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RADC-TR-69-328, Addendum 1
Technical Report
December 1970

WIDE AREA REMOTE SURVEILLANCE (U)

Sylvania Electronic Systems-Western Division

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WIDE AREA REMOTE SURVEILLANCE (U)

A. Z. Steinbergs
H. D. Friedman
D. R. Rothschild

Sylvania Electronic Systems-Western Division

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FOREWORD

(U) This document constitutes an addendum to the previously published RADC-TR-69-328 (February 1970) interim technical report. It was prepared by Sylvania Electronics Systems - Western Division, P. O. Box 188, Mountain View, California 94040 under contract F30602-69-C-0268, Project 681E0000. Mr. S. J. Militello (COTS) was the Rome Air Development Center project engineer.

(U) This report contains classified material extracted from the Classified document listed below:

"USAF Combat Security Police Force for Air Base Defense" AD 383124, Secret, dated August 1967 Classification Secret, Downgrading Group 3.

(U) Distribution of this document is restricted because it describes a surveillance concept which is inherently flexible and applicable to limited war applications on a world-wide basis wherever and/or whenever they may occur. Knowledge outside of DoD would impair the overall effectiveness of the concept which may be utilized surreptitiously in "neutral" areas.

(U) This technical report has been reviewed and is approved.

Approved: Samuel J. Militello
SAMUEL J. MILITELLO
Tactical Surveillance Section
Tactical Applications Branch

Approved: Joseph L. Ryerson
JOSEPH L. RYERSON, Technical Director
Communications & Navigation Division

(U) ABSTRACT

Initial results of tne basic WARS phase I contract are reported in the WARS Interim Technical Report (RADC-TR-69-328, February 1970). An expansion of this program is embodied in changes "A" and "B" to the contract, the results of which are reported herein. WARS system requirements in terms of the problem it will in part solve have been defined. Unique characteristics exhibited by the enemy during preparation for standoff attacks on Air Force installations have been identified. WARS systems analysis and systems design, including surveillance and intra-wide area communications, have been specified. A modular design approach that will be taken in designing the WARS hardware has been developed. Added features that are felt necessary in making the WARS system adaptable to world-wide use and to the wide variety of possible Air Force applications have been identified. These features notably include local alarm data processing units that will reduce the data load on the RSDCS and the complexity of the CSCPD. The applicability of WARS to the Korean situation and how WARS could best be utilized in that situation has been outlined. Overall conclusions and recommendations are put forth. In general, it is concluded that the WARS concept is feasible, practical, and cost effective. In brief appended information, the organization and duties of the WARS team are tentatively stipulated, the susceptibilities/vulnerabilities of the WARS system are discussed, a scenario of the build-up or development of an air base and the parallel development of BESS is described, and a brief outline of how certain DCPG hardware could be integrated into the WARS system is given.

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(U) LIST OF TABLES

Section 1

INTRODUCTION

1.1 (U) SCOPE

This report contains the analysis and design results of changes "A" and "B" to the basic Wide Area Remote Surveillance (WARS) system, Contract F30602-69-C-0268. The results of this report, when combined with those presented in the "WARS Interim Technical Report,"[1] represents the completion of phase I of the contract, which includes:

a. Establishing the feasibility of the WARS concept

b. Design of the WARS baseline system, and recommendations for a more adaptable system

c. The design approach for the WARS baseline system hardware design.

1.2 (C) BACKGROUND

The WARS Interim Technical Report presented the following aspects of the WARS study:

a. A threat analysis to determine if the threat exhibits distinguishing features during his preparations for a standoff attack that can be sensed with an unattended surveillance system.

b. An analysis of his approach routes leading to launch sites to determine where surveillance hardware can best be deployed to detect the threat. These locations are called "wide areas."

c. An analysis of the SEA environment as it would affect the threat's movement and the deployment and operation of a surveillance system.

d. The analysis and preliminary design of a surveillance system to take advantage of the distinguishing threat features, including the deployment configuration of sensors and recommended sensor types.

e. The analysis and preliminary design of a intra-wide area communications system necessary to relay alarm data to the remote sensor data communications system (RSDCS) for final relay of the alarm data to the air base.

f. A preliminary design approach for the surveillance system and communications system hardware.

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1 Stanford, A. G., Friedman, H. D., and Rothschild, D. R., Wide Area Remote Surveillance, Sylvania Electronic Systems-Western Division; February 1970, RADC-TR-69-328.

1.3 (C) CHANGES A AND B TASKS

Changes A and B to the basic contract include the following additional tasks for phase I:

a. An analysis of the intra-wide area communications system to assure that alarm data loss due to message interference (both from intra- and inter-wide area sources) would be tolerable with respect to the type of threat information to be extracted from the data.

b. A detailed analysis of Korea to determine the applicability of WARS to Korean installations.

c. An initial analysis of the adaptability of the WARS system to world-wide use and its adaptability to the variety of Air Force installations to which it may be applied.

d. A study of the use of in-field or local data processing units to reduce the RSDCS data load and to simplify the base central processor.

In addition, all aspects of the WARS system design were re-examined and refined. In total, this has resulted in a system design consisting of the baseline system plus certain features which are felt to completely satisfy the WARS requirements in terms of flexibility, adaptability, and cost effectiveness.

1.4 (U) REPORT CONTENTS

The report is organized into eight (8) major sections and three (3) appendices. Section 2 outlines the WARS system requirements in terms of the problem it will in part solve: prevent stand-off attacks on U.S. air bases.

Section 3 outlines how WARS fits into the base exterior security subsystem (BESS), of which it is a subsystem.

Section 4 contains a detailed presentation of the WARS systems analysis and systems design, including surveillance and intra-wide area communications.

Section 5 contains a detailed presentation of the design approach that will be taken in designing the WARS hardware.

Section 6 covers the added features to the baseline system that are felt necessary in making the WARS system adaptable to world-wide use and to the wide variety of possible Air Force applications.

Section 7 covers the applicability of WARS to Korea. It outlines the Korean situation and demonstrates how WARS could best be utilized in that situation.

Finally, Section 8 presents the conclusions drawn from phase I of the study and recommendations for future work on WARS.

The first of the three appendices (Appendix A) covers certain operational characteristics of WARS, including:

a. The organization and duties of the WARS team needed to deploy and maintain the WARS system for a large installation.

b. The susceptibilities/vulnerabilities of WARS such as jamming, spoofing and direction finding, and measures to counter these.

Appendix B briefly outlines how certain DCPG hardware could be integrated into the WARS system; notably, air-dropped sensors and special-purpose hand-emplaced sensors.

Appendix C presents a scenario of the build-up or development of a hypothetical air base and the parallel development of its BESS. The scenario is used to demonstrate the flexibility and adaptability of WARS to such a situation.

In summary, the WARS concept was found to be feasible and practical to implement, deploy, and operate. The system as presented in this report is an effective means of detecting activities associated with stand-off attacks before they occur, and can, in addition, provide personnel detection and tracking for nearly any tactical application where this is desirable. The system is flexible and can be used to complement any other area surveillance systems that may be deployed.

Finally, Appendix D is the Bibliography.

Section 2

REQUIREMENTS OF THE WIDE AREA REMOTE SURVEILLANCE (WARS) SYSTEM

2.1 (U) BACKGROUND

In support of national objectives, the United States Air Force must maintain air bases in different parts of the world. Some of these air bases are subject to commando-type raids and standoff weapons attacks. Enemy attempts to penetrate the air base perimeter can usually be repelled by a sufficiently strong base security force. However, the air base is particularly vulnerable to surprise mortar, rocket, or artillery attacks launched from outside the base perimeter. The degree of vulnerability is dependent on the ease with which enemy personnel can move through the area, on the closeness of the area to arms supplies, on the political stance of the natives, and on the degree of control exercised by friendly ground forces, police, and native leaders.

If an air base is vulnerable to standoff weapons attacks,then some supplementary protection must be provided. One solution is to augment the base security force with an electronic system which can provide surveillance of enemy activities in the area. This system will permit the use of a relatively small response force operating from the intelligent use of surveillance data. The essential requirements of such a system are outlined below.

2.2 (U) COVERAGE

The system shall provide surveillance over the land surrounding the base out to the maximum effective range of weapons known to be in the enemy's possession.

2.3 (U) DETECTION

The objective of the system is to detect any activity which is associated with the enemy moving along most likely avenues-of-approach toward most likely launch sites. Examples of such activities are as follows:

a. Movement to and from launch sites by either the site selection survey team or weapon crews

b. Movement of munitions to cache sites

d. Establishment of caches

e. Positioning of weapons.

Although the movement of munitions will typically take place over trails by handcarry or backpack, the enemy might also move munitions by means of vehicles and small boats. Hence, detection of vehicles and boats is also essential.

2.4 (U) DISCRIMINATION

The system must have a low false alarm rate. To accomplish this, maximum use shall be made of any unique characteristics possessed by the threat in order to discriminate the enemy from indigeneous people or friendly forces. Examples of the characteristics which might be used are:

a. Time of activity

b. Size and formation of the group

c. Load transported

d. Distance traveled

e. Rate of travel

f. Direction of movement

2.5 (U) DESIRED INTELLIGENCE

The format of the intelligence supplied by the remote surveillance system must permit rapid interpretation and timely application to counter an impending attack. As a minimum, the system shall supply information on the size, speed, location and direction of travel of the detected threat.

2.6 (U) ADAPTABILITY

The design of the system shall offer maximum flexibility for widely varying modes of operation. Examples of features which should be considered are: (1) utilization of modularized equipment designs, (2) flexible interface requirements and (3) adaptability for different levels of alarm discrimination and processing.

2.7 (U) SERVICE CONDITIONS

The system shall be designed and constructed to withstand the various temperature, humidity and other service conditions which will be encountered in a world-wide deployment. The system shall also be designed to experience no degradation due to illumination by high power radars commonly located near air bases.

2.8 (U) OPERATING LIFE

The overall system shall have an operating life of at least six (6) months using standard batteries and minimum power.

2.9 (U) CONCEALMENT

The system components shall be easily concealed via direct burial or appropriate camouflage, and shall be hand deployed.

2.10 (U) SELF DESTRUCTION

Once the components are installed and armed, any attempt to tamper with these, or failure of the battery, shall cause the encoder (and possible other components) to self-destruct.

Section 3

THE BESS CONCEPT

3.1 (U) GENERAL

This section will briefly describe the concept, known as the Base Exterior Security Subsystem, which is intended to fulfill the requirements stated in Section 2. Under this concept the surveillance of the area surrounding an air base will be accomplished by means of a three component system. The three components, or subsystems, are: (1) Wide Area Remote Surveillance (WARS), (2) Remote Sensor Data Communications (RSDC), and (3) Central Security Control Processor and Display (CSCPD). The function of each of these subsystems is described below.

3.2 (C) WARS

The Wide Area Remote Surveillance (WARS) Subsystem will consist of a multitude of detection devices emplaced in groups, or arrays, along likely avenues-of-approach and in the vicinity of likely launch sites. The WARS subsystem is to provide surveillance over an annulus-shaped area extending from about 8 km to about 24 km from the center of the base.

The function of the detection devices, called Sensor/Transmitter (S/T) units, is to emit alarms when an intruder enters the covered area. The alarms emitted by the S/T units are picked up by relays, called Receiver/Relay (R/R) units, and retransmitted to an alarm collection station, called a Receiver/Interface (R/I) unit. The region covered by all S/T units reporting (by relay) to a single R/I unit is called a Wide Area. Hence, the concept Wide Area Surveillance.

3.3 (C) RSDC

The purpose of the RSDC subsystem is to relay the alarm information from the Wide Areas to the air base. The maximum transmission range will be 24 km. The RSDC will be composed of three major components: these are: (1) Long Range Transmitter (LRT), (2) Repeater, and (3) Base Station. Each LRT will be connected to one R/I unit; therefore, there will be as many LRT's as there are Wide Areas. Repeaters will be used only as required; each repeater will be capable of handling more than one LRT. The function of the Base Station is to receive all alarm transmissions and prepare them for input to the CSCPD subsystem. If the LRT's are to be controlled by a command link from the base, the necessary command and control equipment will also be made a part of the Base Station.

3.4 (C) CSCPD

This CSCPD subsystem will be located on the air base and will serve as the alarm processing and display facility. Its function will be to process the individual alarms through space-time correlations, to report intrusions and to derive confidence levels

3.4 (C) (Continued)

on their validity; and to estimate the number, speed, direction and possible mission of the intruding force. In addition to processing and displaying the alarms which originate in the Wide Areas, the CSCPD will also accept and process reports from sensors emplaced along the base perimeter, from human observers (both ground and air) and from airborne sensing devices.

Section IV

WARS SYSTEM DESIGN

4.1 (U) GENERAL

This chapter contains the results of a study which was performed to define the system design of the Wide Area Remote Surveillance system. The material is organized into two major discussions: one dealing with the detection aspects, the other devoted to the alarm transmission aspects.

4.2 (C) DETECTION ANALYSIS

4.2.1 (C) Dual Detector Arrangement

In order to make the S/T unit easily adaptable to operation under widely varying applications, the unit will be designed to accommodate two separate detector assemblies. One of these will be called the primary detector and the other will be called the auxiliary detector. The S/T unit will be capable of operation with the primary detector alone, or with both detectors. A provision will be incorporated to permit either of the two detectors to control the S/T transmitter. The primary detector will also be able to function as a turn-on device for the auxiliary detector. This type of arrangement will reduce the "on-air" time of such active sensors as IR, radar, or EMID. Another application of the auxiliary detector will be to provide special information about the threat; for example, if ferrous metal is part of the load. In this mode of operation, the primary detector will control the S/T transmitter but the output from the auxiliary detector will be used to change the code structure of the transmitted alarm message.

A description of sensors which might serve as the auxiliary detector is provided in Section 6.2 while the proposed primary detector is described below.

4.2.2 (C) The Primary Detector

4.2.2.1 (U) The Sensor

Before a decision was reached on what sensor to use in the primary detector, all the advantages and disadvantages of a number of different types of sensors were carefully evaluated. In the end, it was decided that the seismic sensor is the best candidate. The reasons for arriving at this decision are listed below:

a. Detection Performance

Extensive data base exists for most environments, except arctic. The detection range is judged to be adequate for the WARS application.

b. False Alarm Rejection

Extensive work has been done in the processing of seismic signals. Low false alarm rates are achievable with currently existing discrimination techniques.

4.2.2.1 (C) (Continued)

c. Cost

Seismic sensors are one of the least expensive sensors.

d. Deployment

Seismic sensors fit into compact packages which can easily be carried and deployed. No critical field alignment procedures are required since the detection pattern is circular.

e. Life

No difficulty is anticipated to operate the sensor for 6 months to 1 year. Power requirements are small and the sensor is relatively insensitive to changes in its environs, such as normal growth of plants, etc.

f. Concealment

Since a seismic sensor requires burial, its concealment is easily accomplished.

The theory of operation of a seismic sensor is well known. Therefore, it will suffice to state that a geophone detects intruders by detecting the vibrations set-up in the earth by their footsteps. Walking men and moving vehicles, along with a number of other sources such as aircraft, munitions, and rain, impart energy to the earth and this energy sets up seismic waves. The geophone transduces the vibrations caused by the seismic waves into an electrical signal, which is then amplified to a level suitable for the discriminator to operate on.

4.2.2.2 (C) The Discriminator

4.2.2.2.1 (C) Theory of Operation

The discriminator recommended for the primary detector is known as the VFD. A generalized block diagram of this type of processor is shown in Figure 4-1. The discriminator design has been evolved by Sylvania after an extensive study of seismic signals over the past several years. Statistical methods (pattern recognition techniques) were used to determine the signal parameters which aid most in separating valid targets from false alarm sources with least errors.

The VFD's discrimination capability is based on several derived seismic signature characteristics. These are the characteristics that have been found to be the most significant for determining the presence of personnel and vehicles and for suppressing false alarms. The signal from the geophone is amplified in a high-gain amplifier with an AGC. After amplification, the signal is passed through circuits which derive the desired characteristics of the signal. The measured characteristics of the signal are combined in the combining network which forms a function of the measured characteristics most effective in discriminating between intruders and sources of false alarm.

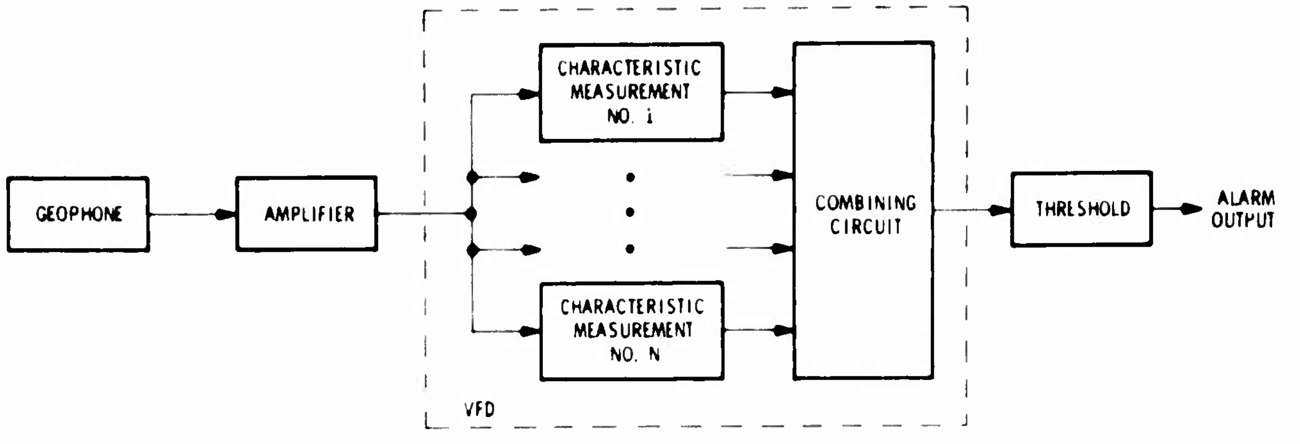

Figure 4-1 (U). Variance Frequency Discriminator Block Diagram (U)

4.2.2.2.1 (C) (Continued)

The result of the combination of the voltages from the measurement characteristic circuits is a voltage which can be applied to a threshold. When the voltage is over the threshold an alarm signal is generated. Alternatively, the output of the threshold can be applied to a counter which sets the number of counts needed in a fixed interval of time to give an alarm. In this fashion, information over a longer period of time can be accumulated before an alarm is given.

Figures 4-2 and 4-3 show samples of the raw seismic signals of personnel, vehicles, and two false-alarm sources. The signatures in Figure 4-2 represent the output of a seismic transducer when one man is passing the sensor, when a number of men are passing the sensor, and when it is raining in the vicinity of the sensor. It is clear that a simple energy detector or threshold crossing detector cannot be used to discriminate against the signal from the rain, since it has nearly the same amplitude as the signals from the intruders. Similarly, the sources of alarm represented in Figure 4-3, two helicopter signatures, a propeller aircraft, and rain cannot be discriminated on the basis of amplitude. The VFD is able to discriminate between the intruders and these sources of false alarms.

4.2.2.2.2 (C) Performance Data

A series of tests have been conducted with the laboratory test setup shown in Figure 4-4 to compare the performance of the VFD against three other discriminators now in use or under development. The United Aircraft discriminator (UAD) is in use in ADSID, the spectral discriminator (SD) is under development at Sylvania, and the FADSID discriminator is in use in Sylvania-built air-deliverable sensors. The effective thresholds of the discriminators were adjusted to obtain approximately equal

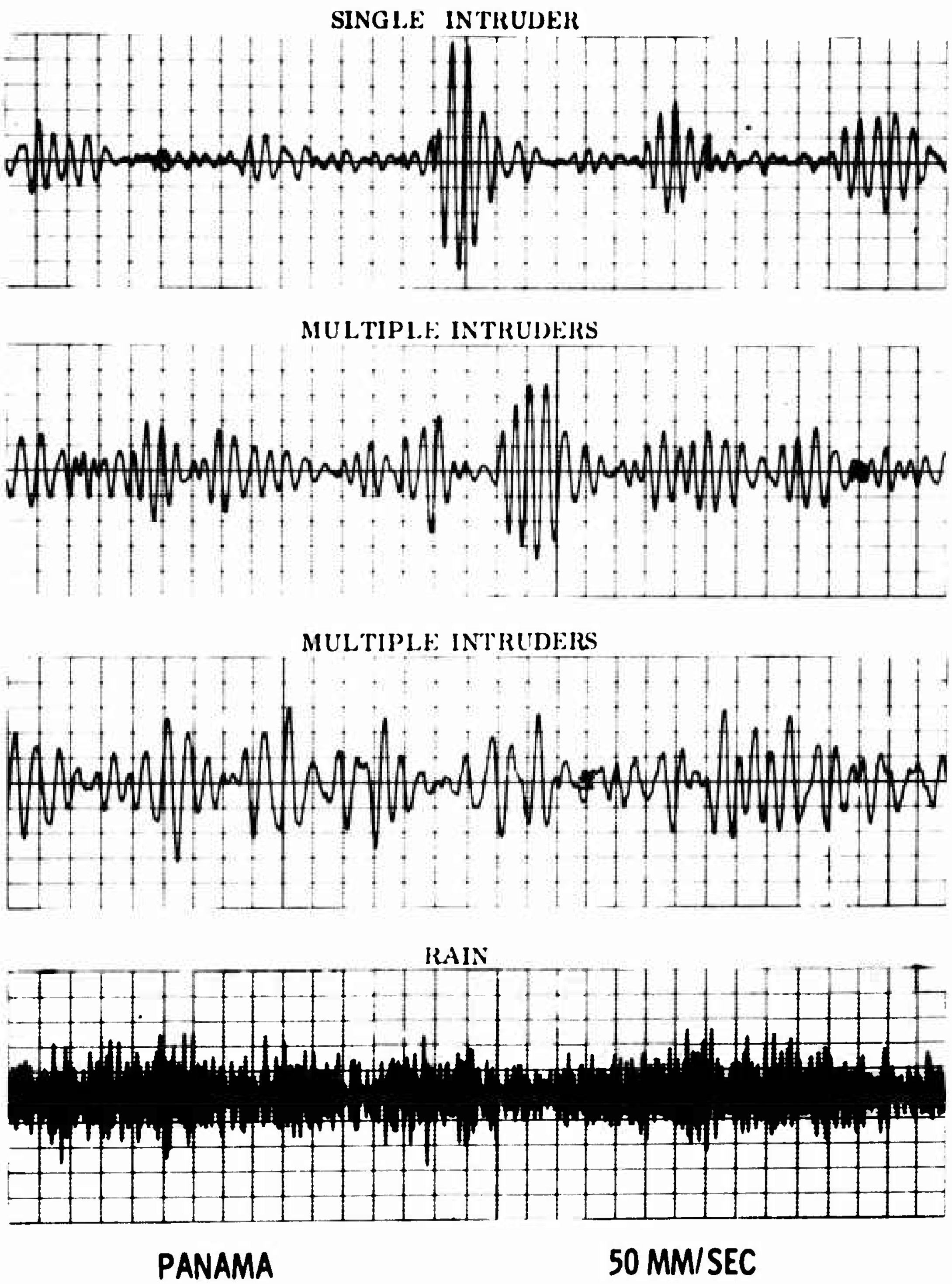

Figure 4-2 (U). Samples of Seismic Signature (U)

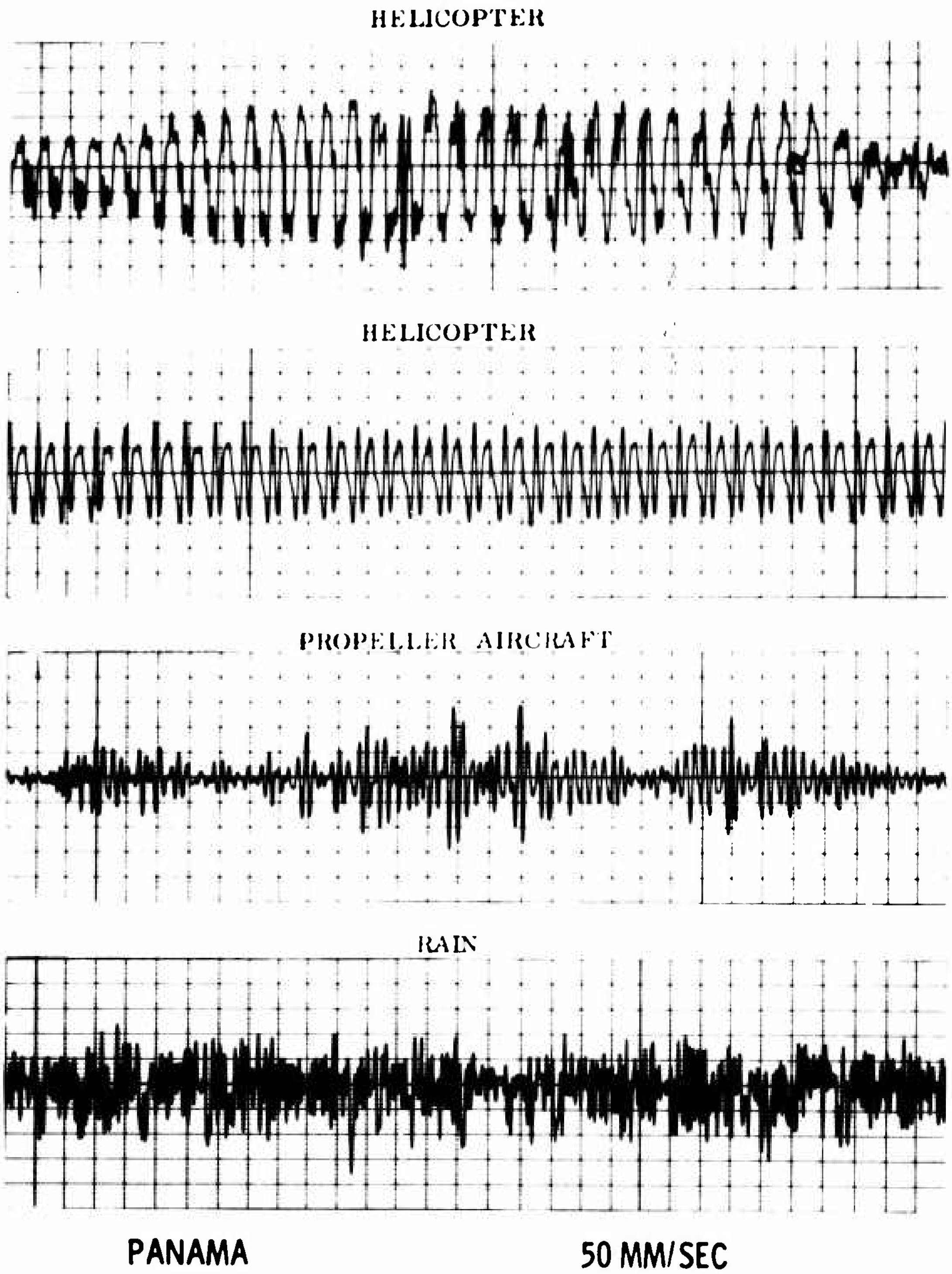

Figure 4-3 (U). Samples of Seismic Signature (U)

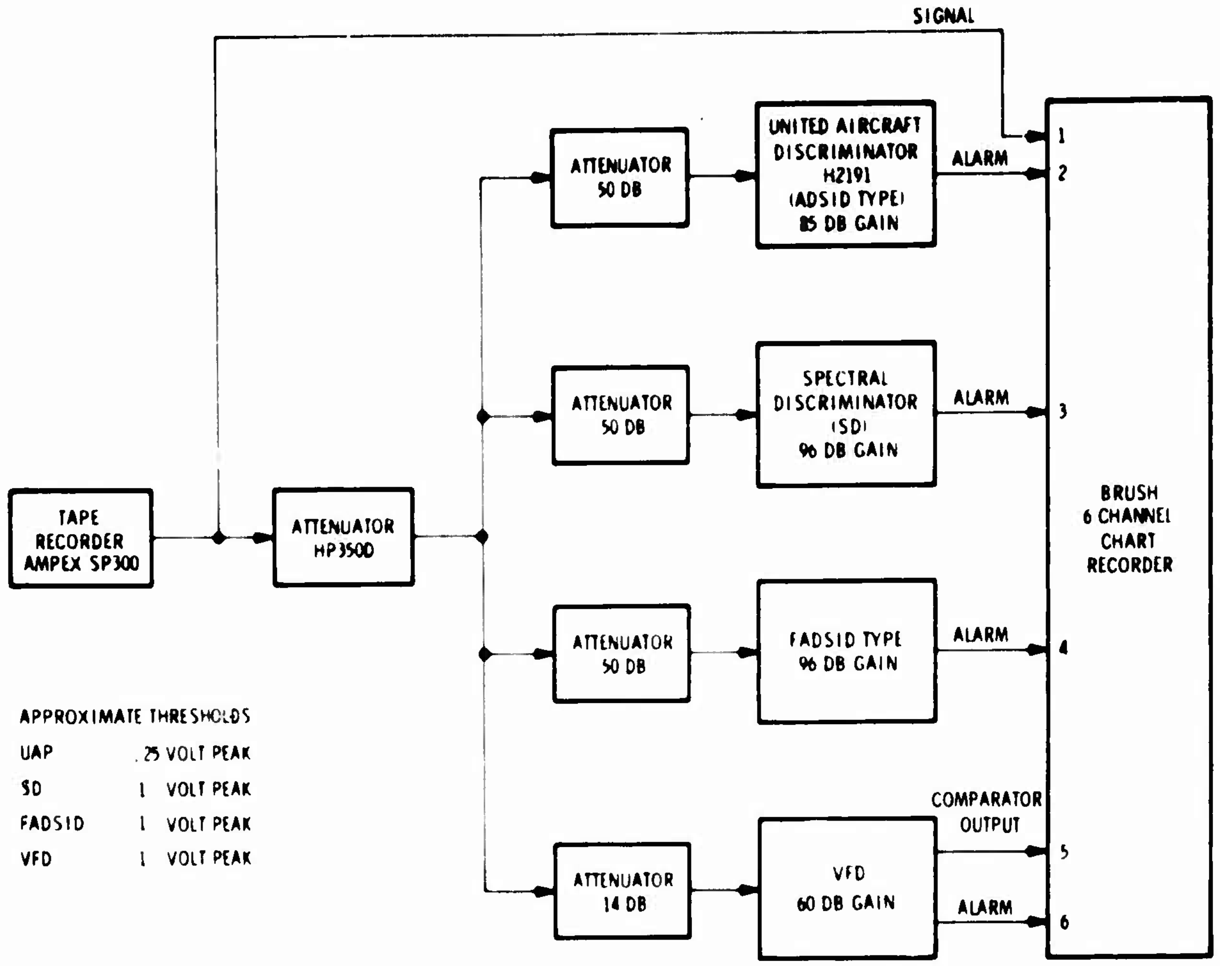

Figure 4-4 (U). Discriminator Test Setup (U)

4.2.2.2.2 (C) (Continued)

detection of one man walking. The resulting gains and thresholds are listed in Table 4-1. Recorded signals from 4 sites were used: Panama, Thailand, Big Basin State Park, California, and Hollister, California. These signals are representative of sites with a wide diversity of geophysical characteristics. Expanded chart recordings of one man walking at each of these sites are shown in Figure 4-5. The signal characteristics vary somewhat between sites. For example, a long duration, high amplitude burst is characteristic of Big Basin Park, which has soft, moist soil. Hollister, which has very hard soil, exhibits a shorter duration and slightly higher frequency signal.

Table 4-1 (C). Gain and Threshold Levels (U)

REC CH	SIGNAL	GAIN	THRESHOLD
1	INPUT	85 db	0.25 V
2	UAD Alarm	85 db	1 V
3	SD Alarm	96 db	1 V
4	FADSID Alarm	96 db	1 V
5	VFD Threshold	96 db	1 V
6	VFD Alarm	96 db	1 V

Note: Since the UAD threshold is approximately 12 db lower than the other processors, the equivalent sensitivity is approximately the same.

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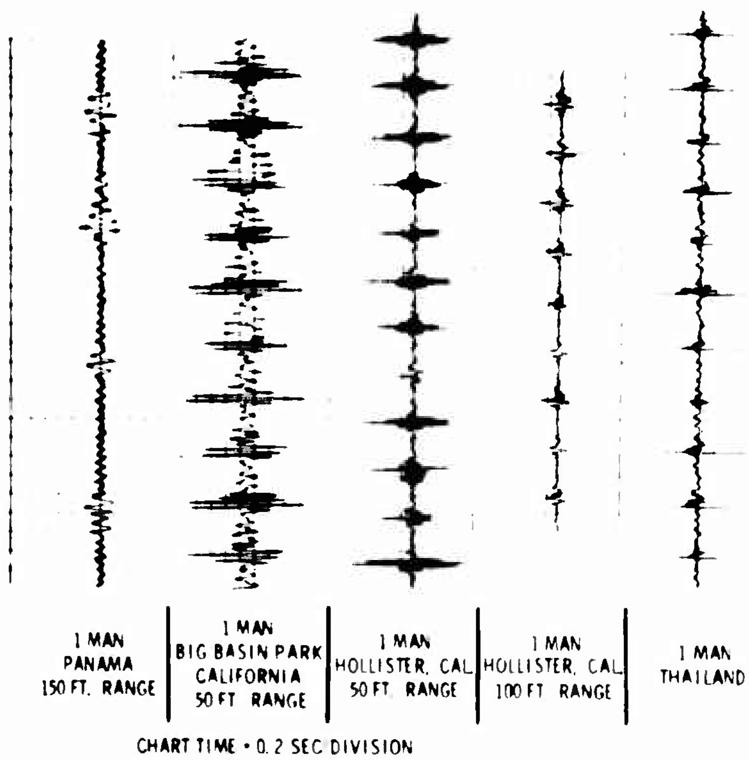

Figure 4-5 (U). Chart Recording of Man Walking-Four Sites (U)

4.2.2.2.2 (C) (Continued)

Figures 4-6 through 4-12 are photo reproductions of the discriminator alarm responses. The maximum alarm rates of the different discriminators are as follows:

UAD - 1 alarm/sec.

SD - 1 alarm/2 sec.

FADSID - 1 alarm/10 sec.

VFD - 1 alarm/3 sec.

Alarm rate is the maximum rate at which the particular processor may alarm, regardless of intrusion size or duration, i.e., VFD may alarm only once every three seconds.

Figure 4-6 displays the responses to one man, 6 men, a single 6 x 6 truck at 10 mph, and rain from the Panama tape. Examination of the one man signal shows that detection is similar for all discriminators with the UAD exhibiting the lowest number of alarms. This adjustment was deliberately made to allow the best possible false alarm rejection by the threshold type unit. The other three discriminators provide at least equal or better detection of the 6 men and the vehicle. Note that the SD and VFD completely reject the rain while both the UAD and the FADSID do not. The FADSID and VFD completely reject the helicopter signals. The VFD, in fact, rejects all false alarm signals in this sequence except the propeller-driven aircraft, while the UAD responds to all of them. (The VFD alarm which occurs at the leading edge of the rain signal is due to the unnaturally fast rise of the signal. The rain signal is only part of a much longer duration rain recording which was re-recorded from a master tape.)

Figure 4-8 shows the same signals as Figure 4-6, but with 3-dB greater attenuation. Detection range of the men and vehicle decreased somewhat for all discriminators, but the UAD continued to alarm continuously throughout the rain signal. Detection performance of all processors increased for the man and vehicle signals when the tape was run at 3-db less attenuation. The response to the false alarm signals showed no change, which verifies that false alarm rejection is not critically dependent on signal amplitude. A study of Figures 4-7 through 4-12 clearly shows that all four discriminators have approximately equal detection performance on most of the man and vehicle signatures. The SD and VFD show slightly better detection of some signals, such as one man at 100-foot range in Hollister. The VFD excels in rejection of all false alarms except propeller type aircraft, although the SD performance is quite close. As expected, the simple threshold type processor detects virtually any signal with sufficient amplitude to exceed threshold.

Since the preceding test was conducted, additional circuit optimization of the VFD has resulted in the elimination of the response to the propeller driven (P2V) aircraft while retaining the same response to the intrusion signals.

The VFD has also been compared to the PID, the Minisid, and the Helosid in laboratory tests conducted at MERDC at Ft. Belvoir. The results were quite similar. The VFD and PID were field tested at Camp A. P. Hill near Ft. Belvoir and at an Army airfield on Ft. Belvoir. Intrusion tests at Camp A. P. Hill consisted of one man, 5 men and a vehicle. The walking rates were 1.3 and 2 steps per second or about 3.6 and 5.5 feet per second. The vehicle speeds were 20 and 30 mph. The detection range of the VFD averaged about 100 feet to 150 feet for the man or men with a maximum range of 200 feet, and about 600 to 800 feet for the vehicle. These ranges were equal to or greater than the range of the PID operated in gain 4.

PROCESSOR ALARM RESPONSES

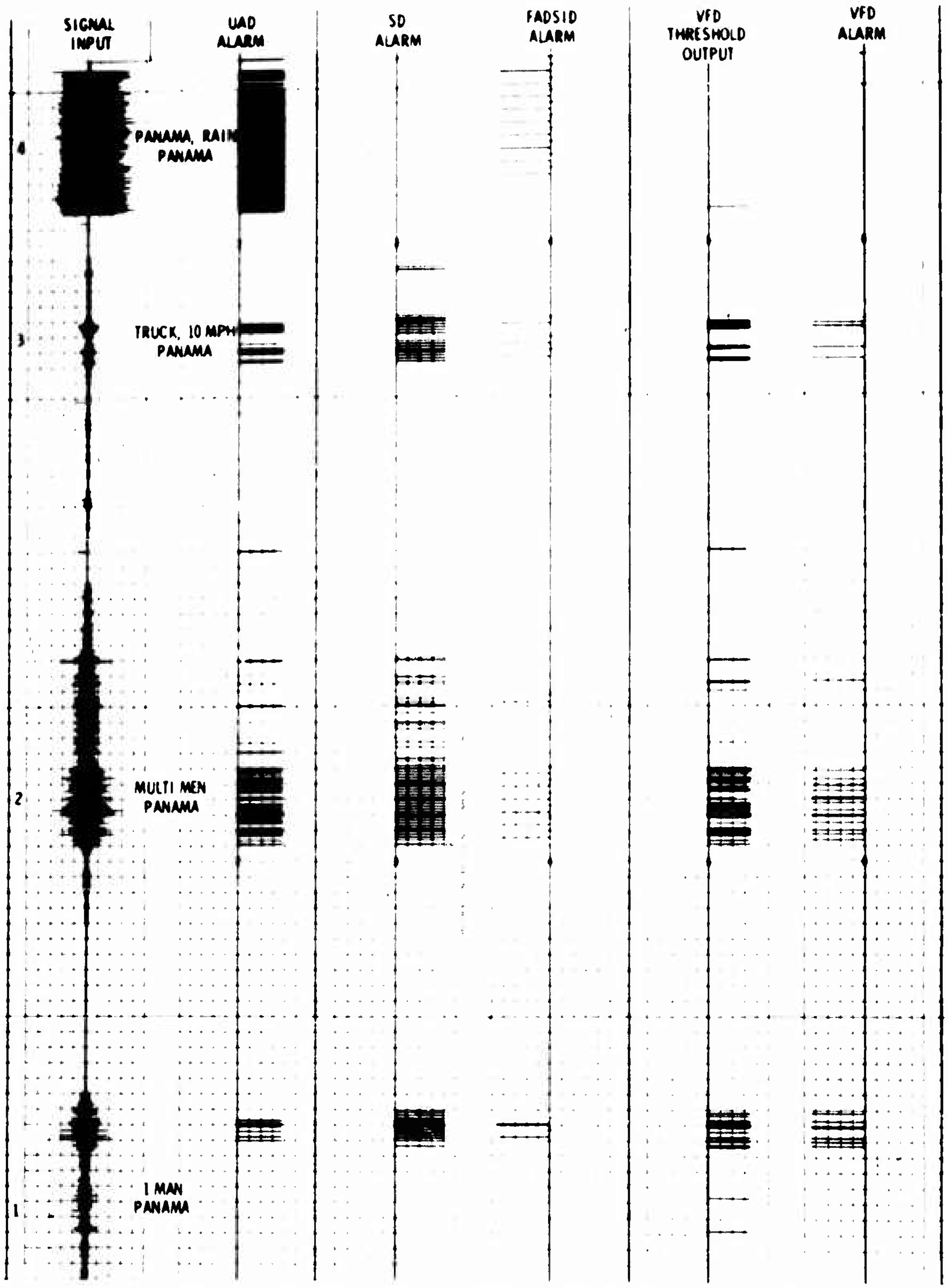

Figure 4-6 (C). Discriminator Alarm Responses (U)

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PROCESSOR ALARM RESPONSES

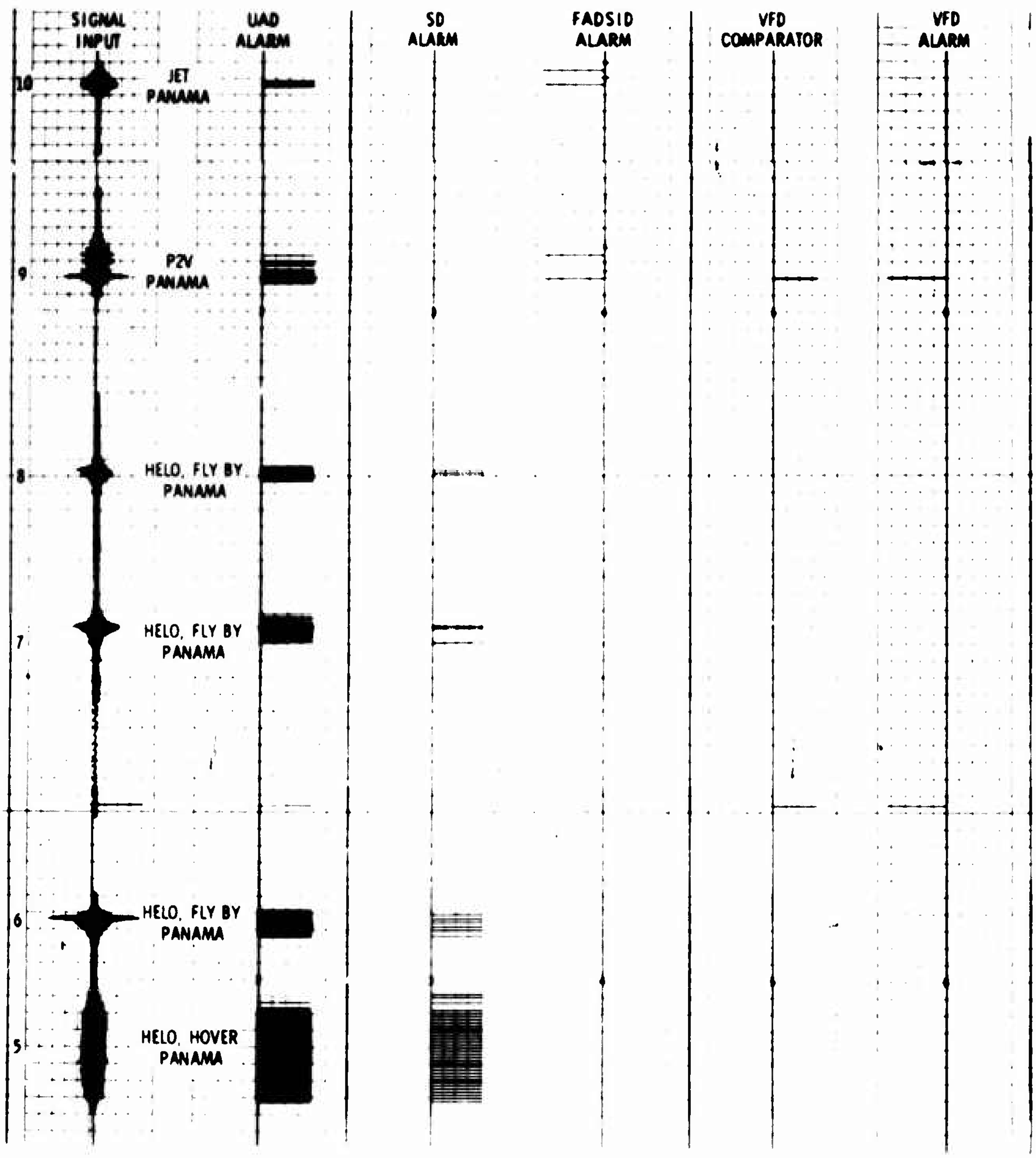

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Figure 4-7 (C). Discriminator Alarm Responses (U)

PROCESSOR ALARM RESPONSES

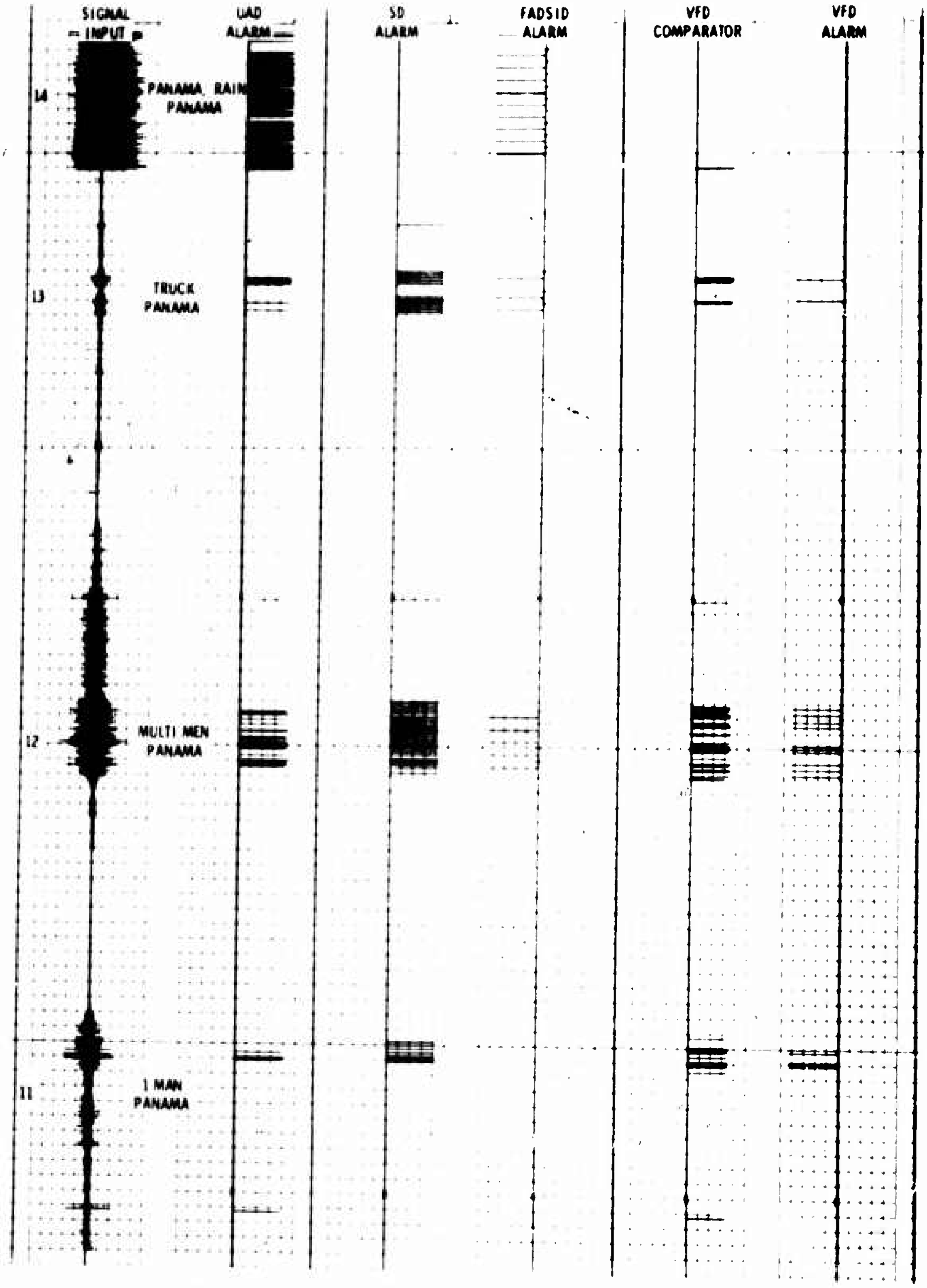


Figure 4-8 (C). Discriminator Alarm Responses (3) (U) (CONFIDENTIAL)

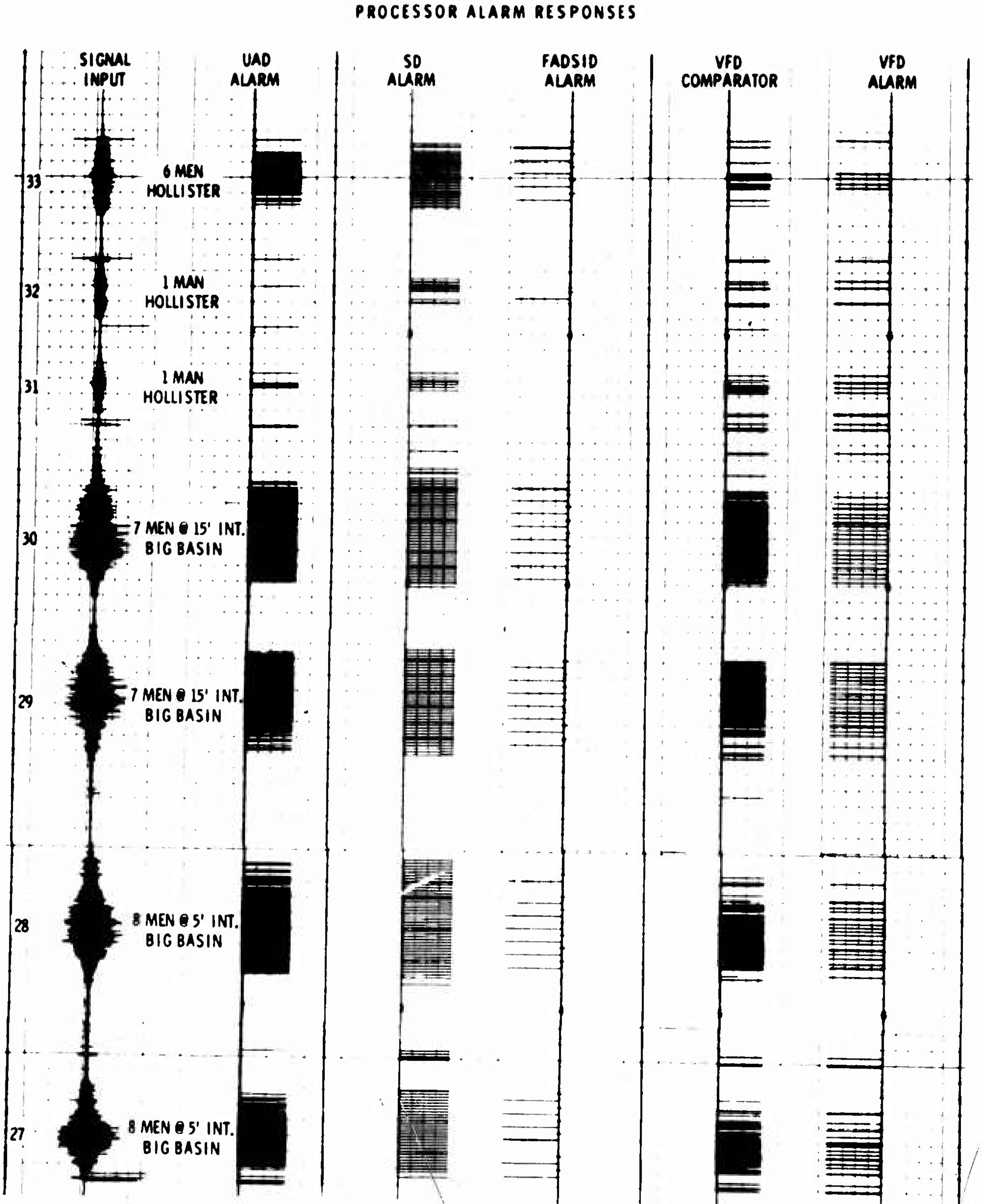


Figure 4-9 (C). Discriminator Alarm Responses (4) (U) (CONFIDENTIAL)

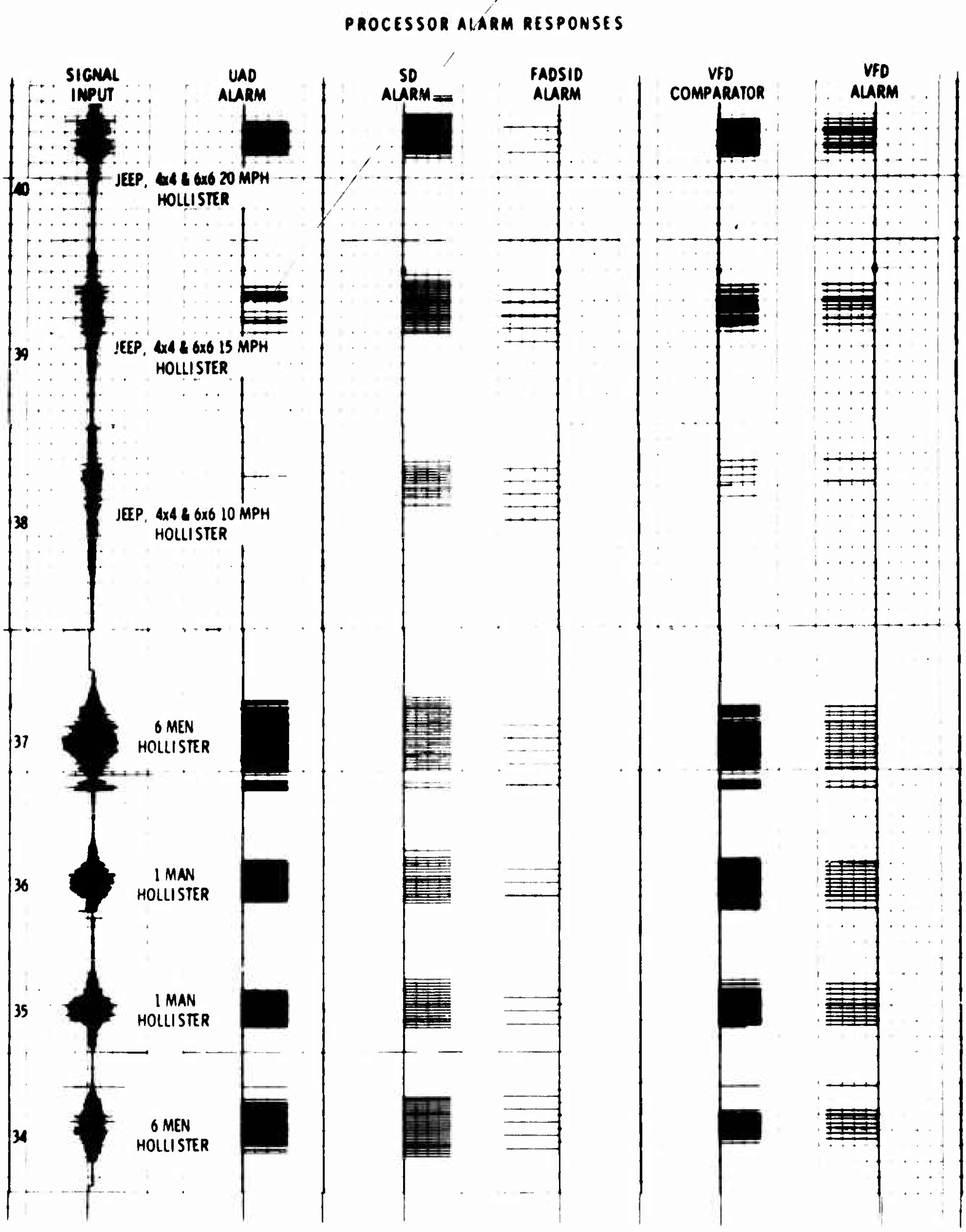
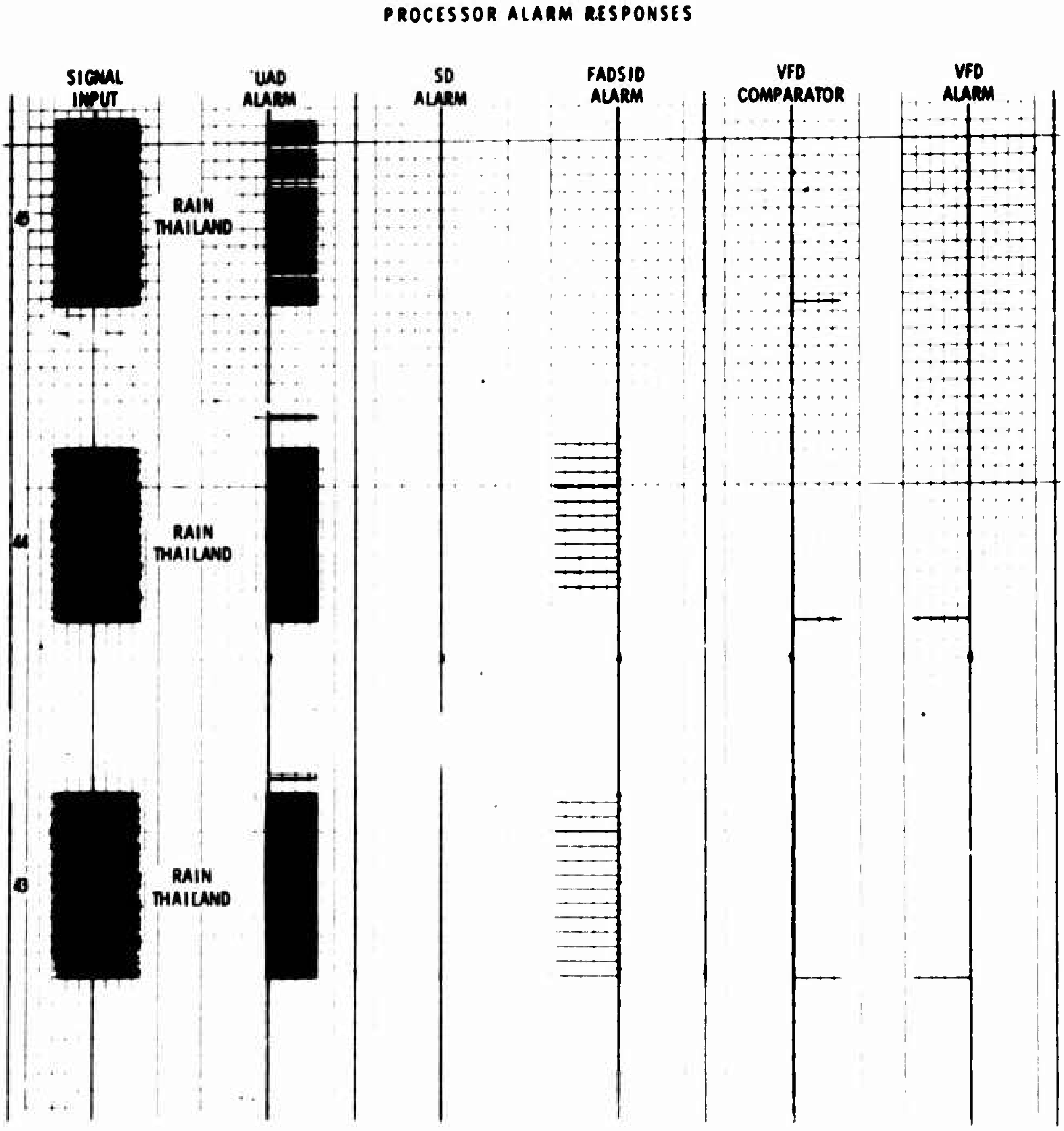


Figure 4-10 (C). Discriminator Alarm Responses (5) (U) (CONFIDENTIAL)



(CONFIDENTIAL)

Figure 4-11 (C). Discriminator Alarm Responses (6) (U)

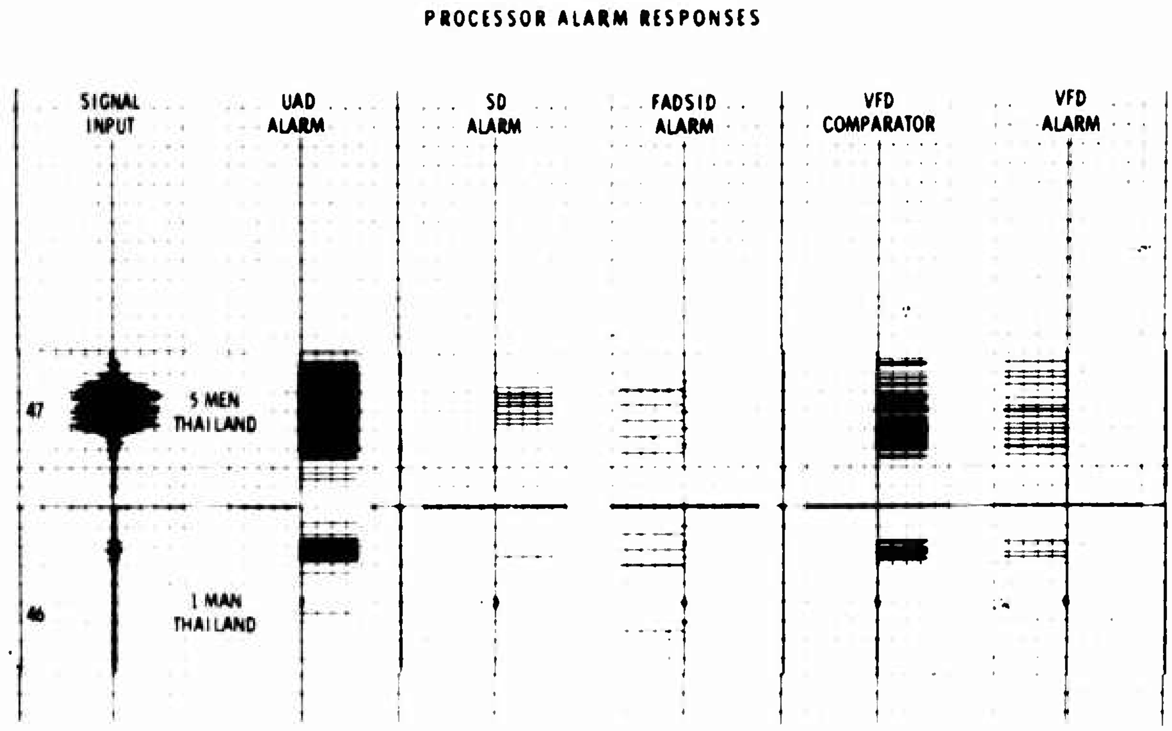


Figure 4-12 (C). Discriminator Alarm Responses (U)

(CONFIDENTIAL)

4.2.2.2.2 (C) (Continued)

The VFD proved its superior performance in false alarm rejection at an airstrip on Ft. Belvoir. The PID and the VFD were set up about 200 feet to one side of and near the end of the runaway. Normal traffic, which was quite heavy, consisting of helicopters (both single and two rotor types) and propellor driven aircraft of various types up to Aero Commander size were monitored for about 1-1/2 hours. A single rotor helicopter then made overflights ranging in altitude from 100 feet to about 1500 feet at both slow and fast rates. It also landed, hovered and lifted off within 100 feet of the sensors. The VFD produced no alarms in response to the helicopters or other aircraft. The noise level at this site was rather high even when no aircraft were nearby and thus the PID was in constant alarm when operated in Gain 4. When operated in Gain 3 it was quiet except when helicopters were within about 1/2 mile or when some of the larger aircraft were taking off or landing.

A detection range of about 70 feet was obtained from both sensors when no aircraft were in the immedate area. When a helicopter was nearby and the PID was thus in constant alarm, a detection range for one man of up to 35 feet was obtained with the VFD. The VFD is thus usable even in the rather high ambient noise environment encountered near an airstrip.

4.2.2.2.3 (C) Alarm Qualification Logic

The VFD will be designed so that the input signal persists for a period of at least 4 seconds before an alarm is generated. This approach will assure that:

a. False alarm signals of short duration will be rejected even if they otherwise have the frequency and amplitude characteristics which would classify them as targets. Typical false alarm signals of this type are thunder and artillery or munitions explosions.

b. An alarm represents several footsteps or meters of vehicle travel. This, in effect, amounts to increasing the information carried by each alarm.

c. Alarms will be transmitted from a given sensor at a maximum rate of one every 4 seconds. This prevents the transmission of redundant information, yet assures the emission of enough alarms to permit recognition of an intrusion.

4.2.2.3 (C) Design Objectives

The primary detector will be designed to meet the following operational objectives.

4.2.2.3.1 (C) Detection Range

Two range settings will be provided: (1) Trail, and (2) Fence. In the Trail mode, the nominal distance away from the detector at which a single man (average weight) walking at a normal pace is detected will be approximately 10 meters while that in the Fence mode will be approximately 30 meters. It is recognized that these detection ranges will vary somewhat for different soil conditions.

4.2.2.3.2 (C) Detection Pattern

The detection pattern will be approximately circular.

4.2.2.3.3 (C) False Alarm Rate

The false alarm rate will be approximately Poisson distributed with a mean rate not to exceed 1 alarm in 40 seconds.

4.2.2.3.4 (C) Reporting Rate

Maximum reporting rate will be 1 alarm per 4 seconds. This will be controlled by the logic circuit of the VFD.

4.2.3 (C) Emplacement of Components

4.2.3.1 (C) Trail Array

The configuration recommended for surveillance of likely avenues of approach is depicted in Figure 4-13. The array will consist of five seismic sensors, each with an effective detection radius of approximately 10 meters. The sensors are to be deployed

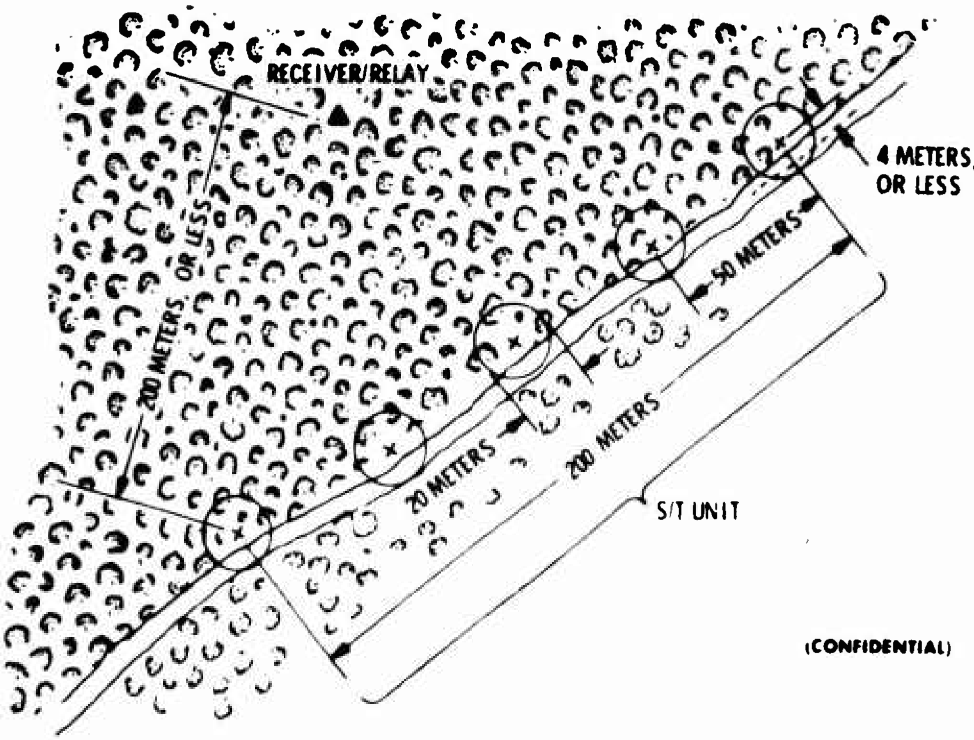


Figure 4-13 (C). Surveillance of a Typical Trail (U)

4.2.3.1 (C) (Continued)

linearly along the trail at 50-meter intervals, and no more than about 4 meters from the centerline of the trail. The reasons for choosing this configuration are as follows:

a. At least two sensors, deployed along a trail, are required to determine an intruder's direction and speed.

b. As shown later in this section, the speed estimate increases in confidence from approximately the 70 percent to the 90 percent level if the estimate is based on alarm data from three rather than two sensors. A fairly accurate estimate of speed is desired to predict intruder whereabouts between arrays. Since estimation of intruder number is also a function of velocity, a good estimate of speed is essential to obtain the best estimate of the intruder count.

c. Certain false alarm events, such as animal movements, can be more easily recognized if the alarms are received from multiple sensors spaced known distances apart.

4.2.3.1 (C) (Continued)

d. The sensor must operate unattended over extended periods of time. Therefore, the addition of the extra two sensors to the three required to extract the desired intruder information will permit the loss of two sensors before the performance of the array will be significantly degraded. In fact, three of the five sensors can be lost and the array will still supply data to produce fair estimates of the intruder characteristics.

e. Addition of 4th or 5th sensor only adds redundancy and is a straight sensor cost vs. increased reliability consideration.

Each sensor will be uniquely identified for intruder direction and speed to be determined. The number of sensors per array may be expanded up to eight if attrition rates in the field indicate that such is warranted. The number to be emplaced may also be reduced to as few as three provided that the sensors exhibit an exceptionally low attrition rate.

The decision to set the sensor detection radius at 10 meters and to place them off the trail centerline by a distance of 4 meters or less is a compromise between:

a. Holding the sensor detection zone to a minimum so that a better resolution of the intruder count can be obtained, i.e., the smaller the zone, the better the estimate of count.

b. Having a large enough detection zone so that the alarm sequence produced by an intruder will clearly indicate his presence. This sequence must consist of three or more consecutive alarms. Therefore, a detection zone of 16 meters or greater is required to assure 3 or more alarms for the expected intruder velocities and the recommended alarm reporting rate. As shown later in Section 4.2.4, this allows the intruder count to be estimated within ±30 percent.

The spacing of 50 meters between sensors was chosen for the following reasons:

a. At this spacing, an average of only 2 to 3 sensors will be simultaneously reporting alarm activity when the array is intruder by large threat groups. Thus, alarm messages converging on an R/R from the sensor array will be kept within tolerance relative to message interference levels.

b. Sensor-to-R/R range will not exceed 200 meters.

c. The sensors are spaced widely enough apart to permit averaging out any short-term variations in intruder speed.

d. The sensors are spaced close enough together so that installation of the array can be completed in a reasonable amount of time. For example, if one assumed that the deployment team moved from one sensor position to another at a rate of 1 to 2 meters/second, it would take less than a minute to get from one sensor to another.

4.2.3.2 (C) Fence Array

The sensor array configuration proposed for launch area surveillance is shown in Figure 4-14. The array has been configured to act as a sensor fence. Placed along the perimeter of a suspected launch area, it will detect anybody moving into the area.

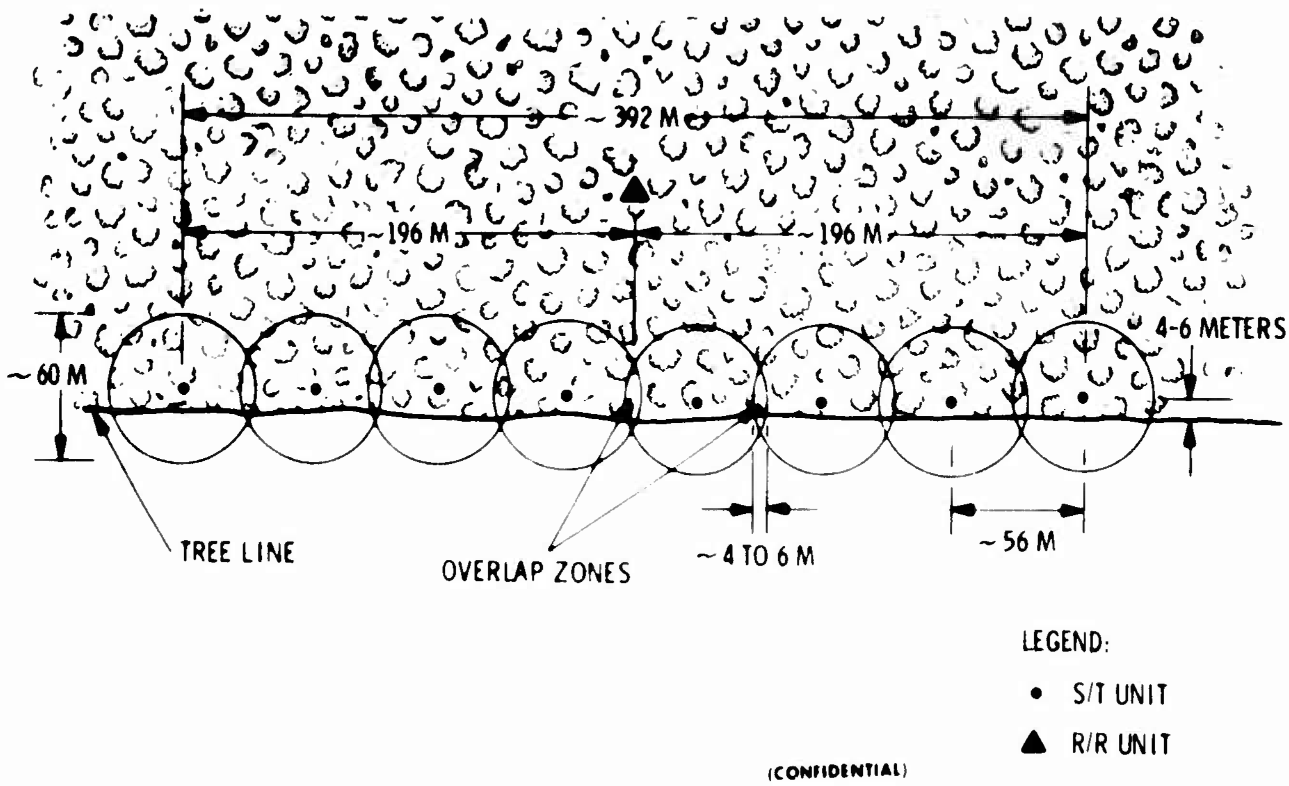


Figure 4-14 (C). Fence Array with Theoretical Deployment Dimensions (U)

4.2.3.2 (C) (Continued)

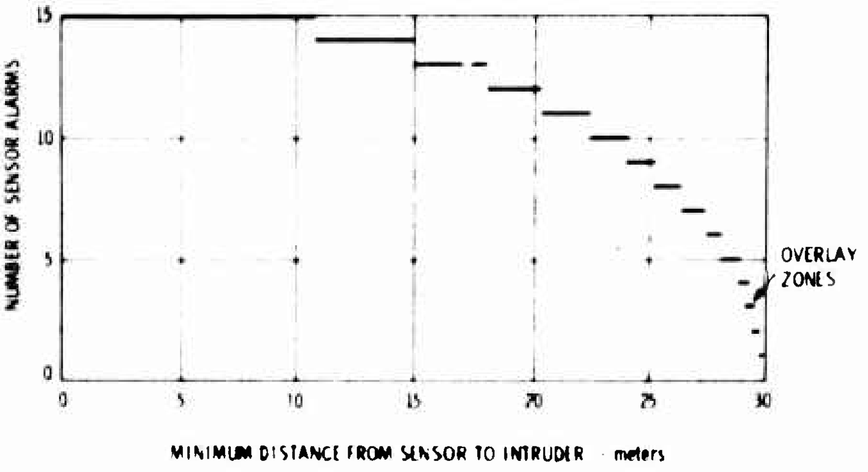
The maximum extent of the array, or fence section, has been set at about 400 meters. This length is based on the maximum effective sensor transmitter range, which is 200 meters through heavy jungle. Each section is made up of 8 seismic sensors, each having an effective detection range of 30 meters. The R/R is placed near the center of the array, so that the two end S/T units must not transmit more than about 200 meters.

The range of 30 meters is considered to be the maximum reliable detection range for a seismic sensor when a low false alarm rate is essential.

It should also be noted that the sensors within the array overlap each other by 2 to 3 meters. This overlap is necessary to keep the array from having dead zones between adjacent sensors. The sensor detection sensitivity is expected to vary somewhat as a function of the soil conditions. The overlap is intended to compensate for this uncertainty.

4.2.3.2 (C) (Continued)

Another reason for the overlap is that the fence sensors must provide an alarm pattern which clearly indicates threat activity in the presence of random false alarms. Figure 4-15 shows a plot of the number of alarms which will be emitted by a 30 meter S/T unit as a function of the distance from the sensor an intruder passes through the sensed field. Intruder's velocity has been assumed to be 1 meter per second. It can be seen from the plot that when adjacent sensor fields are overlapped by 2 meters, all intrusions will cause at least 6 alarms. In fact, the number of alarms will be 10 or greater with a probability of 0.85. An alarm sequence of this length will be clearly recognizable in the presence of false alarms. The alarm numbers just cited are for a single man passing through the fence array. Considerably larger numbers can be expected when a launch party consisting of several men moves into the launch area.



(CONFIDENTIAL)

Figure 4-15 (C). Number of Alarms as a Function of Intruder's Path (U)

It is quite conceivable that a fence array could be deployed in an area where RF propagation losses are not great and false alarm rates are very low. In such a case, the length of the array may be extended beyond the 400 meters by using more than 8 sensors[1], or by separating the sensors so that improbable crossing zones are not covered. Examples of such applications are depicted in Figures 4-16 and 4-17.

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1 Since only 8 sensors can be uniquely identified, expanding the array to more than 8 sensors will require assigning the same ID code for two adjacent sensors, thus decreasing the location resolution by a factor of two.

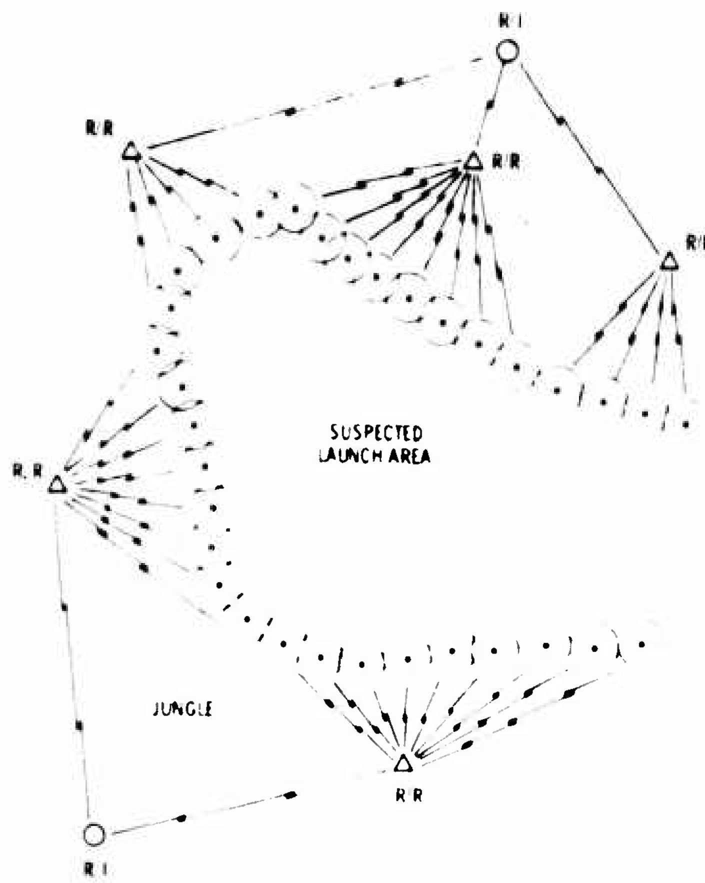

Figure 4-16 (U). Deployment of Fence Arrays for Launch Area Surveillance (U)

4.2.4 (C) Alarm Patterns

4.2.4.1 (C) Computer Simulation

A computer program has been developed to synthesize the alarm patterns which will result when a group of intruders pass through the proposed sensor arrays. The program was designed to permit adequate flexibility in choosing both the intruder group characteristics and the array characteristics. The following parameters were varied:

a. Number of sensors

b. Sensor detection radius

c. Distance from sensor to trail

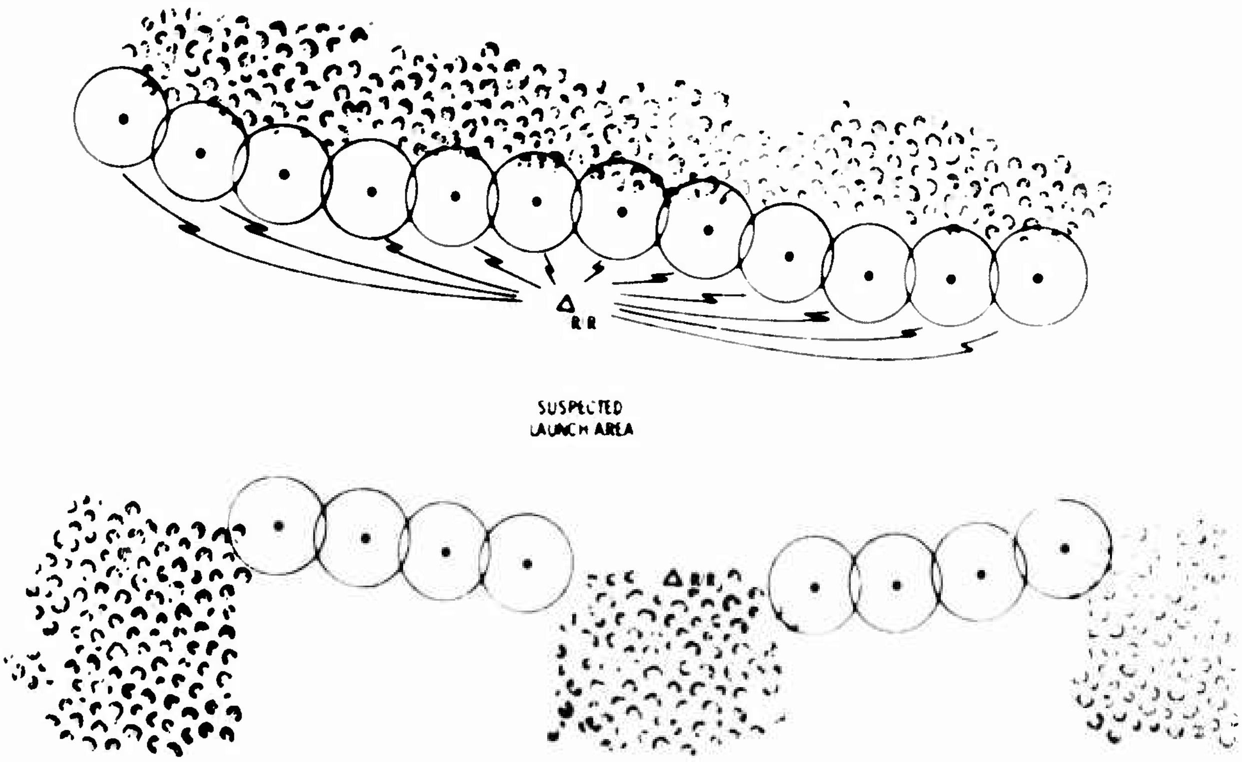

Figure 4-17 (U). Extended Fence Array Deployment Configurations (U)

4.2.4.1 (C) (Continued)

d. Spacing between sensors

e. Sensor maximum reporting rate

f. Number of intruders

g. Minimum spacing between intruders

h. Spacing between intruders

i. Speed of intruders

j. Average false alarm rate.

4.2.4.1 (C) (Continued)

When these parameters were inserted into the program, the actual spacings between intruders and the actual times at which false alarms occur were determined from appropriate probability distributions. The minimum of 2 meters and a most likely spacing of 4.5 meters between intruders were used to define a Rayleigh distribution of the probability of spacings. This is shown in Figure 4-18. The spacings between intruders in a group were then chosen according to this distribution.

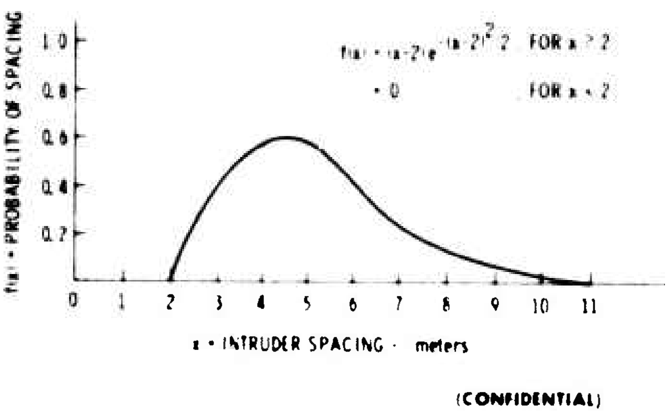

Figure 4-18 (C). Probability Density Function used to Select Intruder Spacing at Random (U)

The decision as to whether or not a false alarm occurred within a time interval T was based on the following procedure. A Bernoulli random variable X was defined with the following values and interpretations:

VALUE	PROBABILITY OF OCCURRENCE	INTERPRETATION
X_1	p	A false alarm occurred in the interval T.
X_2	1-p	No false alarm occurred in the interval T.

This random variable can be modeled by a biased coin where the event "heads" occurs with probability p, and "tails" with probability 1-p. At each interval T, and for each sensor in the array, the biased coin would then be flipped to determine if a false alarm occurred. In the computer simulation, the computer was programmed to insert the false alarms in accordance with a random marker table with the appropriate rate of occurrence.

4.2.4.1 (C) (Continued)

The computer readouts show the sensors from left to right across the page in the same order as they are placed along the trail. On the left hand side of the page, time is shown in 4-second increments. Two alarm patterns are displayed. The first is the pattern in which the cause of each alarm is identified by a different symbol. Thus "O" means that no alarm (False or True) occurred during the interval. A "1" identifies an alarm caused by an intruder while a "2" identifies a false alarm. A "3" means that a false alarm also occurred in the 4-second interval when an alarm was caused by the intruder(s). The second is the alarm pattern that would be received at the CSC. In this case, the cause of individual alarms will not be known and, therefore, all alarms are shown by a ' 1".

4.2.4.2 (C) Results of Computer Simulation

The computer model was used to produce a number of alarm patterns to study the following:

(1) Effect of intruder spacing on alarm sequences

(2) The influence of false alarm rate on the true alarm pattern

(3) Sensor detection radius requirement

(4) The effect of sensor spacing on the number of S/T units active at any one time.

Several important observations were made from these alarm patterns. These are discussed below:

Observation #1: A fixed number of men traveling at a fixed speed will produce a widely varying alarm pattern depending on the spacing between the men in the column.

This is demonstrated in Figure 4-19. Part A shows the alarm pattern produced by two men spaced 4 meters apart. The men produced 9 alarms as they passed Sensor No. 1. In Part B, the spacing was increased to 10 meters. This resulted in producing 12 alarms as the two men passed Sensor No. 1. Part C showed that when the spacing is changed to 17 meters the number of alarms go up to 15.

Observation #2: A 10:1 or better ratio of true-alarm-rate to false-alarm rate is needed to assure that data will not be obscured by randomly occurring false alarms.

This is illustrated in Figure 4-20. Part A shows the alarm pattern produced by one man against an average background false alarm rate of one in 40 seconds. Sensor maximum alarm rate was one in 4 seconds, thus giving a true-to-false alarm rate ratio of 10:1. Note that the alarm pattern produced by the intruder stands out clearly against the background.

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 2

RELATIVE SPACING OF MEN

-10
-4

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	0	0	2	0	1	0	0	1	0
12	1	0	0	0	0	1	0	0	0	0
16	1	0	0	0	0	1	0	0	0	0
20	1	0	0	0	0	1	0	0	0	0
24	1	0	0	0	0	1	0	0	0	0
28	1	0	0	0	0	1	0	0	0	0
32	1	0	0	2	0	1	0	0	1	0
36	1	0	0	0	0	1	0	0	0	0
40	3	0	0	2	0	1	0	0	1	0
44	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0
60	0	0	0	2	0	0	0	0	1	0
64	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0
76	0	0	2	0	0	0	0	1	0	0
80	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0
88	2	0	0	0	0	1	0	0	0	0
92	0	1	0	0	0	0	1	0	0	0
96	0	1	0	0	0	0	1	0	0	0
100	0	1	0	0	0	0	1	0	0	0
104	0	3	0	0	0	0	1	0	0	0
108	0	1	0	0	0	0	1	0	0	0
112	2	1	2	0	0	1	1	1	0	0
116	2	1	0	2	0	1	1	0	1	0
120	0	1	0	0	0	0	1	0	0	0

(CONFIDENTIAL)

Figure 4-19 A (C). Influence of Spacing between Men on Alarm Patterns (U)

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 2

RELATIVE SPACING OF MEN

-10
-10

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	1	0	0	0	0
12	1	0	0	0	0	1	0	0	0	0
16	1	0	0	0	0	1	0	0	0	0
20	1	0	0	0	0	1	0	0	0	0
24	1	2	0	0	0	1	1	0	0	0
28	1	0	0	0	2	1	0	0	0	1
32	1	0	0	0	0	1	0	0	0	0
36	1	0	0	2	0	1	0	0	1	0
40	1	2	0	0	0	1	1	0	0	0
44	1	0	0	0	0	1	0	0	0	0
48	1	0	0	0	0	1	0	0	0	0
52	1	0	0	2	0	1	0	0	1	0
56	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	2	0	0	0	0	1
72	0	2	2	0	0	0	1	1	0	0
76	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0
84	2	0	0	0	0	1	0	0	0	0
88	2	0	0	0	0	1	0	0	0	0
92	0	1	0	2	0	0	1	0	1	0
96	0	1	0	0	0	0	1	0	0	0
100	0	1	0	0	0	0	1	0	0	0
104	0	3	0	0	2	0	1	0	0	1
108	2	1	0	0	0	1	1	0	0	0
112	2	1	0	0	0	1	1	0	0	0
116	0	1	0	0	0	0	1	0	0	0
120	0	1	0	0	0	0	1	0	0	0

CONFIDENTIAL)

Figure 4-19 B (C). Influence of Spacing between Men on Alarm Patterns (U)

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 2

RELATIVE SPACING OF MEN

-10
-17

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	0	2	0	0	1	0	1	0	0
12	1	0	0	0	0	1	0	0	0	0
16	1	2	0	2	0	1	1	0	1	0
20	1	0	0	0	0	1	0	0	0	0
24	1	0	2	0	0	1	0	1	0	0
28	1	0	0	0	0	1	0	0	0	0
32	1	2	0	0	0	1	1	0	0	0
36	1	0	2	0	2	1	0	1	0	1
40	1	0	0	0	2	1	0	0	0	1
44	1	0	0	0	0	1	0	0	0	0
48	1	0	0	0	0	1	0	0	0	0
52	1	0	0	0	0	1	0	0	0	0
56	1	0	0	0	0	1	0	0	0	0
60	1	0	0	0	0	1	0	0	0	0
64	1	2	0	0	0	1	1	0	0	0
68	0	0	0	2	0	0	0	0	1	0
72	0	0	0	0	0	0	0	0	0	0
76	2	0	0	0	0	1	0	0	0	0
80	2	0	0	0	0	1	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	2	0	0	0	0	1
92	0	1	2	0	0	0	1	1	0	0
96	2	1	0	0	0	1	1	0	0	0
100	2	1	0	0	0	1	1	0	0	0
104	0	3	0	0	0	0	1	0	0	0
108	0	1	0	0	0	0	1	0	0	0
112	0	3	0	0	0	0	1	0	0	0
116	0	1	0	0	2	0	1	0	0	1
120	0	1	0	0	0	0	1	0	0	0

(CONFIDENTIAL)

Figure 4-19C (C). Influence of Spacing between Men on Alarm Patterns (U)

4.2.4.2 (C) (Continued)

Observation #2: (Cont) Part B shows the alarm pattern produced by one man against a background false alarm rate of one in 20 seconds. The true-to-false alarm rate ratio here is 5:1. False alarms frequently appear in consecutive or near-consecutive reporting intervals and could be misleading. A sufficient number of false alarms appear at the beginning and end of valid alarm sequences and might cause errors in speed and group size estimates.

Part C shows a one-man alarm pattern against a background false alarm rate of one in 10 seconds. The true-to-false alarm rate ratio under this condition is 5:2. Distinguishing the alarm pattern here is extremely difficult, if not impossible, and many false targets would doubtlessly be reported.

Observation #3: At least three alarms per sensor are needed to assure recognition of an intrusion in the presence of a true-to-false alarm ratio of 10:1.

This is illustrated in Figure 4-20A. With this true- to false-alarm ratio, false alarms appear frequently in clusters of two. If sensors are designed and emplaced to give a minimum of three consecutive alarms for a single intruder, this pattern should be easily recognizable by the CSC.

Observation #4: A 10 meter detection radius satisfies the requirement of at least three alarms for a single intruder traveling at rates of from .5m/sec to 1.5 m/sec. A 5-meter detection radius does not. (Both sensors are placed at a distance of 1/3 their detection radius from the trail.)

Part A of Figure 4-21 shows the alarms produced by a single man passing a 10 meter radius sensor while Part B of the same figure shows the alarms produced by a single man passing a 5-meter radius sensor. Speed in both cases is 1.5m/sec which represents the worst case since for all slower speeds there will be more alarms than shown here.

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 1

RELATIVE SPACING OF MEN

-10

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	0	2	0	2	1	0	1	0	1
12	1	0	0	0	0	1	0	0	0	0
16	3	0	0	0	0	1	0	0	0	0
20	1	0	0	0	0	1	0	0	0	0
24	1	0	0	0	0	1	0	0	0	0
28	1	0	0	0	0	1	0	0	0	0
32	1	0	0	0	0	1	0	0	0	0
36	3	0	0	0	0	1	0	0	0	0
40	2	0	0	0	0	1	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0
52	0	0	0	2	0	0	0	0	1	0
56	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	2	0	0	0	0	1
72	0	0	0	0	2	0	0	0	0	1
76	0	0	2	0	0	0	0	1	0	0
80	2	0	0	0	0	1	0	0	0	0
84	2	0	2	0	0	1	0	1	0	0
88	0	0	0	0	0	0	0	0	0	0
92	0	1	0	0	2	0	1	0	0	1
96	0	1	0	0	0	0	1	0	0	0
100	0	3	0	0	0	0	1	0	0	0
104	0	1	0	0	0	0	1	0	0	0
108	0	3	0	0	0	0	1	0	0	0
112	0	1	0	0	2	0	1	0	0	1
116	0	1	0	0	2	0	1	0	0	1
120	0	0	0	0	0	0	0	0	0	0

(CONFIDENTIAL)

Figure 4-20 A (C). Influence of False Alarm Rate on Alarm Patterns (U)

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 5E-02
NO. OF MEN = 1

RELATIVE SPACING OF MEN

-10

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	2	2	0	0	0	1	1	0	0	0
8	3	0	0	0	0	1	0	0	0	0
12	1	0	2	0	0	1	0	1	0	0
16	1	2	0	0	0	1	1	0	0	0
20	1	2	2	0	0	1	1	1	0	0
24	3	0	0	2	0	1	0	0	1	0
28	1	0	0	2	0	1	0	0	1	0
32	1	2	0	2	0	1	1	0	1	0
36	1	0	0	0	0	1	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0
48	0	0	2	0	0	0	0	1	0	0
52	2	0	0	0	0	1	0	0	0	0
56	0	0	0	0	2	0	0	0	0	1
60	0	0	2	0	2	0	0	1	0	1
64	0	2	0	2	0	0	1	0	1	0
68	2	0	0	0	0	1	0	0	0	0
72	2	0	0	0	0	1	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	2	0	0	0	0	1
84	0	0	0	0	0	0	0	0	0	0
88	0	0	0	2	0	0	0	0	1	0
92	0	1	0	0	2	0	1	0	0	1
96	0	1	0	0	0	0	1	0	0	0
100	0	1	0	0	2	0	1	0	0	1
104	0	1	2	0	2	0	1	1	0	1
108	0	1	0	0	2	0	1	0	0	1
112	0	1	0	0	0	0	1	0	0	0
116	2	1	2	2	0	1	1	1	1	0
120	0	0	2	0	0	0	0	1	0	0

(CONFIDENTIAL)

Figure 4-20 B (C). Influence of False Alarm Rate on Alarm Patterns (U)

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 1E-01
NO. OF MEN = 1

RELATIVE SPACING OF MEN

-10

	ACTUAL ALARM PATTERN					RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	2	0	0	0	0	1	0	0	0	0
8	3	2	0	0	2	1	1	0	0	1
12	1	2	0	0	2	1	1	0	0	1
16	1	2	0	0	0	1	1	0	0	0
20	1	0	2	0	2	1	0	1	0	1
24	1	0	0	2	2	1	0	0	1	1
28	3	2	0	2	2	1	1	0	1	1
32	3	2	0	0	2	1	1	0	0	1
36	3	2	0	2	2	1	1	0	1	1
40	0	2	0	2	0	0	1	0	1	0
44	0	0	0	0	2	0	0	0	0	1
48	0	2	0	0	0	0	1	0	0	0
52	0	0	0	0	0	0	0	0	0	0
56	2	0	2	0	0	1	0	1	0	0
60	0	2	0	0	2	0	1	0	0	1
64	0	0	2	0	2	0	0	1	0	1
68	0	0	2	2	0	0	0	1	1	0
72	0	0	0	0	0	0	0	0	0	0
76	0	2	2	2	2	0	1	1	1	1
80	2	0	2	0	0	1	0	1	0	0
84	2	2	2	2	0	1	1	1	1	0
88	2	0	2	0	0	1	0	1	0	0
92	0	1	2	0	2	0	1	1	0	1
96	0	3	2	2	0	0	1	1	1	0
100	2	3	2	2	0	1	1	1	1	0
104	2	1	2	2	0	1	1	1	1	0
108	2	1	2	2	2	1	1	1	1	1
112	2	3	0	0	0	1	1	0	0	0
116	0	3	0	0	2	0	1	0	0	1
120	0	0	0	2	0	0	0	0	1	0

(CONFIDENTIAL)

Figure 4-20C (C). Influence of False Alarm Rate on Alarm Patterns (U)

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = 1.5
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 1

RELATIVE SPACING OF MEN

-10

ACTUAL ALARM PATTERN						RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	2	0	0	0	1	1	0	0	0
12	1	0	2	0	0	1	0	1	0	0
16	1	0	0	0	0	1	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0

Figure 4-21 A.

SENSOR RADIUS(IN METERS) = 5
INTRUDER VELOCITY (M/S) = 1.5
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-02
NO. OF MEN = 1

RELATIVE SPACING OF MEN

-10

ACTUAL ALARM PATTERN						RECEIVED ALARM PATTERN				
TIME	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
4	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	2	1	0	0	0	1
12	1	0	0	0	0	1	0	0	0	0
16	0	2	0	0	0	0	1	0	0	0
20	0	0	0	0	0	0	0	0	0	0
24	0	2	0	0	0	0	1	0	0	0
28	0	0	2	0	0	0	0	1	0	0

Figure 4-21 B.

(CONFIDENTIAL)

Figure 4-21 (C). Alarm Patterns from Sensors with 5 Meter and 10 Meter Detection Ranges (U)

4.2.4.2 (C) (Continued)

Observation #5: It is unlikely that a group of intruders will cause more than three sensors in a trail array to alarm in a given reporting interval.

This is illustrated in Figure 4-22. For sensors with R_D = 10 m, 50 m between sensors and a 20 man intrusion group with 4.5 meters as the most probable spacing (spacing no closer than 2 meters), the observed alarm sequence is summarized below:

Number of Sensors in Alarm State	Percent of Total Alarm Time
1	31
2	49
3	19
4	0
5	0

It is felt that infiltration in groups larger than 20 men will be seen only rarely since large groups usually fragment to minimize possibility of detection.

4.2.5 (C) Extraction of Intelligence About the Threat

4.2.5.1 (C) General

Section 2.5 listed the type of intelligence information which the remote surveillance system should supply in order to provide the air base with an early warning of an impending attack. This section discusses how such intelligence can be extracted from the alarm patterns emitted by the S T unit and what are some of the accuracy limitations.

Since the trail arrays are the ones intended to provide the early warning of enemy movements, only the trail arrays will be used in the following discussion. However, the information yield from the fence arrays may be derived in a similar manner.

4.2.5.2 (C) Direction of Travel

For a threat group moving down a trail and entering the array, the CSC will normally be able to derive direction of travel as soon as a target is detected. Detection is to be expected at one or the other of the sensors at the extremes of the array. As the enemy approaches other sensors in the array, the alarm sequence will verify initial estimates as to the presence and direction of travel.

4.2.5.3 (C) Speed

Average speed may be initially determined from the distance between the first two sensors to register an alarm and the time between their alarm sequences. Speed may be redetermined as other sensors and, eventually, other arrays detect the threat.

SENSOR RADIUS(IN METERS) = 10
INTRUDER VELOCITY (M/S) = .6
AVERAGE FALSE ALARM RATE(IN ALARMS/SEC)= 2.5E-09
NO. OF MEN = 20

RELATIVE SPACING OF MEN

-8.2151834
-4.0593149
-5.3493146
-5.3709677
-5.7462118
-5.0675708
-4.886692
-5.7077305
-5.8498637
-5.7703161
-3.4815576
-5.8972
-4.6816534
-8.928381
-7.9886147
-4.9644201
-8.6567485
-7.3886567
-4.1922915
-4.2781472

TIME	ACTUAL ALARM PATTERN S1	S2	S3	S4	S5	RECEIVED ALARM PATTERN S1	S2	S3	S4	S5
4	1	0	0	0	0	1	0	0	0	0
8	1	0	0	0	0	1	0	0	0	0
12	1	0	0	0	0	1	0	0	0	0
16	1	0	0	0	0	1	0	0	0	0
20	1	0	0	0	2	1	0	0	0	1
24	1	0	0	0	0	1	0	0	0	0
28	1	0	0	0	0	1	0	0	0	0
32	1	0	0	0	0	1	0	0	0	0
36	1	0	0	0	0	1	0	0	0	0
40	1	0	0	0	0	1	0	0	0	0
44	1	0	0	0	2	1	0	0	0	1
48	1	0	0	0	0	1	0	0	0	0
52	1	0	0	0	0	1	0	0	0	0
56	1	0	0	0	2	1	0	0	0	1
60	1	0	0	0	0	1	0	0	0	0
64	1	2	0	0	0	1	1	0	0	0
68	3	0	0	0	0	1	0	0	0	0
72	1	0	0	0	0	1	0	0	0	0
76	1	0	0	0	0	1	0	0	0	0
80	1	0	0	0	0	1	0	0	0	0
84	1	0	0	0	0	1	0	0	0	0
88	1	1	0	0	0	1	1	0	0	0
92	1	1	0	0	0	1	1	0	0	0
96	3	3	0	0	0	1	1	0	0	0
100	1	1	2	0	0	1	1	1	0	0
104	1	1	0	0	0	1	1	0	0	0
108	1	1	0	0	0	1	1	0	0	0
112	1	1	0	0	0	1	1	0	0	0
116	1	1	2	0	0	1	1	1	0	0
120	1	1	0	0	0	1	1	0	0	0

Figure 4-22 (C). Alarm Pattern for Twenty-man Intrusion Group (U) (Sheet 1 of 2)

(CONFIDENTIAL)

28	1	0	0	0	0	1	0	0	0	0
32	1	0	0	0	0	1	0	0	0	0
36	1	0	0	0	0	1	0	0	0	0
40	1	0	0	0	0	1	0	0	0	0
44	1	0	0	0	2	1	0	0	0	1
48	1	0	0	0	0	1	0	0	0	0
52	1	0	0	0	0	1	0	0	0	0
56	1	0	0	0	2	1	0	0	0	1
60	1	0	0	0	0	1	0	0	0	0
64	1	2	0	0	0	1	1	0	0	0
68	3	0	0	0	0	1	0	0	0	0
72	1	0	0	0	0	1	0	0	0	0
76	1	0	0	0	0	1	0	0	0	0
80	1	0	0	0	0	1	0	0	0	0
84	1	0	0	0	0	1	0	0	0	0
88	1	1	0	0	0	1	1	0	0	0
92	1	1	0	0	0	1	1	0	0	0
96	3	3	0	0	0	1	1	0	0	0
100	1	1	2	0	0	1	1	1	0	0
104	1	1	0	0	0	1	1	0	0	0
108	1	1	0	0	0	1	1	0	0	0
112	1	1	0	0	0	1	1	0	0	0
116	1	1	2	0	0	1	1	1	0	0
120	1	1	0	0	0	1	1	0	0	0
124	1	1	0	0	0	1	1	0	0	0
128	1	1	0	0	2	1	1	0	0	1
132	1	3	0	0	0	1	1	0	0	0
136	1	3	0	0	0	1	1	0	0	0
140	1	1	0	0	0	1	1	0	0	0
144	1	1	0	0	2	1	1	0	0	1
148	1	1	0	0	0	1	1	0	0	0
152	1	1	0	0	0	1	1	0	0	0
156	1	1	0	0	0	1	1	0	0	0
160	1	1	0	0	0	1	1	0	0	0
164		1	0	0	0	1	1	0	0	0
168	1	1	0	0	0	1	1	0	0	0
172	1	1	1	0	0	1	1	1	0	0
176	1	3	1	2	0	1	1	1	1	0
180	1	1	3	0	0	1	1	1	0	0
184	1	1	1	0	0	1	1	1	0	0
188	1	1	1	0	0	1	1	1	0	0
192	1	1	3	0	0	1	1	1	0	0
196	1	3	1	0	[illegible]	1	1	1	0	0
200	1	1	1	0	0	1	1	1	0	0
204	0	1	1	0	0	0	1	1	0	0
208	0	1	1	0	0	0	1	1	0	0
212	0	1	1	0	0	0	1	1	0	0
216	0	3	1	0	0	0	1	1	0	0
220	0	3	1	0	0	0	1	1	0	0
224	0	1	1	0	0	0	1	1	0	0
228	0	1	1	2	0	0	1	1	1	0
232	0	1	1	0	2	0	1	1	0	1
236	0	1	3	0	0	0	1	1	0	0
240	0	1	1	0	0	0	1	1	0	0
244	2	1	1	0	0	1	1	1	0	0
248	0	1	[illegible]	0	0	0	1	1	0	0
252	0	1	1	1	0	0	1	1	1	0
256	0	1	1	3	0	0	1	1	1	0
260	0	1	1	1	2	0	1	1	1	1
264	0	1	1	1	0	0	1	1	1	0
268	0	1	1	1	0	0	1	1	1	0
272	0	1	1	1	0	0	1	1	1	0
276	0	1	1	1	2	0	1	1	1	1
280	0	1	1	3	0	0	1	1	1	0
284	0	1	1	1	0	0	1	1	1	0
288	0	2	3	1	0	0	1	1	1	0
292	0	0	1	1	2	0	0	1	1	1
296	0	0	1	1	0	0	0	1	1	0

Figure 4-22 (C). Alarm Pattern for Twenty-man Intrusion Group (U) (Sheet 2 of 2)

(CONFIDENTIAL)

4.2.5.3 (C) (Continued)

Figure 4-23 shows both a plan view of two trail-array sensors and the alarm sequence produced by a threat group moving past those sensors. To calculate the speed V, at which the threat group moved past the sensors, consider the following equation relating speed to the time between alarm sequences, and the distances as defined in Figure 4-23.

$$V = \frac{D'}{T} = \frac{1}{T}\left[\left(R_{D1}^2 - d_1^2\right)^{\frac{1}{2}} + D - \left(R_{D2}^2 - d_2^2\right)^{\frac{1}{2}}\right] \quad (2)$$

It is apparent that, if the two sensors have the same detection radii and are placed at the same distance from the trail, the above equation reduces to

$$V = \frac{D}{T}, \text{ i.e., } D' = D. \quad (3)$$

It is expected that, generally, sensors will be sufficiently alike in characteristics to permit using this simplified relationship, i.e., small variations in detection radii and distance from trail centerline can be neglected.

Assuming that the arrival times of the alarms are noted accurately at the CSC, good speed estimates are possible if the distance between sensors is known. It should be noted that a given percentage error in the distance measurement assumed will give rise to an equivalent percentage error in the speed estimate.

4.2.5.4 (C) Approximate Count

The number of alarms which the threat group produces as it passes a sensor may be used to estimate the number of men (count) in the group. To examine the validity of a count obtained in this fashion, one must consider the factors which may influence the number of alarms produced by a given number of men.

a. Distance of sensor from the trail – Provided the distance from sensor to trail does not exceed 30 to 40 percent of the sensor's detection radius, a change in sensor-to-trail distance has a negligible effect upon the alarm count.

b. Speed at which the group is moving – The alarm count is related to the intruder speed as follows:

$$\text{No. of Alarms} = \frac{\text{Length of Column} + R_D}{\text{(Speed) (Reporting Interval)}} \quad (4)$$

Speed may be expected to vary from about .5 meters/second to about 1.5 meters/second causing a 3:1 variation in the number of alarms. Fortunately, since speed will be obtained separately, corrections can be made to account for such a variation.

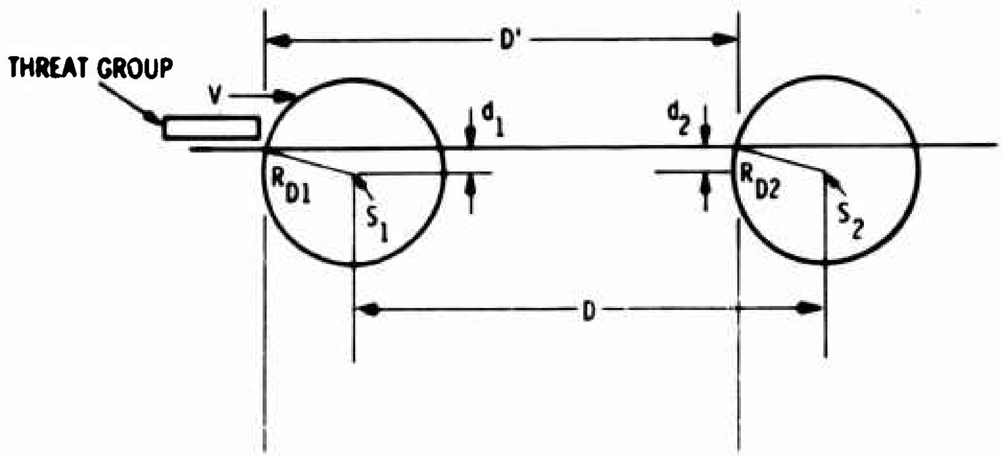

Figure 4-23a (C). Plan View of Two-Trail Array Sensors (U)

(CONFIDENTIAL)

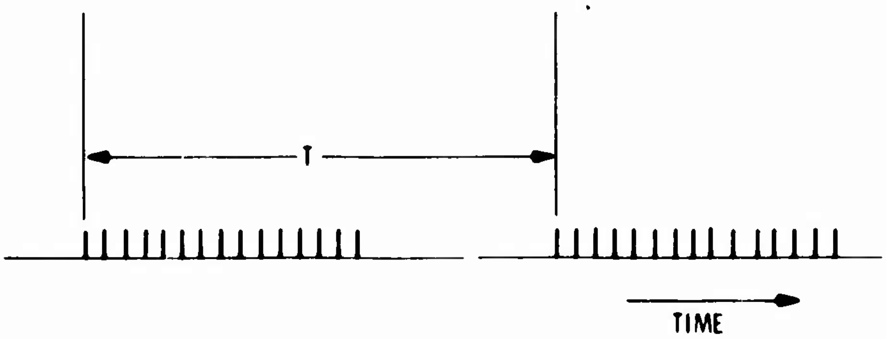

Figure 4-23b (C). Alarm Sequence from Threat Group (U)

(CONFIDENTIAL)

4.2.5.4 (C) (Continued)

c. Spacing between men in the threat group – The alarm count can be changed considerably by varying the spacing between the men in the threat group. This is demonstrated in Figure 4-20. In practice, however, it is not expected that the spacing between men would vary as widely as those chosen for the illustration. Thus the danger of sustaining casualties from an ambush or mines tends to keep the men from moving in close formation while control problems on the other hand, tend to preclude extreme spreading. It is, therefore, expected that by choosing an average spacing of 5 meters between men and converting the alarm count to a count of personnel on this basis will generally give an estimate correct to within 30 percent of the actual count.

The final relationship needed to estimate intruder count is:

$$\text{Count} = \frac{\text{Estimated Column Length}}{\text{Estimated Average Spacing Between Men} = 5 \text{ Meters}}$$

$$= \frac{(NA)\,(V)\,(RI) - 2R_D}{5} \qquad (5)$$

where

NA Total Alarm Count for One Sensor

V Estimated Intruder Speed

RI Sensor Reporting Interval (Assumed to be 4 Seconds)

4.2.6 (C) Shape of the Wide Area

As described in Section 3.2, the S/T units will report their alarms either directly or via an R/R to the R/I unit. The latter for economical and logistics reasons should be located so that it can collect alarms from as many arrays as practical. This leads to the question of the geometrical shape of the Wide Area.

Initially the Wide Area was thought of as a rectangular area of 273,000 square meters with the long side no longer than four times its short side. A Wide Area which conforms to these dimensions and which contains three arrays is shown in Figure 4-24. If the shown trail junction is the only place within the maximum reception range of the R/I where sensors are to be emplaced, then the rectangular shape for the Wide Area is as good as any. However, situations will frequently be encountered where there are other trail junctions within the maximum reception range of the R/I. An illustration of such a situation is shown in Figure 4-25. An examination of this figure leads to the conclusion that in order for all these arrays to be able to report to the same R/I the required shape for the Wide Area shall be circular. Since the maximum reception range in the rectangular area was about 1000 meters, it appears that the radius of the circle shall therefore also be about 1000 meters.

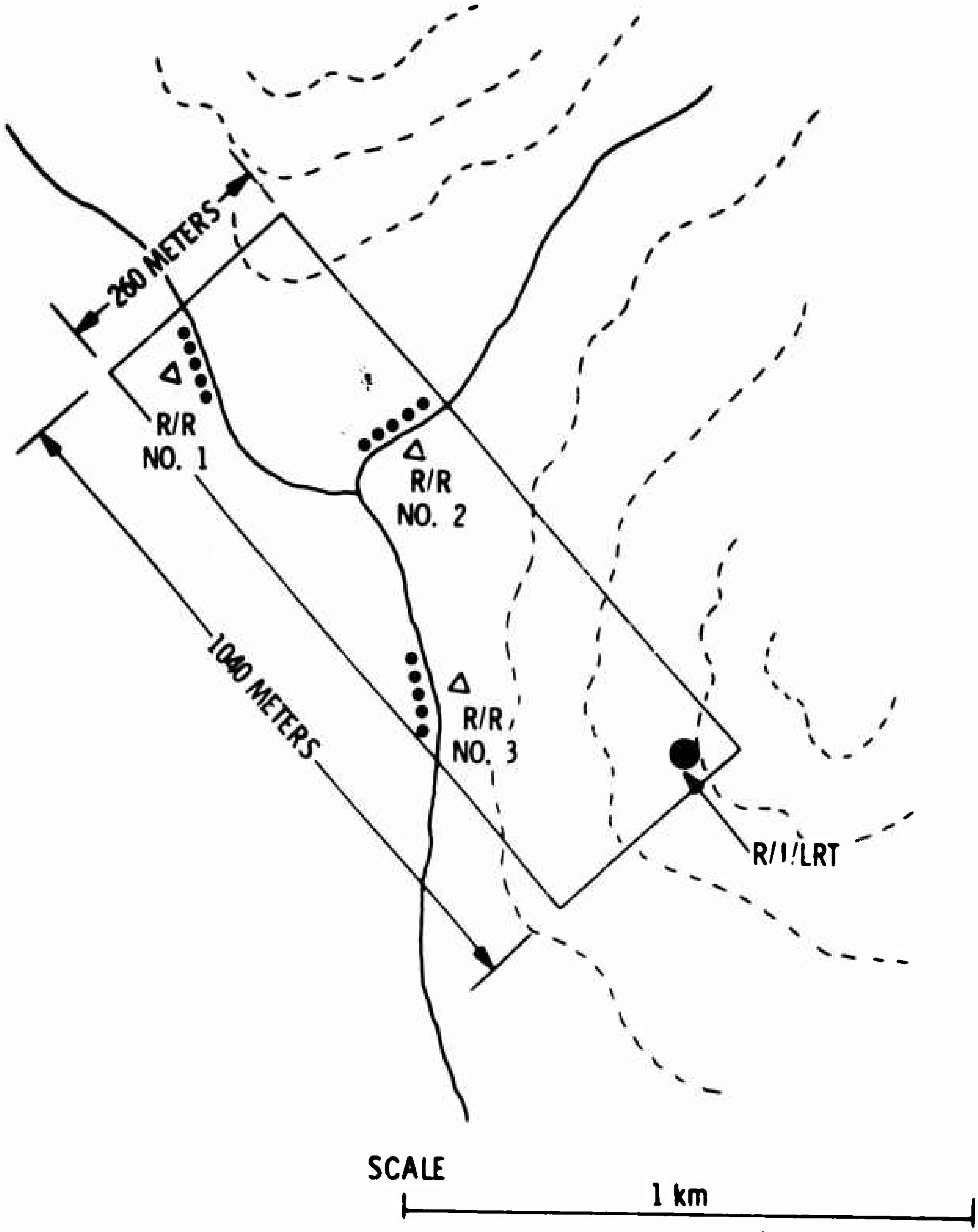

Figure 4-24 (C). Surveillance of a Trail Junction Using Old Wide Area Size and Shape Specifications (U) (CONFIDENTIAL)

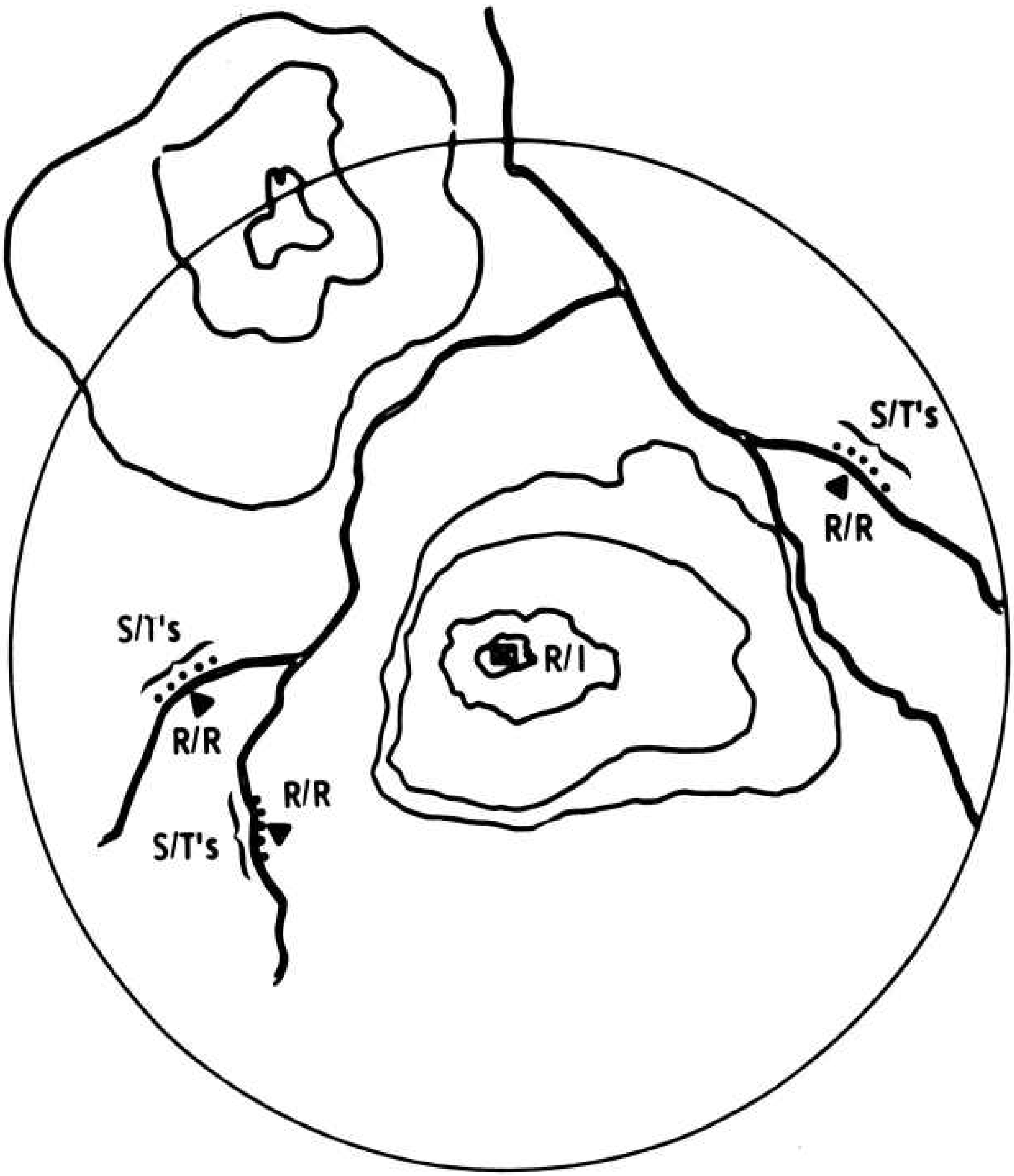

Figure 4-25 (U). Circular Wide Area Configuration (U)

4.2.6 (C) (Continued)

To demonstrate that the circular area concept is superior to the rectangular, an exercise was conducted in which surveillance was to be obtained over an extensive trail network. The following criteria was applied:

a. Surveillance was to be established on all approach routes so that the intruders could be traced as they moved toward the air base.

b. The arrays were to be emplaced so that at least once every hour intruders would pass through an array (assume an average velocity of 0.6 to 1 meter/sec).

c. R/I units were to be placed on high ground, whenever possible, in an effort to minimize propagation losses.

Figure 4-26 shows the resulting distribution of the Wide Areas using the rectangular shape while Figure 4-27 shows the same when the circular shape is used. Comparison of the two results prove the following:

a. Eight Wide Areas are required to meet the trail surveillance requirement using the rectangular as opposed to only six when the circular Wide Areas are used. Thus, a savings of 25 percent was realized in terms of equipment alone.

b. High ground surrounding the trails can be better utilized in placing the R/I's when the circular shape Wide Areas are used.

c. Sensor arrays can be more optimally spread out along the trails using the circular Wide Areas. This leads to a better threat tracking with fewer Wide Areas.

The circular Wide Area concept is also better suited for handling fence arrays. The reason for this is that there will be much less restriction on the possible fence configurations which can be used, i.e., the fence arrays can be spread out more to cover the most probable entry routes into a suspected launch area.

Therefore, it is recommended that a Wide Area is defined as that area which surrounds the R/I within a radius of 1000 meters. It should be noted, however, that this does not require that all Wide Areas are of this size. The definition is only intended to set a logical upper bound on size and shape.

4.2.7 (C) Selection of Wide Areas

4.2.7.1 (U) General

A map exercise was conducted to gain a better insight into the selection process of Wide Areas to protect an airbase. An existing air base (Pleiku, Vietnam) and its environs were selected as representing a typical situation in which the BESS system might be deployed. Although the air base used in this exercise was taken from the SEA theater, it presents a network of trails, roads, rivers and mountains similar

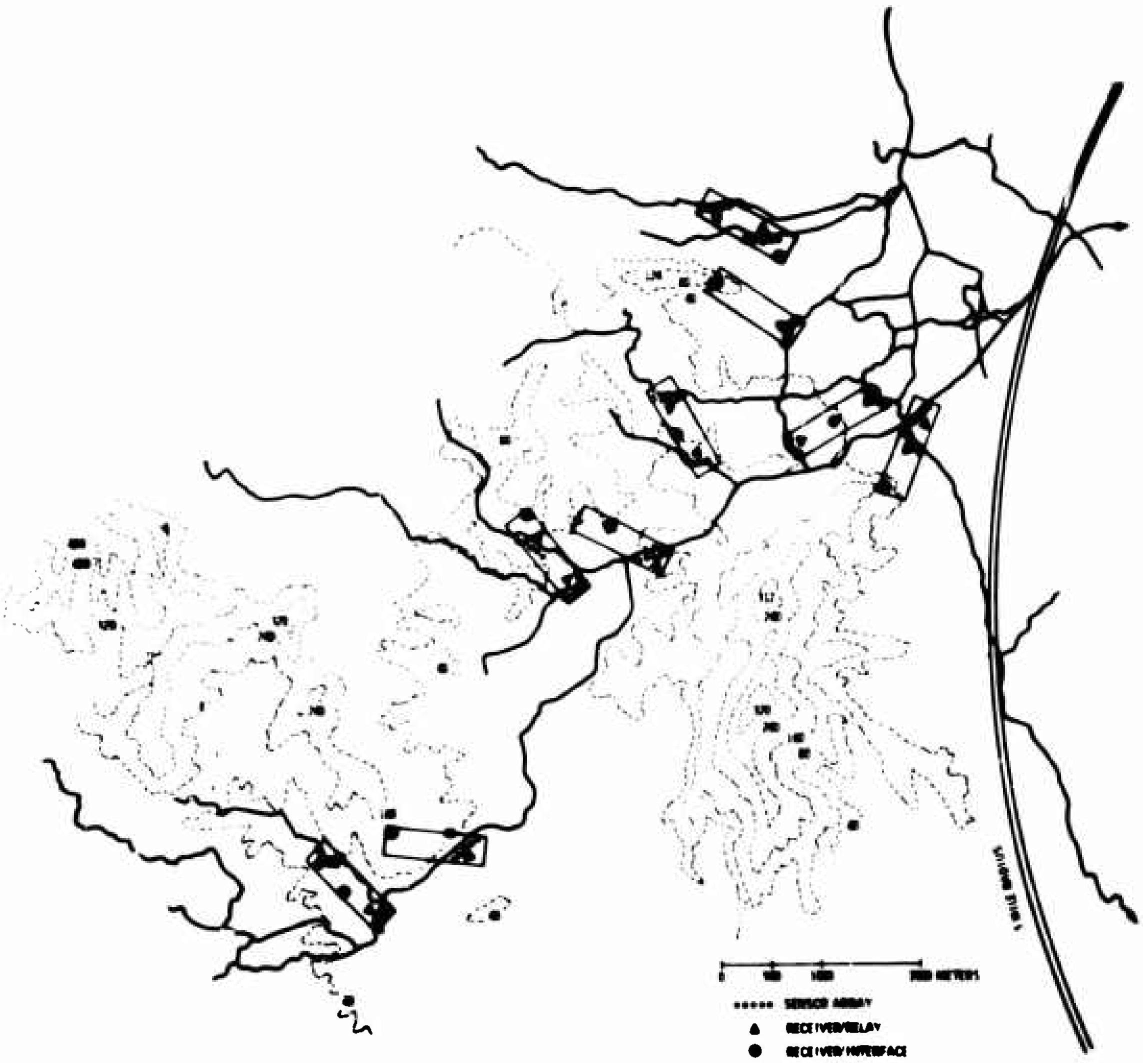

Figure 4-26 (U). Layout Using Rectangular Shape Wide Areas (U)

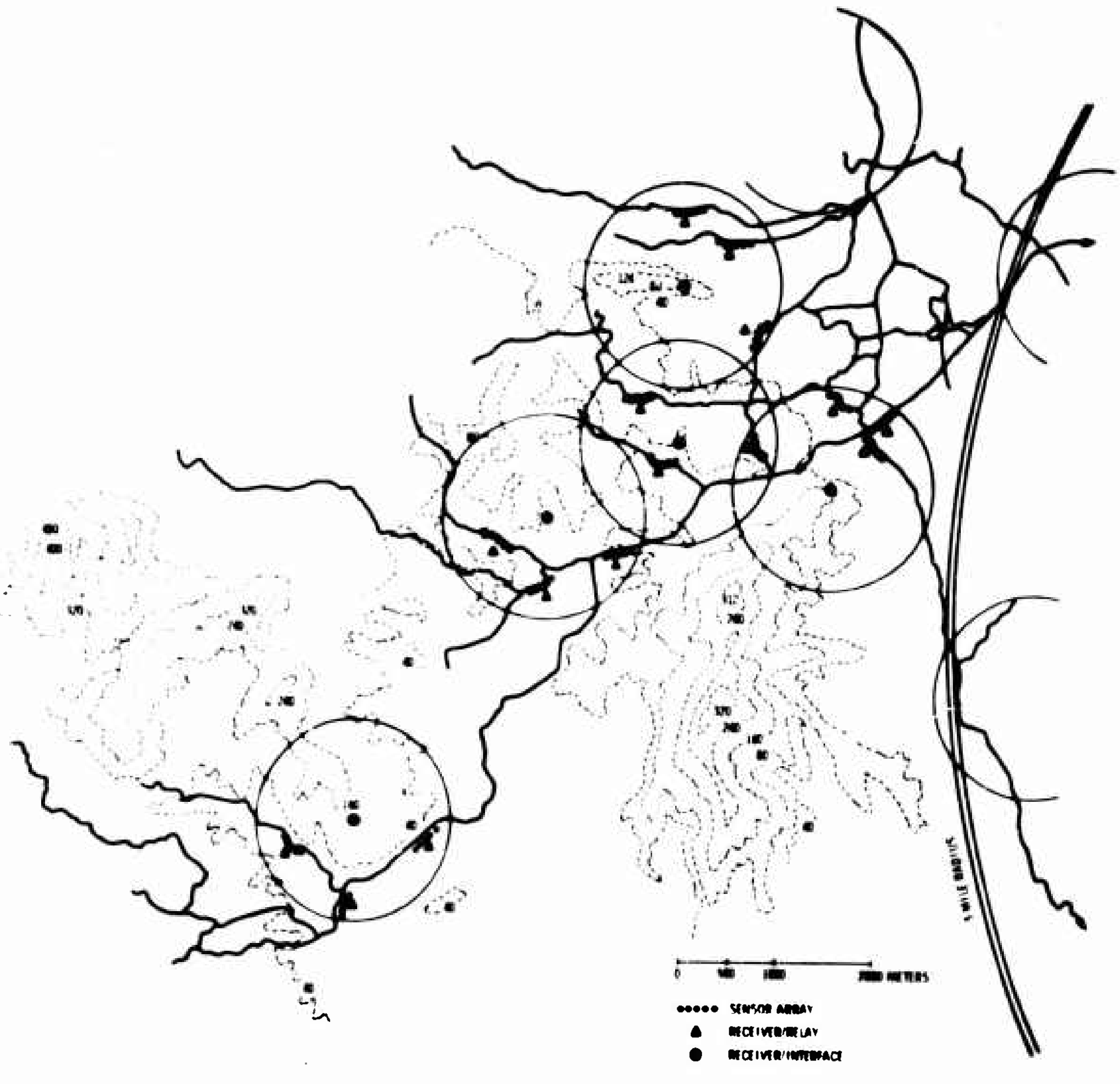

Figure 4-27 (U). Layout Using Circular Shape Wide Areas (U)

4.2.7.1 (U) (Continued)

in many ways to those found any place in the world. Hence, the results of the exercise, shown in Figure 4-28, may be considered to be indicative of what the requirements of the BESS system may be in any world-wide deployment where an omni-directional surveillance over the environs of an air base is required.

The specific objective of the exercise was to determine:

a. Approximately how many Wide Areas are required

b. The distribution pattern of Wide Areas.

4.2.7.2 (C) Selection Criteria

Trail arrays were emplaced to detect significant enemy use of the existing trail and road network. The following criteria were used to select the location of the Wide Areas:

a. Acquire the intruder as soon as possible after he comes within the 24 km. radius. (This is heavily influenced by the considerations mentioned in c and d below.)

b. Re-acquire the intruder at least once more before he reaches the 10 km. radius.

c. Make maximum use of available high ground to provide communications to the base.

d. Provide surveillance over "choke points" in the trail network.

e. Intensify surveillance of trails within the zone from 8 to 10 km from the base.

f. Avoid areas which come under other surveillance. (An example might be a heavily patrolled road.)

g. Where possible, economize by selecting Wide Area locations which permit coverage of several routes of approach.

Fence arrays were emplaced to deny the enemy the use of the most favorable launch points or firing points. The selection of these points was based on:

a. Range of enemy weapons

The maximum range of enemy weapons serves to limit the area from which an attack may be conducted. Allowances must, of course, be made for the added range obtainable from elevated firing points.

b. Foliage and terrain

Launch points must be relatively open and free of terrain obstacles.

Figure 4-28 (C). Example of WARS D

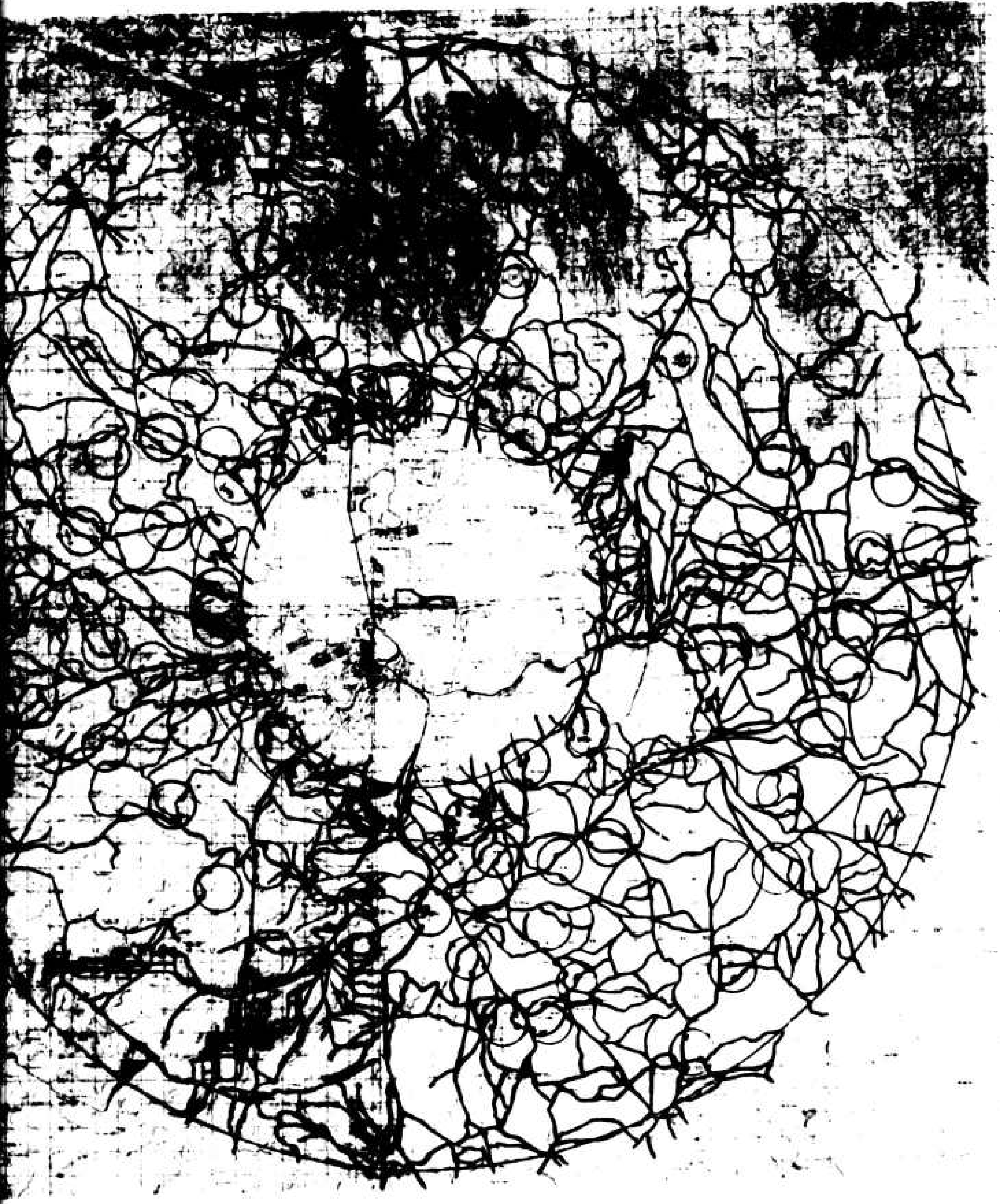

Figure 4-28 (C). Example of WARS Deployment (U)

2

4.2.7.2 (C) (Continued)

c. Visibility to the base

Although it is by no means necessary, the ability to observe the base from the vicinity of the launch point is a distinct advantage in sighting and correcting fire.

d. Long axis of target

It is particularly desirable to launch from those sites where small errors in range will not cause a complete miss of the target.

e. Availability of suitable cache sites, avenues of approach, and withdrawal.

f. Absence of other means of surveillance.

4.2.7.3 (C) Results

The results obtained from this exercise are summarized below:

a. A total of 91 Wide Areas were required to detect enemy personnel moving toward the air base.

b. Each Wide Area contained, on the average, 4 arrays.

c. A total of 225 trail arrays were required.

d. A total of 85 launch area arrays were required.

e. Maximum array density was obtained within the 8-10 km zone where about 30 percent of the arrays were located.

4.2.8 (C) Information to be Conveyed by the Alarms

4.2.8.1 (C) General

Each alarm shall carry a message which, after decoding will answer the following two questions: (1) What caused the alarm? and (2) Where did it come from? In brief, the information which must be conveyed by the alarm signal must consist of: (1) address, and (2) cause, or status. The requirements of each of these are discussed below.

4.2.8.2 (C) Address

The purpose of the address is to allow the CSC to pinpoint the location of the sensor which emitted the alarm. The following "postal zone" concept has been devised to make possible identification of each sensor emplaced within the 8-24 km annulus.

4.2.8.2.1 (C) Number of Sectors

The US Air Force concept for the local ground defense of air bases calls for the establishment of sectors of defense responsibility. The number of sectors per air base will vary from one air base to another but, in general, is expected to be between three and five. In order to permit integration of the BESS system into this air base defense concept, the annulus containing the sensors will be divided into from three to five sectors. Consequently, the sector address must be able to identify one out of five possible sectors. The sector address will be added by the LRT to avoid unnecessary lengthening of the alarm message during the S/T-to-R/I alarm relaying process.

4.2.8.2.2 (C) Number of Wide Areas

Based upon the results obtained during the exercise described in Section 4.2.7, it is postulated that the maximum number of wide areas for any one air base will not exceed 180. If an air base is divided into three defense sectors and assuming that the distribution of the Wide Areas within the annulus is more or less random, each sector could contain as many as 60 Wide Areas. Consequently, the Wide Area address must be able to identify one out of 60 possible Wide Areas. The Wide Area address will be generated at the S/T's to aid in the identification and suppression of other near-by Wide Area signals during the S/T-to-R/T alarm relaying process.

4.2.8.2.3 (C) Number of Arrays

Examination of Figure 4-28 reveals that conditions may be encountered where as many as 8 arrays are located within a single wide area. Therefore, the array address must be able to identify one out of possible 8 arrays. The array address will also be generated at the S/T's.

4.2.8.2.4 (C) Number of Sensors

As discussed in Section 4.2.3, there will be 5 sensors employed in the trail array and as many as 8 sensors in the fence array. Therefore, the sensor address must be able to identify one out of 8 possible sensors. The sensor address will, of course, be generated at each S/T.

4.2.8.3 (C) Type of Alarm

This information is intended to convey: (1) most probable cause of the alarm, (2) indication of the operational status of the S/T unit, and (3) whether or not the auxiliary sensor, if one is used, is also detecting the presence of the target.

4.2.8.3.1 (C) Target Classification

At the present time, the state-of-the-art in alarm discrimination has not yet reached the level of sophistication where the discriminator not only decides that a target is present but also identifies the type of target. It is expected, however, that in the near future, techniques will be developed to make target classification possible. In anticipation of this event, it is required that at least the following three different types of target classifications can be conveyed by the alarm: (1) personnel, (2) vehicles, and (3) nuisance.

4.2.8.3.2 (C) Status of S/T

The encoding of the alarm must be such as to provide a unique indication when the self test of the S/T unit is successfully completed. Failure to receive such an alarm will be interpreted at the CSC that the S/T unit has ceased to perform its function.

4.2.8.3.3 (C) Alarm from Auxiliary Sensor

The encoding of the alarm must also provide a unique indication for the status of the auxiliary sensor, when one is used. Both possible conditions, auxiliary sensor is ON and auxiliary sensor is NOT ON, must be indicated. The information as to whether an auxiliary sensor is being used with a particular S/T unit is to be stored in the CSC and, hence, need not be conveyed by the alarm.

4.3 (C) ALARM TRANSMISSION ANALYSIS

4.3.1 (C) Comments on Overall Approach

To convey the alarms from the S/T's to the R/I, a data link is required to transmit the short, somewhat sporadic, digital messages. A unique facet of the BESS data link is the fact that as much as 25 percent of the raw data may be lost without affecting significantly the probability of detecting a threat. Hence, in contrast to many other types of digital communication systems, the WARS data link does not require an extremely low data loss rate. One can sacrifice, therefore, some data loss in exchange for simplicity in system operation and hardware design. It should also be noted that this data link differs from many other links in that the message lengths are extremely short thus requiring frequent synchronization.

There are various methods of organizing a communication system which can involve a variety of multiplexing and/or modulation methods. However, the most basic resource with which we are dealing in making an appropriate choice of communication system is that of frequency spectrum or channel allocation. After a considerable study and consultation with RADC, a decision was made to use a channel width of 60 kHz. With this decision made, the next most important thing is to use this channel in a most efficient manner so as to require as few of these channels as possible. One could envision, for example, taking a single 60 kHz channel and subdividing it into a number of subbands, each of which is devoted either to, say, individual arrays or perhaps to a single Wide Area. However, such approach would entail the use of filters to provide guardbands and may, therefore, be discarded as inefficient utilization of bandwidth. In fact, it can be shown that the most efficient way to use a single 60 kHz band is to design the communication signal to occupy as much of the available bandwidth as possible without causing unwanted spillover or cross-talk (interference) in either adjacent channel. Signals that make efficient use of available bandwidth (without employing some form or orthogonal coding, i.e., pseudo-random sequences to minimize mutual interference) are those with minimum time-bandwidth (TW) products. This fact suggests a burst-type rf signal with direct modulation by the baseband digital signal. Use of any subcarrier, or tones, in the modulation process will yield a signal with non-minimal TW product and, hence, will tend to make inefficient use of the available spectrum.

4.3.1 (C) (Continued)

The minimum number of frequency channels that the data link requires is two: one for the S/T to R/R links; and the other for the R/R to R/I link. Hence, the simplest wide-open baseline communications system that one can devise is a two frequency channel system with all the S/T to R/R links sharing one channel and all R/R to R/I links sharing the other channel. The principal possible drawback to such a wide-open system is the potential interference of one transmission from other simultaneously occurring transmissions. Before this can be evaluated, it is necessary to determine first how many transmitters operating on the same frequency will be within the reception range of each other. But before this can be determined, we need to analyze the expected propagation losses between the S/T's to R/R's and then from the R/R's to R/I's. This is covered in the next section.

4.3.2 (U) Path Loss Calculations

4.3.2.1 (U) General

In order to intelligently design the system, it is essential to have an accurate method of predicting the propagation loss between the various units which will be located with horizontal separations of 10 to 1000 meters and where the intervening region may vary from thick jungle to open flat land. It is the purpose of this section to derive and illustrate sets of curves from which path loss can be estimated for any diverse situation. In this section, mks units will be used exclusively and all antenna gains will be considered unity.

4.3.2.2 (U) Propagation Through Forests

Since much of the region where WARS system will be deployed is one covered with trees of various degrees of density, the development of a propagation model for such an environment is essential. At short distances, the propagation loss in db has been found to be (Ref. 1) directly proportional to antenna separation. This implies an exponential loss mechanism and suggests that the primary mode of propagation is the direct through-the-forest mode. As the distance increases, a gradual transition to the so-called lateral wave mode occurs, until eventually the direct mode energy received is negligible compared to that of the lateral wave. While the Jansky-Bailey (hereafter JB) empirical model is satisfactory for forested regions similar to the one in which their measurements were made, it is felt that an extension to other density forests is highly desirable. The most promising model for this purpose appears to be that of Dence and Tamier (hereafter DT) (Ref. 2). The DT model is valid only for lateral wave propagation; however, by combining theirs and the JB empirical model, a hybrid model will be developed which will be applicable to all distances and forest densities of interest.

4.3.2.2.1 (U) Dence-Tamir Lateral Wave Model

JB and several other investigators have found strong evidence for lateral wave propagation when the antenna separation exceeds about 200 meters. DT reason that such propagation can be simulated by treating the forest as a lossy dielectric slab extending an effective height above a semi-infinite earth with different lossy dielectric

4.3.2.2.1 (U) (Continued)

properties. Figure 4-29 shows this model. This total loss for propagation between points T and R is shown to be divisible into four distinct contributions:

$$L = L_o + L_s + L_i + L_r \tag{6}$$

The loss L_o is simply the loss from A to B in Figure 4-29:

$$L_o = 20 \log_{10} \left[\frac{8}{3} \pi^2 |n_1^2 - 1| \left(\frac{\rho}{\lambda_o} \right)^2 \right] \tag{7}$$

where $n_1 = \sqrt{\frac{\epsilon_1}{\epsilon_o} - j\,60\,\sigma_1 \lambda_o}$ is the index of refraction of the forest

ρ = horizontal separation between antennas

λ_o = free-space wavelength

L_s is the loss due to propagation in the forest layer.

$$L_s = 8.686 \left(\frac{2\pi}{\lambda_o} \right) \mathrm{Im} \left(\sqrt{n_1^2 - 1} \right) \left(2h - z_t - z_r \right) \tag{8}$$

The meaning of the symbols h, z_t, and z_r are shown in Figure 4-29.

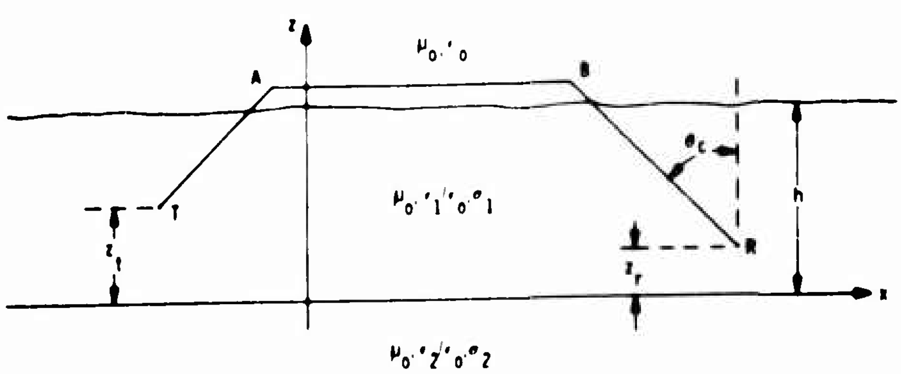

Figure 4-29 (U). Lateral Wave Propagation Model, Dence-Tamir (U)

4.3.2.2.1 (U) (Continued)

While L_o and L_s are independent of how far below the forest-air interface the forest extends, it is obvious that the presence of the relatively lossy ground half-space should incur additional losses if the antennas are reasonably close to it. L_i is an interference loss due to the fact that there are numerous paths for energy to follow in going from T to R within a dielectric slab of finite thickness. It is given by

$$L_i = L_i(z_t) + L_i(z_r) \tag{9}$$

where

$$L_i(z) = -20 \log_{10} \left| \frac{1 + \Gamma e^{-2jk_L z}}{1 - \Gamma e^{-2jk_L h}} \right|$$

$$\Gamma = \frac{n_2^2 (n_1^2 - 1)^{\frac{1}{2}} - n_1^2 (n_2^2 - 1)^{\frac{1}{2}}}{n_2^2 (n_1^2 - 1)^{\frac{1}{2}} + n_1^2 (n_2^2 - 1)^{\frac{1}{2}}}, \quad \text{for vertical polarization,}$$

and

$$k_L = \frac{2\pi}{\lambda_o} (n_1^2 - 1)^{\frac{1}{2}}$$

For frequencies from 50 MHz to 200 MHz, $L_i < 1$ db for vertical polarization and for antenna heights of 1 meter or more. At 0.4 meter a sample calculation for thick forest resulted in a loss, $L_i = -1.43$ db.

The loss, L_r, termed the antenna resistance loss, is due to the change in antenna impedance caused by the proximity of the conducting ground. It is given by

$$L_r = L_r(z_t) + L_r(z_r) \tag{10}$$

where

$$L_r(z) = 10 \log \left| \frac{R(z)}{R_0} \right|$$

$R(z)$ = resistance for an antenna in the forest at height z

R_0 = resistance for an antenna in free space.

4.3.2.2.1 (U) (Continued)

The ratio $R(z)/R_0$ is tabulated by Vogler and Noble (Ref. 3) for infinitesimal dipoles.

In order to encompass all reasonable forest types, DT treat three forest thickness types whose characteristics are defined in Table 4-2.

Table 4-2 (U). Forest Type Characteristics (U)

		THIN	MEDIUM	THICK
Effective Forest Height (m)		5	10	20
Forest	ϵ_1/ϵ_0	1.03	1.1	1.3
	σ_1, mhos/m	0.03	0.1	0.3
Ground	ϵ_2/ϵ_0	5	20	50
	σ_2, mhos/m	1	10	100

The medium forest was chosen to be similar to those measured by JB (1966) and Parker and Makarabhiromya (1967), and the other values were expected to cover the range of types that might reasonably be encountered.

Since L_r is appreciably only at antenna heights of less than a meter, the curves of L_r versus antenna height for the various forest types, shown in Figure 4-30 are useful as a correction, should one or both antenna heights fall in this range.

L_1, being small under all conditions of concern here (±1.5 dB) has been neglected in this analysis. The expression for the remaining loss terms are, at 140 MHz:

$$L_o = 15.17 + 20 \log_{10} |n_1^2 - 1| + 40 \log_{10} \rho \tag{11}$$

and

$$L_s = 25.4 \left[\text{Im} \left(\sqrt{n_1^2 - 1} \right) \right] (2h - z_t - z_r) . \tag{12}$$

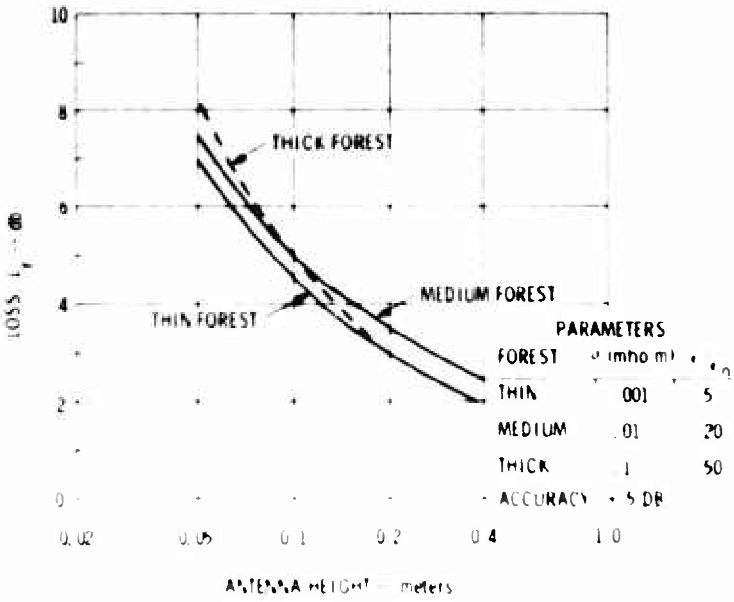

Figure 4-30 (U). Ground Proximity Loss for Infinitesimal Dipole (U)

4.3.2.2.2 (U) Jansky and Bailey Model

From their reams of data taken in an actual forest, JB were able to construct an empirical model which agreed fairly well with the average measurements for ranges from 8m to 1069m. At 140 MHz with antenna at ~3.96m and 1.83m the loss predicted by this model can be expressed as

$$L_{JB} = 15.36 - 20 \log_{10}\left[\frac{.653 \cdot e^{-0.0463\rho}}{\rho} + \frac{0.814}{\rho^2}\right] \qquad (13)$$

For large distances, $\rho > 200$ m, the first term in the brackets is negligible so that at 140 MHz

$$L_{JB}\big|_{\rho \text{ large}} = 17.16 + 40 \log_{10}\rho \qquad (14)$$

At small distances, $\rho < 80$ m, the second term in the brackets is negligible and we have

$$L_{JB}\big|_{\rho \text{small}} = 19.06 + 20 \log_{10}\rho + 0.4015\rho \qquad (15)$$

4.3.2.2.3 (U) Hybrid Model

A hybrid model based on both the JB and DT models was developed next in order to obtain loss prediction for all antenna separations up to several kilometers (JB model) and for various forest types (DT model). An outline of the development of this model follows.

At antenna separations of at least 200 meters both the DT and JB models are valid, and fortunately, both indicate losses which vary as 40 $\log_{10}\rho$ for this region. If we indicate the forest thickness for the JB model by a "j" then the DT model expression for the loss is from Eqs. (11) and (12).

$$L_{jDT} = 15.17 + 20 \log_{10}|n_j^2 - 1| + 40 \log_{10}\rho + 25.4 \left[\mathrm{Im}\sqrt{n_j^2 - 1}\right] (2h_j - z_t - z_r) \qquad (16)$$

The same loss from the JB model is given by Eq. (14).

Since these must be equal, we can see that

$$1.99 = 20 \log_{10}|n_j^2 - 1| + 25.4 \left[\mathrm{Im}\sqrt{n_j^2 - 1}\right] (2h_j - z_t - z_r) \qquad (17)$$

Or if we define

$$20 \log_{10}|n_j^2 - 1| \equiv C_j, \quad 25.4 \left[\mathrm{Im}\sqrt{n_j^2 - 1}\right] \equiv D_j,$$

and

$$2h_j - z_t - z_r \equiv S_j,$$

then

$$C_j + D_j S_j = 1.99 \qquad (18)$$

4.3.2.2.3 (U) (Continued)

For the medium and thick forests with antenna heights equal to those used by JB, we can calculate C_m, C_t, D_m, D_t and S_m, S_t using the parameters of Table 4-2, and can then form the following table of equations:

Table 4-3 (U) Parameters for Various Forest Densities (U)

	C	+	(D)	×	(S)		
Medium	-19.3	+	(.534)		(14.21)	=	-11.71
J-B	C_j	+	D_j		S_j	=	1.99
Thick	-10.4	+	(.894)		(34.21)	=	20.2

Assuming a linear interpolation for the JB forest between the medium and the thick forests of DT, we find that

$$D_j = 0.689$$

and

$$S_j = 22.69$$

From this, the effective height of the JB forest can be found as

$$h_j = 14.24 \text{ m}$$

Now the loss $L_s = DS$ is that due to the propagation of the lateral wave through the layer of foliage so that the coefficient D is proportional to the loss rate for the various forest types. In particular, we have:

D_{thin}	D_{med}	D_j	D_{thick}
.285	.534	.689	.894

4.3.2.2.3 (U) (Continued)

At short distances the JB model, Eq. (15), also contains a term which represents the loss due to propagation through the foliage.

$$L_j = 19.06 + 20 \log \rho + \alpha_j \rho \tag{19}$$

where

$$\alpha_j = .4015$$

Since both α_j and D_j represent rates of through-the-foliage loss for the same foliage density, they are proportional and the constant of proportionality is

$$k = \frac{\alpha_j}{D_j} = .5845$$

assuming the same constant for the other forest types we have

$$\alpha_{thin} = k\ D_{thin} = .1648$$

$$\alpha_{med} = k\ D_{med} = .3115$$

$$\alpha_{thick} = k\ D_{thick} = .5213$$

Using Eq. (10) to correct for antenna heights, Figure 4-31 is a set of curves using Eq. (15) at short antenna separations (≤ 80 m) with smooth curves drawn to the corresponding straight-line curves from Eqs. (11), (12), and (14) at large antenna separations. The curve labeled JB has the same shape as the empirically determined curve from Jansky-Bailey even through the transition region.

All curves were corrected to 1 meter antennas because this is a good reference height and ground effects are not appreciable. The amounts of correction in going from 6 ft. and 13 ft. antennas to one meter antennas are, in order of increasing forest thickness, 1.07 db, 2.02 db, 2.61 db, and 3.39 db respectively.

To assess the effect of frequency changes on the path loss, a second set of curves, Figure 4-32, was generated for 165 MHz. It was found that this much frequency shift increased the losses for each of the four forest types by at most 1.5 to 3 db with smaller changes occurring at the shorter ranges.

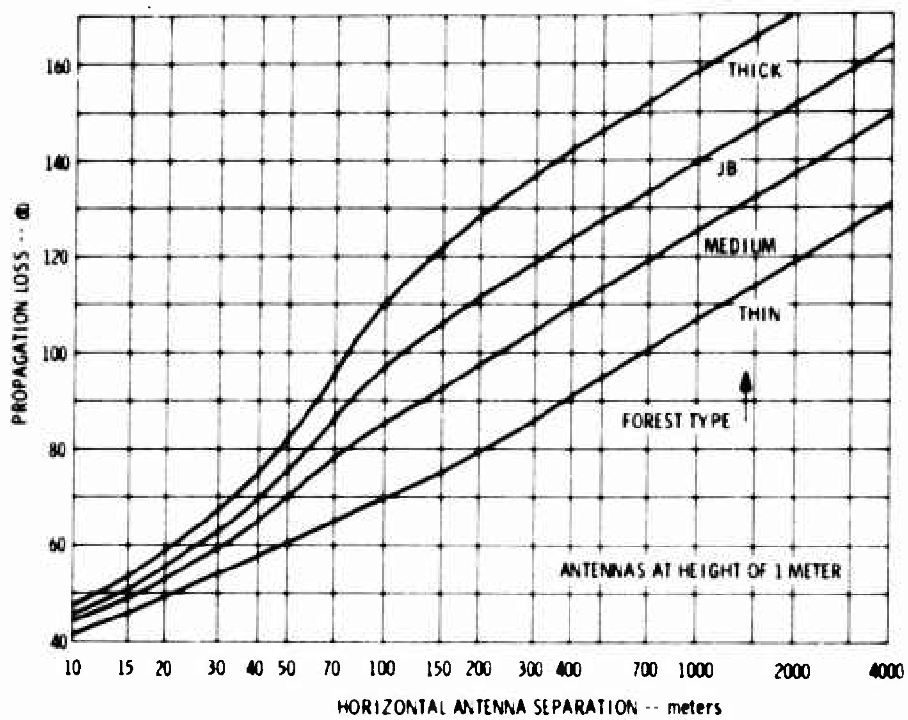

Figure 4-31. (U) Propagation Loss at 140 MHz Over Flat Forested Terrain (Vertical Polarization) (U)

4.3.2.2.4 (U) Confidence and Expected Deviation

JB have made measurements of the propagation loss as the antennas are moved cautiously farther apart. They found two modes of fluctuations. First they observed violent changes in path loss over very small separation changes which is presumed due to multipath constructive and destructive interferences. A second more gradual fluctuation about the mean path loss with distance is attributed to forest and terrain irregularities. The latter is discussed in Paragraph 4.3.2.3.2 for unforested terrain.

JB compile statistical information on the more rapid fluctuations. They show a peak to mean ratio distribution which is of the Rayleigh type and which has a median value of 6.7 dB for vertical polarization at 140 MHz. It is a fair question to ask what the deviation statistics are for the above causes acting together as well as separately. Figure 4-33 supplies these answers. It is based on the following development.

The rough terrain model after Egli has deviations from the mean which are normally distributed about it with a standard deviation of 8.73 dB. This is perhaps a somewhat conservative figure for our case since it assumes hills of 152 meters heights. Such irregularities in a separation of 1 km or less would rarely be encountered. Deviation probabilities due to such terrain irregularities alone are shown by the appropriately labeled curve of Figure 4-33.

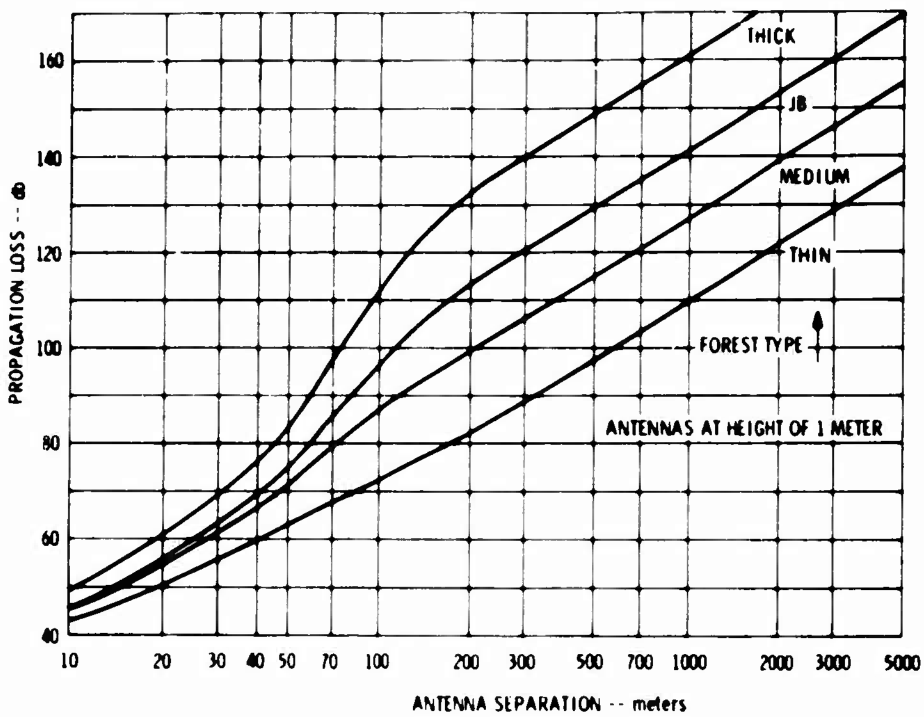

Figure 4-32. (U) Propagation Loss at 165 MHz Over Flat Terrain (Vertical Polarization) (U)

4.3.2.2.4 (U) (Continued)

If we assume that the multipath deviations are sinusoidal in nature, then the total deviation, D, is given by

$$D = R + MC$$

where

D, R, M, and C are random variables

R = deviation due to rough terrain only

M = envelope magnitude of deviation due to multipath

C = Cos θ, determines the shape of the multipath deviation curve assumed uniformly distributed.

The probability that the total path loss will not exceed the mean path loss by more than D_o dB is then given by:

4.3.2.2.4 (U) (Continued)

$$P(D \le D_o) = \frac{\sqrt{2}}{\pi^3} \frac{1}{\gamma\sigma} \int_{-\infty}^{D_o} \int_{0}^{\infty} \int_{-1}^{1} \frac{M}{1 - C^2} e^{-\frac{M^2}{\gamma} - \frac{1}{2}\left(\frac{D-MC}{\sigma}\right)^2} dC\,dM\,dD$$

where

σ = standard deviation due to rough terrain = 8.73

γ = Rayleigh parameter = 64.8

This is represented by the line labeled "combined" in Figure 4-33. The third line of Figure 4-33 labeled "multipath only" shows the deviation statistics caused by multipath alone under the assumption of a sinusoidal shape. Judging from JB continuous measurements with separation increase this is a good assumption. Although these statistics are based on data taken in the JB-type forest, it is expected that they would apply with only minor modifications to other forest types as well.

In those few cases, in which the mean loss curves are significantly exceeded, measures are available for reducing the loss. For instance, the JB data shows that the 90% confidence peak-null separation changes due to multipath effects is only about 1.1 meter at 140 MHz. This means that on the average, if the multipath loss is causing a 6.7 dB loss in excess of the mean, a 13.4 dB improvement can be obtained by moving one antenna a short distance to the minimum loss point. In addition, as discussed in other sections, the raising of the antennas or the reduction of the antenna separation can produce very significant reductions in path loss.

4.3.2.2.5 (U) Effect of Antenna Height Above Forest Floor

Figure 4-34 shows the effect of antenna heights greater than one meter on the path loss. The solid lines represent the height gains for the four types of forest according to the DT theory, Eg. (12). As would be expected, the correction is greater for the thicker forests and increases linearly up to the point at which the antenna penetrates the top of the effective forest height. Although not shown in the figures, one would expect the correction to continue to increase above this, but at a reduced rate. Eventually, a turnover would occur with corrections becoming smaller as the vertical distance between antennas becomes larger with respect to their horizontal separation.

The hatched and dotted lines in Figure 4-34 represent average height corrections measured by JB for two ranges of antenna separations. The most notable feature of these curves is the discrepancy between them and the DT curves for small heights, 1-6 m. This is easily explained by the fact that as an antenna is raised a little above a meter, it doesn:t really begin to penetrate into the dense foliage region for the first several meters. Thus, the height gain foes not really increase much until a height of 5-7 meters is reached. Since the DT model assumes a homogeneous forest layer, no such practical effect would be expected.

No good explanation of the short and long distance loss correction differences is available. Certainly there is no obvious reason for such a sharp transition region from 1600 to 3200 meters, now is it clear why height gain should be a function of horizontal

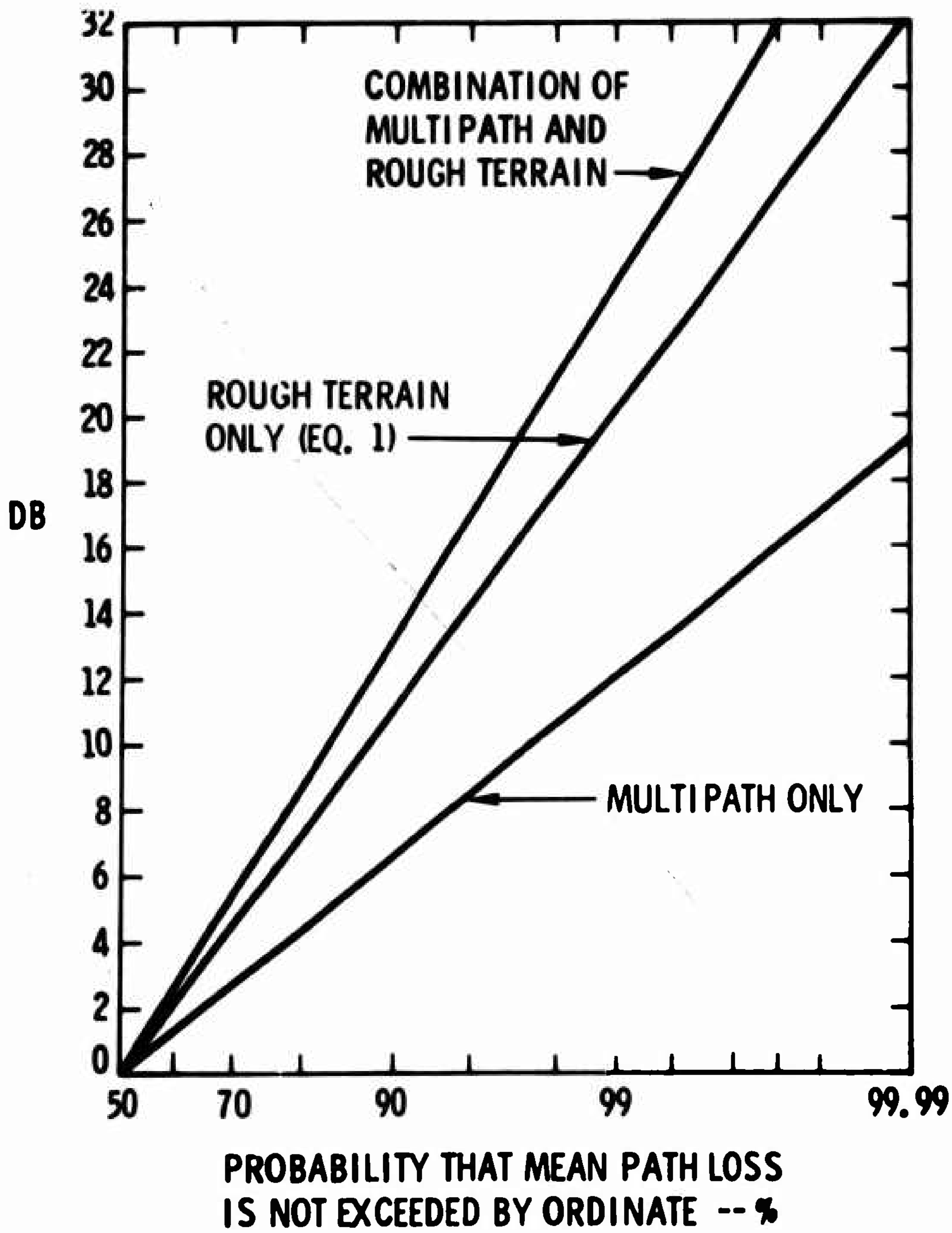

Figure 4-33 (U) Path Loss Deviation Statistics for Thick Forest (JB) (U)

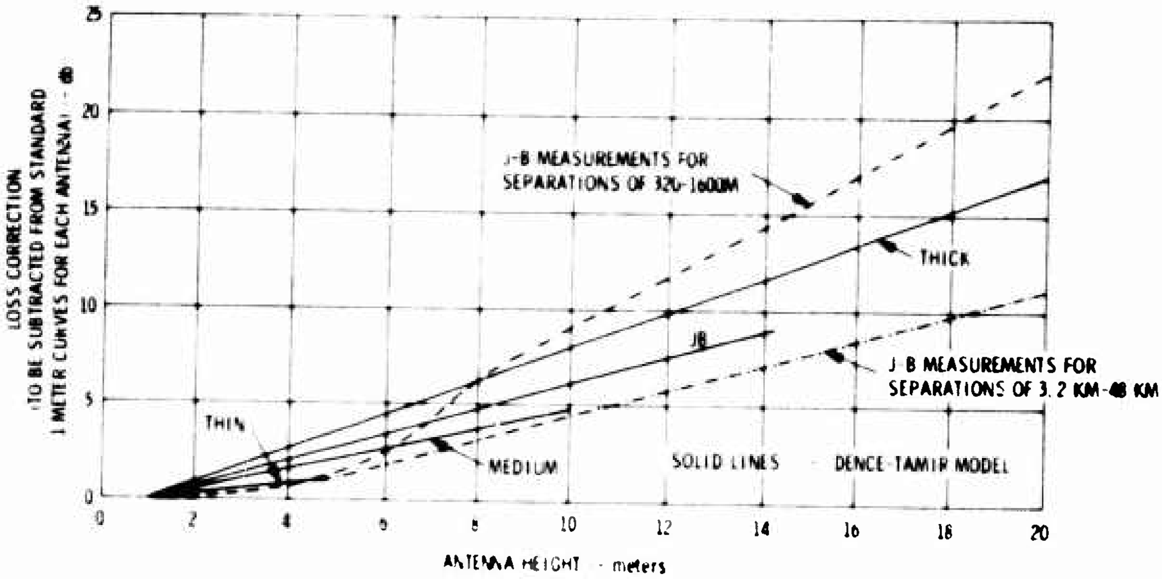

Figure 4-34. (U) Antenna Height Correction Curves (U)

4.3.2.2.5 (U) (Continued)

antenna separation at all four separations greater than 300 meters where the lateral wave is predominant. However, a possible explanation could be terrain masking.

4.3.2.3 (U) Propagation Over Unforested Terrain

4.3.2.3.1 (U) Flat Terrain

The propagation loss for antennas at heights z_t and z_r above a flat conducting earth is given (Ref. 4) as

$$L = 40 \log_{10} \rho - 20 \log_{10} z_t z_r \qquad (20)$$

This formula assumes that the antennas are isotropic, that the ray path is near grazing, and that the antennas are located at least a wavelength above the surface. Figure 4-35 is a plot of Eq. (20) for various geometric mean path heights and path lengths. The minimum loss is bound by the free-space loss which is given at 140 MHz for isotropic antennas by the formula:

$$L_{fs} = 15.36 + 20 \log_{10} \rho \qquad (21)$$

4.3.2.3.2 (U) Rough Terrain

A model for rough terrain attributed to Egli by JB is given for 140 MHz by:

$$L_E = 10.6 + 40 \log_{10} \rho - 20 \log_{10} (z_t \cdot z_r) \qquad (22)$$

4.3.2.3.2 (U) (Continued)

Note that this is the same as Eq. (20) except for an additional constant loss of 10.6 dB. JB found that the following model fit their data somewhat better.

$$L = 0.23 + 40 \log_{10}\rho - 0.656 (z_t + z_r) \tag{23}$$

However, it is meant only for antenna separations of more than 3.2 km and also for forested rough terrains. For the purposes of path loss estimation, it appears that the best we can do is to add some additional loss constant to the curves of Figure 4-34 such as the 10.6 dB recommended by Egli. The good judgment of the designer will have to be used here taking into account that the expected standard deviation from the Egli model prediction is 8.1 dB with a 90 percent confidence range of ±10.53 dB.

Figure 4-36 is meant to aid the designer in this regard. It indicates conversion curves which allow the determination of a geometric mean antenna height from the average path height and the height of one of the antennas. This is useful where an estimate of average path height is available and also the height of the antenna which is on relatively flat ground. It gives the effective geometries mean antenna height required for the use of Figure 4-35 to obtain a loss figure.

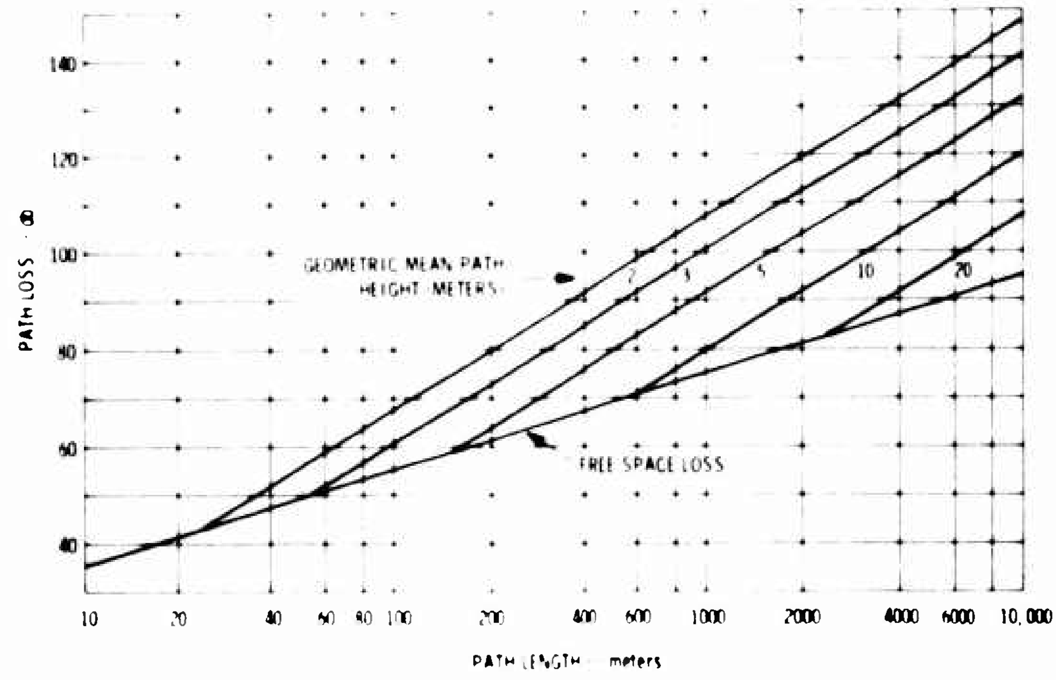

Figure 4-35. (U) Electromagnetic Propagation Loss at 140 MHz over a Flat Earth (U)

4.3.2.3.3 (U) Hilly Terrain

Figure 4-37 shows a curve based on empirically determined loss corrections for situations in which one of the antennas is in a terrain shadow. This information (Ref. 4)

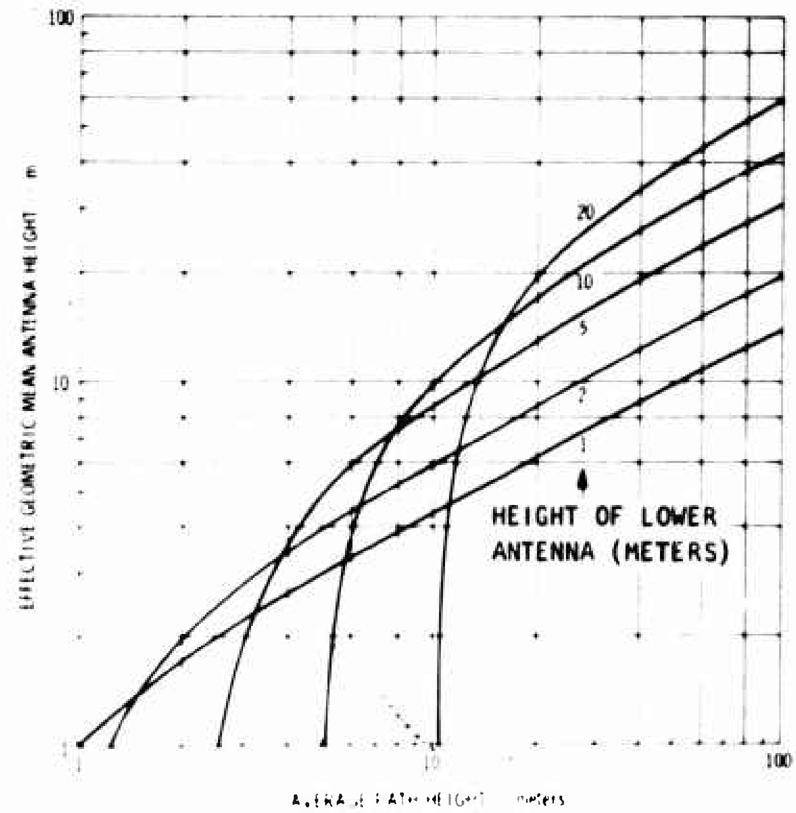

Figure 4-36. (U) Average to Geometric Mean Height Conversion (U)

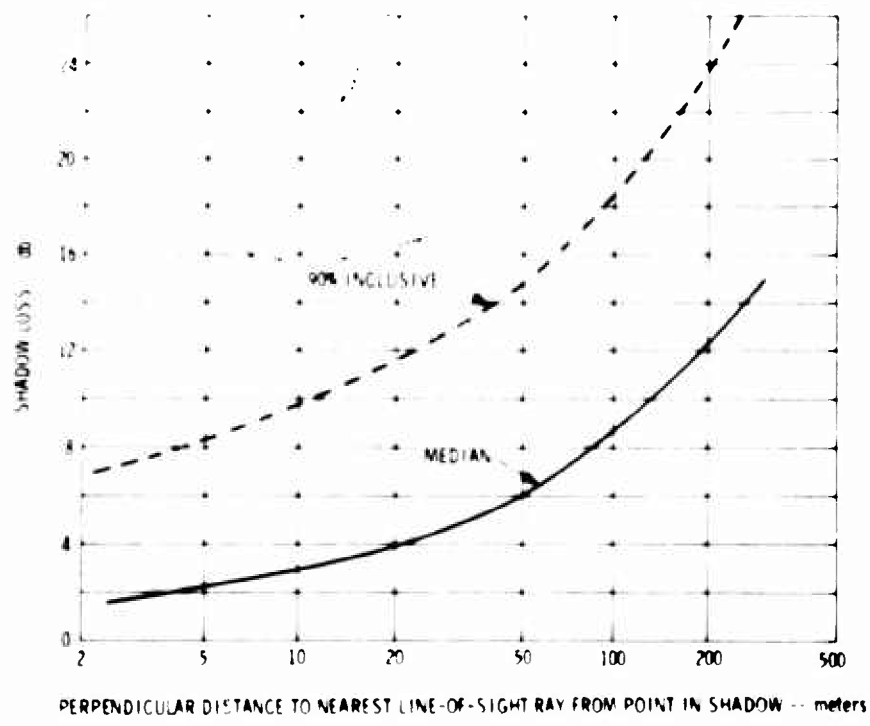

Figure 4-37. (U) Empirical Shadow Loss at 140 MHz (U)

4.3.2.3.3 (U) (Continued)

gives the number of decibels of additional loss to be expected as a function of the distance to the line-of-sight path from the shadowed antenna over the loss for the line-of-sight case at the same distance. It also shows the 90 percent confidence losses.

4.3.3 (C) Transmitter and Receiver Interference Analysis

4.3.3.1 (C) Maximum Reception Range

In order to estimate the number of S/T's which might be within the reception range of an R/R, we first need to determine the maximum distance at which the signal radiated by an S/T might have adequate field strength to be picked up by an R/R. This distance can be estimated in the following manner.

When an S/T is deployed in thick foliage, its transmitter power will be set to maximum to assure the required S/N at its associated R/R. But rarely, if ever, will a forest be encountered which is homogeneous. Therefore, if one plotted a constant field strength contour for an S/T emplaced in forest, it is expected to look much like the one shown in Figure 4-38 (Ref. 5). Thus in those sectors where the tree density is lower, the same field strength will be maintained out to much larger distances than in those where the tree density is high. An estimate as to what this distance might be can be obtained by examining Figure 4-32. There we see that an S/T set to provide adequate field strength over a path of 200 meters through the JB type of forest may provide the same field strength out to a point 1200 meters away through thin forest.

This leads to the conclusion that all those S/T's which are located within approximately 1200 meters from an R/R may fall within the reception range of an R/R. Certainly, this is an upper bound because: (1) some of those S/T's will be set to radiate less power, and (2) as Figure 4-38 shows the constant field strength contour is far from being omnidirectional.

By following the same approach, one can also determine the radius for the reception range circle of an R/I. Again, with the aid of Figure 4-32, one can see that an R/R set to provide adequate field strength over a 1000 meter path through the JB type of forest may provide the same field strength out to a point 6000 meters away through thin forest. Therefore, as an upper bound, all R/R's which are located within approximately 6000 meters from an R/I may be considered to fall within the reception range of an R/I.

4.3.3.2 (C) Number of S/T's and R/R's Capable of Interference

With the circles of reception ranges determined above, it is not the task to estimate the number of S/T:s and R/R's which may be located within these circles.

Basically, two approaches are available. One would arrive at the estimate by first calculating how many non-overlapping Wide Areas, or portions thereof, fit into the two circles and then decide on the number of S/T's and R/R's which might be located within these areas. The other approach would make use of the results which were shown in Figure 4-28 and simply count the maximum number of S/T's and R/R's deployed within the 1200 and 6000 meter circles drawn around any R/R and R/I, respectively.

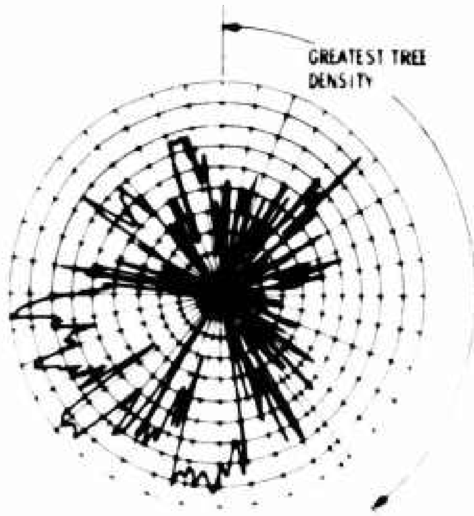

Figure 4-38. (U) Constant Field Strength for a Radiator Emplaced in Forest (U)

4.3.3.2 (C) (Continued)

By using the theoretical approach, it was determined that the maximum number of S/T's that may be located within the reception range of an R/R can be as high as 50, while the corresponding number of R/R's located within the reception range of an R/I can be as high as 150.

Since in a real-world situation it is high unlikely that wide areas will be packed next to each other over an area as large as 6000-meter-radius circle, the above numbers were considered to be unrealistic. Therefore, Figure 4-28 was carefully examined in the search for more meaningful numbers. From this exercise, it was found that the maximum number of S/T's located within a 1200-meter-radius circle is about 30, while the largest number of R/R's which were found situated within a 6000-meter-radius circle was found to be about 40. After some further examination of Figure 4-28, it was concluded that 30 is indeed a reasonable estimate of the maximum number of S/T's. With regard to the R/R's, it was decided that Figure 4-28 may not represent all possible conditions, and that there is a possibility that the maximum number of R/R's could be somewhat higher than 40. For this reason, the estimate for the maximum number of R/R's that may be located within the reception range of an R/I was projected to be 50.

4.3.3.3 (C) Simultaneously Activated S/T's and R/R's

Now that an estimate has been obtained on the maximum number of S/T's and R/R's which are capable of causing interference, it is important to get an assessment on what the activity of these units will be.

To do this, let us review the possible reasons why an S/T or an R/R may be on air. For an S/T, the reasons are as follows:

4.3.3.3 (C) (Continued)

a. False alarms

b. Target caused alarms

c. Friendly troop caused alarms

d. Indigenous people caused alarms

e. Animal caused alarms.

For an R/R, the reasons are as follows:

a. Receipt and address authentication of an alarm sent by an S/T

b. Receiver generated alarm caused by other equipment malfunction or a stray in-band signal.

Let us examine each of these separately.

False alarms will occur randomly with a mean rate which will depend on the type of sensor used, but under no conditions shall exceed 1 alarm in 40 seconds. This holds for all S/T's in the absence of an intrusion. Thus, if there are 30 S/T's located within the reception range of an R/R, there may be as many as 30 alarms received by the R/R in a 40 second interval. This is equivalent to 3 of the S/T's sensing intrusions. It is important to recognize though that a maximum of only 5 of these 30 alarms will cause the R/R to turn on; the rest of them will be rejected on the basis of having an improper array address.

To estimate the number of S/T's which may be on simultaneously as a result of intrusions, the example will be used where the group consists of 20 men spaced an average of 5 feet apart and moving with about 0.6 m/sec velocity. Figure 4-22 in Section 4.2.4 showed that for this type of intrusion no more than 3 out of the 5 sensors will be on at the same time. Consequently, if the 30 S/T's are considered to make up 6 arrays and only one array is being intruded then the total number of S/T's which will be active can be shown to be 5.7. If two arrays are simultaneously intruded by two different 20-men groups, the maximum number of active S/T's will be 8.4 and so on. Figure 4-39 shows the results of these computations for two different false alarm rates. This again is an upper bound since for all other cases where the intruders are animals or composed of a smaller group of people, the number of simultaneously active S/T's will be smaller than those shown in Figure 4-39.

We shall now examine the maximum number of S/T's which may be competing for the same R/I via the 50 R/R's.

To start with, we shall recognize that although there may be as many as 30 S/T's within the reception range of an R/R, the latter will retransmit only the signals associated with its own array because of the built-in address authentication feature. Thus we are talking of a maximum of 250 S/T's that may be controlling the activity of the R/R's located within the reception range of an R/I. We may now follow the same approach as before and, for example, determine that in the absence of any intrusion,

4.3.3.3 (C) (Continued)

the false alarm activity alone will be equivalent to 25 of the 250 S/T's being intruded. If one array is actually being intruded, the number of S/T's trying to reach an R/I via their R/R's goes up to 27.7, and so on.

Figure 4-4ˇ vs the results of these computations for two different false alarm rates.

R/R and R/I receiver-generated alarms are expected to be very few, if any, and therefore, these are considered as negligible in causing interference.

The data loss which results from the inteference of the simultaneously active S/T's and R/R's is analyzed and calculated in Section 4.3.8.

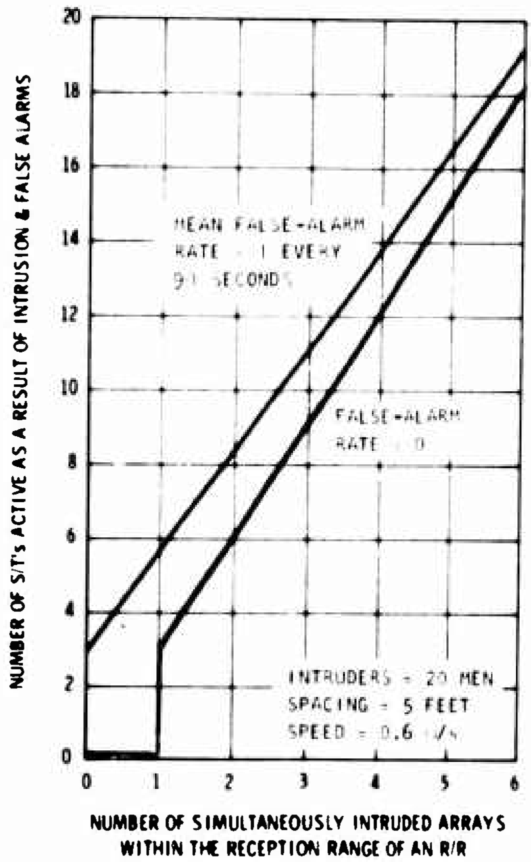

Figure 4-39. (C) Number of S/T's Competing for an R/R (U)

4.3.4 (C) Modulation and Bandwidth

There are a number of possible digital data systems (References 6, 7, and 8) that could be chosen to transmit and receive the sensor messages. However, to minimize

4.3.4 (C) (Continued)

the effects of signal strength fluctuations and noise, the only systems that were considered were those which employ frequency or phase modulation techniques. Thus, the evaluation was limited to: (1) coherent phase-shift-keying (PSK), (2) differentially coherent PSK (DPSK), (3) coherent frequency-shift-keying (FSK), and (4) incoherent FSK, and (5) binary FM. The relative merits of these modulation techniques are compared below on the basis of: (1) what signal-to-noise ratio is required for a fixed bit error rate, and (2) what bandwidth is required to handle fixed bit rate.

4.3.4.1 (C) Required S/N for a Fixed Bit Error Rate

For this exercise, the required bit error rate for the communication system will be taken as 10^{-3}. The detector input signal-to-noise energy ratio required to meet this bit error probability is read from the curve shown in Figure 4-40 and tabulated in Table 4-4. These curves assume common binary No-Reutrn-to-Zero (NRZ) signaling, optimum decoding and bit timing synchronization.

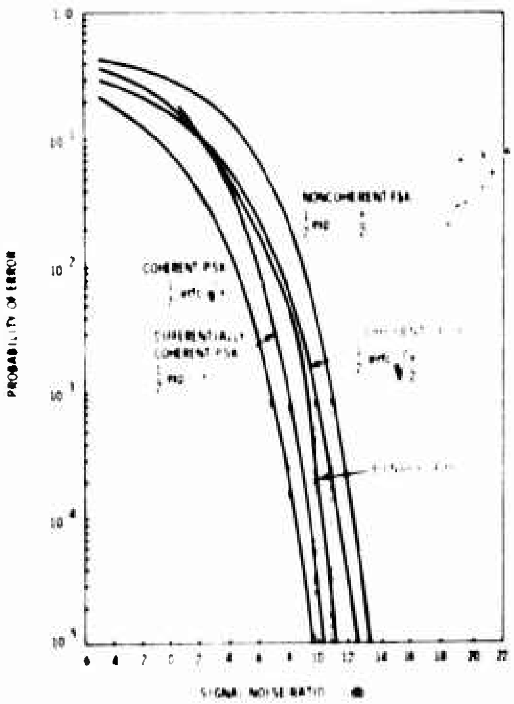

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Figure 4-40. (C) Error Rates for Several Binary Systems (References 6 and 14) (U)

The system requiring the lowest energy ratio of 6.8 dB is coherent PSK and the one requiring the highest of 11.0 dB is incoherent FSK, using bandpass filter detection. Binary FM and DPSK need 9.0 dB and 8.0 dB, respectively.

Although superior in performance, coherent PSK is not considered practical for the WARS application becuase of the necessity of maintain a reference carrier in the receiver which is phase and frequency locked to the input signal. The same comment applies to the inferior coherent FSK system. Therefore, the choice narrows

4.3.4.1 (C) (Continued)

down to DPSK and incoherent FSK. On the basis of performance, DPSK is 3 dB superior to incoherent FSK, using bandpass filter detection. The curve also shows a 1 dB advantage of DPSK over incoherent FSK using discriminator detection. However, the authors of the curve (Reference 15) comment that an additional allowance of 1 dB should be taken to compensate for the reduction in noise margin due to intersymbol interference.

4.3.4.2 (U) Bandwidth Requirement Analysis

Instability of the frequencies of the signal carrier and receiver local oscillator affects the bandwidths of the binary FM and incoherent FSK systems more than those of DPSK. There are three bandwidths which are important: RF signal bandwidth - the actual bandwidth of the transmitted RF signal; RF signal occupancy bandwidth - the total bandwidth which the RF signal may occupy; and the receiver IF bandwidth. These bandwidths will be compared for the three systems under consideration.

Although binary FM and incoherent FSK are generated exactly alike by deviating a VCO, the different types of detection actually affect the RF signal bandwidth and occupancy in different ways. The optimal peak-to-peak deviation for binary FM, or, what amounts to the same thing, the minimum tone frequency spacing for orthogonal signaling (no cross-talk) is incoherent FSK is 1/T, the bit rate (the terminology differs because of the detection method).

Because the bit length is T, and the modulating waveform is low-pass filtered at the frequency 1/2T, the RF signal bandwidth B_{RF} may be computed as follows:

$$B_{RF} = 2(D/2 + f_c)$$

$$= 2/T$$

where D is the peak deviation, and $f_c = \frac{1}{2T}$ is the low-pass filter cutoff frequency.

Now assume that the transmitter VCO and the receiver local oscillator have the nominal ±5 KHz (30 ppm) instability in the upper end of the 160 to 172 MHz band. The effect of the VCO instability is that another 10 KHz must be allowed for the possible occupancy of the RF signal. When the receiver local oscillator instability is taken into account, the total possible signal occupancy becomes 2/T + 20 KHz (see Figure 4-42). The IF bandwidth must be at least this wide to assure that all the signal frequency components are passed uniformly.

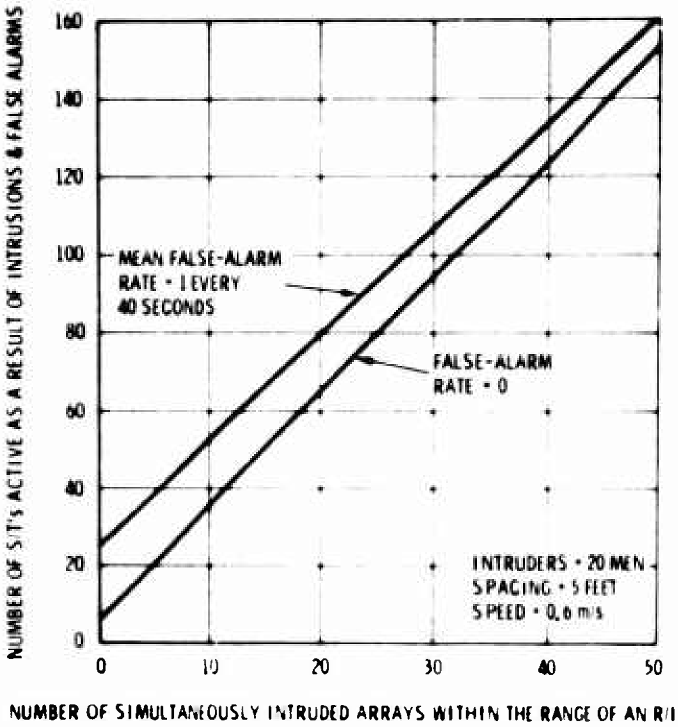


Figure 4-41 (U). Number of S/T's Competing for an R/I

Table 4-4 (U). Required S/N for $P_e = 10^{-3}$ (U)

Coherent PSK	6.8 db
DPSK	8.0 db
Coherent FSK	9.8 db
Incoherent FSK	11.0 db
Binary FM	9.0 db

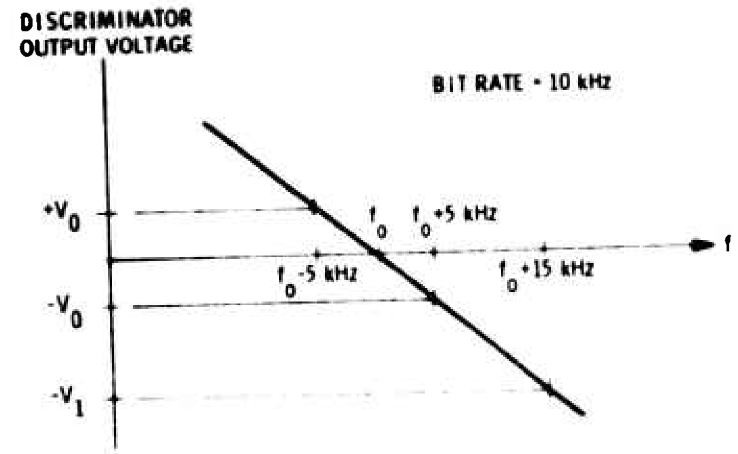
4.3.4.2 (U) (Continued)

Now consider binary FM which employs discriminator detection of the IF signal, and assume the bit rate 1/T to be 10 KHz. The center frequencies of the signal and the discriminator may now differ by as much as 10 KHz. Remembering that the deviation 1/T is 10 KHz, the output of the discriminator (assuming response to these frequencies) is positive (or negative) at both peak frequencies, as shown in Figure 4-42. Such a situation is undesirable from the standpoint of noise and intersymbol interference. To avoid the filtering problems encountered with such a situation, the deviation should be set so that the maximum instability produces a discriminator output, the extreme (corresponding to the peak frequencies) of which have different algebraic signs. This can be accomplished by increasing the total deviation from 10 KHz to 20 KHz, as shown in Figure 4-43. Assuming this is done, the peak-to-peak deviation becomes 1/T + 10 KHz. The RF signal now has a bandwidth of 2/T + 10 KHz (from Eq. (1)) and may occupy another ±5 KHz because fo the VCO instability. Consequently, the receiver IF and the discriminator bandwidths need to be another 10 KHz larger to allow for the local oscillator instability. Under these conditions, the RF signal occupancy is 2/T + 20 KHz, and the receiver IF and discriminator bandwidths are 2T + 30 KHz.

For incoherent FSK, the optimum detector comprises two filters of 3 dB bandwidth $\frac{1}{T}$ whose center frequencies are separated by 1/T (see Figure 4-42). (This detector is a matched filter.) When the original signal, having the peak frequencies separated by 1/T, has an uncertainty in the center frequency of ± 10 KHz, because of the instabilities in the VCO and local oscillator frequencies, the tone filter separation and bandwidths must be increased to avoid intersymbol interference as shown in Figure 4-44a. Using the example of 10 KHz bit rate, the tone frequency separation (or peak-to-peak deviation) increases from 10 to 30 KHz and the filter 3 dB bandwidths from 10 to 30 MHz, as shown in Figure 4-44b. The RF signal bandwidth is now 40 KHz, the total occupancy is 50 KHz, and the IF bandwidth 60 KHz.

The DPSK signal bandwidth is unaffected by the oscillator instabilities. The premodulation filter 3 dB bandwidth is 1/2T and the corresponding RF bandwidth is 1/T. The carrier instability produces a ±5 KHz uncertainty in the carrier frequency, giving a bandwidth of occupancy of 1/T + 10 KHz. To allow for the local oscillator instability, the receiver IF bandwidth must be 1/T + 20 KHz. The reference phase is derived from the signal waveform and is not dependent on any of the frequency instabilities. The modulation waveform detection and integrate-and-dump (matched) filtering likewise is independent of the carrier frequency uncertainty. Table 4-5 summarizes the bandwidth requirements of incoherent FSK, binary FM, and DPSK as a function of bit rate.

DPSK requires the smallest signal bandwidth, signal band occupancy, and receiver bandwidth. The reduced receiver bandwidth also implies a performance relative to incoherent FSK and binary FM better than that predicted by the idealized curves of Figure 4-40. As a result of the instabilities, the detection is no longer optimal because the additional IF bandwidth needed to accommodate these instabilities passes noise in frequencies where no signal components are present. The integrate-and-dump (matched) filtering of DPSK suppresses these noise components. The tone filters of incoherent FSK are.no longer matched to the signal, and pass noise components in non-signal bands to the subsequent envelope detector, which is nonlinear device. This additional noise can suppress components in the signal band and degrade detection performance. The action of the limiter, preceding the discriminator of the binary FM detector, on the out-of-band noise components similarly suppresses the signal components and



Original peak deviation frequencies of $f_0 \pm 5$ kHz give $\pm V_0$ output voltage. Under 10-kHz positive shift, the frequencies $f_0 \pm 5$ kHz give $-V_0$ and $-V_1$ voltage outputs, respectively.

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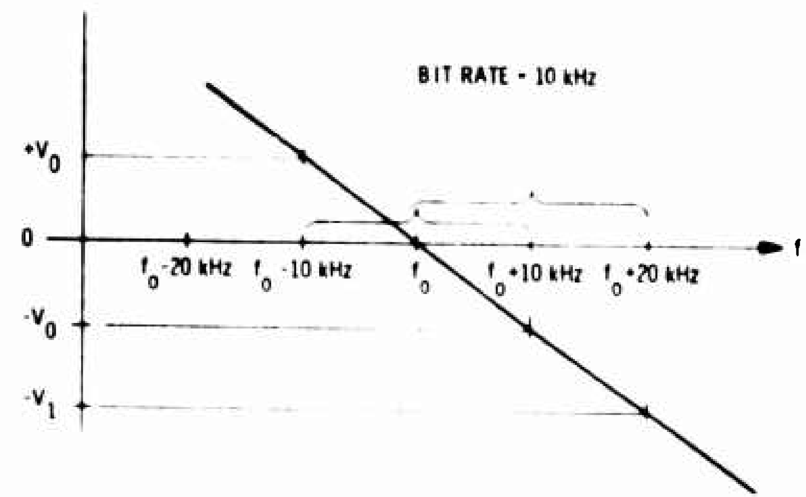
Figure 4-42. (C) Discriminator Outputs Before and After 10 KHz Positive Frequency Shift with 10 KHz Peak-to-Peak Deviation (U)



Original frequencies of $f_0 \pm 10$ kHz give $\mp V_0$ output. Under 10 kHz positive frequency shift, the new frequencies f_0 and $f_0 + 20$ kHz give 0 and $-V_1$ outputs, respectively.

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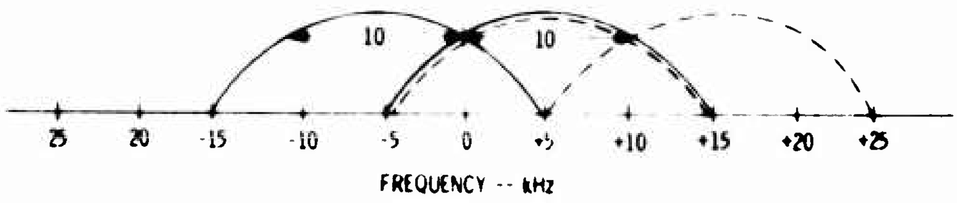
Figure 4-43 (C). Discriminator Output Before and After 10-KHz Positive Frequency Shift with 20-KHz peak-to-peak Deviation (U)



—— ORIGINAL INSTANTANEOUS SIGNAL SPECTRA AND FILTER RESPONSE CHARACTERISTICS

INSTANTANEOUS SIGNAL SPECTRA UNDER 10-kHz POSITIVE FREQUENCY SHIFT

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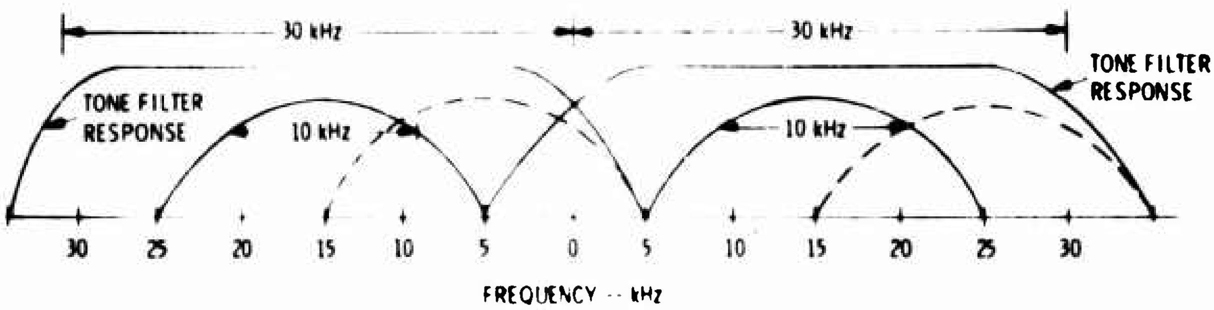
Figure 4-44a (C). Original FSK System Spectra and Tone Filter Responses When Instability Is Not Taken Into Account (U)



—— INSTANTANEOUS SIGNAL SPECTRUM (NO FREQUENCY SHIFT)

INSTANTANEOUS SIGNAL SPECTRUM (10-kHz FREQUENCY SHIFT)

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Figure 4-44b (C). Effect of Frequency Instability on the Instantaneous Signal Spectra, Frequency Deviation, and Tone Filter Response Characteristic of an Incoherent FSK System (U)

Table 4-5. (C) Required Bandwidths (U)

				Effects of Instability	
	Baseband with Pre-Mod Filtering	RF Signal BW	RF Signal BW	Maximum RF BW Occupancy	Receiver IF BW
DPSK	1/2T	1/T	1/T	1/T + 10 KHz	1/T + 20 KHz
Binary FM	1/2T	2/T	2/T + 10 KHz	2/T + 20 KHz	2/T + 30 KHz
Incoherent FSK	1/2T	2/T	2/T + 20 KHz	2/T + 30 KHz	2/T + 40 KHz

4.3.4.2 (U) (Continued)

degrades detection performance. The idealized curves of Figure 4-39 also assume bit synchronization. In practice, the bit synchronization is derived from the demodulated baseband waveform. For binary FM and incoherent FSK, this waveform is noisier than that predicted by the curves. Therefore, the reliability of obtaining synchronization is also adversely affected by the necessarily larger bandwidths of the binary FM and incoherent FSK systems.

The RF signal bandwidths become important because of the constraint of operating within a 60 KHz channel. The occupancy of the DPSK signal is half or less than half that of binary FM or incoherent FSK. To meet a fixed adjacent-channel spillover requirement, the DPSK system can operate at twice the rate of either of the others. Signaling at higher rates is advantageous, because it reduces the probability of overlapping messages and the ECM vulnerability of the system.

4.3.4.3 (C) Choice of Modulation

In the previous discussion, no mention was made of bit timing or synchronization. Bit timing must be derived from the incoming waveform in order to sample at the proper times for making a decision. The method for deriving timing for either FSK will have a noisier waveform because of the larger bandwidths required to offset the instabilities. This makes bit synchronization in FSK more subject to error and uncertain operation. Therefore, considering the lower signal-to-noise required for a given probability of error and the lower RF and receiver bandwidth requirements, DPSK was selected over the other two techniques.

DPSK is a phase-reversal modulation wherein the carrier is switched between 0° and 180° phases under control of the digital data. At the receiving end, the data is recovered by comparing the relative phases of succeeding bits. Thus, a long train of "zeros" consists merely of the carrier frequency, while in a long train of "ones" the phase of the carrier is continuously recersing at the end of each bit time. In conventional digital systems, long sreams of data are sent wherein, on the average, there are as many "ones" as "zeros". This assures that there will be frequent phase reversals from which to extract the necessary synchronization and bit-timing information.

4.3.4.3 (C) (Continued)

This, however, is not the case in the WARS application. First of all, we will not have long streams of data, and, furthermore, some of the messages will contain all "zeros" or all "ones". Therefore, in order to make synchronization possible in the WARS system, we must have a modulation technique that will assure that each of the short messages, irrespective of it composition, contains adequate phase reversals. It is for this reason that it was decided to use the split-phase version of DPSK. In this technique, during the bit interval T, a "1" is represented by a mid-interval phase transition from 0° to 180°, while an "0" is represented by the opposite transition. Thus, a phase transition is transmitted at least once each baud period T from which bit timing can be derived. This subject is further discussed in Section 4.3.5. The decoding performance of this scheme measured in terms of probability of decision error versus signal-to-noise ratio will be the same as conventional DPSK. The bandwidth of this split-phase modulation, however, is twice that which is required in conventional DPSK for the same information bit rate. Note, though, that the modulation bandwidth for a split-frequency FSK would likewise double, if the information bit were were held constant.

4.3.4.4 (C) Bit Rate

The choice of bit rate is influenced by several factors. It enters into determining required signal channel width as well as receiver bandwidth. From the point of view of efficient channel utilization and to minimize interference due to overlapping transmissions, it is desirable to raise the bit rate as high as possible. The factors placing an upper bound on the bit rate are:

a. The need to contain any unwanted or spurious emissions outside the allocated 60 kHz channel

b. The need for excess bandwidth due to transmitter and receiver instabilities

c. The desirability, from a practical equipment implementation point of view, to use some of the available channel width to provide bit timing synchronization.

In order to accommodate the projected transmitter and LO instabilities and to provide some guardband between adjacent channels, it is obvious that no more than about 20 kHz is available for the information bandwidth. With prefiltering at 1/T, this then would permit a bit rate of 20 Kbps. In a split-phase PSK, this amounts to an information bit rate of 10 Kbps. This is then the recommended information bit rate for the WARS data link.

4.3.5 (C) Message Format

4.3.5.1 (C) Bit Structure

As discussed in Section 4.3.4.3, the recommended encoding technique will be split-phase, sometimes referred to as the Manchester code (Ref. 14), in which a phase transition is transmitted halfway through each baud. Encoding a "1" as a "10" produces a transition from an amplitude level of +1 to -1 at time T/2 and encoding a "0" as a "01" results in the opposite transition. Figure 4-45 illustrates the coding and amplitude transitions. Note that such a split-phase data stream may or may not have phase transitions at the end of a baud. These extraneous transitions much be eliminated by the timing circuitry.

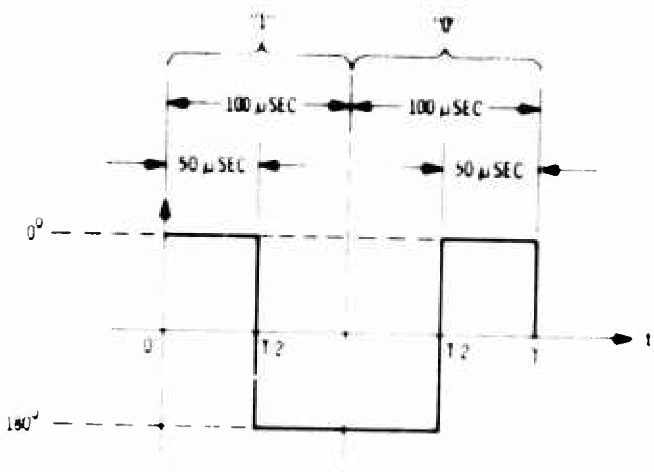

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Figure 4-45. (C) Encoding and Amplitude Transitions (U)

4.3.5.2 (C) Preamble

As a preamble to the message, a five-bit Barker code (11101) has been chosen to provide a frame marker for the start of the message. Preceding the code will be two "0's" to provide two transitions to start the needed bit timing and load the five-bit Barker code shift register. Five bits were chosen for the Barker code to allow for one bit error in the sequence. The probability of encountering two or more errors is negligibly small if the bit error probability is 2×10^{-3}. For one error, the maximum output pulse amplitude will be $+4-1 = 3$ instead of the maximum five. Setting and exceeding the threshold level at just under three will thus furnish a marker pulse even when there is a bit error in the Barker code. The detection of the preamble is described in Section 4.3.7.

4.3.5.3 (C) Address and Status

The address and status information which the data links must convey from each WARS to the CSCPD, were outlined in Section 4.2.8. The number of bits required to accomplish this mission are presented below.

Wide Area Address	Must identify one out of possible 60 locations: hence, this will require 6 bits.
Array Address	Must identify one out of possible 8 arrays; hence, this will require 3 bits.
Sensor Address	Must identify one out of possible 8 sensors; hence, this will require 3 bits.

4.3.5.3 (C) (Continued)

Auxiliary Sensor Status	Must identify one out of 2 states; hence, this will require 1 bit.
Target Classification and S/T Status	Must identify one out of 4 possible states; hence, this will require 2 bits.

4.3.5.4 (C) Parity

To provide a parity check of the bits within the word received at the CSCPD, one (1) bit will be reserved for this purpose.

4.3.5.5 (C) Message Structure

Figure 4-47 shows the message structure which results when the various bit requirements derived about are combined into a single code word

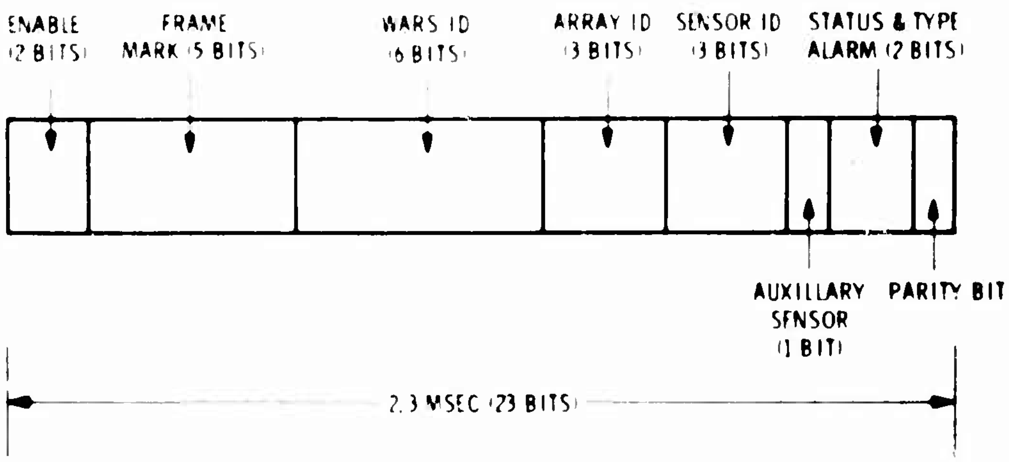

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Figure 4-47. (C) Message Structure (U)

4.3.6 (C) Bit and Frame Synchronization

When digitally encoded information is demodulated in a receiver, the decoding circuitry must have an indication as to where the message starts and where to sample the data stream in order to decide whether a "1" or a "0" was sent. Various tradeoffs and other factors relating to synchronization are considered below.

For a short digital message, a clock whose free-running frequency is close to the bit rate may be employed in the receiver to trigger the sampling circuitry. Although this would eliminate the need for bit synchronization there still would exist uncertainties

4.3.6 (C) (Continued)

in the sampling time within the bit period because of the difference in frequencies of the transmitter and receiver clocks. For the usual (optimal) integrate-and-sample detection of PSK, for example, the unknown and unstable position of the sampling phase is entirely unsuitable. To indicate the start of the message (frame synchronization), the free-running receiver clock is usually triggered by the first bit and then allowed to run free. The initial sampling phase is thus set and the principal problem thereafter is only the relative drift of this clock and the transmitter clock. Assuming that the stability of the receiver and transmitter clocks is each ±1%, the sampling time of the last bit of a 23 bit message may be in error by as much as 0.46 bit periods. This means that in the subsequent integration process only a fraction of the bit will be available thus resulting only in a fraction of the signal energy available for the decision circuits.

Therefore, starting the clock from the first message bit may not be reliable enough. As the entire detection process depends on the correct starting of the clock, it is essential to have a more reliable marker to indicate the start of the message. One such scheme is to use a marker in the form of an n-bit Barker code (References 6 and 10) before the message bits. This Barker code marker is fed to a tapped delay line, which produces output pulse of amplitude $\leq n$, when a match is obtained, and a pulse of magnitude ≤ 1, otherwise. The output pulse is the weighted sum over n pulse intervals, thus providing a signal-to-noise voltage ratio improvement of $(n)^{1/2}$. Unfortunately, a tapped delay line is not easy and economical to implement. The tapped delay line can be replaced by a shift register but then bit timing is required for proper clocking.

From the alternatives presented above, it was decided that the latter offers the best solution. Consequently, the 5-bit Barker code was selected for the frame marker. Bit timing will be derived directly from the incoming signal as discussed in Section 4.3.7.2.

4.3.7 (C) System Configuration and Operation

All S/T-to-R/R links in the WARS system will operate on a common 60 KHz channel and all R/R-to-R/I links on another common 60 KHz channel. When the split-phase PSK encoded signal transmitted by the S/T is received at the R/R, it will be demodulated and decoded to verify address, restored to its original format, and retransmitted to the R/I. During the time the R/R transmitter is energized, the R/R will be disabled. The blanking time will be 5.8 milliseconds to allow a nominal 3 milliseconds for the transmitter warm-up, 2.3 milliseconds for the message transmission and 0.5 milliseconds for shut-down of the transmitter. The received message in the R/R receiver will be checked for the proper array and WARS address to avoid retransmission of the same alarm by more than one R/R. In the R/I, the received message will also be verified to have the proper WARS address before it will be sent to the LRT.

4.3.7.1 (C) Receiver

The block diagram of the receiver is shown in Figure 4-48. The signal that the receiver is to detect is a split-phase PSK signal transmitted at VHF. The receiver is to detect the carrier, lock onto the carrier, synchronize with the bit timing, and decode the information on the carrier that follows the synchronization bits. Synchronization of the receiver to the signal is aided by the structure of the signal and by the preface to the message. Every bit contains a phase transition in the middle of the bit. A "one"

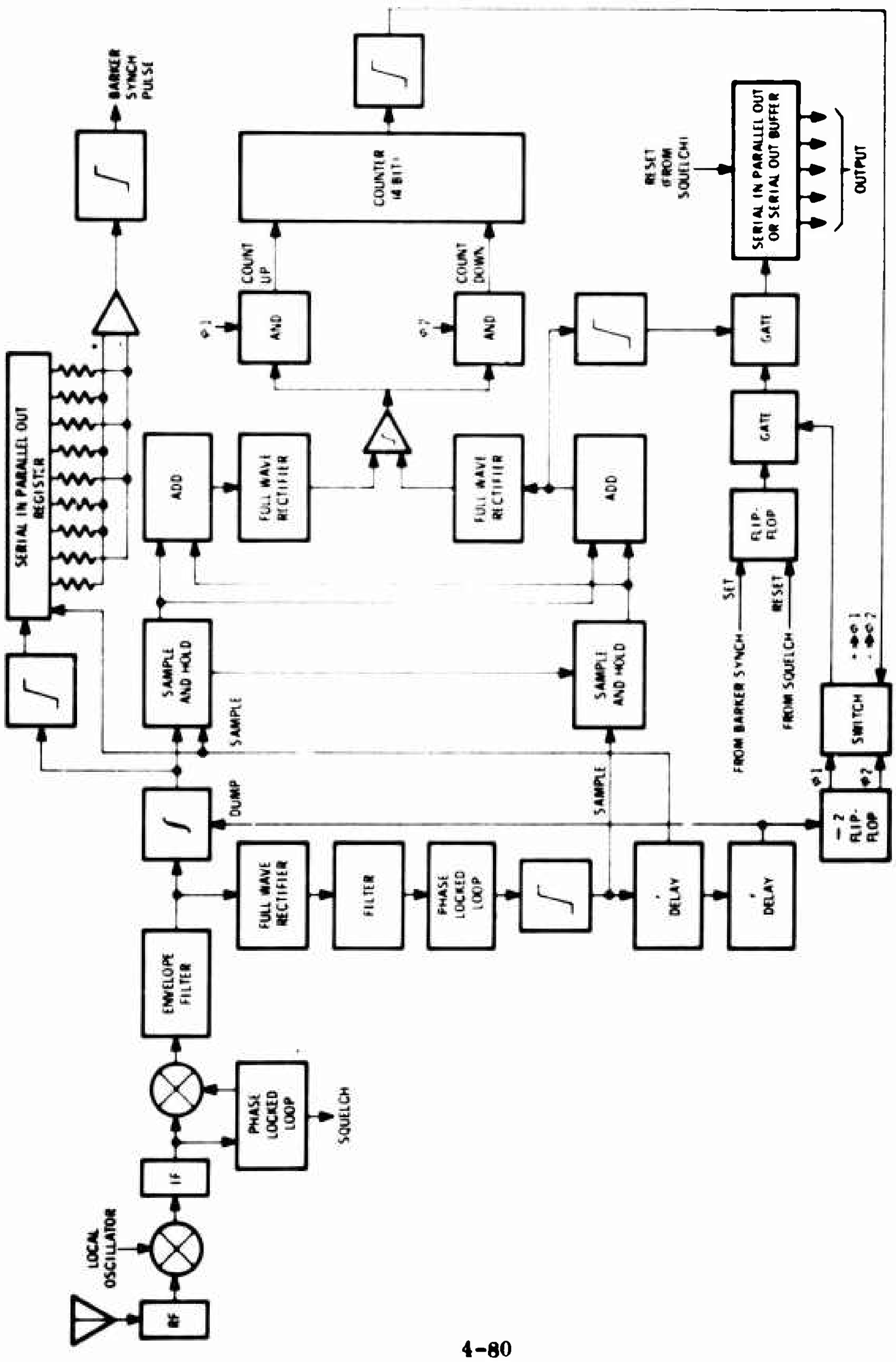

Figure 4-48 (U). Receiver Block Diagram (U)

4.3.7.1 (C) (Continued)

has the transition in one direction, while a "zero" has the transition in the other direction. There may also, but not necessarily, be a phase transition between bits.

The basic structure of the receiver consists of a front end, a demodulator, a bit synchronization generator, a preface synchronization generator, and the demodulator and buffer for the message.

The block diagram of the receiver front end is shown in Figure 4-49a. The front end consists of an antenna, an RF amplifier, a mixer, IF amplifier, and circuitry to begin the demodulation of the signal.

The demodulation scheme used is coherent. The required receiver phase synchronization is supplied by the carrier phase locked loop (Ref. 20). The input signal to the loop is a sinusoid of the carrier frequency which is stripped of phase transitions. This is accomplished by doubling the frequency of the IF amplifier signal, limiting and filtering this signal to obtain double the carrier frequency, and finally, dividing this signal by a factor of 2 to obtain the original carrier frequency. This signal is fed to the loop for phase synchronization. In this manner, the phase modulation is removed from the carrier and the lack of a true carrier in the PSK signal causes no difficulty. No attempt is made to resolve the 180° phase ambiguity that exists by using the phase locked loop in this manner. Following the demodulation mixer is a filter to remove the high frequency noise components from the output.

The remainder of the receiver front end consists of a matched filter in the form of an integrator which is dumped into the storage circuits at intervals synchronized at twice the bit rate.

The front end has two outputs: one output is the output of the integrator just before it is dumped; the second output is the signal from the bit synchronization circuit to provide dump timing.

4.3.7.2 (C) Receiver Demodulation

The basic demodulator is shown in Figure 4-49b. The output of the integrator is sampled and held just before it is dumped. Preceding this, the contents of the first sample and hold circuits are transferred to the second sample and hold. The two sample and hold cricuits, therefore, contain the present and the immediate past output of the integrator.

The outputs of the sample and hold circuits are combined in an adder by weighting one of the outputs positively and the other output negatively. Thus, the output of the integrator at the end of two half bits is added together with one of the half bits inverted. This operation removes the phase inversion in the middle of the bit.

The output of the adder is applied to a threshold centered at zero. A positive voltage from the adder indicates a "one", while a negative voltage from the adder indicates a "zero" at the time that the bit synchronization pulse is received. The output of the threshold is fed through the bit synchronization gate to the output buffer which is reset from the squelch circuit.

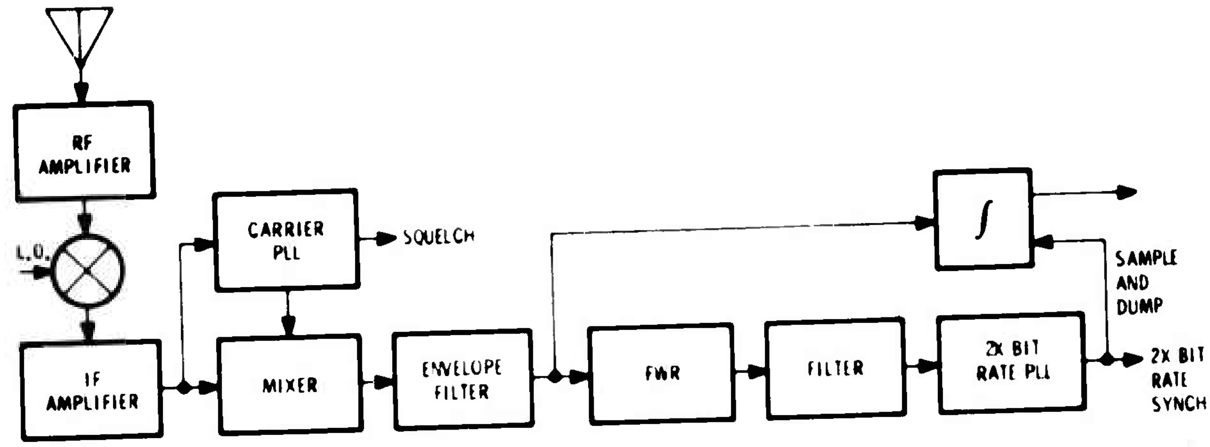

Figure 4-49a (U) Front End (U)

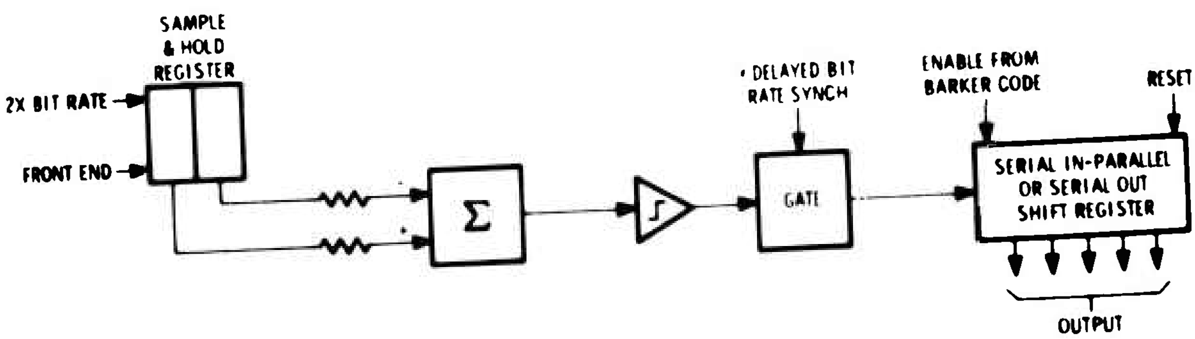

Figure 4-49b (U) Basic Demodulator (U)

4.3.7.2 (C) (Continued)

A frame synchronization signal from the Barker code synchronization circuit initiates the bit synchronization pulse. When a complete message has been received, the shift pulse from this source is turned off and the register contains the message that was transmitted. The message may be obtained from the buffer, either directly from the parallel output of the register or from the serial output by applying an auxiliary shift signal.

4.3.7.3 (C) Bit Synchronization

The phase locked loop in the receiver front end is locked to the bit timing and delivers two pulses per bit. One pulse is delivered at the start of the bit and the second pulse is at the middle. To achieve proper bit synchronization, the correct phase must be selected from the double bit synchronization pulse train.

The block diagram of the circuits which determine the correct phase of the twice bit rate clock is shown in Figure 4-49c. The circuits use the same sample and hold circuits used in the demodulator.

The output of the sample and hold circuits is applied to two adders. In one of the adders, both of the outputs are weighted plus, while in the other, one is weighted plus and the other minus. The outputs of the adders are full wave rectified and applied to a threshold circuit

The output of the threshold is "AND'd" with each of the two (2) clock phases, and used to control the direction of an up-down counter. Phase 1 (ϕ 1) of the clock causes the counter to count up, and Phase two (ϕ 2) to count down. The output of the counter is converted to an analog voltage and compared with a threshold. As the counter will tend to count in one direction, after a short time the input to the threshold circuit will be either positive or negative. A positive voltage indicates that phase one is to be selected, while a negative voltage indicates that phase two is to be selected by the phase selection switch. The output of the selection switch is the correct bit synchronization pulse.

Figure 4-50 shows the timing waveforms that can be expected in the bit synchronization circuits. The first two waveforms show the Phase one and Phase two clocks. The third and fourth waveforms show the outputs of the first sample and hold circuit and the second sample and hold circuit. The output of the second sample and hold circuit duplicates the output of the first sample and hold circuit delayed by one half a bit time.

The output of the first and second adder constitutes the first and sixth waveforms. Note that the output of the first adder is different from zero only when there is a transition between a "one" and a "zero" or a "zero" and a "one" contained in the sample and hold circuits. Similarly, the output of the second adder is zero only when there is a transistion present in the sample and hold circuits. When the outputs of the two adders are full wave rectified, the output of the second adder will be larger than the output of the first adder except during the transition between bits of different types. The output of the phase one clock delayed by a small amount to allow the full wave rectifiers to settle is shown on the seventh waveform. The output of the threshold following the rectifiers is waveform eight. This output is positive only during the time when the phase one clock is sampling the output of the threshold. The input to the

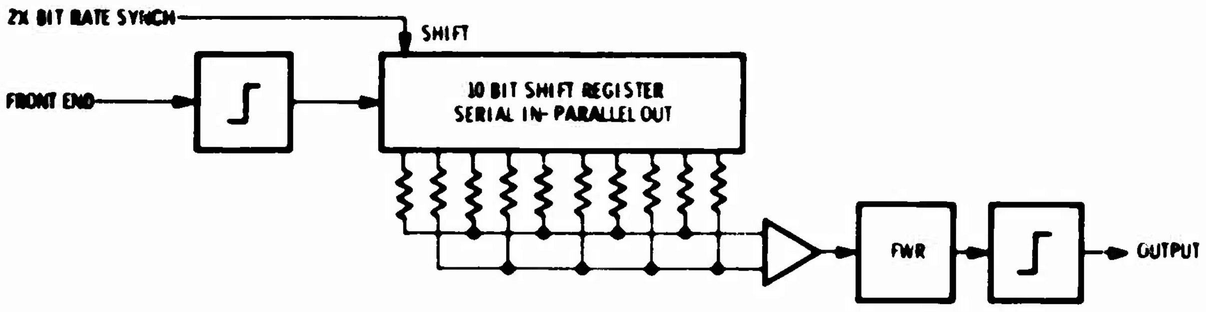

Figure 4-49c (U) Barker Code Switch (U)

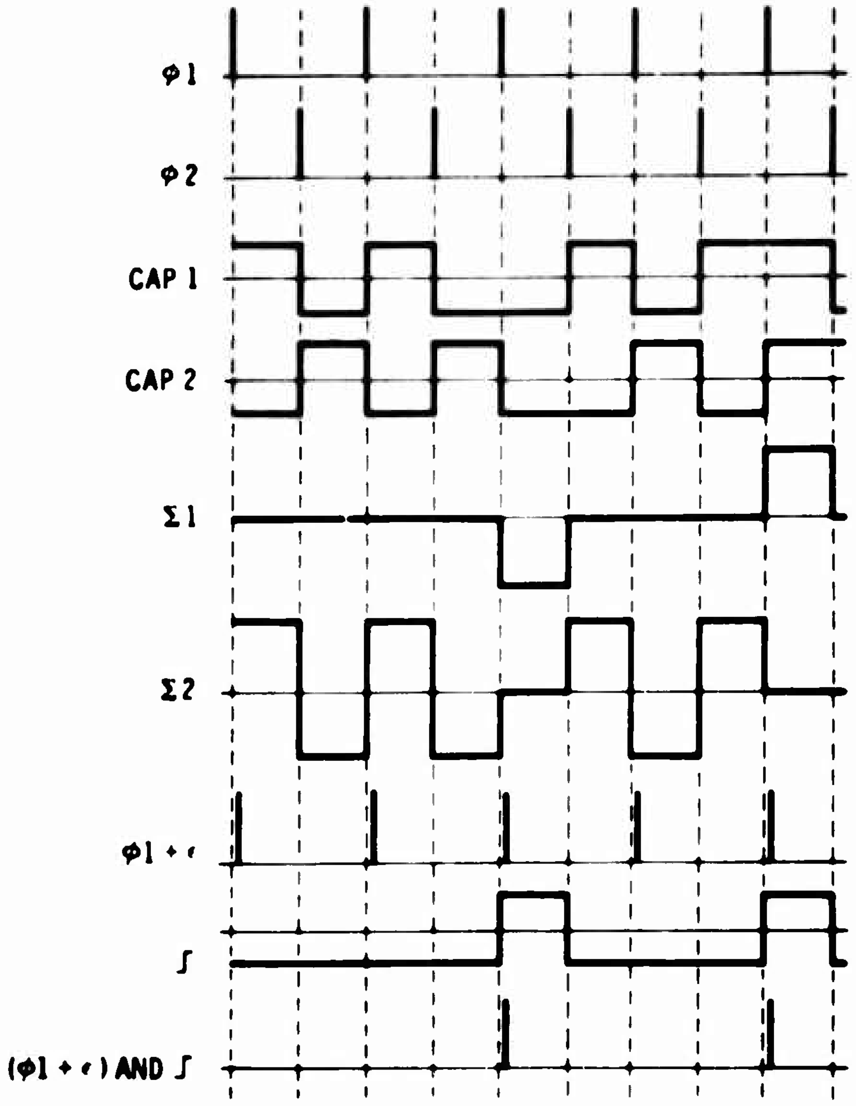

Figure 4-50 (U) Waveforms (U)

4.3.7.3 (C) (Continued)

counter from the phase one "AND" gate will be the two pulses shown in waveform number nine. There will be no pulses from the phase two "AND" gate during this period. Consequently the counter will count up by two counts. The results will be the selection of phase one as the correct phase for the bit synchronization.

4.3.7.4 (C) Barker Code Synchronization

The preface to the message that is to be received consists of a sequence of zeros followed by a Barker code. The message follows the Barker code. Detection of the Barker code serves to provide a frame marker for the message.

Figure 4-49d is a block diagram of the Barker code synchronization circuit. Operation is initiated by making a decision regarding the phase of the dump signal to the integrator in the front end. The logic level indicating this decision is transferred into the shift register when the shift pulse from the phase locked loop at twice the bit rate appears. In this manner, the output of the decisions regarding the state of the input for each half bit of the input are loaded into the shift register.

The output of the shift register is formed by weighting the outputs of each stage of the register either plus or minus and adding. The weights correspond to the levels that would be present in the shift register when the Barker code is contained in the shift register. The "ones" will be weighted plus and the "zeros" weighted minus.

When the Barker code from a new message appears at the input, the output of the weighting network will be small until the Barker code is fully contained in the shift register. When the Barker code matches the weights, the output of the adding network will be either very large negatively or very large positively. The polarity will depend on the phase of the carrier which was selected by the phase locked loop of the front end. The full wave rectifier will change all excursions to positive. The threshold should be set so that 0.4 of the bits can be in error and still cross the threshold. The high error rate allowable for the Barker code to achieve synchronization means that reliable synchronization will be contained even when the error rate for the message is unacceptably high.

4.3.8 (C) Message Error Analysis

As in any other type of communications system, the transmission of the alarm messages will not be perfect because of noise and interfering signals in the channel. Therefore, it will not be always possible to demodulate and reconstruct the transmitted signal in its entirety. Errors will not only be generated in the WARS data channels but also in those of the RSDCS and the CSCPD. Therefore, to determine the probability that a message emitted by an S/T will actually be received and decoded by the CSCPD without any errors, one needs to consider the entire BESS communications link. This, however, is beyond the scope of this study and, therefore, only the expected message loss for the WARS subsystem will be analyzed here.

To facilitate this analysis, notation will be introduced as shown in Figure 4-51. Thus the S/T will be denoted as point X, the R/R as point Y, and the R/I as point Z. In the following sections, the various sources of errors are identified and the data loss derived as a function of the number of active S/T's and the bit error probability.

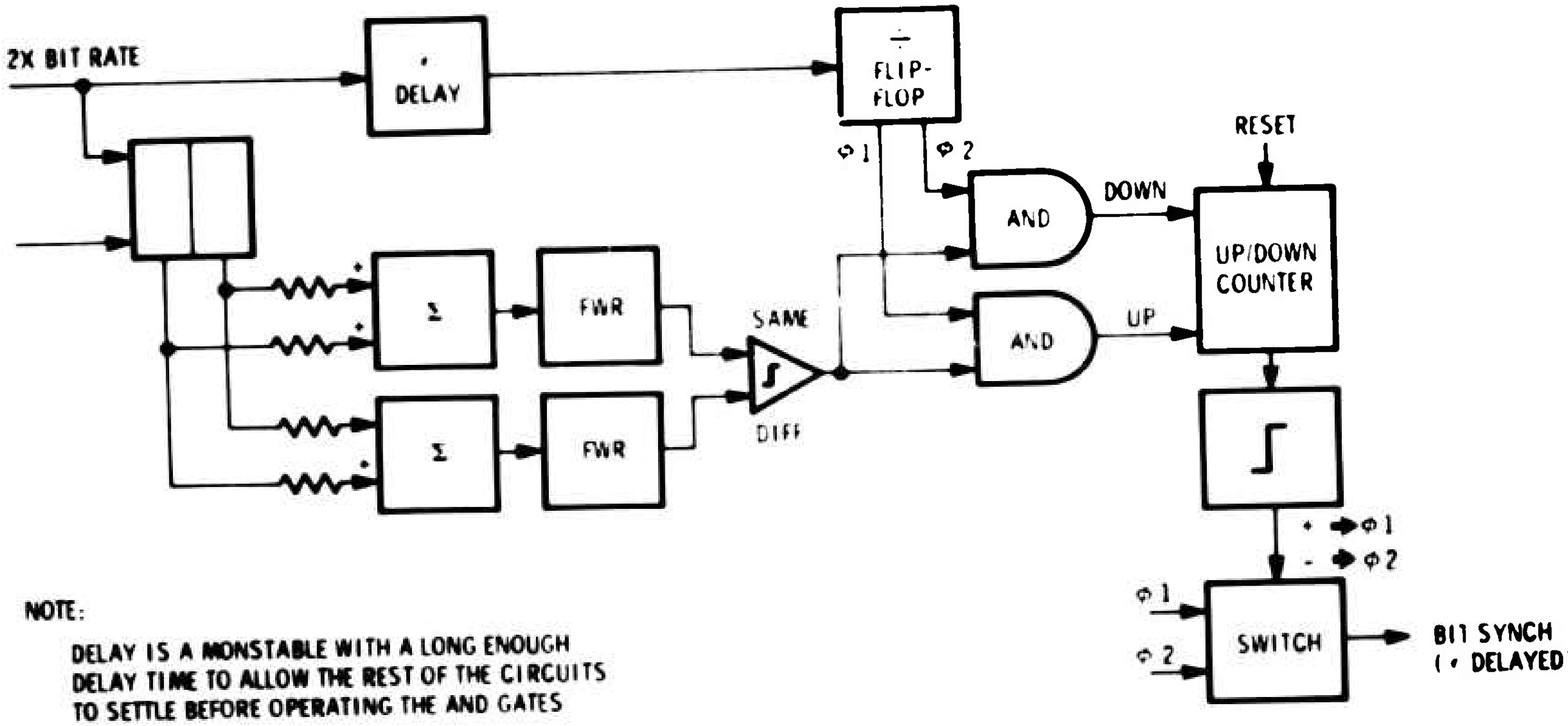

Figure 4-49d (U) Bit Synchronization (U)

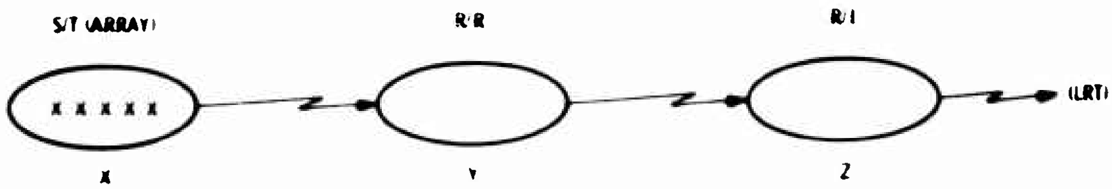

Figure 4-51 (U). Notation Used in Message Error Analysis (U)

4.3.8.1 (C) Source of Errors

Errors can occur at each receiver (at Y or Z) during the synchronization and information phase. In terms of statistical decision theory, errors due to an incorrect decision can result from either misses or false alarms. In the synchronization phase both misses and false alarms are possible, but only misses can result in data loss. During the information phase errors due to confusing a MARK with a SPACE, and vice versa, can occur. This comes from the fact that once a valid frame marker is detected, the message (16 bits) will always be read, correctly or incorrectly. Summarized below are the possible sources of errors at each receiver during both the synchronization and information phases.

Synchronization Phase:

a. False Alarms

Noise

Interfering Signals in-band

Cross Talk - interference from signals in adjacent bands

b. Misses

Noise - Intended signal obscured by noise

Overlap - interference from other (stronger) signals in-band

Cross-talk - interference from strong signals in adjacent band

c. Receiver Blanking

At R/R receiver while transmitter is on

Information Phase:

Noise

Interference - other in-band signals

Cross-Talk - interference from adjacent band signals

4.3.8.2 (C) Data Loss Calculations

To proceed with the analysis, let us define some appropriate notation. In general, let

P = probability of successful transmission

$Q = 1-P$ = probability of unsuccessful transmission

Also, let subscripts denote source of errors, with P_1 referring to sync phase and P_2 referring to information phase; additional letter subscripts will refer to individual source of errors, e.g., P_{2n} = probability of successful transmission during information phase in the presence of noise. Further, let superscripts refer to receiver location, e.g., P_1^Y = probability of successful synchronization at Y. Therefore, the probability of completely successful message transmission, P_T, can be stated as

$$P_T = P_1 P_2 = P^y P^z \tag{24}$$

Each component of (24) can be broken down further, e.g.

$$\begin{aligned} P_1 &= P_1^y P_1^z, \quad P_2 \quad P_2^y P_2^z \\ P^y &\quad P_1^y P_2^y; \quad P^z \quad P_1^z P_2^z \end{aligned} \tag{25}$$

As a slight conflict in notation, but conforming to conventional usage, let p_e be defined as the bit error probability. The probability of not having a bit error is the joint probability of correctly extracting (from the split-phase code transition) the timing pulse for the bit and of making a correct decoding decision at the output of the integrator Since these two events are not independent, only a bound on the bit error probability can be given. Thus

$$\begin{aligned} p_e = 1 - &\text{(probability of correct bit timing)} \\ \times\ &\text{(probability of correct bit decoding)} \end{aligned} \tag{26}$$

It will also be assumed that any errors due to cross talk from adjacent channels are negligible. This will certainly hold for our signals and cannot be estimated for other, non-WARS, signals. Furthermore, we will make a rather unrealistic assumption that any interference due to message overlap will result in a loss of message.

The analysis is performed for arbitrary numbers of active interferers in range of the receivers at the R/R and R/I.

4.3.8.2 (C) (Continued)

τ_m = total length of message

= 2.3 msec

τ_1 = overlap time during sync phase

τ_2 = overlap time during information phase

N^y = number of active, in-range interferers at R/R

N^z = number of active interferers in-range at R/I

Any noise present is assumed to be white gaussian over the channel width.

4.3.8.2.1 (C) Loss During Synchronization Phase

During this phase data loss can result only as a result of "misses". Therefore, the analysis is directed at the problem of obtaining a correct frame timing. The probability of success during synchronization can be represented by

$$P_1 = P_{1n} \cdot P_{1I} \tag{27}$$

Where the subscript n and I stand for noise and interference, respectively. Each of these are analyzed below.

Due to Noise:

If l = length of sync word (Barker Code length)

k = maximum number of errors in sync word permitted for correct recognition

then, the probability of no error at either the R/R or R/I (assuming the same operating S/N and resulting p_e at each point) is

$$P^y_{1n} = P^z_{1n} = \sum_{m=0}^{k} C^l_m (1 - p_e)^{l-m} p_e^{\,m} ;$$

where (28)

$$C^l_m = \frac{l!}{m!\,(l-m)!}$$

With l = 5 and k = 1, Equation (28) reduces to

4.3.8.2.1 (C) (Continued)

$$P^{y}_{1n} = P^{z}_{1n} = (1 - p_e)^4 (1 + 4p_e) \quad (29)$$

Thus,

$$P_{1n} = P^{y}_{1n} P^{z}_{1n} = (1 - p_e)^8 (1 + 4 p_e)^2 \quad (30)$$

Due to Overlap:

In determining loss due to overlap from interfering signals we shall make the very pessimistic assumption that any overlap will cause a loss of the message. This is certainly not true as only signals of equal or greater strength than the intended message are expected in reality to introduce errors. However, if it can be shown that the system will operate in a reasonable manner even with this type of assumption, the actual performance can be expected to be significantly better.

To estimate the data loss due to interference from overlapping alarm messages, a Poisson model will be used. The Poisson probability distribution is given by

$$P(k, \tau) = e^{-m\tau} \frac{(m\tau)^k}{k!} \quad (31)$$

Equation (31) expresses the probability that k events will occur during the time interval τ, where $m\tau$ is the average number of events during the interval. If one sensor alarm is activated from a set of N, the conditional probability that no other alarms occur during the time interval τ is expressed by the Poisson distribution with $k = 0$ and $m = (N - 1)\lambda$, where λ is the alarm message rate, and N is the total number of sensors in the group being considered.

Thus, the result is

$$P(0, \tau) = e^{-(N - 1)\lambda\tau} \quad (32)$$

During the sync phase, the overlap of the intended sync word by another signal results from any transmission starting 5.8 milliseconds prior to the sync word plus any time during the sync word, for a total of

$$\tau_1 = 6.5 \text{ msecs}$$

where

$$\lambda = 0.25 \text{ alarms/second}$$

and using the Poisson model derived above

$$P^{y}_{1I} = e^{-1.625 \times 10^{-3}(N^y - 1)} \quad (33)$$

4.3.8.2.1 (C) (Continued)

where

N^y is as defined in Section 4.3.8.2.

Likewise,

$$P_{1I}^{z} = e^{-1.625 \times 10^{-3}(N^z - 1)} \tag{34}$$

hence,

$$P_{1I} = P_{1I}^{y} \cdot P_{1I}^{z} = e^{-1.625 \times 10^{-3}(N^y + N^z - 2)} \tag{35}$$

Finally, from Equations (30) and (35)

$$P_1 = (1 - p_e)^8 (1 - 4 p_e)^2 e^{-1.625 \times 10^{-3}(N^y + N^z - 2)} \tag{36}$$

4.3.8.2.2 (C) Loss During Receiver Blanking

The receiver at the R/R will be blanked for a total of about 5.8 milliseconds after the reception to transmit an authenticated message. The only data loss that can result from this blanking is the occurrence of an alarm from one of the other sensors of the same array. (The same sensor, of course, cannot transmit again for another 4 seconds.) The probability of no alarm from any one of the 4 other sensors is,

$$P_{1B}^{y} = \exp - [(4)(0.25)(4.3 \times 10^{-3})] \approx 1 - 5.8 \times 10^{-3} = 0.9942 \tag{37}$$

This assumes no blanking at the R/I.

4.3.8.2.3 (C) Loss During Information Phase

The probability of successful transmission during the information phase of the message will be

$$P_2 = P_{2n} \cdot P_{2I} \; .$$

These are calculated below.

Due to Noise:

A message is assumed to be lost if one or more bits out of the 16 information bits are in error. The probability that there will be no bit errors at either the R/R or R/I (assuming the same p_e at each) is from Equation (28):

4.3.8.2.3 (C) (Continued)

$$P_{2n}^{y} = P_{2n}^{z} = (1 - p_e)^{16} \qquad (38)$$

Hence,

$$P_{2n} = P_{2n}^{y} \cdot P_{2n}^{z} = (1 - p_e)^{32} \qquad (39)$$

Due to Overlap:

Overlap of the intended information portion of the message by another signal which does not also overlap the sync word (since we do not wish to count the same loss twice) can occur only for additional transmission starting during the 1.6 milliseconds duration of the information word. Hence, with $\tau_2 = 1.6$ msecs, and therefore

$$P_{2I} = e^{-4 \times 10^{-4}(N^y + N^z - 2)} \qquad (40)$$

And combining Equations (39) and (40), we obtain

$$P_2 = (1 - p_e)^{32} \, e^{-4 \times 10^{-4}(N^y + N^z - 2)} \qquad (41)$$

4.3.8.2.4 (C) Overall Data Loss

The probability of successful transmission from an S/T to its R/I can now be found by combining the result of Equations (36), (37), and (41).

Thus,

$$P_T = 0.9942\,(1 - p_e)^{40}\,(1 + 4\,p_e)^2 \exp\left[-2.025 \times 10^{-3}(N^y + N^z - 2)\right]. \qquad (42)$$

If we let

$$N_T = N^y + N^z - 2 \qquad (43)$$

then N_T represents the sum of the number of simultaneously active interferers within range of an R/R and R/I. Thus an upper bound on the expected data loss is

$$Q_T = 1 - 0.9957\,(1 - p_e)^{40}\,(1 + 4\,p_e)^2\, e^{-2.025 \times 10^{-3} N_T} \qquad (44)$$

4.3.8.2.4 (C) (Continued)

Equation (44) is plotted in Figure 4-52 as a function of N_T for values of $p_e = 0$, 10^{-3}, 2×10^{-3}, 5×10^{-3}, and 10^{-2}. Note that the curve for $p_e = 0$, namely for

$$Q_T = 1 - 0.9942\, e^{-2.025 \times 10^{-3} N_T} \tag{45}$$

represents the data loss when the S/N ratio present at the input to the receiver is so large that no bit errors are made. From this it can be seen that achieving large receiver input SNR's will not guarrantee error free performance for the WARS Data Link. The implication of this is that relatively little would be gained if one kept arbitrarily increasing the transmitter powers.

Next, it is of interest to determine data loss as a function of the sensor false alarm rate. For this exercise, we shall adopt the approach used in Section 4.3.3.3 to calculate the equivalent number of activated S/T's as a result of combined intrusions and false alarms. Such a method provides quite accurate estimates for the lower false alrm rates. The reason for this is that the "equivalent number of activated sensors" approach treats one false alarm overlapping another false alarm as data loss. Nevertheless, it is a convenient way to assess fairly accurately the expected data loss for false alarm rates up to as high as 36 per hour.

A bit error probability $p_e = 2 \times 10^{-3}$ and the previously used threat model of 20 men were employed to obtain results shown in Figure 4-53. From this plot it can be seen that as many as 5 arrays may be simultaneously intruded (thus requiring about 100 men) before the data loss will exceed 10 percent, provided that the sensors used exhibit a mean false alarm rate of no more than 1 every hour. For higher false alarm rates the data loss will be slightly higher.

Another area which we need to examine is data loss for a slower data rate. The assumption will be made that the cahnnel spacing remains unchanged (60 KHz). After some evaluation of all those aspects that enter into the selection of a data rate, a 5-kbs rate was chosen as the only other data rate to be considered. Figure 4-54 is a replot of Figure 4-52 for the 5-kbs data rate. Because of twice the message length, the overlap probability is considerably higher, thus leading to a more severe data loss. However, if the bit error probability could be improved with the lower data rate, the latter would become a more attractive alternative to the proposed 10-kbs rate.

"False alarms" at the receiver will occur by chance due to noise and due to non-intended in-band signals. (Such "false alarms" should not be confused with false sensor alarms, which can be valid message alarms in so far as the receiver is concerned. What is of concern here is that receiver false alarms may occur while there is no sensor alarm present.

Such receiver false alarms do not result in data loss, but conceivably may introduce false data in the CSCPD. An exact evaluation of such receiver alarms is not amenable to straightforward analysis, and furthermore, is not considered to be very important owing to the safeguards built into the system, namely:

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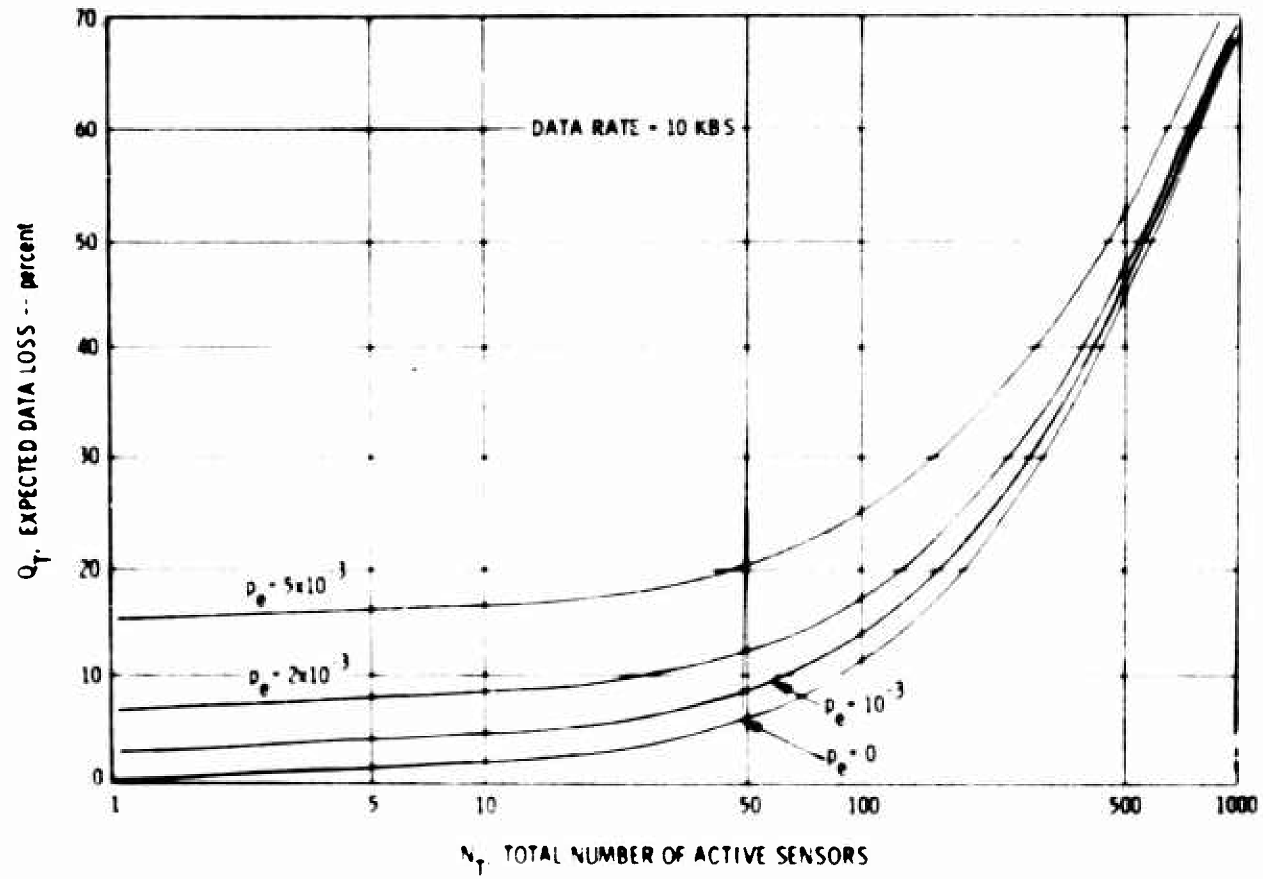

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Figure 4-52 (C) Estimated S/T-to-R/T Data Loss for 10-kbs Data Rate as a Function of Various Bit Error Probabilities (U)

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4.3.8.2.4 (C) (Continued)

Equation (44) is plotted in Figure 4-52 as a function of N_T for values of $p_e = 0$, 10^{-3}, 2×10^{-3}, 5×10^{-3}, and 10^{-2}. Note that the curve for $p_e = 0$, namely for

$$Q_T = 1 - 0.9942\, e^{-2.025 \times 10^{-3} N_T} \tag{45}$$

represents the data loss when the S/N ratio present at the input to the receiver is so large that no bit errors are made. From this it can be seen that achieving large receiver input SNR's will not guarrantee error free performance for the WARS Data Link. The implication of this is that relatively little would be gained if one kept arbitrarily increasing the transmitter powers.

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Another area which we need to examine is data loss for a slower data rate. The assumption will be made that the cahnnel spacing remains unchanged (60 KHz). After some evaluation of all those aspects that enter into the selection of a data rate, a 5-kbs rate was chosen as the only other data rate to be considered. Figure 4-54 is a replot of Figure 4-52 for the 5-kbs data rate. Because of twice the message length, the overlap probability is considerably higher, thus leading to a more severe data loss. However, if the bit error probability could be improved with the lower data rate, the latter would become a more attractive alternative to the proposed 10-kbs rate.

"False alarms" at the receiver will occur by chance due to noise and due to non-intended in-band signals. (Such "false alarms" should not be confused with false sensor alarms, which can be valid message alarms in so far as the receiver is concerned. What is of concern here is that receiver false alarms may occur while there is no sensor alarm present.

Such receiver false alarms do not result in data loss, but conceivably may introduce false data in the CSCPD. An exact evaluation of such receiver alarms is not amenable to straightforward analysis, and furthermore, is not considered to be very important owing to the safeguards built into the system, namely:

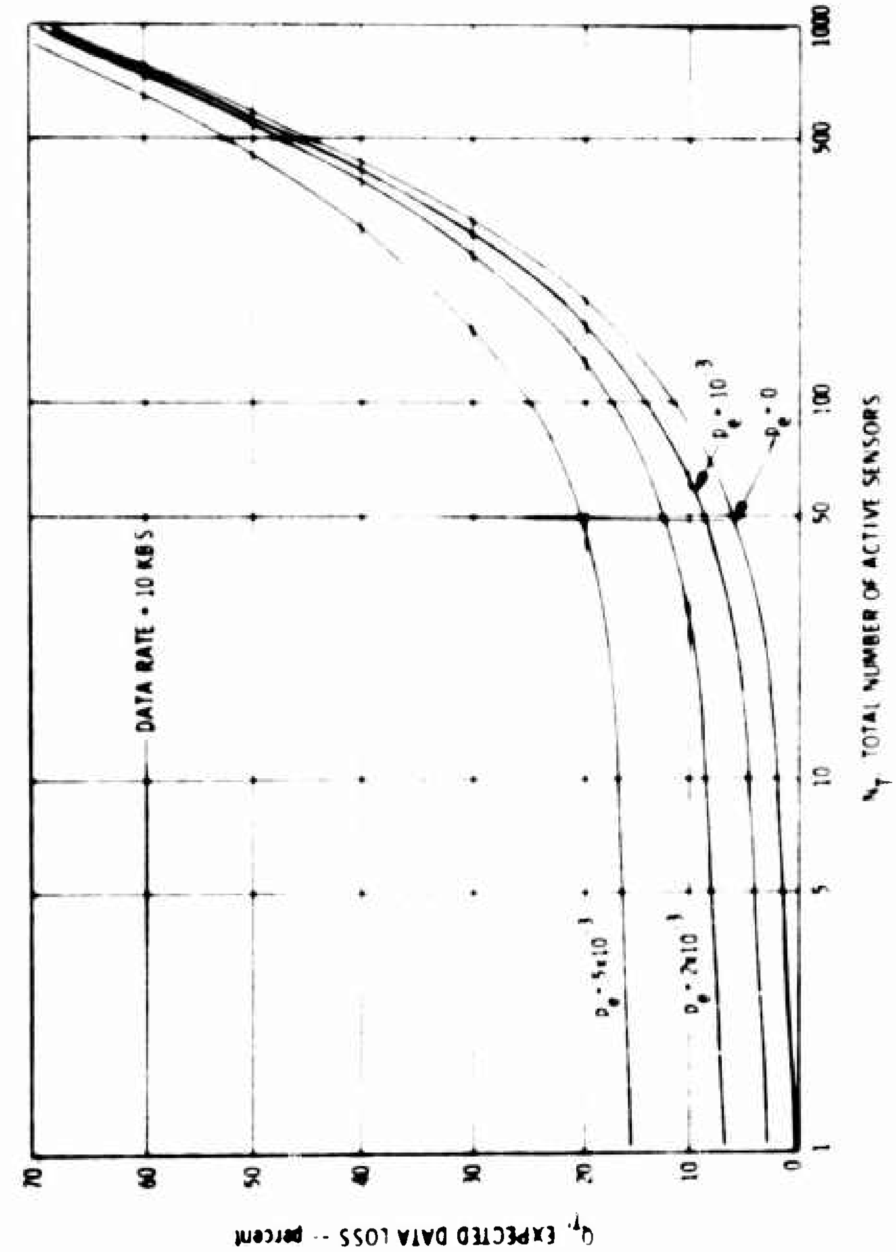

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Figure 4-52 (C) Estimated S/T-to-R/T Data Loss for 10-kbs Data Rate as a Function of Various Bit Error Probabilities (U)

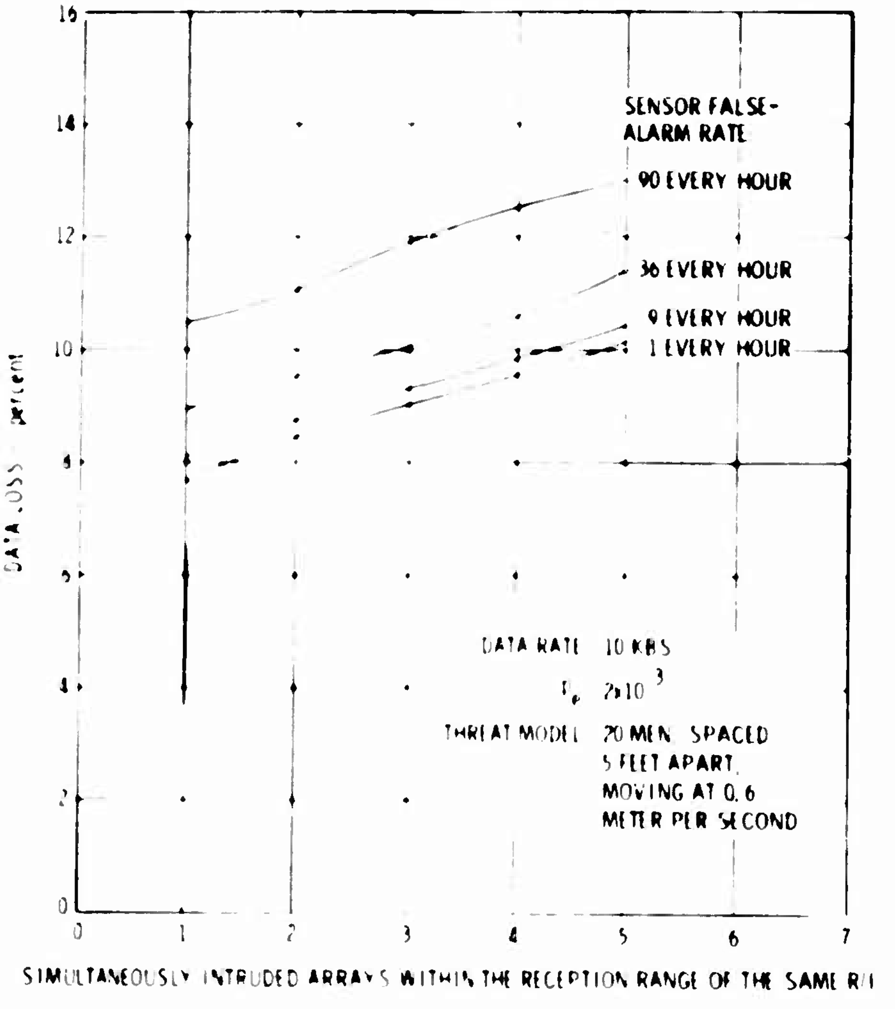

Figure 4-53 (C) Estimated S/T-to-R/I Data Loss for Various Sensor False-Alarm Rates (U)

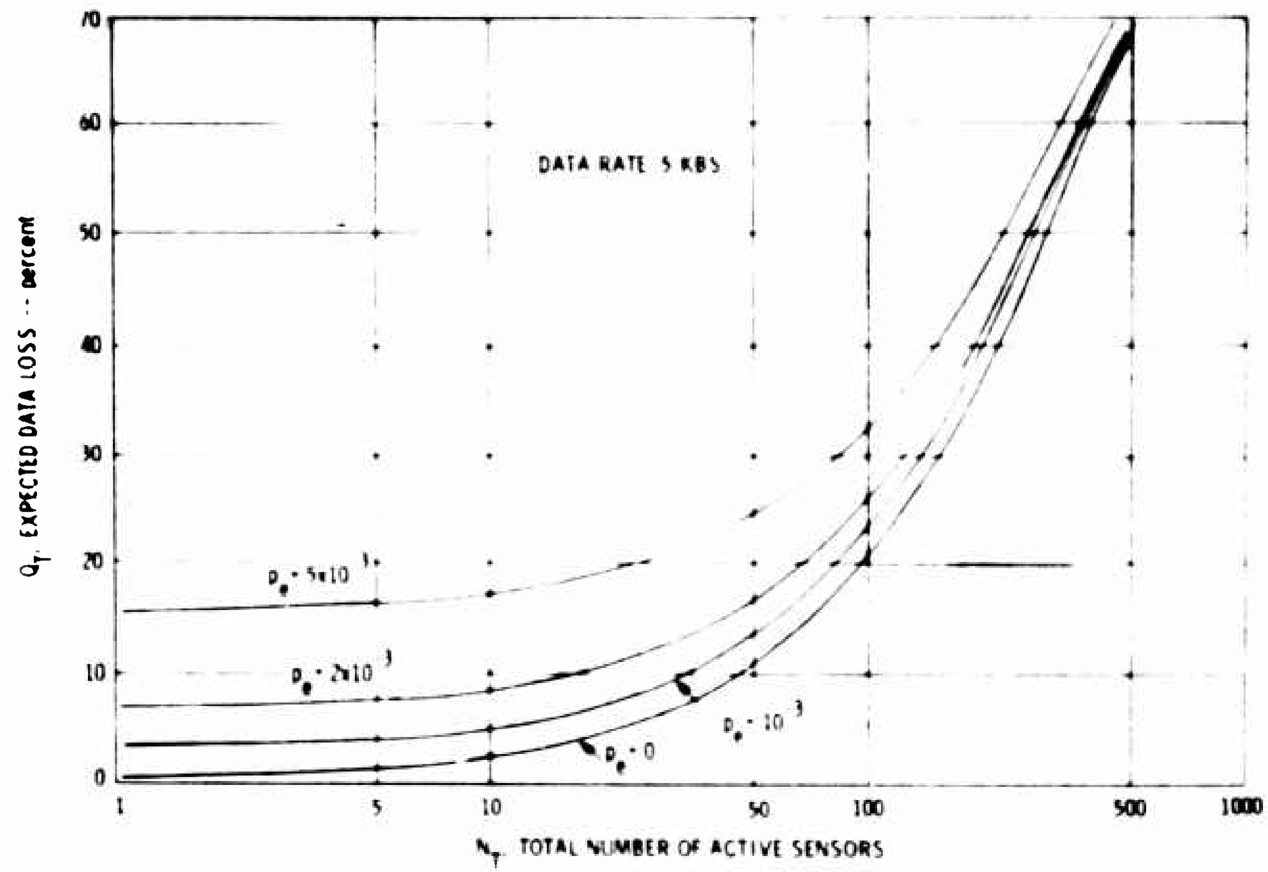

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Figure 4-54 (C) Estimated S/T-to-R/I Data Loss for 5kbs Data Rate as a Function of Various Bit Error Probabilities (U)

4.3.8.3 (C) (Continued)

a. Frame synchronization by means of a Barker Code;

b. authentication of WARS and array address at the R/R,

c. authentication of WARS address at R/I and,

d. correlation and cooroboration of data at the CSCPD.

Thus, even if false receiver alarms did manage to get through the system and arrive at the base, the CSCPD could minimize their impact in much the same manner as false sensor alarms will be treated.

4.3.9 (C) Signal Analysis

4.3.9.1 (U) Voltage Spectrum

Transmission of the rapidly occuring transitions in the data stream requires a large bandwidth. Fortunately this is not necessary because most of the signal power is concentrated in a narrow band whose width is approximately that of the bit rate. Thus excessive receiver noise would be present if a bandwidth was used which is large enough to allow the receiver to respond exactly to the rapid transitions of the data stream. The proper filtering characteristic will now be derived with the aid of spectral considerations.

The split-phase signal, m(t), can be represented mathematically as follows:

$$m(t) = \left\{ \sum_{k=0}^{n-1} a_k \left[\mu_o(t - kT) - \mu_o\left(t - kT - \frac{T}{2}\right) \right] \right\} \circledast \text{rect}\left(\frac{2t}{T}\right) \qquad (46)$$

where

$$\mu_o(t) = \text{the impulse function,} \qquad (47)$$

$$\text{rect}(t) = \begin{cases} 1 & 0 < t < 1 \\ 0 & \text{elsewhere,} \end{cases}$$

T = is the information bit period, and a_k = +1 or -1, each with a probability of 1/2. The symbol "$\circledast$" denotes convolution and the letter "n" the total number of bits in the message.

The autocorrelation of the signal is given by

$$R_s(\tau) = E\,(S(t) \cdot S(t + \tau))$$

and the Spectrum is supplied by the Fourier transform of the autocorrelation function.

$$S_s(f) = \int_{-\infty}^{\infty} R_s(t)\, e^{j\omega t}\, dt$$

$$\text{where } f = \frac{\omega}{2\pi}$$

4.3.9.1 (U) (Continued)

The power spectrum for several different types of signal has been generated using a computer. The results are shown in Figures 4-55, 4-56, and 4-57. At the top left of each figure, the phase of the signal for a "one" is shown. The phase waveform for the "zero" adds 180° or π radians to the waveform for the "one".

Figure 4-55 shows the spectrum when the signal has the form of Equation (46). The bit rate is 10 kilobits per second. Seven percent of the energy of this signal lies above the carrier plus 20 KHz. 4.6% of the energy lies above 30 KHz.

Figure 4-56 shows the spectrum of a signal whose phase is smoothed. For this signal only 3.2% of the energy lies higher than 20 KHz above the carrier and 2.4 % of the energy lies higher than 30 KHz above the carrier. The smoothed waveform reduces the energy outside a given band by about 3 dB from the energy of the idealized signal.

Figure 4-57 shows the spectrum for a very smooth phase waveform. The energy which is more than 20 KHz above the carrier frequency is 2.5% of the energy. The energy of the signal which is more than 30 KHz above the carrier frequency is less than 0.8% of the energy of the signal. For this very smooth signal, the interference with an adjacent channel will contain less than 1% of the energy of the signal. Filtering of the signal at about 1.5 times the bit rate will reduce the interfering signal still further if desired.

It has been established (References 11 and 12) from bandwidth, intersymbol interference, and probability of bit error considerations in telemetry and telegraphy that the signal shaping filter should be gaussian (or maximal linear) with the 3 dB point at 1/T and 36 dB per octave attenuation. (This response can be approximated by six cascaded R-C lowpass states.)

The bit streams in telegraphy or telemetry are usually more random and longer than the bit streams will be in the WARS application. For this reason, it is not enough here just to consider the average spectrum, because some of the sequences may contain nearly all "1's" or "0's". Therefore, let us consider two cases: (1) A bit stream of all "1's", and (2) a bit stream of alternating "0's" and "1's". The first will have the largest spectral spread, because there is a transition every T/2 seconds. The second, on the other hand, will have the smallest because the transitions take place only every T seconds.

The spectrum of the waveform corresponding to the signal of Equation 46 is

$$S_x(f) = \sum_i \left(\frac{\sin \pi f n T}{\sin \pi f f T} \right)^2 \left(\sin(\pi (f - \frac{i}{T}) n T)\right)^2$$

when $a_k = 1$ for all k

and

$$S_x(f) = \sum_i \left(\frac{\sin(\pi f 2 n T)}{\sin(\pi f 2 T)} \right)^2 \left(\sin (\pi (f - \frac{i}{T}) n T)\right)^2$$

when $a_k = 1$ k even

$= -1$ k odd.

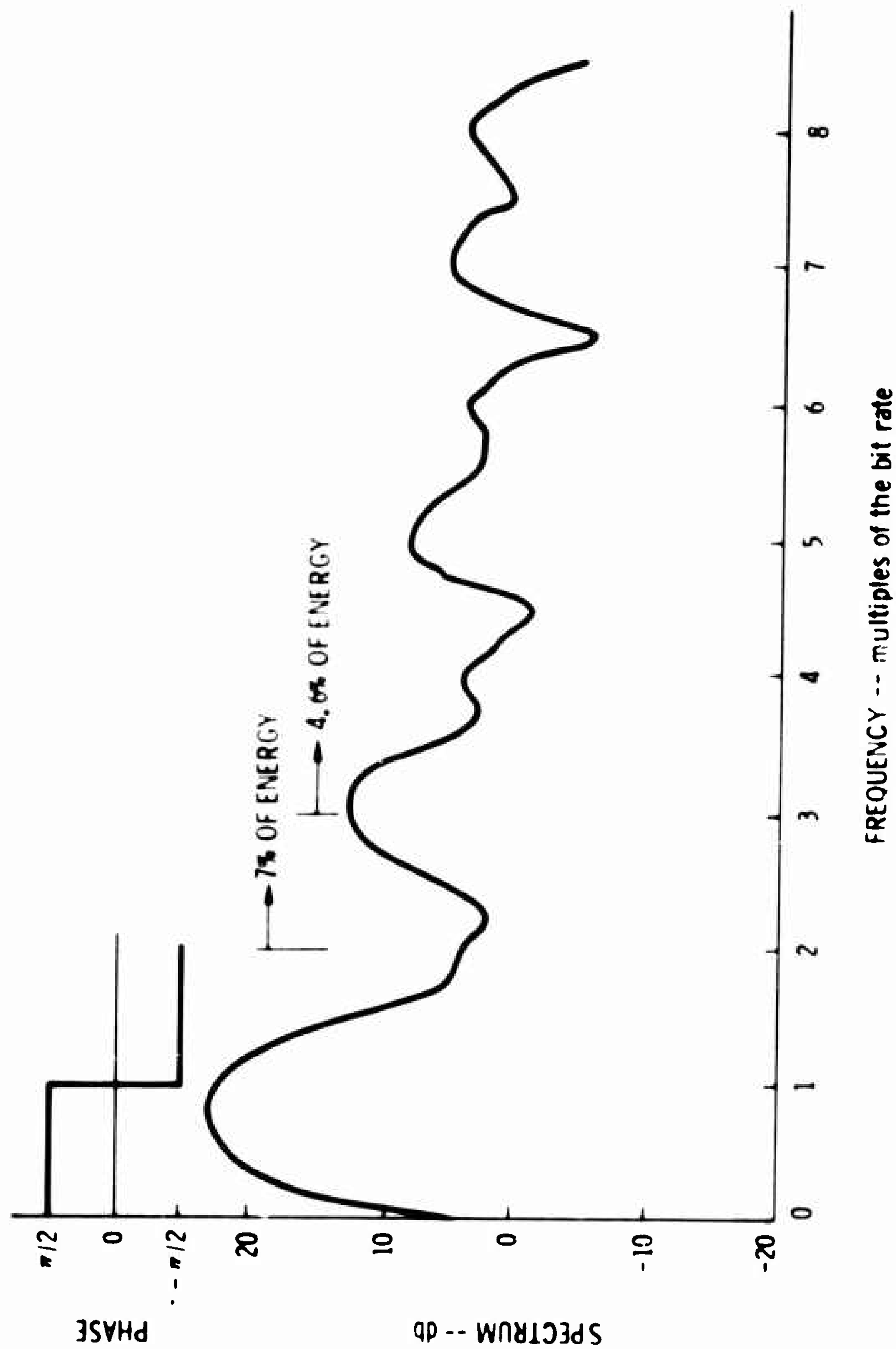

Figure 4-55 (U) Spectrum for a Stabilized Square Phase Waveform (U)

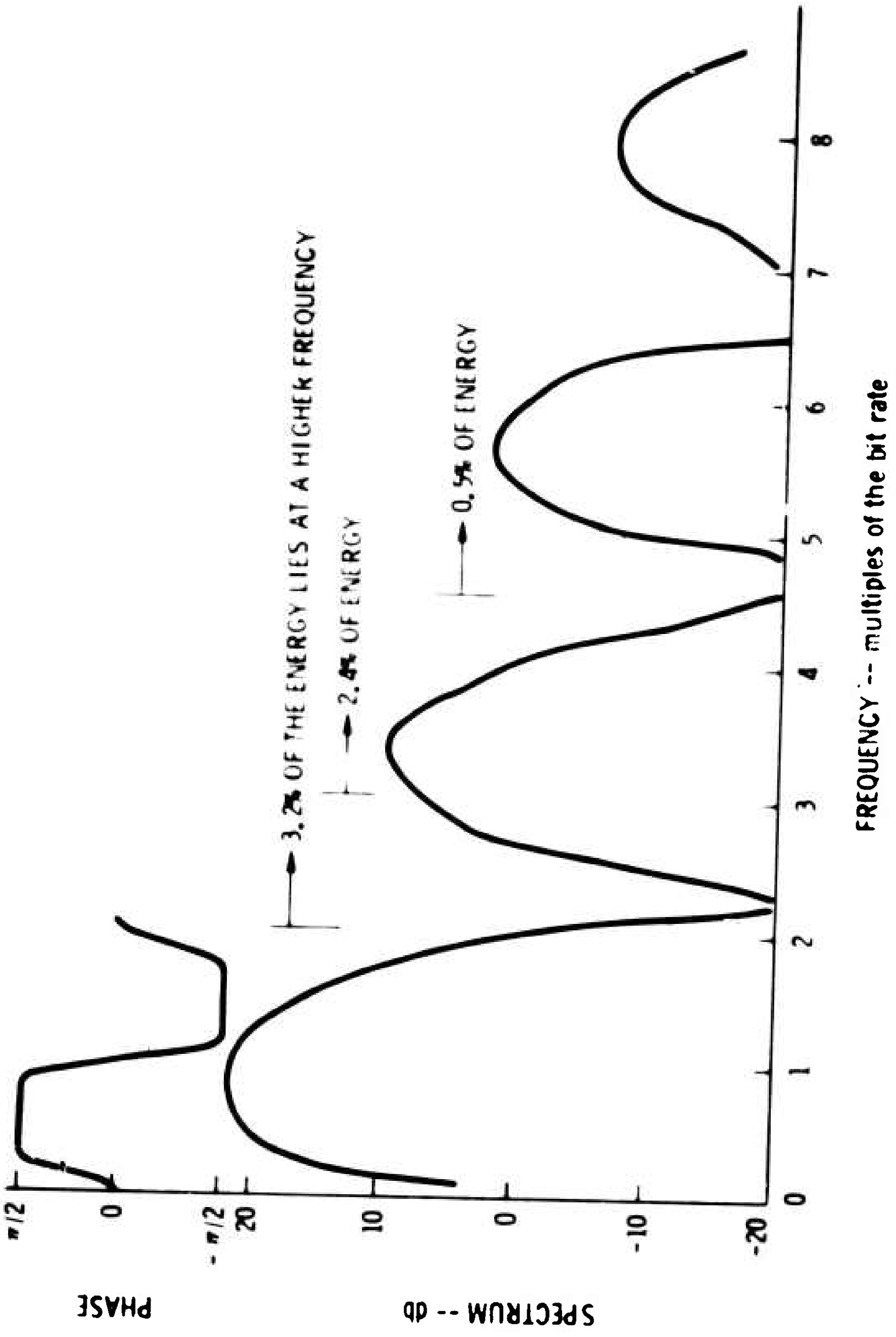

Figure 4-56 (U) Spectrum for a Smoothed Waveform (U)

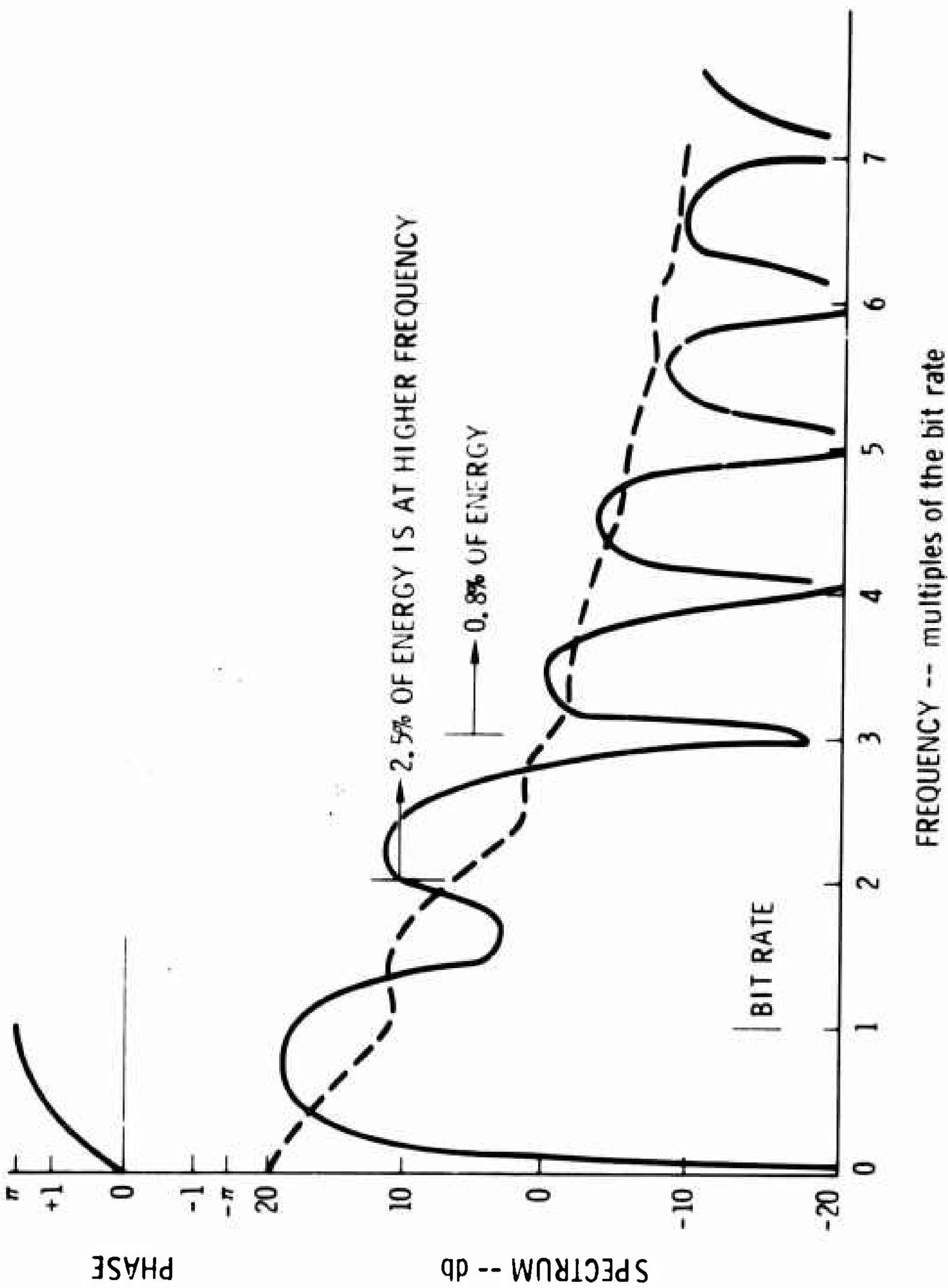

Figure 4-57 (U) Spectrum for a Very Smooth Phase Waveform (U)

4.3.9.1 (U) (Continued)

The voltage spectra oorresponding to the above equations is indicated in Figure 4-50. The power spectra are equal to the square of the voltage spectra. Note that the energy in the harmonics decreases with the square of the number of the harmonicis and that only the odd harmonics are present.

The spectra of the signals with the smoothed phase waveforms will be similar to the spectra of Figure 4-58. Of course, the smoothed phase will mean that the coefficients for the $\left(\frac{\sin x}{x}\right)^2$ at each harmonic will be smaller than the $\frac{1}{n^2}$ coefficients that result from square wave modulation.

4.3.9.2 (C) Channel Spillover

In order to estimate the amount of power that may be spilled into an adjacent channel as a result of the split-phase signal, the worst case of the all "1" (or "0") sequence is used to provide a bound. The channel is 60 KHz. The expected instability in the carrier frequency is ±5 KHz (at 170 MHz). Using the approximation that the power is contained in spectral lines at odd multiples of 1/T, one can use the coefficient evaluated at these frequencies to estimate the percentage of the total power in these frequencies. When the maximum carrier instability of 5 KHz has occurred, the band edges will be be +25 and -35 KHz from the carrier. Therefore, the channel contains power at frequency offsets (from the carrier) at -30 KHz, -10 KHz, and +10 KHz. The power at +30 KHz occurs at 5 KHz beyond the band edge. Using the 36 dB/octave filter which is 3 dB down at 10 KHz, this signal is found to be attenuated by 75 dB. Any spillover power at other frequencies will be attenuated by at least this factor. Taking all this into account of performing an approximate integration, the spillover power in adjacent channels on one side of the RF signal will be at least 85 dB below the total power in the modulated carrier.

The spectra due to the smoothed phase modulations will decrease fast enough with increasing frequency that it may be possible to accept the spillover that lies outside of the band and the filter placed after the phase modulator could then be eliminated.

4.3.9.3 (C) Summary of Signal Analysis

The waveform analysis has shown that filtering the modulation waveform with a gaussian (or maximal linear) filter whose 3 dB point is (1/T + 1/nT) and whose rolloff characteristic is 36 dB/octave will produce waveform for carrier modulation. If the bit rate 1/T is 10 KHz, the 3 dB point of the filter should be roughly 10.5 KHz. Signals for all bit sequences will pass through this filter, yielding the required shaped pulses at the output. The worst case of power spillover into an adjacent channel occurs with all "1" or "0" sequences and is approximately 85 dB below the power in the 60 KHz wide channel of operation. Hence, if necessary, say for purposes of expansion of the system, the information bit rate could be increased to the order of 15 kilobits per second and still yield a spectrum which would not produce cross-talk in adhacent channels.

Further ananlysis may show that the spectrum of a smoothed phase waveform will decrease fast enough that filtering is not required to eliminate cross-talk.

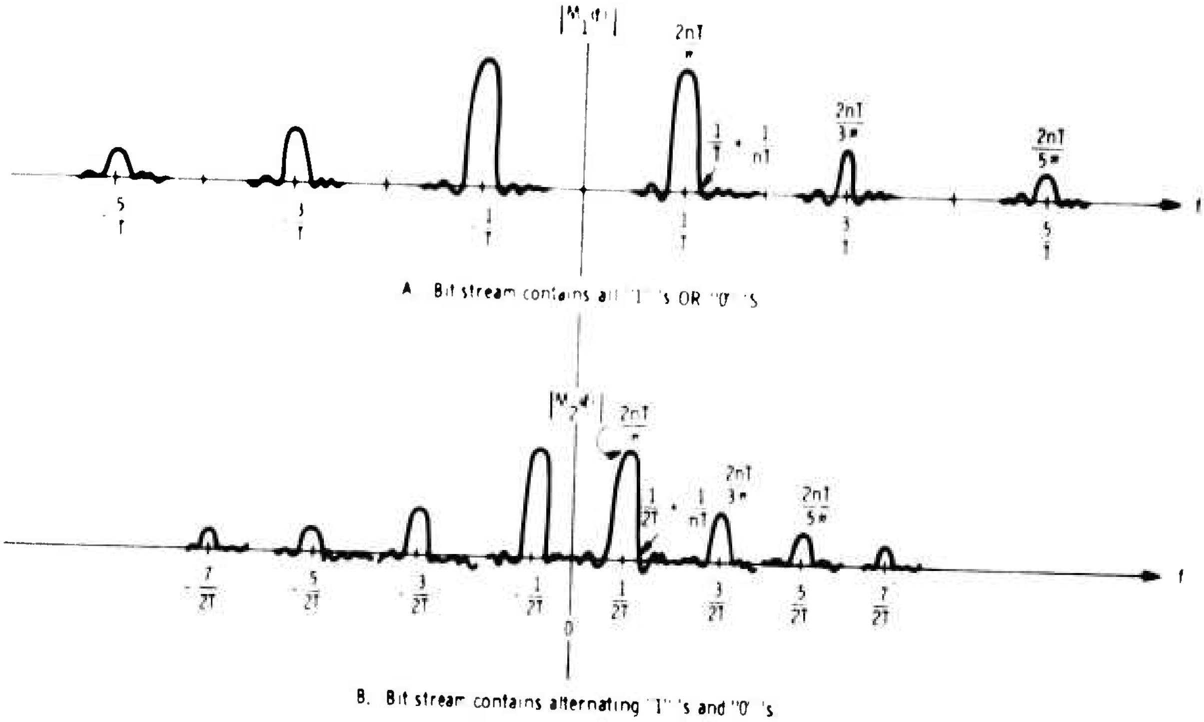

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Figure 4-58 (C) Voltage Spectra of Split-Phase Signal (U)

4.3.10 (C) Power Budget Analysis

4.3.10.1 (C) Bit Error Probability and S/N

As indicated by Equation (26), the probability of bit error p_e is dependent upon the joint event of obtaining correct bit timing and a correct bit decoding decison. The decoding in the proposed system will be such that if a transition at the center of an information bit (at or near the split-phase transition) is missed, no decoding of that bit will occur. Let p_m represent the probability of missing a bit timing transition and q_e represent the conditional probability that a decision error is made while sampling the output of the integrator, given that correct bit timing has been established. Thus the total probability of bit error will be

$$p_e = p_m + (1 - p_m)q_e \tag{53}$$

q_e is thus the normal error probability that appears in the conventional bit error probability versus signal-to-noise ratio (E/N_o) curves of standard texts (References 6, 7, 8). These standard curves are derived on the basis that timing synchronization is firmly established.

For a specified input S/N_o, q_e can be obtained directly from standard curves. However, the transition miss probability p_m is not obtainable in a straightforward manner. In fact, q_e and p_m are not independent since the noise at the transition time and at the integrator sampling instant are correlated. Therefore, no rigorous solution to the complete problem is available at this time. However, in order to be able to complete the design values, we shall make the assumption that both the transition miss probability p_m and the conditional decoding error probability q_e will be equal, i.e.,

$$p_m = q_e \tag{54}$$

With this assumption, Equation (53) becomes

$$p_e = q_e (2 - q_e) \tag{55}$$

From the curves of Figure 4-52, a bit error probability of 2×10^{-3} is taken as a reasonable choice because the data loss will then be only about 6% greater than that for a link with $p_e = 0$. Hence, with $p_e = 2 \times 10^{-3}$, q_e from (55) becomes

$$q_e \approx 10^{-3} \tag{56}$$

4.3.10.1 (C) (Continued)

From standard curves for DPSK (Reference 7), whose performance the proposed system approximates,

$$\gamma = \frac{E}{N_o} = 7.5 \text{ dB} \tag{57}$$

Since the receiver must have a bandwidth wider than the signal bandwidth of 20 kHz to accommodate possible frequency instabilities of the transmitter and receiver local oscillator, the 3 dB receiver IF bandwidth will be designed to be 40 kHz. With W = 40 kHz and a bit time T = 0.1 milliseconds, TW = 4. Since

$$\frac{E}{N_o} = TW \frac{S}{N}, \tag{58}$$

the receiver input

$$\frac{S}{N} = 1.9 \text{ dB}. \tag{59}$$

4.3.10.2 (C) Receiver Sensitivity

The receiver sensitivity, defined as the minimum usable input signal level to yield a $p_e = 2 \times 10^{-3}$, is determined as follows:

KTB = -174 dBm + 46 dB	=	-128 dBm
Receiver Noise Figure (nominal)	=	7 dB
Receiver Internal Noise N_R	=	-121 dBm
S/N in bit rate bandwidth for $p_e = 2 \times 10^{-3}$	=	7.5 dB
Bandwidth correction factor 40 KHz/10 KHz	=	6.0 dB
Required receiver IF S/N for $p_e = 2 \times 10^{-3}$ ideal DPSK demodulator (7.5-6.0 dB).	=	1.5 dB
Demodulator performance degradation allowance (from ideal)	=	4.5 dB
Required IF S/N for $p_e = 2 \times 10^{-3}$ for degraded demodulator (2.4 + 3.6 dB)	=	6.0 dB
Minimum signal level for decoding (-121 dBm + 6 dB)	=	-115 dBm

If the receiver NF is allowed to go to 10 dB in the worst case, then a minimum signal level for decoding would be -112 dBm.

4.3.10.2 (C) (Continued)

A 4.5 dB demodulator performance degradation is a composite of phase locked loop acquisition performance degradation for the short acquisition times allowed, timing synchronization accuracy loss and decoding losses for the signal format chosen and likely degradation due to the factors of component tolerances.

The degradation of the performance of a demodulator due to jitter in the reconstructed carrier phase is developed in Reference 20 (see Page 4-96) at the same time the degradation due to a degraded correlation factor is developed. We estimate the correlation between two bits of opposite type to be approximately -0.8. The degradation of the performance through the lack of perfect correlation and the phase jitter will require an increase in signal-to-noise ratio of 1 dB to maintain the required error rate. Timing inaccuracies should require less than an additional 0.5 dB signal-to-noise ratio to maintain the performance. The remaining 3 dB should be an adequate allowance for the effects of component tolerance, especially in such points as thresholds and amplifier gain.

The 4.5 dB performance degradation allowed for the demodulator should be adequate for the actual circuit.

The presence of indigenous noise will tend to reduce the receiver performance. The prediction of indigenous noise levels, however, can at best be only a very rough approximation. Atmospheric noise need not be considered at VHF; in fact, the only plausible natural noise is of Galactic origin. For the frequencies of interest, mean Galactic noise levels can be as high as 5 dB above KTB. Any other contribution to indigenous noise must be man-made.

It is estimated that man-made noise could reach a level of 14 dB above KTB, but only in cases where the intra-wide area communication receivers are operating in close proximity to communications centers, or industrial centers. When the communications receivers are deployed in remote locations, the mean man-made noise reaching the receivers can be expected to be no greater than Galactic levels. It will be shown that the intra-wide area link can be reliably closed using the indigenous noise 5 dB above KTB and closed at some loss in transmission range using the worst case of 14 dB above KTB.

For a nominal receiver NF of 7 dB and a realistic indigenous noise level of 5 dB above KTB:

Incident indigenous noise level (KTB + 5 dB)	-123 dBm
Antenna Gain	-2 dB
Input indigenous noise at Receiver Input = NI	-125 dBm
Combined Input Noise Level $N_T = N_I + N_R$ = (-125 dBm combined with a -121 dBm)	-119.5 dBm
IF S/N (for -112 dBm signal signal level)	7.5 dB

4.3.10.2 (C) (Continued)

Thus, there is 1.5 dB of margin for nominal receiver noise figure and with degraded demodulator performance. Noise figure degradation to 10 dB would result in a small loss in transmission range for a J&B forest. Figure 4-31 indicates that range would only have to be reduced in a few percent from maximum to pick up the 1.5 dB required in received signal level for a 6 dB IF S/N.

For the unlikely case of 14 dB above KTB in a J&B forest environment:

Incident indigenous noise level (KTB + 14 dB)	-114 dBm
Antenna Gain	-2 dB
Indigenous noise at receiver input NI	-116 dBm
Combined input noise level $N_T = N_I + N_R$ = (-116 dBm combined with -121 dBm)	-115 dBm
Minimum received signal level	-112 dBm
IF S/N	3 dB

Thus, the received signal level would have to increase to -109 dBm for a nominal receiver noise figure and with degraded demodulator performance, and to -106 dBm for additional noise figure degradation to 10 dB. This would result in approximately 15 percent and 30 percent transmission range loss respectively for a J&B forest.

A reasonable compromise R/I sensitivity is -112 dBm for a $p_e = 2 \times 10^{-3}$. By requiring that this level be present at the receiver input terminals through a J&B forest and at the end-of-life transmitter power output, subsequent analysis will show that reasonable R/R transmitter output power requirements result. For the S/T to R/R link the receiver sensitivity requirement can be relaxed and still result in very reasonably S/T transmitter power requirements as will be seen in subsequent analysis. Requiring that a -105 dBm signal level be present at the R/R receiver input, and controlling the receiver NF and demodulator trade-offs (by establishing a R/R receiver IF S/N of 6 dB as in the R/I receiver) will permit operation in extremely high indigenous levels without transmission range degradation. Since there is more flexibility in R/I location in general than R/R location, it is believed that a reasonable compromise is required receiver sensitivity has been made.

4.3.10.3 (C) Required Transmitter Power

The required transmitter power for the S/T and the R/R will be highly dependent upon the propagation path loss, which is a function of the local environment. The results of the propagation path loss analysis were presented in Section 4.3.2. The greatest path loss occurs at the higher frequencies so the design will be based for 165 MHz. At this frequency the propagation path loss in a fairly thick jungle forest (JB curve of Figure 4-32) for antennas at a height of 1 meter are given as follows:

4.3.10.3 (C) (Continued)

Range, Meters	Mean Path Loss, dB
200	113
1000	141

We may now find the required transmitter power, P_t, and the transmitting and receiving antenna gains G_t and G_r, by recalling that

$$P_r \geq P_t + G_t + G_r - L_b \tag{60}$$

where

P_r = the receiver sensitivity, and

L_b = path loss

Thus for the R/R transmitter, Equation (60) becomes (P_r = -112 dBm)

$$P_t + G_t + G_r \geq +29 \text{ dBm}$$

and for the S/T transmitter (P_r = -105 dBm)

$$P_t + G_t + G_r \geq 8 \text{ dBm}$$

Quarter wave monopole antennas will give a gain of at worst -2 dB with respect to isotropic for the intended deployment. Therefore

$$G_t + G_r \leq -4 \text{ dB}$$

or

$$P_t = +33 \text{ dBm at end-of-life}$$

Experience to date has shown that battery operated transmitters required to operate unattended for as long as 6 months can be built to deliver an initial 4 watts into the antenna which will degrade to about 2 watts (the required figure) at the end of battery life.

For the S/T the antenna performance may be degraded since the S/T to R/R distances is short and propagation may frequently be by the direct wave and at low elevation angles where the antenna gains are expected to be from. A total S/T and R/R antenna contribution of -9 dB is allocated to account for the additional losses

4.3.10.3 (C) (Continued)

$$G_t + G_r \leq -9 \text{ dB}$$

$$\therefore \quad P_t = +17 \text{ dBm}$$

For the S/T, the end-of-life transmitter power will be 50 mw. An initial S/T transmitter power of 100 mw will be required to give sufficient allowance for battery degradation over the operating life.

To avoid unnecessarily strong radiations where the foliage is thin, the S/T as well as the R/R transmitters will be designed to provide two power outputs: one 10 dB less than the other.

4.3.11 (C) Summary of Data Link Analysis

A relatively simple efficient baseline communication svstem has been evolved. This system uses two frequency channels for all the links; one frequency is for the S/T-to-R/R links and a second frequency for the R/R-to-R/I links. Each sensor alarm will be encoded in a short burst digital transmission of 23 bits duration at a bit rate of 10 kilobits per second.

The system will operate so that the R/R will act as a regenerative repeater, i.e., it will perform demodulation, decoding, authentication of address, regeneration of the received code word, and frequency translation. The R/R receiver will be blanked while the retransmission is taking place (approximately 4.3 milliseconds). A capability also exists for the system to grow in that the data rate can be increased by about 50 percent without introducing intolerable splatter or cross-talk in adjacent channels.

Channel minimization is accomplished by letting multiple transmitters share a common channel. This, of course, leads to a certain amount of data loss attributed to message overlap. The estimated S/T-to-R/I data loss, however, appears to be quite reasonable when one considers that the overall BESS data loss can go up to 25 percent before any significant degradation of the system performance occurs. The percent data loss caused by message overlap is determined by the false-alarm rate of the sensors used and the degree of activity near the arrays. Calculations show that if five of the arrays located within the reception range of an R/I are simultaneously intruded by five 20-man groups and if the deployed sensors exhibit a mean false alarm rate of 1 every hour, the S/T-to-R/I data loss will be of the order of 10 percent.

Table 4-6 summarizes the principal characteristics for the baseline WARS communication system.

Table 4-6 (C). Summary of Data Link Characteristics (U)

Frequency Band	138-172 MHz
Number of Channels	2
Channel Width	60 kHz
Channel Separation	3 MHz
RF Signal BW	20 kHz
Receiver IF BW's (3 db)	40 kHz
Modulation	PSK
Information Bit Rate	10 kbps
Signal Coding	20 kbps split-phase (Manchester Code)
Baseband Filtering	10.5 kHz @ 36 db/oct, Gaussian response
Message Lengths	23 Bits**
Enable Bits	= 2 *
Frame Marker	= 5
WARS ID	= 6
Array ID	= 3
Sensor ID	= 3
Status and Type Alarm	= 2
Self Test	= 1
Parity	= 1
S/T Transmitter Power (Initial)	100 mw and 10 mw
R/R Transmitter Power (Initial)	4 W and 0.4 W
R/I Receiver Sensitivity	-112 dBm
R/R Receiver Sensitivity	-105 dBm
Receiver Bit Error Probability	2×10^{-3}
Estimated Data Loss (Upper Bound)	20 percent

* In order to increase system flexibility a twenty-fourth bit may be added for use with auxiliary inputs.

** Enable shall be two or more bits.

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Section V

WARS HARDWARE DESIGN

5.1 (U) GENERAL

This section is intended to serve as a preliminary design plan for the hardware which is required to implement the system design presented in Section IV. Both electrical and physical design are outlined for the three components of the WARS subsystem: (1) S/T, (2) R/R, and (3) R/I.

5.2 (C) ELECTRICAL DESIGN

5.2.1 (C) Sensor/Transmitter (S/T) Unit

A block diagram of this unit is shown in Figure 5-1. The major subsystems of this unit are: (1) Primary Detector, (2) Encoder and Power Control, (3) Modulator, (4) Transmitter, (5) Antenna, and (6) Battery Pack. The proposed electrical design of these are covered in the following sections.

5.2.1.1 (C) Primary Detector

A block schematic diagram of this module is shown in Figure 5-2. The major component of this module are:

a. Geophone

b. Amplifier

c. Discriminator

d. Self Test

e. Alarm Pulse Generator

f. Voltage Regulators

5.2.1.1.1 (C) Geophone

The geophone is an electro-mechanical device which converts vertical earth motion (in the order of 10^{-7} inches) generated by personnel, vehicles, aircraft, etc., into electrical signals. The primary parts of the geophone are the permanent magnet and the coil-mass. The coil is wound on a known mass which is attached to the stationary case by a spring. The magnet and case are rigidly and mechanically coupled to the earth. When the earth moves, the magnet and case also move. The coil, however, tends to remain stationary and lags behind the motion of the earth. Consequently, the relative motion between the magnet and coil generates a current

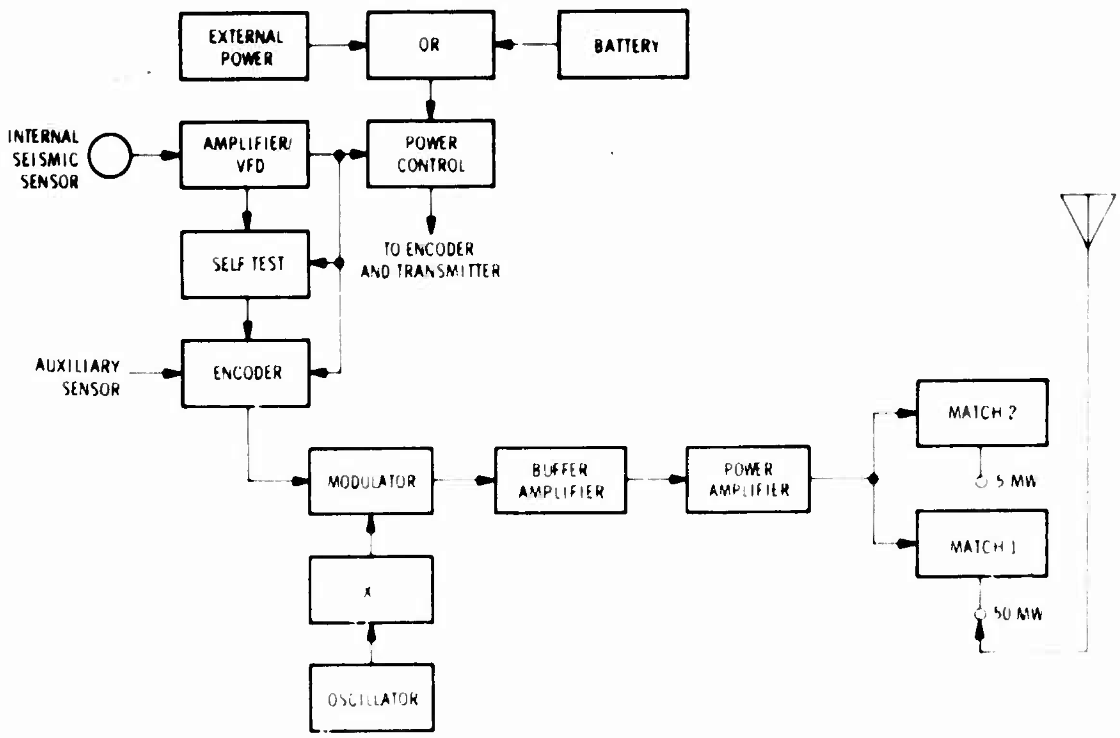
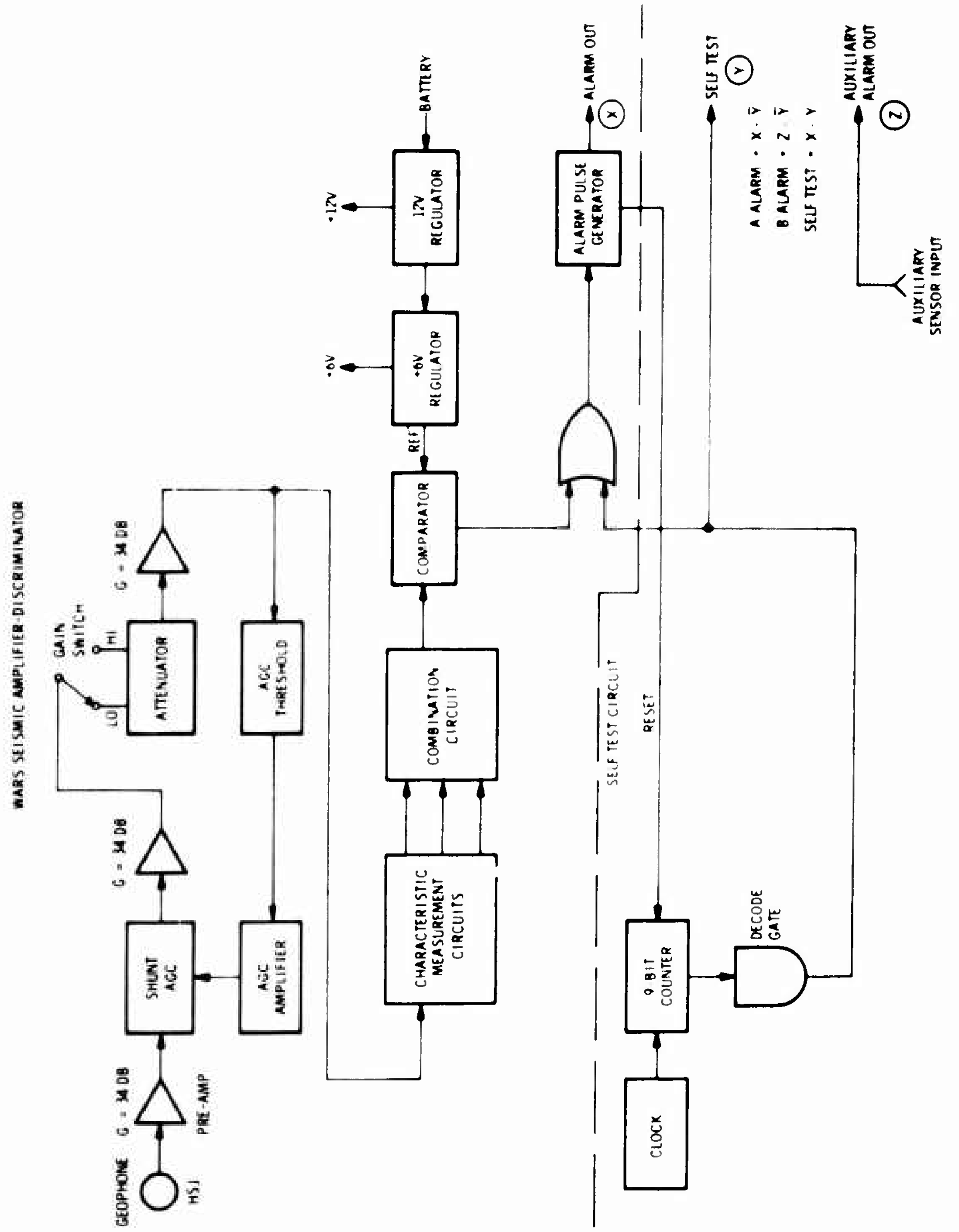


Figure 5-1 (C). Block Schematic, S/T Unit (U) (CONFIDENTIAL)

in the coil proportional to the relative velocity between the magnet and coil. The moving coil cuts the magnetic flux lines, thereby generating a current. Provided the resulting signals are large enough, relative to normal background and geophone noise, further amplification and processing readily yields a recognizable seismic signature.

Two geophones are being considered for use as the Primary Sensor. Both devices are characterized by proven reliability, small size, light weight, ruggedness, and low cost. These geophones have been tested extensively by Sylvania and have been used in numerous other seismic intrusion detection systems. The geophone specifications are as follows:

Parameter	MARK Products Ltd.	Geo Space Corp.
Model No.	L-9	HSJ-61
Natural Frequency	10 Hz	10 Hz
Coil Resistance	2200 Ω	2200 Ω
Height	1"	1"
Diameter	.875"	.875"
Weight	1.8 oz.	1.8 oz.



(CONFIDENTIAL)

Figure 5-2 (C). Block Schematic, Seismic Amplifier-Discriminator

5.2.1.1.2 (C) Amplifier

The output signal from the geophone will be amplified by a three-stage, 96-dB (nominal) voltage gain amplifier. The gain stability over the specified temperature range will be ± 1 dB. The frequency response will be down 3 dB at 12 and 120 Hz. The choice of bandwidth for the amplifier is governed by he Variance Frequency Discriminator. Since the signals generated by personnel walking are generally in the 20-to-40 Hz band, the higher frequency signals passed by the amplifier will be used to improve signal discrimination thus reducing the false alarm rate.

The amplifier will consist of three low-power, stabilized-bias transistor stages. The first stage input will be protected from large signals which otherwise would destroy the first stage. Such large signals can be generated by dropping the sensor or by a nearby artillery shell burst. The first stage will also be optimized for low noise operation to avoid sensitivity limitation by amplifier noise. The output noise level will be less than 10 mV rms for an equivalent input noise of approximately 0.15 μV rms. The final stage of the amplifier will be followed by a buffer driver necessary to drive the AGC and the processor.

Shunt AGC will be employed between the first and second gain stages to allow distortion-free operation over a wide dynamic range of input signals. The AGC will have a 40 dB-dynamic range with a 1 second delay-attack time and a 10 second release time.

A field selectable gain switch will be added between the second and third stages to set the approximate detection range of the Primary Sensor to either 10 or 30 meters for personnel.

5.2.1.1.3 (C) Discriminator

The output of the amplifier is fed into the VFD. The signal is first fed into the circuits which generate the characteristic measurements which have been determined to be most effective in the discrimination between the intruders which are to be detected and the sources of false alarm. Contrary to the usual procedure for selecting such characteristics consisting of guessing at a set of characteristics which might work when trying the resulting circuits in a test, the characteristics used in the VFD were selected through a much more thorough and exhaustive procedure. A large number of different types of measurements were made on the output of the amplifier associated with the seismic transducer or geophone. Particular emphasis was placed on such simple measurements as the amplitude, the frequency, the variations of the amplitude, the variations of the frequency, and cross-correlations of these different quantities. The amplitude of the signals can be measured with an energy detector or envelope detector. The frequency of the signals can be measured in a number of different ways. One technique is to use a low frequency discriminator constructed in much the same way that high frequency discriminators are constructed with integrated-circuit operational amplifiers supplying the function of the transformers usually required.

Secondary measurements were also made on the signals from the primary signal characteristic measurement devices. Such operations as filtering can be easily performed. In addition, such things as the average frequency of the envelope, the average amplitude of the envelope, the peak-to-peak variation of the envelope

5.2.1.1.3 (C) (Continued)

and similar measurements of the frequency of the signal were measured by simply applying the primary circuit measurement devices to the output of the primary circuit measuring devices. Cross correlations of the primary and secondary measurements could also be approximated by using moderately simple mixing operations followed by filtering operations.

In the manner described above a large number of characteristics of the amplitude and of the frequency of the signals due to personnel, to vehicles, and to rain and planes of differenc types were measured. An additional possible measurement that was not included for theoretical reasons was a phase measurement. It was considered that the phase measurements would be almost entirely random for each of the types of signals and would therefore supply little information about the origin of the signal.* A computer was used to explore the possible useful variations of the measurements and the techniques for combining the measurements to arrive at the best possible combination of characteristics of the signal. This combination is not "optimum" as a detector of the intruders, since there is almost surely a more complicated set of measurements which will perform the desired discrimination more precisely. However, the characteristics which were selected will detect intruders reliably with simply constructed circuits.

5.2.1.1.4 (C) Self Test

The self-test circuitry consists of a low frequency clock, a 9-bit counter, and a decode gate. The counter divides the clock frequency by 29 to achieve a one hour cycle time. The decode gate detects the end of a one hour period and triggers the Alarm Pulse Generator. Since a sensor alarm is a valid verification that the Primary Detector and the rest of the S/T are operational, it is unnecessary to transmit self test messages during periods of activity. Consequently, a sensor alarm will reset the 9-bit counter to begin a new one hour period. If no sensor alarms have occurred during a one hour period, a test message will be sent at the end of that period. A minimum of one message will be transmitted every hour. The clock is a low frequency, low power, discrete component clock. The 9-bit counter and the decode gate are low power COS-MOS integrated circuits.

5.2.1.1.5 (C) Alarm Pulse Generator

The alarm pulse generator initiates power turn-on to the encoder, modulator, and transmitter, and limits the alarm rate to 1 per 4 seconds maximum. The alarm pulse will be of sufficient length to turn power on and to permit the encoder time to stabilize. Following circuit stabilization, the encoder will assume the power control function and maintain power on until the message transmission is complete. The alarm pulse must be larger than six volts in amplitude and from 0.5 to 2 ms long. The auxiliary sensor must also generate a similar alarm pulse and must contain a built-in alarm rate limiter.

5.2.1.1.6 (C) Voltage Regulators

The +12 V and +6 V regulators will supply voltages for the amplifier and VFD and will be on continuously. The +12 V regulator will exhibit a low output impedance (<1Ω) and good input voltage transient response. Since the battery voltage will vary

5.2.1.1.6 (Continued)

widely during a transmission cycle, special care must be taken to prevent the transients from introducing high noise levels into the amplifier, possibly forcing the amplifier AGC to reduce gain. The regulator will employ a Darlington pass transistor configuration with short circuit output protection. A low current LVA zener diode will supply the reference voltage and will be compensated with a transistor base-emitter junction. The +6 V regulator will operate from the +12 V regulator and will be of very simple, low power shunt configuration.

5.2.1.1.7 (C) Alarm Qualification Logic

The Auxiliary Detector alarm signal will be applied to the encoder without further processing or gating with the Primary Detector. Two options for combining these are discussed in Chapter 6. Since the sensor which is generating the alarm or a self test must be identified in the transmitted message, it is necessary to include some control logic to identify the alarm source/self test. The lines X, Y, and Z (see Figure 5-2) will be used as follows:

X = Primary Sensor Alarm

Y = Self Test

Z = Auxiliary Sensor Alarm

$X \cdot \overline{Y}$ = Primary Sensor Alarm

$Z \cdot \overline{Y}$ = Auxiliary Sensor Alarm

$X \cdot Y$ = Self Test

5.2.1.1.8 (U) Power

Power will be supplied continuously to the amplifier and the discriminator.

5.2.1.2 (C) Encoder and Power Control

5.2.1.2.1 (C) General

The primary function of the encoder is to generate the message of the S/T unit in response to an alarm signal received from the Primary Detector. The response message is a digital word consisting of 23-bits designated as follows:

5.2.1.2.1 (C) (Continued)

Bit Nos.	Description
1 - 2	Enable (00)
3 - 7	Frame Marker (11101)
8 - 13	WARS ID
14 - 16	Array ID
17 - 19	Sensor ID
20	Aux. Sensor Alarm
21 - 22	Status & Type Alarm
23	Parity

The encoder will provide for external control of the WARS ID, Array ID, sensor ID, and identification parity bits by selections made on a code plug. The code plug setting will be made prior to field deployment. The remaining bits of the response message are set internally by the encoder circuitry. The parity bit will depend on all bits except the enable and frame marker bits.

The encoder timing circuitry will determine the duration of the transmission of the S/T unit. Upon receipt of an alarm from the Primary Detector, the encoder will generate a power control signal to enable the power switches. Thus, power will be applied to the transmitter for the duration of the power control signal.

5.2.1.2.2 (C) Description of Operation

A block diagram of the encoder and power control subsystems is shown in Figure 5-3. The encoder is inactive in the non-alarm state. The battery voltage is applied to the power control flip-flop and the power switch of the encoder, resulting in a continuous current drain of 10 microamperes. The system can also be operated with an external DC power source as shown.

An alarm pulse from the processor acts as a temporary enable signal for the power switch which applies the battery voltage to the +12 volt regulator. A regulated +12 volts DC is applied to the encoder circuitry and to the transmitter. The current drain will be less than 40 milliamperes. The reset circuit, which is triggered when the +12 volts is applied, generates two reset pulses R1 and R2. R1 triggers the power flip-flop which generates a sustained enable signal for the power switch. Reset pulse R2 is generated 1 ms after power is applied and is used to trigger the load command circuit and turn on the clock. The 1 ms delay allows the transmitter time to reach the proper frequency and power level before the message is transmitted. Figure 5-4 shows a timing diagram of some of the signals generated in the encoder. The load command pulse clears the bit counter and acts as a control signal for the shift

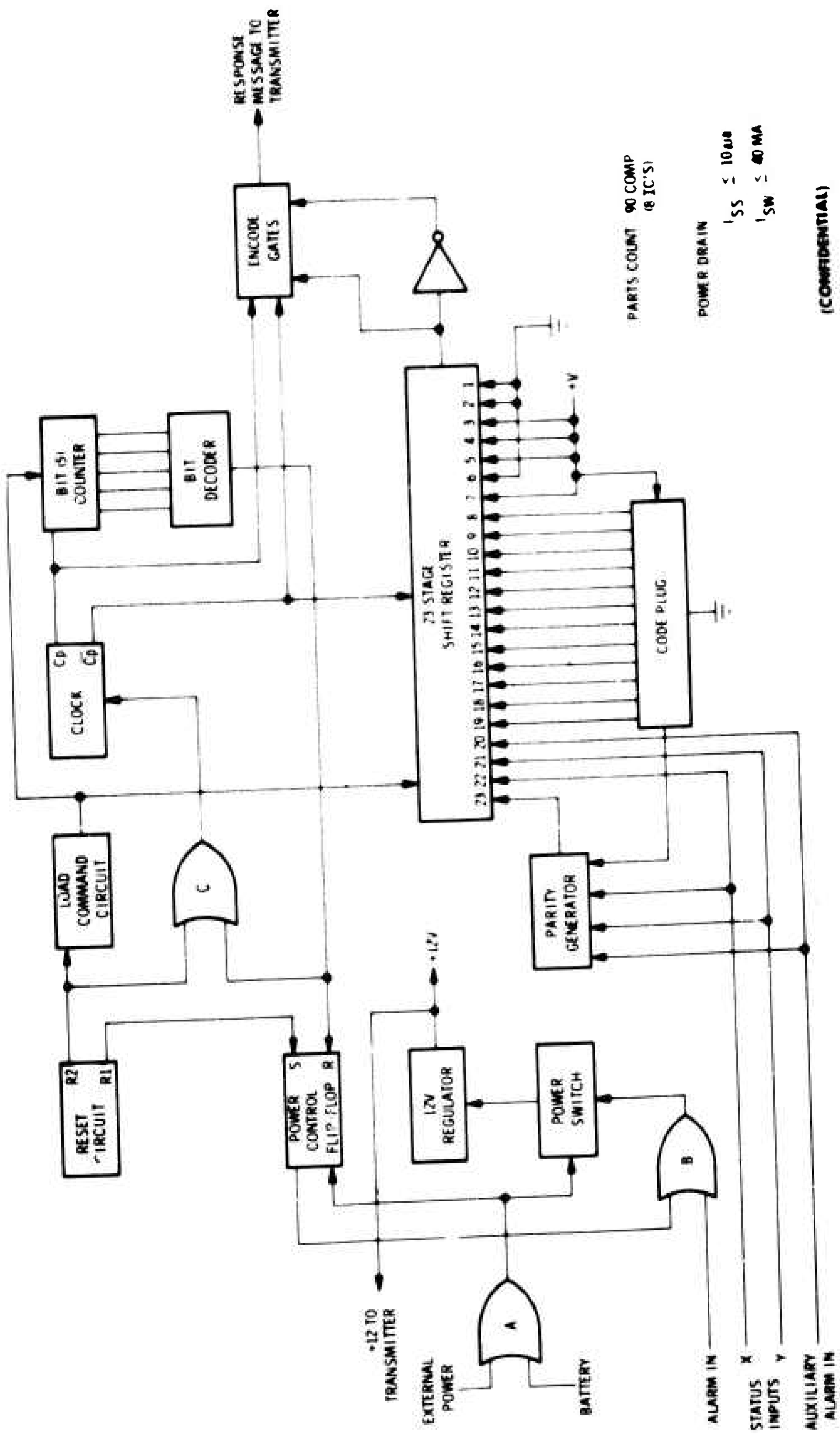


Figure 5-3 (C) Encoder and Power Control Of S/T Unit (U)

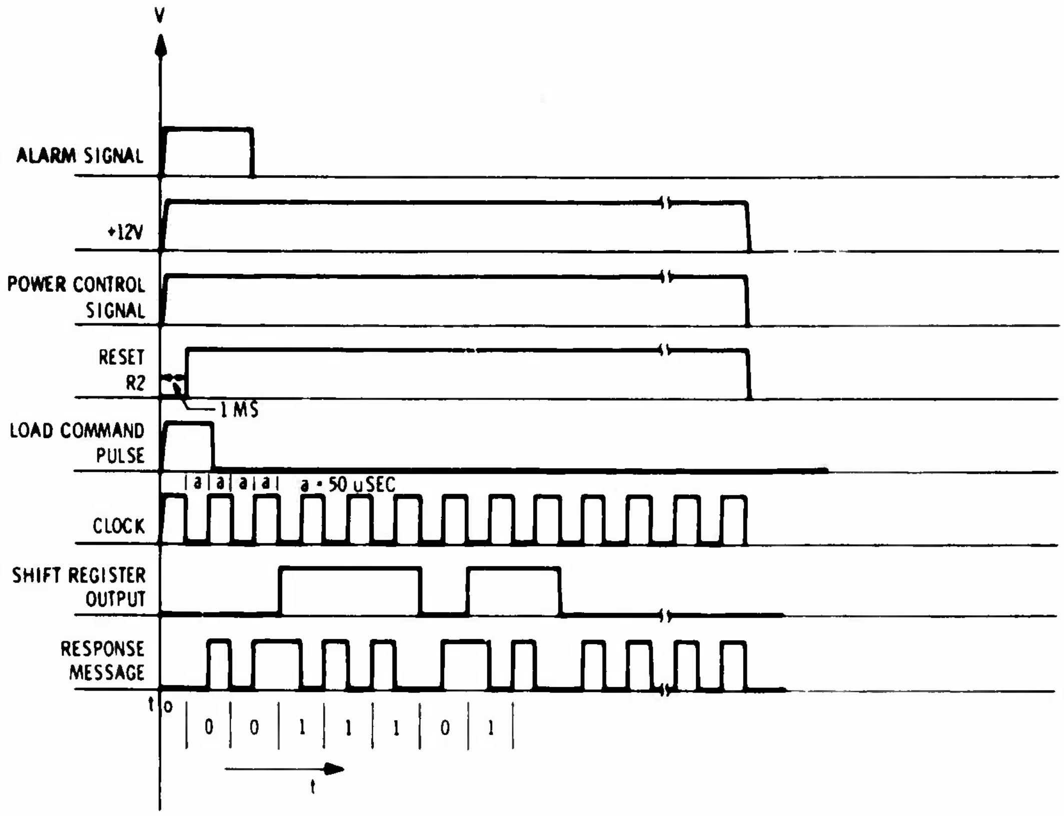


Figure 5-4 (C) Encoder Timing Diagram (U) (CONFIDENTIAL)

5.2.1.2.2 (C) (Continued)

register. The occurrence of a load command pulse with a negative transition of the clock $\bar{C}p$ causes a parallel transfer of data into the shift register. Note that the state of the parallel inputs (1 - 23) to the shift register represents the message. Parallel inputs 1 - 7 are generated internally. Inputs 8 - 19 are controlled by selections made on the code plug. A "one" is programmed by cutting a jumper wire which applies a positive voltage to the shift register. No action is necessary to program a "zero" since the jumper wires are already connected to ground. Inputs 20, 21, and 22 are status inputs from the Primary Detector. A parity generator generates the parity input (23). Inputs to the parity generator are from bits 20 through 22 and from the code plug, where a field setting indicates parity status of bits 8 through 19.

The first negative transition of the clock waveform is used to load the register and each additional negative transition is used to serially read out the shift register. The output and inverted output of the shift register are gated with the clock outputs in the encode gate to generate the "ones" and "zeros" of the message. The encode gate generates a "zero" when the register output is zero volts, and a "one" when the register output is +12 volts. Figure 5-4 shows the correct description of "one" and "zero" bits. The bit counter keeps count of the number of bits generated by counting the clock pulses. The frequency of the clock is 10 Khz. After 23 bits are transmitted, the counter decode gate generates a pulse which resets the power control

5.2.1.2.2 (C) (Continued)

flip-flop and turns off the clock. Thus, the enable signal for the power switch is removed and the +12 volts is turned off. The transmission time is 3.3 ms (2.3 ms for the message and 1 ms for transmitter stabilization).

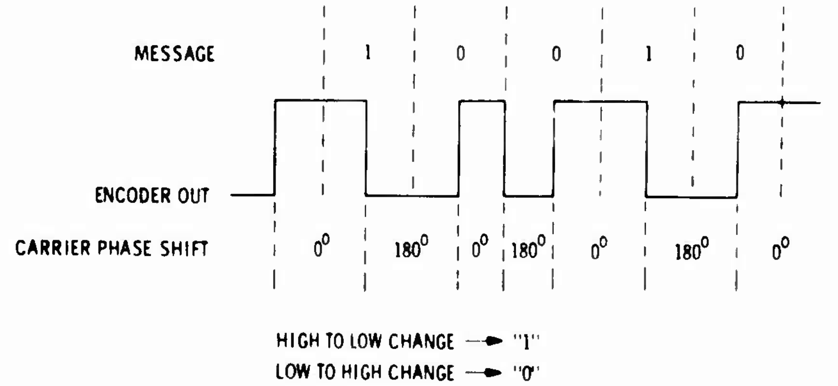
In summary, the S/T message format is determined by selections made on a code plug and other internal connections. An alarm from the Primary Detector will drive the power control circuitry to apply power to the encoder. After a 1 ms delay for transmitter stabilization, the digital data on the parallel inputs on the shift register are stored in a 23 stage register. The register is read out serially. This serial output is gated with the 10 kHz clock to generate the S/T message.

5.2.1.3 (C) Modulator

The proposed modulation format for the WARS system is binary phase modulation, where difference between a mark and space is transmitted by changing the phase of the RF carrier by 180° (see Figure 5-5). In order to maintain a high average power during each bit transmission and to minimize the transmission bandwidth and spillover, two other requirements must also be placed on the modulator. The first requirement indicates that little or no amplitude modulation be placed on the carrier during the phase modulation process; and the second, that the bandwidth of the modulating waveform be limited to just that necessary for the bit rate and modulation format involved.

In order to preserve the benefits obtained by the use of premodulation filtering, a linear phase modulator is required such that the phase of the carrier varies linearly with the modulating waveform and thus, no amplitude modulation is introduced

There are several basic types of linear phase modulators available for use in this application. The final choice will be determined during the initial equipment design phase preceding the preparation of the design plan. However, a typical Armstrong linear phase modulator is described below.



(CONFIDENTIAL)
Figure 5-5 (C). Split-Phase PSK Bit Structure (U)

5.2.1.3 (C) (Continued)

The modulating voltage is applied to a balanced mixer which is also fed by the basic carrier oscillator. The resulting output is a double sideband signal with the carrier suppressed by the rejection balance of the mixer. When a 90° shifted carrier is reinserted to the DSB signal in the adder, a phase modulated signal is produced. In this technique, the maximum linear phase shift available is in the order of 0.5 radian; therefore, frequency and thus phase multiplication must follow to increase the phase shift to π radian. A small amount of amplitude modulation is also produced which is eliminated by the limiter and the class C amplifiers in the transmitter output and drive chain.

5.2.1.4 (C) Transmitter

5.2.1.4.1 (C) General

The S/T requires a high stability VHF transmitter operating at a single crystal controlled frequency in the range of 138 to 174 MHz.

A block diagram of the transmitter module is shown in Figure 5-6. The basic elements are a fifth-overtone-mode crystal oscillator, X2 multiplier, output amplifier, and antenna matching networks.

5.2.1.4.2 (C) Oscillator

The oscillator is a Pierce configuration, which offers excellent frequency stability for crystal oscillator operation.

The Pierce oscillator utilizes a fifth-overtone-mode crystal as a series component in the feedback network. Capacitors used in the feedback network are chosen to satisfy the oscillation criterion as well as to swamp out device capacitances. The RF output is taken from a low-impedance point on a capacitive divider, thereby providing a constant load on the device.

The crystal is operated at the fifth overtone and has a specified stability of ±25 ppm from -55°C. Overall oscillator stability is ±30 ppm over the temperature range.

The oscillator utilizes an FET device which has a flicker noise (1/f) corner frequency of approximately 100 Hz compared to bipolar flicker noise corner frequencies of about 10 kHz. This factor, coupled with the high Q of the oscillator, minimizes the incidental frequency modulation.

5.2.1.4.3 (U) Multiplier

A class C multiplier will be used to take advantage of the fact that the oscillator is unmodulated. The multiplier consists of a one-stage 2N918 class C amplifier with a parallel resonant tank circuit on the output. The capacitive branch of the tank circuit is a capacitive divider used to match to 50 ohm mixer input. The multiplier bias is set by the oscillator output level. See Figure 5-7.

5.2.1.4.4 (C) Output Stage and Antenna Matching

The power amplifier will be two (2) cascaded 2N3866 stages giving 19 dB of gain. This gives a +18 dBm power amplifier output and a +17 dBm output to the antenna when in the 50 mW mode of operation.

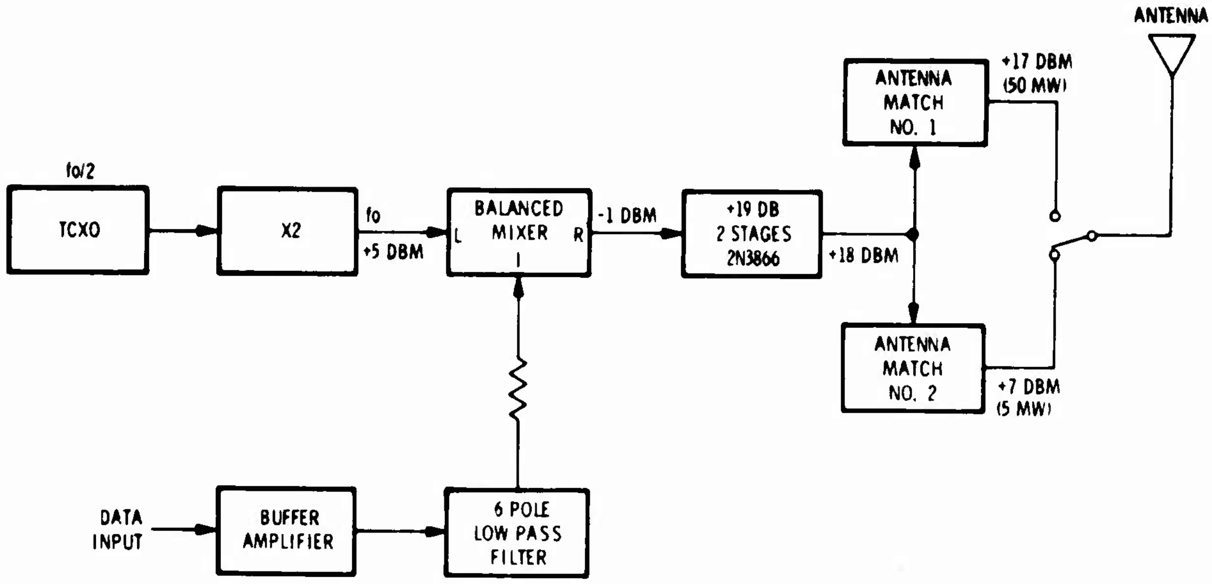


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Figure 5-6 (C). Sensor Transmitter Block Diagram (U)

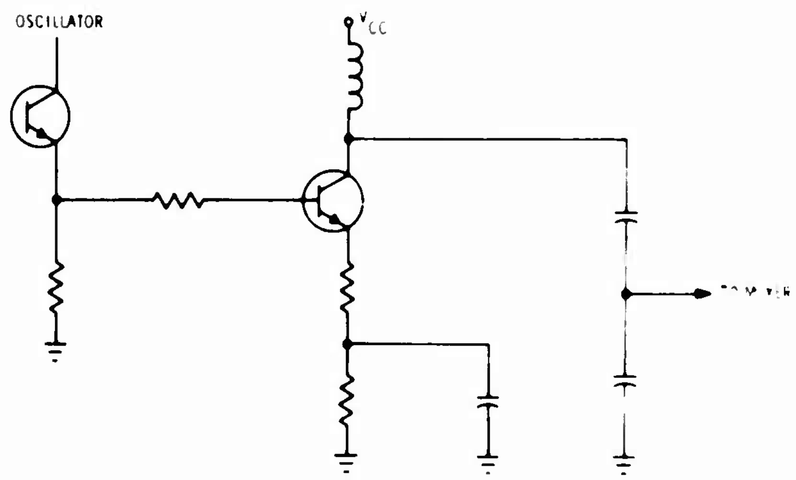


Figure 5-7 (U). Multiplier Schematic Diagram (U)

5.2.1.4.4 (C) (Continued)

The driver will operate Class B due to low gain requirements and a desire for good efficiency. The output stage will operate Class C so that the output power is a function of the output load R_L and Vcc only.

The antenna matching networks will be coupled to the collector of the final amplifier as shown in Figure 5-8. Proper power level will be selected by connecting the antenna to connector #1 for 50 mW output or to connector #2 for 5 mW output. The matching network connected to the 50 ohm antenna will reflect a load R_L to the output amplifier, giving a power level:

$$50 \text{ mW} = P_{o1} = \frac{V_{cc}^2}{2 R_{L_1}} \quad \text{for antenna connected to connector \#1,}$$

and

$$5 \text{ mW} = P_{o2} = \frac{V_{cc}^2}{2 R_{L_2}} \quad \text{for antenna connected to connector \#2.}$$

R_L will be selected to give the proper output level at minimum Vcc as power will decrease with decreasing supply voltage.

The matching network not connected to the antenna (open circuited), will be designed to reflect an open at the collector of the final amplifier, thus consuming no power from the output amplifier. This type of matching network, reflecting 50 ohms for a 50 ohm termination and ∞ for open termination, has been built and successfully tested. See Figure 5-9 for a network analyzer plot.

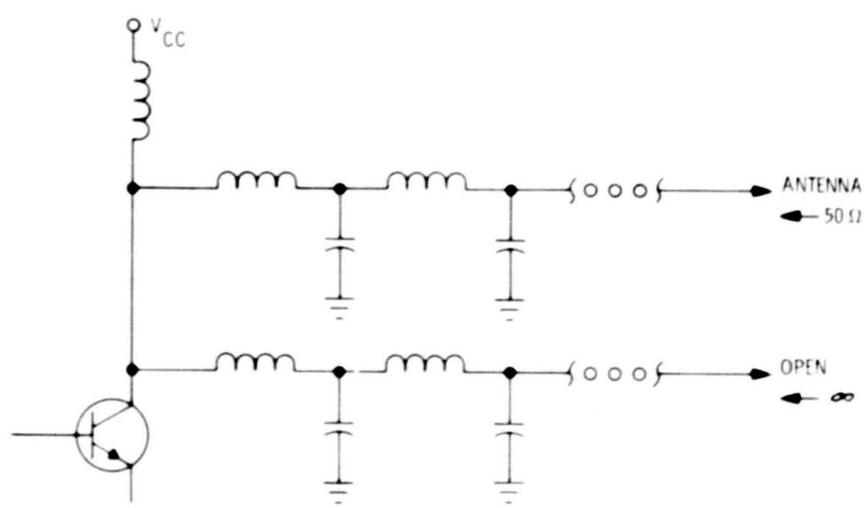
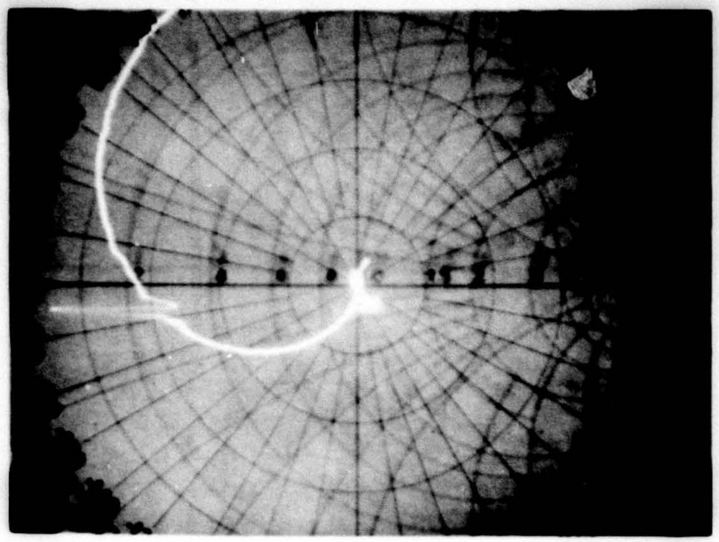


Figure 5-8 (C). Antenna Matching Networks (U) (CONFIDENTIAL)

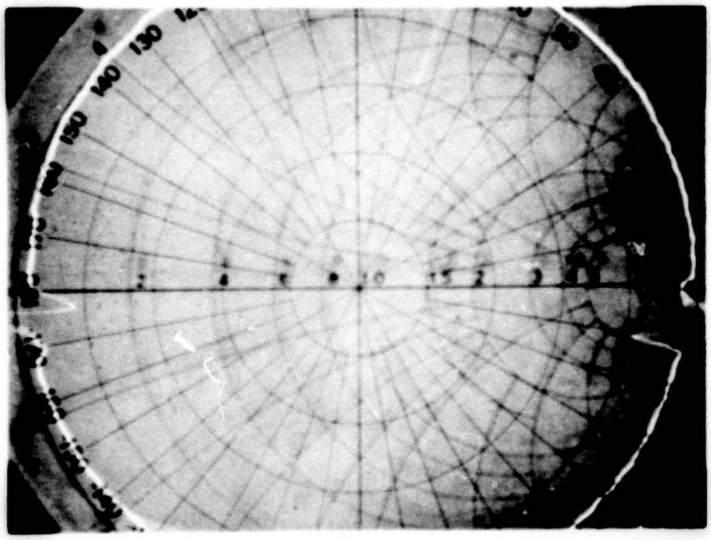


A. Matching network terminated in 50 Ω

CENTER - NORMALIZED TO 50 Ω

- 155 MHz

1ST MARKER - 205 MHz



B. Matching network open termination

CENTER - NORMALIZED TO 50 Ω

- 1ST MARKER (RIGHT) 155 MHz

- 2ND MARKER (LEFT) 205 MHz

Figure 5-9 (U). Antenna Matching Network Performance (U)

5.2.1.4.4 (C) (Continued)

The four pole output filter network components will be resonated at the desired frequency to attenuate the spurs generated in the Class C output stages (see Figure 5-10).

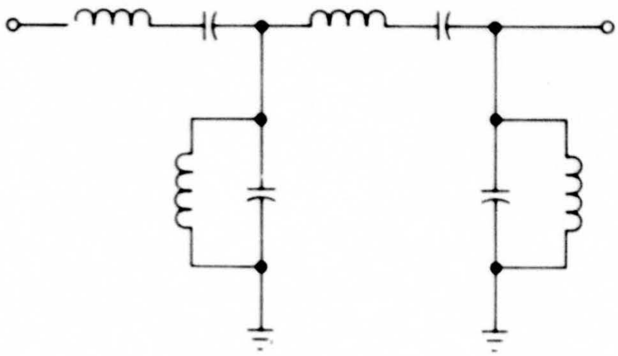


Figure 5-10 (U). Output Filter (U)

5.2.1.4.5 (C) Power Switching

The power will be supplied by an 18-volt battery. The battery voltage will be connected directly to the final amplifier which is biased Class C and will remain in the cutoff mode until driven on by the preceding stage. The remaining circuits will be supplied from a switched 12-volt regulator controlled by the power control circuit. The final state will have about 60% efficiency and will draw

$$I_c = \left(\frac{P_{out}}{V_{batt.}}\right)\left(\frac{1}{0.6}\right) = \frac{60\ \text{mW}}{(15\text{V})\ (0.6)} = 6.7\ \text{mA}$$ for high power level at end of battery life

5.2.1.5 (C) Antenna

5.2.1.5.1 (C) General

Physical size is of prime importance for the antenna to be used with the WARS subsystem components. The antenna will be the only part of the units above ground level and, therefore, is to be as inconspicuous as possible. The antenna must also be simple in construction to avoid high cost of parts and assembly.

An antenna which best meets the above requirements is the quarter wavelength monopole shown in Figure 5-11. Such an antenna consists of a vertical radiator and four radials. The radials are 90 degrees apart with respect to one another and form the necessary ground plane. This same antenna will be used for all three units: S/T, R/R, and R/I.

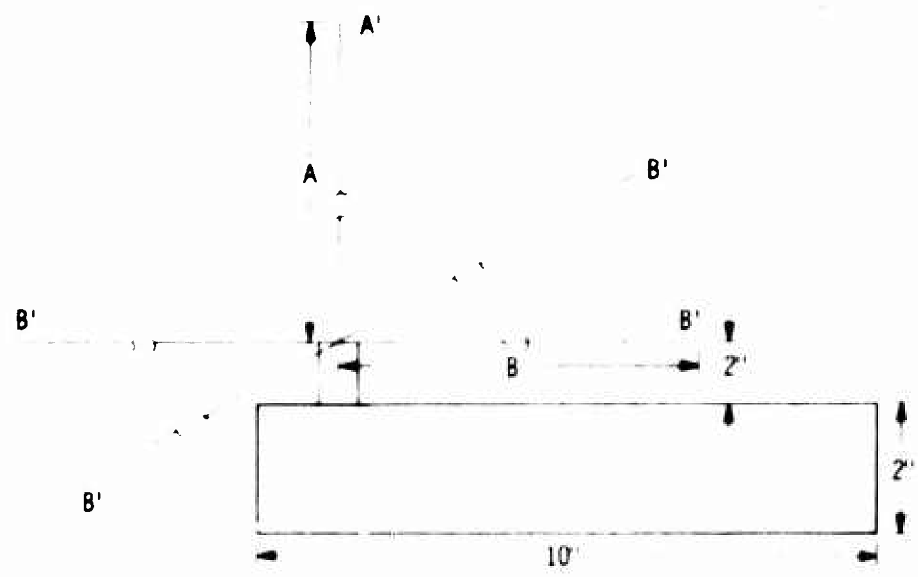


Figure 5-11 (U). Antenna Using Four Ground-Plane Radials (U)

5.2.1.5.2 (C) Expected Performance

A breadboard model of the antenna has been built with the radiator 17.6 inches long (quarter wavelength at 168 MHz) and the ground plane radials 21 inches long. The antenna was mounted on one end of a metallic box with dimensions of 2x4x10 inches. The ground plane was 2 inches above the box top. The container was buried so that the top was flush with ground level.

The vertical radiator and ground radials, made of 12 gauge copper wire, were trimmed until the antenna exhibited the best electrical characteristics. With dimension A = 16.5 inches and dimension B 20.5 inches, the antenna had a bandwidth of 20 MHz (161-181 MHz) with the VSWR below 2:1 in the frequency range. In the frequency band of interest, 162-174 MHz, the VSWR was below 1.7:1, as shown in Figure 5-12. The gain of this antenna was -2.1 dB with respect to a half wave dipole at the beam maximum. This is shown in Figure 5-13.

Next, the radials were depressed so that contact with the ground was made. The soil was moist, due to rain, and this therefore made the ground a good ground plane. Ground loading dropped the VSWR to 1.1:1 at 164 MHz and below 2:1 over a 25 MHz band (155-180 MHz). Again, in the frequency band of interest, the VSWR was below 1.5:1. The gain was - 3 dB with respect to a half wave dipole at the beam maximum (see Figure 5-13).

The wire radiator and radials were then replaced by 1/2 and 1/4 inch metal tapes and the experiments repeated. Little improvement in bandwidth or VSWR was observed.

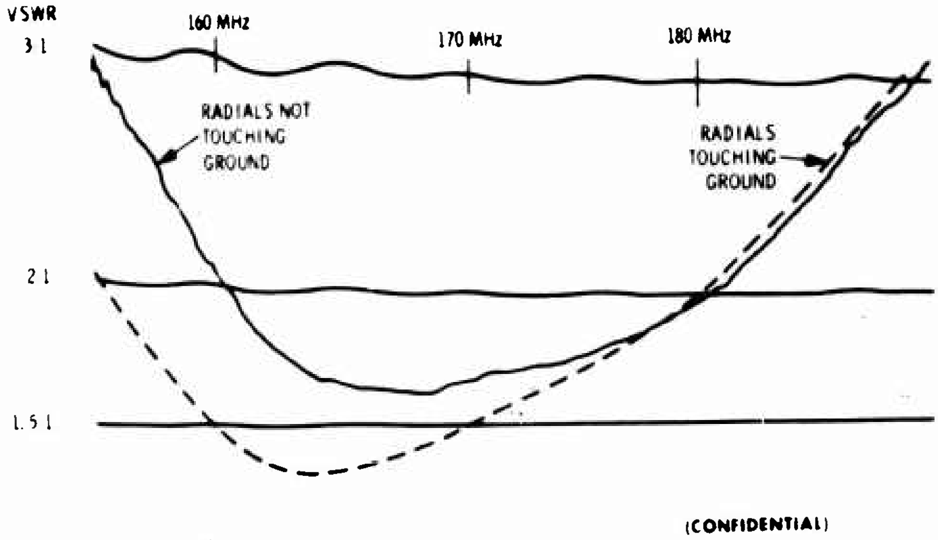


Figure 5-12 (C). Performance of Proposed Antenna (U)

5.2.1.5.2 (C) (Continued)

Subsequently, experiments were conducted with different number of ground plane radials. The results are shown in Table 5-1. With no radials, the antenna exhibits the best VSWR due to ground losses. As the number of radials is increased, the antenna shows better and more consistent performance. The best change in gain is shown in going from three radials to four. Although six or more radials would give somewhat better performance, the cost versus improvement ratio would be quite high. Therefore, considering cost and performance, the monopole with four ground plane radials is judged to best fulfill the antenna requirement.

In summary, the proposed antenna design may be described as follows:

a. The antenna dimensions will be:

   Radiator: 16.5 inches long

   Radials: 20.5 inches long

b. Four (4) ground plane radials will be used.

c. Twelve-gauge wire or 1/2 inch metal tape will be used to construct the radials.

d. Bandwidth of 20 MHz (161-181 MHz) can be achieved with a VSWR better than 2:1.

e. A gain of -1 dBi can be achieved.

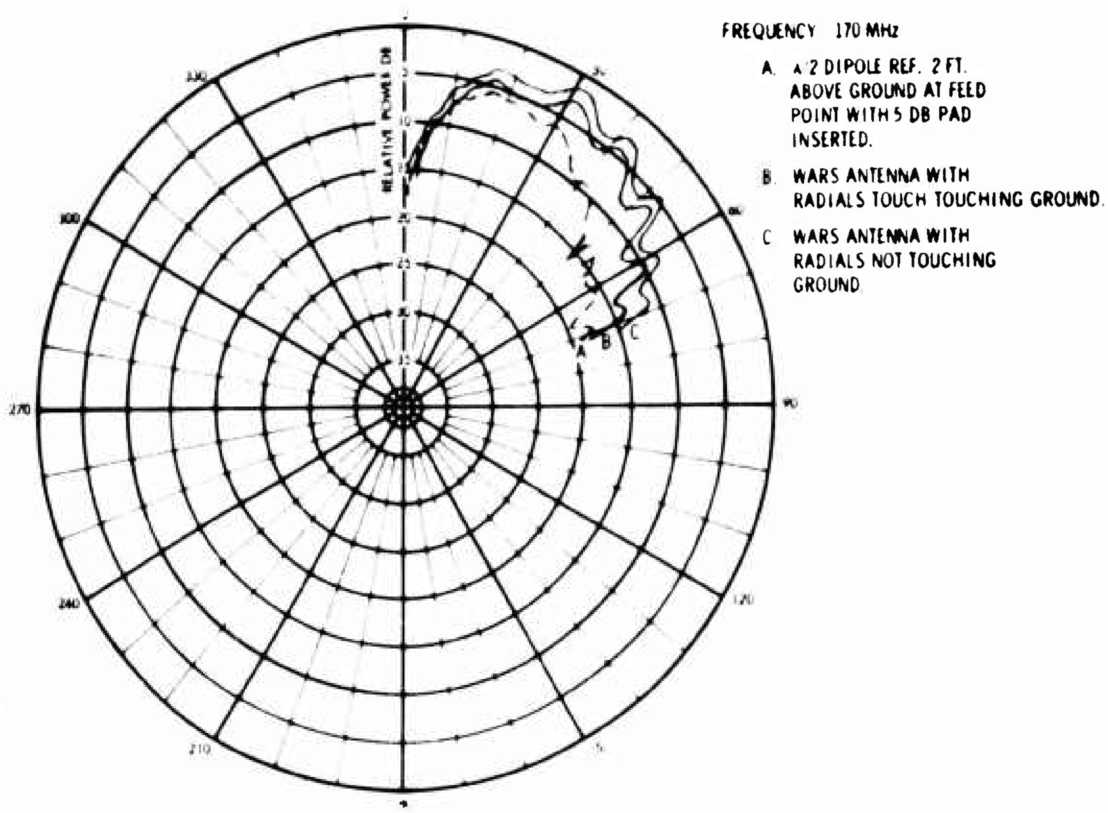


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Figure 5-13 (C). Elevation Pattern of Proposed Antenna (U)

f. Soil conditions will have an effect on the characteristics of the antenna; i.e., moisture content of the soil will vary the performance of the counter-poise and hence, the antenna characteristics.

5.2.1.6 (C) Battery

5.2.1.6.1 (C) General

The cells proposed to supply power to the units of the WARS subsystem are the Union Carbide Alkaline E95 "D" and E-93 "C" cells. The electro-chemical system of these alkaline cells consists of a zinc anode of large surface area, a manganese-dioxide cathode of high density, and a potassium-hydroxide electrolyte.

The alkaline cell was selected for the following reasons:

a. It has good weight and volumetric efficiency.

Table 5-I. (C) Antenna Performance vs. Number of Ground Plane Radials (U)

NUMBER OF RADIALS	VSWR AT RESONANT FREQUENCY		GAIN AT BEAM MAXIMUM (REF: λ/2 DIPOLE)	
	GROUND PLANE RADIALS NOT TOUCHING GROUND	GROUND PLANE RADIALS TOUCHING GROUND	GROUND PLANE RADIALS NOT TOUCHING GROUND	GROUND PLANE RADIALS TOUCHING GROUND
0	—	1.1:1*	—	-5 dB*
3	1.2:1	1.1:1	-2.9 dB	-3.6 dB
4	1.4:1	1.1:1	-2.1 dB	-3.0 dB
5	1.4:1	1.1:1	-2.1 dB	-2.4 dB
6	1.4:1	1.1:1	-2.0 dB	-2.0 dB

*Metallic box touching ground

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5.2.1.6.1 (C) (Continued)

b. The shelf life characteristics of the alkaline cell is considered good in that after one year storage at 70°F it can still be expected to supply more than 90% of its rated capacity.

c. The internal impedance is quite low. This allows large currents during transmit periods with little change in the voltage level. Impedance of the "D" cell is less than 0.18 ohms, and of the "C" cell less than 0.25 ohms.

d. These cells are primary and are intended to be disposed of at the end of service life. The low cost of this type cell makes it a cost-effective item.

e. The low temperature performance of the alkaline cell at -20 F is good; it can be expected to deliver as high as 30% of its rated capacity.

The proposed alkaline battery packs will all have 200% of the nominal capacity required to provide six months of service life at 70°F. This will assure about 3 to 4 months of service at -20°F. The alkaline cells may be used normally up to 130°F. Sustained periods of 160°F will result in some decrease in battery life.

As is generally the case with electrochemical power sources, there are some design trade-offs which must be considered. Thus the alkaline cell has the advantages listed above; however, it does not exhibit the highest volumetric efficiency. Consequently, the volume of the alkaline battery pack will be greater than that of a mercury battery pack of equivalent capacity. The weight, on the other hand, will be about the same. The mercury battery pack was primarily rejected for the reason that at -20°F, mercury cells deliver only about 5% of their rated capacity.

Another alternative which was considered was the use of silver cells. This approach, however, was also rejected because of the high cost of silver-cadmium and silver-zinc cells.

5.2.1.6.2 (C) S/T Battery

5.2.1.6.2.1 (C) Required Capacity

The total capacity required to power the S/T unit for 6 months is calculated as follows:

Continuous Drain:

Encoder and Power Control	10 μA
Primary Detector	300 μA
Self Test	50 μA
Total	360 μA

Capacity required for continuous drain for six months: (360 μA) (4320 hrs) = 1.6 Ah

5.2.1.6.2.1 (C) (Continued)

Intermittent Drain:

Encoder and Power Control	20 mA
Transmitter	25 mA
Total	45 mA

The expected duty cycle is 0.02%; hence, the capacity required for the intermittent drain over six months (45 mA) (0.9 hr.) = 40.5 mAh. Therefore, the total capacity required is approximately 1.65 Ah.

5.2.1.6.2.2 (C) Pack Description

A battery pack which will meet the above requirement consists of twelve E-93 "C" cells. This pack will provide an initial voltage of 18 volts, with a nominal capacity of approximately 3.5 Ah at 70°F to an end point voltage of 13 volts. The pack will occupy a volume of approximately 35 cubic inches and weigh about 3 lbs.

5.2.2 (C) Receiver/Relay (R/R) Unit

5.2.2.1 (C) General

An overall block diagram of the R/R unit is shown in Figure 5-14. The purpose of the R/R is to receive the alarm signals from as many as eight S/T units and retransmit these signals to the R/I unit. To accomplish this mission, the unit requires the following components:

a. Receiver

b. Demodulator

c. Decoder

d. Address Comparator/Encoder (AC/E)

e. Transmitter

f. T/R Switch

g. Antenna

h. Battery

The design of each of these are discussed in the following sections.

5.2.2.2 (C) Receiver (Figure 5-15)

The proposed receiver is one which was developed by Sylvania under an Independent Development program. The principal modifications required to adapt this receiver to the R/R application will be:

5.2.2.2 (C) (Continued)

a. frequency stability improvement

b. operation over a wider temperature range, and

c. replacement of the FM demodulator with a PSK demodulator.

The receiver is crystal controlled and may be factory set to any frequency in the frequency band from 162 to 174 MHz. It is of the single-conversion superheterodyne type with two stages of RF amplification and an 8-pole crystal filter in the 21.4 MHz IF amplifier. A schematic diagram and photograph of this FM receiver are shown in Figures 5-16 and 5-17, respectively. The power consumption of this unit is less than 6 mW (2 mA at 3 V). Although the schematic diagram appears conventional, extensive computer-aided design was used to obtain circuit optimization at the extremely low bias currents. In each circuit, overall performance has been evaluated as a function of operating power consumption.

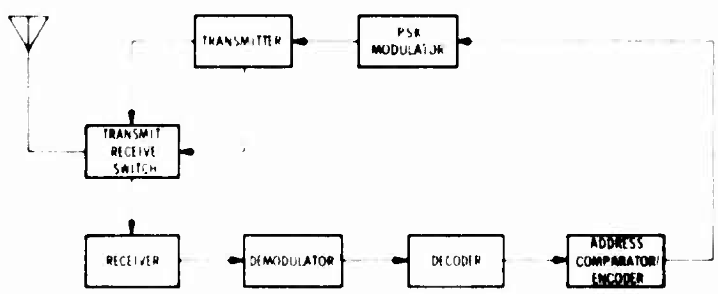


Figure 5-14 (C). Block Diagram of R/R

The modifications which will be implemented to meet the R/R requirements are listed below:

a. Reduce the IF bandwidth to 40 kHz at the -6 dB points.

b. Incorporate an 8-pole crystal filter to provide a $\frac{(BW) 60\ dB}{(BW)\ 6\ dB} = \frac{1.8}{1}$,

with less than 0.5 db peak-to-peak ripple in the passband.

c. Incorporate a crystal-controlled local oscillator to operate at one-half the LO injection frequency of 140.6 to 152.6 MHz. The frequency tolerance over the environmental range must not exceed ±30 ppm.

d. Replace the FM discriminator with a phase locked PSK demodulator.

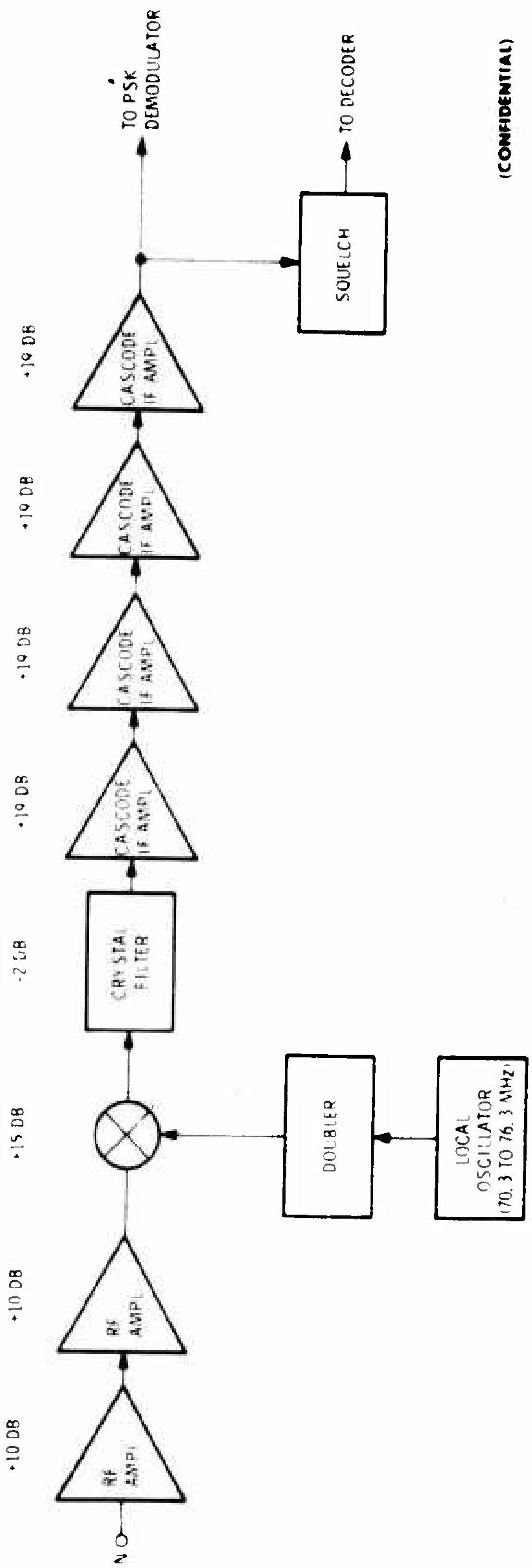


Figure 5-15 (C). R/R Receiver Block Diagram

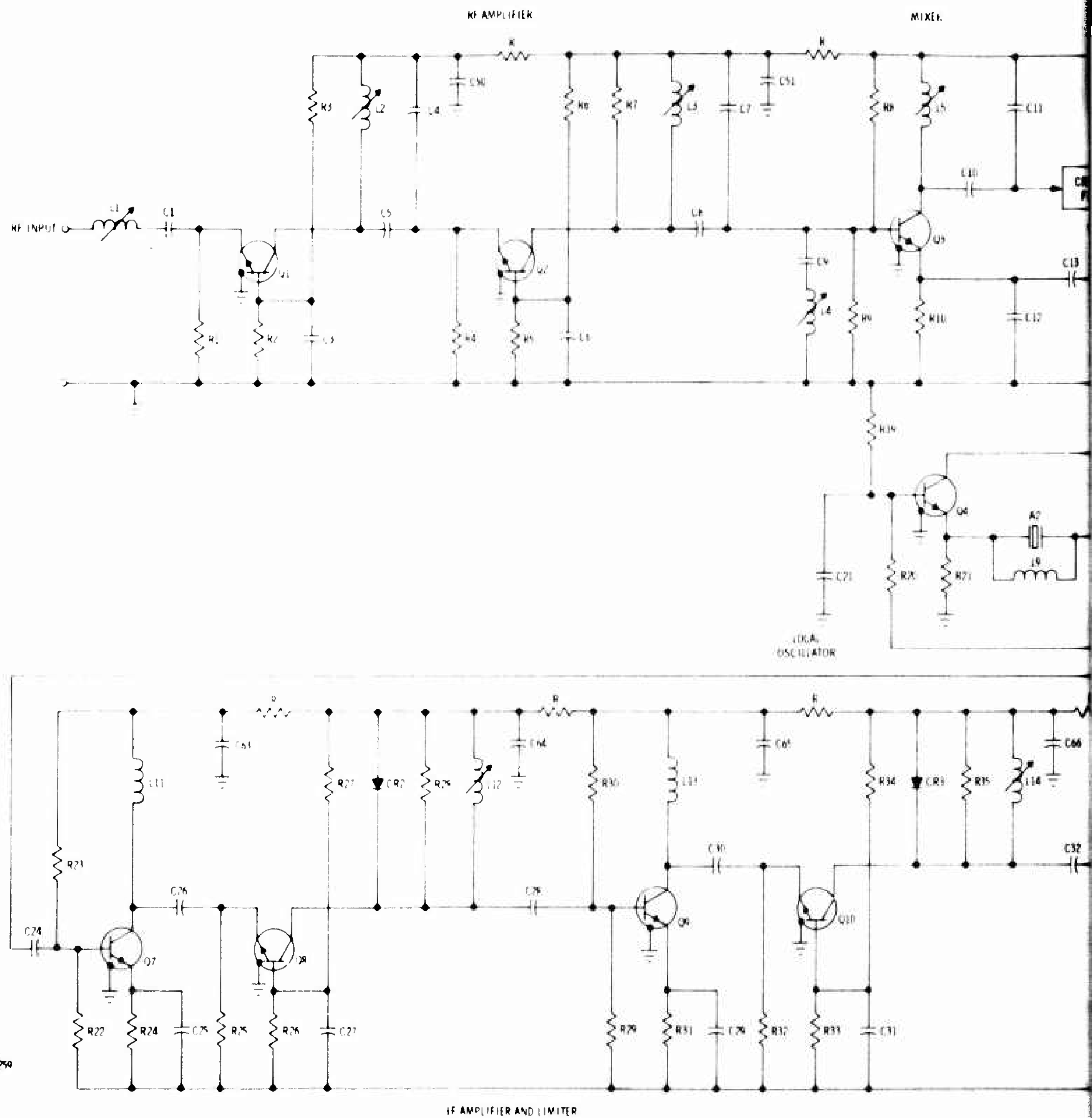
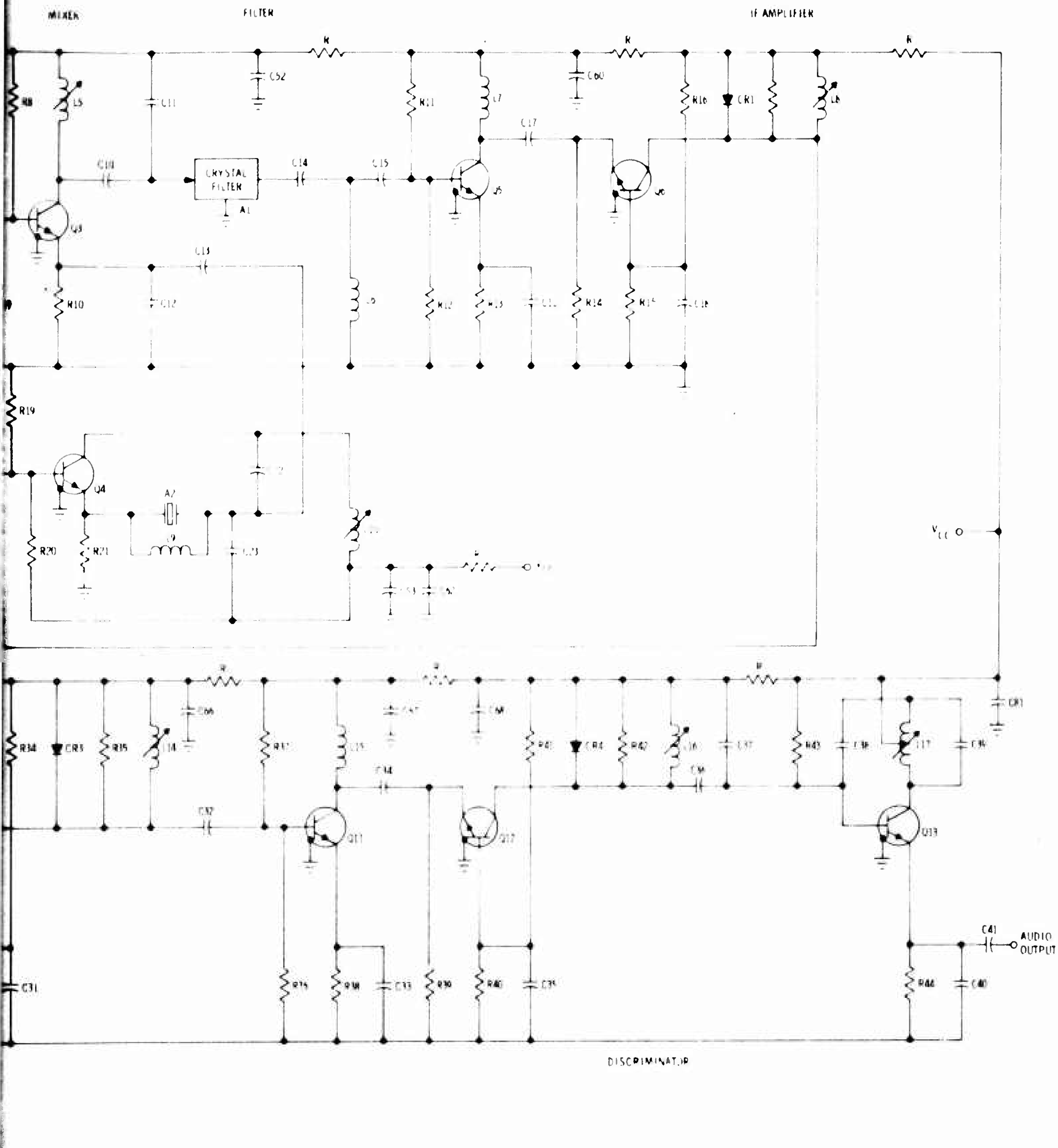


Figure 5-16 (U). Schematic Diagram Low-Power Consumption VHF FM Receiver (U)


MIXER
FILTER
IF AMPLIFIER
CRYSTAL FILTER
A1
A2
VCC
AUDIO OUTPUT
DISCRIMINATOR

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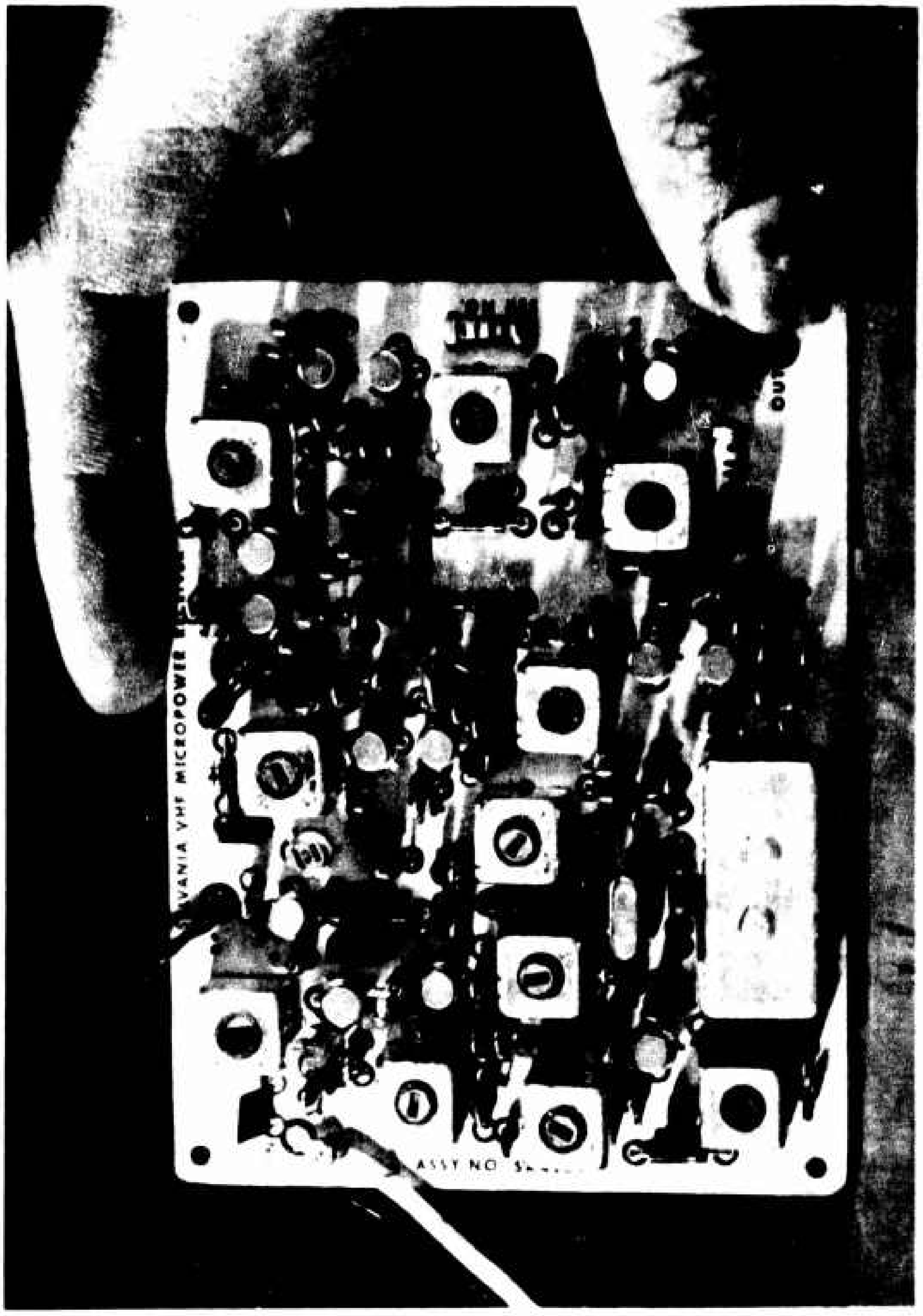

Figure 5-17 (U) Photo of VHF FM Receiver (U)

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5.2.2.2 (C) (Continued)

e. Incorporate a T/R switch to protect the receiver input circuits during retransmission. The receiver sensitivity must be -105 dBm for $^{S+N}/_{N}$ = 6 dB.

f. Incorporate a squelch circuit to gate off power to all decoding stages when the S/N at the IF output is inadequate to decode properly. (This is to conserve battery power).

A block diagram of the proposed R/R receiver is shown in Figure 5-17. The RF amplifiers will consist of two common base amplifiers with high Q single-tuned interstage coupling and matching networks. The input matching network will also be single-tuned and designed to match the input of the receiver to 50 ohms with less than 2:1 VSWR. All transistors for the RF and IF amplifiers and the oscilloscope will be 2N4259's. The mixer will be active, with emitter injection of the LO and base injection of the signal. The output of the mixer will be matched directly into the 8-pole crystal IF filter at 21.4 MHz. This filter will be a TC-FIL-0515, manufactured by TMC, Inc. The limiting IF amplifier will consist of 4 cascaded cascode pairs with synchronously tuned single-pole bandpass interstage coupling networks. The bandwidth of this amplifier, without the crystal filter, will be 0.5 MHz.

5.2.2.3 (C) PSK Demodulator

The proposed demodulator is as described in 4.3.7.2.

5.2.2.4 (C) Decoder

Power will be applied to the decoder when sufficient signal energy is received to quiet the receiver. The decoder will then check the incoming signal for the Barker code frame marker. Once this code has been qualified, the remaining message will be clocked into the address comparator encoder (AC/E) for an address check and retransmission. The proposed decoder is described in detail in 4.3.7.1, 4.3.7.3, and 4.3.7.4.

5.2.2.5 (C) Address Comparator Encoder (AC/E).

The purpose of the AC/E is to accept the decoded message from the decoder, compare its address with the address of the R/R, and, if a match is obtained, encode the received message and send it on to the modulator. In addition, this unit will also contain the power control circuits for the transmitter. The functioning of this unit is described below.

A block diagram of the proposed approach is shown in Figure 5-18. In the quiescent state, battery voltage will be applied only to the power-control flip-flop and the power switch. When a message is received, the receiver will generate a squelch signal and this will be used to temporarily enable the power switch. This applies the battery voltage to the regulator which provides a regulated +12 volts DC for the AC/E circuitry. A reset circuit, which will be triggered when the +12 volts DC is applied, clears the binary counter, parity flip-flop, and clock inhibit flip-flop. The AC/E will then be ready to receive data and clock pulses from the decoder. A 16-stage shift register will be used to store bits 8 through 23 of the incoming message. The

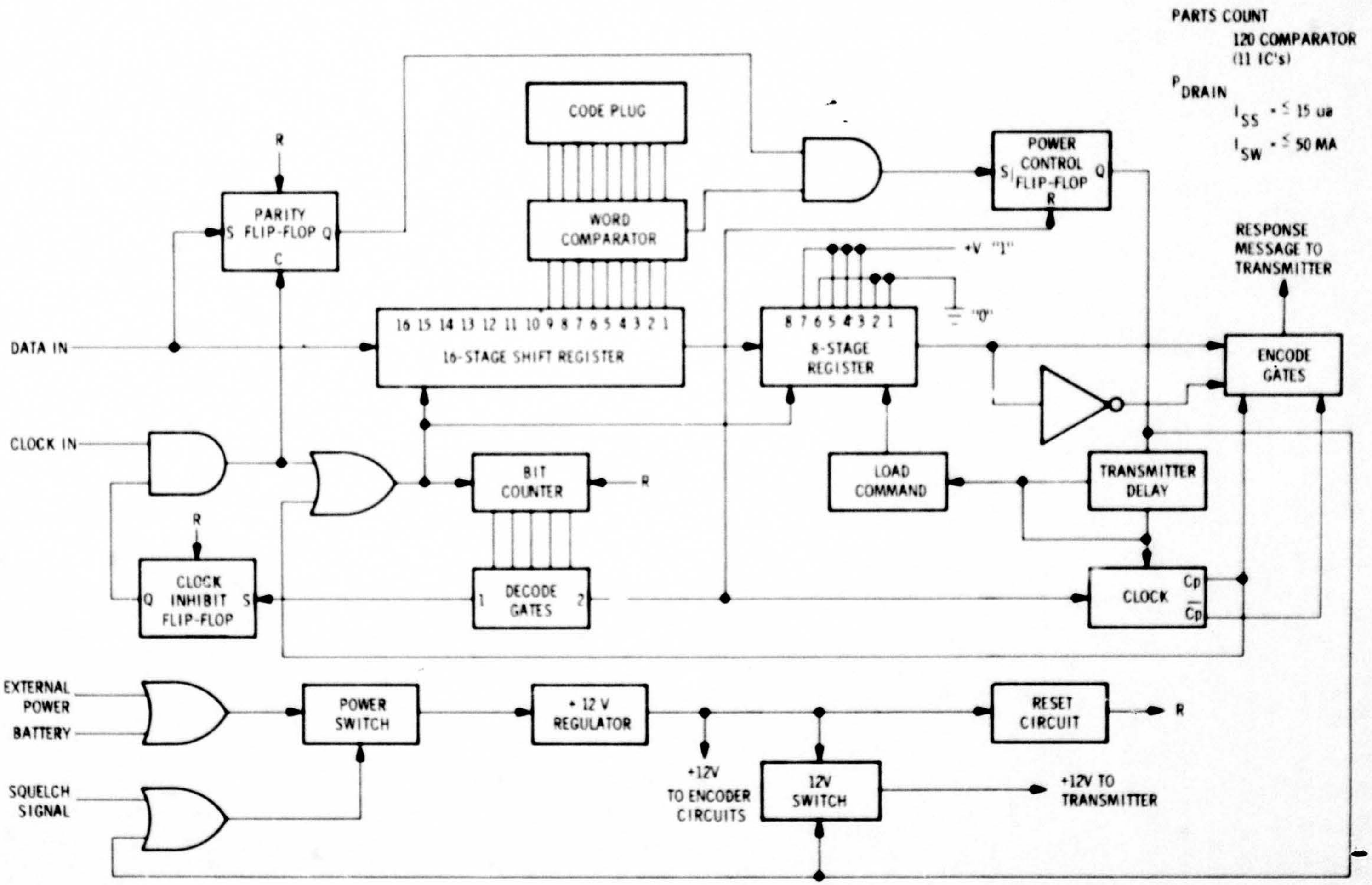

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Figure 5-18 (C). R/R Encoder and Power Control (U).

5.2.2.5 (C) (Continued)

6 WARS ID and 3 Array ID bits will be stored in stages 1 through 6 and 7 through 9, respectively, of the shift register. A bit counter will count the incoming clock pulses. When 16 clock pulses are received, the decode gate will trigger the clock inhibit flip-flop to inhibit additional clock pulses, or noise. The parity flip-flop will be set to a "one" state whenever the received data is a "one." After the received data has been serially read in, the output of the parity flip-flop should be in a "one" state if the data contains an odd number of "ones." Next, the WARS ID and Array ID bits will be compared with bits in the code plug and, if they are identical, a pulse will be generated. The bits of the code plug will be set prior to field deployment. A "one" will be programmed by cutting a jumper wire which applies a positive voltage to the word comparator. No action will be necessary to program a "zero" since the jumper wires will already be internally shorted to ground. The outputs from the parity FF and comparator will be applied to an AND gate which will set the power control FF to the Q state. The power control output will be an enable signal for the power switch and the 12-volt switch during the transmission period. Note that the +12 volts will be applied to the transmitter only after the incoming message has been checked.

Upon completion of address information, the message will be ready for transmission. To accomplish this, the power control output will trigger the transmitter delay one-shot to enable the clock-and-load command circuit. One millisecond of delay will be provided by the one-shot to permit the transmitter to reach the proper frequency and power level before the transmission takes place. The occurance of a load command pulse with a negative transition of the clock CP will cause a parallel transfer of data into the 8-stage shift register. This parallel data will consist of the enable and frame marker bits. Note that the data in the 16-stage register will be shifted one position to the right with the first negative transition of the clock. Each additional negative transition of the clock will serially read out the 24-stage shift register. The output and the inverted output of the register will be gated with the clock outputs in the encode gate to generate the "ones" and "zeros" of the message. The encode gate will generate a "zero" when the register output is zero volts, and a "one" when the register output is +12 volts. The bit rate frequency is 10 kHz. After 23 additional clock pulses have been counted by the bit counter, the decode gate will generate a pulse which will reset the power control flip-flop and turn off the clock. Thus, power to the transmitter and the AC E will be turned off. The transmission time will be approximately 3 msec.

5.2.2.6 (C) Transmitter

The R/R transmitter, whose block diagram is shown in Figure 5-19, will use several circuits identical to those of the S/T transmitter. Identical will be the oscillator, X2 multiplier, modulator, and data filter. The portions which will differ will be:

a. power amplifier,

b. input power switching, and

c. antenna matching networks.

5.2.2.6 (C) (Continued)

By referring to Figure 5-19, it can be seen that the -1 dBm mixer output will be applied to a 2N3866 pre-driver amplifier stage with 13 dB of gain. This output is then fed to a 2N3866 Class C driver amplifier which also has 13 dB gain and which drives the output stage with +25 dBm. The output power amplifier transistor will be the 2N5641. This device will be operated Class C with 11.5 dB of gain and will provide 4.5 or 0.45 watts into the switch-selected matching network. To protect the power amplifier against very large VSWR (open or short circuit) loads, it will be necessary to insure that the output transistor chip is capable of safely dissipating the total power applied to it. The total (P_T) is given by

$$P_T = P_{in} + P_{dc} - P_L$$

where

P_T = total power

P_{in} = the power input from the previous stage

P_{dc} = power drawn from the battery

P_L = power delivered to the load

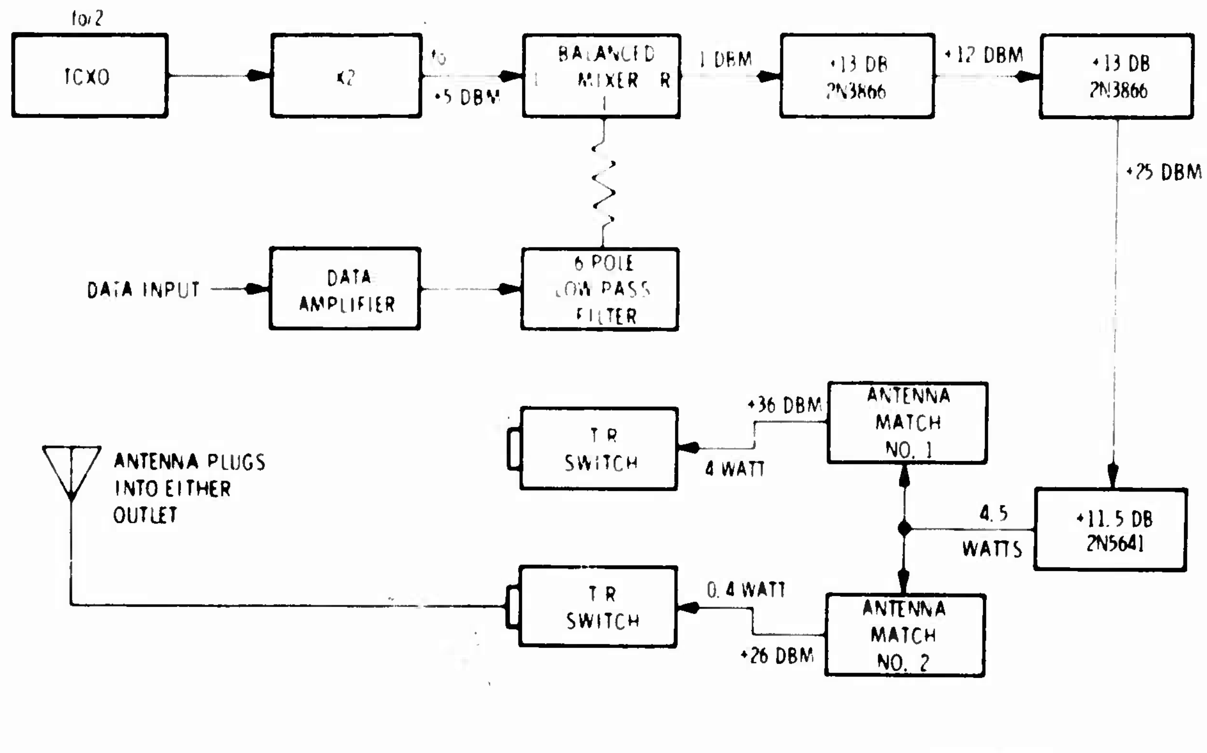

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Figure 5-19 (C). R/R Transmitter Block Diagram (U)

5.2.2.6 (C) (Continued)

For this stage:

P_{in} = 0.3 watts, P_L = 4.5 watts, efficiency = 70%

$$P_{dc} = \frac{P_L}{\text{Efficiency}} = \frac{4.5}{0.7} = 6.4 \text{ watts, approximately}$$

Therefore, under matched load conditions:

$$P_T = 0.3 + 6.4 - 4.5 = 2.2 \text{ watts}$$

and under conditions of very large VSWR:

$$P_T = 2.2 + 4.5 \quad 6.7 \text{ watts}$$

The 2N5641 with proper chip mounting and heat sink is capable of dissipating 11.5 watts at 25°C, or a minimum of watts at 75°C. Therefore, the design will be within safe limits even under worst-case conditions.

The two matching networks will be connected to the collector of the 2N5641 in the same manner as it is done in the S/T transmitter. All circuits with the exception of the final amplifier will be powered from a 12-volt regulator line switched on by the AC/E unit. The final amplifier will be biased Class C and will be turned off except when driven on by the previous stages. For this reason battery voltage will be applied to the final amplifier at all times.

5.2.2.7 (C) T/R Switch

The T/R switch network utilizes a parallel diode (D1) on the receiver input network that is biased on by the power control during transmission and prevents the transmitter from damaging the receiver input. When the diode D1 is in a low impedance state during transmission, L1 and C1 present a high impedance to the antenna port. During the receive mode, L1, C1, and L2 reflect 50 ohms to the antenna port, matching the antenna to the receiver input. The circuit is depicted schematically in Figure 5-20. Figure 5-21 shows a Smith Chart representation of the impedance transformations described above.

During transmission, the output matching network not connected to the antenna reflects an open circuit to the output stage. The output matching network connected to the antenna reflects the proper load resistance to the output amplifier for the required output power level. In the Receive mode, the transmitter output amplifier is cut off and the amplifier output impedance is very high. The transmitter matching network is designed to reflect this high impedance as a high impedance to the antenna by taking advantage of reciprocity, $Z_{12} = Z_{21}$, when designing for Z_{in} = for R_L = The received signal loss due to the transmitter will be less than 0.5 dB.

The antenna will employ a U-plug feed that will connect A to B for output power #1, and B to C for output power #2. The antenna, therefore, will be connected to the receiver (port B) in either case.

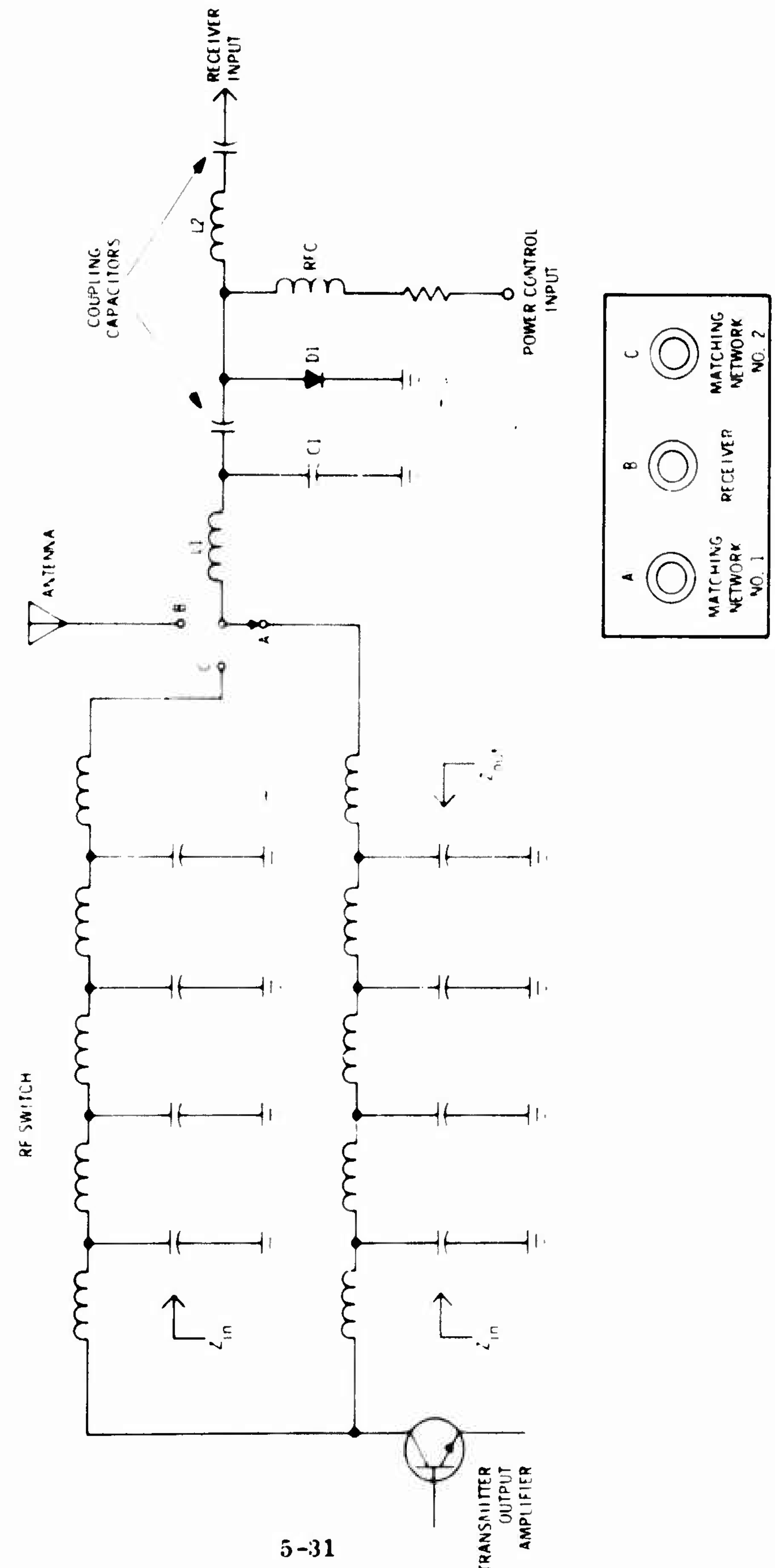

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Figure 5-20 (C). Schematic Diagram, T/R Switch (U)

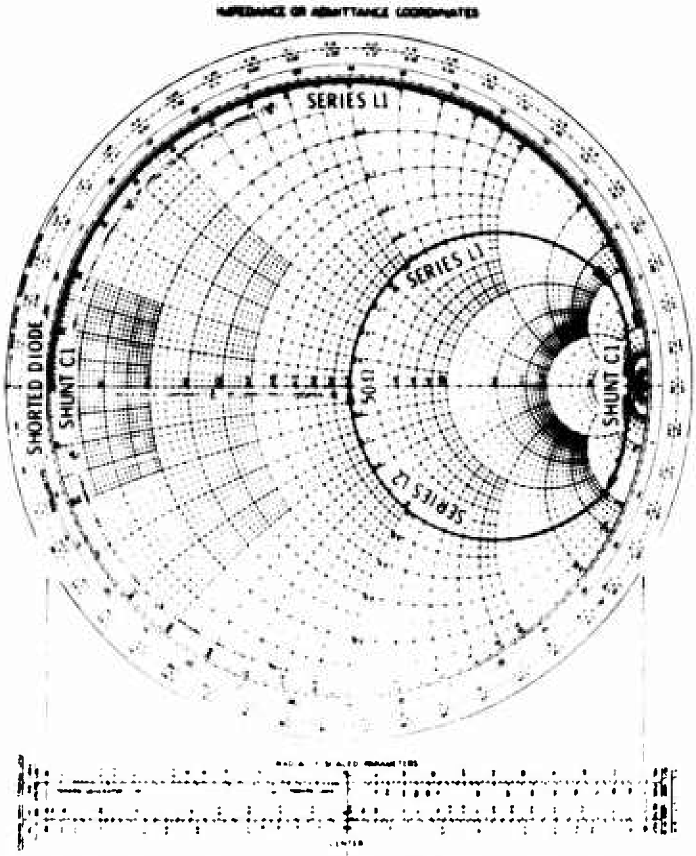

Figure 5-21 (C). Receiver 50Ω:50Ω Matching Network (U)
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5.2.2.8 (C) Switching-Mode Voltage Regulator

A switching-mode voltage regulator will be employed in the R/R and the R/I units to reduce the power usually dissipated in a conventional voltage regulator. This type of regulator utilizes a transistor switch and an LC network in addition to the conventional feedback amplifier and voltage reference. The main advantage of this regulator is that it dissipates very little power. Therefore, efficiencies of 90% or better are possible.

A block diagram of the regulator is shown in Figure 5-22. It consists of the following elements:

a. Regenerative transistor switch,

b. An LC network,

c. Freewheeling diode,

d. Voltage reference,

e. Feedback amplifier.

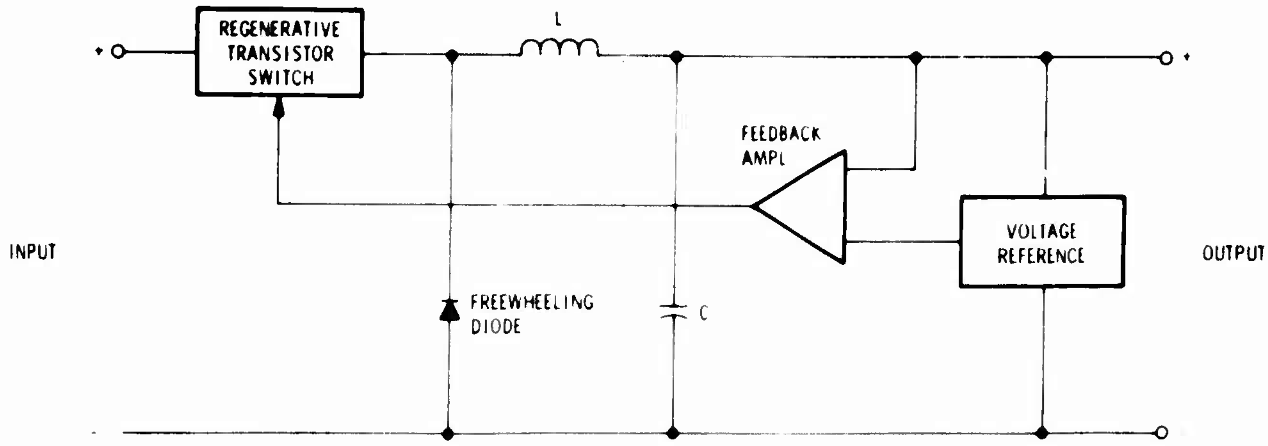

Figure 5-22 (U). Switching-Mode Voltage Regulator (U)

5.2.2.8 (C) (Continued)

The pulse rate of the transistor switch is controlled by the feedback amplifier. When the switch is on, current flows through the inductor L, charges the capacitor C, and supplies the load current. When the switch turns off, the back emf of the inductor drives the current through the freewheeling diode and continues to charge the capacitor until the energy stored in the inductor is dissipated. The switching frequency varies with load and input voltage. Because the energy is stored in elements L and C and not dissipated in a series-pass transistor network as in a conventional regulator, the steady state input current to this regulator can be less than the output current. For example:

$$\eta = \text{efficiency} = \frac{P_{out}}{P_{in}}$$

$$I_{in} = \frac{P_{out}}{V_{in}} = \frac{V_{out}\, I_{out}}{\eta \quad V_{in}}$$

If $V_{out} = 3\ \text{V}$

$I_{out} = 5\ \text{mA}$

$\eta = 0.9$

$V_{in} = 28\ \text{V}$

then $I_{in} \cong 0.6\ \text{mA}$

5.2.2.8 (C) (Continued)

With a high-gain, low-power operational amplifier, used as the feedback amplifier, very low output ripple may be achieved. If necessary, further decoupling is possible using a capacitance multiplier circuit.

5.2.2.9 (U) Antenna

Same as described in Section 5.2.1.5.

5.2.2.10 (C) Battery

5.2.2.10.1 (C) Required Capacity

The total battery capacity required to power the R/R unit is calculated as follows:

Continuous Drain

Receiver	0.25 mA
AC/E and Power Control	0.02 mA
Total	0.27 mA

Capacity required for continuous drain for six months:

$(0.27\ \text{mA})\ (4320\ \text{hours}) \cong 1.2\ \text{Ah}$

Intermittent Drain

AC/E and Power Control	50 mA
Decoder	50 mA
Transmitter	450 mA
Total	550 mA

The expected duty cycle is 0.1%; hence the capacity required for the intermittent drain over a six month interval is (550 mA) (4.32 hours) = 2.4 Ah. Therefore, the total capacity required to power the R/R unit will be 3.6 Ah.

The battery which is proposed to power the R/R unit will consist of eighteen E-95 "D" cells for an initial voltage of 27 volts. This battery pack will have a nominal capacity of 7 Ah at 70°F to an end point voltage of 18 volts. The volume will be about 80 cubic inches and weigh about six pounds.

5.2.3 (C) Receiver/Interface (R/I) Unit

5.2.3.1 (C) General

The purpose of the R/I unit is to receive signals sent by the R/R units located within the same Wide Area, decode these signals, compare the WARS address of the

5.2.3.1 (C) (Continued)

received signal with that stored in the R/I and, if a match is obtained, restore the code format and transfer the received message over a wire line to a Long Range Transmitter (LRT). To accomplish this mission, the R/I unit will require the components shown in the block diagram of Figure 5-23. The design of each of these is discussed in the following sections:

5.2.3.2 (U) Antenna

Same as described in Section 5.2.1.5.

5.2.3.3 (C) Receiver

The receiver for the R/I unit will be similar to the one described in Section 5.2.2.2. The only difference is the requirement for an improved sensitivity. As shown in Section 4.3.10, a sensitivity of -112 dBm is required to produce a 6 dB $\frac{S+N}{N}$ at the IF output. Hence, this receiver must be 7 dB more sensitive than the one in the R/R unit. One to two dB improvement will be obtained by elimination of the T/R switch, since no receiver blanking is required in the R/I. The remaining 5 dB will be obtained at the expense of increased current consumption in the RF amplifiers and mixer to improve the noise figure and gain of these stages. The operating current of this receiver will be 3 mA at 3 V as contrasted to the 2 mA for the R/R receiver.

The increased current consumption will also provide an improved dynamic range and better spurious response characteristics for the R/I receiver. This will have a particular advantage in that this receiver may be exposed to signals from a nearby four-watt R/R transmitter while the R/R receivers will have to cope only with the 100 mW S/T transmitters. In all other respects the R/I receiver will be identical to that used in the R/R unit.

5.2.3.4 (U) Demodulator

Same as described in Section 5.2.2.3.

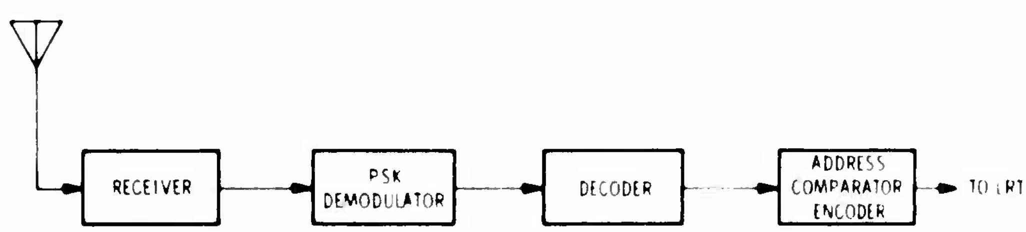

Figure 5-23 (C). Block Diagram, R/I Unit (U)

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5.2.3.5 (U) Decoder

Same as described in Section 5.2.2.4.

5.2.3.6 (C) Address Comparator/Encoder (AC/E)

The AC/E circuits of the R/I unit, shown in Figure 5-24, will be similar to those used in the R/R unit, with the following exceptions:

a. Only the WARS ID bits will be compared. This, again, will be programmed via a code plug.

b. Since the R/I unit does not include a transmitter, no delay for transmitter turn on or power switching to the transmitter is required. The code transmission time will be approximately 2.3 ms.

c. The binary message out of the Encode Gate will be fed into a Line Driver, which will then send the message over a transmission line to a Long Range Transmitter (LRT). The Line Driver will provide the power required to send data over a low-impedance transmission line.

5.2.3.7 (C) Battery

5.2.3.7.1 (C) Required Capacity

The total battery capacity required to power the R/I unit has been estimated as follows:

Continuous Drain

Receiver	500 μA
AC/E	15 μA
Total	515 μA

Capacity for continuous drain for six months is:

(515 μA) X (4320 hrs) = 2.2 Ah.

Intermittent Drain

AC/E	50 mA
Decoder	50 mA
Total	100 mA

The duty cycle of the R/I unit may, as an upper bound, be as much as eight times that of the R/R unit. The duty cycle of the R/R unit was assumed to be 4.32 hours in a six-month period. Therefore, the total on-time of the R/I unit could be as much as 35 hours. Hence, the intermittent drain capacity will be (100 mA) X (35 hrs) = 3.5 Ah. Therefore, the total capacity of the unit for six months will be 5.7 Ah.

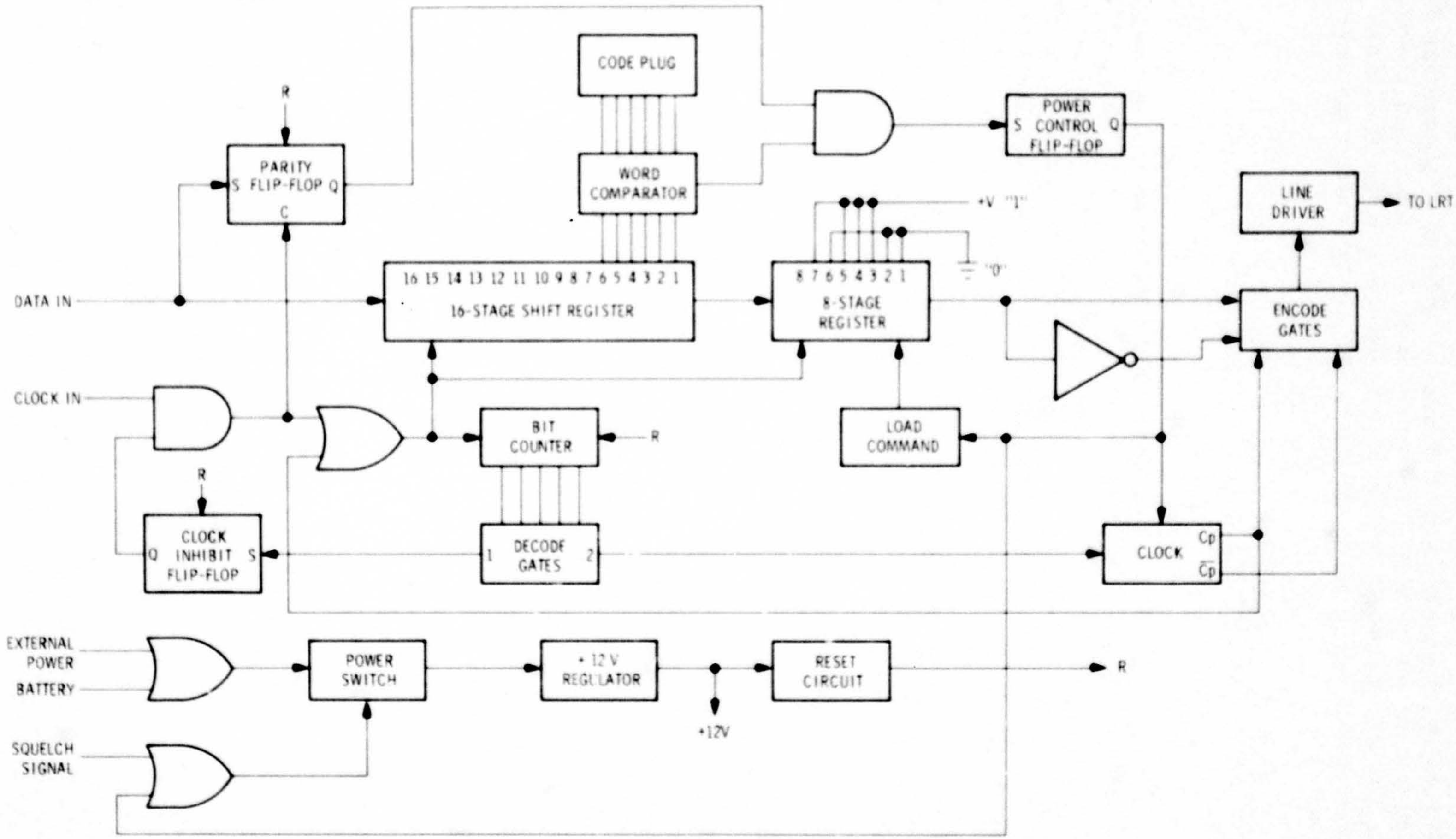

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Figure 5-24 (C). Encoder and Power Control, R/I Unit (U).

5.2.3.7.2 (C) Pack Description

The battery proposed for the R/I unit will consist of twenty-four E-95 "D" cells connected in a series parallel combination to provide for an initial voltage of 18 volts and an end point voltage of 13 volts with a nominal capacity of 12 Ah at 70°F. The pack is estimated to occupy a volume of approximately 130 cubic inches and weigh about nine pounds.

5.3 (C) PHYSICAL DESIGN

5.3.1 (U) General

Establishing priorities among design goals that represent the most favorable set of compromises was the first objective of this study. As a result of this, three different design approaches were generated. These design approaches, discussed in the following paragraphs, each represent a workable packaging concept. Each has its own particular advantages and disadvantages, while retaining the capability to meet the total system physical design requirements.

After a discussion of these concepts, a selection of the optimum package is made, and reasons for the selection given. Subsequent to this, other major parameters are discussed to show that these also will be met by the proposed approach.

5.3.2 (U) Modular Packaging Concepts

5.3.2.1 (U) Primary Chassis

This concept would include within a main chassis frame all those electronic elements required to perform the function of the unit. A typical chassis is illustrated in Figure 5-25. For example, if this is the S/T unit, the main chassis would house everything but the Primary Detector and Battery.

5.3.2.1.1 (U) Fabrication

The main housing is a casting with integral slides into which the cards fit. The front panel contains all required connections as well as a motherboard to accept the individual cards. Electrical plugs and connectors would have silicone rubber cores to effect a seal, thus providing a good overall environmental packaging.

5.3.2.1.2 (U) Advantages

The utilization of a casting provides a great degree of flexibility in the packaging approach. Almost any shape can be made, and with proper design and material selection a very favorable strength-to-weight ratio can be achieved. With hard tooling, die casting is possible, reducing production costs to a minimum for this style of packaging. Sealing a casting of this type is also relatively simple since it can be designed with but one major interface to be considered. Accessibility is also excellent for this configuration, since removing the front panel withdraws the cards and exposes all circuitry. Sensors, batteries, and antennas can all be changed without affecting the main chassis. Future expansion of main chassis circuitry can be accomplished by providing spare card slots and motherboard connections.

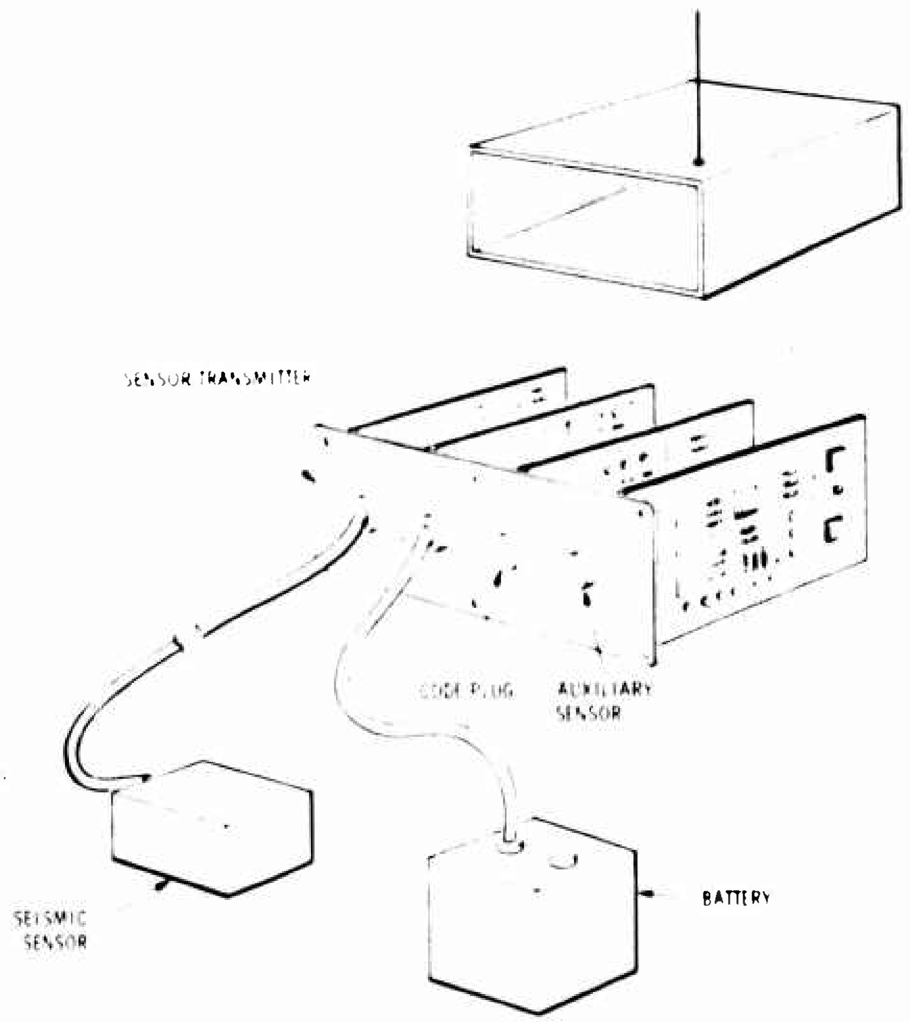

Figure 5-25 (U). Primary Chassis Concept (U)

5.3.2.1.3 (U) Disadvantages

Unless a complex shape is being considered, a fabricated chassis will always weigh less than a cast one.

The flexibility achieved by providing separate connectors is negated by the requirement to conceal the unit. In this case it would require three separate holes plus cable concealment, or one large hole.

This could be reduced by incorporating the batteries within the unit, but only at the cost of a more bulky package and the expense of battery holders. The amount of space available for additional circuitry, however, has a practical limit since space usually increases size, weight, and cost.

In summary, while this concept is attractive in many aspects, it does not appear to possess the degree of modularization and flexibility envisioned for this program.

5.3.2.2 (U) Functional Modules

This design approach considers individual modules, each possessing a complete circuit function. The modules all possess a common physical interface, and thus can be combined in a variety of ways resulting in great system flexibility.

5.3.2.2.1 (U) Cylindrical Chassis Modules

This concept would use cylindrical external chassis with circular printed circuit assemblies grouped within, as shown in Figure 5-26.

5.3.2.2.1.1 (U) Fabrication

The chassis is formed from a tube closed at one end and sealed at the other with a rolled double seam. Individual modules are assembled in series.

5.3.2.2.1.2 (U) Advantages

Cylindrical shapes offer a high degree of strength, and are economically available in many sizes and low weight materials. The assembly of the circular PC cards can be done inexpensively on a flow solder machine and eliminates the need for most internal plugs and connectors. The series connection of the modules provides an almost unlimited degree of flexibility in design, application, and future expansion of the system.

5.3.2.2.1.3 (U) Disadvantages

The sealing of the upper lid on the cylinder represents a special process requiring special tooling. It also encumbers adjustment and maintenance of the modules. While the cylindrical chassis is an inexpensive item of a throw away nature, the opening and closing of this system imposes special requirements on supply and maintenance organizations. The use of circular cards requires that more cards of a smaller size be used. This results in some circuit discontinuities and design inconveniences. The replacement of individual cards also tend to be more difficult and thus requiring a

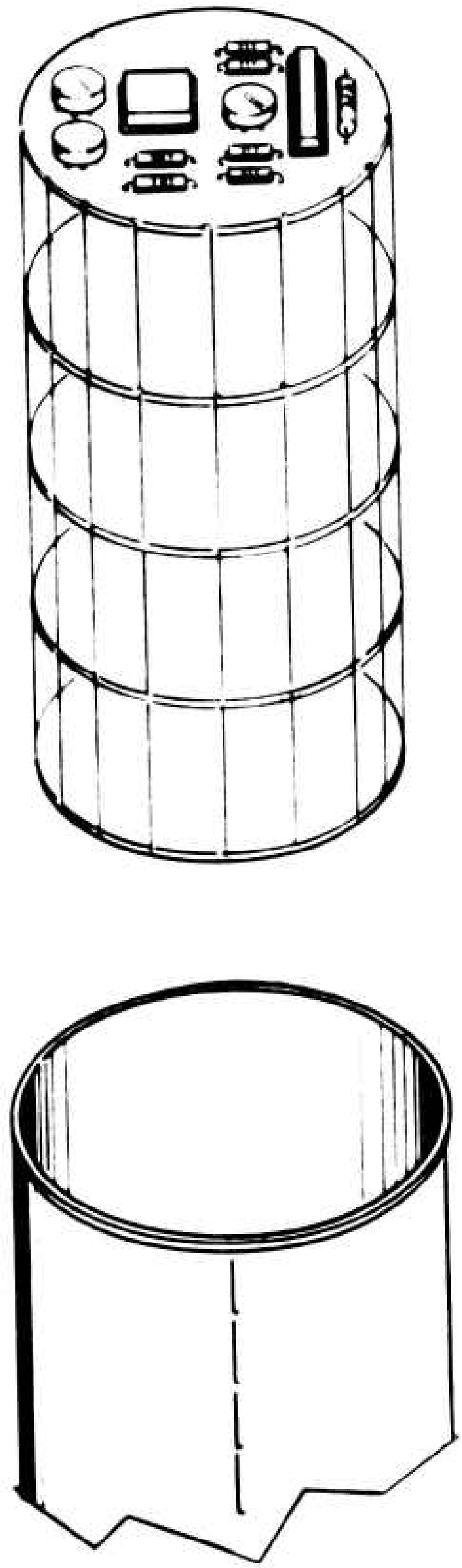

Figure 5-26 (U). Cylindrical Chassis Module (U)

5.3.2.2.1.3 (U) (Continued)

no-maintenance, throw-away design. While throw-away concept is a possibility, it is not felt to be justified at this time by the cost of the modules.

In summary, the cylindrical modules possess the degree of flexibility required by this program. Their major drawback is the difficulty in access for adjustments or maintenance. This limits the application of this concept.

5.3.2.2.2 (U) Rectangular Modules

This concept calls for a series of rectangular chassis, with single function circuitry in each, as shown in Figure 5-27.

5.3.2.2.2.1 (U) Fabrication

The design requires continuous extrusions to form the sides of a square chassis. Fabrication consists of making two opposing extruded sides of a standard length, each containing PC board slides. These opposing sides are mated with two flat sheets by welding, and the resultant form cut into lengths to form the individual modules. The top housing assembly contains a small motherboard that interfaces with the circuit boards. Additionally, it provides a mounting space for the Antenna RF connectors, Code Plug Cap, auxiliary sensor connectors, and self-destruct circuitry if required.

5.3.2.2.2.2 (U) Advantages

The square extruded shape offers all the advantages of accessibility possessed by the primary chassis, with none of its limitations in terms of deployment. The square shape, like the cylindrical, lends itself to each deployment. The series stacking nature of the modules, and the lack of external cables also are attractive features. Battery size can be readily altered with this configuration should the need arise for longer or shorter operational times.

The system can be assembled in minutes using the snaplock connectors which fasten the modules together; tested, disassembled, and transported to a deployment site in back packs. The square shape provides the greatest packing density, while the modularization offers a variety of weight distribution combinations to the carriers. Future needs and requirements of the system can be met through: (1) replacement of a module, (2) addition of a module, (3) increasing or decreasing the size of a module to utilize new circuitry, or (4) combining new and existing cards.

5.3.2.2.2.3 (U) Disadvantages

Cost of fabrication of this concept will be midway between the Primary Chassis and the Cylindrical Chassis. It requires fewer connectors than casting but more than the circular cards, because a motherboard and internal connector are used.

Sealing of the individual modules against one another will require careful consideration to assure a functional and producible design.

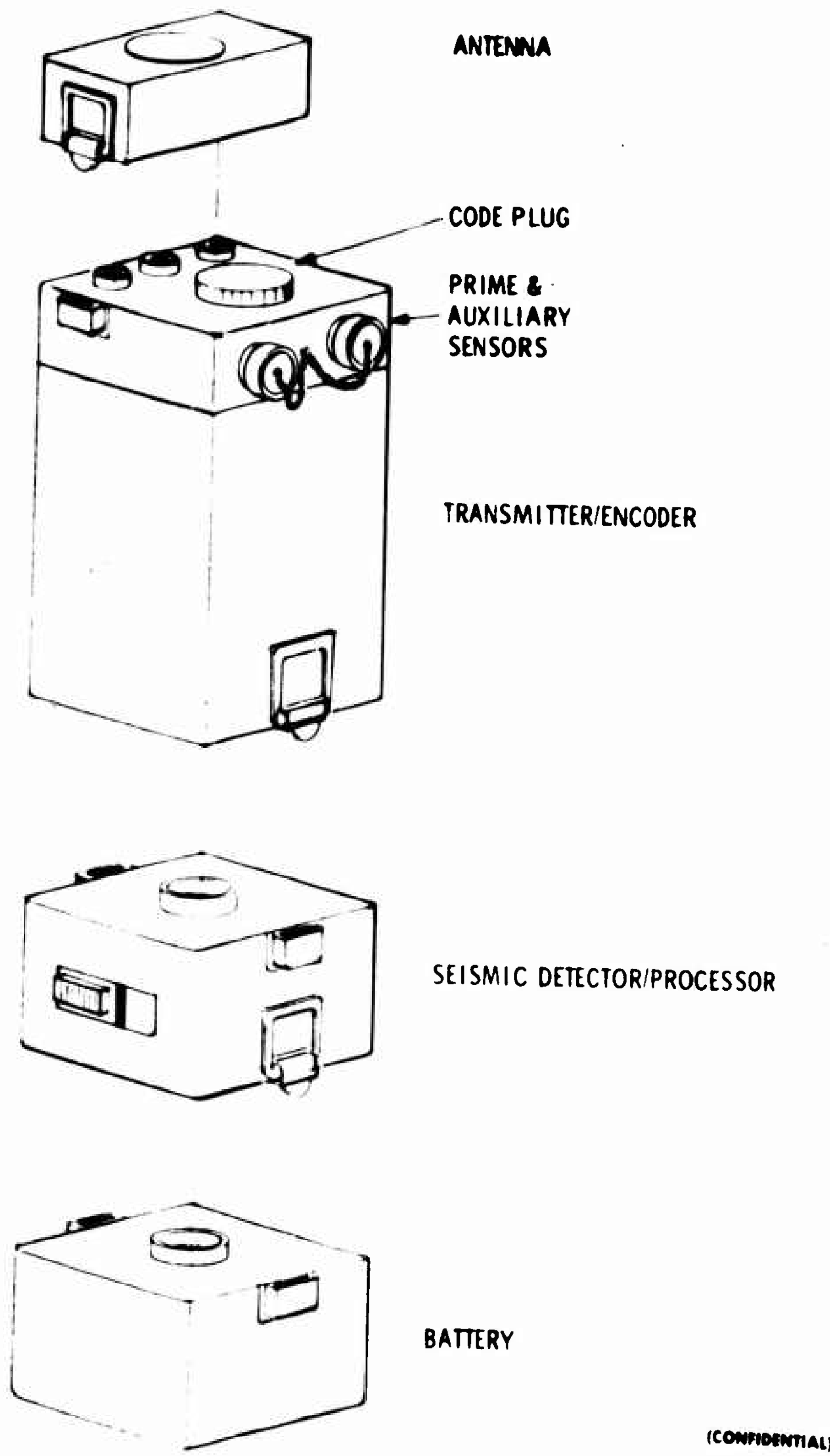

Figure 5-27 (C). Artist's Concept of Proposed S/T Package (U)

5.3.2.2.2.3 (U) (Continued)

In summary, it seems that this concept offers the best approach not only for a producible design but also to meet the requirements of flexibility in application and simplicity of production.

5.3.2.3 (U) Summary of Packaging Concept Analysis

The functional module concept offers greater flexibility to the user in immediate assembly of a required system, but at a greater cost than the Primary chassis. This approach is, therefore, selected to be used in the physical design of the WARS hardware.

5.3.3 (C) Review of Other Physical Design Parameters

5.3.3.1 (C) Adjustments

Due to the environmental requirements of the WARS hardware, every effort was made to limit interfaces between the environment and the unit's internal structure, and to reduce the unit complexity. This impacts mostly in the area of controls. The required functions are detailed in Table 5-2.

Table 5-2 (C). Adjustments Required ((U)

Function	S/T	R/R	R/I
Activation	Field	Field	Field
Sensor Gain	Base	N.A.	N.A.
XMTR. Frequency	Base	Base	N.A.
XMTR. Power	Field	Field	N.A.
Rec. Frequency	N.A.	Base	Base
Code	Base	Base	Base
Auxiliary Sensor	Field	N.A.	N A.
Day/Night Activation	Base	Base	Base

5.3.3.2 (C) Controls

5.3.3.2.1 (C) Unit Activation

The unit will become operational when the Battery is attached to the main housing. This is done to eliminate an extra switch access hole.

5.3.3.2.2 (C) Seismic Sensor Sensitivity

The two-position gain switch will be provided on the side of the seismic sensor. The actual switch will be located internally to the seismic sensor and activated magnetically through the unit's case.

5.3.3.2.2 (C) (Continued)

This will be accomplished by sliding a plastic switch containing a magnet from one detent to another; resulting in the required switching action while preserving the unit's environmental seal.

5.3.3.2.3 (C) Transmitter Power

A power level change of 10 dB will be provided by installing the Antenna in one of two positions. Three RF connectors will be provided on the top housing cover of the R/R unit. The central plug will be for the receiver while the two outer plugs will be for the transmitter. Only one of the transmitter plugs will be utilized: one being for low power output and the other for high. The antenna assembly itself will have only two plugs: the central receiver plug and a transmitter plug. Installation of the antenna can occur in two positions 180° apart. Which of these positions is chosen depends on the transmitter output required.

Two RF connectors will be provided on the top housing cover of the S/T unit. Transmitter power output will be selected by selection of the proper connector for insertion of the antenna.

5.3.3.2.4 (C) Transmitter and Receiver Frequency

Frequency changes will be accomplished by replacing a transmitter or receiver card with another of the desired frequency.

5.3.3.2.5 (C) Coding

Code plugs will be contained under the removable code caps on the upper housing of each unit. The code plugs will be programmed by clipping and removing wire links, thus providing code flexibility using a common plug furnished with all units.

5.3.3.2.6 (C) Day/Night Activation

Operation of the WARS System at night only will be made possible by removing the code plug cover and replacing it with a clear plastic cap which contains a light-sensitive cell. This will be held in position by a threaded wing. Circuitry for this type of operation may be provided with each unit (optional). To make use of it, only the cell will need to be installed at the base.

5.3.3.3 (C) Maintenance

5.3.3.3.1 (C) Accessibility

All units will offer complete accessibility to the circuits and components once they are opened for inspection, since all circuitry will be exposed when the cover is removed. Test points which will provide test access to major circuit functions will be provided internally to reduce access posts. Those circuits that require alignment (Transmitter and Receiver) will be placed at the outside of the circuit assembly so that the operator can perform the adjustment with no additional disassembly other than removal of the unit housing.

5.3.3.3.2 (U) Maintenance Ground Equipment

The maintenance philosophy has not been defined as yet; however, as a minimum, it is recommended that the following aspects be considered.

5.3.3.3.2.1 (U) Field

A simple Go-No-Go tester is recommended to provide the installation crew with final check on equipment performance before they leave the scene or activate the disable mechanism. This test set can be a hand-held, self-powered unit of small size designed to check out the operation of all major circuit functions within the unit.

5.3.3.3.2.2 (U) Base Testing

In addition to the Field test set, the base is expected to be equipped with a Go-No-Go tester for individual cards, allowing fault-isolation down to a defective board or chassis assembly.

5.3.3.4 (C) Commonality

5.3.3.4.1 (C) Circuit Boards

Maximum utilization will be made of any common circuit designs that exist between the units. Present design plans call for a single transmitter/modulator design for both the S/T and the R/R units. The basic difference in these designs will be in the buffer and final RF Amplifier because of the different power output requirements of these units. To standardize on transmitter design, a common board will be used in both applications with the exception that the buffer and final amplifier will be on a separate sub-board. This sub-board, which plugs directly into the main board, will be easily interchanged.

The same approach will be used on the receiver design in that the varying sensitivity requirements of the R/R and R/I will be met by using a common design with a plug-in R. F. stage. Similarly, a common board will be used for the R/R and R/I Address Comparator/Encoder. The design will be identical except for the components of the power switch and for checking an additional three bits which will be left off the R/I board.

5.3.3.4.2 (U) Chassis Assemblies

Battery and circuit requirements dictate chassis requirements. However, by assembling these in the most favorable manner it is possible to achieve a design that will use the same basic chassis for both the R/R and R.I.

The impact of this type of maximum circuit and chassis utilization will not only reduce production cost, but also maintenance and logistic requirements as well.

5.3.3.4.3 (U) Antenna

The antenna design employed will be the same for all three units. This is described in Section 5.2.1.5.

5.3.3.3.2 (U) Maintenance Ground Equipment

The maintenance philosophy has not been defined as yet; however, as a minimum, it is recommended that the following aspects be considered.

5.3.3.3.2.1 (U) Field

A simple Go-No-Go tester is recommended to provide the installation crew with final check on equipment performance before they leave the scene or activate the disable mechanism. This test set can be a hand-held, self-powered unit of small size designed to check out the operation of all major circuit functions within the unit.

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5.3.3.4.3 (U) Antenna

The antenna design employed will be the same for all three units. This is described in Section 5.2.1.5.

5.3.3.7.2 (C) Arming

The actual energizing of the destruct mechanism will not occur until the unit has been emplaced and functionally tested. Energizing the destruct circuit will require the insertion, by screwing in, of a magnetic plug into a sealed cavity in the upper housing. This plug will close a proximity switch which completes the destruct circuit. The activating magnet will be contained within a molded plastic key, as shown in Figure 5-28. This key, when screwed into the tapered hole, will cause it to jam at the bottom of its travel and thus shear off at its neck constriction. This leaves the unit sealed with no way to remove the magnet. Destruction will be effected on tilting, tampering, or end of battery life.

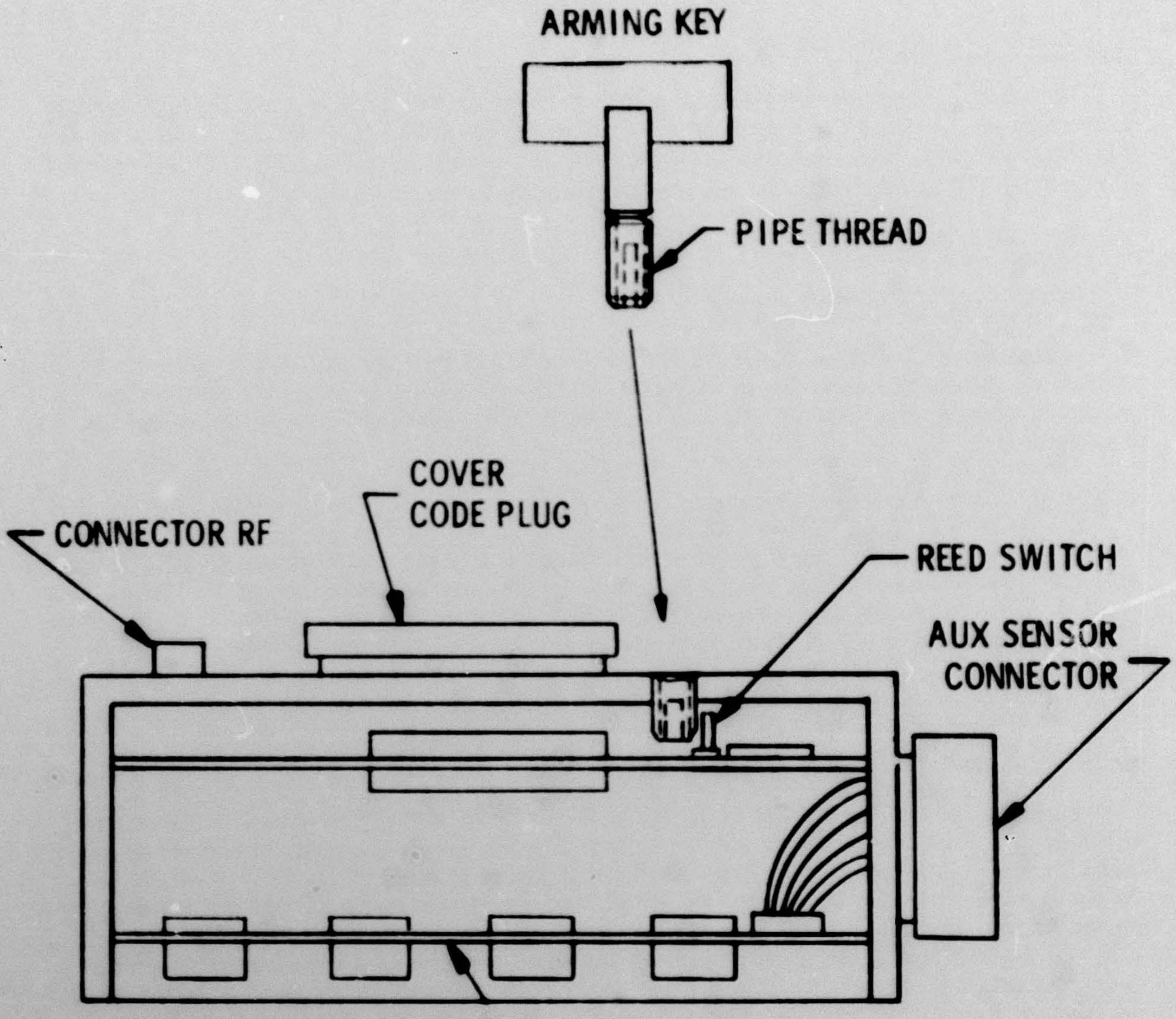

Figure 5-28 (C). Mechanism for Self-Destruct Arming (U)

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5.3.3.8 (C) Antenna Compatibility

The antenna design for the units will consist of a $\lambda/4$ vertical with radial ground plane. A single configuration will be utilized on all three units. The antenna will be a self-contained unit, consisting of stainless steel elements enclosed in a plastic housing, as shown in Figure 5-29. Prior to intallation, the antenna will be completely covered by a housing that seals it against the environment. After the unit is installed, the housing cover will be removed and the lanyard extended to its maximum length. This action will cause the antenna container to rotate, thus erecting the antenna. The tips of each element will be coated with a vinyl plastic that will serve to limit the erection length and further seal the element openings in the housing against environmental effects.

5.3.4 (C) Expansion Capability

The use of a modularization concept offers a great degree of flexibility in meeting future system changes. Each module of an individual unit will be capable of expansion or change to meet future requirements. Examples of how this requirement for flexible design will be met are discussed below.

5.3.4.1 (C) Batteries

Battery requirements will vary for each unit. To simplify the design, standard cells will be used wired in series-parallel combinations to supply the correct operating voltages. Present design requirements will be met with the battery packs described in Section 5.2. However, should future operational requirements change, battery capacity can be altered by adding or subtracting from the number of cells employed. This is possible since the battery source will be external to the unit and as a separate module will be alterable without affecting the interface of the modules. Auxiliary Power can be used by connecting a secondary supply voltage, through the existing battery connector, on the unit.

5.3.4.2 (C) Antenna

Antennas of similar frequency and construction can be mounted in a manner similar to the suggested design.

If a different frequency, or larger configuration, is ever required, this can be accommodated by emplacing the antenna remote from the unit and connecting the antenna to the unit by an RF cable.

5.3.4.3 (C) Sensors

It is within the capability of the S/T unit to use almost any type of currently available sensor. In all cases the electrical interface between the sensor and the unit will remain the same. The proposed design uses a seismic sensor as a plug-in module. This offers the advantage of single sensor employment in the baseline system.

Auxiliary sensors will interface with the two available plugs located on the central module housing. Any type of sensor can be employed with the seismic sensor. This is discussed further in Section 6.2.

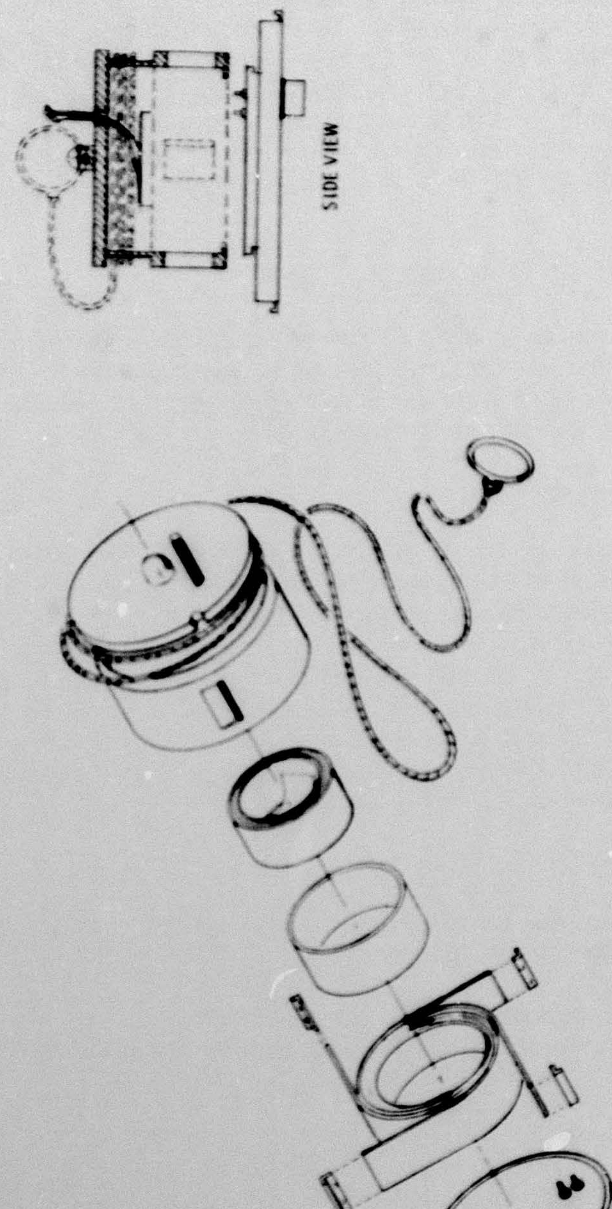

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Figure 5-29 (C). Exploded View of Proposed Antenna (U)

5.3.4.4 (U) Special Feature Equipment

This subject is covered in Chapter 6.0.

5.3.5 (C) Component Packaging of Baseline System

5.3.5.1 (C) S/T Unit

The S/T package, an artist's concept of which is shown in Figure 5-27, will be composed of four modules: Battery, Seismic Sensor, Encoder/Transmitter, and Antenna. With the exception of the Antenna, each module will be approximately 3-1/3" in width and breadth and will vary individually only in height. The contents of each module are described below:

The battery supply will consist of twelve E-95 "D" cells. These cells will be arranged in a stack of 3 x 3 with the extra three cells stacked behind and at right angles to the main stack. The stacked cells will be mold-potted enclosing the cells, the plug, and fastener mounting plate to form the completed module of 4" in height.

The seismic Amplifier/Processor will be composed of approximately 200 components. These will be mounted on four 3" x 3" boards resulting in a package height of 4".

The Transmitter/Encoder will be composed of approximately 235 components. Of these, the Transmitter will require 135, and the Encoder comprises the remaining 100. These circuits will occupy four 3" x 4" boards resulting in an overall package height of 6-1/2" including the upper housing.

The plug-in antenna unit will be approximately 1" high, 1-1/2" wide, and 3-1/2" in length in its furled condition.

5.3.5.2 (C) R/R Unit

The R/R package, an artist's concept of which is shown in Figure 5-30, will be composed of three modules: Battery, Receiver/Code Regenerator/Transmitter, and Antenna. With the exception of the Antenna, each module will be approximately 4" in width and breadth and will vary individually only in length. The contents of each module are described below.

The battery supply will consist of eighteen E-95 "D" cells. These cells will be arranged in a stack of 5 by 3 with the extra 3 cells stacked behind and at right angles to the main stack. This cell stack will be fabricated in the same manner as the S/T and will result in a battery with an overall height of 7".

The Receiver/Transmitter/Encoder will be composed of approximately 480 components: of these, the Receiver will require 210, and the Transmitter and the Encoder 135 each.

These circuits will occupy four 3" x 7" boards resulting in an overall package height of 8-1/2" including the upper housing.

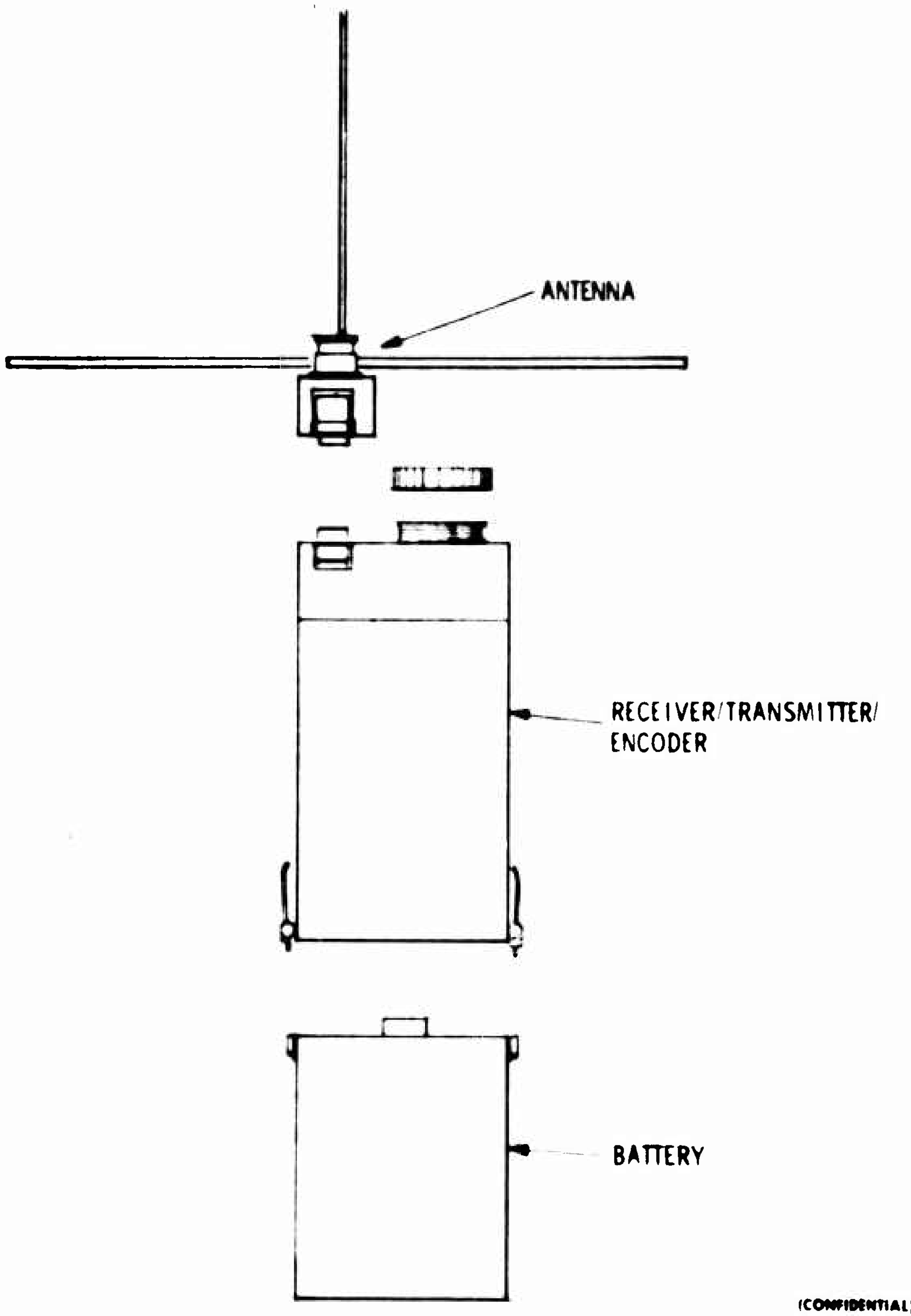

Figure 5-30 (C). Artist's Concept, R/R Unit (U)

5.3.5.3 (C) R/I Unit

The R/I package, an artist's concept of which is shown in Figure 5-31, will be composed of three modules in the same manner as the R/R. These modules will be of the same width as the R/R and will differ only in length and content as described below.

The battery supply will consist of twenty-four E-95 "D" cells. These cells will be arranged in a stack of 6 x 3, with the extra 6 cells stacked behind and at right angles to the main stack. The cell stack will be fabricated in a like manner as the S/T and will result in a battery with an overall height of 8-1/2".

The Receiver/Encoder will be composed of approximately 345 components; of these, the Receiver will require 210 and the Encoder the remaining 135. These circuits will occupy 4 boards resulting in an overall package height of 6-1/2" including the upper housing.

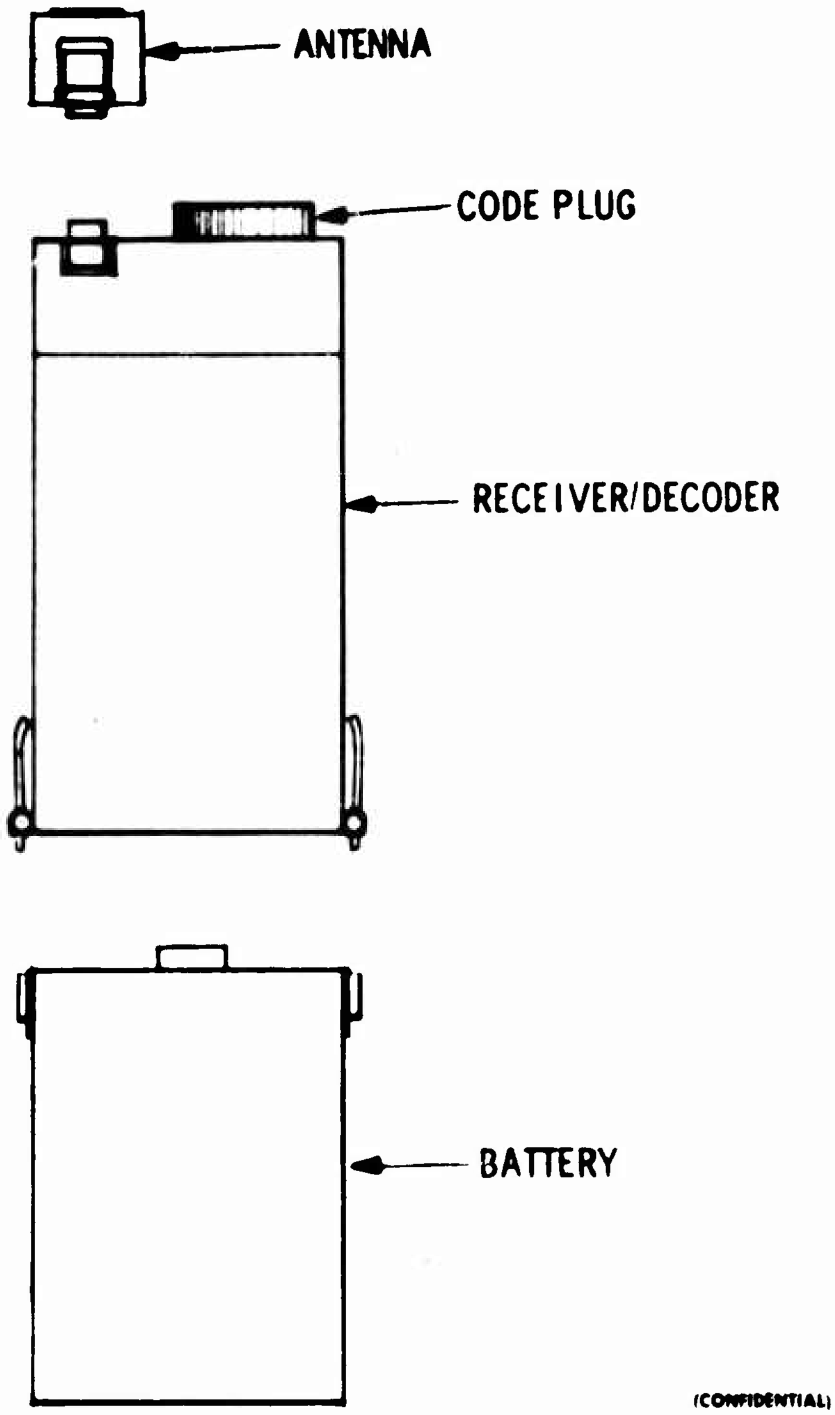

Figure 5-31 (C). Artist's Concept, R/I Unit (U)

Section 6

SPECIAL FEATURES

6.1 (U) GENERAL

This chapter discusses features which will greatly enhance the flexibility and adaptability of the WARS subsystem and further ensure its compatibility with widely varying world-wide applications and/or modes of operation. All of the features discussed can be provided by simply substituting a component or inserting an additional component in the baseline system. No redesign of the system described in Chapter 5 will be required provided that a decision as to what features will be used with the Baseline System is made prior to initiation of the hardware design.

What the required components are, how they function, and what some of the applications may be are discussed in the following sections on a per-unit basis, i.e., the features which can be provided with the S/T unit are taken up first, followed by those of the R/R, and then R/I, followed by a brief analysis of the impact of on-site alarm processing on the overall performance of the BESS system.

6.2 (C) OPTIONS OF THE S/T UNIT

The optional features which can be provided with the S/T unit are: (1) Auxiliary Detector and its associated Sensor Combination Logic module, (2) Subterranean Antenna, and (3) Diurnal Switch. The available options are depicted in Figure 6-1. A description of each of these follows.

6.2.1 (C) Auxiliary Detector

The Auxiliary Detector may be used in three different modes of operation: (a) as an independent secondary sensor, (b) as a substitute for the Primary Detector, and (c) in conjunction with the Primary Detector where the latter is used as a pre-qualifier. These modes of operation will be realized by inserting a Sensor Combination Logic module into the baseline S/T, between the Primary Detector and the Encoder. The operation of this module is described next.

6.2.1.1 (C) Sensor Combination Logic Module

This module, shown in a block diagram form in Figure 6-2, will normally operate in Mode A. Operation in the other two modes will be accomplished by selecting the proper switch setting. Each of the three modes are now discussed below.

6.2.1.1.1 (C) Mode A, Primary Sensor With or Without Auxiliary Sensor

When operating in Mode A, the Primary and Auxiliary sensors are both operational and not dependent on each other. In Mode A, the unit can operate with only the Primary sensor or with both the Primary and Auxiliary sensors. An alarm from the Primary Detector will turn on the S/T while an alarm from the Auxiliary Detector will control the message bit reserved for the status of the Auxiliary Detector.

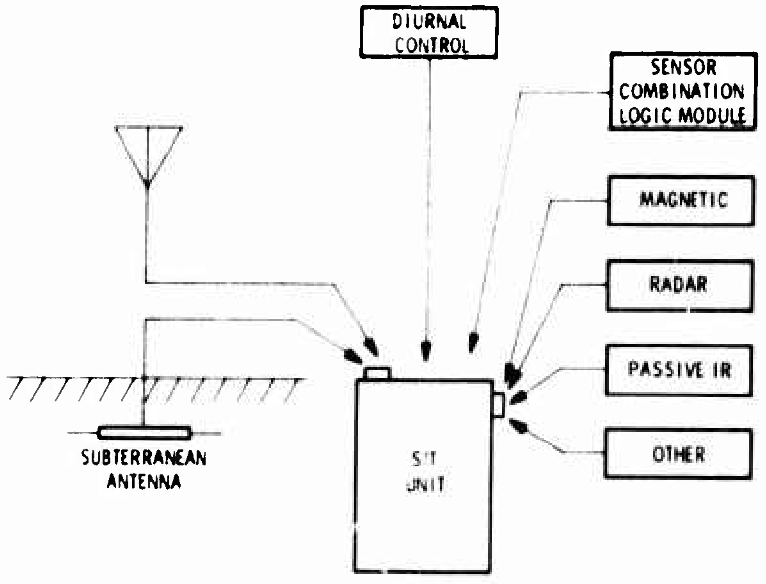

Figure 6-1 (U). Options of S/T Unit (U)

6.2.1.1.2 (C) Mode B, Auxiliary Sensor Without Primary Sensor

In Mode B, the Auxiliary sensor replaces the Primary sensor. In this mode, only alarms from the Auxiliary sensor will be transmitted. This function can be readily realized by breaking the connection between the Primary sensor and the S/T unit.

6.2.1.1.3 (C) Mode C, Auxiliary Sensor Qualified by Primary Sensor

In Mode C, the Primary sensor controls the Auxiliary sensor. The Auxiliary sensor will be maintained in an off state during a period of inactivity. When an alarm occurs in the Primary sensor, power will be switched on to the Auxiliary sensor for a period of 5 to 60 seconds, depending on the specific sensor used, to permit that sensor to alarm. An application of Mode C might be when the Primary sensor controls a passive infrared sensor employed for personnel counting. This is further described in Section 6.2.1.2.3.

6.2.1.2 (C) Candidate Sensors

The sensors to be discussed here were selected on the basis that they offer detection characteristics different from those of the seismic sensor proposed for the Primary Detector. Thus, only the magnetic, radar, and passive IR will be considered here; however, there is nothing that would preclude the use of any other sensor as well. In fact, the only constraint that a candidate for the Auxiliary Detector must meet is the electrical interface requirement with the S/T unit.

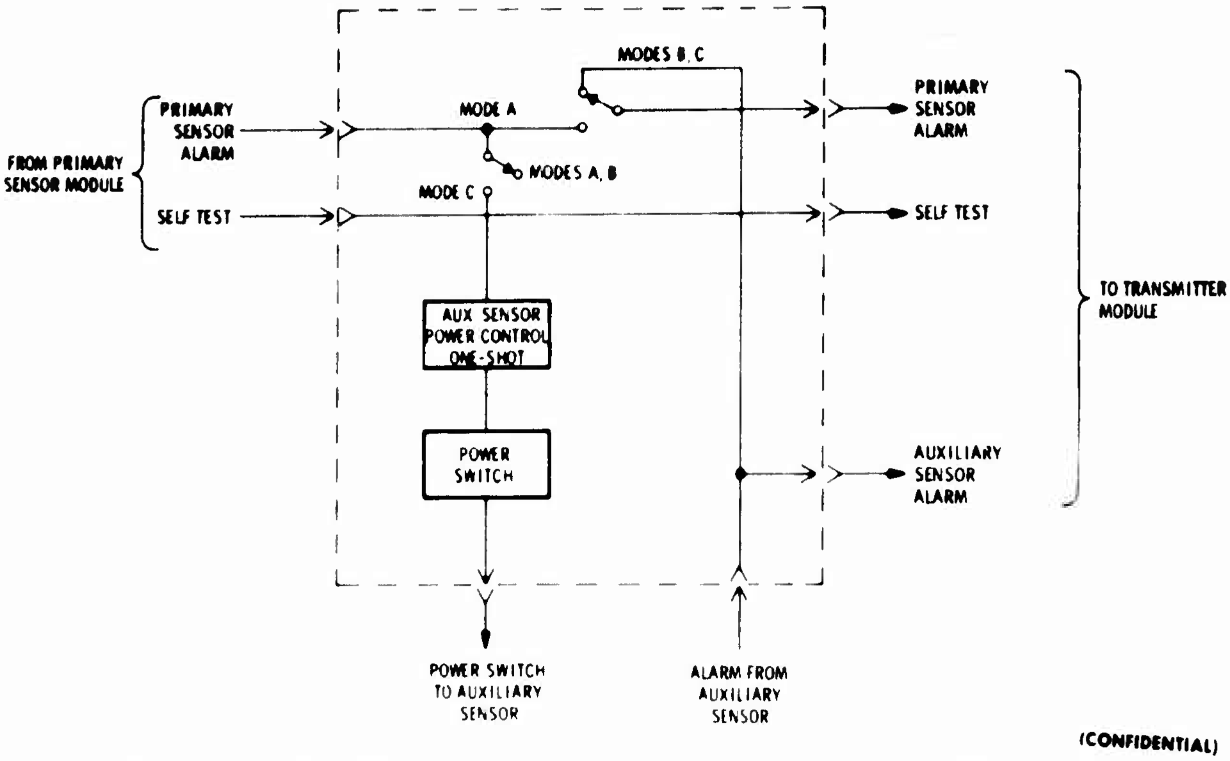

Figure 6-2 (C). Block Diagram, Sensor Combination Logic Module (U)

6.2.1.2.1 (C) Magnetic

6.2.1.2.1.1 (C) Description

Magnetic sensors are used to detect the passage of ferrous metal by sensing a local change in the earth's magnetic field. A device called MAGID, DT-368/GSQ, which has been used in SEA, employs two search coils in a differential mode to sense a local change while remaining insensitive to magnetic changes which occur over a large area. Figure 6-3 depicts a typical installation of this sensor. Emplacement of the unit is rather time-consuming since considerable digging is necessary to conceal the three components of the MAGID plus the connecting cables. Some of the more important characteristics of this unit are as follows:

Range:	3-6 meters for man with rifle
Weight:	12 pounds
Life:	45 days minimum

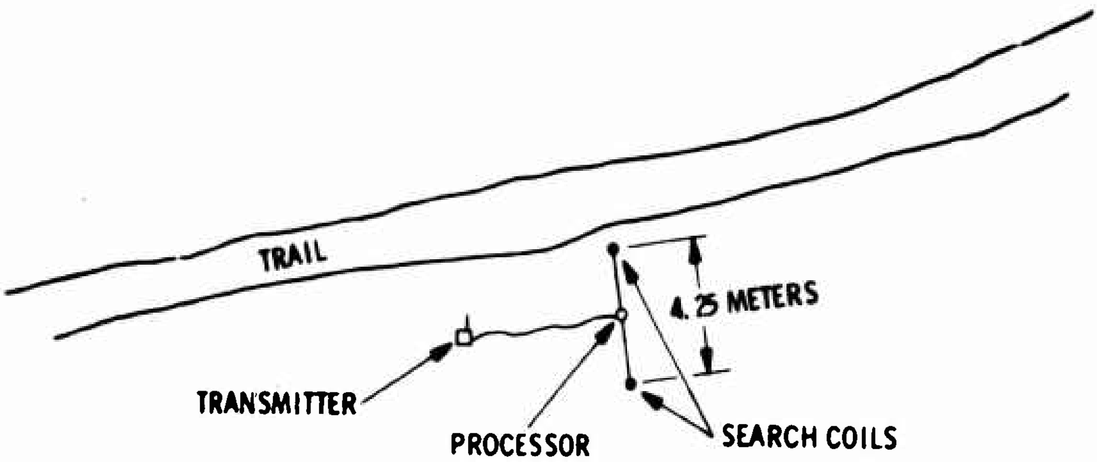

Figure 6-3 (C). Typical Deployment of MAGID Sensor (U)

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6.2.1.2.1.1 (C) (Continued)

Known sources of false alarms:	Lightning, nearby radio transmissions
Development Agency:	U.S. Army (MERDC)
Contractor:	Honeywell

Magnetic sensors using flux gates and thin-film magnetometers are currently being developed under the Magbuoy program at USAMERDC. Once developed, these will be more suitable for WARS application than the MAGID.

Projected characteristics of Magbuoy are:

Range:	Equal to or better than MAGID
Weight:	10 pounds
Life:	45 days
Known sources of false alarms:	No field experience to date
Development agency:	U.S. Army (MERDC)
Contractors:	Grumman, Burroughs

6.2.1.2.1.2 (C) Application Considerations

The magnetic sensor will find its application almost exclusively in avenue-of-approach arrays. The limited detection range of the device makes it mandatory that it is used where the path to be taken by the intruder is well defined. Since the magnetic

6.2.1.2.1.2 (C) (Continued)

sensor is capable of detecting ferrous metal which is almost always possessed by an attacking force, it may be used to aid in the discrimination of threat from animals and indigenous personnel. The value of employing this technique in a given area will best be determined by the user after learning more of the daily activities of the indigenous personnel.

Should it be decided that a magnetic sensor will be included in an array, it may be used as a Primary Detector or as an Auxiliary Detector. Ordinarily, use of the magnetic sensor as an auxiliary sensor will be the best choice. In this arrangement, the magnetic sensor and the Primary Detector will be operated in Mode "A". To convey to the CSC the information that the auxiliary sensor has alarmed, the special bit reserved for this purpose in the S/T message will be changed to "1". Figure 6-4 depicts the use of a magnetic sensor as an auxiliary sensor in a trail array. Note that the sensor is placed near the trail to make best use of its limited detection range.

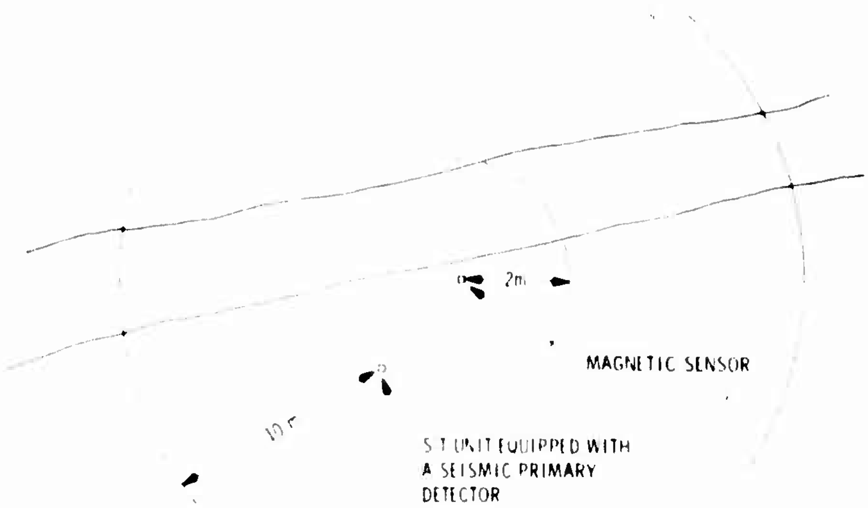

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Figure 6-4 (C). Magnetic Sensor in a Trail Array (U)

6.2.1.2.2 (C) Radar

6.2.1.2.2.1 (C) Description

When an intruder is moving in the vicinity of the antenna of a doppler radar, a reflected signal will be received which is shifted in frequency from that originally emitted. Doppler radar techniques for personnel detection have been used widely for a number of years. Generally, these radars have been manned by operators who make the final decision when a target has been detected. Recently, however, units have been developed which rely upon automatic signal processing in the unit to perform the discrimination function.

6.2.1.2.2.1 (C) (Continued)

Radars of this type, of course, would be very attractive for obtaining surveillance over suspected launch sites. One such unit is reported to be under development by Conductron Corporation. The preliminary performance characteristics of that unit are as follows:

Range:	90 meters nominal for one man through light forest. Up to 180 meters over open ground.
Frequency:	Selectable among 10 frequencies in a 100 MHz band centered at 430 MHz.
Weight:	7.5 pounds
Life:	52 weeks with 25% duty factor
Suspected sources of false alarms:	Wind-driven objects, other rf emissions, animals
Developer:	Conductron Corporation

An artist's concept of this device is shown in Figure 6-5.

6.2.1.2.2.2 (C) Application Considerations

The doppler radar will be useful in both avenue-of-approach (waterway) and launch area arrays.

Waterway approaches of considerable width (up to about 90 meters for the unit described above) can be covered from bank to bank. It is possible also that the unit may be able to compensate for tidal variations of water level better than other sensors. Figure 6-6 depicts the deployment of a radar with a cardioid-shaped antenna pattern for detection of watercraft.

Radar appears to be particularly well suited for launch area applications because of its great range. A single radar with its 90-meter detection range can replace three seismic sensors in the fence array covering a suspected launch area.

6.2.1.2.3 (C) Passive Infrared

6.2.1.2.3.1 (C) Description

The passive infrared sensor monitors the infrared energy in its field of view and notes when a change occurs as a result of an intruder entering into it. Typically, two fields of view separated by a small angle are used, together with logic circuitry, to reduce false alarms due to natural variations in infrared energy. In such a scheme the intruder is required to enter first one field of view and then the other within a

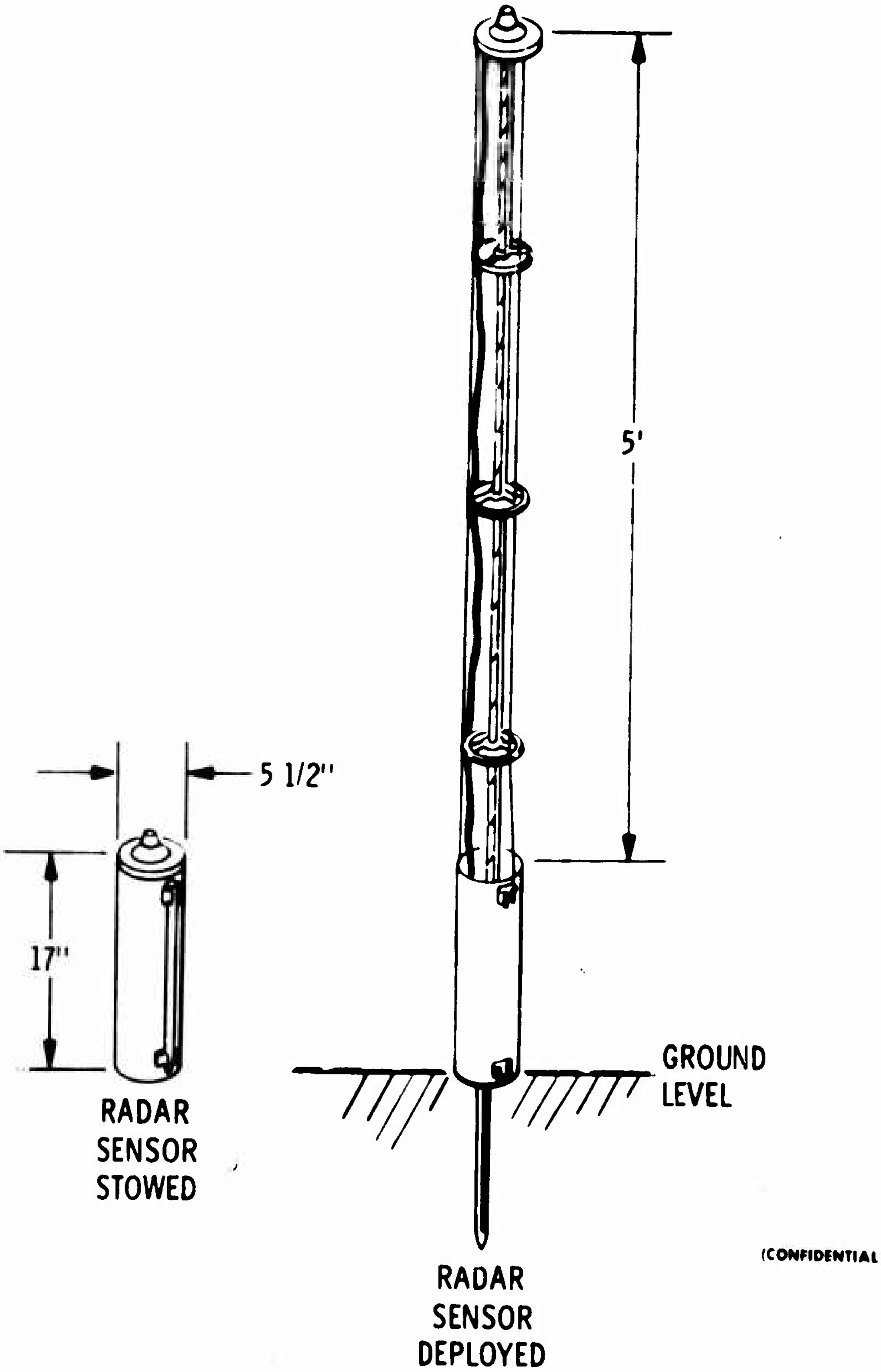

Figure 6-5 (C). Remote Radar Intrusion Sensor (U)

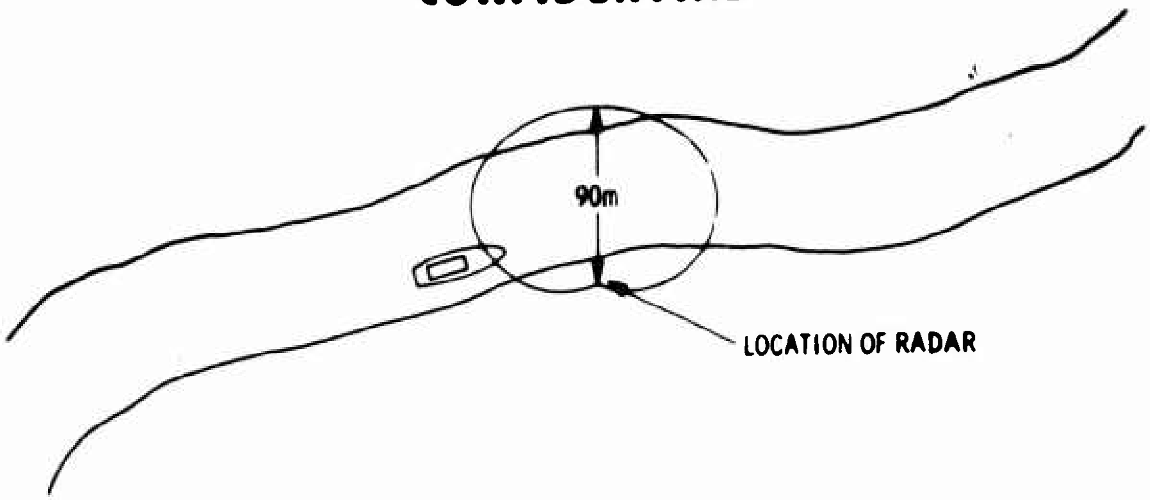

Figure 6-6 (C). Use of Doppler Radar for Watercraft Detection (U)

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6.2.1.2.3.1 (C) (Continued)

specified time to produce an alarm. A passive infrared sensor called PIRID, DT-367/GSQ, has been used in SEA. This unit has the following characteristics:

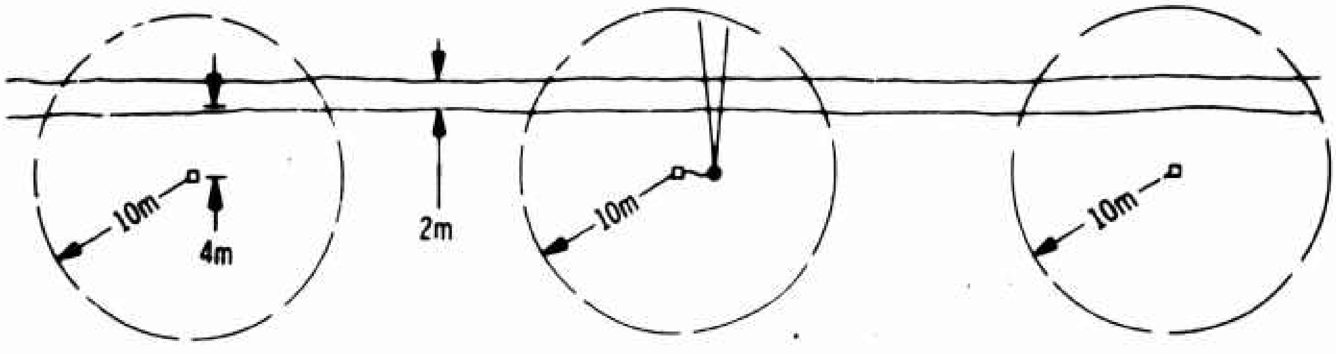
Range:	15 meters for a single man
Weight:	3.5 pounds
Life:	45 days
Known sources of false alarms:	Movement of detection head by wind. (Avoidable with good installation procedures).
Responsible Agency:	U.S. Army (MERDC)
Contractor:	Hughes Aircraft

A similar unit has also been developed by Barnes. The characteristics of this unit are reported to be:

Range:	20 meters for a single man
Weight:	Unknown
Power Requirement:	12 mW
Suspected false alarm sources:	Same as those mentioned above
Developer:	Barnes

6.2.1.2.3.2 (C) Application Considerations

A passive infrared sensor can be used effectively in either trail or waterway arrays. In a trail arra., the most obvious application is high-resolution counting of personnel. Figure 6-7 shows an IR sensor used as an auxiliary sensor in a trail array.



(CONFIDENTIAL)

Figure 6-7 (C). Passive Infrared Sensor for Personnel Counting (U)

To achieve high resolution in counting, the IR sensor must be able to emit a fairly high alarm rate (approximately one or two alarms per second). Should conditions arise which cause false alarming, these will also be transmitted at a high rate and thus cause increased message loss, high battery drain, etc. By inhibiting the alarms from the passive infrared sensor except for, say, eight seconds after each seismic alarm, the probability of false alarms will be greatly reduced.

A passive infrared sensor, may also be used as the Primary Detector in a waterway array. Figure 6-8 shows an array of sensors covering a narrow stream (less than 20 meters in width). For wider streams it is necessary to provide a similar array for the opposite bank. Probably the greatest obstacle to the successful application of passive infrared sensors on waterways is the difficulty of compensating for the tidal and seasonal water level variations.

6.2.2 (U) Subterranean Antennas

Under certain conditions, it may be desirable to bury the S/T units entirely underground. Certainly, in areas with insufficient ground cover or highly populated areas such a capability would greatly enhance the chances of covert operation. Therefore, the feasibility of supplying such an option was briefly examined. A discussion of this follows.

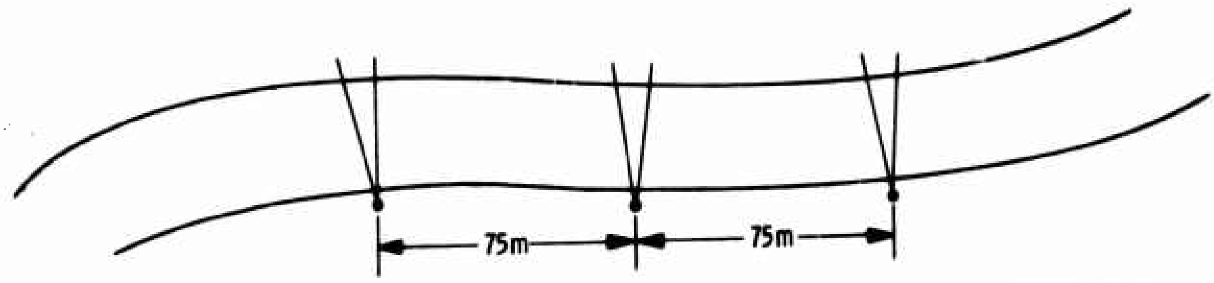


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Figure 6-8 (C). Passive Infrared Sensors in a Waterway Array (U)

6.2.2.1 (U) Expressions for Calculating Field Strength

The work of Baños (Reference 1) is directly applicable to this problem. Baños derives expressions for the field strengths at any point in air due to an infinitesimal dipole beneath the surface. He assumes free-space properties for the air and considers both vertical and horizontal polarization. Using a Green's function integral formulation and assuming that the conduction currents exceed the displacement currents in the earth, he derives the following expressions for the electric field components in the far field for a horizontal dipole buried close to the surface.

When $r > 5\lambda$

$$E_{2r} \cong \frac{j k_1 p}{2\pi\sigma n r^2} e^{j k_2 r + j k_1 h} \tag{1}$$

$$E_{2z} \cong \frac{E_{2r}}{n} \tag{2}$$

where

j = -1

n = index of refraction in earth = k_2/k_1

k_2 = $\omega \sqrt{(\mu_o \epsilon_o)}$

p = dipole moment

σ = conductivity of earth

r = horizontal antenna separation

[1] Banos, A. (1966), "Dipole Radiation in Presence of Conducting Half Space", Pergamon Press, Oxford, England

6.2.2.1 (U) (Continued)

$k_1 = j\sqrt{\omega\mu_0\sigma}$

h = depth of transmitting antenna

ω = radian frequency

6.2.2.2 (U) Derivation of Path Loss

In the preceding section expressions for the electric field components were given in terms of known variables and p, the dipole moment. If $\Delta 1$ is the effective length of the antenna and I is the current flowing into it, p is determined from $p = I\Delta 1$.

The loss from input power to received power is given by

$$L = 10 \log_{10} \frac{W_{in}}{W_L} \qquad (3)$$

where

$W_{in} = I^2 \,\mathrm{Re}(Z_{in}) = I^2 R_{in}$ (input power to the transmitting antenna)

R_{in} = the real part of the impedance seen at the transmitter looking into the transmitting antenna

W_L = power delivered to the load of the receiving antenna.

The voltage developed across an antenna is given by

$$V \doteq E\ell. \qquad (4)$$

and the maximum power delivered to the load of the receiving antenna is

$$W_L = \frac{V^2}{4R_L} \qquad (5)$$

where it is assumed that the receiving antenna's radiation resistance is equal to the receiver's load resistance and all other losses are negligible.

6.2.2.2 (U) (Continued)

Thus, by substituting Equations (4) and (5) into Equation (3), one obtains

$$\frac{W_{in}}{W_L} = \frac{4\, I^2\, R_{in}\, R_L}{E^2\, \ell^2} \tag{6}$$

It can be shown that

$$\left(\frac{I}{E}\right)^2 = \frac{16\pi\sigma f\, r^4}{C^2\, \mu_o} \tag{7}$$

For a quarter-wave dipole buried in a conductive soil, the input resistance is given by (Reference 2).

$$R_{in} = \frac{\omega\mu_o \,\Delta\ell}{8} \tag{8}$$

where

$$\Delta\ell = \sqrt{\frac{\pi}{4\,\mu_o \sigma f}} \tag{9}$$

Furthermore, assuming a $\lambda/2$ dipole for the receiving antenna

$$R_L = R_r = 73\Omega$$

and

$$\ell = 0.32\,\lambda$$

After the individual terms listed above are substituted into Equation (6), it can be shown that

$$L = -\,49.5 + 35 \log_{10} f_{MHz} + 40 \log_{10} r + 5 \log_{10} \sigma \tag{10}$$

[2] Brezovic, R.T. and Steinbergs, A.Z., Short-Range VHF Communications Through Earth Subsurface, June 1969, Sylvania Technical Memorandum No. 69-SSO-009

6.2.2.2 (U) (Continued)

Because the loss increases as 3.5 power of the frequency, it is necessary that some lower frequency, such as 50 MHz, is used for a submerged S/T-to-above ground R/R link. At this frequency

$$L = 10 + 40 \log r + 5 \log \sigma \qquad (11)$$

The conductivities of $\sigma = 10^{-3}$, 10^{-2}, and 10^{-1} correspond to values Dence and Tamir used for soils under thin, medium, and thick forests, respectively.

Then,

$$L_{thin} = 40 \log r - 5 \qquad (12)$$

$$L_{med} = 40 \log r - 5 \qquad (13)$$

$$L_{thick} = 40 \log r + 5 \qquad (14)$$

Figure 6-9 is a plot of the above relationships.

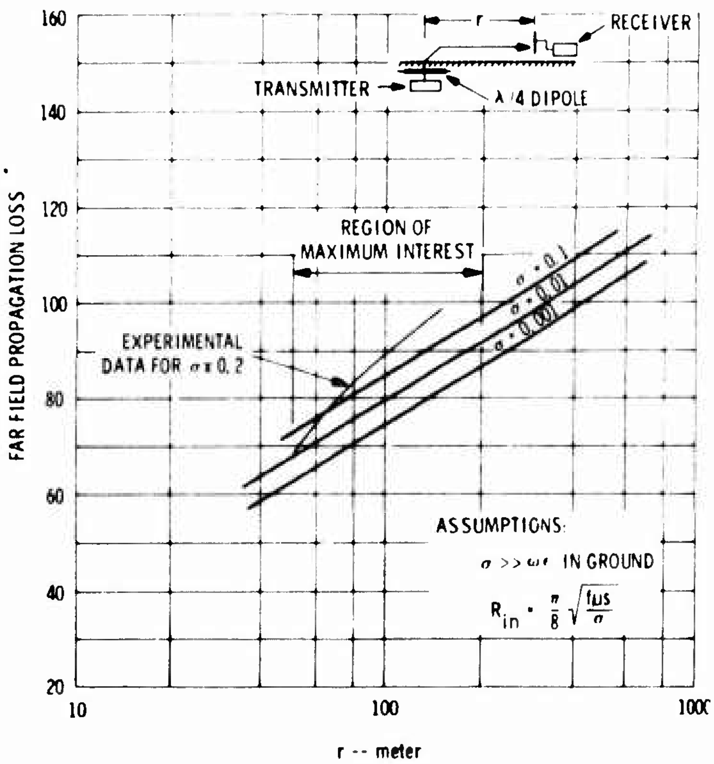

Figure 6-9 (U). Ground-to-Air Path Loss at 50 MHz (U)

6.2.2.3 (U) Experimental Verification

To check out the data presented in Figure 6-9, the results of a test conducted under the auspices of a Sylvania Independent Research and Development program were superimposed on top of the calculated path loss curve for $\sigma = 0.01$. This is shown in Figure 6-9 by the cross-hatched line. The experimentally found path loss is about 8 db higher than the calculated values. This discrepancy is believed to be due to imperfect antenna-to-earth coupling which is not accounted for in the calculations. Therefore, careful embedding of the antenna will be essential in reducing losses. Nevertheless, the experimental data shows that about a one-half watt transmitter power at 50 MHz should be sufficient for transmitting alarms from the completely submerged S/T to a 200-meter distant R/R.

The antenna which was used in this test is the same as could be used in the WARS application. A brief description of it is given in the next section.

6.2.2.4 (U) Candidate Antenna

An antenna which has been developed by Sylvania for subterranean applications is shown in Figure 6-10. It is constructed of 0.625-inch diameter aluminum rod. The two arms are joined by a miniature balun transformer which is used for isolation and impedance matching. The center section is constructed from 0.750-inch fiberglass rod. The insulation for the center half is made from 0.750-inch phenolic tubing with a 0.0675-inch wall thickness. All joints are press fitted and sealed to eliminate moisture and possible electrolysis problems.

6.2.3 (C) Diurnal Switch

6.2.3.1 (C) For Power Control

Some theaters of operation will require intrusion information only during the nighttime hours. For this application, intrusion detection and reporting during day-time may not only be unnecessary, but even undesirable. This requirement would necessitate inhibiting or turning off the sensor power during daylight hours and enabling or turning it on during nighttime hours. Such mode of operation would also reduce the continuous power drain, thereby extending the life of the unit. The day-night, off-on function can be accomplished with the use of a diurnal switch. The baseline S/T unit can be shut down by turning off the +12-volt regulator in the Primary Sensor Module. The diurnal switch and associated comparator logic can be fed into an AND gate along with the +12-volt regulator switching translator. In this application, the +12-volt regulator will operate normally when the Diurnal Power Switch is not attached. When the Diurnal Power Switch is connected, the +12-volt regulator will assume the day-night, off-on function. During the off period, the system current drain can be reduced to that required by the diurnal switch and comparator logic (approximately 10 μa).

Figure 6-10 (U). Subterranean Antenna (U)

6.2.3.2 (C) For Self-Test Control

The self-test method proposed for the baseline system, transmits a self-test message once every hour provided no sensor alarms have occurred during the preceding hour. A method employing a diurnal switch would reduce the frequency of self-test message transmissions to two per day. A self-test message would be transmitted every time there is a day-night and night-day transition. There would be no dependency on the alarm rate, since two self-test messages, based on the presence of daylight, would be transmitted daily. A photosensitive device can be used as a part of a comparator which will detect the change in resistance of the device as the light intensity varies. The comparator output could be integrated to prevent the generation of multiple self-test messages during periods of transition or during changes in daylight intensity. The output of the comparator could be fed into a differentiator which, in turn, would trigger a self-test message transmission.

This method will, however, require care during implant to ensure that the photosensitive device is not buried or covered by opaque objects.

6.3 (C) Options of the R/R Unit

The options which can be provided with the R/R Unit are depicted in Figure 6-11. By plugging any of the shown equipment into a plug provided on the R/R Unit, the equipment will be electrically inserted between the Address Comparator/Encoder and the Modulator. The inserted equipment will thus be placed in a position to operate on the already authenticated and regenerated 23-bit message before the latter is transmitted. These operations are covered below under the individual equipment discussions.

6.3.1 (C) Spurious Alarm Suppressor (SAS)

6.3.1.1 (U) Theory of Operation

The theory is based upon differentiation between alarms which are emitted: 1) at a low level from all sensors in a random manner; 2) at a high level from all sensors; and 3) consistently and predominately from one or two sensors. The first kind is usually associated with false alarms, the second with rain or planes and only the third type is typical of that produced by intrusions.

A block diagram of the SAS is shown in Figure 6-12. The operation can be explained as follows.

When an alarm is received, it will be passed on to the buffer where a standard signal is generated. For example, this may be a pulse of ten volts amplitude for four seconds each time an alarm occurs at the associated sensor. After the four-second period, the signal would return to a zero level. The signal from the buffer is then passed through a resistive weighing network containing the necessary amplifier for further buffering to a set of integrators.

If we let the state of the buffer X_i be indicated by a "1" or a "0" depending upon whether the voltage from the buffer is in the high state or in the low state, the output of the resistive network to the j^{th} integrator, Y_j will be

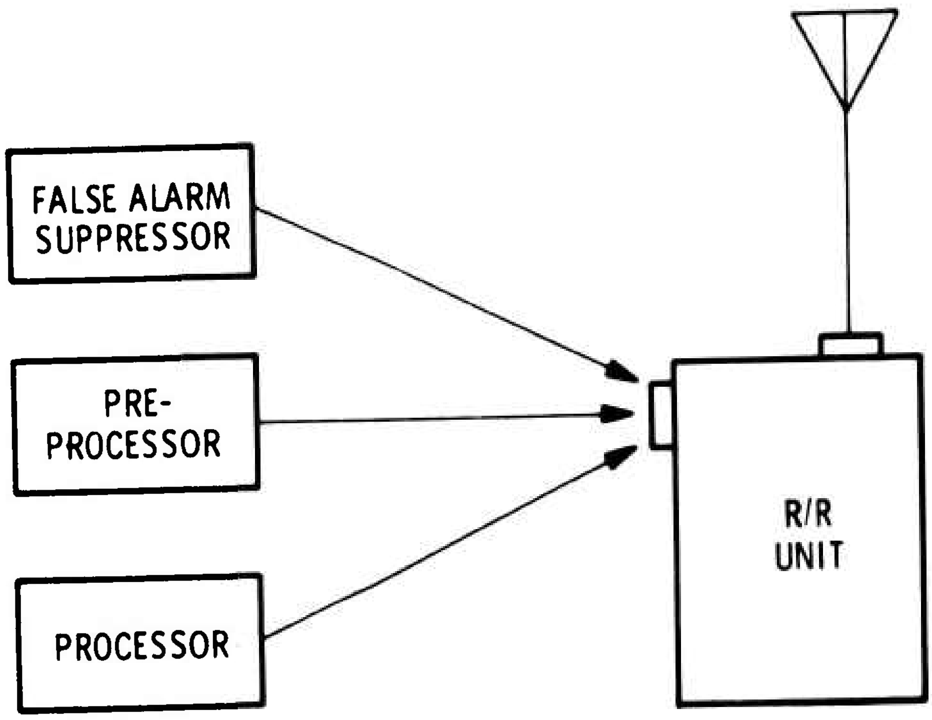

Figure 6-11 (C). Options of the R/R Unit (U) (CONFIDENTIAL)

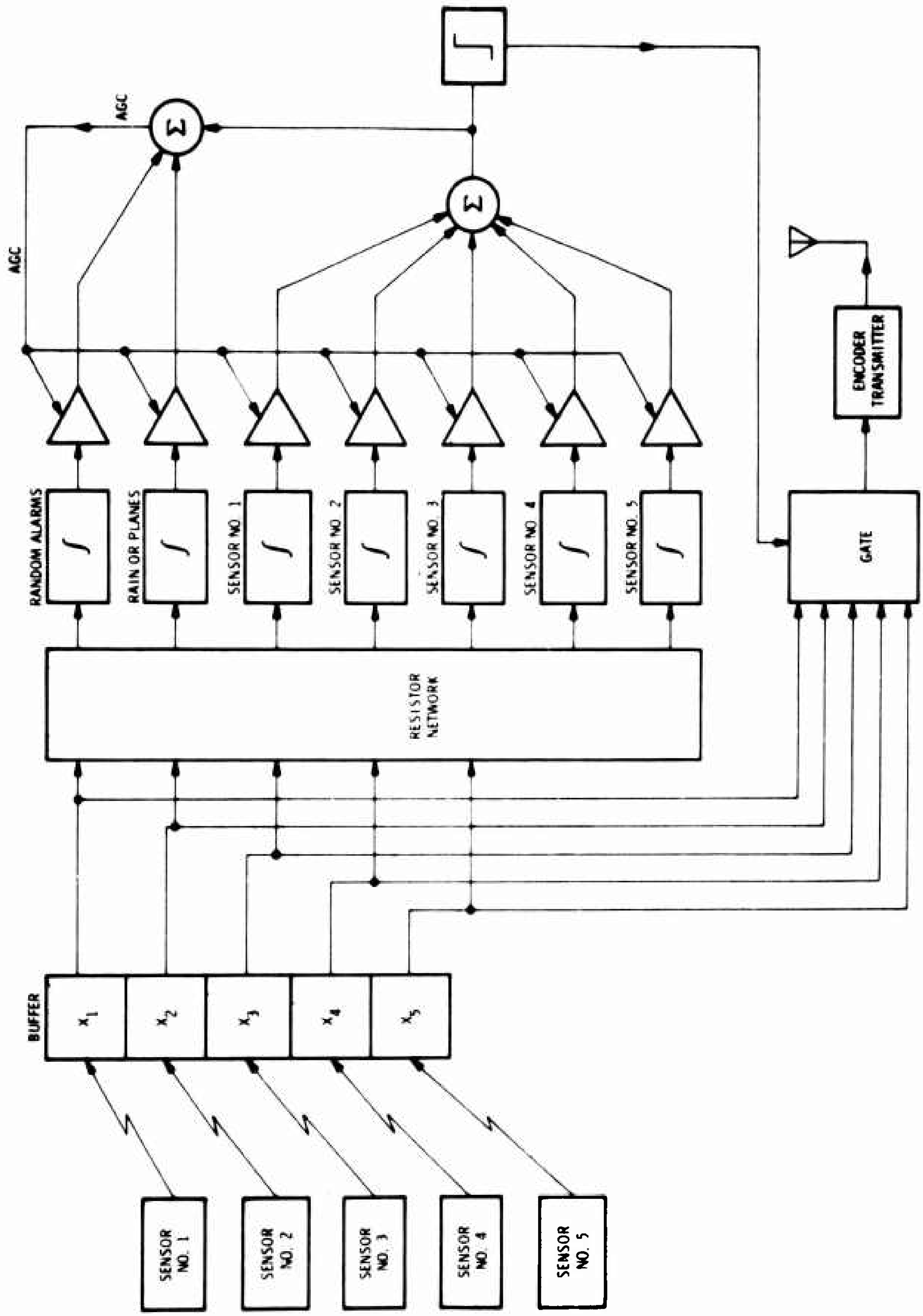

Figure 6-12 (U). Block Diagram, Spurious Alarm Suppressor for Five-Sensor Array (U)

6.3.1.1 (U) (Continued)

$$Y_j = C \sum_{i=1}^{5} \left[X_i \log P_i^j + (1 - X_i) \log (1 - P_i^j) \right] \qquad (15)$$

where P_i^j is a parameter associated with the i^{th} sensor and is described below. The base of the logarithm is arbitrary and C is an arbitrary constant.

The function of the buffer and resistor network is to deliver to the input of the integrator a voltage which is the sum of voltages from each of the stages of the buffer. The contribution of the i^{th} buffer is to be a voltage proportional to log P_i^j, if $X_i = 1$, and to log $(1 - P_i^j)$, when $X_i = 0$.

The numbers P_i^j are probabilities of occurrence of an alarm at the i^{th} sensor when the j^{th} condition is present. Thus, when there are only random alarms, the probability of an alarm will be the same for each sensor and will be represented by some small number, such as $P_i^1 = 0.005$. An example of what the other probabilities may be is shown below:

For

$j = 1$: low level random alarms:

$$P_i^1 = 0.005$$

$j = 2$: high level random alarms:

$$P_i^2 = 0.5$$

$j = 3$: alarms mostly originating at the first sensor:

$$P_1^3 = 0.8,\ P_2^3 = 0.1,\ P_3^3 = 0.005,\ P_4^3 = 0.05,\ P_5^3 = 0.05$$

$j = 4$: alarms mostly originating at the second sensor:

$$P_1^4 = 0.1,\ P_2^4 = 0.8,\ P_3^4 = 0.1,\ P_4^4 = 0.05,\ P_5^4 = 0.05$$

$j = 7$: alarms mostly originating at the fifth sensor:

$$P_1^7 = 0.05,\ P_2^7 = 0.05,\ P_3^7 = 0.05,\ P_4^7 = 0.1,\ P_5^7 = 0.8$$

6.3.1.1 (U) (Continued)

The integrators should be the RC type with a long time constant compared to the timing of the buffers; for example, 5 minutes.

The output of the integrators will be passed through variable gain amplifiers whose gain is changed by an Automatic Gain Control (AGC) voltage. A desired range of gain is at least 10 to 1.

The output of the amplifiers are added in two adders. One adder adds all of the outputs representing the presence of an intruder. This sum will then be added to the outputs associated with the sources of false alarm to form the AGC voltage. The function of the AGC voltage is to maintain the output of the final summer at a nearly constant level independent of the input levels to the integrators. Consequently, an increase in the AGC voltage will decrease the gain of each of the amplifiers equally until the desired level is again restored.

The affect of the AGC will be to depress the level of the output associated with one condition when states X_1, X_2, ..., X_5 are such that another condition is more likely as indicated by an increased output from the associated integrator.

The output of the adder associated with the presence of an intruder will be compared with a threshold. This threshold should have a built-in hysteresis, i.e., should switch to the "on" state as soon as the input exceeds the present value, but return to the "off" state at a much lower level to avoid the AGC action from closing the gate before the transmission is completed. Thus, when the threshold is in the "on" state, the sensors will be passed through to the transmitter whereas, when the threshold is in the "off" state, no alarms will be passed through.

6.3.1.2 (C) Hardware Design

The block diagram configuration of Figure 6-13 shows a spurious alarm suppressor composed of three main portions: The input section, the analog processing section, and control section. The sensor alarm transmissions are decoded in the input section in random order of occurrence and the steering logic provides the decision as to whether the data is to be transferred to the accumulation register or read out directly to the modulator. If the analog processor has supplied an enabling level to the steering logic all data accumulated and present at the input is to be transmitted unconditionally. The input portion of the analog processor consists of four-second one-shots for temporarily holding the alarm asynchronously. The input decoder analyzes the sensor ID to decide which of the five one-shots is to be triggered.

The one-shot time duration selection (4 seconds in this case) is based on such factors as maximum alarm rate, sensor spacing, sensor range, and other related system parameters. The analog processing section analyzes the statistical distribution of alarms at the input to determine whether valid intrusions exist. The existence of valid intrusions as determined by the analog processor, produces an enabling logic level which allows the transmission of the alarm words present at the accumulator and input register with their respective sensor identification. The steering logic controls the transmission of the sensor alarms when the analog processor supplies the enabling level.

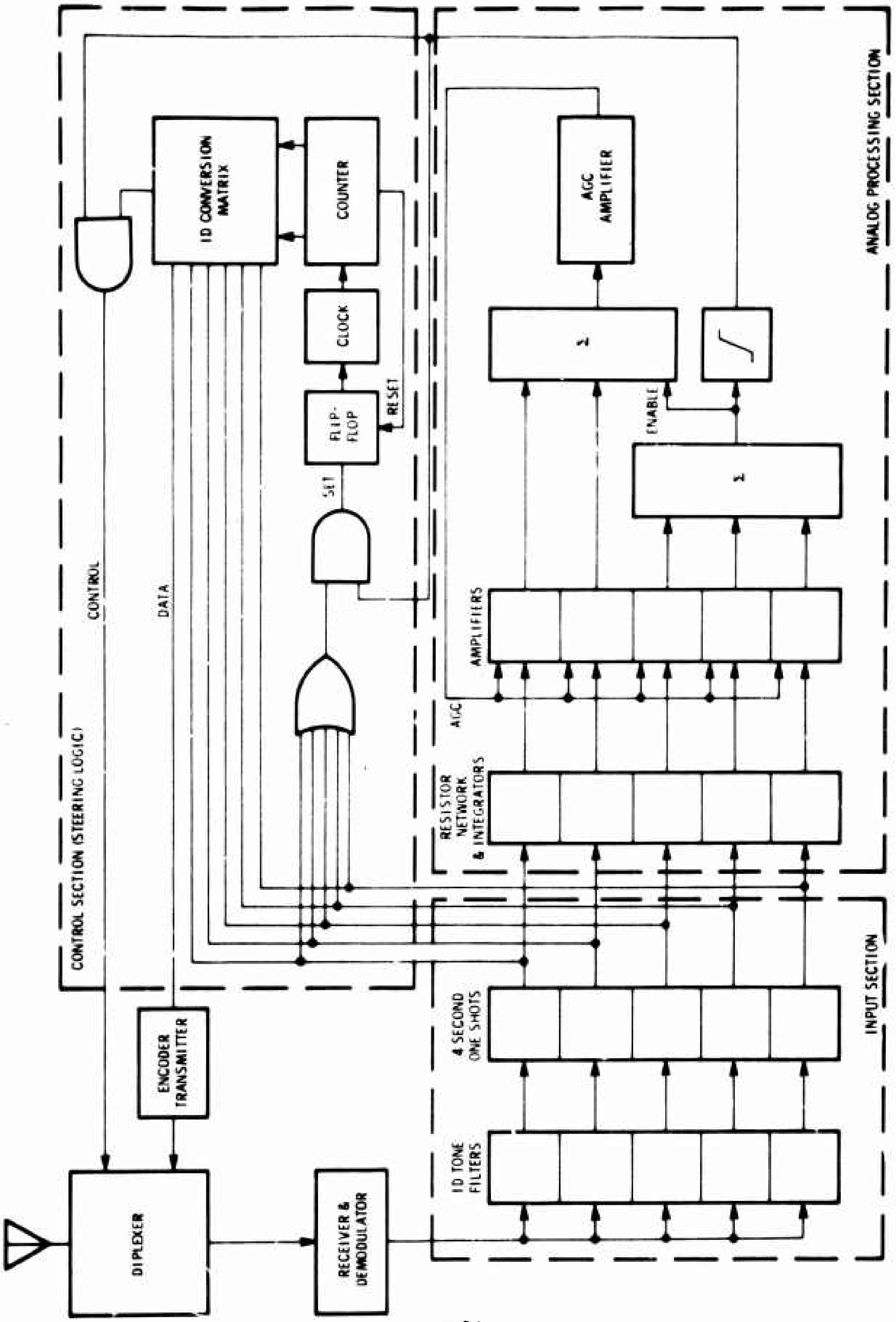

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Figure 6-13 (C) Block Diagram. Spurius Alarm Suppressor (U)

6.3.1.2 (C) (Continued)

The analog processor section consists of the resistive weighting and summing networks, electronic integrators with transfer functions of the form $\frac{G}{1+pRC(1+G)}$ operational amplifiers with provision for AGC feedback loop, and a threshold detector which supplies the enabling level for the steering logic. The theory of operation of the analog processing section was discussed in Section 6.3.1.1.

The input register decoder also analyzes for presence of a test message by examining the sensor status bits. If a test message is present at the input when no intrusion activity exists, the steering logic will command a readout directly from the input register to the modulator.

It has been estimated that three printed circuit boards 6" x 4" will be required to house the 28 IC's and 180 other components required to implement the SAS circuitry. Eveready #520 battery may be used to power the circuits. The overall package size is estimated to be 6" x 6" x 9-1/2". An artist's concept of the SAS unit is shown in Figure 6-14.

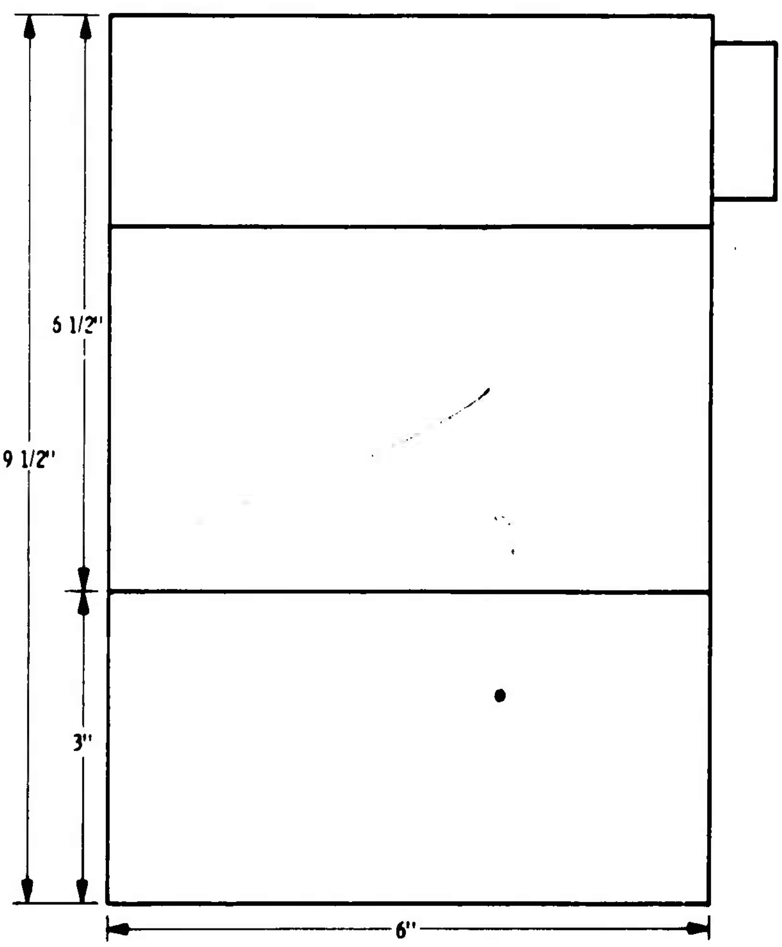


Figure 6-14 (U). Artist's Concept, Spurious Alarm Suppressor (U)

6.3.2 (C) Alarm Pre-Processor

6.3.2.1 (C) Theory of Operation

There are several reasons why it may be desirable to do a certain amount of the alarm processing within the Wide Area. Some of these reasons are:

a. The number of Wide Areas is too small to warrant employment of a full scale CSCPD.

b. The "on-air" time must be kept to a minimum in order to reduce reliability of interception, location by direction finding, or jamming.

c. Extend the life of the system.

d. Reduce the complexity and/or the number of channels required by RSDCS.

In order to determine what pre-processing might be done at the R/R, we will re-examine the material discussed in Section 4.2.5. There it was shown that,

a. Direction of travel can be found by noting whether sensor #1 or sensor #5 alarmed first.

b. Approximate velocity of the intruders, V, can be found from

$$V \approx \frac{D}{T} \tag{16}$$

where

D = separation between two adjacent sensors

T = time it takes for the pivot man of an intruder group to travel from one sensor to the next.

c. Approximate count of the intruders, C, can be found from performing the following calculation:

$$C \simeq \frac{(N)\ (V)\ (RI)\ -\ 2\ R_D}{S} \tag{17}$$

where

N = total number of alarms reported by one sensor

RI = interval between alarms

S = expected average spacing between intruders

R_D = radius of the circular detection area of a sensor.

6.3.2.1 (C) (Continued)

Let us now more closely examine the equations stated above to determine how many of the terms are actually unknowns. Thus, D and R_D for the trail array type of sensors were specified to be about 50 and 10 meters, respectively. Although these distances will never be known with any great accuracy, these must be treated as constants since the alarms will not convey any more information about them, anyway. Another parameter that is known is RI since this was specified to be 4 seconds and can be controlled quite accurately. The expected average spacing between intruders is difficult to determine but, in general, will be approximately 4 meters. By substituting these constants into Equations (16) and (17), the following simplified expressions are found:

$$V \approx \frac{50}{T} \tag{18}$$

$$C \approx NV - 5 \tag{19}$$

Thus, the only two parameters which need to be extracted from the received alarms are T and N. What these parameters are for each sensor is shown in Figure 6-16 for a trail array intruded by a group of people moving from left to right.

To estimate how many bits will be required to represent these measurements, we must determine the maximum values that N and T may take on. For T, this can be determined by recalling that the expected bounds for V are

$$0.6 < V < 1.2 \text{ meters/second.}$$

From this

$$41 < T < 83 \text{ seconds.}$$

Hence, 7 bits will be required to represent all values of V.

To determine the bounds for N, we must decide on what the maximum number of intruders will be in any group passing an array. For the general case this would be impossible; however, for the RAM threat one may safely assume that the number C will rarely exceed 40. Having established C_{max}, it can be shown that

$$5 < N < 75$$

Hence, again, 7 bits will be required to represent all values of N.

Direction can only take on two different values; from left-to-right and from right-to-left. Therefore, only one bit will be required to convey direction information.

6.3.2.1 (C) (Continued)

Consequently, the structure of the message leaving the pre-processor will be that shown in Figure 6-15. Note that the Sensor address has been dropped since this is no longer needed. Depending on the reliability of the overall R/R-to-CSDPD communications link, this message may be repeated several times in rapid succession before it is discarded and the pre-processor reset to handle another intrusion.

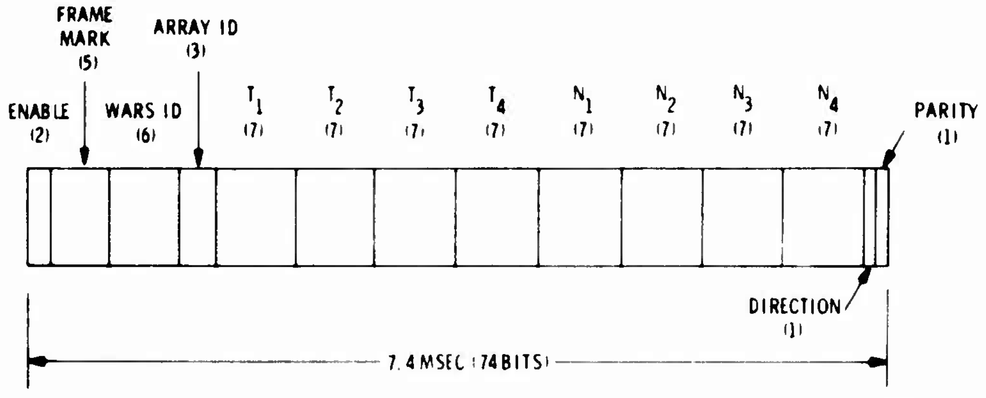


Figure 6-15 (C). Message Structure for Pre-Processor (U)

Figure 6-16 illustrates quite vividly the advantage of using a pre-processor if reduction in data processing or on-air time is essential.

The hardware design of a device capable of performing the pre-processing discussed above is outlined in the next section.

6.3.2.2 (C) Implementation

A block diagram of the proposed pre-processor is shown in Figure 6-17. The device will be designed to handle alarm messages from any array of five sensors. The message decoding register will accept the qualified 23-bit serial alarm messages, examine the sensor identity, and provide an output on one of five lines accordingly.

An alarm-counting register will be provided for each of the five sensors to accumulate alarm counts. When the system is in the quiescent, no-traffic state, all counters, registers, and flip-flops will be in the cleared, or reset, state. A sensor alarm at either end of the array will cause the control flip-flop to be set, thus starting the running-time oscillator and counter. At the same time, the direction logic will determine whether the target is approaching from the left or right and set the direction bit accordingly. Likewise, the time-counting register for the next adjacent sensor will begin to count running-time clock pulses until the first alarm count is received for that sensor.

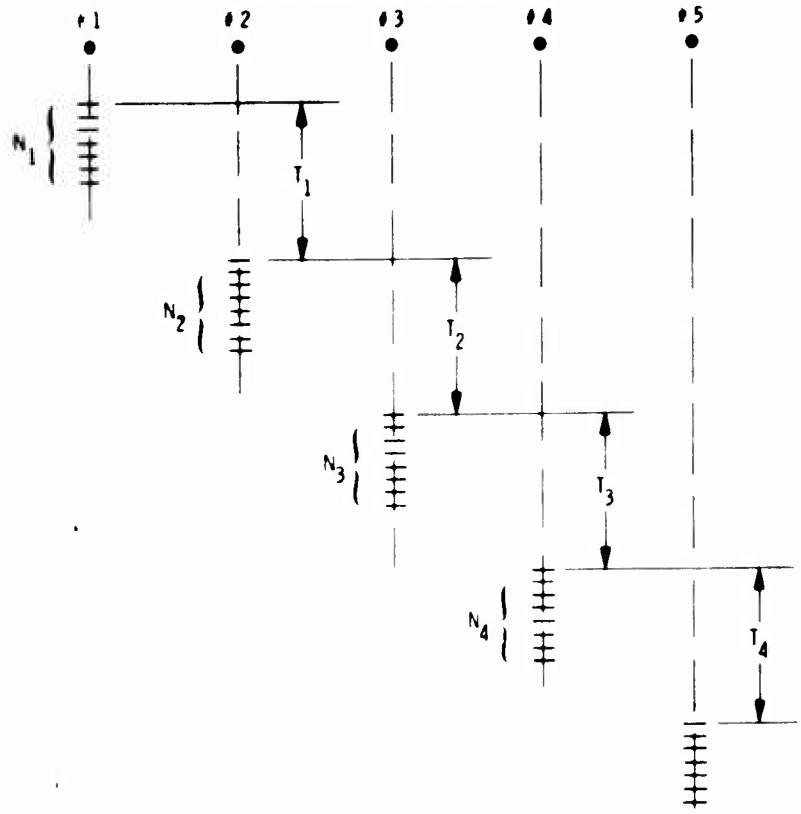


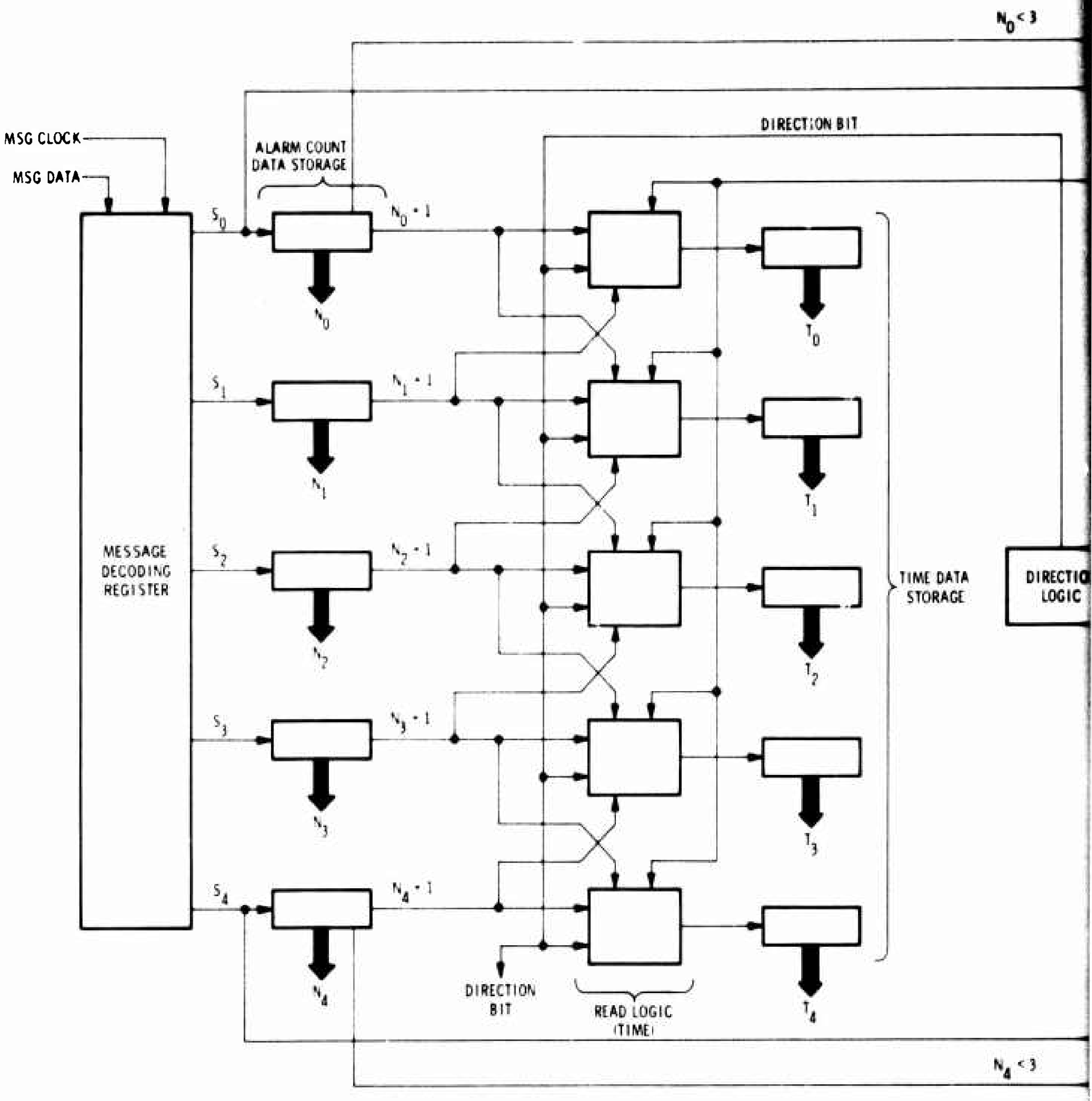
Figure 6-16 (C). Number of Bits Sent by an Array as a Function of Number of Intruders (U) CONFIDENTIAL

6.3.2.2 (C) (Continued)

In order for the running time to continue, either of the two end sensors must accumulate three or more alarm counts within the time frame T_a. If this criterion is not satisfied, the system will automatically be reset to the no-traffic state.

If running time is allowed to continue by virtue of the initial traffic at the first sensor, the alarm counter and time data will accumulate at the second time-count register. As the target approaches the next sensor in the array, the first alarm count from the second sensor will be used to halt and store time T1 in the alarm time data storage register corresponding to the second sensor. Accumulation of alarm count and reading of initial alarm time at each successive sensor will be accomplished progressively in a like manner. The sequence of time accumulation initiation and halting will be controlled by the direction bit. When sufficient time has elapsed, as controlled by the running time counter, the stored data of direction, sensor alarm counts, and time of alarm will be read into a parallel-to-serial encoder, along with the preamble and address data, for construction of a new message. The latter will contain, along with a direction bit, four discrete values for time traveled between successive sensors (7 bits each) and four discrete values for alarms per sensor (7 bits each).

It has been estimated that three printed circuit boards approximately 6" x 3" in size will be required to house the 31 I.C.'s and 17 other components required by the



$N_0 < 3$
DIRECTION BIT
MSG CLOCK
MSG DATA
ALARM COUNT
DATA STORAGE
S_0
$N_0 + 1$
N_0
T_0
S_1
$N_1 + 1$
N_1
T_1
MESSAGE
DECODING
REGISTER
S_2
$N_2 + 1$
N_2
TIME DATA
STORAGE
DIRECTIO
LOGIC
T_2
S_3
$N_3 + 1$
N_3
T_3
S_4
$N_4 + 1$
N_4
DIRECTION
BIT
READ LOGIC
(TIME)
T_4
$N_4 < 3$

1

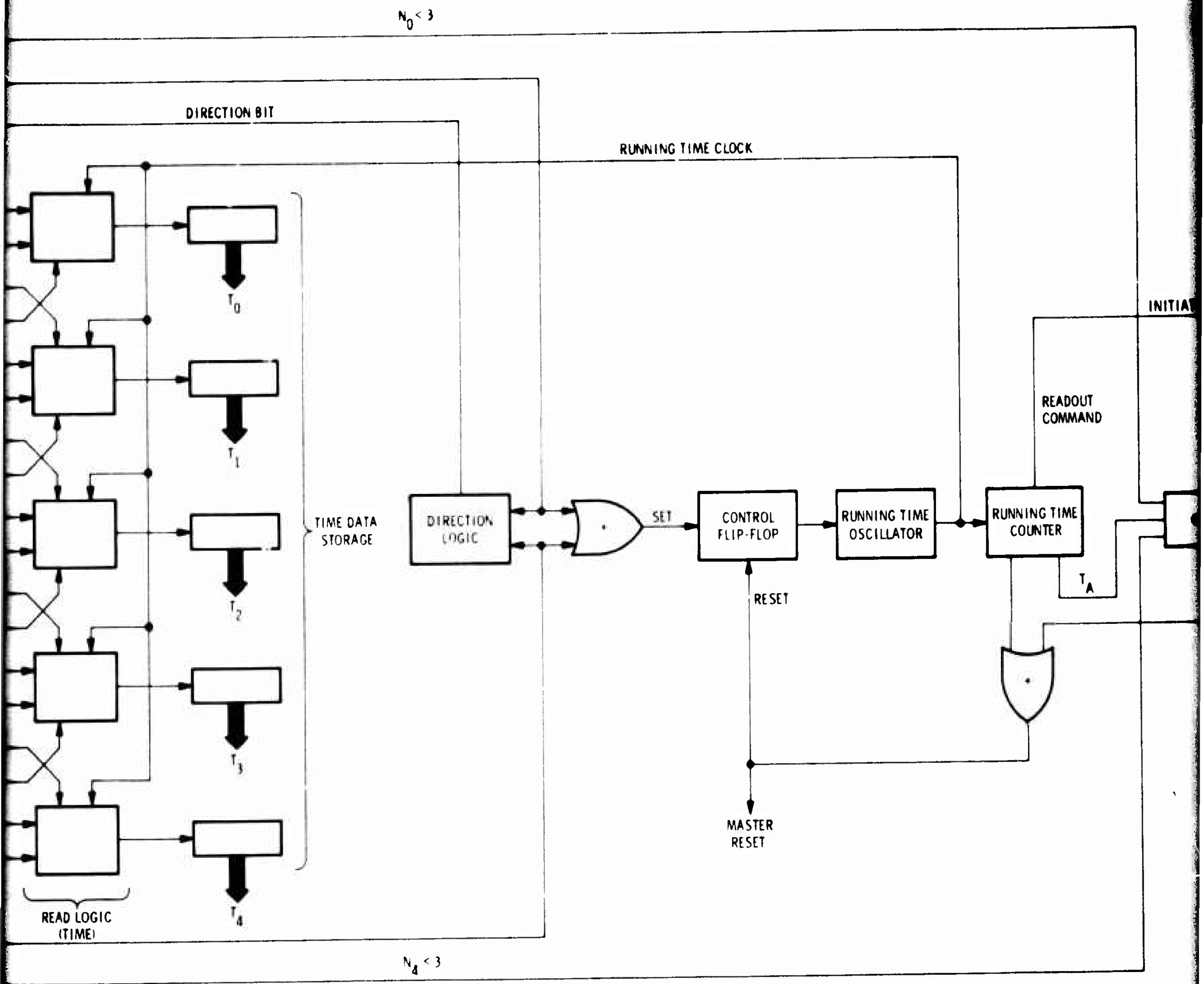

N0 < 3
DIRECTION BIT
RUNNING TIME CLOCK
INITIA
READOUT COMMAND
TIME DATA STORAGE
DIRECTION LOGIC
SET
CONTROL FLIP-FLOP
RUNNING TIME OSCILLATOR
RUNNING TIME COUNTER
RESET
MASTER RESET
READ LOGIC (TIME)
N4 < 3

Figure 6-

2

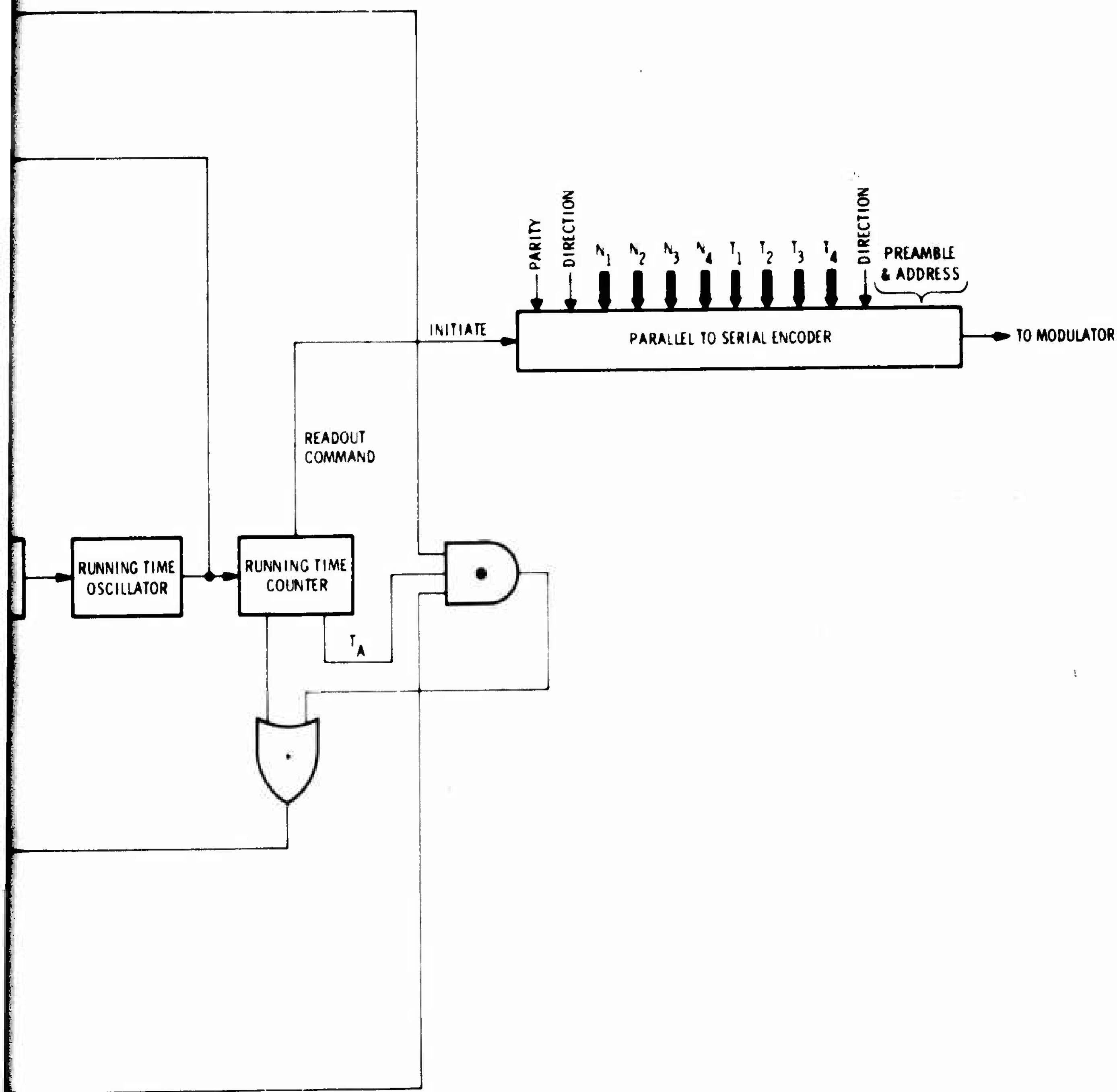


Figure 6-17 (C). Pre-Processor Block Diagram (U)

6.3.2.2 (C) (Continued)

Pre-processor circuitry. Eveready #520 battery may be used to power this circuitry. The overall package size is estimated to be 6" x 6" x 7-1/2". An artist's concept of the Pre-processor is shown in Figure 6-18.

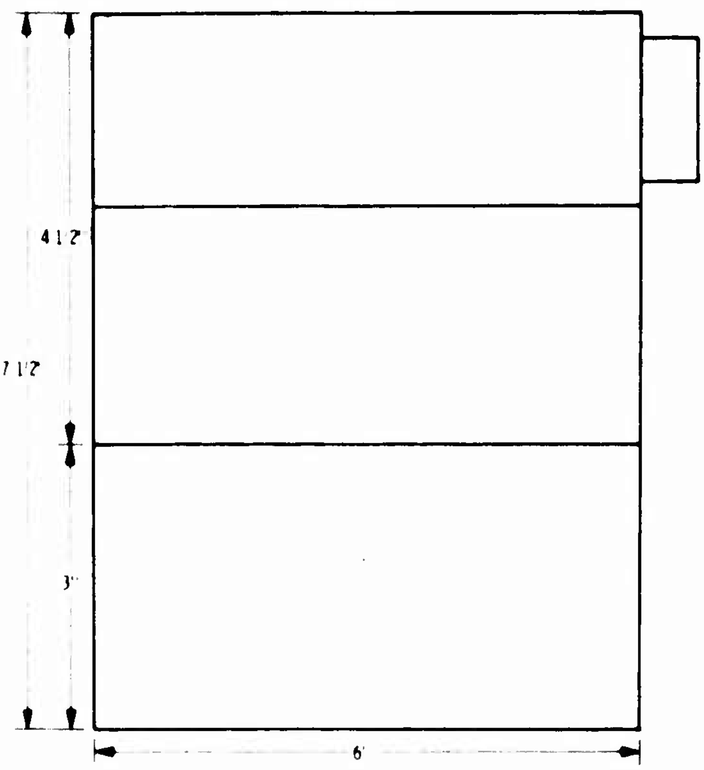


Figure 6-18 (U). Artist's Concept of Pre-Processor (U)

6.3.3 (C) Alarm Processor

6.3.3.1 (C) Theory of Operation

By performing a couple of additional operations on the results of the Pre-processor, complete data processing will have been accomplished within the Wide Area. These two operations are: 1) calculation of the speed and count as observed by each individual sensor, and 2) calculation of the average speed and count as observed by the entire array. A device which contains a pre-processor and the necessary arithmetic logic will be called an Alarm Processor. A block diagram of such a unit is shown in Figure 6-19.

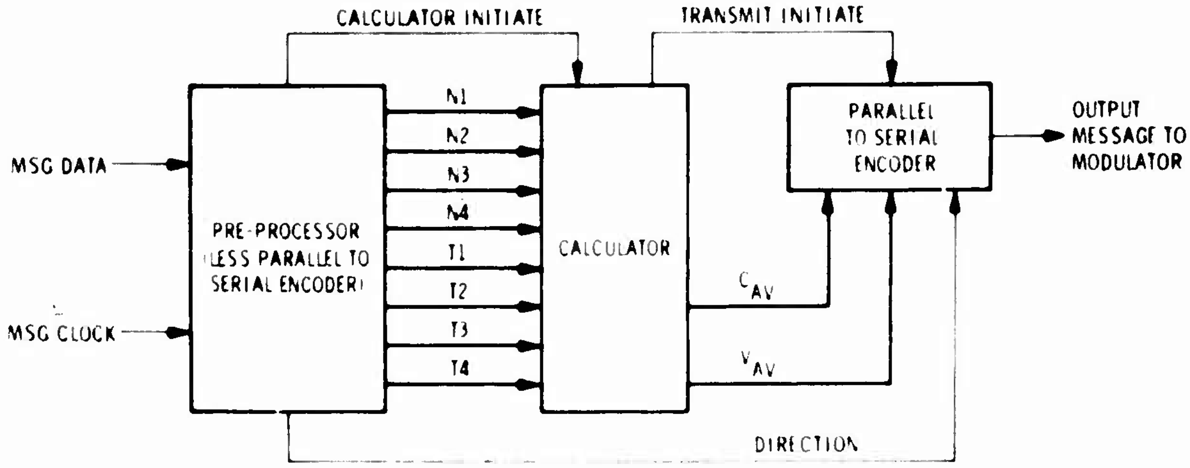


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Figure 6-19 (C). Block Diagram, Alarm Processor (U)

6.3.3.1 (C) (Continued)

Employment of this unit will not only essentially eliminate the need for WARS data processing at the CSCPD, but also further reduce the length of the message which must be relayed from each array to the CSCPD. To estimate how many bits will be required in this message, we will recall that

$$0.6 < V < 1.2 \text{ meters/second}$$

and

$$1 < C < \text{ intruders per group.}$$

From this, it can be seen that four bits will be required to report velocity with 0.1 meter/second resolution and six bits will be required to report the estimated number of intruders in the column. Consequently, the message structure resulting from the use of the Alarm Processor will be as shown in Figure 6-20.

The arithmetic logic, or calculator, will be energized and perform its function only upon a command from the pre-processor. A command will also be given for the calculator to read the calculated final values into the parallel-to-serial encoder. Since the pre-processor will be as described in Section 6.3.2, only the calculator will be discussed here.

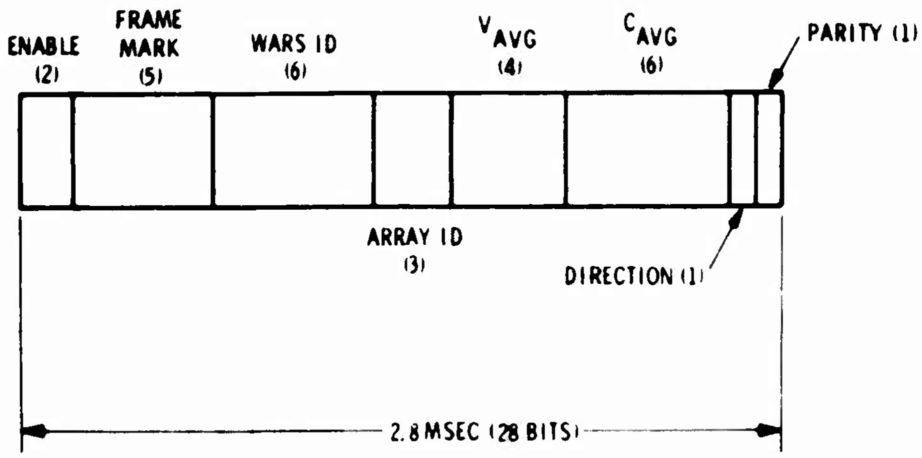

Figure 6-20 (C). Message Structure for Processor (U)

6.3.3.2 (C) Calculator Design

The purpose of the Calculator, a block diagram of which is shown in Figure 6-21, is to manipulate four time words ($T_1 \ldots T_4$) and four number words ($N_1 \ldots N_4$) producing C_{AV} and V_{AV} as defined below:

$$V_n = D/_{T_n} \tag{20}$$

$$V_{AV} = \frac{V_1 + V_2 + V_3 + V_4}{4} \tag{21}$$

$$C_n = N_n V_n - 5 \tag{22}$$

$$C_{AV} = \frac{C_1 + C_2 + C_3 + C_4}{4} \tag{23}$$

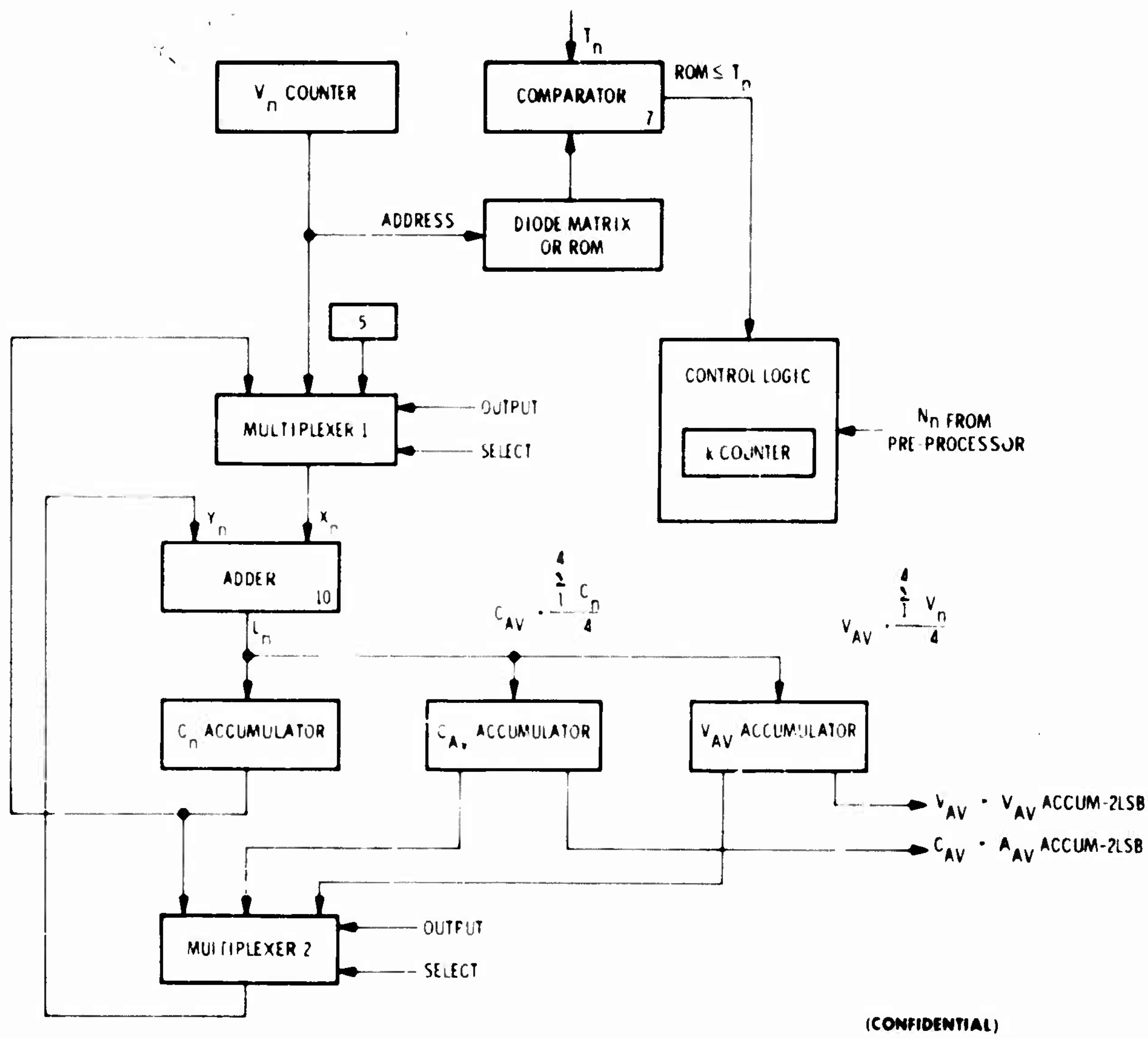

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Figure 6-21 (C). Calculator Block Diagram (U)

6.3.3.2 (C) (Continued)

The flow diagram, shown in Figure 6-22, indicates the sequence of operation of the Calculator. A start pulse is received from the pre-processor indicating that all data is ready. All accumulators and counters will be reset. The K counter is then incremented to 1. The logic will select T_1 and enter it into the T_n register. It will then preset the V_n counter to 12. The V_n counter will address the diode matrix (or the ROM) and the control logic will then look at the comparator to determine if the time word at that address (12) in the ROM is less than or equal to T_1. If not, the V_n counter will be decremented to 11 and the comparator will again be interrogated. This will continue until the time word output of the ROM is less than or equal to T_1 at which point the V_n counter contains the velocity.

The control logic will then enable the V_{AV} accumulator through multipler #2 to one input of the adder and enable the V_n counter through multiplexer #1 to the other input of the adder. (Recall that V_{AV} is zero.) The logic will enter the output of the adder into the V_{AV} accum and it will then contain V_1.

Since ($K' = 1$), N_1 will be entered into the N_n counter. The V_n counter and the C_n accum will be enabled to the adder through their respective multiplexers. The logic will then add ($C_n + V_n$), V_1 times. When completed, -5 is gated to the adder and added with the accumulation in C_n producting C_1. C_1 will then be added with C_{AV} which at this point is zero.

After the first pass, the accumulators will contain:

$$C_n = C_1$$

$$C_{AV} = C_1$$

$$V_{AV} = V_1$$

After the second pass, the accumulators will have:

$$C_n = C_2$$

$$C_{AV} = C_1 + C_2$$

$$V_{AV} = V_1 + V_2$$

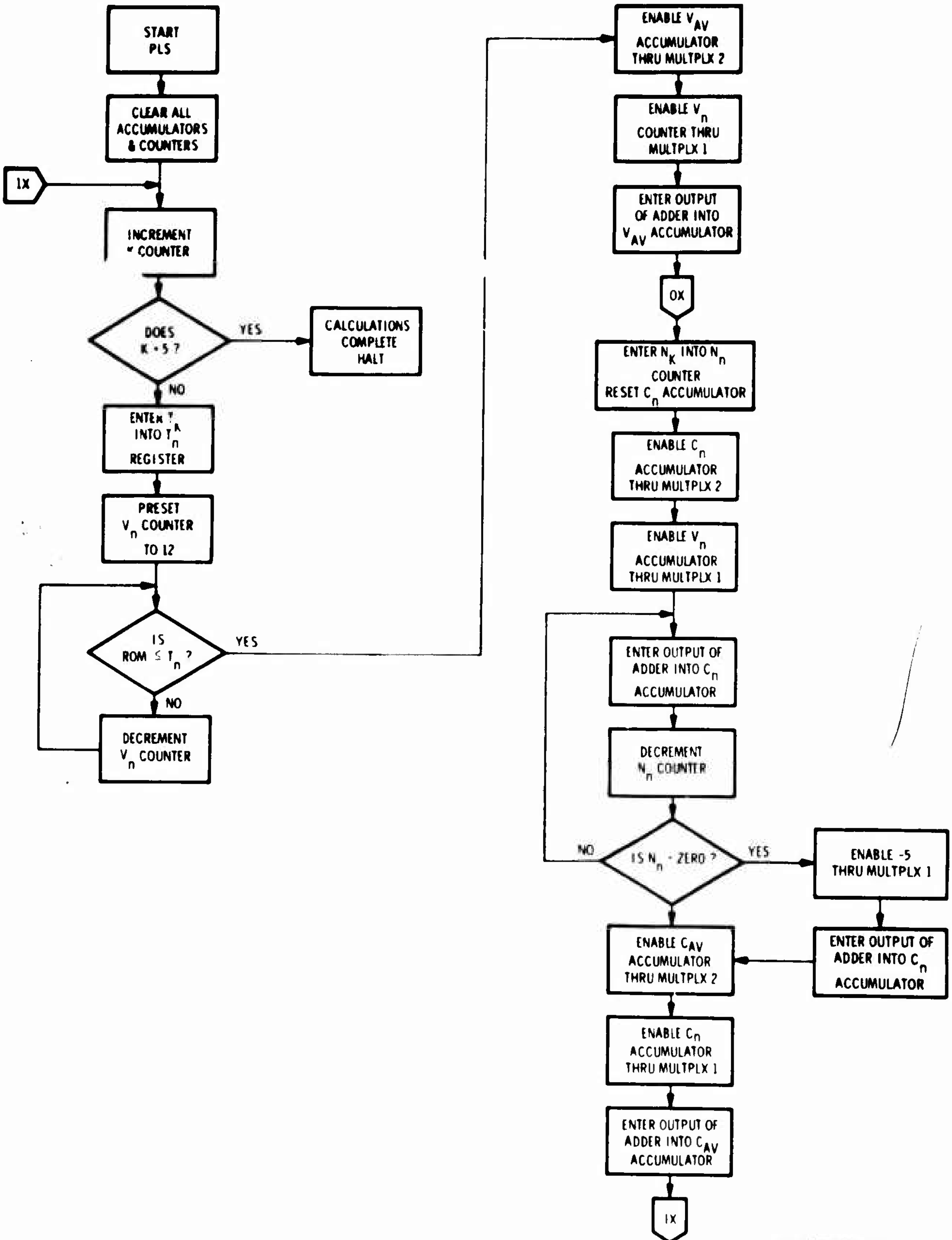


Figure 6-22 (C). Calculator Flow Diagram (U)

(CONFIDENTIAL)

6.3.3.2 (C) (Continued)

After the last pass, the logic will increment the K counter to fire and this will halt the calculator. Then,

$$C_{AV} = C_{AV} \text{ ACCUM less the two least significant bits}$$

$$V_{AV} = V_{AV} \text{ ACCUM less the two least significant bits}$$

This completes the calculation.

It has been estimated that four 6" x 4" printed circuit boards will be required to house the 78 I. C.'s and 45 components required to implement the Alarm Processor circuits. An Eveready #520 battery will supply power to the circuits. The overall package size is estimated to be 6" x 6" x 8-1/2". An artist's concept of this unit is shown in Figure 6-23.

6.4 (C) Options of the R/I Unit

Only one additional optional feature is shown for the R/I Unit. This device, called an Alarm Accumulator, will be connected between the R/I and the LRT. A brief description of how this unit functions is given below. Note that the processing options presented for the R/R can also be located at the R/I with slight modification.

6.4.1 (C) Alarm Accumulator

Under certain conditions it may become necessary to provide a buffer between the WARS subsystem and the RSDCS where the alarm messages can be accumulated for a short time. For example, if polling is used in order to make more effective use of the RSDCS channel, the alarms must be stored during the communication cycle.

A block schematic of a device which is capable of accomplishing this is shown in Figure 6-24.

The shown Alarm Accumulator will accumulate incoming random alarm messages and serially readout, in controlled sequence and interval, each message received in its identical, unique format, for retransmission by the RSDCS. The alarm accumulator will have a storage capacity of 40 alarm words and will cycle automatically between the "accumulate" mode and readout mode. Provision is also made for readout upon receipt of a remote interrogation command which will override the automatic cycling.

As indicated in the block diagram, the device will accept the 23-bit message from the R/I. In addition to the message, the R/I will also supply synchronization for the readin mode by means of the message clock pulses. A message presence pulse from the R/I will also be required as a stepping command for the sequencing counter during the accumulate or readin mode.

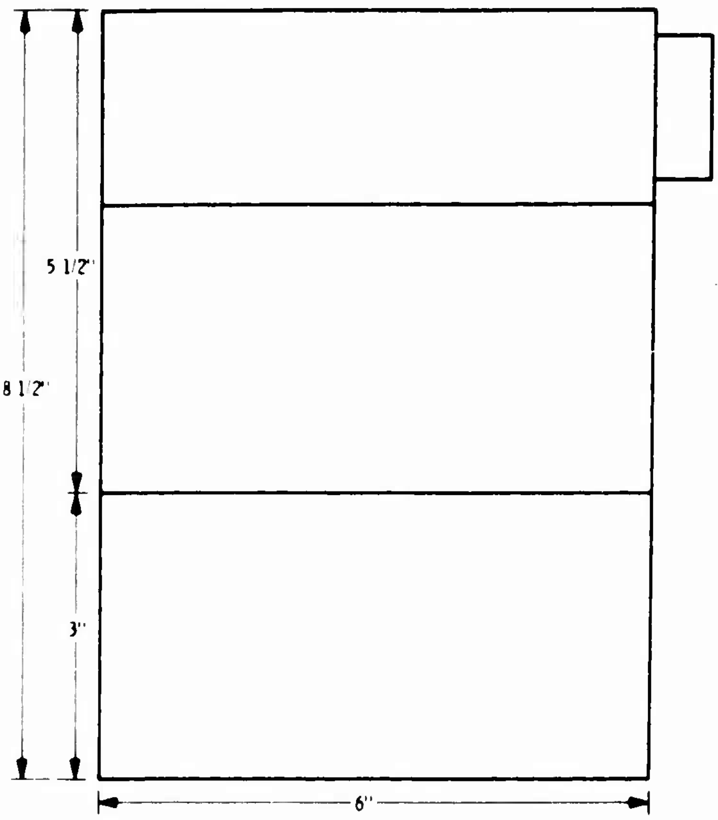


Figure 6-23 (U). Artist's Concept of Processor (U)

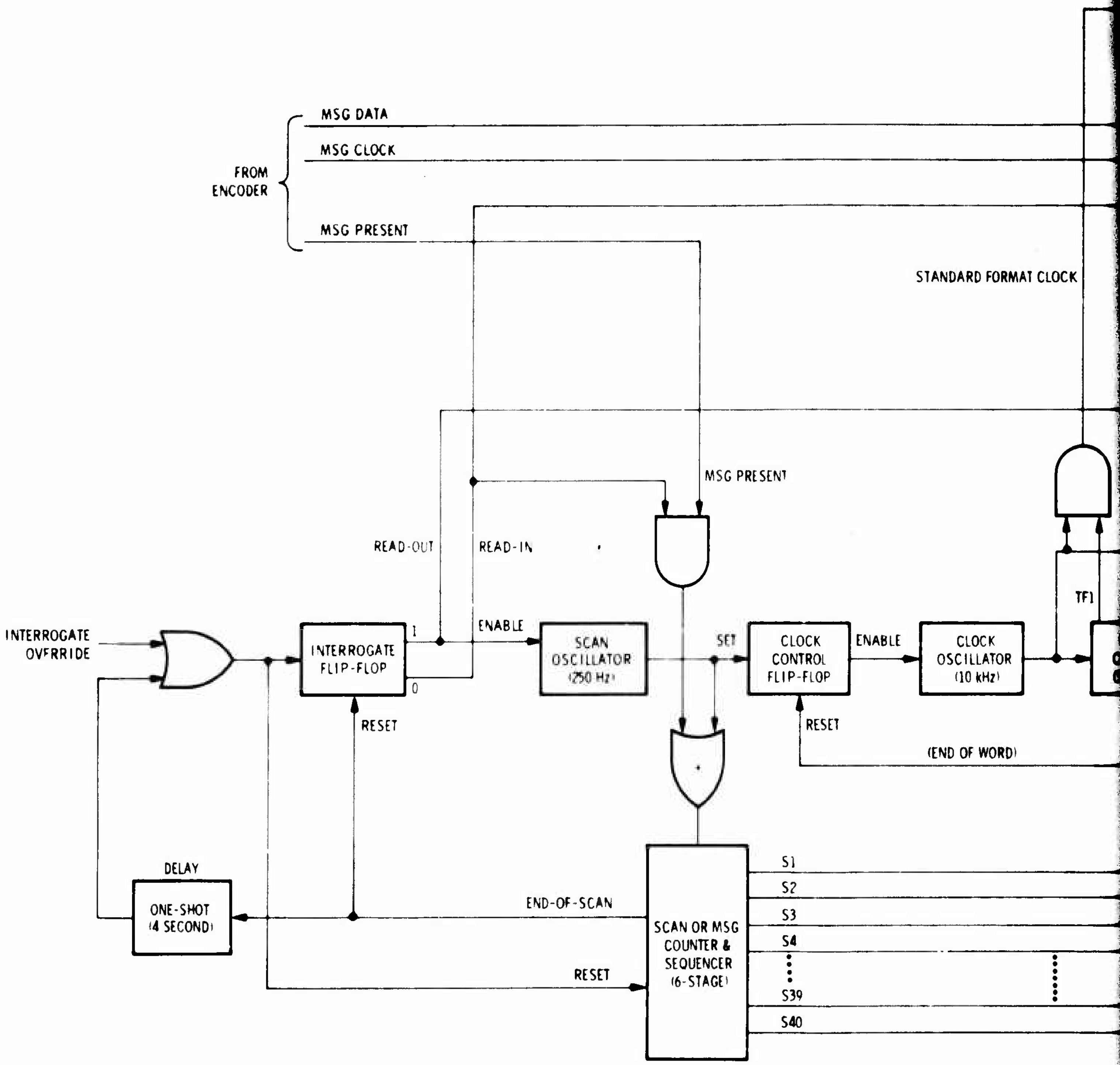
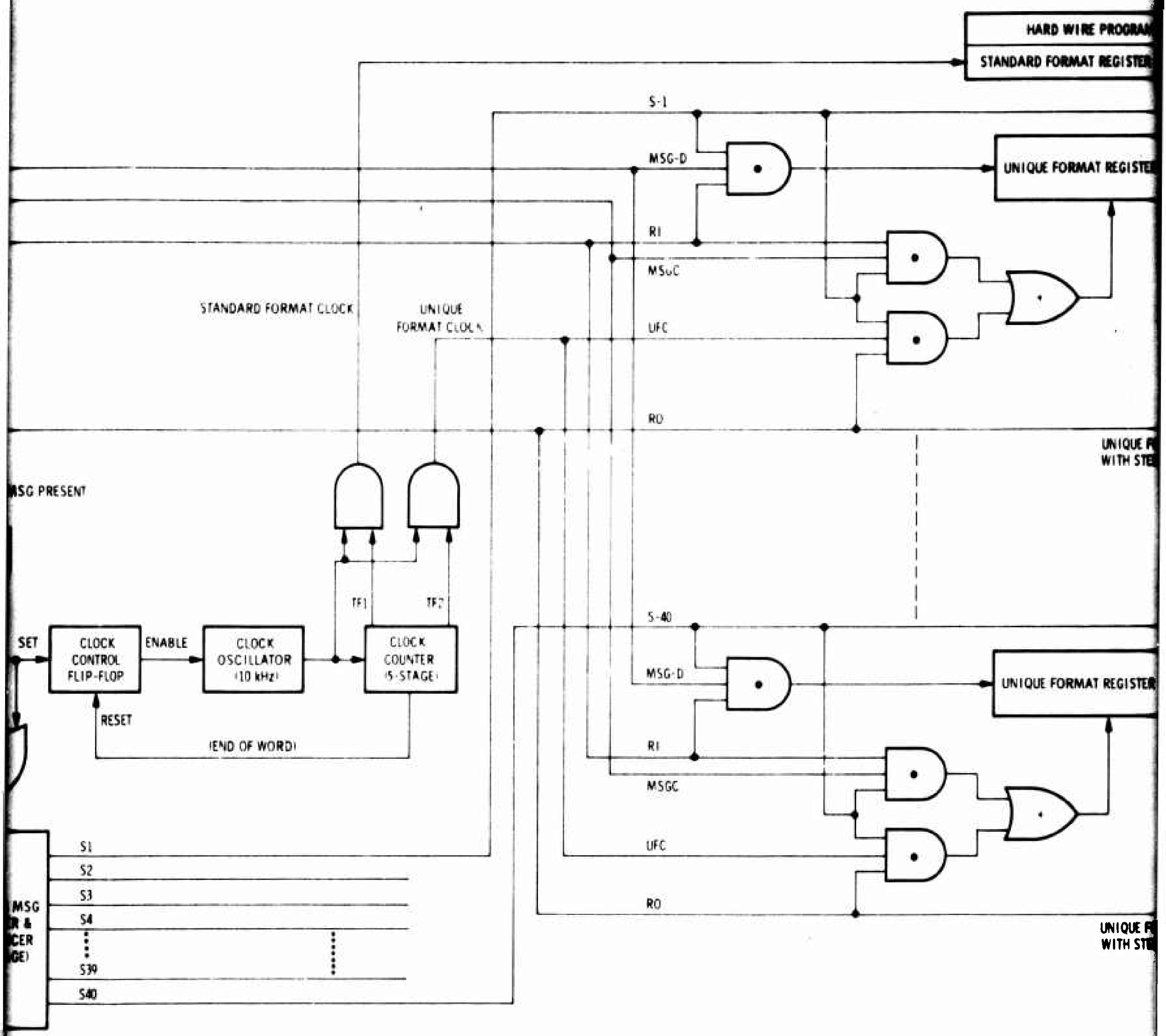


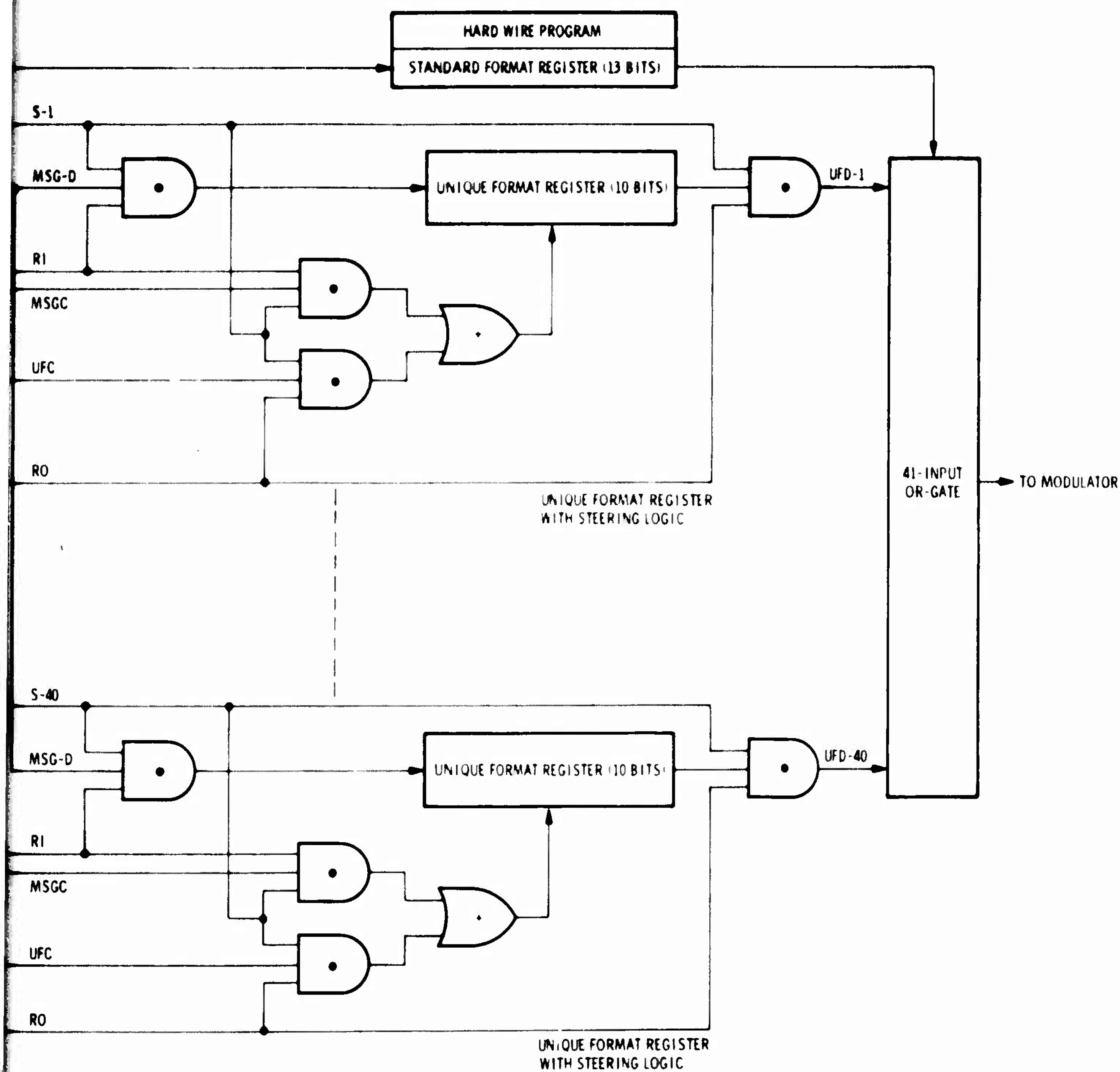
Figure 6-24 (C). Block Schematic, Alarm Accumulator (U)



HARD WIRE PROGRAM
STANDARD FORMAT REGISTER
S-1
MSG-D
UNIQUE FORMAT REGISTER
RI
MSGC
STANDARD FORMAT CLOCK
UNIQUE FORMAT CLOCK
UFC
RO
UNIQUE F
WITH STE
MSG PRESENT
TF1
TF2
S-40
SET
CLOCK CONTROL FLIP-FLOP
ENABLE
CLOCK OSCILLATOR (10 kHz)
CLOCK COUNTER (5-STAGE)
RESET
(END OF WORD)
MSG-D
UNIQUE FORMAT REGISTER
RI
MSGC
UFC
RO
UNIQUE F
WITH STE
S1
S2
S3
S4
S39
S40
MSG
R &
CER
GE)

arm

2


HARD WIRE PROGRAM
STANDARD FORMAT REGISTER (13 BITS)
S-1
MSG-D
UNIQUE FORMAT REGISTER (10 BITS)
UFD-1
RI
MSGC
UFC
RO
41-INPUT OR-GATE
TO MODULATOR
UNIQUE FORMAT REGISTER WITH STEERING LOGIC
S-40
MSG-D
UNIQUE FORMAT REGISTER (10 BITS)
UFD-40
RI
MSGC
UFC
RO
UNIQUE FORMAT REGISTER WITH STEERING LOGIC

6.4.2 (C) Use of R/R Options at R/I

It will be merely mentioned here that all the optional features provided with the R/R Unit can also be designed to work at the R/I Unit. The difference, of course, will be that an alarm processing device used at the R/I must be able to handle as many as eight arrays instead of the single one associated with an R/R Unit. The theory of operation, however, would be the same except for the addition of array decoding circuits which are required to separate the alarms on a per array basis.

6.5 (C) Impact of On-Site Alarm Processing on the Overall BESS System Performance

On-site alarm data processing will impact on the overall BESS performance in essentially three areas:

1. RSDCS operation.
2. CSCPD operation.
3. Deployment Flexibility, including cost

This section will cover each of these areas to demonstrate that on-site processing adds the dimension of flexibility to BESS necessary to handle the variety of world-wide deployment situations.

6.5.1 (C) RSDCS Operation

The impact of on-site processing on the RSDCS is a significant reduction in its data handling requirements. As an example, a single intruder passing through a trail array will cause the array sensors to alarm approximately 20 times (4 alarms/sensor, 5 sensors/array). Given that the alarm message transmitted by an S/T unit contains 23 bits, the total number of bits transmitted during the intrusion would be 20 x 23 = 460. Using local processing, the intruder information of interest (direction, speed, and group size) would be extracted and relayed to the Air Base in single 28 bit message (see Figure 6-20). Assuming (as a worst case) that the message is repeated 4 times to [illegible]sure correct reception, the total number of bits transmitted would be 4 x 28 = [illegible]. This represents a 4 to 1 reduction in RSDCS data load in the worst case, i.e., single man intrusions. Note that for an intruder group of any length the message length emitted by the processor always remains at 28 bits. Therefore, as intruder groups get longer the reduction in RSDCS data load becomes more dramatic. This is illustrated clearly in Figure 6-25.

If the local pre-processor were used instead of the processor, the reduction in RSDCS data load would not be as great but still quite significant as illustrated by Figure 6-26.

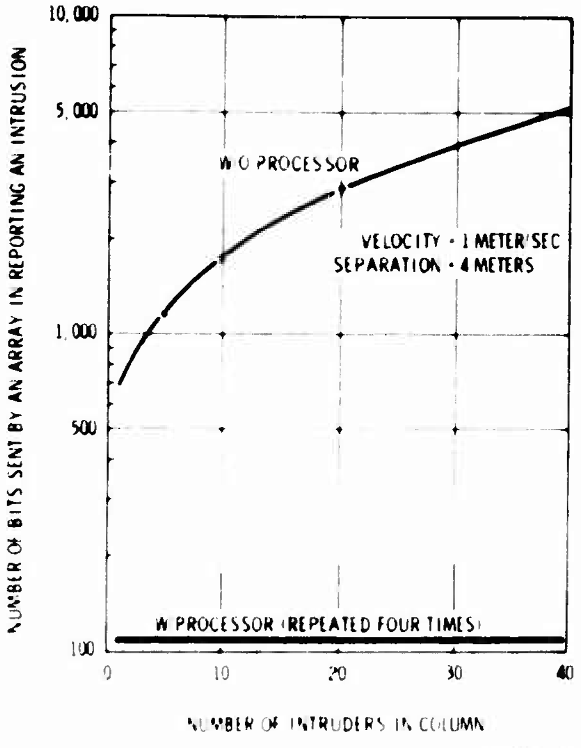


Figure 6-25 (C). Reduction in RSDCS Data Load Using Local Processor as a Function of Number of Intruders (U)

6.5.2 (C) CSCPD Operation

Local processing or pre-processing impacts on the CSCPD is essentially two ways:

a. The amount or density of data that must be handled by the CSC processor, and

b. The complexity of the processing that must be done.

When using local processors in the WARS subsystem, the data arriving at the CSC is ready for immediate interpretation after proper decoding. That is, the incoming messages contain the sensor, array, and Wide Area addresses, and the measured intruder parameters. Therefore, in small deployment situations, the CSC would simply consist of a message decoder and a convenient display, such as a standard teletype(s). More elaborate displays could, of course, be used for ease of data management, but the simple teletype display would allow a newly deployed BESS to be in operation almost immediately after the WARS and RSDCS equipment is deployed.

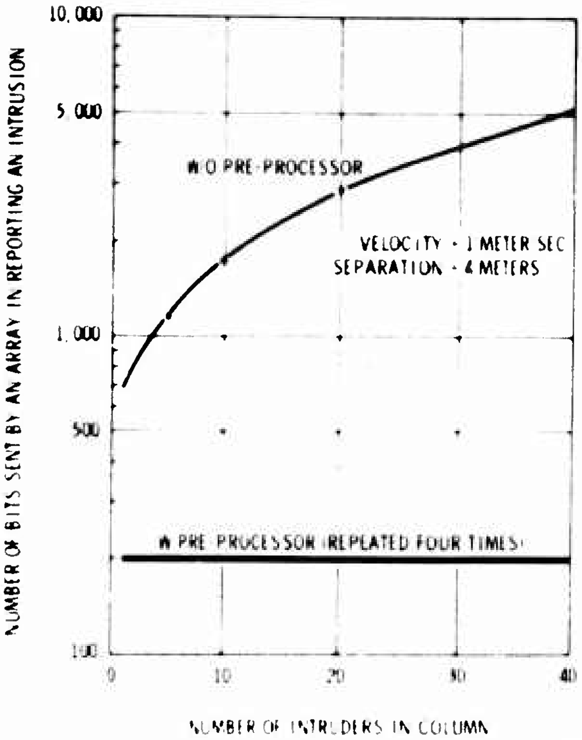


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Figure 6-26 (C). Reduction in RSDCS Data Load Using Local Pre-Processor as a Function of Number of Intruders (U)

6.5.2 (C) (Continued)

If local pre-processing were employed, the CSC would require centralized processing capability since the message data arriving at the CSC would not be in a form for immediate interpretation. However, as illustrated in Figure 6-26, the reduction in data density realized through the use of pre-processing would greatly reduce the data handling or computational requirements of the CSC.

6.5.3 (C) Deployment Flexibility

Perhaps the most important impact of on site processing on the BESS is the flexibility it adds to the BESS concept. As illustrated in the previous section, local processing will allow the deployment of BESS at a small installation (< 500 sensors) with a minimum need for CSC data processing capability. It is also cost-effective as illustrated by Table 6-1. Note that the cost given for a WARS central display with processing is an estimate for a production unit which could be used as an alarm data processor serving 2000 or more deployed sensors. This includes message decoding, calculating, and display equipment.

In addition to its desirability for small installations, local processing allows the orderly growth of a given installation. This is illustrated in Appendix C which

Table 6-1 (U). Cost Comparison of BESS Equipment for Small Installation (U)

COST COMPARISON BARE BASE

	BASE LINE	BASE LINE + PROCESSOR
165 Sensors	51,000	51,000
33 Receiver Relays	23,000	23,000
9 Processors		33,000
5 Receiver Interface	3,000	3,000
1 WARS Central Display (with processing)	136,000	
1 WARS Central Display (without processing)		5,000
TOTAL	213,000	115,000

6.5.3 (C) (Continued)

presents a scenario of the growth of the BESS for a hypothetical air base starting from a small configuration.

Table 6-2 gives a cost comparison for a large base installation (2000 sensors) for various levels of local processing. It can be seen that centralized processing at the CSC is the most cost effective approach to BESS deployment in this situation, by at least 15% in cost.

6.5.4 (C) Summary of Local Processing Impact on BESS

Summarized below are the more important features of on-site processing as it impacts on BESS:

a. Make BESS adaptable to any size base or installation.

b. Permits rapid deployment of WARS sensors with immediately useful output.

c. No requirement for full CSCPD for smaller installations.

d. Lower hardware cost for small base installations (for example, 25 Wide Areas with 500 sensors).

e. Reduces the impact of physical attack on the CSC, i.e., in many cases the CSC can be simply and cheaply replaced if destroyed.

f. Allows an alternate command post access to WARS data at low cost.

g. Gives a factor of 10 reduction in average RSDCS on air time making the RSDCS less vulnerable to RF direction finding.

h. Factor of 10 reduction in RSDCS on air time allows a 10 to 1 reduction in RSDCS bandwidth requirements, or utilization of full bandwidth for reduction of jamming vulnerability.

Table 6-2 (U). Cost Comparison of BESS Equipment for Large Air Base Installation (U)

COST COMPARISON LARGE BASE

	BASE LINE	BASE LINE +POLLED RSDCS	BASE LINE +PRE-PROCESSOR	BASE LINE +PROCESSOR
2000 Sensor/Transmitters (Standard)	620,000	620,000	620,000	620,000
100 Receiver Relays	275,000	275,000	275,000	275,000
100 Pre-Processors			280,000	
100 Processors				362,000
100 Receiver Interface	65,000	65,000	65,000	65,000
100 Direct RSDCS	47,000		47,000	47,000
100 Polled RSDCS		362,000		
25 RSDCS Relays	43,000	43,000	43,000	43,000
1 WARS Central Display (with processing)	136,000		56,000	
1 WARS Central Display (with processor) (+ command TX)		156,000		
1 WARS Central Display (without processor)				36,000
TOTAL	1,186,000	1,521,000	1,306,000	1,448,000

Section 7

APPLICATION OF WARS IN KOREA

7.1 (U) OBJECTIVES AND ORGANIZATION OF THE STUDY

The purpose of this study was to estimate the applicability of the WARS concept to air bases in South Korea. In order to accomplish this objective, a brief examination was made first of the overall situation in South Korea and then a more detailed analysis was conducted of two scenarios: (1) Osan, an actual air base, and (2) Samyong, a hypothetical air base. Subsequent to this, an example was worked out of how a limited version of the WARS subsystem might be deployed in South Korea to warn the Osan Air Base of an impending attack.

7.2 (C) FACTORS BEARING ON THE PROBLEM

7.2.1 (C) General Background

While there are differences in weather and topography between Korea and other places in the world, such as Vietnam, primary consideration for determining the degree of validity of the WARS concept must be given to the fact that air bases in Korea are located in secure areas, and have no history of stand-off attacks. Consideration must also be given to the elements which provide a large measure of this security: the densely populated areas which extend from the base perimeter fence outward beyond the 5 to 15 mile annulus.

At the present time, the North Koreans are infiltrating agents/saboteurs into South Korea for the purpose of establishing guerrilla bases and organizing a communist infrastructure. These highly trained groups have proven their combat effectiveness by conducting harassment raids along the demilitarized zone and even on the capital itself. This indicates they have the capability to launch limited standoff attacks against air bases amd AC&W sites. The majority of these infiltrators are brought into South Korea by sea, landing 25 to 35 man groups in the proximity of known guerrilla strongholds. Although it is known that weapon caches have been established, to date weapons from these caches have not been used against Air Force installations.

This reluctance to attack air bases can be attributed, in part, to the lack of support given the communists by the South Korean populace and the aggressiveness of the Korean National Police. The possibility, however, exists that such attacks may be attempted in the future and therefore the U.S. and Korean commands must maintain up-to-date contingency plans which, among other things, should include early detection of an impending RAM attack on air bases.

7.2.2 (U) Topography and Climate

Korea is largely mountainous with broad fertile river valleys framed by rugged, general north-south ridges. Elevations are not extreme, however, and only one peak, Paektu Mountain, is over 9,000 feet. The mountain mass slopes northeast to southwest,

7.2.2 (U) (Continued)

giving way to broad plains along the Yellow Sea and on the southern edge of the Peninsula. The principal ranges run southward from the eastern extension of the northern frontier. The Taebaek Range, which parallels the east coast from Yonghung Bay in the North to roughly the 37th parallel in the South, forms the backbone of the Peninsula. This rugged terrain is well-suited to guerrilla operations and a number of peaks in the South have been focal points of such activity since the outbreak of the Korean War. In addition to the Taebaek Range near Samchok, guerrilla sanctuaries have been established on the Chii Mountain, about 40 miles north of Yosu, the Halla Mountain on Cheju-do, and the Chiri-san Mountains in south central Korea.

Most of the major rivers, including the Yalu, the Ch'ongch'on, the Taedong, the Imjin, the Han and the Kum, flow into the Yellow Sea. The Naktong drains into the Korean Strait. In the mountainous region, rivers are generally winding with swift currents, while in the lowlands they are sluggish, silt-laden, and usually navigable for small craft throughout the year.

Temperature varies widely between summer and winter, and there is great regional diversity. In the mountainous northern interior the winters are bitterly cold; along the southern coast average monthly temperatures are above freezing. Frost-free days vary from 130 in the northern interior and 170 in the central region around Seoul to 226 in the South around Pusan. Summers are generally hot and humid and show less regional variation than the winters. Most of the rainfall occurs during the summer months throughout the country varying from 25 to 60 inches a year. Climatic conditions also reflect the presence of warm and cold currents in the waters which surround the Peninsula on three sides.

Except for more rain in mid-summer and drier winters, South Korea's climate resembles that of the American eastern seaboard. The climate on the east coast is conditioned by the Sea of Japan, with mild winters and relatively hot, wet summers.

The parts of the country well-suited to agriculture are the coastal plains and the wide inland river valleys. Most arable land in the country has been under cultivation for decades. It is estimated that 23 percent of all land in South Korea is arable.

South Korea's total acreage is only 24.3 million acres. More than half of the 5 million acres of arable land is paddy; the rest are dry fields on uplands and mountain slopes. Half of the total land under cultivation lies in three provinces: Kyonggi-do, where the city of Seoul (and Osan Air Base) is located; Kyongsang-pukto, the largest province; and Cholla-namdo. In the mountanious centers are small pockets of plains-like land, creating upland areas of diversified farming.

The plains areas support the largest and most closely located communities. Farm houses are typically grouped into a compact village, surrounded by fields and usually close to a stream or river. There are communities in the river valleys of the uplands, but since the quality and quantity of arable soil decrease in the mountains, the villages become smaller and the houses more widely spaced. In the mountainous areas, the houses are scattered about the fields and are not banded together in villages.

7.2.2 (U) (Continued)

The village is a cooperative unit reflecting Korean family values and way of life on a larger scale. Often all the inhabitants of a village have the same family name. Traditionally, each unit of six or seven adjacent families in the villages has a chief, the panjang, who represents his group before the myon (township) officials. This cooperative existence makes it extremely difficult for an agent to penetrate. Korean National Police uses this situation to their advantage, requiring villagers to report any and all strangers.

7.2.3 (C) Political Environment

The unpleasant experience that many South Koreans had with the North Koreans and their sympathizers during the periods of occupation and the close contacts with the millions of refugees from the North have made it difficult for the North Korean agents to gain support.

Communist efforts have also been hampered by the effectiveness of the South Korean security agencies. The National Police, the Counterintelligence Corps of the Army, and the South Korean Central Intelligence Agency, working in cooperation with United States security forces have been able to limit, to a high degree, the activities of Communist agents.

An important feature of North Korea's subversive efforts is the large number of residents in South Korea with close relatives in the North. Many South Korean political, military, and other leaders have parents, brothers, and other relatives in the North. While generally unpublicized, the possibility of pressure or actual physical harm to these relatives cannot be ruled out as a means of facilitating the activities of the threat.

The South Korean peasants, although anti-communist, are still considered by the threat as a potentially fertile field for communist subversive efforts. Many of them, living in abject poverty, are susceptible to communist propaganda which stresses the theme that their plight is brought upon them by "corrupt and incompetent" government officials. Despite North Korean efforts, open manifestations of peasant dissidence have been virtually negative since the signing of the truce in 1953.

Members of the military and police forces are among the most reliable elements in South Korea. The military, nevertheless, continues to be a major target for North Korean subversive efforts. The North Korean regime has announced that preferential treatment would be given to South Korean servicemen who came over to the North, individually or in groups, for the "honor of the nation" and for the "unification of the fatherland".

Policemen were promised the same consideration as military servicemen. However, despite these communist efforts, defections have been few, and it is doubtful that North Korean offers of special treatment are effective.

7.2.4 (U) National Police

The National Police, under the rigid regime of President Rhee (1948-1960), was built up to a strength of some 40,000 to 50,000 men. During the frequent periods when martial law was imposed, the police, in addition to their customary duties, were used

7.2.4 (U) (Continued)

in conjunction with military forces to maintain the regime in power by suppressing political opposition. This created animosity toward the National Police.

Since the overthrow of President Rhee, governmental efforts toward separating the police system from political influence have met with widespread approval. Moreover, the police force has been reduced to approximately 30,000 and much of its former arbitrary authority has been curtailed. As of mid-1964, the principal police missions included the maintenance of law and order, the enforcement of laws and regulations pertaining to public health, public safety, smuggling, the protection of life and property, cooperation with civil authorities in civil defense matters, the administration of conscription laws, the control of refugees, and action against guerrilla or subversive groups.

The National Police, since mid-1954, has functioned under the Ministry of Home Affairs, through a headquarters called the Public Security Burearu.

7.2.5 (C) Military Forces

The South Koreans (ROK's) have an army of 640,000 men supported by a 23,000-man Air Force and a 55,000-man Navy. In addition, the U.S. Army fields 50,000 troops and a 5,000-man Air Force.

The North Koreans have 18 infantry divisions, comprising nearly 400,000 men, a 20,000-man Air Force, and an 88,000-man Navy which includes 186 torpedo boats and "agent" boats: fast craft disguised as fishing vessels, for landing infiltrators on South Korea's coasts.

Military planners in South Korea have agreed that the greatest threat to air bases in South Korea is this 20,000 man Air Force with its roughly 1000 airplanes. The planners, therefore, relied heavily on anti-aircraft for base defense and minimized the threat of a Rocket, Artillery and Mortar (RAM) attack. The rationale behind this decision is based on the inability of the communists to move unobserved in the South, especially in vicinity of air bases. This, they feel, would make it virtually impossible for the threat to infiltrate a force capable of launching a standoff attack against an air base without detection. This may or may not be a valid appraisal of the situation. The fact remains that North Korea has arrayed 180,000 troops along the northern trace of the DMZ, many of whom make regular forays into the South. In 1966, North Korean Premier, Kim Il Sung, declared an all-out effort to establish guerrila bases in South Korea. He has since carried his promise into action. In 1967, his agents intruded 566 times; in 1968, this figure nearly doubled. He has also positioned a 2,400-man commando force just north of the DMZ which sends small teams deep into South Korea bent on sabotage and terrorist activities.

The North Korean military planners have learned from the war in Vietnam that the gravest threat they face in the event of a resumption of hostilities is from air attacks. They have also witnessed the effectiveness of the North Vietnamese RAM attacks on U.S. bases and it must be assumed that the North Koreans are integrating similar tactics into their scheme of maneuvers.

7.2.6 (U) Weapons

The North Koreans will have available to them any weapon in the communist bloc inventory. It must be assumed, however, that the unique situation in South Korea which denies the threat a source of porters will limit the weapons he would use for a standoff attack to those that are man-portable. Some of these are shown in Figure 7-1.

7.3 (C) SCENARIOS

Two air bases, Osan Air Base and a hypothetical one, Samyong Air Base, will be used in this study to illustrate typical scenarios which are encountered in Korea. The location of these air bases is shown in Figure 7-2. The reason for choosing a hypothetical air base was to illustrate conditions other than those found at Osan Air Base.

7.3.1 (C) Osan Air Base

7.3.1.1 (C) Physical

Osan Air Base, the layout of which is shown in Figure 7-3, is located 42 miles south of Seoul and 13 miles inland from the Yellow Sea. Approximately 65 percent of the area is flat and intermingled with rice paddies. The southeastern portion of the base is dominated by two hills which extend approximately 150 to 225 meters above the runway level. The on-base ammunition storage area (see Figure 7-3) surrounds another steep, 100-meter hill. The northern and western areas outside the perimeter are relatively flat with minor vegetation which does not obstruct the line-of-sight. The southeastern portion of the base is surrounded by villages. In the case of the ammunition storage area, the village dwellings look down into the storage sites. A concrete block wall is being constructed as a perimeter barrier between the village and the base. There is an off-base ammunition storage area located approximately three and one-half miles from the base. The Chinwi River forms the northern boundary and the Korean National railway traces the eastern limits of the base. Figure 7-4 shows a view looking north from the Osan Air Force Base.

7.3.1.2 (C) Mission

Osan Air Base is the headquarters of the 314th Air Division and is a key installation for the U.S. Air Force in Korea. Other operational units with headquarters at Osan are: (1) Det 1, 347th Tactical Fighter Wing which provides a deterrent capability as well as air defense, (2) the 94th Fighter Interceptor Squadron which provides air defense for Osan and central Korea, (3) Det 6, 556th Reconnaissance Squadron which provides support for air operations in Korea, and (4) the 6314th Support Wing which provides transportation, logistics, and personnel responsibility for all USAF units in Korea. In short, Osan Air Base serves as the center for tactical defense and air operations throughout Korea.

7.3.1.3 (C) Aircraft

The following types of aircraft are based at Osan Air Base:

F-106	F-4C	T-33	Helicopters
C-130	C-47	U-6	
C-123	T-29		

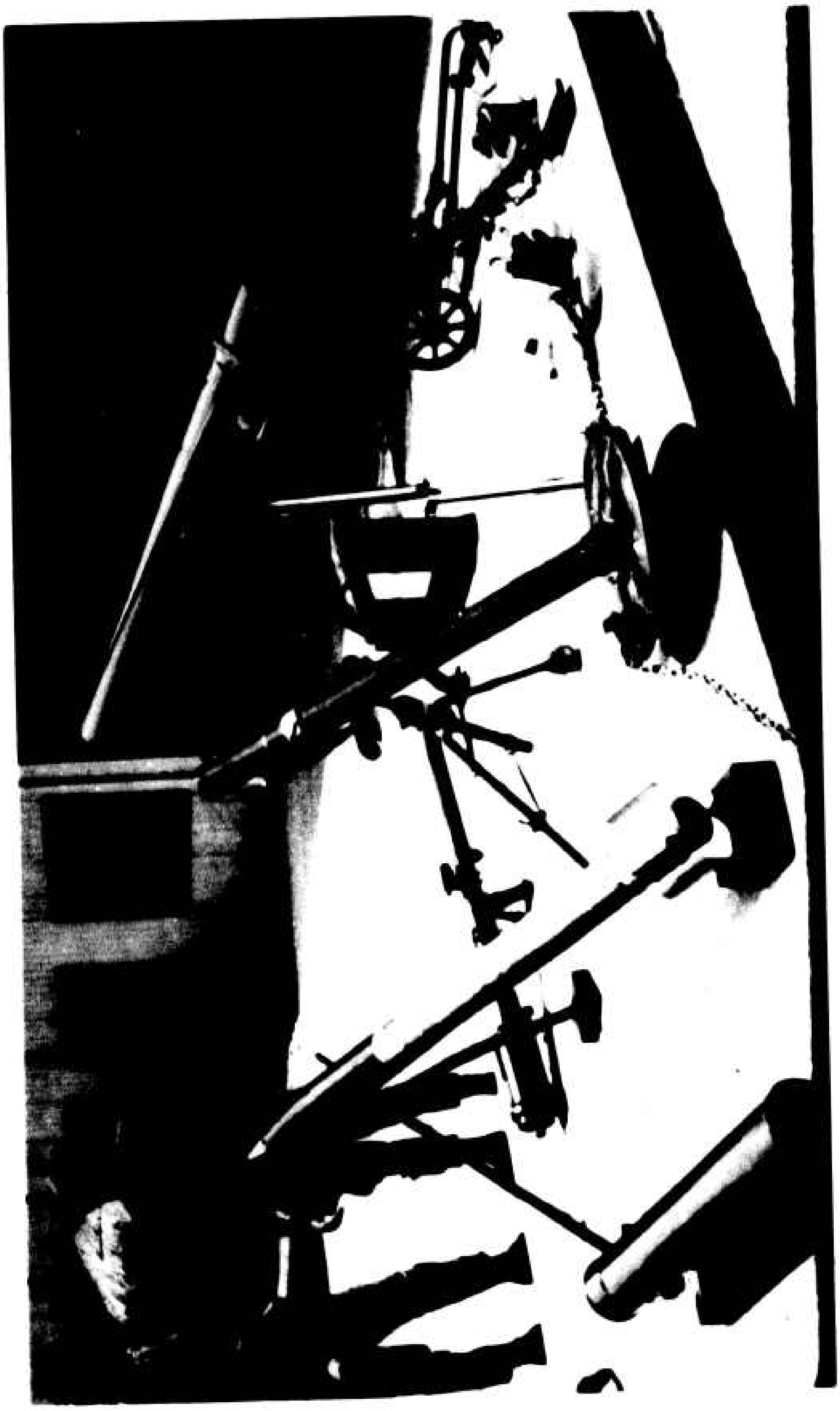

Figure 7-1 (U). Weapons Available to the Threat for Use in a Standoff Attack. Left-to-Right: 140-mm Launcher Tube, 122 mm Rocket, 82 mm Mortar, 122 mm Launcher Tube on Mount. Behind: 57 mm Recoilless Rifle, 140 mm Rocket (U)

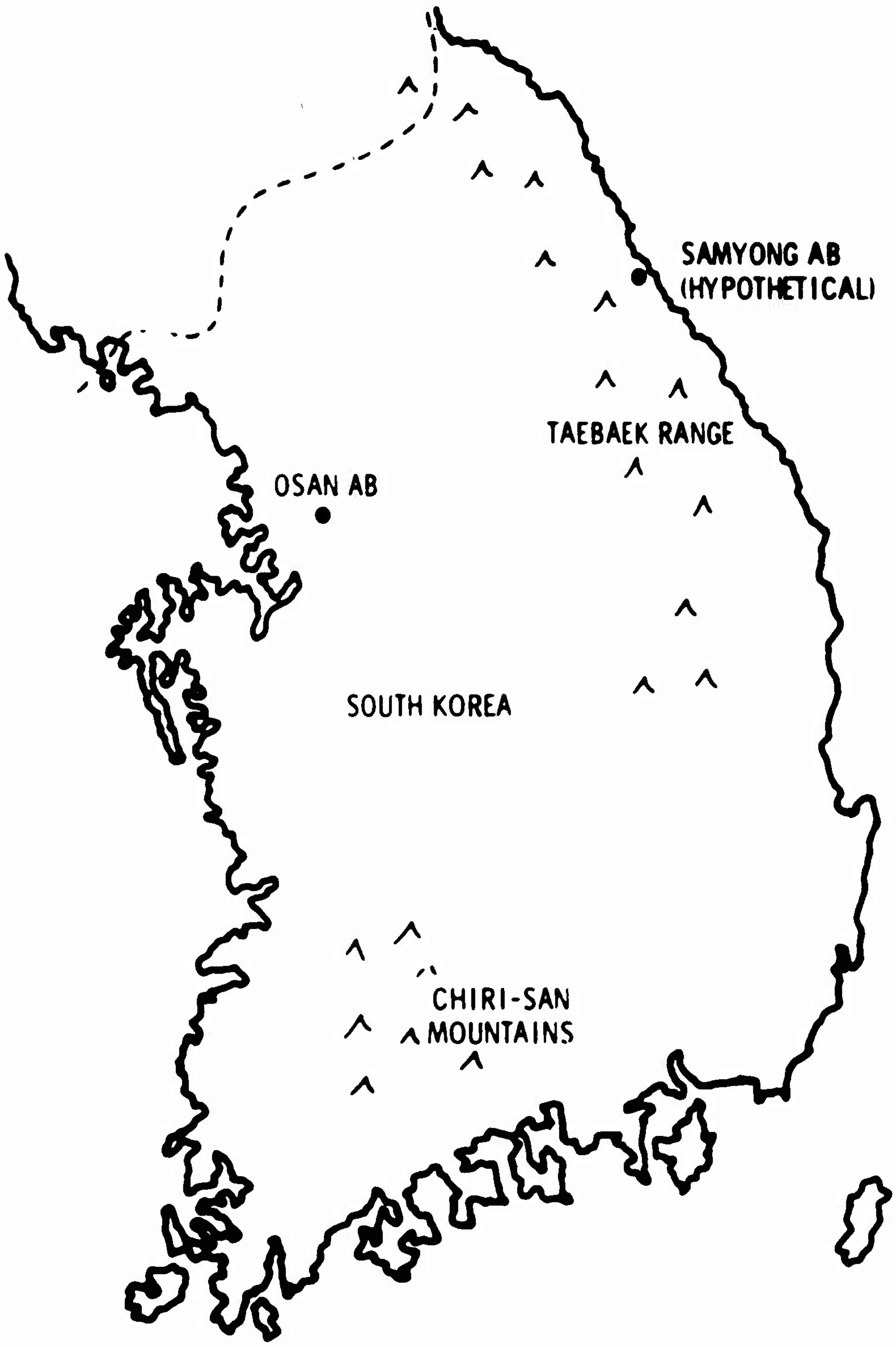

Figure 7-2 (U). Map Showing Air Bases used in Scenarios (U)

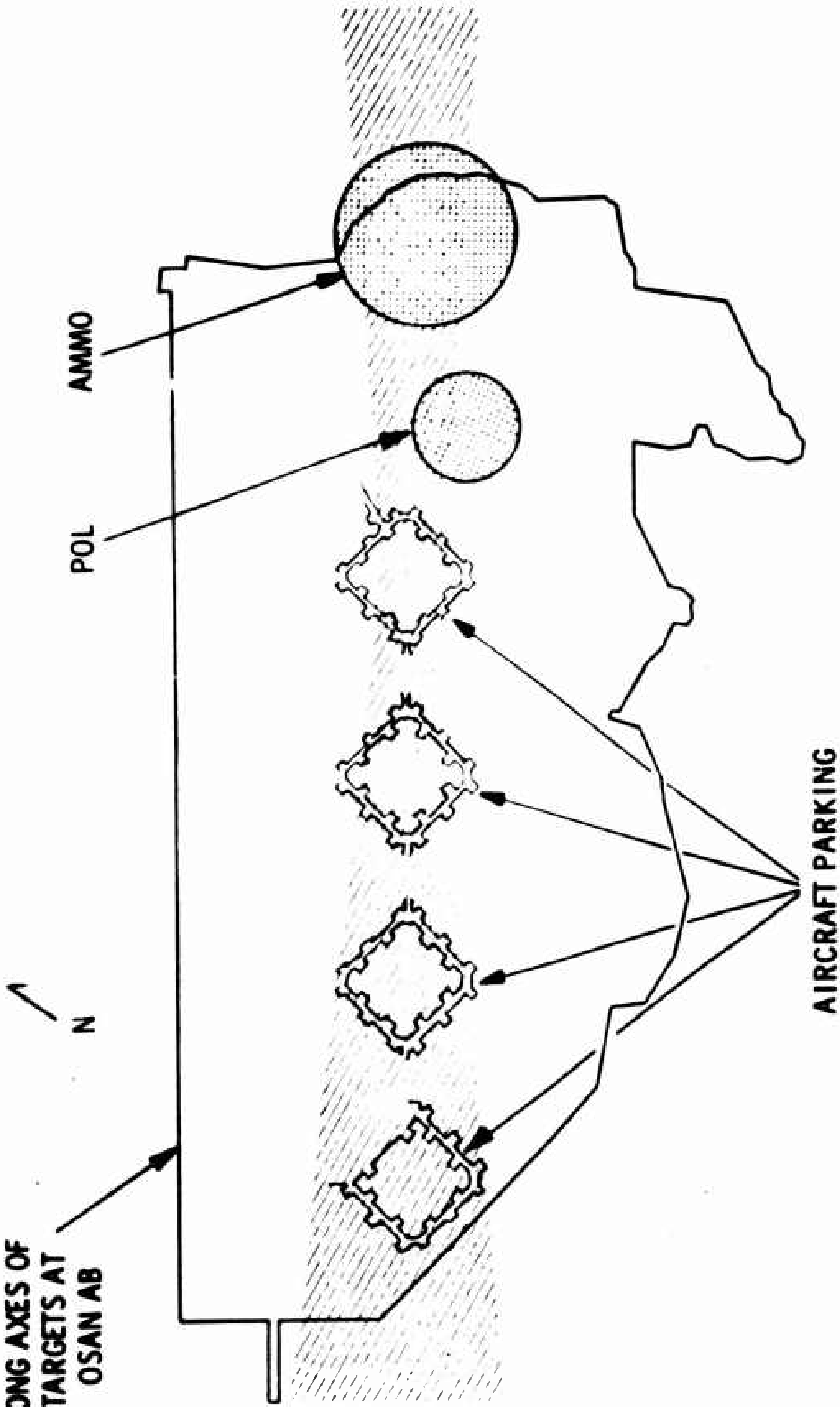

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Figure 7-3 (C). Layout of Osan Air Base (U)

Figure 7-4 (U). View Looking North from Osan Air Base (U)

7.3.1.4 (U) Soil Data

The soil consists primarily of sand, clay, and rock down to 2 feet, followed by a foot of sand then clay to the water table at 7-1/2 feet. The maximum frost depth is 40 inches. The entire area is open and offers few concealed routes of approach.

7.3.1.5 (U) Climatology

During all seasons of the year, there exists the possibility of fog moving off the Yellow Sea and obstructing visibility. The problem becomes a major one during late winter, spring, and the early months of summer. Storm centers passing through central Korea frequently lower the ceiling to 1,000 feet or less. Low cloud cover oftens prevails for as long as two hours during which time the visibility is lowered to 1/2 mile. Because of the absence of heavy industry in the area, smoke pollution is limited and seldom restricts visibilities to less than three miles. A Climatology Chart of Osan Air Base is presented in Table 7-1.

7.3.1.6 (C) Threat Estimate

Osan Air Base is not particularly vulnerable to a standoff type of an attack. The 5-15 mile annulus around Osan Air Base includes single family dwellings, villages, rice paddies, heavily traveled roads, a railroad, and some high ground to the southeast and west. The proximity of the base to the Seoul metropolitan area ensures a heavy concentration of security forces and an enforced curfew in the area. A stranger in the area would immediately become suspect and a group with weapons and munitions of sufficient size to constitute a threat to the base would find it extremely difficult to reach launch sites unobserved. However, the possibility of a RAM attack exists to some degree for every military installation in South Korea. Even Osan Air Base is vulnerable to an attack from a determined, well-trained enemy. A terrain analysis of the area around Osan Air Base indicates Osan Air Base is most vulnerable to an attack from the West. The attack, which would probably use a combination seaborne/overland approach to firing points, would be launched from one or more launch sites on the high ground approximately 8 km west of base perimeter. The fire team, using launch sites in this area, would be able to take advantage of the long axis of the target and would have observation of the target. A more detailed discussion of how such an attack may be executed and how the WARS subsystem might be deployed to obtain an early warning of the impending attack is covered in Section 7.5.

7.3.2 (U) Samyong Air Base (Hypothetical)

7.3.2.1 (U) Physical

Samyong Air Base is situated on the east coast of the Korean peninsula bordering the Sea of Japan. It is approximately 100 miles south of the eastern terminus of the DMZ south of the villages of Sam Chok and Pukpyong. The air base is relatively flat and lies in a 6-mile-wide valley that extends 25 miles northeast to southwest. The base is dominated on the west by the 1353 meter Tut-a-san mountain, on the south by the 1263 meter Tog-ye mountain and on the east by the 500 meter Hamaum plateau. A view of the Tut-a-san Mountain is shown in Figure 7-5. The Yong-Dong railroad (Seoul to Kangnung), parallels the western perimeter fence at the base of the Tut-a-san mountain.

Table 7-1 (U). Climatology Chart, Osan Air Base (U)

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TEMPERATURE (°F)												
Extreme Max	55	61	71	81	89	97	97	99	91	83	71	65
Mean Max	33	39	49	62	73	79	85	87	78	67	53	40
Mean Min	15	21	31	42	52	62	72	72	60	45	34	23
Extreme Min	-16	-11	14	24	39	48	57	58	38	26	14	0
PRECIPITATION (in.)												
Monthly Mean	1.1	1	2.4	4.4	3	5	15.4	8.4	6.5	1.8	1.7	1.2
24-Hr Max	2.5	2.5	2.5	5.8	3.7	10	20	10	10	2.5	2.5	2.5
SNOW (in.)												
Monthly Mean	8	2	1	#	0	0	0	0	0	#	#	3
Max Snow Depth	18	6	1	#	0	0	0	0	0	0	1	14
24-Hr Max	10	6	2	#	0	0	0	0	0	#	1	14
WIND (kts)												
Prevailing Direction	NW	WNW	W	W	W	W	SW	E	E	E	E	NW
Mean Speed	5	5	5	6	5	4	5	4	4	4	4	4
Max Speed	54	30	29	43	27	25	35	35	34	21	27	33
MEAN NUMBER OF DAYS WITH												
Precipitation	7	4	7	8	8	10	16	12	9	6	8	6
Snowfall (greater or equal to 0.1 in.)	6	2	1	#	0	0	0	0	0	#	1	2
Thunderstorms	0	#	#	1	1	1	5	3	1	#	#	#
Fog less than 7 mi	13	12	16	15	15	18	22	20	20	19	17	15

Figure 7-5 (U). Tutasan Mountain which Dominates Samyong Air Base on the West (U)

7.3.2.2 (U) Mission

Samyong Air Base is the home base of: (1) Det 2, 347th Tactical Fighter Wing which provides a deterrent capability and air defense; (2) 99th Fighter Interceptor Squadron which provides air defense for eastern Korea, and (3) 620th Troop Carrier Squadron which provides the air lift capability for the 173rd Airborne Brigade located 40 miles to the south. The base also provides logistical support for a 120-man ROK Army security force located in temporary billets atop the Hamaum plateau.

7.3.2.3 (U) Aircraft

The following types of aircraft are based at Samyong Air Base:

F-106

F-4E

C-130

Helicopters

7.3.2.4 (U) Soil Data

The soil on the valley floor consists mainly of reddish-brown latosols on basalt-derived parent materials. The rugged Tabaek Mountains are characterized by steep limestone rocks which have a minimum of soil cover. Basalt crags jut into the Sea of Japan at the mouth of the valley. Extensive agriculture has been crowded into the valley and partially on the slopes of the surrounding hills.

7.3.2.5 (U) Climatology

The east coast of Korea enjoys relatively mild winters due to the warmer currents in the Sea of Japan. The mountains which generally parallel the coast are snow covered from November through February. A Climatology Chart for Samyong Air Base is shown in Table 7-2.

7.3.2.6 (U) Trails

There are relatively few parallel trails traversing the Taebaek range from north to south. The main route follows a general course along the creast, meandering somewhat to bypass major obstacles. Cross-trails, usually leading to the valleys, intersect where connecting ridges join the main ridge.

The major trails range upward to one meter from a width of 14 inches, and are narrowest where they weave around boulders and pass through crevices. The trail surface is rocky as a result of the top soil eroding from centuries of travel. In wet weather, however, a fine layer of soil on this rocky base makes the trails extremely slippery. In places where the terrain rises or descends sharply, steps have been cut or worn into the limestone. Water coursing down some of the trails has caused trail erosion creating treacherous footing. Many of the trails lead to abandoned mine shafts. Recent usage of these trails could indicate a weapons cache in the mine.

Table 7-2 (U). Climatology Chart for Samyong Area (U)

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TEMPERATURE (°F)												
Extreme Max	55	63	73	83	91	95	95	97	93	81	73	67
Mean Max	36	40	48	58	69	75	83	85	77	67	55	43
Mean Min	24	28	35	44	55	64	73	74	63	51	40	31
Extreme Min	4	8	16	30	46	50	62	62	46	36	20	14
PRECIPITATION (in.)												
Monthly Max	2	3	3	7	5	23	19	8	14	3	4	3
Monthly Mean	2	1	3	4	3	4	10	8	5	2	2	2
Monthly Min	*	*	*	2	1	2	3	5	2	*	1	*
24-Hr Max	1	1	1	2	3	8	8	6	7	3	1	1
SNOW (in.)												
Monthly Mean	12	3	1	*	0	0	0	0	0	*	1	8
Max Snow Depth	28	27	*	0	0	0	0	0	0	0	2	24
24-Hr Max	10	4	2	*	0	0	0	0	0	*	5	16
WIND (kts)												
Prevailing Direction	N	MNW	NW	NW	NW	W	W	SW	SW	NE	E	N
Mean Speed	8	8	8	8	7	7	7	8	7	6	6	6
MEAN NUMBER OF DAYS WITH												
Precipitation	10	7	7	7	7	10	13	10	9	6	7	10
Snow	8	4	1	0	0	0	0	0	0	0	1	4
Thunderstorms	0	0	-	1	1	1	4	6	2	1	-	-
Fog less than 5/8 mi	69	67	96	84	66	83	88	42	45	43	52	61

*Less than 0.5 in.

7.3.2.7 (U) Vegetation

Rather mild winters in the Samyong areas is conducive to the growth of short (4-10 meter) deciduous trees together with a squat thorny underbrush. A tough wiry grass 12-24 inches high grows in the more open areas. The foothills and lower slopes of the mountains are under cultivation, usually rice and beans. All available land in the valley supports paddy rice. Heavier forest areas are found at higher elevations in the Taebaek range.

7.3.2.8 (U) Background

Samyong was constructed during the Korean War (1952), and served as an Air Force logistical base to support U.N. Forces operating in the eastern portion of Korea. It was deactivated in 1956 and assigned to ROKAF control. The ROKAF stationed a caretaker unit at Samyong and made no attempt to improve or maintain the defense fortifications.

In 1970, the base was reactivated as a USAF installation and work commenced immediately on repair of buildings and facilities. Hasty revetments consisting of earth filled oil drums were replaced by reinforced concrete domes. An 8 foot chain link fence topped with barbed wire was erected around the perimeter. For the present, open storage is being utilized. The villagers of Samchok and Pukpyong resent the reopening of the base, claiming the aircraft noise is detrimental to fishing in the area.

In 1967, the ROK Navy destroyed a North Korean coastal vessel which was caught unloading agents and munitions two miles south of Samchok. Twenty-three agents were apprehended and nine escaped. The South Korean CIA has estimated that approximately 80 agents have crossed the DMZ and established scenarios in the Taebaek Mountains west of Samyong air base. ROK Army operations have failed to locate these sanctuatires.

The United Nations commander has recently tasked the USAF Combat Security Police with the responsibility of gathering and correlating intelligence out to 30 km from the base.

7.3.2.9 (U) Threat Estimate

Samyong Air Base is vulnerable to either land-based or sea-borne standoff attack. For the purpose of this scenario, only the land-based attack will be considered.

7.3.2.9.1 (U) Sea-Borne Attack

The numerous small boats fishing in the waters off the coast of Samchok-Pukpyong and the obvious hostility of the local fisherman offer the North Koreans a golden opportunity to infiltrate rocket-equipped "fishing boats" close enough to shore to cause considerable damage to the air base. The troop billets and base headquarters are well within the range of recoilless rifles and mortars. The aircraft parking areas, ammunition and POL storage areas, communications buildings, TACAN, and control towers are all likely targets for a rocket attack. Following a sea-borne attack, the threat can either beach his craft and move to the Taebaek sanctuaries or move out to sea. Figure 7-6 shows a view of the coastal area near Samyong Air Base.

Figure 7-6 (U). View of Coastal Area Near Samyong Air Base (U)

7.3.2.9.2 (U) Land-Based Attack

The long axes of the targets at Samyong Air Base run northwest and southwest as shown in Figure 7-7. Both axes will allow the threat to launch a standoff rocket attack from concealed firing points on the upper slopes of the Taeback Mountains. Pin-point or specific targets such as the POL and ammunition storage areas, TACAN sites, and individual aircraft could be attacked with shorter range weapons (mortars, recoilless rifles), from the lower slopes of the Taeback range.

7.3.2.9.3 (U) Likely Avenues of Approach

Threat sanctuaries in the Taeback mountains will allow carrying parties and fire teams to move via covered routes to firing points. Supply points and caches may already have been established and firing positions need only be prepared in the vicinity of launch sites. Figure 7-8 indicates some possible firing points and likely avenues of approach for Samyong Air Base.

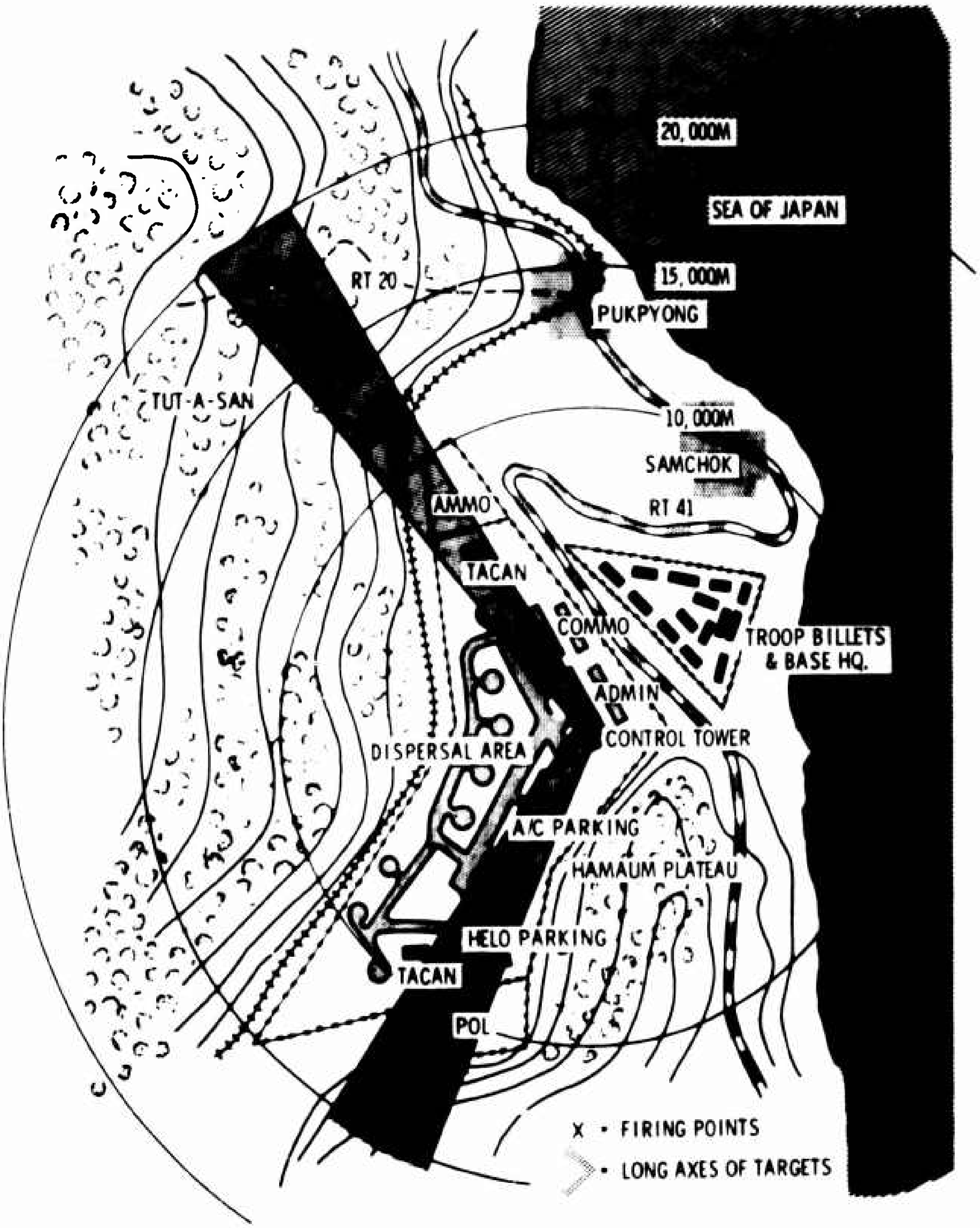


Figure 7-7 (U). Samyong Air Base Showing Long Axes of Targets and Possible Firing Points (U)

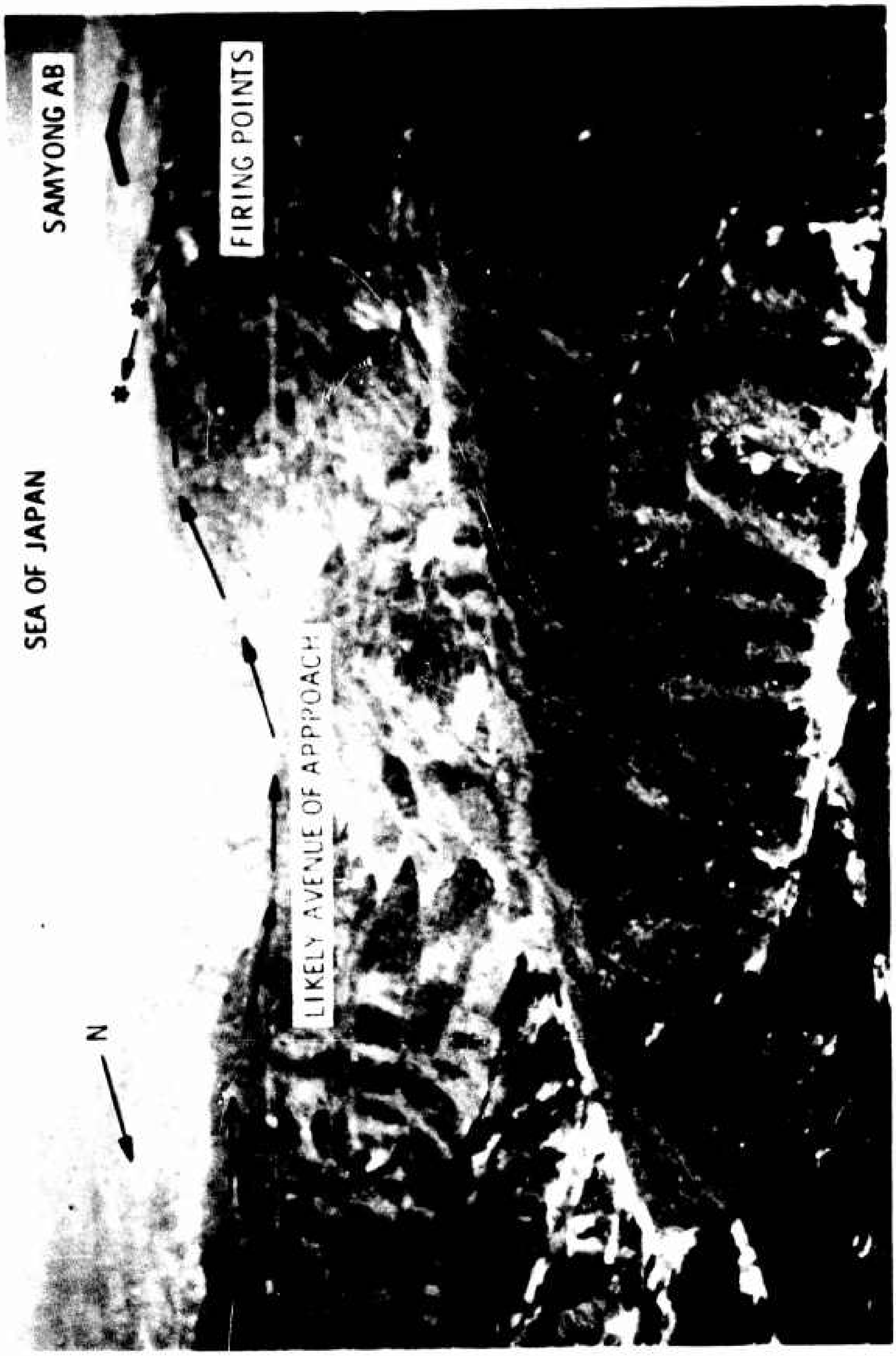


Figure 7-[illegible] (U) View Looking East Toward Samyong Air Base from Possible Firing Points in the Taebaek Mountains (U)

7.4 (C) AN OVERALL ASSESSMENT OF THE THREAT

7.4.1 (C) AC&W Sites

Most vulnerable, but not necessarily the most disabling, Air Force targets are the Aircraft Control and Warning (AC&W) sites. The requirement for positioning these sites on high ground dictates that many of them be located in remote areas. This permits the threat to move to within range of the site with considerably less chances of being detected than would be found in the more populated areas. The physical location of the site on dominant terrain, plus the distinctive size, shape and color of the radomes, readily identifies these targets. The threat, by taking advantage of cross-corridors and rugged terrain could launch an attack and then withdraw rapidly via a relatively secure route to his sanctuaries. Figure 7-9 shows a typical Aircraft Control and Warning Site.

7.4.2 (C) Air Bases

At the present time, the two U.S. host air bases in South Korea, Osan and Kunsan, are reasonably safe from a Vietnamese-type RAM attack. Both bases are located in densely populated rear areas which do not support communist attempts at infiltration. Nor does the terrain in the vicinity of the base lend itself to guerrila-type operations. An attack of sufficient magnitude that could be considered other than a harassment, will require the movement of men carrying distinctive appearing weapons and munitions for great distances through an anti-communist population heavily saturated with security forces. Suitable firing points are few and far between and are subject to constant surveillance. It would be practically impossible to establish long-term caches within the 5-15 mile annulus as envisioned under the WARS concept, because of the daily inch-by-inch coverage of the area by local farmers. Figure 7-10 shows typical farm coverage in the vicinity of air bases in South Korea.

Kunsan and, to some extent, Osan are vulnerable to a sea-borne attack. Kunsan, abutting as it does on the Yellow Sea, could be attacked by North Korean torpedo boats running the gauntlet of ROK Naval patrol boats. It could also be subjected to a rocket attack from high speed PT-type boats disguised as fishing boats.

The situation is not quite the same for Osan Air Base. There the threat would need to disembark firing teams and ammunition bearers from boats and then move inland to firing points prior to an attack.

If the situation in Korea deteriorates to a point where the United States Commander directs the establishment of additional host bases, the situation may change. (This was discussed in Section 7.3.2). In this event, the new air bases as well as additional AC&W sites could become subject to RAM attacks.

7.5 (U) USE OF WARS CONCEPT IN KOREA

7.5.1 (C) General Assessment

Full scale WARS application is not considered appropriate for implementation around existing U.S. Air Force bases in Korea without some modification. A comparative analysis of the tactical situation and threat capabilities that now exist in

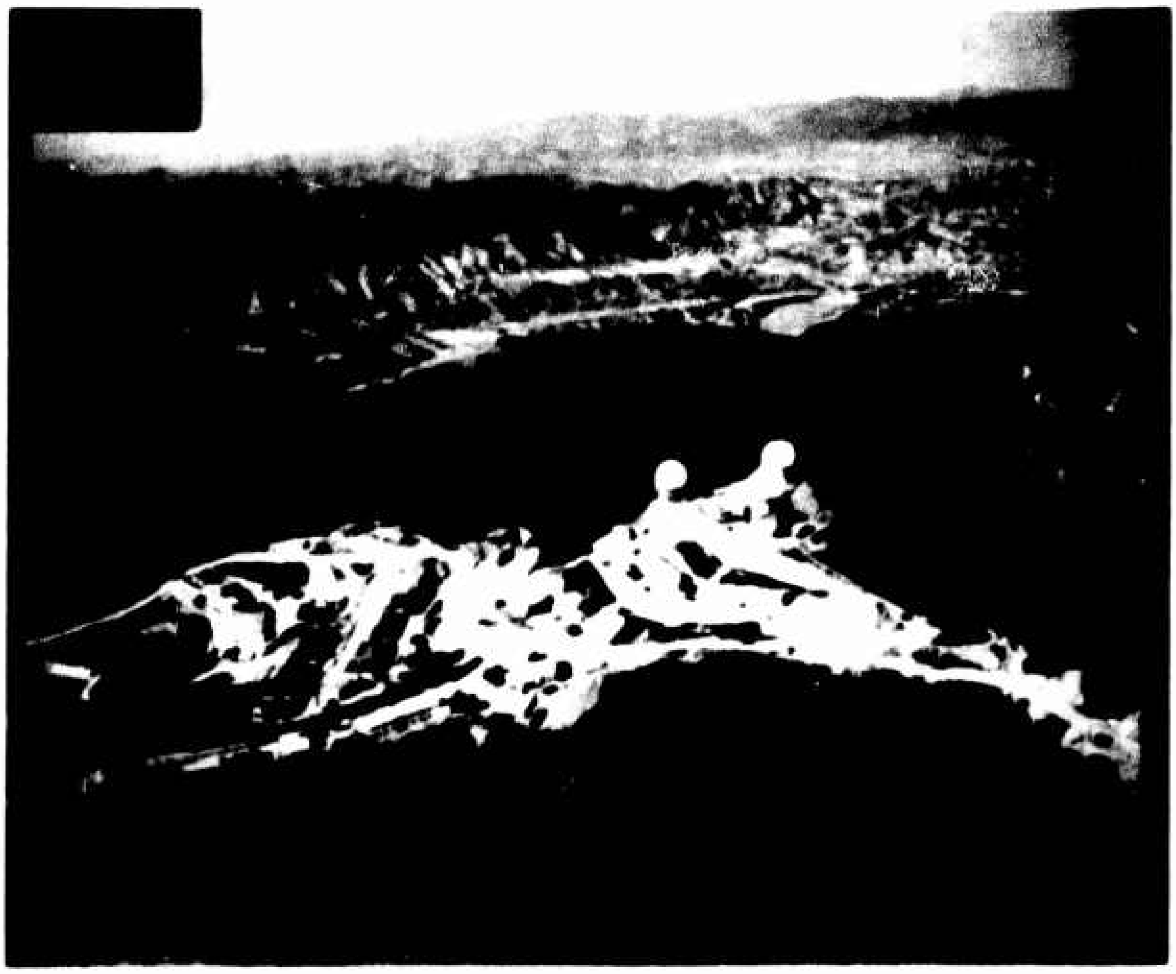


Figure 7-10 (U). Typical Farm Coverage in Vicinity of Airbases in South Korea (U)

7.5.1 (C) (Continued)

South Vietnam and South Korea reveal that the two have little in common. In Vietnam, for example, the threat has available a source of manpower to transport weapons and munitions, firing points which have secure routes of approach and withdrawal, and a chain of supply points. Furthermore, people indigenous to the suspected area would not advise the Government of any observed attack preparations, because of their constant fear of retaliation. This all comes about because there are no battle lines with secure flanks in Vietnam as there are in South Korea where every front-line division has its own rear-area security forces.

In the event of a resumption of hostilities in Korea, the conflict would be more conventional. Flanks would be secure along the entire Forward Edge of the Battle Area (FEBA), from the Yellow Sea to the Sea of Japan. Coastal defenses could be intensified and enemy infiltration held to a bare minimum. Support areas and known guerrilla sanctuaries can be isolated and kept under constant surveillance. The populace, already anti-communist, will be mobilized and alerted with the imposition of martial law. The relatively small number of guerrillas now in hiding in South Korea will find it difficult to exist, let alone conduct overt attacks on air bases.

Nevertheless, some harassment can be expected. Convoys traversing roads in the vicinity of guerrila sanctuaries may be attacked. Sabotage and even suicidal sapper attacks may be launched against the air base proper. This type of enemy action, however, does not fall into the category of a RAM attack.

In general then, it may be said that at the present time, the most valuable asset the U.N. forces in Korea have is the strongly anti-communist population of South Korea. The villages and farms are the sensors. The people themselves are the processors. A need exists, however, for a rapid means of transmitting this information from the people to the CSCPD. A scaled-down WARS subsystem could be used quite effectively in many areas; for example, on the restricted routes of approach to AC&W sites and in sections around the Samvong type of air bases. It could also be used to monitor the approaches to Osan Air Base from coastal attacks. The Wide Area concept would be reduced more to a Selected Area concept with these areas not necessarily restricted to the 5-15 mile annulus. The emplacement of sensor arrays on selected routes leading to and from the Taeback, Chiri-San and Holla Mountain Sanctuaries, especially during summer months, would be effective in monitoring threat movements directed toward these air bases or AC&W sites. Sensor arrays on parallel ridgeline routes in the vicinity of AC&W sites would provide early warning of threat movements and intentions.

The strategic emplacement of ground sensors reporting during curfew hours to an airbase CSCPD or its counterpart at an AC&W site would greatly reduce the chance of a surprise North Korean RAM or ground attack being launched against these installations. A hamlet communications system tied into the district National Police net would also provide a wealth of information which could aid both the Combat Security Police and the KNP in spotting infiltrators before they could move to launch sites.

7.5.2 (C) An Example

Timing is of utmost importance to the threat in an attack against Osan Air Base. His seaborne approach must coincide with outward-bound, local fishing vessels. His movement through the Punyang-man inlet to landing points must be timed to take

7.5.2 (C) (Continued)

advantage of the tide, otherwise, he could be stranded on mud flats for hours. His cross-country approach, attack, and withdrawal must be accomplished in sufficient time to allow him to mingle with local fisherman returning with their catches.

There are four likely landing points west of Osan where the threat could disembark and start his overland movement. These are shown in Figure 7-11. From these four points, numerous trails lead to the first of two 100-plus meter hills. Suitable firing points are located along the entire 6-km length of the westernmost hill mass, however, best firing points are located at bench mark (BM) 135 (north), and BM 112 (south). Of these two firing points, BM 112 would probably be the one selected because of its accessibility and rapid routes of withdrawal. The high ground at BM 120 and BM 155 mask the other firing points on the western hill mass disallowing the fire team the opportunity to observe their fire. The most likely method of attack the threat might take is estimated to be as follows:

An agent boat with an 18-20 man strike team would lay offshore until the local South Korean fishing fleet moves out at dusk for their fishing grounds. The agent boat would then move into the Punyang-man inlet and discharge the strike team at Won Mok. The team, with 8 rockets and one or two launchers would then move via Route 4 along relatively high ground from Won Mok to Highway 317, then proceed north to firing points at BM 112. From this launch area, the team would have a clear view of Osan Air Base and will have the long axis of the target available to them. The movement from Won Mok to BM 112 should take no more than two hours. Prior reconnaissance would have located exact launch sites, thus minimizing the time for on-site preparation. Following the attack, which should not exceed one hour including preparation of the firing position, the team would use the most direct route back to their boat (approach Route 3). The withdrawal would be executed as rapidly as possible in order to get beyond Route 317 before a reaction force from Osan Air Base making use of Highway 32 and Highway 317, could establish blocking positions to intercept the fire team before it reaches the boat. If time allows, the threat would probably mine the bridge on Route 32 at coordinates 220018. Allowing approximately one hour for withdrawal from the firing points to the boat, only four hours will have elapsed from the time the team disembarked until it was back aboard the escape boat. This four-hour period, depending on the tides, would probably be from midnight to 4:00 A.M.

Sensor arrays with diurnal switches strategically emplaced along the approach routes would provide an early warning to the CSCPD during curfew hours. Fence arrays around the possible firing points would alarm as the fire team moved into the area and started preparing the firing position. This advance warning would permit the CSCPD to dispatch a reaction force before the threat could carry out the attack.

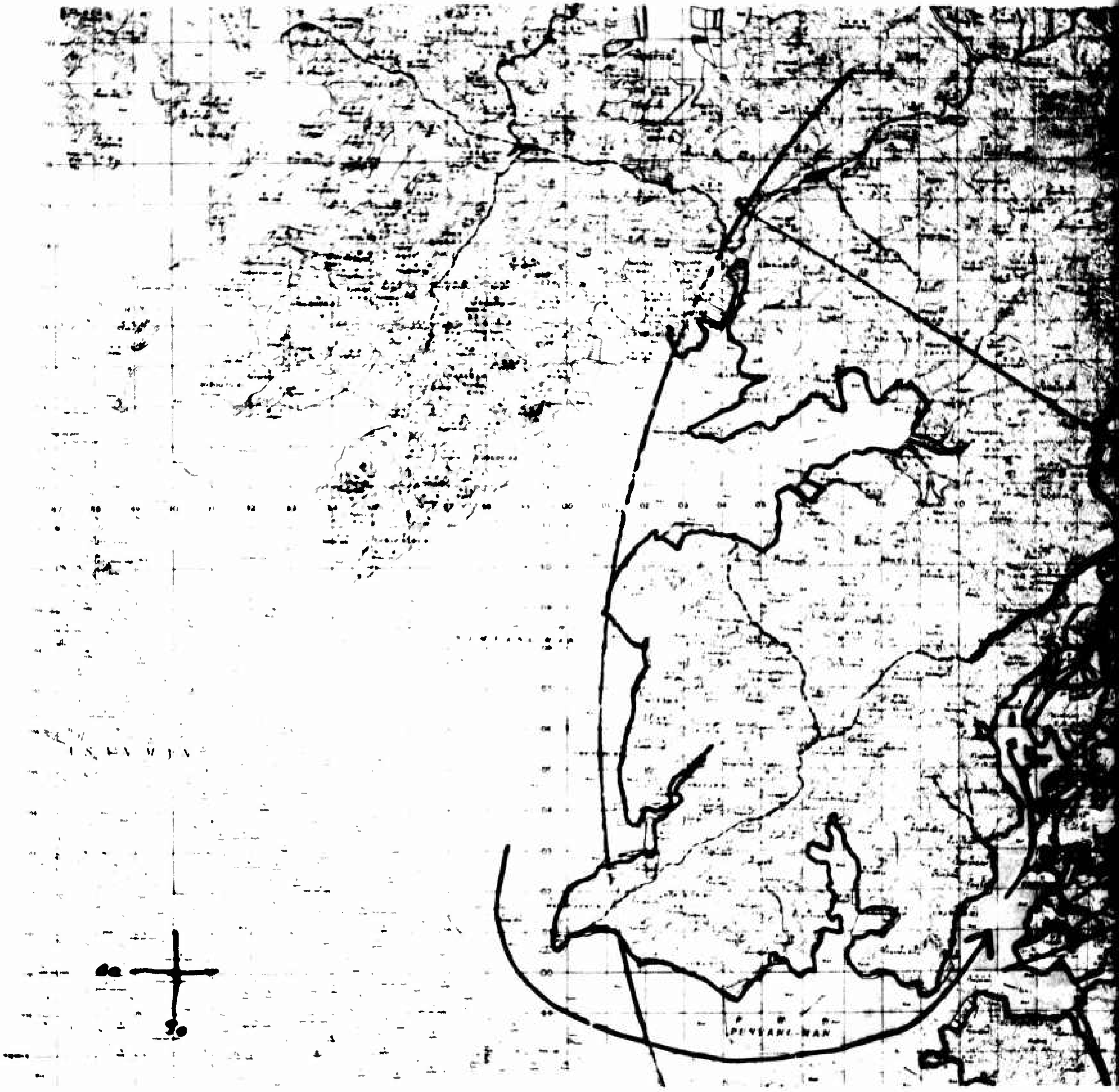
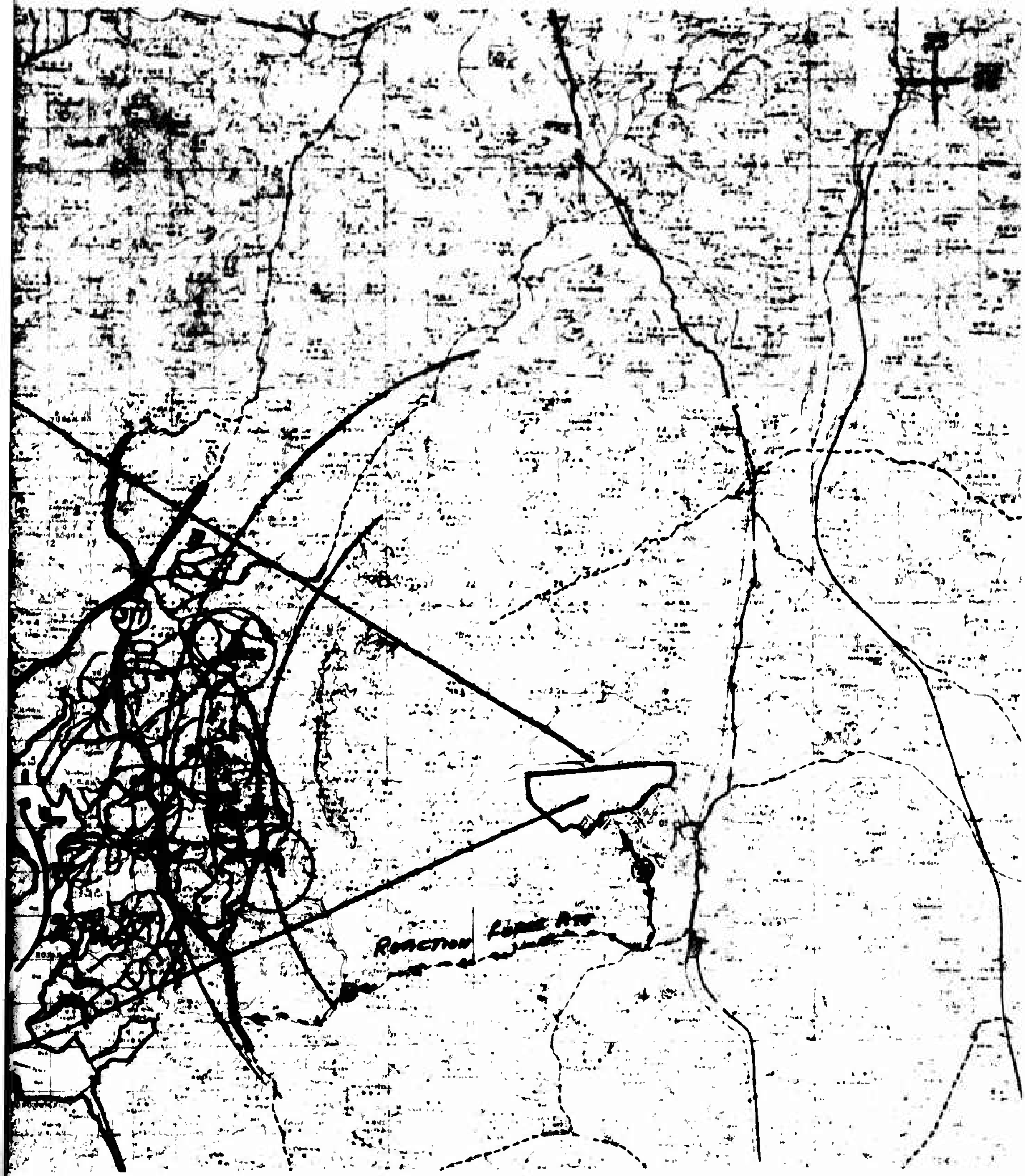


Figure 7-11 (C). Avenues of Approach and Firing Points West of Osan Air Base (U)



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Section 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 (C) CONCLUSIONS

This study reached the following conclusions:

a. The threat, in preparing a standoff attack, exhibits unique characteristics which are detectable by the proper choice of sensing techniques, the judicious placement of sensors, and the careful analysis of alarm information.

b. The deployment configurations and type of sensors required for Wide Area surveillance is dependent upon:

   (1) The type of threat information to be derived from alarm data, i.e., threat direction of movement, speed, group size, and load carried.

   (2) The terrain features of the monitored area.

   (3) The sensor characteristics, e.g., detection range and pattern.

   (4) The environment as it affects sensor deployment and operation.

   (5) The temerity of the threat (enemy) in (1) launching an attack on the air base and, (2) in locating and destroying the sensors.

c. Wide areas were redefined as circular areas normally having a radius of 1 km.

d. Local processing increases the adaptability of this system to many diverse situations and is cost-effective for small and medium size bases.

e. The use of foliage penetration RADAR looks promising for launch site monitoring.

f. Message interference within the WARS communication system will not be serious. In the worst case, a 10-15% loss can be expected. Computer analysis has shown this to be tolerable.

8.1 (C) (Continued)

g. System Characteristics (Baseline)

(1) Surveillance System

Sensing Techniques	
Primary	Seismic
Auxiliary	Radar, IR, Magnetic, etc.
Alarm Rate	1 every 4 seconds
Maximum Tolerable Mean False Alarm Rate	1 every 40 seconds
Distribution of False Alarms	Approximately Poisson
Detection Pattern	Approximately Circular
Detection Range (Personnel)	
Trail Array	Approximately 10 meters
Fence Array	Approximately 30 meters
Sensors Per Array	
Trail	5
Fence	8
Arrays per Wide Area	1 to 8
Estimated No. of Wide Areas for 360 Coverage	
Average	90-110
Maximum	180
Estimated No. of Sensors for 360° Coverage	
Average	1600-2400
Maximum	4000

8.1 (C) (Continued)

System Characteristics (Baseline)

(2) Communications System

Mode of Operation	Real-Time
Frequency Range	138-172 MHz
Channels Required	2
Channel Width	60 kHz
Channel Separation	3 MHz
Modulation	Split-Phase PSK
Information Bit Rate	10 kbps
Message Length	23 Bits
Bit Error Probability	2×10^{-3}
Transmitter Power	
S/T	50 mw and 5 mw
R/R	4 watts and 0.4 watts
Transmitter and L.O. Frequency Stability	±30 PPM
Receiver Sensitivity	-109 DBM

h. Useful life (one year nominal and 6 months at -20°C).

i. Modular packaging best fits the many possible applications and allows orderly upgrading of the system.

j. A 15 man WARS team will be able to handle the installation and checkout of the equipments, the maintenance of the equipment and the operation of the system.

8.2 (C) RECOMMENDATIONS

Based on the results of this study, the following recommendations are made:

a. Proceed with the development of the hardware specified for the Baseline System.

b. Incorporate local processing into overall WARS concept.

c. Incorporate a receiver module and alarm accumulator into the WARS concept that will allow DCPG sensors to be used with WARS. The receiver will be located with receiver/interface unit. This will provide compatibility with existing sensor systems, particularly air deliverable devices.

d. Investigate the feasibility of incorporating IFF capability into WARS to aid in identifying friendly groups passing through Wide Areas as opposed to threat groups.

e. Conduct an additional study of the applicability of world wide use of the WARS concept. This study would include Central/South America, the Mideast and Western Europe.

Appendix A

OPERATIONAL CHARACTERISTICS OF WARS

A.1 (C) DEPLOYMENT AND OPERATION OF THE WARS SYSTEM

A.2 (C) TASKING AND ORGANIZATION

There are a number of distinct tasks which must be performed in order to install, maintain, and operate a WARS System for a large base. It is felt that a WARS team will be needed to efficiently perform these tasks. Such a team might be organized in the following way:

a. Receiving Section (2 men)

Orders, receives, issues, and ships WARS equipment for the base. Maintains the records of equipment inventory, equipment on order, etc.

b. Assembly and Checkout Section (2 men)

Assembles, checks, and maintains WARS equipment as directed.

c. Operations Section (4 men)

Maintains overall supervision of the WARS effort. Conducts planning for future WARS activities. Issues installation orders. Maintains records on status of WARS system.

d. Installation Section (5 men)

Completes detailed planning of installation missions. Coordinates and conducts installation missions.

e. CSC Section (7 men)

Operates the Central Security Control. Reports detected activity. Maintains awareness of WARS System status through equipment tests.

It is expected that, since the team will be relatively small, most team members will be cross-trained to allow considerable flexibility within the organization.

A.3 (C) PLANNING AND CONDUCTING A WARS OPERATION

A.3.1 (C) Operational Planning

Operational Planning begins with a detailed threat analysis. From this analysis comes a determination of which avenues of approach, methods of attack, etc. are likely to be used by the threat. The information from the threat analysis plus an assessment of the friendly situation enables the planner to establish priorities for surveillance. Consideration is given to the various methods of surveillance available, and an overall surveillance plan is formulated.

For those areas where the surveillance plan calls for WARS equipment, detailed planning must be done to provide for good detection and communications. Array locations are chosen with the objective of effectively detecting and reporting the threat with a minimum amount of equipment. Trail and road networks are examined for "choke-points" which may not be easily avoided by an infiltrating enemy. The terrain is analyzed to determine the best locations for relays. Code and frequency assignments are made in such a way that information may be read-out in an orderly fashion. Consideration is given to the problems of system expansion and maintenance.

Once the planner has arrived at a system deployment which he is confident will give coverage of the assigned areas, an implementation timetable is prepared and the actual installation begins.

A.4 (C) CONDUCTING A MISSION

A.4.1 (C) Mission Preparation

Mission preparation begins when an order to emplace WARS equipment is received. A map study and/or aerial surveillance is conducted and a detailed plan is formulated for completing the mission. Equipment is obtained, checked-out and assembled. Coordination is made with supporting groups (escort troops, transportation, etc.) to assure their availabilty for the mission. A test procedure is developed by the monitoring section and installation section to provide for final field tests of equipment.

A.4.2 (C) Mission Accomplishment

The actual mission begins with the movement of the installation section, equipment, and escort forces to the WARS sector. The area is secured and communications are established with the monitoring section at the CSC. Installation is accomplished by first installing an RI/LRT unit and checking its operation, then installing subordinate R/R units and checking, and, finally, installing arrays and checking. Operability is confirmed by checking with the CSC at each stage of the installation. After completing and camouflaging the installation, the forces withdraw from the area. The same procedure is repeated in other areas if multiple installations are made on a single mission. After all installations are complete, the forces return to base and the installation team is debriefed. Records are updated from the information obtained in this debriefing.

A.5 (C) INVENTORY AND TEST FACILITIES

A.5.1 (C) Inventory

It will be necessary to maintain a local inventory at bases where a WARS system is deployed. The inventory will provide the means for quickly replacing inoperative equipment, will make it easier to conduct routine system maintenance, and will allow immediate upgrading of the system if a particular vulnerability or threat is recognized. A typical local inventory (2 weeks supply) for a large air base might be as follows:

	EQUIPMENT (less batteries)	BATTERIES
Sensor Transmitters	80	100
Receiver Relays	16	20
Processors	4	-
Receiver Interface	5	6

A.5.2 (C) Test Facility

A single test facility and assembly area will be required and will include:

a. 10' x 12' test area with work bench

b. One Go/No/Go Tester

c. Miscellaneous test equipment and tools

A.6 (C) REPLACEMENT PROCEDURE

A replacement procedure must be devised which permits effective maintenance of the WARS System. There are at least two distinct maintenance requirements which may arise:

a. Routine Maintenance

Nominal battery life is one year for system components in the field. It is therefore expected that maintenance will routinely be required approximately on an annual basis. All equipment in a given area should be replaced or refurbished on this annual maintenance trip.

Before discussing how the maintenance should be accomplished, several factors should be mentioned:

(1) Equipment which has been hidden for a full year will generally be difficult to relocate.

(2) Security forces as well the installation team are required throughout the time during which any search for equipment is conducted.

A.6 (C) (Continued)

(3) There is a very real danger that threat forces will recognize the pattern of returning for WARS equipment and booby-trap any such equipment (or the area around the equipment) that they might find.

(4) Considerable time must be allowed for the recovery of any equipment where booby-trapping is a possibility.

(5) The probability of the threat's finding equipment is greatest for that equipment located near the trails, i.e., the sensor/transmitters are more likely to be discovered than the R/R's or R/I - LRT's.

After considering the factors just listed, it was decided that attemps to recover equipment should normally be limited to the R/R or R/I - LRT units. Old R/R's or R/I - LRT's should be recovered for later refurbishing and replaced with new units. Sensor/transmitters should generally be left in place and new units should be installed. (There will doubtless be exceptions to this rule. For example, it may prove economical to recover sensor/transmitters used near a perimeter.) By installing S/T's with new codes and using appropriately programmed R/R's and R/I - LRT's, it should be possible to avoid any ambiguities arising from old S/T's left in the area.

b. Maintenance Requirements due to Equipment Failure or Loss

Occasionally it is to be expected that equipment will cease to function before the end of its one year life. If the lost unit is a single sensor/transmitter, it is probably not a critical loss and action may not be taken. Loss of several S/T's in a given area may be justification for rescheduling the annual maintenance and completely replacing the equipment in the area. Loss of an R/R becomes a more important matter, and a judgment as to the impact of the loss must be made. If a trip is made to an area to replace an R/R, consideration should be given to rescheduling maintenance and replacing all equipment in the area. Loss of an R/I - LRT will almost certainly require prompt action to restore communications from the affected sensors.

A.7 (S) VULNERABILITY/SUSCEPTIBILITY AND COUNTERMEASURES

A.7.1 (S) Introduction

Several vulnerabilities/susceptibilities of the WARS system should be recognized. Three of the system vulnerabilities are listed here and possible countermeasures are suggested.

A.8 (S) SUSCEPTIBILITIES

A.8.1 (S) Jamming

The system is susceptible to jamming, and jamming may have a significant effect upon the system if more than 30% of the messages are lost during an intrusion. Jamming may be difficult to recognize if it occurs at the R/R or R/I level.

A.8.2 (S) Spoofing

Spoofing may be attempted if the threat develops a capability to receive and retransmit or simulate WARS transmissions. Successful spoofing might result in the waste of U.S. materiel and/or a loss of system effectiveness.

A.8.3 (S) Location of Equipment

Equipment may be located and thus lose its effectiveness if the threat develops direction-finding capabilities and/or an effective physical search technique. The loss of higher-echelon equipment such as the R/I - LRT would be especially serious.

A.8.4 (S) Sensing Communication of Alarms

Arrays of sensors may be located within 200 meters by listening on a small insensitive radio for the transmissions of the alarms from the sensors. A lead-man would be able to warn a following group to take an alternate route when he passed an active sensor array.

A.9 (S) COUNTER-COUNTERMEASURES

A.9.1 (S) Jamming

A possible method for countering jamming at the R/R or R/I levels is to incorporate the ability to detect jamming at these units and report this information to the CSC.

A.9.2 (S) Spoofing

Several countermeasures may be employed against spoofing. The RSDCS with a polling mode may be used. Any attempts at spoofing must then be synchronized with the polling. CSC procedures may be adopted to verify transmissions before reporting or engaging a suspected intruder.

A.9.3 (S) Location of Equipment

Two susceptibilities were mentioned, a susceptibility to direction-finding and the susceptibility to physical search techniques. The former may be countered by using local processing to significantly reduce "on air" time and thus limit the threat's opportunities to df. The latter may be countered by using good camouflage and installation procedures. A further technique is suggested in Section A.9.4 below.

A. 9. 4 (S) Sensing Communication of Alarms

The ability of an intruder to sense the communication of alarms can be greatly reduced if the transmission of the alarm is delayed. A delay of 300 to 400 seconds in the transmission of alarms would allow an intruder column to pass entirely through the array before an alarm was transmitted. The effectiveness of the array would be only slightly reduced, since the alarms would provide an operator with the ability to predict the current location from alarms 300 to 400 seconds in the past. The delay mechanism can be easily constructed from a 4-second astable multivibrator and a 100 bit serial shift register which can be obtained in one integrated circuit. The alarms would be entered into the shift register as they occurred. One hundred counts or 400 seconds later the alarm would emerge and could be used to trigger the encoder-transmitter.

Appendix B

INTEGRATION OF DCPG SENSORS INTO THE WARS SYSTEM (U)

B1.0 (C) INTRODUCTION

DCPG has under development or in production a series of seismic, acoustic, magnetic, IR and related sensors. These sensors all have the same basic alarm transmitter format, a 300 baud FSK transmitter operating in the 162 to 174 MHz frequency band. The paragraphs below discuss the Phase III code format, the types of sensors available, their applicability to WARS, and a proposed receiver for converting the DCPG sensor information to the WARS format.

B2.0 (C) DISCUSSION

B2.1 (C) Phase III Data Characteristics

The Phase III system is an outgrowth of the Phase I and Phase II programs. Problems with a shortage of available frequency channels (there were 31 channels spaced 375 kHz apart) and identification codes (27 were available and composed of a combination of 19 kHz, 25 kHz and 32 kHz tones) forced consideration of a narrow band format system. The system which evolved is a series of channels spaced 18.75 kHz apart each coded at 300 baud rate, FSK code with 3 kHz deviation. Sixty-four possible identification codes are available for each frequency. Only alternate channels are utilized in order to provide adequate guard bands. The use of a 75 baud data rate and channel spacings of 6.25 kHz with the appropriate increased transmitter frequency stability are planned for the future.

The message format is as shown in Figure B-1 for real-time (or non-commandable sensors) as well as commandable sensors. For the Type I message the first 8 data bits are all 0's and are referred to as the preamble. The ninth bit is a one and is the frame marker. The tenth and eleventh are the message ID which for real-time units are 0's. The twelfth through seventeenth bits are the sensor identification codes while the eighteenth bit is parity, which is odd and selected on the basis of bits twelve through seventeen. The Type II and III messages are only appropriate to commandable sensors. They will not be discussed further within this report except to say that certain sensors do have a commandable capability and may operate as real-time or non-real-time sensors. In non-real-time, the alarm data is stored until the sensor is interrogated and the data read out. This type of sensor also has an analog mode where analog data can be listened to and analyzed on a real-time basis. However, since no command system is planned for WARS, it is the non-commandable (real-time) systems which are of prime interest.

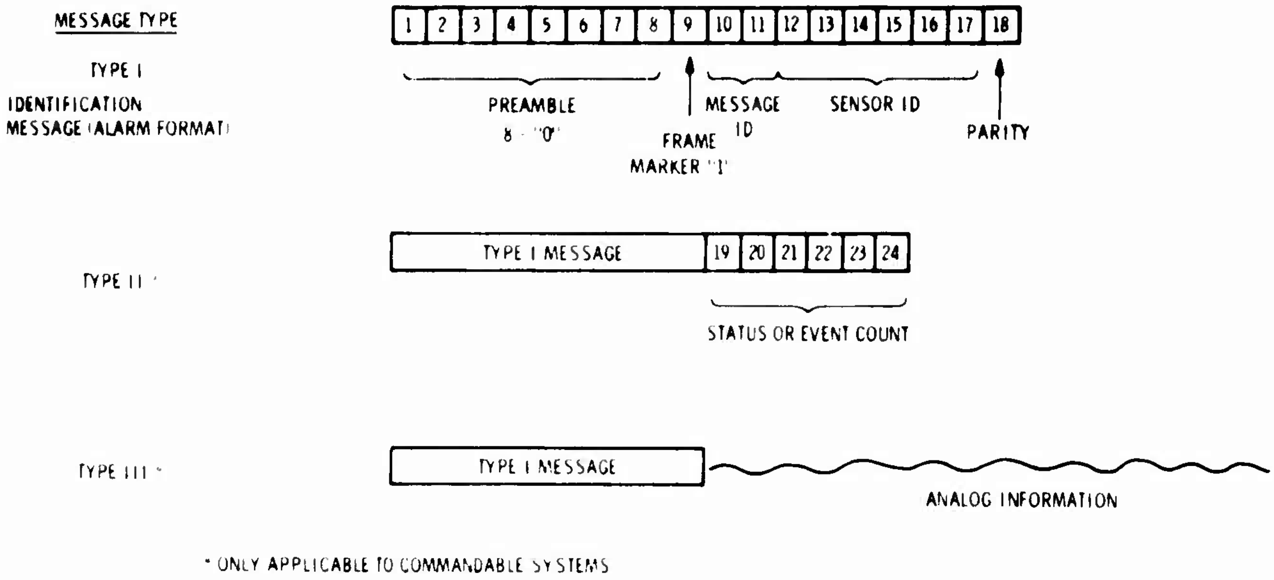


Figure B-1 (C). Phase III Signal Format (U) (CONFIDENTIAL)

B2.1 (C) (Continued)

The alarm response of the real-time sensor is the Type I message and it is this that will be transformed into the WARS format by means of the special receiver. The alarms or real-time transmissions/Type I format will be received, demodulated and decoded at the R/I as discussed in Section B2.3.

B2.2 (C) DCPG Sensors

There are several basic sensor types: seismic, magnetic, electromagnetic, IR, and acoustic with the magnetic and IR normally worked in conjunction with the seismic type. Table B-1 is a summary of various DCPG sensors. The early ADSID, FADSID, etc., are being phased out in favor of the new series of Phase III sensors. Another type sensor not listed is the noiseless button bomblet (NBB) which transmits an RF signal when moved. NBB units look like rocks or other jungle litter and are strewn along a trail. Their signal is picked up by a relay (ARFBUOY) and transmitted. One other major sensor which should be mentioned is PSID. It is a small seismic sensor, four of which report to a centrally located receiver to protect a patrol on localized camp. It is not readily adaptable into the WARS reporting scheme, but rather is mentioned here for completeness.

The hand implanted seismic sensors are implanted along trails or used in perimeter defense to track traffic or protect a base camp. The information is then received on a Phase III Portatale (AN/USQ-46) for local use or received by an orbiting aircraft for relay back to the Infiltration Surveillance Center (ISC). These sensors,

Table B-1 (C). Summary of DCPG Sensors (U)

Sensor Name	Sensor Type	Comments
MINISID III	Seismic	Real-time unit, hand implant, makes use of common modules.
MICROSID III	Seismic	Lightweight, small, real-time unit, hand implanted.
DSID	Seismic	Low cost, hand implanted, real-time unit.
MAGID	Magnetic	Hand implanted, used in conjunction with the MINISID.
PIRID	IR	Hand implanted used in conjunction with MINISID.
Common Module Program	Multiple	Adaptable to many type sensors, planned to allow use of commandable and non-commandable sensors of various configurations.
ADSID III	Seismic	Air delivered, prime common module sensor.
EMID III	Electromagnetic	Hand implanted, used for waterway surveillance as well as personnel and vehicle detection.
Acoubuoy	Acoustic	Hung up in trees, outgrowth of sonobuoy.
ADSID, ADSID Short, FADSID, HELOSID, HANDSID	Seismic	Phase I and II sensors, not compatible with Phase III alarm format.

B2.2 (C) (Continued)

if implanted in an area adjacent to a WARS site, could funnel in additional information by use of the Phase III Receiver Interface unit. The magnetic and IR sensors (MAGID and PIRID) would be particularly useful in identifying large metallic objects (rockets, ammunition, pack howitzers) and/or trucks or motorized vehicles moving into a WARS area or toward a WARS protected area.

The air delivered units can be dropped when hand implantation is unfeasible or extremely difficult (from helicopter or high-speed aircraft). The ADSID III is similar to the original Phase I ADSID except it is compatible with the Phase III system. This is the major air delivered sensor.

B2.2 (C) (Continued)

The ADSID III, MINISID III, MICROSID III and DSID sensors all have essentially the same processing scheme. A simple threshold crossing detector plus counting/timing circuitry is utilized. Detection ranges would be comparable with the WARS sensors. A shortcoming of all these units is the high false alarm rates for the high gain operation needed for the greater detection ranges. DCPG has been investigating alternate processing schemes to reduce false alarms while maintaining adequate detection ranges.

The Acoubuoy is an air delivered sensor which is hung up in trees. They are capable of detecting trucks at ranges of 300 to 500 meters. They are particularly useful in helping locate truck parks and storage areas as hoods and doors are closed and supplies moved. Two other acoustic devices, the ACAD and HYDAD, are being developed. The ACAD is a hand-emplaced unit designed to detect the exhaust burst from a sampan motor. The exhaust pulse is converted to an electrical signal which resembles a damped sine wave. The frequency is approximately 200 Hz repeated at intervals determined by the rpm of the engine. The HYDAD is implanted in a stream and waterway and listens for the unique hydroacoustic signatures of a motorized sampan.

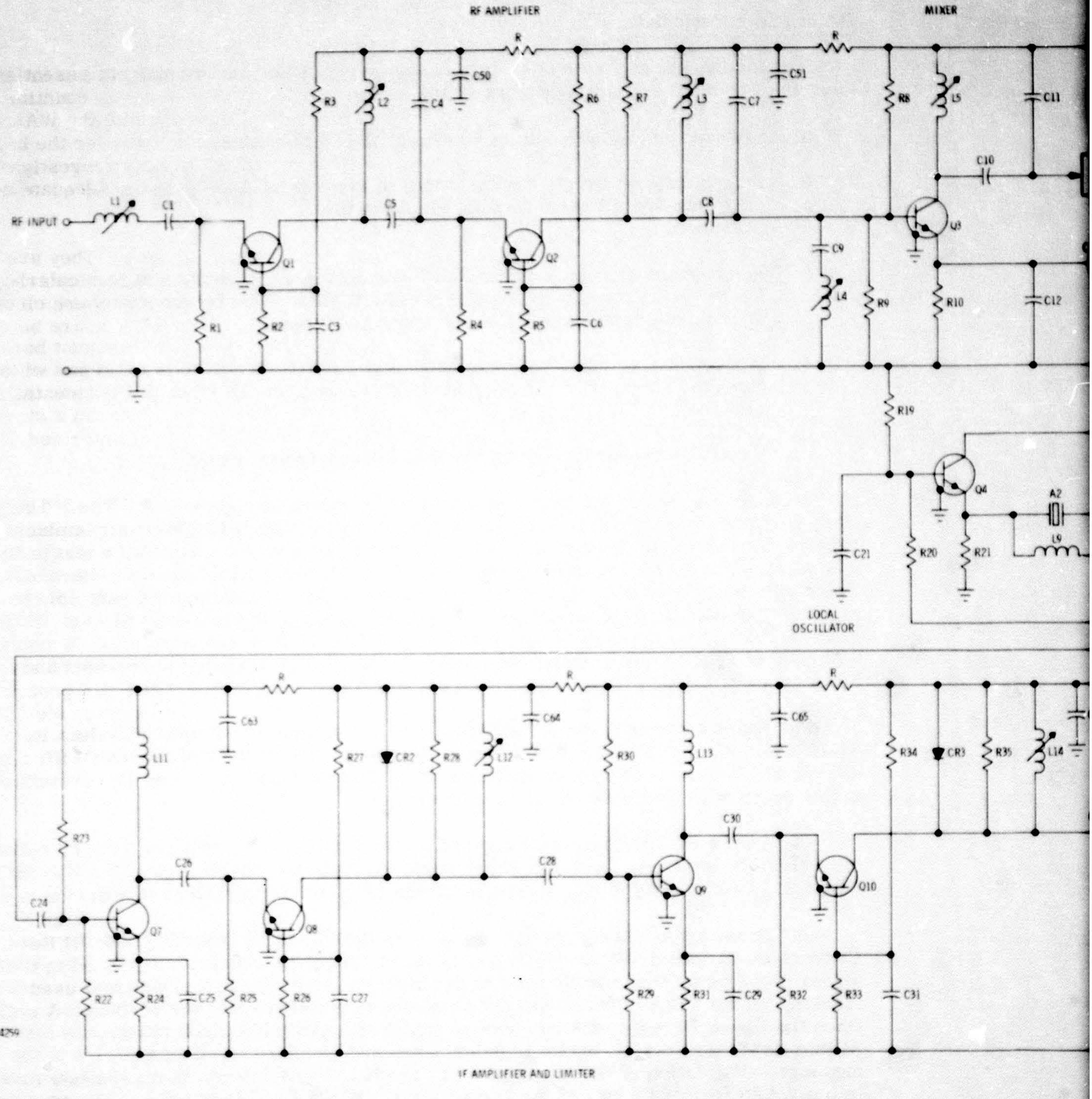
The last group of sensors which is of interest is the gun delivered type. These are relatively new but hold high promise. The MODS, an 81 mm mortar emplaced sensor, utilizes electronics similar to the ADSID. This system is in the test phase. A 155 mm howitzer system, MARDS, is in the early development state. Because of the accuracy of gun fire and no jeopardy of personnel during emplacement, this technique should replace air delivered sensors in many areas.

In summary, there are two basic implant methods used: hand implanted and air delivered, with a third method, gun delivery, under development. Seismic processing is the basis for the majority of sensors with more interest in IR, magnetic, electromagnetic, and acoustic being generated as new techniques become available. By means of the Phase III Receiver Interface units the information from ADSID III, MINISID III, MICROSID III, DSID, MAGID, PIRID and any other Phase III system which is developed will be readily adaptable to the WARS format.

B2.3 (C) Phase III Receiver Interface

The purpose of the Phase III Receiver Interface unit is to allow conversion of a Phase III sensor's code into the WARS code format. The alarm message of the Phase III DCPG sensor will be received, demodulated, and decoded by the Phase III Receiver Interface. After parity is checked, the sensor identification will be encoded in the WARS format with the three sensor identification bits and the bits normally used for auxiliary sensor, status, and alarm type utilized to convey the information. A separate receiver unit will be used for each Phase III channel employed.

The receiver is crystal controlled and will be depot set at any frequency in the 162 to 174 MHz range. It is a single conversion superheterodyne receiver with two stages of RF amplification and an 8-pole crystal filter in the 21.4 MHz IF amplifier. A schematic diagram of this receiver is shown in Figure B-2. It is basically the same receiver used in the base-line R/R and R/I units.



RF AMPLIFIER
MIXER
RF INPUT
L1 C1 R1 Q1 R2 C3 R3 L2 C4 C50 C5 R4 Q2 R5 C6 R6 R7 L3 C7 C8 C51 C9 L4 R9 R8 L5 Q3 C10 R10 C11 C12
R19 Q4 C21 R20 R21 A2 L9
LOCAL OSCILLATOR
R R R
C63 C64 C65
L11 R27 CR2 R28 L12 R30 L13 R34 CR3 R35 L14
R23 C26 C28 C30
C24 Q7 Q8 Q9 Q10
R22 R24 C25 R25 R26 C27 R29 R31 C29 R32 R33 C31
ALL Q's 2N4259
IF AMPLIFIER AND LIMITER

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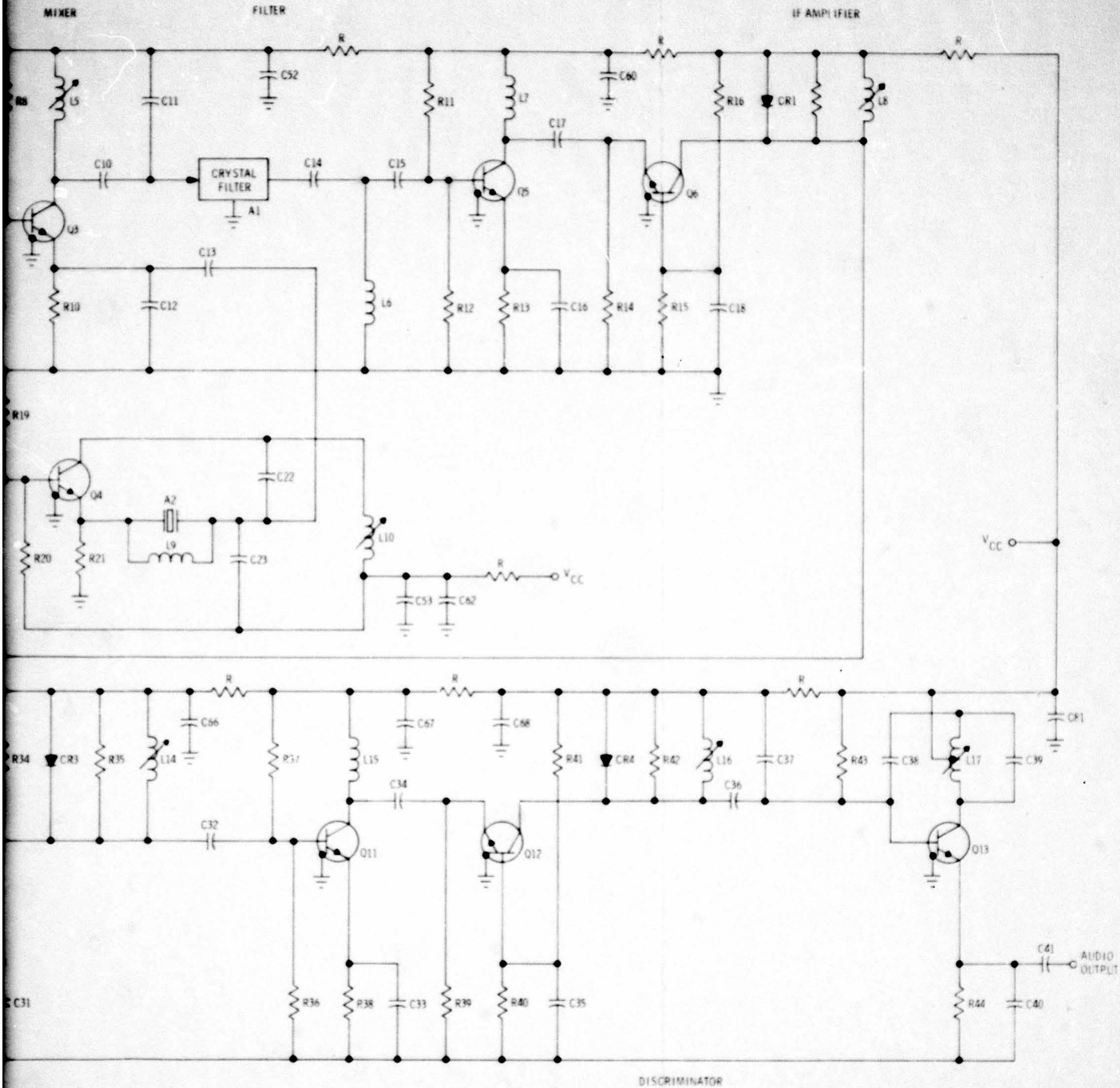

Figure B-2 (U). Schematic Diagram, Low-Power Consumption VHF Receiver
Block Diagram (U)

2

B2.3 (C) (Continued)

The modifications to the base-line receiver which will be implemented in order to meet the Phase III requirements are listed below:

a. Reduce the IF bandwidth to 40 kHz at the -6 db points.

b. Incorporate an 8-pole crystal filter to provide a $\frac{(BW)\ 60\ dB}{(BW)\ 6\ dB} = \frac{1.8}{1}$, with less than 0.5 dB peak-to-peak ripple in the passband.

c. Incorporate a crystal-controlled local oscillator to operate at one-half the LO injection frequency of 140.6 to 152.6 MHz. The frequency tolerance over the environment range must not exceed ± 30 ppm.

d. Incorporate a signal-to-noise detecting squelch circuit to gate off power to all decoding stages when the signal-to-noise ratio at the IF output is less than +10 dB.

e. Provide for operation over the WARS temperature range.

A block diagram of the proposed receiver is shown in Figure B-3. The RF amplifiers will consist of two common base amplifiers with high Q single-tuned interstage coupling and matching networks. The input matching network will also be single-tuned and designed to match the input of the receiver to 50 ohms with less than 2:1 VSWR. The mixer will be active, with emitter injection of the LO and base injection of the signal. The output of the mixer will be matched directly to the 8-pole crystal IF filter at 21.4 MHz. The limiting IF amplifier will consist of four cascaded cascode pairs with synchronously tuned single-pole bandpass interstage coupling networks. The bandwidth of this amplifier, without the crystal filter, will be 0.5 MHz.

The squelch circuit, shown in Figure B-4, is a signal-to-noise ratio detector which examines the power distribution at the output of a linear AM detector following a bandpass limiter. The noise suppression effects of such a bandpass limiter combination allow S/N decisions for squelch operation.

The Phase III Decoding and Format Conversion Circuitry will receive and validate the Phase III messages, and convert the data bits into the WARS format for retransmission. In a standby mode, power is turned off to minimize power drain.

The presence of carrier turns on power to the Phase III Decoding and Format Conversion Circuitry (Figure B-5) by way of the receiver squelch output. The demodulated receiver output is processed to reconstruct the original message and to recover clocking information. The message is consequently shifted into the 24-bit shift register. Once the Phase III message preamble is qualified, additional clock pulses are inhibited. At this time, the data bit parity is determined and compared to the parity bit in the message. Validation of the message will permit the data information to be converted into a WARS format by way of the transfer gates and a Load Command. The remaining WARS message (Barker Code Preamble, etc.) is also loaded into the format shift register at this time. Once the message is validated and loaded into the WARS format,

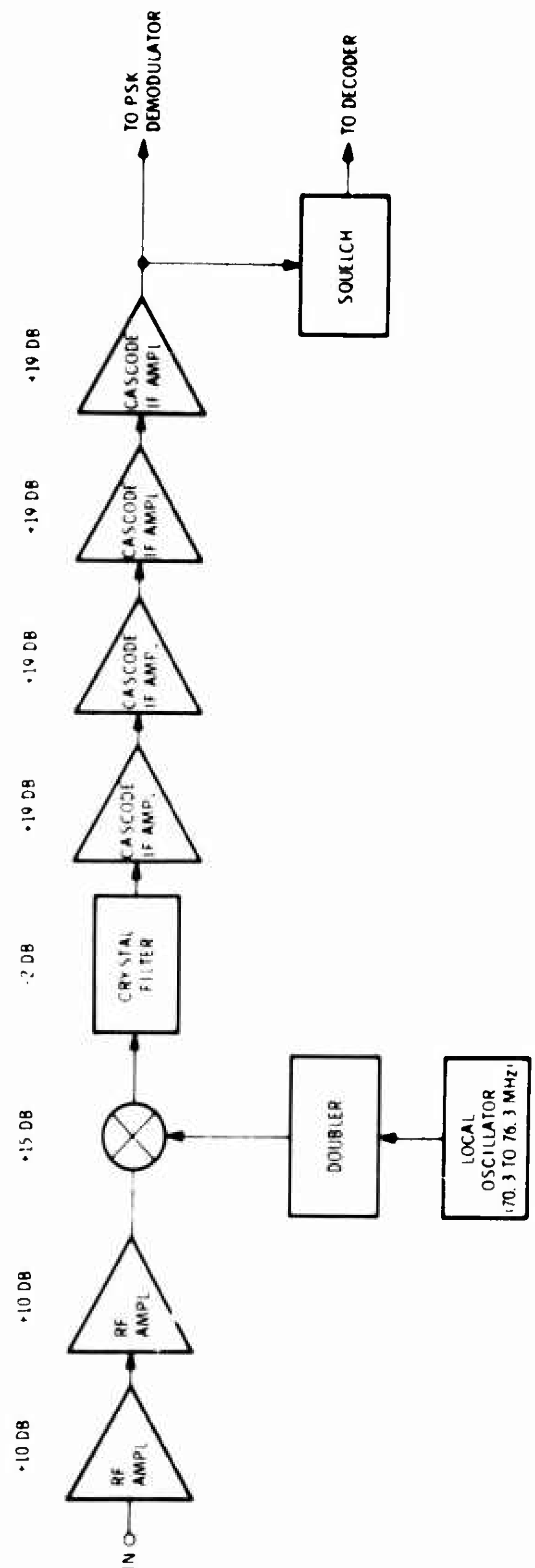

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Figure B-3 (C). R/R Receiver Block Diagram (U)

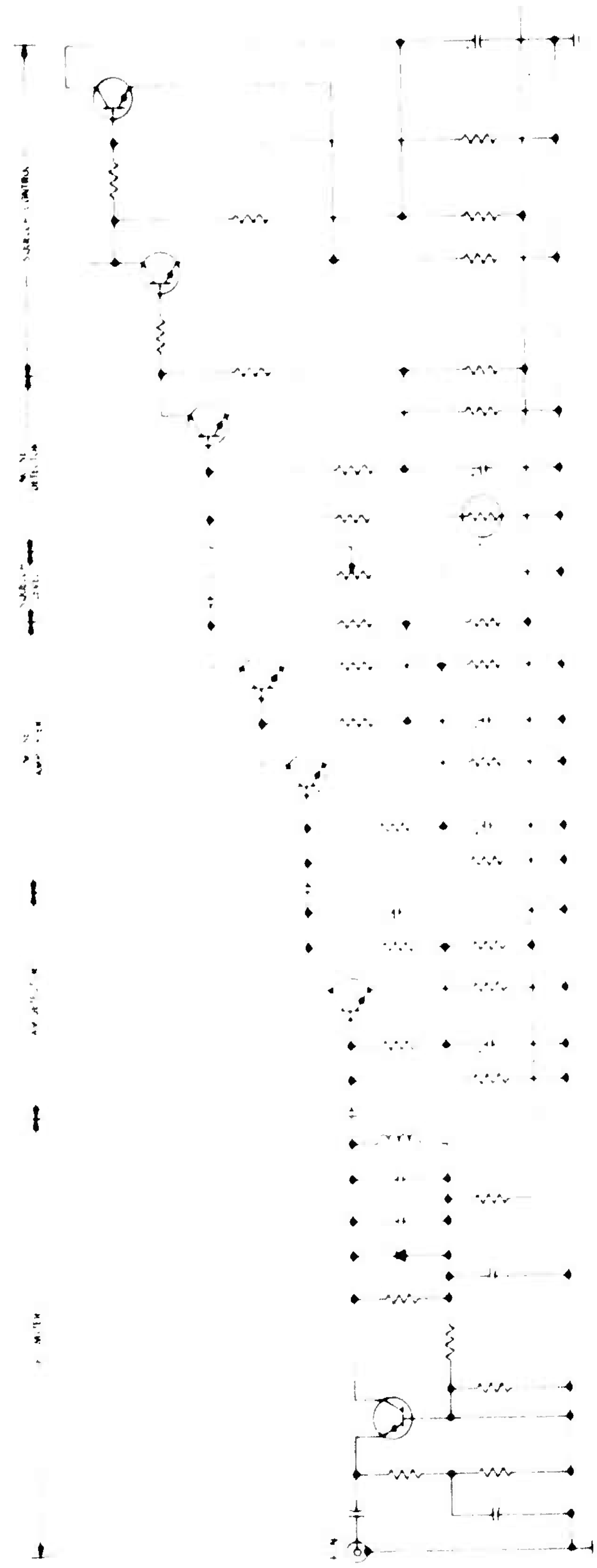

Figure B-4 (U). Schematic Diagram, Squelch Circuit (U)

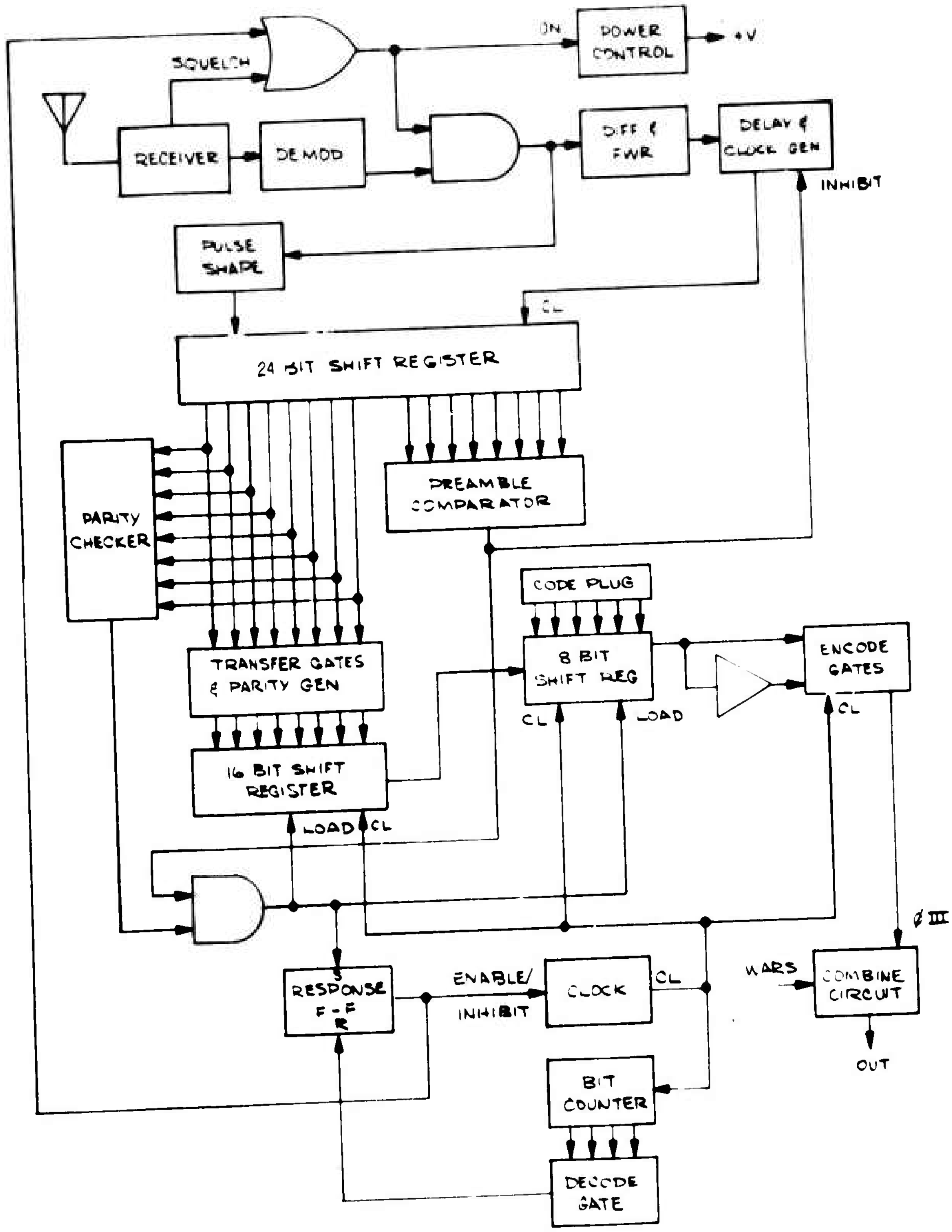

Figure B-5 (U). Receiver/Decoder-Coder Block Diagram (U)

B2.3 (C) (Continued)

the Response Flip-Flop is set to enable the clock. The clock shifts the WARS message into the Encode Gates and subsequently into the Combine Logic. The number of clock pulses are counted by the Bit Counter. After the counter has reached 23, the Decode Gate resets the Response Flip-Flop which turns power off and thereby completes the cycle.

The Combine Logic is functionally an OR Gate which will accept either a converted Phase III channel message or a WARS channel message.

B3.0 (C) SUMMARY

With the use of the Phase III Receiver Interface, the DCPG Phase III sensors can be used to supplement the WARS sensors. Of particular interest is the air-deployed ADSID III which can be dropped in otherwise inaccessible areas. The MAGID and PIRID sensors are quite useful to supplement the seismic sensors. One Receiver Interface unit is needed for each Phase III channel employed.

Typical situations involving 6-12 DCPG sensors in the vicinity of a given WARS would require only one channel for tolerable data loss.

It should be noted that MAGID and PIRID sensors can be interfaced directly into the WARS systems as auxiliary sensors.

Appendix C

BESS EVOLUTION SCENARIO

C.1 (C) INTRODUCTION

The following scenario discusses briefly the development of a hypothetical air base and its associated Base Exterior Security Subsystem (BESS). The air base is assumed to initially exist as a minimum base installation and to expand to a complete air base with ammunition dumps, POL, a number of high performance aircraft, etc. Its appeal to the enemy as a lucrative target for standoff attacks is assumed to grow in direct proportion to the growth of the air base.

C.2 (C) AIR BASE AND BESS DEVELOPMENT

PHASE I (Figure C-1)

A base with a short airstrip was established in the vicinity 018117 to provide a means of airlifting supplies to Free World Military Forces (FWMF) operating in the area.

WARS fence arrays were deployed in a perimeter role around the base and trail arrays were deployed along avenues of approach in the immediate vicinity of the base. Arrays were also used to detect any attempt to destroy the bridges on Highways 10 and 12 since loss of these bridges would limit the usefulness of the base by restricting the movement of supply vehicles.

Because of the close proximity of the sensor arrays to the base, they were able to communicate directly to a receiver/interface unit located at the base, thus eliminating the need for RSDCS hardware at this stage of development. A local processor was used at the R/I unit to process incoming alarm data. Therefore, the CSC required was simply a message decoder and a simple display.

PHASE II (Figure C-2)

As activ ty within the area increased, the base was enlarged. The storage of POL and munitions on base plus the increased number of aircraft on the ground caused the enemy to launch occasional standoff attacks against the facility.

Additional fence arrays were necessary to protect the expanded base perimeter, and additional trail arrays and fence arrays were strategically located in the areas that could be used by the target to launch his standoff attacks. This expansion in the number of arrays necessitated the incorporation of RSDCS equipment into the BESS, due to the fact that many of the new arrays were deployed far out into the area surrounding the airbase.

Local processing at the Receiver/Interface was still utilized, so that expanding the CSC facilities only amounted to adding RSDCS receivers and additional receiver/interfaces with local processors and displays.

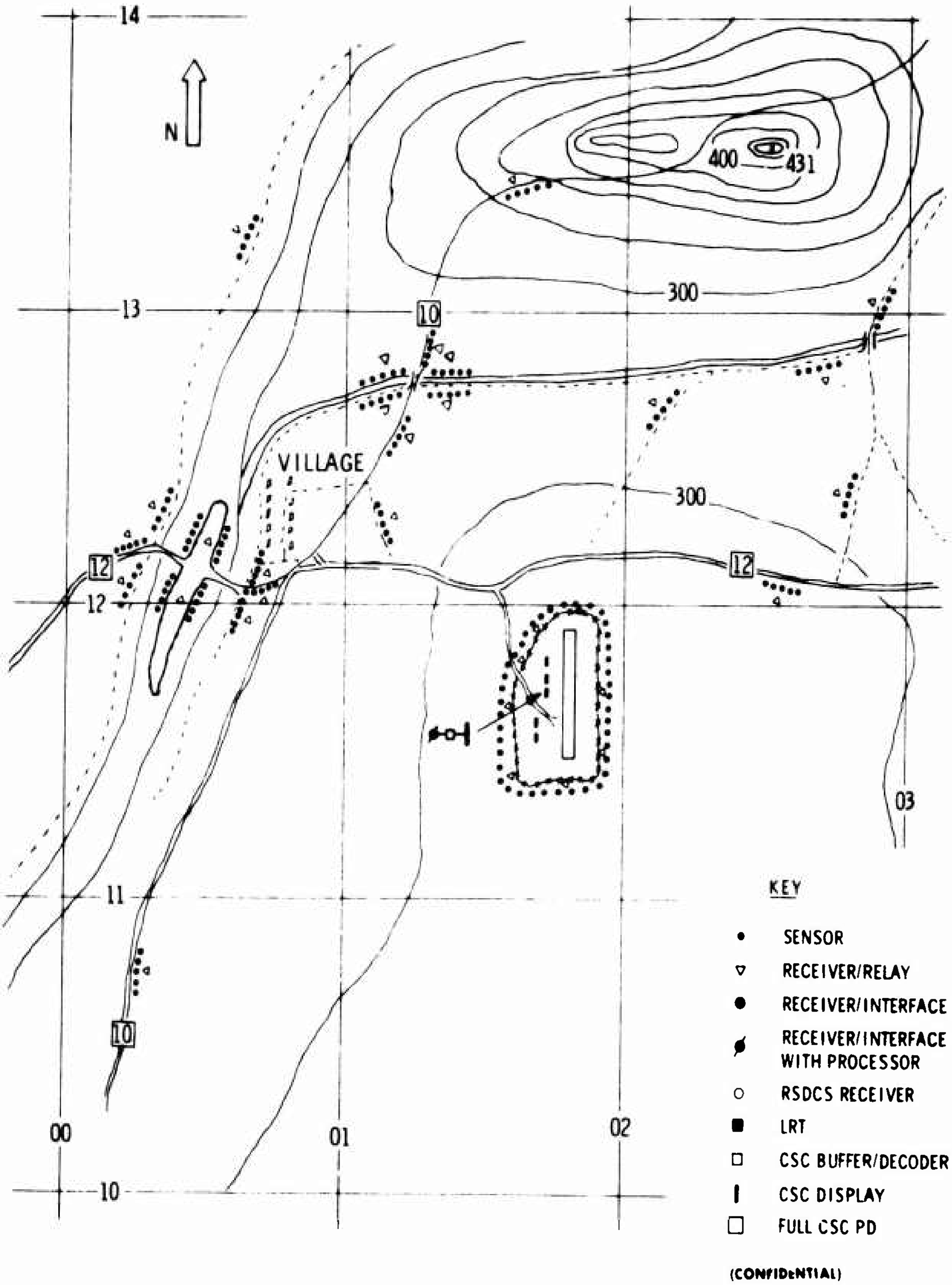

Figure C-1 (C). Air Base and BESS Development, Phase I (U).

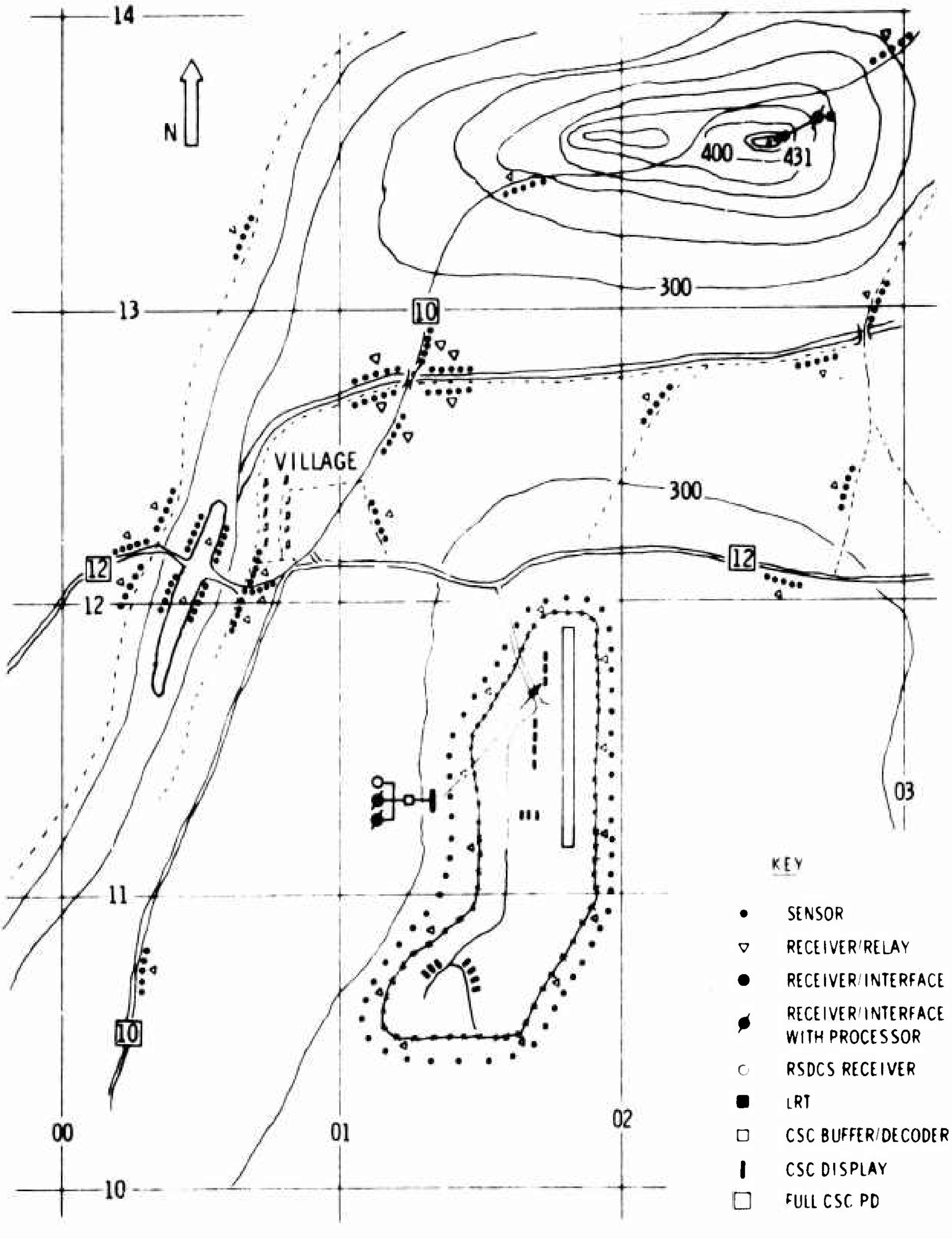

Figure C-2 (C). Air Base and BESS Development, Phase II (U).

C.2 (C) (Continued)

PHASE III (Figure C-3)

During Phase III of the air base expansion the airstrip was lengthened and improved to permit high-performance aircraft to operate from the base. This increased activity at the base made it an extremely desirable threat for stand-off attacks.

In response to more frequent attacks, the BESS was expanded to full WARS area coverage. This expansion amounted to an approximately 100% increase in the number of required Wide Areas. Therefore, it was deemed desirable to incorporate a centralized alarm data processor and associated display at the CSC. The Wide Areas deployed in the expansion were required with pre-processor units to reduce the data flow to the CSC.

PHASE IV (Figure C-4)

An AC&W site was installed on Hill 431. A perimeter system and intensified surveillance on approach routes to the site were deployed. The AC&W site was equipped with a Receiver/Interface (with processor), and a display so that activity in the immediate vicinity of the site could be monitored by site personnel. Processed alarm data from these additional sensor arrays was also relayed by a long range transmitter (LRT) to the air base so that the complete BESS status could be accessed at the CSC.

C.3 (C) DISCUSSION

The inherent modular design of the WARS System made it easily adaptable to each phase of the air base and associated BESS development. Initially, a receiver/interface and simple information display met the needs of the small facility. As the base expanded, RSDCS equipment was easily incorporated into the BESS and, at full expansion, the complete CSC data processing and management system was added.

C.4 (C) CHANGES WHEN THE RELAY DOES NOT HAVE A PROCESSOR

Consider the development process if a modular system had not been used. In the first phase of development, the base would either have used no automatic data processing at all or used automatic data processing equipment that was much too elaborate for the situation. With no data processing, operators would have performed all the analysis of alarm signals, and several well-trained men would have been required. In Phase II, a data processing capability would surely be required. The data processor would be installed at the CSC and would be adequate for handling the system expansion under Phase II and Phase III. Servicing the AC&W site installed in Phase IV would be awkward without local processing. Either a separate RF link from the central station back to the AC&W site or manual readout at the site would be required.

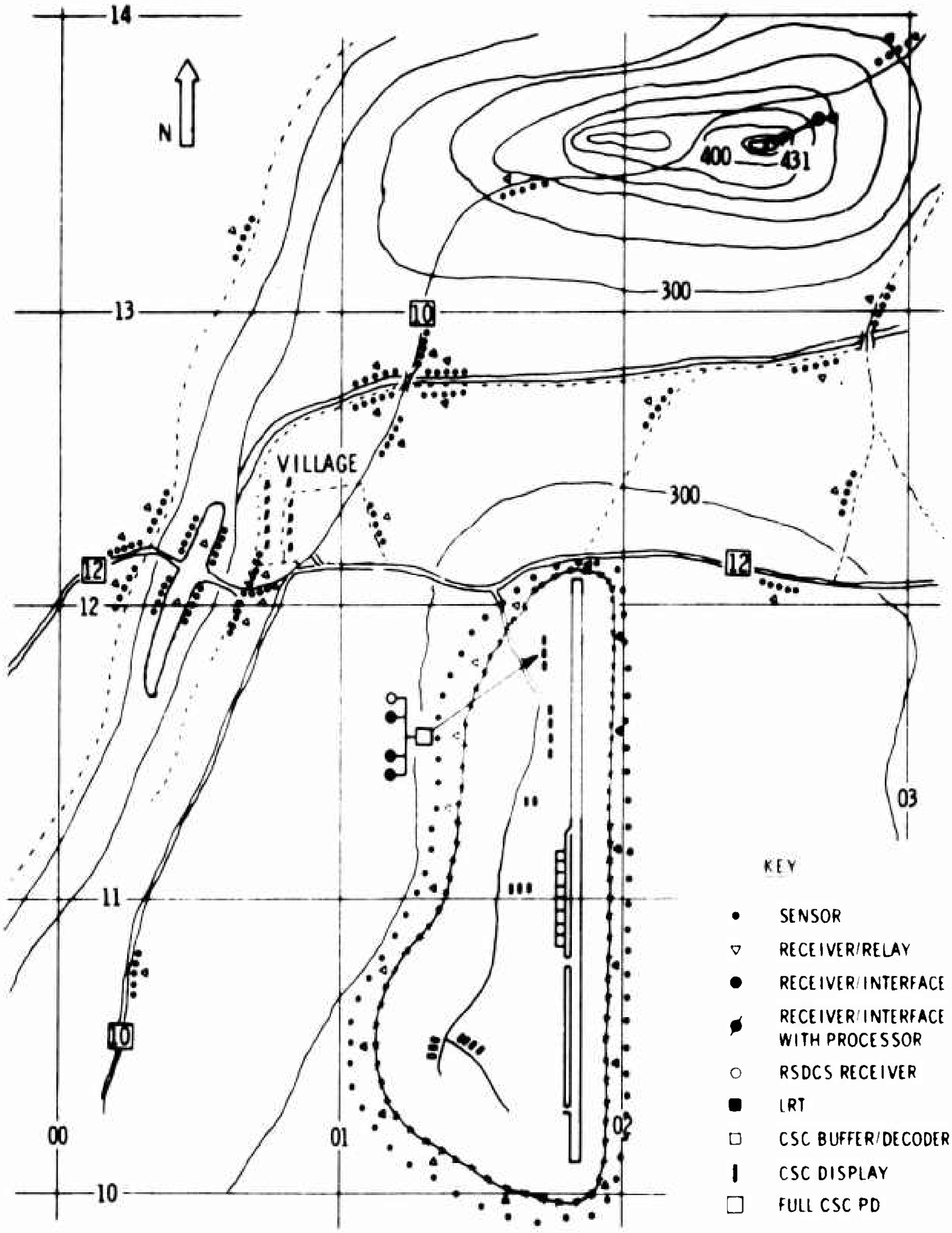

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Figure C-3 (C). Air Base and BESS Development, Phase III (U).

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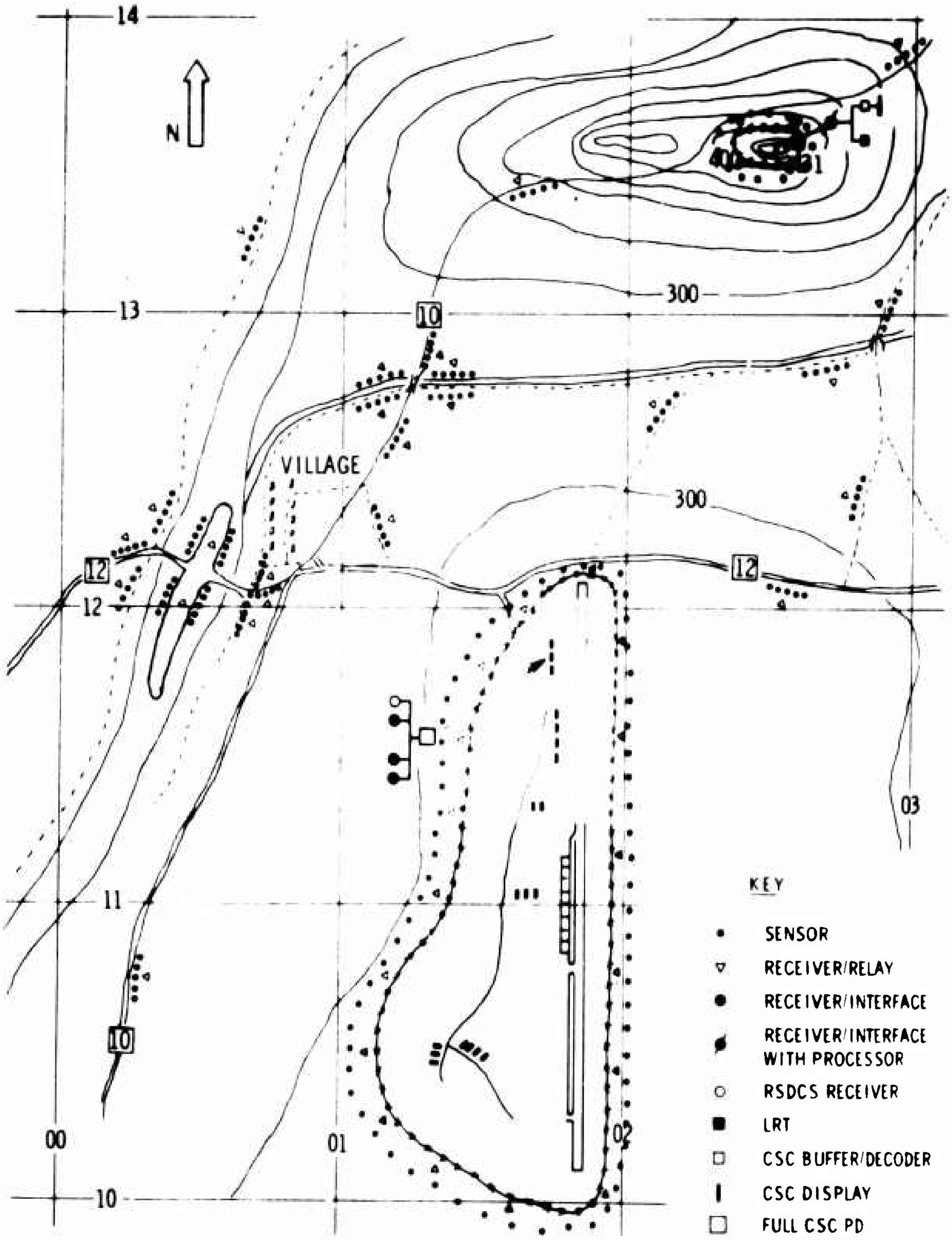

Figure C-4 (C). Air Base and BESS Development, Phase IV (U).

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C.5 (C) CONCLUSIONS

Substantial advantages are obtained during system development by using a modular system with processors in the receiver/interface. In addition, the local processor permits installation of small systems without a large investment in trained manpower for monitoring a full, poorly utilized, CSC processor unit. An orderly transition from local processing to a complete CSC data processing and management system may be achieved. There is no degradation of system effectiveness during the change-over.

Both local processing and central processing have a distinct place in the WARS System. Both capabilities are necessary to provide a flexible, cost-effective system.

Appendix D

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WARS system requirements in terms of the problem it will in part solve have been defined. Unique characteristics exhibited by the enemy during preparation for stand-off attacks on Air Force installations have been identified. WARS systems analysis and systems design, including surveillance and intra-wide area communications, have been specified. A modular design approach that will be taken in designing the WARS hardware has been developed. Added features that are felt necessary in making the WARS system adaptable to world-wide use and to the wide variety of possible Air Force applications have been identified. These features notably include local alarm data processing units that will reduce the data load on the RSDCS and the complexity of the CSCPD. The applicability of WARS to the Korean situation and how WARS could best be utilized in that situation has been outlined. Overall conclusions and recommendations are put forth. In general, it is concluded that the WARS concept is feasible, practical and cost-effective. In brief appended information, the organization and duties of the WARS team are tentatively stipulated, the susceptibilities/vulnerabilities of the WARS system are discussed, a scenario of the build-up or development of an air base and the parallel development of BESS is described, and a brief outline of how certain DCPG hardware could be integrated into the WARS system is given.

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Stand off Attack						
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Probability of Detection						
Communication Links						
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