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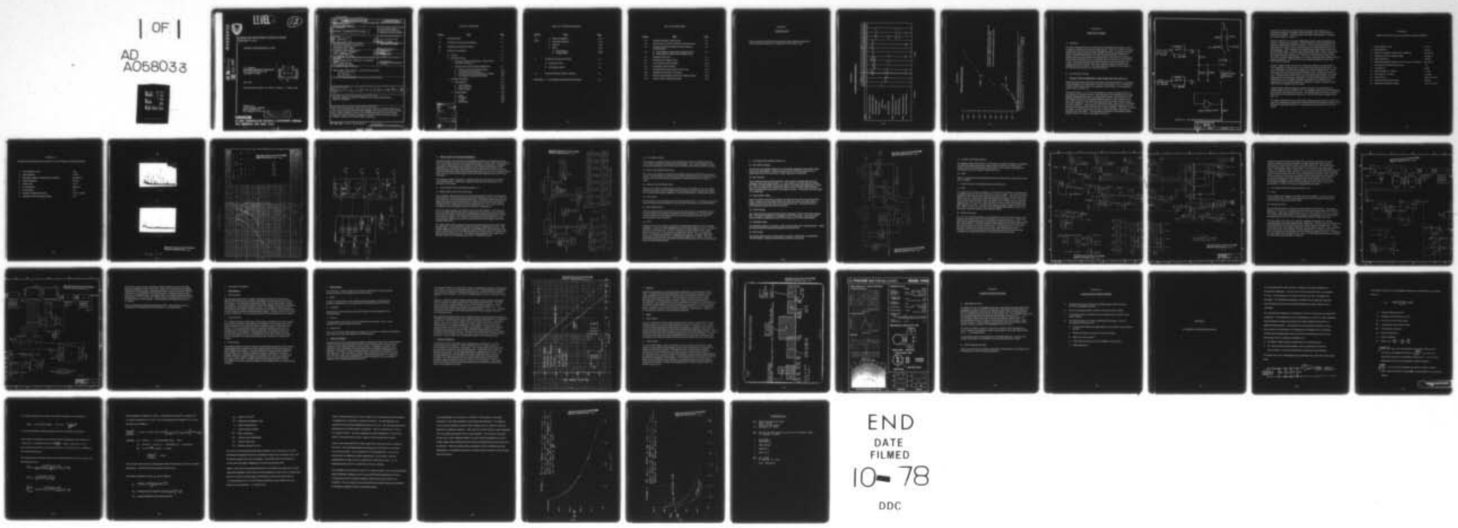

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-77-0190-2

VEHICULAR INTERCOMMUNICATION SYSTEM

C. F. Wedaman
CINCINNATI ELECTRONICS CORPORATION
2630 Glendale-Milford Road
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July 1978

Second Quarterly Report for Period 1 January - 31 March 1978

Prepared for:
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US ARMY COMMUNICATION RESEARCH & DEVELOPMENT COMMAND
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This is the second quarterly report for the design study of a vehicular intercommunication system primarily used in tracked vehicles. The report covers the time period from 1 January through 31 March 1978. Accomplishments for the period include preliminary trade-off studies of multiplex systems for signal routing and analysis of inductive radiators for wireless audio accessories.

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SECTION I

INTRODUCTION

This is the Second Vehicular Intercom System Study Quarterly Report and covers technical progress from 1 January 1978 to 31 March 1978.

SECTION II

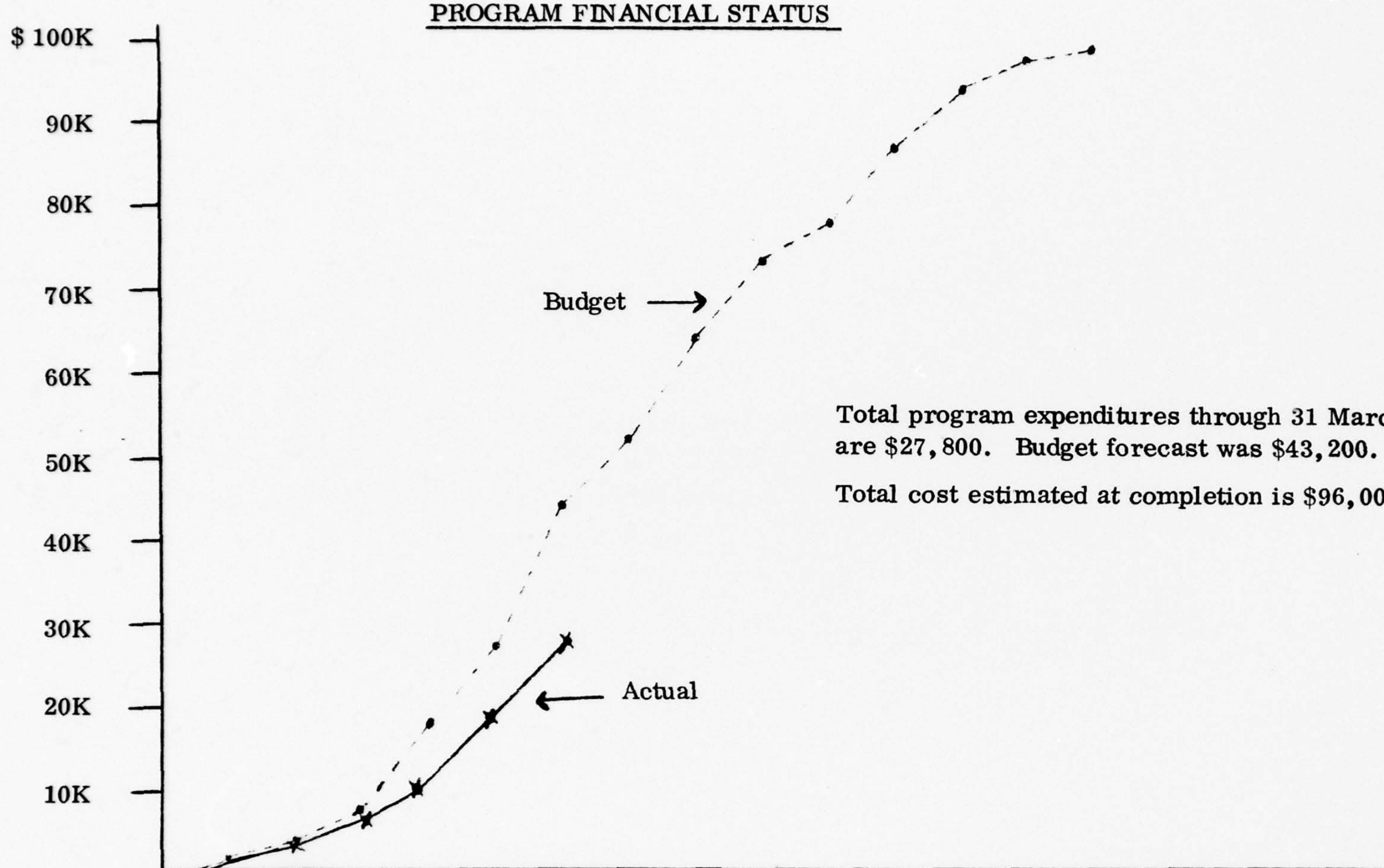
<u>CONTRACT DELIVERY SCHEDULE</u>

CLIN	Oct 1977 (1)	Nov 1977 (2)	Dec 1977 (3)	Jan 1978 (4)	Feb 1978 (5)	Mar 1978 (6)	Apr 1978 (7)	May 1978 (8)	Jun 1978 (9)	Jul 1978 (10)	Aug 1978 (11)	Sep 1978 (12)	Oct 1978 (13)	Nov 1978 (14)	Dec 1978 (15)
0002 Technical Data Exhibit A															
A001 Quarterly Reports			D△ #1	G△	F△ D*1	D△ #2 G*1 F*1	G△ D*2	F△	D△ #3	G△	F△				
A002 Final Report												D△	G△	F△	
A003 LSA Plan															
- Conference	△														
- Plan		D△	G△ D* G*	F△ F*											
A004 LSA Model						D△		G△				F△			
0003 Technical Data Exhibit B															
B001 Design Plan												D△	G△	F△	
B002 Specifications												D△	G△	F△	
0004 Technical Data Exhibit C															
C001 Contract Fund Status				△ #1			△ #2			△ #3			△ #4		

△ = Schedule   * = Actual

SECTION III

PROGRAM FINANCIAL STATUS



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Budget $K	1.1	1.6	5.5	9.0	12.0	14.0	12.0	7.0	5.0	5.0	6.0	9.0	7.0	1.0	1.0
Actual $K	.9	1.4	5.0	3.9	7.9	8.7									

Total program expenditures through 31 March 1978 are $27,800. Budget forecast was $43,200.

Total cost estimated at completion is $96,000.

SECTION IV

RESULTS OF STUDIES

A. GENERAL

Two basic techniques have been considered for multiplexing information in order to reduce or eliminate the intercom system wiring. They are: Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM). In general, the FDM system uses simpler electronics and requires a linear wideband transmission system, while the TDM system uses more complex electronics and can use a pulsed transmission system due to the digital nature of the data to be transmitted. At this point in the study effort, no conclusion has been drawn as to which system is best. This decision will be made after all systems have been studied; cost versus performance trade-offs have been compiled; and these discussed with potential users of the system. This report presents results of current studies of the FDM and TDM systems and wireless techniques.

B. MULTIPLEX SYSTEMS

1. Frequency Division Multiplexing - Study Results with VCO's and PLL's

LM565 and LM566 phase lock loops and voltage controlled oscillators in integrated circuit packages were ordered and received in early January 1978. Breadboard of a monitor audio system model was completed soon thereafter; a block diagram of which is shown in Figure 4.1.

As shown in Figure 4.1, VCO #1 was adjusted to oscillate at 50 kHz and VCO #2 was adjusted to oscillate at 80 kHz. Both oscillators were modulated with an audio frequency signal and that audio was demodulated, filtered, and monitored at TP1. The outputs of both VCO's were added together through 5.1 kohm resistors such that, at the junction of these resistors, both 50 kHz and 80 kHz would be present at the same amplitude. The PLL was breadboarded with a switch which would select one of two resistors. These resistors work with a fixed timing capacitor such that the larger the resistance the lower the PLL's center frequency. Therefore, by using the switch, we were able to cause the PLL to break lock with one frequency and reacquire lock with another. This simulates the function of the proposed monitor selector switch on a crew or commander control box.

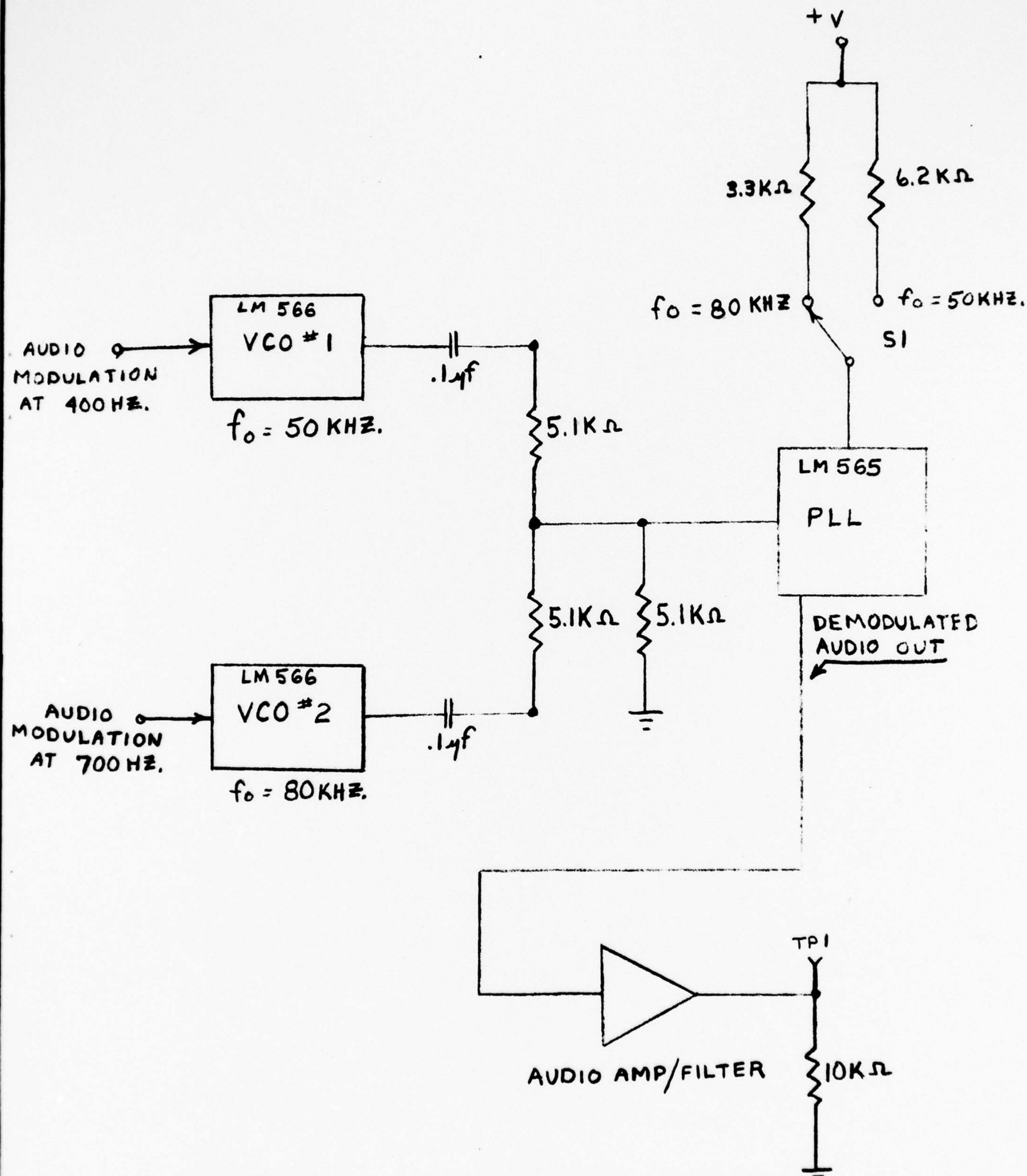


FIGURE 4-1. BREADBOARD MONITOR AUDIO SYSTEM

SIZE	CODE IDENT NO.	
A	80045	
SCALE	REV	SHEET 4-2

Lock-up time, distortion, capture range, hold range, VCO stability, VCO sensitivity, and power consumption were parameters which were checked and found to be acceptable. These parameters and other characteristics of interest are listed in Figure 4-2 and 4-3.

However, analysis of the proposed multiplexing scheme using the breadboard of Figure 4-1 did uncover a problem: noise and distortion of the demodulated audio caused by undesired phase detector products. These undesired frequencies are produced by the 80 kHz, 50 kHz, and their harmonics intermixing within the PLL phase detector. These frequencies then appear at the phase detector output with the demodulated audio. Filtering in the audio amplifier/filter removes frequencies above the audio range; however, undesired audio frequencies are also produced by the phase detector mixing action. The more VCO frequencies present at the PLL input, the more products appear in the audio range; and, these products become higher in amplitude. With three VCO's, the undesired frequencies were about 20 dB below the desired.

To date, it appears that the best way to reduce this problem is to attenuate the VCO frequencies to which the PLL is not locked at the phase detector input. This is accomplished by a tunable filter ganged to the monitor selector switch. Thus, when a new radio receiver is to be monitored, the PLL is shifted to that radio's VCO frequency and the bandpass filter is shifted to that new frequency at the same time. This filter does not increase system cost significantly; because at the low frequencies the PLL operates, inexpensive, op-amp, active filters can be used. Measurements on the breadboard indicate attenuation of the undesired VCO frequencies 12 dB at the phase detector is sufficient to achieve a signal-to-noise ratio of 40 dB or better at the PLL output.

Undesired phase detector outputs are shown in Figure 4-4A and the effect of a bandpass filter is shown in Figure 4-4B. The bandpass filter used in the breadboard was a second order type with a Q of six. Its characteristics are shown in Figure 4-5. Distortion and noise without the filter was 7% and with the filter it dropped to less than .5%.

The latest configuration for the FDM monitor audio approach is shown in Figure 4-6. Parts list containing the tunable filter mentioned above and microphone audio circuitry discussed in Quarterly Report No. 1 were generated and turned over to the LSA Group.

FIGURE 4-2

PHASE LOCK LOOP LM 565 ELECTRICAL CHARACTERISTICS

1.	Power Supply Current	8.0 mA
2.	Input Impedance	5 Kohms
3.	Operation Frequency Temperature Coefficient	100 ppm/°C
4.	Frequency Drift with Supply Voltage	100 ppm/%
5.	Output Impedance	3 Kohms
6.	Demodulated Output Voltage for ± 10% Frequency Deviation	300 mVPP
7.	Recovered FM Distortion (maximum)	.75%
8.	AM Rejection	40 dB
9.	Capture Range (f_o = 50 kHz)	± 7 kHz
10.	Hold Range (f_o = 50 kHz)	± 18 kHz
11.	Lock-up Time	Less than 50 ms
12.	Maximum Operating Frequency	500 kHz
13.	Operating Temperature Range	-55°C to +125°C

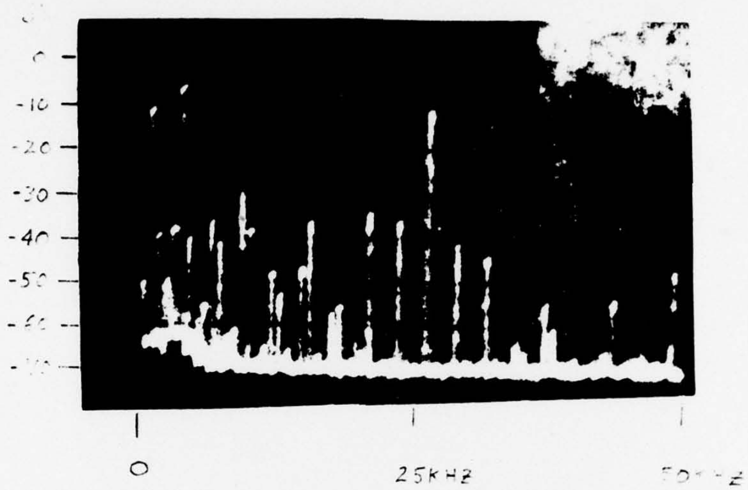
FIGURE 4-3

VOLTAGE CONTROLLED OSCILLATOR LM 566 ELECTRICAL CHARACTERISTICS

1.	Power Supply Current	8 mA
2.	Input Impedance	1 Mohm
3.	Operating Frequency Temperature Coefficient	100 ppm/^{o}C
4.	Output Impedance	50 ohms
5.	Output Level	2 VPP
6.	VCO Sensitivity	6600 Hz/V
7.	FM Distortion	.75%
8.	Operating Temperature Range	-55^{o}C to +125^{o}C
9.	Frequency Drift with Supply Voltage	1%/V

A.

PHASE DETECTOR OUTPUT
BEFORE BANDPASS FILTER



B.

PHASE DETECTOR OUTPUT
AFTER BANDPASS FILTER

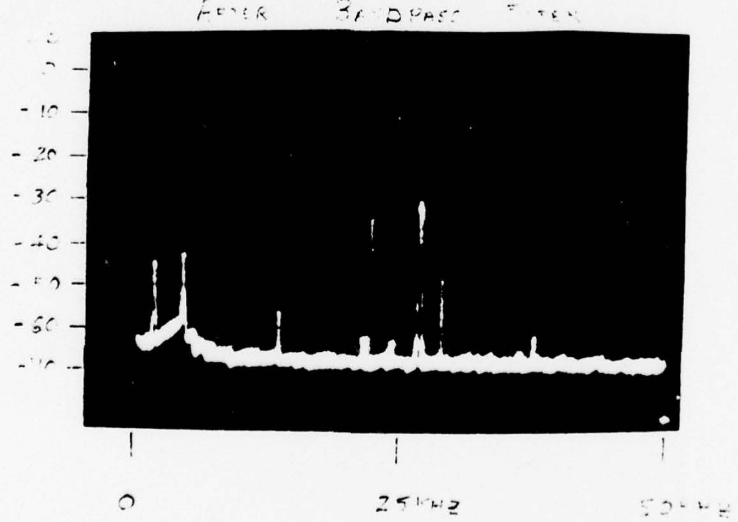


FIGURE 4-4

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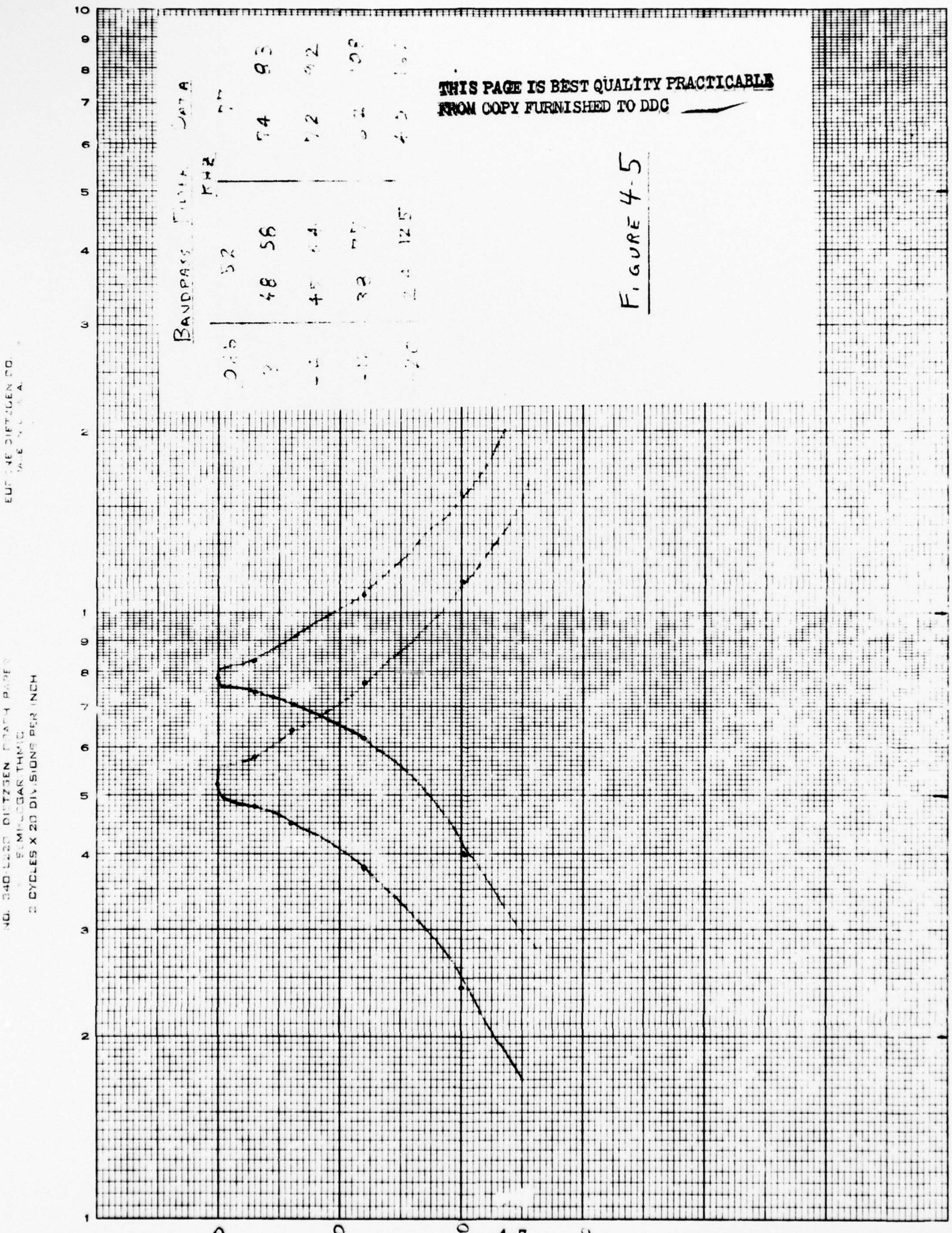

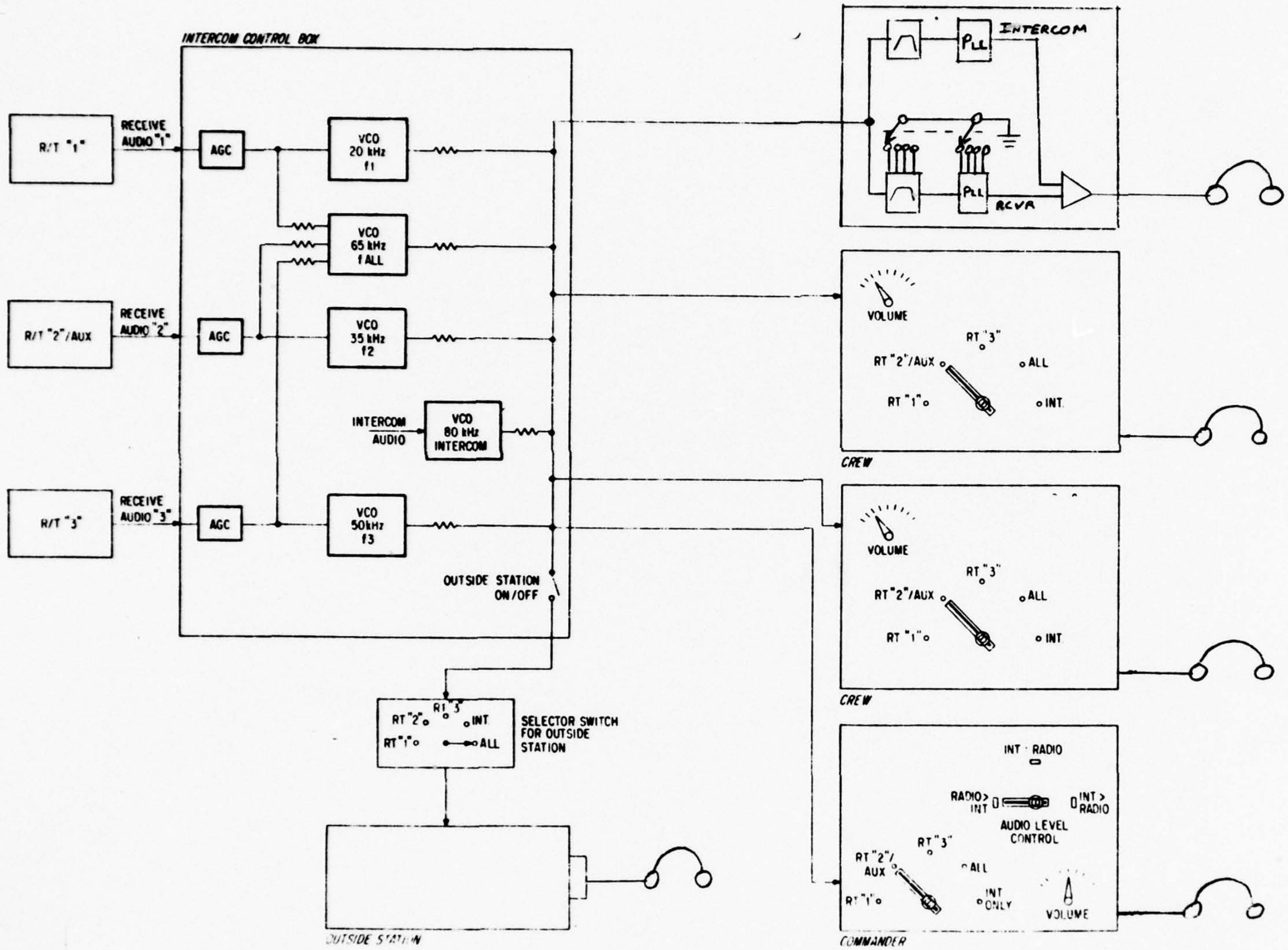

FIGURE 4-6. FDM APPROACH/MONITOR AUDIO

2. Minimum Wire Time Division Multiplexing

General concepts of how time division multiplexing functions and arrangements of the data stream was presented in the First Quarterly Report. In this report, block diagrams of a central control unit and a user station are presented and discussed. In addition, schematics of a breadboard which implements most of the functional blocks of the block diagrams is presented and discussed. This breadboard is intended to check out important parameters of time division multiplexing and, as such, is not a complete system. Hence, not all of the functional blocks shown in the block diagrams can be found on the schematics.

The breadboard system comprising a central control unit and one user is presently in the checkout stage. Therefore, a detailed discussion of the schematics is not presented in this report.

a. Central Control Unit Block Diagram (Figure 4-7)

(1) Output Enable Control and Load Timing

The load timing circuitry generates the parallel load pulses to the four and sixteen bit shift registers. The load pulse to the sixteen bit shift register occurs once every 128 clock cycles and is the Frame Initiate Pulse (FIP). This pulse loads the eight bit sync pattern plus four bit guard bands in front and behind the sync into the shift register. All other timing is referenced to the Frame Initiate Pulse. (For a review of frame composition, see First Quarterly Report, Section IV, paragraph 2.)

There are eight load pulses per frame to the four bit shift register. The first pulse occurs 20 clocks after the FIP and the remaining seven occur every fourteen clocks. These eight load pulses load the data selected by the data output selector to be sent to one of the user stations. For example, if user station #1 has selected RT #2, the first load pulse would load four bits of audio data which the data output selector had selected from RT #2.

The output enable control causes the Control Unit to put data on the bus at the proper time intervals. Four clocks after the FIP, the output is enabled to 20 counts. This includes eight bits of sync data, eight bits of guard band data, and the first four bits of user #1's time slot, since the first four bits of each user's time slot contains audio data from the control to the user. The output is then enabled for four counts every fourteen counts for the remaining seven users to complete the frame.

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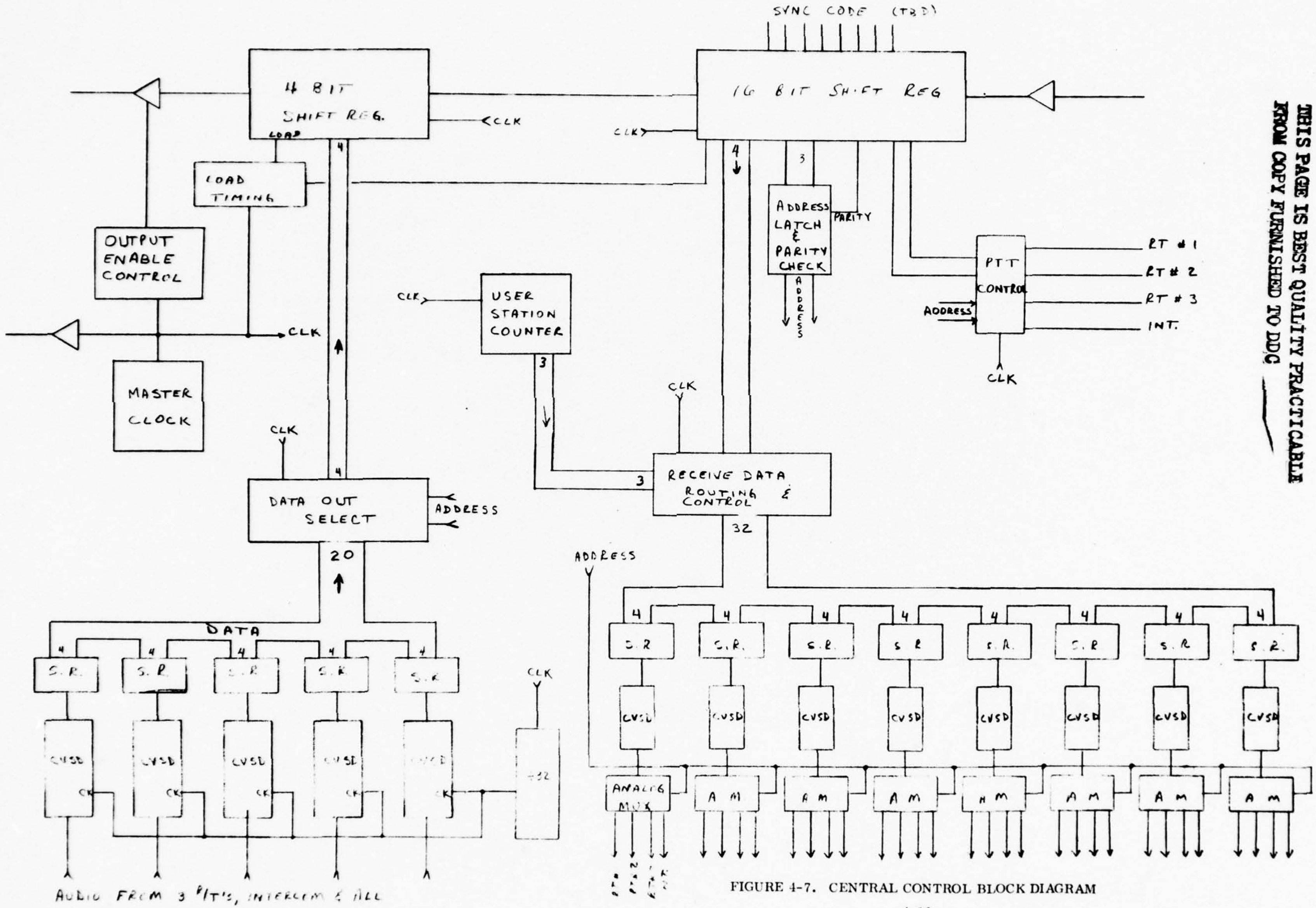

FIGURE 4-7. CENTRAL CONTROL BLOCK DIAGRAM

(2) User Station Counter

This counter is zeroized with each frame initiate pulse and is incremented with each of the parallel load pulses to the four bit shift register. The count information is used to steer the audio data received from each user station to the proper CVSD for decoding.

(3) Receive Data Routing and Control

The input to this section is the four bits of parallel audio data received from each user station. These four bits are steered by the address generated by the User Station Counter to four of 32 lines which are then converted to a serial data stream to the input of a CVSD.

(4) Address Latch and Parity Check

Three bits of address information plus a parity bit are received from each user station. If parity checks good, then the address bits are latched to provide steering information to the receive audio analog multiplexers, the data output selector, and the PTT circuitry.

(5) PTT Control

The two data lines to this section are RT PTT and Intercom PTT. The address lines steer the RT PTT lines to the selected RT while intercom PTT provides an override function.

(6) Data Output Selector

Audio information from each of the RT's, the intercom and ALL is individually encoded to a serial data stream and then converted to four bit parallel form. The data output selector selects four bits of data from the source selected by the address lines to be transmitted to the user station.

(7) Audio

Audio data from each of eight user stations is individually decoded and fed to an analog multiplexer. Each of the eight multiplexers has four analog outputs: (1) RT #1, (2) RT #2, (3) RT #3, and (4) Intercom. All RT #1 audio lines are then mixed to form a single audio source for RT #1. This process is repeated for RT #2, RT #3, and Intercom. "ALL" is created by mixing the four composite audio signals. The audio output from the three RT's, Intercom and ALL is individually encoded in five CVSD's. The five serial data streams are then converted to four bit parallel forms, which is the twenty-line input to the data output selector.

b. *User Station Block Diagram (Figure 4-8)*

(1) Sync Pattern Detector

The detector is constantly looking at the 12-bit pattern appearing at the parallel output of the 12-bit shift register. When this pattern exactly matches the eight-bit sync pattern plus the four bit guard band, a single output pulse is generated.

(2) Sync Circuitry

Once a valid sync pulse has been detected, a sync window is created which prevents reacting to false sync pattern detects. If a sync pattern is not found inside the window, the window is opened slightly and the user station is prevented from putting data on to the bus. If no sync patterns are detected in N tries, the sync circuitry is then allowed to search the entire data stream until a valid pattern is found. At this time, the sync window is re-established.

(3) Output Enable Timing

Each user station is allowed to transmit on the data bus for ten bits out of each 128-bit frame. Based on the user station number and valid sync detect, the output buffer is enabled for the last ten bits of the user's assigned time slot. (The first four bits of his fourteen-bit format is the data he receives.)

(4) Control Timing

The control timing circuitry provides the data latch pulse for both received and transmit data. This pulse corresponds to recognition of a valid sync pulse. At the sync pulse, the user station's assigned slot in the 128-bit frame is at the 16-bit shift register.

(5) Destination Select

The destination selector is merely an octally encoded switch with a parity generator. These four lines provide the steering information to the Control Unit.

(6) PTT Control

This circuit passes the PTT switch closures to either a selected RT or the Intercom. Any PTT closure switches the CVSD from a decoder to an encoder.

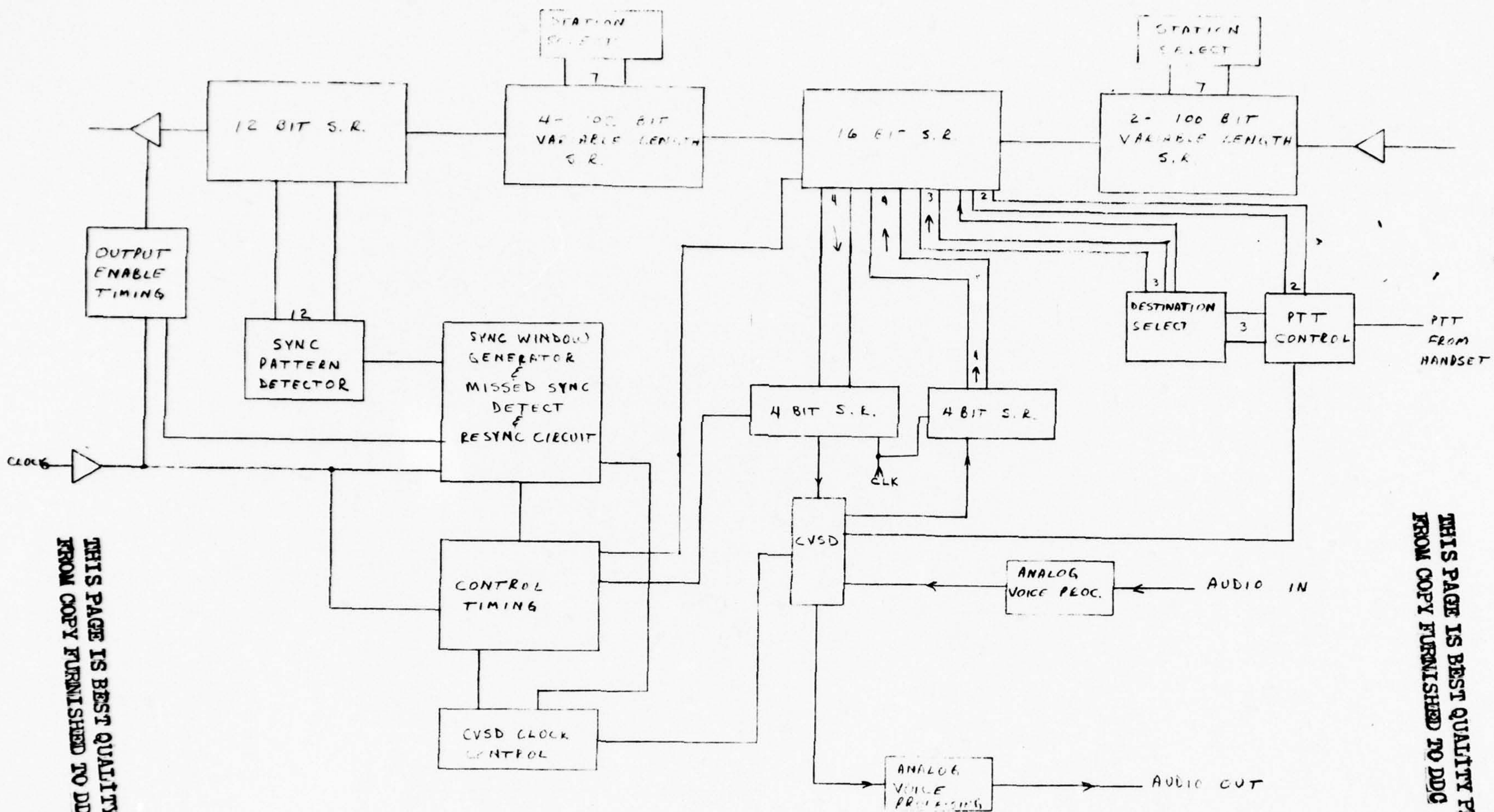

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FIGURE 4-8. USER STATION BLOCK DIAGRAM

(7) Variable Length Shift Registers

The lengths of these shift registers is adjusted to accomplish two things: (1) maintain the total shift register length from input to output at 128 bits, and (2) adjust the position of the 16-bit shift register such that the 14 bits closest to the output port corresponds to the user stations assigned time slot.

(8) CVSD

This is a Continuously Variable Slope Delta voice encoder/decoder operating at a data rate of 32 Kbps.

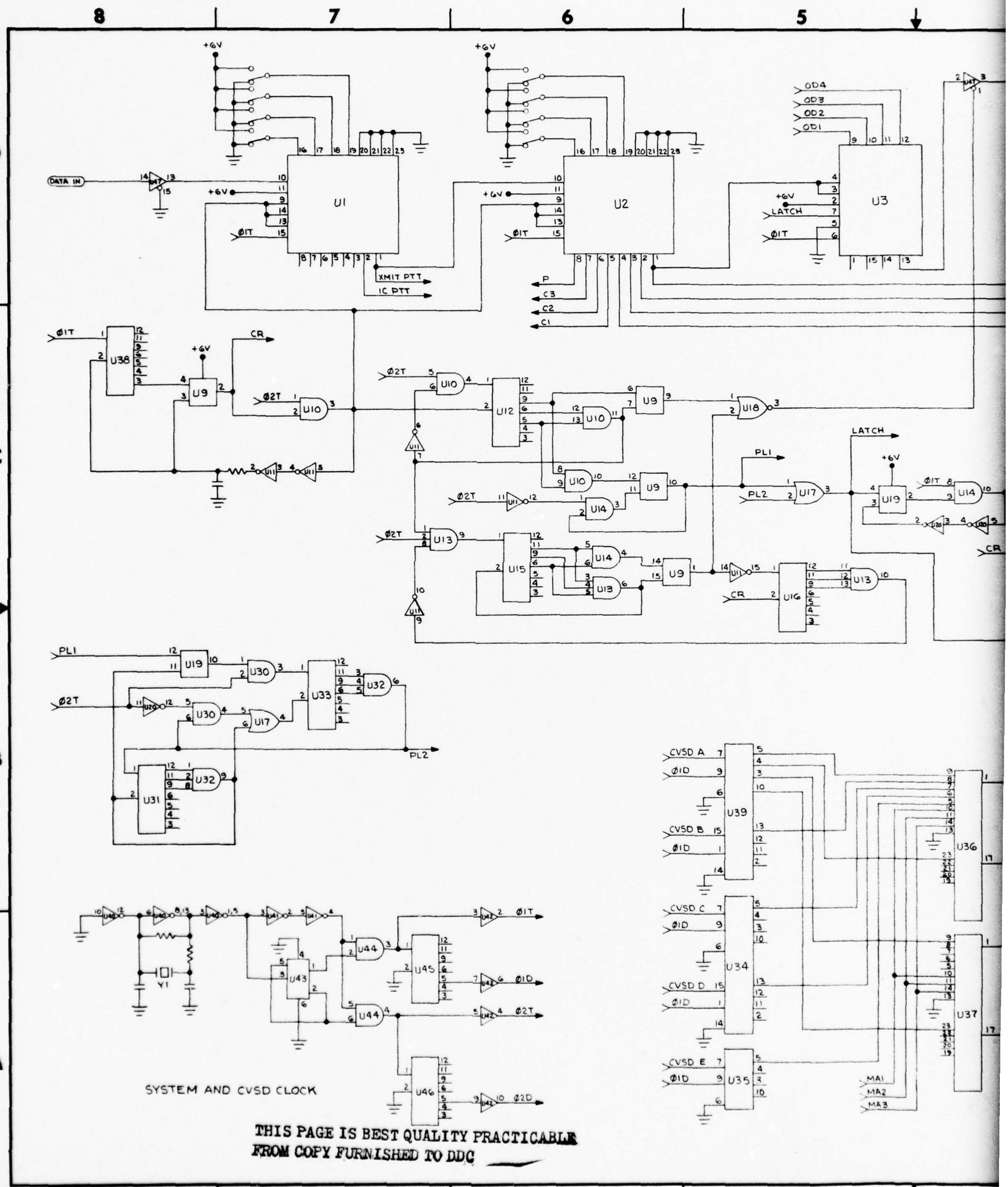
c. Central Control Unit Breadboard Schematic (Figure 4-9)

(1) Clock

The system clock circuitry consisting of Y1 and U40-U46, generates a two-phase non-overlapping clock as well as the clock for the various CVSD's. Each of the two phases operates at 1.024 MHz and the CVSD clocks operate at 32 kHz. The phase one clock (Ø1T) is used as a data clock to shift data through shift registers U1-U3. Ø1D is the 32 kHz shift clock used to shift CVSD data from the R/T's and the intercom into shift registers U34, U35, and U39. Phase two (Ø2T) is used to load the sync pattern into shift registers U1 and U2. All other control timing and data routing is derived from Ø2T. Ø2D is used to clock received audio data through shift registers U7 and U8 to provide the serial data stream to the receiver CVSD's.

(2) Timing and Control

U9, U10, U11, and U38 generate a Frame Initiate Pulse every 128 clock pulses which loads the sync pattern into U1 and U2 initializes the control circuitry. Counter U12 along with its associated gating and U9 generates a pulse 20 clock pulses long, 4 counts after Frame Initiate. This pulse enables the data output driver for the 16-bit frame sync plus the first 4 bits of user #1's time slot. The first four bits of each user's time slot is used for the Central Control Unit to send audio data to the user. Counters U15 and U16 along with the associated gating and latch U9 generates the remaining seven output enable pulses for the other seven user stations.



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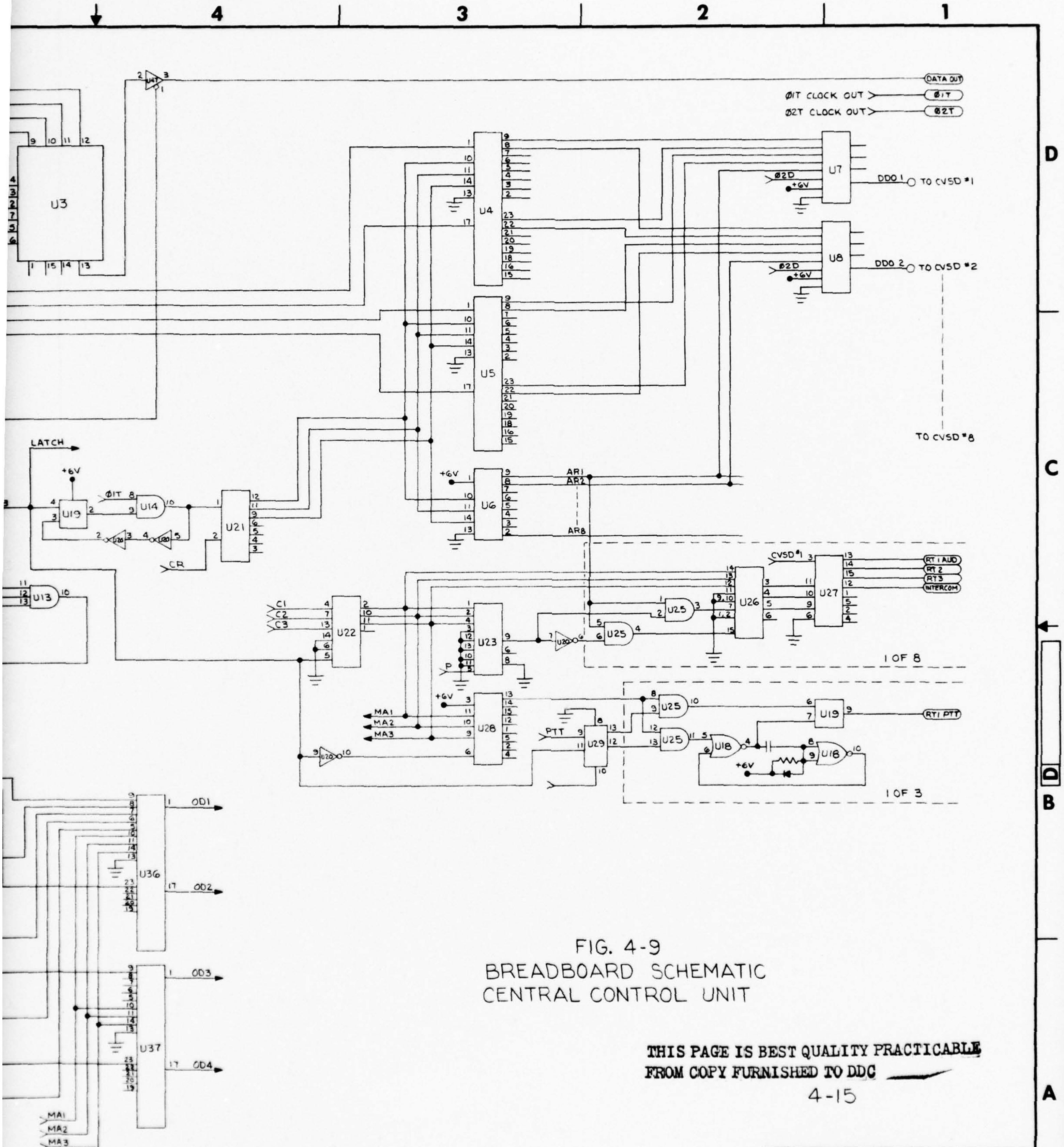

FIG. 4-9
BREADBOARD SCHEMATIC
CENTRAL CONTROL UNIT

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SIZE	CODE IDENT	DWG NO.
D	98230	
SCALE	CONTRACT NO.	

Counter U12 and the decoding associated with count 20 plus counters U31 and U33 and their decoding circuitry generate the 8 parallel latch pulses which loads the audio data to be sent to the user stations into shift register U3. These latch pulses also increment station counter U21 to route the received audio data to the proper CVSD. The multiplex address control bits C1, C2, and C3 are also latched with the same 8 pulses to create MA1, MA2, and MA3. These 3 address bits then control the routing of the PTT lines through U28, U29, and the subsequent PTT circuits. MA1, MA2, and MA3 are also used to route the user station received analog audio to the proper R/T or intercom through one of eight routing circuits shown typically in U26 and U27. Transmit audio routing is also controlled by MA1, MA2, and MA3 at U36 and U37. These digital multiplexers select the proper digitized audio from one of the R/T's, the intercom, or "ALL" to be sent to the appropriate user station.

d. User Station Breadboard Schematic (Figure 4-10)

(1) Clock

The two-phase nonoverlapping 1.024 MHz clock, Ø1T and Ø2T, is received from the Central Control Unit. Ø2T is also divided down to 32 kHz to provide an audio data shift clock and a timing clock to the CVSD.

(2) Timing and Control

The received data stream is clocked into shift registers U1 through U8. The parallel outputs of U1 and U2 are constantly checked for the eight-bit sync pattern and a four-bit guard band. This check is performed by U10, U11, U28, and U29. U3, U4, U7, and U8 are variable length shift registers whose lengths are programmed such that the parallel data appearing at U5 and U6 is one of eight fourteen-bit user station time slots.

The four counters U22, U24, U25, and U30, magnitude comparator U26, and the associated gating generate the Output Enable Control line. This line is active when the ten information bits to be transmitted by the user station appear at the output of U1. This is the only time the user station is allowed to put data onto the data line. Since generation of this control line can be initiated only after recognitition of a valid sync pulse, any given user station can only put data on the line during its assigned time slot. Consequently, if a user station fails to identify the sync word, it is effectively prevented from accessing the system until synchronization is achieved.

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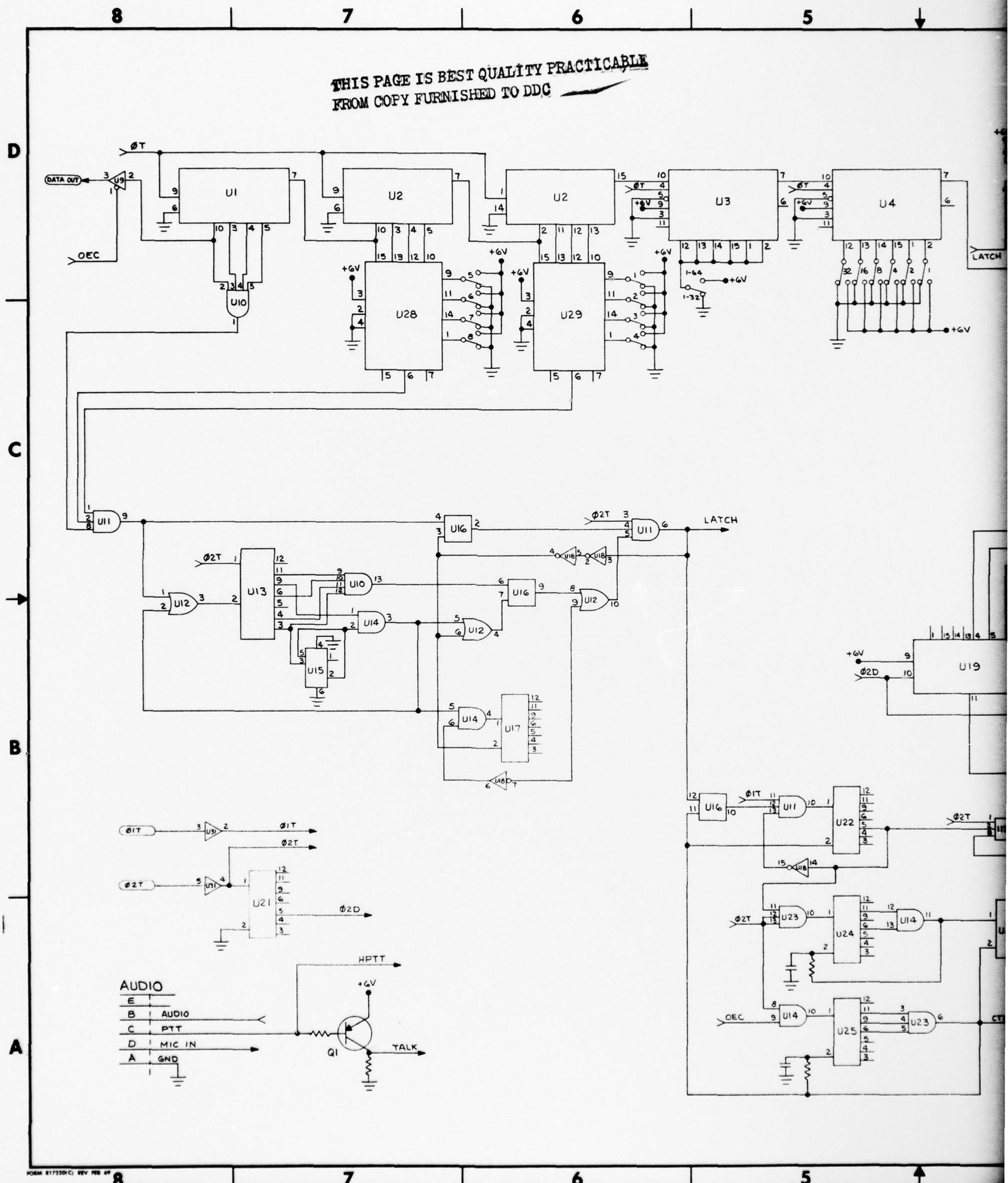

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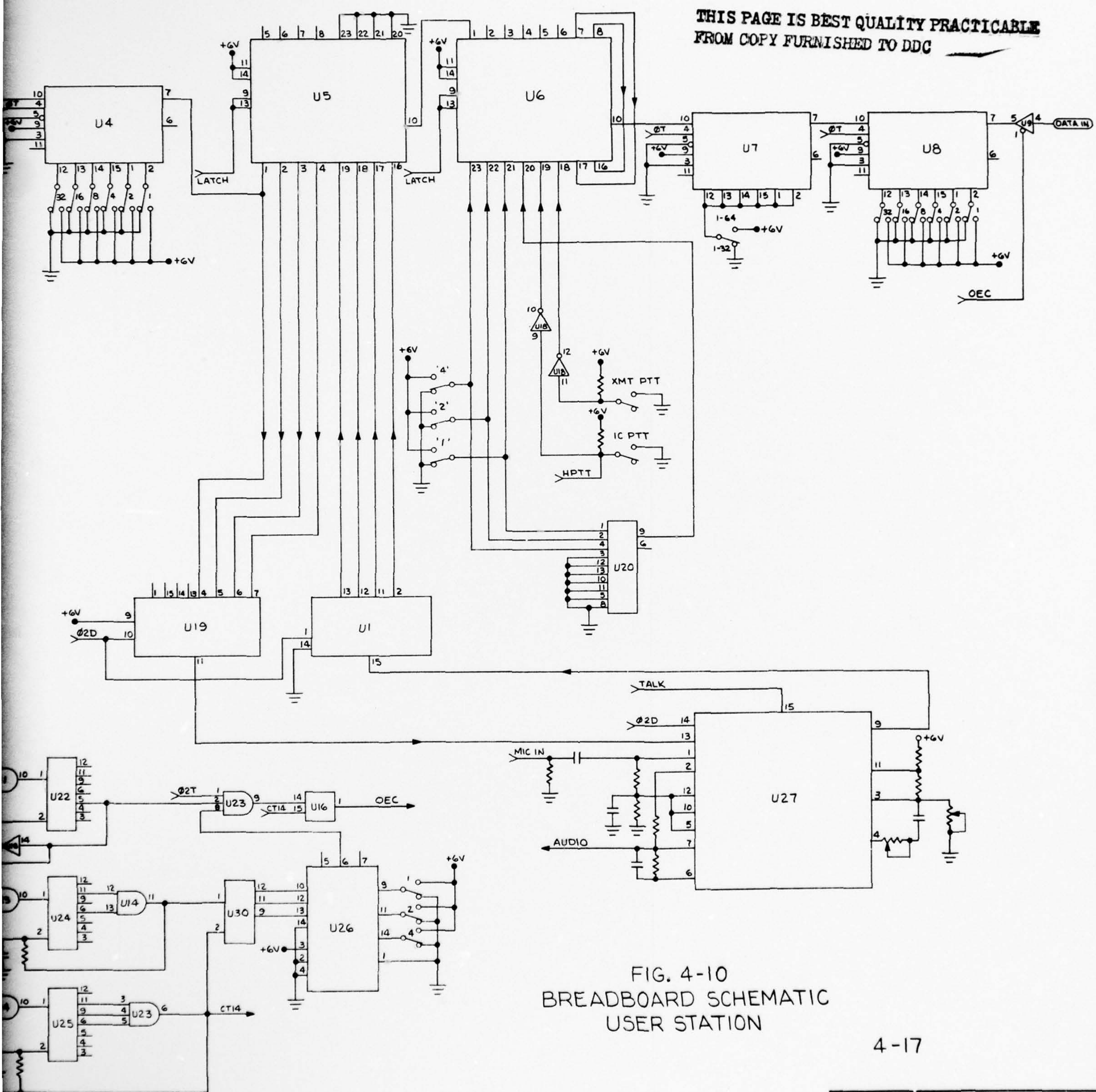

FIG. 4-10
BREADBOARD SCHEMATIC
USER STATION

SIZE	CODE IDENT	DWG NO.
D	98230	
SCALE	CONTRACT NO.	

In the receive mode, U19 is a parallel-to-serial converter for the receive audio data and is clocked at 32 kHz to the CVSD. While in the receive mode, the digital output of the CVSD generates a quieting pattern that is sent to the serial-to-parallel converter U1 to be loaded into U5 by the latch pulse. During the transmit mode, this line is the digitized audio. The output of the User Control Switch generates the control lines C1, C2, and C3 to the Central Control and indicates which of the R/T's or intercom the user has selected. U20 generates an even parity bit based on C1, C2, and C3.

U27 is a CVSD encoder/decoder operating at 32 kHz. The encode/decode line is controlled by PTT making the intercom operate in a half duplex mode.

C. WIRELESS TECHNIQUES

1. Inside Stations

a. Total Wireless

The technique chosen must be capable of flooding the interior of the vehicle with signal so that the devices work by the crewmembers can transmit and receive from any location. The reflection characteristics of flat, curved, and irregular surfaces are important. If the technique allows interference patterns to exist due to reflections, nulls might be created where reception is poor. The radiation of signals from the crewmember to the master control unit must also be considered. The bandwidth must be great enough to handle the multiplexed audio signals. A local control box is carried by each crewmember. This box must contain all of the mux-demux circuitry needed.

b. Local Link Only

If a wireless technique is used only to connect each crewmember to his local control box, several of the above considerations are changed. It is no longer necessary to flood the interior of the vehicle, but rather to limit coverage to a particular crew station. If it is not practical to limit the coverage of each link, then it will be necessary to provide separate channels so that each crewmember will hear only the audio which he has selected. The bandwidth can be considerably less since only one audio signal needs to be transmitted at any one time; and the box carried by the crewmember can contain less electronics and, therefore, be smaller and cheaper.

c. Other Factors

The freedom gained by the use of wireless communications inside the vehicle must be weighed against the increased cost of the wireless system and the inconvenience of using a battery power supply. If primary batteries are used, storage and disposal are a problem; and, if secondary batteries are used, recharging is a problem, probably requiring a charging system to be installed in the vehicle. In either case, the life of a battery capable of supplying enough power to run an audio amplifier loud enough to be heard in a tracked vehicle and yet small enough to be carried conveniently will be short enough that batteries will probably need to be changed during a mission.

2. Outside Station

The inclusion of a person outside of the vehicle in the intercom system presents several problems not associated with the inside stations.

a. Range

In order to accommodate a wide variety of tactical situations, communications should be maintained over a 50 meter radius in all directions from the vehicle.

b. TEMPEST

Some means must be provided to prevent the enemy from eavesdropping on the communications.

c. Terrain

Communications should not be cut off by obstacles such as bushes, trees, rocks, and hills to as great an extent as practical.

d. Interference

Since several vehicles might operate in proximity to each other, it might be advantangeous to provide several discrete channels to avoid interference.

3. Inductive Radiators

Experiments have been conducted using inductive radiators for short range communications. It was felt that RF fields generated by vehicle radio equipment could be received by the radiator's coil and cause interference in the receiver. In addition, the electric field component of the transmitting coil can interfer with the transmitter integrated circuit operation. Elimination of these potential problems was achieved by shielding the coil with copper foil. Care was taken to spiral wrap the copper with an insulator to prevent both ends of the copper from being grounded. With both ends grounded, the copper foil acts as a one-turn secondary winding whose output is shorted; and, as a consequence, reduction of the radiated magnetic field occurs.

The selected bandwidth of 12 kHz allows 8 kHz for modulation and deviation requirements and 4 kHz for receiver-to-transmitter frequency error. Specifications on the selected VCO's and PLL's indicate this frequency tolerance can be achieved without expensive frequency control schemes. PLL and VCO specifications are shown in Figures 4-2 and 4-3.

Figure 4-11 shows the signal strength measured using a series resonant transmitting coil and a parallel resonant receiving coil, both shielded and unshielded. This data shows a decrease in signal strength of 16 or 18 dB per octave of distance. Signal strength should be adequate for at least 5 feet, even with the shielded coils. The overall dimensions of the radiators used was approximately 1" x 1.3" x 2.4". Further refinements of the design are probably possible and will be investigated during the next reporting period.

The experiments reported above were directed toward very short range communications. Preliminary calculations indicate that a magnetic moment of approximately 4 amp(meter)^2 would be necessary to radiate a signal which is receivable at 50 meters. This would require a fairly large antenna and high drive power, both of which are obstacles to implementation in a manpack configuration. For example, a 10 turn square loop carrying 1 amp would need to be .63 meter (2 feet) square. In addition, the antenna would need to be an array of two elements, directed at right angles to each other to assure omnidirectional coverage. The size of the antenna would also be an obstacle to mounting on the outside of an armored vehicle where it would be vulnerable to being shot away. Further studies will be conducted during the next reporting period.

4. Ultrasonic Radiators

A preliminary study of the possibility of using ultrasonic radiations for wireless communications was conducted. Linden Laboratories, Inc. of State College PA was contacted for information on transducers. They recommended their Model 70100 as most nearly meeting the intercom requirements. A data sheet on this device is attached to this report. Several negative aspects are apparent from this data. The directional pattern has two deep nulls which would create dead spots in external coverage and at least 2 units (probably 3) would be required for omnidirectional coverage. The 6 dB bandwidth of 0.4 kHz would severely restrict the data rate so that not enough information could be carried for a voice message. Unless other devices can be found which provide better performance, ultrasonic communications will not be considered any further.

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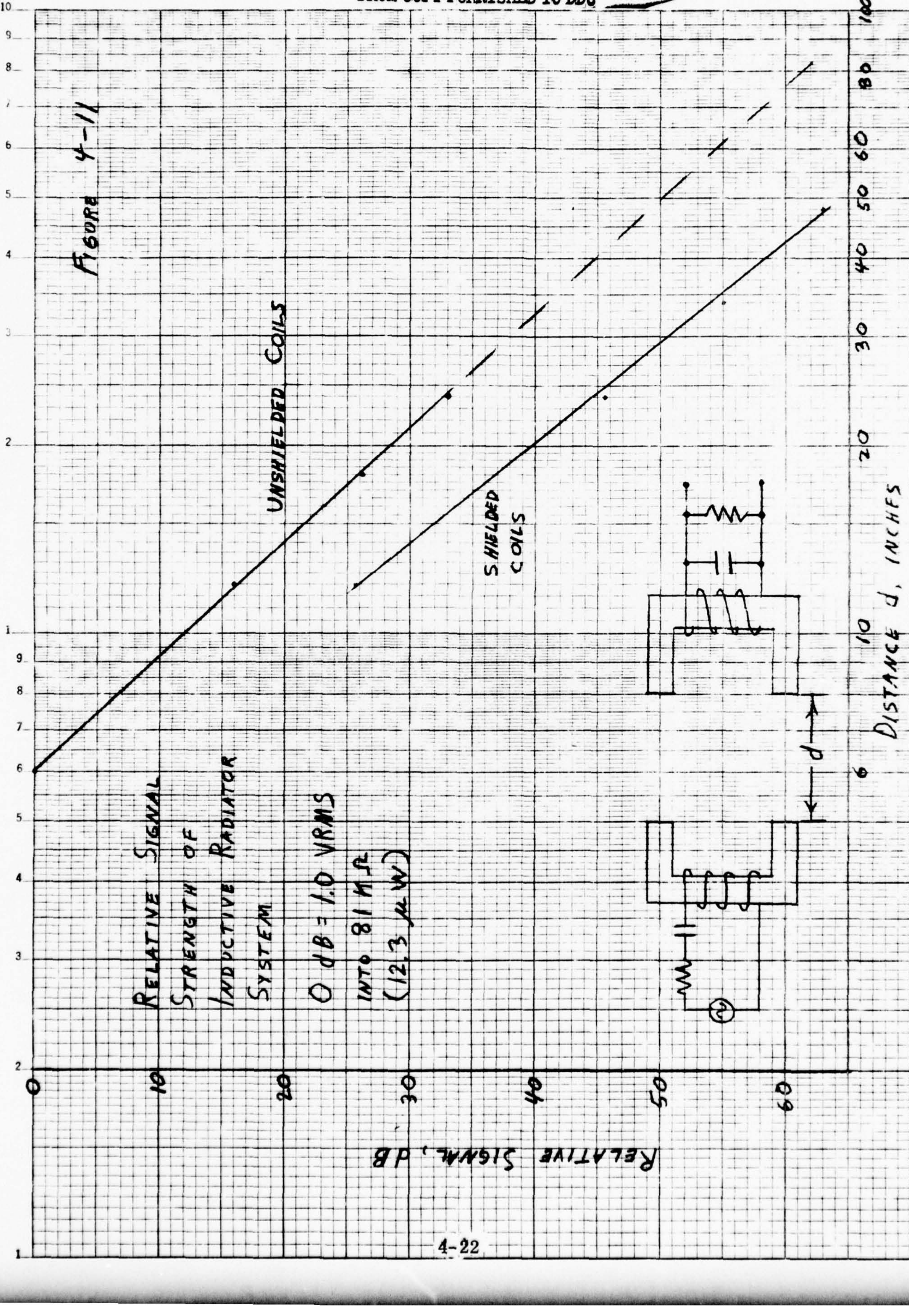


5. Infrared

Infrared communications would be particularly applicable to a pulsed system such as TDM. It might be that the rapid attenuation of IR versus distance (12 dB per octave) would eliminate the need to secure an outside link for TEMPEST protection which would be a large point in its favor. Also, the emitters and detectors are simple and inexpensive. Negative points to consider relative to IR are the directivity of the elements, which would require an array of emitters and detectors for omnidirectional coverage, the nonavailability of discrete channels, the uncertainty of reflection into all parts of all vehicles, and the fact that even the slightest obstacle such as precipitation, bushes, clothing, or dust or dirt on the lens could block communications. Appendix A is the report of a study on IR communications conducted.

6. Radio

a. Inside Stations

The use of microwave radiation (approximately 3 GHz) has been considered for a total wireless sytem where it is necessary to flood the interior of a vehicle. Such a system would use simple, inexpensive transmitters and receivers. Reflection of microwaves would be more efficient than infrared and less susceptible to blockage by dust, dirt, etc. Although standing wave patterns might exist, the short wavelength (approximately .1 meter) should cause any nulls to be small enough that they would not cause a problem. The use of radio for individual links is not recommended due to the increased complexity of the transmitters and receivers needed to provide a discrete channel for each crewmember.

b. Outside Station

The main disadvantage of radio for outside use is the necessity of providing a crypto system to prevent enemy eavesdropping, since the field strength will not attenuate fast enough for TEMPEST protection. Advantages of radio are that discrete channels can be provided at somewhat increase cost; if needed, omnidirectional radiation is not difficult to obtain, and terrain features will usually not block communications (except for large hills if microwaves are used). The following government fixed mobile frequency bands will be considered: 162-173 MHz, 1.71-1.85 GHz, and 4.4-4.99 GHz, all of which are removed from normal vehicular communications bands so that interference should not be a problem, as shown in the following chart "Ground Combat Vehicle EM Profile" (Figure 4-12).

GROUND COMBAT VEHICLE EM PROFILE

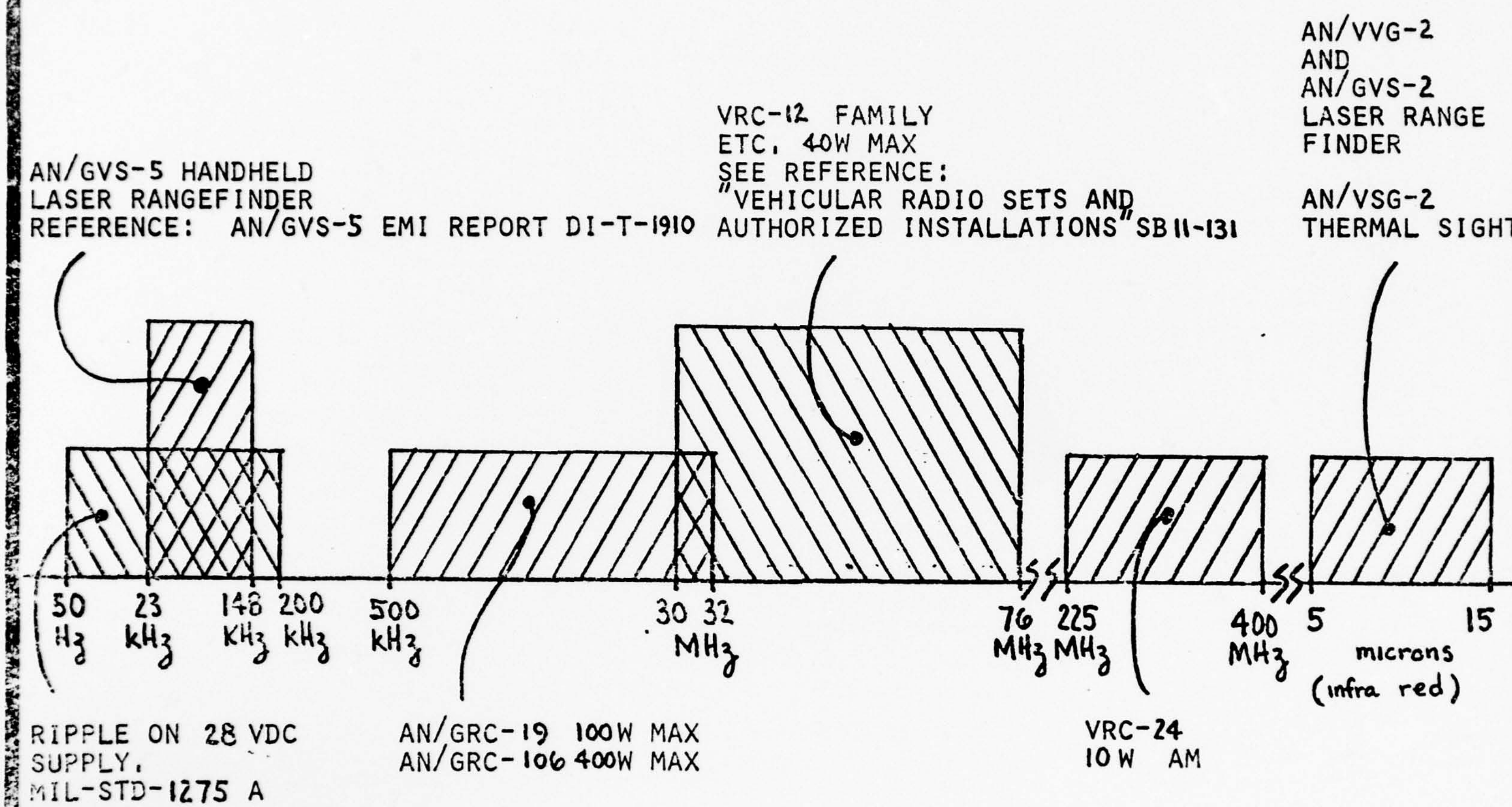
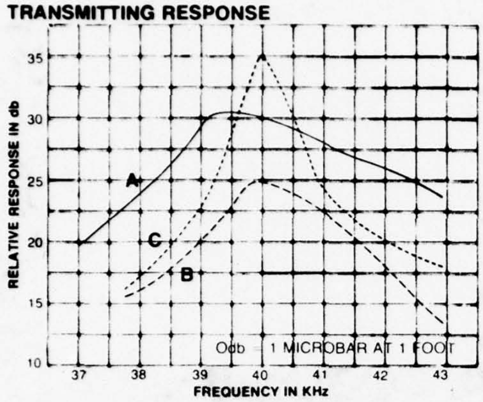


FIGURE 4-12

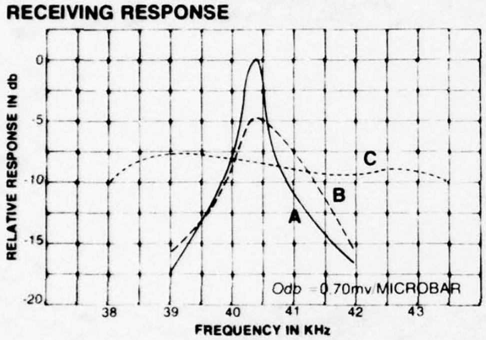
ULTRASONIC AIR TRANSDUCERS — MODEL 70100

PERFORMANCE CHARACTERISTICS

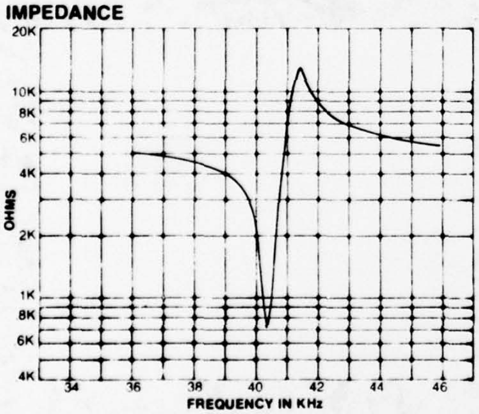
TRANSMITTING RESPONSE

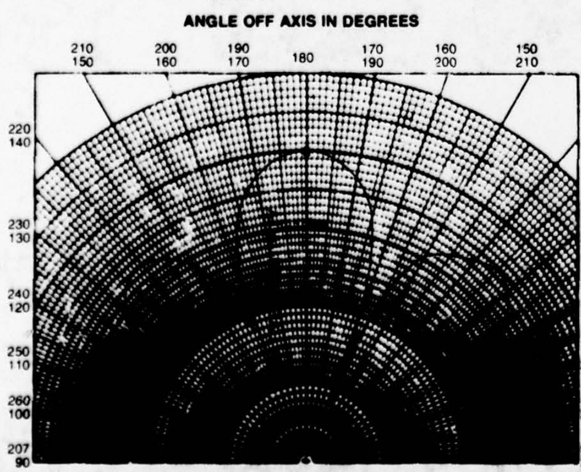


RECEIVING RESPONSE



IMPEDANCE



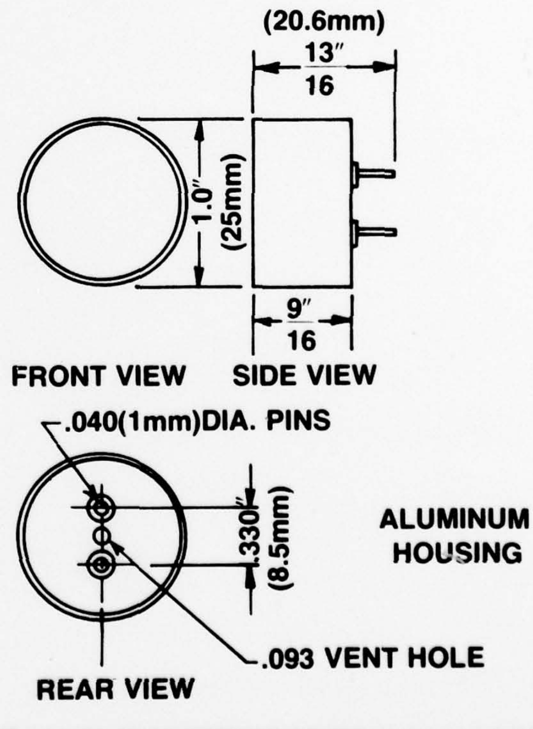


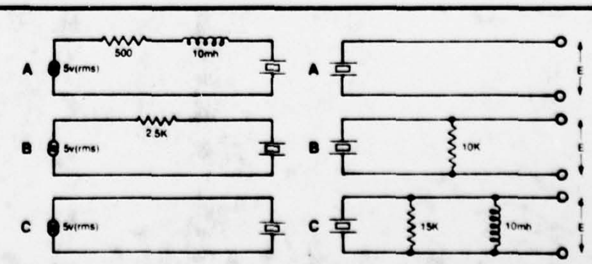
DIRECTIONAL RADIATION PATTERN AT 40 KHz

SPECIFICATIONS

	25 KHz	40 KHz
HOUSING	Model 70100, Aluminum	
FREQUENCY	25 KHz ± 2 KHz	40 KHz ± 2 KHz
BANDWIDTH	.4 KHz at -6db	.4 KHz at -6db (open untuned circuit)
TRANSMITTING SENSITIVITY	+23 db	+25 db (re 1 microbar/volt at 1 meter)
RECEIVING SENSITIVITY	-50db	-60db (re 1 volt per microbar)
CAPACITANCE	1500 picofarad	1600 picofarad (nominal)
POWER RATING ...	.2 watts	.2 watts (watts, CW, maximum)
TEMPERATURE RATING	5%	5% (maximum percentage change) in resonant frequency over a temperature range from -30°F to 150°F)
TUNING INDUCTANCE ...	26 mh	10 mh

MECHANICAL SPECIFICATIONS





TRANSMITTING RECEIVING

SECTION V

LOGISTIC SUPPORT ANALYSIS

A. PROGRESS TO DATE

A preliminary parts count prediction prepared in accordance with MIL-HDBK-217B, paragraph 3.0, shows an MTBF of greater than 5100 hours for the FDM approach. The initial prediction showed that the volume controls, MIL-R-94 potentiometers (RV-4), comprised more than 30% of the total failure rate. An investigation performed by Component Engineering revealed that Allen-Bradley makes an RV-4_ _ _ _EJ extra long life version of the MIL-R-94 (40 times greater rotational life). It was determined that the EJ version is better than the MIL-R-94 version. Using this information, a stress prediction was performed on the potentiometers which yielded a decrease in failure rate contribution from 30% to 9%.

The 5100 hour MTBF is based on Class B IC's, JAN TX level semiconductors, level S resistors and capacitors, and the stress failure rate for the Allen-Bradley RV-4_ _ _ _EJ potentiometer.

The preliminary parts count prediction for the TDMA approach, using the same criteria as the FDM, was predicted to be greater than 3900 hours MTBF.

B. NEXT QUARTER EFFORT

Plans for the next quarter include performing a GEMM analysis on both approaches to determine the most cost-effective approach.

SECTION VI

PLANS FOR NEXT REPORT PERIOD

A. Remaining information required for GEMM program will be generated for the two multiplexing systems.

B. Ways of minimizing inductive radiator "null" effect will be studied.

C. Conventional means of achieving wireless operation for the outside station will be studied.

D. The control unit and crew station breadboards will provide a means to investigate the following areas:

1. Frame synchronization and optimization of sync detection and verification circuits.
2. Problems caused by missed sync in the crew station.
3. Audio noise and cross talk.
4. 1 MHz data transmission on various lengths of coaxial cable.
5. CVSD performance.

APPENDIX A

IR COMMUNICATIONS SYSTEM REPORT

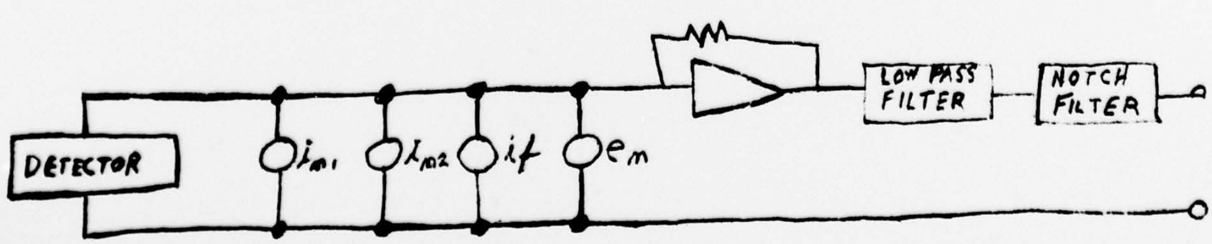
An IR communications system has been considered as a possible candidate for a tank intercom application. Previous work in this area has been done at a wavelength of 0.9 μ. This wavelength is not visible to the human eye and is compatible with fiberoptics. The atmospheric absorption is relatively low at 0.9μ, and $G_A A_S$ light emitting diode (LED) sources and silicon photodiodes are readily available at this wavelength.

The most efficient modulation for transmission of voice in an IR system was determined analytically. Two possibilities for voice transmission are: AM/CW or pulse modulation. Pulse modulation is assumed to include direct analog modulation/demodulation or digital coded transmission. The selection of the most efficient modulation scheme must consider the characteristics of transmission and reception at this wavelength. To determine what performance can be achieved, the characteristics which are the determining factors in selection of modulation are:

a. The detector output current is proportional to the incident IR power.

b. The detector and pre-amp parameters, such as capacitance and internal noise generators, limit the achievable pulse response and noise spectrum.

The detector pre-amp, and background were modeled for the circuit shown in the sketch below:



The signal-to-noise ratio of a preamplifier followed by a low pass filter and a matched filter is:

$$S/N = \frac{2\,(R A_o\, \tau_o\, \tau_f H\,[1 - k_o])^2}{N_o\; B}$$

R = Detector Responsivity (A/W)

H = Irradiance on the Detector (W/cm^2)

A_o = Area of the receiver optics (cm^2)

τ_o = Transmission of the receiver optics

τ_f = Transmission of the filter

k_o = Receiver obscuration

B = System bandwidth

$$N_o = 2q\,(I_B + I_D) + \frac{4kT_s}{R_F} + \frac{4kT_s}{R_D} + \frac{\bar{e}_n^{\,2}}{R_F}$$

$\sqrt{2q(I_B + I_D)} = i_{n_1}$ is the noise equivalent current due to detector dark current, I_D, and background current, I_B. $\sqrt{\frac{4kT_s}{R_F}} = i_{f1}$ is the noise equivalent current due to preamplifier Johnson noise. T_s is the system temperature and R_F is the preamplifier feedback resistance.

$\sqrt{\frac{4kT_s}{R_D}} = i_{n2}$ is the noise equivalent current due to detector Johnson noise. R_D is the detector resistance $\bar{e}_n$ is the preamplifier noise equivalent voltage.

For a delta modulation (DM) system, the effective bandwidth can be expressed as:

$$B_{DM} = \frac{1}{T - \tau' + \tau' e^{-T/\tau'}}, \text{ where, } \tau' = \frac{e_n (C_F + e_D)}{\sqrt{N_o}}$$

C_F is the preamplifier feedback capacitance and e_D is the detector capacitance.

The irradiance on the detector from a given source is proportional to the output power of the source. In the pulsed DM case, $H \propto \frac{W_{SDM}}{F_S T}$, where, W_{SDM} is the average power of the source and $F_S T$ is the source duty cycle. In the AM/CW case, $H \propto W_{SAM}$, the average source power.

The average power of each type system can be related to the S/N out of the system by the following expressions:

$$W^2_{S-DM} = \frac{(F_S T/2)^2 N_o \, S/N - DM}{2(RA_o \tau_o \tau_F (1-k_o) r)^2 (T - \tau' + \tau' e^{-T/\tau'})}$$

$$W^2_{S-AM} = \frac{N_o B_{AM} \, S/N - AM}{(RA_o \tau_o \tau_F (1-k_o) r)^2}$$

$$\frac{W^2_{S-DM}}{W^2_{S-AM}} = \frac{(F_S T/2)^2 (S/N - DM)}{2 (T - \tau' + \tau' e^{-T/\tau'}) (B_{AM}) (S/N - AM)}$$

When operating at a frequency of 16 kHz, a CVSD system will produce an output S/N of 12.5 dB for an input S/N of 11.6 dB. For 16 kHz operation and an output S/N of 12.5 dB, the ratio can be written as:

$$\left(\frac{W_{SDM}}{W_{SAM}}\right)^2 = 11.6\text{ dB} - 12.5\text{ dB} - 9\text{ dB} + 10\log\left[\frac{1}{(B_{AM})(T - \tau' + \tau' e^{-T/\tau'})}\right] - 20\log\left(\frac{1}{F_S T}\right)$$

Assuming, $F_S = 16$ kHz, $T = 1.5$ microseconds, $B_{AM} = 3$ kHz,

$I_B = 30$ nA, $I_D = 30$ mA, $C_F = 2$ picofarads, $C_D = 6$ picofarads,

$\overline{e}_n = 5 \times 10^{-9} V/\sqrt{Hz}$, and $R_F = 4.7\ M\Omega$

$$\left(\frac{W_{SDM}}{W_{SAM}}\right)^2 = -18\text{ dB}$$

Thus, the DM system requires 9 dB less power than the AM system to achieve comparable performance. Therefore, the DM system was chosen for use.

The detector background current, I_B, can be written as:

$$I_B = \frac{\pi N_\lambda (1 - k_o) \tau_o \tau_t D_\lambda A_D R e^{-\sigma R}}{4F^2}$$

N_λ = background source spectral radiance $\left(\frac{W}{cm^2 \cdot \mu \cdot sr}\right)$

D_λ = spectral bandwidth of the system (microns)

A_D = detector area (cm^2)

σ = atmospheric absorption (1/km)

R = range of operation (km)

F = receiver optics f/number

τ_f = filter transmission

τ_o = receiver optics transmission

k_o = receiver obscuration

RR = detector responsivity (A/W)

The use of a narrowband optical filter allows operation even in the presence of strong broad spectrum background sources by limiting the energy at all wavelengths which reach the detector except at the source wavelength. This greatly reduces the background current while only slightly attenuating the received source signal level.

Figures 1 and 2 show the predicted performance of an IR link using continuously variable slope delta modulation (CVSD) with an IR link consisting of a source with an average output power of 5 mW and 3 dB beam angle of 130^o pulsed at 16 kHz with a pulse width of 1.5 microseconds and a 0.316 inch diameter photodiode receiver placed at the focal point of a one inch diameter f/1 receiver lens.

Figure 1 shows the predicted S/N versus range for the case wherein the source radiation is reflected off of a wall before it reaches the receiver. The wall reflectance was assumed to be 0.05 and the background current to be 70 mA. This case approximates the performance of an IR link inside of an enclosure. The S/N is greater than 15 dB out to a range of 105 feet. The source output power could be dropped to 0.1 mW and still achieve a S/N greater than 15 dB at a range of 7 feet, the tank turret diameter.

Figure 2 shows the predicted S/N versus range for the case of the receiver looking at the source. This case approximates the performance of an IR link in the open field. Two curves are shown: one, for operation for low background (I_B = 70 mA) levels and the other, for operation for high background (I_B = 20 uA) levels. When the background level is high, the S/N is greater than 15 dB out to 135 feet. For low background levels, the S/N is greater than 15 dB out to 390 feet.

The advantages of an IR system are that it is a wireless system; it can be constructed using small, lightweight components, such as G_AA_S LED's, silicon photodiodes and plastic Fresnel lenses; and it is intrusion resistant in that the source beam width can be controlled. Thus, the system can be made narrow beam thereby reducing the probability of intercept as compared to that of a wide beam system.

The disadvantages of an IR system are as follows: If the system is made highly directional, it will require pointing to achieve good communications. The frequency of the IR sources and filters cannot be easily changes; thus, the system is locked into operation at a particular frequency. Also, there are several sources of signal attenuation which may make transmission via an IR link impossible. The IR signal is attenuated by rain, fog, or other inclement weather, by mud or dust contaminating the source or receiver lenses and by obstructions such as trees or bushes between the transmitter and the receiver. If the source beam width is narrowed in order to facilitate long range transmission, it is possible to present an eye safety hazard to personnel within the beam close to the source.

FIGURE 1 S/N VERSUS RANGE FOR RECEIVER VIEWING A REFLECTED SOURCE. REFLECTANCE IS 0.05. AVERAGE SOURCE POWER 5 mW. SOURCE BEAMWIDTH 130°. DETECTOR DIAMETER 0.316 INCHES. RECEIVER OPTICS ONE INCH DIAMETER f/1 LENS.

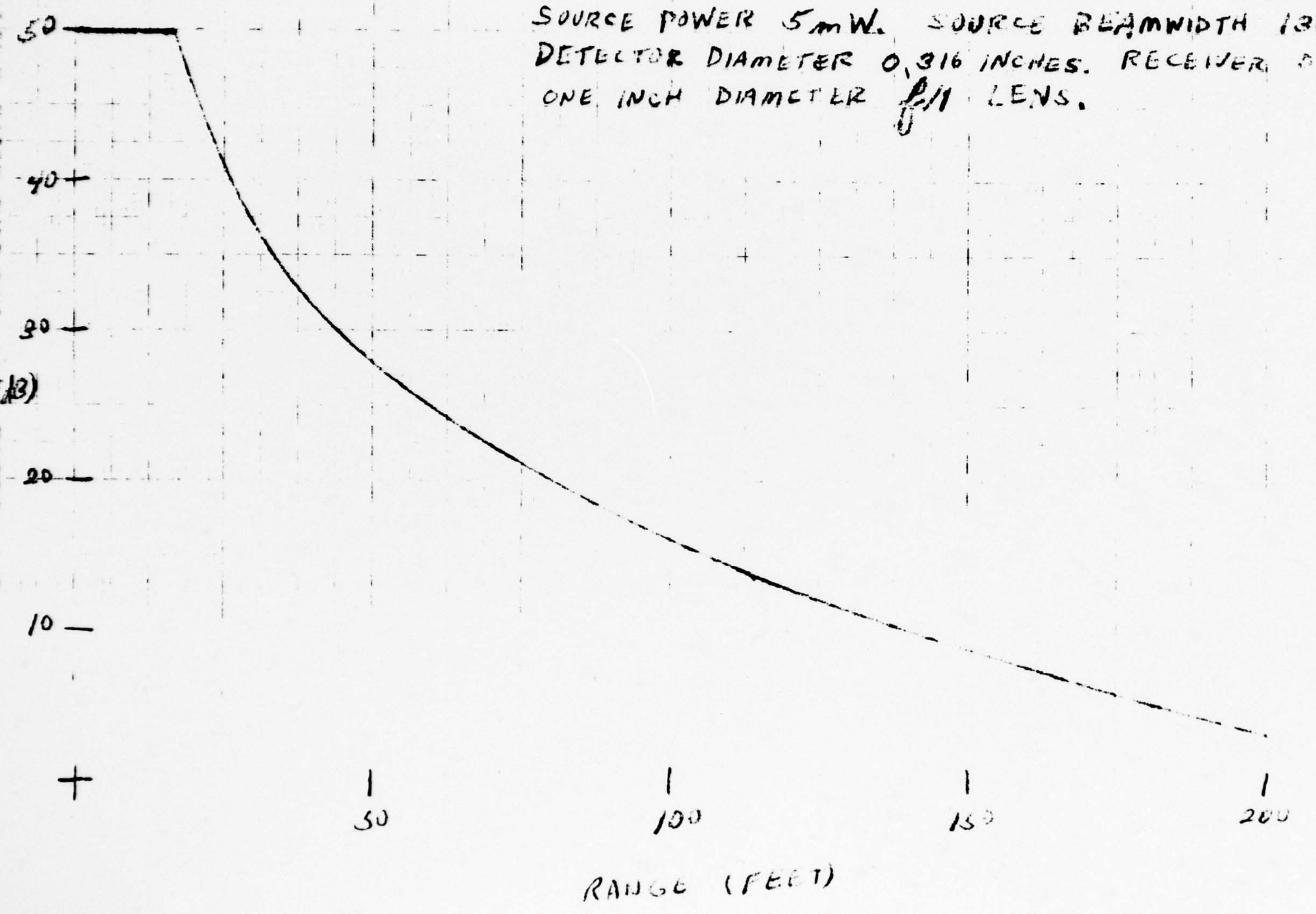
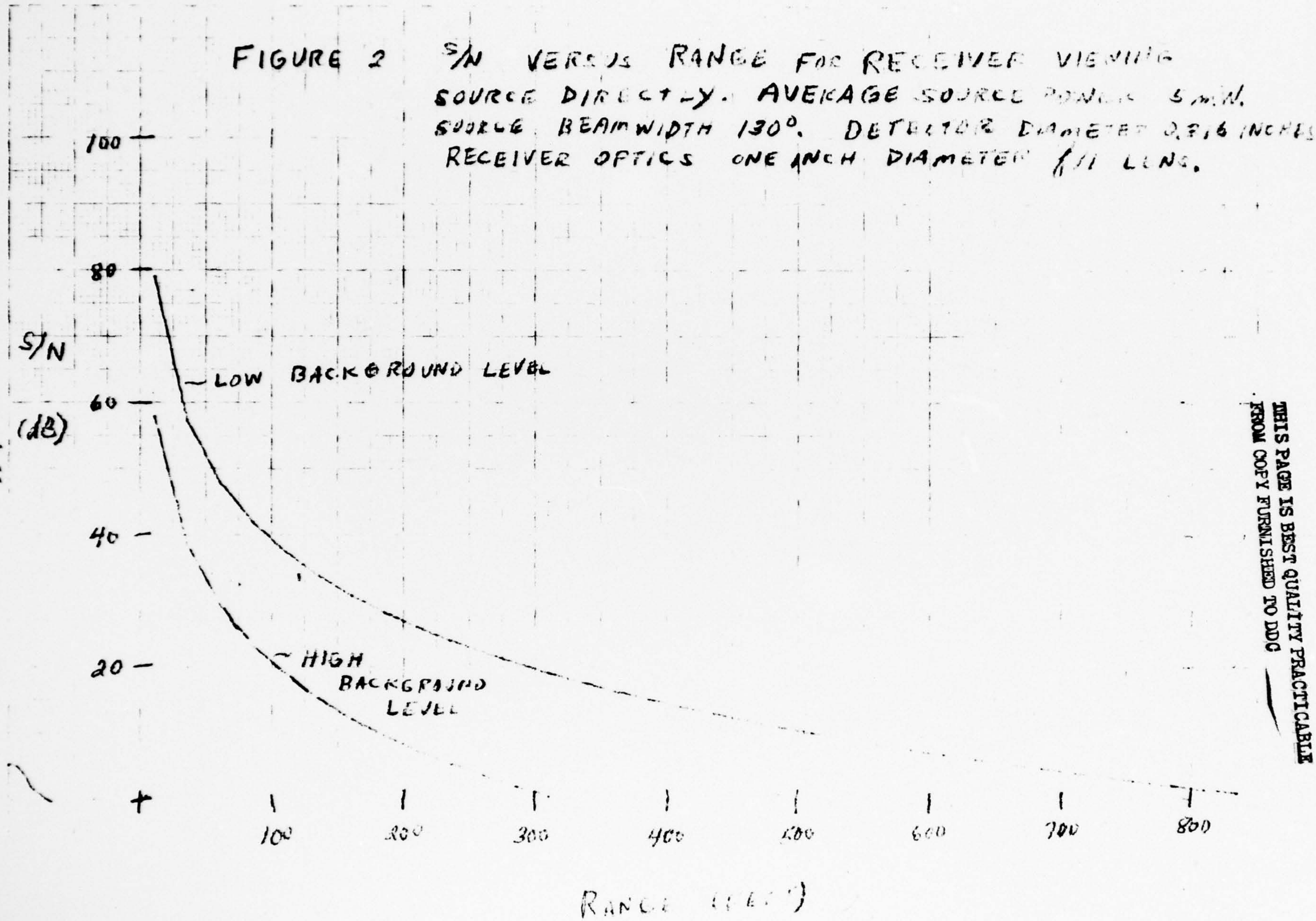


FIGURE 2 S/N VERSUS RANGE FOR RECEIVER VIEWING SOURCE DIRECTLY. AVERAGE SOURCE POWER 5 mW. SOURCE BEAMWIDTH 130°. DETECTOR DIAMETER 0.316 INCHES. RECEIVER OPTICS ONE INCH DIAMETER f/1 LENS.



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