

REPORT



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Approved by

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AROD SYSTEM TEST MODEL
(Contract No. NAS8-11835)
FINAL REPORT
AROD LABORATORY TEST
AND EVALUATION PROGRAM

45678970

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SECTION I

1. INTRODUCTION

The AROD Test and Evaluation Program is a portion of Contract No. NAS 8-11835 performed for NASA, Instrumentation and Communication Division, Astrionics Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama.

1.1 THE AROD SYSTEM

The AROD System is a vehicle-based ranging system; the functions of timing, control, station selection, and data extraction are all performed in the vehicle. The remaining equipment, that associated with the transponder stations, is correspondingly simplified and serves mainly as a means of amplification and frequency translation.

The vehicle equipment is intended to operate with up to four stations simultaneously. Two radio frequency links are used which accomplish the functions of station control, acquisition aid, and the determination of the relative range and velocity to each station. The relative range is derived from the two-way time delay of the ranging modulation on the S-band transmission. The relative velocity is derived from the two-way Doppler shift of the S-band carrier from the vehicle to the transponder station and return.

The system is fully coherent in the tracking mode. All r-f carriers, as well as the ranging modulation, are derived from a common source. This permits the use of each signal to aid others in acquisition as well as providing the means of mutual assistance under conditions of high dynamics or spotty signal reception.

The primary goals of the AROD system were to provide range measurements to over 2000 km and velocity measurements to over 12,000 m/s with accuracies better than the then state of the art. The

actual hardware resulted in an instrumented unambiguous range measurement of 3042 km with a resolution of 0.183 meters and velocity measurements of 0 to 13,500 m/s with a resolution of 0.026 m/s. A detailed description of the vehicle and transponder equipments is contained in their respective Operation Handbooks, Documents No. 68-24763H and 68-24764H.

1.2 PURPOSE OF TESTS

The principal objectives of the Test Evaluation Program were:

1. To obtain statistical and long term stability performance data under controlled operating conditions.
2. To study system characteristics and search for anomalies under conditions simulating actual operation, and
3. To evaluate the vehicle borne system design to certain environmental conditions of space hardware which are design requirements but not equipment requirements of the Test Model Hardware.

The tests conducted were natural extensions of the subsystem acceptance tests. The acceptance test program provided the means to verify that the hardware had been properly built and performed in accordance with its design. The Test Evaluation Program, however, was comprised of three types of tests. The first group of tests was somewhat an extension of the acceptance tests. These tests were designed to obtain further detail engineering data of the two subsystems operating with the checkout equipments.

This permitted simulation of all normal operating conditions and provided for statistical evaluation of delay measurements and acquisition measurements under a variety of signal conditions. These tests provided two important outputs: (1) the statistical mean and variance of range and range rate measurements, acquisition time, and probability of acquisition as a function of signal dynamics, and (2) calibration stability, as a function of signal dynamics, temperature, and long term drift.

The second group of tests was more of a demonstration and exploratory nature. These tests were designed to simulate, as nearly as practical, an actual operating situation. The purpose was to demonstrate fully automatic operation in acquisition and sequencing of the transponder stations. As such, the tests were directed primarily toward exercising the equipment and observing rather than obtaining qualitative data. The output of these tests was the investigation and analysis of anomalies (and subsequent corrections) arising from the complete automatic system operation.

In conjunction with the two test sequences described above, evaluation of one vehicle receiver and both vehicle transmitters was carried out under simulated space environment conditions. Tests were conducted under vacuum conditions to determine the need for pressurization, and to verify that the heat transfer characteristics were as designed, and were satisfactory.

1.3 SCOPE OF REPORT

The scope of this report is such as to give a good understanding of the performance characteristics of the AROD equipment. Sections II and III provide the background for the system tests, giving important subsystem test data and a summary of the instrumentation used in the actual testing.

Section IV presents data obtained during initial tests: operational checks and thresholds, and detailed acquisition tests with jamming.

Detailed single channel test results are presented in Section V. These tests included acquisition thresholds and acquisition times, range and velocity measurements, and tracking characteristics performed at various signal level conditions. Section VI shows the results of multiple channel tests. The tests were designed to show the effects on range and range rate measurements of jamming due to varying signal level and Doppler conditions. Also included in Section VI are detailed bit error tests of the S-band data link.

The effects of the environmental stresses of temperature and vacuum are presented in Section VII. These tests were conducted on one vehicle receiver (Channel C) and both vehicle transmitters. The long term effects of drift and aging are presented in Section VIII.

Section IX is a summary of recommendations for improvement of AROD.

Two appendices are included in the report. Appendix A-1 describes the Doppler reverse system in AROD, the problems it presented, and the solutions provided for these problems. Appendix A-2 summarizes the velocity measurement problems encountered.

1.4 SUMMARY OF PERFORMANCE

A summary of the performance of the AROD System compared to specified goals and to design theoretical performance is given in Table I-1. An inspection of this chart reveals that essentially all of these specified goals were met or exceeded by the equipment performance. The exceptions are in range rate accuracy and acquisition time.

1.4.1 Range Measurement

The critical parameters of the range measurement process, resolution, and accuracy appear to have been met or exceeded. The data presented in Section V shows that these goals were met over a wide range of signal level and Doppler (velocity) conditions. The reduced maximum range from 20,000 km to 10,000 km is a relatively insignificant factor (in relation to the specified goal of 2000 km).

1.4.2 Range Rate Measurements

The maximum range rate capability and range rate resolution of the AROD hardware are in essential agreement with the specified goals. The data of Section V shows that the mean of 120 consecutive range rate measurements is consistently within the specified goal of 0.015 m/s. The design theoretical goal was to have the rms range rate within the specified goal of 0.015 m/s. The

TABLE I-1. AROD System, Comparison of Expected Performance with Specified Goals

Characteristic	Specified Goal	Design Theoretical Performance	Measured Performance	
			Vehicle Equipment	Transponder Equip.
Range: Maximum	2000 km*	20,000 km* 3042 km Ambiguity Resolution	10,000 km* Acq. Threshold, -125 dbm Trk. Threshold, -128 dbm	10,000 km* Acq. Threshold, -124 dbm Trk. Threshold, -128 dbm
Resolution Accuracy	0.25 meter ±0.5 meter	0.183 meter 0.604 meter, rms	0.183 meter 0.5 meter, rms	N/A 0.5 meter, rms
Range Rate: Maximum	±12,000 m/s	±13,500 m/s	±13,500 m/s	N/A
Resolution	0.02 m/s	0.026 m/s	0.026 m/s	N/A
Accuracy	0.015 m/s	0.0148 m/s rms 0.0699 m/s peak	0.06 ms/rms	N/A
Readout Rate	4 times/sec	4 times/sec	4 times/sec	N/A
Acquisition Time	2 seconds	3.3 seconds	L-Code - 2.5 sec. H-Code - 0.17 sec.av	Doppler Reverse 3.2 sec. max.
Size: Vehicle Transponder	1600 cu. in. 20 cu. ft.		1578 cu.in.	12 cu. ft.
Weight: Vehicle Transponder	55 lb. 300 lb.		51 lb.	290 lb. ₀
Power: Vehicle Transponder	150 watts 400 watts		143 w @ 28 vdc	220 w @ 110v, 60 Hz
Reliability: Vehicle Transponder	0.95 for 200 hrs. 0.99 for 200 hrs.	0.968 0.978		

*Maximum range calculated on basis of specified xmtr power, antenna gain, and receiver threshold.

measured rms value was about four times this goal or 0.06 m/s. Additional work is required to achieve the design theoretical goal of 0.015 m/s rms.

1.4.3 Acquisition Time

Two factors contribute to making the system acquisition time longer than the design goal. First, due to the design configuration of the station control logic and the receiver and transmitter code controls, a delay of approximately 2.5 seconds is inserted between transponder states T1-a and T-2. This delay was added to allow the transponder range loop to settle prior to H-code acquisition. At shorter ranges this time period is also used by the vehicle to search the L-code, so that the delay is of little consequence. At longer ranges, where the vehicle L-code search is short, the delay adds perhaps 1.5 seconds to the system acquisition.

The second contribution to increasing acquisition time is the increased Doppler reverse sweep time required to permit tracking during the sweep by the vehicle. This time may vary between 0.25 second and about 3.2 seconds, depending on vehicle velocity. The maximum is about one second, average, greater than had been anticipated.

1.4.4 Mechanical Characteristics

The size, weight, and power requirements of the specified goal are all satisfied by the present hardware.

1.4.5 Reliability

While sufficient data is not available to establish an actual MTBF for either the vehicle or transponder, sufficient data is available to establish that the specified goals have been exceeded. During the program, the vehicle equipment was operated for over 2100 hours. There were no part failures during this time. The transponders were operated for about 1500 hours each with but one failure -- a potentiometer.

SECTION II

2. ABSTRACT OF ACCEPTANCE TEST DATA

The following data is a summary of selected parameters measured during acceptance tests. These data are presented for reference only. No attempts are made herein to analyze or justify the data.

2.1 TRANSMITTER POWER OUTPUTS

All power measurements were made with an HP-431B Power Meter with calibrated attenuators to produce on-scale readings. Table II-1 presents the results of these tests.

TABLE II-1. Transmitter Power Outputs (Acceptance Test Data)

Transmitter	Frequency MHz	Power Output	
		dbm	Watts
Vehicle, VHF	138	37.0	5.03
Vehicle, S-Band	2214	8.1*	6.5 mW*
Transponder No. 1	1800	37.4	5.5
Transponder No. 2	1800	36.0	3.98
Transponder No. 3	1800	36.2	4.18

*Without TWTAs

The data indicates that the transponder power outputs were below the desired value of 8 watts (+39 dbm). Later tests (see para. 8.2.1) show that the above readings were biased by a calibration error.

2.2 RECEIVER NOISE FIGURES

The receiver noise figures measured during acceptance testing are presented in Table II-2.

2.3 THRESHOLD

Tables II-3 and II-4 summarize the acquisition and tracking thresholds measured during acceptance testing. Acquisition threshold is

the minimum signal level which will permit the equipment to lock in that mode, be it L-code or H-code. Tracking threshold is the minimum signal level at which the equipment will remain locked.

TABLE II-2. Receiver Noise Figures (Acceptance Test Data)

Receiver	Frequency	Noise Figure
Vehicle, S-Band	1800 MHz	.8.3 db
Transponder No. 1 VHF	138 MHz	.5.4 db
Transponder No. 2 VHF	138 MHz	5.1 db
Transponder No. 3 VHF	138 MHz	5.1 db
Transponder No. 1 S-Band	2214 MHz	9.0 db
Transponder No. 2 S-Band	2214 MHz	9.0 db
Transponder No. 3 S-Band	2214 MHz	10.0 db

TABLE II-3. Vehicle Equipment Thresholds (Acceptance Test Data)*

Channel	L-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Acquisition Threshold	H-Code Tracking Threshold
A	-127 dbm	-131 dbm	-123 dbm	-125 dbm
B	-128 dbm	-131 dbm	-126 dbm	-128.5 dbm
C	-128 dbm	-131.5 dbm	-124 dbm	-126 dbm
D	-129 dbm	-131.5 dbm	-125 dbm	-127 dbm

TABLE II-4. Transponder Equipment Thresholds (Acceptance Test Data)*

Transponder	L-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Acquisition Threshold	H-Code Tracking Threshold
No. 1	-129 dbm	-130 dbm	-125 dbm	-126 dbm
No. 2	-128 dbm	-130 dbm	-123 dbm	-126 dbm
No. 3	-128 dbm	-131 dbm	-124 dbm	-125 dbm
Transponder	VHF Receiver Acquisition Threshold		VHF Receiver Tracking Threshold	
No. 1	-124 dbm		-126 dbm	
No. 2	-128 dbm		-130 dbm	
No. 3	-131 dbm		-132 dbm	

*See final data in Table VIII-1, Page 8-2.

SECTION III

3. INSTRUMENTATION

The instrumentation for the AROD Test Evaluation Program was centered around the checkout equipments -- Vehicle Borne Equipment Checkout System (P/N 01-22442H01) and Transponder Equipment Checkout System (P/N 01-22443H01). Auxiliary equipment consisted of special test fixtures, commercial test equipment, and an inter-connecting cable system.

3.1 VEHICLE CHECKOUT SYSTEM

The vehicle checkout system permits the controlled exercise of all vehicle equipment functions, the monitoring of the vehicle status and acquisition states, and selected measurements on the vehicle equipment. The vehicle checkout is described in detail in its Operation Handbook, Document No. 68-24765H. Its basic operation is in one of two distinct modes -- transponder simulator or translator mode.

3.1.1 Transponder Simulator Mode

In the simulator mode, the checkout equipment functions as two separate transponder transmitters. It provides transmissions on any two of the four L-band channels simultaneously and permits the measurements of receiver thresholds, acquisition sequence, acquisition time, range and velocity readouts, and dropout characteristics. The transponder-to-vehicle L-band frequencies are synthesized from independent 12.8 MHz VCO's which also drive transmitter code generators. This permits the insertion of signal dynamics on both the carrier and the modulation. Manual S-band data encoders modulate the code to simulate the S-band data transfer over this link. The S-band message is set by toggle switches and contains station ID and status bits. A block diagram showing the operational hookup in this mode is given in Figure 3-1. Operation in the coherent, or zero velocity, mode

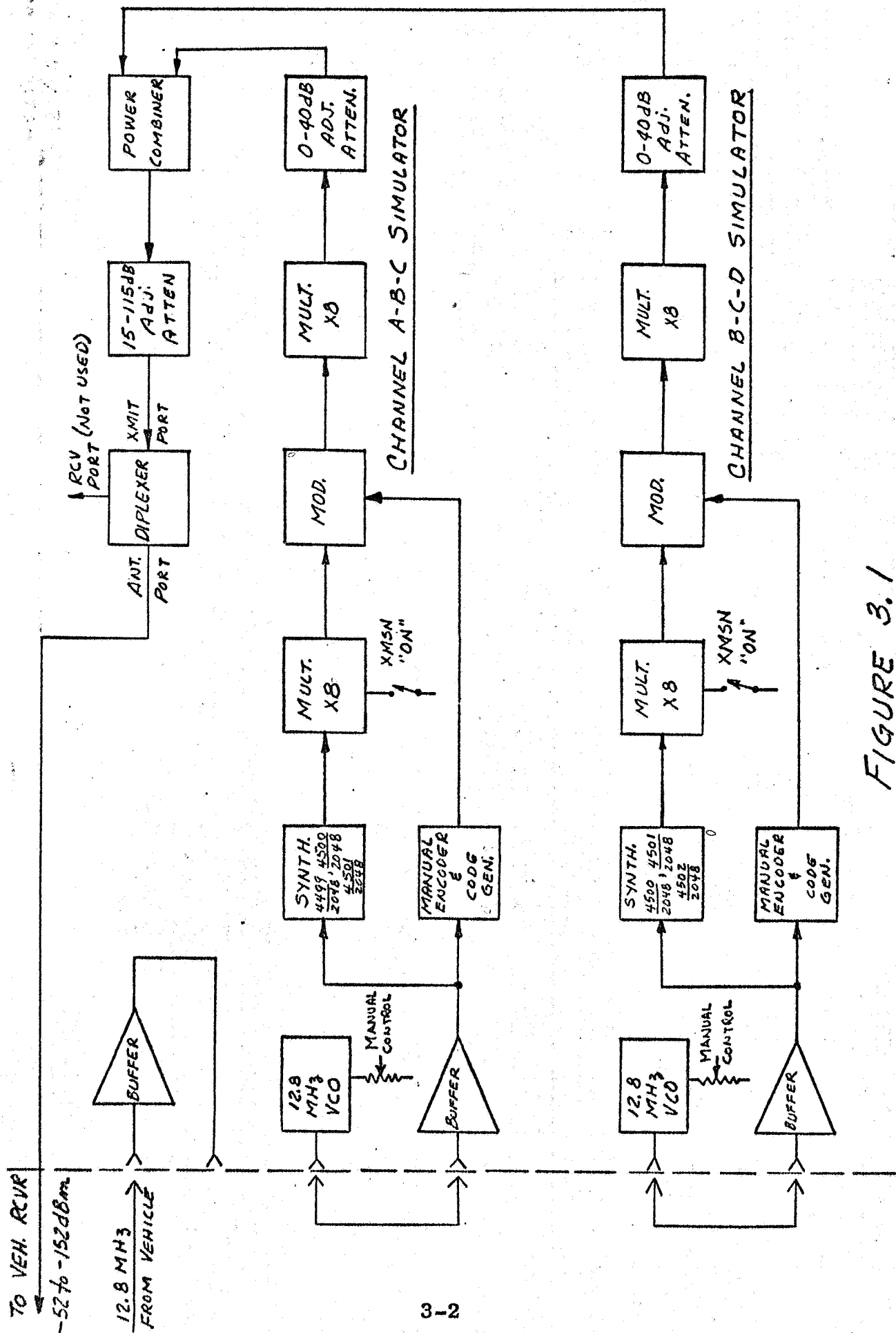


FIGURE 3.1
BLOCK DIAGRAM
VEHICLE CHECKOUT EQUIPT.
SIMULATOR MODE

is obtained by patching in the vehicle 12.8 MHz reference in place of the internal 12.8 MHz VCO.

3.1.2 Translator Mode

In the translator mode, the checkout equipment functions to translate the vehicle 2214 MHz output to a coherent 1800 MHz receiver test signal. This mode is used primarily to measure the total time delay in the vehicle transmitter/receiver channels. Signal dynamics are inserted in the transmitted signal -- both carrier and modulation components. The checkout equipment contains a 12.8 MHz VCO which is set manually to represent a constant velocity (Doppler). This signal is used to drive both the vehicle transient code generator and the synthesizer used to derive the 414 MHz translation frequency. Outputs may be obtained on any one of the four receiver frequencies. A block diagram showing the translator mode of operation is given in Figure 3-2. As above, operation in the coherent, or zero velocity, mode is obtained by patching in the vehicle 12.8 MHz reference in place of the internal 12.8 MHz VCO.

3.1.3 Other Operating Characteristics

3.1.3.1 Memory Loading

The vehicle checkout equipment contains a memory program generator which permits loading the vehicle magnetic core memory. This includes prime and alternate station ID's and maximum ranges. Loading is accomplished one prime and one alternate station at a time by the use of 24 toggle switches.

3.1.3.2 Transmitter Monitoring

Provision is made to monitor the S-band and the VHF transmitter outputs for power and spectrum shape. Known values of attenuation are inserted and the power measured with a HP-431B Power Meter. The spectrum is inspected using a HP-851/8551 Spectrum Analyzer.

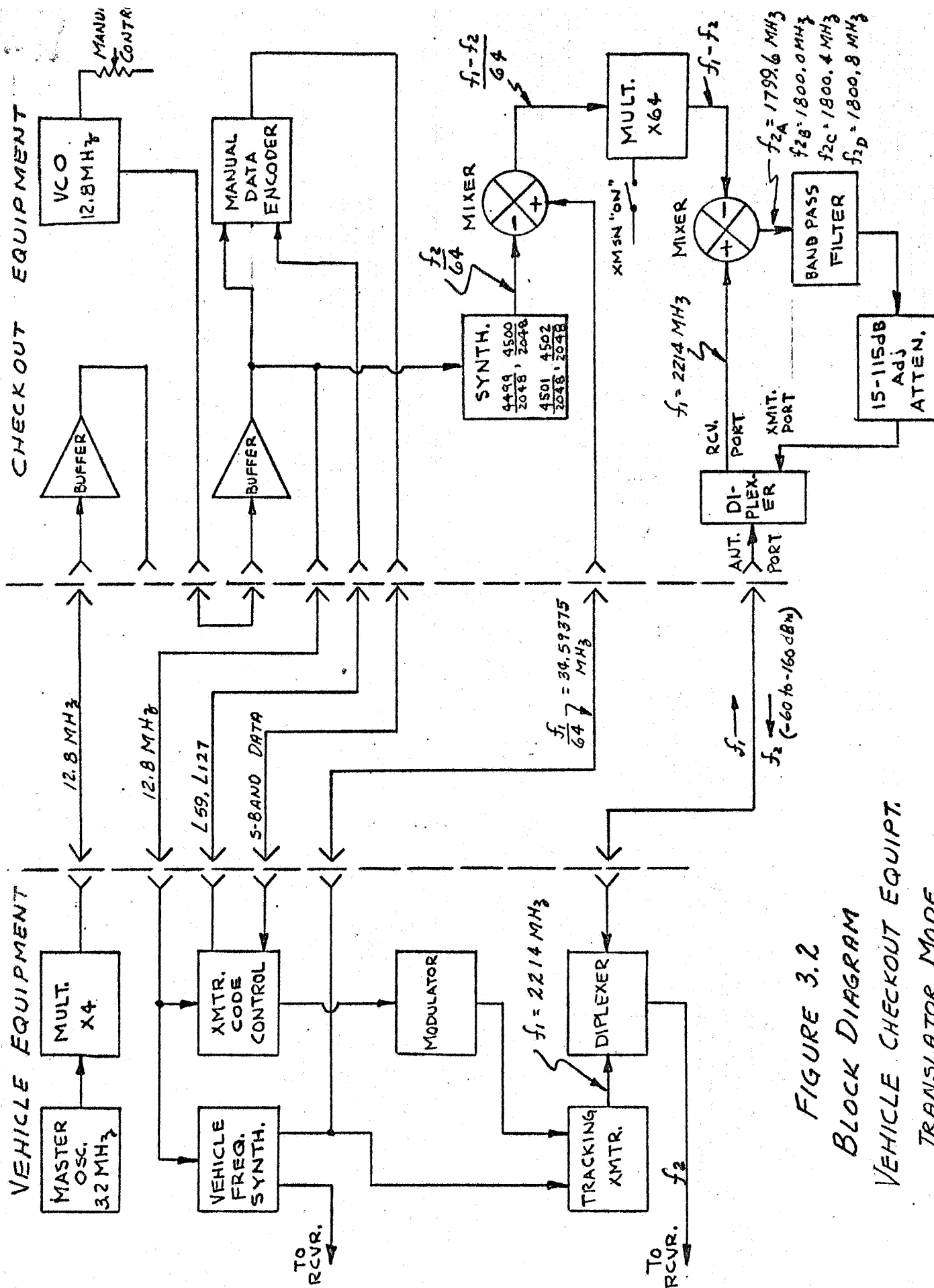


FIGURE 3.2
BLOCK DIAGRAM
VEHICLE CHECKOUT EQUIPT.
TRANSLATOR MODE

3.1.3.3 VHF Modulation

The 138 MHz VHF output is demodulated in a receiver simulator and the recovered modulation is compared to the original sub-bit data. This provides a check on the complete VHF transmitter operation.

3.1.3.4 Variogon Phase Shifter

A Variogon phase shifter is provided for use on a 12.8 MHz signal which can be used for a variety of functions requiring the insertion of a calibrated delay to one signal.

3.1.3.5 Vehicle Prime Power

The vehicle checkout equipment provides the 28 vdc prime power required to operate the vehicle equipment. It is adjustable over a range of 24-32 volts to simulate field conditions.

3.1.3.6 Vehicle Voltage Monitor

Monitoring points are provided to monitor the vehicle package operating voltages. These include ± 3.5 volts, ± 10 volts, -15 volts and -28 volts.

3.1.3.7 Test Points

The checkout equipment provides monitoring access to the following vehicle functions (for each receiver channel)

SPE	VI
AGC	V2
VRL ₁₂₇	V3
CAD	V4
A _H	DPE
A _L	SITE DATA

3.1.3.8 Data Readout

A provision exists in the vehicle checkout equipment for printing out the data output of the vehicle package, one word at a time. The desired word is selected by a front panel control on Vehicle Checkout equipment. The major limitation of this facility

is that it is not possible to obtain more than one reading for a given instant of time. For instance, Velocity A and Range A could not be obtained with the same time reference. This fact necessitated the additional facility discussed in paragraph 3.3.4.

3.1.4 Vehicle Checkout Equipment Characteristics

3.1.4.1 Vehicle Control Drawer

1. Transponder Simulator Mode

Output frequencies

Channel A-B-C: 28.11875 MHz,
28.125 MHz, or
28.13125 MHz.
12.8 MHz (Test)

Channel B-C-D: 28.125 MHz,
28.13125 MHz, or
28.1375 MHz.
12.8 MHz (Test)

Stability: 1 part in 10^5 , long term, 0° to 65°C . Better than 1 part in $10^7/\text{min}$, short term.

Output levels: -2 dbm ± 3 db

Output impedance: 50 ± 10 ohms

Adjust capability: ± 1200 Hz minimum (referred to 12.8 MHz)

2. Coherent Translator Mode

Input frequency: 34.59375 MHz

Output frequencies: 6.475 MHz,
6.46875 MHz,
6.4625 MHz, or
6.45625 MHz.

Stability: Same as in paragraph 3.1.4.1 a.

Output level: -3 $\pm$ 3 dbm
Output impedance: 50 $\pm$ 10 ohms

3.1.4.2 R-F Translator Drawer

1. Transponder Simulator Mode

Input frequencies: 28.11875 MHz,
28.125 MHz,
28.13125 MHz, or
28.1375 MHz.

Output frequencies: 1799.6 MHz,
1800.0 MHz,
1800.4 MHz, or
1800.8 MHz.

Note: Operation is possible on any two of the above frequencies simultaneously.

Output level: Adjustable, approximately -40 to
-140 dbm.

Load Impedance: 50 ohms resistive.

2. Coherent Translator Mode

Input frequencies:

S-band - 2214 MHz

HF Signal - 6.475 MHz,
6.46875 MHz,
6.4625 MHz, or
6.45625 MHz.

L-Band Output

Frequencies: 1799.6 MHz,
1800.0 MHz,
1800.4 MHz, or
1800.8 MHz.

Output level: Adjustable, approximately -52 to
-152 dbm

Note: S-Band Input and L-Band Output signals use common
diplexer port.

Load Impedance: 50 ohms, resistive.

3.2. TRANSPONDER CHECKOUT EQUIPMENT

The transponder checkout equipment provides the capability necessary to control and exercise the transponder stations. It provides the following functions.

1. Frequency translator to translate the L-band transmitter output (1800 MHz) to the S-band receiver frequency (2214 MHz).
2. VHF transmitter simulator with manual data encoder.
3. Time delay phase measurement.
4. Monitoring and control functions.

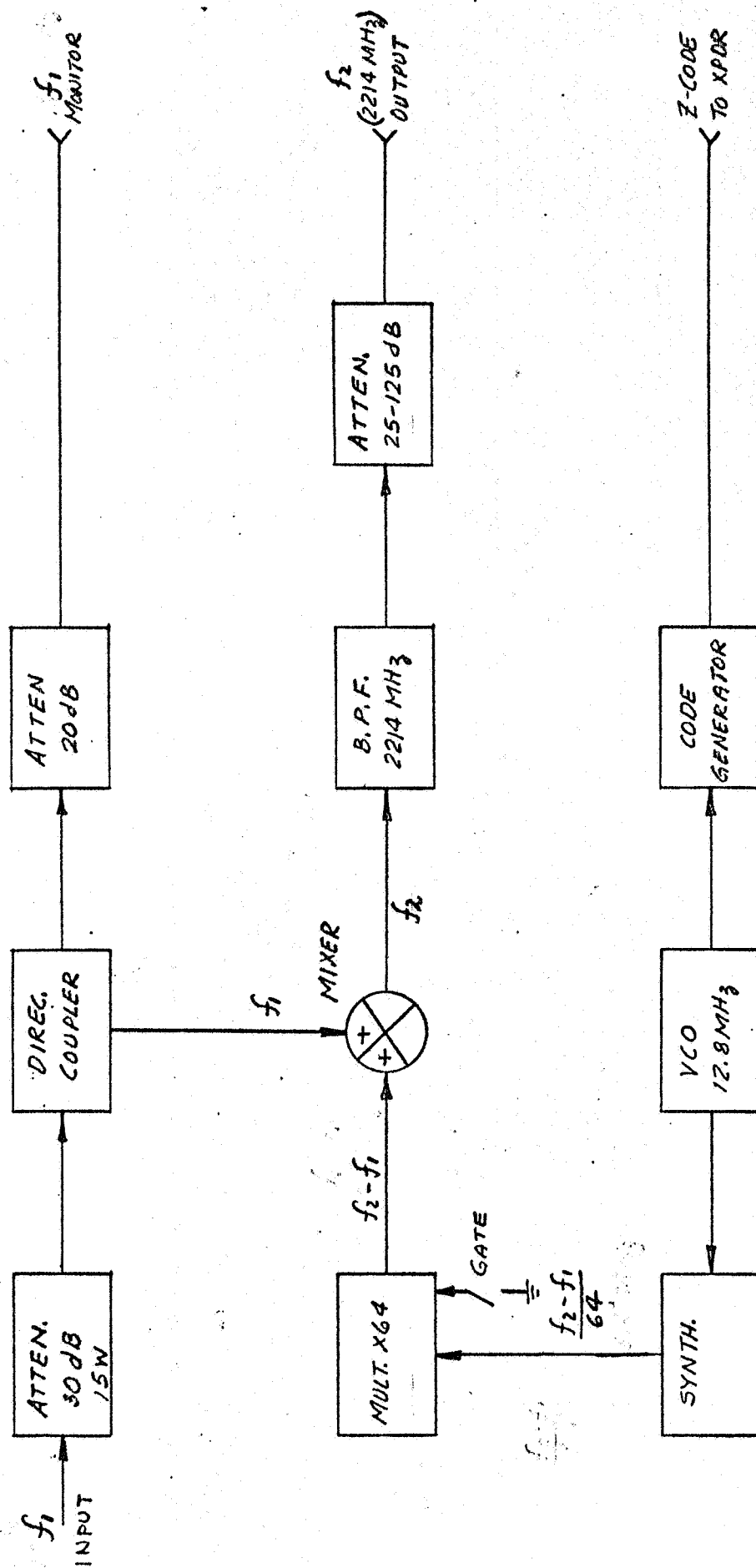
A detailed description of the transponder checkout equipment is contained in its Operation Handbook, Document No. 68-24766H.

3.2.1 Frequency Translator

A block diagram of the frequency translator is shown in Figure 3-3. This unit translates the L-band transmitter output (1800 MHz) to S-band (2214 MHz) and inserts signal dynamics on the modulation and carrier. The checkout transmitter code generator is used to replace the transponder transmitter code generator during test. Both the code generator and the translation multiplier are driven from the same 12.8 MHz VCO upon which signal dynamics may be inserted. The 2214 MHz signal can be gated ON to measure acquisition times. The output signal level is calibrated and may be lowered below receiver threshold.

3.2.2 VHF Transmitter Simulator

The VHF transmitter simulator consists of a manually operated digital message encoder and a VHF low power modulator/transmitter.



$f_{1A} = 1799.6 \text{ MHz}$
 $f_{1B} = 1800.0 \text{ MHz}$
 $f_{1C} = 1800.4 \text{ MHz}$
 $f_{1D} = 1800.8 \text{ MHz}$

FIGURE 3-3
TRANSPONDER 90 FREQUENCY TRANSLATOR

The digital message is formed by a set of toggle switches and is synchronized with the checkout code generator. The carrier frequency is synthesized from the 12.8 MHz VCO (paragraph 3.2.1) and, therefore, contains the correct Doppler in relation to the S-band frequency. The 138 MHz signal may be gated ON and OFF to measure acquisition. The output signal is calibrated and may be reduced below receiver threshold level. The message encoder is used to program the transponder through the various operational modes.

3.2.3 Time Delay Phase Measurement

A provision is made in the checkout equipment to measure the transponder transmitter/receiver turnaround time delay. The delay is read as a phase delay between the checkout equipment and transponder 6.4 MHz high speed code clocks. The measurement has a resolution of 1.22 nanoseconds. The reading includes the checkout equipment delay, so is a relative measurement, until the latter delay is subtracted.

3.2.4 Monitoring and Control Functions

1. Provision is made in the checkout equipment to monitor the L-band transmitter output power and spectrum by means of a power meter and spectrum analyzer.
2. The following indicators are provided to show transponder status:

STANDBY	Transponder	A _L
ON	has	A _H
TRACK	responded	REVERSE DOPPLER
T-0		TRUE DOPPLER
T-1A		DATA LOCK
T-2		
T-3		
T-1B		

3. The following status test points are provided.

Standby	Reverse Doppler	T-0
On	True Doppler	T-1A

Track	T-A _L	T-1B
Data <u>Lock</u>	T-A _H	T-2
T-L ₁₂₇	CAD	T-3

In addition, all transponder internal power voltages may be monitored at the front panel of the checkout equipment.

3.2.5 Transponder Checkout Equipment Characteristics

3.2.5.1 Transponder Control Drawer

1. Reference Generator

Oscillator Frequency:	12.8 MHz
Oscillator Sensitivity:	1 kHz/volt
Output Frequencies:	6.4 MHz
	12.8 MHz
	19.2 MHz
Mixer Input Frequency:	34.5 MHz
Mixer Output Frequency:	8.9 MHz
Output Levels:	-2 dbm $\pm$ 2 db
Output Impedances:	50 $\pm$ 10 ohms

2. VHF Circuitry

Oscillator Frequency:	34.5 MHz
VHF Synthesizer Loop Gain:	6000
Bandwidth:	$\beta_L = 100$ Hz
Data Frequency:	400 Hz
Subcarrier Frequency:	18.75 kc
Modulation Method:	PCM/PSK/PM
Modulation Index:	0.3 at 34.5 MHz
Modulation Output Level:	-2 dbm $\pm$ 2 db
Output Impedance:	50 $\pm$ 10 ohms

3. Channel VCO's

Oscillator Frequency -	
Channel A:	6.475 MHz
Channel B:	6.46875 MHz
Channel C:	6.4625 MHz
Channel D:	6.45625 MHz

Synthesizer Loop Gain:	4000
Synthesizer Loop Bandwidth:	10 Hz
Output Level:	-2 dbm ± 2 db
Output Impedance:	50 ± 10 ohms

4. Code Generator

Clock Frequencies -

Low Code:	6.25 kHz ($F_H/1022$)
High Code:	6.4 MHz (F_H)

Sequence Length -

Low Code:	127 bits
High Code:	511 bits

5. Delay Counter

Inputs:

T - F_{HS}
C/O - F_{HS}

C/O - F_H

Output:

Visual readout of seven-stage binary counter proportional to delay between T - F_{HS} and C/O - F_{HS} .

3.2.5.2 R-F Translator Drawer

1. VHF Circuitry

Input Frequency:	34.5 MHz
Input Level:	-2 dbm ± 2 db
Input Impedance:	50 ± 10 ohms
Input Modulation Index:	0.3
Output Frequency:	138 MHz
Output Level:	-55 to -155 dbm (carrier power)
Output Impedance:	50 ± 10 ohms
Output Modulation Index:	1.2

2. S-Band Circuitry

Input Frequencies

L-Band Carrier (A):	1799.6	MHz
(B):	1800.0	MHz
(C):	1800.4	MHz
(D):	1800.8	MHz

Multiplier Input (A):	6.475	MHz
(B):	6.46875	MHz
(C):	6.4625	MHz
(D):	6.45625	MHz

Output Frequencies

Multiplier Output (A):	414.4	MHz
(B):	414.0	MHz
(C):	413.6	MHz
(D):	413.2	MHz

S-Band Carrier:	2214	MHz
-----------------	------	-----

Signal Levels

L-Band Carrier with TWTAs:	+40 dbm ± 1 db
L-Band Carrier without TWTAs:	+10 dbm ± 3 db
Multiplier Input:	-2 dbm ± 2 db
Multiplier Output:	+10 dbm ± 3 dbm
S-Band Carrier:	-63 to -163 dbm
Impedance Level:	50 ± 10 ohms (all R-F signals)

3.3 AUXILIARY TEST FIXTURES

The following special test fixtures were necessary to supplement the checkout equipment in performance of the test evaluation program.

3.3.1 Status Indicators

When operating the transponders or the vehicle equipment without checkout equipment, it was necessary, during the test program, to still have an indication of equipment acquisition status. Therefore, four status indication assemblies were designed and

built (one for each transponder, and one for the vehicle equipment). These provide test points and visual indicators for:

Transponder:	T-0	A _L	Data Lock
	T-1A	A _H	Standby
	T-1B	Reverse Doppler	On
	T-2	True Doppler	Track
	T-3		
Vehicle:	V-0		
	V-1		
	V-2		
	V-3		
	V-4		
	A _L		
	A _H		

The status indicator assemblies operate on self-contained power supplies from the 115-volt, 60-Hz power line.

3.3.2 Wideband Frequency Synthesizer

In order to apply dynamics to the vehicle equipment to simulate Doppler during single channel test, it is necessary to substitute an external, controllable, wide bandwidth, 276 MHz synthesizer for the narrow bandwidth vehicle transmitter synthesizer. This fixture was designed and constructed in accordance with the block diagram of Figure 3-4. It utilizes the 12.8 MHz VCO of the transponder check-out equipment as the reference input. It may be driven, also, with the vehicle 12.8 MHz reference to simulate the zero velocity (zero Doppler) case.

3.3.3 19.2 MHz Reference Synthesizer for Doppler Reverse

In making single channel tests with Doppler on the vehicle VHF and S-band carriers, the transponder station would present its S-band signal such that it compensates for a return Doppler also. There being none in the laboratory, vehicle lock would be prohibited. This difficulty was circumvented by the implementation of the 19.2 MHz reference synthesizer which replaces the fixed 19.2

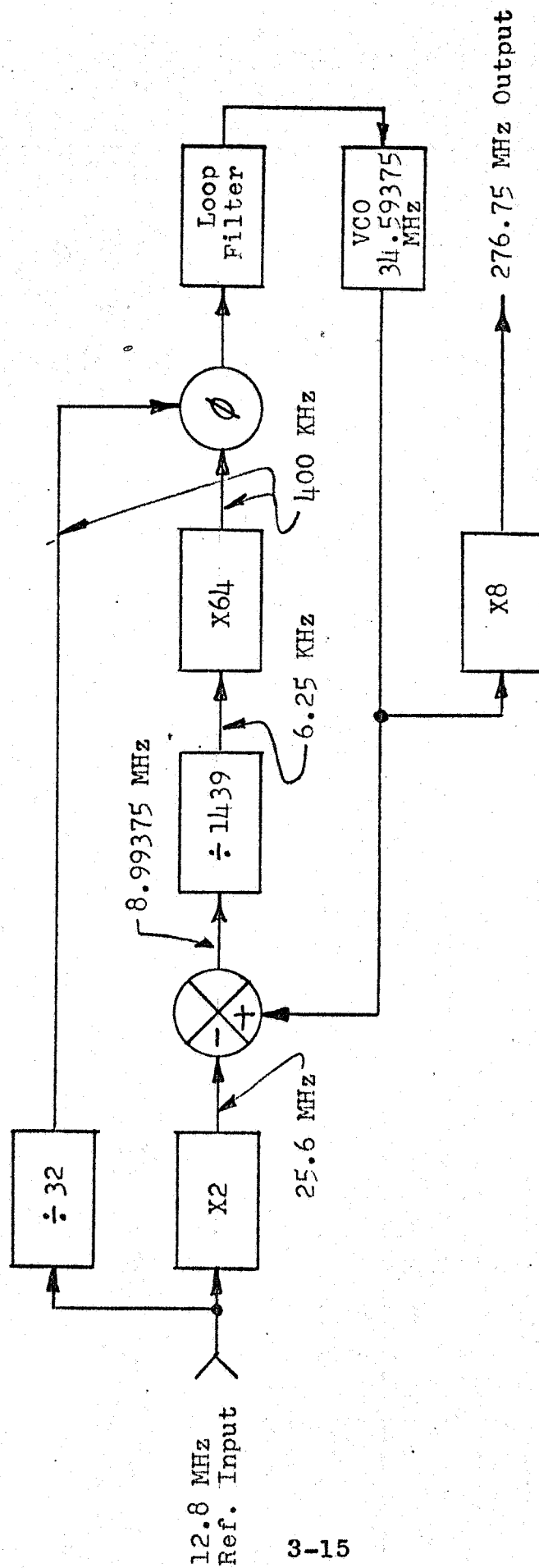


Figure 3-4. Wideband Frequency Synthesizer

MHz transponder reference frequency. The synthesized 19.2 MHz reference contains half Doppler so that, when fed into the transponder Doppler reverse circuitry, the transmitter Doppler is swept from zero Doppler to + Doppler instead of from - Doppler to + Doppler as in normal operation. A block diagram of this implementation is shown in Figure 3-5.

3.3.4 AROD Recorder Interface

Storage of the vehicle output data was made on magnetic tape, using a Precision Instrument Model PI-1177 Tape Recorder, along with the AROD Recorder Interface. The latter permitted direct storage of the AROD data output on tape for subsequent read-in to a digital computer for analysis. A complete frame of time related AROD data consists of ten 30-bit words. Four frames are read out in one second for a serial data rate of 1200 bits per second. The recorder provides a capability of 200 six-bit words plus parity, per second, which is equal to the AROD data rate. Each 30-bit AROD data word is divided into five six-bit words. A block diagram of the recorder interface is given in Figure 3-6.

3.3.4.1 Inputs

The only inputs to the recorder interface are the 30 AROD data lines and a "record" switch. The data lines are sampled at a 40 pps rate and stored in a buffer register. Timing of the "record" switch is synchronized so that data is printed until a given record is completed. Startup is synchronized to start at the beginning of a record.

3.3.4.2 Outputs

All outputs are synchronized from a 400 Hz, $\pm 0.1\%$, self-contained oscillator. The 400 Hz is divided down to provide internal timing, clock pulses to the tape recorder, AROD Reset TM (4 pps) to synchronize the AROD equipment, and a 40 Hz square wave to the AROD vehicle checkout equipment to permit simultaneous operation of the digital printer.

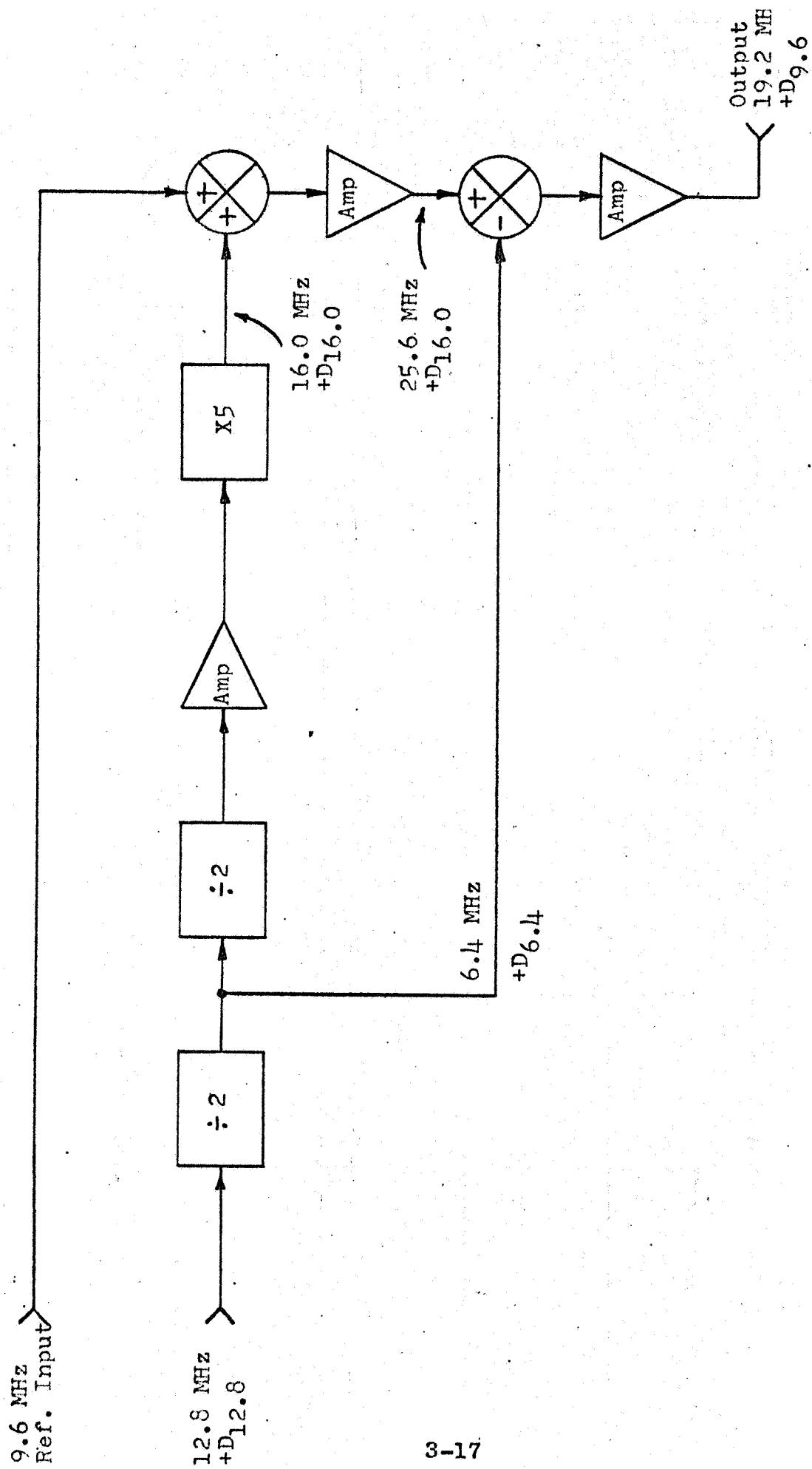


Figure 3-5. 19.2 MHz Reference Synthesizer

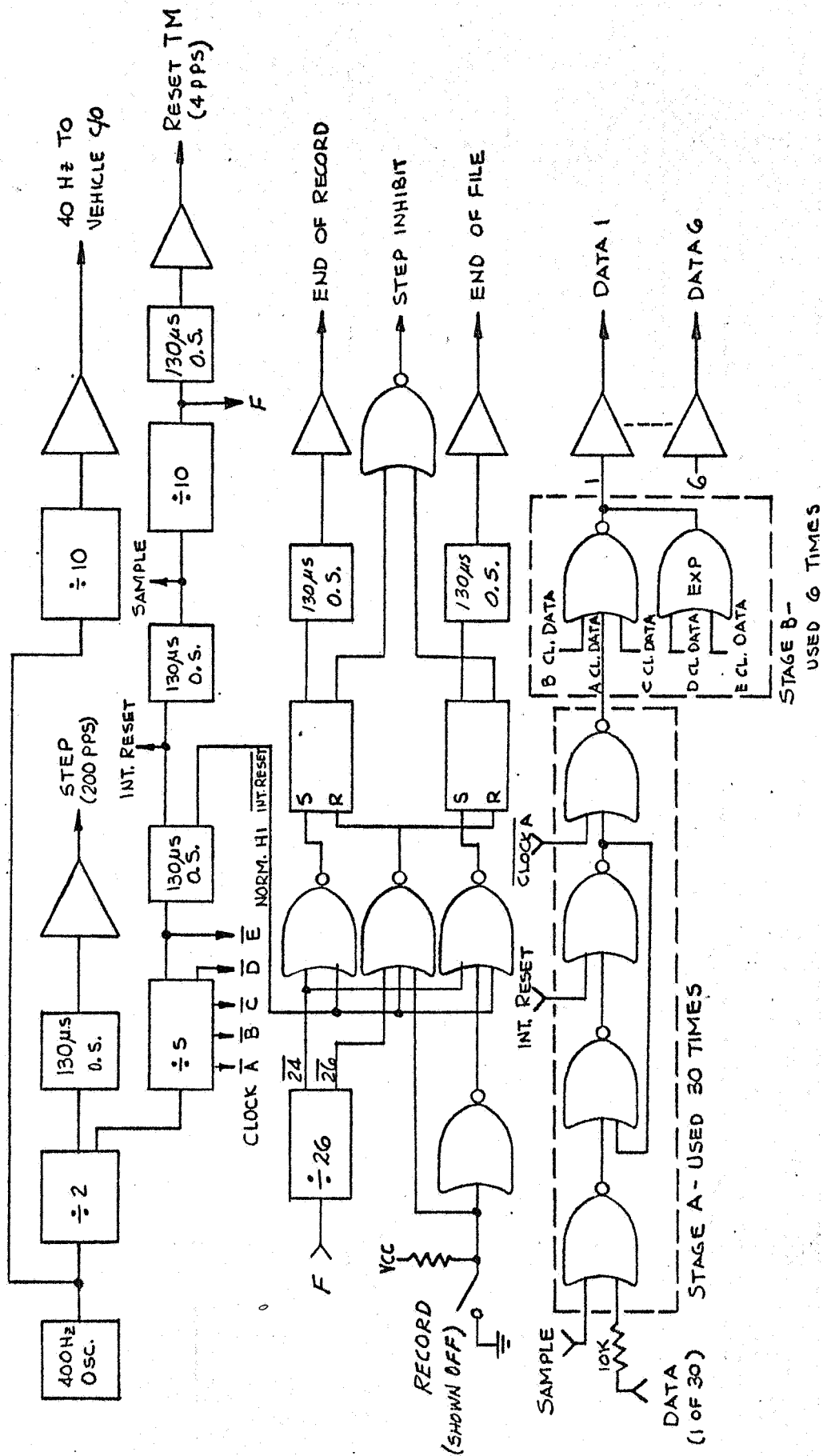


Figure 3-6. AROD Recorder Interface Block Diagram

Recorder output No. 1 will read out, in 5 millisecond intervals, AROD bits 1, 7, 13, 19, and 25 of each data word. The other bits are provided on outputs 2 through 6. Five sampling clocks are used to gate the data to each output. The step pulse (200 pps, 130 μ s wide) enables the recorder to write in the data during the center of the appropriate clock. After 24 complete AROD data frames (7200 data bits) have been recorded, an "end-of-record" signal of 1/2 second is generated. This interval allows the computer to process the data prior to insertion of the next data block. Timing is arranged to always start and stop with word "one".

3.3.5 Computer Data Reduction and Analysis

The data reduction and analysis is facilitated by two separate programs for the SDS 930 computer. Both programs are preceded by an unpacking and storage routine in which the ten 30-bit AROD data words are broken down into more usable data words and stored for further processing. Normally, about 800 samples of data are taken for computer analysis.

3.3.5.1 Standard AROD Data Reduction Program

The standard program provides a printout of the following data:

1. Real time
2. Velocity of each channel, in m/s
3. Range of each channel, in meters
4. Status bits 0 and 29 of both the range and velocity words.

The computer searches the data and marks velocity readings which differ from the first reading by more than three meters per second and range readings differing by more than 13 meters (13 km for L-code lock only) from the first reading. It then eliminates those readings and computes the mean, standard deviation, and probable error at 90 percent confidence level for both velocity and range. Samples of the computer printout showing 5 sec of data (for "Record Number 20") and the test summary sheet are given in Figures 3-7 and 3-8, respectively.

NO	CHANNEL TIME	A DATA VHF STATUS	VELOCITY	VELOCITY BITS 0+29	RANGE	RANGE BITS 0+29	CHANNEL STATUS	STATION ID
1	184.63256	5	.103	3	98.99	3		20
1	184.89621	5	-.026	3	99.18	3		20
1	185.13957	5	-.205	3	99.18	3		20
1	185.40321	5	-.051	3	99.18	3		20
1	185.64658	5	.000	3	99.54	3		20
1	185.88994	5	-.077	3	98.99	3		20
1	186.15358	5	-.051	3	99.72	3		20
1	186.39695	5	.128	3	98.81	3		20
1	186.64031	5	-.128	3	99.54	3		20
1	186.90396	5	-.026	3	98.81	3		20
1	187.14732	5	.128	3	99.36	3		20
1	187.39068	5	-.103	3	98.99	3		20
1	187.65433	5	-.103	3	99.72	3		20
1	187.89769	5	.103	3	98.99	3		20

RECORD NUMBER 20

NO	CHANNEL TIME	A DATA VHF STATUS	VELOCITY	VELOCITY BITS 0+29	RANGE	RANGE BITS 0+29	CHANNEL STATUS	STATION ID
1	188.64806	5	.000	3	98.99	3		20
1	188.89143	5	-.103	3	99.36	3		20
1	189.15507	5	-.077	3	99.18	3		20
1	189.39843	5	.154	3	99.36	3		20
1	189.64180	5	-.051	3	98.99	3		20
1	189.90544	5	-.026	3	99.36	3		20
1	190.14881	5	.026	3	99.18	3		20
1	190.39217	5	-.103	3	99.54	3		20
1	190.65581	5	-.051	3	98.81	3		20
1	190.89918	5	.051	3	99.72	3		20
1	191.14254	5	.000	3	98.81	3		20
1	191.40619	5	-.077	3	99.36	3		20
1	191.64955	2	.051	3	98.99	3		20
1	191.89291	5	-.026	3	99.18	3		20
1	192.15656	5	-.128	3	98.99	3		20
1	192.39992	5	.077	3	98.99	3		20
1	192.66357	5	.051	3	98.99	3		20
1	192.90693	5	-.026	3	98.99	3		20
1	193.15029	5	.000	3	99.36	3		20
1	193.41394	5	.103	3	98.81	3		20
1	193.65730	5	-.077	3	99.54	3		20

FIGURE 3-7
COMPUTER TEST DATA PRINTOUT

SUMMARY DATA FOR TEST NUMBER 2

THERE WERE 0 SAMPLES WITH BITS 0 AND 29 MISSING, CHANNEL A
 THERE WERE 0 SAMPLES WITH BIT 0 MISSING, CHANNEL A
 THERE WERE 0 SAMPLES WITH BIT 29 MISSING, CHANNEL A
 TOTAL NUMBER OF SAMPLES 672 CHANNEL A
 NUMBER OF REJECTED RANGE SAMPLES 2
 NUMBER OF REJECTED VELOCITY SAMPLES 0

	VELOCITY	RANGE
MEAN	.002	99.20
STD. DEVIATION	.079	.28
CONF. INDEX	.00501	.01788

AEENDJOB.

FIGURE 3-8
 COMPUTER PRINTOUT
 RANGE AND VELOCITY COMPUTATIONS

3.3.5.2 Correlation Program

In order to correlate data variations to other events, a program was written which permits computations of auto-correlation and cross-correlation between paired sets of data. This permits observing such effects as a cyclic range variation caused by the H-code search circuitry in the vehicle equipment.

3.3.6 S-Band Bit Error Detector

In order to determine the bit error rate of the S-band data link, a single bit error detector and counter was constructed. It compares the original data from the vehicle equipment to the reconstructed data at the transponder and indicates any errors of a five-stage binary counter. The counter is supplied an input from A_L such that A_L lock is required before counting can occur.

3.3.7 Cable Interconnection System

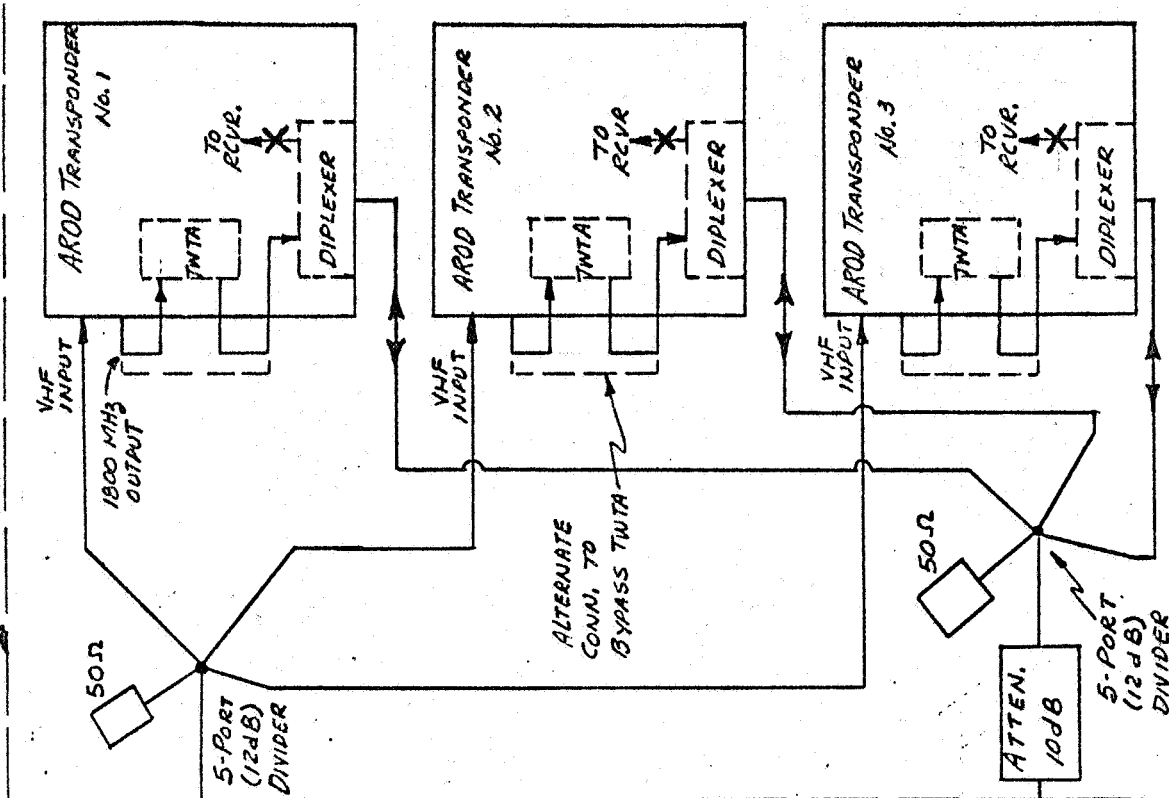
For the purposes of the tests, the AROD equipments were set up as shown in Figure 3-9. Path losses were calibrated and system delays were measured with this configuration. The system permits a wide latitude in signal level settings from below threshold to above -80 dbm. System delays (in meters) are shown in Table III-1. In addition, attenuators to independently control the input signal levels to the individual transponders were added between the diplexer and the receiver, when required by the test.

3.4 MEASUREMENT ACCURACY

3.4.1 Signal Levels

At all points in the system, signal levels were known to an absolute accuracy within ± 1 db. This was possible through careful initial calibration and frequency checks for drift following initial calibration. S-band signal levels could be adjusted to approximately ± 0.5 db, while the VHF signal level was adjustable in ± 1.0 db increments.

SHIELDED ENCLOSURE



X - Attenuators to Control transponder sig. levels independently are inserted here.

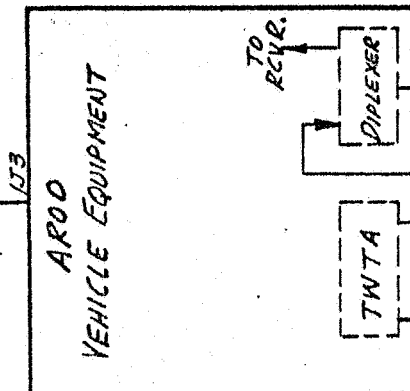
+28V

COAX RELAY (NIC)

ATTEN 0-73dB

ATTEN. 30dB 15W

VHF OUTPUT



Dir. Coupl

ATTEN. 20-120dB

FIGURE 3-9 CABLE INTERCONNECTION SYSTEM

TABLE III-1. AROD Test Setup System Delays

System Component	Delay, Meters	
	Without TWTA	With TWTA
Vehicle, Chan A	50.34	53.81
Vehicle, Chan B	50.94	54.50
Vehicle, Chan C	51.17	54.69
Vehicle, Chan D	51.13	54.95
Cable, to XPDR #1	36.98	36.32
Cable, to XPDR #2	37.02	36.32
Cable, to XPDR #3	37.43	36.72
System, with XPDR #1	90.51	94.32
System, with XPDR #2	89.07	93.73
System, with XPDR #3	90.30	95.24
Transponder No. 1	2.59	3.50
Transponder No. 2	1.11	2.91
Transponder No. 3	1.94	4.02

3.4.2 System Delays

With initial calibration and measurement each drift test interval, system range delays were known within approximately ± 0.25 meter. The various delays shown in Table III-1 are mean delays having standard deviations which range between 0.17 and 0.31 meter.

SECTION IV

4. INITIAL TESTS

4.1 OPERATIONAL CHECKS

The first stage of tests was conducted with the equipments connected to their respective checkout equipments. While most operational characteristics were normal (the equipments had passed acceptance testing) some deficiencies were uncovered. These included problems in data readout, local oscillator spurs, improper threshold adjustments, etc. After adjustments were made and satisfactory operation achieved with the checkout equipment, a complete system hookup was made using one or more transponders and one transponder simulator (vehicle checkout). With this arrangement the vehicle could lock to the simulator channel, freezing the memory program, and thereby permit a wide range of operating latitude with the three transponders. Tests proving acquisition sequence correct and dropout, acquisition, and tracking characteristics were investigated.

4.2 THRESHOLDS

The various thresholds were measured after final corrections and/or adjustments had been made. These measurements are felt to be within ± 1.0 db and are somewhat different than those reported in paragraph 2.1.3. These differences are attributed to the following:

1. More precise signal level calibration
2. More precise adjustments of equipment circuitry
3. A redefinition (in the case of the transponder L-code) of acquisition threshold.

Tables IV-1 and IV-2 list the thresholds measured during initial tests. The readings show a general increase over those given in Tables II-3 and II-4. The approximate 5 db increase in transponder

TABLE IV-1. Vehicle Equipment Thresholds (Initial Tests)*

Channel	L-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Acquisition Threshold	H-Code Tracking Threshold
A	-129 dbm	-133 dbm	-127 dbm	-129 dbm
B	-128.5 dbm	-133 dbm	-127 dbm	-130 dbm
C	-130.5 dbm	-133 dbm	-126 dbm	-128 dbm
D	-129 dbm	-132 dbm	-126 dbm	-128 dbm

TABLE IV-2. Transponder Equipment Thresholds (Initial Tests)*

Transponder	L-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Acquisition Threshold	H-Code Tracking Threshold
No. 1	-134 dbm	-136 dbm	-126 dbm	-127 dbm
No. 2	-133 dbm	-135 dbm	-126 dbm	-129 dbm
No. 3	-133 dbm	-135 dbm	-126 dbm	-128 dbm
Transponder	VHF Receiver Acquisition Threshold		VHF Receiver Tracking Threshold	
No. 1	-126 dbm		-129 dbm	
No. 2	-126 dbm		-129 dbm	
No. 3	-126.5 dbm		-130 dbm	

*See final data in Table VIII-1, Page 8-2.

L-code thresholds is due primarily to a redefinition of threshold as that point where L-code just acquires, but H-code does not ever acquire. There is a narrow range of signal levels (around -130 dbm) where H-code tries to acquire, and upon dropping out, causes the transponder to also drop L-code. The minimum reading was used to define L-code to better observe drift and aging characteristics.

4.3 ACQUISITION TESTS WITH JAMMING

Tests were conducted to determine system acquisition characteristics, and to show any range and range rate data degradation which might occur, when adjacent channel(s) were occupied.

4.3.1 Multichannel Acquisition

This test was designed to simulate the automatic acquisition sequence. A program was loaded into the vehicle memory which allowed the transponders to be sequentially dropped from one vehicle receiver channel and reacquired in another channel. In this manner each transponder was acquired in each receiver channel. The test was performed satisfactorily.

4.3.2 Acquisition Margin for Co-Channel Jamming Signals

These tests measured the maximum co-channel jamming margin of each vehicle receiver for each acquisition phase. In the first series of tests, the vehicle checkout equipment was used to provide the jamming signal. The jamming signal was held at a level of -75 dbm (a very strong signal) with a Doppler representing approximately 120 m/s velocity. With this signal acquired on one channel, the other three channels were measured, using the other checkout equipment simulator, for V-2, and V-4 acquisition, and V-2 and V-4 dropout. The data obtained are summarized in Figures 4-1 (H-code jamming) and 4-2 (L-code jamming). These data indicate that the actual performance is an average of 6 db from that predicted from previous calculations. These calculations indicated a 34 db jamming margin, L-code to L-code and 32 db jamming margin for H-code to H-code. With L-code jamming and H-code acquisition, or vice versa, the jamming margin was calculated to be 29 db. Channels B and D were somewhat more susceptible to adjacent channel interference than channels A and C, but performed about average for two-channel separation. All channels appear to be adequate for field operation in regard to adjacent channel jamming; however, a two or three db improvement would be desirable.

4.3.3 Multichannel Jamming Tests

Multichannel jamming tests were performed on each channel while all of the remaining three channels were acquired (in V-4) at a strong signal level (approximately -90 dbm each). Jamming signals were supplied by two transponders and one checkout channel, with

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL A

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
B	27	22	33	29
C	35	21	37	30
D	39	24	41	29

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL B

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	31	24	34	31
C	30	26	34	30
D	35	26	40	32

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL C

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	27	27	>34	29
B	26	23	33	28
D	31	21	34	28

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL D

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	>34	30	>34	32
B	30	20	>34	31
C	26	24	32	29

Figure 4-1. Jamming Margin for Two-Channel Operation
Jamming Signal Acquired in State V-4.

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL A

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
B	26	26	29	28
C	42	30	43	32
D	44	28	48	32

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL B

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	24	26	30	31
C	28	24	32	27
D	38	25	43	32

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL C

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	>34	31	>34	34
B	25	27	30	30
D	27	27	31	32

JAMMING MARGIN (db)
WITH STRONG SIGNAL
ON CHANNEL D

Test Chan.	V-2ACQ	V-4ACQ	V-2DROP	V-4DROP
A	>34	27	>34	29
B	>34	27	>34	31
C	26	26	32	32

Figure 4-2. Jamming Margin for Two-Channel Operation
Jamming Signal Acquired in State V-2.

Doppler representing 120 m/s velocity. The test channel was supplied by the second checkout simulator. The data obtained are presented in Figure 4-3. As expected, the jamming margins measured during these tests are less than obtained in the two-channel tests. The results are quite uniform, ranging between 20 and 25 db for L-code acquisition and between 20 and 23 db for H-code acquisition.

	Test Channel			
	A	B	C	D
V-2 ACQ	20	22	25	20.5
V-4 ACQ	20	21	23	20
V-2 DROP	22	24	28	23
V-4 DROP	22	26	27	25

Figure 4-3. Four-Channel Jamming Threshold (db)

It can be noted that all acquisition and drop thresholds measured in the jamming tests show deterioration from the single channel noise thresholds. The highest pair, channel D, acquired in V-2 with a 44 db difference, with a -75 dbm, V-2 jamming signal on channel A. This is -119 dbm, compared to the single channel L-code acquisition threshold for channel D of -129 dbm given in Table IV-1.

SECTION V

5. SINGLE CHANNEL TESTS

An extensive amount of data was taken under single channel system tests concerning acquisition thresholds, acquisition times, range and velocity readouts, and tracking characteristics. These data were obtained under various conditions of signal level and Doppler. Figure 5-1 shows the basic interconnection diagram used in making the single-channel tests.

5.1 THRESHOLD MEASUREMENTS

During single-channel tests both acquisition and tracking thresholds were measured on each transponder, and on each of the four vehicle receiver channels.

5.1.1 Transponder Thresholds

Transponder thresholds were determined by attenuating the signal going to the transponder S-band receiver and measuring the signal level at the receiver antenna terminal. Threshold was defined as the minimum signal at which the transponder would reliably acquire L-code or H-code. Tracking thresholds are defined as the minimum signal levels at which L-code or H-code lock can be maintained. These tests are presented in Table V-1. These data compare favorably with data taken earlier during Initial Tests using the checkout equipment.

5.1.2 Vehicle Equipment Thresholds

The vehicle acquisition thresholds were likewise determined by attenuating the S-band signal from the transponder to the lowest level at which the vehicle would attain state V-4. Tests were repeated with each transponder, for each vehicle receiver channel. The results of these tests are presented in Table V-2. These data are within about 1 db of earlier data taken during Initial Tests using the checkout equipment.

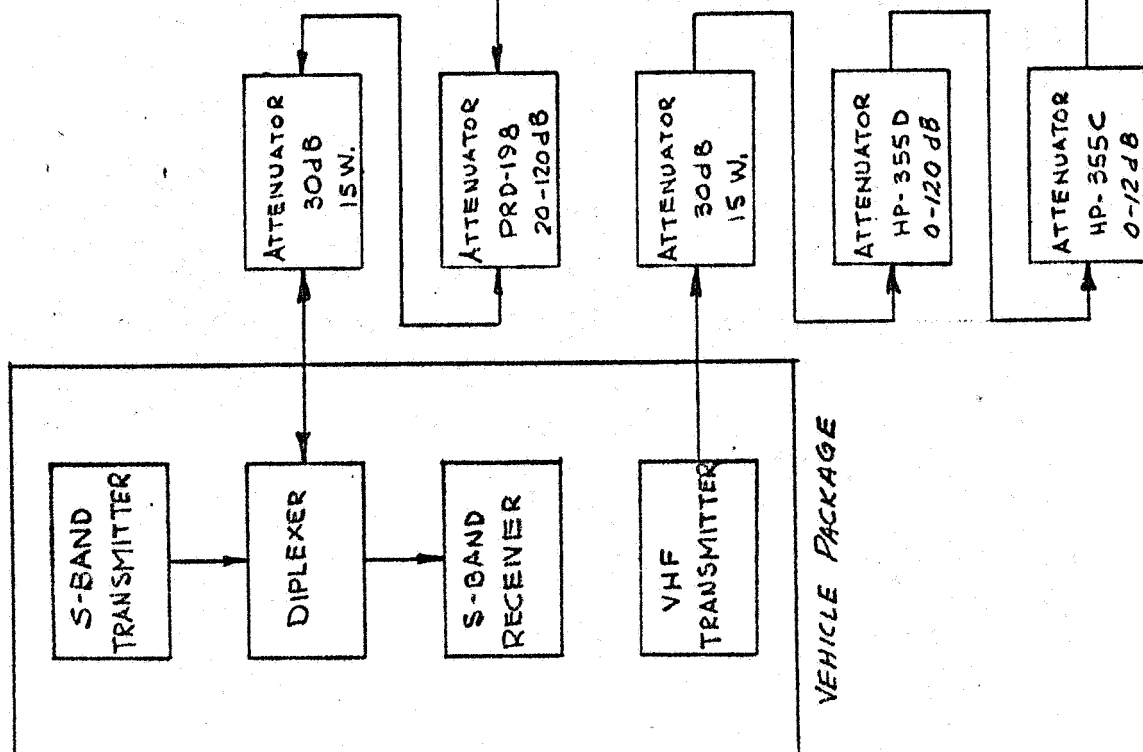
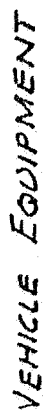
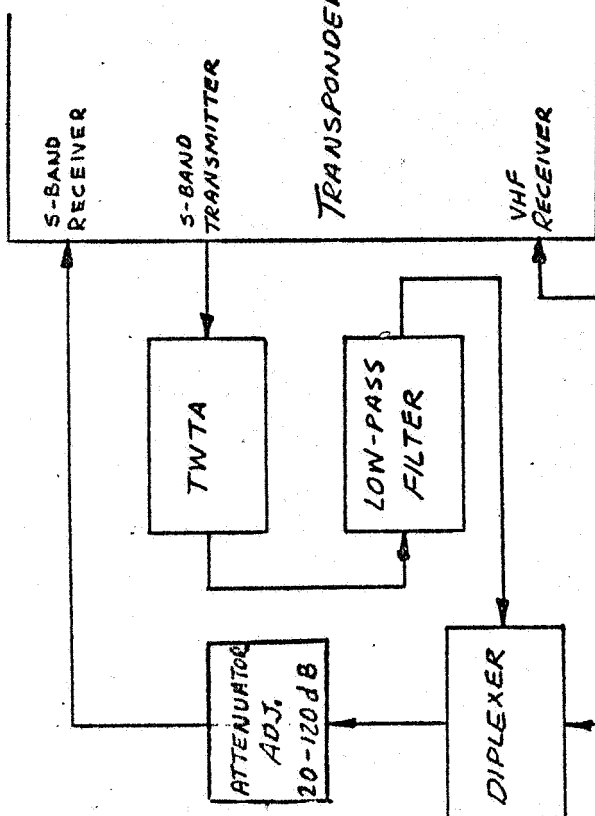
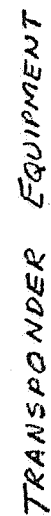


FIGURE 5-1
SINGLE CHANNEL TESTS
BASIC BLOCK DIAGRAM

TABLE V-1
Transponder Thresholds

Transponder	L-Code Threshold		H-Code Threshold	
	Acquisition	Tracking	Acquisition	Tracking
1	-131 dbm	-132 dbm	-126 dbm	-128 dbm
2	-130 dbm	-132 dbm	-125 dbm	-127 dbm
3	-130 dbm	-133 dbm	-125 dbm	-127 dbm

TABLE V-2
Vehicle Acquisition Thresholds

Transponder	Vehicle Receiver			
	Chan A	Chan B	Chan C	Chan D
1	-126.5 dbm	-127.5 dbm	-125 dbm	-126 dbm
2	-126 dbm	-127 dbm	-125 dbm	-126 dbm
3	-125.5 dbm	-126 dbm	-125 dbm	-125.5 dbm

*See Final Data in Table VIII-1, Page 8-2.

5.2 ACQUISITION TIME

The system acquisition time, being that time interval between the ON command at the transponder and the V-4 state in the vehicle was measured using Transponders No. 2 and 3 and channels A and B vehicle receivers. Data was taken as a function of signal level and Doppler.

5.2.1 Acquisition Time in the AROD System

The AROD System acquisition time can be broken down into the following theoretical values:

1. L-code search
20 ms per bit x 127 bits
(Due to short range during tests)
2. ID Comparison time
3. Doppler Sweep (40 kHz/sec)*
4. De-Code DRC
5. H-code search

Time, Sec.		
MIN	NOM	MAX
	2.54	
0.20	0.30	0.40
0.25		1.80
0.20	0.30	0.40
0.00	0.125	0.250

Total Acquisition time at Max. Doppler 5.175 sec nominal, 5.81 sec. Max., 4.78 sec. Min.

For zero Doppler, the total acquisition time should be 1.55 sec. (1.80 - 0.25) less than that at maximum Doppler or 3.63 sec. nominal, 4.26 sec. max., and 3.23 sec. minimum.

5.2.2 Test Data

The test data obtained is presented in tabular form in Table V-3. Separate readings were taken to show L-code search (state V-2 in vehicle) as it is the largest single contributor to acquisition time. Each number given in Table V-3 is the average of nine readings.

*Maximum Doppler is taken as 70 kHz at the 1800 MHz transmission frequency. This represents a velocity of approximately 12,000 m/s

TABLE V-3

Signal Level	Acquisition Time, Sec.					
	-80 dbm		-100 dbm		-119 dbm	
	L-Code	H-Code	L-Code	H-Code	L-Code	H-Code
0 Doppler	2.38	3.78	2.52	3.81	2.56	4.68
+ Doppler	2.29	4.97	2.24	5.41	2.55	8.01
- Doppler	2.29	5.27	2.74	5.94	2.56	7.51

Due to the manner in which measurements were taken, a time error of about 0.3 second was fairly consistently made. After sending the "Return to T-0" signal, the vehicle equipment goes to V-1 for L-code search. Starting at maximum range, it searches toward zero range. As our operating range is near zero, nearly the full code must be searched, approaching 2.54 seconds. To start the time count, the transponder ID was manually switched to the correct ID after observing the vehicle going from V-0 to V-1 state. This brought a human delay into the readings. The ON command decoding delay of somewhat less than 0.1 second was also neglected as the ON signal at the transponder provided the START of the measurement interval. All L-code acquisition readings should be approximately 2.54 seconds. Most readings in Table V-3 show somewhat less, for the reasons stated above. One reading, - Doppler at -100 dbm, turned out high -- 2.74 seconds. This was due to one high reading of 6.72 seconds caused by some difficulty in transponder acquisition which resulted in a second search cycle. Without this reading the average time would have been in line with the other averages.

The high readings on H-code acquisition at -110 dbm were due primarily to a difficulty of transponder to acquire, resulting in one or two very high readings. For instance, at + Doppler and -119 dbm, seven of the nine readings were between 5.76 and 7.51 seconds with an average of about 6.5 seconds.

5.3 RANGE AND VELOCITY MEASUREMENTS

Range and velocity data versus signal strength were recorded using the magnetic tape recorder and recorder interface. Thirty seconds of data (120 readings) from the vehicle data readout were taken at each test condition: from -70 dbm to threshold signal levels and with zero, plus, and minus Doppler. The computer was programmed to compute and print out mean range and velocity along with standard deviations and 90 percent confidence interval. For the velocity measurements, the vehicle equipment was set up to use with wideband synthesizer (para. 3.3.2) in place of the vehicle XN synthesizer loop and used an external wideband synthesizer loop as a substitute for the vehicle local oscillator. In addition, the standard velocity extractor for channel A was removed and a substitute breadboard unit was installed. All channels were measured using the breadboard channel A extractor. These substitutions provided velocity measurements having a minimum "jitter" or standard deviation, and an acceptably low mean error. See discussion on problems of velocity data in Appendix A-2 of this report.

5.3.1 Transponder Tests

The transponders were tested by attenuating the signals to the transponders. The tests used vehicle channel B receiver with signal level held constant at -80 dbm.

5.3.1.1 Range Delay Data

Range data was taken at the three conditions of Doppler -- zero, plus, and minus. The latter two were set to represent a velocity of 12,000 m/s. The data obtained are presented in Table V-4, and are plotted against signal level in Figure 5-2. The curves show that the range data are well within the design goal of ± 0.5 meter for all velocities, except at signal levels below about 115 dbm.

The vertical displacement between zero Doppler and maximum Doppler curves represents the error due to the range readout clock (6.4 MHz) being 512 Hz off center frequency. This error

TABLE V-4

Transponder Range Delay Versus Signal Level
and Doppler Condition. Doppler = ± 512 Hz @ 12 MHz (12,000 M/S)
Using Vehicle Channel B @ -80 dbm

TRANSPONDER	DOPPLER	SIGNAL LEVEL, Dbm											
		-70		-90		-110		-120		-125			
		R	T	R	T	R	T	R	T	R	T	R	T
1 FILE #18	-	89.22	0.18	89.18	0.18	89.09	0.35	88.02	1.03	87.46	1.34	1.76	
	0	89.01	0.18	89.00	0.20	88.78	0.29	87.68	0.66	86.61	1.26	2.40	
	+	89.17	0.19	89.13	0.17	88.97	0.28	87.99	0.93	86.92	1.38	2.25	
2 FILE #27	-	88.66	0.17	88.65	0.18	88.80	0.52	89.14	1.66	90.52	2.87	1.86	
	0	88.55	0.19	88.51	0.18	88.51	0.26	88.80	0.56	89.08	1.05	0.53	
	+	88.47	1.04 *	88.32	0.18	88.44	0.45	88.44	1.71	88.38	2.68	0.15	
3 FILE #19	-	89.28	0.19	89.20	0.22	89.13	0.29	89.01	0.88	89.23	1.31	0.27	
	0	89.06	0.17	89.00	0.18	89.05	0.25	88.22	0.72	88.06	1.15	1.00	
	+	88.97	0.17	88.91	0.17	89.15	0.26	89.81	0.85	88.67	1.39	1.14	

* LOST LOCK MOMENTARILY

TRANSPONDER RANGE DELAY

VARIATION WITH SIGNAL LEVEL
AND DOPPLER CONDITION

DOPPLER = $\pm 512 \text{ Hz}$ @ 12.8 MHz ($12,000 \text{ m/s}$)

VEHICLE CHAN. B @ -80 dBm

—○— = ZERO DOPPLER

—□— = MAX NEGATIVE DOPPLER

—◇— = MAX POSITIVE DOPPLER

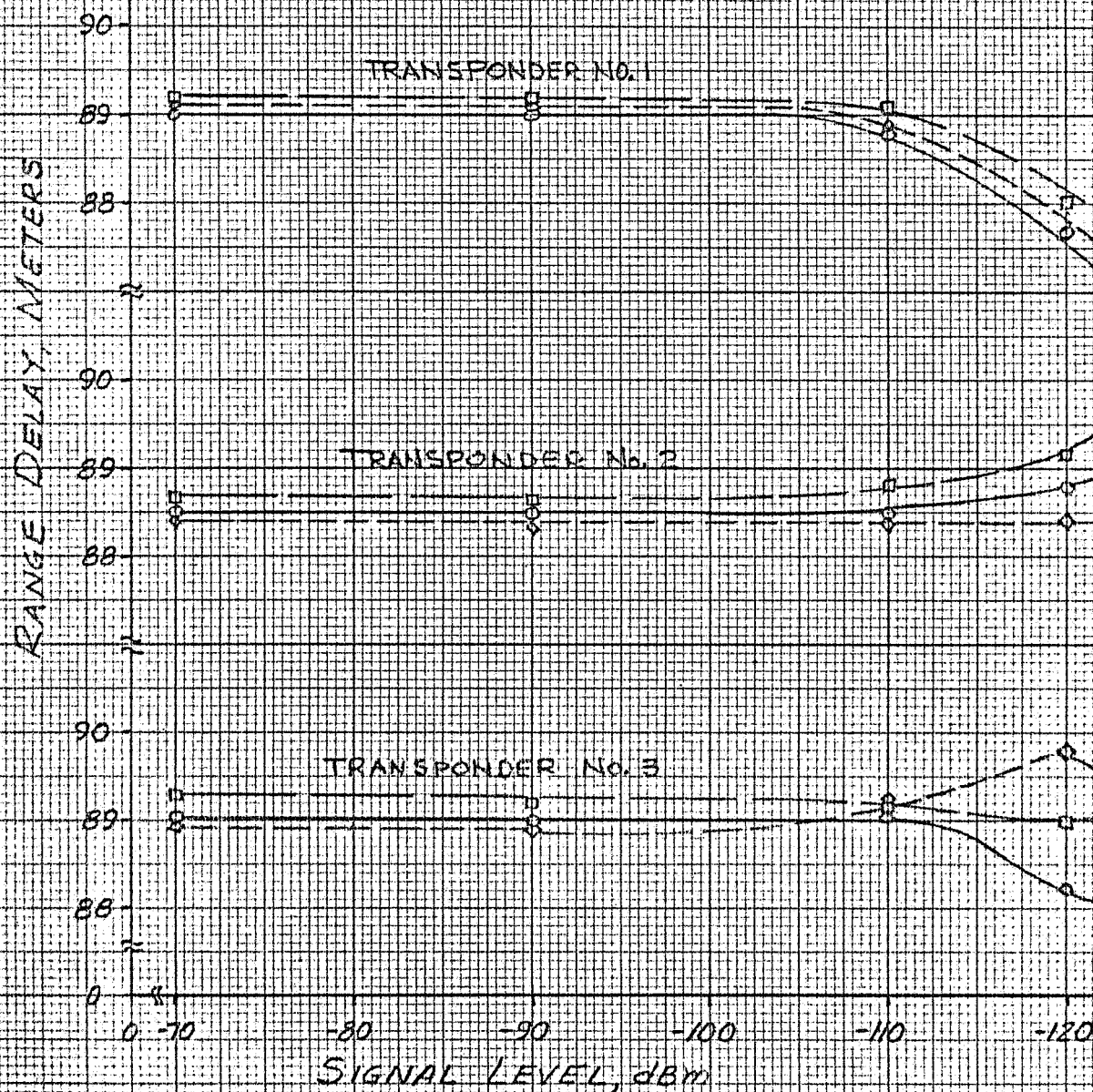


FIGURE 5-2

was predicted to be 0.234 meter. All curves shown in this section demonstrate this effect. The apparent increase of this error at low signal levels is due to the increased standard deviation. If the number of range delay samples were increased, that is, if more data were taken at a given point, this spread should reduce to the same error shown at lower signal levels.

The range delay error increases at lower signal levels are caused by coherent leakage of the reference signals into the range loop. This low-level leakage only takes effect at or near threshold. Depending on the phase of the leakage, the range delay curve may break either up or down.

5.3.1.2 Velocity Data

The velocity data was taken under conditions of zero Doppler only (velocity = 0) and is presented in Table V-5. The data is plotted to show both the mean and standard deviation in Figure 5-3. The standard deviation provides a measure of the velocity "jitter" which is discussed in detail in Appendix A-2.

Figure 5-3 indicates an rms "jitter" of about two counts of velocity readout. The one high point on Transponder No. 3 at -120 dbm was due to several very bad readings which may have been caused by a short dropout. This point would normally be equal to or less than the -123 dbm point.

The plot of the mean shows that all points are well within the design goal of 0.015 meter, except the last point of Transponder No. 2. The 90 percent confidence interval at this point, however, is 0.0128 which indicates that there is a 90% probability of this point being less than 0.0128 meter.

5.3.2 Vehicle Tests

The vehicle channels were tested by attenuating the signals to the vehicle equipment while maintaining a constant signal at the transponder receiver. Transponder No. 2 was used for the velocity tests and No.'s 1 and 3 for the range data.

TABLE V-5

Transponder Velocity Data Versus Signal Level

Zero Velocity (0 Doppler) Condition

Using Vehicle Channel B @ -80 dbm

SIGNAL LEVEL D _{bm}	-70	-80	-90	-100	-110	-120	-123
TRANSPONDER	V	V	V	V	V	V	V
	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$	$\frac{\sigma_V}{C.I.}$
1	$\frac{.039}{.005}$	$\frac{.048}{.005}$	$\frac{.041}{.004}$	$\frac{.038}{.007}$	$\frac{.047}{.001}$	$\frac{.050}{.004}$	$\frac{.058}{.009}$
	$\frac{.0058}{.0058}$	$\frac{.0073}{.0073}$	$\frac{.0062}{.0062}$	$\frac{.0058}{.0058}$	$\frac{.0070}{.0070}$	$\frac{.0075}{.0075}$	$\frac{.0088}{.0088}$
2	$\frac{.061}{.000}$	$\frac{.062}{.008}$	$\frac{.070}{.008}$	$\frac{.056}{.010}$	$\frac{.055}{.000}$	$\frac{.066}{.003}$	$\frac{.085}{.017}$
	$\frac{.0092}{.0092}$	$\frac{.0093}{.0093}$	$\frac{.0118}{.0118}$	$\frac{.0084}{.0084}$	$\frac{.0083}{.0083}$	$\frac{.0099}{.0099}$	$\frac{.0128}{.0128}$
3	$\frac{.045}{.004}$	$\frac{.051}{.009}$	$\frac{.046}{.002}$	$\frac{.044}{.005}$	$\frac{.049}{.006}$	$\frac{.083}{.002}$	$\frac{.051}{.003}$
	$\frac{.0068}{.0068}$	$\frac{.0076}{.0076}$	$\frac{.0068}{.0068}$	$\frac{.0066}{.0066}$	$\frac{.0074}{.0074}$	$\frac{.0124}{.0124}$	$\frac{.0085}{.0085}$

GEN. DIE. CO.
MADE IN U.S.A.
PH P
20 X 20 PER INCH
NO

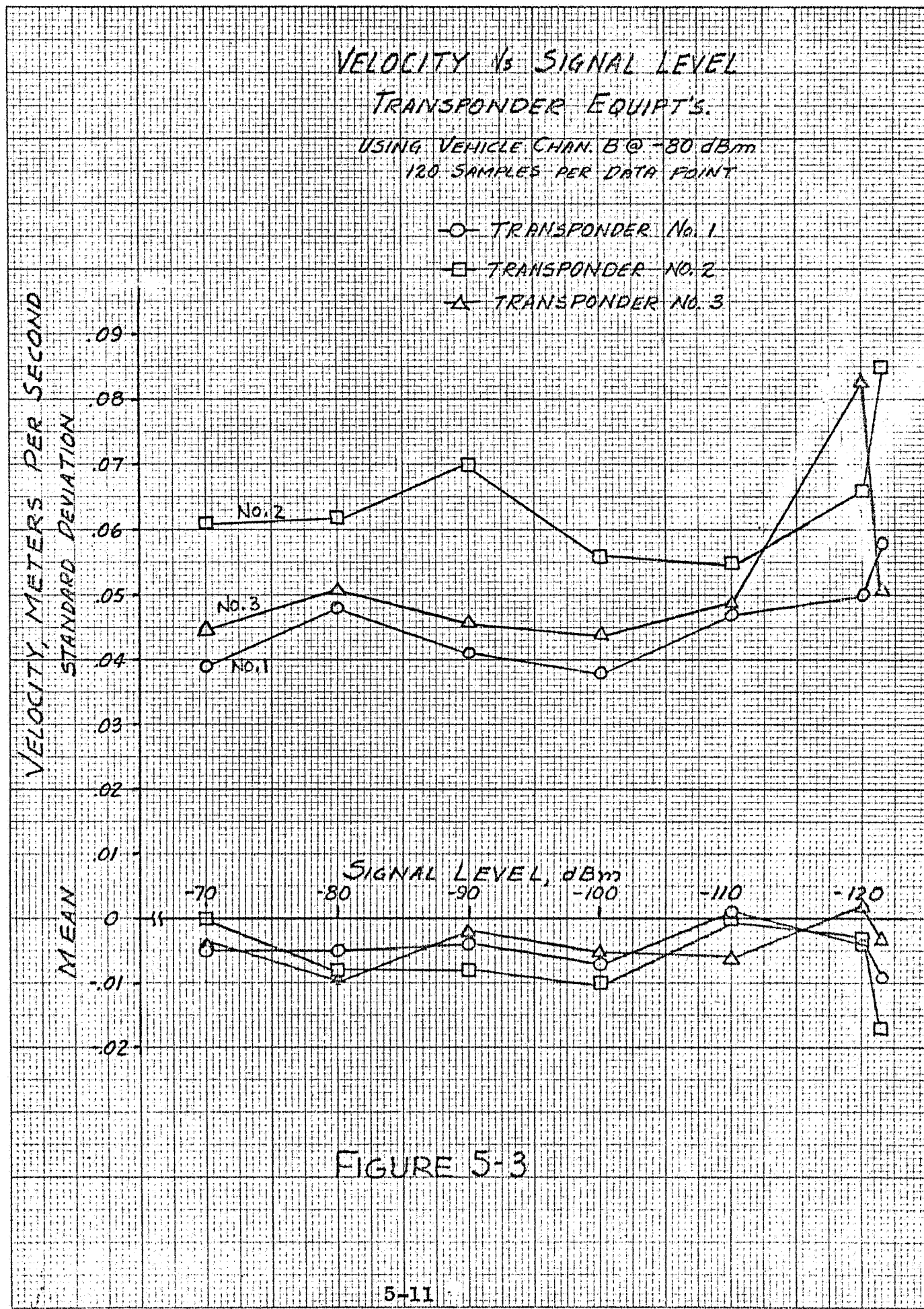


FIGURE 5-3

5.3.2.1 Range Delay Data

Range data was recorded at three conditions of Doppler -- zero, positive, and negative. The latter were taken with ± 512 Hz at 12.8 MHz, representing approximately 12,000 meters per second velocity. In addition, readings were made at signal levels from -70 dbm to threshold, about -125 dbm. These data are presented in summarized form in Tables V-6 and V-7 and are plotted in Figures 5-4 and 5-5. The data in all plots fall generally within the design goal of ± 0.5 meter with the exception of readings taken near threshold where coherent leakage contributes a noticeable effect. Channels B and D are appreciably better in this respect.

5.3.2.2 Velocity Data

The velocity data was taken at the zero velocity condition at signal levels from -70 dbm to -120 dbm. The data is summarized in Table V-8 and is plotted in Figure 5-6 to show both standard deviation and computed mean. The standard deviations follow very closely the curve of Transponder No. 2 given in Figure 5-3. There is little significant difference between the four channels. The mean shows that all measured points are within the design goal of 0.015 meter/second.

5.3.3 System Tests

These tests were conducted by attenuating the signal in both directions such that the received signal at each terminal was equal. Measurements were made at signal levels between -70 dbm and threshold and were made at zero Doppler condition only.

Range delay was measured using vehicle channel B receiver with each of the transponders. The data is summarized in Table V-9 and is plotted in Figure 5-7. These curves turn out to be simply a composite of Figures 5-2 and 5-4/5-5. Since the characteristic of channel B (Figure 5-4/5-5) breaks down at low signal level, the operation with transponders 1 and 3 which are also down-breaking (Figure 5-2) results in a composite which is down-breaking.

TABLE V-6
SINGLE CHANNEL TEST, PARA. 4.2 (ATTENUATING SIGNAL TO VEHICLE)
XPWR #1, @ REV. = -82Dbm
DOPPLER = 512 Hz @ 12.8 MHz
FILE #22

CHANNEL	DOPPLER	RANGE, METERS																							
		-70 Dbm			-80 Dbm			-90 Dbm			-100 Dbm			-110 Dbm			-120 Dbm			-126 Dbm			Δ		
		R	T	C.F.	R	T	C.F.	R	T	C.F.	R	T	C.F.	R	T	C.F.	R	T	C.F.	R	T	C.F.			
A	-	89.13	0.25	.037	88.71	0.27	.041	88.62	0.28	.047	88.58	0.31	.047	88.54	.43	.065	87.57	1.07	0.161	86.40 ⁻¹²⁶	1.84	0.278	2.53		
	0	88.96	0.21	.031	88.53	0.27	.041	88.46	0.28	.043	88.45	0.32	.049	88.41	0.44	.067	87.83	1.56	0.234	86.97 ⁻¹²⁶	1.91	0.287	1.99		
	+	88.81	0.20	.030	88.37	0.27	.041	88.28	0.27	.040	88.23	0.27	.041	88.18	0.43	.065	87.75	0.94	0.141	87.08 ⁻¹²⁶	1.51	0.207	1.73		
B	-	89.76	0.18	.027	89.51	0.19	.026	89.44	0.19	.029	89.43	0.22	.033	89.49	0.38	.059	89.79	1.08	0.17	89.69	1.90	0.316	0.33		
	0	89.66	0.16	.025	89.39	0.22	.030	89.35	0.19	.028	89.32	0.21	.031	89.33	0.34	.051	89.36	1.10	0.17	89.20	1.86	0.285	0.46		
	+	89.59	0.18	.027	89.33	0.18	.028	89.25	0.20	.028	89.24	0.19	.030	89.29	0.37	.058	89.33	1.27	0.20	89.02	2.16	0.30	0.57		
C	-	89.87	0.16	.022	89.79	0.17	.026	89.74	0.19	.029	89.76	0.22	.032	89.77	0.61	.094	87.91 ⁻¹¹⁸	1.74	0.27				1.96		
	0	89.78	0.16	.025	89.68	0.16	.027	89.63	0.17	.026	89.61	0.20	.031	89.80	0.45	.069	90.02	1.99	0.28	88.36 ⁻¹²⁴	4.58	0.93	1.66		
	+	89.70	0.16	.022	89.58	0.16	.024	89.53	0.18	.032	89.47	0.37	.056	89.58	0.93	.143	88.05	2.61	0.40				1.65		
D	-	90.01	0.38	.049	89.78	0.35	.054	89.69	0.20	.035	89.68	0.31	.043	89.69	0.41	.062	89.48	1.48	0.23	89.44 ⁻¹²⁴	1.81	0.23	0.57		
	0	89.89	0.18	.027	89.67	0.18	.025	89.65	0.31	.048	89.61	0.21	.027	89.59	0.41	.057	90.03	1.26	0.164	89.63	1.90	0.267	0.44		
	+	89.83	0.29	.045	89.60	0.20	.036	89.56	0.18	.025	89.55	0.20	.031	89.66	0.43	.067	90.25	1.41	0.280	90.61	2.31	0.491	1.06		

VEHICLE RANGE DELAY

VARIATION WITH SIGNAL LEVEL & DOPPLER CONDITION

DOPPLER = $\pm 512 \text{ Hz}$ @ 12.8 MHz (12,000 m/s). TRANSP. NO. 1

- ZERO DOPPLER
- MAX NEGATIVE DOPPLER
- ◇ MAX POSITIVE DOPPLER

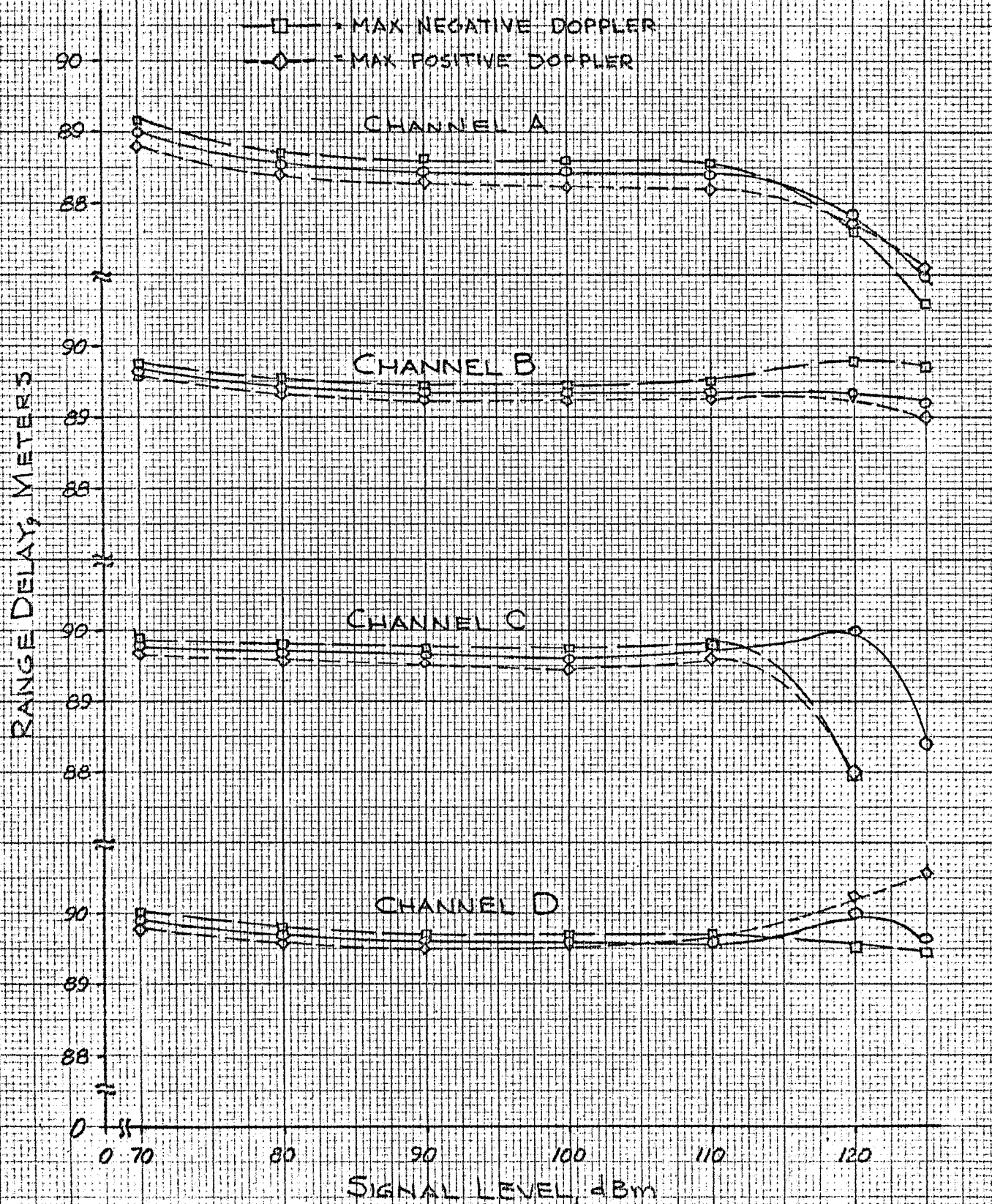


FIGURE 5-4

TABLE V-7

SINGLE CHANNEL TEST. PARA. 4.2. (ATTENUATING SIGNAL TO VEHICLE)

XPROR. #3, @ Rcv. = -82 dBm

DOPPLER = 512 Hz @ 12.8 MHz

FILE #231 #24

		RANGE, METERS																							
CHANNEL	DOPPLER	-70 dBm			-80 dBm			-90 dBm			-100 dBm			-110 dBm			-120 dBm			-124 dBm			Δ		
		R	σ	C.F.	R	σ	C.F.	R	σ	C.F.	R	σ	C.F.	R	σ	C.F.	R	σ	C.F.	R	σ	C.F.			
A	-	89.86	.20	.030	89.44	.26	.040	89.35	.25	.038	89.32	.28	.042	89.23	.41	.061	89.45	1.44	.217				1.41		
	O	89.66	.20	.030	89.25	.28	.042	89.14	.26	.039	89.12	.31	.047	88.96	.47	.070	89.50	1.65	.251				2.16		
	+	89.50	.20	.031	89.08	.26	.038	88.99	.25	.038	88.96	.26	.037	88.83	.37	.072	88.20	1.44	.217				1.30		
B	-	90.31	.17	.025	90.05	.17	.026	89.99	.17	.026	90.03	.65	.111	89.97	.38	.058	90.13	1.33	.204	89.83	2.19	.360	0.48		
	O	90.11	.13	.020	89.86	.20	.030	89.84	.17	.026	89.86	.21	.050	89.81	.39	.060	89.49	1.31	.201	89.14	1.81	.278	0.93		
	+	90.05	.16	.025	89.80	.17	.026	89.73	.18	.028	89.74	.21	.033	89.68	.37	.057	89.53	1.59	.273	89.72	2.02	.491	0.52		
C	-	90.42	.15	.024	90.32	.15	.023	90.26	.18	.027	90.20	.25	.038	89.99	.71	.108	89.00	2.29	.352				1.42		
	O	90.29	.18	.027	90.17	.17	.026	90.14	.17	.026	90.10	.24	.036	90.02	.69	.106	89.20	1.91	.294				1.09		
	+	90.16	.15	.023	90.05	.16	.024	90.01	.19	.029	89.91	.33	.050	89.50	1.00	.153	90.69	2.58	.512				1.19		
D	-	90.60	.18	.028	90.26	.18	.028	90.22	.18	.024	90.22	.23	.036	90.14	.71	.109	90.52	1.79	.274				6.38		
	O	90.32	.22	.034	90.08	.18	.027	90.07	.18	.027	90.01	.23	.036	90.02	.45	.067	90.19	1.67	.238				0.31		
	+	90.18	.18	.028	89.98	.17	.024	89.96	.18	.028	89.93	.20	.025	90.06	.42	.057	90.30	1.57	.242				0.37		

VEHICLE RANGE DELAY

VARIATION WITH SIGNAL LEVEL & DOPPLER CONDITION

DOPPLER = $\pm 512 \text{ Hz}$ @ 12.8 MHz ($12,000 \text{ m/s}$). TRANSP. No. 3

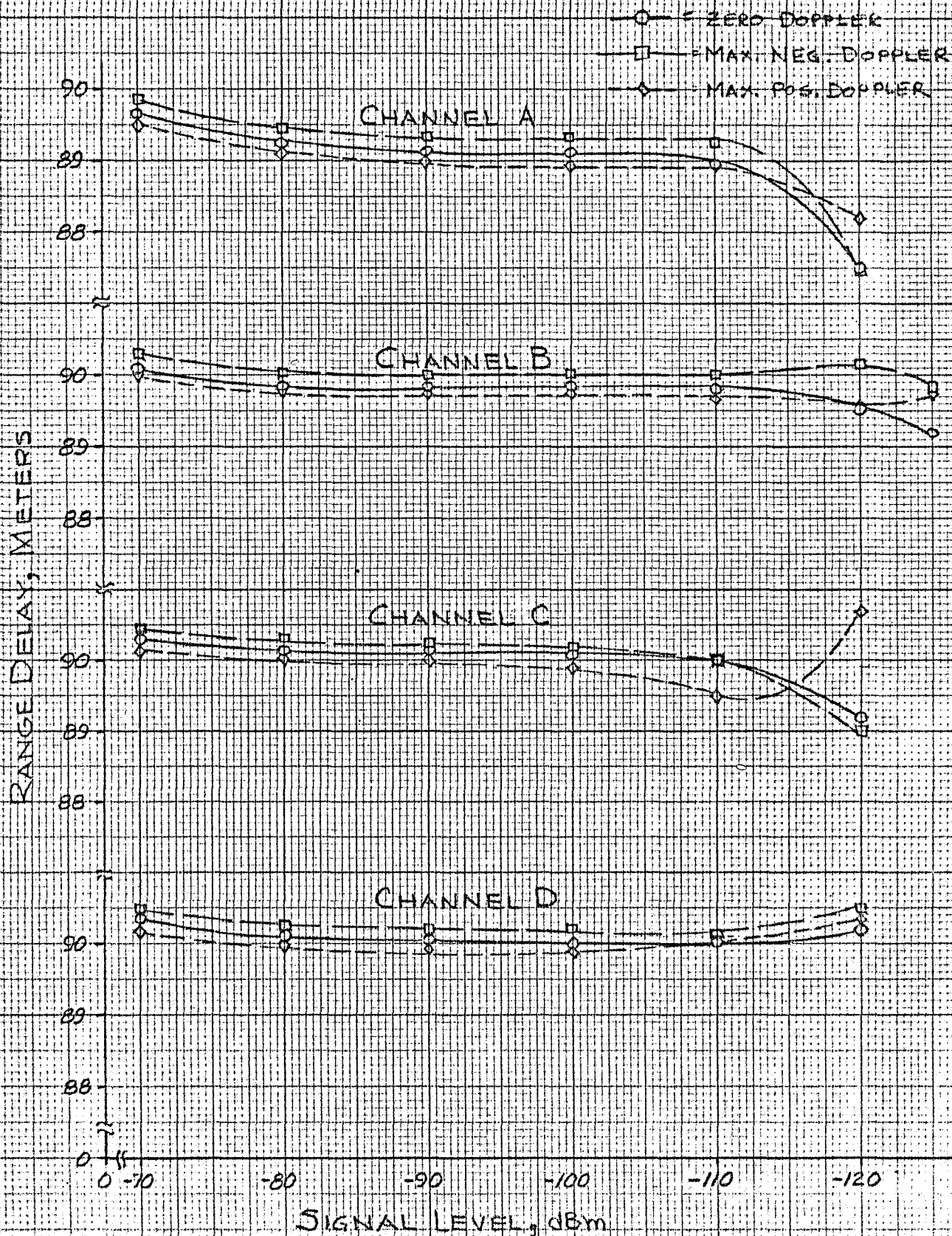


FIGURE 5-5

TABLE V-8

Vehicle Velocity Data

Versus Signal Level

Zero Velocity (0 Doppler) Condition

Using Transponder No. 2 @ -80 dbm

SIGNAL LEVEL D _{bm}	-70		-80		-90		-100		-110		-120		-123	
RECVR. CH.	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$	V	$\frac{\sigma V}{C.I.}$
A	-.012	.090 .0135	-.006	.057 .0086	-.010	.065 .0098	-.003	.068 .0102	-.007	.066 .0098	.001	.070 .0089		
B	.005	.073 .0110	-.002	.065 .0097	-.005	.064 .0096	-.006	.061 .0092	-.010	.074 .0112	-.001	.063 .0095	.005	.067 .0100
C	-.001	.056 .0084	-.005	.053 .0080	.000	.055 .0083	-.014	.071 .0106	-.007	.054 .0081	-.005	.067 .0100		
D	-.007	.060 .0090	-.006	.065 .0098	-.003	.067 .0101	-.012	.073 .0109	-.005	.057 .0085	-.006	.063 .0094	-.004	.068 .0102

VELOCITY VS SIGNAL LEVEL
FOR EACH VEHICLE REC. CHAN.
WITH XPDR #2 AT -80 dBm
120 samples per data point

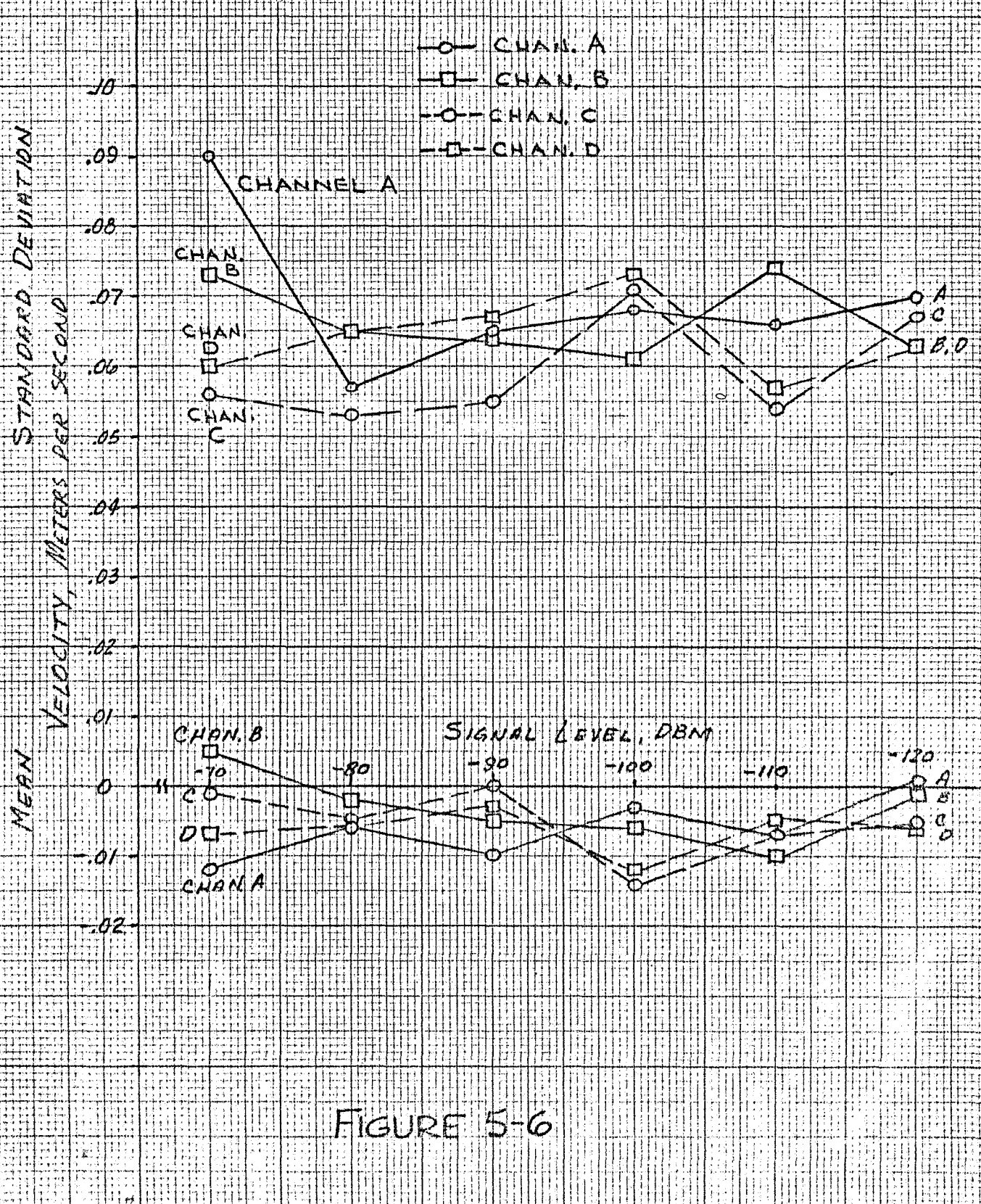


FIGURE 5-6

Conversely, Transponder No. 2 breaks upward at low signal level, resulting in a composite which is nearly flat. Overall, the results plotted in Figure 5-7 show that all readings are within the design goal of ± 0.5 meter, except the low -125 dbm reading on Transponder No. 1.

The velocity data presented in Table V-10 and plotted in Figure 5-8 appear to be a duplication of the plots of Figure 5-6. This leads to the conclusion that signal level is of very little significance in the velocity measurement mechanism so long as a solid system lock is maintained.

5.4 TRACKING CHARACTERISTICS

The purpose of these tests was to demonstrate the system tracking characteristics under dynamic conditions -- zero to maximum velocity and maximum acceleration. The wideband synthesizer (para. 3.3.2) was used. This was driven by a low frequency triangular wave generator to produce an S-band frequency varying by ± 89 kHz (at 2214 MHz) over a 30-second period. This modulation simulated a velocity varying from +6000 meters/sec to -6000 meters/sec and an acceleration of 400 meters/sec/sec. This is the maximum acceleration expected in the AROD system.

During the test, the carrier tracking loop static phase error was monitored to observe any tendency for the loop to unlock. The loop remained stable throughout the tests. Figure 5-9 demonstrates the loop stability. The lower trace of this oscillogram represents the frequency change of the S-band transmitter. It is actually the triangular wave of voltage applied to the transmitter VCO. The upper trace is the voltage appearing at the carrier loop dynamic phase error point. This indicates no tendency to become unlocked.

Approximately ten minutes of range data was taken during these tests and the results used to compute the auto-correlation function of range. The resulting data were used to compute the peak range error due to acceleration of 0.12 meter. This value is a

TABLE V-9. System Range Delay Zero Velocity (0 Doppler) Condition Using Vehicle Channel B.

TRANSPONDER	SIGNAL LEVEL, Dbm AND RANGE, METERS														
	-70		-80		-90		-100		-110		-120		-125		
	R	T	R	T	R	T	R	T	R	T	R	T	R	T	
		C.F.		C.F.		C.F.		C.F.		C.F.		C.F.		C.F.	C.F.
1	88.28	0.17 .024	87.93	0.20 .031	87.90	0.19 .029	87.75	0.20 .030	87.85	0.29 .045	87.49	0.81 .105	86.10	1.75 .246	2.18
2	88.44	0.18 .028	88.04	0.18 .027	87.98	0.18 .027	87.98	0.19 .030	88.00	0.35 .054	88.32	1.23 .189	87.96 ⁻¹²⁴	2.50 .440	0.48
3	89.89	0.15 .023	89.68	0.31 .048	89.59	0.19 .032	89.49	0.20 .030	89.48	0.38 .054	89.43	0.82 .126	89.00	1.51 .233	0.89

TABLE V-10. System Velocity Data Transponder No. 2 -- Vehicle Channel B

SIGNAL LEVEL, Dbm	-70			-90			-110			-120			-123		
	V	σ_v	C.I.	V	σ_v	C.I.	V	σ_v	C.I.	V	σ_v	C.I.	V	σ_v	C.I.
TEST PARAMETER															
DATA	.001	.066	.0099	-.004	.055	.0083	-.007	.060	.0090	-.013	.069	.0103	-.005	.074	.0112

SYSTEM RANGE DELAY VARIATION WITH SIGNAL LEVEL COMMON PATH ATTENUATION USING VEHICLE CHANNEL B, ZERO DOPPLER

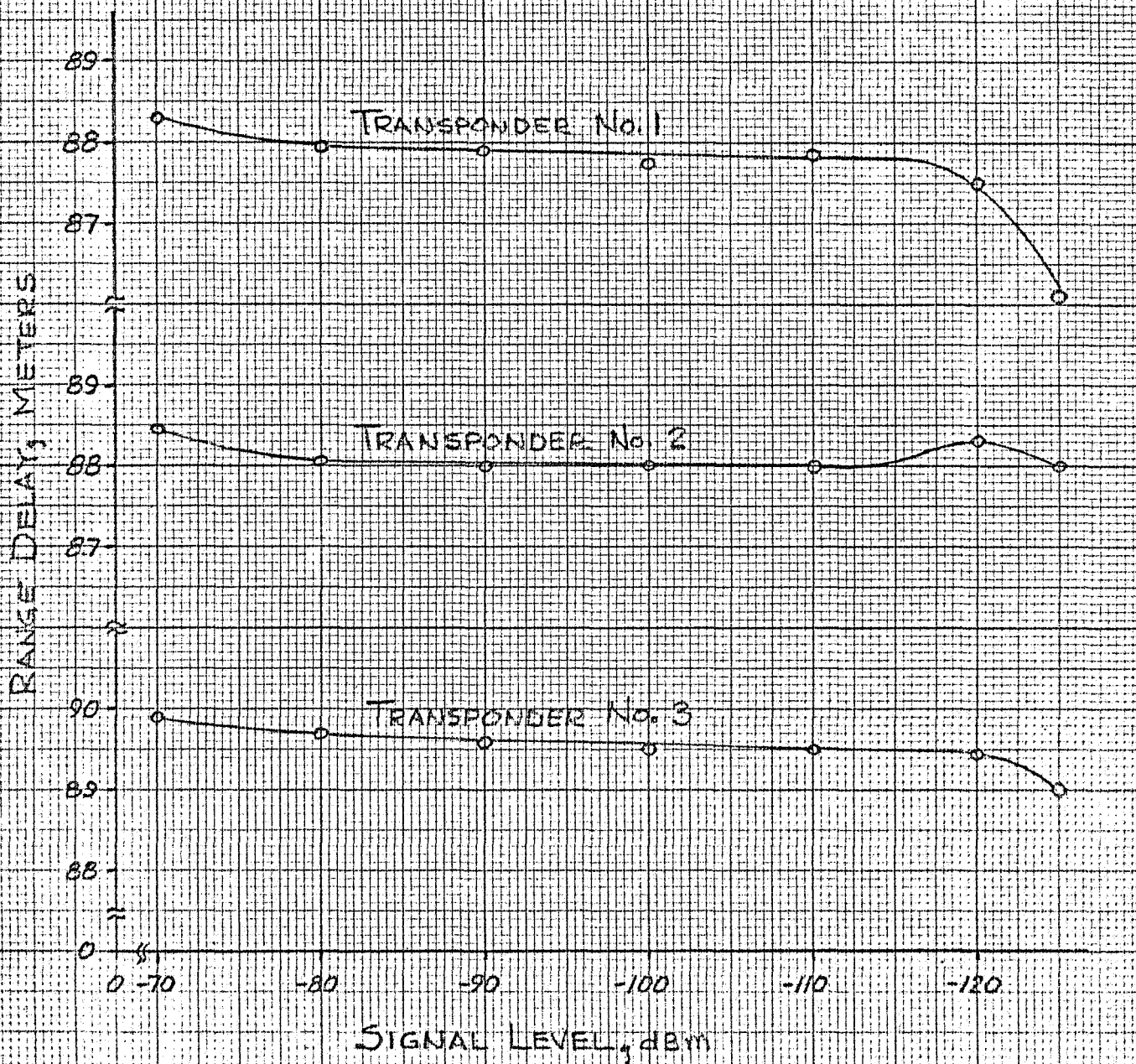


FIGURE 5-7

VELOCITY vs SIGNAL LEVEL
COMMON PATH ATTENUATION
VEHICLE CHAN. B - TRANSPONDER NO. 2
120 SAMPLES PER DATA POINT

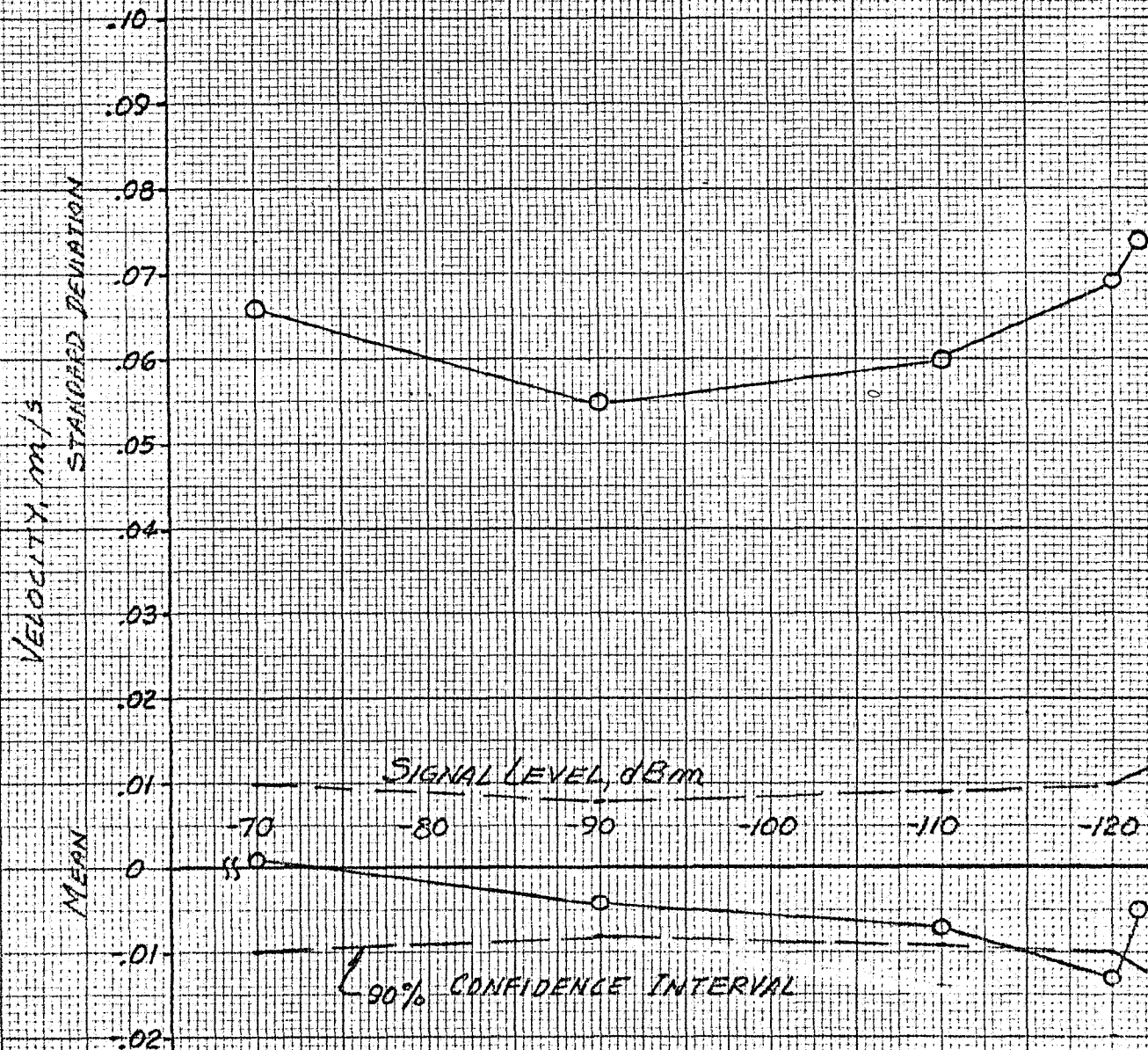


FIGURE 5-8

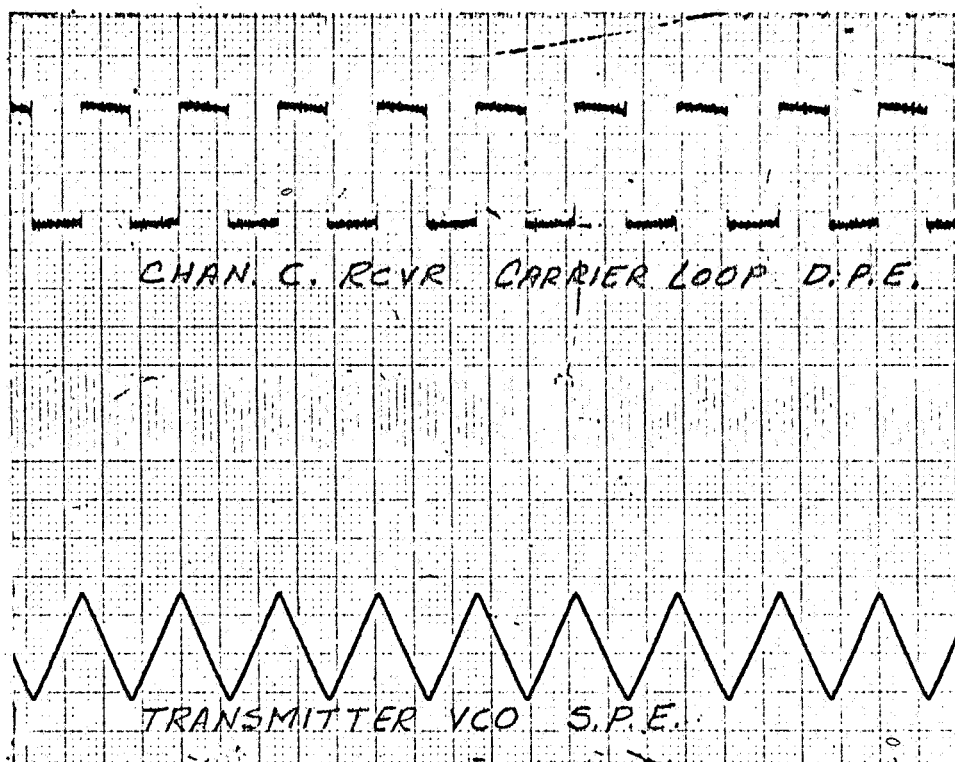


Figure 5-9. Carrier Loop Tracking Characteristics

factor of four times that expected from previous calculations. The results are clouded, however, by the error resulting from the velocity, and are felt to be reasonable under the conditions of the test. The results would have been more precise if the maximum acceleration could have been applied with zero velocity, as would be the case in the field. This was not possible in the laboratory.

SECTION VI

6. MULTICHANNEL TESTS

Multichannel tests were conducted to determine the degree of data degradation with adjacent channels in operation. Tests were conducted with one, two, and three interfering signals both with and without Doppler.

6.1 SIGNAL LEVEL EFFECTS

Tests were conducted with signal level variations from -80 dbm to threshold. Data readouts were taken on both range and velocity. The velocity data utilized the revised circuitry described in paragraph 5.3. The test channel for both range and velocity data utilized common path attenuation: that is, both terminals were adjusted to the same signal level.

6.1.1 System Range Delay Tests

The two-channel tests were conducted with channel A locked to the checkout equipment at a signal level of -80 dbm and with +10 Hz of Doppler at 12.8 MHz (a velocity of about 120 m/s). Range data was taken with channel B vehicle receiver and No. 3 transponder, and was repeated using channel C and D vehicle receivers. A summary of this range data is presented in Table VI-1. The threshold of -105 dbm is typical with strong signal adjacent channel occupancy (see para. 4.3.2 and 4.3.3). The range data for all three 2-channel tests is plotted in Figure 6-1. The curves indicate that the coherent leakage effect discussed in para. 5.3.1.1 contributes very little, since the threshold here is much higher. All data points are within ± 0.25 meter with channels B and C showing a much smaller spread.

Range data with interference from two and three channels were obtained with three additional tests of channel B - Transponder No. 3:

1. With interference from checkout channels A and C.
Channel A: -80 dbm, +120 m/s velocity
Channel C: -80 dbm, -120 m/s velocity
2. With interference from checkout channel A and Transponder No. 2 on channel C.
Channel A: -80 dbm, +120 m/s velocity
Channel C: -80 dbm, 0 velocity
3. With interference from checkout channels A and C and Transponder No. 2 on channel D.
Channel A: -80 dbm, +120 m/s velocity
Channel C: -80 dbm, -120 m/s velocity
Channel D: -80 dbm, 0 velocity

The results of these tests are summarized in Table VI-2. The data are plotted on Figure 6-2, with a somewhat expanded scale. All three curves fall within a ± 0.5 meter range.

6.1.2 System Velocity Tests

The system velocity tests under multichannel conditions consisted of measuring the velocity on vehicle channel B and Transponder No. 2 with interference as follows:

- Test 1. Channel A on checkout equipment at -80 dbm
- Test 2. Channel A and C on checkout equipment at -80 dbm
- Test 3. Channel A and C on checkout equipment at -80 dbm and channel D locked to Transponder No. 3 at -80 dbm.

The data was taken on channel B at signal levels of -80 dbm to threshold and is summarized in Table VI-3. Plots of the velocity mean and standard deviation are given in Figure 6-3. It can be concluded from the curves that the 3-channel interference case produces more fluctuating plots and the single channel interference case produces more stable plots. This is as might be expected.

TABLE VI-1. System Range Data Two-Channel Tests

CHANNEL TESTED	- 80 Dbm		- 85 Dbm		- 90 Dbm		- 95 Dbm		- 100 Dbm		- 105 Dbm	
	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.
B	89.50	0.17 .030	89.47	0.20 .031	89.46	0.28 .043	89.48	0.29 .044	89.68	0.50 .077	89.84	0.52 .079
C	89.86	0.18 .031	89.87	0.17 .026	89.85	0.18 .028	89.88	0.20 .031	89.92	0.30 .047	90.23	0.56 .086
D	89.93	0.19 .029	89.91	0.20 .030	89.90	0.19 .029	89.94	0.21 .032	90.04	0.27 .042	90.58	0.60 .092

TABLE VI-2. System Range Data Multi-Channel Tests

TEST CONDITIONS	- 80 Dbm		- 85 Dbm		- 90 Dbm		- 95 Dbm		- 100 Dbm		- 105 Dbm		- 110 Dbm	
	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.	R	σ C.F.
CH A & C TC C/O CH D TO XFR DR #2	89.80	0.23 .029	89.80	0.21 .025	89.81	0.25 .038	89.94	0.41 .063	90.43	0.79 .122	90.67	0.77 .137	89.77	0.16 .025
CH A & B TC C/O CH D TO XFR DR #2	89.69	0.17 .026	89.68	0.18 .028	89.65	0.21 .032	89.79	0.26 .040	90.08	0.31 .048	90.11	0.61 .094	89.83	0.22 .034
CH A & B TC C/O CH D TO XFR DR #2	89.75	0.20 .030	89.72	0.21 .032	89.74	0.20 .046	89.94	0.33 .050	90.34	0.71 .109				

SYSTEM RANGE DATA

MULTI-CHANNEL TESTS

INTERFERENCE ON CHANNEL A: -80 dBm

WITH DOPPLER OF 10 Hz @ 12.8 MHz (120 m/s)

TEST CHANNEL USING TRANSPODER No. 3

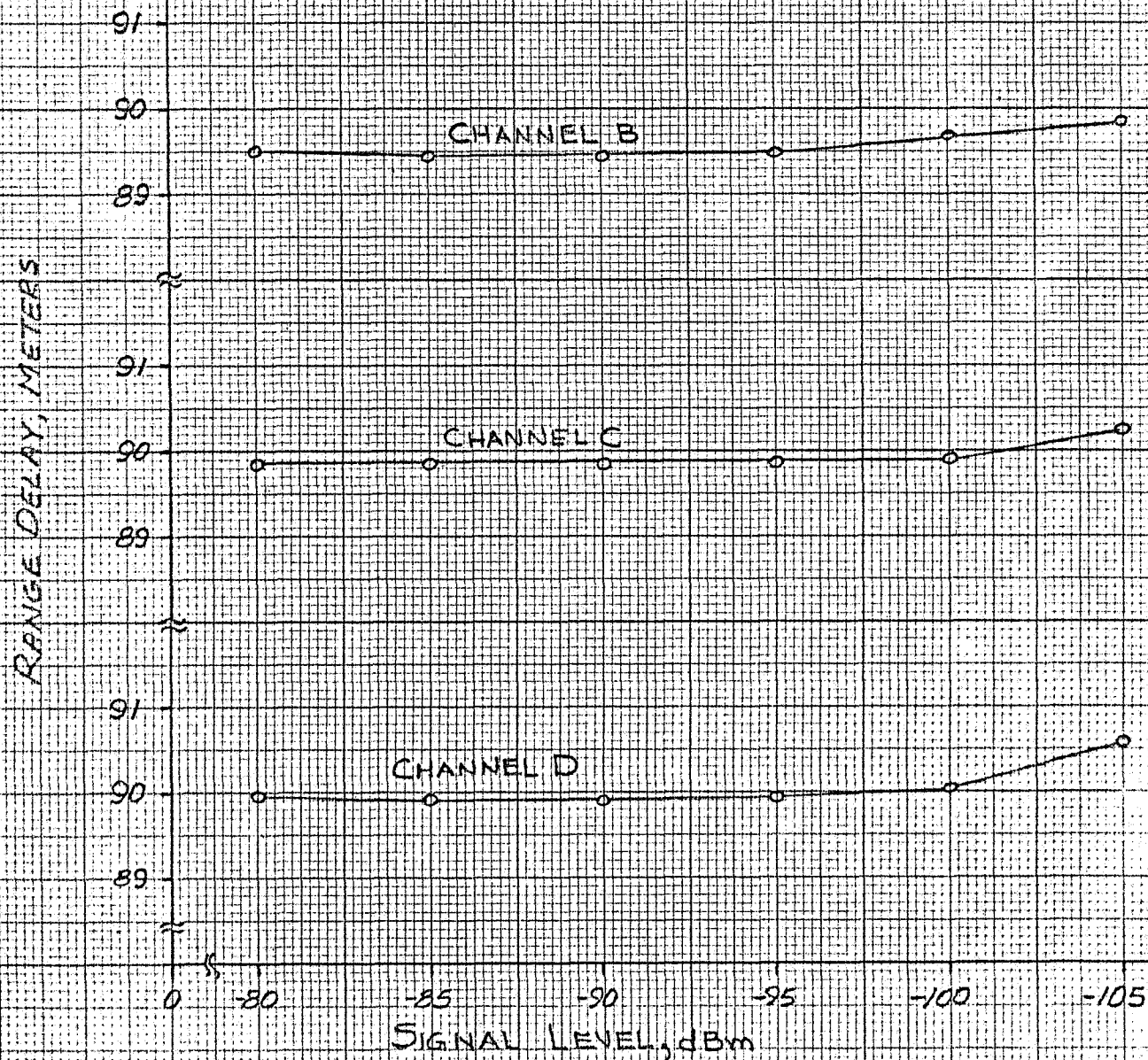


FIGURE 6-1

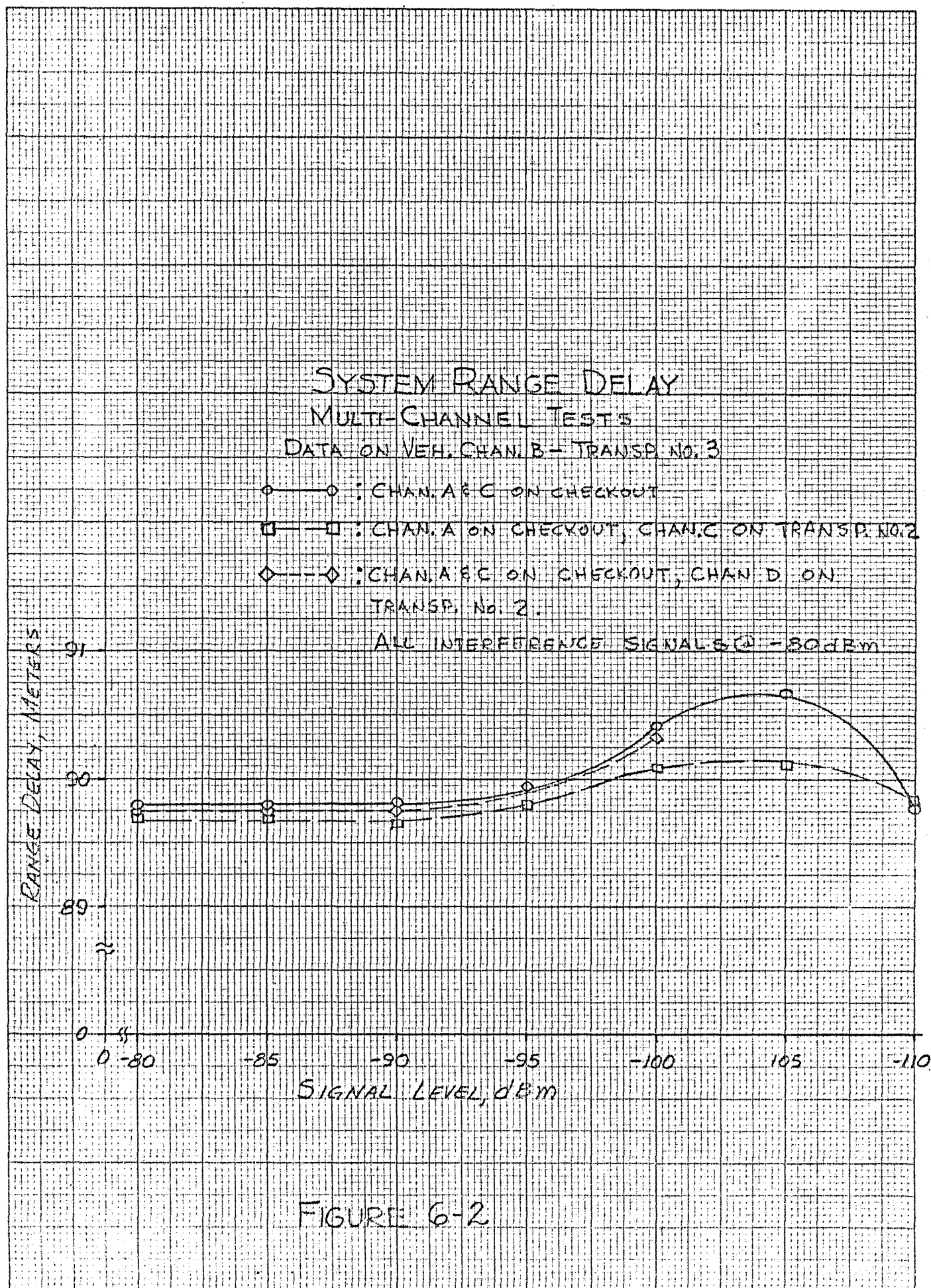


FIGURE 6-2

TABLE VI-3

SYSTEM VELOCITY DATA

MULTI-CHANNEL TESTS

TEST CHANNEL - VEHICLE CHANNEL B

WITH TRANSPONDER NO. 2

TEST SIGNAL LEVEL, Dbm	-80	-85	-90	-95	-100	-104
TEST CONDITIONS	V	V	V	V	V	V
CH. A + DOP -80Dbm To C/O	$\frac{\sigma_v}{C.I.}$.063 .002	$\frac{\sigma_v}{C.I.}$.063 -008	$\frac{\sigma_v}{C.I.}$.068 -004	$\frac{\sigma_v}{C.I.}$.062 .002	$\frac{\sigma_v}{C.I.}$.060 -004	$\frac{\sigma_v}{C.I.}$.071 -003
CH A + DOP -80Dbm To C/O	$\frac{\sigma_v}{C.I.}$.060 .005	$\frac{\sigma_v}{C.I.}$.063 -006	$\frac{\sigma_v}{C.I.}$.071 -002	$\frac{\sigma_v}{C.I.}$.071 -004	$\frac{\sigma_v}{C.I.}$.068 -000	$\frac{\sigma_v}{C.I.}$.099 -015
CHC - DOP -80Dbm To C/O	$\frac{\sigma_v}{C.I.}$.066 -004	$\frac{\sigma_v}{C.I.}$.054 .001	$\frac{\sigma_v}{C.I.}$.071 -013	$\frac{\sigma_v}{C.I.}$.075 -000	$\frac{\sigma_v}{C.I.}$.066 -009	$\frac{\sigma_v}{C.I.}$.079 -001
CHD ODOP -80Dbm To C/O	$\frac{\sigma_v}{C.I.}$.0098	$\frac{\sigma_v}{C.I.}$.0081	$\frac{\sigma_v}{C.I.}$.0106	$\frac{\sigma_v}{C.I.}$.0112	$\frac{\sigma_v}{C.I.}$.0099	$\frac{\sigma_v}{C.I.}$.0118

VELOCITY vs SIGNAL LEVEL MULTI-CHANNEL TESTS OF VEHICLE CHANNEL B. TEST SIGNAL FROM TRANSPONDER No. 2.

- With Chan. A interference
- With Chan. A & C interference
- △ With Chan. A, C, & D interference

120 samples per data point

VELOCITY, METERS PER SECOND
STANDARD DEVIATION
MEAN

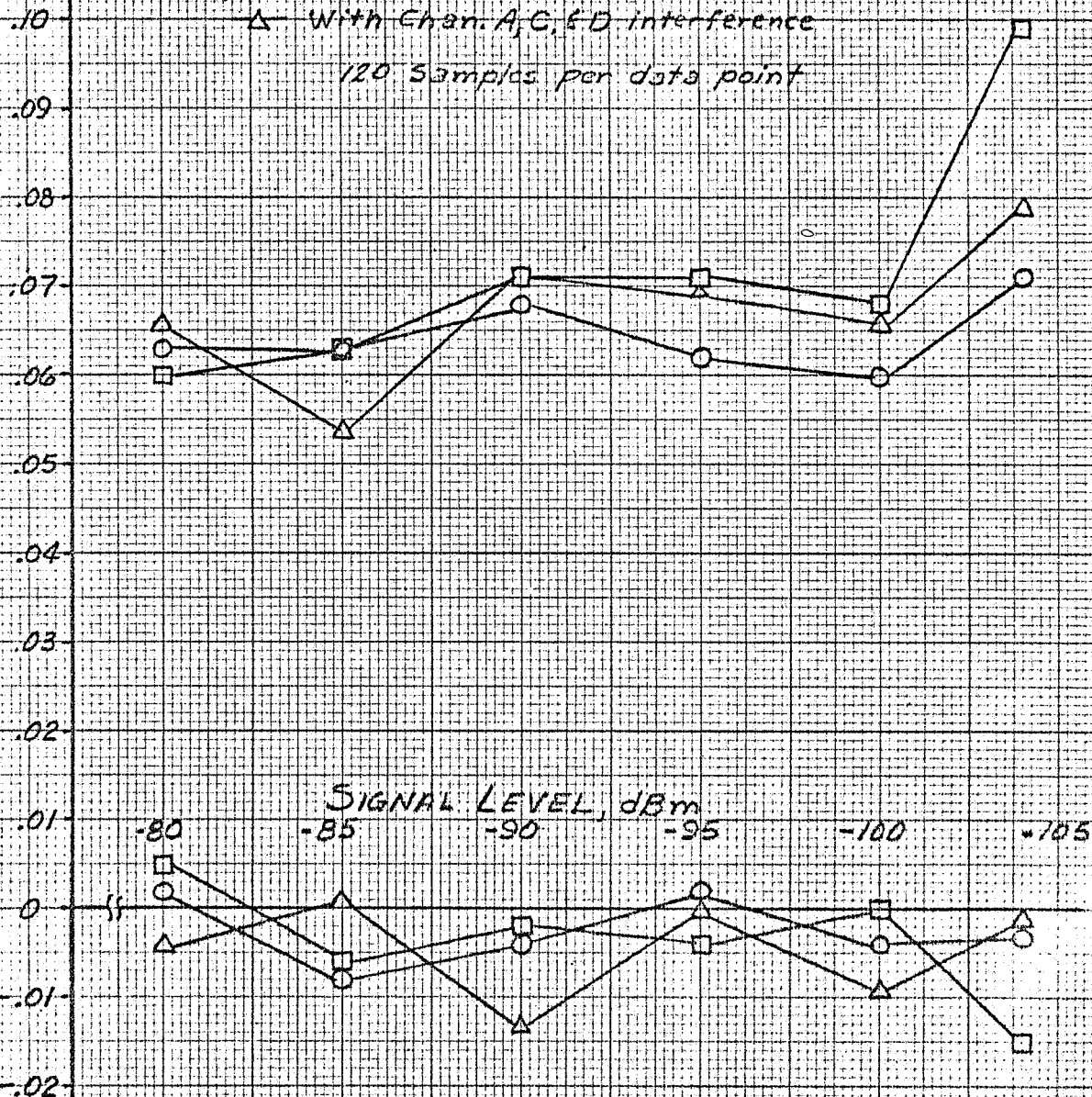


FIGURE G-3

All points of the mean plots are within the design goal of 0.015 m/s.

6.2 DOPPLER EFFECTS

The effect on range delay of an interfering channel as a function of Doppler (velocity) was investigated by making identical tests with and without Doppler. Channel B vehicle receiver was locked to Transponder No. 3 and tested from a signal level of -80 dbm to threshold while the channel A receiver was locked to the checkout equipment at zero Doppler. The test was then repeated with full Doppler (12,000 m/s velocity) -- positive on channel A and negative on channel B. A data summary is presented in Table VI-4 with a greatly expanded range delay plot in Figure 6-4. The effect of Doppler in this case is essentially negligible. An appreciable difference (0.25 meter) is obtained only near threshold.

6.3 BIT ERROR RATE TESTS

Bit error rate tests were performed to obtain data on the probability of making errors in the S-Band Transponder-to-vehicle data link. Tests were conducted versus signal level for all vehicle channels acquired in both V-2 and V-4, using checkout equipment and then repeated in state V-4 with Transponder No. 3. The checkout equipment was used to permit acquiring in V-2 state and to permit the signal levels to be controlled more precisely. Further tests were conducted on channel B receiver/No. 3 transponder with a jamming signal acquired on channel A receiver both with and without Doppler influence.

6.3.1 Single Channel Tests

Bit error data was taken by comparing the S-band up-link data from the transponder (or checkout) before transmission to the demodulated up-link data at the vehicle. Errors were accumulated for a sufficient amount of time to provide a significant number of errors. The time period might be fairly short (100 sec) near threshold or quite long (3000 sec) at higher signal levels. Signal

TABLE VI-4

SYSTEM RANGE DELAY
AS A FUNCTION OF SIGNAL LEVEL
AND DOPPLER CONDITION

SIGNAL LEVEL, Dbm: OF CH.B.	RANGE, METERS					
	A = +10 Hz DOPPLER B = 0 Hz DOPPLER			A = +512 Hz OF DOPP. B = -512 Hz OF DOPP.		
	A	B		A	B	
		R	Δ C.F.		R	Δ C.F.
-80		89.50	.17 .029		89.58	.18 .027
-85		89.47	.20 .030		89.54	.18 .028
-90		89.46	.28 .043		89.49	.21 .032
-95		89.48	.29 .044		89.51	.26 .039
-100		89.68	.50 .076		89.67	.34 .052
-105		89.84	.52 .079		89.97	.55 .085
-108		90.07	.58 .089		90.40	.80 .123

DATA DEGRADATION DUE TO

DOPPLER AND SIGNAL LEVEL

TWO-CHANNEL TEST

○—○ CHAN. A, 0/0 @ -80 dBm
ZERO DOPPLER, CHAN. B ON
XPOR No. 3, ZERO DOPPLER

□—□ CHAN. A, 0/0 @ -80 dBm
+512 Hz DOPPLER,
CHAN. B ON XPOR No. 3
-512 Hz DOPPLER

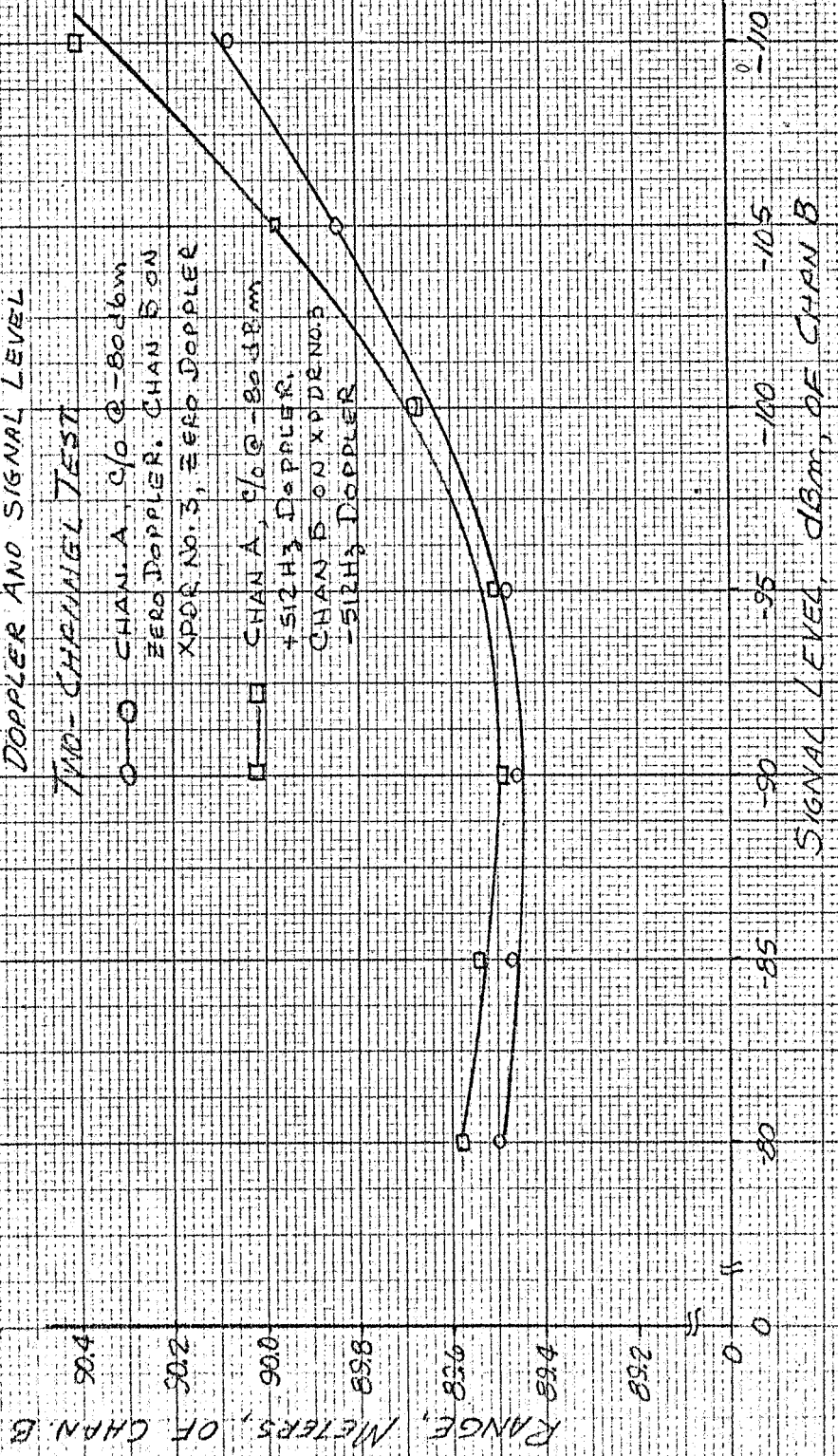


FIGURE G-4

levels were calibrated with great care and are felt to be within ± 0.5 db for the tests with the checkout equipment and within ± 1.0 db for tests with the transponder.

Tests were first made with the checkout equipment, which permitted stopping the acquisition sequence in state V-2. Figure 6-5 presents the first series of data showing the results of the checkout equipment tests of channels A and B. The calculated V-4 curve is computed as follows:

KTB noise	=	-174 dbm/Hz
noise figure		<u>8.3 db</u>
		-165.7 dbm/Hz

Bandwidth

8 L-code periods x 1/2 for time sharing =

$$\frac{511 \times 2}{6.4 \times 10^6} \times 8 \times \frac{1}{2} = 1590 \text{ Hz}$$

or 32.0 db

<u>32.0 db</u>
-133.7 dbm

For a probability of error of 10^{-3} , from the standard error function curve, a signal-to-noise ratio of 6.8 db is required.

<u>6.8 db</u>
-126.9 dbm

Thus 10^{-3} and -126.9 db represent one point on the calculated curve of Figure 6-5.

The data for channels A and B in V-4 agree quite well with the calculated curve. Channel A is about 1 db off at the worst point and channel B is consistently within 1/2 db of theoretical.

The curves for V-2 should be 3 db higher than the curves for V-4, since there is no time sharing between range loop and carrier loop in the V-2 state. (The 1/2 factor in the bandwidth equation above does not apply in V-2.) The data shows that channel A is 3.5 db higher in V-2 and channel B is 2.5 db higher. This error represents just about our measurement accuracy.

FIGURE 6-5 BIT ERROR RATES WITH C/D EQUIP. ABC SIM.

x measured V-4
o measured V-2

Data 6-28-67

CH A. —————
CH B. - - - - -

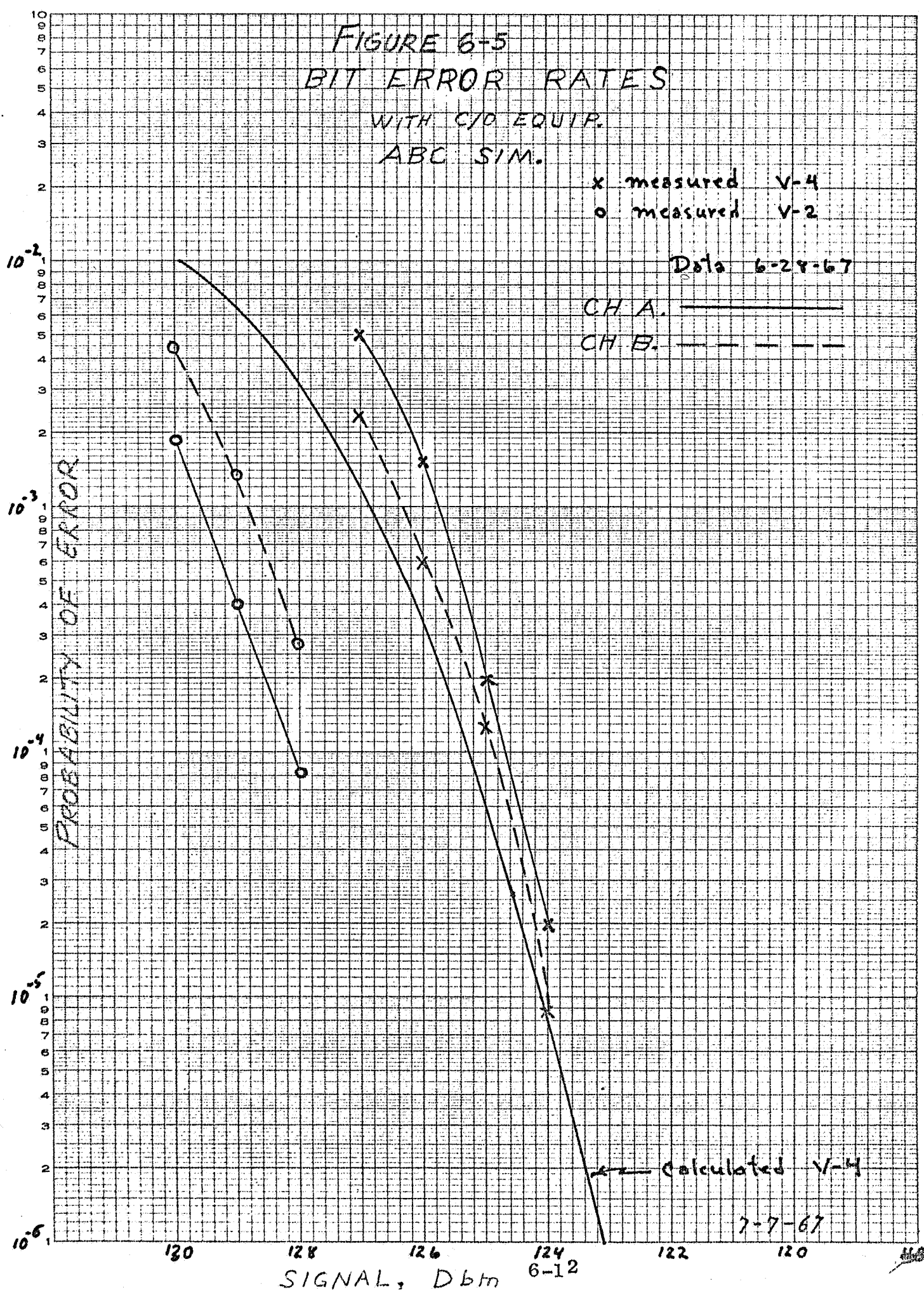


Figure 6-6 presents the same data for channels C and D. Here, the first run in V-4 indicated an obvious fault in the channel C receiver. This fault was isolated to one of two cordwood modules -- the second mixer and the balanced demodulator. Both of the modules were found to have been below normal in original test, but had been accepted for frame assembly. Both of the modules were replaced, and the tests re-run to produce the second V-4 channel C curve. The agreement of both channels is quite good, although channel D appears to be a bit low.

Tests with Transponder No. 3 bear out the results with the checkout equipment. Figure 6-7 shows the results of all four receiver channels with Transponder No. 3. The calculated curves are repeated for each channel for clarity with the channel data plotted alongside. All channels are within 1 db of theoretical, except for channel D which diverges to about 2 db at threshold. In general, the receivers are felt to be operating very near the theoretical prediction.

6.3.2 Two-Channel Tests

Tests were made to show error probability with adjacent channel interference. While the data, as plotted in Figure 6-8 are not absolute, they indicate co-channel interference thresholds essentially in agreement with the data of Section IV. The calculated curve is plotted merely to show the shape of the curve.

The tests were repeated with a velocity on both channel A and B of 6000 m/s. Channel A was given a positive velocity and channel B a negative velocity. This, in effect, makes channel A frequency high and channel B frequency low so that the channel separation is only about 240 kHz instead of 400 kHz. The resulting increase in effective jamming reduces the signal margin by about 3 db.

FIGURE 6-6 BIT ERROR RATES

WITH C/O EQUIP.

CH C: ABC SIM. + CH D: BGD SIM.

X MEASURED V-4
O MEASURED V-2

CH C —————
CH D - - - - -

CH C
AFTER
MOD.
ON
7-10-67

PROBABILITY OF ERROR

CALCULATED V-4

7-7-67

SIGNAL, Dbm 6-14

MADE IN U. S. A.

SEMI-LOGARITHMIC
5 CYCLES X 10 DIVISIONS PER INCH

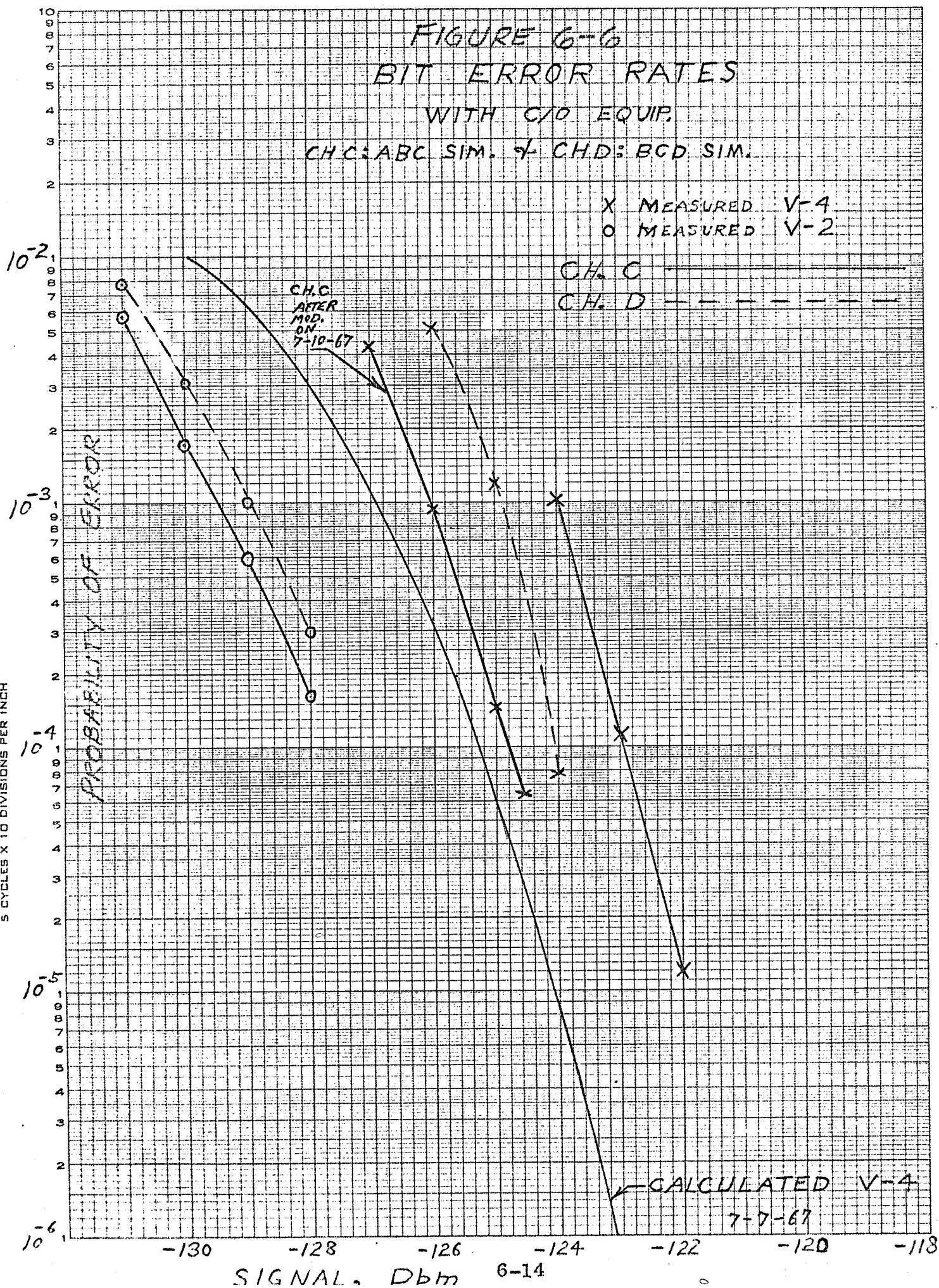


FIGURE 6-7
 BIT ERROR RATES
 WITH XPNDR. 3.
 VEH. RCVR. CH. A, B, C & D.
 7-12-67

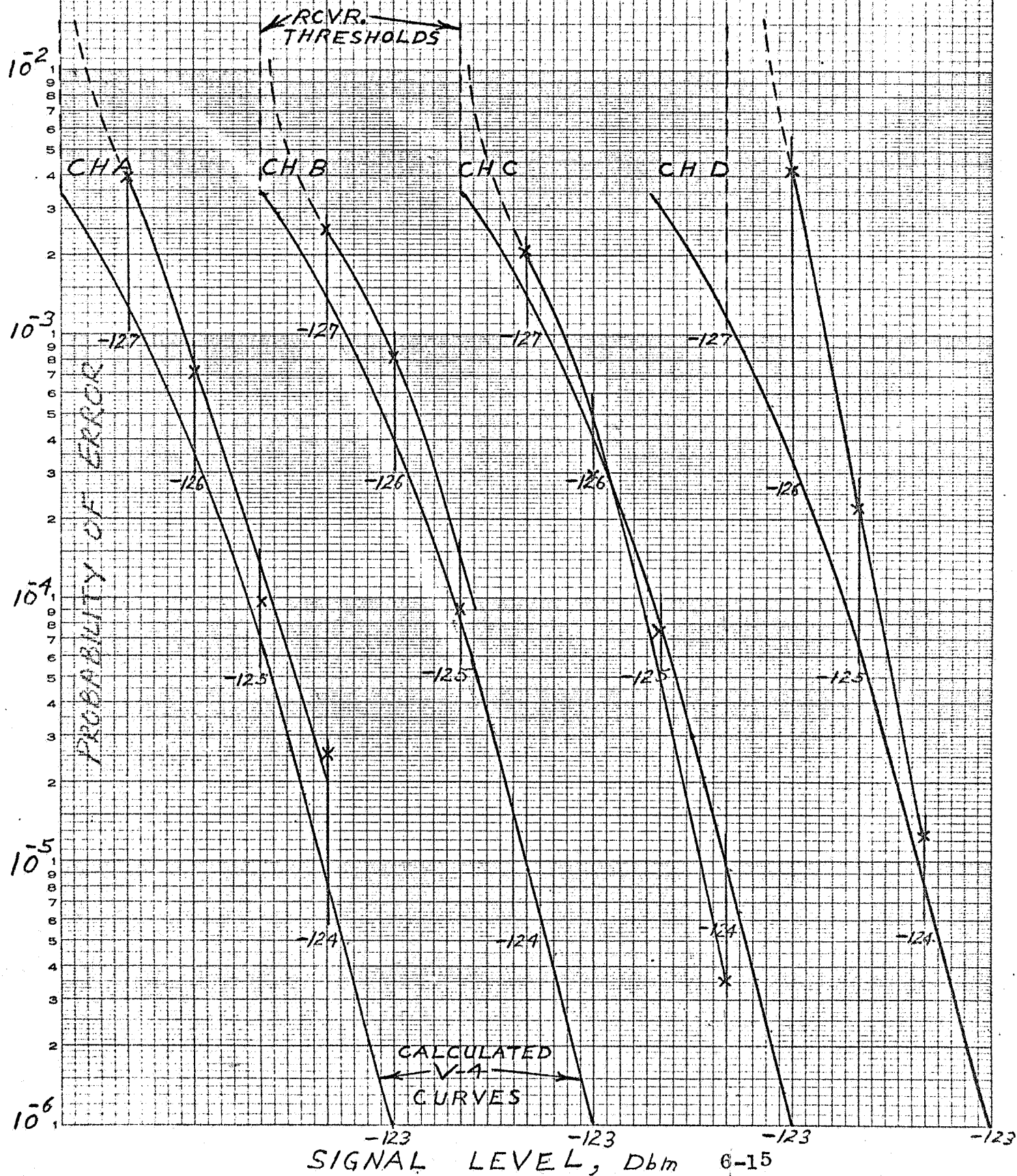
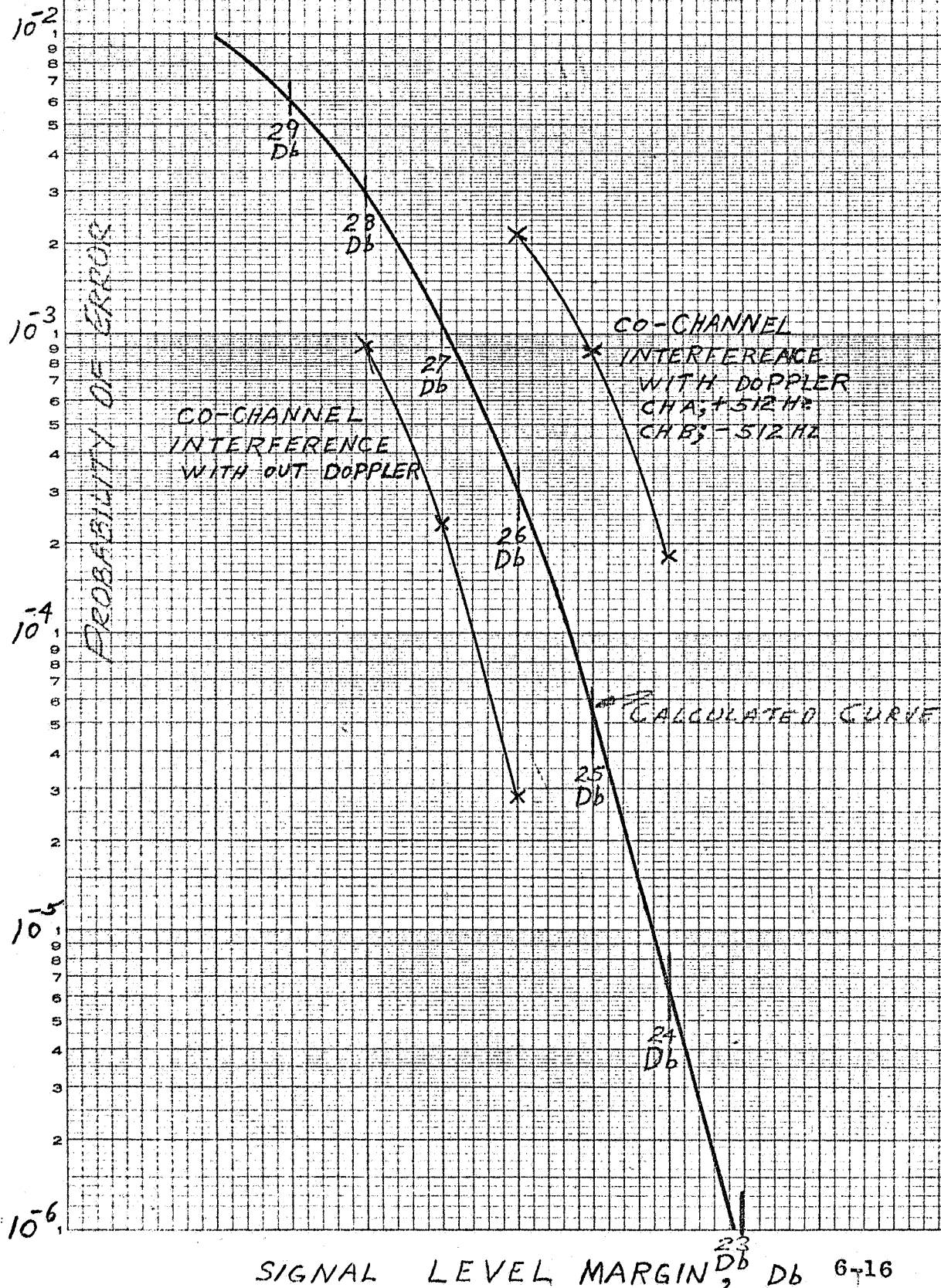


FIGURE 6-8 CO-CHANNEL INTERFERENCE BIT ERROR RATES

CH B WITH XPNDR. 3. @ -106 Dbm.
INT. ON CH A. FROM C/I @ -78 to -82 Dbm.
7-12-67



SECTION VII

7. ENVIRONMENTAL TESTS

7.1 TEMPERATURE TESTS OF STATION CONTROL TRANSMITTER

Temperature tests of the station control transmitter were made to determine power output degradation with temperature. The data obtained is given in Table VII-1 and VII-2. Figure 7-1 is a plot of this data. The influence of a vacuum on the transfer of heat from the unit is presented in Figure 7-2. During this test, the transmitter was operated at full power output while its temperature increased. As the ambient pressure decreased, heat loss due to convection was eliminated and a rapid heat rise occurred in the package. This test indicates the need for a possible redesign of the transmitter frame to increase heat conduction to the baseplate.

TABLE VII-1. VHF Transmitter Vacuum Test (Without Heat Sink)

Total Elapsed Test Time Minutes	Pressure mm Hg	Output Power dbm - watts		Unit Temp °C	-28 Volt Supply Current ma
0	760	37.4	5.5	25.0	540
10	760	37.0	5.0	44.0	540
20	760	36.7	4.7	48.3	540
30	760	36.6	4.5	48.9	540
35	11	36.4	4.35	53.9	530
50	1 x 10 ⁻²	35.7	3.7	57.2	525
55	1 x 10 ⁻³	35.3	3.3	61.7	510
60	5 x 10 ⁻⁵	35.3	3.3	66.1	490
65	2.4 x 10 ⁻⁶	34.0	2.5	76.7	470
75	2.4 x 10 ⁻⁶	33.2	2.12	85	450
85	2.4 x 10 ⁻⁶	31.8	1.51	100	400
90	2.2 x 10 ⁻⁶	31.8	1.51	103	400

TABLE VII-2. VHF Transmitter Vacuum Test (With Heat Sink)

Total Elapsed Test Time Minutes	Pressure mm Hg	Output Power dbm - watts		Unit Temp °C	-28 Volt Supply Current ma
0	760	37.4	5.5	25	540
5	760	37.4	5.5	37.8	540
15	760	37.2	5.2	45.0	540
20	760	37.15	5.18	45.6	540
25	760	37.1	5.15	46.1	540
35	2.5×10^{-1}	36.7	4.7	50.0	530
50	2.0×10^{-2}	36.4	4.35	53.9	520
55	4×10^{-6}	36.3	4.25	56.7	515
65	4×10^{-6}	36.2	4.15	58.9	510
70	2.7×10^{-6}	36.0	3.98	63.3	505
75	2.7×10^{-6}	35.8	3.85	65.0	500
85	2×10^{-6}	35.6	3.65	69.4	495
95	2×10^{-6}	35.4	3.4	72.2	490
115	2×10^{-6}	35.4	3.4	75.6	480
118	0.1	36.1	4.05	73.3	515
120	0.1	36.2	4.15	71.1	518
130	0.1	36.3	4.3	67.2	520

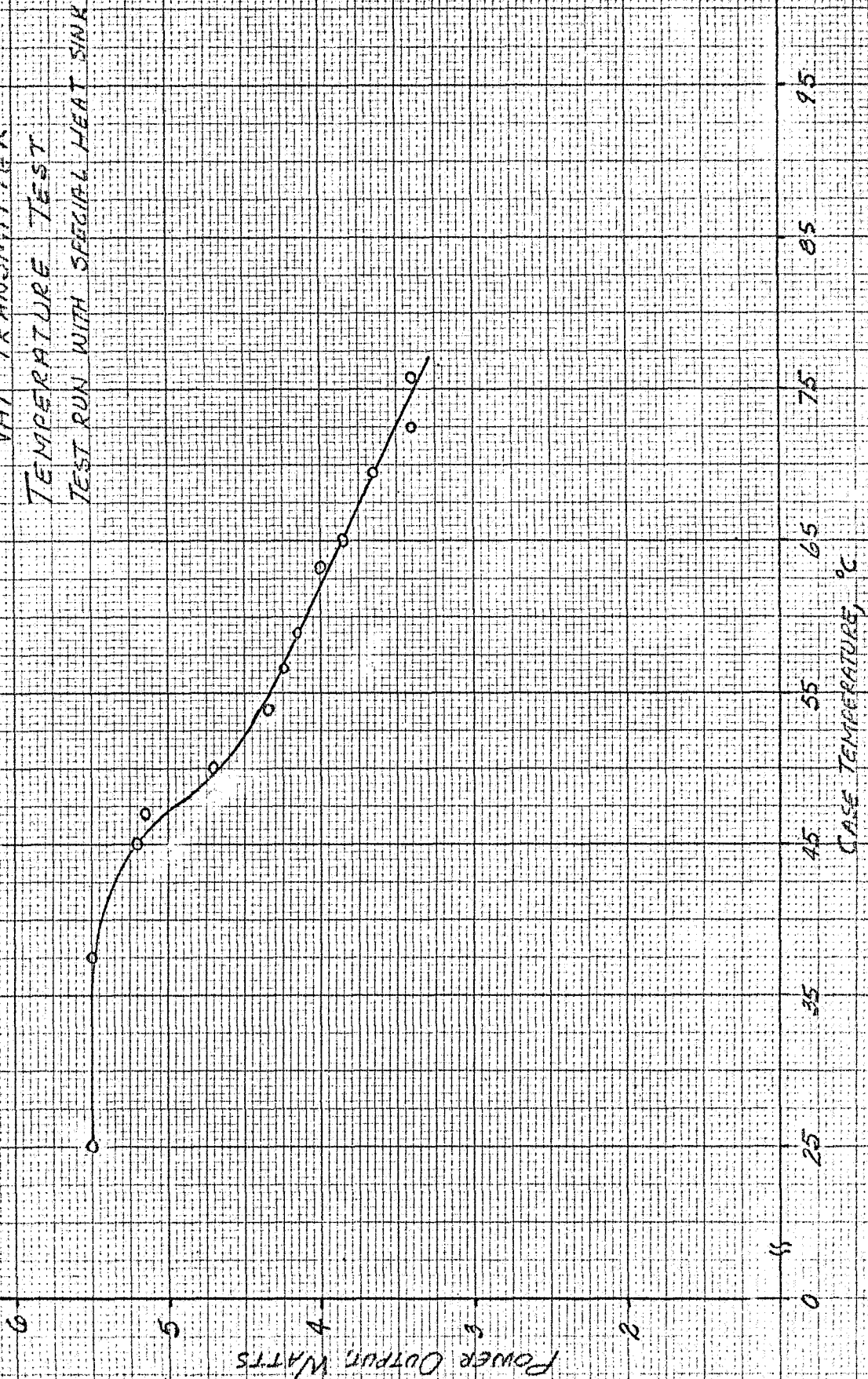
7.2 VACUUM TESTS

The purpose of the vacuum tests was to evaluate portions of the vehicle equipment under conditions of simulated high altitude to determine operational possibilities without pressurization. Three assemblies were tested -- the station tracking transmitter, the station control receiver, and one tracking receiver.

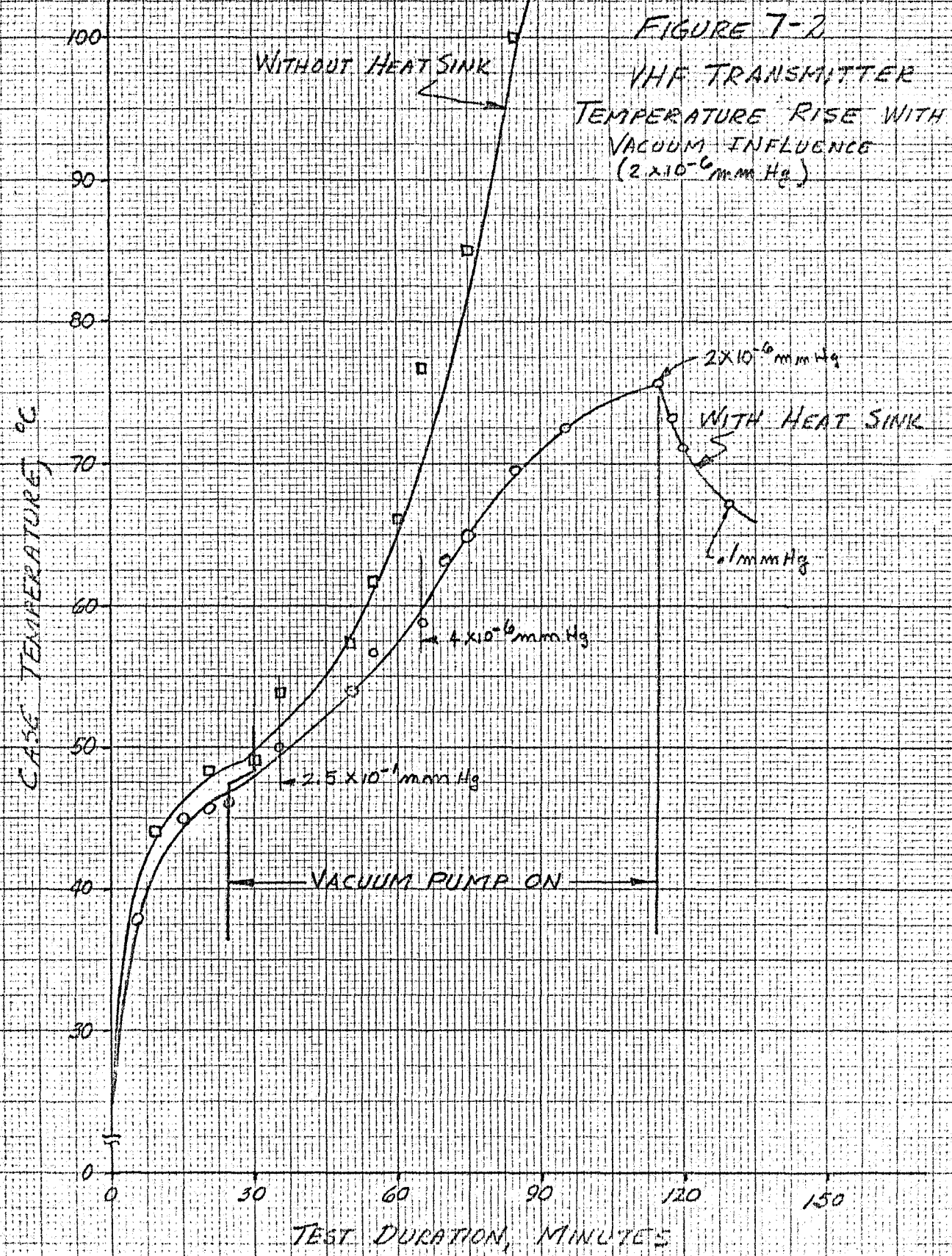
7.2.1 Station Control Transmitter

While preliminary tests indicated that the station control transmitter would operate for extended periods at atmospheric pressure without additional heat sinking, operation in the vacuum chamber indicated that additional heat sinking was required. After a new

FIGURE 7-1
VHF TRANSMITTER
TEMPERATURE TEST
TEST RUN WITH SPECIAL HEAT SINK



MADE IN U. S. A.
20 X .20 PER INCH



heat sink was assembled, a second vacuum test run was made. No corona effects were noted at any pressure. However, any vacuum effects on power output were masked due to the temperature rise of the transmitter. Subsequently, a third run was made in which power was applied and readings taken, at discrete intervals, thus maintaining the transmitter temperature at approximately 25°C. The test data is given in Table VII-3. No degrading effects were noted whatsoever in either power output or spectrum shape during the vacuum run.

7.2.2 Vehicle Tracking Transmitter

The vehicle tracking transmitter, tested under the same conditions as the station control transmitter, showed a very minor decrease in power output at the higher vacuums. This was most likely due to a slight detuning effect. The overall effects of vacuum, felt to be nearly insignificant, are given in Table VII-4. The test setup used for both transmitters is shown in Figure 7-3.

The vacuum test on the S-band diplexer (breadboard) was carried out separately from the transmitter using a CW signal with the hookup shown in Figure 7-4. The results of the test are summarized in Table VII-5. The unit apparently fails due to corona, partial shorting, or detuning, over the middle portion of the vacuum range. At pressures below 200 microns, the effect is not self-sustaining; that is, if the signal is removed and then reapplied, operation is normal. The test could be repeated at will, indicating that no permanent damage was inflicted upon the diplexer. A plot of the output power versus pressure is given in Figure 7-5.

7.2.3 Vehicle Tracking Receiver

The channel C receiver (Carrier Tracking Loop, Modulation Tracking Loop, and Code Control frames) was tested in the vacuum chamber utilizing breadboard components as shown in Figure 7-6. Tests were conducted at atmospheric pressure and at 10^{-6} mm of mercury for acquisition and tracking thresholds, acquisition times, and carrier loop and transfer loop SPE. The data taken

is summarized in Table VII-6. No significant effects of the vacuum were noted. The increase in L-code acquisition time at high vacuum conditions is apparently a chance happening. The manner of conducting the test permitted the timer to start at some time after L-code search had started. Any time measurement under 2.5 seconds is perfectly satisfactory.

TABLE VII-3. VHF Transmitter Vacuum Test

Chamber Pressure mm Hg	Output Power		Unit Temperature °C
	Watts	dbm	
760	5.7	+37.6	27
2.5 x 10 ⁻¹	5.7	+37.6	27
1 x 10 ⁻²	5.7	+37.6	28
1 x 10 ⁻³	5.7	+37.6	29
1 x 10 ⁻⁴	5.7	+37.6	30
0.2 x 10 ⁻⁵	5.7	+37.6	29

TABLE VII-4. S-Band Transmitter Vacuum Test Data (without TWTA)

Chamber Pressure mm Hg	Output Power dbm	Carrier Null db	Unit Temperature °C
760	+8.0	-40	27
2.5 x 10 ⁻¹	+8.0	-40	27
1 x 10 ⁻²	+7.9	-40	27
1 x 10 ⁻³	+7.9	-40	27
1 x 10 ⁻⁴	+7.9	-40	27
0.2 x 10 ⁻⁵	+7.8	-40	27

TABLE VII-5. Diplexer Vacuum Test Data

Chamber Pressure mm Hg	Power Output dbm
760	+36.3
0.8 x 10 ⁻³	+36.3
0.5 x 10 ⁻³	+23.0
0.2 x 10 ⁻³	+20.0

TABLE VII-5. Diplexer Vacuum Test Data (cont)

Chamber Pressure mm Hg	Power Output dbm
1 x 10 ⁻⁴	+17
0.7 x 10 ⁻⁴	+16.5
0.5 x 10 ⁻⁴	+17
1 x 10 ⁻⁵	+19
3 x 10 ⁻⁶	+26
2.5 x 10 ⁻⁶	+36.3

TABLE VII-6. Receiver Vacuum Test Data

	Atmospheric Pressure	10 ⁻⁶ mm Hg Chamber Pressure
L-Code Acq.	-129 dbm	-128 dbm
H-Code Acq.	-126 dbm	-126 dbm
L-Code Track	-132 dbm	-132 dbm
H-Code Track	-129 dbm	-129 dbm
L-Code Acq. Time		
-90 dbm	1.75 Sec.	1.96 Sec.
-100 dbm	1.60 Sec.	1.93 Sec.
-110 dbm	1.33 Sec.	1.87 Sec.
-120 dbm	1.56 Sec.	1.77 Sec.
-125 dbm	1.28 Sec.	1.87 Sec.
H-Code Acq. Time		
-90 dbm	0.20 Sec.	0.08 Sec.
-100 dbm	0.20 Sec.	0.15 Sec.
-110 dbm	0.22 Sec.	0.38 Sec.
-120 dbm	0.16 Sec.	0.16 Sec.

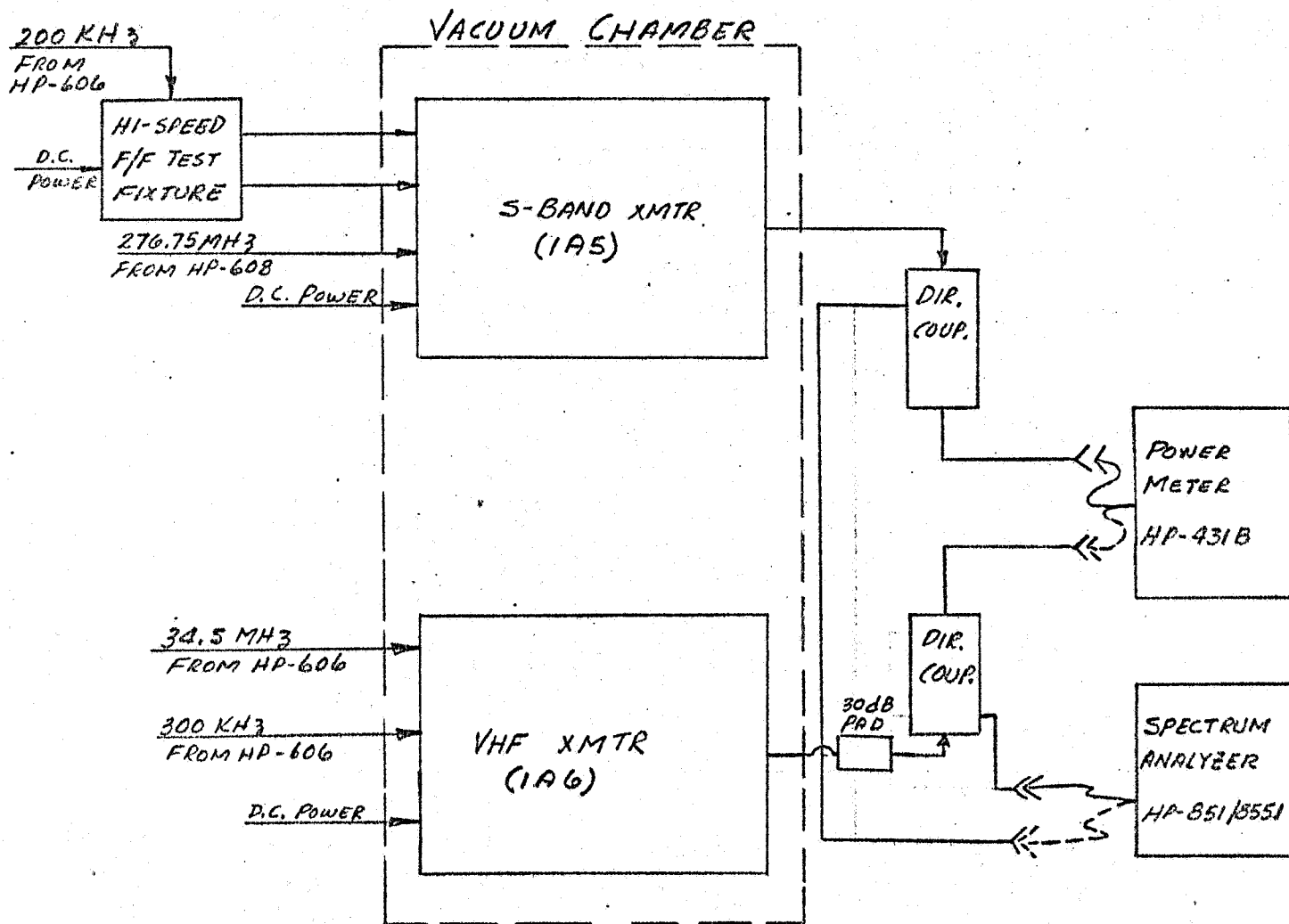


FIGURE 7-3
 VACUUM TEST SETUP
 VEHICLE TRACKING TRANSMITTER (1A5)
 STATION CONTROL TRANSMITTER (1A6)

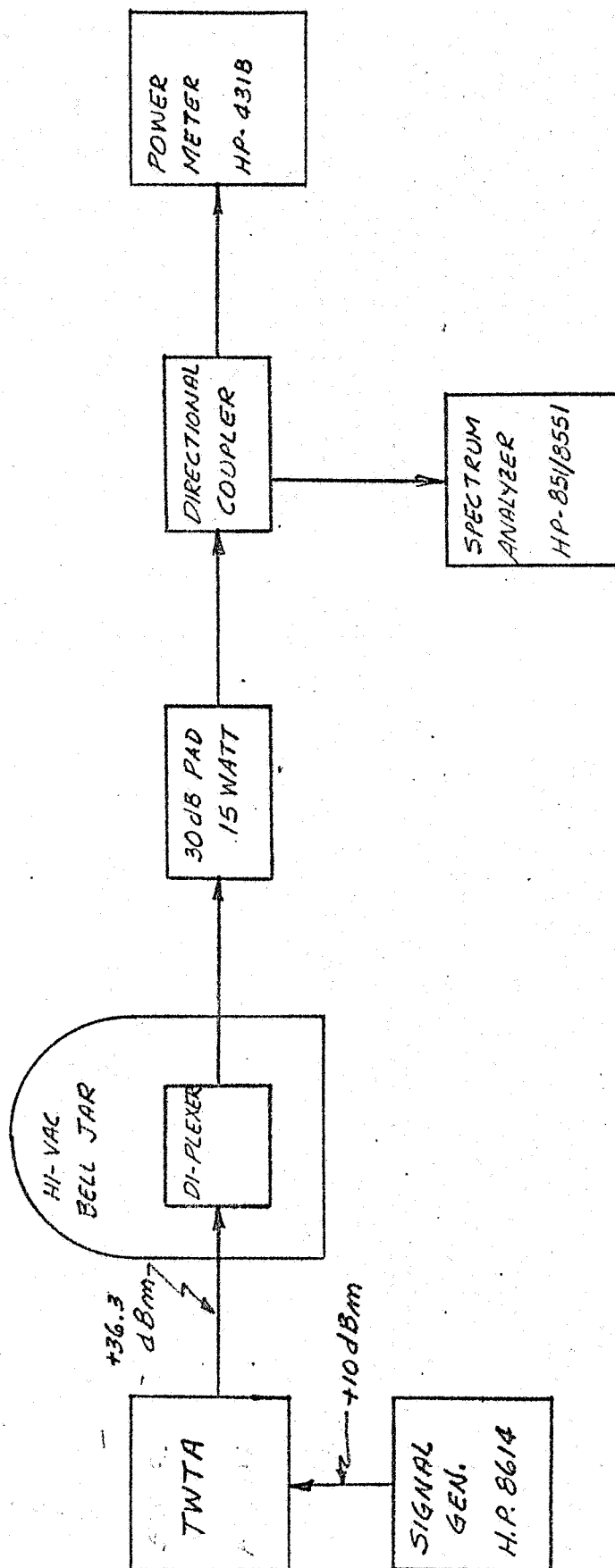
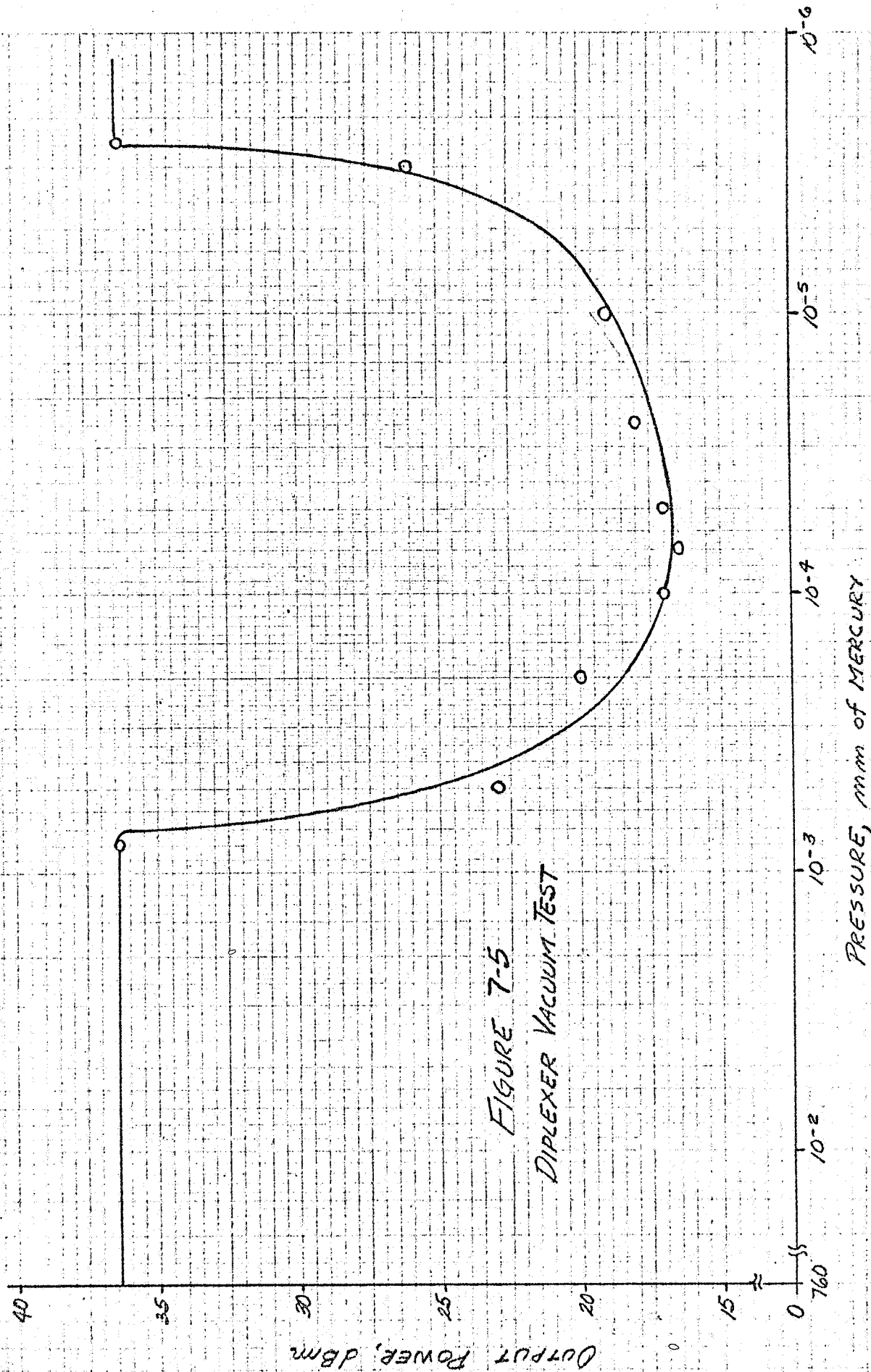


FIGURE 7-4
TEST SETUP, 5-BAND DIPLEXER



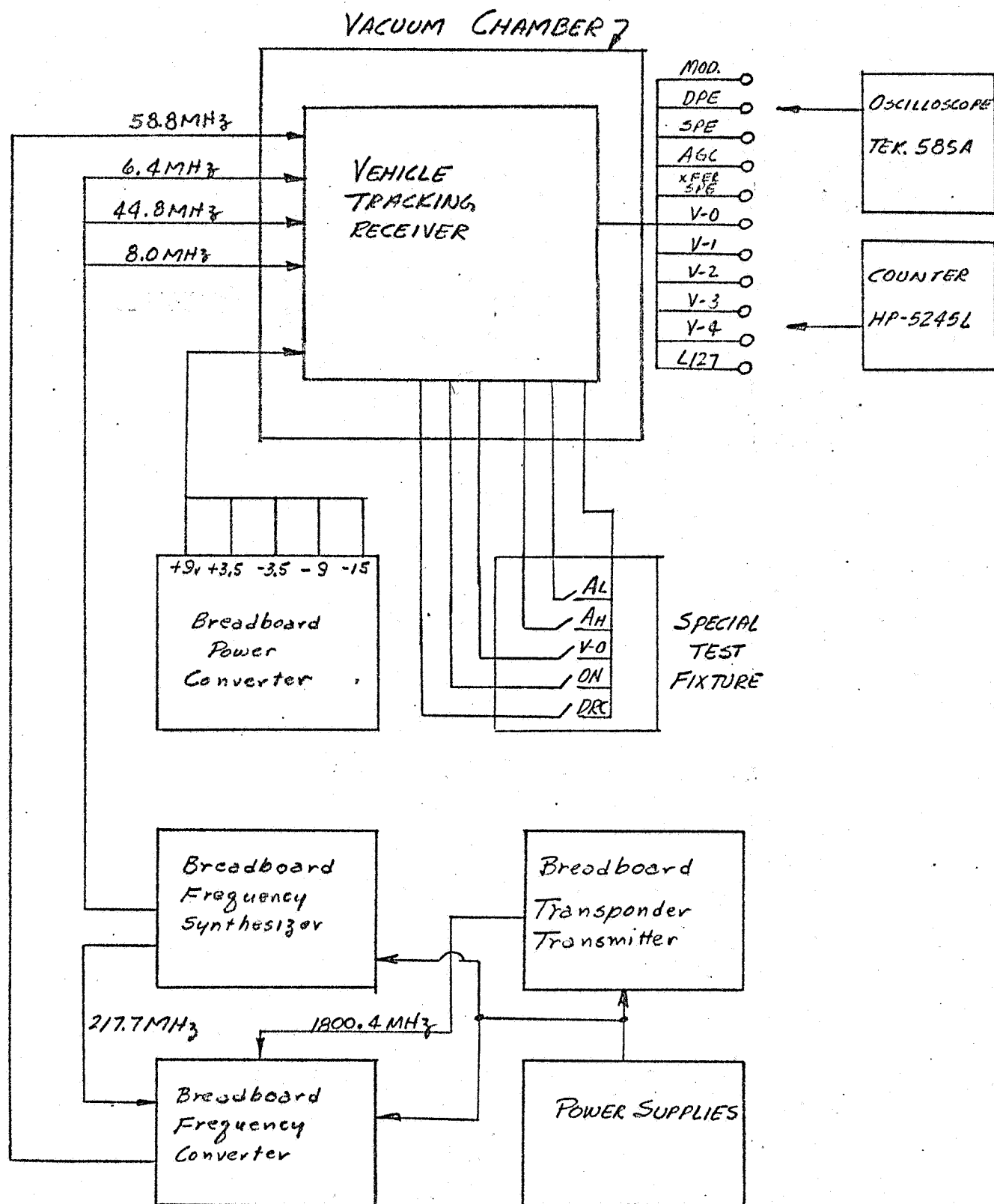


FIGURE 7-6
VEHICLE RECEIVER
VACUUM TEST SETUP

SECTION VIII

8. LONG TERM EFFECTS

In order to determine whether the more critical characteristics of the AROD system were subject to drift as a result of aging, measurements of selected parameters were repeated at approximately one-month intervals over the 6-month course of the Test and Evaluation program. These parameters were, for the vehicle equipment:

1. S-band transmitter power
2. VHF transmitter power
3. Acquisition and tracking thresholds
4. Vehicle range delay
5. Master oscillator frequency

and for the transponder equipments:

1. Transmitter power outputs
2. VHF receiver thresholds
3. S-band receiver thresholds
4. Master oscillator frequencies

8.1 VEHICLE SUBSYSTEM

8.1.1 S-Band Transmitter

The S-band transmitter power output measured without TWTA, showed a gradual decline of 0.3 dbm during the program, the original output of +8.1 dbm dropped to +7.8 dbm. This small decline would be completely eliminated by the limiting action of the TWTA. No discernable change in the output spectrum shape was observed.

8.1.2 VHF Transmitter

The VHF transmitter performed without incident during the test program. The power output readings showed a minimum of +37.5 dbm and a maximum of +37.7 dbm. This is so small a difference that it could be entirely in the instrumentation.

8.1.3 Acquisition Thresholds

The initial acquisition thresholds of -129 ± 1 , dbm in L-code and $-126, \pm 1$, dbm in H-code were held without problem through the first 3 monthly drift measurements. After these measurements were made, the demodulators were desensitized by 2 to 4 db, in an effort to reduce the acquisition of code spurs. This was later discovered to be an erroneous procedure. The range loop of each receiver was then correctly realigned, resulting in the restoration of thresholds to the previous levels along with good spur rejection. The final acquisition and tracking thresholds are presented in the table below.

TABLE VIII-1.

Channel	L-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Acquisition Threshold	H-Code Tracking Threshold
A	-130 dbm	-132 dbm	-127 dbm	-129 dbm
B	-129 dbm	-131 dbm	-126 dbm	-128 dbm
C	-131 dbm	-133 dbm	-127 dbm	-129 dbm
D	-131 dbm	-133 dbm	-125 dbm	-128 dbm

These readings are within about ± 1 db of the respective readings given for initial tests in Table IV-1 indicating no degradation over the 6-month period.

8.1.4 Vehicle Range Delay

Vehicle range delay was measured using the test setup shown in Figure 8-1. The data taken on each receiver over the six months program shows a variation in range delay of from 0.9 meter on channel A to only 0.15 meter on channel D. This can be seen by comparing the final data given below to that of Table III-1. It is felt that much of the variation (especially in channels A and B) was due to the realignment of the range loops as described in para. 8.1.3 and that the variation shown for channel D is more representative of system drift. Note the close correlation between

VEHICLE EQUIPMENT

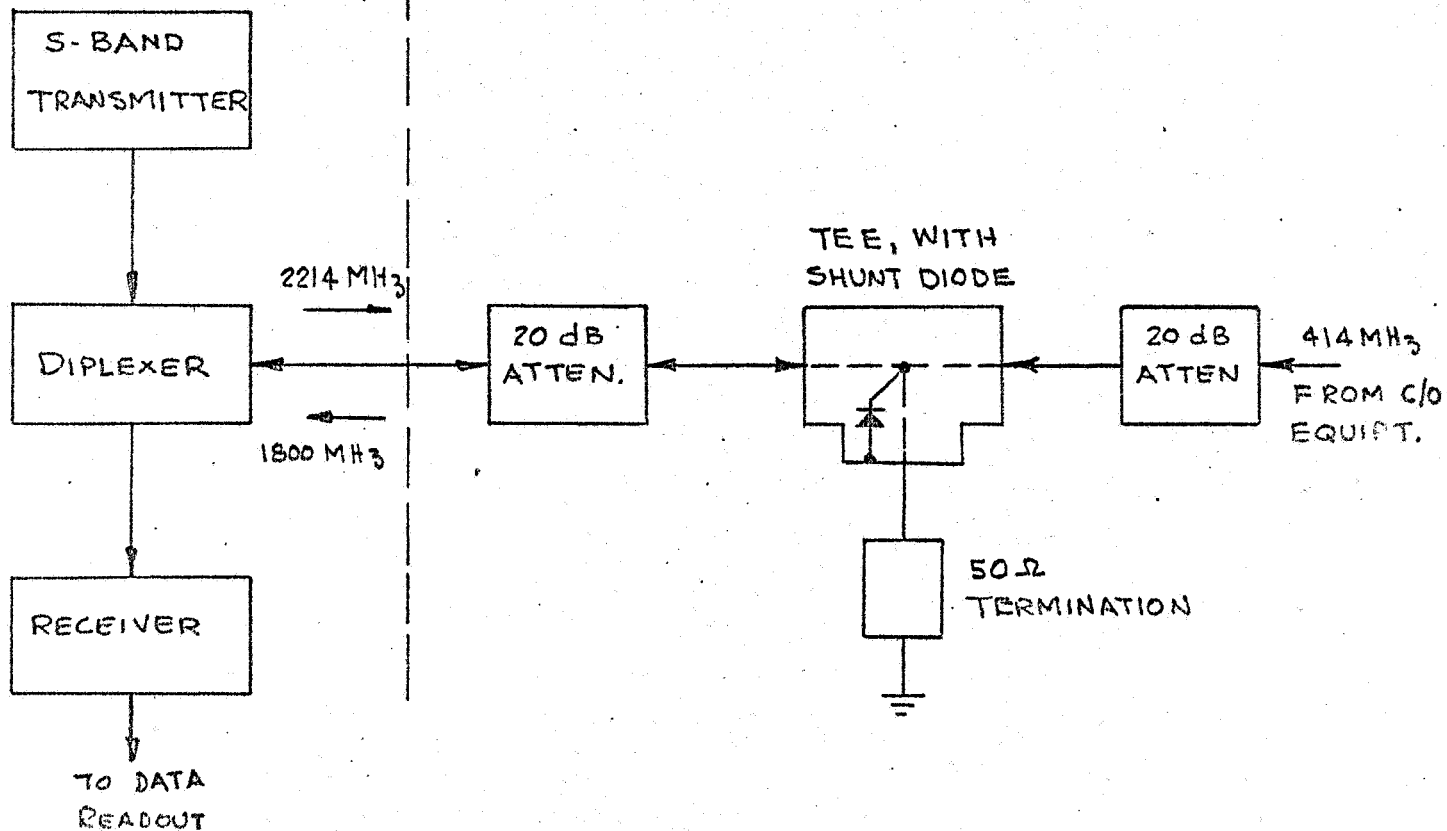


FIGURE 8-1
VEHICLE SYSTEM DELAY
TEST SETUP

channels in the data below, which is not true in the data of Table III-1, the latter data having been taken before range loop realignment.

FINAL VEHICLE RANGE DELAY DATA

<u>Channel</u>	<u>Delay, Meter</u>
A	51.24
B	51.50
C	51.40
D	51.48

8.1.5 Vehicle Master Oscillator

The vehicle master oscillator showed excessive drift (0.7 Hz high) near the beginning of the test program and had to be re-adjusted to permit system operation. Following this adjustment, a drift of less than 0.1 Hz per month has been noted. The original drift problem can therefore be attributed to an initial crystal aging and stabilization period.

8.2 TRANSPONDER SUBSYSTEMS

8.2.1 Transmitter Power Output

The first drift test readings indicated that a problem existed in the Acceptance Test readings which are listed in paragraph 2.1. A comparison of these readings is as follows:

<u>XPDR No.</u>	<u>Power Output (Para. 2.1.1)</u>	<u>Power Output Drift Test No. 1</u>
1	37.4 dbm	38.8 dbm
2	36.0 dbm	38.5 dbm
3	36.2 dbm	39.6 dbm

Throughout the test program, the power output measurements of each transponder were within a tolerance of ± 0.5 db. The incremental changes are of a random nature indicating more of a measurement problem than of transmitter power drift. We can conclude that there was no degradation of performance over the course of the test program.

8.2.2 VHF Receiver Threshold

The VHF receivers performed without incident during the test program. No drift was observed in thresholds -- a reading of -125 dbm ± 1 db would encompass essentially all readings for all three receivers. Even a good portion of this variation may be attributed to measurement accuracies.

8.2.3 S-Band Receiver Thresholds

As described in para. 8.1.3 there was some variation in thresholds which resulted from improper settings of L-code and H-code demodulators and range loop adjustments. As shown in the following table (the final drift test readings), all thresholds are within about 1 db of those of the initial tests in Table IV-1.

TABLE VIII-2

Transponder No.	L-Code Acquisition Threshold	H-Code Acquisition Threshold	L-Code Tracking Threshold	H-Code Tracking Threshold
1	-134 dbm	-125 dbm	-136 dbm	-129 dbm
2	-134 dbm	-124 dbm	-136 dbm	-128 dbm
3	-133 dbm	-124 dbm	-135 dbm	-128 dbm

In view of the fact that it is felt not possible to repeat readings with an accuracy of much better than ± 0.5 db, the remaining threshold drifts are quite insignificant.

8.2.4 Transponder Master Oscillators

No transponder master oscillator was ever found to depart by more than 0.1 Hz from a nominal 3,200,000.1 Hz. However, due to excessive short term jitter, the No. 1 transponder's Master Oscillator was replaced by a new Master Oscillator on 4/28/67.

SECTION IX

9. RECOMMENDATIONS FOR IMPROVEMENT

The following recommendations apply primarily to future AROD systems. While future systems may not be required to exhibit precisely the same characteristics as the present system due to differing missions, the basic points mentioned here should apply.

9.1 CHECKOUT EQUIPMENT INTERFERENCE

Some interference results from apparent inadequate buffering between the vehicle equipment and the checkout equipment under certain conditions. While the following defects could have been rectified by the addition of suitable buffering, the additional cost was not felt to be warranted for the present program.

9.1.1 Status Cable

When operating the vehicle with the checkout equipment and one or more transponders, transients may enter through the status cable to cause errors on the VHF transmission. These errors may cause a "Load Memory", "Load Memory Error", or "Return to T-0" command to be transmitted to the transponder. The latter causes the transponder to drop out of lock and return to "T-0". The problem has been circumvented by disconnecting this cable, when not required, from the vehicle package.

9.1.2 Carrier Loop Dynamic Phase Error (DPE) Test Points

The DPE test points brought over to the checkout equipment are unusable for two reasons due to pickup in the cable. The 100,000-ohm isolation resistors in the vehicle cause the signal to be reduced below the level of the noise in the cable. Therefore, the signal cannot be observed at the checkout equipment test points. Going the other direction, the 100,000-ohm resistors do not provide sufficient isolation, so that the operation of the carrier loop is adversely affected. During the test program these wires were disconnected at the vehicle end of the cable.

In future systems, better provisions from a line-driving standpoint should be made for checkout of system functions. Additional buffering should be provided -- not necessarily within the package, but possibly close to the vehicle connectors. Additional thought should be given to vehicle signals which need buffering to preserve waveshape and avoid crosstalk effects.

9.2 VHF SPECTRUM

Due to a probable error in the design of the VHF premodulation filter, modulation harmonics are present at the output of the transmitter which slightly exceed the permissible level. While this is satisfactory for laboratory use, the filter should be redesigned before the system goes into operation in the field. The fifth, and higher, harmonics of the 18.75 kHz modulation sub-carrier must be reduced, as they fall outside the permissible 75 kHz bandwidth of the 138 MHz carrier.

9.3 VELOCITY READOUT

Several problems are associated with the velocity readout system. These are described below.

9.3.1 Velocity Extractor Design Errors

Through design errors, two deficiencies were incorporated into the velocity extractors:

1. The wrong preset number was built in. This results in a fixed readout error or bias.
2. In order to determine precisely the last bit of velocity data, it is necessary to compare the phase of the counting signal at both the start and conclusion of the counting interval. As designed, the phase at the end of the interval only is inspected to determine the last bit. This is actually not sufficient information.

These two factors are somewhat inter-related in the velocity extraction process and it is not possible to eliminate the error entirely by altering the data reduction program.

9.3.2 Gross Velocity Extractor Fault

A possible intermittent part or connection apparently exists in circuitry providing gating signals to the velocity extractors. This results in occasionally measuring velocity over 12 L-code periods instead of the correct ten period with a resulting error of 3341.422 meters/sec. The data reduction program was set up to delete these readings as they occurred. A correction, unless the condition worsened, was felt to be unnecessarily expensive.

9.3.3 Velocity Jitter

Velocity jitter occurs as a result of short term instabilities in the r-f signals generated within the AROD system. These instabilities occur generally in the digital frequency synthesizers in both the vehicle and transponder equipments. Tests show that each synthesizer in the loop may contribute from 0.015 to 0.05 meter/sec of rms jitter to the total. For a further discussion of this problem, see Appendix A-2.

The problems listed above should obviously be cleared up in any new system. If possible, the vehicle synthesizer should be redesigned and rebuilt on the present system such that the best possible performance can be realized with the equipment, as shipped.

9.4 STATION CONTROL LOGIC/CODE CONTROLS

It is recommended for future systems that the station control logic and associated receiver and transmitter code controls be redesigned to permit independent operation of the code control units. This would allow the receiver to fully acquire the L-code and H-code prior to receipt of an ON command from the vehicle. Only the transmitter code control would be reset to T-0 by vehicle command. After the receipt of an ON command, the transponder could respond immediately with an L-code transmission, thereby reducing the system acquisition time by up to 2.5 seconds.

9.5 OPERATION IN A VACUUM

While not a necessity for the present system, it seems desirable to extend operation in future systems to operation in a vacuum. Not only would this permit a simplified case, if desired, but would also permit continued operation in the present configuration, if pressurization was lost. The present design is very close to this goal -- apparently only two or three factors need consideration.

1. Redesign S-band diplexer using higher dielectric spacings, potting compound, or foam.
2. Redesign frame structure of VHF transmitter for higher conductivity to base. The present design relies a great deal on convection and radiant heat transfer to adjacent frames to maintain a reasonable operating temperature. Without these heat loss paths (in a vacuum) the operating temperature will approach 80°C. This is a workable temperature, but performance is reduced, component stresses increased, and hence reliability may suffer considerably.
3. Item 2 may also apply to the power converter -- this frame was not tested. Testing in a vacuum would be required before making a decision, but it appears likely this frame might also require some redesign, as it is a high power assembly.

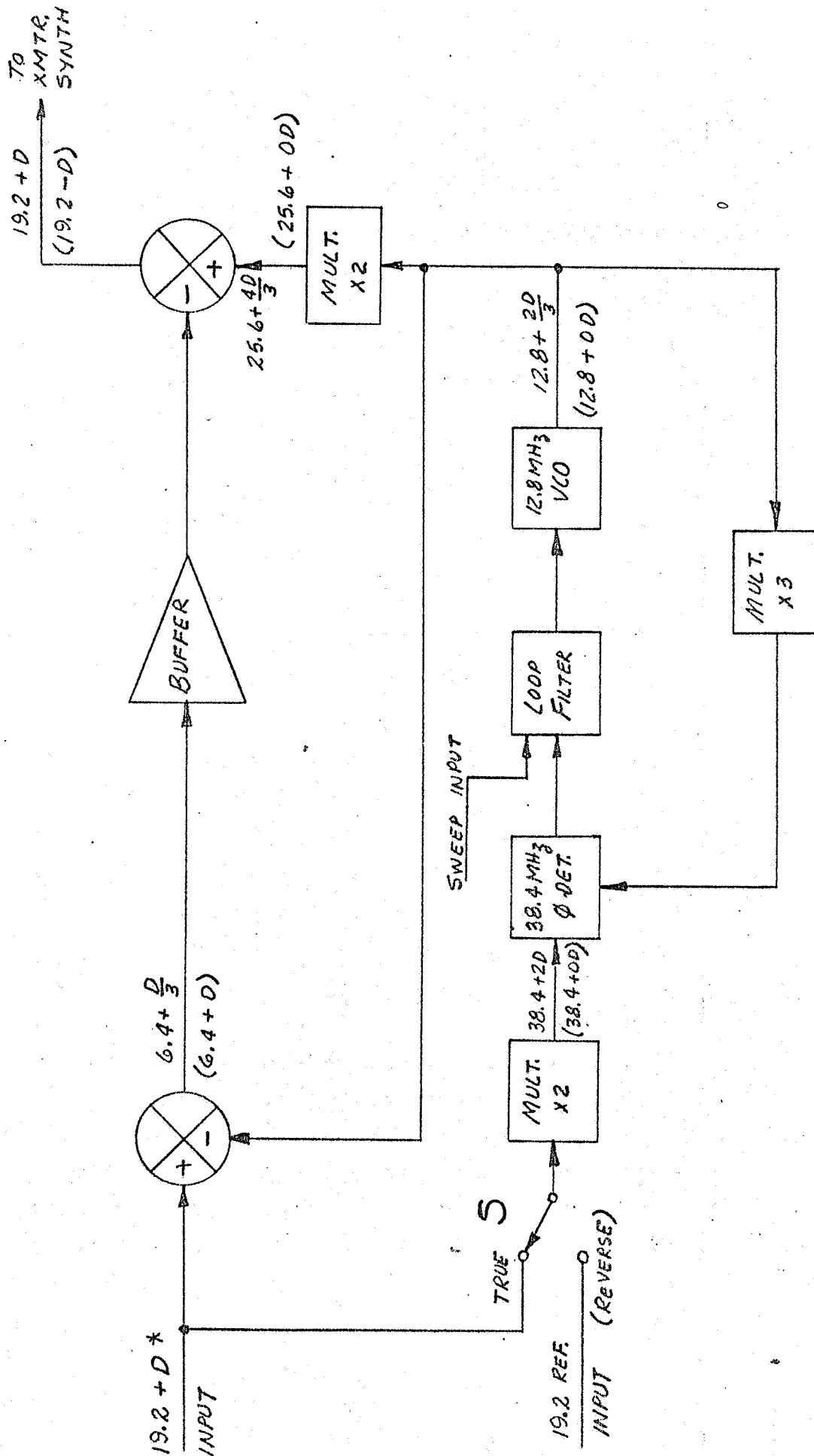
APPENDIX A-1

DOPPLER REVERSE IN THE AROD SYSTEM

The mechanism of Doppler reverse in the AROD System is best understood by inspection of the block diagram of Figure A1-1. The intent is that the transponder lock to the down-link S-band transmission and synthesize the up-link transmission with reverse Doppler, such that the received S-band signal at the vehicle contains zero Doppler. This enables a much more rapid acquisition sequence in the vehicle. After L-code is acquired, in the vehicle, the transponder sweeps the Doppler to the true condition. Referring to Figure A1-1, the $19.2 \text{ MHz} + \text{Doppler (D)}$ input is synthesized in the station TRACKING receiver. The 19.2 MHz reference is obtained from the transponder master oscillator ($3.2 \text{ MHz} \times 6$).

With the switch, S, in the REVERSE position, the Doppler is reversed to produce a $19.2 \text{ MHz} - \text{D}$ output. Throwing the switch, S, to the TRUE position produces an output identical to the input, $19.2 \text{ MHz} + \text{D}$. (D, of course, is a quantity which may be either positive or negative in itself.)

When using the wideband synthesizer (see para. 3.3.2) with Doppler simulated on the down-link, a slightly different mechanism is required. This is shown in Figure A1-2. In the laboratory, there is no Doppler effect on the up-link. Therefore, in the REVERSE mode, the transmitted signal must be at zero Doppler instead of "minus" Doppler. This is accomplished by using the 19.2 MHz reference synthesizer (para. 3.3.3) to produce a $19.2 \text{ MHz} + \text{D}/2$ signal. With switch, S, of Figure A1-2 in the REVERSE position, the output is precisely 19.2 MHz. With the switch in TRUE position, the output is $19.2 \text{ MHz} + \text{D}$ as before.



* FREQUENCIES IN MHZ,
D = DOPPLER OF 19.2 MHZ

FIGURE A1-1
DOPPLER REVERSE LOOP
SYSTEM IMPLEMENTATION

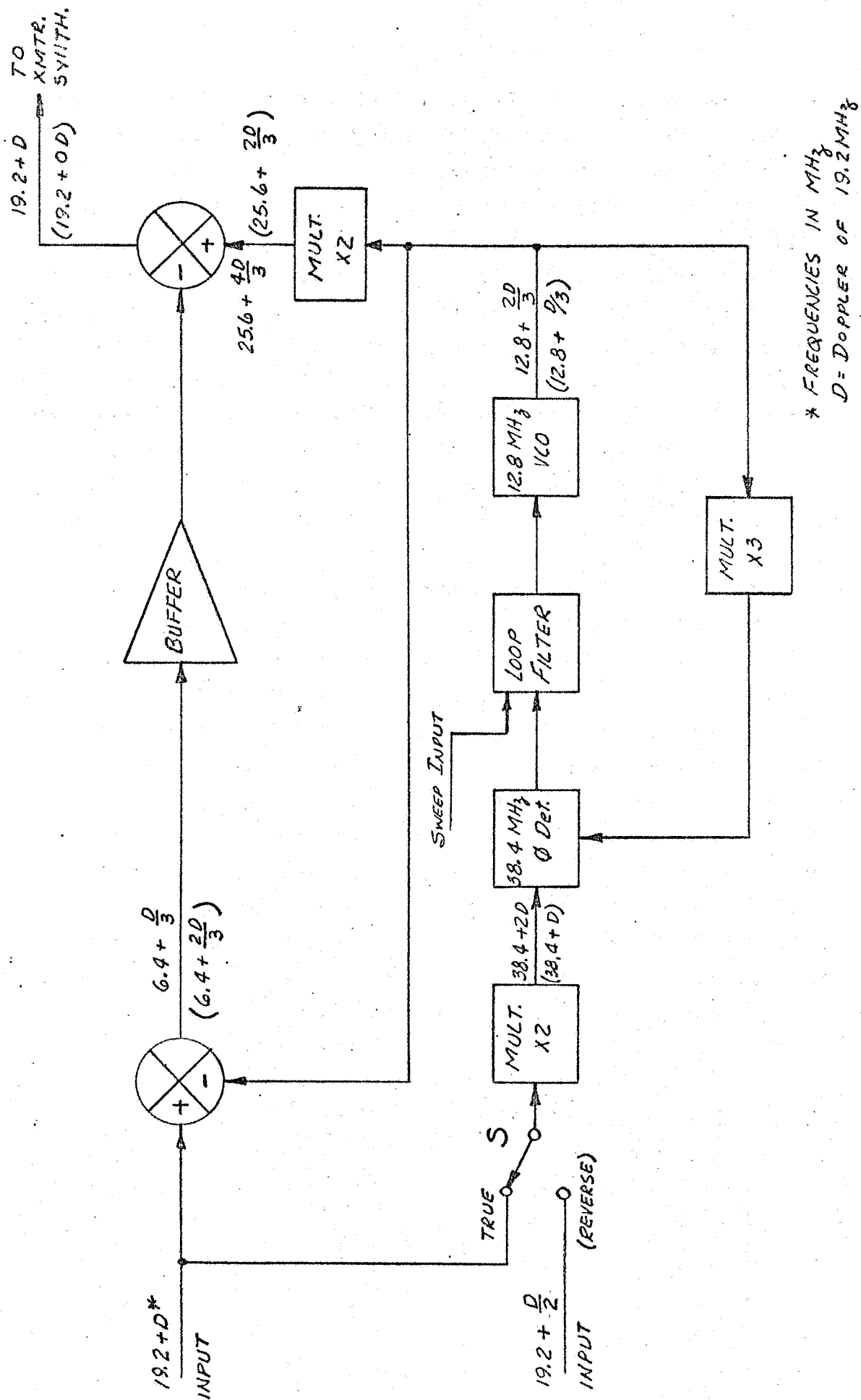


FIGURE A1-2
DOPPLER REVERSE LOOP
WIDEBAND SYNTHESIZER IMPLEMENTATION

The diagrams of Figures A1-1 and A1-2 are somewhat simplified in that additional circuitry is required to provide a controlled sweep of the L-band output frequency having a rate of approximately 40 kHz per second. This corresponds to a sweep rate of approximately 284 Hz per second at the 12.8 MHz VCO. A block diagram showing the original concept for sweeping the 12.8 MHz VCO is shown in Figure A1-3. With the transponder locked in state T-2, and prior to initiating Doppler reverse, the phase detector (ϕ_d) is at zero volts and the coherent amplitude detector (CAD) output is 1.0 volt. The transistor switch is shorted, permitting normal operation of the loop filter. Upon receipt of the "Track" command, the switch, S, of Figure A1-1 is switched to the TRUE position such that the 19.2 MHz input of Figure A1-3 changes from 19.2 MHz Ref to 19.2 MHz + D. The outputs of ϕ_d and CAD become beat notes (swinging around 0 volts) having a frequency of 2D with the CAD output lagging or leading the ϕ_d output in phase by 90° depending upon whether Doppler is positive or negative. The sign detector examines the polarity of the CAD at the phase detector plus-to-minus zero crossings and provides an output of "one" or "zero" depending on the Doppler polarity. The sign converter produces an output of plus or minus 1 volt depending on this input. The disappearance of the 1-volt steady state CAD output causes the transistor switch to open, removing the short on the loop filter input. The sign converter output is therefore applied to the loop filter input, driving its output to plus or minus saturation. This step output is integrated to a ramp by the action of R1, R2, and C to drive the 12.8 MHz VCO in the direction to reduce the frequency of the beat note to zero. At this point, the CAD goes to the 1-volt level, shorting the transistor switch, thereby disabling the sweep input. As the phase detector input is now zero volts, the loop remains locked. The CAD also provides a logic input to enable the DRC command which initiates transmission of the H-code by the transponder.

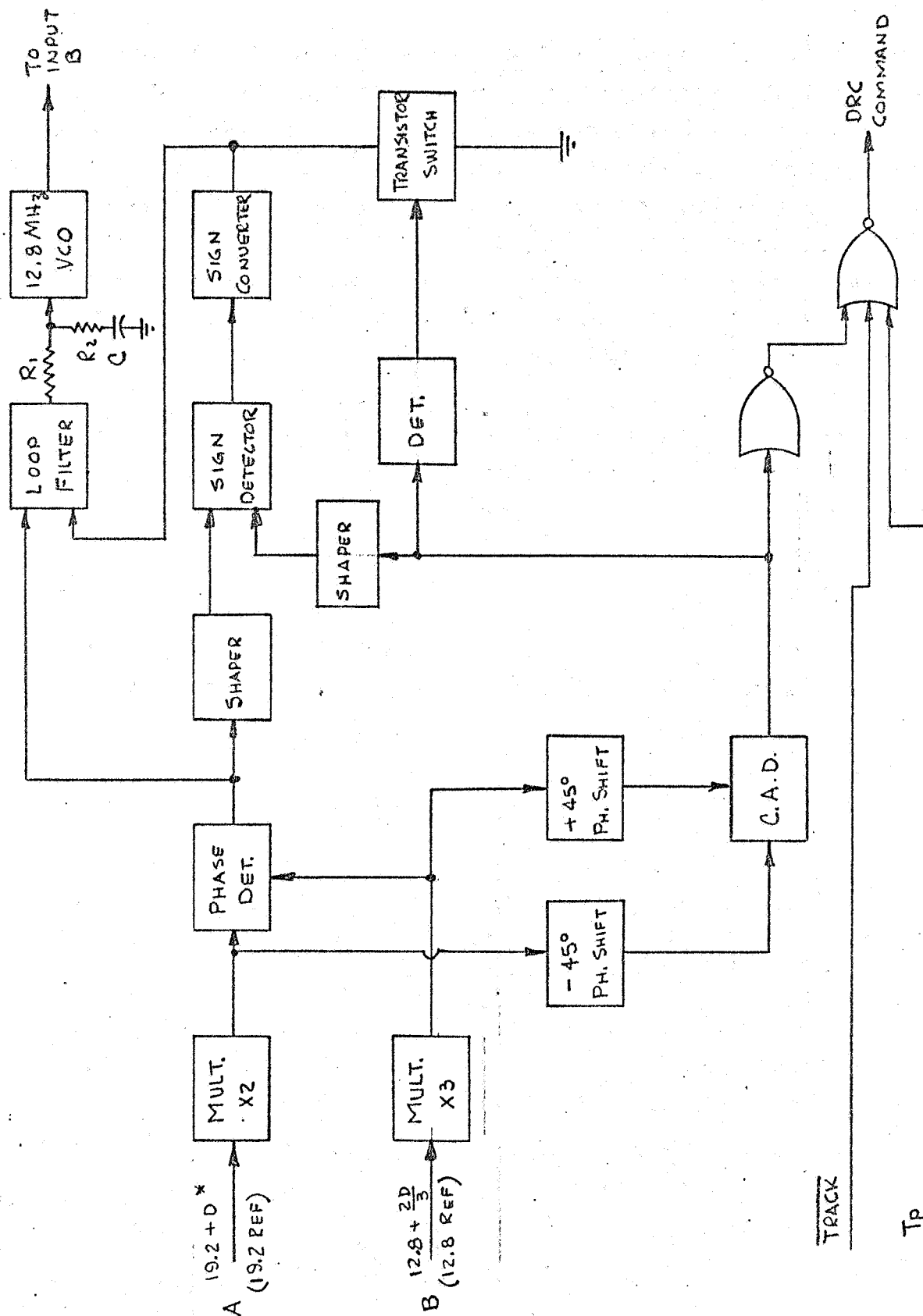


FIGURE A1-3
DOPPLER SWEEP GENERATOR

Several defects were noted in the system during laboratory evaluation. Operation was, at best, erratic. The problem stemmed mainly from transients during the reversing process which could not be tracked by the vehicle equipment. The loop filter R1, R2, and C produced a step of voltage at the start of the sweep and the DRC circuitry almost invariably caused a dropout at the end of the sweep by providing a DRC command and H-code application before the vehicle loops had settled. In addition, the sweep would restart and stop if transponder lock occurred at the phase detector zero crossing where the CAD output is -1 volt. This would immediately cause vehicle dropout, since the vehicle receiver had gone to the narrow bandwidth mode following the DRC transmission. Extensive revisions were required to correct these deficiencies.

The following steps were taken:

1. The loop filter was reconfigured to permit relocating R2 of Figure A1-3 to eliminate the initial step in the ramp.
2. The sweep signal level was reduced and the loop opened during the sweep (by shorting the input to the loop filter) to permit linear operation of the loop filter amplifier.
3. Logic was installed which allows stopping of the sweep signal only at those zero crossings of the phase detector at which time the CAD output is at a +1 volt level. This was done to prevent random restarts of the sweep.
4. Logic was installed to delay the opening of the transistor switch (Figure A1-3) for a finite period after application of the sweep voltage to permit stabilization.
5. Circuitry was added to maintain the Track signal at the "1" level for a finite time period to overcome a race problem between the Track signal and the CAD signal level.
6. The DRC signal was delayed for a finite time period to permit stabilization of the vehicle loop before it is commanded to state V-3.

Figure A1-4 is a block diagram of the revised Doppler sweep generator which accomplishes these steps. Typical waveforms are shown in Figure A1-5.

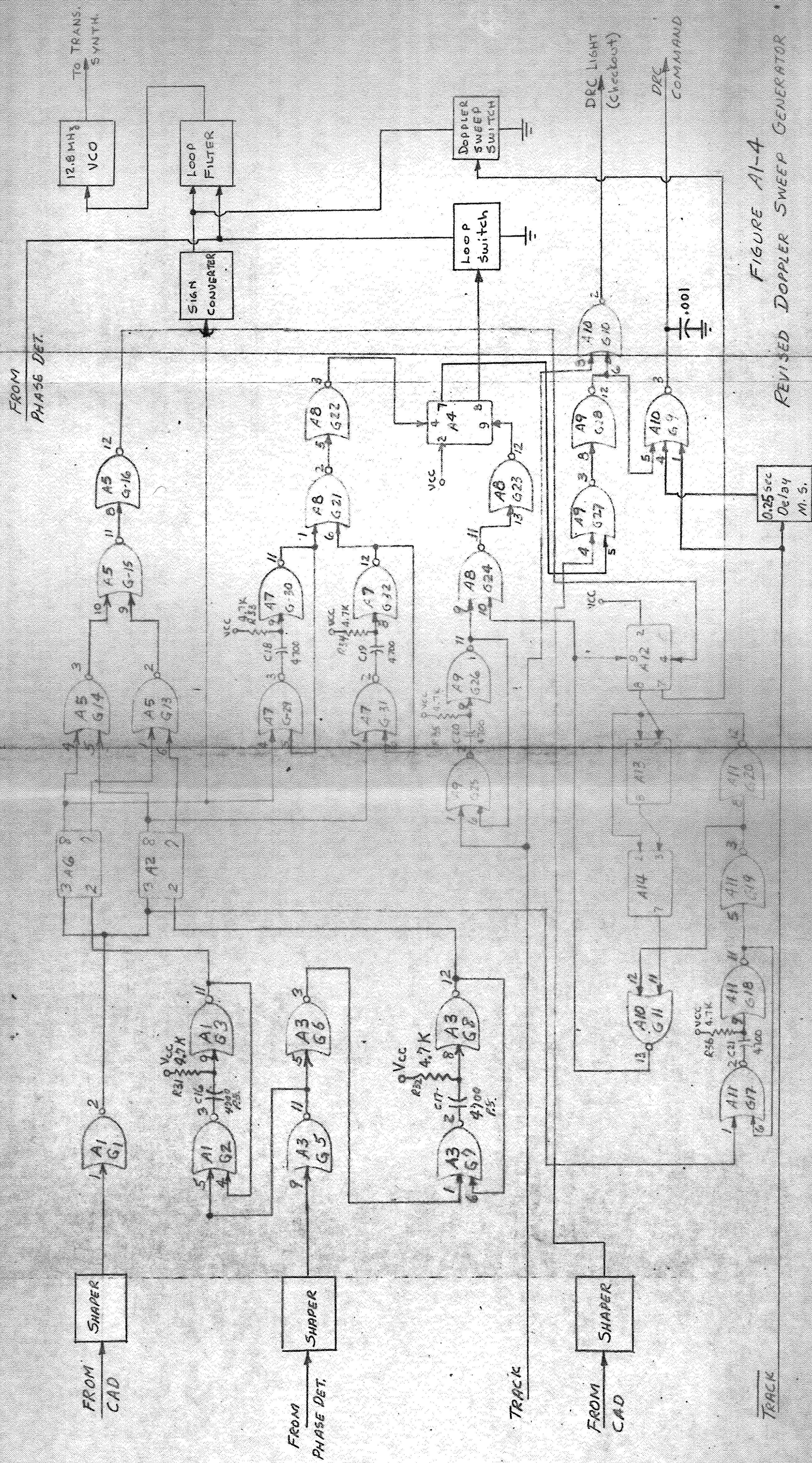


FIGURE A1-4
REVISED DOPPLER SWEEP GENERATOR

FOLDOUT FRAME 1

FOLDOUT FRAME 2

A1-9, A1-10

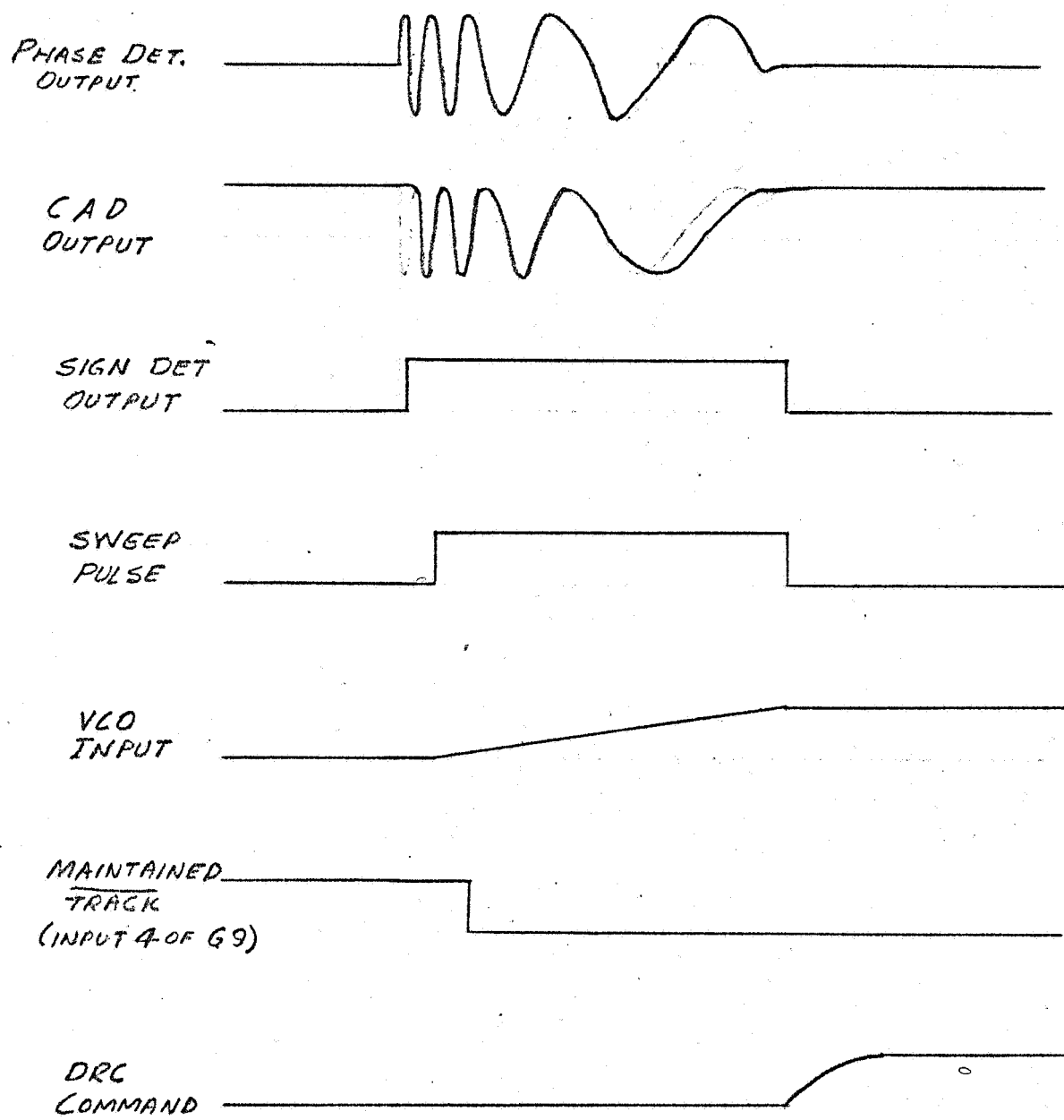


FIGURE A1-5
DOPPLER SWEEP WAVEFORMS

APPENDIX A-2

VELOCITY MEASUREMENT PROBLEMS

Probably the most serious problem encountered with the AROD equipments during the Laboratory Test and Evaluation Program was that of refining the velocity data to an acceptable error level. The velocity extraction process is based on counting the number of cycles of the frequency, f , occurring during ten L-code periods, or 202.8 milliseconds. The frequency, f , is 3.2 MHz, plus or minus eight times the Doppler frequency associated with 3.2 MHz. The counter is preset such that if the Doppler frequency is zero (velocity = 0) then the counter indicates a count of zero. Any jitter or frequency instability of the vehicle master oscillator, transmitter frequency, local oscillator frequency, or the transponder transmitter or local oscillator frequencies contribute to causing velocity readout errors. In other words, the jitter may be introduced in any of the S-band synthesized frequencies, which in operation are coherent with the vehicle master oscillator.

As an example, observe the plot of velocity data of Figure A2-1. These data were taken under conditions identical to those from which Figure 5-3 were plotted, the upper curve being the standard deviation and the lower, the mean. At this point in the test program, Transponder No. 1 had excessive jitter in its transmitter synthesizer. Transponder No. 2 was better, as can be seen in the plot of Figure A2-2. It is still much worse than that of Figure 5-3, however. A relatively minor design correction produced equivalent results in all three transponders.

The major improvements in velocity data resulted from the construction of new synthesizer loops for the vehicle transmitter frequency (2214 MHz) and the vehicle receiver local oscillator (1741.6 MHz). The original synthesizers were constructed as shown in Figure A2-3. The loop gain of each loop is about 100 and the noise bandwidth about 5 Hz. The breadboard synthesizers used

VELOCITY VS SIGNAL LEVEL
 VEHICLE CHAN. BCD-BM-BM
 WITH TRANSPONDER NO. 1
 ZERO VELOCITY (CORR. 14)

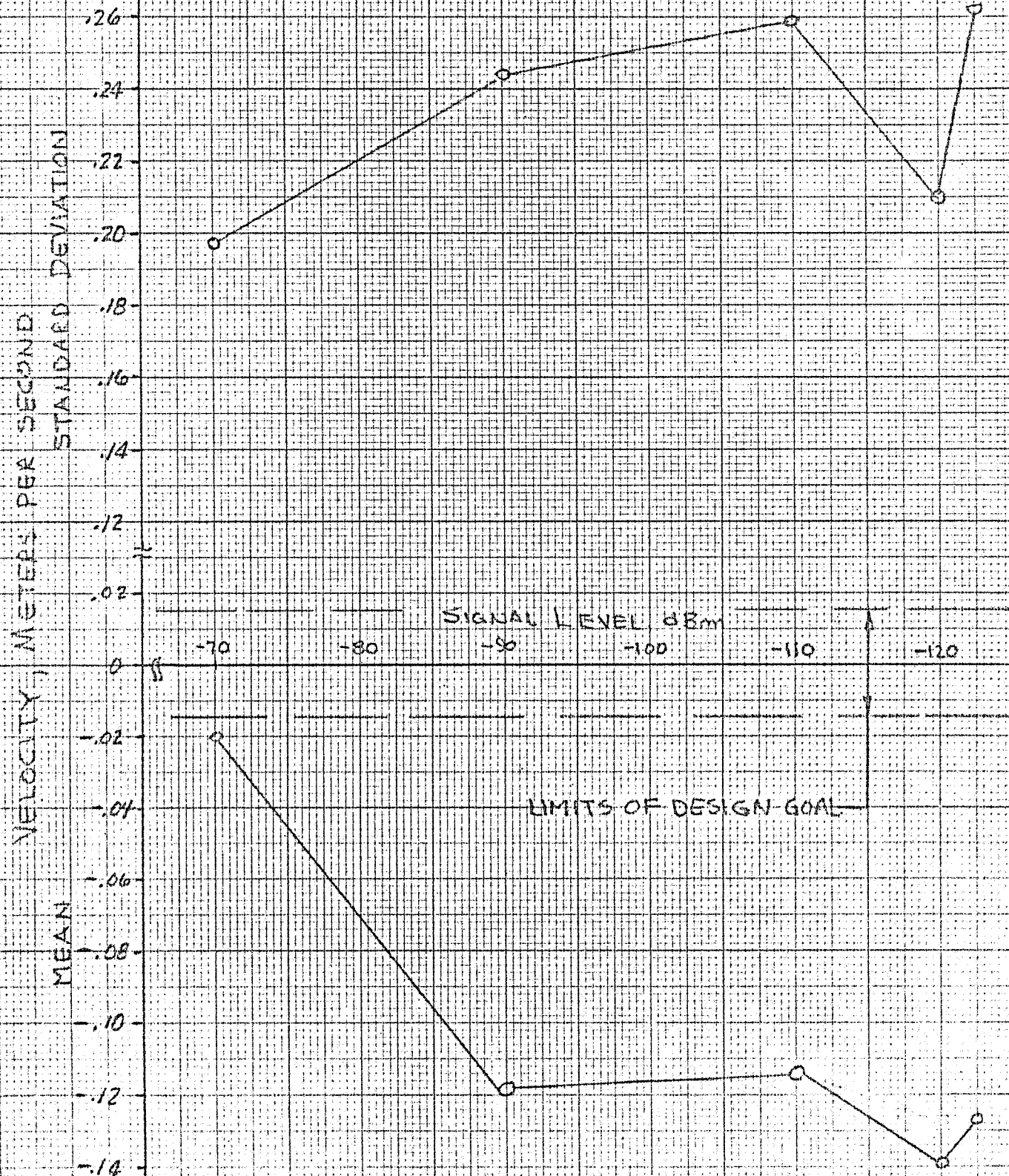


FIGURE A2-1

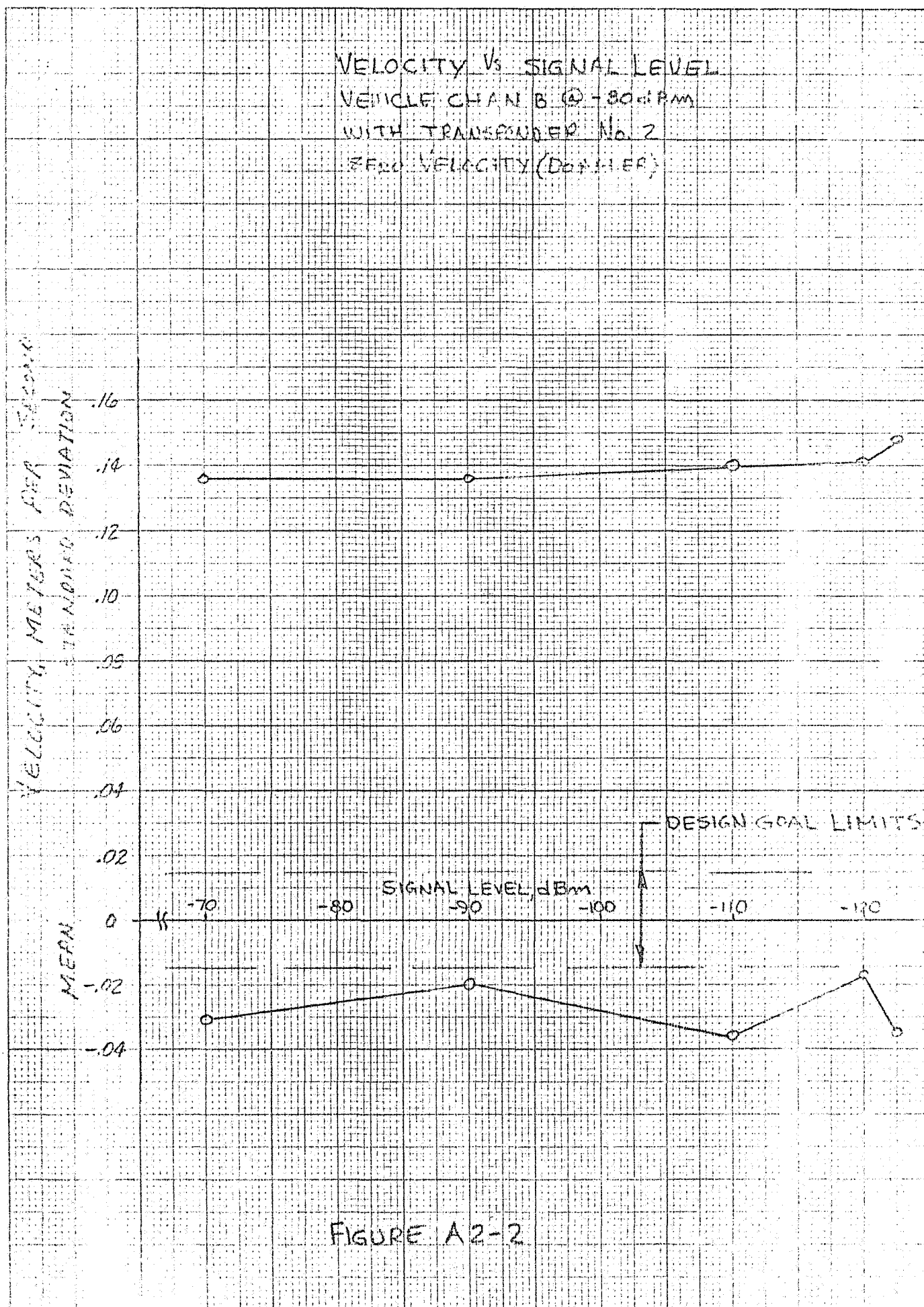
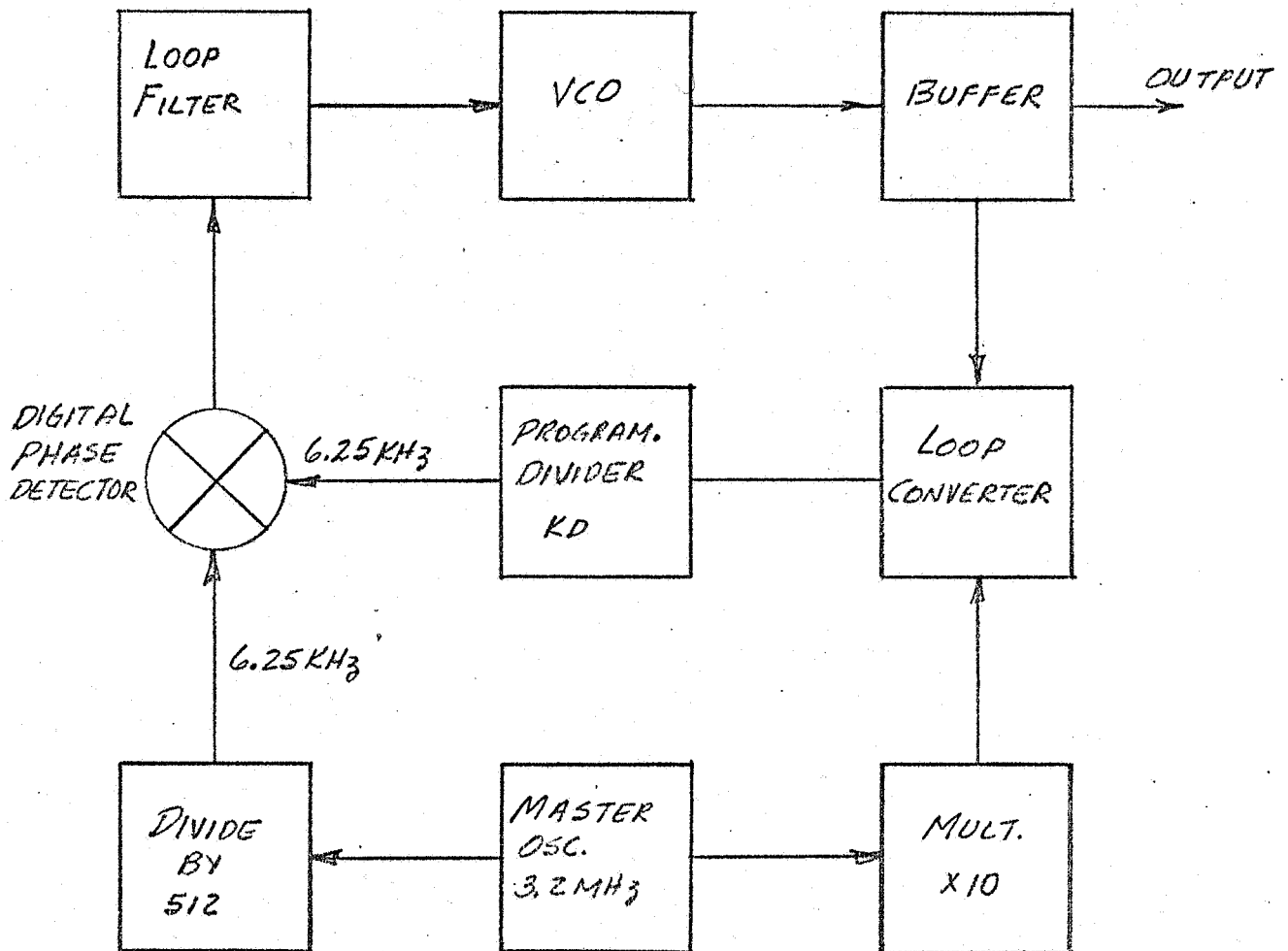


FIGURE A2-2

BLOCK DIAGRAM ORIGINAL VEHICLE SYNTHESIZER



FOR TRANSMITTER SYNTHESIZER

$$K_D = 415$$

$$VCO = 34.59375 \text{ MHz}$$

FOR L.O. SYNTHESIZER

$$K_D = 766$$

$$VCO = 27.2125$$

FIGURE A2-3

the loop configuration shown in Figure 3-4. In fact, the wideband synthesizer described in paragraph 3.3.2 was used as the vehicle transmitter synthesizer during the tests of paragraph 5.3. These loops have a loop gain of about 6400 and a noise bandwidth of about 100 Hz. Phase detection is performed at 400 kHz instead of 6.25 kHz.

The final data on velocity presented in Sections V and VI of this report utilized these external synthesizer loops. As the same type loop was originally utilized in the transponder transmitters, no refinements were made in them. The transponder receiver local oscillators are synthesized by multiply-and-add techniques and are felt to be relatively clean.

The final results of velocity test of Section V of this report showed results which were a factor of two to three times better than indicated in Figure A2-2. Any additional improvements are felt to be possible only through a complete redesign of the S-band frequency synthesis technique.