NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

OVER THE HORIZON RADAR

Graduation Project
EE- 400

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Dedicated To:

My wonderful children

Mohmmad and Deema

TAWALBEH

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Abstract

The word radar, formed from the italicized letters in radio detection and ranging, signifies a means of employing radio waves to detect and locate material objects. Location of an object is accomplished by determining the distance and direction from the radar equipment to the object, a little of the energy of the radio wave transmitted From the radar set travels to the object, a portion is reflected, and some of the reflected energy returns to the radar set

During the late 1940s, NRL foresaw the need to detect moving targets, including aircraft and missiles, at distances and altitudes beyond the line-of-sight. NRL began to investigate the use of radar operating in the high frequency (HF, or short wave) portion of the radio spectrum to extend the range beyond the horizon. Operating at low-power HF radar system called Multiple Storage, Integration, and Correlation (MUSIC). Using signals reflected by the ionosphere as well as by the target, MUSIC allowed the detection of missile launches at distances up to 600 nautical miles

Over-the-horizon (OTH) radars were developed to detect military targets far beyond the optical horizon. They use 5-28-MHz radio waves, which reflect from the ionosphere, reaching up to 3,500 km in one "hop." Properties of the ocean surface are extracted from the minute amount of energy scattered by the sea surface back to the radar. To find out how we extract ocean-surface properties. OTHR (relocatable over the horizon radar)

Fleet Surveillance Support Command was established in July 1987 to operate the Navy's Relocatable Over-the-Horizon Radar (ROTHR) in support of Fleet units worldwide. This unique radar system was originally designed to provide tactical warning to battle group commanders of air and surface threats at an extended range allowing time for responsive engagement. Two US Navy high-frequency (HF) over-the-horizon (OTH) radars known as ROTHR (Relocatable Over-the-Horizon Radar) are operated at Corpus Christi TX and Chesapeake VA, with coverage of the Caribbean Sea and portions of the Atlantic Ocean and the Gulf of Mexico. The OTHR in Virginia and Texas are presently in full-time use for counter-narcotics surveillance, and a third is scheduled for installation in Puerto Rico in the near future.

TABLE OF CONTENTS

INTRODUCTION

Chapter One Talk about the OTH radar fundamental and how to determine the distance of the reflecting object, determined from the frequency difference between the echo and the wave being transmitted at the time of

Chapter 2 illustrates transmitter produces the short duration high-power r.f pulses of energy that are radiated into space by the antenna. Two main types of transmitters are now in common use.

Chapter 3 discusses, the modulator controls the radar pulse width by means of a rectangular D.C pulse (modulator pulse) at a required duration and amplitude. The peak power of the transmitted r.f pulse depends on the amplitude of the modulator pulse.

In Chapter 4, we talk about Radar that makes use of the atmospheric reflection and refraction phenomena to extend its range of detection beyond line of sight. Over-The-Horizon radars may be either forward-scatter or back (OTH-B)-scatter systems.

Chapter five discuss Over-the-horizon radar technology has grown out of a number of related technologies and, before embarking on the history in more detail,

The continent of chapter 6 describe the Over-the-horizon (OTH) radar performs very wide-area surveillance by taking advantage of the reflected and multi path nature of high frequency (3 to 30 MHz) propagation through the ionosphere.

Chapter 7 goes through the Dual-OTHR map of the complex pattern of surface currents between Florida, Cuba, and the Bahamas.

Chapter 8 taking about the Problems of the OTH Radar although the physical principles underlying sky wave current.

CHAPTER ONE
PULSED RADAR

1.1 pulsed radar

The word radar, formed from the italicized letters in radio detection And ranging, signifies a means of employing radio waves to detect and Locate material objects. Location of an object is accomplished by determining the distance and direction from the radar equipment to the object And requires, in general, the measurement of three coordinates-usually range and angles of azimuth and elevation. Radar detection depends upon the reflection of radio waves from an Object. A radar set may be compared with a searchlight and an observer stationed beside the light.

A small portion of the light wave from the Searchlight strikes an object near by and is reflected. a fraction of the reflected wave returns to the observer and indicates the presence of the object. Similarly, a little of the energy of the radio wave transmitted From the radar set travels to the object, a portion is reflected, and some of the reflected energy returns to the radar set, where it is detected. Advantages of radar over detection systems employing light are:

1. Radar operates over greater ranges-aircraft can be detected more than 100 miles, away.
2. Radar operates in any weather, through smoke, fog, rain, or snow, or directly into blinding sun.
3. Radar determines range simply and accurately by measuring the time required for the two-way trip of the radio wave.

Another feature of radar, which is an advantage in wartime applications, is that radio waves are invisible thus the enemy must have special equipment in order to discover that a radar set is searching for him

The reflected waves-called radio echoes because of the analogy to Sound echoes-enable radar sets to perform a variety of tasks. Applied

First in war time, radar searched the sea for enemy ships and surfaced Submarines and kept watch in the sky for aircraft. Radar aided air and Sea navigation and directed fighter and bomber aircraft. Radar information was used to aim large guns and antiaircraft weapons, and air-borne Radar controlled the dropping of bombs. In peacetime, radar and allied Techniques contribute greatly to the safety of air and sea travel. Radar equipped ships move through fog without danger of colliding with other ships or with ice floes. Despite weather conditions of poor visibility, air- craft can be prevented from colliding in mid-air and the capacity of air Fields can be greatly increased by radar traffic-control and landing systems. An example of a very different application of radar is the tracking Of balloons sent aloft to gather meteorological data.

Most of the circuits, devices, and principles of operation found in radar equipment have wide application in nearly every kind of electronic equipment. Many techniques used in radar are doubly important because they appear also, for example, in television, in pulse-time communication systems, in industrial electronic devices, in equipment for measuring the height of the ionosphere, and in high-speed computing machines.

Radar Determination of Range: a number of different methods have been used to determine the range of objects that reflect radio waves.

Two transmitter-receiver sets separated a considerable distance can be used for triangulation, as in optical ranging, but the method is cumbersome, and the required angular accuracy is hard to obtain with radio waves. Better methods time the interval required for the radio wave to make the trip from radar set to object and back. Because the speed of propagation of radio waves is known with great accuracy, range can be determined as accurately as the time interval can be measured. In one scheme, the frequency of a transmitter is changed at a constant rate and The distance to the reflecting object determined from the frequency difference between the echo and the wave being transmitted at the time the echo returns.' By far the most important range-measuring method, which probably had its origin in the measurements of height of the ionosphere, 2 employs a transmitter that operates in bursts of very short duration and measures range in terms of the time interval between transmission of a pulse and reception of an echo pulse so important is pulsed

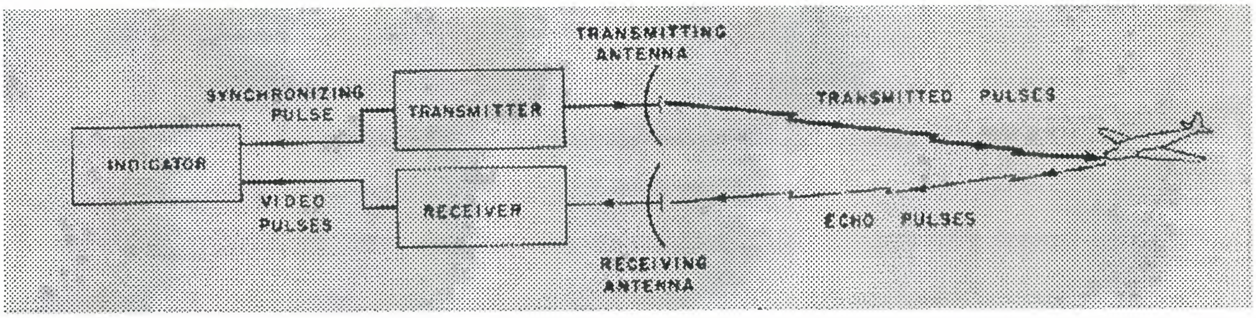


Fig 1.1 Elementary radar set.

Bandwidth, and beam angle by desired performance features such as range, resolution, and speed of data collection are often conflicting. For example, if small objects are to be detected at long range, a long pulse should be used to provide high pulse energy, the repetition frequency should be low to minimize the average power and prevent range ambiguity, the antenna should have high gain and should rotate so slowly that each object is illuminated by a long succession of pulses, and the receiver bandwidth should be correctly related to the pulse duration. Use of along pulse is, however, in conflict with the requirement for range resolution; a higher repetition frequency, broader antenna beam, and more rapid antenna-scanning motion should be used to obtain data more rapidly; and a greater receiver bandwidth should be employed for accurate determination of range. These conflicting requirements are the reason that radar sets are made with a variety of different characteristics, each suited to its own application.

1.2 Radar subsystems

Upon completion of this chapter, the student will be able to:

- Describe, in general terms, the function of a radar synchronizer.
- State the basic requirements and types of master synchronizers.
- Describe the purpose, requirements, and operation of a radar modulator.
- Describe the basic operating sequence of a keyed-oscillator transmitter.
- Describe the basic operating sequence of a power-amplifier transmitter.
- State the purpose of a duplexer.

- State the operational principles of tr and atr tubes.
- Describe the basic operating sequence of series and parallel connected duplexers.
- List the basic design requirements of an effective radar receiver.
- List the major sections of a typical radar receiver.
- Using a block diagram, describe the operational characteristics of a typical radar receiver.

1.3 Introduction to Radar Subsystems

Any radar system has several major subsystems that perform standard functions. A typical radar system consists of a SYNCHRONIZER (also called the TIMER or TRIGGER GENERATOR), a TRANSMITTER, a DUPLEXER, a RECEIVER, and an INDICATOR. These major subsystems were briefly described in chapter 1. This chapter will describe the operation of the synchronizer, transmitter, duplexer, and receiver of a typical pulse radar system and briefly analyze the circuits used. Chapter 3 will describe typical indicator and antenna subsystems. Because radar systems vary widely in specific design, only a general description of representative circuits is presented in this chapter.

1.3.1 Synchronizers

The synchronizer is often referred to as the "heart" of the radar system because it controls and provides timing for the operation of the entire system. Other names for the synchronizer are the TIMER and the KEYER. We will use the term synchronizer in our discussion. In some complex systems the synchronizer is part of a system computer that performs many functions other than system timing.

1.3.2 Synchronizer Function

The specific function of the synchronizer is to produce TRIGGER PULSES that start the transmitter, indicator sweep circuits, and ranging circuits.

Timing or control is the function of the majority of circuits in radar. Circuits in a radar set accomplish control and timing functions by producing a variety of voltage waveforms, such as square waves, saw-tooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks. Although all of these circuits can be broadly classified as timing circuits, the specific function of any individual circuit could also be wave shaping or wave generation. The operation of many of these circuits and associated terms were described in detail in the Introduction to Wave-Generation and Wave-Shaping Circuits.

1.3.3 Synchronizer operation

Radar systems may be classified as either SELF-SYNCHRONIZED or EXTERNALLY SYNCHRONIZED systems. In a self-synchronized system, the timing trigger pulses are generated in the transmitter. In an externally synchronized system, the timing trigger pulses are generated by a MASTER OSCILLATOR, which is usually external to the transmitter.

The master oscillator in an externally synchronized system may be a BLOCKING OSCILLATOR, a SINE-WAVE OSCILLATOR, or an ASTABLE (FREE-RUNNING) MULTI-VIBRATOR. When a blocking oscillator is used as a master oscillator, the timing trigger pulses are usually obtained directly from the oscillator. When a sine-wave oscillator or an astable multivibrator is used as a master oscillator, pulse-shaping circuits are required to form the necessary timing trigger pulses. In an externally synchronized radar system, the pulse repetition rate (prr) of the timing trigger pulses from the master oscillator determines the prr of the transmitter.

In a self-synchronized radar system, the prr of the timing trigger pulses is determined by the prr of the modulator or transmitter. associated with every radar system is an indicator, such as a cathode-ray tube, and associated circuitry. The indicator can present range, bearing, and elevation data in visual form so that a detected object may be located. Trigger pulses from the synchronizer are frequently used to produce gate (or enabling) pulses. When applied to the indicator, gate pulses perform the following functions:

- Initiate and time the duration of the indicator sweep voltage

- Intensify the cathode-ray tube electron beam during the sweep period so that the echo pulses may be displayed
- Gate a range marker generator so that range marker signals may be superimposed on the indicator presentation

The time relationships of the various waveforms in a typical radar set. The timing trigger pulses are applied to both the transmitter and the indicator. When a trigger pulse is applied to the transmitter, a short burst of transmitter pulses (rf energy) is generated.

This energy is conducted along a transmission line to the radar antenna. It is radiated by the antenna into space. When this transmitter energy strikes one or more reflecting objects in its path, some of the transmitted energy is reflected back to the antenna as echo pulses. Echo pulses from three reflecting targets at different ranges are illustrated in figure 2-1. These echoes are converted to the corresponding receiver output signals as shown in the figure. The larger initial and final pulses in the receiver output signal are caused by the energy that leaks through the duplexer when a pulse is being transmitted.

The indicator sweep voltage shown in figure 1-2 is initiated at the same time the transmitter is triggered. In other applications, it may be more desirable to delay the timing trigger pulse that is to be fed to the indicator sweep circuit. Delaying the trigger pulse will initiate the indicator sweep after a pulse is transmitted.

. The distance to the reflecting object determined from the frequency difference between the echo and the wave being transmitted at the time the echo returns.' By far the most important range-measuring method, which probably had its origin in the measurements of height of the ionosphere, 2 employs a transmitter that operates in bursts of very short duration and measures range in terms of the time interval between transmission of a pulse and reception of an echo pulse so important is pulsed

Note in figure 2-1 that the positive portion of the indicator intensity gate pulse (applied to the cathode-ray tube control grid) occurs only during the indicator sweep time. As a result, the visible cathode-ray tube trace occurs only during sweep time and is eliminated during the fly-back (retrace) time. The negative portion of the range-marker gate pulse also occurs during the indicator sweep time. This negative gate pulse is applied to a range-marker generator, which produces a series of range marks.

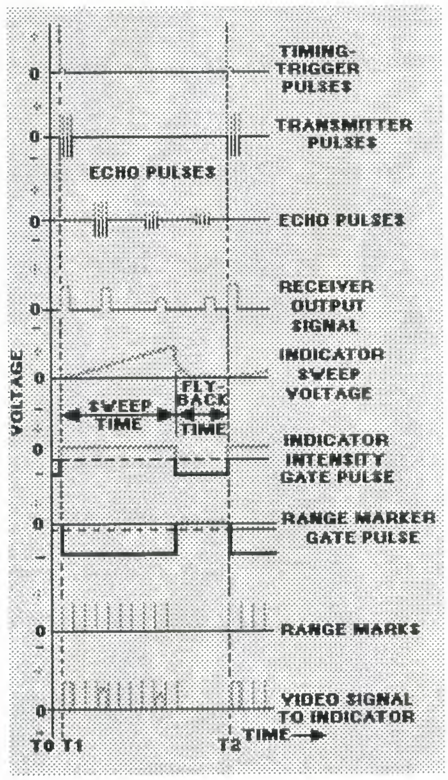


Figure 1.2.Time relationship of waveforms

The range marks are equally spaced and are produced only for the duration of the range-marker gate pulse. When the range marks are combined (mixed) with the receiver output signal, the resulting video signal applied to the indicator may appear as shown at the bottom of figure 2-1.

1.3.4 Basic Synchronizer Circuits

The basic synchronizer circuit should meet the following three basic requirements:

- It must be free running (astable). Because the synchronizer is the heart of the radar, it must establish the zero time reference and the prf (prr).
- It should be stable in frequency.
- For accurate ranging, the prr and its reciprocal, pulse-repetition time (prt), must not change between pulses.
- The frequency must be variable to enable the radar to operate at different ranges.

Three basic synchronizer circuits can meet the above mentioned requirements. They are the sine-wave oscillator, the single-swing blocking oscillator, and the master-trigger (astable) multivibrator.

Figure 2-2 shows the block diagrams and waveforms of these three synchronizers as they are used in externally synchronized radar systems. In each case, equally spaced timing trigger pulses are produced. The prr of each series of timing trigger pulses is determined by the operating frequency of the associated master oscillator.

. In the sine-wave oscillator synchronizer (figure 2.2, view A), a sine-wave oscillator is used for the basic timing device (master oscillator). The oscillator output is applied to both an overdriven amplifier and the radar indicator. The sine waves applied to the overdriven amplifier are shaped into square waves. These square waves are then converted into positive and negative timing trigger pulses by means of a short-time-constant In the sine-wave oscillator synchronizer (figure 2.2, view A), a sine-wave oscillator is used for the basic timing device (master oscillator). The oscillator output is applied to both an overdriven amplifier and the radar indicator. The sine waves applied to the overdriven amplifier are shaped into square waves. These square waves are then converted into positive and negative timing trigger pulses by means of a short-time-constant

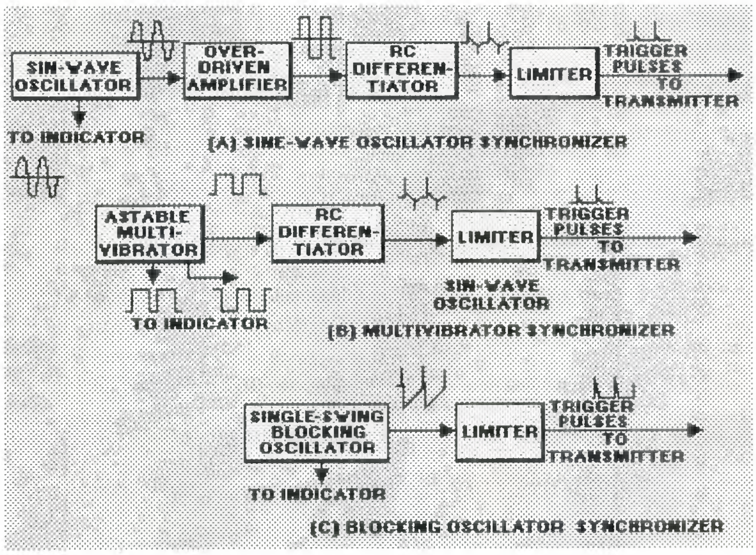


Figure 1.3. Timers used in externally synchronized radar systems

Sine-Wave Oscillator Synchronizer RC differentiator.

By means of a limiter, either the positive or negative trigger pulses from the RC differentiator are removed. This leaves trigger pulses of only one polarity. For example, the limiter in view A of figure 1-2 is a negative-lobe limiter; that is, the limiter removes the negative trigger pulses and passes only positive trigger pulses to the radar transmitter. A disadvantage of a sine-wave oscillator synchronizer is the large number of pulse-shaping circuits required to produce the necessary timing trigger pulses.

1.3.5 Master Trigger (Astable) Multivibrator Synchronizer

In a master trigger (astable) multivibrator synchronizer (view B, figure 1-2), the master oscillator generally is an astable multivibrator. The multivibrator is either ASYMMETRICAL or SYMMETRICAL. If the multivibrator is asymmetrical, it generates rectangular waves. If the multivibrator is symmetrical, it generates square waves. In either case, the timing trigger pulses are equally spaced after a limiter removes undesired positive or negative lobes.

There are two transistors in an astable multivibrator. The two output voltages are equal in amplitude, but are 180 degrees out of phase. The output of the astable multivibrator consists of positive and negative rectangular waves. Positive rectangular waves are applied to an RC differentiator and converted into positive and negative trigger pulses. As in the sine-wave synchronizer, the negative trigger pulses are removed by means of a negative-lobe limiter, and the positive pulses are applied to the transmitter.

Both positive and negative rectangular waves from the astable multivibrator are applied to the indicator. One set of waves is used to intensify the cathode-ray tube electron beam for the duration of the sweep. The other set of waves is used to gate (turn on) the range marker generator.

1.3.6 Single Swing Blocking Oscillator Synchronizer

In the single-swing, blocking-oscillator synchronizer, shown in view C of figure 1-2, a free-running, single-swing blocking oscillator is generally used as the master oscillator. The advantage of the single-swing blocking oscillator is that it generates sharp trigger pulses without additional shaping circuitry. Timing trigger pulses of only one polarity are obtained by means of a limiter.

Gating pulses for the indicator circuits are produced by applying the output of the blocking oscillator to a one-shot multivibrator or another variable time delay circuit (not shown). Crystal-controlled oscillators may be used when very stable frequency operation is required.

CHAPTER TOW

TRANSMITTER

2.1 Transmitters

The transmitter produces the short duration high-power r.f pulses of energy that are radiated into space by the antenna. Two main types of transmitters are now in common use. The first is the Keyed –oscillator type. In this transmitter one stage or tube, usually a magnetron, produces the rf pulse. The oscillator tube is keyed by a high-power dc pulse of energy generated by a separate unit called the modulator (discussed in the following section). The second type of transmitter consists of a power amplifier chain. This transmitter system begins with an rf pulse of very low power. This low-level pulse is then amplified by a series (chain) of power amplifiers to the high level of power desired in a transmitter pulse. In most power-amplifier transmitters, each of the power-amplifier stages is pulse modulated in a manner similar to the oscillator in the keyed-oscillator type. Because the modulator is common to both types of transmitter systems, the operation of a typical modulator will be discussed first.

2.1.1 Radar modulation

The modulator controls the radar pulse width by means of a rectangular dc pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted rf pulse depends on the amplitude of the modulator pulse.

Figure 2-3 shows the waveforms of the trigger pulse applied by the synchronizer to the modulator, the modulator pulse applied to the radar transmitter, and the transmitted rf pulse.

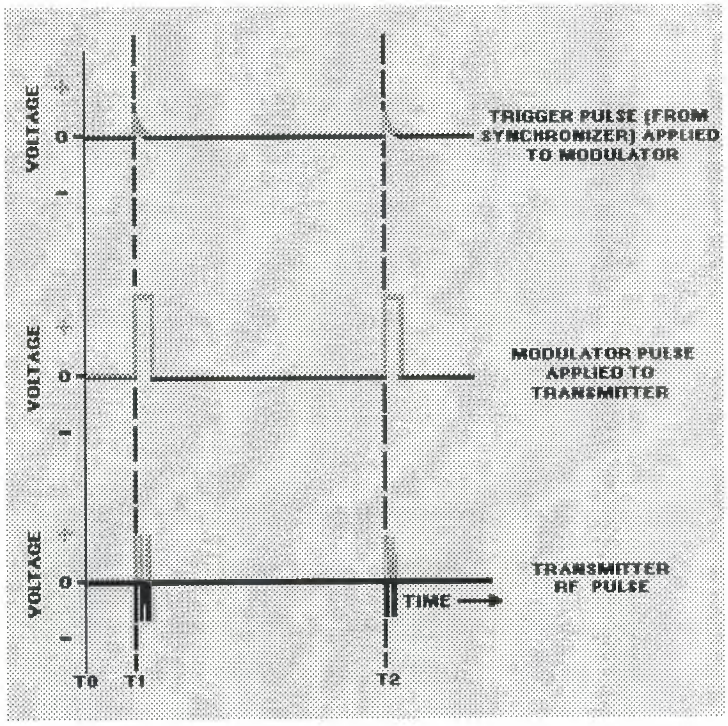


Figure 2.1 Transmitter waveforms

As we can see in the figure, the modulator pulse is applied to the transmitter the instant the modulator receives the trigger pulse from the synchronizer (T1, T2). The modulator pulse is flat on top and has very steep leading and trailing edges. These pulse characteristics are necessary for the proper operation of the transmitter and for the accurate determination of target range. The range timing circuits must be triggered the instant the leading edge of the transmitted rf pulse leaves the transmitter. In this way, the trigger pulse that controls the operation of the modulator also synchronizes the cathode-ray tube sweep circuits and range measuring circuits.

2.1.1.1 Magnetron Oscillators

Magnetron oscillators are capable of generating rf pulses with very high peak power at frequencies ranging from 600 to 30,000 megahertz., However, if its cathode voltage changes, the magnetron oscillator shifts in frequency. To avoid such a frequency change, you must ensure that the amplitude of the modulator (dc) pulse remains constant for the duration of the transmitted rf pulse. That is, the modulator pulse must have a flat top. The range of cathode voltages over which a magnetron oscillates in the desired frequency spectrum is relatively small.

When a low voltage is applied to a magnetron, the magnetron produces a noise voltage output instead of oscillations. If this noise enters the receiver, it can completely mask the returning echoes. If a modulator pulse builds up and decays slowly, noise is produced at both the beginning and end of the pulse. Therefore, for efficient radar operation, a magnetron requires a modulator pulse that has a flat top and steep leading and trailing edges. An effective modulator pulse must perform in the following manner:

- Rise from zero to its maximum value almost instantaneously
- Remain at its maximum value for the duration of the transmitted rf pulse
- Fall from its maximum value to zero almost instantaneously

In radars that require accurate range measurement, the transmitted rf pulse must have a steep leading edge. The leading edge of the echo is used for range measurement. If the leading edge of the echo is not steep and clearly defined, accurate range measurement is not possible. The leading and trailing edges of echoes have the same shape as the leading and trailing edges of the transmitted rf pulse.

A transmitted rf pulse with a steep trailing edge is essential for the detection of objects at short ranges. If the magnetron output voltage drops gradually from its maximum value to zero, it contributes very little to the usable energy of the transmitted rf pulse. Furthermore, part of the magnetron output voltage enters the receiver and obscures nearby object echoes.

2.1.1.2 Types of Modulators

The two types of modulators are the LINE-PULSING MODULATOR and the HARD-TUBE MODULATOR. (A hard tube is a high-vacuum electron tube.) The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse-forming network. The hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. The hard tube modulator has been replaced by the line-pulsed modulator in most cases. This is because the hard-tube modulator has lower efficiency, its circuits are more complex, a higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsing modulator is easier to maintain because of its less complex circuitry. Also, for a given amount of power output, it is lighter and more compact. Because it is the principally used modulator in modern radar, it is the only type that will be discussed.

- The power supply.
- The storage element (a circuit element or network used to store energy).
- The charging impedance (used to control the charge time of the storage element and to prevent short-circuiting of the power supply during the modulator pulse).
- The modulator switch (used to discharge the energy stored by the storage element through the transmitter oscillator during the modulator pulse)

View A of figure 2-3 shows the modulator switch open and the storage element charging. With the modulator switch open, the transmitter produces no power output, but the storage element stores a large amount of energy. View B shows the modulator switch closed and the storage element discharging through the transmitter. The energy stored by the storage element is released in the form of a high-power, dc modulator pulse. The transmitter converts the dc modulator pulse to an rf pulse, which is radiated into space by the radar antenna. Thus, the modulator switch is closed for the duration of a transmitted rf pulse, but open between pulses.

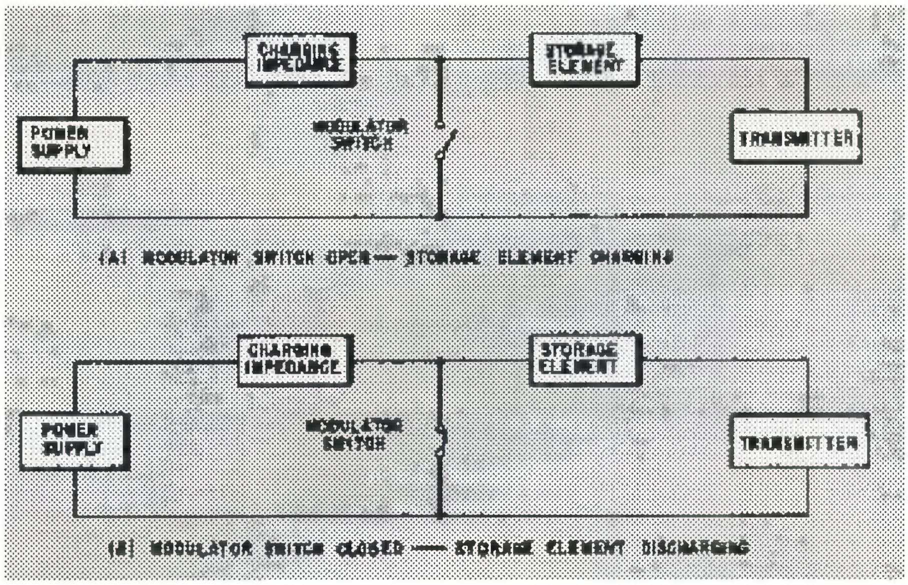


Fig.2.2 Shows the basic sections of a radar modulator, as fallows:

Many different kinds of components are used in radar modulators. The power supply generally produces a high-voltage output, either alternating or direct current. The charging impedance may be a resistor or an inductor. The storage element is generally a capacitor, an artificial transmission line, or a pulse-forming network. The modulator switch is usually a thysratron.

2.1.1.3 Modulator Storage Element

Capacitor storage elements are used only in modulators that have a dc power supply and an electron-tube modulator switch. The capacitor storage element is charged to a high voltage by the dc power supply. It releases only a small part of its stored energy to the transmitter. The electron-tube modulator switch controls the charging and discharging of the capacitor storage element.

The artificial transmission line storage element, shown in view A of figure 2-5, consists of identical capacitors (C) and inductors (L) arranged to simulate sections of a transmission line. The artificial transmission line serves two purposes: (1) to store energy when the modulator switch is open (between transmitted rf pulses) and (2) to discharge and form a rectangular dc pulse (modulator pulse) of the required duration when the modulator switch is closed.

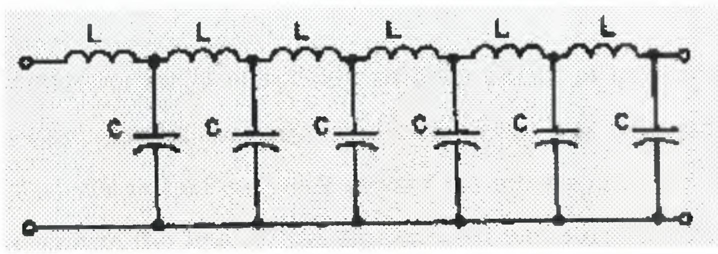


Figure 2.3 Modulator storage elements

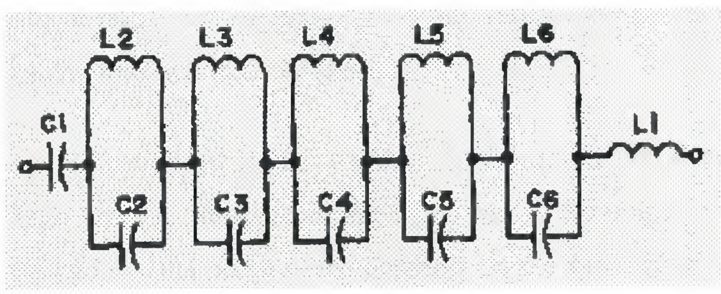


Figure 2.4 Modulator storage elements.

The duration of the modulator pulse depends on the values of inductance and capacitance in each LC section of the artificial transmission line in view A and the number of LC sections used. Other arrangements of capacitors and inductors (such as the pulse-forming network shown in view B) are very similar in operation to artificial transmission lines. are used more often than the capacitor-type storage elements.

2.2.1 Artificial Transmission Line.

a radar modulator that uses an artificial transmission line as its storage element. A modulator switch controls the pulse-repetition rate. When the modulator switch is open (between transmitted rf pulses), the transmission line charges.

The charge path includes the primary of the pulse transformer, the dc power supply, and the charging impedance. When the modulator switch is closed, the transmission line discharges through the series circuit. This circuit consists of the modulator switch and the primary of the pulse transformer.

The artificial transmission line is effectively an open circuit at its output end. Therefore, when the voltage wave reaches the output end of the line, it is reflected. As the reflected wave propagates from the output end back toward the input end of the line, it completely discharges each section of the line. When the reflected wave reaches the input end of the line, the line is completely discharged, and the modulator pulse ceases abruptly. If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, the voltage pulse that appears across the transformer primary equals one-half the voltage to which the line was initially charged.

The width of the pulse generated by an artificial transmission line depends on the time required for a voltage wave to travel from the input end to the output end of the line and back. Therefore, we can say the pulse width depends on the velocity of propagation along the line (determined by the inductances and capacitances of each section of the line) and the number of line sections (the length of the line).

2.2.2 Pulse Forming Networks.

A pulse-forming network is similar to an artificial transmission line in that it stores energy between pulses and produces a nearly rectangular pulse. The pulse-forming network in view B of figure 2-5 consists of inductors and capacitors so arranged that they approximate the behavior of an artificial transmission line.

Each capacitor in the artificial transmission line, shown in view A, must carry the high voltage required for the modulator pulse. Because each capacitor must be insulated for this high voltage, an artificial transmission line consisting of many sections would be bulky and cumbersome.

The pulse-forming network, shown in view B of figure 2-5, can carry high voltage but does not require bulky insulation on all of its capacitors. Only series capacitor C1 must have high-voltage insulation. Because the other capacitors are in parallel with the corresponding inductors, the modulator-pulse voltage divides nearly equally among them. Thus, except for C1, the elements of the pulse-forming network are relatively small.

Pulse-forming networks are often insulated by immersing each circuit element in oil. The network is usually enclosed in a metal box on which the pulse width, characteristic impedance, and safe operating voltage of the network are marked. If one element in such a network fails, the entire network must be replaced.

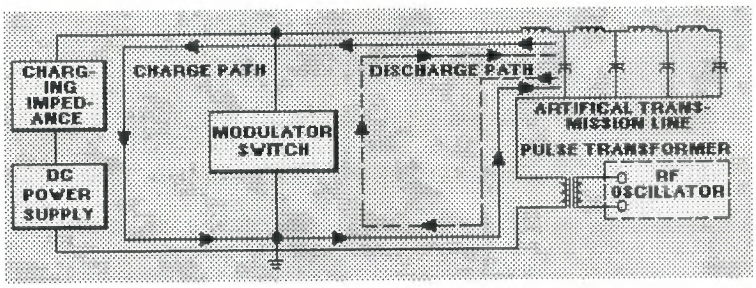


Figure 2.4 Modulator with an artificial transmission line for the storage element

The charge path includes the primary of the pulse transformer, the dc power supply, and the charging impedance. When the modulator switch is closed, the transmission line discharges through the series circuit. This circuit consists of the modulator switch and the primary of the pulse transformer.

The artificial transmission line is effectively an open circuit at its output end. Therefore, when the voltage wave reaches the output end of the line, it is reflected. As the reflected wave propagates from the output end back toward the input end of the line, it completely discharges each section of the line. When the reflected wave reaches the input end of the line, the line is completely discharged, and the modulator pulse ceases abruptly. If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, the voltage pulse that appears across the transformer primary equals one-half the voltage to which the line was initially charged.

The width of the pulse generated by an artificial transmission line depends on the time required for a voltage wave to travel from the input end to the output end of the line and back. Therefore, we can say the pulse width depends on the velocity of propagation along the line (determined by the inductances and capacitances of each section of the line) and the number of line sections (the length of the line).

2.3 Power Amplifier Transmitter

Power amplifier transmitters are used in many recently developed radar sets. This type of transmitter was developed because of the need for more stable operation of the moving target indicator (MTI). In a magnetron transmitting system, the high-power magnetron oscillator has a tendency to drift in frequency because of temperature variations, changes in the modulating pulse, and various other effects. Frequency drift is compensated for, in part, by the use of automatic frequency control (afc) circuits designed to control the frequency of the local oscillator in the receiver system. This, however, does not completely eliminate the undesirable effects of frequency drift on(MTI) operation. ,The power-amplifier transmitter system does the same thing as the keyed-oscillator transmitter but with fewer stability problems. It generates, shapes, and amplifies pulses of rf energy for transmission. ,Figure 2-5 is a block diagram of a typical power-amplifier transmitter system. In this transmitter system a multi-cavity klystron tube amplifies lower-powered rf pulses that have been generated and shaped in other stages. CROSSED-FIELD AMPLIFIERS (AMPLITRONS) are used in radar systems with a wide band of transmitted frequencies because they are stable over a wider frequency range. A crossed-field amplifier transmitter

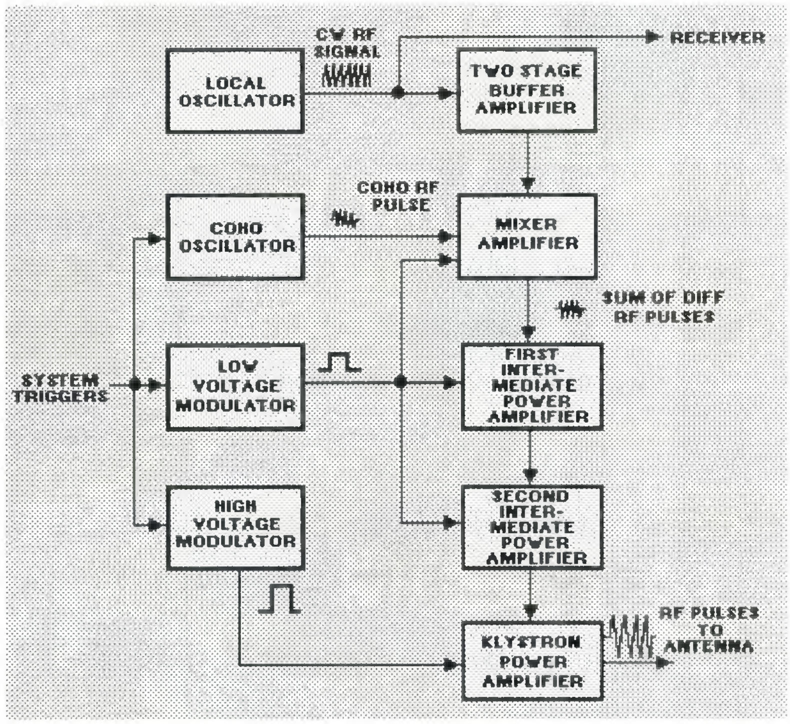


Figure 2.5 Power amplifier transmitter block diagram.

a block diagram of a power-amplifier transmitter that uses a frequency synthesizer to produce the transmitted frequency rather than the heterodyning mixer. The frequency synthesizer allows the transmitter to radiate a large number of discrete frequencies over a relatively wide band. Such a system is commonly used with frequency-scan search radars that must transmit many different frequencies to achieve elevation coverage and to compensate for the roll and pitch of a ship.

In figure 2-5, the power-amplifier chain input signals are generated by heterodyning (mixing) two frequencies. That is, two different frequencies are fed to a mixer stage (mixer amplifier) and the resultant, either the sum or difference frequency, may be selected as the output. (The operation of mixer circuits is explained in more detail in the section on receivers.) The low-power pulse is then amplified by intermediate power amplifier stages and applied to the klystron power-amplifier. The klystron power-amplifier concentrates the rf output energy into a very narrow frequency spectrum. This concentration makes the system more sensitive to smaller targets. In addition the detection range of all targets is increased.

To examine the operation of the transmitter, we will trace the signal through the entire circuit. The local oscillator shown at the left of figure 2-10 is a very stable rf oscillator that produces two cw rf outputs. As shown, the cw output is sent to the receiver system; the cw output is also one of the two rf signals fed to the mixer amplifier by way of the two BUFFER AMPLIFIER STAGES. The buffer amplifiers raise the power level of the signal and also isolate the local oscillator.

The COHERENT OSCILLATOR (COHO) is triggered by the system trigger and produces as its output an rf pulse. This rf pulse is fed directly to the mixer amplifier.

The mixer-amplifier stage receives three signals: the coherent rf pulse, the local oscillator cw rf signal, and a dc modulating pulse from the low-voltage modulator. The coherent and local oscillator signals are mixed to produce sum and difference frequency signals. Either of these may be selected as the output. The modulator pulse serves the same purpose as in the keyed-oscillator transmitter, because it determines the pulse width and power level. The mixer stage functions only during the modulator pulse time. Thus the mixer amplifier produces an output of rf pulses in which the frequency may be either the sum or difference of the coherent and local oscillator signals.

The mixer-amplifier feeds the pulses of rf energy to an intermediate power amplifier. This amplifier stage is similar to the buffer-amplifier stage except that it is a pulsed amplifier. That is, the pulsed amplifier has operating power only during the time the modulator pulse from the low-voltage modulator is applied to the stage. The amplified output signal is fed to a second intermediate power amplifier that operates in the same manner as the first.

From the second intermediate power amplifier, the signal is fed to the KLYSTRON POWER AMPLIFIER. This stage is a multi-cavity power klystron. The input rf signal is used as the exciter signal for the first cavity. High-voltage modulating pulses from the high-voltage modulator are also applied to the klystron power amplifier. These high-voltage modulating pulses are stepped up across a pulse transformer before being applied to the klystron. All cavities of the klystron are tunable and are tuned for maximum output at the desired frequency.

Provisions are made in this type of transmitter to adjust the starting time of the modulating pulses applied to the coherent oscillator, mixer amplifier, intermediate power amplifiers, and klystron power-amplifier. By this means the various modulator pulses are made to occur at the same time.

This transmitter produces output rf pulses of constant power and minimum frequency modulation and ensures good performance.

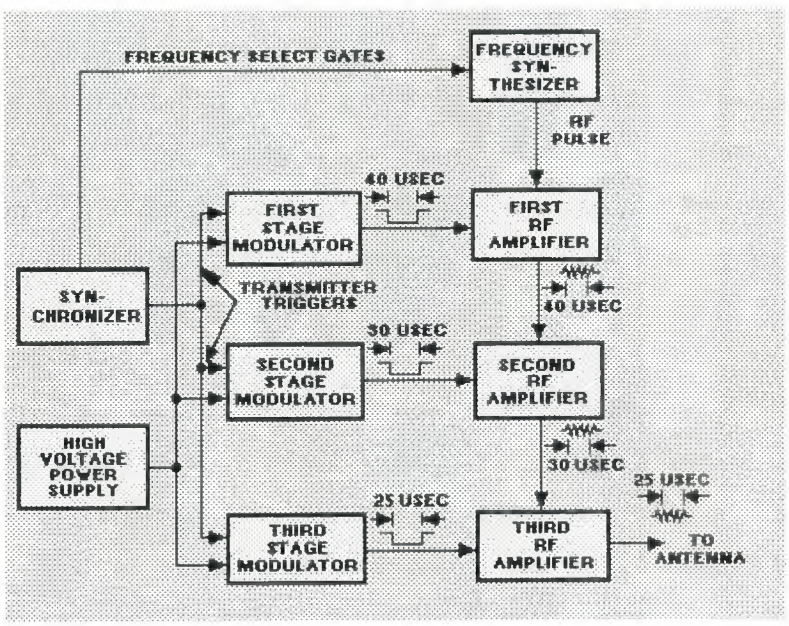


Figure 2.6 Power amplifier transmitter using crossed-field amplifiers

A typical frequency synthesizer consists of a bank of oscillators producing different fixed frequencies. The outputs of a relatively few fixed oscillators can be mixed in various combinations to produce a wide range of frequencies. In mti systems the selected oscillator frequencies are mixed with a coherent oscillator frequency to provide a stable reference for the mti circuits. The frequency synthesizer also produces the local oscillator signals for the receiver system. Because the transmitted pulse changes frequency on each transmission, the local oscillator signal to the receiver must also change and be included in the transmitted frequency. A system of this type is frequency-programmed by select gates from the synchronizer.

The detailed operation of frequency synthesizers is beyond the scope of this manual but may be found in the technical manuals for most frequency scan radar systems.

The first rf amplifier receives the pulses of the selected frequency from the synthesizer and a modulator pulse (from the first stage modulator) at the same time. The rf pulse is usually slightly wider than the modulator pulse which prevents the amplifier tube from pulsing when no rf energy is present. Most pulsed rf amplifiers will oscillate at an undesired frequency if pulsed with out an rf input. The output of the first rf amplifier is an amplified rf pulse that is the same width as the first stage modulator pulse. The second stage modulator is designed to produce a pulse slightly narrower than the first stage modulator pulse; this also prevents the amplifier from pulsing when no rf is present. Therefore, the second stage amplifier receives a modulator pulse a short time after the first stage rf arrives at the input. As shown in figure 2-6, the same procedure is repeated in the third and final stage.

The amplifiers in this type of power-amplifier transmitter must be broad-band microwave amplifiers that amplify the input signals without frequency distortion. Typically, the first stage and the second stage are traveling-wave tubes (twt) and the final stage is a crossed-field amplifier. Recent technological advances in the field of solid-state microwave amplifiers have produced solid-state amplifiers with enough output power to be used as the first stage in some systems. Transmitters with more than three stages usually use crossed-field amplifiers in the third and any additional stages. Both traveling-wave tubes and crossed-field amplifiers have a very flat amplification response over a relatively wide frequency range.

Crossed-field amplifiers have another advantage when used as the final stages of a transmitter; that is, the design of the crossed-field amplifier allows rf energy to pass through the tube virtually unaffected when the tube is not pulsed. When no pulse is present, the tube acts as a section of waveguide. Therefore, if less than maximum output power is desired, the final and preceding cross-field amplifier stages can be shut off as needed. This feature also allows a transmitter to operate at reduced power, even when the final crossed-field amplifier is defective.

2.4 Atmospheric Conditions Effect

Is the speed and direction of travel of electromagnetic wave fronts traveling through the air. Under normal conditions, the wave fronts increase uniformly in speed as altitude increases which causes the travel path to curve downward. The downward curve extends the radar horizon as shown in the illustration. The density of the atmosphere, the presence of water vapor, and temperature changes also directly affect the travel of electromagnetic wave fronts.

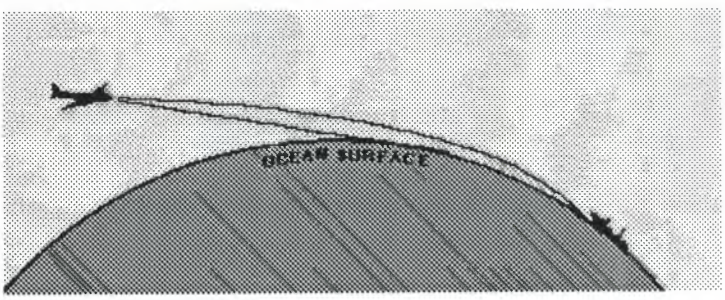
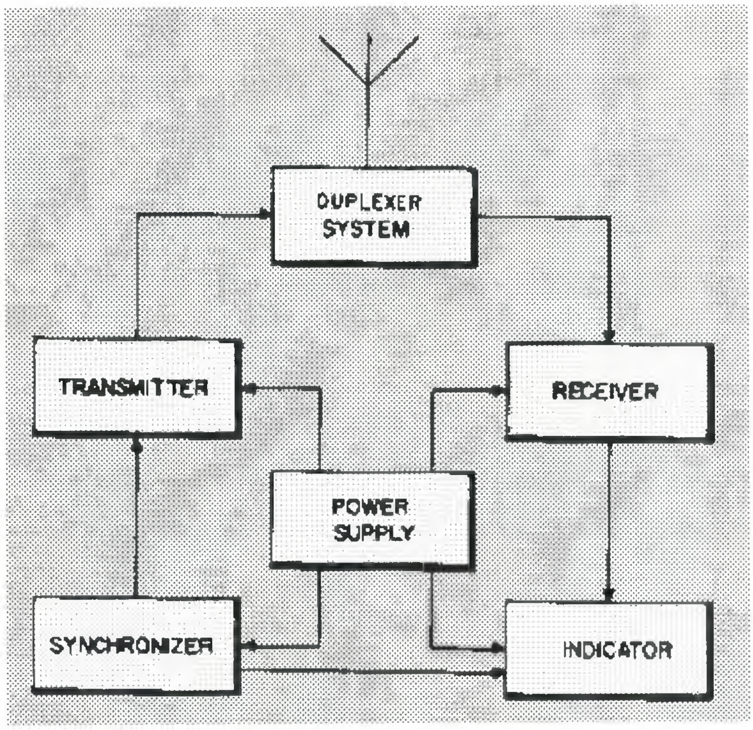


Figure 2.7 atmosphere condition effect

The major components in a typical PULSE RADAR SYSTEM are shown in the illustration. The SYNCHRONIZER supplies the timing signals to coordinate the operation of the entire system. The TRANSMITTER generates electromagnetic energy in short, powerful pulses. The DUPLEXER allows the same antenna to be used to both transmit and receive. The RECEIVER detects and amplifies the return signals. The INDICATOR produces a visual indication of the range and bearing of the echo.



Fgure2.8 The receiver detects and amplifies the return signals

SCANNING is the systematic movement of a radar beam while searching for or tracking a target.

STATIONARY-LOBE SCANNING is the simplest type of scanning and is usually used in 2D search radar. Monopulse scanning, used in fire-control radars, employs four signal quantities to accurately track moving targets. The two basic methods of scanning are MECHANICAL and ELECTRONIC.

Radar systems are often divided into operational categories based on energy transmission methods--continuous wave (cw), frequency modulation (fm), and pulse modulation (pm).

The CONTINUOUS WAVE (cw) method transmits a constant frequency and detects moving targets by detecting the change in frequency caused by electromagnetic energy reflecting from a moving target. This change in frequency is called the DOPPLER SHIFT or DOPPLER EFFECT.

In the FREQUENCY MODULATION (fm) method, a signal that constantly changes in frequency around a fixed reference is used to detect stationary objects.

The PULSE-MODULATION (pm) METHOD uses short pulses of energy and relatively long listening times to accurately determine target range. Since this method does not depend on signal frequency or target motion, it has an advantage over cw and fm methods. It is the most common type of radar.

Radar systems are also classified by function. SEARCH RADAR continuously scans a volume of space and provides initial detection of all targets. TRACK RADAR provides continuous range, bearing, and elevation data on one or more specific targets. most radar systems are variations of these two types.

CHAPTER THREE
RADAR FREQUENCEY

3.1 Radar Frequencies

The frequencies of the radio waves employed in radar lie in the general region of 100 to 30,000 MHz. How extremely high these frequencies of billions of cycles per second are may possibly be suggested by the comparison of power, communication, and Communication, and light frequencies. Light frequencies in Fig3.1 On the logarithmic scale of this figure, radar frequencies lie closer to visible light than to electric-power frequencies. It is not strange, then, that much radar equipment (for example, the antenna with paraboloidal reflector) resembles optical devices more closely than low-frequency electrical equipment. Radar wavelengths range from 1 cm to 3 m in contrast to 200 to 550 in for the low-frequency radio-broadcast band and 0.00004 to 0.00008 cm for visible light. The relation between frequency and wave length, indicated by the scales in Fig. 17, is determined as follows: A wave of frequency f moves forward one wavelength X in each cycle of oscillation. Therefore, the speed with which the wave progresses, which is the distance moved forward in one unit of time, is ft. For radio waves, this speed is c, the speed of light, 299.8 m per M5* Therefore,

$$C = \lambda f$$

f in (MHz/s) and (λ) in (m),c in m/sec.

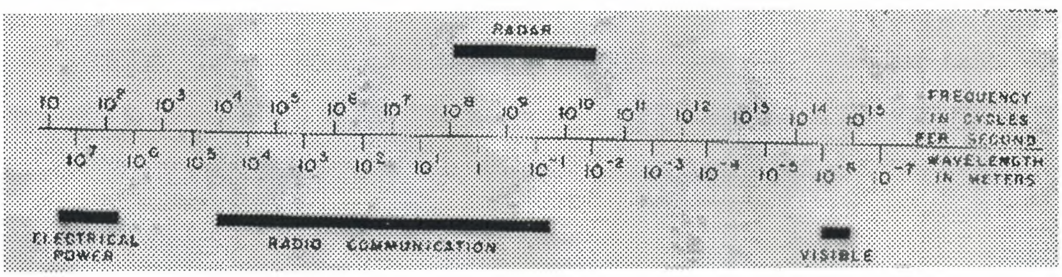


Figure 3.1 Communication, and light frequencies, on the logarithmic scale

Important early applications of the CW radar principle were the proximity (VT) fuze and the FM-CW altimeter. The CW proximity fuze was first employed in artillery projectiles during World War II and greatly enhanced the effectiveness of both field and antiaircraft artillery.

The first practical model of the FM-CW altimeter was developed by the Western Electric Company in 1938, although the principle of altitude determination using radio-wave reflections was known ten years earlier, in 1928.

The CW radar is of interest not only because of its many applications, but its study also serves as a means for better understanding the nature and use of the doppler information contained in the echo signal, whether in a CW or a pulse radar (MTI) application. In addition to allowing the received signal to be separated from the transmitted signal, the CW radar provides a measurement of relative velocity which may be used to distinguish moving target from stationary objects or clutter.

3.2 Doppler Effect

Consider the simple CW radar as illustrated by the block diagram of the transmitter generates a continuous (un modulated) oscillation of frequency fo, which is radiated by the antenna. A portion of the radiated energy is intercepted by the target and is scattered, some of it in the direction of the radar, where it is collected by the receiving antenna. If the target is in motion with a velocity e, relative to the radar, the received signal will be shifted in frequency from the transmitted frequency fo by an amount + fa as given by . The plus signal associated with the Doppler frequency applies if the distance between target ,and radar is decreasing (closing target), that is, when the received signal frequency is greater than the transmitted signal frequency. The minus sign applies if the distance is increasing (receding target).The received echo signal at a frequencyf0 ±fj enters the radar via the antenna and is heterodyned in the detector (mixer) with a portion of the transmitter signal fd to produce a doppler beat note of frequency fd. The sign of fd is lost in this process.

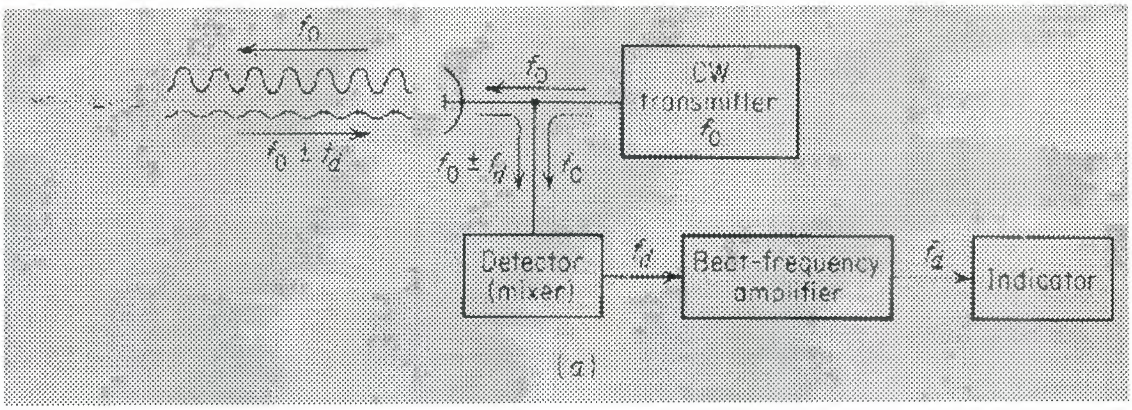


Figure 3.2.1 simple cw radar block diagram

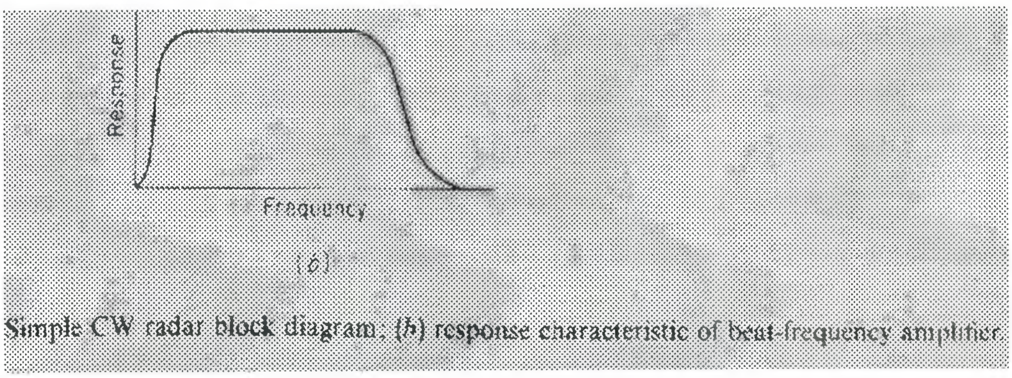


Figure 3.2.2 response characteristic of beat frequency

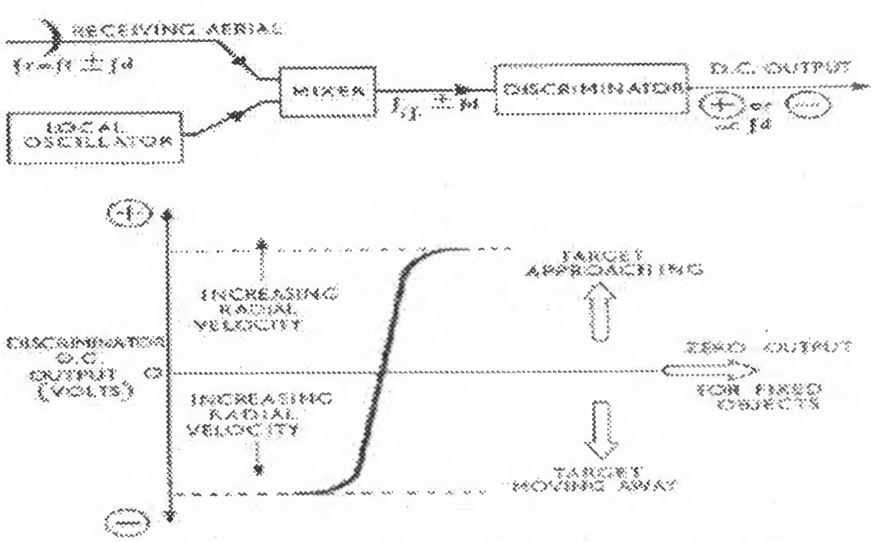


FIG 9. INDICATION OF MOVING TARGETS

Figure 3.2.3 moving target indication

3.3 Sky Wave propagation and Frequency Management

3.3.1The effect of the ionosphere on the propagation of radio waves.

The sky-wave radar engineer seeks to capitalize on these effects, particularly refraction, to look beyond the horizon. Of the three ionized regions in the ionosphere D, E and F. only the E and F regions turn out to be useful for sw radar. The free-electron content of the D region (70-90 km altitude) is insufficient to scatter HF radio waves and the layer acts as an unwanted absorber of radio energy. This absorption occurs because the electrons, while trying to oscillate with the incident radio wave experience, many collisions with neutral air molecules.

The E region is a narrow layer of ionization at about 110 km altitude.

the ionization is uneven, but can be very intense at times (owing to auroral effects and intense patches known as sporadic F, and it is essentially a day-time phenomenon. The maximum electron density of approximately 10^{12} [electrons m-3] occurs near midday and corresponds to a critical frequency called the f0E) of 2.8 MHz, meaning that this is the highest frequency that will be reflected at vertical incidence. Frequencies higher than f,3E pass straight through the F layer if traveling vertically but can be scattered if they are transmitted at oblique incidence.

The F1 layer often divides into two layers, Fl and F2, during daytime

the lower Fl layer lies between 130 and 210 km altitude and has a maximum ionization of about 2×10^{11} [electrons m-3] at noon, giving f0F1=4 MHz. The F2 layer usually has the strongest electron density at about 10^{12} [electrons m3] during the day ($f_oF_2 = 9$ MHz,

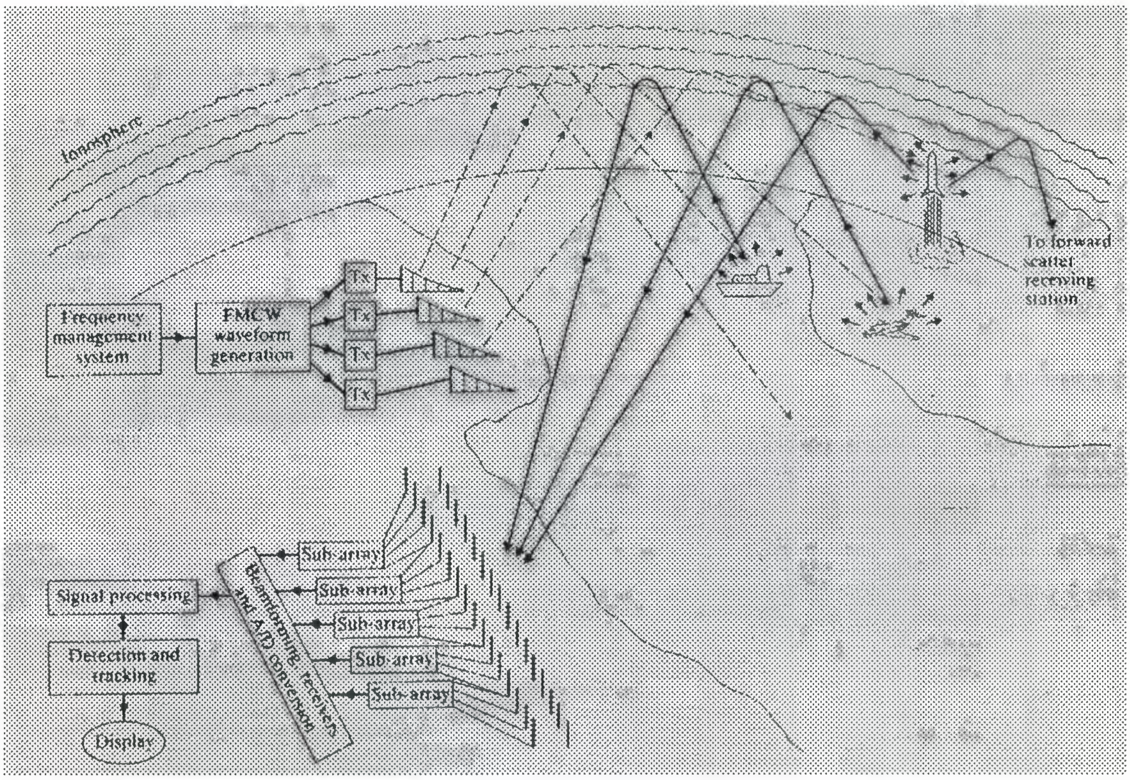


Figure 3.3 shows the TX &RX transmitted and scattered sky wave.

We discuses the effect of the ionosphere on the propagation of radio waves. The sky-wave radar engineer seeks to capitalize on these effects, particularly refraction to look beyond the horizon. of the three ionized regions in the ionosphere, D, E and F. only the E and F regions turn out to be useful for sw radar. The free-electron content of the D region (70-90 km altitude) is insufficient to scatter HF radio waves and the layer acts as an unwanted absorber of radio energy. This absorption occurs because

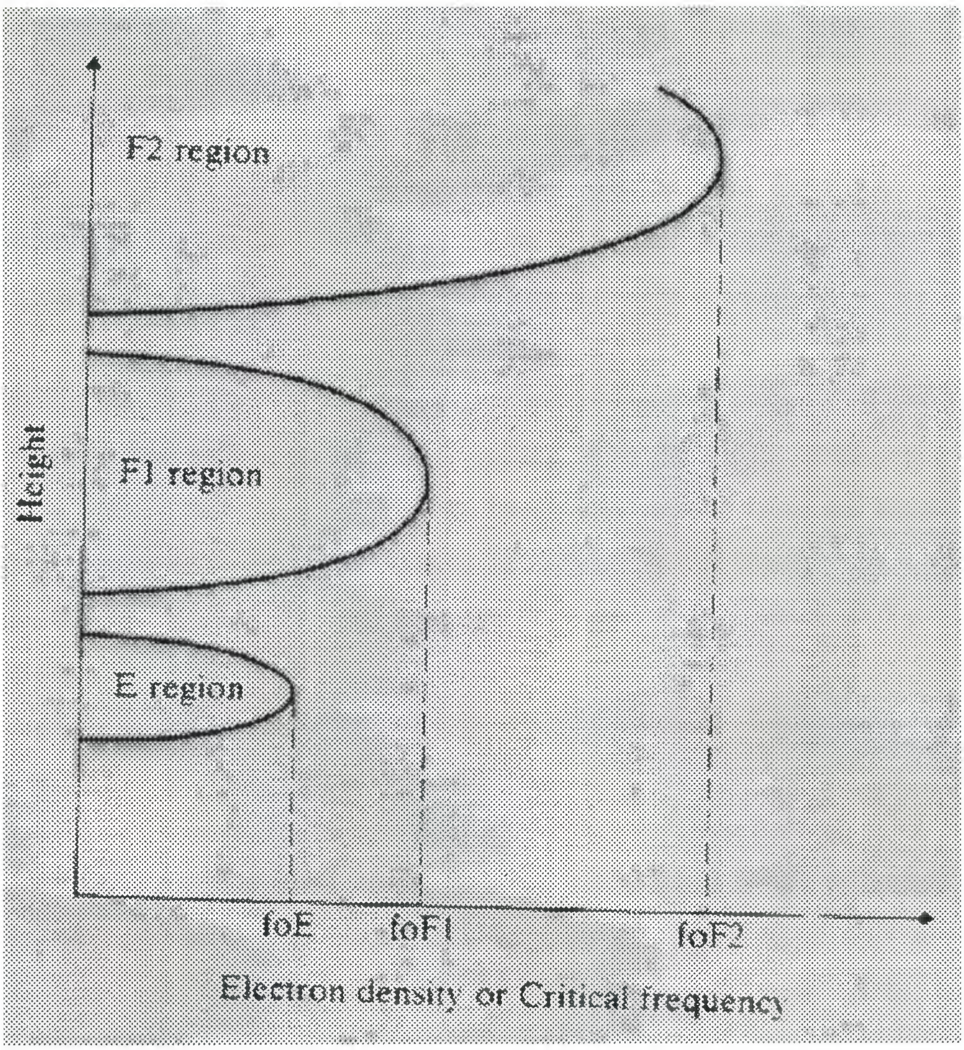


Figure 3.4 the E and F regions of the ionosphere

the electrons, while trying to oscillate with the incident radio wave, experience many collisions with neutral air molecules.

The E region is a narrow layer of ionization at about 110 km altitude. The ionization is uneven, but can be very intense at times (wing to autoral effects and intense patches known as sporadic E), and it is essentially a daytime phenomenon. The maximum electron density of approximately 10^{11} [electrons m-3] occurs near midday and corresponds to a critical frequency Called the f0E) of 2.8 MHz, meaning that this is the highest frequency that will be reflected at vertical incidence. Frequencies higher than foE pass straight through the e layer if traveling vertically but can be scattered if they are transmitted at oblique incidence.

The F layer often divides into two layers, Fl and F2, during daytime (See Fig. 10.6). The lower Fl layer lies between 130 and 210 km altitude and

Has a maximum ionization of about 2×10^{11} [electrons m-3] at noon, giving

f0F= 4 MHz. The F2 layer usually has the strongest electron density at About l0i [electrons m-3] during the day (fof2 =9 MHz), and this ,layer persists during the night with the ionization falling to around 5 x 10+10 [electrons m-3] [f0F2 = 2 MHz].

The bottom of the ionosphere is not smooth, but has a roughness comparable with the scale sizes of the hills and valleys on the earth's surface, With the added complication that the roughness is moving and changing With the background neutral wind and electric fields. All three ionospheric Layers are subject to various disturbances, irregularities and anomalies, and The electron densities may vary with time of day, season, and location and solar Activity.

The ionosphere is thus an uncertain and ever-changing medium of propagation, and there may be many paths by which a signal can pass from.

The transmitter to the target and back to the receiver-this can cause a single

Target to appear at many apparent ranges (see Fig. 10.7). There is also a Limited band of frequencies that can be used to illuminate a target at any Given range, and, as with HF communications, the band required may be Congested with radio traffic and high background noise levels.

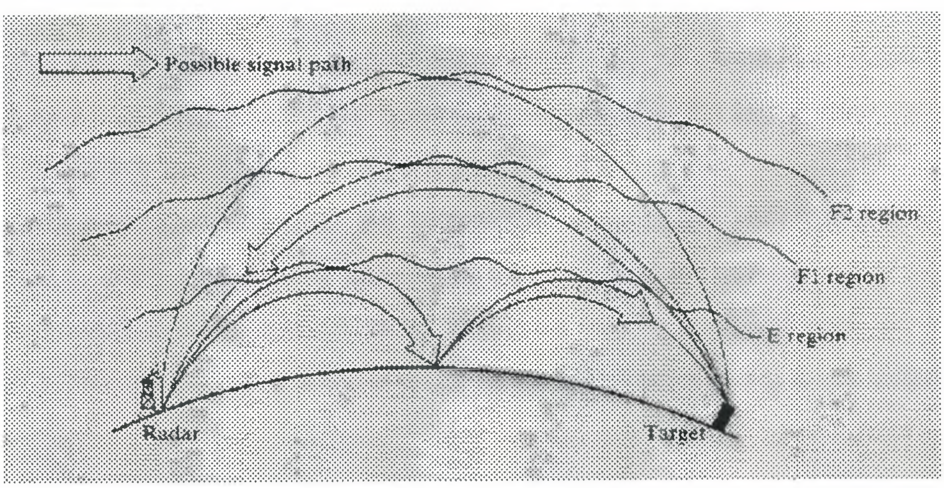


Figure 3.5 possible signal path

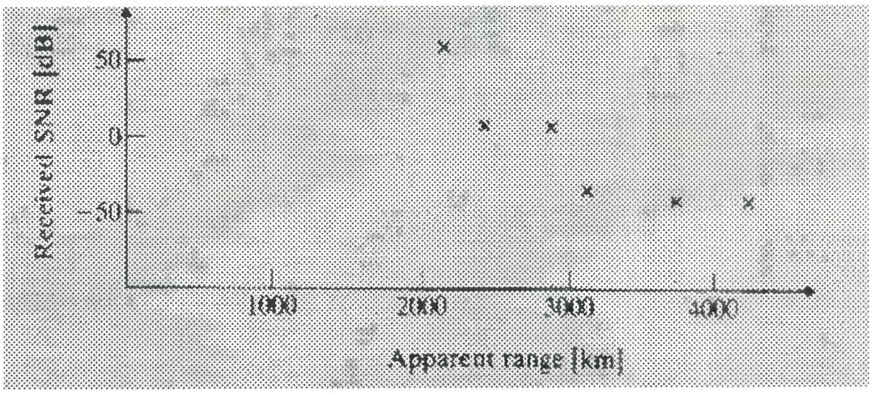


Figure 3.6 receivers SNR with distance

Radio signals may follow any combination of E and F region outward and return paths to give several apparent ranges and values of SNR for a signal target.

3.3.2 Ground wave 0TH Radar.

The type of 0TH radar described in the above that propagates via refraction from the ionosphere is sometimes called sky-wave radar. It is also possible at HF to propagate energy around the curvature of the earth by diffraction. This is commonly called ground-wave propagation. A ground-wave radar can detect the same kind of targets as can a Sky-wave,radar.

Detection is somewhat easier than with sky-wave propagation since ionospheric effects are not present and clutter returns from aurora generally can be eliminated by time gating. The ground-wave radar has a far shorter range than can be obtained via sky wave because of the propagation loss which increases exponentially with range. A ground-wave radar of a size and frequency comparable to the sky-wave radar discussed in the above might have a range against low-altitude aircraft targets of perhaps 200 to 400 km.

The microwave radar that uses the over-ocean evaporative duct to obtain extended propagation to detect low-altitude or surface targets beyond the normal line of sight is also sometimes called over-the-horizon radar. It should not be confused with the HF radars described in this section that operate at much lower frequencies and at much longer ranges.

CHAPTER FOUR
OTH RADAR

4.1 Definition of OTH Radar

Radar that makes use of the atmospheric reflection and refraction phenomena to extend its range of detection beyond line of sight. Over-The-Horizon radars may be either forward-scatter or back (OTH-B)-scatter systems.

4.2 Over the Horizon Radar Waves

* The two types of over-the-horizon radar
* Surface-wave radar
* Sky-wave radar

Over-the-horizon radars are even less perfect than microwave systems, but
The rewards for seeing over the horizon are worth pursuing.

4.3 Introduction

It has been known since the experiments of Guglielmo Marconi in 1901 thatRadio waves could propagate beyond the horizon because of the signals heSuccessfully transmitted from Poldhu in Cornwall, UK, to St John's,Newfoundland. Investigations into the cause of this propagation soonRevealed that the solution to Maxwell's equations for a wave at a planeInterface between two media gives a space wave (free-space propagation)And a surface wave (a wave guided along the interface). With the discoveryOf the earth's ionosphere in the 1 920s, it was realized that there was also aThird possible mode of propagation, the ionospheric wave, which turned outTo be the explanation of Marconi's transatlantic communications

. The propagation of HF (3-30 MHz) radio waves over great distances
Has always been exploited in communications, and sometimes frequencies
Lower than HF are used, as listeners to long-wave radio will know. During

World War II the UK air defence radar `Chain Home', operating on
20-30 MHz, was occasionally troubled by `nth-time-around' clutter created

4.4 Principle of Over the Horizon Radar

When the radio signal was scattered by the ionosphere and traveled unusually long distances. Under these conditions the normal operating PRF of 25 Hz Was reduced to 12.5 Hz (details in Neal'). In other countries, similar Discoveries were made, and many radar engineers began thinking of turning This unwanted propagation to advantage.

From the early experiments with long-range propagation, two kinds of HF radar or `over-the-horizon' (0TH) radar have been developed, known As surface-wave (or ground-wave) radar and sky-wave radar, making use of The surface-wave and the ionosphere modes of propagation respectively Surface-wave systems were first operated in the early 1 950s and effective sky-wave systems a little later. The reason for the slow development of 0TH Radar compared to more conventional systems is not a reflection on the Ability or the imagination of the engineers involved but rather the constraints of the technology available at the time.

Surface-wave radar uses the surface-wave propagation mode to look Over the immediate horizon, and it may be used to survey ranges up to a maximum of certainly no more than 400 km. It is most useful as a local area Defence system and as a method of collecting good-quality wave and tidal information over restricted area of ocean. Although bistatic systems have Been operated successfully, surface-wave radar is regarded as being a Predominantly monostatic technique with a relatively low capital cost.
sky-wave radars, on the other hand, are almost always large, bistatic ,and very expensive. These radars make use of the ionosphere to scatter radio waves very long distances beyond the horizon, sometimes in forward scatter mode to a receiver beyond the target. The minimum range is about 1000 km and the maximum useful range is around 4000 km. sky-

wave radar is thus more suited to the defence and Remote Ocean sensing needs of countries of such continental proportions as the USA, the former USSR and Australia.

4.5 Surface Wave Radar

The principle of surface-wave or ground-wave (gw) radar is that a surface Radio propagation mode can be utilized to make a radar signal follow the Surface of the sea as it disappears over the horizon. The method works only For vertically polarized antennas in contact with salty conducting water; it Cannot be used over land, on freshwater lakes, or where fresh water dilutes the sea, such as in the Baltic or the Nile Delta.

The propagation of radio waves along surfaces has been analyzed Extensively in the past; the theory is complex and is, for all practical purposes, impossible to solve manually. However, intuitively we would expect to find Such propagation because, although the sea is a good conductor, it is not perfect and it supports a small horizontal electric field induced by

4.6 OTHR (relocatable over the horizon radar)

Fleet Surveillance Support Command was established in July 1987 to operate the Navy's Relocatable Over-the-Horizon Radar (ROTHR) in support of Fleet units worldwide. This unique radar system was originally designed to provide tactical warning to battle group commanders of air and surface threats at an extended range allowing time for responsive engagement. Two US Navy high-frequency (HF) over-the-horizon (OTH) radars known as ROTHR (Relocatable Over-the-Horizon Radar) are operated at Corpus Christi TX and Chesapeake VA, with coverage of the Caribbean Sea and portions of the Atlantic Ocean and the Gulf of Mexico. The OTHR in Virginia and Texas are presently in full-time use for counter-narcotics surveillance, and a third is scheduled for installation in Puerto Rico in the near future.

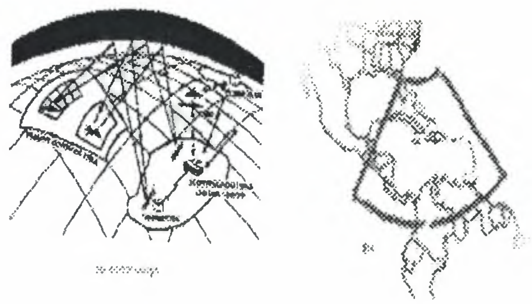


Figure4.1 shows the coverage area of oth radar and wave propagation of wave www.fas.org/nuke//guide/usa/air def

A prototype ROTHR system was installed on the isolated Aleutian Island of Amchitka, Alaska, where it surveilled the eastern coast of Russia 24 hours a day, seven days a week from April 1991 to March 1993.Amchitka ROTHR U.S. Navy Base provided essential base support services for the 235-person Navy station at Amchitka Island, 1,400 miles southwest of Anchorage in the Aleutian Chain, from December 1988, until the base's closure in 1993. The system on Amchitka was dismantled at the end of the Cold War, but the first production system was installed in Chesapeake, Va., and declared operational in April 1993 in a counter-drug role in support of U.S. Atlantic Command. A second system was installed in Texas and became operational in July 1995. The FSSC team of officers, enlisted, civilian and contractor personnel operate and support ROTHR from Naval Security Group Activity, Northwest in Chesapeake, where the Operations Control Center and the Receiver Site are located.

The ROTHR Virginia surveillance **area covers more than 2.2 million square miles** of the Caribbean extending north-south from southern Florida to the northern coast of South America and east-west from the western coast of Central America to the Lesser Antilles. This coverage is achieved using **5-28**-MHz radio waves that reflect from the ionosphere. ROTHR is land-based, high-frequency (HF) radar which can cover a **64 degree** wedge-shaped area at ranges of **500** to **1,600** nautical miles.

This extended range is achieved when the ionosphere onto distant targets refracts transmitted HF energy. The faint energy reflected back from these targets (backscatter) is detected by the radar receive antenna after returning along the refraction path. The surface of the earth and the targets in the area of interest reflect some of this energy back through the ionosphere to a separate receive site, where it is processed to generate target track information.

The High Frequency Band (3 to 30 MHz) is a candidate for radar because it enables surface to surface radar to target distances well beyond the horizon. Radar to target ranges of 1000 nautical mile and more are typical. Use of the 10 to 60 meter wavelengths associated with HF radar requires physically large antennas. Each ROTHR achieves a nominal half degree azimuth angular resolution with a 2.58-km-long linear phased receiving array consisting of 372 twin-monopole elements. Each monopole pair has a receiver and analog-to-digital converter attached to it. Digital beam former forms 18 beams which are then Doppler processed to separate the moving targets from the ground clutter. Range resolution is achieved by transmitting a 25-kHz continuous frequency-modulated waveform. A radar resolution cell on the ocean surface is therefore about 6 km in range by about 15 km in azimuth, for the frequency and range used. Radar frequency is variable and is selected sing real-time sweep frequency ionospheric soundings.

The propagation path is by ionospheric refraction which provides a "mirror" but with considerable variability. This variability is not predictable on a short-term basis; in addition, target illumination is generally by multiple paths. Tracking information thus has varying degrees of accuracy due to the changes and uncertainties of the ionosphere caused by factors such as the time of day, season, sun spot number, and other solar activity. HF radar must measure and adapt to the environment in real time, and oblique backscatter soundings are routinely taken.

Because the existing Over-the-Horizon Radar Systems were originally designed to perform a military mission and not a counter drug mission, enhancements to provide a better capability to provide surveillance are being developed by the Counter drug Technology Development Program. A series of adaptive waveforms have been developed to deal with the problem of Spread Doppler Clutter and its impact on Relocatable Over-the-Horizon Radar (ROTHR) systems for the sponsored Counter drug Surveillance and Interdiction Program. The class of waveforms developed and demonstrated are non-recurrent waveforms with quadratic phase coding (NRWF/QPC). The waveforms were tested at Rome Laboratory sites in Ava (transmit) and Verona (receive) looking south into the Caribbean. During periods of SDC, where targets detections would not be possible, the use of the new waveforms shifted the SDC out of the area of interest to allow target detections.

4.7 HF over the Horizon Radar

The frequencies at VHF or lower are seldom used for conventional radar applications because of their narrow bandwidths, wide beam width, high ambient noise levels, and the potential interference from other users of the crowded electromagnetic spectrum. In spite of these limitations, the HF region of the spectrum is of special interest for radar because of its unique property of allowing propagation to long distances beyond the curvature of the earth by means of refraction from the ionosphere. A single refraction allows radar ranges to be extended to almost 4000 km. The targets of interest to I-IF over-the-horizon (0TH) radar is the same as those of interest to microwave radar and include aircraft, missiles, and ships. In addition, the long wavelengths characteristic of HF radar also provide distinctive information regarding the sea, as well as aurora, meteors, and land features. (Although the HF band is officially defined as extending from 3 to 30 MHz, for radar usage the lower frequency limit might lie just above the broadcast band, and the upper limit can extend to 40 MHz or more.) The ability to see a target at long range by means of ionospheric refraction depends on the nature of the ionosphere (the density of electron concentration) and the radar frequency, as well as the normal parameters that

Enter into the radar range equation. Unlike conventional microwave radar,

The specific frequency to be used by an 0TH radar is a function of the range that is desired and the character of the ionosphere. Since the ionosphere varies with time of day, season, and solar activity, the optimum radar frequency will vary widely Such radars must therefore be capable of operating over a wide portion of the HF band, as much as three octaves (4 to 32 MHz for example).2' The ionosphere often consists of more than one refracting region. The highest region, denoted F2, and the most important for HF propagation, are at altitudes of from 230 to 400 km. It provides the greatest ranges for a single refraction and can support the highest usable frequencies.

The F1 region, from about 180 to 240 kin, is observed only during the day and is more pronounced during the summer than the winter. The E region, which lies between 100 and 140 kin, can also support refraction. At these heights there can appear at times patches of high-density ionization called sporadic E which, when available, can be quite effective in providing stable propagation. The multiple refracting regions give rise to multi path propagation which can result in degraded performance because of the simultaneous arrival of radar energy at the target via more than one propagation path, each with different time delays. The effects of multi path can be reduced by the proper selection of frequency and by use of narrow elevation beam widths which allow the energy to travel to the target via only a single path. The presence of the various refracting regions with different ionization densities at different altitudes requires good frequency management if an 0TH radar is to operate with reliability. The minimum range to which HF energy can be propagated by ionospheric refraction is determined by the lowest frequency at which the radar can operate. A nominal value for the minimum range (or skip distance) is about 1000 km. The backscatter from the earth's surface is generally many orders of magnitude larger than the echo from desired moving targets. Thus HF radar must employ some form of Doppler processing such as MTI, pulse-doppler, FM-CW, or CW radar to separate desired moving targets from clutter. The equivalent of a high-pass filter must be used to detect moving aircraft and missiles and reject stationary surface clutter. The detection of ships requires more sophisticated processing since the relatively low velocity of ships produces doppler-frequency shifts comparable to those of the sea (which is also a moving target). Even though the radar cross section of ships is often greater than that of aircraft, longer observation times are required to provide sufficient resolution in Doppler frequency. Character of 0TH radar: The factors affecting the design of an HF 0TH radar are slightly different than those affecting conventional microwave radar.

During the late 1940s, NRL foresaw the need to detect moving targets, including aircraft and missiles, at distances and altitudes beyond the line-of-sight. NRL began to investigate the use of radar operating in the high frequency (HF, or short wave) portion of the radio spectrum to extend the range beyond the horizon. By 1955, NRL was operating a low-power HF radar system called Multiple Storage, Integration, and Correlation (MUSIC). Using signals reflected by the ionosphere as well as by the target, MUSIC allowed the detection of missile launches at distances up to 600 nautical miles and of atomic explosions at distances up to 1700 nautical miles. A much improved system called Magnetic-Drum Radar Equipment (MADRE) was developed in 1961 and was installed at NRL's Chesapeake Bay Detachment.

CHAPTER FIVE
USES OF THE OVER THE HORIZON RADAR

5.1 Advantages of using the over the horizon radar

Over-the-horizon radar technology has grown out of a number of related technologies and, before embarking on the history in more detail, it is appropriate to establish the basis of how OTHR operates and what advances were required to make it feasible.

All radar operates by transmitting radio frequency energy to a distant "target" which scatters the energy. Part of the scattered energy returns in the direction from which it came. By comparing the returned energy with that sent out, and in particular by measuring the time taken for the energy to go and return, the target range can be determined. The direction of the target corresponds to the radar's direction of look, so both direction and range are determined. Hence the acronym RADAR, Radio Detection and Ranging. Radio frequency energy, like light, travels in a straight line in free space so the distance over which radar is effective is limited by obstacles and, in particular, by the bulge of the earth. Raising the height of radar, as for an optical instrument or observer, allows you to see further around the bulge distance to the horizon is increased, but it is a square root relationship. Doubling the horizon distance calls for a quadrupling of radar height.

As an alternative to increasing the radar height, use of ionospheric reflection to bounce radar signals well beyond the horizon is an obvious and attractive proposition for long range radar detection.

A shell of ionisation called the ionosphere surrounds the earth in a number of more-or-less distinct layers at heights between 70 and 350km. It has been known for many years that these layers affect radio frequency transmissions and that for a range of frequencies the ionosphere has the effect of bending back radio transmissions as if by reflection. Thus, the ionosphere is, crudely, a mirror in the sky for the frequency band for which it is effective.

So-called shortwave communication has since the earliest days of radio used these reflective properties of signals are bounced between the ionosphere and the earth's surface a number of times to communicate between points on the surface which can be on opposite sides of the globe. It is hardly surprising that radar workers should also contemplate the ionosphere as an aid to greatly increased range and to seek ways of implementing radar in the high frequency (shortwave) band to capitalize on ionospheric reflection.

5.2 Over the Horizon Backscatter

Information that affects climate The U.S. Air Force's over-the-horizon-backscatter (OTH-B) air defense radar system is by several criteria the largest radar system in the world. Six one-million-watt OTH radars see far beyond the range of conventional microwave radars by bouncing their 5-28-MHz waves off the ionosphere, an ionized layer about 200 km above the earth. It was developed over 25 years at a cost of $1.5 billion to warn against Soviet bomber attacks when the planes were still thousands of miles from US air space.

In 1970 Air Force Rome Air Development Center [RADC] engineers developed and constructed components for a frequency modulation/continuous wave (FM/CW) radar capable of detecting and tracking objects at over-the-horizon ranges. The radar installation and evaluation was accomplished on 15 September, while flight tests of a Beverage array antenna were completed on 30 September. On 30 October 1970 the radar and the Beverage array were integrated and operated as a single system for the first time.

The Department of Defense initially planned a central sector radar facing south, and an Alaska System facing north, to complement OTH-B radars on the east and west coast to detect enemy bombers and cruise missiles. With the end of the Cold War the military requirement for the central-sector radar had largely disappeared, and it was being pursued now almost exclusively for the drug interdiction mission.

The Congress found this system to be redundant and unnecessary for this effort.

The total value of the ceiling price of that contract for the first and second sectors of the portion of the OTH-B radar program known as the Alaskan System was estimated at

$530,000,000. The unexpected cost growth in the deployment of the first sector of the Alaskan OTH-B system defined procurement of the second sector of this system until at least fiscal year 1991.

The main reason for the cost growth is the high cost of construction of this type of facility at the site selected by the Air Force. Consequently, the deployment of the Central CONUS system was deferred at least until fiscal year 1992, with land acquisition required no earlier than fiscal year 1991.

With the end of the Cold War, just months after their deployment, the three OTH radars on the West Coast were mothballed, and the incomplete Alaska System cancelled, but the three radars in Maine were redirected to counter-narcotics surveillance. In 1994 the Congress directed the Air Force to continue operating the East Coast OTH-B radar at no less than a 40 hour per week schedule, and to ensure that all OTH-B tracking data was transmitted directly to DOD and civilian agencies responsible for providing counter drug detection and monitoring support to law enforcement agencies. In order to utilize the full potential of this wide-area sensor, the Congress directed DOD to (1) assist the Air Force in linking the East Coast OTH-B radar site data directly to users, including but not limited to the U.S. Customs/Coast Guard C3I Center, Miami; Joint Task Force 4 Operations Center, Key West; U.S. Southern Command Operations Center, Key West; and U.S. Southern Command Operations Center, Panama; and (2) fully cooperate with efforts of other government agencies to utilize the dual-use capabilities of this system for remote environmental and weather monitoring and other purposes.

The Air Force maintains the six East Coast and West Coast OTH-B radars in a state called "warm storage," which preserves the physical and electrical integrity of the system and permits recall, should a need arise. It would require at least 24 months to bring these first generation OTH-B radars out of caretaker status and into an operational status-if such a decision to do so were made. Major upgrades costing millions of dollars would be necessary to bring the outdated technologies up to modern standards. The incremental cost of operating the East Coast OTH-B system for environmental research and services is about $1.0M to $1.5M per year. The environmental monitoring aspects of the system are unclassified. Similar coverage in the eastern Pacific could be obtained at about the same cost.

In 1991, NOAA recognized the potential of these military relics of the cold war for environmental monitoring and asked the Air Force's permission to look at the part of the radar echo that the Air Force throws away -- the ocean clutter. NOAA's tests

Showed that this clutter can be processed to extract ocean surface wind direction over huge, data-sparse ocean areas , vital and the ocean's circulation. Tropical storms and hurricanes were tracked, and a system for delivering radar-derived winds to the National Hurricane Center was developed.

5.3 Coverage of OTH Radar

The combined coverage of the six OTH-B radars is about 90 million square kilometers of open Ocean where few weather instruments exist. Recent tests have also demonstrated OTH radars ability to map ocean currents.

5.4 Working of OTH Radar

Over-the-horizon (OTH) radars were developed to detect military targets far beyond the optical horizon. They use 5-28-MHz radio waves, which reflect from the ionosphere, reaching up to 3,500 km in one "hop." Properties of the ocean surface are extracted from the minute amount of energy scattered by the sea surface back to the radar. To find out how we extract ocean-surface properties

from what the military discards as "sea clutter

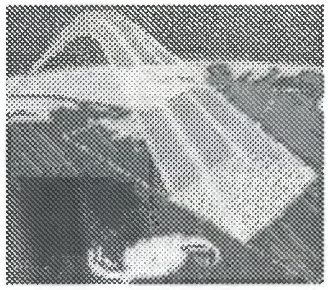


Figure 5.1 show radiation pattern of OTH Radar

5.5 Ocean Measurement Properties of OTH Radar

In order of increasing difficulty,

1. Surface wind (Bragg-resonant wave) direction

2. Radial surface currents (current vectors with two radars)

3. Sea state (eg., rms wave height)

4. Surface wind speed

5. Dominant wave period

6. Dominant wave direction

7. Non-directional (scalar) ocean wave spectrum

8. Combined swell and wind-wave spectrum

5.6 The Distance That OTH Radars Can See

Using one ionospheric reflection, OTH radar normally covers the range interval between about 500 ad 3,500 km. This experimental surface wind-direction map, which covers about 40-million square Kilometers of the Pacific Ocean, was made in about three hours with the three Air Force OTH-B radars on the California-Oregon border. Only direction is indicated here; wind speed was not measured. Even so, mess scale structure of surface cyclones, anticyclones, and fronts is clearly resolved.

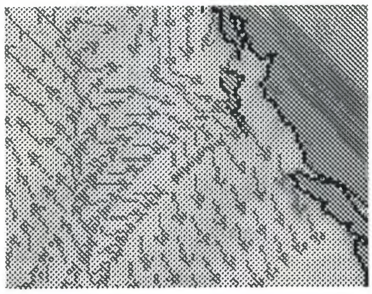


Figure 5.2 map surface wind streamlines in the hurricane

www.Etl,noaa.gov/technol/gov/othr

5.7 Synoptic And Meso Analysis Over The Tropical Atlantic

The Air Force adapted OTH-B radars in Maine to map surface wind streamlines in the hurricane breeding grounds of the tropical Atlantic. Tropical waves crossing the Atlantic can be seen in detail not available with any other sensor. Under favorable conditions, such waves develop into tropical storms and hurricanes. Hurricane Research Division, provided these experimental maps to the National Hurricane Center for 40 days during the 1994 hurricane season.

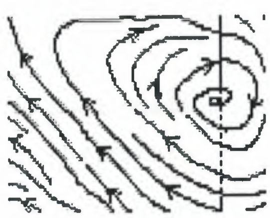


Figure 5.3 surface wind stream lines OTH radars Can track tropical storms and hurricanes.

This surface wind direction map was made in less than one hour with the Air Force **OTH-B** radar in Maine, just as Hurricane Andrew was heading toward its devastating encounter with the South Florida coast.

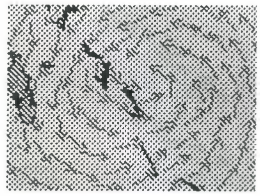


Figure 5.2 images of the surface wind-direction pattern

5.8 Tracking Hurricane Claudette

The OTH-B radar in Maine captured five images of the surface wind-direction pattern associated with 1993 Hurricane Claudette, which just missed Bermuda. Eye locations derived from these radar images are compared here with the official National Hurricane Center track for the storm.

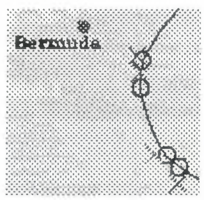
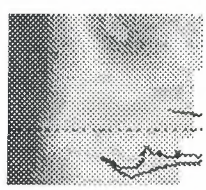


Figure 5.3 north Virginia. Currents

www.Etl,noaa.gov/technology/othr

5.9 Surface Currents In The Florida Straits

This map of the radial component of ocean surface currents was made using the U.S. Navy to Replace Over-the-Horizon Radar (ROTHR) to the north in Virginia. Currents flowing toward the radar (that is, nearly northward) are colored red and orange. Currents flowing away from the radar are colored green and blue.



www.Etl,noaa.gov/technology/othr

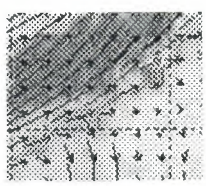
5.10 Surface Currents In The Western Caribbean and Gulf of Mexico

This map of radial currents made by the Texas ROTHR (to the northwest) shows details of the Atlantic Western Boundary Current as it flows through the Yucatan Passage, makes a 180-deg turn in the Gulf of Mexico (the Loop Current) and flows eastward into the Florida Straits. Bifurcations and eddies in the western Caribbean reveal the influence of bottom topography.

www.Etl,noaa.gov/technology/othr

5.11 The First Dual OTH Radar Surface Current Map

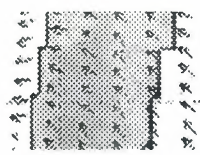
This test, performed by simultaneously illuminating the Florida Straits with both the U.S. Navy ROTHR radars in Texas and Virginia, reveals the structure of the Florida Current, and ancillary flows, with 10-km resolution [1996]



www.Etl,noaa.gov/technology/othr

5.12 AN OTH Radar Data Can Be Merged with Satellite Data

The color strips show coverage over the North Atlantic. Wind speed is color coded, with orange indicating highest speeds. The OTH-B wind directions for the same day are superimposed, filling in the gaps in the satellite data.



www.Etl.noaa.gov/technology/othr

5.13 The Availability Of OTH Radar Data Now

The Air Force and Navy radars have so far been for research and demonstration purposes only. Therefore, only archival data are available. The Air Force has deactivated its OTH-B system and now maintains the six East Coast and West Coast OTH-B radars in a state called warm storage, which preserves the physical and electrical integrity of the system and permits recall, should a need arise.

The two U.S. Navy R(OTHRs) in Virginia and Texas are presently in full-time use for drug interdiction surveillance. Our oceanographic research using OTHR has not been permitted since October, 1999. Other OTH radars in France, Australia, and Russia could be adapted to environmental monitoring.

5.14 The Next

The purpose of piggybacking our research on military OTH radars has been to demonstrate the ocean-monitoring potential of this technology, not a long-term monitoring solution. The next step is to design a low-cost sky-wave radar dedicated to oceanographic applications and let potential users decide whether the cost is justified by the kinds of services we have demonstrated. A possible installation would focus on the Gulf of Mexico, the Caribbean Sea, and the hurricane approaches to the U.S. East Coast and Gulf Coast.

5.15 Description

Sky waves Over-the-horizon Backscatter radar system (OTH-B RS) depend on ionosphere propagation conditions. These change with many different cycles; the diurnal cycle, the seasonal cycle and the solar cycle; and with the geographic location and design of the system. Testing the radars under conditions that represent the range of possible variations is difficult. An operational test of a half year or less, can obtain representative data for all but the solar cycle. Missing geographic ionosphere test conditions can be obtained by using data gathered in other locations and by using historical data. Testing system performance over the solar cycle can be accomplished by modeling and simulation. Several models have been developed to accomplish this task. The drawback to this approach is that modeling requires forecasts for the next solar cycle which the scientific community has great difficulty providing. This paper reviews the impact of solar cycle ionosphere changes have on OTH-B RS that operate in the mid-latitude ionosphere, and view the polar and the equatorial ionosphere. These effects are related to the solar cycle changes in solar flux and geomagnetic conditions. The lack of success of the solar-terrestrial physics community in forecasting the next solar cycle and the accompanying geomagnetic disturbances is considered. Finally, an approach to circumvent the need for a forecast of the solar flux magnitude and timing in OTH-B RS performance modeling is suggested.

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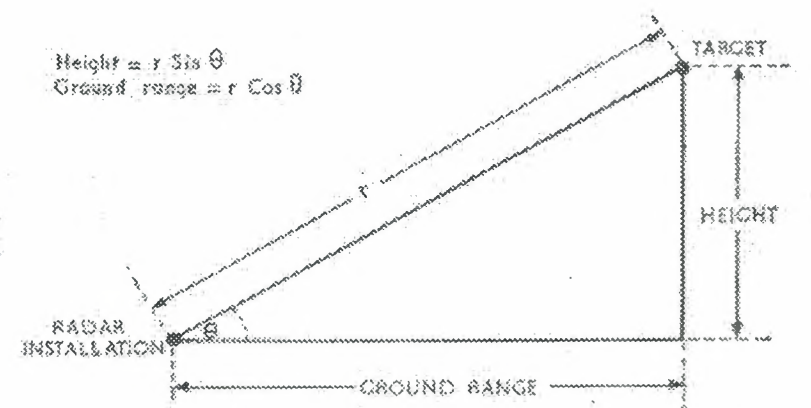
CHAPTER SIX

MATCHED FIELD ALTITUDE OF OVER THE HORIZON RADAR

6.1 MATCHED FIELD ALTITUDE ESTIMATION FOR OVER THE HORIZON RADAR

Over-the-horizon (OTH) radar performs very wide-area surveillance by taking advantage of the refractive and multi path nature of high frequency (3 to 30 MHz) propagation through the ionosphere. OTH radar is currently used in such diverse applications as: 1) locating small aircraft carrying illegal drugs destined for the United States, and 2) remote sensing of ocean surface conditions from the Doppler frequency spectra of radar backscatter. Aircraft targets are discriminated from ground clutter in OTH radar by detecting peaks in delay-Doppler maps which correspond to returns with non-zero Doppler frequency shifts. After the detection of a target, its position is tracked in delay (i.e. slant range), horizontal wave number (i.e. slant azimuth), and Doppler frequency. Although OTH radars have long been capable of localizing targets in range and azimuth, these radars have not previously been able to estimate aircraft altitude. Determining aircraft altitude is critically important in many applications since it is facilitates the discrimination of targets of interest from general aviation traffic. The phenomenology which can be used for aircraft height finding are the differential delays and Doppler frequency shifts between bistatic micro-multi path returns from the radar In work by others, large bandwidth radar waveforms.

Super-resolution techniques and spectral analysis of target fade characteristics have been proposed in order to resolve the micro-multi-path returns and then estimate altitude. However, this approach requires signal bandwidths in excess of 100 kHz. and/or observation times in excess of 30 minutes, which is well beyond what is typically available in OTH radar applications. Straightforward application of acoustic matched-field signal processing techniques is complicated by the fact that since the target scattering function is unknown, the relative micro-multi-path amplitudes and phases of the return from a single dwell are impossible to predict. Thus traditional passive sonar MFP approaches which assume point-source radiation and then correlate individual snapshots of data with replica fields determined solely by the propagation channel are precluded. In our work, we've extended matched-field processing techniques to this application by processing a sequence of revisits on a target [i.4, iv.3, iv.4, iv.8]. Multi-dwell matched-field altitude estimation (MFAE) works by modeling the changes in the coherent, but unresolved, direct and surface reflected target returns from dwell-to-dwell. In particular, the pattern of rapid shape changes due to aircraft motion, seen as fading of the complex-valued radar return in delay-Doppler space, are strongly dependent on aircraft altitude. Using a ray-trace multi-path propagation model to predict rapid fading, and first-order Markov modeling to handle slow fluctuations due to target aspect changes and medium fluctuations, a maximum likelihood estimate (MLE) of aircraft altitude has been developed. The MLE involves the generalized correlation of consecutive radar dwells where the multi-path propagation model is used to compensate for target altitude-dependent changes of the return between revisits. Further, as more revisits to the target are made, the likelihood function for aircraft altitude is updated to achieve more accurate estimation. An example of the resulting time-evolving logarithmic function obtained using actual radar returns off a small twin-engine aircraft at a distance 2300 km away from the receive site at an altitude of only 5,000feet is shown in Figure .



CALCULATION OF HEIGHT AND GROUND RANGE

FIGUR 6.1

Using one ionospheric reflection, OTH radar normally covers the range interval between about 500 and 3,500 km. This experimental surface wind-direction map, which covers about 40-million square kilometers of the Pacific Ocean, was made in about three hours with the three Air Force OTH-B radars on the California-Oregon border. only direction is indicated here; wind speed was not measured. Even so, mesoscale structure of surface cyclones, anticyclones, and fronts is clearly resolved.

6.2 Over The Horizon Radar Types

* The two types of over-the-horizon radar
* Surface-wave radar
* Sky-wave radar

Over-the-horizon radars are even less perfect than microwave systems, but
The rewards for seeing over the horizon are worth pursuing.

It has been known since the experiments of Guglielmo Marconi in 1901 that Radio waves could propagate beyond the horizon because of the signals he Successfully transmitted from Poldhu in Cornwall, UK, to St John's, Newfoundland. Investigations into the cause of this propagation soon Revealed that the solution to Maxwell's equations for a wave at a plane Interface between two media gives a space wave (free-space propagation) And a surface wave (a wave guided along the interface). With the discovery of the earth's ionosphere in the 1 920s, it was realized that there was also at third possible mode of propagation, the ionospheric wave, which turned out To be the explanation of Marconi's transatlantic communications

.The propagation of HF (3-30 MHz) radio waves over great distances Has always been exploited in communications, and sometimes frequencies Lower than HF are used, as listeners to long-wave radio will know. During World War II the UK air defence radar `Chain Home', operating on 20-30 MHz, was occasionally troubled by `nth-time-around' clutter created

When the radio signal was scattered by the ionosphere and traveled unusually Long distances. Under these conditions the normal operating PRF of 25 Hz

Was reduced to 12.5 Hz (details in Neal'). In other countries, similar Discoveries were made, and many radar engineers began thinking of turning This unwanted propagation to advantage.

From the early experiments with long-range propagation, two kinds of HF radar or `over-the-horizon' (0TH) radar have been developed, known As surface-wave (or ground-wave) radar and sky-wave radar, making use of The surface-wave and the ionosphere modes of propagation respectively Surface-wave systems were first operated in the early 1 950s and effective sky-wave systems a little later. The reason for the slow development of 0TH Radar compared to more conventional systems is not a reflection on the ability or the imagination of the engineers involved but rather the constraints

Of the technology available at the time. surface-wave radar uses the surface-wave propagation mode to look over the immediate horizon, and it may be used to survey ranges up to a maximum of certainly no more than 400 km. It is most useful as a local area Defence system and as a method of collecting good-quality wave and tidal Information over restricted area of ocean. Although bistatic systems have Been operated successfully, surface-wave radar is regarded as being a Predominantly monostatic technique with a relatively low capital cost.

Sky-wave radars, on the other hand, are almost always large, bistatic and very expensive. These radars make use of the ionosphere to scatter radio waves very long distances beyond the horizon, sometimes in forward scatter mode to a receiver beyond the target. The minimum range is about 1000 km and the maximum useful range is around 4000 km. sky-wave radar is thus more suited to the defence and Remote Ocean sensing needs of countries of such continental proportions as the USA, the former USSR and Australia.

6.3 Surface Wave Radar

The principle of surface-wave or ground-wave (gw) radar is that a surface Radio propagation mode can be utilized to make a radar signal follow the Surface of the sea as it disappears over the horizon. The method works only

For vertically polarized antennas in contact with salty conducting water; it Cannot be used over land, on freshwater lakes, or where fresh water dilutes

The sea, such as in the Baltic or the Nile Delta.

The propagation of radio waves along surfaces has been analyze Extensively in the past; the theory is complex and is, for all practical purposes, Impossible to solve manually. However, intuitively we would expect to find Such propagation because, although the sea is a good conductor, it is Not perfect and it supports a small horizontal electric field induced

6.4 Modeling and performance Of HF/OTH Radar Target Classification Systems

The effects of a class of multi-path propagation channels on the performance of a over-the-horizon (OTH) radar target classification system are considered .a Ricans frequency-selective fading channel model is employed to characterize the effects of the multi-path propagation medium and evaluate the performance of radar target classification systems. The performance of classification algorithms that employ relative amplitude, relative phase, and absolute amplitude measurements as features is investigated. Performance estimates of the various classification algorithms for interesting sets of channel parameters are obtained /by means of Monte-Carlo simulations.

6.5 The Over The Horizon Radar Equation

The sky-wave radar equation is generally expressed as follow:

$$\mathrm{SNR} = \frac{P_t G_t G_r \sigma \lambda^2 t_i L_s l_{it} l_{ir}}{(4\pi)^3 R_t^2 R_r^2 F_a k T_0} \quad [\quad] \qquad \text{............ (1)}$$

Where Pt = mean transmitted power f[W]; GiGt = antenna gains relative to

An isotropic radiator in free space [ ]; σ = target cross-section, not

Free-space but as measured, i.e. including any surface reflection effects .

λ= radar wavelength[m] ; t = coherent integration time [s]; Is, = system

Loss factor [ ];l it,Iir = additional path Josses on outward and return paths due to **D** and **E** region absorption, Rt, R1 = outward and return distances to target; and F,kT0 = apparent external noise level [W Hz'], with Fa the effective antenna noise factor, usually expressed in db above kT0, above -204 dB W Hz'. The bandwidth is assumed to be 1/ri.

Except during auroral absorption the loss factors Iit and Iir may amount To only a few decibels during the day and are near zero at night (details of How to calculate these losses may be found in reference 4). System losses are More severe and are due to a variety of causes related to the antenna design And signal processing. Typical system losses are listed in Table 10.2 and, While they may vary from one system to another, they seldom fall below 10 db.

The effective antenna noise factor Fa (the result of external noise) Increases with increasing wavelength, and over the range 3-15 MHz a Realistic value to choose for back-of-the-envelope performance estimates is

$$Fa=60-2f_{MHZ} \quad [dB]$$

So that the noise level in a bandwidth, β [dB Hz] is given by

$$Next=60-2.f_{Mh}-204+B \quad [dBW]$$

More detailed formulae, representing different noise environments in the USA, are to be found in Skolnik5. The classic work in this field is the which, although p a very useful database of global atmospheric noise levels.

Table 10.2 Typical over-the-horizon radar system losses

Loss	Typical value
Transmitter feeder and voltage standing-wave ratio losses	1.0 dB
Transmit antenna ground and resistive losses	0.5 dB
Transmit antenna weighting loss	0.8 dB
Target not in centre of the transmit beam	
Azimuth	0.9 dB
Elevation	0.5 dB
Target not in centre of the receive beam	
Azimuth	0.9 dB
Elevation	0.5 dB
Receive antenna weighting loss	1.1 dB
Receive antenna ground loss	1.0 dB
Degradation by internal noise sources and intermodulation products	0.5 dB
Eclipsing losses due de-ramping (only correctly timed at one range) —pulse radars use protection gating giving a similar eclipsing loss	0.9 dB
Receiver filter and digitization losses	0.2 dB
Range weighting loss over one frequency modulation sweep	1.2 dB
Target not in centre of range bin	0.5 dB
Fast Fourier transform weighting loss in doppler processing	2.2 dB
Target not in centre of fast Fourier transform doppler bin	0.4 dB
Range and doppler smearing due to target movement during dwell time	0.6 dB
Loss due to constant false-alarm rate thresholding process	1.3 dB
Total system loss L_s for over-the-horizon radar	15.0 dB

It is commonly assumed that nobody can look around corners. However, some radars can. The 'corner' to be looked around is the horizon, and more often than not there are interesting surface objects which are below the horizon but still at ranges where surveillance coverage is desired. The beams emitted by 'ordinary' radars operating at microwave frequencies follow the rules of ray optics - their signals propagate along a straight line and that's about it. These radars can be overcome by aircraft approaching at extremely low altitudes (on the order of 10m) - a tactics employed by military aircraft and drug transporters alike.

Over the Horizon radars close the low altitude gap and provide advance warning which directly translates into reaction time. There are two different mechanisms which can be exploited: HF Sky-wave and HF Ground Wave. The HF or 'High Frequency' range is the part of the electromagnetic spectrum between 3MHz and 30MHz.

CHAPTER 7

THE CASE FOR BUILDING A CURRENT MAPPING OVER THE-HORIZON RADAR

7.1 THE CASE FOR BUILDING A CURRENT MAPPING OVER THE HORIZON RADAR

Results of recent tests with the U.S. Air Force and U.S. Navy over-the-horizon (TH) radars show that it is possible to map near-surface currents with 10-15-km resolution to ranges greater than 2,500 km. The technique is similar to that used by commercially available high-frequency current-mapping radars, except that range is greatly extended by bouncing the radar beam off the ionosphere. Current maps made with U.S. Navy OTH
Often shown .

Dual-OTHR map of the complex pattern of surface currents between Florida, Cuba, and the Bahamas on 14 May 1997. A portion of the Florida Current (upper left) is diverted to the south of the Cay Sal Bank, and into a cyclonic eddy to the east of the bank.The radars that made this map are in Texas and Virginia. Figure 7.1&7.2

7.2 Radar Measuring Resolution

Sky wave radars illuminate the sea surface in a sequence of patches that typically measure 150 km in the azimuth dimension and 200 km in the range dimension and each of which requires separate propagation management. Each patch is divided into several hundred cells that determine the radar's spatial resolution. From each cell (typically 6 x 15 km), the radar obtains a spectrum of the sea echo from which information about surface winds, waves, and currents is extracted.

The Case For Building a Current Mapping Over The
Horizon Radar

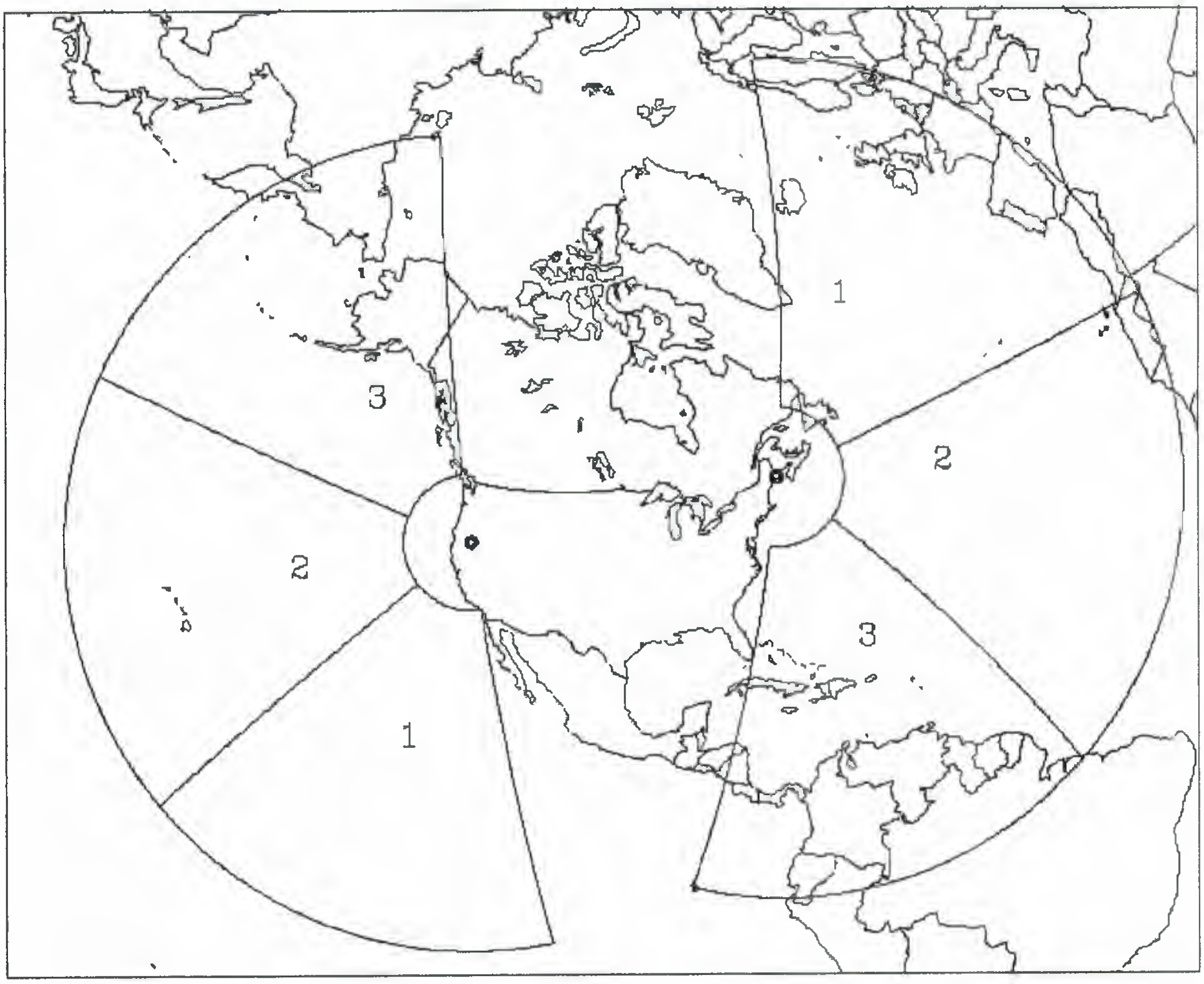


Figure 7.1

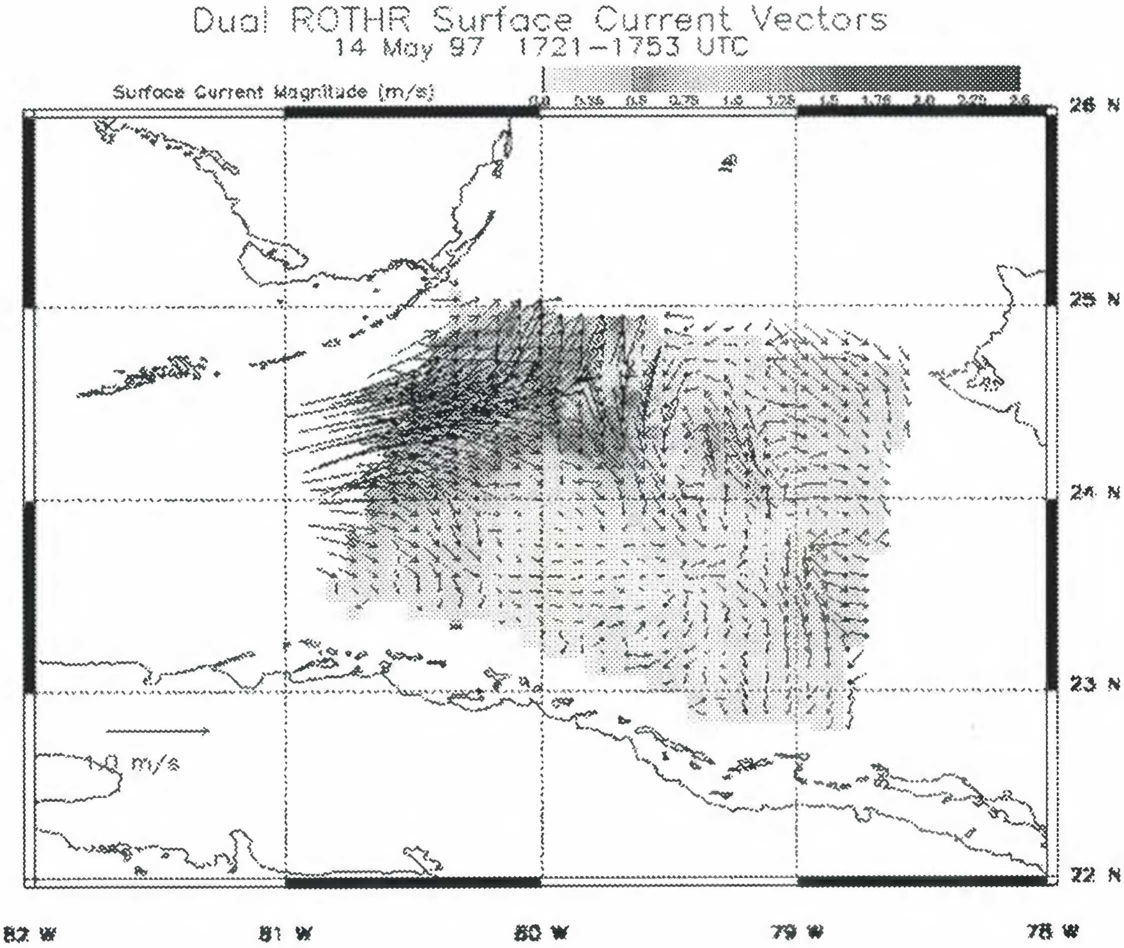


Figure7.2 OTHR map of the complex pattern of surface currents between Florida, Cuba, and the Bahamas

7.3 uses of the over-the-horizon radar

Over-the-horizon radar technology has grown out of a number of related technologies and, before embarking on the history in more detail, it is appropriate to establish the basis of how OTHR operates and what advances were required to make it feasible.

All radar operates by transmitting radio frequency energy to a distant "target" which scatters the energy. Part of the scattered energy returns in the direction from which it came. By comparing the returned energy with that sent out, and in particular by measuring the time taken for the energy to go and return, the target range can be determined. The direction of the target corresponds to the radar's direction of look, so both direction and range are determined. Hence the acronym RADAR, Radio Detection and Ranging. Radio frequency energy, like light, travels in a straight line in free space so the distance over which a radar is effective is limited by obstacles and, in particular, by the bulge of the earth. Raising the height of a radar, as for an optical instrument or observer, allows you to see further around the bulge the distance to the horizon is increased—but it is a square root relationship. Doubling the horizon distance calls for a quadrupling of radar height.

As an alternative to increasing the radar height, use of ionospheric reflection to bounce radar signals well beyond the horizon is an obvious and attractive proposition for long range radar detection.

A shell of ionisation called the ionosphere surrounds the earth in a number of more-or-less distinct layers at heights between 70 and 350km. It has been known for many years that these layers affect radio frequency transmissions and that for a range of frequencies the ionosphere has the effect of bending back radio transmissions as if by reflection. Thus, the ionosphere is, crudely, a mirror in the sky for the frequency band for which it is effective. So-called shortwave communication has since the earliest days of radio used these reflective properties—signals are bounced between the ionosphere and the earth's surface a number of times to communicate between points on the surface which can be on opposite sides of the globe. It is hardly surprising that radar workers should also contemplate the ionosphere as an aid to greatly increased range and to seek ways of implementing radar in the high frequency (shortwave) band to capitalize on ionospheric reflection.

7.4 Over The Horizon Backscatter

Information that affects climate The U.S. Air Force's over-the-horizon-backscatter (OTH-B) air defense radar system is by several criteria the largest radar system in the world. Six one-million-watt OTH radars see far beyond the range of conventional microwave radars by bouncing their 5-28-MHz waves off the ionosphere, an ionized layer about 200 km above the earth. It was developed over 25 years at a cost of $1.5 billion to warn against Soviet bomber attacks when the planes were still thousands of miles from US air space.

In 1970 Air Force Rome Air Development Center [RADC] engineers developed and constructed components for a frequency modulation/continuous wave (FM/CW) radar capable of detecting and tracking objects at over-the-horizon ranges. The ra`dar installation and evaluation was accomplished on 15 September, while flight tests of a Beverage array antenna were completed on 30 September. On 30 October 1970 the radar and the Beverage array were integrated and operated as a single system for the first time.

The Department of Defense initially planned a central sector radar facing south, and an Alaska System facing north, to complement OTH-B radars on the east and west coast to detect enemy bombers and cruise missiles. With the end of the Cold War the military requirement for the central-sector radar had largely disappeared, and it was being pursued now almost exclusively for the drug interdiction mission.

The Congress found this system to be redundant and unnecessary for this effort.

The total value of the ceiling price of that contract for the first and second sectors of the portion of the OTH-B radar program known as the Alaskan System was estimated at $530,000,000. The unexpected cost growth in the deployment of the first sector of the Alaskan OTH-B system defined procurement of the second sector of this system until at least fiscal year 1991.

The main reason for the cost growth is the high cost of construction of this type of facility at the site selected by the Air Force. Consequently, the deployment of the Central CONUS system was deferred at least until fiscal year 1992, with land acquisition required no earlier than fiscal year 1991.

With the end of the Cold War, just months after their deployment, the three OTH radars on the West Coast were mothballed, and the incomplete Alaska System cancelled, but the three radars in Maine were redirected to counter-narcotics surveillance. In 1994 the Congress directed the Air Force to continue operating the East Coast OTH-B radar at no less than a 40 hour per week schedule, and to ensure that all OTH-B tracking data was transmitted directly to DOD and civilian agencies responsible for providing counter drug detection and monitoring support to law enforcement agencies. In order to utilize the full potential of this wide-area sensor, the Congress directed DOD to (1) assist the Air Force in linking the East Coast OTH-B radar site data directly to users, including but not limited to the U.S. Customs/Coast Guard C3I Center, Miami; Joint Task Force 4 Operations Center, Key West; U.S. Southern Command Operations Center, Key West; and U.S. Southern Command Operations Center, Panama; and (2) fully cooperate with efforts of other government agencies to utilize the dual-use capabilities of this system for remote environmental and weather monitoring and other purposes.

The Air Force maintains the six East Coast and West Coast OTH-B radars in a state called "warm storage, which preserves the physical and electrical integrity of the system and permits recall, should need arise. It would require at least 24 months to bring these first generation OTH-B radars out of caretaker status and into an operational status-if such a decision to do so were made. Major upgrades costing millions of dollars would be necessary to bring the outdated technologies up to modern standards. The incremental cost of operating the East Coast OTH-B system for environmental research and services is about $1.0M to $1.5M per year. The environmental monitoring aspects of the system are unclassified. Similar coverage in the eastern Pacific could be obtained at about the same cost.

In 1991, NOAA recognized the potential of these military relics of the cold war for environmental monitoring and asked the Air Force's permission to look at the part of the radar echo that the Air Force throws away -- the ocean clutter. NOAA's tests

Showed that this clutter can be processed to extract ocean surface wind direction over huge, data-sparse ocean areas , vital and the ocean's circulation. Tropical storms and hurricanes were tracked, and a system for delivering radar-derived winds to the National Hurricane Center was developed.

7.5 Matlab Demonstrations

The following demo files are available: (Please close all windows and clear all variables before running each demo)

polarisation_demo.m

statistics_demo.m

segmentation_demo.m

separation_demo.m

k_demo.m

weibull_demo

correlation_demo.m

change_demo.m

k_detection_demo.m

cfar_theory_demo.m

cfar_sim_demo.m

7.5. 1 polarization demo m

This simulates multivariate polar metric samples and compares to theory.

7.5. 2 Segmentation_demo.m

Shows how to load actual Air-SAR data from a rice growing area in Japan. Decompresses from the Compressed Stokes form and corrects the scene to have positive-definite covariance matrices due to the slightly lossy compression. Maximum likelihood segmentation is performed by merging single pixels. Expectation maximization is used to automatically classify the scene into 5 classes. The sample covariance matrices are generated. The theoretical separation distance (related to classification error) between Urban and Vegetation classes is calculated using components of the covariance matrix. .

7.5.3 Separation demo m

This script verifies the class separation theory in `Polar metric Classification using Expectation Methods', G Davidson et al. that, as far as I know, is an unpublished result.
It gives an expression for the Maximum Likelihood polar metric classification accuracy between two classes based on the number of looks and the eigenvalues of the ratio of covariance matrices. This assumes that the polar metric samples are completely described by their covariance matrices i.e. no texture or environmental variation.
There is a small chance of it failing, if so run it again (I don't how to generate example class covariance matrices that are guaranteed positive definite).
The output is text only and basically tests the accuracy of multiple pole ,m if the code is changed for look s=1 then single pulse m can be tested as well. Due to Mat lab's inability to recognize certain types of matrices, operations like the determinant of a positive definite covariance matrix are o(1 + j*eps). Floating point accuracy is repeatedly checked to remove the erroneous complex component

7.5.4 Statistics demo m

This simulates univariate speckle distributions from exponential, gamma,

7.5.5 k demo m

Independent Identically Distributed samples from the K distribution are generated for various shape parameter nu. The normalised log estimate is used to obtain the sample estimate of nu. See correlation demo .m for a method of generating correlated K.

7.5.6 weibull demo m

Independent Identically Distributed samples from the Weibull distribution are generated for various shape parameter a. A numerical MLE search is used to obtain the sample estimate of the mean mu. for a thorough treatment of Weibull clutter.

7.5.7 Correlation demo m

Generation of correlated compound K is demonstrated using the algorithm from [1]. Correlated gamma is generated with a desired autocorrelation function by modifying the correlation of the source Gaussian. The compound formulation is used to generate the appropriate K. Great effort and a bit of luck has helped get this numerically stable.

7.5.8 change demo m

Illustrates the general theory of change detection for homogenous clutter. . The maximum likelihood measure for a change in the underlying intensity between two speckled areas is the ratio of their mean Unfortunately, very few references recognise that this measure is distributed according to an F distribution. By using this, the math's it can be considerably simplified.

7.5.9 k detection demo m

This demonstrates the generation of K-distributed clutter in the presence of thermal noise. It shows that for a reasonable Probability of Detection, and typical Probability of False Alarm, the existing Swerling Theory can be used for detection prediction of the Swerling target models. It also shows the significant increase in False Alarm Rate if a threshold is based on theory which assumes Gaussian clutter (i.e. exponential in intensity).
See RSNlap a more detailed description of this theory (and a method of determining the correct threshold for multi-look K distribution in thermal noise).
The generated Clutter to Noise Ratio of 0dB. Targets fluctuating according to the Swerling models are introduced for various signals to Interference Ratios. The approximate theory is in agreement with Monte Carlo results.

7.5.10 Cfar Theory demo m

This demo reproduces the results from which calculated the expected detection losses associated with various Constant False Alarm Rate (CFAR) processors. These include Cell Averaging (CA), Cell Averaging Greatest (CAGO), Cell Averaging Smallest Of (CASO), Order Statistics (OS) and Trimmed Mean (TM). Comparison can be made to the Optimum

Processor as assumed by the Swerling Detection theory. All plots assume a Swerling target in Gaussian clutter (i.e. exponential in intensity).

7.5.11 Cfar sim demo m

Various CFAR processor architectures have been implemented in C and compiled as a mix file for speed. This demonstrates these functions upon simulated speckle. The False Alarm rate is measured from CA, CAGO, CASO, OS and TM processors using similar window sizes and parameters to that in cfar theory_demo.m
The output is text only, and shows that the desired Pfa of 1e-4 is in agreement with theory, within statistical uncertainty, for all considered processors.

7.5.12 k noise demo m

This simulates clutter drawn from the K distribution in the presence of thermal noise. Sample results are compared to theoretical PDF and CDFs. These are non-trivial expressions that require time-consuming numerical integration. The integration is quite sensitive; the code demonstrates how a singularity was removed and how to integrate to an effective infinity. Note the results plot both the PDF and the

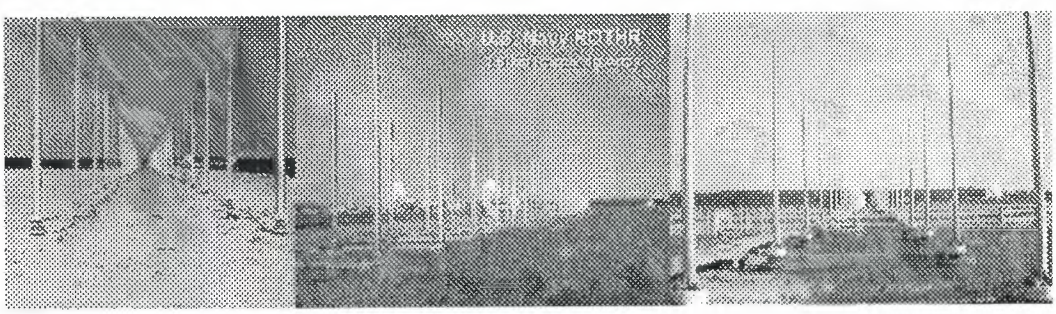
CHAPTER EIGHT
PROBLEMS OF THE OTH RADAR

8.1. Problems Of The OTH Radar

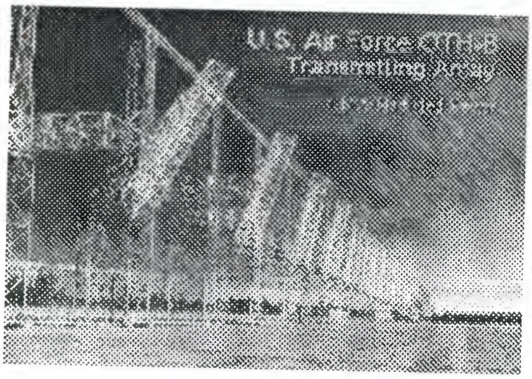
Although the physical principles underlying sky wave current measurements are identical to those of surface-wave HF radars [10], there are many practical differences. Illuminating the sea over long ionospheric paths poses additional processing obstacles and added system complexity.

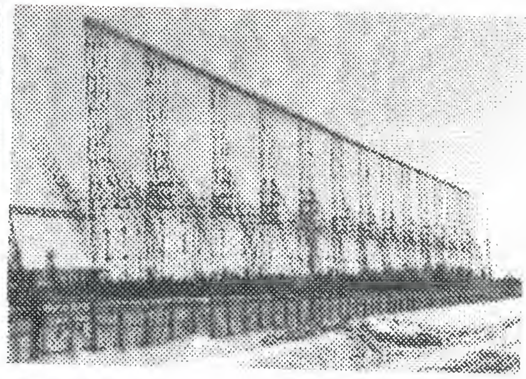
8.2 Large Receiving Array

The main component of a sky wave radar system is a large-aperture steer able receiving antenna array. The need for a large aperture antenna array is not easily compromised. Beams of 1 or less are required to resolve the most interesting current structures at a range of 1,000 km or more. Larger beams would smear out spatial detail. At a range of 1000 km, a 1 beam would produce a radar cell about 18 km wide and would require a 1-km array aperture for a typical radar frequency of 15 MHz. Furthermore, a narrow azimuth beam is required to reduce azimuth multi path caused by ionospheric in homogeneity [11]. The array should be steer able over ±45 in azimuth. "



Figyre8.1 Rx & Tx antenna





The two transmit antenna arrays at Lost Hills are made up of log-periodic elements that can transmit over the frequency range from 6-30 MHz

Two digitally controlled and steer able receiving antennas are arrayed over distances of 2.3 and 2.5 km to receive the HF illuminating signals transmitted and returned via the ionosphere

8.3 Multiple Frequencies

A sky-wave radar must be able to operate anywhere between about 5 and 28 MHz to adapt to prevailing ionospheric conditions. Generally, only a narrow range of frequencies can provide stable propagation to a given patch of ocean at a given time. Finding the best frequency for a given path and time requires real-time 'propagation management,' that is, sampling of the ionosphere's reflecting properties at many frequencies. In addition, a spectrum monitoring system is required for avoiding interference to and from other users of the crowded HF spectrum.

8.4. Ionospheric Distortions

A major problem with a sky wave radar compared with a surface-wave radar is dealing with the contaminations the radar signal suffers during two reflections from the ionosphere. Contamination often occurs, even if propagation management is performed correctly. Fortunately, a number of strategies have been developed over the years to cope with these contaminations. Some attempt to avoid the conditions known to cause them, whereas others correct for or remove distorted data after it is collected. For current mapping in particular, we have found it desirable to wait for stable ionospheric conditions, such as typically occur near midday, and to use lower ionospheric layers, (E and F1) whenever possible.

8.5 Costs

The greatest challenge in designing a sky wave radar for ocean monitoring is making the technology affordable to civilian users. Modern military over-the-horizon radars cost upwards of $100M.

A major cost driver is the receiving antenna system, which cannot be made much more compact than its military counterparts without degrading the radar's spatial resolution to an unacceptable level.

In general, observing systems such as this would be expected to yield their ultimate benefit to society as parts of an integrated regional ocean observing system. Such a system would combine data from multiple complementary sensors with ocean-circulation models and make usable products readily available to customers.

8.6 HF Ground Wave Propagation Diffraction

The calculation of propagation paths via ray optics is only valid if the wavelength is much smaller than the dimensions of any other objects which happen to be around.

The case of sending an HF signal of some 100m wavelength along the boundary between air and a surface cannot be handled with the methods of ray optics. Rather, it is to be dealt with using the laws of diffraction between media of different dielectric properties. Diffraction means that the beam of electromagnetic energy is bent into the direction of the material which is more 'dense', or has the bigger epsilon value. The net effect is that an HF signal is hugging the ground, or creeping along the boundary. This is the HF ground wave.

Of course, diffraction occurs with light as well. A famous example is the sunset, preferably observed from a bar at the shores of a South Pacific island. When the sun appears to be touching the ocean's surface then it actually is already below the horizon. The density of the atmosphere significantly decreases with height and at this time of day, the sunlight enters the atmosphere from a grazing angle. Thus the propagation path gets bent towards the ground and even human eyes get a chance to look around the corner. Diffraction is also responsible for the dark orange or red color that the sun takes on in this situation: the effect of diffraction is more pronounced at longer wavelengths, and the red/orange parts of the visible spectrum represent the longer wavelengths. At sunset, sunlight still contains the yellow, green and blue colors (that is, the shorter wavelengths) too but these get diffracted to a lesser degree. Thus, only the red/orange parts get bent down

And eventually hit the ground whereas the other colors only 'touch' the atmosphere and leave it through the back door, To sum it up, the atmosphere works like a huge prism which splits sunlight into its components and sends them into different directions. HF ground wave has been employed for communications since the first days of radio, but research into radar applications began no earlier than in the late 1980s.

The HF ground wave can yield up to 200km coverage over sea, with no gap in the elevation coverage. Application areas are surveillance of littoral waters or detection of sea-skimming missiles. Some prototypes exist, but operational types are not yet known.

CONCLOUSION

In chapter one, we discuss the radar fundamental and how itt determine the distance of the reflecting object determined from the frequency difference between the echo and the wave being transmitted at the time the echo returns. radar searched the sea for enemy ships and surfaced Submarines and kept watch in the sky for aircraft., Radar aided air and Sea navigation and directed fighter and bomber aircraft Radar equipped ships move through fog without danger of colliding with other ships or with ice floes. Radar Determination of Range: a number of different methods have been used to determine the range of objects that reflect radio waves.

.In chapter tow illustrates transmitter produces the short duration high-power r.f pulses of energy that are radiated into space by the antenna. Two main types of transmitters are now in common use. The modulator controls the radar pulse width by means of a rectangular dc pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted (RF) pulse depends on the amplitude of the modulator pulse.

Chapter three discuss, the modulator controls the radar pulse width by means of a rectangular dc pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted rf pulse depends on the amplitude of the modulator pulse.

Chapter four talk about Radar that makes use of the atmospheric reflection and refraction phenomena to extend its range of detection beyond line of sight. Over-The-Horizon radars may be either forward-scatter or back (OTH-B)-scatter systems.

Chapter five discuss thae Over-the-horizon radar technology has grown out of a number of related technologies and, before embarking on the history in more detail, it is appropriate to establish the basis of how OTHR operates and what advances were required to make it feasible.

The continent of chapter six describe the Over-the-horizon (OTH) radar performs very wide-area surveillance by taking advantage of the refractive and multi path nature of high frequency (3 to 30 MHz) propagation through the ionosphere.

Chapter seven go through the Dual-OTHR map of the complex pattern of surface currents between Florida, Cuba, and the Bahamas on 14 May 1997. A portion of the Florida Current (upper left) is diverted to the south of the Cay Sal Bank, and into a cyclonic eddy to the east of the bank. The radars that made this map are in Texas and Virginia.

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