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FINAL REPORT

RESEARCH AND DEVELOPMENT OF INSTRUMENTATION PROGRAM EVALUATION OF BREADBOARD PROJECTILE AIRBURST AND IMPACT LOCATING SYSTEM (PAILS)

JUNE 1978

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The Projectile Airburst and Impact Locating System (PAILS) is a concept utilizing a trilateration radar network to locate the positions of airburst or ground impacts of artillery or mortar projectiles at proving-ground installations. This report describes tests conducted on a single breadboard radar (one of three required for a complete system) at US Army Aberdeen Proving Ground from 6 January 1975 to 8 May 1978. A description of the radar and its specifications is provided. Measurement of static and dynamic cont →

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ABSTRACT

The Projectile Airburst and Impact Locating System (PAILS) is a concept utilizing a trilateration radar network to locate the positions of airburst or ground impacts of artillery or mortar projectiles at proving-ground installations. This report describes tests conducted on a single breadboard radar (one of three required for a complete system) at US Army Aberdeen Proving Ground from 6 January 1975 to 8 May 1978.
A description of the radar and its specifications is provided. Measurement of static and dynamic performance is described. It is concluded that: sufficient data is not available to assess the capability of the PAILS concept; the cause of the inability of the breadboard PAILS to lock-up on the terminal portion of the trajectory is unknown; additional tests of the breadboard PAILS will require 5,000 to 7,500 man-hours over a 1 year period; the risk is high that additional tests would not provide the required data; the payoff for TECOM test ranges is minimal; further testing is neither prudent nor justifiable. It is recommended that an alternative scoring approach be utilized.

FOREWORD

The Materiel Testing Directorate, US Army Aberdeen Proving Ground was responsible for procurement, contract monitoring, test planning, execution, and reporting. Mr. Ken Balliet contributed to the design of the data acquisition system and assisted in the operation and testing of PAILS. Mr. Palmer Paules was responsible for initial procurement, contract monitoring, and test planning.

SECTION 1. BODY

1. BACKGROUND

In response to a US Army Test and Evaluation Command (TECOM) requirement, Sanders Associates, Inc., Nashua, New Hampshire performed a design study (reference 1) for a projectile airburst and impact locating system (PAILS). This system is to be used to locate the position of artillery and mortar projectiles at airburst or ground impact and determine the time of flight of these projectiles. The study considered the use of optical, acoustic, and microwave techniques for meeting the requirements. The conclusion reached by the study was that the best approach would be a matrix consisting of three range-only radars linked by telemetry to a real-time computer. Each radar would independently acquire the projectiles and determine their range. The range data from the three radars would be processed in a dedicated minicomputer using 3-dimensional trilateration to obtain the spatial coordinates of the projectile. The projectile location would be used to update the positioning of the radar antennas. This tracking procedure would continue until the airburst or impact event occurs.

Based on the design study a 3-phase development program was initiated. Phase I consisted of detailed design and consideration of questions raised in the earlier design study (reference 2). Phase II involved the fabrication of a single radar to serve as an engineering breadboard. The breadboard was built using an excess AN/TPQ-32 forward area alerting radar (FAAR) for microwave components and shelter and a surplus MPQ-10 mortar locating radar for an antenna pedestal. Phases I and II were carried out by Sanders Associates during the period from 26 June 1973 through 13 December 1974 under contract DAAD05-73-C-0556. Phase III involved the field testing and evaluation of the breadboard at US Army Aberdeen Proving Ground (APG) by Materiel Testing Directorate (MTD) personnel with Sanders Associates support during the period 6 January 1975 through 15 October 1976.

A study considering the utilization and implementation of a working PAILS at APG and US Army Yuma Proving Ground (YPG) is in reference 3. A similar study for US Army Jefferson Proving Ground (JPG) is in reference 4.

2. DESCRIPTION OF MATERIEL

2.1 INTRODUCTION

The breadboard PAILS is composed of the following major components: a system power supply, a microwave transmitter, a microwave receiver, a signal processor, an antenna, an antenna pedestal, a pedestal controller, and a system shelter. A system block diagram is in figure 2.1-1.

2.1 (Cont'd)

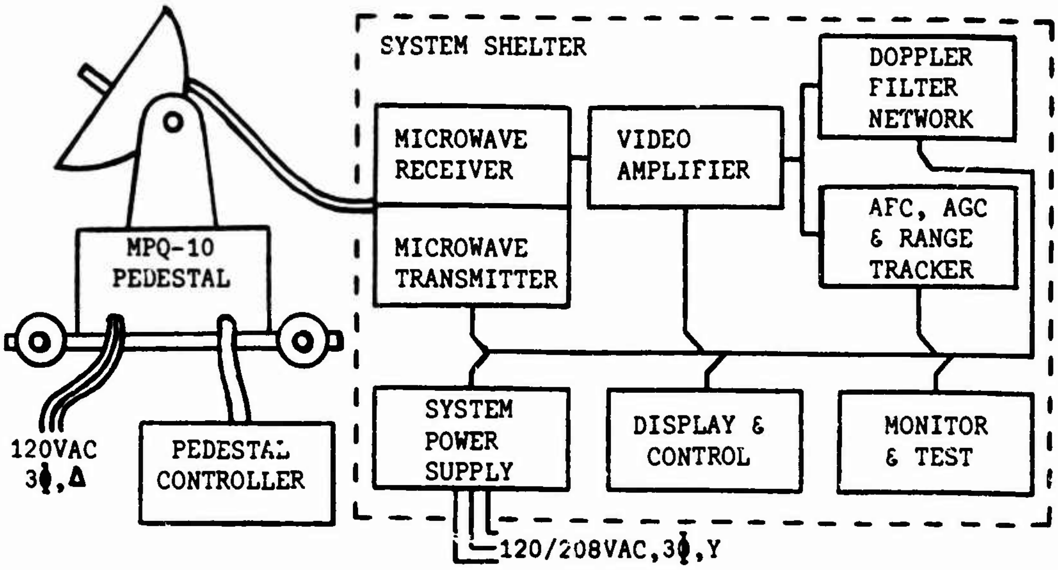

Figure 2.1-1. PAILS block diagram.

Block diagrams of the major subsystems shown in the system block diagram are in appendix B. A picture of the inside of the system shelter is in figure 2.1-2.

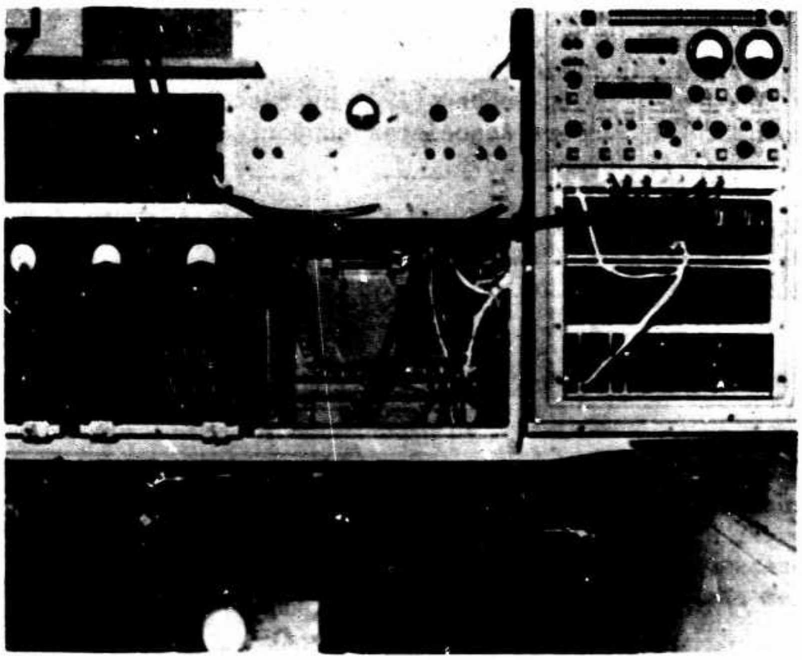

Figure 2.1-2. Electronics mounted in system shelter.

2.1 (Cont'd)

The microwave transmitter is at bottom center, the microwave receiver at top center, the monitor and test panel is below the receiver, the display and control panel is at top right, the signal processor is at right center, and the power supplies are at left center.

A picture of the antenna mounted on the MPQ-10 pedestal is in figure 2.1-3.

Figure 2.1-3. Antenna mounted on MPQ-10 pedestal.

A picture of the pedestal controller is in figure 2.1-4. The paper tape reader is at the top of the unit and MPQ-10 control panel at the bottom.

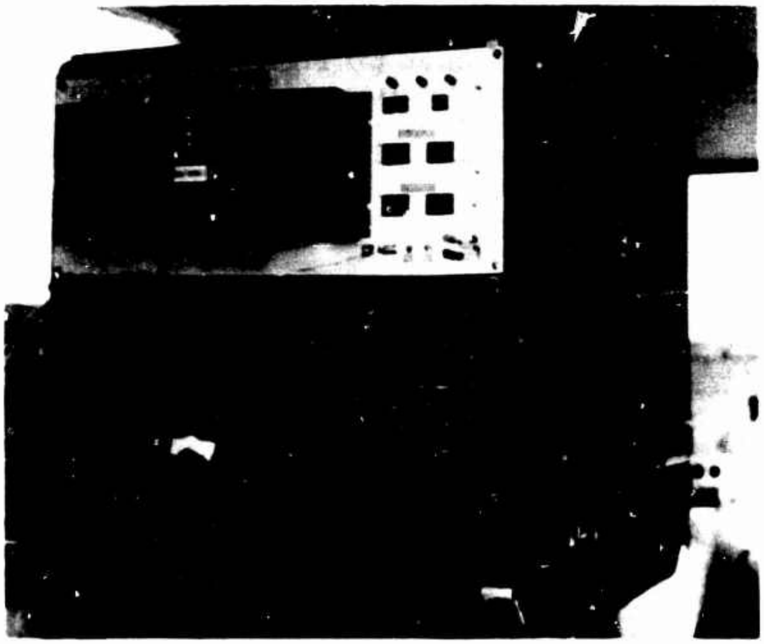

Figure 2.1-4. Pedestal controller.

2.2 SPECIFICATIONS

Power required - radar: 120/208-VAC, 400-Hz, 3-phase wye.
Power required - pedestal: 120-VAC, 60-Hz, 3-phase delta.

Radar power consumption: 2,000 watts.

Frequency: 1,280 MHz.

Average transmitter power: 120 watts.

Peak transmitter power: 5,000 watts.

Pulse width: 4.0 microseconds.

Pulse repetition rate: 6 kHz.

Power amplifier type: Travelling wave tube (TWT).

Receiver type: Homodyne.

Doppler bandwidth: 100 to 3,000 Hz.

2.2 (Cont'd)

Velocity range: 11 to 351 meters per second.

Instrumented range: 0.75 to 16 kilometers.

Digital range tracker resolution: ±0.125 meter.

Range tracker interface output: 14 binary bits (LSB = 1 m).

Minimum detectable signal (MDS): -179 dBW.

Subclutter visibility (SCV): -72 dB.

Antenna height: 9 feet to center of dish.

Antenna beamwidth (two way): 15° (contractor's specification - not verified).

Antenna gain: 15 dB (contractor's specification - not verified).

Signal monitor points: Video (Ch 1 and Ch 2).
Range gate trigger (Ch 1 and Ch 2).
Range gate doppler (Ch 1 and Ch 2).
Range gate multiplexer (Ch 1 and Ch 2).
Transmitter trigger.
Audio gain control
Audio frequency control.
Sensitivity time control
Correlator (Ch 1 and 2).
Range error.
Filtered doppler.

Monitor indicators: Power supply a-c input voltages meter.
Power supply d-c output voltages meter.
TWT parameters meter.
Processor power supplies and video balance meter.
Processor parameters meter.
STAMO level meter.
Range 5 digit light emitting diode (LED) display.
Mode indicator LED's.
Frequency analog LED display (Ch 1 and Ch 2).
Range tracker lock lights.
Doppler audio speaker.

Operator controls: Transmitter drive.
Video balance (Ch 1 and Ch 2).
Transmitter power.
Receiver gain.
Audio frequency.
Doppler audible monitor volume.

Audio gain.
Range slew.
Range error scale.
Range preset.
Range offset/calibration.
Range increment.
Fade.
Search frequency start.

2.3 DETAILS OF OPERATION

2.3.1 Antenna Tracking

Since only one of the three proposed radars was available, pointing the antenna in the correct direction was accomplished by using punched paper tapes (PPT). Prior to firing, a survey of the coordinates of the gun and the antenna was made. This information along with the type of weapon, charge, ballistic coefficients, direction of fire and range were input into a computer program. The program generated the projectile trajectory and the azimuth and elevation coding required for the PPT. The PPT provides 7 bits of data for azimuth and elevation. Azimuth is limited to 180° of rotation for 0.703° resolution per bit. Elevation is limited to 90° of rotation for 0.352° resolution per bit. The PPT reader is started by a signal from the gun at time of fire.

2.3.2 Radar Operation

The processor is designed so that the operation can be automatic after the controls have been preset and the transmitter has been placed in operation. Prior to firing of a round the acquisition range must be set to an appropriate value for the particular trajectory being fired and the processor reset for the acquisition mode. Once a signal is detected the processor then proceeds to acquire and range track the target automatically.

3. OBJECTIVES

The major objective of the APG test was to provide a realistic environment for the evaluation of the breadboard PAILS. It was desired to gather sufficient information to establish a basis for determining whether the PAILS approach provides a satisfactory solution to the problem of scoring artillery and mortar projectiles. In particular the performance was to be assessed by evaluating the following areas:

a. Acquisition and lock-up capability of the processor.

b. Digitally programmed antenna positioning capability.

c. Radar cross sections for different projectiles, trajectories, and radar positions.

d. Clutter rejection capability.

e. Minimum microwave power required.

f. Function signature for airburst and base ejection rounds.

g. Ability to track short fall projectiles.

h. Range accuracy.

i. Antenna polarization effects.

4. DETAILS OF STUDY

4.1 NONFIRING TESTS

The nonfiring tests were conducted to measure system performance and specifications under static or simulated conditions. The equipment used for these tests included a processor test set (PTS) (described in appendix C), a target and clutter simulator (TCS) (described in appendix D), a range target simulator (RTS) (described in appendix E), a microwave power meter, assorted microwave components, and standard laboratory instrumentation.

4.1.1 System Parameter Measurements

4.1.1.1 Transmitter Pulse Width. A direct measurement of the transmitted pulse was not possible. An indirect measurement was made by monitoring the beam pulse amplitude of the TWT. This measurement was made using an oscilloscope with a 50 ohm termination. The pulse width was 4.0 ± 0.1 microseconds.

4.1.1.2 Transmitter Repetition Rate. The transmitter pulse repetition rate was measured in the same way the pulse width was measured in paragraph 4.1.1.1. The repetition rate was 6.0 ± 0.1 kHz.

4.1.1.3 Transmitter Output Power. The transmitter average output power was measured using the setup shown in figure 4.1-1. The transmitter drive was peaked for maximum output power. The power meter readings and calculated average and peak output powers are shown in table 4.1-1.

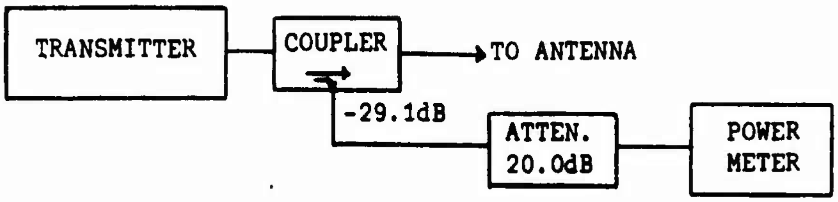

Figure 4.1-1. Transmitter output power measurement.

TABLE 4.1-1. TRANSMITTER AVERAGE AND PEAK OUTPUT POWER

Mode	Power Meter Reading (dBm)	Average Power Output (watts)	Peak Power Output (kilowatts)
A	1.4 ± 0.2	112 ± 5	4.67 ± 0.21
B	1.4 ± 0.2	112 ± 5	4.67 ± 0.21
C	1.3 ± 0.2	110 ± 5	4.58 ± 0.21
D	1.2 ± 0.2	107 ± 5	4.46 ± 0.21

4.1.1.4 Cable Losses. The losses in the transmitter and receiver cables going to the antenna were determined by measuring the power at each end of the cable. Output power from the stabilized master oscillator (STAMO) was used rather than full output power. A 20.0 dB attenuator was used at the input to the power meter. The power meter readings and calculated cable losses are in table 4.1-2.

TABLE 4.1-2. RECEIVER AND TRANSMITTER CABLE LOSSES

Measurement	Power Meter Reading (dBm)	Difference (dB)	Remarks
STAMO output	- 8.4	-3.0	Transmitter cable.
Antenna connector	-11.4		
Receiver cable input	-10.6	-6.0	Receiver cable.
Receiver input	-16.6		

4.1.1.5 Minimum Detectable Signal. The MDS is a measurement of the smallest signal which the receiver/processor can reliably lock onto in the automatic mode (the more negative the number the more sensitive the receiver). The measurement was made using the TCS with the connections of figure 4.1-2. The clutter and target channel attenuators were set for maximum attenuation and doppler frequency F4(1.7 kHz) was selected. The processor was placed in the automatic mode, the range was set at 1,700 m to evaluate channel 1, and the sensitivity-time control (STC) was turned off. The target channel attenuation was slowly decreased until a detection was indicated by the transition from search mode to coarse track mode. The setting of the target channel attenuator and the power meter reading of the target channel monitor were recorded. The MDS is then calculated to be:

Target channel monitor reading (-21 dBm)	= - 51 dBW
Target channel attenuation	= - 55 dB
TCS insertion loss (target channel)	= - 54 dB
Transmitter cable loss	= - 3 dB
Duty cycle factor (= 10 log $\frac{1}{0.000004 \text{ sec} \times 6 \text{ KHz}}$)	= - 16 dB
MDS (channel 1)	= -179 dBW

The procedure was repeated except that the range was set for 1,004 m to evaluate channel 2. The target channel attenuation was -50 dB at detection. All other factors were the same as for channel 1 so that the MDS for channel 2 was -178 dBW.

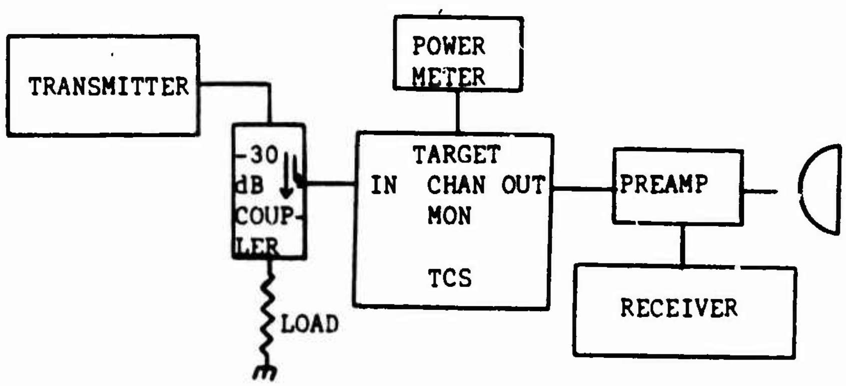

Figure 4.1-2. Connections required to measure minimum detectable signal.

4.1.1.6 Subclutter Visibility. The SCV is a measure of the ability of the processor to reject large clutter signals (the less negative the number the better the clutter rejection of the processor). The measurement was made using the TCS with the connections of figure 4.1-2 except that the power meter was connected to the clutter channel monitor. The clutter and target channel attenuators were set for maximum attentuation and the clutter channel phase was adjusted to be in phase with the transmitter. The processor was placed in the automatic mode, the range set for 1,500 m, and the STC control was turned off. The clutter channel attenuation was slowly decreased until a detection was indicated by a transition from search mode to coarse track mode. The setting of the clutter channel attenuator and the power meter reading of the clutter channel monitor were recorded. The clutter power is then calculated to be:

Clutter channel monitor reading (-9 dBm)	= - 39 dBW
Clutter channel attenuation	= - 1 dB
TCS insertion loss (clutter channel)	= - 48 dB
Transmitter cable loss	= - 3 dB
Duty cycle factor	= - 15 dB
Clutter power P_C	= -107 dBW

The clutter power was larger for all other phase adjustments. The SCV is:

$$SCV = MDS - P_C = 179 \text{ dBW} - (-107 \text{ dBW}) = -72 \text{ dB}.$$

This value of SCV means that the processor can reject clutter approximately ten million times larger than the smallest signal that it can detect.

4.1.2 System Calibrations

4.1.2.1 Audio Gain Control. The audio gain control (AGC) maintains the level of the signal applied to the doppler filter network and the digital range tracker at a constant level (see figure 2.1-1). The AGC voltage provides a convenient means of measuring the strength of the target signal. To make use of this voltage requires that the AGC voltage be calibrated with reference to microwave power input to the receiver. The calibration was carried out using the TCS with the connections of figure 4.1-2. The AGC voltage was measured at the AGC monitor point of the monitor and test panel. The clutter and target channel attenuators of the TCS were set for maximum attenuation. The radar range was adjusted to 1,700 m. The target channel attenuation was then decreased until a detection was indicated by a transition from search mode to track mode. The AGC voltage was recorded for this power level. The microwave power was increased in 5 dB increments and the AGC voltage recorded at each stage. This procedure was carried out with the STC on and with STC off. A plot of the results is in figure 4.1-3.

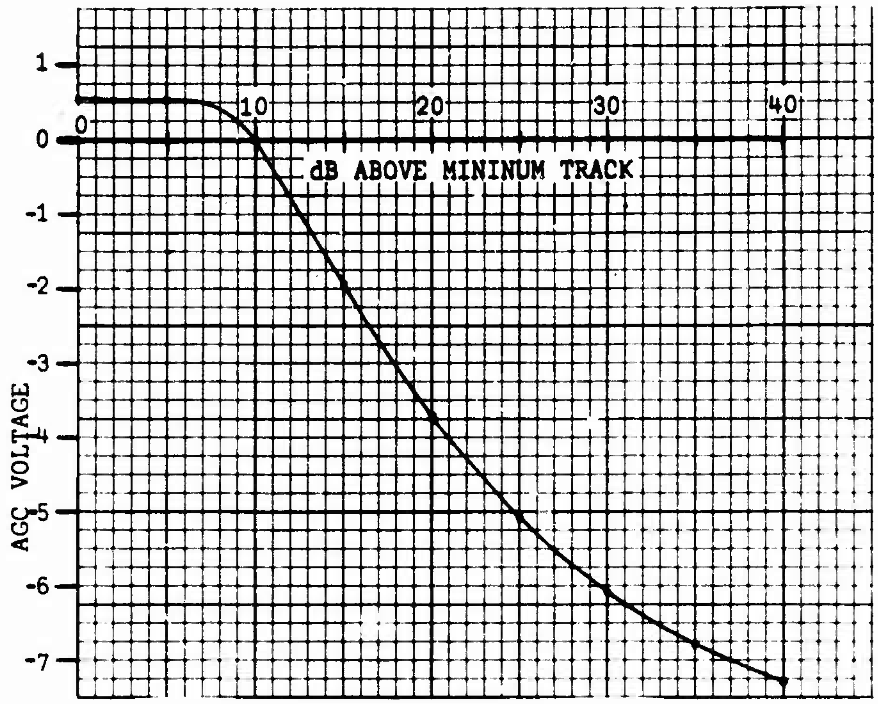

Figure 4.1-3. Plot of AGC voltage versus dB above minimum track.

4.1.2.2 Audio Frequency Control. The audio frequency control (AFC) is a function of the frequency applied to the doppler filter network. The AFC voltage provides a convenient means of measuring the frequency of doppler. The AFC voltage must be calibrated with reference to the doppler frequency input to the receiver. The calibration was carried out using the audio test generator built into the monitor and test panel as a variable frequency generator. The AFC voltage was measured at the AFC monitor point of the monitor and test panel. The frequency was measured at the VIDEO IN monitor point of the monitor and test panel. In the range 500 to 3,000 Hz, the relation between the frequency f in Hertz and the AFC voltage V in volts is

$$f = 296 \text{ Hz/volt} \times V$$

with an accuracy of $\pm 5\%$.

4.1.2.3 Sensitivity-Time Control. The STC changes the gain of the microwave receiver as a function of projectile range. By attenuating the microwave signal as range decreases, the STC reduces signal and clutter saturation effects. The STC calibration is required to correlate the receiver attenuation to the radar range. The calibration was made using the TCS with the connections of figure 4.1-2. An oscilloscope was connected to the video monitor point of the monitor and test panel. The radar range gate was preset to a value greater than 4,000 m. The target channel attenuator was set at maximum attenuation and the clutter channel attenuator was set at a value which gives an observable signal on the oscilloscope. The clutter channel phase shifter was adjusted for maximum amplitude of signal on the oscilloscope and this signal level was noted. Then, the range gate was preset to 4,000 m, the clutter channel phase and attenuation adjusted to produce the same amplitude signal noted earlier on the oscilloscope. This procedure was repeated at intervals until a range of 0 was reached. A plot of the results is in figure 4.1-4. The accuracy of the attenuation is ±1 dB.

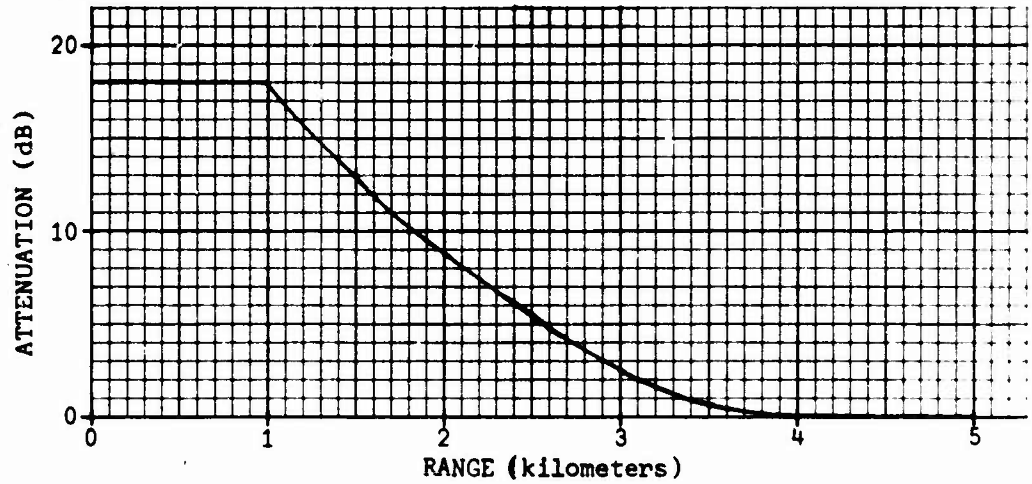

Figure 4.1-4. Plot of range versus STC attenuation.

4.1.2.4 Range Zero. The range determining circuitry requires that zero range be adjusted to account for internal system and cable delays. The calibration was carried out using the TCS with the connections of figure 4.1-5.

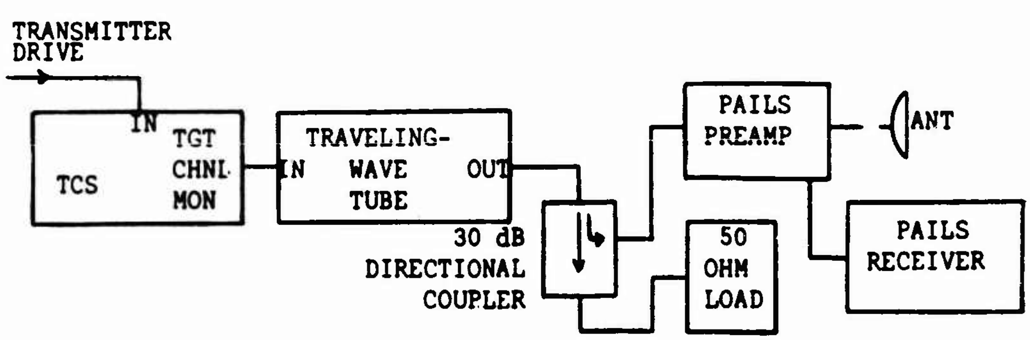

Figure 4.1-5. Connections required to calibrate zero range.

In addition, the blanking switch in the microwave receiver which disconnects the receiver for ranges below 600 m was bypassed. All extra cable lengths were kept to a minimum. The clutter channel attenuator was adjusted for maximum attenuation. The target channel attenuator was set to provide sufficient signal for acquisition and track and the doppler oscillator was turned on. The processor was allowed to acquire and track the signal in mode D while the OFFSET/CAL control was adjusted to give zero range on the range display.

4.1.3 Performance Measurements

4.1.3.1 Range Accuracy and Polarization Test. An evaluation of the range accuracy capability and the effect of antenna polarization was carried out using the RTS. The RTS was placed on an observation tower 1,158 m from the radar at heights of 9.2 m and 18.4 m above the ground. The radar acquired and tracked the RTS with no difficulty even though the return was not observable in the clutter. The digital range outputs were recorded on magnetic tape at a rate of 100 words per second for several seconds. Data samples were taken at both heights for vertical and horizontal antenna polarizations. An additional data sample was obtained for the 18.4 m height and vertical antenna polarization with the radar microwave power reduced by a factor of 2,400 from normal. A survey to determine the distances from the radar antenna to the RTS locations on the tower was obtained. The average range and standard deviation in the average range was calculated for 4 seconds of data at 0.2 second intervals. The results are in table 4.1-3.

TABLE 4.1-3. ACCURACY AND POLARIZATION TEST RESULTS

Height Above Ground (m)	Radar Range (m)	Range Difference (Radar-Survey) (m)	Std Dev in Range (m)	Polarization	Radar Power (watts)
9.2	1157.8	0.3	0.8	H	120
9.2	1158.2	0.7	2.7	V	120
18.4	1157.7	0.0	0.9	H	120
18.4	1158.3	0.6	0.7	V	120
18.4	1157.4	-0.1	1.6	V	0.05

H = Horizontal.
V = Vertical.

The results indicate that the accuracy and precision of the range measurements were better for horizontal polarization than for vertical. For horizontal polarization the range accuracy and precision are within the limits required to score to ±5 m in x, y, and z.

4.1.3.2 Weather Tests. An evaluation of the effect of snow and rain on radar operation was carried out using the RTS during periods of rain and snow. The RTS was placed on a tower 1,158 m from the radar at a height of 18.4 m above the ground. The radar acquired and tracked the RTS with no difficulty. There was no apparent difference in radar performance during the snow or rain operation as compared to normal operation. No quantitative measure of the rate of fall of the snow or rain was available. Qualitatively, the snow-fall rate was moderate and the rain-fall rate was heavy. In neither case could the tower be seen.

4.1.3.3 False Targets. The capability to reject false targets (vehicles, birds, and planes) was evaluated as an on-going test during all other portions of the testing. The following field conditions existed:

a. The radar was located 100 m from a road carrying approximately ten vehicles per hour.

b. Large turkey buzzards and other birds were observed in the radar beam at least five times per hour.

c. The test site was located 10 km from a military airport where a combination of helicopter and fixed-wing aircraft operate.

d. A commercial airline corridor is located outside the proving ground boundary and large jets could be visually observed at the rate of two an hour.

An occasional false target was detected. The type of target was unknown but was believed to be a small airplane landing or taking off from the airport mentioned in c above. Intentional attempts to detect the birds or large jets were not successful.

4.1.3.4 Microphonics. The largest generator of false detections was microphonics in the microwave receiver. The microwave receiver was housed in a retangular box which was not sufficiently rigid and which was not isolated from the equipment rack. As a result, vibration in the shelter was coupled to the box causing the box to vibrate at its resonant frequencies which was in turn coupled into the microwave receiver due to leakage in components. The amplitude and frequency of the microphonics were sufficient to render the system unuseable when they were present. Additional isolation and damping were introduced which reduced the effect of the microphonics but never eliminated them.

4.2 FIRING TESTS

The firing tests were conducted to measure system performance and specifications under dynamic conditions with the projectile types and trajectories that PAILS would normally be expected to measure.

4.2.1 Data Acquisition System

A special data acquisition system was developed to record the PAILS signals required for this test. This system consisted of the following components:

a. A portable 14 channel analog tape recorder.

b. A calibrator to insert a-c or d-c calibration signals on the analog tape.

c. A digital-to-analog (D/A) interface card to convert the digital mode and lock signals to an analog form for recording on the analog tape recorder.

d. A parallel to serial interface card to convert the 14 parallel bits of the digital range word (DRW) to a serial bit stream signal plus a bit sync signal for recording on the analog tape recorder.

e. A D/A interface card to convert bits 5 through 12 of the DRW into an analog signal for recording on the analog tape recorder.

f. A D/A interface card to convert bits 0 through 5 of the DRW into an analog signal for recording on the analog tape recorder.

g. An events marker interface to allow the time-of-fire, infrared chronograph, and sky screen events to be recorded on a single channel of the analog tape recorder.

h. A parallel to serial interface card to convert the 8 parallel bits of azimuth and the 8 parallel bits of elevation into a serial bit stream signal plus a bit sync signal for recording on the analog tape recorder.

i. A parallel to serial interface card to convert the two mode bits, the weak lock bit, and the hard lock bit into a serial bit stream signal for recording on the analog tape recorder.

j. A tone generator to mark when data was being recorded.

In addition to the components required in the data acquisition system, a special data retrieval system was developed to convert the serial digital words recorded on the analog tape back into a parallel digital word. The parallel word was then recorded in standard computer compatible format on a 9-track digital tape recorder.

The signals that were recorded on the analog tape recorder were:

a. Tone used for data reduction.

b. Coarse analog range - a 0- to 1-volt d-c analog signal corresponding to a range of 0 to 8,000 m with 32 m resolution.

c. Fine analog range - a 0- to 1-volt d-c analog signal corresponding to a range of 0 to 64 m with 1 m resolution.

d. Analog mode/lock - a 0- to 1-volt d-c analog signal with 16 voltage steps corresponding to the possible mode/lock combinations.

e. AGC - a +1- to -7-volt d-c analog signal with a calibration curve established in paragraph 4.1.2.1.

f. Recorder servo - a tape recorder signal used to ensure proper playback speed.

g. AFC - a 0 to 10-volt d-c analog signal with a calibration curve established in paragraph 4.1.2.2.

h. Range error - a -10- to 10-volt d-c analog signal indicating the error in the processor range loop.

i. Doppler - a 0- to 2-volt RMS analog signal giving the filtered doppler signal.

j. DRW - a serial pulse train containing the 14-bit DRW.

k. DRW bit sync - a serial pulse train containing the bit synchronization pulse required to interpret channel j.

l. Events marker - a serial pulse train containing coded event information.

m. Voice label - a voice channel used to annotate the tape.

4.2.2 <u>Test Details</u>

The firing tests were conducted at APG on 19 November 1975 and 15 January 1976. The PAILS radar was located between F and C towers near the Old Bombing Field. A 105-mm howitzer M102A1 was located at Romney Creek Position 11. Both the gun and radar positions were located to the nearest meter. PPT's were prepared for a number of projectiles and trajectories. The distance from the radar to the gun was 4,493 m. Table 4.2-1 is firing table data for the rounds fired.

TABLE 4.2-1. FIRING TABLE DATA
FOR ROUNDS FIRED

Rd	Chg	QE (mils)	Range (m)	MV (mps)	TML Vel (mps)	Max Ord (m)	FLT Time (sec)	Type Code
M1	3	500	4,500	247	209	639	22	I1
M1	7	143	4,500	494	306	197	12	I5
M314	3	774	4,327	232	-	-	24	B1
M1	5	1,275	4,500	325	256	4,034	57	I4
M1	4	1,287	3,500	278	233	3,118	51	S4

TML Vel = Terminal velocity.
FLT Time = Flight time.

A setback switch was attached to the gun so that the time of fire could be transmitted to the PAILS site as a start signal for the paper tape reader. One person operated the radar and data acquisition systems while another person operated the paper tape reader.

4.2.3 Data Processing

The data collected on analog magnetic tape was processed in the following manner:

a. Channels containing analog signals were digitized. The digitized data was used to generate tables and/or plots.

b. The DRW and DRW bit sync channels were converted back to parallel digital data and recorded on digital tape. The digital tapes were used to generate tables.

4.2.4 Test Results

4.2.4.1 Processor Acquisition and Lock-Up Capability. The objective of this test was to determine how well the processor can acquire a signal, lock-up on that signal, and then maintain a lock on.

This capability was evaluated by examining the mode/lock signal. There are four modes (A, B, C, and D) and three lock conditions (no lock, weak lock (WL), and hard lock (HL)). Acquisition is defined to be when the mode switches from A to B. Final lock-up is defined to be when the mode switches to D/HL. The normal mode/lock switching sequence should be: A, B, B/WL, B/HL, C/HL and D/HL. Other sequences can occur if there is signal dropout. The time spent in each mode is dependent on the signal strength. Range tracking is initiated in mode B and becomes finer in modes C and D. Table 4.2-2 contains data on acquisition and lock-up.

4.2.4.1 (Cont'd)

TABLE 4.2-2. MODE AND LOCK-UP DATA

Rd No.	Rd Type	Time Spent in Mode (sec) B	B/WL	B/HL	C/HL	Final Lock	Acquire	Note
1	I1	-	-	-	-	Yes	Yes	1
2	I1	0.19	0.19	0.38	0.48	Yes	Yes	
3	I1	.14	.17	.46	.48	Yes	Yes	
4	I1	.14	.12	.50	.50	Yes	Yes	
5	I1	.17	.14	.48	.48	Yes	Yes	
6	I1	-	-	-	-	Yes	Yes	2
7	I1	.17	.50	.12	.48	Yes	Yes	
8	I1	.14	.17	.43	.48	Yes	Yes	
9	I4	-	-	-	-	Yes	Yes	3
10	I4	-	-	-	-	Yes	Yes	3
11	I5	-	-	-	-	N/A	Yes	4
12	I5	-	-	-	-	N/A	No	5
13	I5	-	-	-	-	N/A	Yes	6
14	B1	.14	.14	.50	.48	Yes	Yes	
15	B1	-	-	-	-	N/A	N/A	7
16	B1	-	-	-	-	Yes	Yes	3
17	B1	.14	.14	.50	.48	Yes	Yes	
18	S4	.10	.12	.55	.48	Yes	Yes	

Notes:
1. Operator error - no time data.
2. Instrumentation problem - no time data.
3. Mode/lock sequence not normal.
4. Pedestal did not move - no time data.
5. Processor did not acquire.
6. Pedestal started too soon.
7. Pedestal pointed in wrong direction - no data obtained.

Of the 17 rounds where the antenna was initially pointed in the correct direction, in only one case (round 12) did the processor fail to acquire the round. Round 12 was fired at an elevation slightly below the lower limit PAILS was designed to work at. Rounds 11 and 13 fired at this same elevation were acquired. Once acquired, rounds 2, 3, 4, 5, 7, 8, 14, 17, and 18 locked-up in a normal sequential manner. Rounds 9, 10, and 16 locked-up satisfactorily, however, the mode/lock sequence was not the normal one. Of the remaining rounds, pedestal problems prevented the complete locked-up sequence from taking place.

An additional consideration is the ability to relock following periods of zero doppler. Zero doppler occurs when the angle between the projectile velocity vector and a line joining the radar and projectile is close to 90°. All the test rounds fired have a zero doppler condition near impact. However, these zero doppler points could not be observed (see paragraph 4.2.4.2). Rounds 9 and 10 have additional zero doppler points in their trajectories at approximately 3.9 and 26.4 seconds of flight. Round 9 unlocked and relocked automatically for both zero doppler conditions. In both cases 2.5 seconds elapsed from time of unlock to relock. For round 10 the processor did not relock automatically after the first zero doppler condition. The processor had to be manually reset to search mode before projectile lock-up would begin again. The second zero doppler point relocked automatically.

A final consideration is maintaining lock-up during the terminal portion of the trajectory of ground impact rounds when the clutter level is substantial. However, all ground impact rounds lost lock prior to reaching this portion of the trajectory. Additional tests to resolve this uncertainty were beyond the resource and funding level of this project.

4.2.4.2 Digitally Programmed Antenna Positioning Capability. The objective of this test was to determine how well the digitally programmed antenna position agreed with the actual trajectory.

The test rounds were observed by personnel equipped with transits and stopwatches. The range and the time of flight (TOF) were obtained from these observations. These ranges and times along with the ranges and times of the digital program are listed in table 4.2-3. Round 3 was missed by the observers and rounds 14 through 18 are excluded since they are airburst.

TABLE 4.2-3. PROGRAMMED AND OBSERVED RANGES AND TIMES OF FLIGHT

	Observed		Programmed	
Rd No.	Range (m)	TOF (sec)	Range (m)	TOF (sec)
1	4,141	21.8	4,500	22.9
2	4,334	24.0	4,500	22.9
4	4,435	25.0	4,500	22.9
5	4,491	25.2	4,500	22.9
6	4,614	24.2	4,500	22.9
7	4,597	26.3	4,500	22.9
8	4,616	24.8	4,500	22.9
9	4,887	62.1	4,500	61.8
10	4,471	57.7	4,500	61.8
11	4,402	12.4	4,500	12.3
12	4,493	12.6	4,500	12.3
13	4,457	12.6	4,500	12.3

The maximum TOF difference is 4.1 second and the largest range difference is 387 m. It is interesting to note that the maximum TOF and range differences did not occur on the same round, but that the round with the maximum TOF difference had a very small range difference and the round with the maximum range difference had a very small TOF difference.

An attempt was made to improve the antenna positioning capability by modifying the paper tape reader. The crystal oscillator controlling the rate at which the PPT was read was removed and a variable frequency oscillator was substituted. The frequency was adjusted so that the rounds TOF was the same as the time required to read the tape. The net result was to worsen the situation as some rounds would not lock-up with this change.

4.2.4.3 Function Signatures for Airburst and Base Ejection Rounds. The objective of this test was to generate a data base of function signatures for airburst and base ejection rounds and to correlate the function signature to infrared chronograph function time.

Since the system did not maintain lock during the latter part of the trajectory when the function signature is produced, a data base of function signatures was not generated. On one round, a lock-up was maintained to the point of function. However, the doppler signal was so weak at this point that no correlation to the fuze chronograph could be made.

4.2.4.4 Antenna Polarization Effects. The objective of this test was to determine the best antenna polarization to use.

Both horizontal and vertical polarizations were used during the firing tests. No noticeable difference could be observed in the acquisition or lock-up capability for either polarization. Since the system did not maintain lock-up during the latter part of the trajectory, no data covering this part of the trajectory was generated.

4.2.4.5 Other Test Objectives. Since the system did not maintain lock-up during the latter part of the trajectory, no data is available to address the following test objectives:

a. Radar cross section.

b. Clutter rejection capability.

c. Minimum microwave power.

d. Short fall projectile capability.

e. Range accuracy.

5. DISCUSSION

5.1 TEST ALTERNATIVES

If additional testing is to be carried out, the first requirement is that an alternative antenna positioning system must be implemented.

There are two basic approaches: a tracking system located at the PAILS site or a tracking system located at the gun site.

A system located at the PAILS site would require the following:

a. Conversion of the tracking system elevation and azimuth signals into a form compatible with PAILS.

b. Interconnecting cables.

c. Modification of PAILS to accept the external signals in place of the paper tape reader signals.

This system would be fairly easy to implement, but would be risky in that no good downrange tracking system exists. In addition, interference could occur from closely located radars.

A system located at the gun site would require the following:

a. Conversion of the tracking system elevation and azimuth signals into a form compatible with a digital computer.

b. A digital computer with a real-time capability to translate the tracking system measurements into the proper reference system for PAILS use.

c. A telemetry link capable of transmitting the digital data from the gun site to the PAILS site.

d. Modification of PAILS to accept the external signals in place of the paper tape reader signals.

This system would be fairly complex to implement, but not as risky as the first alternative.

It is estimated that 5,000 to 7,500 man-hours (3/4 of this design/instrumentation engineer level work) would be required to implement one of the alternatives, prepare the breadboard PAILS for the test, and carry out the firing test. It is estimated that this effort would require approximately 1 year.

5.2 TRACKING PERFORMANCE

Although the inability of the antenna positioning system to accurately track projectiles contributed to the loss of radar lock during the terminal portion of the trajectory, it is not known for certain that this was the only cause. Thus, it is possible that if additional tests were run with an alternative tracking system the end result might be the same because the failure is due to some other factor.

5.3 COST EFFECTIVENESS

Although references 3 and 4 indicate that locations can be found at APG, YPG, and JPG where PAILS could be implemented, the logistical constraints (particularly at APG and JPG) make use of PAILS at these installations time consuming and expensive.

6. CONCLUSIONS

It is concluded that:

a. Sufficient data is not available to assess the capability of the PAILS concept.

b. The cause of the inability of the breadboard PAILS to maintain lock-up during the terminal portion of the trajectory is unknown.

c. Additional tests of the breadboard PAILS will require 5,000 to 7,500 man-hours over a 1 year period.

d. The risk is high that additional tests would not provide data adequately assessing breadboard PAILS capability.

e. The pay off for TECOM test ranges would be minimal.

f. Further testing of the breadboard PAILS is neither prudent nor justifiable.

7. RECOMMENDATIONS

It is recommended that if a requirement for an airburst and impact scoring system still exists, an alternative approach be utilized.

It is recommended that the PAILS project be terminated.

SECTION 2. APPENDIXES

APPENDIX A - REFERENCES

1. Final Report, Projectile Airburst and Impact Locating System (PAILS), Submitted by Sanders Associates, Inc. under Contract No. DAAD05-71-C-0115, 12 August 1971.

2. Interim Technical Report, Projectile Airburst and Impact Locating System (PAILS), Submitted by Sanders Associates, Inc. under Contract No. DAAD05-73-C-0556, 1 October 1973.

3. First Partial Report, Evaluation of Projectile Airburst and Impact Locating System, TECOM Project No. 5-CO-APO-PLS-201, Report No. APG-MT-4859. US Army Aberdeen Proving Ground, August 1976. (Distribution Controlled by US Army Test and Evaluation Command, ATTN: DRSTE-RU.)

4. Addendum 1 to First Partial Report, Evaluation of Projectile Airburst and Impact Locating System, TECOM Project No. 5-CO-APO-PLS-201, Report No. APG-MT-4859 (Addendum 1). US Army Aberdeen Proving Ground, March 1977. (Distribution Controlled by US Army Test and Evaluation Command, ATTN: DRSTE-RU.)

5. Operating Manual for Processor Test Set (PTS), Submitted by Sanders Associates, Inc. under Contract No. DAAD05-75-C-0725, 4 November 1974.

APPENDIX B - SYSTEM BLOCK DIAGRAMS

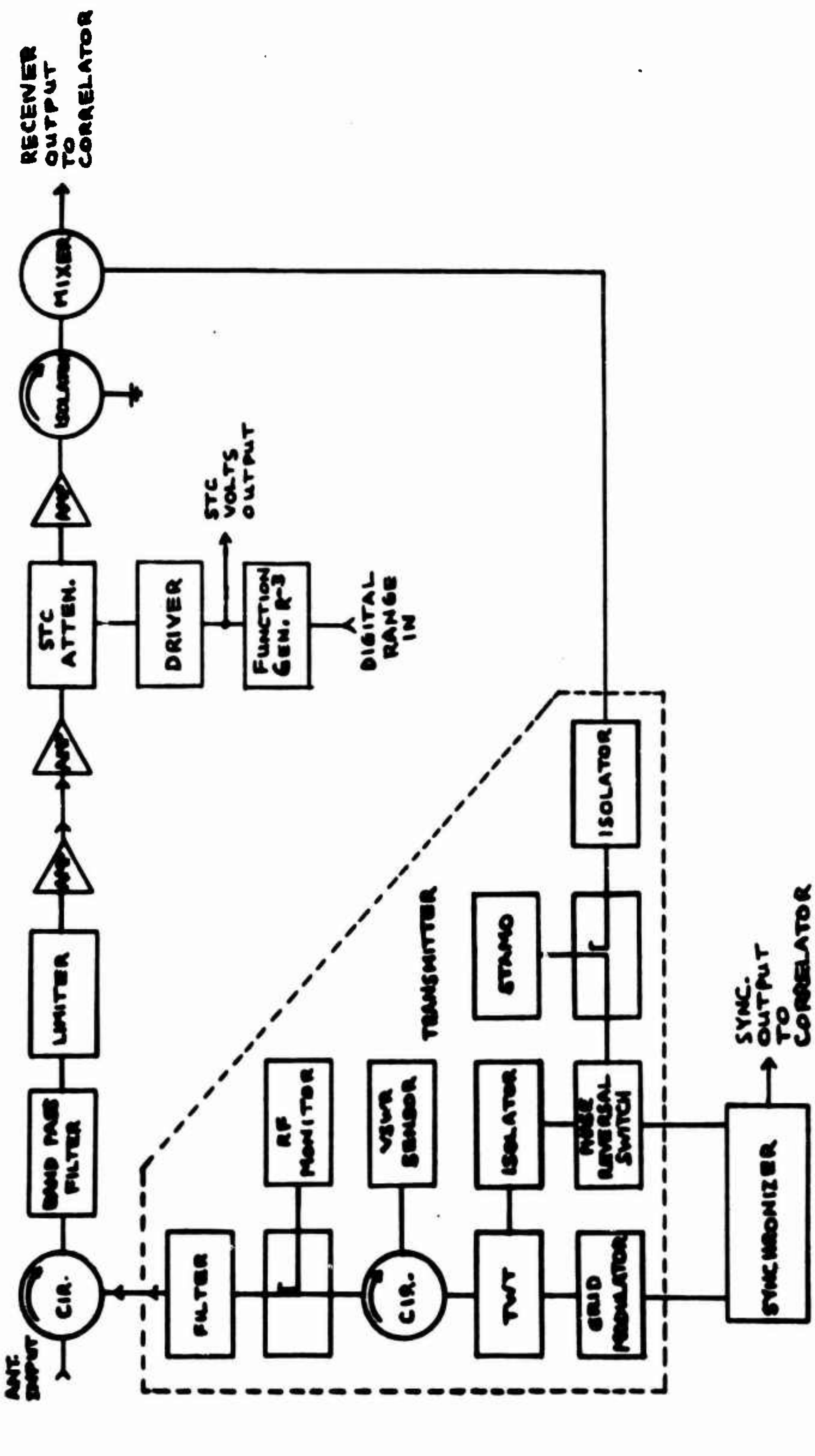

Figure B-1. Block diagram of the microwave receiver and transmitter.

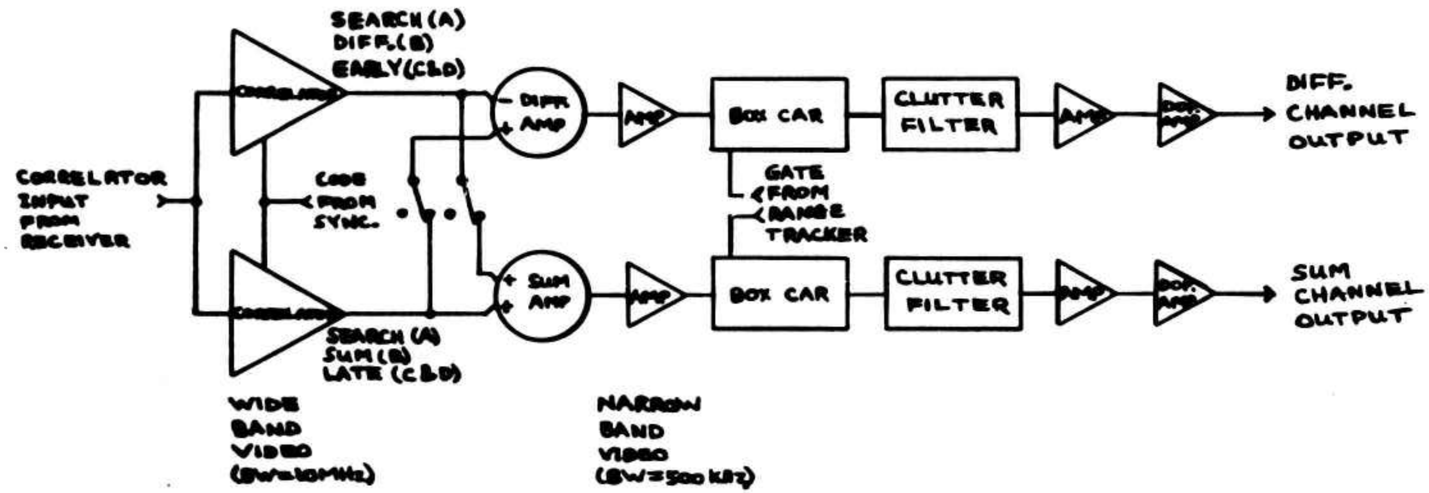

Figure B-2. Block diagram of processor video amplifier channels.

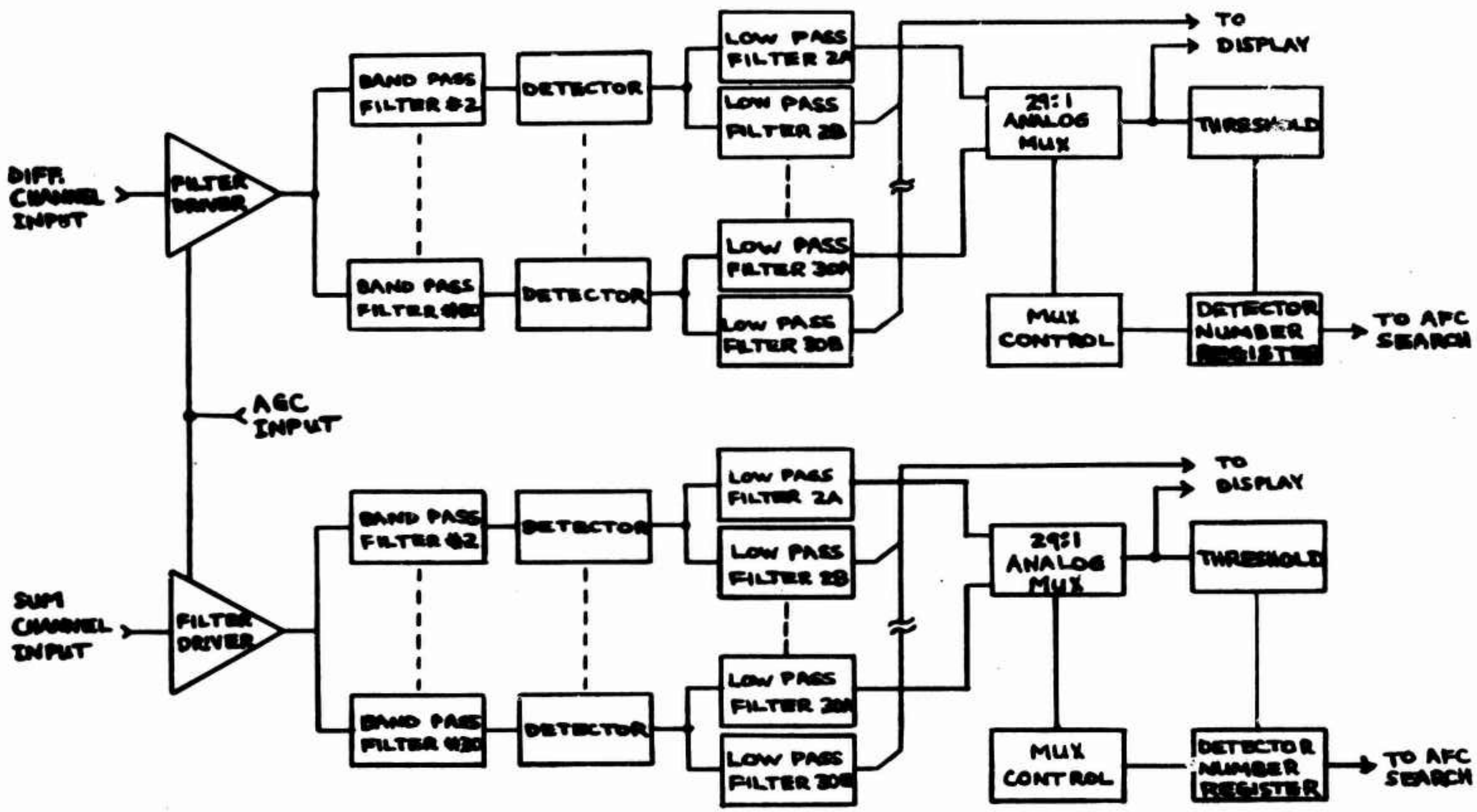

Figure B-3. Block diagram of processor doppler filter network.

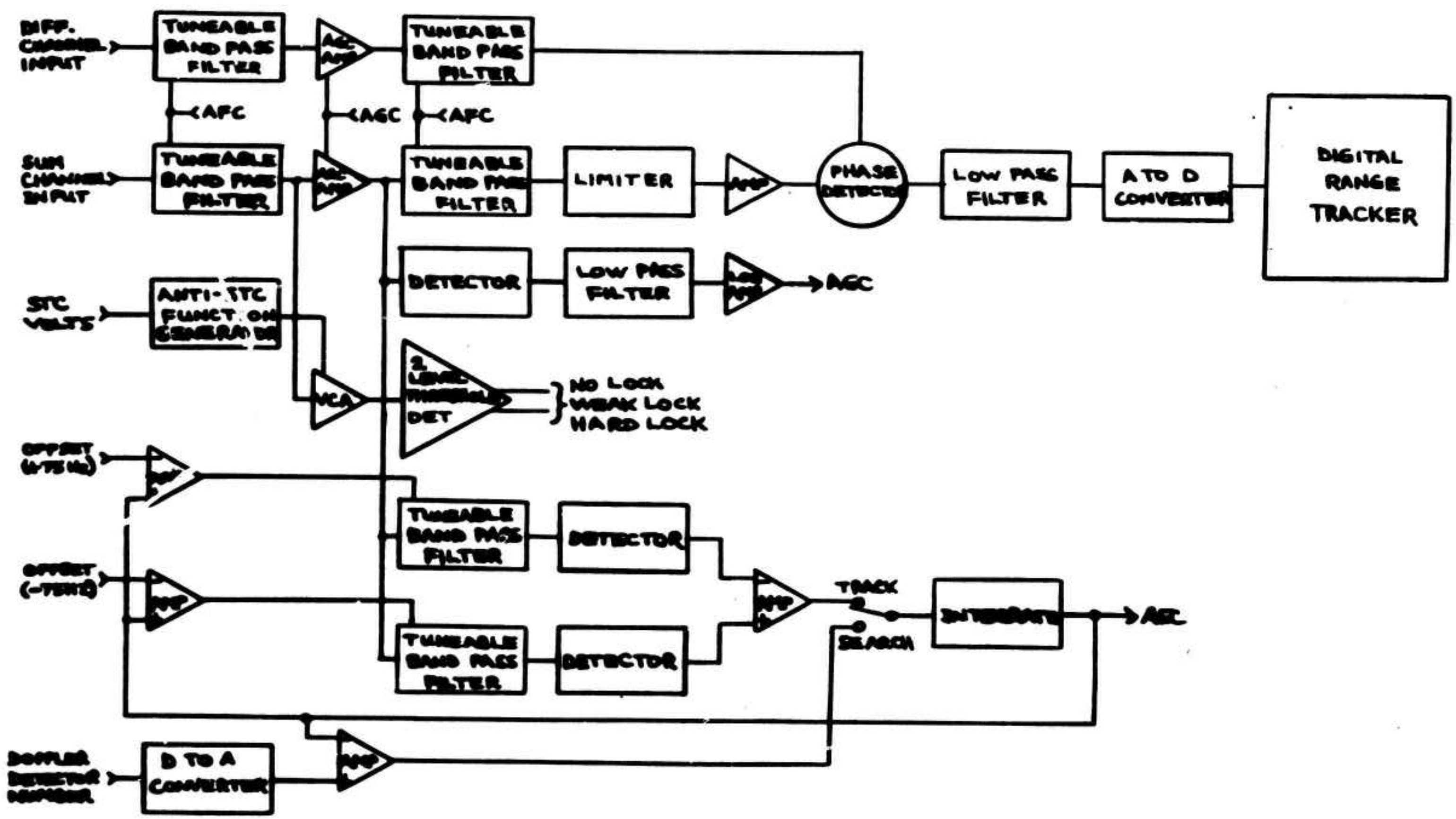

Figure B-4. Block diagram of processor AFC, AGC, and range tracker circuitry.

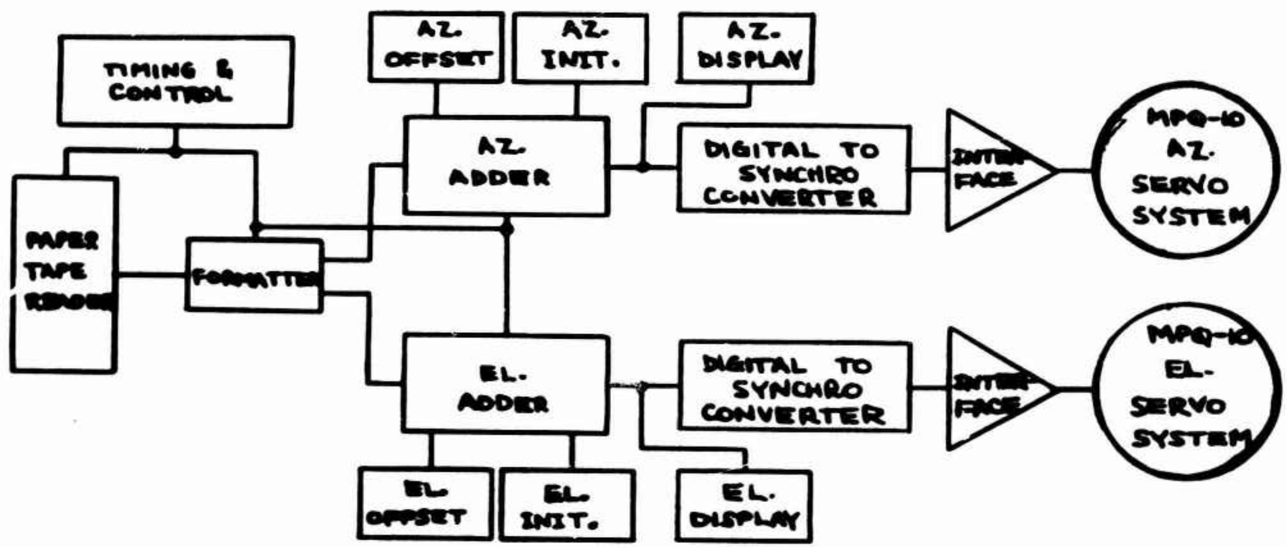

Figure B-5. Block diagram of the pedestal controller.

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APPENDIX C - PROCESSOR TEST SET

1. BACKGROUND

During the fabrication of the breadboard PAILS it was recognized that in-depth testing of the processor required a number of pieces of test equipment and a fairly complicated setup. In order to avoid the problems associated with a setup of this kind and to expedite field testing, it was determined that a single dedicated piece of test equipment would be desirable. Sanders Associates, Inc., Nashua, New Hampshire, designed and fabricated a processor test set (PTS) to meet these requirements.

2. DESCRIPTION OF MATERIEL

2.1 INTRODUCTION

The PTS is designed to test the doppler search and doppler range track functions of the PAILS processor. The PTS is designed to determine if:

a. The acquisition and lock-up sequence is operating properly.

b. The range determining circuitry is operating properly.

The PTS generates an amplitude modulated pulse similar in characteristics to those received by the PAILS receiver during actual operation. The PTS range, velocity, acceleration, and amplitude are adjustable to simulate a wide variety of conditions.

The output waveforms are referenced to the 6-kHz PAILS transmitter trigger and change modes automatically to coincide with the operating mode of PAILS. Power for the PTS is supplied by PAILS. A picture of the PTS is in figure C-1.

A block diagram of the PTS is in figure C-2 (page C-2).

An operating manual was supplied by the contractor (reference 5).

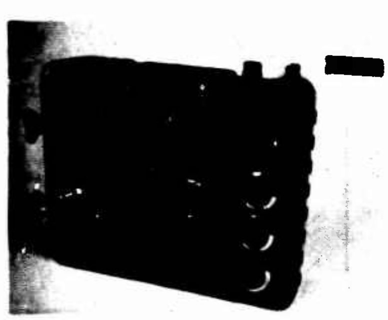

Figure C-1. Processor test set.

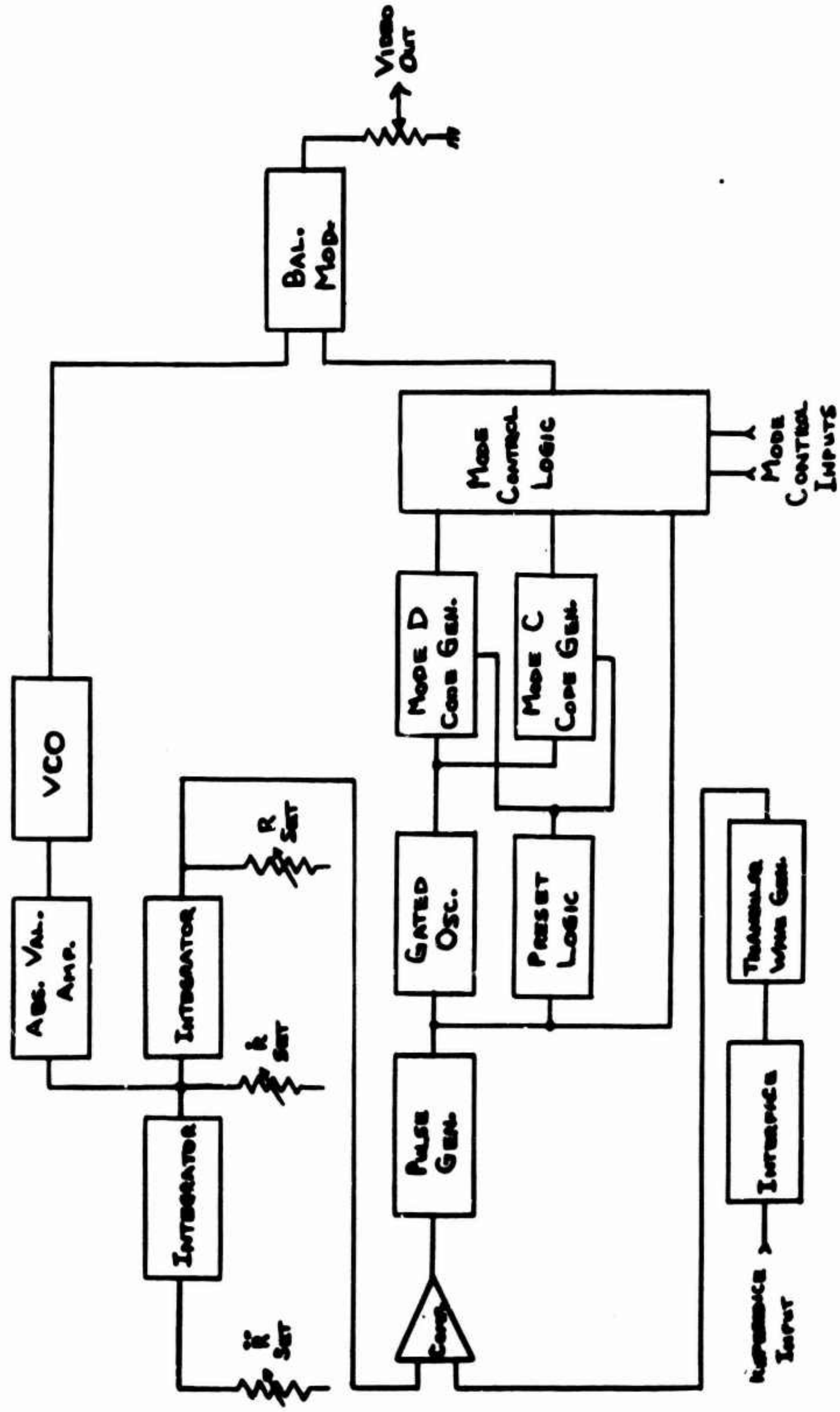

Figure C-2. Block diagram of processor test set.

2.2 SPECIFICATIONS

Power required - ±15 VDC and +5 VDC.

Dial range - 0 to 10 kilometers.

Tracking range - 0 to 12.5 kilometers.

Dial velocity - 0 to ±422 mps.

Dial acceleration - 0 to ±3 meters per second per second.

Video output level - 0.4 V peak-to-peak into a 50-ohm load.

2.3 DETAILS OF OPERATION

To place the PTS in operation, the control cable and video output cable must be connected. The control switch is placed in the MANUAL position and the RANGE, VELOCITY, and ACCELERATION controls are set to the desired initial values. When the control switch is placed in the AUTO position, the simulated target position will begin to slew at a rate determined by the control settings. The video output may be adjusted to any desired level by the GAIN control.

APPENDIX D - TARGET AND CLUTTER SIMULATOR

1. BACKGROUND

The AN/TPQ-32 includes as standard test equipment a target and clutter simulator (TCS). Since the PAILS transmitter and receiver are modified AN/TPQ-32 components, the TCS is capable of serving as test equipment for PAILS.

2. DESCRIPTION OF MATERIEL

2.1 INTRODUCTION

The TCS is designed to test the microwave receiver and processor functions of PAILS. Specifically, the TCS is designed to determine:

a. The minimum detectable signal.

b. The subclutter visibility.

In addition, the TCS can be used for other system tests.

The TCS uses a sample of the transmitter output power as a reference signal. This signal is divided into target and clutter channels which are independently processed. The target channel modulates the signal to simulate doppler. The clutter channel provides an adjustable phase shift. The amplitudes of the two channels are independently adjustable. Following the processing, the two channels are combined and delayed for a time which corresponds to approximately 1100 meters. Thus, the signal at the output of the TCS simulates a doppler modulated return at a range of 1100 meters in the presence of clutter. Power for the TCS is supplied by PAILS. A picture of the TCS is in figure D-1. A block diagram of the TCS is in figure D-2 (page D-2).

Figure D-1. Target and clutter simulator.

2.1 (Cont'd)

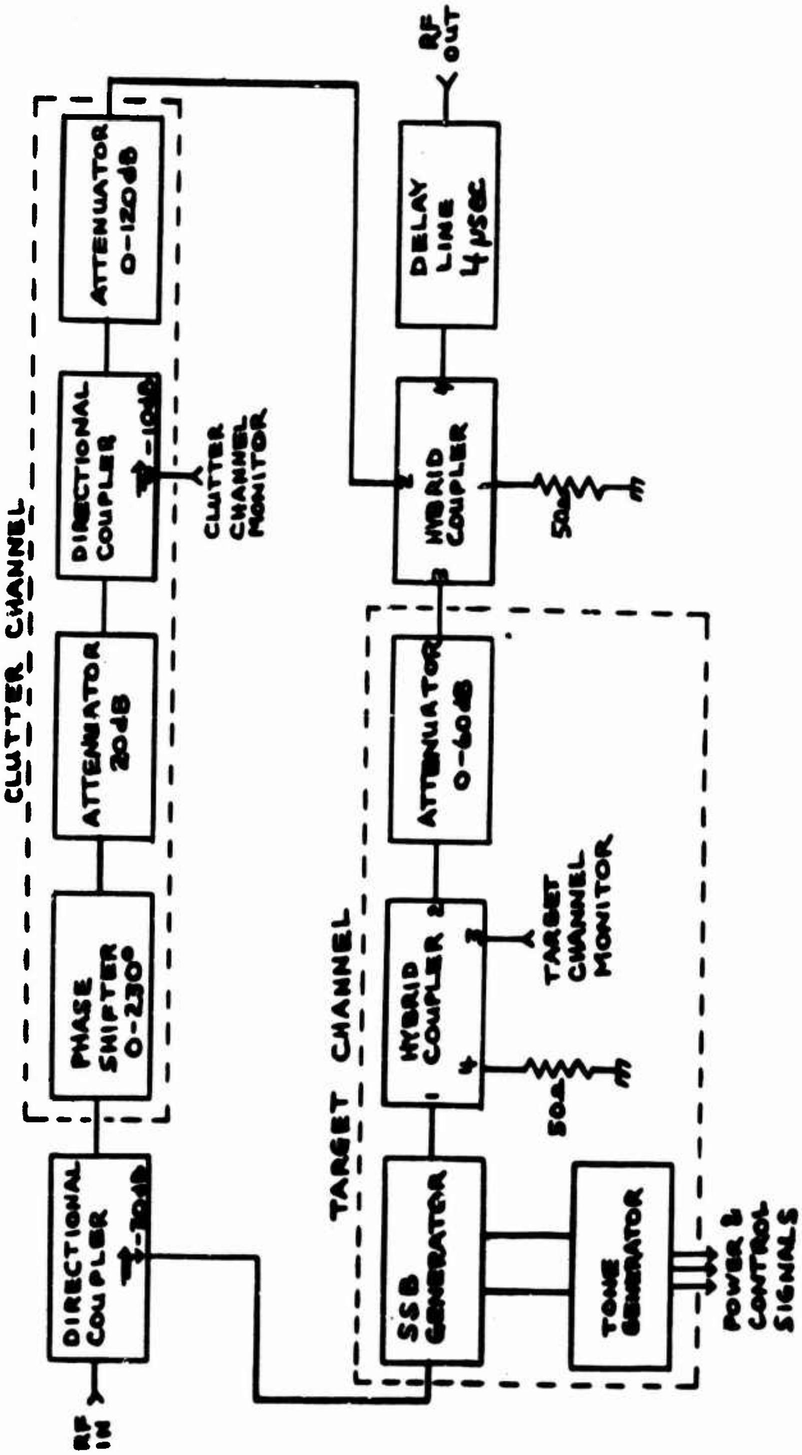

Figure D-2. Block diagram of TCS.

2.2 SPECIFICATIONS

Power required - ± 12 VDC.

Maximum power input - 200 milliwatts.

Clutter channel output - -70 to -190 dB below input signal.

Target channel output - -90 to -150 dB below input signal.

Doppler frequencies - 536, 725, 1040, 1702, 2314 Hz.

2.3 DETAILS OF OPERATION

The interconnections required to implement the TCS are in figure D-3. Note that the cable between the antenna and preamp is disconnected. Once these connections are made and power is applied, then the TCS is ready for use. The target channel attenuator and doppler frequency and the clutter channel attenuation and phase are adjusted for the particular test requirement.

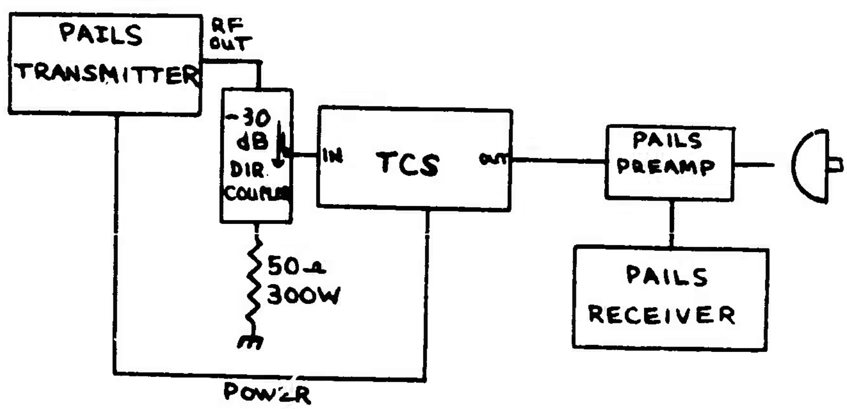

Figure D-3. Interconnections required to implement the TCS on PAILS.

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APPENDIX E - RANGE TARGET SIMULATOR

1. BACKGROUND

During the course of testing, the need for a cooperative target at a known range to provide a reliable test signal became apparent. Using a combination of components from the TCS and other sources, a range target simulator (RTS) was fabricated to fill this need.

2. DESCRIPTION OF MATERIEL

2.1 INTRODUCTION

The RTS is designed to test the microwave receiver and processor functions of PAILS. In particular, the RTS allows a determination of performance on a radar target in the presence of real clutter and multipath effects.

The RTS picks up a sample of the transmitted PAILS signal using a horn antenna. This signal is modulated to simulate a doppler signal. The signal is then radiated by the antenna back to the PAILS. Thus, the RTS simulates a doppler modulated return at whatever range the unit is placed from PAILS. In addition, the naturally occurring clutter and multipath are present to provide a more realistic simulation than the Target and Clutter Simulator. Two different modulation frequencies are available. The RTS is powered by batteries to allow portability in the field. A block diagram of the RTS is in figure E-1. A picture of the RTS is in figure E-2.

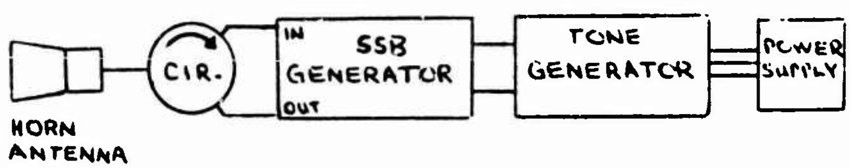

Figure E-1. Block diagram of RTS.

Figure E-2. Range target simulator.

2.2 SPECIFICATIONS

Power required - ±12 VDC supplied by batteries.

Insertion loss - -6 dB.

Antenna beamwidth - 40° full width at half power.

Antenna gain - 9 dB (contractor specified - not verified).

Doppler frequencies - 725 and 1702 Hz.

2.3 DETAILS OF OPERATION

The RTS is placed in a location where the PAILS antenna can be seen. The RTS horn antenna is pointed in the direction of the PAILS antenna and vice-versa. Since both antenna beamwidths are large, critical alignment is not required. With the PAILS transmitter on and the RTS power on, the tests can be carried out. The doppler frequency is set for the particular test requirement. Due to PAILS receiver blanking, the RTS can only be employed at ranges of 600 meters or greater.

APPENDIX F - ABBREVIATIONS

ac = alternating current
AFC = audio frequency control
AGC = audio gain control
D/A = digital-to-analog
dB = decibels
dBW = decibels referenced to one Watt
dBm = decibels referenced to one milliwatt
dc = direct current
DRW = digital range word
FAAR = forward area alerting radar
HL = hard lock
Hz = hertz
kHz = kilohertz
km = kilometer
LED = light emitting diode
m = meter
mps = meters per second
MDS = minimum detectable signal
MHz = megahertz
MTD = Materiel Testing Directorate
PAILS = projectile airburst and impact locating system
PTS = processor test set
PPT = punched paper tape
RMS = root mean square
RTS = range target simulator
STAMO = stabilized master oscillator
SCV = subclutter visibility
STC = sensitivity-time control
TCS = target and clutter simulator
TOF = time of flight
TWT = travelling wave tube
VAC = volts alternating current
VDC = volts direct current
WL = weak lock

APPENDIX G - DISTRIBUTION LIST

TECOM Project No. 5-CO-APO-PLS-201

Addressee	Final Report
Commander US Army Test and Evaluation Command ATTN: DRSTE-AD-I DRSTE-AD-M DRSTE-SG-H Aberdeen Proving Ground, MD 21005	 3 1 1
Commander US Army Jefferson Proving Ground ATTN: STEJP-TD Madison, IN 47251	1
Commander US Army Yuma Proving Ground ATTN: STEYP-MMI Yuma, AZ 85364	1
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