

Waveform Generator-Package and Receiver

(Mancarried and Helicopter Receiver Portion)

Prepared for

**UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES**

by

**Collins Commercial Telecommunications Division
Circuit Switching Systems Operation
Cedar Rapids, Iowa 52406**



Rockwell International

FINAL REPORT

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November 1976

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16. Abstract The Man-carried and Helicopter Receivers were developed under the contract for trapped miner location. This program was a five phase program with 15 man-carried and 5 helicopter production receivers delivered under Phase IV and equipment documentation required under Phase V.			
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FOREWORD

This report was prepared by Collins Radio Group, Rockwell International, Cedar Rapids, Iowa under USBM Contract Number H0242010. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of PM&SRC with Dr. H. K. Sacks acting as the Technical Project Officer. Mr. Frank Pavlich was the contract administrator for the Bureau of Mines.

This is a summary of the work completed as part of this contract during the period April, 1974 to March, 1976.

This report was submitted by the author on November 30, 1976.

This report covers the mancarried and helicopter receivers part of the contract. Additional reports for the transmitter and downlink receiver complete the final report package.

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1.0 INTRODUCTION

This final report covers the Man Carried and Helicopter Receiver Portion of USBM Contract H0242010. This contract consists of three separate tasks that include the packaging of waveform generators, design and building mancarried and helicopter receivers, and the design and packaging of a voice downlink receiver with a waveform generator. The final report for the packaging of waveform generators has been completed. The downlink receiver task is now in process and a report will be written at the completion of this task. The three reports taken together will complete the final reporting requirements for contract H0242010.

The design and building of mancarried and helicopter receivers portion of this contract consisted of the design and build of 15 mancarried and 5 helicopter receivers. These receivers are used for trapped miner location during a mine disaster. The helicopter receiver is a six channel ULF receiver used to detect a ULF transmitter that would be carried by a miner and turned on during a mine disaster. Immediately after a disaster a helicopter is flown over the area and with the aid of the helicopter receiver coarse location, and the active channels are determined. Final precise location is made with the single channel mancarried receiver.

15 mancarried receivers including antenna and headset were built and delivered to the Bureau. 5 helicopter receivers including headsets and a 50 foot tethering cable to support the suspended helicopter antenna were delivered to the Bureau. This production experience has resulted in a firm producible electrical and mechanical design that can now be manufactured in quantity.

The information in the following sections discusses the details of the mancarried and helicopter receivers. From Phase I - Define problem and identify

possible solutions through Phase IV build and deliver production units. A phase V documentation is provided under another package that includes schematics, parts list, fabrication drawings, production test requirements, and instruction manuals.

2.0 PHASE I DEFINE PROBLEM AND IDENTIFY SOLUTION

This section will discuss the receiver requirements and present the receiver electrical and mechanical design to fulfill these requirements. Other design information such as uplink signal to noise ratio, filter response, antenna design and battery comparisons are included.

2.1 RECEIVER DESCRIPTION

The mancarried and helicopter receivers are used to detect and locate the position of a pulsed transmitting antenna below the surface. These receivers operate from 1050 to 3030 hertz and use a loop antenna approximately 15 inches in diameter to detect a null in the vertical magnetic field of a transmitting loop below the surface. The transmitting antennas are a portable 90 foot loop or a fixed 400 foot loop. Location depths to 1600 feet have been detected. The position directly over the transmitting antenna is indicated by a null in the vertical magnetic field. This null is indicated by a panel meter and a headset on the receivers. The helicopter receiver is essentially six mancarried receivers in one package with two operator positions that enable switching to any of the six channels. The helicopter receiver also uses a loop antenna that is suspended 50 feet below the helicopter to provide isolation from helicopter electrical noise.

2.2 RECEIVER SPECIFICATIONS

The following receiver specifications are the final design values. Changes from the original specification are as follows: Bandwidth changes were made to provide a reasonable cost filter, BNC output connectors were eliminated because of limited panel space, mancarried rechargeable batteries were replaced by primary cells to provide better service, the helicopter receiver was changed to have two operator positions to provide better operation.

2.2.1 MANCARRIED RECEIVER

Receiver Bandwidth

3 DB points NMT 30 HZ

60 DB pointw NMT 125 HZ

Sensitivity

.05 microvolts for 6DB S+N/N ratio.

Environmental Requirements

-40C⁰ to +50C⁰

Waterproof case, connectors and switches.

Operator Controls

On-off, battery test, frequency select, and gain control. Antenna hand held and manually oriented to select field component being measured.

Frequencies

Designed for Channel 18, 1050 to Channel 51, 3030 HZ. Channel frequency (HZ) = Channel No. X 60 - 30. Channel 2 to 16 and channel 52 to channel 99 available with reduced performance, due to 1000 to 3000 HZ bandpass filter of first stages. Channel 17 and 1 are unuseable.

Signal Strength Range

.05 Microvolts to 100 microvolts

Shelf Life

Five Years

Power

Four 3.0 volt lithium batteries LR 660

Continuous Operation Requirement

Unit shall operate continuously for 120 hours, with fresh batteries.

Measurements

A visual field strength meter is provided. A XTAL headset is provided.

Antenna

Potted 500 turn loop approximately 15 inch diameter.

Intrinsic Safety

Approved by Mesa Permit number 331.

2.2.2 HELICOPTER RECEIVER

Sensitivity

.05 microvolts for 6DB S+N/N ratio. .5 microvolts without pre-amplifier.

Receiver Bandwidth

3DB points NMT 30HZ 60DB points NMT 125HZ

Environmental Requirements

-40C⁰ to 50C⁰

Operator Controls

On-off-battery test, frequency select, gain control and receiver select.

Receiver select allows two operators to select any of the six receiver outputs.

Frequencies

Designed for channel 18, 1050 HZ to channel 51, 3030Hz. Channel Frequency (HZ)=
Channel No. X 60-30. Channel 2 to 16 and channel 52 to 90 available with
reduced performance, due to 1 to 3 KHZ bandpass filter of first stages. Channel
17 and 1 are unuseable.

Signal Strength Range

.05 microvolts to 100 microvolts.

Power

12 VDC rechargeable lead acid battery. Can operate from external 12 VDC auto
battery.

Operational Use

With 6 month maintenance recharge. Unit will operate a minimum of 8 hours.

With 8 hour recharge unit will operate for 16 hours.

Antenna

Potted 500 turn loop approximately 15 inch diameter. Includes 20DB preamplifier and voltage follower powered from receiver. Antenna is suspended by 50 foot cable.

Measurements

Six visual field strength meters and two switchable headset outputs are provided.

2.3 Mancarried Receiver Electrical Design

The required minimum detection of .1 UA/Meter field results in an antenna voltage of

$$VOS = 8\pi^2 \times 10^{-7} AfH_n$$

$$N = 500$$

$$H_n = .1 \times 10^{-6} \text{ Amp/Meter}$$

$$f = 1 \text{ KHZ}$$

$$A = .113 \text{ Meter}^2$$

For the above antenna, H field and frequency,

$$VOS = .044 \text{ Microvolts}$$

.05 microvolts requires a gain of approximately 160 DB to obtain an acceptable level to drive the headset and panel meter.

The required gain of 160DB would not be stable if the gain is all at one frequency, therefore the gain distribution and up conversion of figure 1 was chosen. This frequency scheme provides isolation for input and output frequencies except for channel 17 (990 HZ). At this frequency the isolation provided by the XTAL filter is not sufficient to eliminate oscillation, so

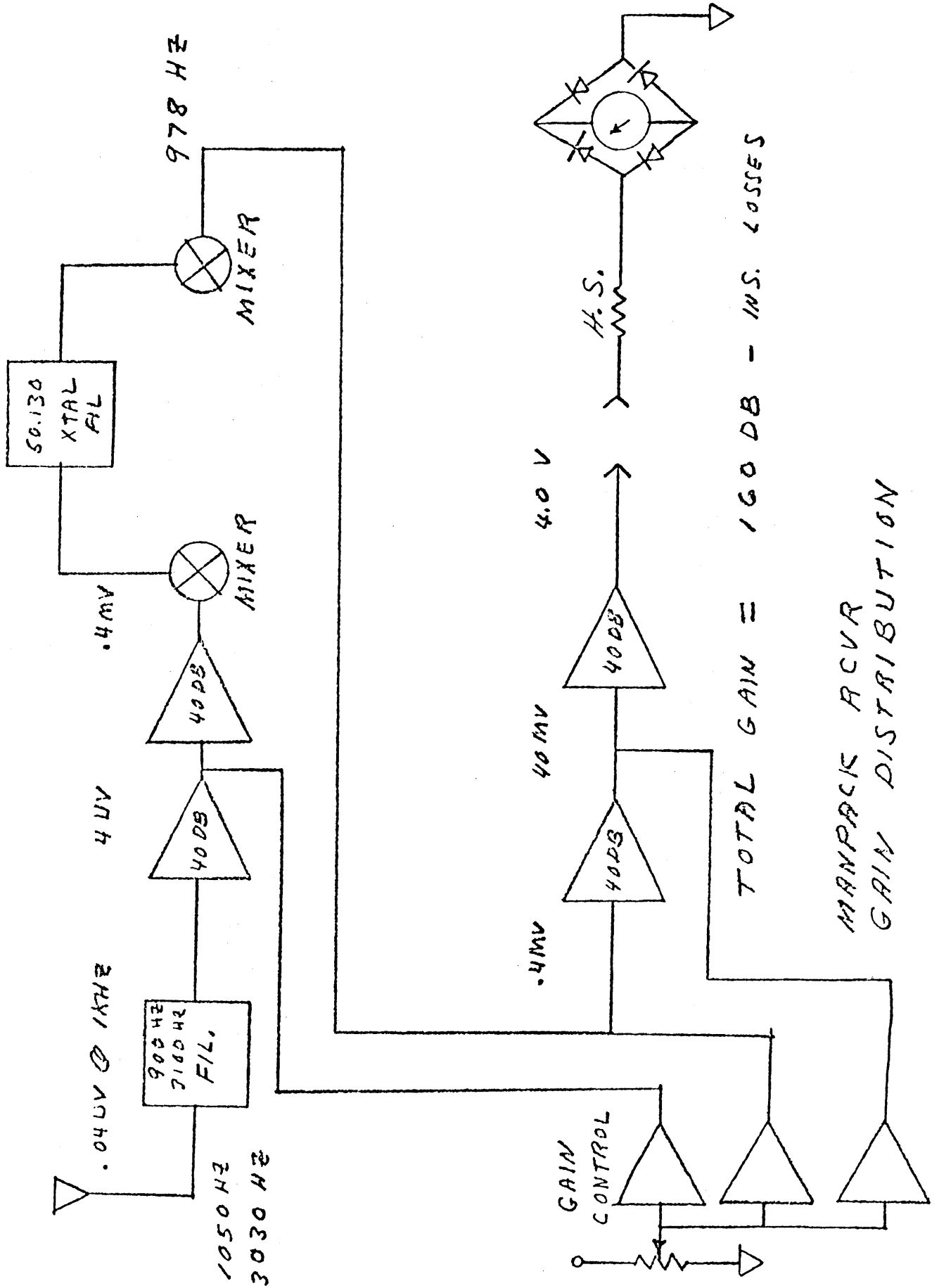


FIGURE 1

that channel 17 is unuseable.

A complete block diagram of the receiver including the synthesizer is shown in figure 2.

The received signal is amplified 80 DB and filtered before mixing with a variable injection frequency from the SMO to provide sum and difference frequencies. The sum frequency (upper sideband) 50130 Hertz is passed by the selective 50130 HZ XTAL filter. All other frequencies are rejected by the filter. After passing through the filter a second mixer with a fixed SMO injection frequency of 49152 Hertz results in sum and difference frequencies of 99 282 Hz and 978 Hz. The difference frequency is amplified 80 DB while the sum frequency is completely attenuated by a low pass filter. The resulting 978 HZ signal drives the panel meter and the headset. All incoming signals 1050 to 3030 Hz are converted to 978 HZ by this conversion scheme.

2.4 HELICOPTER RECEIVER DESIGN

The helicopter receiver design is identical to the mancarried receiver except that the first 20DB of gain is removed from the receiver and put in the antenna package. Figure 3 shows a block diagram of the multiple channel helicopter receiver.

2.5 MECHANICAL

Preliminary layouts of the manpack receiver and helicopter receiver were completed during Phase I. The manpack receiver is comprised of a hydroformed aluminum can with spotwelded beltloop and fusion welded nut blanks. The cover is an investment cast aluminum with a recessed gasket surface and projecting edge to offer protection for the connectors and controls. A vacuum-formed polycarbonate cover is slipped over the top of the receiver for protection against dirt during long periods of storage. A picture of the mancarried receiver is shown

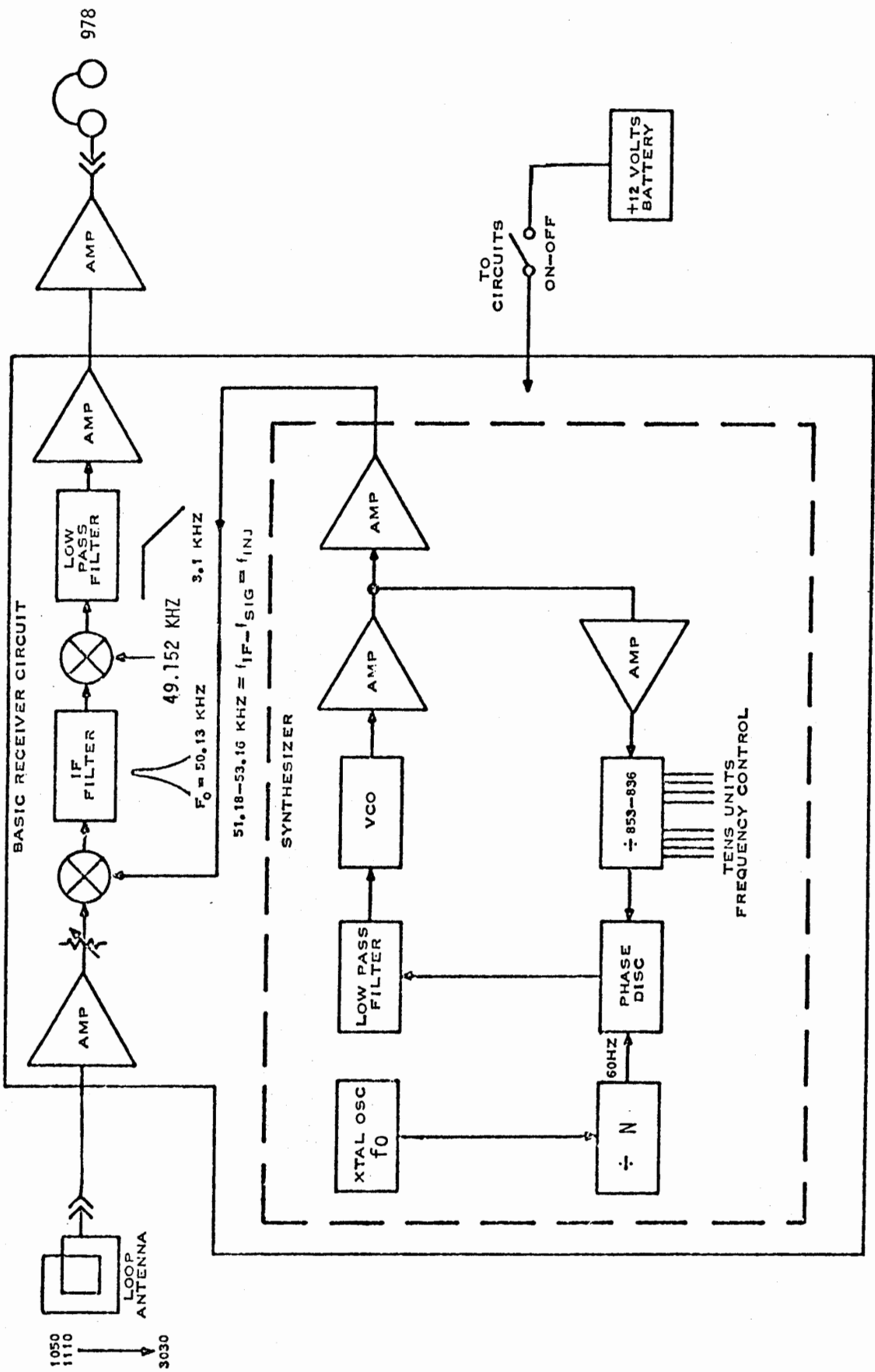


Figure 2 Mancarried Receiver System

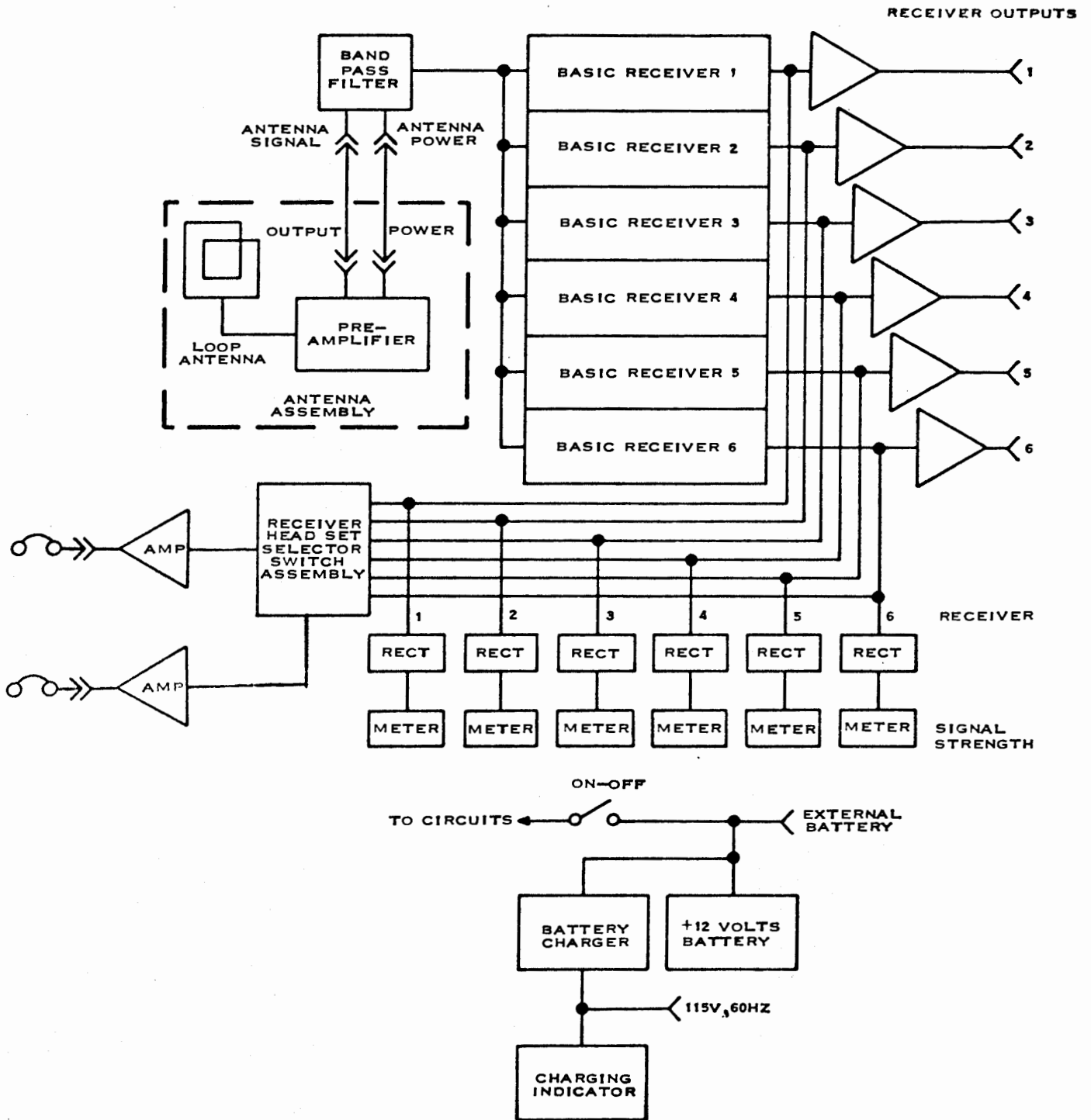


Figure 3 Multiple Channel ULF Helicopter Receiver System.

in figure 4. Additional detail can be obtained from the documentation package.

The helicopter receiver consists of two sand cast aluminum sides which serve as handles and protection for the front panel and the connectors and power cord on the rear panel. Heavy gauge aluminum sheet will be used for the remainder of the chassis to provide a low cost, light weight, yet rugged unit. A picture of the helicopter receiver is shown in figure 5. Additional detail can be obtained from the documentation package.

2.6 FILTER RESPONSE

The filter pulse response for a practical three pole butterworth filter, similar to the filter considered for this design, and a minimum ringing Gaussian filter was theoretically investigated.

Figure 6 shows the theoretical dynamic response of a three pole butterworth bandpass filter with figure 7 showing the dynamic response of a Gaussian bandpass filter to a 100 ms pulse. The pulse is a simulation of the input signal to the receiver from the waveform generator. The graphs simulate the response of the receiver to the pulses with nominal 10 Hz bandwidth.

From these graphs, it can be seen that although the Gaussian filter does exhibit minimum ringing, no apparent overshoot or objectionable ringing will occur for the three pole butterworth bandpass filter.



Figure 4

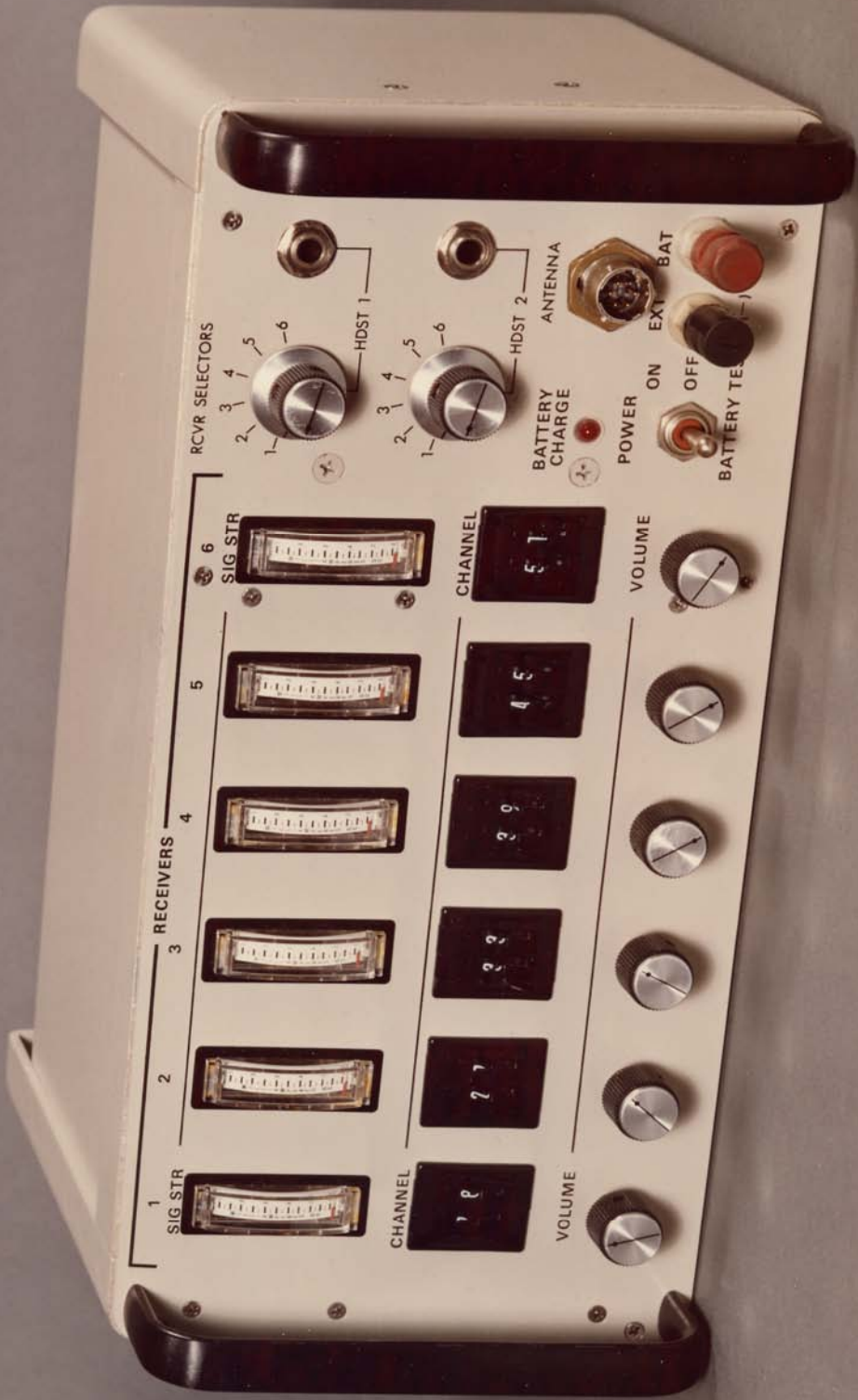
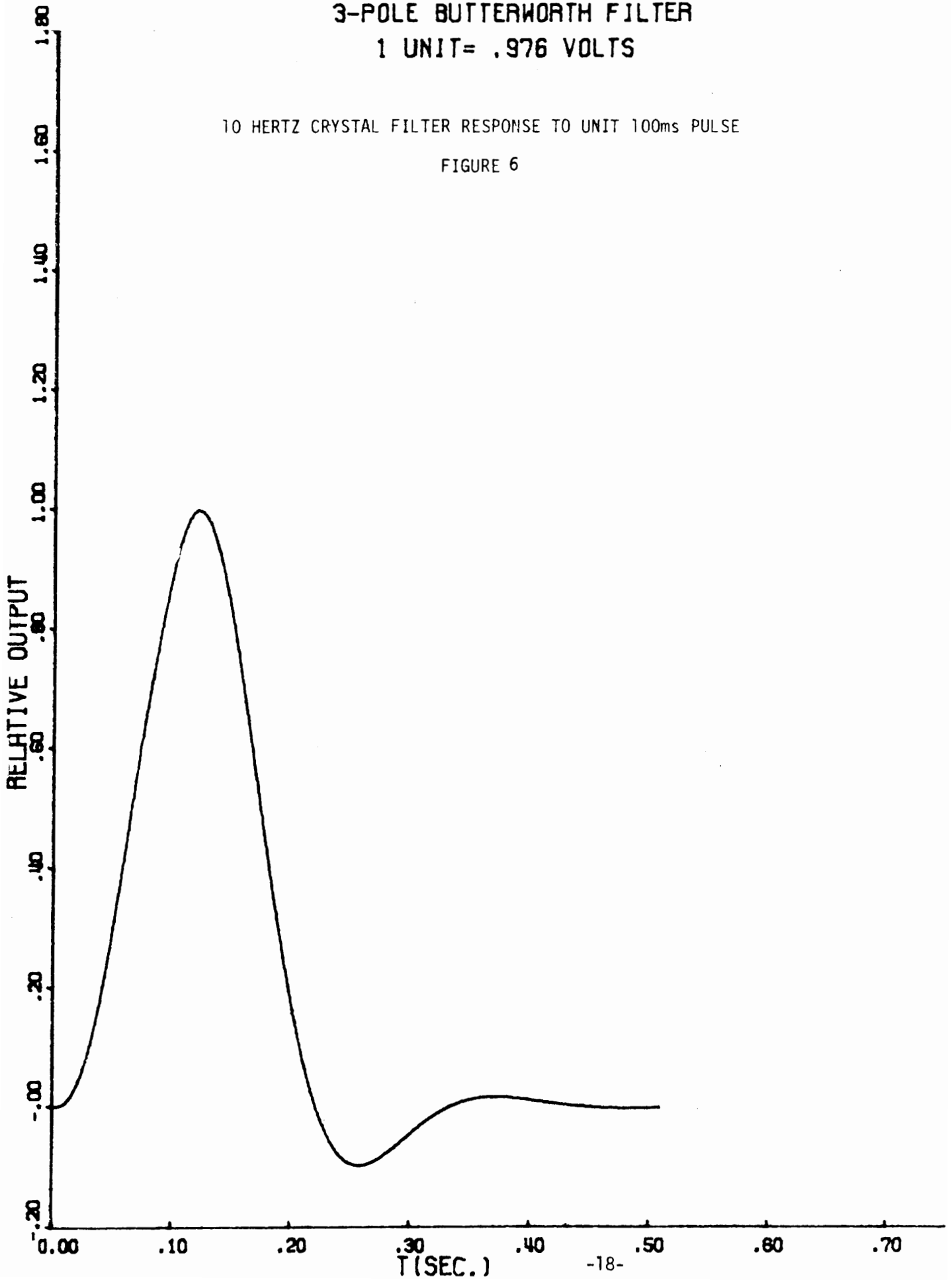


Figure 5

3-POLE BUTTERWORTH FILTER
1 UNIT = .976 VOLTS

10 HERTZ CRYSTAL FILTER RESPONSE TO UNIT 100ms PULSE

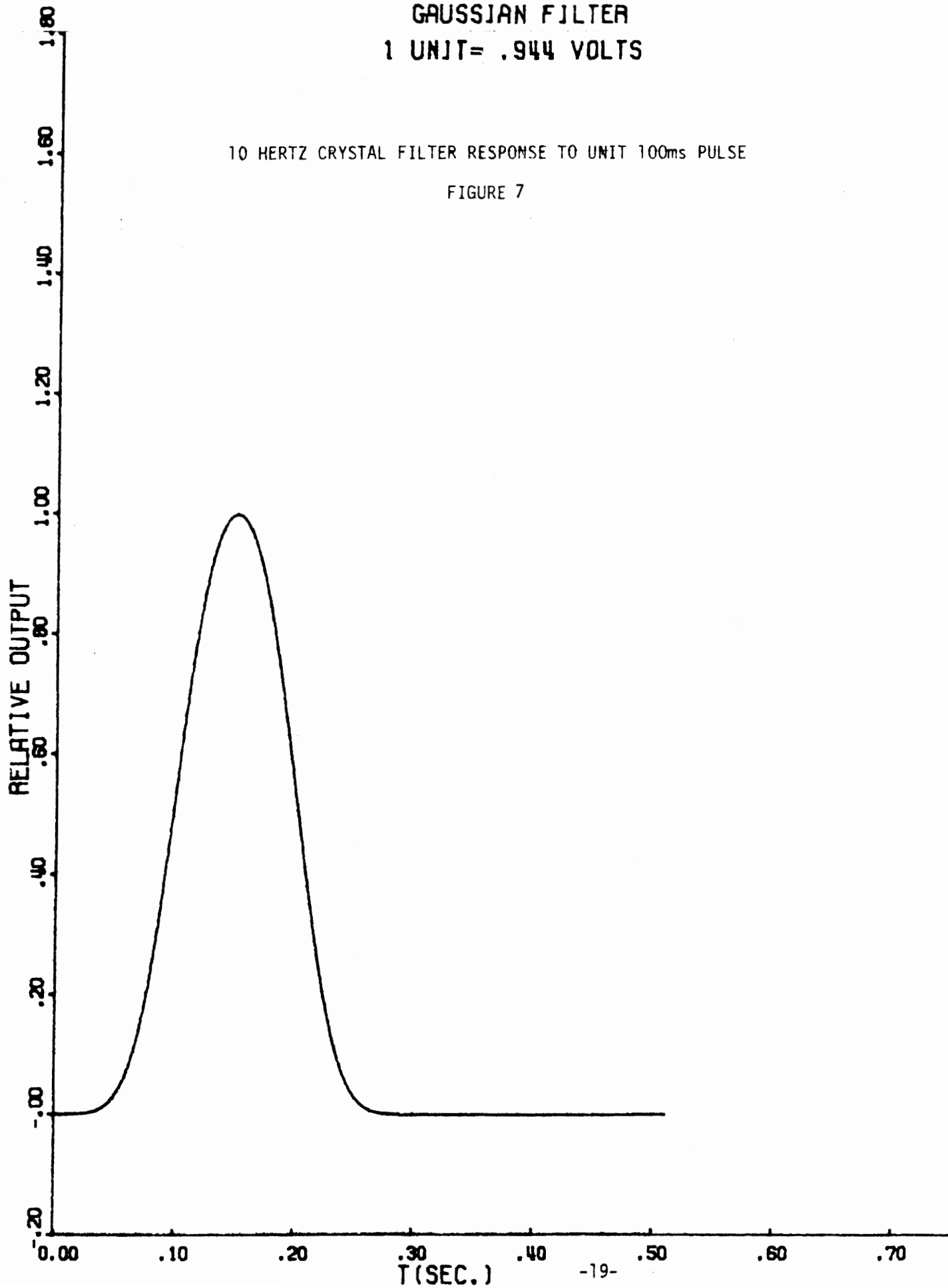
FIGURE 6



GAUSSIAN FILTER
1 UNIT = .944 VOLTS

10 HERTZ CRYSTAL FILTER RESPONSE TO UNIT 100ms PULSE

FIGURE 7



2.7 Receiver Noise Figure and Antenna Determination

Phase I theoretical investigations were completed relating to antenna design and receiver noise figure. The resulting calculations determine the minimum loop radius, for a given loop weight, that if this radius is increased beyond the minimum size, nothing will be added to the reception of the signal or its received signal-to-noise ratio.

This minimum radius for the receiving antenna is:

$$* a \leq 3.968 \times 10^{-7} \frac{1}{f H_n} \sqrt{\frac{\eta F \Delta f}{W}}$$

Where

F = Total receiver noise factor

H_n = Minimum noise field in $\mu\text{a/m}$ for bandwidth Δf

W = Loop weight in Kgm

f = Receiver frequency in Hz

Δf = Receiver noise bandwidth in Hz

η = Amount received ambient noise is greater than internal receiver noise.

Using this equation with $\eta = 10$, $f = 1$ KHz, $W = 3.46$ Kgm, $F = 31.62/15$ db, $\Delta f = 10$ Hz, and $H_n = 0.05$ $\mu\text{a/m}$ the minimum radius for an untuned receiver is 9.48 inches which is close to the radius of the present loop antenna.

* For derivation see R. P. Decker, "Signal to Noise Analysis for Loop-to-Loop Mine Communications", Final Report Contract H0232056 Page 5-10.

From these calculations it currently appears that both the mancarried and helicopter receivers can be broadbanded eliminating any tuning capacitors.

2.8 Re-examination of Uplink Signal-To-Noise Ratio

The following Figures 8 and 9, are propagation calculations for expected S/N_0 (for a 1 Hz bandwidth) using the newest NBS noise data available 21 December 1973.

Calculations were made for both Mean Surface Noise and Minimum Surface Noise Grades using both a 100 foot transmitting loop and a 400 foot transmitting loop. Overburden depths varied between 50 meters and 300 meters for conductivities of 0.01 mhos/meter.

Although these calculations have no direct effect on the actual design, they can be used to determine what effects various transmitter loop sizes and powers have on the surface fields.

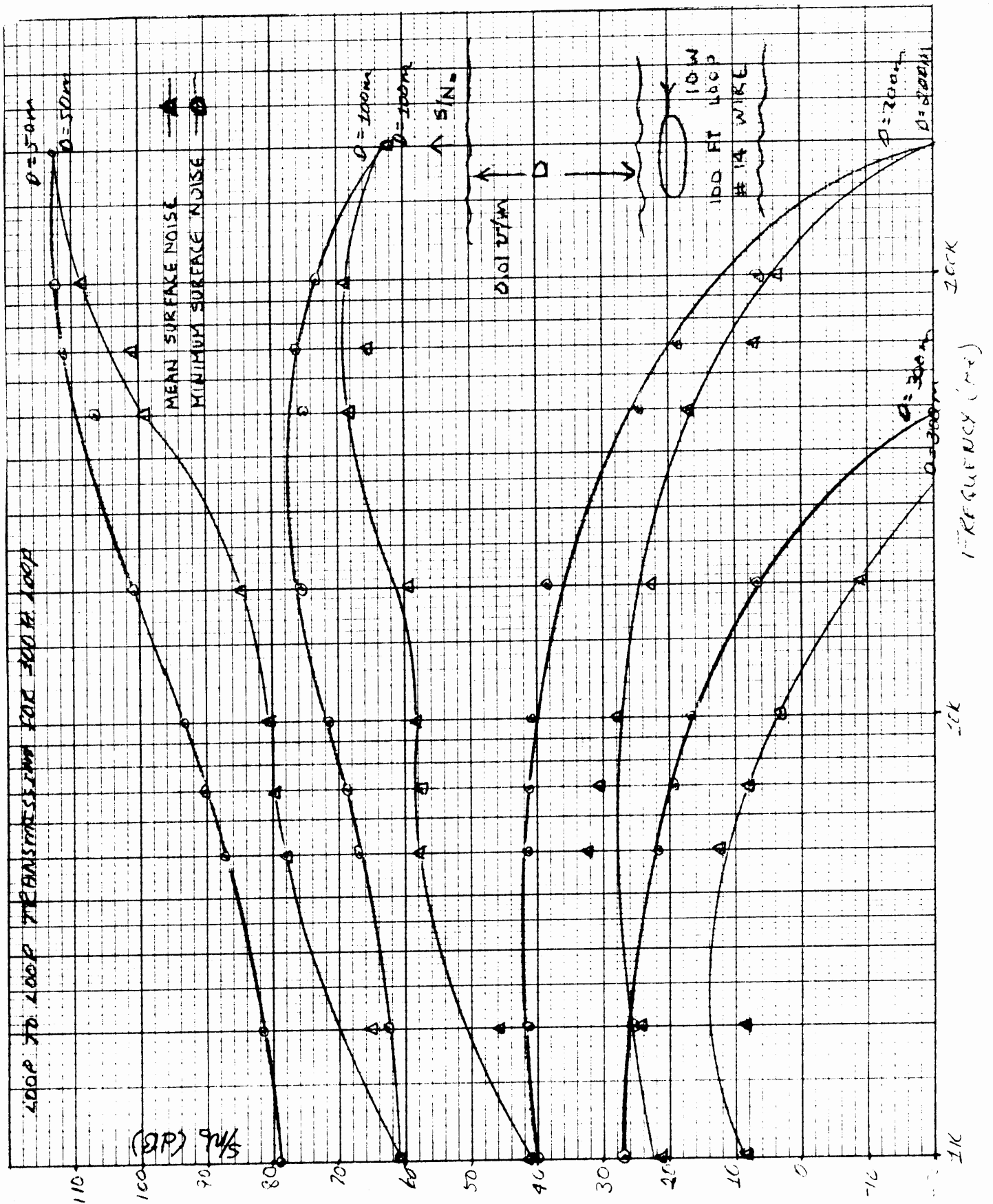


Figure 8

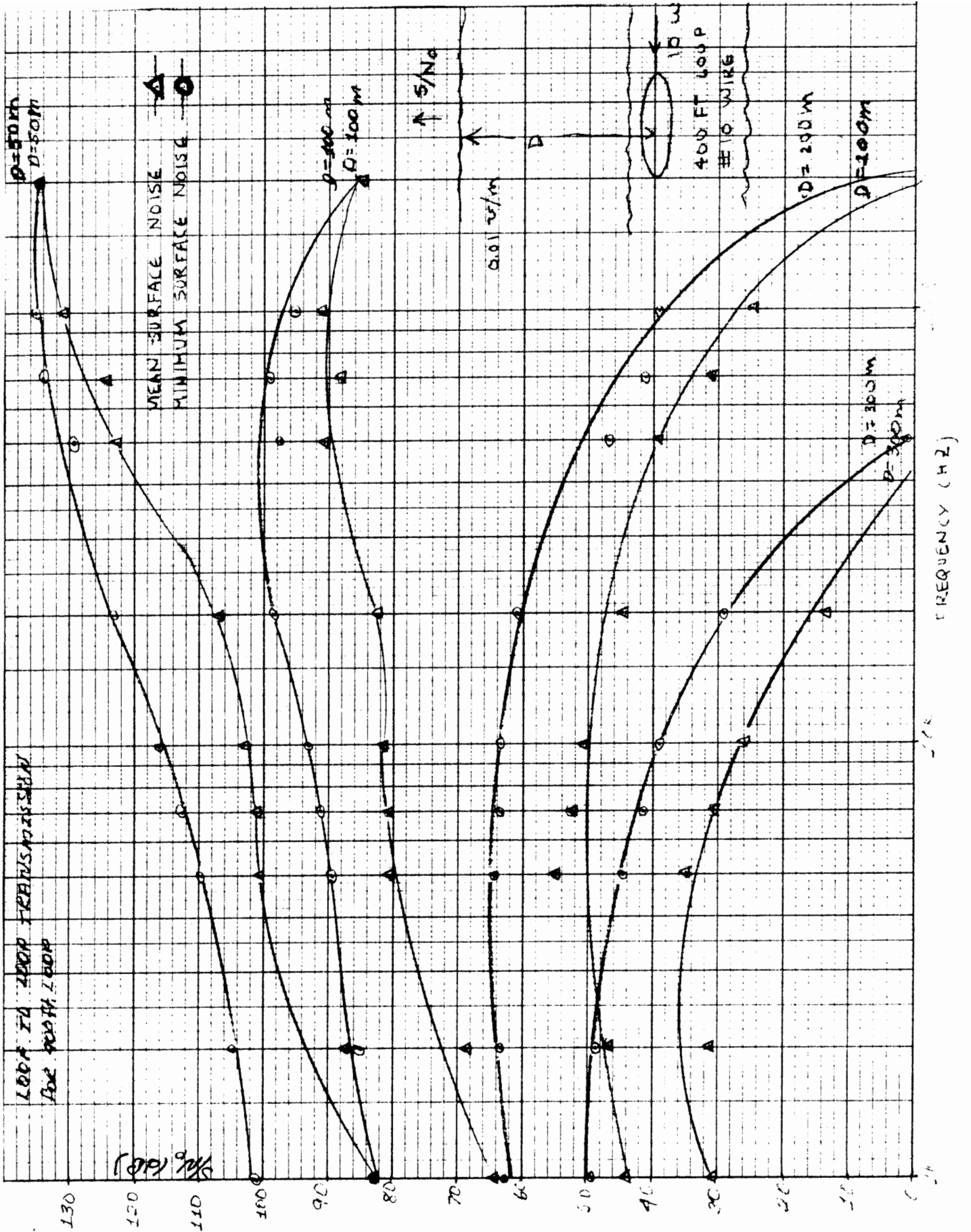


Figure 9

2.9 Battery Selection and Charger Results

2.9.1 Helicopter Receiver

Two 6 volts 4.5 A.H. batteries are required for the helicopter receiver. The choice for these batteries are the Gates lead acid cell type. The other battery considered was the Globe gel cel. This battery was discarded in favor of the Gates because of the amount of hydrogen and oxygen vented. The gel cell has a low pressure seal that vents easily during charging, whereas the Gates has a high pressure seal that has a minimum amount of venting. This venting of hydrogen and oxygen is deemed undesirable because of corrosion and possible explosion in a sealed, water-tight enclosure.

The 4.5 A.H. battery will meet the 8 hour operation requirements between charges. The requirement for 6 hour operation after a one hour preparation time can also be met, but it is recommended that a 6 month maintenance program be established so that a one hour fast charge preparation time is not required. The reasons for establishing a six month maintenance program are that lead acid battery manufacturers do not recommend storage in a discharged state, deleting the fast charge will simplify the charger, and operation readiness will be enhanced. The low self discharge rate of 6 - 8% per month with a 6 month maintenance charge will provide the required 6 hours of operation without a one hour preparation time.

The charger for the helicopter receiver will be self-contained and will consist of an integrated circuit U723 regulator in a constant voltage charging configuration.

2.9.2 Manpack Receiver

Two 6 volt 1 A.H. batteries are required for the manpack receiver to provide the required 20 hours of operation. A Gates cell of this size is not available so that a choice had to be made between a Globe gel cell, Ni-Cad or lithium primary cell. A detailed comparison of all of these battery types is shown in Figure 10. The gel cell has venting problems and the Ni-Cad has poor self-discharge and a cell reversal memory problem. The lithium primary cell is lightweight, has long shelf life and appears to be ideal for this application but is not rechargeable. The lithium cell would not require a 6 month maintenance program, but would require a shelf life replacement time of 3 - 5 years. The 4 AH would provide approximately 80 hours of operation. No preparation time or charger is required.

BATTERY COMPARISON
(MANPACK RECEIVER)

<u>MODEL</u>	<u>KIND</u>	<u>COMPANY</u>	<u>VOLTS</u>	<u>CELL NO.</u>	<u>CAPACITY</u>	<u>WEIGHT</u>	<u>SIZE</u>	<u>STORAGE SELF DISCHARGE</u>	<u>TEMPERATURE</u>
GC1215	Lead-Acid	Globe	12V	6	1.5 A-H	1.15 lb	7.02"L 1.33"W 2.58"H	2% - 3%/month	-60°C to +60°C
<p>Comments: (-) Excessive venting of hydrogen and oxygen due to fast charging and overcharging, at -40°C capacity down to 40%.</p>									
0811-001	Lead-Acid	Gates	12V	6	2.5A-H	2.01 lb	4.05"L 2.70"W 2.03"H Individually 1.35"Diameter 2.03"Height	6% - 8%/month	-40°C to +35°C
<p>Comments: (-) Too large and heavy</p>									
950/195	Lithium	ACR Electronics	12V	6	4 A-H	.37 lb	1.874"L 1.874"W 1.937"H		-40°C to +70°C
<p>Comments: (-) Must carry extra set don't know charge of cell. (+) light weight and small no battery charger 3 years service life</p>									
XFCR1.0ST	NI-CAD	General Electric	12V	10	1.2A-H	.938 lb	4.5"L 1.8"W 1.937"H	20%-30% /month	-40°C to +40°C
<p>Comments: (-) poor self discharge memory problem (+) can be fast charged cell reverse problem</p>									

Figure 10

3.0 PHASE II DESIGN EQUIPMENT

3.1 INTRODUCTION

The following information and data were the recommended phase II design for the receivers of the "Waveform Generator Package and Receiver", contract No. H0242010.

During this phase, the outlined solutions from Phase I were used as a guide and the receiver circuits were designed, breadboard, and tested. The final mechanical configuration and design was completed.

Electrical design, schematics, significant test results, mechanical design, drawings and selected specifications were presented for Bureau comments, changes and approval. This section reflects the final design with all changes incorporated.

3.2 ELECTRICAL DESIGN

3.2.1 Man Carried Receiver

With reference to Figure 11, the schematic of the man carried receiver, a description of the receiver operation will be discussed.

The received signal picked up by the antenna ranges from .1 UA/M to 100 MA/M or .05 UV to 50 MV. To raise the minimum voltage to a 1 V level without losses to drive a headset requires 146 dB of gain.

The first 40 dB of gain is obtained by two FET stages. The low noise characteristic of FETS are used for the first stages to obtain the required S+N/N ratio. The last FET stage is buffered by an emitter follower before the next 40 dB of op amp gain. This operational amplifier

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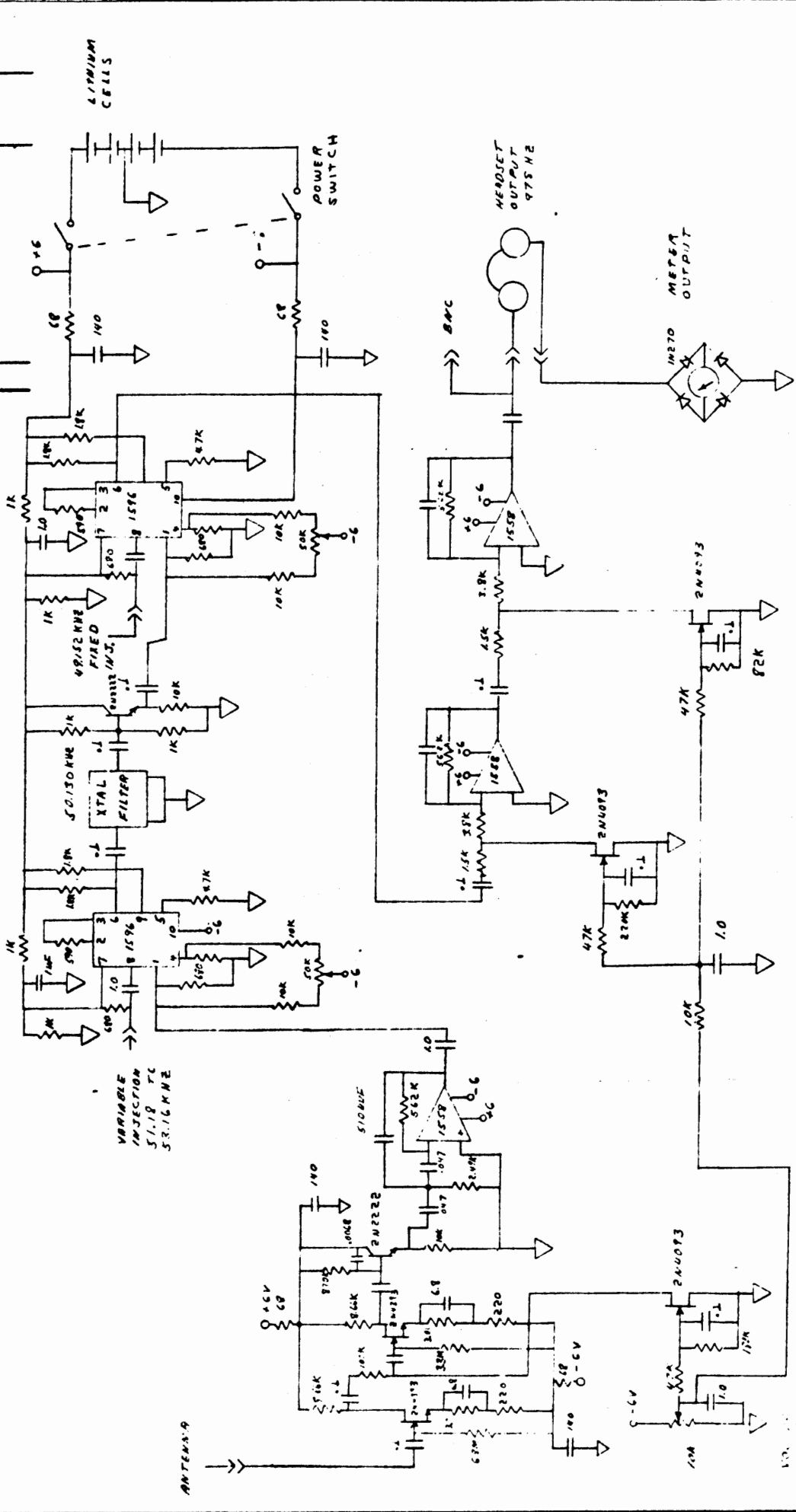


FIGURE 11

COLLINS RADIO COMPANY DALLAS, TEX NEWPORT BEACH, CALIF CEDAR RAPIDS, IA	
CONTRACT NO. PREP 10120174/SA	
CHK	
APVD	
SIZE	CODE IDENT
C 13499	OWG NO
SCALE	SHEET
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES; TOL ON DEC DIM.: .XX = ±.02, .XXX = ±.008 HOLE DIAMETERS: UNDER .251 DIA = +.005-.005 OVER .500 DIA = +.006-.005 ANGLES: ±1.0° ECCENTRICITY BETWEEN DIA ON AN AXIS NOT TO EXCEED .010 DIA PART SHALL COMPLY TO 580-5400-001	
MATERIAL FINISH	

is configured as a high pass active filter to further reject noise outside of the desired receiver bandwidth. High frequency noise is attenuated by the inherent high frequency roll off of the op amp and the feedback capacitor at the emitter follower.

The received signal is then mixed with the variable injection from the synthesizer to produce sum and difference frequencies. A 1,050 Hz received signal mixes with 51,180 Hz to produce 52,230 Hz and 50,130 Hz. The 52,230 Hz is rejected by the crystal filter while the 50,130 Hz signal is passed through the filter with little attenuation. After buffering and matching by an emitter follower, the 50,130 Hz signal is mixed with a fixed injection frequency of 49,152 Hz, producing a 978 Hz and a 99,282 Hz signal. The 978 Hz signal is passed through the final two op amp stages with a gain of approximately 80 dB. The op amp frequency response is rolled off above 1 kHz so that the 99,282 Hz image is rejected. This final 978 Hz signal drives the headset and meter circuit. This offset frequency scheme provides isolation between the input signal and output signal to minimize the possibility of oscillations caused by coupling between the antenna and output circuits.

The large (120 dB) of signal range .1 UA/M to 100 MA/M is accommodated by 3 FET attenuators controlling 3 gain stages. These FETs are used as voltage controlled variable resistors all being driven by a single volume control.

The receiver is powered by four 3.0 volt lithium primary cells. These cells are configured to provide +6 volts and -6 volts. Battery life is estimated to be 80 hours. The batteries are made intrinsically safe by the addition of a small internal resistor by the battery manufacturer.

3.2.2 Frequency Synthesizer

Figure 12 is a schematic of the digital ULF synthesizer which derives a total of 34 discrete RF output frequencies by using a single phase-locked RF frequency determining loop. The accuracy and stability of the derived RF output signal is identical to that of the self-contained frequency standard. Additionally, a single second injection frequency is supplied.

The synthesizer is composed of two major sections: frequency standard section consisting of a 245.76 kHz reference oscillator, reference oscillator divider, and second injection reference divider; and a phase-locked RF frequency determining loop consisting of variable divider, discriminator VCO, buffer amplifier, and output amplifiers.

The reference oscillator, reference oscillator divider, and second injection reference divider supply fixed frequency signals. The reference oscillator is a crystal controlled anti-resonant oscillator circuit consisting of one gate section in a 4049AE C-MOS Hex buffer and a 245.76 kHz crystal with associated capacitors and resistors. This crystal oscillator drives both the reference divider and the second injection divider. The reference divider employs a C-MOS 4020AE 14 stage binary divider using 12 stages to divide the 245.76 kHz to the desired 60 Hz reference frequency for injection into the phase-locked loop. The second injection divider takes the 245.76 kHz output of the crystal reference oscillator and by use of a C-MOS 4027AE dual J-K flip-flop and part of a 4013AE dual D flip-flop, divides the crystal frequency by five to obtain the 49.152 kHz which is amplified and buffered in two additional gates of the 4049AE and supplied externally for the second injection signal.

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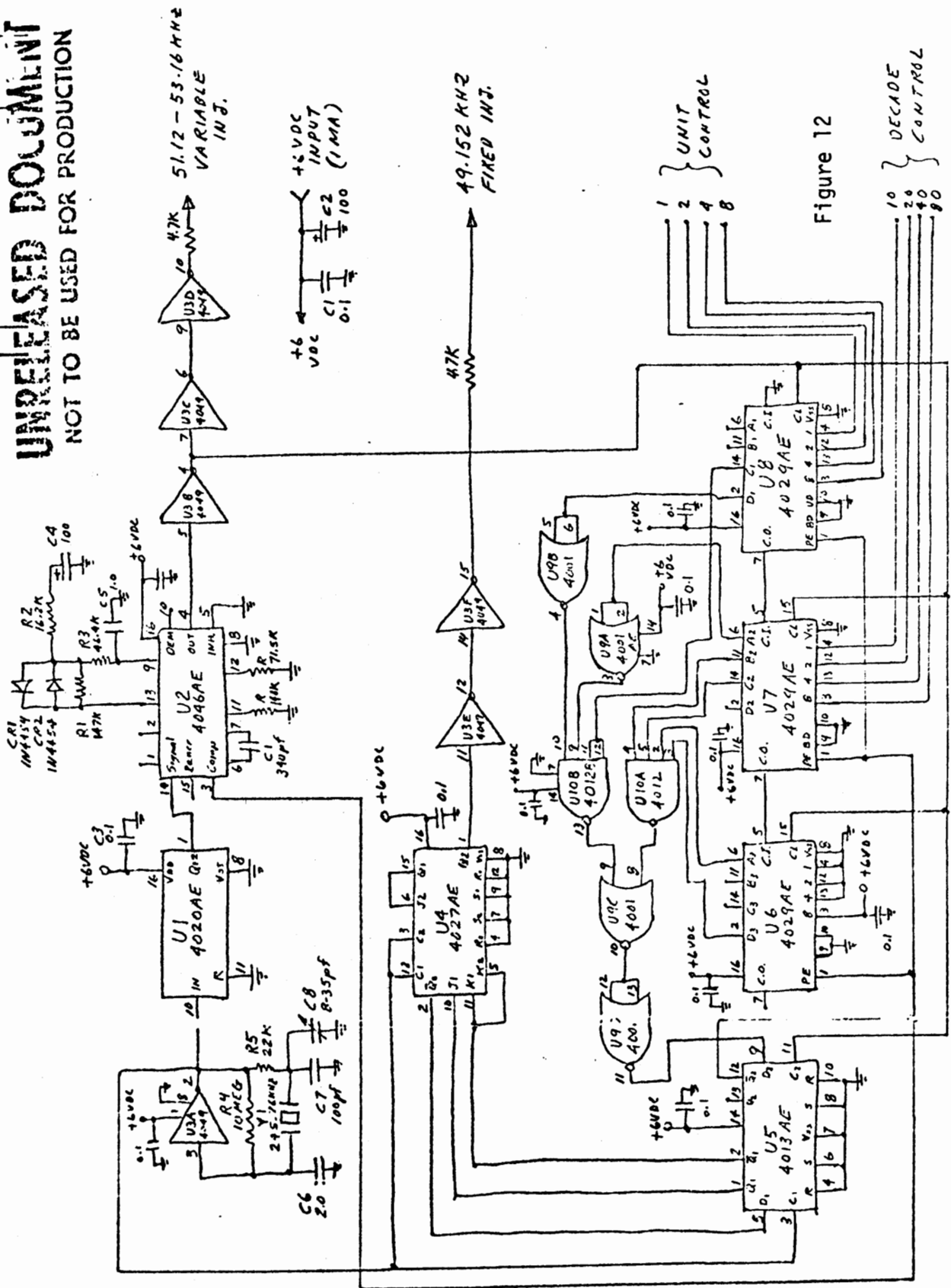


Figure 12

NOTES:
1. UNLESS OTHERWISE SPECIFIED, RESISTANCE VALUES ARE IN OHMS AND CAPACITANCE VALUES ARE IN MICROFARADS.

MATERIAL		UNLESS OTHERWISE SPECIFIED		CONTRACT NO.	
FINISH		DIMENSIONS ARE IN INCHES; 10L ON DEC DIM.: .XX = ±.02, .XXX = ±.008		COLLINS RADIO COMPANY	
		HOLE DIMETERS: UND/R .251 DIA = +.005-.005 .251 TO .500 DIA = +.006-.005 OVER .500 DIA = +.008-.005		DALLAS, TEX NEWPORT BEACH, CALIF CEDAR RAPIDS, IA	
		ANGLES: ±1.0° ECCENTRICITY BETWEEN DIA ON AN AXIS NOT TO EXCEED .010 DIA		PREP JAN 10-26-74	
		PART SHALL COMPLY TO 540-5400-101		CHK	
				APVD	
				SCALE	
				SIZE CODE 10LNT	
				DWG NO.	
				C 13499	
				SYNTHESIZER, ULF	
				SHEET	

The phase-locked RF frequency determining loop consists of a 853 to 886 divider, a C-MOS phase-locked loop and various amplifiers. The RF frequency originates from the VCO contained in the C-MOS 4046AE circuit. This VCO is set to cover the proper frequency range 51.18 to 53.16 by the addition of a capacitor on pins 6 and 7 and by the application of the proper control voltage into pin 9. The output of the VCO is buffered and supplied two places: the output amplifier which drives the first mixer of the radio, and the variable divider which is controlled to divide by 853 to 886 and drive the phase comparator in the 4046AE pack. The phase comparator in the 4046AE pack compares the variable divider signal with the reference divider signal of 60 Hz and supplies a DC control voltage thru the low-pass filter, CR1, CR2, R1, R2, R3, C4 and C5 to the VCO control. The VCO frequency is divided by the variable divider until it is 60 Hz. Setting the variable divider at 853, channel 18, for instance will force the VCO to go to 51.18 kHz where the loop will become balanced. Likewise setting the divider to 886, channel 51, will force the VCO to go to 53.16 kHz.

The variable divider consists of three sections; a programmable section consisting of two presettable decade dividers, a fixed divide-by-eight and state recognition-reset circuitry. The complete divider uses a total of five and one half integrated circuits. The divider has a division ratio capability of 800 through 899 but produces the required ratios of 853 through 886 in response to channel number (18 to 51) in BCD encoded form. Division ratios are accomplished by setting the counter to the channel number in BCD and allowing it to count down through its sequence. Note here that the 100's counter is fixed $\div 8$ so for channel

18 it is set to 818. It is allowed to count down through zero and on to the recognition state of 967. It then takes one more count to trip the strobe flip-flop (1/2 of 4013AE) and one more count to strobe in the dial setting which also supplies a pulse to the comparator input of the 4046AE pack. The sequence then continues again. The counts add up as follows: with the controls set on 18, 818 is set into the counter. It counts down through zero to 967, $818 + 33$, and requires two more counts to completely reset, $818 + 33 + 2 = 853$ the division ratio required for channel 18. If channel 51 is desired, 851 is set in and counting down through zero to 967 plus two more for resetting gives a total of 886, $851 + 33 + 2 = 886$, which is the division ratio desired for channel 51. The 967 count is recognized by gates 4001AE and 4012 as $\boxed{1}00\boxed{1} - 0\boxed{110} - \boxed{01}11$. The other bits are redundant.

3.2.3 Helicopter Receiver

The helicopter receiver schematic seen in Figure 13 is the same basic receiver as the man carried receiver. The first FET stage from the basic receiver is installed with a voltage follower at the antenna. A voltage emitter follower is required to provide buffering and a low impedance source to minimize pickup. A schematic of the antenna, and pre-amp is also seen in Figure 14.

The helicopter receiver is powered by a gates sealed lead acid rechargeable 12 V battery with a center tap to provide +6 volts and -6 volts. A self contained charger is supplied. The charger is an off the shelf low cost limited temperature range power supply that is readily packaged into the receiver case. The capability to operate from an external

REVISIONS	DESCRIPTION	DATE	APVD
LTR			

UNRELEASED DOCUMENT
NOT TO BE USED FOR PRODUCTION

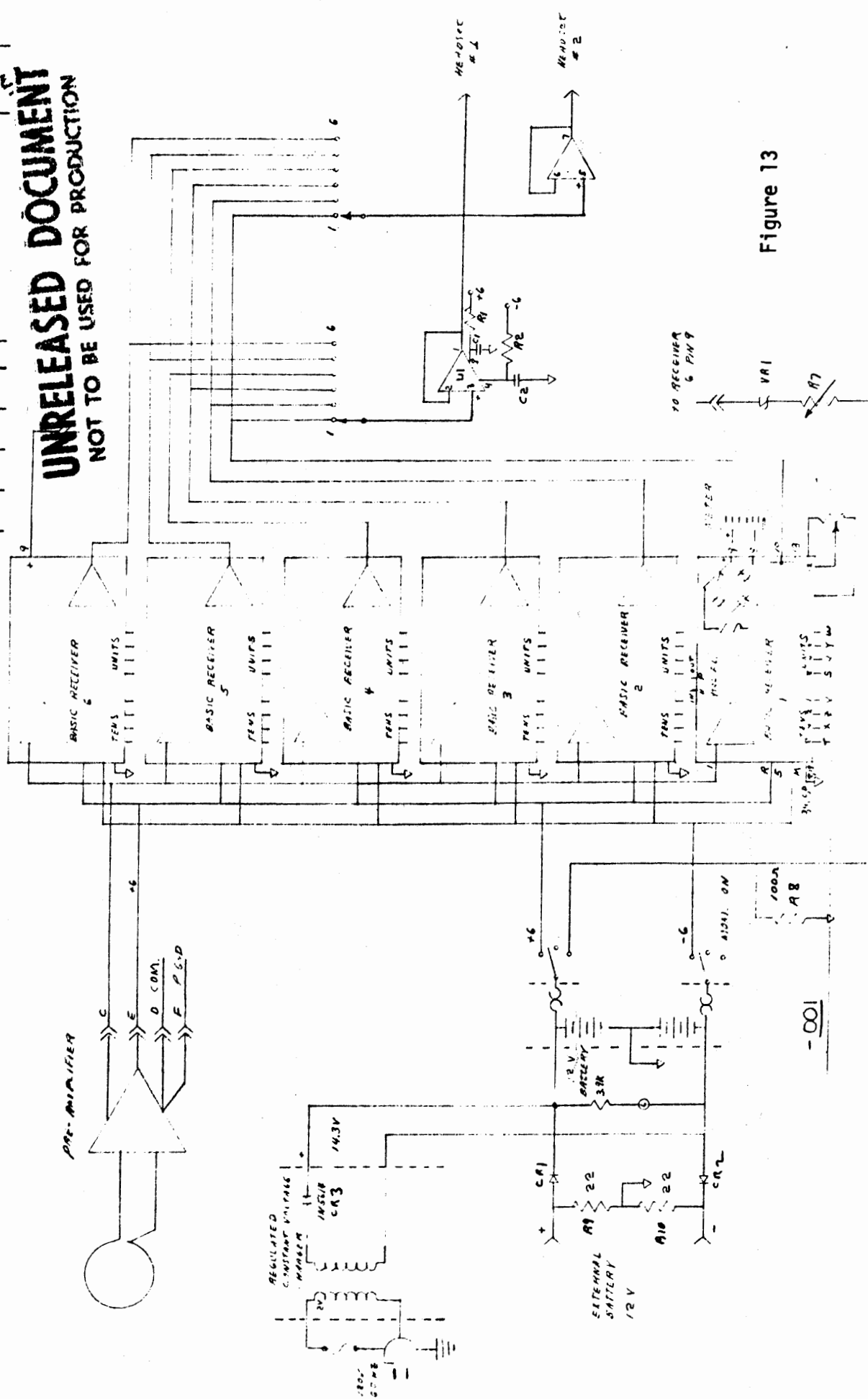
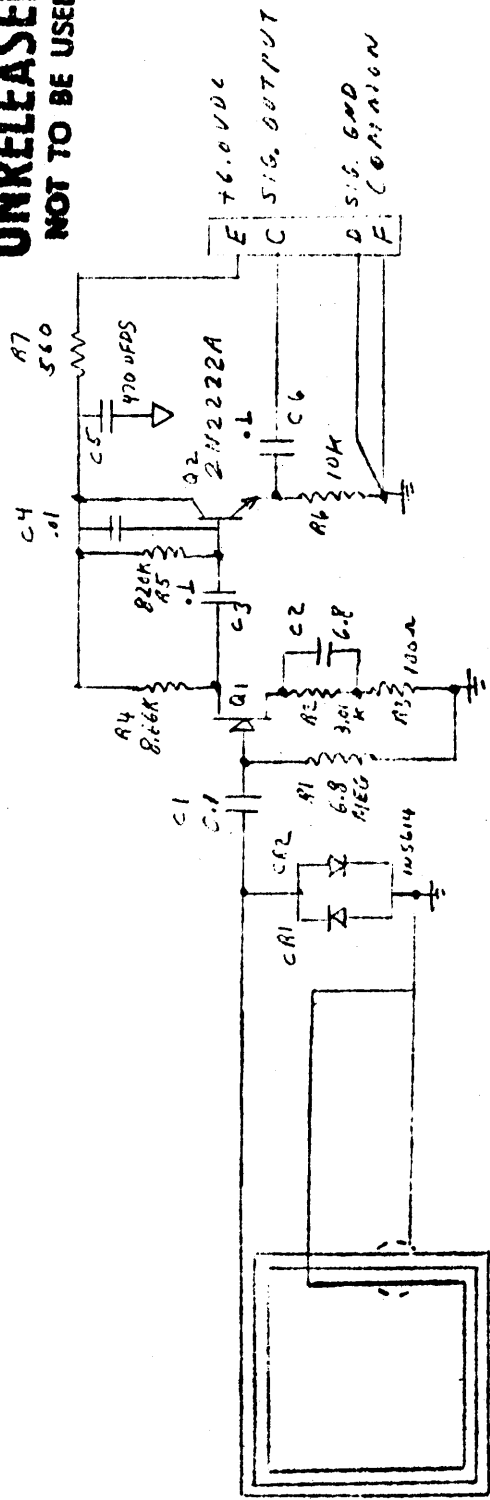


Figure 13

ROCKWELL INTERNATIONAL CORPORATION COLLINS RADIO GROUP <small>DALLAS TEXAS • NEW YORK N.Y. • LOS ANGELES CALIF. • CHICAGO ILL.</small>	
SCHMATIC HLCPT RECEIVER	
CONTRACT NO.	1013015
PREP.	ANEMA
CHK	
APVD	
SIZE	CODE IDENT DWG NO
C13499635-3924	
SCALE	NONE
SHEET	
<small>UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ON DWGS ARE IN INCHES. METRIC DIMENSIONS IN PARENTHESES. SINGLE DIMENSIONED DRWS ARE IN INCHES.</small>	
METRIC TOL ON METRIC DIM. X = ±0.5, XX = ±0.2, XXX = ±0.08 HOLE DIAMETERS: UNDER 6.38 (1/4) = +0.13 - 0.13 6.38 TO 12.7 (1/2) = +0.15 - 0.13 OVER 12.7 (1/2) = +0.20 - 0.13 ANGLES ±1.0° ECCENTRICITY BETWEEN DIAMETERS ON AN AXIS NOT TO EXCEED 0.25 (1/16) PART SHALL COMPLY TO 580-5400-001 -- THIRD ANGLE PROJECTION	
US CUSTOMARY TOL ON DIM. XX = ±0.2, XXX = ±0.08 HOLE DIAMETERS: UNDER 251 (10) = +0.005 - 0.005 251 TO 500 (20) = +0.006 - 0.005 OVER 500 (20) = +0.008 - 0.005 ANGLES ±1.0° ECCENTRICITY BETWEEN DIAMETERS ON AN AXIS NOT TO EXCEED 0.10 (1/16) PART SHALL COMPLY TO 580-5400-001 -- THIRD ANGLE PROJECTION	
MATERIAL	NONE
FINISH	NONE

REVISIONS	DESCRIPTION	DATE	APPROVED
LTR			

UNRELEASED DOCUMENT
NOT TO BE USED FOR PRODUCTION



LOOP
 ANTENNA
 L = 200MH

Figure 14

COLLINS RADIO COMPANY DALLAS, TEX NEWPORT BEACH, CALIF CEDAR RAPIDS, IA	
CONTRACT NO. <i>PREP 300 1211-PS</i>	
CHK	
APVD	
SIZE	CODE IDENT DWG NO.
B	13499
SCALE	SHEET

MATERIAL	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES; TOL ON DEC DIM.: .XX = +0.2, .XXX = 1.008 HOLE DIAMETERS: UNDER .251 DIA = +.005-.005 .251 TO .500 DIA = +.006-.005 OVER .500 DIA = +.008-.005 ANGLES: ±1.0° ECCENTRICITY BETWEEN DIA ON AN AXIS NOT TO EXCEED .010 DIA PART SHALL COMPLY TO 580-5400-001
FINISH	

TYPE NO: _____ FROM NFP REL REV. _ _ TC _ _ CR _ NB _ DL _ TO _

01525488 (REV. 3-77)
 NEXT ASSY:

12 V auto battery is provided. Access is through two spring loaded binding posts. The two headset outputs can be switched to listen to any one of the 6 channels.

3.2.4 Antenna Design

The equations used for the antenna design will be derived in detail to show the various relationships between receiver design, antenna parameters, and ambient noise.

Noise contributed by the receiver is first examined and then this noise is used in the overall system noise evaluation resulting in an optimum antenna design.

3.2.5 Receiver Noise

Before the antenna design can be completed, the noise contribution due to the receiver must be used with the noise received by the antenna. This calculation is as follows:

Assume a noisy receiver with a gain of A. The noise factor F is given by:

$$\begin{array}{c}
 \text{Noisy Rec} \\
 \text{in} \rightarrow \boxed{\text{Gain} = A} \rightarrow \text{out} \quad (1) \\
 F = \frac{S_i/N_i}{S_o/N_o} \quad \begin{array}{l} \text{Ideal} \\ \text{Actual} \end{array}
 \end{array}$$

where S_i/N_i is the S/N at the input and S_o/N_o is the S/N at the output. Both S/N ratios are expressed as a power ratio.

The signal out equals the signal in multiplied by the gain A:

$$S_o = S_i A$$

Substituting for S_o :

$$F = \frac{S_i/N_i}{S_i A/N_o} = \frac{1/N_i}{A/N_o} = \frac{N_o}{A N_i}$$

$$F = \frac{N_o}{A N_i}$$

Rearranging:

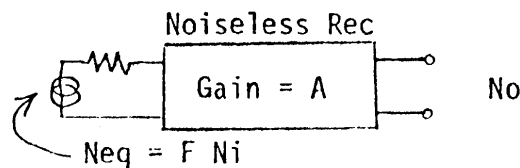
$$N_o = F A N_i$$

Set the noise output N_o equal to a noise equivalent N_{eq} at the input multiplied by the gain A:

$$N_o = A N_{eq}$$

or

$$\begin{aligned} N_o &= F A N_i = A N_{eq} \\ F N_i &= N_{eq} \\ N_{eq} &= F N_i \end{aligned} \quad (2)$$



The total noise power of the receiver is expressed in terms of the noise factor and the input noise power N_i .

Now assume a generator source impedance of R on the input of the receiver. The noise generated by this resistor R is given by:

$$N_R = 4K T R \Delta f$$

where K = Boltzmann's constant

$$= 1.38 \times 10^{-23} \text{ joules/deg.}$$

T = temperature, $^{\circ}K$

$$= 273 + ^{\circ}C$$

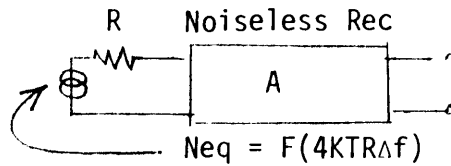
R = resistance in ohms

Δf = noise bandwidth in hertz

Since the noise input N_i is N_R , the noise in the generator R , equation 2 can be written as:

$$N_{eq} = FN_R$$

$$N_{eq} = (F) (4KTR\Delta f)$$

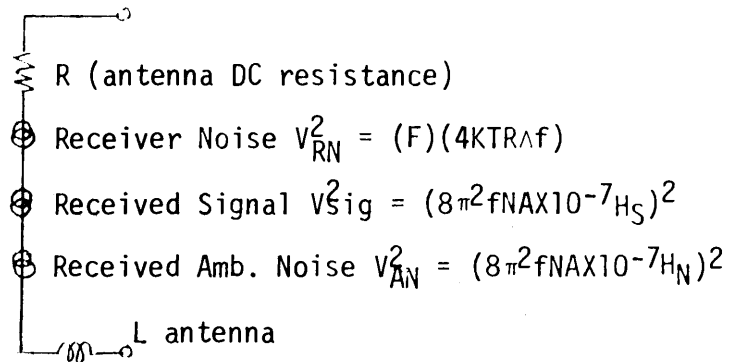


Consequently, the noise generator is now in terms of the receiver noise factor F , the generator resistance R , and the bandwidth Δf . The receiver can now be considered noiseless with a gain of A .

This equation is used in the following analysis of the loop antenna.

3.2.6 System Analysis and Antenna Design

Assume a loop antenna with a received signal V_{sig} , a received ambient noise voltage V_{AN} , and the total receiver noise V_{RN} as follows:



NOTE: V_{sig} and V_{AN} derived as V_{O2} in R.P. Decker's paper: Signal to Noise Analysis for Loop-To-Loop Mine Comm., page 3.

f = frequency, Hz

N = number of turns

A = loop area, m^2

H_S = magnetic intensity of signal, amps/m

H_N = magnetic intensity of noise, amps/m.

Now for systems analysis, let the external ambient noise contribution override the receiver noise by a factor of η . In other words, let η be the amount that V_{AN}^2 is greater than V_{RN}^2 .

$$V_{AN}^2 = \eta V_{RN}^2$$

or:

$$(8\pi^2 f N A \times 10^{-7} H_N)^2 = \eta (F) (4KT \Delta f R) \quad (3)$$

Also, from page 6 and 8 of R. P. Decker's report, the equation for the loop wire loss is:

$$R_L = 2\pi N a R_W$$

where a = radius of loop in meters

$$\text{and } R_W = \frac{2\pi a N}{W} \left(\frac{\rho}{\sigma}\right) \text{ in ohms/m}$$

where W = weight in Kgm

$$\rho = \text{wire density in Kgm/m}^3$$

$$\sigma = \text{wire conductivity mho/m}$$

Substituting for R_W in R_L :

$$R_L = (2\pi N a) \left(\frac{2\pi a N}{W}\right) \left(\frac{\rho}{\sigma}\right) \text{ or}$$

$$R_L = R = \frac{4\pi^2 N^2 a^2}{W} \left(\frac{\rho}{\sigma}\right)$$

Substituting for R in equation (3) and solving for the minimal acceptable antenna radius a :

$$(8\pi^2 f N A \times 10^{-7} H_N)^2 = \frac{\eta F 4KT \Delta f 4\pi^2 N^2 a^2}{W} \left(\frac{\rho}{\sigma}\right)$$

$$[8\pi^2 f N (\pi a^2) \times 10^{-7} H_N]^2 = \left[\frac{\eta F 4KT \Delta f 4\pi^2 N^2 a^2}{W} \left(\frac{\rho}{\sigma}\right) \right]^{1/2}$$

$$2\pi^2 f a \times 10^{-7} H_N = \left[\frac{\eta F 4KT \Delta f}{W} \left(\frac{\rho}{\sigma}\right) \right]^{1/2}$$

$$a \geq \frac{1}{10^{-7} H_N f 2\pi^2} \left[\frac{\eta F 4KT \Delta f}{W} \left(\frac{\rho}{\sigma}\right) \right]^{1/2}$$

Substituting for:

$$\frac{\rho}{\sigma W} \Big|_{\text{copper}} = \frac{1}{6.52 \times 10^{-3}} \text{ ohm } \text{kg/m}^2$$

$$KT = 4 \times 10^{-21} \text{ Joules}$$

The minimal acceptable radius now becomes:

$$a \geq \frac{10^7}{2\pi^2} \frac{1}{H_N f} \left(\frac{\eta F 4 \times 10^{-21} \Delta f}{6.52 \times 10^{-3} W} \right)^{1/2}$$

$$a \geq 3.968 \times 10^{-7} \frac{1}{f H_N} \left(\frac{\eta F \Delta f}{W} \right)^{1/2} \quad (4)$$

The loop antenna radius is now in terms of the frequency f , the ambient noise field intensity H_N , the noise factor F , the bandwidth Δf , the copper weight W , and the factor η .

The factor η will be related to the input signal and noise for easier evaluation.

Assume a worst case S/N ratio of 6 dB or 4 for the threshold of detectability of the receiver:

$$\frac{V_{\text{sig}}^2}{V_{\text{RN}}^2 + V_{\text{AN}}^2} = 4$$

or

$$V_{\text{sig}}^2 = 4(V_{\text{AN}}^2 + V_{\text{RN}}^2)$$

substituting for

$$V_{\text{RN}}^2 = \frac{V_{\text{AN}}^2}{\eta}$$

$$V_{\text{sig}}^2 = 4\left(V_{\text{AN}}^2 + \frac{V_{\text{AN}}^2}{\eta}\right)$$

$$= \frac{4V_{\text{AN}}^2}{\eta} (1+\eta)$$

$$V_{\text{sig}} = 2V_{\text{AN}} \left(\frac{1+\eta}{\eta} \right)^{1/2}$$

$$\frac{V_{\text{sig}}}{V_{\text{AN}}} = \frac{H_{\text{sig}}}{H_{\text{AN}}} = 2 \left(\frac{1+\eta}{\eta} \right)^{1/2} \quad (5)$$

The factor η can now be calculated.

The minimum ambient noise at 1 kHz from Westinghouse Final Report, July 1973, page 16, for winter is:

$$H_{AN}(15 \text{ Hz}\Delta f) = 0.0236 \text{ } \mu\text{a/m}$$

Also, the minimum detectable signal level is specified as:

$$H_{sig} = 0.1 \text{ } \mu\text{a/m} .$$

Solving for n in equation (5);

$$\begin{aligned} \frac{H_{sig}}{H_{AN}} &= 2 \left(\frac{1+n}{n} \right)^{1/2} = \frac{0.10}{0.0236} \\ \frac{1+n}{n} &= \left(\frac{.050}{.0236} \right)^2 = 4.49 \\ n &= 0.287 \end{aligned} \quad (6)$$

The antenna radius can now be calculated using equation (4):

$$a \geq 3.968 \times 10^{-7} \frac{1}{fH_N} \left(\frac{nF\Delta f}{W} \right)^{1/2}$$

where

$$n = 0.287 \text{ (from (6) based on } S/N = 6 \text{ dB)}$$

$$f = 1000 \text{ Hz (lowest frequency)}$$

$$H_N = 0.0236 \text{ } \mu\text{a/m (from Westinghouse Report)}$$

$$F = 50 \text{ or } 17 \text{ dB (measured in lab)}$$

$$\Delta f = 15 \text{ Hz (filter bandwidth)}$$

$$W = 1.73 \text{ Kgm or } 3.81 \text{ lbs. (same weight as used in Westinghouse units)}$$

$$a = \underline{0.187 \text{ m or } 7.37 \text{ in.}}$$

This is essentially the size loop that is presently being used in the breadboard model. If the noise factor can be improved during the phase III build, then the size of the loop could be reduced according to equation 4. Furthermore, if the weight of the loop is reduced with all other parameters remaining the same, then the size of the loop increases.

For example:

Let $W = 1.0$ Kgm

(Other parameters unchanged)

$a = .246$ M or 9.69 inches

Once the final antenna weight and radius has been calculated, the antenna's number of turns and wire size can be determined by

$$N = \frac{3.53 \times 10^4 W}{a A_c} \quad (7)$$

where a is the loop radius in meters, W is loop weight in Kgm, and A_c is loop wire area in circular-mils.

Therefore, using the antenna weight of 1.73Kgm and antenna radius of 0.187 meters, the final number of turns can be calculated from equation 7 selecting number 22 wire. This calculation results in the following antenna parameters:

$N = 508.7$ turns

Radius = 0.187 meters or 7.37 inches

Wire Size = Number 22

Weight = 1.73 Kgm/3.81 lbs.

3.2.7 Significant Test Results

A complete breadboard of the receiver was constructed and tested. The synthesizer and front end stages of the receiver were temperature tested from -40°C to $+50^{\circ}\text{C}$ with satisfactory results. Frequency shift was +1.6 Hz at 50°C and -8 Hz at -40°C . Numerous battery charge and discharge cycles were conducted to determine that the 8 hour allotted charging time could be accommodated by the charger.

A graph showing the attenuation range of the volume control is shown in Figure 15.

S+N/N ratio of the receiver was measured to be 10 dB for an input signal of .05 uV with a resulting noise figure of 17 dB.

A graph showing the XTAL filter characteristics with temperature variations is shown in figure 16.

FREDERICA POST

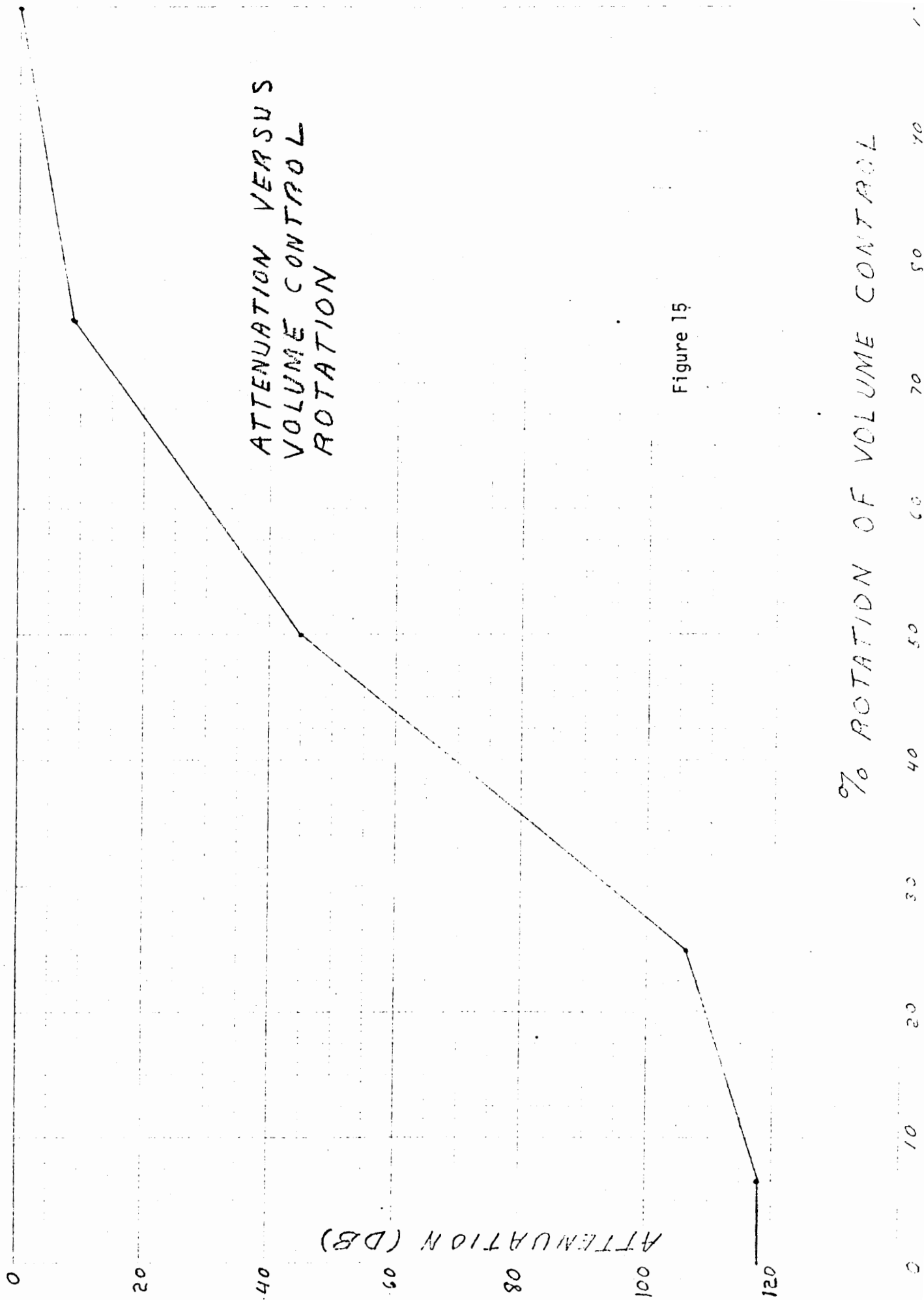


Figure 15

#1

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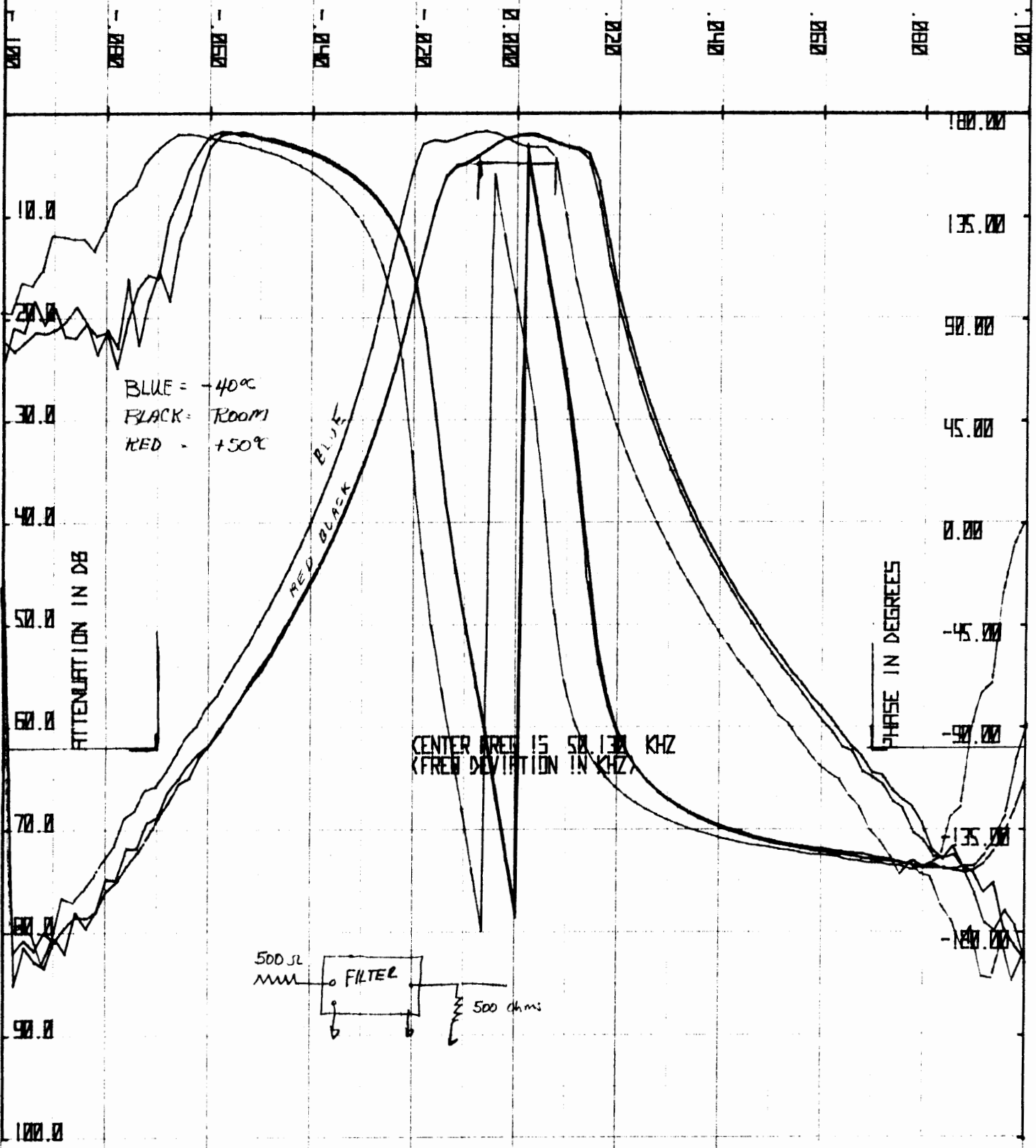


FIGURE 16 - CRYSTAL FILTER RESPONSE

3.3 MECHANICAL DESIGN

3.3.1 Manpack Receiver

The manpack receiver consists of a deep drawn aluminum can with an investment cast aluminum cover (see Figure 17). The cover is complete with a recessed groove for a molded gasket and projecting edges to protect the front panel controls (see Figure 18). All switches and connectors are a sealed variety in order to meet the water submersion requirements of the receiver.

The three-sided inner chassis is attached to the front panel and mounts two printed circuit boards on the sides of the chassis with a spring steel battery holder on the bottom. Access to the four C-sized lithium batteries is readily gained by removing two screws in the front panel and lifting the entire assembly from the case. Battery replacement exposes no more of the receiver's circuitry than the back sides of the two printed circuit boards. For further maintenance, the removal of the printed circuit boards is required.

A belt loop is spotwelded to the case, enabling the receiver to be worn on either a miner's or a conventional belt. Human Factors' recommendations were incorporated in the panel layout, resulting in a package which can conveniently be operated when worn on either side of center by both left and right handed operators, without interference from the handheld antenna or headset cable.

3.3.1 Antenna, Man-Carried

The hand-held antenna consists of five hundred turns of number twenty-two magnet wire, wound on a fifteen inch diameter form. Following winding, aluminum foil used as a faraday shield is spirally wrapped around the coil of wire for electrostatic shielding. The foil is grounded to the center braid of the antenna coax. This assembly is then completely potted with a tough, resilient urethane for protection.

3.4 Helicopter Receiver

The helicopter receiver, because of a low anticipated build quantity, will utilize a spot-welded aluminum chassis. Tooling costs will be kept to a minimum since all chassis parts can be punched in the flat on numerically controlled machines prior to forming and welding. The side panels, symmetrically designed to be used for both left and right, extend to the rear to serve as legs as well as to protect the AC power cord which is stored on the rear panel.

The front panel is removeable to provide access to the radio. Handles are mounted on the front panel for carrying, for easy removal of the receiver from the wraparound, and for protection of the knobs, switches, and connectors. These controls, under the advisement of Human Factors Engineering, have been systematically arranged according to functional importance and subdivided into the six individual receivers. Connectors have been positioned in such a way as to least obscure or hamper the operator with the connecting cables.

The inner chassis with card cage is attached to and removed with the front panel (see Figure 19). Six identical printed circuit boards, each containing a complete receiver and frequency synthesizer, insert

in card guides and engage edge-on connectors in the bottom of the card cage. This facilitates trouble shooting and receiver maintenance. The battery pack and the power supply/battery charger are mounted in the wraparound due to weight and heatsinking considerations.

3.4.1 Antenna, Helicopter

The antenna for the helicopter receiver will use the same winding and faraday shield as the hand-held antenna for the manpack receiver. However, this antenna will be mounted on an aluminum plate containing eye bolts so that the antenna may be lowered from the helicopter on a tethering cable. Also, the plate provides room for mounting the preamplifier and antenna filter.

4.0 PHASE III CONSTRUCT WORKING MODEL

During this phase one mancarried receiver and helicopter receiver including antennas and headsets were constructed. These units were constructed as planned during phase II with slight changes. During this period BNC connectors were dropped from the helicopter receivers because of panel space.

The separate input bandpass filter was also dropped because it was not making any apparent improvement. The connector for the antenna and headset was changed because of an intermittent reliability problem noticed particularly on the helicopter antenna during bureau tests. The helicopter receiver was modified to have two operator positions because bureau tests indicated one operator monitoring six channels proved to be a difficult task.

During this phase a calibrated loop generating a .1 UA field was set up to check out the total system. The 90 foot portable loop was driven by a ULF transmitter with a 3.9 meg ohm resistor inserted in series. The power stages of the transmitter had to be removed for this test and direct connections to the MOS circuitry were made because the receiver picks up the ULF transmitter operating without an antenna at distances of 15 feet. With the noise levels expected near an industrial complex the field had to be increased to .37 UA/meter before the receiver could detect the signal above the noise level.

Minor problems encountered during the build of the first units, required additional decoupling from the lithium batteries that have a higher internal resistance to make them intrinsically safe. A capacitor used in the synthesizer phase locked loop will have to be selected for some units. Some C-MOS failures due to static charges were observed during the building of the working model receivers. Other than these parts and minor mechanical problems the design is reproducible.

During this phase printed circuit board layouts of both receivers were made, mechanical parts were fabricated and the two receivers were assembled, tested and delivered to the Bureau for evaluation.

During the Bureau field evaluation it was determined that the use of a XTAL head set gave a better null than the inductive type headset. All headsets are now of the XTAL type to provide a better null and totally eliminate inductive feedback from the headset to the antenna.

An interaction problem between channels on the helicopter was observed in the field. This problem was eliminated by running separate grounds and adding additional filtering in the preamplifier and other gain stages. Also it was determined during field use that a sound isolating ear muff would be beneficial for use with the helicopter receiver. To provide this isolation the XTAL headset for the helicopter receivers are now inserted into an MSA. MARK II sound barrier ear protector. This provides the isolation required for the noisy helicopter environment.

5.0 PHASE IV BUILD PRODUCTION UNITS

During this phase all drawings and documentation were updated to reflect all changes as a result of the phase IV construction and evaluation. Fifteen mancarried and 5 helicopter receivers were assembled, tested and delivered to the Bureau. These units were assembled and tested with a minimum amount of difficulty. Again selection of the capacitor for the SMO was required on some units and some MOS failures occurred due to static charges. Additionally some MOS devices failed after delivery to the Bureau. The only other quality problems during the build of these units was one fractured headset and a loose piece of plastic in one of the panel meters. These parts were returned by the Bureau for replacement.

6.0 INTRINSIC SAFETY

The 515H-1 mancarried receiver is designed to be intrinsically safe. It was approved by MESA permit 331, October 9, 1975.

The 515H-2 helicopter receiver is not intended for underground use and is not intrinsically safe. The battery charger transformer, large filter capacitor, and battery prevent the helicopter receiver from being intrinsically safe.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This five phase program has resulted in the development and documentation of a mancarried and helicopter receiver that is now ready for production in quantity, after the completion of some additional field testing by the Bureau.

Because of the significant number of MOS failures due to static, it is recommended that future units be constructed using high reliability ceramic MOS devices, and complete static discharge protection be exercised throughout the assembly and test phases of production.