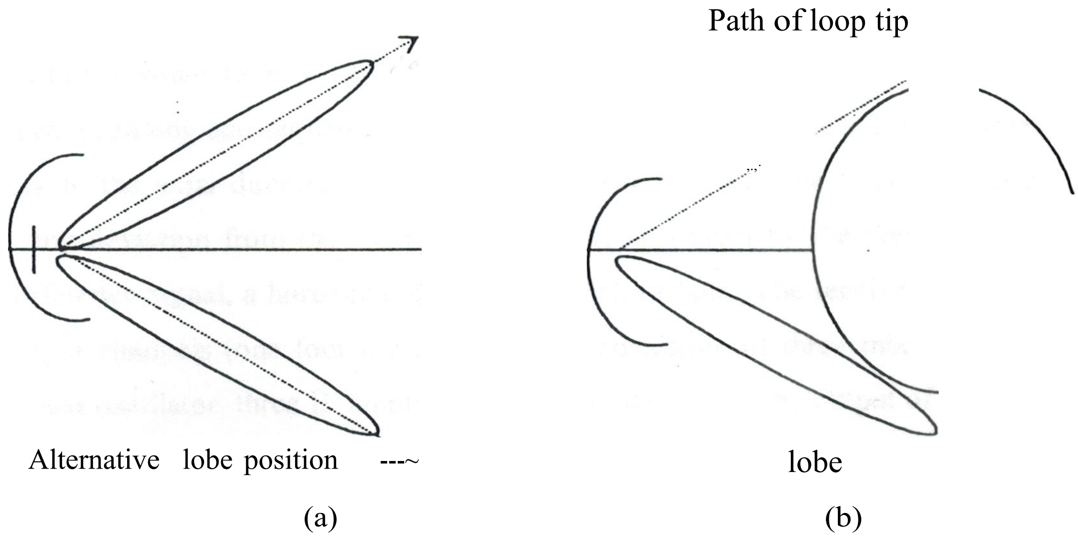


Figure 2.4 Antenna tracking. (a) Lobe switching; (b) conical scanning.

There are two disadvantages of the use of either sequential lobing or conical scanning. The first and most obvious is that the motion of the antenna is now more complex, and additional servomechanisms are required. The second drawback is due to the fact that more than one returned pulse to locate a target accurately (a minimum of four are required with conical scan, one. for the e~eme displacement of the antenna). The difficulty here is that if the target cross section is changing, because its change in attitude or for other reasons, the echo power will be changing also. Hence the effect conical scanning (or sequential lobing, for that matter) will be largely nullified. Form this point of view, the ideal system would be in which all the information obtained by conical scanning could be achieved with just one pulse. Such a system fortunately exists and is called monopulse.

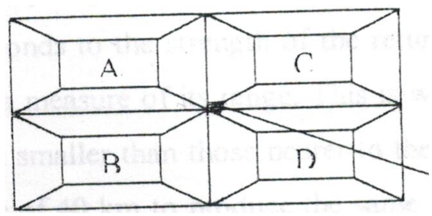
In an amplitude-comparison monopulse system. Four feeds are used with the one-paraboloid reflector. The system using four horn antennas displaced about the central focus of the reflector is shown in figure 2.5. The transmitter feeds the horns simultaneously by a single horn, In reception, a duplexer using a rat race, is employed to provide the following three signals: the sum A+B+C+D, the vertical difference (A+C)-(B+D) and the horizontal difference (A+B)-(C+D).

Each of the four feeds produces a slightly different beam from the one reflector, so that in transmission four individual beam "stab out" in to space, being centered on a direction a beam would have had from single feed placed at the focus of the reflector. As in conical scanning and sequential lobing, no differences will be record if the target is precisely in the axial direction of the antenna. However, once the target has been acquired, any deviation from the central position will be shown by the presence of a vertical difference signal, a horizontal difference signal, or both. The receiver has three separate input channels (one four the three signals) consisting of three mixers with a common local oscillator, three IF amplifiers and three detectors. The output of the sum channel is used to provide the data generally obtained from a radar receiver, while each of the difference or error signals feeds a servo amplifier and motor; driving the antenna so as to keep it pointed exactly at the target, once this has been done, the output of the sum channel can be used for the automatic control of gunnery that is the function of the radar.

The advantage of monopulse, as previously mentioned, is that it obtains one pulse the information, which required several pulses in conical scanning. Pulse is not subject to errors due to the variation in target cross section. It requires extra receiving channels and a more complex duplexer and feeding arrangement will be bulkier and more expensive.

Some antennas arc required providing a certain amount of tracking themselves too bulky to move, e.g., the 120-by-50-m BMEWS antennas a Greenland. The feed is scanned on either side of the focus of the reflector. In simple systems, the feed horn may actually move, but in others a multiple-feed arrangement is used. This is rather similar to the monopulse feed but contains far more horns; signal is then applied to each horn in turn (also referred to as the "organ-pipe" scanner). An alternative to this system, which is rather similar to an interferometer, of using a number of fairly closely spaced fixed antennas and varying the dirt the scanning beam by changing the relative phase of the signals fed to the antennas. The name given to this is phased array. Note that no antenna movement required for scanning with either the phased array or the organ-pipe scanner. A description of various aspects of phased array radars is given in Section 3-3.

Feed horns
(relative size is
exaggerated)



Focus of paraboloid

Figure 2.5 Feed arrangements for monopulse tracking

2.3 Display Methods

The output of a radar receiver may be displayed in any of a number of ways the following three being the most common: deflection modulation of a cathode-screen as in the A scope, intensity modulation of a CRT as in the plan-position indicator (PPI) or direct feeding to a computer. Additional information, such as height or velocity, may be shown on separate displays.

A scope as can be seen from Figure 2.6, the operation of this display system rather similar to that of an ordinary oscilloscope. A sweep waveform is applied horizontal deflection plates of the CRT and moves the beam slowly from left across the face of the tube, and then back to the starting point. The fly back period is rapid and occurs with the beam blanked out. In the absence of any received signal, the display is simply a horizontal straight line, as with oscilloscope. The demodulation receiver output is applied to the vertical deflection plates and causes the departures from the horizontal line, as seen in Figure 2.6. The horizontal deflection saw tooth waveform is synchronized with the transmitted pulses, so that the width of the CRT screen corresponds to the time interval between successive pulses. Displacement from the left-hand side of the CRT corresponds to the range of the target. The first 'blip" is due to the transmitted pulse, part of which is deliberately applied to the CRT for reference. Then come various strong blips due to reflections from the ground and nearby objects, followed by noise, which is here called ground clutter (the name is very descriptive, although the pips due to noise are not constant in amplitude or position). The various targets then show up as (ideally) large blips, again interspersed with grass. The height of each blip corresponds to the strength of the returned echo, while its distance from the reference blip is a measure of its range. This is why the blips on the right of the screen have been shown smaller than those nearer to the left. It would take a very large target indeed at a range of 40 km to produce the same size of echo as a normal target only 5 km away!

Of the various indications and controls for the A scope, perhaps the most important is the range calibration, shown horizontally across the tube. In some radars only one may be shown, corresponding to a fixed value of 1 km per cm of screen deflection, although in others several scales may be available, with suitable switching for more accurate range determination of closer targets. It is possible to expand any section of the scan to allow more accurate indication of that particular area (this is rather similar to band spread in communications receivers). It is also often possible to introduce pips derived from the transmitted pulse, which have been passed through a time-delay network. The delay is adjustable, so that the *marker* blip can be made to coincide with the target. The distance reading provided by the marker control is more accurate than could have been estimated from a direct reading of the CRT. A gain control for vertical deflection is provided, which allows the sensitivity to be increased for weak echoes or reduced for strong ones. In the case of strong signals, reducing the sensitivity will reduce the amplitude of the ground clutter.

By its very nature, the A scope presentation is more suitable for use with tracking than with search antennas, since the echoes returned from one direction only are displayed; the antenna direction is generally indicated elsewhere. Plan-position indicator, the PPI display shows a map of the target area. The CRT is now intensity-modulated, so that the signal from the receiver after demodulation is applied to the grid of the cathode-ray tube. The CRT is biased slightly beyond cutoff, and only blips corresponding to targets permit beam current and therefore screen brightness. The scanning waveform is now applied to a pair of coils on opposite sides of the neck of the tube, so that magnetic deflection is used, and a saw tooth current is required. The coils, situated in a yoke similar in appearance to that around the neck of a television picture tube, are rotated mechanically at the same angular velocity as the antenna. Hence the beam is not only deflected radically outward from the center and then back again rapidly but also rotates continuously around the tube. The brightness at any point on the screen indicates the presence of an object there, with its position corresponding to its actual physical position and its range being measured radically out from the center.

Long-persistence phosphors are normally used to ensure that the face of the PPI screen does not flicker. It must be remembered that the scanning speed is rather low compared to the 60 fields per second used with television, so that various portions of the screen could go dim between successive scans. The resolution on the screen tic-ponds on the beam width of the antenna, the pulse length, the transmitted frequency. And even on the diameter of the CRT beam. Circular screens are used with diameters ranging up to 40 cm, but 30 cm is most often used.

The PPI display lends itself to use with search radars and is particularly suitable when conical scanning is employed. Note should also be taken of the fact that distortion of true map positions will take place if PPI is used on an aircraft, and its antenna does not point straight doWIL The range then seen on the screen is called the slant range. If the antenna of a mapping radar points straight down from the aircraft body. But the aircraft is climbing; the terrain behind will appear shortened, while the area ahead is

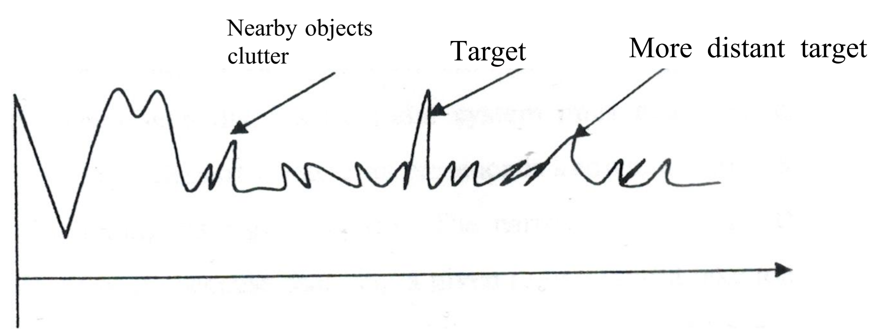


Figure 2.5 A scope display

distorted by being lengthened. If required, computer processing may be used to correct for radar attitude, therefore converting slant range into true range. It should be noted that the mechanics of generating the appropriate waveforms and scanning the radar CRT are similar to those functions in TV receivers. Discussion of those, including the need for saw tooth scanning waveforms, in conjunction with television receivers.

Automatic target detection the performance of radar operators may be erratic or inaccurate (people staring at screens for long hours do get tired); therefore the output of the radar receiver may be used in a number of ways that do not involve human operators. One such system may involve computer processing and simplification of the received data prior to display on the radar screen. Other systems use analog computers for the reception and interpretation of the received data, together with automatic tracking and gun laying (or missile pointing). Some of the more sophisticated radar systems are discussed later.

2.4 Pulsed radar system

A radar system is generally required to perform one of two tasks: It must either search for targets or else track them once they have been acquired. Sometimes the same radar performs both functions, whereas in other installations separate radars are used. Within each broad group, further subdivisions are possible, depending on the specific application. The most common of these will now be described.

2.4.1 search radar systems

The general discussion of radar so far in this chapter has revealed the basic features of search radars, including block diagrams, antenna scanning methods and display systems. It has been seen that such a radar system must acquire a target in a large volume of space, regardless of whether its presence is known. To do this, the radar must be capable of scanning its region rapidly. The narrow beam is not the best antenna pattern for this purpose, because scanning a given region would take too long. Once the approximate position of a target has been obtained with a broad beam, the information can be passed on to tracking radar, which quickly acquires and then follows the target. Another solution to the problem consists in using two fan-shaped beams (from a pair of connected cut paraboloids,), oriented so that one is directional in azimuth and the other in elevation. The two rotate together, using helical scan, so that while one searches in azimuth, the other antenna acts as a height finder, and a large area is covered rapidly. Perhaps the most common application of this type is the air-traffic-control radar used at both military and civilian airports.

If the area to be scanned is relatively small, a pencil beam and spiral scanning can be used to advantage, together with a PPI display unit. Weather avoidance and airborne navigation radars are two examples of this type. Marine navigation and ship-to-ship radars are of a similar type, except that here the scan is simply horizontal, with a fan-shaped beam. Early-warning and aircraft surveillance radars are also acquisition radars with a limited search region, but they differ from the other types in that they use UHF wavelengths to reduce atmospheric and rain interference. They thus are characterized not only by huge powers, but also by equally large antennas. The antennas are stationary, so that scanning is achieved by moving-feed or similar methods.

2.4.1 Tracking Radar Systems

Once a target has been acquired, it may then be tracked, as discussed in the section dealing with antennas and scanning. The rmst comıron tracking method used purely for tracking are the conical scan and monopulse systems described previously. A system that gives the angular position of a target accurately is said to be tracking in angle. If range information is also continuously obtained, tracking in range (as well as in angle) is said to be taking place, while a tracker that continuously monitors the relative target velocity by Doppler shift is said to be tracking in Doppler as well. If radar is used purely for tracking, then search radar must be present also. Because the two together are obviously rather bulky, they are often limited to ground or ship borne use and are employed for tracking hostile aircraft and missiles. They may also be used for fire control, in which case information is fed to a computer as well as being displayed. Toe computer directs the antiaircraft batteries or missiles, keeping them pointed not at the target, but at the position in space where the target will be intercepted by the dispatched salvo (if all goes well) some seconds later. Airborne tracking radars differ from those just described in that there is usually not enough space for two radars, so that the one system must perform both functions. One of the ways of doing this is to have a radar system, such as the World War II SCR-584 radar, capable of being used in the search mode and then switched over to the tracking mode, once a target has been acquired. The difficulty, however, is that the antenna beam must be a compromise, to ensure rapid search on the one hand and accurate tracking on the other. After the switchover to the tracking mode, no further targets can be acquired, and the radar is "Blind" in all directions except one.

Track-while-scan (TWS) radar is a partial solution to the problem, especially if the area to be searched is not too large, as often happens with airborne interception; Here a small region is searched by using spiral scaruiing and PPI display. A pencil beam can be used, since the targets arrive from a general direction that can be predicted. The operator can mark blips on the face of the CRT, and thus the path of the target can be reconstructed and even extrapolated, for use in fire control. The advantage of this method, apart from its use of only the one radar, is that it can acquire some targets while tracking others, thus providing a good deal of information simultaneously. If this becomes too much for an operator; automatic computer processing can be employed, as in the semiautomatic ground environment (SAGE) system used for air defense. The disadvantage of the system, as compared with the pure tracking radar, is hat although search is continuous, tracking is not, so that the accuracy is less than that obtained with monopulse or conical scan.

Tracking of extraterrestrial objects, such as satellites or spacecraft, is another specialized form of tracking. Because the position of the target is usually .predictable, only the tracker is required. The difficulty lies in the small size and great distance of the targets. This does not necessarily apply to satellites in low orbits up to 600 km, but certainly is true of satellites in synchronous orbits 6,000 km up, and also of space vehicles. Huge transmitting powers, extremely sensitive receivers and enormous fully steer able antennas are required.

2.5 **Moving target indicator (MTI)**

It is possible to remove from the radar display the majority of clutter, that is, echoes corresponding to stationary targets, showing only the moving targets. This is often required, although of course not in such applications as radar used in mapping or navigational applications. One of the methods of eliminating clutter is the use of MTI, which employs the Doppler effect in its operation.

Doppler effect is the apparent frequency of electromagnetic of sound waves depends on the relative radial motion of the source and the observer. If source and observer are moving away from each other, the apparent frequency will decrease, while if they are moving toward each other, the apparent frequency will increase. This was postulated in 1842 by Christian Doppler and put on a firm mathematical basis by Armand Fizeau in 1848. The Doppler effect is observable for light and is responsible for the so-called red shift of the spectral lines from stellar objects moving away from the solar system. It is equally noticeable for sound, being the cause of the change in the pitch of a whistle from a passing train. It can also be used to advantage in several forms of radar.

Consider an observer situated on a platform approaching a fixed source of radiation, with a relative velocity + V, . A stationary observer would note *t.* wave crests (or troughs) per second if the transmitting frequency were *J;.* Because the observer is moving toward the source, that person of course encounters more than *t,* crests per second. The number observed under these conditions is given by

$$f_t + f_t' = f_t\left(1 + \frac{v_r}{v_c}\right) \tag{2.1}$$

Consequently,

$$f_d' = \frac{f_t v_r}{v_c} \tag{2.2}$$

Where, *I,* + JJ' is the new observed frequency

I, " is the Doppler frequency difference

Note that the foregoing holds if the relative :1elocity, *v,,* is less than about 10 percent of the velocity of light *Ve,* if the relative velocity is higher that (most unlikely in practical eases), relativistic effects must be taken into account, and a some-what more complex formula must be applied. The principle still holds under those conditions, and it hold equally well if the observer is stationary and the source is in motion. Equation (2.2) was calculated for a positive radial velocity, but if, *v,* is negative, f" in Equation (2.2) merely acquires a negative sign. In radar involving a moving target, the signal undergoes the Doppler shift when impinging upon the target. This target becomes the "source" of the reflected waves, so that we now have a moving source and a stationary observer (the radar receiver). The two still approaching each other, and so the Doppler effect is encountered a second time, and the overall effect is thus double. Hence the Doppler frequency for radar is

$$f_d = 2f_2' = \frac{2f_t v_r}{v_c} = \frac{2v_r}{\lambda} \tag{2.3}$$

Since $f_t / v_c = 1/\lambda_t$ where λ_t is the transmitted wavelength.

The same magnitude of Doppler shift is observed regardless of whether a target is moving toward the radar or away from it. With a given velocity. However, it will represent an increase in frequency in the former case and a reduction in the latter. Note also that the Doppler effect is observed only for radial motion, not for tangential motion. Thus no Doppler effect will be noticed if a target moves across the field of view of radar. However a Doppler shift will be apparent if the target is rotating, and the resolution of the radar is sufficient to distinguish its leading edge from its trailing edge. One example where this has been employed is the measurement of the rotation of the plant Venus (whose rotation cannot be observed by optical telescope because of the very dense cloud cover).

On the basis of this frequency change, it is possible to determine the relative velocity of the target, with either pulsed or CW radar, as will be shown. One can also distinguish between stationary and moving targets and eliminate the blips due to stationary targets. This may be done with pulsed radar by using moving-target indication.

2.5.2 Fundamentals of MTI

Basically, the moving target indicator system compares a set of received echoes with those received during the previous sweep. Those echoes whose phase has remained constant are then canceled out. This applies to echoes due to stationary objects, but those due to moving targets do show a phase change; they are thus not canceled, nor are noise, for obvious reasons. The fact that clutter due to stationary targets is removed makes it much easier to determine which targets are moving and reduces the time taken by an operator to "take in" the display. It also allows the detection of moving targets whose echoes are hundreds of times smaller than those of nearby stationary targets and which would otherwise have been completely masked. MTI can be used with a radar using a power oscillator (magnetron) output, but it is easier with one whose output tube is a power amplifier, only the latter will be considered here.

The transmitted frequency in the MTI system of Figure 2-7 is the sum of the outputs of two oscillators, produced in mixer 2. The first is the stalo, or stable local oscillator (note that a good case can be made for using a varactor chain here). The second is the coho, or coherent oscillator, operating at the same frequency as the intermediate frequency and providing the coherent signal, which is used as will be explained. Mixers 1 and 2 are identical, and both use the same local oscillator (the stab); thus phase relations

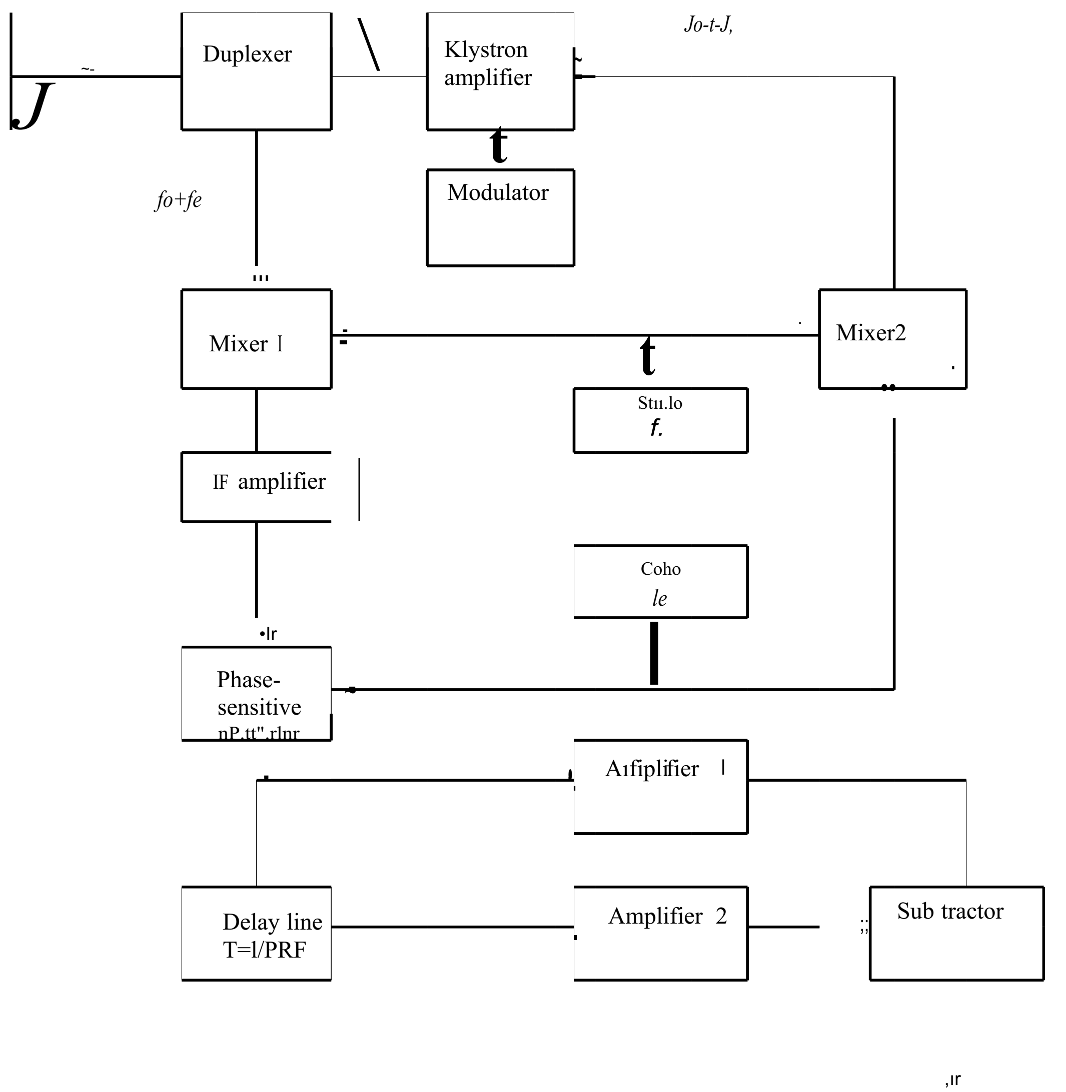
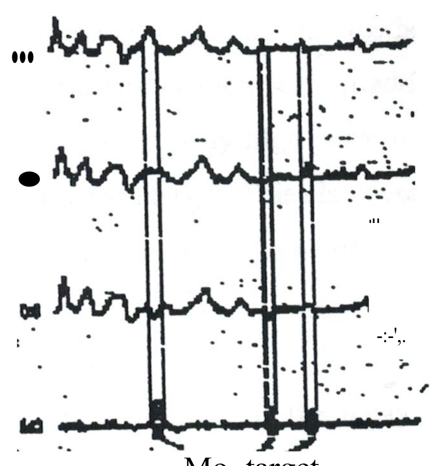


Figure 2.7 Block diagram of MTI radar using power amplifier output

existing in their inputs are preserved in their outputs. This makes It possible to use the Doppler shift at the IF, instead of the less convenient radio frequency fo+f.. The output of the IF amplifier and a reference signal from the echo are fed to the phase-sensitive detector, a circuit very similar to the phase discriminator;

The coho is used for the generation of the RF signal, as well as for reference in the phase detector. And the mixers do not introduce differing phase shifts. The trans-mined and reference signals are locked in phase and are said to be coherent; hence the name of the coho. Since the output of this detector is phase sensitive, an output will be obtained for all fixed or moving targets. The phase difference between the transmitted and received signals will be constant for fixed targets, whereas it will vary for moving targets. This variation for moving targets is due to the Doppler frequency shift, which is naturally accompanied by a phase shift, but this shift is not constant if the target has a radial component of velocity. If the Doppler frequency is 2000 Hz and the return time for a pulse is 124 μs (10 nmi), the phase difference between the transmitted and received signals will be some value ⟠ (the same as for stationary target at that point) plus 2000/124 =16.12 complete cycles, or 16.12 *2ır= 101.4 rad, When the next pulse is returned from the moving target, the latter will now be closer, perhaps only 123 μs away, giving a phase-shift of 101.4 x 123/124 = 100.7 rad. The phase shift is definitely not constant for moving targets. The situation is illustrated graphically, for a number of successive pulses, Figure 2.8



Mo~target

Figure .-8 operation of Mn radar ,(a),(b),(c) phase detector output for three successive pulses; (d) sub tractor output.

It is seen from Figure 2-8 that those returns of each pulse that correspond to stationary targets are identical with each pulse, but those portions corresponding to moving targets keep changing in phase. It is thus possible to subtract the output for each pulse from the preceding one, by delaying the earlier output by a time equal to the pulse interval, or 1/PRF. Since the delay line also attenuates heavily and since signals must be of the same amplitude if permanent echoes are to cancel, an amplifier follows the delay line. To ensure that this does not introduce a spurious phase shift, an amplifier is placed in the undelayed line, which has exactly the same response characteristics (but a much lower gain) than amplifier 1. The delayed and undelayed signals are compared in the sub tractor (adder with one input polarity reversed), whose output is shown in Figure 2-8d. This can now be rectified and displayed in the usual manner.

2.5.3 other analog MTI system

These include area MTI, which involves subtracting a complete scan from the previous one and displaying only the difference; it is done with storage CRTs. Another system is almost identical to the one described but uses a pulsed magnetron oscillator instead of an amplifier. A different technique must be employed here to achieve coherence, because each cycle of the magnetron oscillations begins with a phase quite unrelated to the previous pulsed ·cycle. Noncoherent MTI is also sometimes used, deriving the required phase variations by comparing the returns from stationary and radially moving targets. This method suffers from the disadvantage of requiring stationary targets in each scan in addition to the moving target. Note .that all coherent systems require a fairly high pulse repetition frequency to ensure the return of several pulses from each target. This also describes airborne moving-target indicator (AMTI), in which compensation for the motion of the radar set is an added requirement.

2.5.4 delay lines

Delay lines Because of the delay times required, it would be unthinkable to use electromagnetic delay means in MTI. If the PRF is 1000, then the delay required is I ms, in which time an electromagnetic wave in an air-dielectric line travels 300 km! The method adopted to provide the requisite delay in practice is rather similar to that used with mechanical filters. The signal is converted into acoustic vibrations, passed through a mechanical resonant circuit and converted into an electrical signal at the output end, with a suitable transducer. The most commonly used material for the delay line is fused quartz, in which the velocity of *sound* is 5.44 m/ms.

Since this is still quite large (though manageable), the line can be folded. This consists in having a many-sided prism, in which the acoustic waves are reflected from the planeside. The signal then emerges 1 μs later if the total length of the folded path is 5.44 m. The attenuation in such a line is in excess of 40 dB, and this explains the amplifier accompanying the line on the block of Figure 2.7.

2.5.5 Blind speeds

When showing how phase shift varies if the target has relative motion, a :fictitious situation, which gave a phase difference of 101.4 - 100.7 = 0.7 rad between successive pulses on the target was described in a previous section. If the target happens to have a velocity whose radial component results in a phase difference of exactly 2rc rad between successive pulses, this is the same as having no phase shift at all. The target thus appears stationary, and echoes from it are canceled by the MTI action. A radial velocity corresponding to this situation is known as a blind speed, as are any integral multiples of it. It is readily seen that if a target moves a half-wavelength between successive pulses, the change in phase shill will be precisely 2rc rad.

We may state that

$$v_b = PRF \frac{n2}{2} \qquad (2.3)$$

Where, v_b is the blind speed

A is the wavelength of transmitted signal

n is the any integer (include 0)

The fact that blind speeds exist need not be a serious problem and does not normally persist beyond a small number of successive pulses. A target flying directly toward the radar set at a constant velocity could cause this, but it would be sheet coincidence, and a far-fetched one at that, for a target to do this accidentally. We do live in a world that produces sophisticated electronic countermeasures, and it is not beyond the realm of possibility that a target may be flying at a blind speed on purpose. A wideband receiver and microprocessor on board the target aircraft or missile could analyze the transmitted frequency and PRF and adjust radial velocity accordingly. The solution to that problem is to have a variable PRF. That presents no difficulty, but varying the delay in the MTI radar does. Having two delay lines and compensating amplifiers can do it. One of these can be a small delay line, having a delay that is 10 percent of the main delay, This second line will then be switched in and out on alternate pulses, changing the blind speed by 10 percent each time.

2.5.6 Digital MTI

ls possible to replace the delay line and amplifier arrangement of an analog MTI system with digital-to-analog conversion of the received signal. After the signal has been digitally coded, it can be stored in a computer memory. Toe echoes received from each pulse are now subtracted in the memory from those received from the previous pulse, whereupon the difference is converted to analog form and displayed as before. With digital MTI (or DMTI). No difficulties arise in varying the PRF. It may be varied almost randomly from one pulse to the next. Interestingly enough, the resolution limit in DMTI is governed, in part, by quantizing noise. Just like in pcm, ana-logsignals must be quantized before their conversion to digital form.

2.6 Radar Beacons

Is a small radar set consisting of a receiver, a separate transmitter and an antenna which is often omni directional~When another radar transmits a coded set of pulses at the beacon, i.e., *interrogates* it, the beacon *responds* by sending back its specific pulse code. Toe pulses from the beacon, or *transponder* as it is often called, may be at the same :frequencyas those from the interrogating radar, in which case the main station together with its echo pulses receives them. They may alternatively be at a special beacon frequency, in which case the interrogating radar requires a separate receiver. Note that the beacon does not transmit pulses continuously in the same way as a search or tracking radar but only responds to the correct interrogation.

One of the functions of a beacon may be to identify itself The beacon may be installed on a target, such as an aircraft, and will transmit a specific pulse code when interrogated. These pulses than appear on the PPI of interrogating radar and inform it of the identity of the target. The system is in use in airport traffic control and also for military purposes, where it is called identification, friend or foe (IFF).

Another use of radar beacons is rather similar to that of lighthouses, except that radar beacons can operate over much larger distances. An aircraft or ship, having interrogated a number of beacons of whose exact location it may be unaware (on account of being slightly lost), can calculate its position from the coded replies accurately and automatically.

The presence of a beacon on a target increases enormously the distance over which a target may be tracked. Such active tracking gives much greater range than the passive tracking so far described, because the power transmitted by the beacon 9modest though it normally is) is far in excess of the power that this target would have reflected had it not carried a beacon. This is best demonstrated quantitatively, as in the next section.

Beacon range equation following the reasoning used to derive the general radar range equation;

$$r, = \frac{AprI'ır:os}{4nr} \qquad (2.4)$$

Where all symbols have their previously defined meanings, except that the subscript T is now used for quantities pertaining to the transmitter of the main radar, and Bis used for the beacon functions. A_{0B} is the capture area of the beacon's antenna. If $P_{min.B}$ is the minimum power receivable by the beacon, the maximum range for the interrogation link will be:

$$r_{\max,I} = \frac{A;tPırAos}{41rPmin,B} \qquad (2.5)$$

Substituting into Equation (2.4) for the power gain of transmitter antenna from Equation (2.5) and for the minimum power receivable by the beacon from equation (2.6), and than canceling, we obtain the final from of the maximumrange for

The interrogation link that is

$$\text{"max:.!} = \frac{A_{PT} P_{tT} A_{0B}}{\lambda^2 k T_0 \delta f (F_B - 1)} \tag{2.6}$$

it has been assumed in equation (2.6) that the bandwidth and antenna temperature of the beacon are the same as those of the main radar. By an almost identical process of reasoning, the maximum range of the reply link is

$$r_{\max .R} = \frac{A_{PT} P_{tT} A_{0B}}{\lambda^2 k T_0 \delta f (F_T - 1)} \tag{2.7}$$

Antenna is also tripled. A foldout, metallized umbrella spacecraft antenna with a 3-m (1O-ft) diameter is certainly feasible. Again, the 13-dB noise figurefor the beacon receiver is conservative, and reducing it to 1O-dB (still fairly conservative) would further increase the range. A slower PRF and less insistence on pulses with steep sides would permit a tenfold bandwidth reduction and a similar pulse power increase from the beacon. A total range for the reply link could comfortably exceed 1000 million km, even allowing for the degradations mentioned above. That distance puts within all the planets up to and including Saturn.

CHAPTER THREE

HAWK SYSTEM

3.1. INTRODUCTION:

The HAWK surface to air missile system provides medium-range, low to medium altitude air defense against a variety of targets, including jet and rotary wing aircraft, unmanned aerial vehicles, and cruise missiles. This mobile, all-weather day and night system is highly lethal, reliable, and effective against electronic countermeasures. The Hawk was originally named for the predatory bird but later the name was turned into an acronym for "Homing All the Way Killer."

The HAWK system has provided US forces with low to medium altitude air defense for the past forty years. The Hawk System has been the Marine Corp's primary air defense since the early 1960's. Basic HAWK was developed in the 1950s and initially fielded in 1960. The system has been upgraded through a series of product improvements beginning with the Improved HAWK in 1970. The Phase III product improvement and the latest missile modification were first fielded in the early 1990s to the US Army and US Marine Corps (USMC). The system has maintained it's effectiveness against succeeding generations of high technology aircraft through periodic preplanned product improvement programs. An evolving system, HAWK is now in its Phase III configuration with research and development underway to obtain a tactical missile defense capability.

This success leads many NATO countries to adopt HAWK as a primary air defense weapon. Today, HAWK systems are in the arsenals of over fifteen countries, inc\uding most of "N.ı\.'1'0 countnes. 1.n tb.e coming, '3~ars, "HAWK -wi\\ continue its proıı\inent position by undergoing system upgrades to allow it to deal with the changing nature of the battlefield threat.

Although the U.S. Army deployed HAWK missile batteries during the conflicts in Vietnam and Persian Gulf, American troops have never fired this weapon in combat The first combat use of HAWK occurred in 1967 when Israel successfully fired the missiles during the Six Day War with Egypt. Even though it was not used by the coalition during Operation Desert Storm, the HAWK missile did see action during the Persian Gulf war. Kuwaiti air defense units equipped with U.S. HAWK antiaircraft missiles downed about 22 Iraqi aircraft and one combat helicopter during the invasion of 2 August 1990.

Current developments will provide an engagement capability against Tactical Ballistic Missiles (TBM). The US Marine Corps and the Ballistic Missile Defense Organization (BMDO) have jointly funded improvements to the Marine Corp's HAWK system. The HAWK has been modified and tested to intercept short-range ballistic missiles. Because HAWK is a well-established system, the current program of upgrades and enhancements is seen as a low risk, near-term missile defense solution against short-range ballistic missiles and other airborne threats such as aircraft or unmanned aerial vehicles. In this role, HAWK can be considered a lower-tier missile defense system. All US HAWK systems are owned and operated by the Marine Corps and, as the Marine's only ballistic missile defense system, it will be relied on to protect Marine expeditionary forces. In September 1994, two LANCE target missiles were successfully intercepted by the modified HAWK system in an operational test by Fleet Marine Forces at White Sands Missile Range, New Mexico. The end of 1997 over has modified one third of the active Marine Corps HAWK equipment to provide a basic, short-range tactical ballistic missile defense (TBMD) for expeditionary Marine forces. The entire fleet inventory was modified by the end of 1998 year.

Units with HAWK missiles are teamed with acquisition radar, a command post, tracking radar, an Identification Friend or Foe (IFF) system, and three to four launchers with three missiles each. The system can be divided into three sections: acquisition, fire control, and firing sections. Target detection is provided to the fire control section from pulse and continuous wave radars for engagement evaluation. Target data can also be received from remote sensors via data link. The fire control section locks onto the target with high-powered tracking radar. A missile or missiles can be launched manually or in an automatic mode from the firing section by the fire control section. Radars and missile have extensive electronic counter counter measures (ECCM) capabilities.

The HAWK Fire Unit is the basic element of the HAWK system.. The actual firing battery has two identical fire units, each consisting of a command post that houses the operator console, a continuous wave acquisition radar (CWAR) for target surveillance, a high power illuminator for target tracking, MK XII IFF interrogator set, and three launchers with three missiles each. Normally the HAWK is deployed in a battalion configuration, communicating with the controlling unit (usually a TSQ-73 Missile Minder) over an Army Tactical Data Link (ATDL-1) connection as well as on voice.

The TSQ-73 Missile Minder Fire Direction Center (FDC) is the system used for the Army HAWK Battalion and Air Defense Brigade. The TSQ-73 supplies command, control and communications for the Army fire units (both Patriot and HAWK) and provides a link to the Air Force C3I units (MCE and AWACS). The Brigade and HAWK battalion units rely on information passed over the data links to produce a comprehensive air picture, while the HAWK battalion can also deploy the Pulse Acquisition Radar (PAR) to generate its own air picture. With the command and control of Army fire units being moved to the Information Coordination Center (ICC) and Army ADTOC (Air Defense Tactical Operations Center), the TSQ-73 is gradually being phased out over the next several years. However, it still plays a vital role in the coordination of SAM assets into the integrated theater air defense environment.

The new HAWK systems will be composed of three major components: the TPS-59 radar, the HAWK launcher and HAWK missiles, and the Air Defense Communications Platform (ADCP). The TPS-59 radar provides target detection, discrimination, and tracking. The HAWK launcher transports, protects and launches the missiles. Each HAWK launcher can carry up to three missiles. HAWK missiles use radar guidance and destroy their targets in proximity explosions. Finally, the ADCP will connect the TPS-59 with the HAWK and the remainder of the theater missile defense architecture in order to create missile defense in depth. Under the current program, the TPS-59 radar and the HAWK launcher and missiles are being upgraded, while the Air 'Defense Communications Platform [ADCP] will be a new addition.

The most prominent upgrade to the HAWK system includes modifying the Marine Corps primary air surveillance radar, the TPS-59. The AN/TPS-59 Radar Set is a Marine Air Command & Control System which serves as the primary sensor for the Marine Air Ground Task Force (MAGTF), providing air target information and raw video to the Tactical Air Operations Module (TAOM). It can also be forward deployed as a stand-alone remote sensor and air traffic controller. The improved radar will detect theater ballistic missiles out to 400 nautical miles and up to 500,000 feet in altitude. These improvements will give the radar the sort of surveillance and tracking ability needed for theater ballistic missile defense (TBMD). The first units were equipped with upgraded TPS-59s in FY98.

The Air Defense Communications Platform, an entirely new addition to the HAWK system, will link the TPS-59 to the HAWK battery and will also transmit formatted data to other theater sensors. This will allow the HAWK to communicate with other TBMD systems through the Joint Tactical Information Distribution System. These links will allow the air defense commander to cue HAWK with other missile defense systems and integrate the HAWK into the theater missile defense architecture. The ADCP is fully developed, and began production in FY97.

The HAWK missile and warhead were modified to allow the HAWK to better engage enemy ballistic missiles. Specifically, the upgrade improved the HAWK's missile fuse and warhead, which resulted in an "improved lethality missile." Additionally, improvements to the launcher made the HAWK more mobile and better able to interface with the missiles.

These new HAWK systems underwent extensive testing. In August of 1996, a single Marine Corps battery equipped with upgraded HAWK systems intercepted and destroyed a LANCE short range theater ballistic missile and two air breathing drones simultaneously in an operational test at White Sands Missile Range, NM. When fielded, the upgraded TPS-59 radars and ADCP's will belong to the Marine Air Control Squadrons, part of the Marine Air Wings.

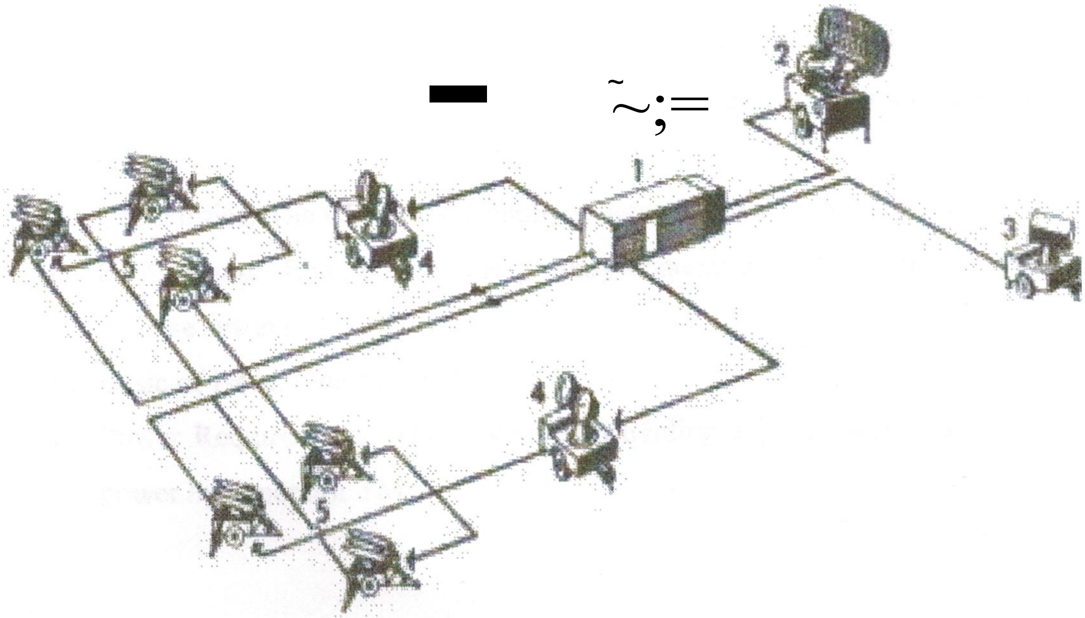


Fig.3.1. Hawk Battery System

3.2. CW Acquisition Radar (CWAR)

Aircraft detection at the lowest altitudes, in the presence of heavy clutter, is the primary feature the CWAR brings to HAWK. The CWAR and PAR are synchronized in azimuth for ease of target data correlation. Other features include FM ranging, Built-in Test Equipment (BITE) and band frequencies. FM is applied on alternate scans of the CWAR to obtain target range information. During the CW scan, range rate minus range is obtained. The Automatic Data Processor (ADP) in the ICC processes this information to derive target range and range rate. This feature provides the necessary data for threat ordering of low-altitude targets detected by the CWAR~

The Phase III program makes same major modifications to the CWAR. The basic function of the CWAR as the system's low-altitude acquisition sensor remains unchanged, however the transmitted waveform was changed to permit the radar to determine both target range and range rate an a single scan. A Digital Signal Processor (DSP) using a Fast Fourier Transform (FFT) was added to process digitally target Doppler into detected target data. The DSP provides this digital data to a new microcomputer located in the CWAR. The microcomputer performs much of the CWAR target processing, formerly done by the ADP in the ICC and transmits the processed target track data to the PCP/BCP in serial digital format over a field telephone wire interconnection. The full duplex digital link eliminates the need for a large, heavy multi-conductor cable between the CWAR and PCP/BCP.

A. Description: The CWAR, Radar set AN/MPQ-62 is trailer mounted continuous type radar.
B. Capabilities: The CWAR is capable of detecting low to medium altitude aircraft.
C. Employment: Employed as the primary acquisition radar of the HAWK of air defense system.
D. Basic ofIssue: One per HAWK unit.
E. Power Requirements: The CWAR is providing 3 phase, 416VAC, and 400HZ power by generator TM.

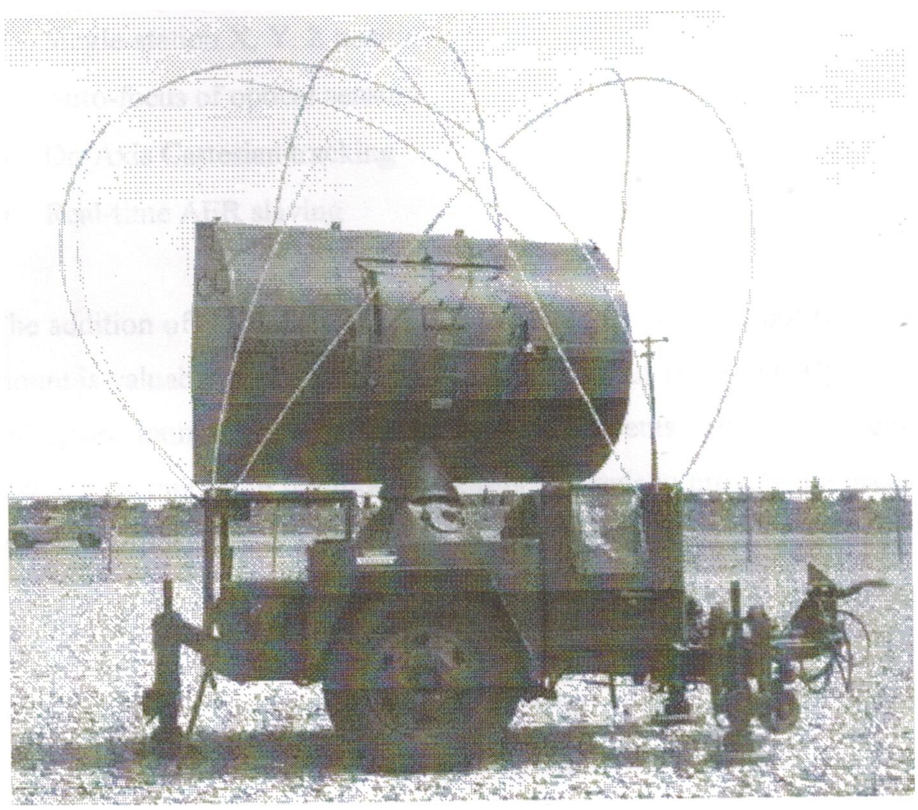


Fig.3.2. CWAR

3.3. Range-Only Radar (ROR)

This is K-band pulse radar that provides quick response range measurement when the other radars are denied range data by enemy countermeasures. During a tactical engagement, the radar is designated to obtain ranging information, .which is used in the computation of the fire command. The ROR reduces its vulnerability to jamming by transmitting _only when designated. The ROR is not retained in the Phase III system.

With the need for a compact, lightweight, low-cost RF ranging sensor for optical tracking systems at test ranges in the U.S. and overseas, BAE SYSTEMS combined our expertise in computer-based radar and optical tracking systems to develop a Low-Cost X-band Range Only Radar. This radar blends proven tracking techniques with the reliability, flexibility and cost effectiveness of off-the-shelf components and Pc-based hardware and software. The availability of a low-cost radar sensor enables the addition of real-time autonomous range data to optical tracking mounts for the price of an optical sensor. Autonomous range data allows an intelligent optical tracking mount (or host system) to produce:

- Single-station X, Y, Z position
- Auto-focus of optical sensors
- On-Axis Cartesian tracking
- Real-time AER slaving

The addition of range data to an otherwise highly accurate but two-dimensional optical mount is valuable in nearly all testing situations but is particularly crucial for the testing of smart munitions: a scenario in which events happen too quickly and unpredictably to permit more traditional tracking methods to provide the necessary data consistently and efficiently. A major consideration in radar, which needs to be light and small, is its operating frequency. In this case tradeoffs between X and Ka-bands were evaluated:

Ka-band radars have a narrower beam width than X-band units for a given antenna size. For range only radar this results in higher loop gain and less clutter in the beam. However, Ka-band also has higher atmospheric losses and greater susceptibility to weather interference. A very narrow beam may also not be desired, especially during acquisition. Higher transmitting powers are readily available at X-band which helps offset the lower loop gain. Cost was a major consideration in our design. Ka-band components are significantly more expensive that X-band both to purchase and to repair. Considering the expense of the components as well as test equipment and the ready availability of proven X-band modules in the commercial marine and aviation field, X-band was the more attractive alternative. The basic low-cost Range Only Radar consists of a small lightweight electronics package with a parabolic antenna and a simple, yet versatile interface to the system operator. The electronics package contains a proven off-the-shelf Receiver/ Transmitter unit and PC-based range data processing and interface hardware and software. The electronics package is designed to mount on a single sensor station such as a Photo-Sonics, Kinetic, Contrives or other small optical mount. The antenna attaches to the front of the electronics package.

The radar Receiver/Transmitter unit is an integrated unit proven in commercial service worldwide. The R/T unit operates at 9.4 GHz with an output peak power of 10 kW. Two pulse widths are selectable: 0.25 and 0.5 ms. Pulse repetition frequencies are programmable within duty cycle limitations up to 1280 pps. The radar receiver uses MIC low noise technology, matched IF filters, and a 60 MHz IF output. With a 0.8-meter (31 inch) parabolic antenna and operating at 0.5 ms pulse width, the radar will track a 0.1-meter RCS target to at least 10 km. The antenna typically provided is a 0.8-meter Cass grain designing with a beam width of 2.8. and a gain of 35 dB. A larger or smaller antenna can be provided as needed with applicable differences in performance. The antenna may be mechanically interfaced to the electronics package to allow for constraints in the configurations of the mount, other sensors, or the mount cover.

A ruggedized PC-AT-bus off-the-shelf controller is included with the radar. Input, output, and interrupt is passed between the range processor board and the host controller over the PC-AT-bus. The controller has a software range tracker already proven in our VME-bus design and ported to the PC-bus. The software range track loop is a Type II computed in floating point in an 80486 processor for maximum granularity of data. A software alphabet filter is used which provides velocity memory. The Type II tracking loop provides good track response and zero-lag on non-accelerating targets. A programmable track bandwidth is available to match the range track servo loop performance to the target dynamics. The hardware tracker card includes precision 21 MHz on-board oscillators for range clocking. The assembly also contains the PRF generator, the radar video digitizer and the means to accept external time tag interrupts. For graphical video display purposes, a peak detector and FIFO memory are used to capture each PRF video.

The ROR design minimizes requirements for real-time operator interface. Once the optical mount is aligned on the proper target, the operator only needs to push one button to place the range tracker into an automatic acquisition mode. In the auto-acquisition mode, the radar automatically searches a preset range window for a valid target return. After target acquisition, the range tracker provides a continuous real-time parallel range data output. If track is lost, the operator activates the same single button to re-start the auto acquisition process. A keyboard input and VGA output is provided on the radar host controller for access to internal parameters of the radar such as search window, PRF, pulse width, range bias and other pre-mission setup values. The operator can configure the radar to fit various mission profiles through a menu-driven sequence.

The open architecture of the radar hardware and software enables various options and customized features to be incorporated without lengthy and costly re-engineering. Options include:

- Expanded host processor functions such as coordinate conversion, special sequential search commands, parallel data outputs, and real-time data recording.
- Expanded and customized control panels including touch screen controls and target selection.
- Output video either for display on a Color A-Scope or superimposed on standard video signals.
- Integration of the ROR with other PC-AT-bus-based hardware such as annotators, encoders, clocks, recorders, serial and parallel data communications devices and fiber optic interfaces.
- Extended range performance using either a larger antenna or higher power transmitter.

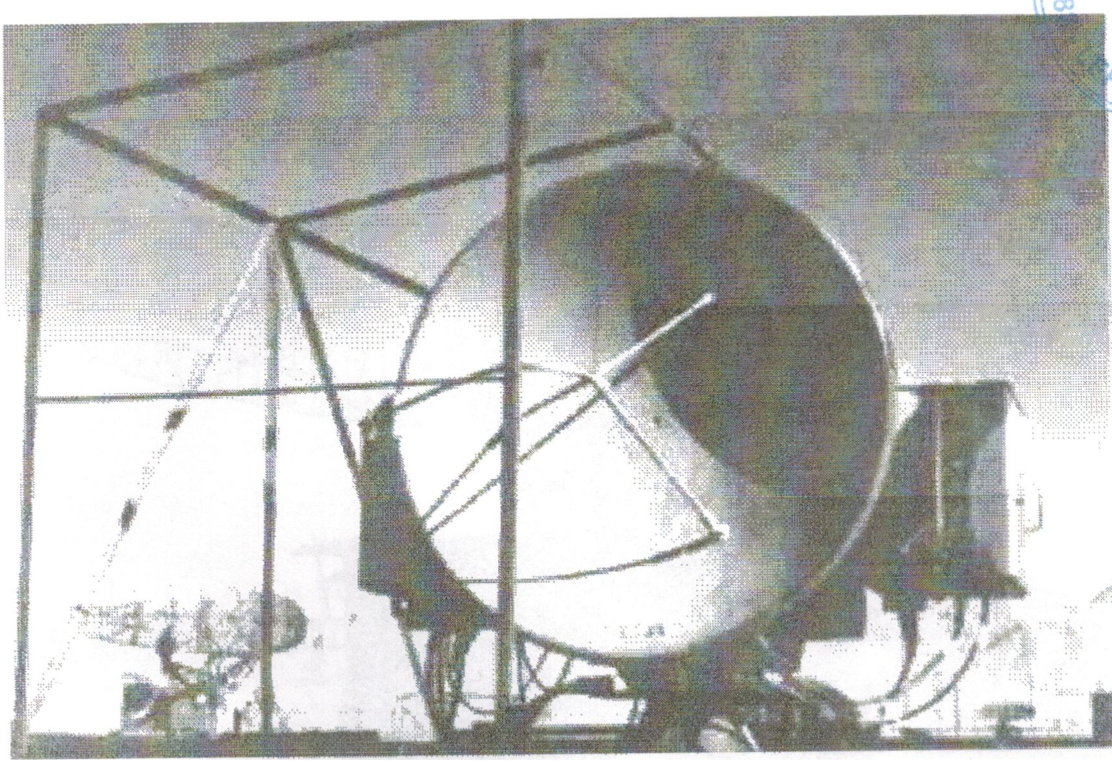


Fig.3.3. ROR

3.4. Pulse Acquisition Radar (PAR)

The PAR is the primary source of high- to medium-altitude aircraft detection for the battery. The C-band frequency allows the radar to perform in an all-weather environment. The radar incorporates a digital MTI to provide sensitive target detention in high-clutter areas and a staggered pulse repetition rate to minimize the effects of blind speeds. The PAR also includes several ECCM features and uses off the air tuning of the transmitter. In the Phase III configuration the PAR is not modified.

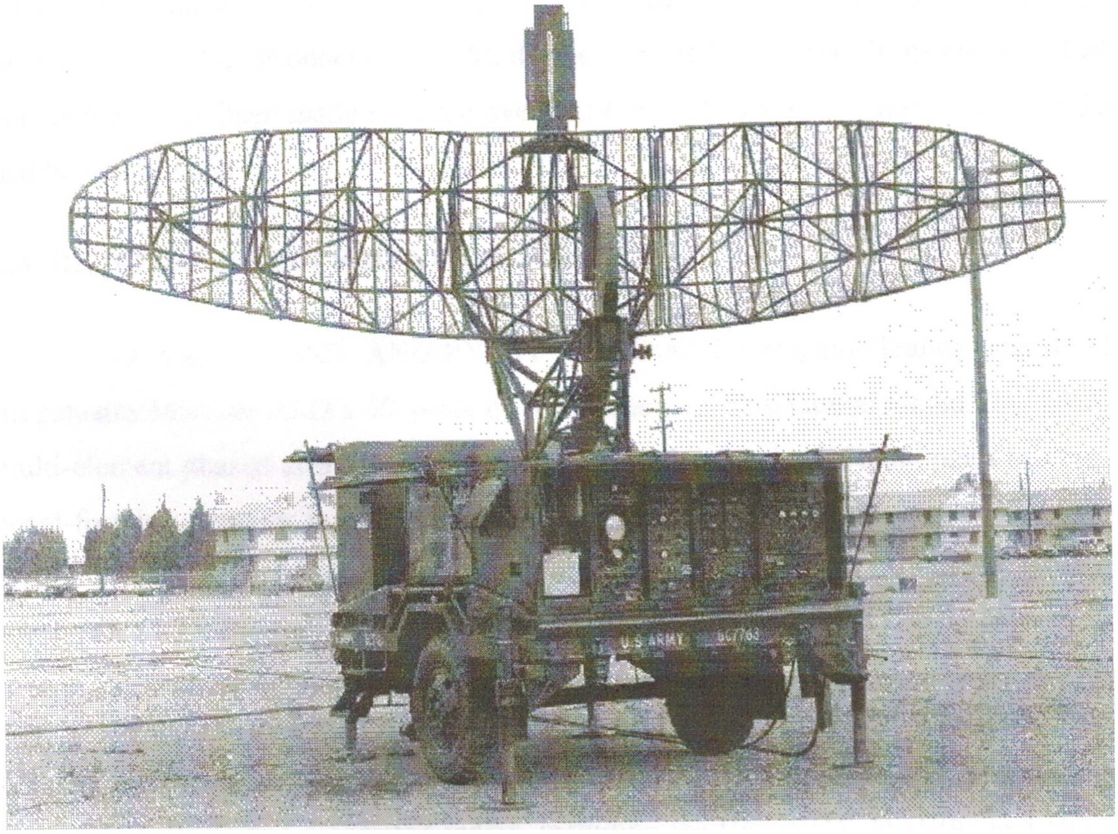


Fig.3.4. PAR

3.5. Tracking Adjunct System (TAS)

The Northrop Corporation Electronic Systems Division TAS is the video target identification system installed on the HPI radar. It enhances the HAWK missile system survivability by allowing for increased passive operations in providing preferential target illumination and performing the raid counts, recognition and classification as well as damage assessment tasks.

It comprises a two field of view closed circuit TV camera system, which is mounted on a gyro-stabilized platform and enhanced by a x10 magnification telescope. It is currently a day-only system that has been upgraded to

(A) Improve its daytime performance (in terms of increased range and haze penetration capabilities),

(B) Add an automatic target search capability,

(C) Add an infrared focal plane array for day/night usage.

The fully functional day/night system is then designated Improved TAS (ITAS). Final development of the ITAS ended in 1991 with the field demonstration and trials phase in early 1992. Production of TAS devices for the US Marine Corps began in 1980 and exports have been made to seven overseas I-HAWK users. By early 1997 over 500 had been produced.

3.6. IDENTIFICATION FRIEND OR FOE (IFF)

The Marconi ASD AN/APX-111 Combined Interrogator/Transponder (CIT) perpetuates Marconi ASD's 50 years of IFF leadership. Fuselage-mounted, low profile multi-element phased-array antennas utilize electronic scanning of monopoles beams. A beam-forming network is located within the fuselage. The antennas are in production for the F/A-18 aircraft and have been selected for the F-16 Mid-Life Update program and Japan's FSX fighter.

Today, Marconi Aerospace provides a full family of antennas for ground-to-air IFF and secondary surveillance radar systems. These are compatible with a wide range of missile systems and associated radars, including the PATRIOT, HAWK, and NIKE-HERCULES configurations and most version of the AN/FPS and AN/TPS radar sets.

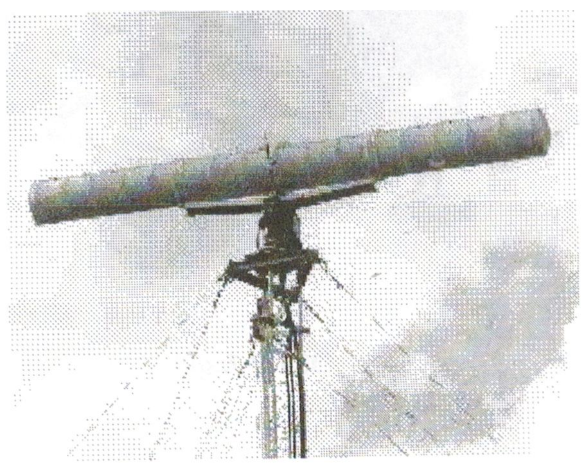


Fig.3.5. IFF

3.7. Information Co-ordination Central (ICC)

The ICC is the fire-control data processing and operational communications center for the battery. It provides rapid and consistent reaction to critical targets. Automatic detection, threat ordering, the IFF followed by automatic target assignment and the ICC provides launch functions. The ICC contains ADP, IFF, and battery terminal equipment and communications equipment.

The ADP comprises an Electronic Data Processor (EDP) and a Data Take-Off unit (OTO). The OTO forms the interface between the other system equipment and EDP. With the exception of inputs from a solid-state reader and outputs to a printer, all communications with the ECP are through the OTO. The EDP is a militarized, general-purpose digital computer especially adapted to this role.

Phase III eliminates the ICC and transfers its data processing and communications functions to the Phase III PCP and BCP described below.

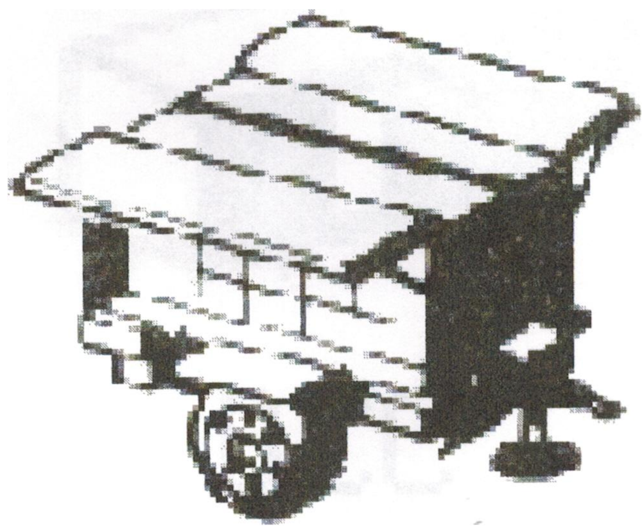


Fig.3.6. ICC

3.8. Battery Control Central (BCC)

The BCC provides the facilities for the man/machine interface. The Tactical Control Officer (TCO) is in command of all the BCC operations and maintains tactical control over all engagement sequences. The TCO monitors all functions and has the authority and facilities to enable or pre-empt any engagement or change established priorities. The Tactical Control Assistant (TCA) assists the TCO in detection, identification, evaluation and coordination with higher commands. The tactical control console gives these two operators the necessary target and battery status information and controls required. The azimuth-speed operator has the sole mission of obtaining the earliest possible detection of low-altitude targets. The azimuth-speed indicator console, separate radar B-scope display, provides ICW AR target data for this purpose. Targets selected for manual engagements are assigned to one of the two fire-control operators. Each operator uses the fire-control console displays and controls for rapid HPI target lock, target track, missile launch and target intercept evaluation.

In the Phase Illl configuration the BCC is removed from the system and replaced by the BCP described below.

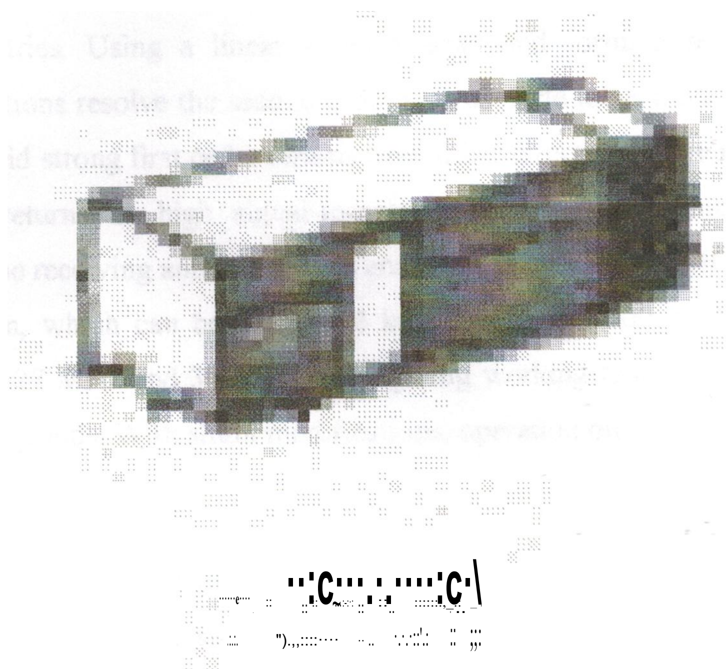


Fig.3.7. BCC

3.9. Height Finder Radar (HFR)

HF radar in oceanography makes use of backscatter of electromagnetic waves of 10 m to 50 m wavelength from the rough sea surface. The backscattered signal can be analyzed to derive ocean surface current and wave parameters. Several HF radars have been developed all over the world and significant progress both in technology and algorithms has been achieved since the discovery of the basic physics in 1955 by D. D. Combine.

The main requirements for successful measurement of ocean waves are:

1. Access to the second order reflections from the sea surface and
2. An increased signal-to-noise ratio of the measured Doppler spectrum, because the second order returns are much weaker compared to the strong first order reflections, which are used to derive surface current information.

Based on these requirements, a new system called WERA (Welled Radar) has been designed within the European project SCAWVEX (Surface Current and Wave Variability Experiments), which brings together the potential of 8 partners from 4 European countries. Using a linear antenna array and forming beams to different azimuthal directions resolve the second order returns. Side lobes have to be suppressed carefully to avoid strong first order returns from other directions to be misinterpreted as second order returns. A high signal-to-noise ratio has been achieved by parallel processing of the receiving antenna signals and using an advanced FMCW technique for range resolution, which can be set to 1.2 km, 600 m and 300 m. WERA has been operated in the 27 MHz and 30 MHz band, giving working ranges of up to 55 km for mapping current fields. With slight modifications, operation on other frequency bands is possible.

Ocean surface current fields are derived from the radar data using the University of Hamburg algorithms; the spatial distribution of wave height directional spectra is calculated using the University of Sheffield wave algorithm. Both-information's can be gained from the same data set, so simultaneous measurements of currents and waves are possible. This opens new possibilities to environmental monitoring, coastal engineering and increasing ship safety.

Operational forecasting of current and wave fields in coastal regions got more and more important in the last decades, both for coastal management and for security aspects. One of the key tools in this context are high-resolution numerical models, which however require accurate forcing and handling of the boundary conditions to give results which are close to nature. HF radar remotely sensed current and wave fields can significantly increase the data quality of the models, if these on-line measurements are assimilated. In some cases, when the oceanographic processes induce high local variability, such as mesoscale eddies and fronts, this approach might be the only way to get reliable now- and forecasts.

In Europe, the European Radar Ocean Sensing (Euro ROSE) project has demonstrated the feasibility and performance of HF radar based ocean monitoring system in support of safe navigation in port approach areas and otherwise densely operated sea areas. Two demonstrations were carried out off the Norwegian coast north of Bergen, and at the North Spanish coast near Gijon. During each of these demonstrations, WERA (Wellen Radar) HF radars of the University of Hamburg were deployed. WERA measured surface currents within an area of about 4()-,km by 40-km with a spatial resolution of about I-km and with a temporal sampling of 1O-minutes. Ocean wave fields have been processed by the University of Sheffield's wave algorithm.

This paper presents the design of the integrated measurement/model system, which has been used within EuroROSE, as well as the result of a performance assessment. In addition, a vision on HF radar networks to cover basin-wide. scales is developed and problems like allocation of frequency bands and techniques of sharing frequencies by simultaneous operation of multiple HF radars are discussed.

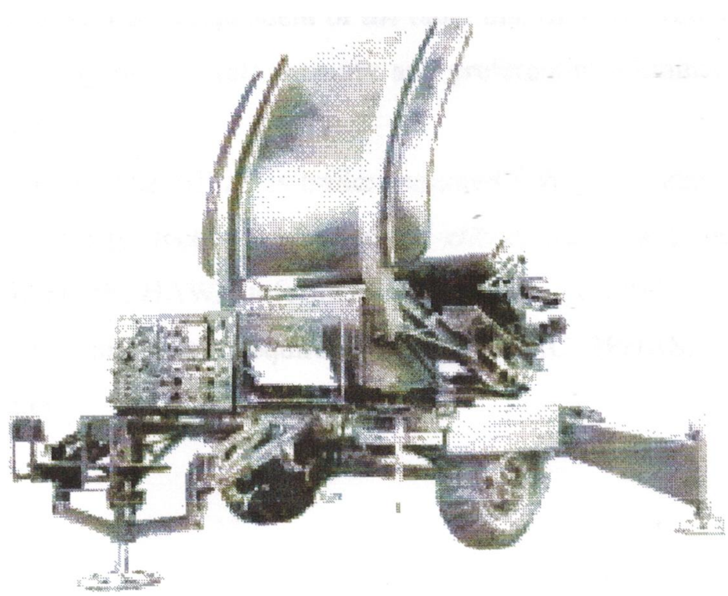


Fig.3.8. HF Radar

3.10. High-Power Illuminator (HPI)

The HPI automatically acquires and tracks designated targets in azimuth, elevation and range rate. It serves as the interface unit-supplying azimuth and elevation launch angles computed by the ADP to up to three launchers. The HAWK missile for guidance also receives the HPI J-band energy reflected off the target. A missile reference signal is transmitted directly to the missile by the HPI. Target track is continued throughout missile flight and after intercept HPI Doppler data are used for kill evaluation. The HPI receives target designations from the BCC and automatically searches a given sector for rapid target lock on. The HPI incorporates ECCM and BITE.

The Phase III program includes two major modifications to HPI. One is the addition of a wide beam transmitting antenna which is used to illuminate a much larger volume for missile guidance during use of the Low-Altitude Simultaneous HAWK Engagement (LASHE) made of operation against multiple target attacks. The second is the addition of a digital microcomputer, which processes HPI target data and provides full-duplex serial digital communications between the HPI and the PCP.

The Northrop Tracking Adjunct System (TAS) used in the HAWK-PIP Phase III upgrade for the HPI radar was derived from the US Air Force's TISEQ (Target Identification System, Electro-Optical) device and provides a passive tracking capability with remote real-time video presentation.

The day-only TAS is designed to complement the illuminator and can be used either coincidentally with or independent of the radar line of sight. Manual or automatic acquisition and tracking modes, rate memory and preferential illumination are the key features of the system.

(A) Description: The HIPIR is trailer mounted CW type radar that illuminates the target with RF energy, receives reflected RF energy from the target and provides tracking information to the HAWK information coordination central.

(B) Power Requirements: Requires 400Hz, 416VAC, 3PHASE electrical power provide by generator.

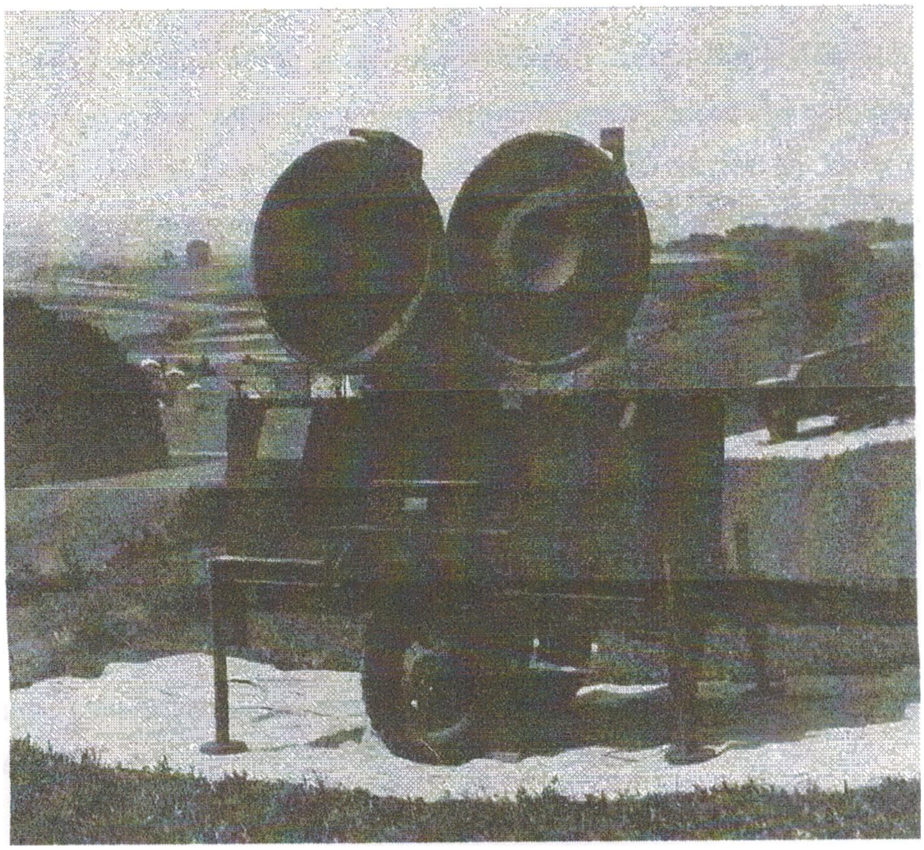


Fig.3.9. HPIR

CONCLUSION

Much remains of the air aerospace detection, command, and control systems built during the cold war. Although only a fraction of the radar stations built during the 1950s and 1960s remain in military hands, many are still operational under FAA control. However, the FAA is in the process of completing its modernization program to replace Air Force 1960s vintage FPS model radars. At former ADC sites, the radars have been removed and the facilities have been converted to perform new functions. Many sites, especially in remote locations, simply have been abandoned.

The blockhouses that once hosted SAGE centers remain intact at many locations, although the Whirlwind II computers and command consoles have long been removed. The four ROCCs built during the 1980s remain intact and operational. The intruding aircraft in the 1990s represent a different threat; attempting to smuggle illegal drugs into the country.

The BMEWS system will remain intact for the foreseeable future as long as more countries gain the capability to launch ballistic missiles. Cheyenne Mountain Colorado, still serves as the nerve center of the North America's missile tracking sensors.

Historians will long argue what brought about the demise of the Soviet Union and why World War III never was fought. While one school argues that the Soviet system collapsed under its own weight of inefficiency, another school vigorously contends that American military vigilance significantly contributed to the Soviet demise.

Nuclear deterrence, it is argued, eliminated direct military confrontation as an option for the Soviets. If such is the case, then the rules of the thousands of men and women who operated the radar stations and command centers during the Cold War cannot be overlooked. They contributed to the desistence into ways. First, by being able to direct interceptor forces against intruding aircraft, the air defenders reduced the opponent's confidence level for mission success. Second, and more importantly, the warning provided by the air defense and later missile defense warning sensors gave America's nuclear forces the forewarning necessary to deliver a devastating retaliatory blow.

When viewing the hundreds of abandoned air defense structure dotting the American landscape. One should reflect on the roles of the thousands of men and women who operated the air defense systems. Part of there legacy is their contribution to the United States' triumph in the Cold War.

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APPENDIX A

Basic HAWK: production complete. (Some may still be in service).

I-HAWK: in production and in service with the following countries:

Country	No.Of launchers	PIP/Phase	Service
Bahrain	3	3	Air Force (1 battery)
Belgium	39 (3 in store)	2	Air Force (2 battalions)
Denmark	36	2	Air Force (8 batteries)
Egypt	120+	3	Air Defense Command
France	69	2	Army (1 regiment)
Germany	216	2	Air Force (36 Squadrons)
Greece	42	2/3	Army (2 battalions)
Iran	120+	1/2	Army (12 battalions)
Israel	180	2	Air Force (17 battalions)
Italy	60	2	Army (4 regiments)
Japan	192	2/3	Army (32 batteries)
Jordan	56	2	Army (14 batteries)
Korea, South	110	2	Army (3 battalions)
Kuwait	24	3	Air Force (4 batteries)
Netherlands	54	3	Air Force
Saudi Arabia	126	2/3	Air Force (16 incl. 10 TRIAD's)
Singapore	18	2	Air Force (1 Sqn of 6 batteries)
Spain	24	2	Army (1 regiment)
Sweden	12	2	Army (1 battalion)
Taiwan	100+	1/2	Army (4 battalions)
UAE	30	2/3	Air Force (5 batteries)
USA	200+	3	Army/Marines (4/2 battalions)

APPENDIXB

Service	Marine Corps
Contractor	Raytheon
Mission	surface-to-air missile defense
Diameter	13.5 inches (3.84 centimeters)
Weight	1400 pounds (635 kilograms)
Range	Officially: 14.9 miles (24 kilometers) 40 km, in excess of 20 NM
Speed	Officially: Supersonic 800 m/sec, in excess of mach 2.4
Altitude	Officially: 30,000 feet (9.14 kilometers) in excess of 60 KFT
Propulsion	Solid propellant rocket motor
Guidance system	Radar directed semi-active homing
Warheads	One 300 pound (136.2 kg) high explosive missile
Type of fire	Operator directed/automatic modes
Magazine capacity	48 missiles/battery
Missile guidance	Semi-active homing
Target detection	Continuous wave radar and pulse acquisition radars
Target tracking	High power illuminating continuous wave radar and passive optical
Rate of fire	1 missile every 3 seconds
Sensors	High power continuous wave radar (HIPIR) Continuous wave acquisition radar (CWAR) Pulse Acquisition Radar (PAR) and passive optical scan
Transport	C-130/C-141/C-5 and heavy lift helo (extended load)

Deployment	One Light Antiaircraft Missile Battalion in each Marine *Air Control* Group of each Marine *Air* Wing *(two active, one Reserve).* *Firing* Platoon: 2 Fire sections of up to 3 Launchers per (1) PAR and (1) CWAR 3 missiles per launcher
Units	2 active duty and 1 reserve Light Anti-aircraft Missile Battalion
Crew	*Officer:* **I** *Enlisted:* 49
Program status	Operational
First capability	Air Defense - 1962 Missile Defense -
Quantity	total inventory is 37,000 missiles
Unit Replacement Cost	$250,000 per missile $15 million per fire unit $30 million per battery