General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NASA CONTRACTOR REPORT NASA CR-141411

FINAL REPORT OF THE ADVANCED APPLICATION FLIGHT EXPERIMENT BREADBOARD PULSE COMPRESSION RADAR ALTIMETER PROGRAM

(NASA-CR-141411) ADVANCED APPLICATION FLIGHT EXPERIMENT BREADBOARD PULSE COMPRESSION RADAR ALTIMETER PROGRAM Final Report, Jul. 1974 - Dec. 1975 (Hughes Aircraft Co.) 147 p HC $6.00 CSCL 17I G3/43

N76-30638

Unclas 50419

Prepared Under NASA Contract NAS6-2558 by

Hughes Aircraft Company

Ground Systems Group

Fullerton, California

SEP 1976
RECEIVED
NASA STI FACILITY
INPUT BRANCH

NASA
National Aeronautics and Space Administration

Wallops Flight Center
Wallops Island, Virginia 23337
AC 804 824-3411

August 1976

1. Report No. NASA CR- 141411	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Final Report of the Advanced Application Flight Experiment Breadboard Pulse Compression Radar Altimeter Program		5. Report Date August 1976
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No. FR 76-14-183
		10. Work Unit No.
9. Performing Organization Name and Address Hughes Aircraft Company Ground Systems Group Fullerton, California 92634		11. Contract or Grant No. Contract No. NAS6-2558
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Wallops Flight Center Wallops Island, VA 23337		13. Type of Report and Period Covered Contractor Report July 1974 to December 1975
		14. Sponsoring Agency Code
15. Supplementary Notes This is a final report.		

16. Abstract

Design, development and performance of the NASA/AAFE Pulse Compression Radar Altimeter is described. The high resolution breadboard system is designed to operate from an aircraft at 10 Kft above the ocean and to accurately measure altitude, sea wave height and sea reflectivity. The mini-computer controlled Ku-band system provides six basic variables and an extensive digital recording capability for experimentation purposes. Signal bandwidths of 360 MHz are obtained using a reflective array compression (RAC) line. Stretch processing is used to achieve 1000:1 pulse compression. The system range command LSB is 0.62 ns or 9.25 cm. A second order altitude tracker, aided by accelerometer inputs is implemented in the system software. During flight tests the system demonstrated an altitude resolution capability of 2.1 cm and sea wave height estimation accuracy of 10%. The altitude measurement performance exceeds that of the Skylab and GEOS-C predecessors by approximately an order of magnitude.

17. Key Words (Suggested by Author(s)) Radar, Radar Altimetry, High Resolution, Pulse Compression, STRETCH, RAC, High Speed Clock, Software Tracker, Computer Control, Sea State, AAFE		18. Distribution Statement Unclassified - Unlimited STAR Category 43	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 145	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22151

FOREWORD

This is the Final Report on the design, development, and performance of the Advanced Application Flight Experiment (AAFE)/Pulse Compression Radar Altimeter Project which was performed by Hughes Aircraft Company under Contract No. NAS 6-2558 for the National Aeronautics and Space Administration Wallops Flight Center, Wallops Island, Virginia. This new generation experimental breadboard system was designed and developed by Hughes Aircraft Company, in Fullerton, California; the program was managed by Mr. R. Sidlo and system design and test activities were directed by Mr. E. Kulikauskas and Mr. L. Delp. Mr. D. Effinger and Mr. T. McGrath were the principal engineers of the Transceiver and Analog/Digital subsystems; Mr. M. Dehghanmanesh developed the system software.

The system was flight tested in a C-54 aircraft at the Wallops Flight Center in Virginia where it was delivered to the contracting agency.

Successful development of the AAFE Pulse Compression Radar Altimeter was due primarily to Mr. W. F. Townsend, NASA/Wallops Program Manager, who provided considerable technical direction, made available the helpful technical expertise of Dr. R. Dooley of Technology Service Corporation, and sought out the supplemental funding necessary for program completion.

CONTENTS

PRECEDING PAGE BLANK NOT FILMED

SECTION A
SUMMARY

PRECEDING PAGE BLANK NOT FILMED

1. TECHNICAL OBJECTIVES AND ACHIEVEMENTS

Hughes Aircraft Company has successfully completed the breadboard development of the next generation spacecraft radar altimeter employing high resolution stretch processing and extensive computer control for NASA/AAFE (Advanced Application Flight Experiment). The experimental breadboard system, presented in the facing figure, was delivered to NASA Wallops Flight Center in Virginia and flight tested in a C-54 aircraft. Objectives and achieved performance of this novel system are summarized in the table (page A-2).

The experimental system was designed to operate from an aircraft platform at 10 kft over the ocean. With sea conditions ranging from 1 to 10 meters in significant wave height, the system provides three basic measurements: altitude above the sea, sea wave height, and sea reflectivity of radar signals.

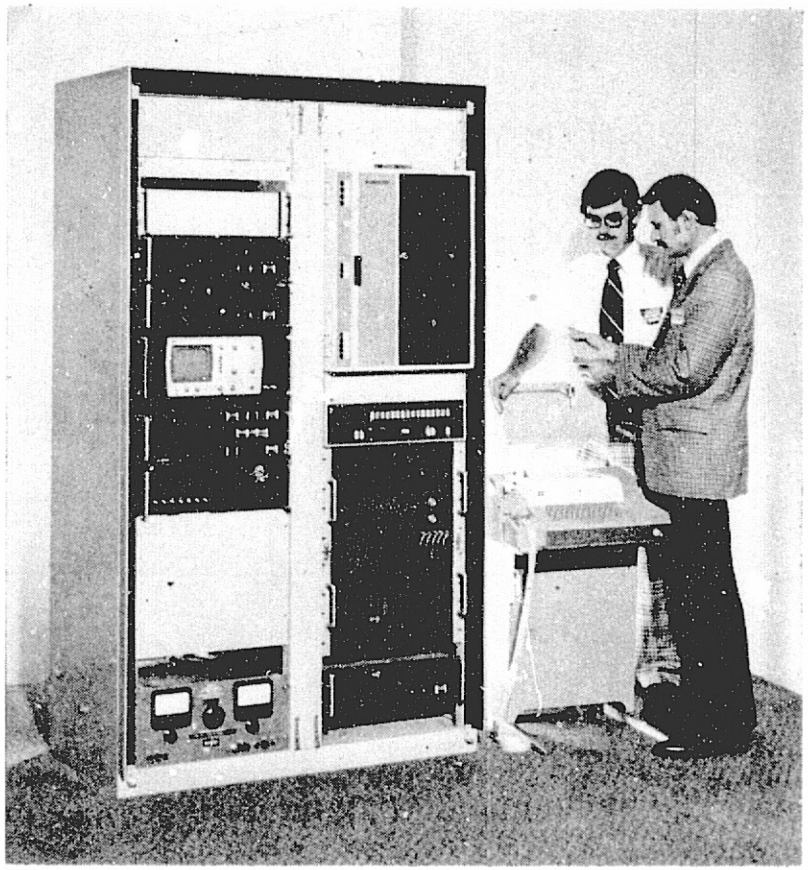
Achievement of altitude measurement with a resolution of 10 cm or less, at a data rate of one measurement per second, was the dominant objective. The absolute altitude measurement accuracy after system calibration was to be ±25 cm or better. A drift of less than 50 cm/hr in the altitude measurement, as a result of component or signal drift, was also required. In order to provide for quick recovery after passing over land the system was required to have an acquisition time of less than 5 seconds; i.e., quality data was to be provided within 5 seconds of initiation of the sea surface search. Satisfaction of all of the altitude measurement related requirements was demonstrated in-plant and during the flight program. As indicated in the table, a number of these requirements were substantially exceeded and the achieved performance represents an order of magnitude improvement with respect to the Skylab and GEOS-C predecessors. The 2.1 cm altitude resolution demonstrated during the Acceptance Flight Test and obtained on several other flights during low sea state conditions is considered to be an outstanding achievement. The precise absolute measurement capability (±1.4 cm) is a result of the novel calibration mode implemented in the system.

A wave height measurement accuracy of 10% was demonstrated during the Flight Test program using a laser profilometer as ground truth; the required accuracy was 25%. The inherent system capability may even be better since the 10% result was obtained with accurate but simple algorithms which employ only some of the available signal data.

Sea reflectivity measurement accuracy was estimated in-plant by evaluation of the individual errors which affect the estimate. Determination of the accuracy by flight tests was not possible because of a lack of accurate ground truth. The in-plant evaluation indicated that the accuracy is 2.1 dB and is somewhat poorer than the required 1.5 dB. The achievable S/N ratio for the specified 6 dB sea reflectivity was determined to be substantially less than the required 20 dB. Provisions for a back-up higher gain TWT were made, however, because of the greater than expected sea reflectivity, the system operated successfully as designed.

The experimental nature of the system called for implementation of variable parameters as well as state-of-the-art performance. To satisfy this requirement, selectable pulse width, PRF, Early and Late gate widths, tracker bandwidth and track point, and a comprehensive digital recording capability are implemented in the radar system.

NASA AAFE PULSE COMPRESSION RADAR ALTIMETER



KEY TECHNICAL OBJECTIVES AND DEMONSTRATED PERFORMANCE

PARAMETER	OBJECTIVE	ACHIEVED
ALTITUDE RESOLUTION	$\pm$10 CM RMS	$\pm$2.1 CM RMS
ABSOLUTE ALTITUDE	$\pm$25 CM	$\pm$1.4 CM
WAVE HEIGHT	$\pm$25%	$\pm$10%
ACQUISITION TIME	<5 SECONDS	<4.5 SECONDS
DRIFT RATE	<50 CM/HR	<10 CM/HR
σ_o ACCURACY	$\pm$1.5 dB	$\pm$2.1 dB
S/N (σ_o = 6 dB)	20 dB	11.8 dB

2. SUMMARY OF THE PROGRAM

The AAFE Radar Altimeter program consisted of a 17-month development and test effort which was followed by a training course and delivery of an operation/maintenance manual and oral and written final reports. The program performance is indicated in the schedule (p. A-6). Subsystem development and integration involved an 11-month effort. During this period, the equipments were designed, parts were procured, hardware was fabricated, and the system software was developed; a substantial amount of system integration was also accomplished. Although the Radar Altimeter is a relatively small system, its complexity is not unlike that of a large computer-controlled radar. The high bandwidth (360 MHz) and precision timing (0.62 ns LSB) impose additional fabrication and test constraints which are not common in other systems. As a result, timing, radar/computer interface, and recording problems were encountered; although these and other problems were overcome, delivery schedule was affected.

A comprehensive battery of 32 In-Plant Performance Tests (IPPT) were conducted in order to verify compliance with the system specification. These included vibration and altitude/temperature testing of the Transceiver and Analog/Digital subsystems as well as specially designed end-to-end electrical performance tests. All key performance requirements were satisfied, and the system was shipped to the NASA Wallops Flight Center in Virginia for Flight Acceptance testing on a C-54 aircraft. The flight test program was essentially dedicated to verification of system operation in an aircraft environment and evaluation of the system altitude resolution, acquisition time, and wave height measurement accuracy. The flight test program and the subsequent testing proved the system to be an unqualified success both from a performance standpoint as well as operability. During the flight test program, the system demonstrated an exceptional altitude resolution capability. When operating during low sea state conditions, the system altitude measurement resolution was determined to be 2.12 cm. Failure-free operation has been achieved for the last 6 months.

The technical success of the AAFE Radar Altimeter program is to a great extent due to the technology and the innovative engineering of the Hughes Aircraft Company. The system design was based on the proposed design (Ref. 1) and the analysis and recommendations provided in the Technology Service Corporation (TSC) study report (Ref. 2). Key technical decisions made during the development of the altimeter are summarized in the table (p. A-7). Participation in these decisions and helpful technical guidance provided by NASA/Wallops Flight Center and their TSC consultants throughout the program were deciding factors in the resulting significant advances made in radar altimetry by this challenging program.

The stretch processing approach using a RAC implementation was selected early in the program as a result of the available technology at Hughes Aircraft Company and the TSC recommendations. The subnanosecond timing required by the system was implemented by splitting a high-frequency clock signal; this approach was selected on the basis of its success on other systems. Continuous monitoring of noise, calibration and bias levels without interruption of basic system operation was made possible by computer-controlled interleaving of these submodes with the radiate submode; availability of radar data by virtue of the extensive radar/computer data interface allowed incorporation of some novel computer processing to achieve high precision time delay calibration and correction for radar filter gain and bias unbalances.

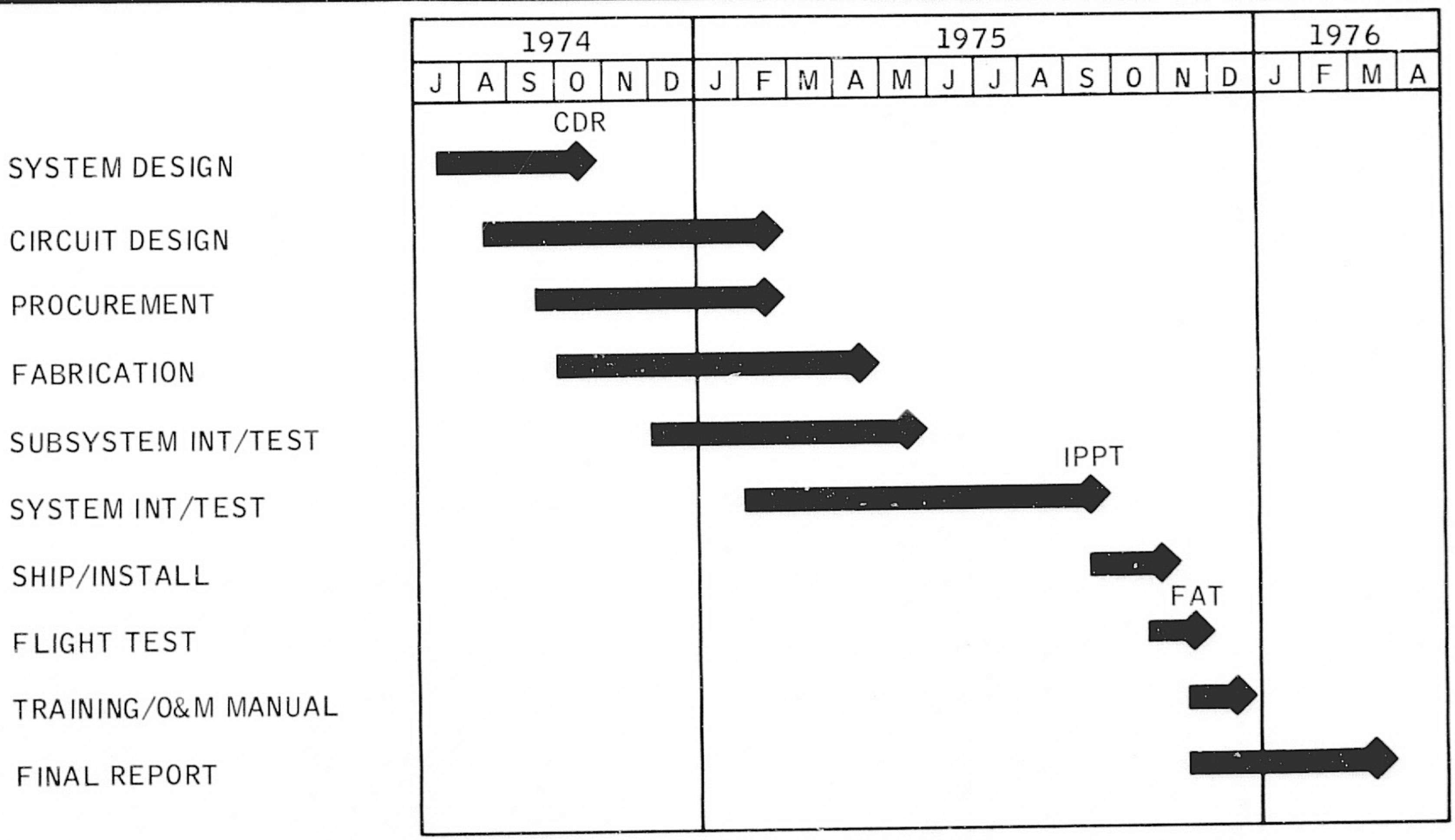
 PRECEDING PAGE BLANK NOT FILMED

The requirement to provide precision tracking from the C-54 aircraft platform imposed unusual design constraints which were more severe than those of satellite altimeters where the platform is relatively stable. A second-order tracker aided by a vertical accelerometer was incorporated in the design in order to overcome the vertical dynamics of the aircraft. Because of the flexibility of computer processing, the altimeter tracker was implemented entirely in the software. This enabled relatively easy incorporation of the vertical accelerometer inputs and a design which was adaptive with changes in sea wave height; also the position and velocity (α, β) coefficients were readily changeable for experimentation purposes. It should be noted that the software tracker design and its simulation were accomplished primarily on Hughes Aircraft Company's IR&D funds. Performance assessment in real time motivated implementation of real time computation and readout of altitude, sea reflectivity and wave height. Because of the experimental nature of the system, the mini-computer implementation was determined to be advantageous both from system operation and data reduction aspects; an extensive digital recording capability (approximately 300 distinct parameters) was implemented and stand-alone data reduction software developed for the system.

Reference 1. Proposal for a Breadboard Model of a High Resolution Pulse Compression Radar Altimeter, Hughes Aircraft Company/Ground Systems Group, Fullerton, California, Report No. FP 74-14-10, January 18, 1974.

Reference 2. Dooley, R. P., et al, Study of Radar Pulse Compression for High Resolution Satellite Altimetry. NASA Report No. CR-137474, December, 1974; TSC Report No. WO-111.

AAFE BREADBOARD RADAR ALTIMETER PROGRAM PERFORMANCE



KEY PROGRAM DECISIONS

SYSTEM REQUIREMENT	SYSTEM APPROACH
PULSE COMPRESSION	• FULL STRETCH PROCESSOR • REFLECTIVE ARRAY COMPRESSOR (RAC)
GHz TIMING RESOLUTION	• 108 MHz CLOCK • 15:1 DIGITAL CLOCK SPLITTING
NOISE ESTIMATION/CALIBRATION/BIAS	• INTERLEAVED NOISE/CAL MODES • FILTER SPLITTING FOR CAL • FILTER AVERAGING TO REMOVE BIAS AND GAIN UNBALANCES
PRECISION TRACKING FROM UNSTABLE PLATFORM	• α, β TRACKER • ADAPTIVE IN WAVE HEIGHT • ACCELEROMETER AIDED • MANUALLY ADAPTIVE IN EARLY AND LATE GATE WIDTHS
ALTITUDE, σ_o, WAVE HEIGHT MEASUREMENTS	• REAL TIME COMPUTATION AND READOUT
SIGNAL PROCESSING IN UNKNOWN ENVIRONMENT	• MINICOMPUTER • ALL SOFTWARE PROCESSOR FOR FLEXIBILITY • STAND ALONE DATA REDUCTION

3. OVERVIEW OF THE ALTIMETER

The Radar Altimeter system consists of the three subsystems and the microwave equipments indicated in the figures (A-9, A-10). The mini-computer controlled Ku-band radar is designed to provide very high precision altitude data, sea wave height, and sea reflectivity measurements under 1-10 m sea wave height conditions. Unlike its Skylab and GEOS-C spacecraft predecessors, this new generation system is dedicated to experimentation and as a tool to aid in the definition and evaluation of future satellite radar altimeter designs. For this purpose it is installed in an aircraft and incorporates six basic variables: PRF, pulse width, Early and Late gate widths, tracker bandwidth and track point.

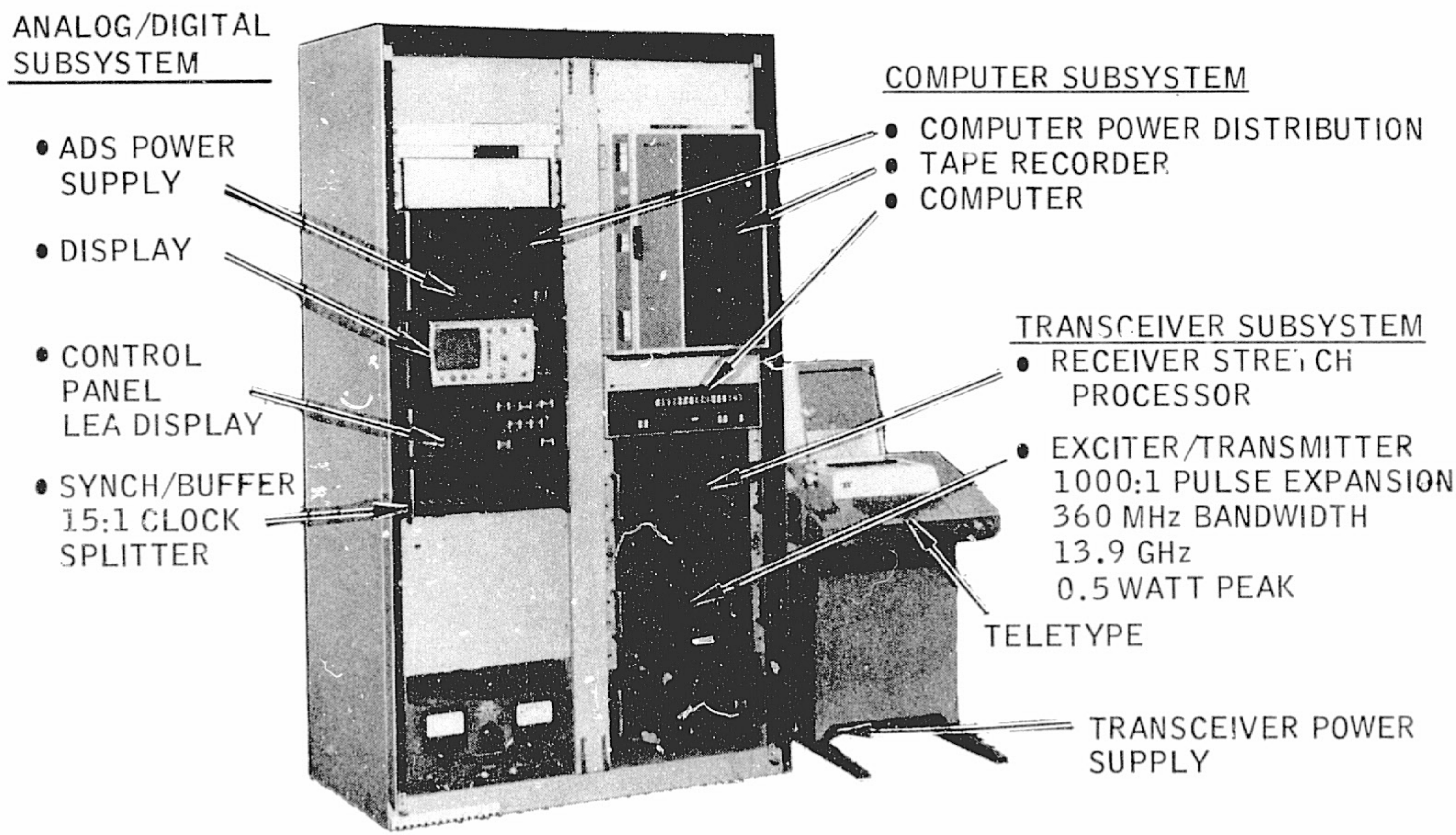
The system consists of an exciter which generates 360 MHz frequency-coded transmitter drive and reference signals using a reflective array expansion (RAC) line, a low-power TWT transmitter with a net peak output of 0.5 watts, and a 15° beamwidth horn antenna. The triple conversion receiver employs stretch processing and contains analog filter/detector/integrator chains for the early and late gate signal generation required by the tracker, and 24 analog ramp filters/detectors for analysis of the leading edge of the sea return signal. Signals are A/D converted by the digital unit which also provides timing, displays, and system controls, and interfaces with the computer subsystem; the computer subsystem includes a mini-computer with 16K of core, a digital tape recorder and a teletype. System operation is under computer control once a configuration has been selected at the control panel.

The pulse radar altimeter includes the following unique features:

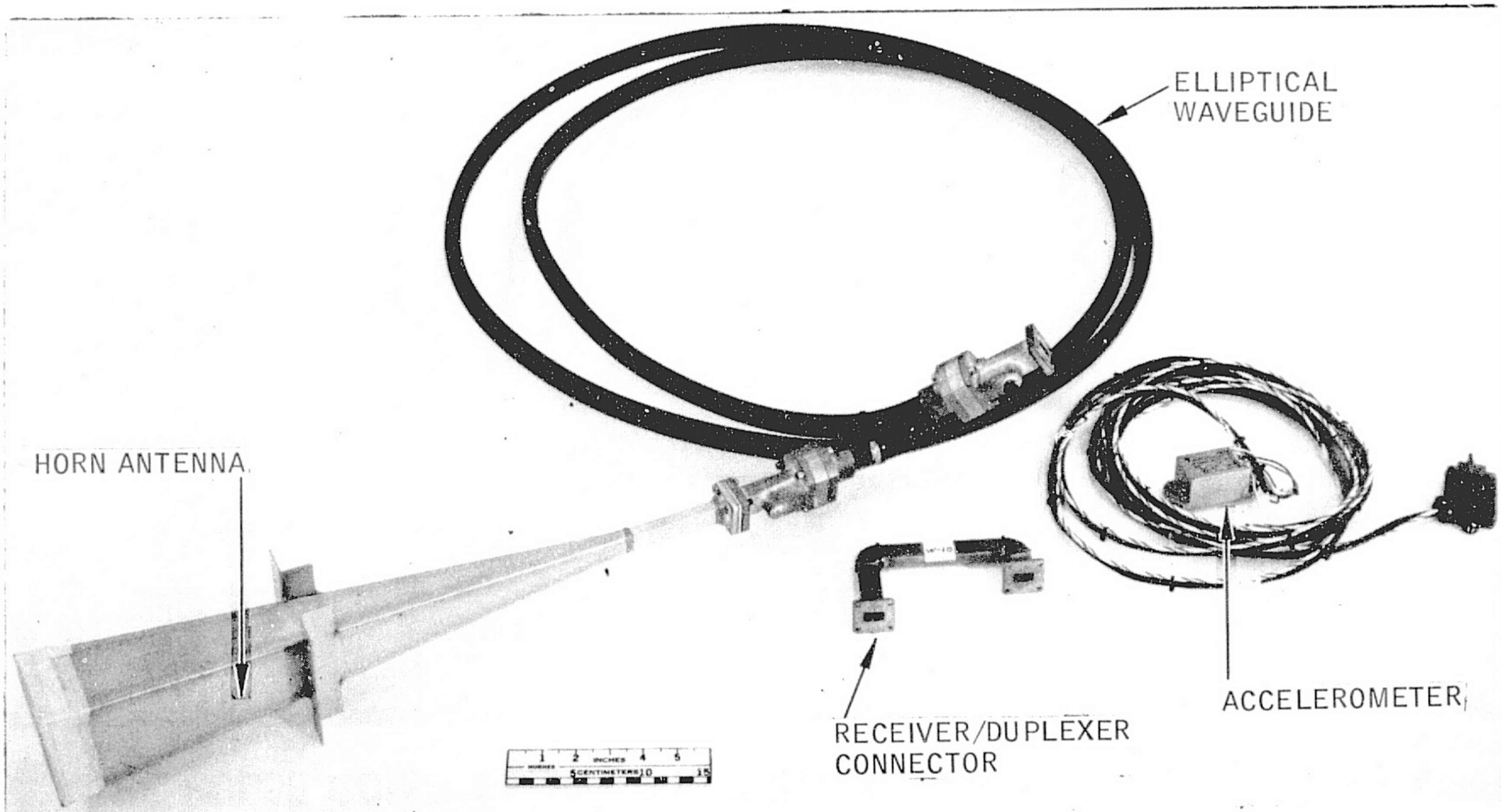
1. Stretch signal processing using a reflective array expansion line which provides 360 MHz of signal bandwidth and 3 μs to 3 ns pulse compression (1000:1).
2. Range command LSB of 0.62 ns (9.3 cm) which is obtained by means of 15:1 subdivision of a 108 MHz clock signal.
3. Extensive computer control including acquisition and tracking of the sea surface, AGC control, submode control, filter gain alignment, reflectivity and wave height estimation, delay calibration, noise estimation, and data collection/recording on digital magnetic tape recorder — the system records approximately 300 distinct data items.
4. Second-order split gate tracker using early and late gates aided by accelerometer inputs to overcome aircraft platform altitude variations.
5. Triple conversion receiver with 24 analog filters each 1/3 MHz bandwidth (2.8 ns or 42 cm) which enable collection of signal returns from the leading edge of 1 to 10m waves.
6. Four interleaved submodes: Radiate, Noise Estimation, Bias (signal amplitude) and Calibration (signal delay).
7. Calibration submode internal test target filter (gate) output splitting to determine system drifts to an order of one cm.
8. Stand-alone data reduction capability.

During the flight test program the system demonstrated an altitude resolution capability of 2.12 cm, an acquisition time of less than 4.5 seconds, and sea wave height estimation accuracy of ±10%.

AAFE PULSE COMPRESSION RADAR ALTIMETER



ANTENNA, WAVEGUIDE AND ACCELEROMETER



4. SYSTEM FLEXIBILITY THROUGH DESIGN

The radar altimeter design includes substantial flexibility in system control by virtue of the radar control panel and the software design. The system can be operated in the Normal radiate mode or a Test mode with an internal test target generated and used to exercise the tracker and the system. The design also provides for system operation under Computer control, or Panel control which can be used in trouble shooting. The Panel control configuration allows the operator to select parameters and set AGC and test target, noise, or radiate submode switches. When operating under Panel control the computer continues to interface with the system (unless inhibited) and to process the data as well as output data for recording. A recording control is on the system panel which enables outputting computer processed information on magnetic tape.

Besides these basic control switches the system control panel shown in the facing figure includes six primary parameters each of which has several selectable states. These parameters include the pulse width, PRF, Early gate width, Late gate width, tracker bandwidth and track point. An oscilloscope display and an light emitting diode array display (LEA), both of which are supplied data by the computer subsystem, are designed to display essential information during system operation. The four digit LEA can output wave height, reflectivity, altitude, in centimeters or meters, AGC and tracker error. The oscilloscope display outputs consist of average Ramp filter and Early, Late and Plateau gate outputs of noise or sea return data depending on operator selection.

The panel also includes indicators for equipment power, track status, and radar/computer data transfer error.

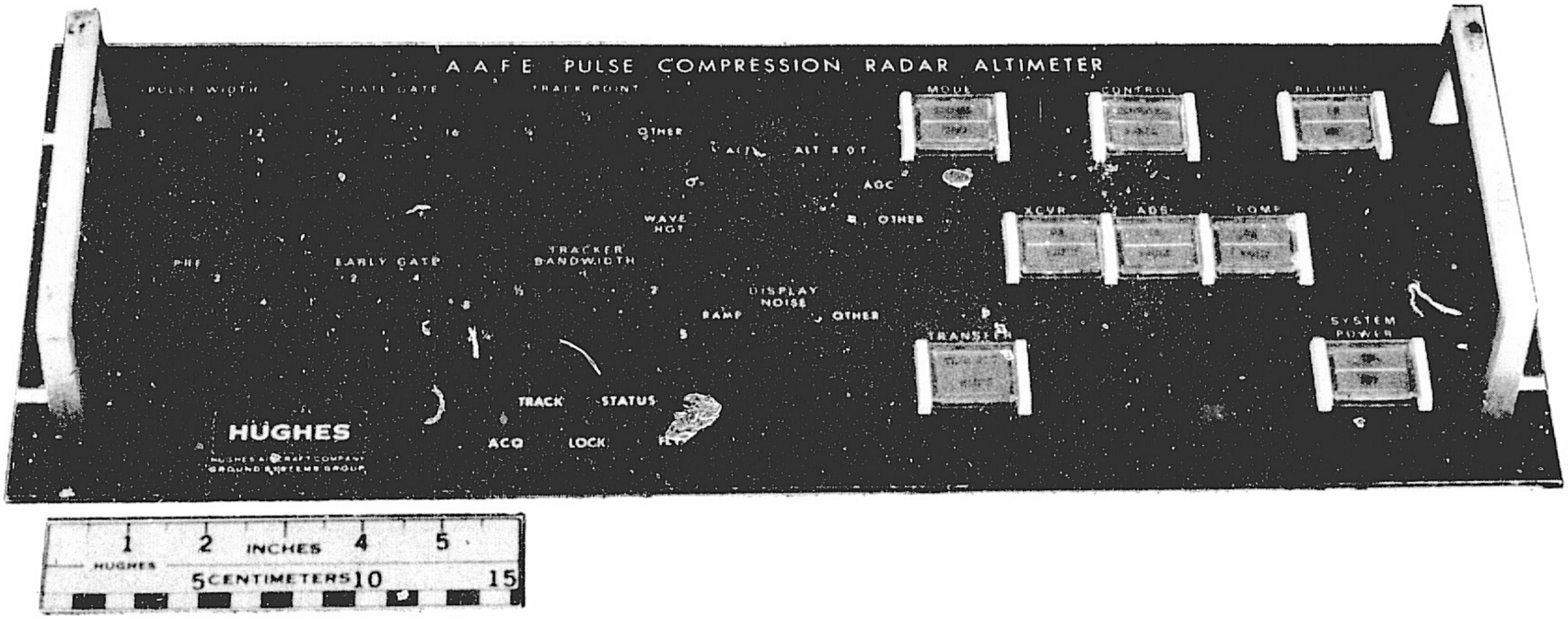
When operating under Panel control, additional switches are available (not shown) which allow setting of the AGC, the radar submodes (calibration, noise, or radiate) and cycle the command range; a switch is also available for inhibiting the radar computer interface in the event that stand alone radar trouble shooting is desired.

In addition to the controls and selections available at the control panel, a number of parameters can be changed readily within the software. The flexibility available directly and that available through moderate logic modifications in the software is summarized in the table (p. A-14). In most cases, the flexibility can be obtained by changing one or a few parameters or constants within the software. This flexibility was utilized during the development of the system as well as during optimization of parameters throughout the flight test program.

PRECEDING PAGE BLANK NOT FILMED

ORIGINAL PAGE IS
OF POOR QUALITY

AAFE PULSE COMPRESSION RADAR ALTIMETER CONTROL PANEL



SYSTEM FLEXIBILITY THROUGH SOFTWARE

AVAILABLE DIRECTLY

- SYSTEM OPERATION
  - SIGNAL DYNAMIC RANGE LOCATION VIA AGC THRESHOLD
  - NOISE, BIAS, CALIBRATION SUBMODE EXECUTION RATE AND DURATION
  - AGC BANDWIDTH
- ACQUISITION
  - EARLY AND LATE GATE THRESHOLDS
  - SEARCH STEP SIZE
- TRACK
  - TRACKER α , β PARAMETERS
  - BANDWIDTH
  - TRACK POINT
- WAVE HEIGHT, DROOP, REFLECTIVITY
  - WAVE HEIGHT AVERAGING INTERVAL
  - WAVE HEIGHT AND DROOP ESTIMATION
  - REFLECTIVITY SCALE FACTOR

AVAILABLE VIA LOGIC MODIFICATION

- ACQUISITION, TRACK, WAVE HEIGHT ALGORITHMS
- DATA DISPLAYED ON OSCILLOSCOPE AND LEA

5. REVIEW OF THE IN-PLANT PERFORMANCE TEST

The In-Plant Performance test consisted of a comprehensive set of 32 tests which responded to each item of the system specification. These tests were designed to demonstrate the satisfaction of routine as well as significant performance requirements.

The altitude resolution test which was conducted with a specially built 14 us delay line and the internal test target demonstrated that the system is capable of 2 centimeters resolution. The altitude calibration accuracy of the system was shown to be on the order of one centimeter. The drift rate was demonstrated to be less than 10 centimeters per hour which is substantially less than the 50 centimeters per hour required. The pulse compression ratio was demonstrated to be 1100:1. The range LSB was shown to be 0.62 nanoseconds by test, which again is substantially less than the one nanosecond required. In addition, an extensive environmental test was performed where the ADS and Transceiver equipments were subjected to vibration and altitude/temperature extremes. This verified that the equipment was indeed operable in the aircraft environment. The acquisition and altitude resolution tests demonstrated end-to-end electrical operability and provided confidence that the system would operate properly from the electrical standpoint.

These tests also indicated that corrective action was necessary in some areas. After correction of discrepancies by Hughes, the equipment was accepted with 4 failures. These 4 failures included ocean backscatter coefficient accuracy, signal-to-noise ratio, overload protection and weight. The ocean backscatter coefficient measurement accuracy was determined to be ±2.1 dB whereas the required accuracy was ±1.5 dB; this inability to provide the required accuracy was due to the approach taken in making the backscatter measurements and involved the calibration of large losses. The signal-to-noise ratio achieved was on the order of 12 dB whereas that required for a reflectivity of 6 dB was 20 dB; during the flight test program it was found that the sea reflectivity is greater than expected and that the system can be successfully operated as designed. This discrepancy was due primarily to excessive losses encountered in switches. Absence of an overload protection network on the 2 volt power supply caused a failure with respect to this requirement. Four of the units exceeded the 50 pound weight requirement and consequently failed the weight test; with the exception of the magnetic tape unit, all units are under 73 pounds and are portable.

PRECEDING PAGE BLANK NOT FILMED

AAFE PULSE COMPRESSION RADAR ALTIMETER IN PLANT PERFORMANCE TESTS

TEST NUMBER	TEST	PASS	FAIL	CORRECTED
0	INVENTORY OF REQUIRED EQUIPMENT	✓		
1	MATERIAL, CONSTRUCTION AND WORKMANSHIP		✓	✓
2	PRE-OPERATIONAL SETUP PROCEDURE		✓	✓
3	TEST POINTS AND DIAGNOSTICS	✓		
4	INTERCABLE INSPECTION		✓	✓
5	EMI TEST	✓		
6	ALTITUDE RESOLUTION	✓		
7	ALTITUDE CALIBRATION	✓		
8	DRIFT RATE	✓		
9	OCEAN BACKSCATTER COEFFICIENT MEASUREMENT DEMO	✓		
10	OCEAN BACKSCATTER COEFFICIENT ACCURACY		✓	
11	WAVE HEIGHT ACCURACY		✓	✓
12	ACQUISITION TIME	✓		
13	PULSE COMPRESSION RATIO	✓		
14	ANTENNA TEST	✓		
15	TRANSMITTER POWER	✓		

INPLANT PERFORMANCE TESTS

TEST NUMBER	TEST	PASS	FAIL	CORRECTED
16	OPERATING FREQUENCY	✓		
17	S/N RATIO		✓	
18	SYSTEM CONTROLS, STATUS AND HOUSEKEEPING		✓	✓
19	COHERENT SYSTEM	✓		
20	WARM-UP TIME	✓		
21	RELIABILITY	✓		
22	EIGHT-HOUR RELIABILITY OPERATION	✓		
23	RANGE LSB	✓		
24	AGC RESOLUTION	✓		
25	TRANSMITTER POWER ACCURACY	✓		
26	A/D RESOLUTION	✓		
27	SYSTEM CONTROLS		✓	✓
28	ENVIRONMENTAL VERIFICATION TEST	✓		
29	PRIME POWER CONSUMPTION	✓		
30	OVERLOAD PROTECTION		✓	
31	WEIGHT AND VOLUME TEST		✓	

6. SUMMARY OF SYSTEM INSTALLATION AND INSTALLATION TESTING

Installation of the altimeter commenced on 13 October 1975 aboard the NASA C-54 instrumentation aircraft N427NA. All altimeter equipment except the antenna, accelerometer and teletype were installed in equipment racks 8 and 9 as shown in the figures (p. A-21, A-22). Installation problems were all minor and of a mechanical nature, such as slide interference and waveguide orientation.

The antenna was mounted in the instrumentation port below and slightly aft of rack 9. The antenna mount was designed and fabricated on site by NASA. The accelerometer was located on the antenna mount, however it can be easily relocated if an optimum position is found.

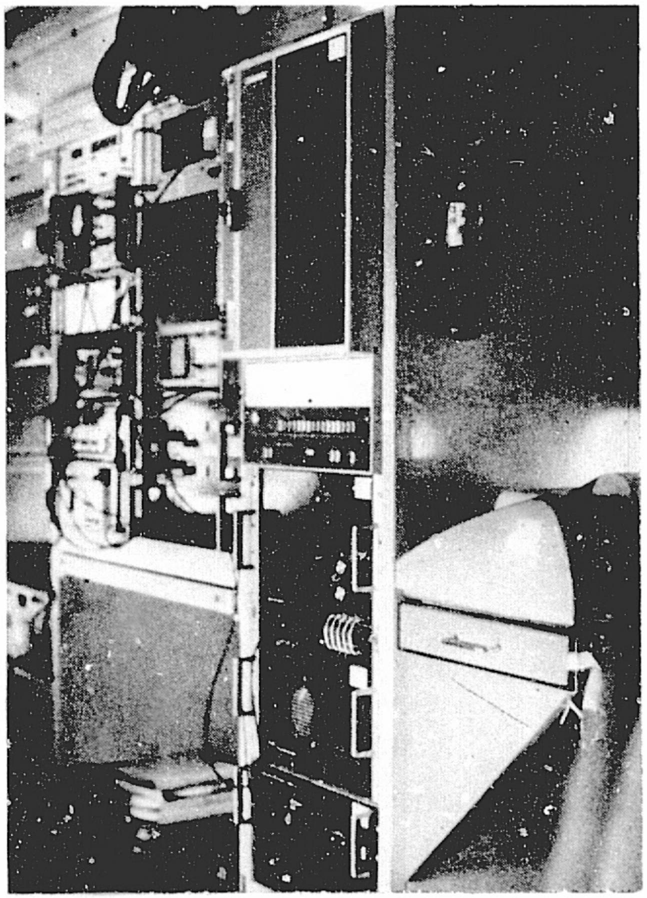
The teletype was located on a sliding mount at the aft side of rack 9. The teletype mount was designed by Hughes and fabricated and installed by NASA.

This system installation has proven to be convenient for operation and maintenance. Access to the Transceiver subsystem has been improved by the addition of waveguide quick disconnects and sections of flexible waveguide between the duplexer and receiver and between the duplexer and semi-rigid waveguide to the antenna. This installation also allows easy removal of the Computer subsystem for stand-alone data reduction on the ground when the aircraft is unavailable.

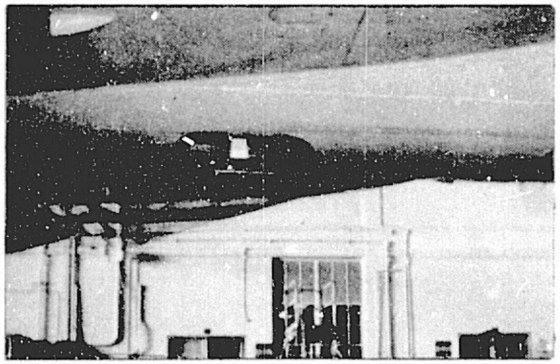
The installation and checkout tests summarized on p. A-23 were successfully completed on an informal basis as operation verification checks. The EMI test was the only new test and was formally conducted by Hughes and monitored by NASA. The test was successful and no interference to the altimeter or by the altimeter was encountered.

PRECEDING PAGE BLANK NOT FILMED

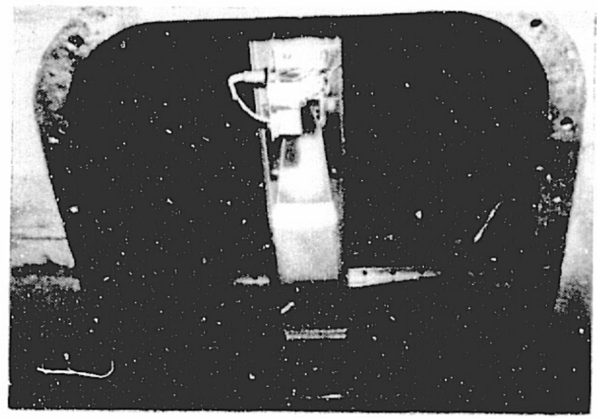
AIRCRAFT INSTALLATION



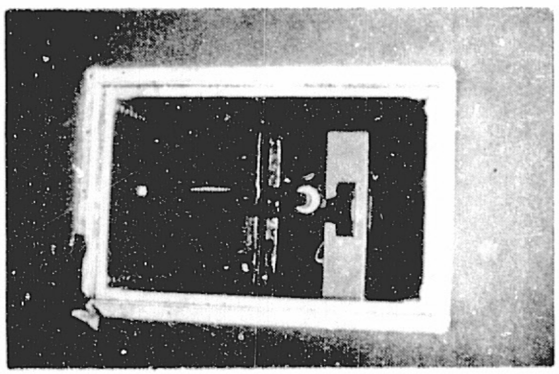
AIRCRAFT INSTALLATION



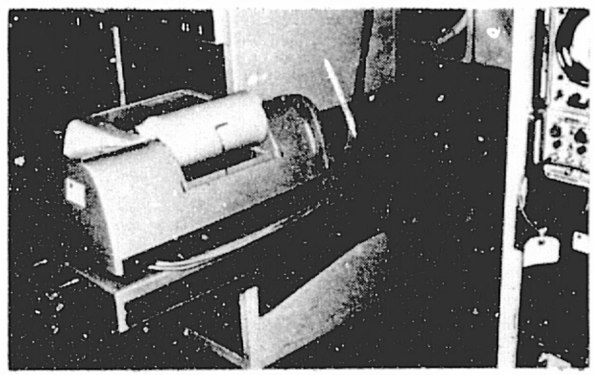
INSTRUMENTATION PORT



ANTENNA AND ACCELEROMETER



TOP VIEW OF ANTENNA



TELETYPE MOUNT

AAFE PULSE COMPRESSION RADAR ALTIMETER

INSTALLATION AND CHECKOUT TESTS

	TEST NO.
INVENTORY	0
INSPECTION	1,4
TURN ON/SETUP	2
TEST POINTS	3
COMPRESSION RATIO	13
TX PWR	15
OPERATING FREQUENCY	16
RANGE LSB - CHECK ONLY	23
TX PWR ACCURACY	25
WAVEHEIGHT	11
ALTITUDE RESOLUTION	6
CONTROLS AND HOUSEKEEPING	18
E.M.I.	5

7. RESULTS OF THE FLIGHT TEST PROGRAM

Flight testing in a C-54 aircraft followed the installation of equipment. The Flight Test program consisted of five flights and was highly successful; acquisition time, altitude resolution and wave height accuracy tests demonstrated that the system performance exceeds requirements. The flight test program is summarized in the table (p. A-28).

Flight #1 included electrical and mechanical checkout and some parameter variation tests. This flight demonstrated that the system operates in the aircraft environment and has a basically good altitude resolution capability. Subsequent flights were essentially dedicated to acquisition and wave height estimation improvement. The flight demonstrated that accelerometer inputs are necessary in order to provide good tracking data; it was also apparent that higher acquisition thresholds should be used since premature acquisition resulted in substantial oscillation during the early segment of the track. During intentional platform oscillatory motion of ±100 feet, the system demonstrated that it could continue to track. Post-flight data reduction revealed that the Plateau gate gain had been erratic and had caused erratic AGC behavior; AGC is derived on the basis of the Plateau gate signal by the software. Also, minor software corrections were necessary.

Flight #2 objectives were to confirm the tracker altitude estimates by comparison with the FPQ-6 precision radar track of the platform and to conduct further parameter variation tests. The difference between the FPQ-6 and altimeter was found to be primarily a constant; good consistency in estimated platform vertical motion was obtained. Higher acquisition thresholds were selected on the basis of this flight and further effort in wave height estimation was indicated by the results. The initial design was based on providing wave height estimates at a rate equal to the reciprocal of the tracker bandwidth. This was considered unnecessary, and lower rates allowing greater averaging of signals were implemented for succeeding flights. Some modification of the adaptive track concept, which depends on wave height estimates, was required as a result of the longer averaging time allowed for wave height estimation. This eventually led to segmenting of the 1-10 meter wave height region into five overlapping intervals and definition of representative wave height values to be used by the tracker initially until an estimate is provided by the Wave Height Estimation module. Consideration was also given to obtaining more solid noise averages which are used in determining the filter gain alignment factors and have a bearing on the wave height accuracy. The noise averages were finally based on 4096 pulses. A receiver warm-up problem was noted during this flight. That is, the Receiver unit appeared to require several hours of warm-up before filter outputs stabilized. This problem continued to persist during succeeding flights. It was finally corrected by temperature-controlled heaters in the Receiver; these heaters were supplied by Hughes and installed by NASA.

Flight #3 was dedicated to wave height estimation. A laser profilometer was flown during this flight and was used as the ground truth. Modifications of the software had been made prior to the flight, and 10-second averaging of the Ramp filter data was performed for wave height estimation. This resulted in a significant reduction in the wave height estimate fluctuation and later proved to be in good agreement with the profilometer data. The difference between the radar altimeter estimates and those of the profilometer were on the order of 10% which is substantially less than the required ±25%. The sea state during this flight was on the order of 2 to 3 meters.

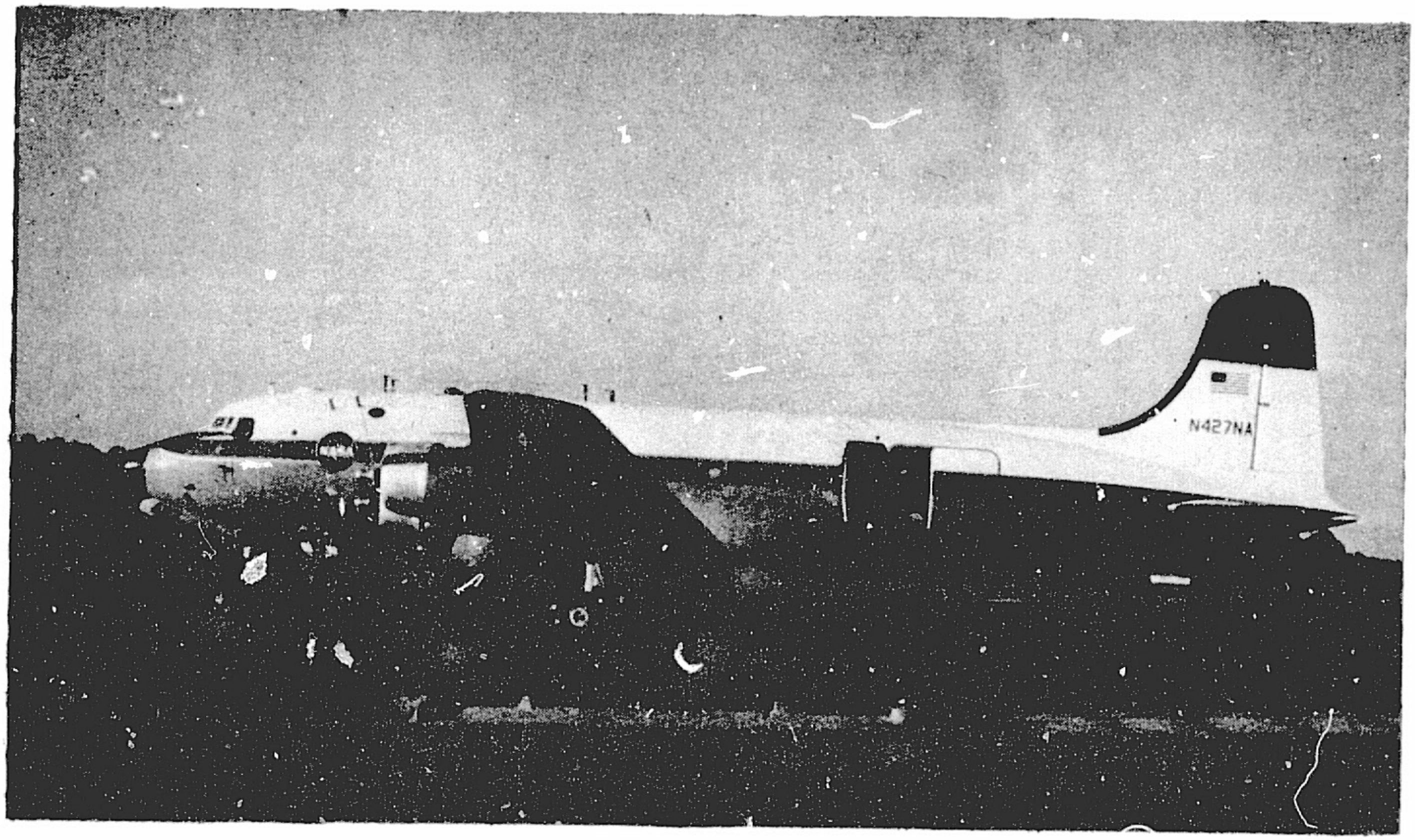
Flight #4 constituted the dry run of the final acceptance test. Ramp filter averaging for 30 seconds was used for wave height determination during this test. Although the flight was considerably rougher than the previous three flights, the performance of the system was adequate to proceed with the final acceptance tests which were performed during the next flight.

The acceptance test flight was intended to demonstrate acquisition, altitude resolution, and wave height estimation. This was a smooth flight and the system demonstrated exceptionally good performance. The system acquisition time was shown to be 4.5 seconds or less. The altitude resolution of the system was determined to be 2.12 centimeters and the wave height estimation accuracy within the required ±25 percent. Results are summarized on p. A-29. For detailed descriptions of the results, refer to Appendix A.

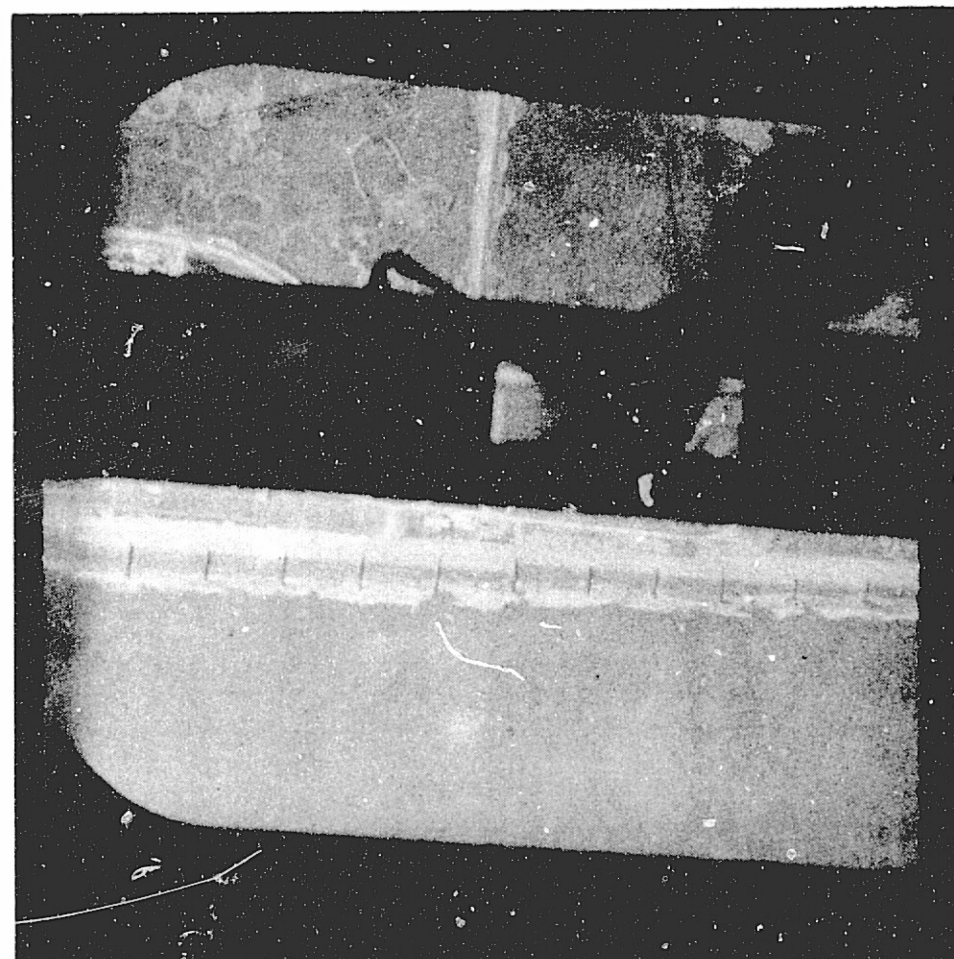
Flight test data reduction was performed primarily by the use of the Radar Altimeter Computer subsystem and the data reduction programs developed for the system. When the aircraft was not available, the Computer subsystem was removed from the aircraft and installed in the laboratory. Availability of data reduction and essentially failure-free system operation were deciding factors in the brevity and success of the Flight Test program. In addition to the test results described above and in Appendix A, other data was obtained which tended to verify good system operation and to substantiate design assumptions.

RADAR ALTIMETER TEST PLATFORM C-54

ORIGINAL PAGE IS
OF POOR QUALITY



VIEW THROUGH ANTENNA PORT DURING FLIGHT TEST



- CROSSING BEACH AT 10 KFT

AAFE PULSE COMPRESSION RADAR ALTIMETER FLIGHT TEST SUMMARY

FLIGHT NO.	DATE	DURATION	PURPOSE	RESULTS
1	10-28-75	3 HOURS	ELECTRICAL AND MECHANICAL C/O PARAMETER VARIATION TESTS • ACQ THESHOLDS • INIT. WAVE HT. • β • INIT. DROOP • ACCELEROMETER • VARIOUS CONFIGURATIONS • TRACKER BW • PLATFORM ±100 FT	GOOD SYSTEM AND TRACKER OPERATION IMPROVED PERFORMANCE WITH • HIGHER ACQ THESHOLDS • ACCELEROMETER INPUTS PLATEAU GATE ERRATIC MINOR SOFTWARE CORRECTIONS
2	11-4-75	2 HOURS	FPQ-6 PLATFORM TRACK PARAMETER VARIATION TESTS • ACQ THRESHOLDS • 16K NOISE AVE • 10 Hz AGC • PRF • TRACKER BW • ACTIVE WAVE HT.	HIGHER ACQ THESHOLDS SELECTED POOR PERFORMANCE WITH ACTIVE WAVE HT. RECEIVER WARM-UP PROBLEM
3	11-5-75	0.5 HOURS	PROFILOMETER WAVE HT. TEST PARAMETER VARIATION TESTS • INITIAL WAVE HT. • 10 SEC AVE FOR WAVE HT. EST.	SIGNIFICANT IMPROVEMENT IN WAVE HT. EST. RECEIVER ADJUSTMENT IN-FLIGHT
4	11-14-75	2.5 HOURS	PARAMETER VARIATION TESTS • 4, 16K NOISE AVE • ACTIVE WAVE HT./DROOP WITH 30 SEC SIGNAL AVE ACCEPTANCE TEST DRY RUN	ROUGH FLIGHT POORER ALT. RES. (5-10 CM) GOOD WAVE HT. EST. PLATEAU GATE PROBLEM (CORRECTED POST FLIGHT)
5	11-19-75	1.5 HOURS	ACCEPTANCE TESTS • ACQ. • ALT RESOLUTION • WAVE HEIGHT EST.	SMOOTH FLIGHT EXCEPTIONALLY GOOD PERFORMANCE • ALT RES 2.1 CM

AAFE RADAR ALTIMETER ACCEPTANCE FLIGHT TEST RESULTS

- ALTITUDE RESOLUTION

  2.12 CM (10 CM REQUIRED)

- ACQUISITION TIME

  1.99 CM ALT RES IN 4.5 SEC (10 CM IN 5 SEC REQUIRED)

- WAVE HEIGHT ACCURACY

  RMS FLUCTUATION 10.8%
  ACCURACY $< \pm 25\%$ ($\pm 25\%$ REQUIRED)
  FLIGHT NO. 3 DEMONSTRATED 10% ACCURACY

SECTION B
SYSTEM DESIGN

PRECEDING PAGE BLANK NOT FILMED

1. PRINCIPLES OF OPERATION

The AAFE Radar Altimeter is designed to measure altitude, wave height and sea reflectivity. System design and operation are based on knowledge of backscattered signal characteristics which depend on geometry, radar parameters, and environment. References 1-3 contain the significant theoretical and experimental data used as basis for the system design.

The radar geometry is illustrated on p. B-2. The nominal radar platform altitude is 10,000 feet. The radar antenna beamwidth is approximately 15 degrees, and the basic range resolution cell of the system is 41.67 centimeters. Because of the wide antenna beamwidth, the system operation is primarily pulse limited. With the exception of longer ranges, the sea return amplitude as a function of time is not affected significantly by the antenna pattern. The transmitted signals are reflected by the surfaces of the waves and upon reception by the system are resolved in 41.67 centimeter intervals. The fine resolution provided by the system enables mapping of the reflections from the peak to the trough of the wave. An accompanying diagram based on the flat earth model indicates the distances corresponding to the platform altitude and the range resolution. On the basis of the flat earth model, the very first range cell encompasses scattering from the sea surface of a circular area with a radius of 50 meters. The half angle subtended by this radius or area is approximately 1 degree. The furthermost range cell (Late gate) of the system is centered at 15.4 meters with respect to the altitude and receives reflections from a circular annulus having a radius of 306 meters. The corresponding half angle from nadir is 5.8 degrees.

The next figure illustrates the theoretical signal strength as a function of time or range; the radar transfer function (range sidelobes) and antenna pattern effects are implicit in these plots. Amplitude data is shown for 0.5 to 10 meter significant waveheights. The characteristic features of the amplitude function are a leading edge ramp and a dropping plateau at longer ranges. The leading edge ramp is primarily due to the wave height phenomena. The lower wave heights exhibit a steeper ramp than the higher wave heights. This ramp rises as the transmitted signal penetrates deeper into the wave. Initially, the backscattering is obtained from the peaks of the waves. Succeeding range cells obtain backscatter from intervals deeper into the wave until finally signals are backscattered by the trough of the wave. At this time a peak amplitude is obtained and maintained. The droop in the plateau at longer ranges is a function of the fall-off of the antenna pattern gain and the sea reflectivity as a function of angle. It should be noted that the amplitude plots are normalized such that with the antenna pattern and reflectivity fall-off effects absent, the plateau would remain constant at unity value. This normalization results in an apparently lower signal amplitude for the lower wave heights at long ranges. However, in a presentation of amplitude where no normalization is performed, the low wave height signal strengths are greater than those from the high wave heights. The half-power points of each curve or, more correctly, the zero time on the axis of the diagram corresponds to the mean sea level; it is the altitude with respect to the mean sea level that is of interest. Slight deviation of the amplitudes at zero time from the half-power point is due to the radar system transfer function (filter width and sidelobes) and sea wave and antenna pattern induced effects.

The figure on p. B-4 presents radar altimeter oscilloscope display data. It represents a 10-second exposure of the face of the oscilloscope when operating at a PRF of 850 pulses per second. This figure illustrates another important aspect of the sea return signal. That is, the sea return signal is a fluctuating signal. The fluctuation is due to the pulse-to-pulse decorrelation caused by wave and platform motion; the degree of decorrelation is dependent on wave height, platform motion, and PRF.

The fourth figure illustrates the radar altimeter tracking and wave height measurement mechanization. The radar tracker utilizes an Early and a Late gate which are separated by 15.4 meters. It strives to maintain the ratio of the output powers of these two gates to be equal to a selected value. In order to track the mean sea level (half-power point), the system is designed to correct for the amplitude deviation at zero time and plateau droop due to the antenna pattern and sea reflectivity at the position of the Late gate. The gate placement is achieved by range commands from the tracker. Thus the range command is in fact the predicted altitude of the platform above the mean sea level. For the purpose of wave height estimation 24 Ramp filters or gates are implemented. These gates are in essence connected to the Early gate and sample the leading edge or ramp of the sea return. A number of algorithms can be utilized to process the amplitude information from these gates and to derive the sea wave height. A simplified approach was developed which utilized only gates 11 through 14. Amplitudes from these gates are utilized to compute a ramp slope, and the slope is then related to the wave height by means of a polynomial. The sea reflectivity measurements were based on the amplitude of the Plateau gate which is located at the same position as the Late gate. In order to overcome the random fluctuation of the sea return signal, two types of averaging are implemented in the system. The first averaging is on a range cell to range cell basis and is controlled by means of Early and Late gate width selection at the radar control panel. The second type of averaging is performed pulse to pulse and based on the tracker bandwidth and PRF selections at the control panel.

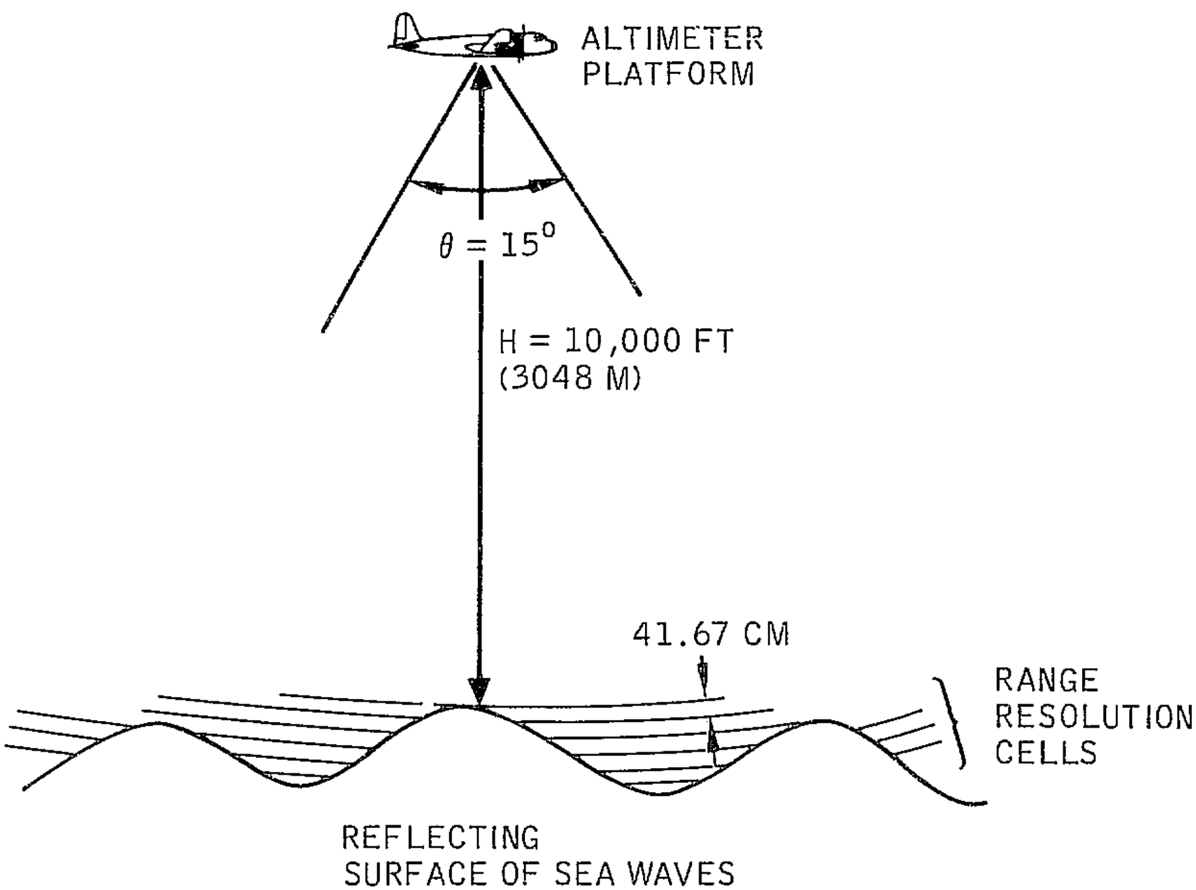
Reference 1 – Barrick, D.E., "Remote Sensing of Sea State by Radar", Chapter 12 of Remote Sensing of the Troposhere, V.E. Derr (ed.), NOAA, August, 1972.

Reference 2 – Dooley, R.D., et al, Study of Radar Pulse Compression for High Resolution Satellite Altimetry, NASA Report # CR-137474, December, 1974; TSC Report # WO-111.

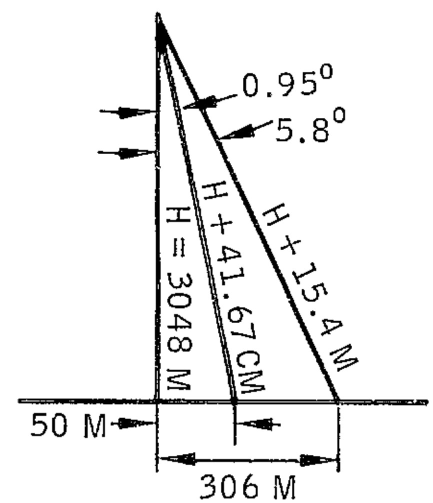
Reference 3 – Walsh, E., "Analysis of Experimental NRL Radar Altimeter Data", Radio Science, pp 711-722, August – September, 1974.

RADAR ALTIMETER GEOMETRY

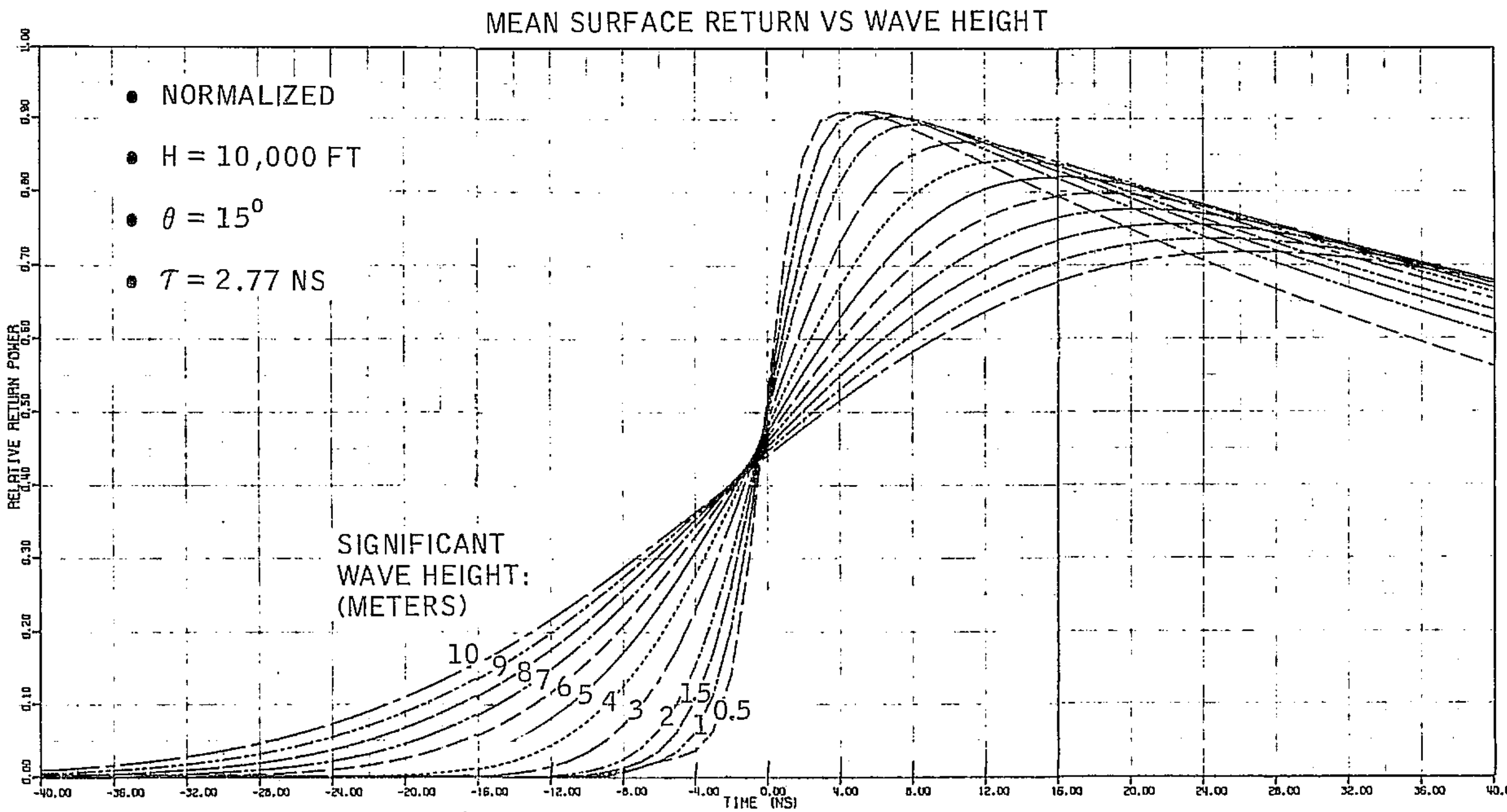
- REFLECTION OF SIGNAL BY WAVES



- FLAT EARTH MODEL

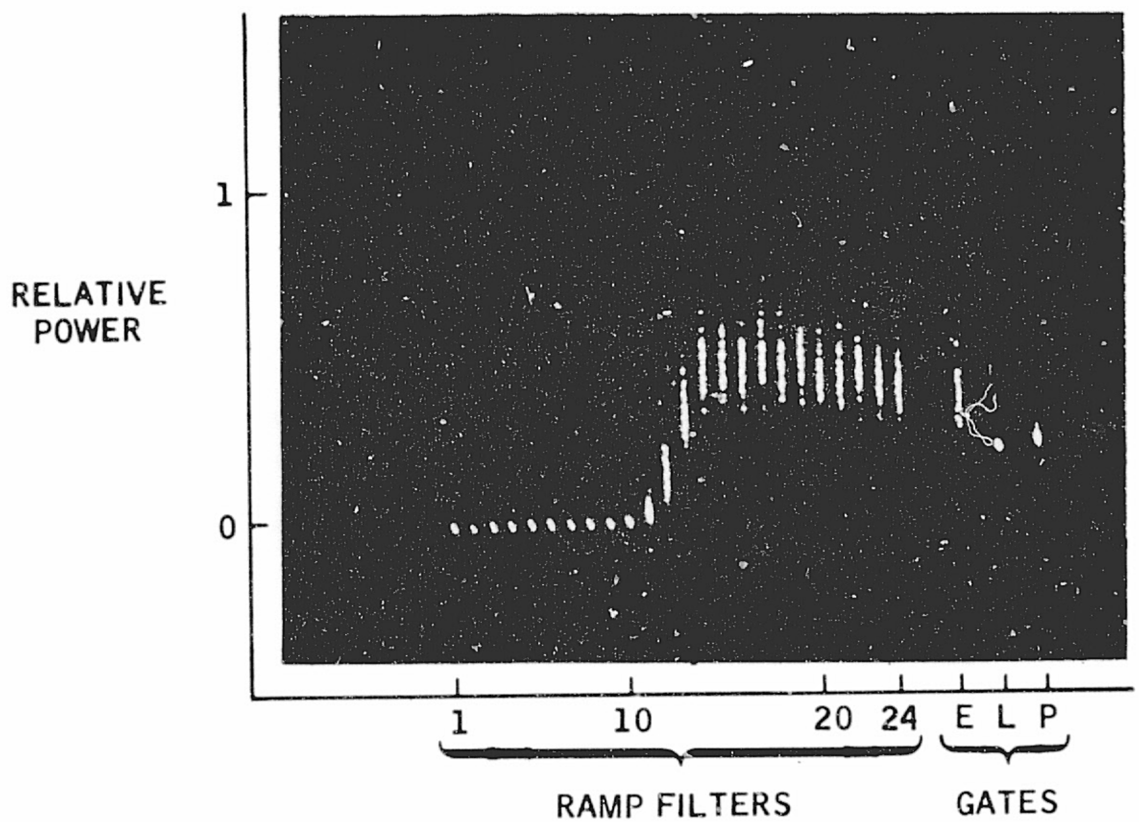


THEORETICAL SEA RETURN

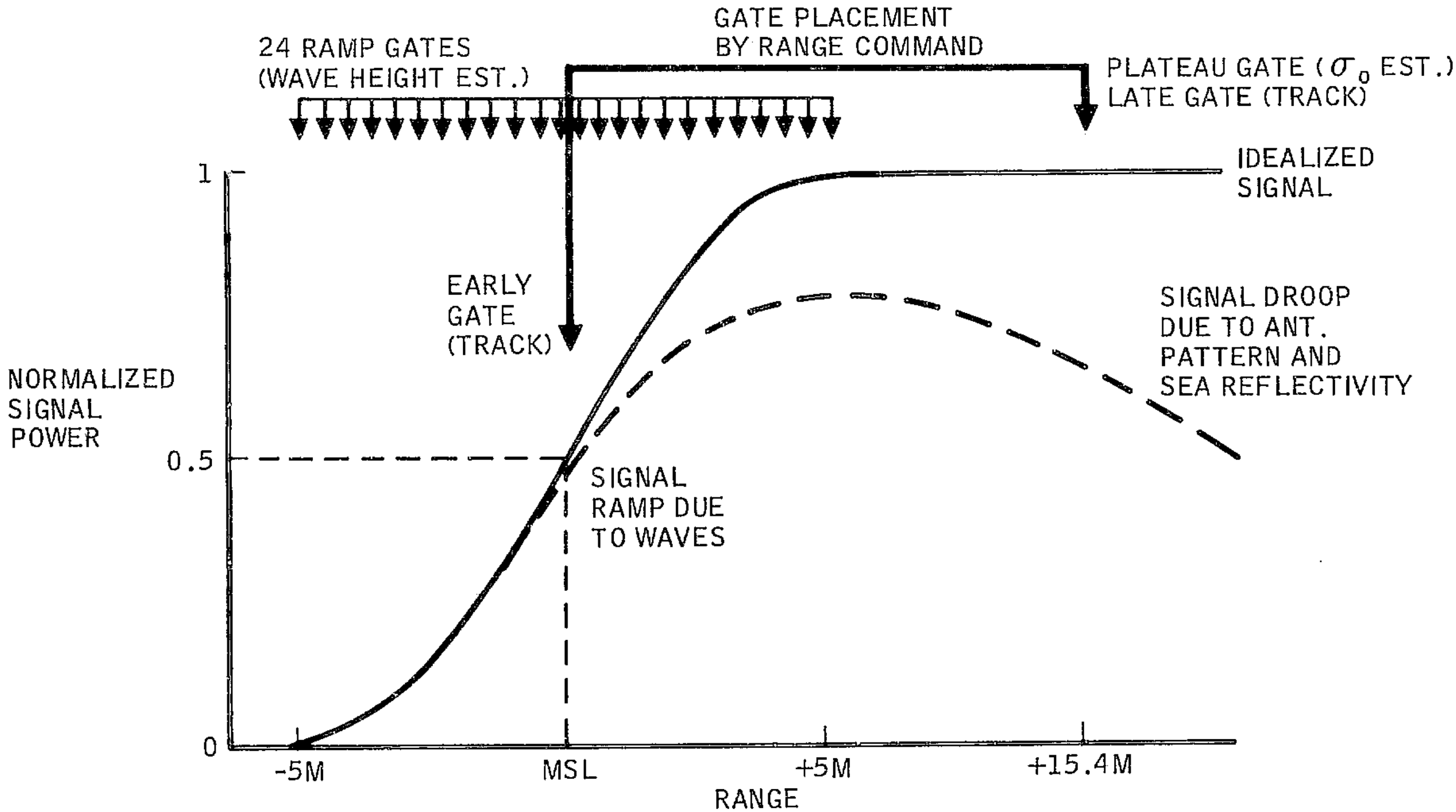


RADAR ALTIMETER OSCILLOSCOPE DISPLAY OUTPUT

- SEA RETURN SIGNAL RAMP, FLIGHT NO. 2
- 10 SEC EXPOSURE



SEA RETURN SIGNAL SAMPLING AND UTILIZATION



2. IMPLEMENTATION OF STRETCH TECHNIQUE

Fine range resolution is the key feature of the altimeter design which enables it to achieve the required performance. This fine resolution capability is implemented using the stretch technique which employs a correlation mixer as opposed to a compression line for processing the reflected signals. Implementation of this novel technique with 1000:1 pulse compression is primarily due to the Reflective Array Compression/Expansion line technology at the Hughes A/C Co.

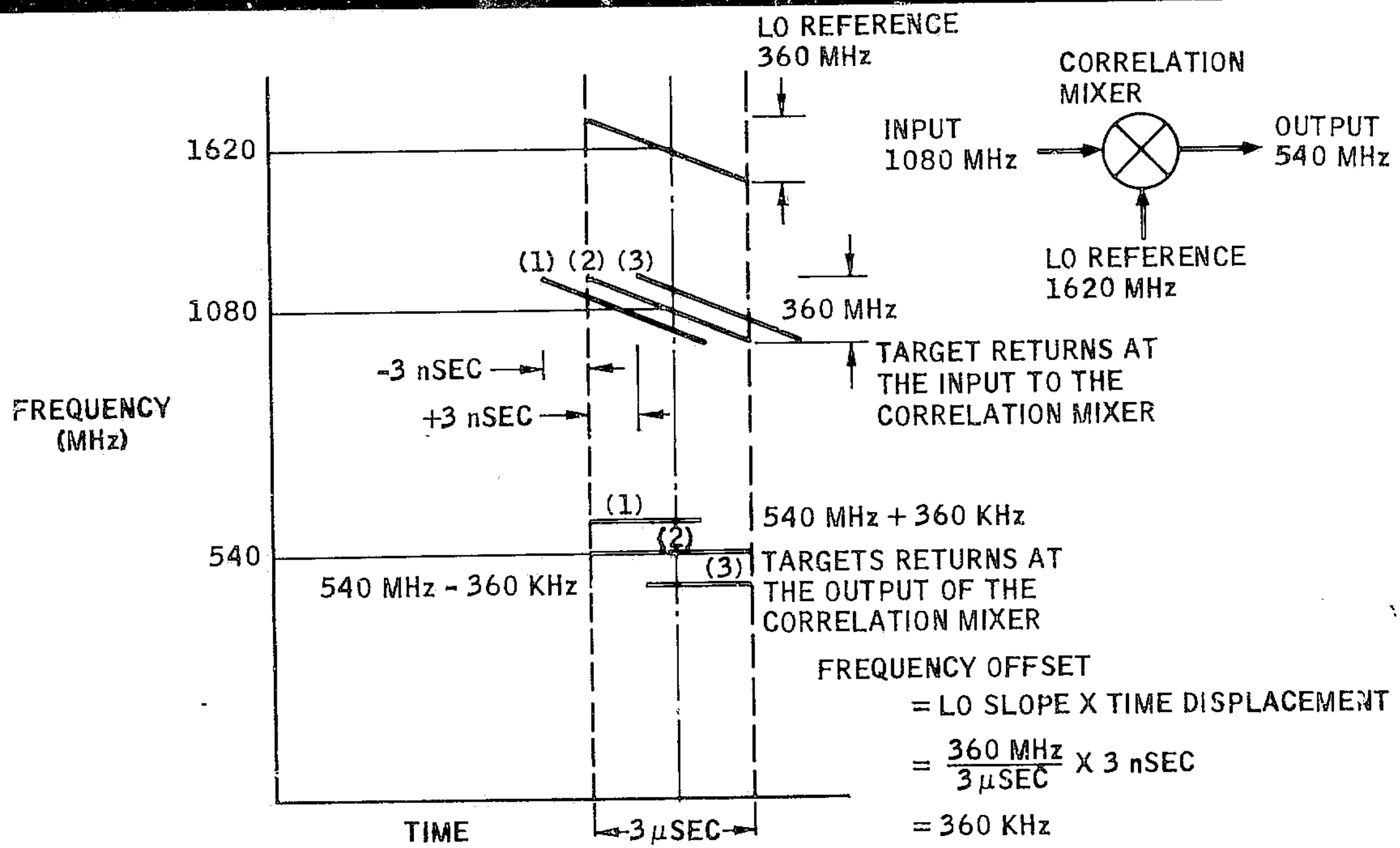
The radar altimeter stretch processing is depicted in the facing figure. The stretch technique is based on transmitting a coded signal and correlating the reflected return with a replica of the transmitted signal. The diagram illustrates this process which takes place in the second mixer. The first mixer is primarily a down conversion operation which results in translating the 13.9 GHz signals to the second IF of 1080 MHz. These second IF signals which still contain the frequency modulation are mixed in the second mixer with a coded signal of the same type as transmitted. The output consists of signals at the third IF (540 MHz) with offsets in frequency which are proportional to signal time delays.

The diagram illustrates three returns from three discrete scatterers which are displaced 45 cm in range. The return signal of the first scatterer arrives 3 nsec earlier than the reference signal. Scatterer #2 signal arrives at a time coincident with the reference and Scatterer #3 arrives at a time 3 nanoseconds later than the reference. When these three signals are mixed with the coded reference signal, the result is three gated CW signals with differing center frequencies. Thus, range delay is converted to a frequency differential. Since the coding or modulation slope is 120 kHz per nanosecond, a time delay of 3 nanoseconds results in a frequency differential of 360 kHz. The 3 gated CW signals can then be distinguished or range gated by means of filters in the frequency domain. The system employs 24 Ramp filters with a bandwidth and spacing of a 1/3 MHz which corresponds to 2.77 ns or 41.67 cm and can resolve these three scatters. The absolute range is determined from the reference signal time which is commanded by the software tracker. An important advantage of this approach is that the signals that are ultimately converted to digital form are basically 3 microseconds in duration. Thus, A to D conversion requirements or sample rates are substantially less severe than in the normal implementation of pulse compression where the result would be range cells of 2.77 nanoseconds. This would impose severe A to D sampling requirements.

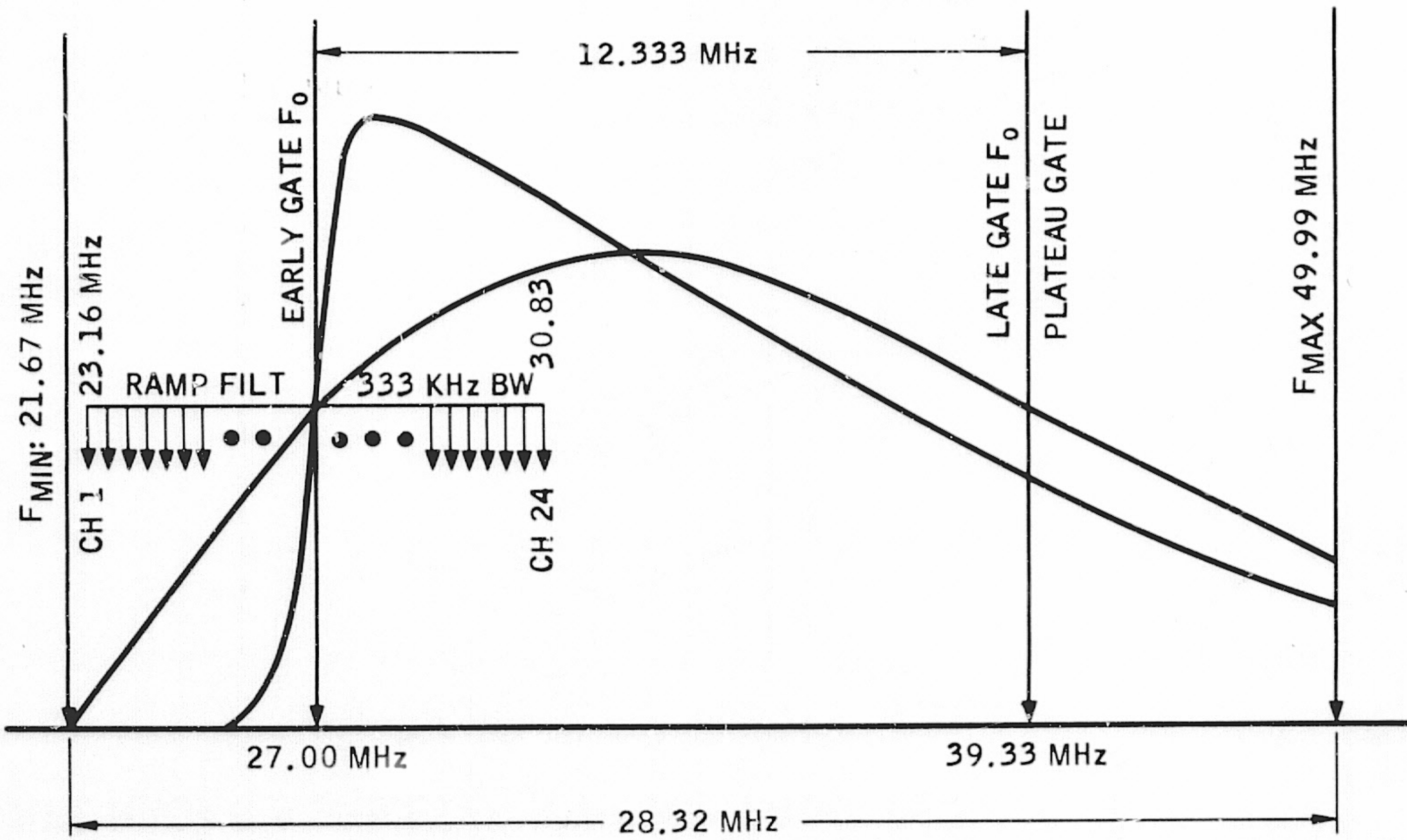
The next figure indicates the frequencies and location of the various gates. The 24 ramp filters straddle the 27 MHz third IF frequency and allow mapping or analysis of the leading edge or ramp of the sea return; their coverage corresponds to 10 meters in range. The Late gate and the Plateau gate is offset from the Early gate by 12.333 MHz which corresponds to 102.77 nanoseconds or approximately 15.4 meters. The outputs of these gates are sampled, held, multiplexed and converted to digital form. In this form, they are sent to the computer where they are processed and recorded.

ORIGINAL PAGE IS
OF POOR QUALITY

AAFE RADAR ALTIMETER STRETCH PROCESSING



FILTER POSITION REFERENCED TO SURFACE RETURN



3. HARDWARE FUNCTIONAL DESCRIPTION

A summary of the key AAFE Radar Altimeter system parameters is given in the table (p. B-12) and a system block diagram is presented in the next two figures.

The source of signal generation is a 108 MHz oscillator located in the Exciter portion of the Transceiver subsystem. It serves as the reference clock in the synchronizer of the Analog/Digital subsystem (ADS) which originates all triggers and gates and provides the base frequency from which signals are derived. A delay implementation in the ADS unit provides 15:1 time splitting of this signal resulting in an effective 1.6 GHz clock and a range command LSB of 0.62 ns, or 9.3 cm. Using frequency multiplication and division of the 108 MHz signal, the Exciter generates the basic 540 MHz signal and the 567 MHz third LO signal. A 540 MHz CW signal is supplied to the spectrum generator where it is gated to 5 ns by means of a delay technique. This gated signal provides the necessary input bandwidth for the acoustic dispersive delay line which expands the pulse to 3 μs. Due to the available technology at Hughes Aircraft Company, a reflective array compression or expansion (RAC) delay line is used to provide the high bandwidth linear FM signals with minimum phase error characteristics. The RAC line provides a modulation slope of 180 MHz/3 μs which results in a center frequency of 1080 MHz and 360 MHz bandwidth over the 3 μs pulse after a times two frequency multiplication. A gate driven switch after the multiplier provides for selection of 0.75, 1.5, or full 3.0 μs pulses with 90, 180 or 360 MHz of bandwidth. This signal is used to supply the Transmitter drive and the 2nd LO signal for the correlation or stretch processing. Range or time of generation of the 2nd LO signal depends on the platform altitude and is determined by the software tracker. Economy considerations dictated a serial method of generating the Transmitter drive and 2nd LO using the same hardware; as a result the system minimum range of operation is approximately 7,000 feet, or 14 us. The transmitter drive at 13.9 GHz is generated by amplifying the 1080 MHz coded frequency multiplier output and mixing it with the 12.82 GHz oscillator signal; this stable oscillator also provides the 1st LO signals to the Receiver.

The 13.9 GHz signal is amplified by a TWT amplifier operating in a CW mode. Pulse gating of the TWT output is used to reduce transmitter noise. The output signal is sampled and detected for monitoring transmit power and radiated through the duplexer and horn antenna. The net peak power at the duplexer output is approximately 0.5 watts. The antenna has a beamwidth of approximately 15.6 degrees and gain of 21.6 dB. During the Calibration submode, radiation is inhibited by a switch after the transmitter output coupler and the transmitter output sample is coupled directly into the Receiver. Calibration submode signals are generated during normal receive time, i.e., the transmitter output is generated at the same time as the coded 2nd LO reference signal (zero time delay).

The received signals are down-converted to the 1080 MHz IF frequency using the 12.82 gHz 1st LO signals and amplified; the Receiver noise figure is 13.3 dB. A manually controlled step attenuator with a range of 69 dB in 1 dB steps is provided for controlling the amplitude of the input signals.

A 102.77 delay line is implemented in order to provide a Late gate test target simultaneously with the Early gate test target; the delay line output is switched in when operating in the Calibration mode. Mixing of the received signals with the coded 2nd LO signal constitutes the correlation or stretch process; this operation translates time delays to frequency offsets and preserves the basic pulse length. The time of generation of the 2nd LO signal, which is under

PRECEDING PAGE BLANK NOT FILMED

computer control, and the frequency offset of a given scatterer, determine its total time delay or range. These signals are than filtered to reduce Receiver noise and mixed down to the 27 MHz 3rd IF. A computer-controlled AGC maintains the signals within the desired region of the dynamic range of the filters/detectors which follow; the AGC is controllable in 0.75 dB steps over a 47.25 dB range. The signal is successively split and amplified to provide inputs to the Early, Late, Plateau and the 24 Ramp filters. Linear detectors follow each of the 24 Ramp filters with 1/3 MHz bandwidth and spacing; this is equivalent to 41.67 cm resolution. Early and Late gate filter widths are selectable for reducing signal fluctuation by range cell-to-range cell integration. Along with the Plateau gate, the Early and Late gate filter bandwidths depend on the selected pulsewidth; the square law detectors of these gates are followed by integrators which are matched to the pulse width. See a succeeding topic on Control Panel for available bandwidths.

The filter outputs, along with the Transmitter power sample and accelerometer output, are simultaneously sampled, held, multiplexed and converted to digital form by the 12-bit A/D converter of the ADS subsystem. In the ADS, the linearly detected Ramp filter outputs are squared and truncated to the 16 MSB's. These 29 unbuffered signals are then sent directly to the computer for processing each pulse period; seven other 16-bit words containing control panel switch codes and NASA time data are also transmitted to the computer by ADS. Each pulse period the ADS receives 6 words which include mode, parameter, AGC and altitude commands and data for display on the oscilloscope and the light emitting diode array (LEA). The Radar Control Panel provides the controls and switches for selection of radar operation; the wrap-around implementation with the computer and computer command indications by LED's on the control panel insure proper transmittal, implementation, and recording of the operator selected configuration.

The computer provides processing of signals, originates range commands by means of the tracking function, provides AGC commands and data for display. It also outputs performance and housekeeping data for recording on the 7-track magnetic tape unit; a comprehensive set of approximately 300 distinct parameters is recorded. The teletype unit is used for loading programs, troubleshooting, and data reduction but is not required during normal system operation. The Computer Subsystem and the associated data reduction software provide a stand-alone data reduction capability. With the exception of the magnetic tape unit, each of the other units weighs less than 73 pounds and is man portable; total weight is 548 pounds. The system occupies less than two standard 19-inch racks and consumes 1.5 kW of power.

During flight tests the system demonstrated an altitude resolution of 2.12 cm, acquisition time of 4.5 seconds, and wave height prediction accuracy of 10%.

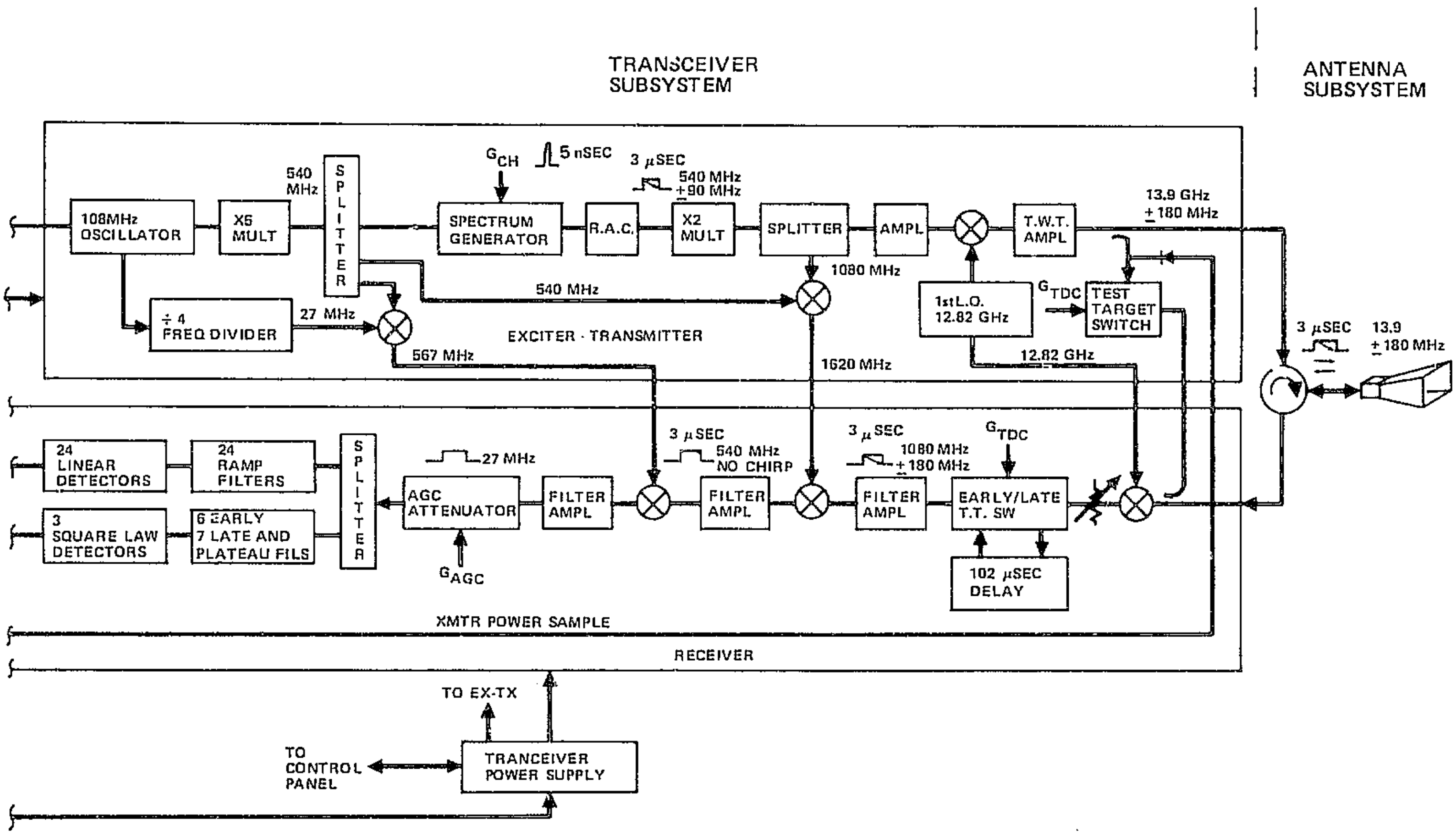
AAFE PULSE COMPRESSION RADAR ALTIMETER SYSTEM PARAMETERS

FREQUENCY	13.9 GHz
PEAK POWER	0.5 WATT (MAX)
INSTANTANEOUS BANDWIDTH	360, 180, 90 MHz
WAVEFORM CODING	LINEAR FM
TYPE OF PROCESSING	STRETCH
PULSEWIDTH	
UNCOMPRESSED	3, 1.5, 0.75 μS
COMPRESSED	3, 6, 12 NS NOMINAL
PRF	118 TO 1883 Hz
RANGE LSB	0.62ns
NUMBER OF RAMP RESOLUTION CELLS	24
TOTAL SAMPLE PERIOD	67 NS (~ 10 M)
EARLY GATE	1, 2, 4, 8 CELLS
LATE GATE	1, 4, 16 CELLS
ALTITUDE TRACKER	SPLIT GATE AIDED BY ACCELEROMETER
TRACKER BANDWIDTH	SELECTABLE 1/4 TO 5 Hz
ALTITUDE RESOLUTION	< 10 CM
ACQUISITION TIME	< 5 SEC

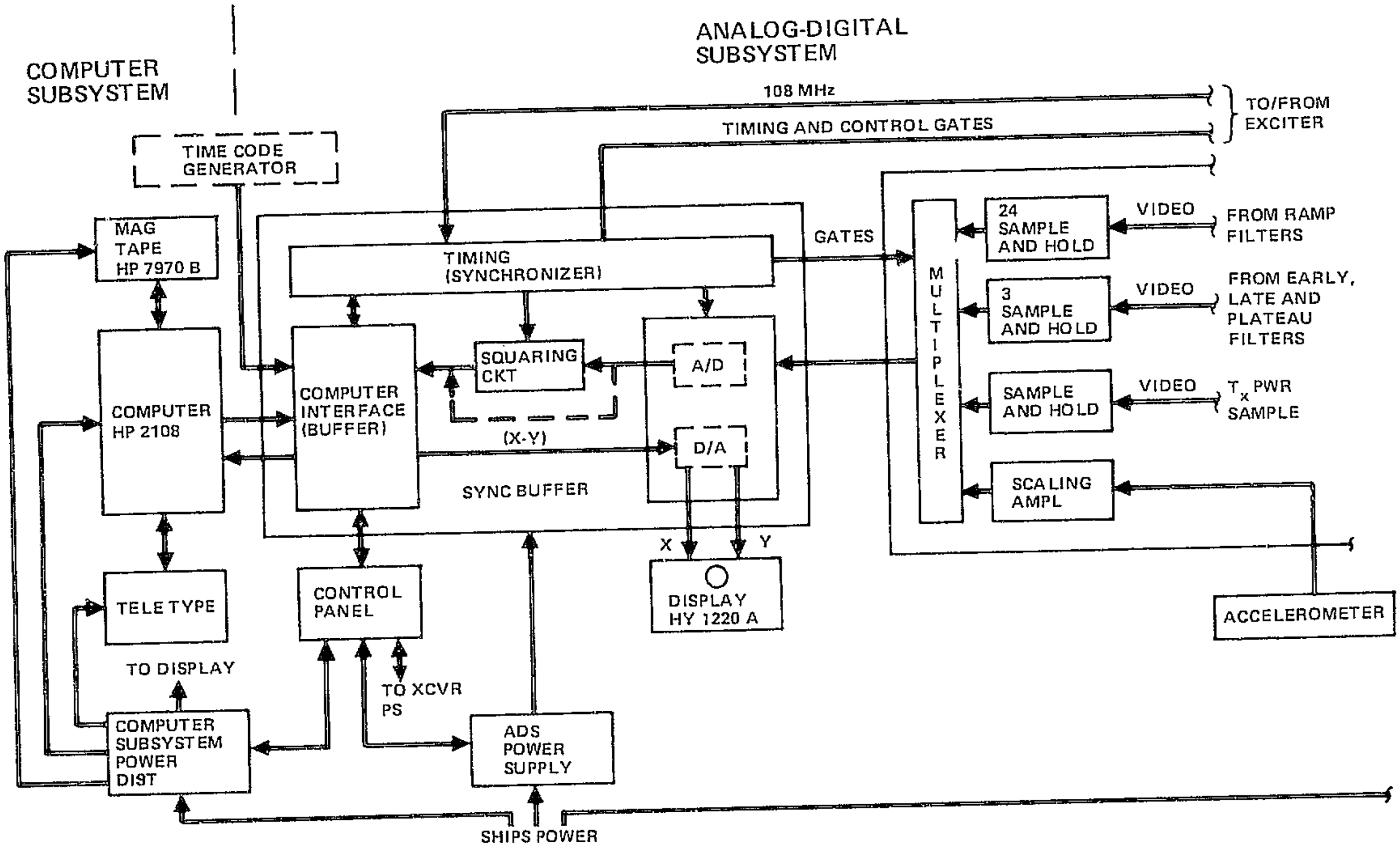
TYPE OF TRANSMITTER TUBE	CW-TWT WITH GATED OUTPUT
TYPE OF ANTENNA	WAVEGUIDE HORN
GAIN	21.6 dB
BEAMWIDTH (AZ/EL)	15.6 DEGREES
SYSTEM NOISE FIGURE	13.3 dB
SYSTEM S/N RATIO	11 dB (σ_0 = 6 dB)
COMPUTER	16K MEMORY MINICOMPUTER
DATA RECORDED (≈ 300 PARAMETERS)	CONTROL PANEL SETTINGS AGC, S/N ALTITUDE, TRACKER ERROR VELOCITY, ACCELERATION WAVE HEIGHT, σ_0 TRANSMIT POWER NOISE LEVEL – ALL FILTERS BIAS LEVELS – ALL FILTERS CALIBRATION DATA SIGNAL LEVELS – ALL FILTERS
DATA STORAGE	7 TRACK MAGNETIC TAPE
TELEPRINTER	ASR 33
TYPE OF DISPLAY	OSCILLOSCOPE
WEIGHT	548 LB
POWER CONSUMPTION	≈ 1.5 KW
OPERATIONAL ALTITUDE	8 TO 12 KFT

ORIGINAL PAGE IS
OF POOR QUALITY

AAFE PULSE COMPRESSION RADAR ALTIMETER BLOCK DIAGRAM



AAFE PULSE COMPRESSION RADAR ALTIMETER BLOCK DIAGRAM



4. SOFTWARE FUNCTIONAL DESCRIPTION

The computer and software have a key role in the radar altimeter system. The software provides system control, processing, display and recording functions. The recorded information contains housekeeping data as well as signal levels and performance data. The basic operational functions are summarized in the table on p. B-18 and described below.

Mode and sub-mode control is provided by the software. It commands and cycles the Noise, Bias, Calibration, Acquisition and Track submodes. The software also provides range control on the basis of tracker processing. It commands the time or range at which the second LO reference signal is generated. This signal determines the frequency offset of the backscattered signals. AGC control is also resident in the software. During acquisition and high bandwidth track operation the AGC bandwidth is 10 Hz; during normal track operation, AGC bandwidth is 0.25 Hz. The AGC command is derived from the Plateau gate amplitude and is designed to maintain the signals within the desired dynamic range region of the receiver.

The software includes acquisition and tracking processing logic. During search it steps the range until threshold crossings are obtained in the Early and Late gate denoting that the sea return signal is present. At that time, a high bandwidth tracking lock-on operation is initiated and after two seconds normal tracking follows. The tracker logic utilizes Early and Late gate amplitudes and accelerometer inputs. The accelerometer inputs are necessary to compensate for platform motion effects.

The software also processes Calibration mode data. This processing includes filter splitting or, equivalently, range gate splitting of the calibration test target. From this data system delay variations can be accurately established.

The 24 Ramp filter data is averaged over 0.1 sec intervals in order to minimize the recording requirements. Averaging of up to 30 sec is also performed for wave height estimation.

The software provides processed data for display on the system oscilloscope and the light emitting diode array (LEA) display. Averaged noise or sea return data of the Ramp, Early, Late and Plateau gates is generated for display on the oscilloscope. Processed altitude, tracker altitude correction (error), sea reflectivity, wave height and AGC data is output for display on the LEA display.

Using Noise and Bias submodes, the software derives filter gain and bias corrections which are used throughout the program for adjusting signal amplitudes.

Comprehensive data recording is included in the design. This provides for outputting processed data such as altitude, wave height and reflectivity as well as noise and signal amplitudes of the filters, and data which is useful in configuration control and fault and performance monitoring. Approximately 300 distinct parameters are recorded on the 7 track magnetic tape.

The basic architecture of the operational program is indicated in the figure on p. B-19. It consists of four sequences: start, acquisition, track and termination. Software initialization occurs during the start phase of the program. The acquisition sequence consists of executing Noise, Bias and Calibration and Acquisition submodes of the radar. Upon acquiring the sea return, the operation then resides in the track sequence where Track, AGC, Ramp Preprocessing and Wave Height Estimation subroutines are executed. In addition, on an interleaved basis Noise, Bias and Calibration sub-modes are executed. The latter submodes are executed at a rate of one pulse per 0.1 sec; all

PRECEDING PAGE BLANK NOT FILMED

three submodes are completed approximately every 7 minutes. Data recording, radar I/O and data processing for display are performed concurrently. The radar input and output consists of 6 and 36 words respectively and transfer is executed each pulse. The data display processing which provides data for the oscilloscope and LEA displays occurs on a time available basis each pulse. Operation continues in the track sequence until an occurrence of a fault (e.g. loss of track) or operator action. In these cases, operation is properly terminated by waiting until magnetic tape recording is completed. At that time, a halt indication is displayed on the computer panel and operation can be restarted by the operator.

RADAR ALTIMETER OPERATIONAL PROGRAM FUNCTIONS

MODE AND SUBMODE CONTROL

RANGE CONTROL

AGC AND AGC BANDWIDTH CONTROL

ACQUISITION

TRACKING

TIME DELAY CALIBRATION

RAMP DATA PRE-PROCESSING

OSCILLOSCOPE AND LEA DISPLAY DATA GENERATION

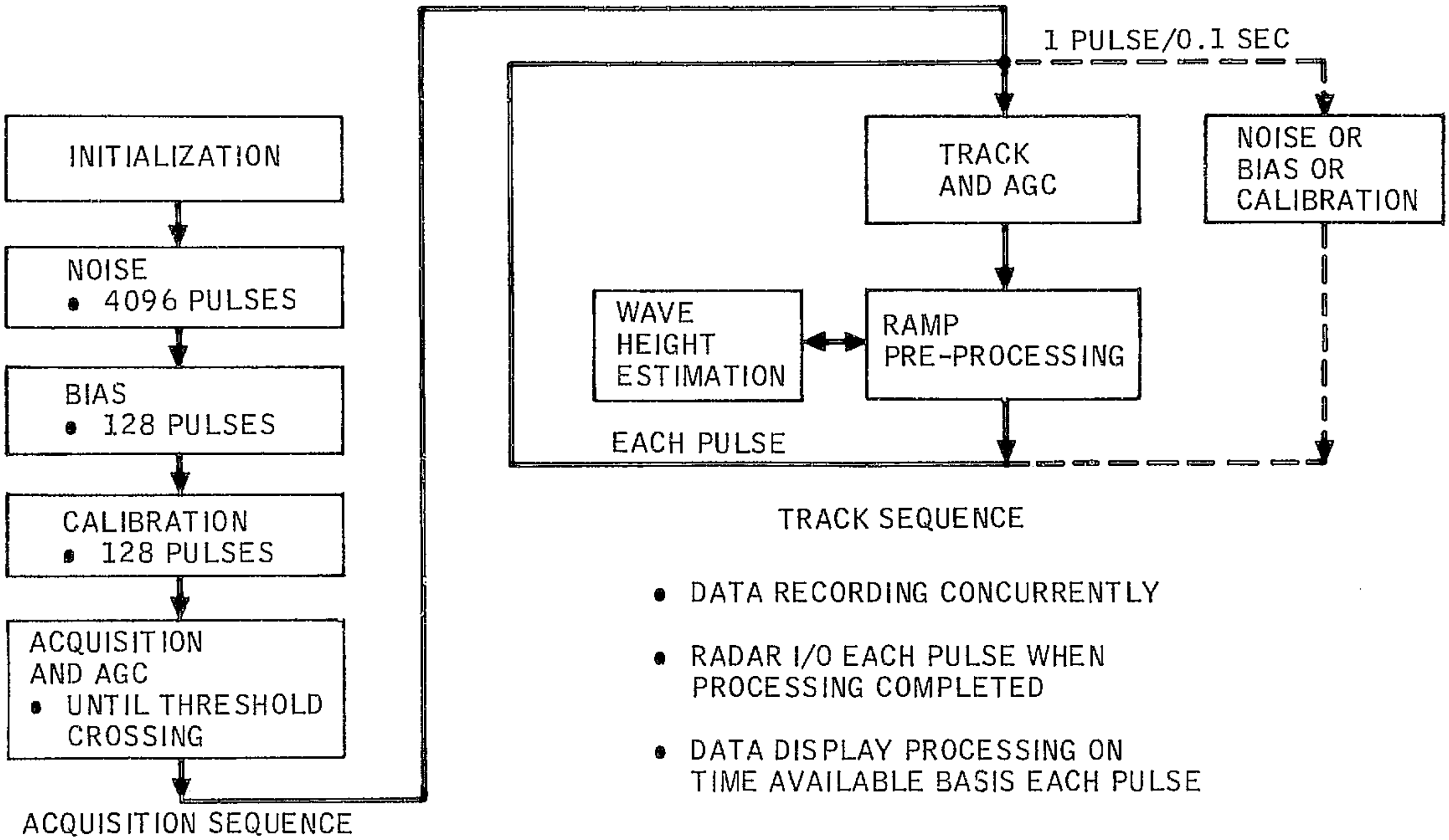
CORRECTIVE PROCESSING - FILTER GAIN AND BIAS CORRECTION

DATA RECORDING

REAL TIME DATA PROCESSING - WAVE HT, σ_0

CONFIGURATION, FAULT AND PERFORMANCE MONITORING

AAFE PULSE COMPRESSION RADAR ALTIMETER OPERATIONAL PROGRAM ARCHITECTURE



- DATA RECORDING CONCURRENTLY
- RADAR I/O EACH PULSE WHEN PROCESSING COMPLETED
- DATA DISPLAY PROCESSING ON TIME AVAILABLE BASIS EACH PULSE

5. CONTROL OF SYSTEM PARAMETERS

The system includes the Radar Control Panel which provides the necessary controls and switches for radar operation and selection of system parameters. A photograph of the control panel is provided in the figure on p. B-22. The three switches in the upper right hand corner provide for selection of the mode (Normal/Test), for system control from the panel or computer and for magnetic recording (on/off). In the Normal mode, the system transmits and radiates signals through the antenna; in the Test mode the system generates an internal target which is coupled into the receiver. The Panel/Computer control switch provides the capability to select the operating configuration from the panel; this configuration is used for hardware testing and troubleshooting and the commands sent from the computer are not used by the system. The XCVR, ADS, COMP indicators below provide power status information for the Transceiver, ADS, and Computer subsystem. When the system on/off switch, at the lower right hand corner, is depressed, power is applied (or removed) to all units of the system. The transfer fault indicator provides an indication in the event 16 or more pulse intervals are skipped before commands are received by the radar from the computer.

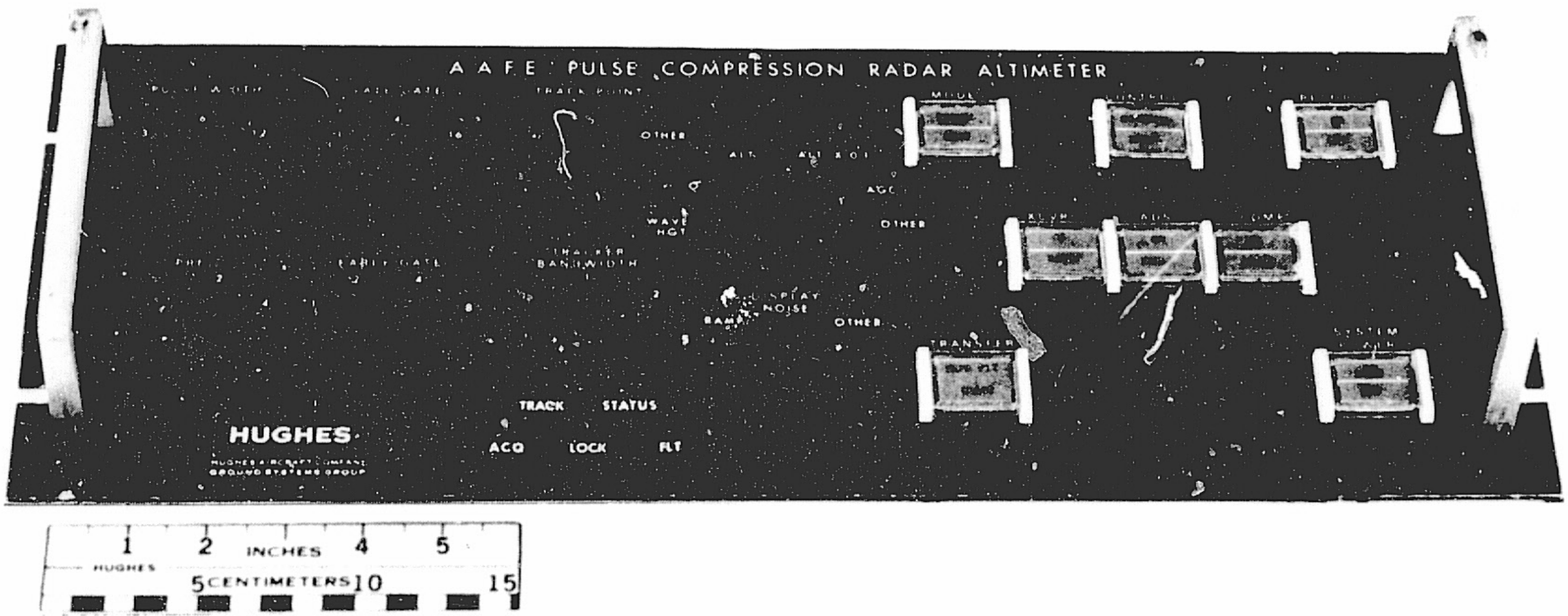
The left side of the Control Panel provides six switches for selecting the system parameters. These include the pulse width, PRF, the Late and Early gate widths, the track point, and the tracker bandwidth. The available selections are discussed below. The two switches at the center of the panel provide for selection of data to be displayed on the LEA and oscilloscope display. The LEA output consists of a 4 digit numeric and for this display the operator can select wave height, reflectivity, altitude in meters or centimeters, AGC and the tracker altitude correction (error). The oscilloscope display selections are limited to the sea return ramp data and noise data. In the case of the sea return, the oscilloscope display presents 0.1 sec averages of each of the 24 Ramp filters and the Plateau gate; the Early and Late gate signal averages are based on the reciprocal of the tracker bandwidth. Three track related status indicators also appear on the panel. These are acquisition, track lock and track fault. The acquisition indicator is lighted when the software initiates the search for the sea surface; the track lock indicator is lighted when tracking has been initiated. Track fault indicator is lighted under low signal-to-noise ratio or excessive altitude step size conditions.

A wrap around method of implementation was used for the 6 primary parameter selection switches. That is, upon operator selection of the desired settings the signals are transferred to the computer; the computer checks these values and sends them back to the radar. Upon receipt of the selection codes, the radar lights light emitting diodes (LED's) located at the switches and implements the commands. This approach not only insures that proper commands are implemented but also that they are recorded. A second feature of the system design, which insures the recording of switch positions, is that upon a change of any switch setting, the software will halt the system and cause operation to be restarted. During the restart, the software records an extensive initialization table which also contains the switch codes.

The numerical values of the six basic parameters are indicated in the table on p. B-23. Four PRF selections are available for each of the three pulse widths. The design PRF values are related to the decorrelation PRF. For example, the decorrelation PRF for a nominal compressed pulse width of 3 nanoseconds (2.77 nanoseconds) is 235 Hz when the radar platform velocity is 140 knots and altitude is 10 Kft. The other PRF selections for this pulse width are multiples of the decorrelation PRF. Similarly, PRFs for a nominal pulse width of 6 and 12 nanoseconds are derived on the basis of their respective decorrelation PRFs. The PRF follows a square root dependence with the pulse width. Several Early and Late gate widths selections are available. These are also dependent on pulse widths. For the 3 μs transmitted pulse width or 2.77 ns compressed pulse width, the minimum gate or filter width is 1/3 MHz. Available selections are in terms of multiples of this minimum width.

In addition to the built-in switches and controls in the Radar Control Panel, a number of parameters can be varied by means of changes in the software. In many cases, this is a matter of changing single constants. Significant processing flexibility is available via logic modifications. Extensive use of this flexibility was made during the development and testing of the system (see Topic A-4).

AAFE PULSE COMPRESSION RADAR ALTIMETER CONTROL PANEL



AAFE PULSE COMPRESSION RADAR ALTIMETER CONTROL PANEL SELECTABLE PARAMETERS

COMPRESSED PULSE WIDTH	PRF				EARLY GATE WIDTH				LATE GATE WIDTH		
	1/2	1	2	4	1	2	4	8	1	4	16
3N SEC	118Hz	235Hz	471Hz	850Hz	0.333MHz	0.666MHz	1.333MHz	2.666MHz	0.333MHz	1.333MHz	5.333MHz
6	165	330	659	1318	0.666	1.333	2.666	5.333	0.666	2.666	10.666
12	235	471	850	1883	1.333	2.666	5.333	10.666	1.333	5.333	21.333

TRACK POINT 1/4 POWER 1/2 POWER OTHER

TRACKER BAND WIDTH 1/4, 1/2, 1, 2 5Hz

6. MODE AND SUB-MODE CONTROL

When the system is operating under computer control, sub-modes are controlled or sequenced automatically by the software. The basic mode (Normal or Test) is selected at the control panel. The facing table summarizes the key characteristics of the submodes and modes when under computer control. It should be noted that equivalent operation is also possible under Panel control; however, AGC and noise or test target generation must be selected via switches on the front panel.

In the Noise submode, the software commands zero db of AGC and the filter output signals consist of the receiver noise. The purpose of this mode is to obtain average noise levels both for extraction from the signal plus noise levels in track processing and, also, for gain correction of the filters in the event the filters are not accurately manually aligned. A set of noise submode data consists of average amplitudes of 4096 pulses.

The Bias submode is intended to provide the filter biases. For this reason, the software commands maximum AGC of 47.25 dB. With this amount of AGC, all signals and noise are suppressed. The residual outputs are Receiver filter biases. The average bias data is extracted from the signal plus noise amplitudes in various processing areas. Biases are successfully extracted only from the Early, Late and Plateau gate signals; Ramp filter biases must be checked and properly set prior to operation. The Bias submode is executed for 128 pulses before averaging the values.

The Calibration submode is designed to monitor the time delays within the system. It utilizes a test target. The signal amplitudes of the Ramp filters are processed to determine the position of the test target and thereby the time delay within the system. In order to minimize the effects of noise, a large test target is used and 30 dB of AGC is applied. The Calibration submode is executed for 128 pulses.

Track or acquisition submodes during Normal mode operation consist of radiating through the duplexer and antenna and receiving the sea return signals which are then processed by the computer. In the case of the Test mode, no radiation takes place but rather an internal test target is generated and exercises the tracker. In both cases, the AGC is dynamic; that is, it is based on the amplitude of Plateau gate signals.

Noise, Bias, and Calibration submodes are interleaved with the Track submode by the software logic. A pulse is dedicated each 0.1 sec for these three submodes and they are executed sequentially to completion every 435 sec. This provides an automatic update of the bias, noise, filter scale factors, and time delay data.

AAFE PULSE COMPRESSION RADAR ALTIMETER MODES AND SUBMODES

- COMPUTER CONTROL

SUBMODE	NORMAL MODE	TEST MODE
NOISE	NOISE SIGNAL AGC = 0 dB	NOISE SIGNAL AGC = 0 dB
BIAS	NOISE SIGNAL AGC = 47.25 dB	NOISE SIGNAL AGC = 47.25 dB
CALIBRATION	TEST TARGET AGC = 30 dB	TEST TARGET AGC = 30 dB
TRACK OR ACQUISITION (RADIATE)	SEA RETURN SIGNAL AGC = DYNAMIC	TEST TARGET AGC = DYNAMIC

- PANEL CONTROL

  MANUALLY SELECTABLE MODES, SUBMODES, AND AGC

7. DESIGN OF TRACKER

The radar altimeter employs an alpha-beta tracker aided by accelerometer inputs. The tracker development was funded primarily by internal Hughes funds. A detailed block diagram of the tracker is presented in the facing figure.

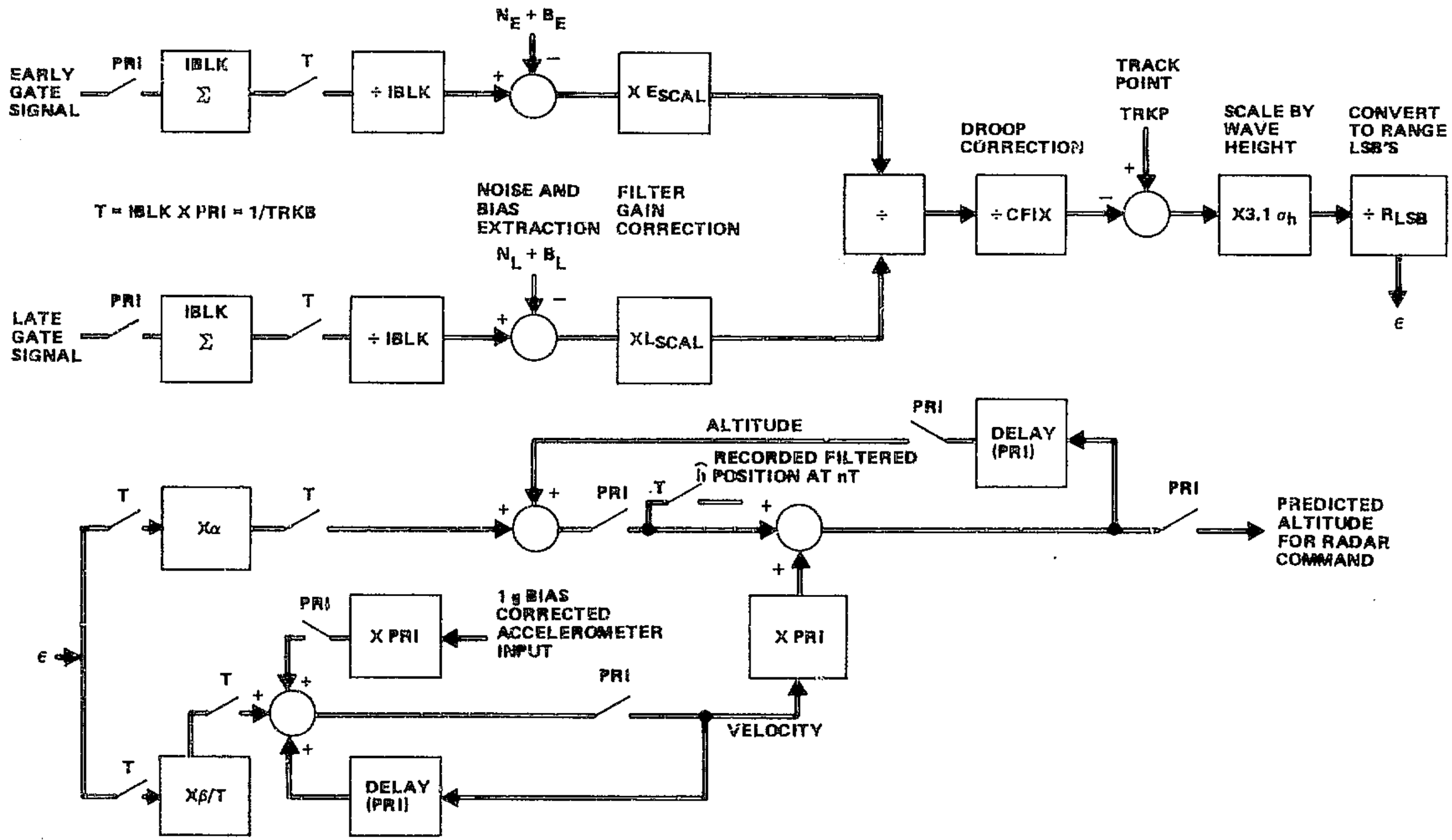
The tracker utilizes Early and Late gate signals to determine the position with respect to the selected track point and to correct the altitude accordingly. The Early and Late gate signals are summed for a number of pulse intervals depending on the selected tracker bandwidth. The average Early gate and Late gate signals are corrected for bias and filter gain misalignment and receiver noise. The corrected Early and Late gate values are used to form a ratio which is modified by a constant (CFIX) to account for the droop in the plateau due to antenna pattern and sea reflectivity effects. The result is the idealized Early to Late gate ratio which is then compared with the selected track point. The difference of this comparison is scaled to dimensional units and converted to range LSB's. The scale factor is proportional to the rms sea wave height and for this reason the tracker is adaptive to sea state conditions; a wave height estimate is supplied to the tracker every 30 sec by the Wave Height Estimation Module. This result is the tracker error which is used to update both altitude and vertical velocity as indicated in the lower half of the diagram.

The tracker error is scaled by the constant alpha and the result is added to the current altitude. This update occurs every 0.1 sec during the high bandwidth lock-on operation (first 2 sec); afterwards the update period is equal to the reciprocal of the selected tracker bandwidth. In a similar manner, the error is scaled by the constant beta and added to the current velocity estimate. During a given period, the velocity estimate is corrected each pulse by accelerometer inputs and used each pulse to update the prediction of the tracker altitude. The tracker output is used directly as the altitude command for the next pulse. Thus, tracker smoothing or estimation of range or altitude and velocity takes place at a rate equal to the reciprocal of the tracker bandwidth and altitude and velocity estimate updating (prediction) is performed every pulse using accelerometer inputs and velocity data.

The smoothed or estimated altitude is recorded on tape in range cells and fractions thereof; whereas the altitude supplied for radar commands is rounded to the nearest range cell.

The tracker design utilizes an alpha of 0.8 and a beta of 0.4. This yields slightly correlated altitude estimates and for this reason if uncorrelated outputs are required the system should be operated at a higher bandwidth than ultimately desired. The resulting altitude data can then be manually averaged or by means of data reduction programs to yield the desired bandwidth or data rate.

AAFE RADAR ALTIMETER SOFTWARE TRACKER BLOCK DIAGRAM



ORIGINAL PAGE IS

8. OVERVIEW OF DATA COLLECTION

The radar altimeter design includes a comprehensive data recording capability. The data recorded is summarized in the facing table and consists of approximately 300 distinct items.

The Initialization module decodes and supplies a 48 parameter table (100 computer words) for recording which contains the switch setting information and internal software constants and parameters. This module is executed only at the start of operation. However, the system is designed such that whenever any parameter is changed at the control panel, operation is terminated and a restart is required. Consequently, the Initialization subrecord is always recorded. The Noise, Bias, and Calibration modules provide primarily average filter output data for the Ramp filters and the Early, Late, and Plateau gates. In addition, the Bias module outputs gain correction scale factors for the filters which are computed on the basis of the biases as well as the average noise levels provided by the Noise Estimation module. The Calibration module performs filter splitting and outputs the test target position in addition to the average filter levels. During acquisition these modules and the corresponding modes are executed sequentially and require minimum time. During track, the data is accumulated by means of dedicated pulses every 0.1 sec; consequently, complete execution of all three sub-modes at any PRF is performed only once every 435 seconds.

The Acquisition module provides a 7 word subrecord each pulse. When the Acquisition mode is executed for an extended period of time it can cause a recording overload and loss of data. However, this will not occur for the operational environment intended. The 7 data words include altitude, AGC and Early and Late gate amplitudes and associated counter values. The Track module subrecords are output at a rate corresponding to the reciprocal of the tracker bandwidth. The 15 data items include Early and Late gate outputs, altitude, the tracker error, velocity, acceleration and signal-to-noise ratio.

The Ramp Pre-processing module provides average Ramp filter amplitudes every tenth of a second. It also includes the Plateau gate value and commanded AGC. The Wave Height subroutine is executed every 30 seconds and it outputs the wave height estimate, reflectivity and the droop correction factor estimates.

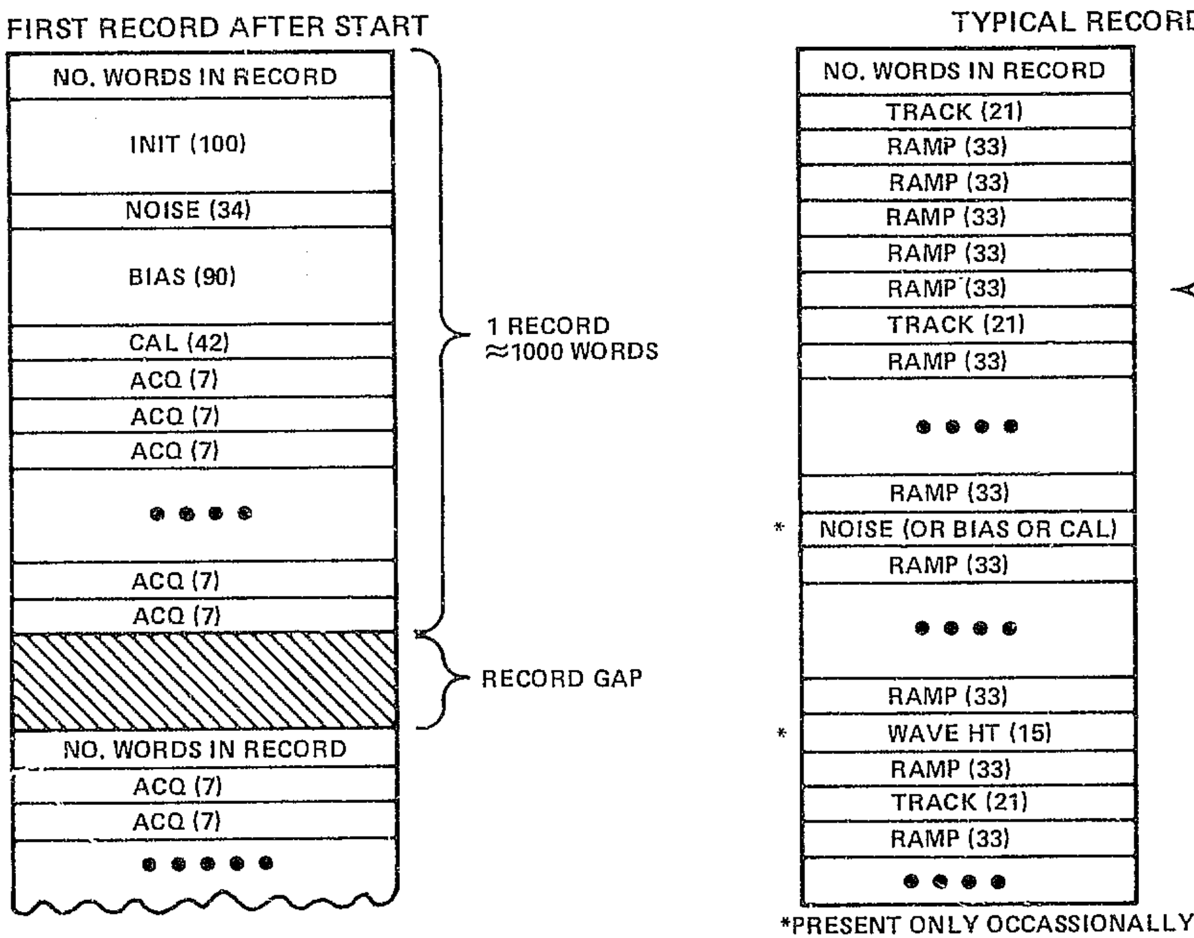
In addition to the above data, a 5 word subrecord is output whenever the Receiver step attenuator is changed. This subrecord contains the time of the change and the step attenuator value.

Recording formats are indicated in the figure on p. B-30. The basic structure of the recording implementation consists of accumulating subrecords with 5 to 100 computer words and storing these subrecords into 1,000 word records. The design includes a double buffered approach which eliminates loss of data; while one buffer of a 1000 words is being output to magnetic tape the other buffer can be filled with new data. With the exception of the Acquisition subrecord, each subrecord contains the NASA time information which is stored in words 2-4. The first word of each subrecord is intended for subrecord identification. The required recording speed is well within the magnetic tape recording capability of 45 ips at 800 bpi or 12,000 16-bit words per second.

DATA RECORDING SUMMARY

OPERATIONAL PROGRAM MODULE	NUMBER OF DATA ITEMS IN SUB RECORD	SUBRECORD OUTPUT RATE	DESCRIPTION
INITIALIZATION	48	AT START ONLY	SWITCHES, CONSTANTS, PARAMETER VALUES
NOISE ESTIMATION	34	435 SEC	4096 PULSE MEAN NOISE FOR EACH FILTER
BIAS	90	435 SEC	128 PULSE MEAN BIAS, UNBIASED NOISE, NOISE BASED GAIN FACTORS FOR EACH FILTER
CALIBRATION	40	435 SEC	128 PULSE MEAN OUTPUT FOR EACH FILTER AND TEST TARGET DELAY ESTIMATE
ACQUISITION	7	0.001 - .01 SEC (EVERY PULSE)	EARLY AND LATE GATE OUTPUTS, AGC, ALTITUDE
TRACK	15	0.1 - 4 SEC	EARLY AND LATE GATE OUTPUTS, ALTITUDE, ERROR VELOCITY, ACCELERATION, S/N
RAMP PRE-PROCESSING	33	0.1 SEC	MEAN PLATEAU GATE AND RAMP FILTER OUTPUTS, AGC
WAVE HEIGHT	10	30 SEC	WAVE HEIGHT, σ_0, DROOP FACTOR
EXECUTIVE	5	STEP ATTEN CHANGE ONLY	TIME AND RECEIVER STEP ATTENUATOR CODE
TOTAL :	282	DISTINCT DATA ITEMS (347 16-BIT COMPUTER WORDS)	

RADAR ALTIMETER RECORDING FORMAT



TRACK SUBRECORD DETAIL

1	SUBRECORD TYPE (21)
2-4	NASA TIME
5	EGT
6	LGT
7-8	EGAVF
9-10	LGAVF
11-12	ACCELERATION
13-14	ALTITUDE
15-16	ERROR
17-18	VELOCITY
19	S/N
20	S/N U-D COUNTER
21	ERROR U-D COUNTER

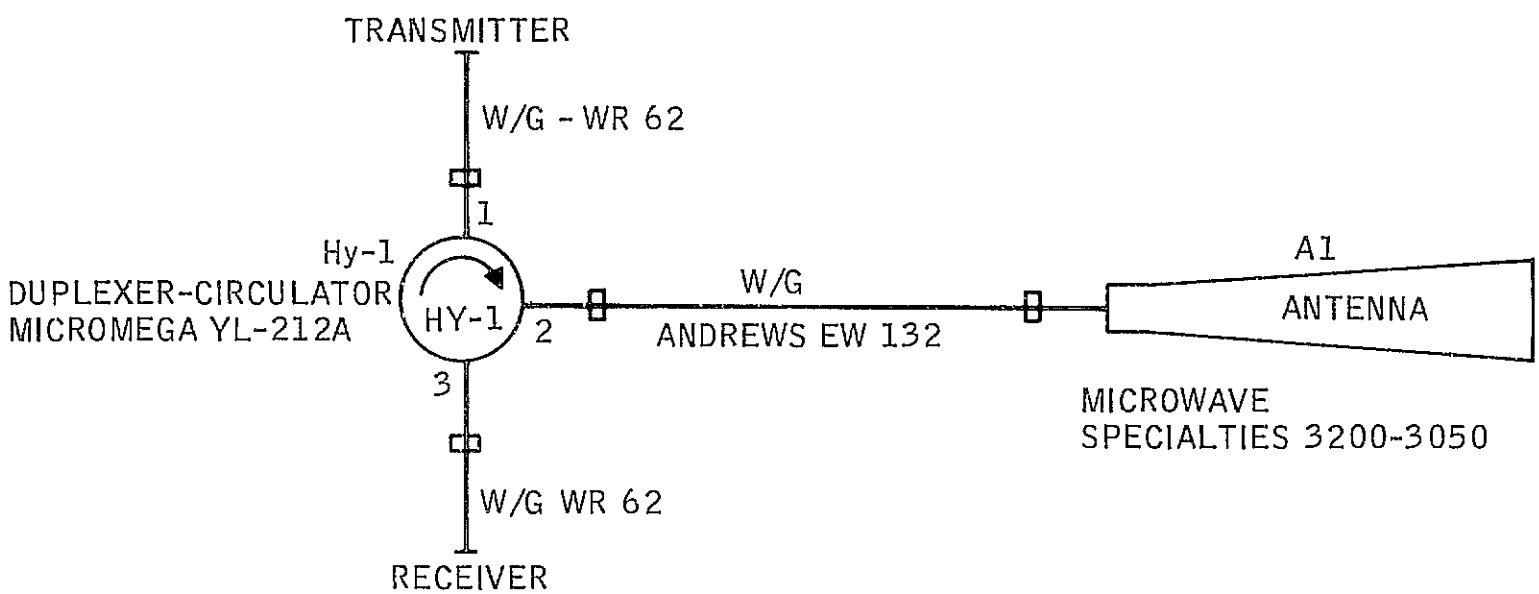
SECTION C
THE MICROWAVE SUBSYSTEM

1. DESCRIPTION OF MICROWAVE EQUIPMENTS

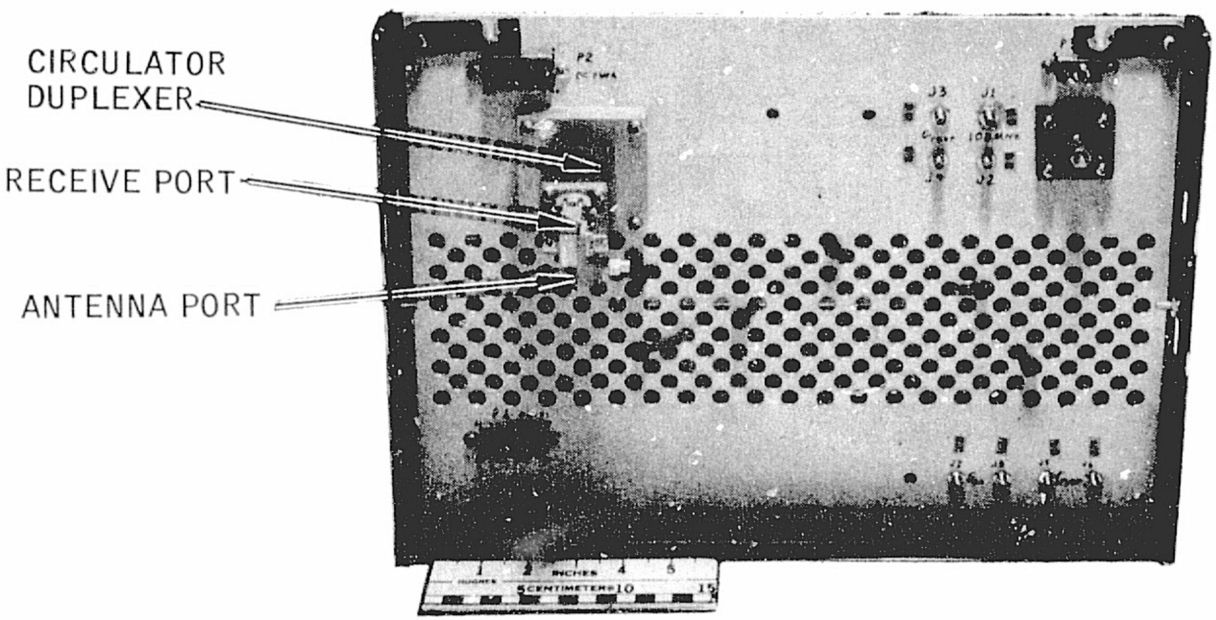
The microwave equipments interface with the Transmitter and Receiver and provide the duplexing and radiation functions. A block diagram showing the duplexer, horn antenna, waveguide and interfaces is presented in the facing figure. A three-port circulator provides the duplexing function; its isolation during transmit is approximately 30 dB. A semi rigid elliptical waveguide connects the duplexer to the antenna; this waveguide was selected for ease of installation and because of its low phase distortion properties. The horn antenna provides a one-way 3 dB beamwidth of approximately 15.6 degrees and gain of 21.6 dB; the horn antenna is 22 inches in length and has a 3.6 x 2.6 inch aperture.

The duplexer is located at the rear of the Transmitter-Exciter unit as shown in the figure on p. C-2. The antenna, waveguide and receiver/Duplexer connector are shown in the next figure; the accelerometer included in the figure is mounted on the antenna but is actually a part of the ADS Subsystem. The antenna pattern with an expanded mainlobe plot is presented in the figure on p. C-4; peak sidelobes which are approximately 13 dB have no bearing on system performance.

ANTENNA SUBSYSTEM BLOCK DIAGRAM

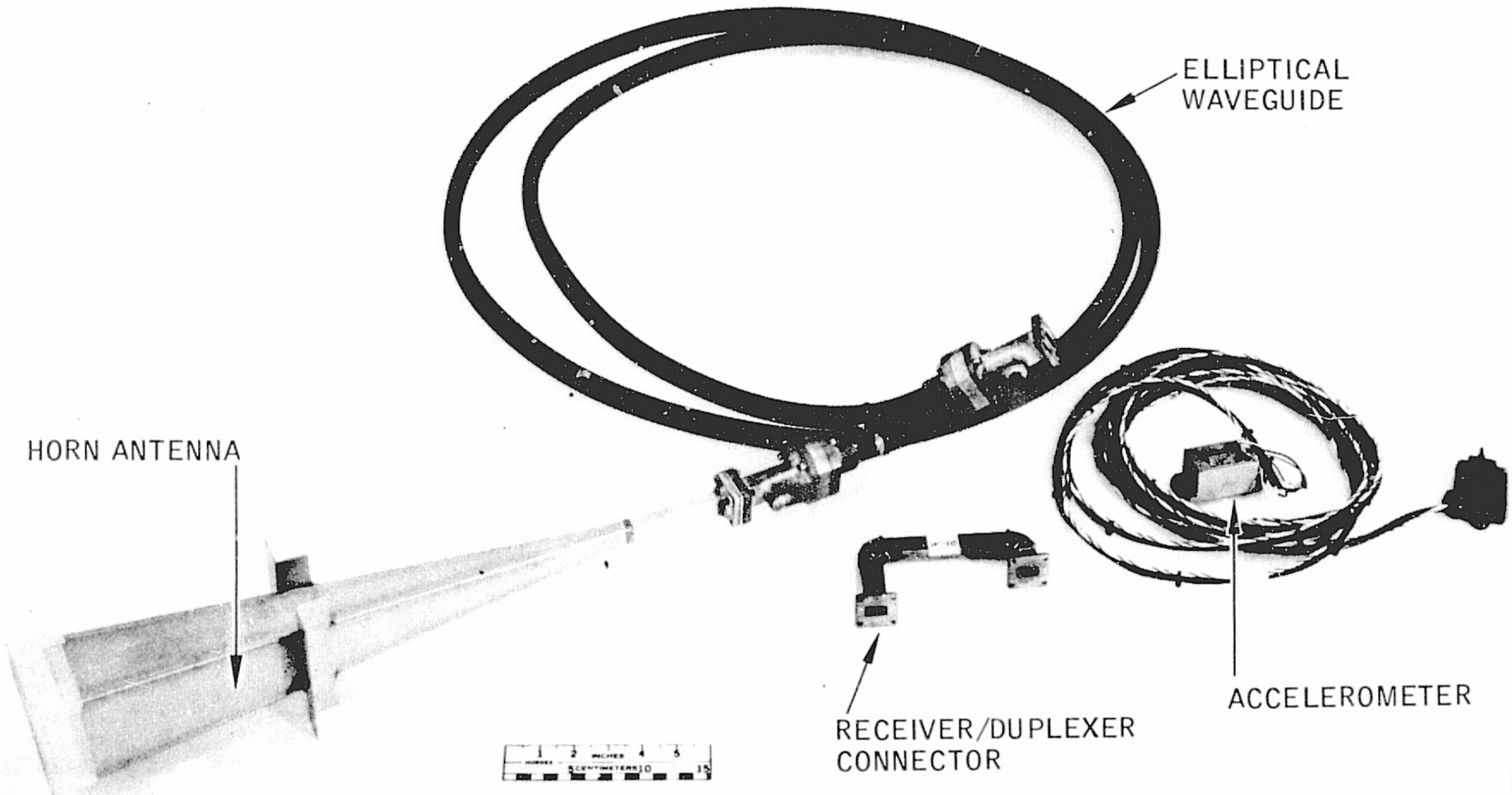


DUPLEXER (REAR OF EXCITER)

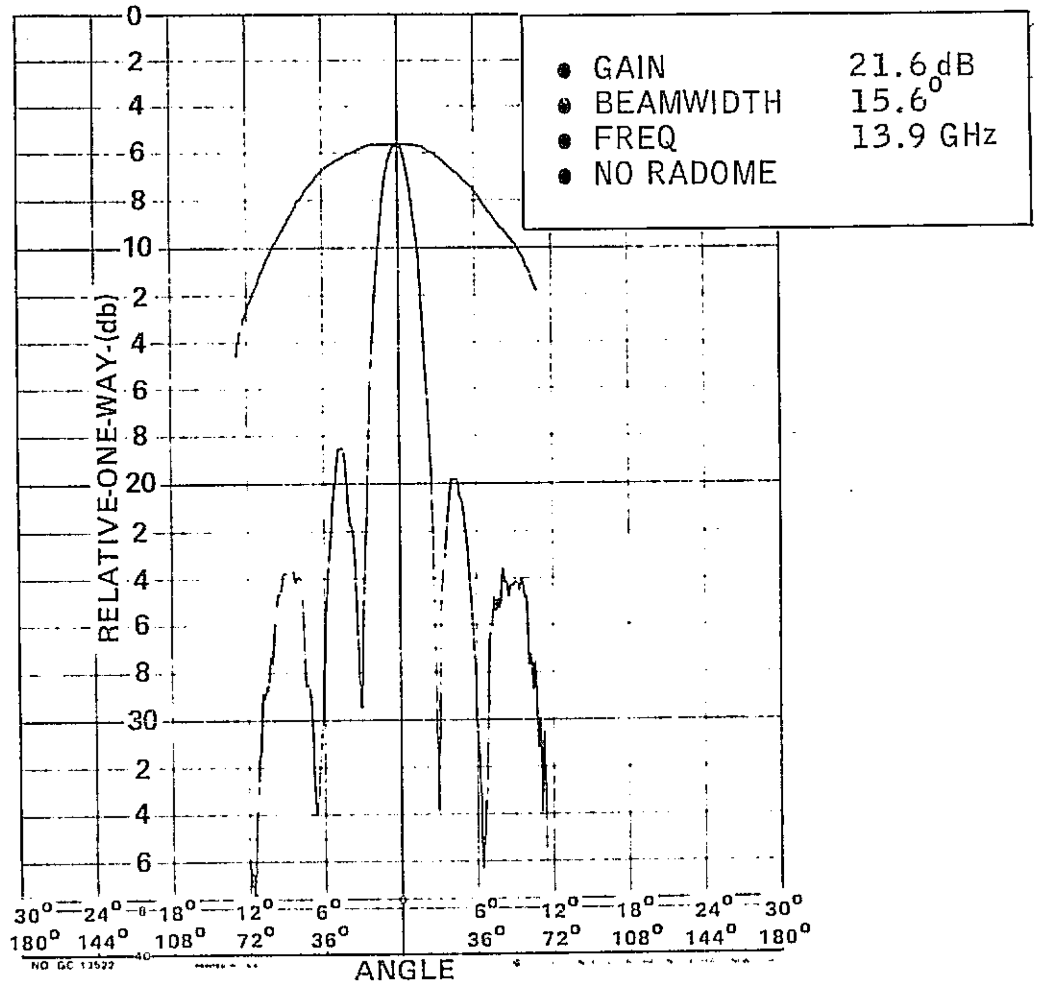


- 28 TO 32 dB ISOLATION
- 0.1 to 0.14 dB LOSS

ANTENNA, WAVEGUIDE AND ACCELEROMETER



AAFE PULSE COMPRESSION RADAR ALTIMETER ANTENNA GAIN



SECTION D
TRANSCEIVER DESIGN

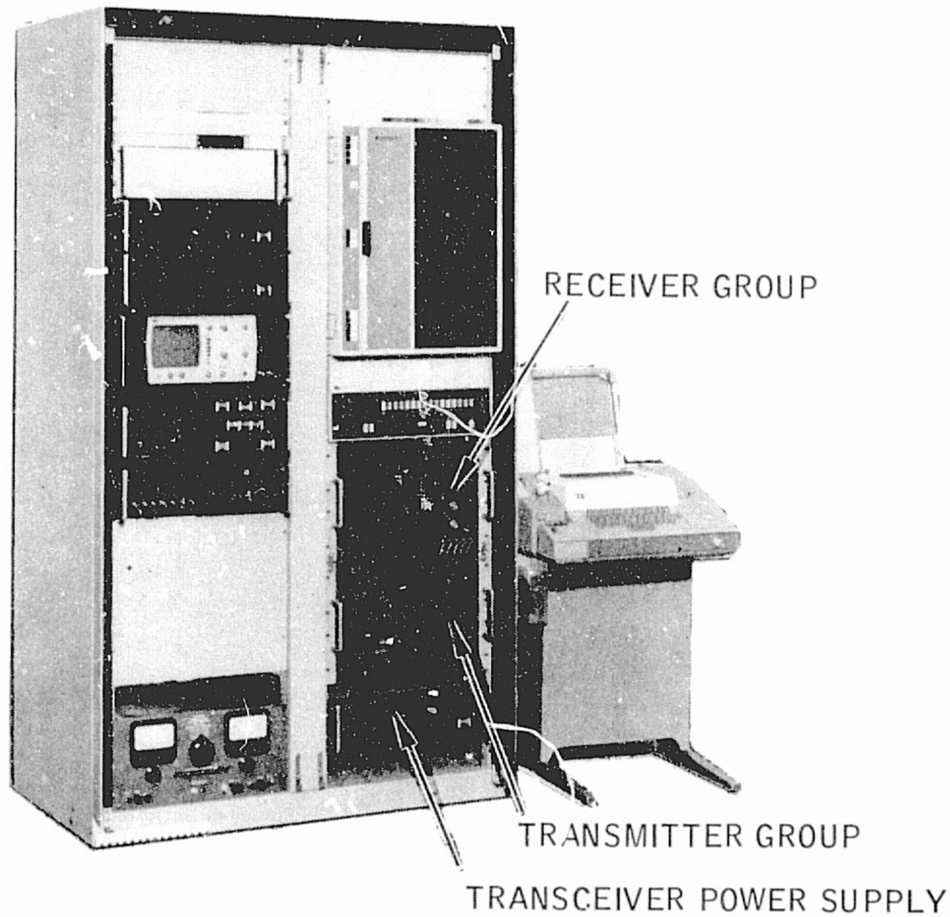
1. TRANSCEIVER OVERVIEW

The Radar Altimeter Transceiver consists of the Exciter, Transmitter and Receiver equipments which are packaged in the three units indicated in the figure. The Transceiver provides signal generation, amplification and analog processing of the received sea return signals and incorporates a number of novel design features.

The Exciter uses a reflective array compression (RAC) line which was developed by Hughes Aircraft Co. to generate 3 μs pulses with 360 MHz of linear F.M. chirp; the RAC line is described in a succeeding topic. Pulse compression of 1000:1 is obtained using correlation or stretch processing in the Receiver as opposed to standard pulse compression. Succeeding topics and topic B-2 provide a description of the stretch processing and its advantages. The Receiver incorporates 24 Ramp filters for analysis of the leading edge of the sea return signal which contains the sea wave height information. It also incorporates selectable width Early and Late gate (filters) for use by the system split gate tracker in tracking the surface of the sea. A triple down-conversion Receiver implementation is used; the second conversion constitutes the stretch correlation process and is performed with the RAC coded reference signal.

Each of the three units shown in the figure is removable and the Transmitter and Receiver drawers are mounted on slides for ease of maintenance.

TRANSCEIVER EQUIPMENT



2. EXCITER/TRANSMITTER OVERVIEW

The Radar Altimeter Exciter and Transmitter supply the transmit signal to the antenna, 1st, 2nd, and 3rd LO to the Receiver, clock to the ADS and a transmit test target signal for self-test application. The figure on p. D-4 provides an overall block diagram of the Exciter and Transmitter.

A crystal oscillator generates the 108 MHz signal. This signal is divided by four to generate a 27 MHz signal and is also multiplied by five to generate a 540 MHz signal; both signals are filtered. The 540 MHz signal is sent to a three-way power splitter and the resulting three signals are amplified and provide inputs to the Waveform generator and the two mixers which generate the 2nd and 3rd LO signals. The 567 MHz 3rd LO is a CW signal and is derived by mixing the 27 MHz and 540 MHz signals. The Waveform generator provides a 3, 1.5, or 0.75 μs coded pulses with 360, 180 or 90 MHz as described below. The coded Waveform generator output is used in deriving the Transmitter drive signal and the 2nd LO signal. The 2nd LO signal center frequency is 1620 MHz and the signal is obtained by mixing the pulsed Waveform generator output with the 540 MHz CW signal. The 2nd LO signal is used as the reference signal in the Receiver correlation mixer where time delay is converted to a frequency offset; a short coax delay is located in the 2nd LO signal path to compensate for the slightly longer path of the transmit signal within the radar.

The other output of the power divider following the Waveform generator is amplified to a level capable of driving the IF port of the RF mixer. This mixer is used as an up converter to generate the Transmitter drive signal. It combines a stable 12.82 GHz signal from the 1st LO with the Waveform generator signal to generate a 13.9 GHz signal. A switch is placed in series with the 12.82 GHz signal to switch off the LO to the up converter during the system receive time. The 13.9 GHz signal is passed through a circulator and a filter and is amplified by a 40 dB gain TWT. At this point the signal is nearly limited which makes the signal relatively flat in amplitude across the 360 MHz band.

The 35 dBm TWT output is sent to the duplexer through a Transmitter on/off switch, the direct path of a directional coupler, and through an isolation switch. The Transmitter power sample and the test target output are obtained from the coupled port of the directional coupler and a power divider. A Calibration switch provides an output test target during the Calibration submode. A coax delay line is located in the test target path to match the propagation delay with the signal path delay through the duplexer. The test target signal passes through fixed attenuators in order to reduce it to a level which will not saturate the Receiver front end. The Transmitter output sample is detected, amplified, and sent to the ADS.

Waveform Generator

The Waveform generator block diagram is given in the next figure (p. D-5) and described below.

A burst generator/switch driver takes a 3 μs gate and generates a 5 nanosecond pulse using a 5 nsec coax delay line and a NAND gate. This pulse is current amplified so that it is capable of switching two balanced RF switches. The switches gate the 540 MHz CW signal thus forming a burst of RF at 540 MHz with a pulse width of 5 nanoseconds.

A reflective array compression line (RAC) developed by Hughes is used to provide an expanded pulse with the proper linear FM code. It accepts the RF pulse input which has a sin x/x spectrum and generates a chirp signal which is approximately 3 μs wide with a frequency characteristic which is linear with time. The pulse spectrum has a 180 MHz bandwidth centered at 540 MHz. The RAC line has approximately 46 dB insertion loss and 30 dB of expansion loss (5 ns to 3 μs). The RAC operating principles and performance are described in a succeeding topic.

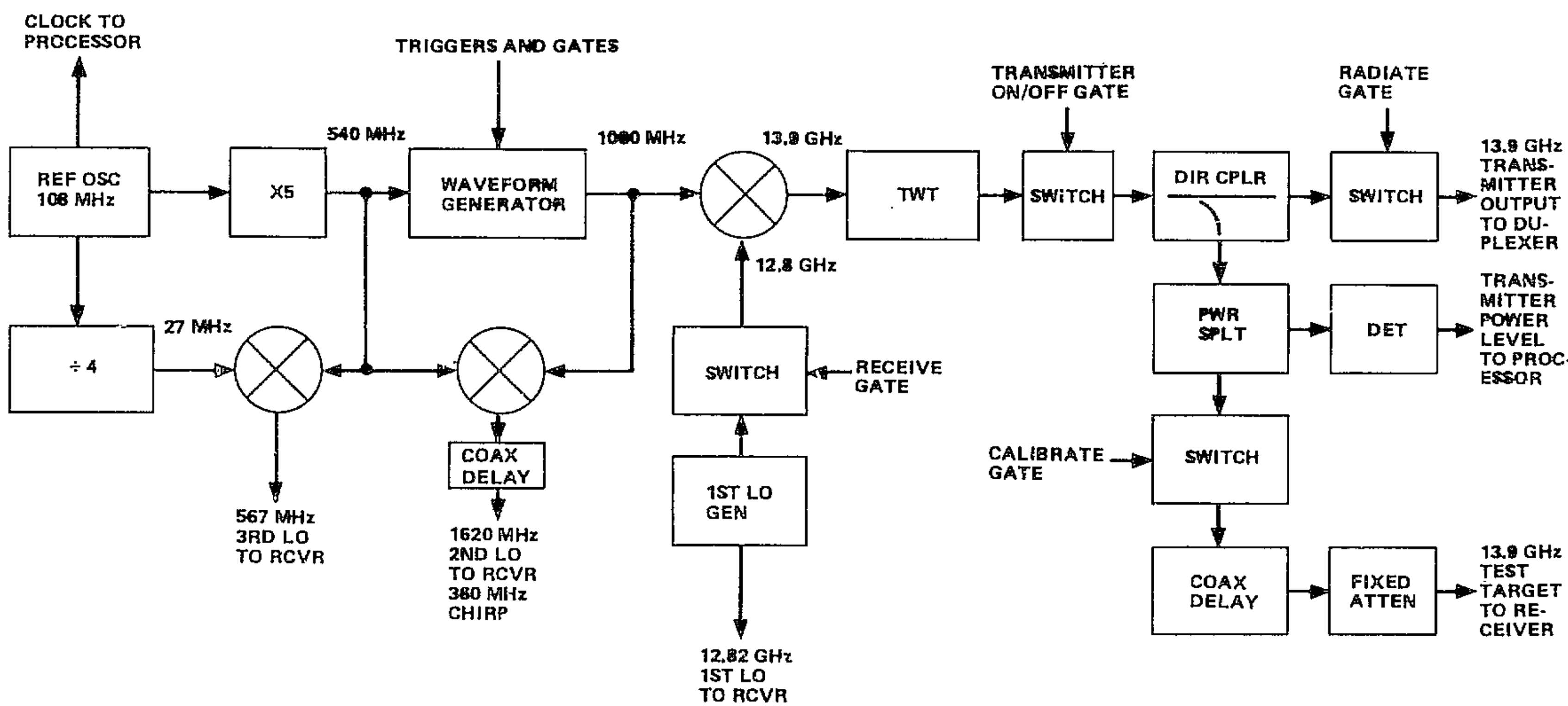
A high gain amplifier takes the -60 dBm output of the RAC and amplifies it to +10 dBm which drives the balanced diode frequency doubler. The 1080 MHz output of the doubler has a 360 MHz bandwidth. This signal is applied to an RF switch where it is gated to the exact 0.75, 1.5 or 3 μs pulse width by the input gate.

This signal then passes through a 500 MHz bandwidth filter, is amplified, and split to provide signals for Transmitter drive and 2nd LO generation.

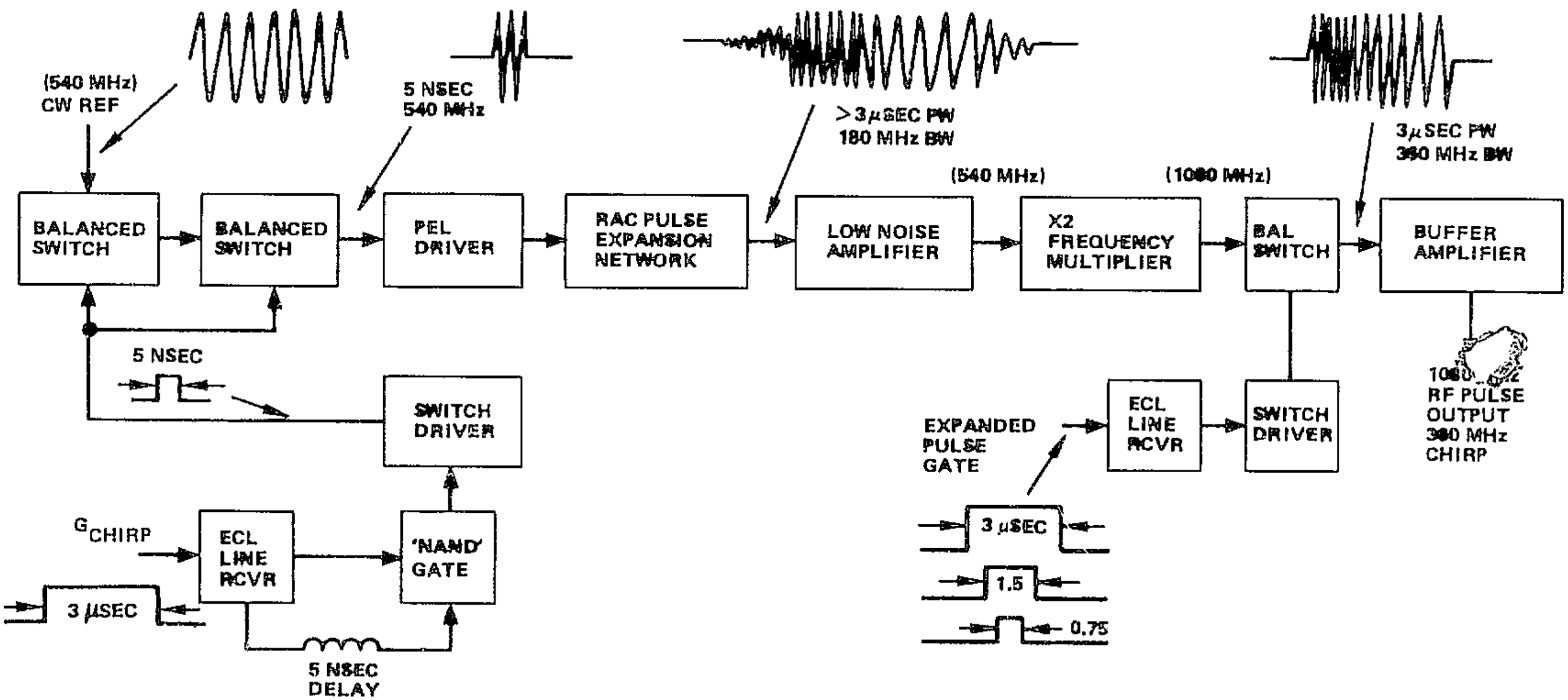
Significant Exciter Waveforms and spectra are illustrated on p. D-6. An even more uniform spectrum is obtained as a result of the nearly saturated operation of Transmitter.

ORIGINAL PAGE IS OF POOR QUALITY

TRANSMITTER BLOCK DIAGRAM



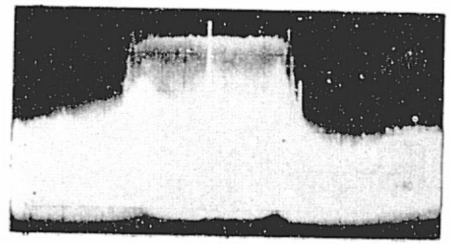
TRANSMITTER WAVEFORM GENERATOR



ORIGINAL PAGE IS
OF POOR QUALITY

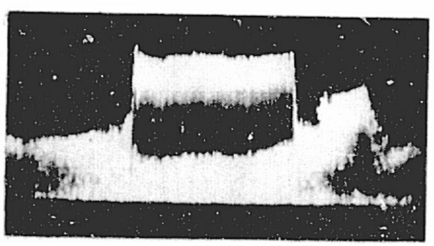
TRANSMITTER WAVEFORMS

540 MHz BURST
APPLIED TO P.E.L.
HORZ: 2 n SEC/DIV



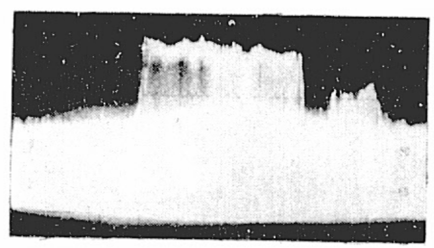
EXPANDED PULSE SPECTRUM

AT P.E.L. OUTPUT
VERT: 10 dB/DIV
HORZ: 50 MHz/DIV
f_o: 540 MHz



EXPANDED PULSE SPECTRUM

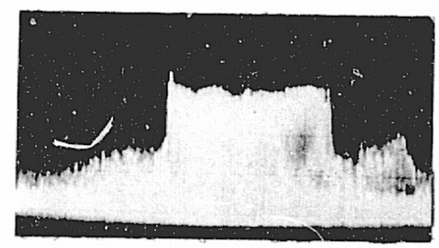
AT X2 FREQ MULTIPLIER OUTPUT
VERT: 10 dB/DIV
HORZ: 100 MHz/DIV
f_o: 1080 MHz



EXPANDED PULSE SPECTRUM

AT TRANSMITTER OUTPUT WITH
TWT BYPASSED

HORZ: 100 MHz/DIV
f_o: 13.9 GHz



RECEIVER 2ND L.O. AT
WAVEFORM GEN OUTPUT

HORZ: 100 MHz/DIV
f_o: 1620 MHz

3. REFLECTIVE ARRAY COMPRESSION (RAC) PERFORMANCE

Optimum stretch processing performance can only be achieved when the transmitted chirp waveform has low amplitude and phase errors. This high performance standard was met in the altimeter system by using a RAC dispersive filter to passively generate a linear FM waveform having nearly ideal amplitude and phase characteristics.

The RAC approach to implementing high performance dispersive filters was first developed by researchers at MIT's Lincoln Laboratories (Ref. 1, 2). The details involved in designing and fabricating these devices are extensively covered in the literature (Ref. 2, 3) and will not be discussed here. The operation of a RAC line may be understood by examining the photograph of the RAC filter used in the system. As shown in the figure (p. D-10), the operation of a RAC line is primarily controlled by a pair of reflecting gratings made by etching variable spaced grooves into the surface of a piezoelectric crystal. The grooves in the arrays are arranged in a herringbone fashion so that the acoustic signal launched by the input transducer is partially reflected at a 90° angle by the first array and then reflected another 90° by the second array and directed to the output transducer. The spacings of the grooves are designed so that the length of the U-shaped propagation path is a linear function of the synchronous reflection frequency of the two gratings so as to generate the desired linear FM output response.

The manipulation of the acoustic waves by the grooves is strictly a mechanical process and therefore the RAC's response is not degraded by the second order effects that have seriously distorted the response of previous filters made with conventional metal electrodes. If needed, the inherent performance capabilities of a RAC line can be further improved by individually tailoring its response to compensate for measured amplitude and phase errors. The amplitude response of a filter can be altered by changing the groove depth profile used in etching the reflecting arrays. The phase errors can be corrected by depositing a specially contoured metal film between the reflecting gratings. With these characteristics the RAC design approach has revolutionized the performance standards previously achieved in large compression ratio chirp filters and was an ideal choice for meeting the requirements of this system.

The amplitude response of the RAC line developed for this system is shown on p. D-11. This flat response was achieved with our first groove depth profile design, and did not require any special trimming techniques. The slowly varying amplitude variations of ±1.5 dB are reduced in the system by soft limiting the expanded impulse response of the line when amplified by the TWT which operates near saturation levels.

The line's phase deviation from an ideal quadratic phase response is shown in the next figure. This phase error response was found to be a sensitive function of how the impedance matching networks for the input and output transducers were tuned and could have been reduced to even smaller levels by making changes in the metal phase correction pattern deposited between the reflecting arrays. However, since the 20° peak-to-peak phase error shown in the figure was slowly varying it was determined that the resulting phase errors in the dechirped waveform would not affect the performance of the overall system. As a consequence no further phase correction trimming was required for the line.

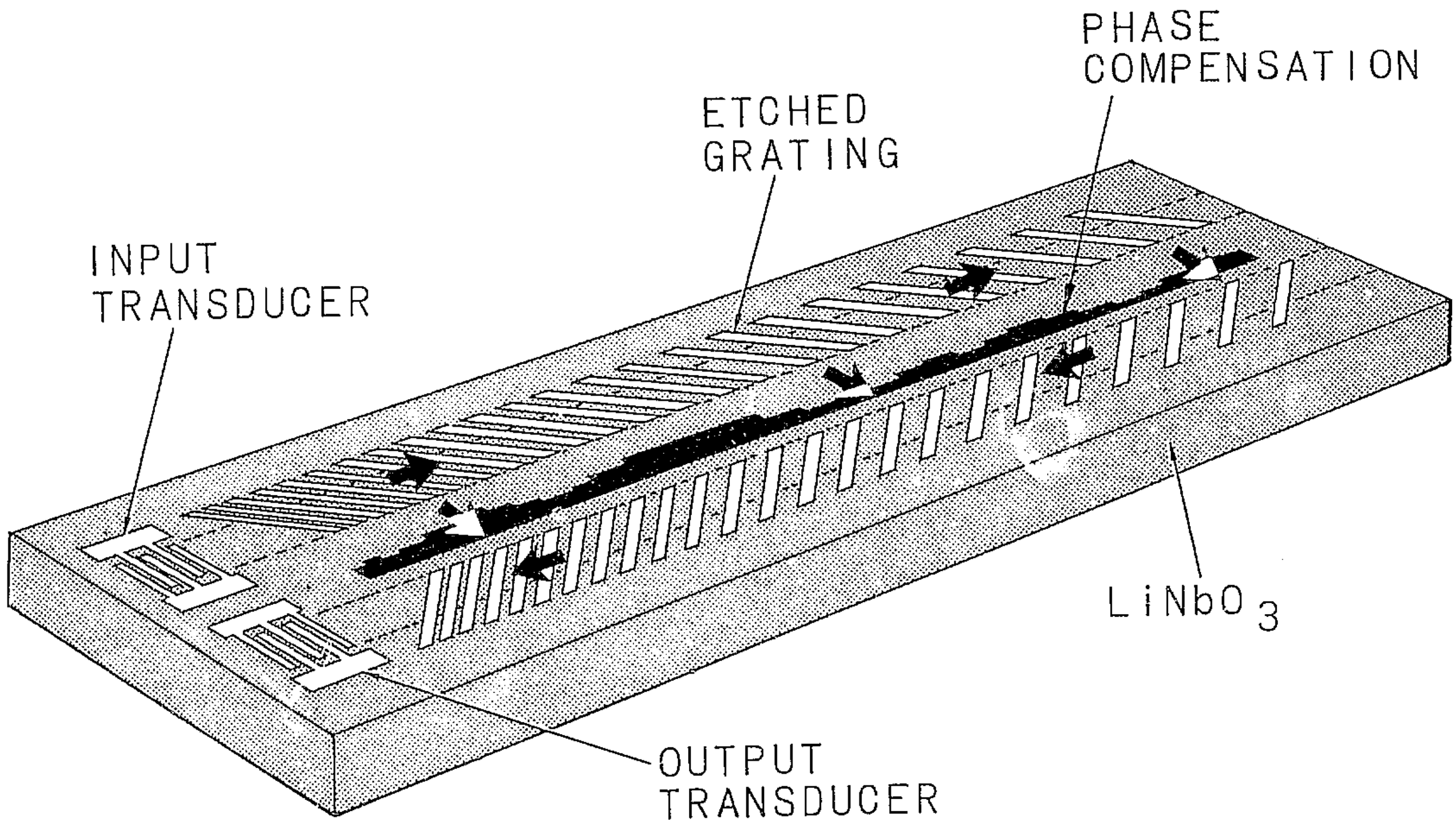
Reference 1. R. C. Williamson and H. I. Smith, "Large time-bandwidth-product surface wave pulse compressor employing reflective gratings," Electronic Letters, Vol. 8, No. 16, pp 401-402, Aug. 1972.

PRECEDING PAGE BLANK NOT FILMED

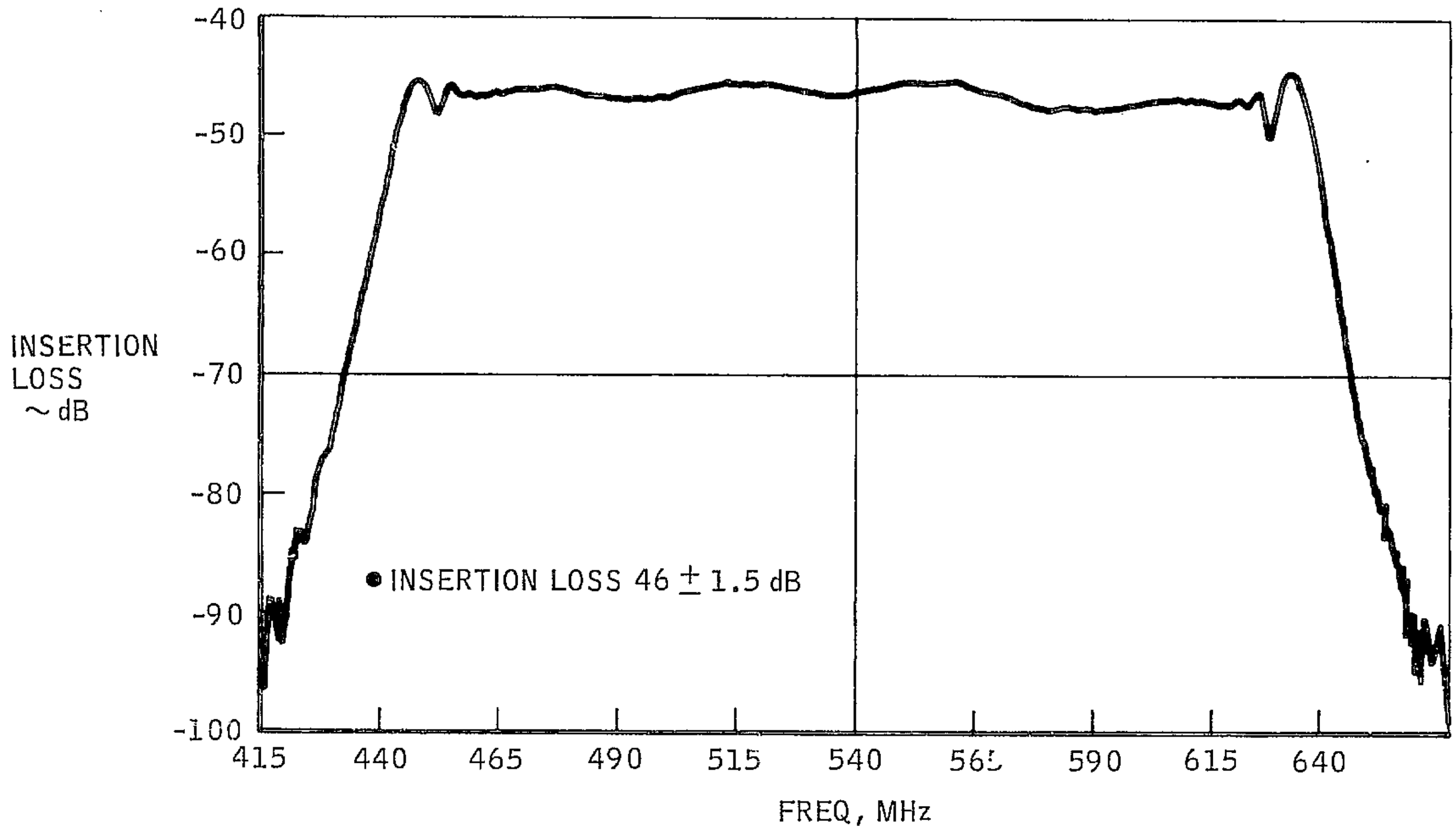
2. R. C. Williamson and H. I. Smith, "The use of Surface-elastic-wave reflection gratings in large time-bandwidth pulse-compression filters," IEEE Trans. on Sonics and Ultrasonics, Vol. SU-20, No. 2, pp 113-124, April 1975.
3. H. M. Gerard, O. W. Otto, R. D. Weglein, "Wideband Dispersive Filters," Final Report ECOM-73-0110-F, Contract No. DAAB07-73-C-0110, December 1974.

NASA ALTIMETER

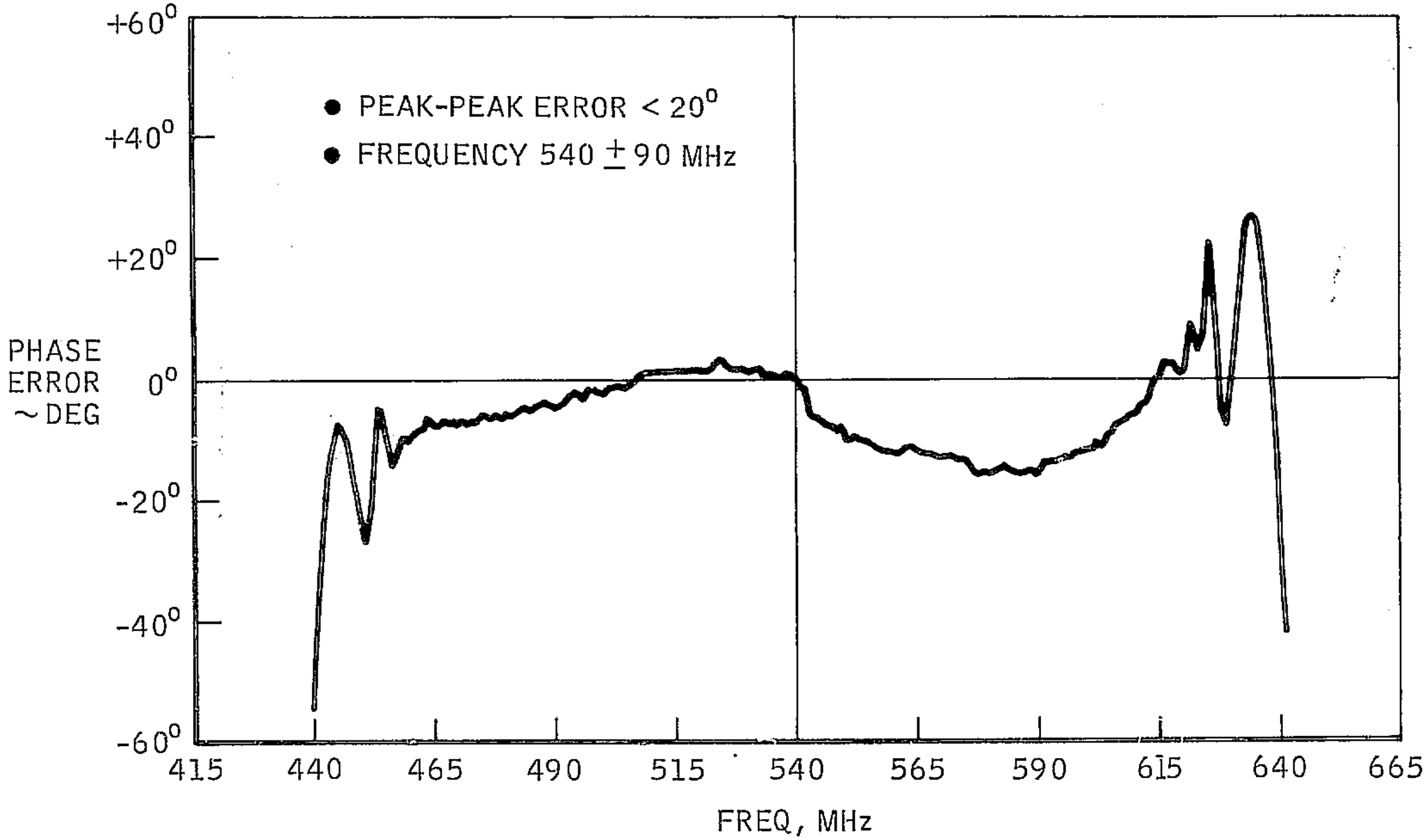
CONFIGURATION OF REFLECTIVE ARRAY DISPERSIVE FILTER



RAC LINE AMPLITUDE RESPONSE



RAC LINE PHASE ERROR CHARACTERISTICS



4. TRANSMITTER PACKAGING

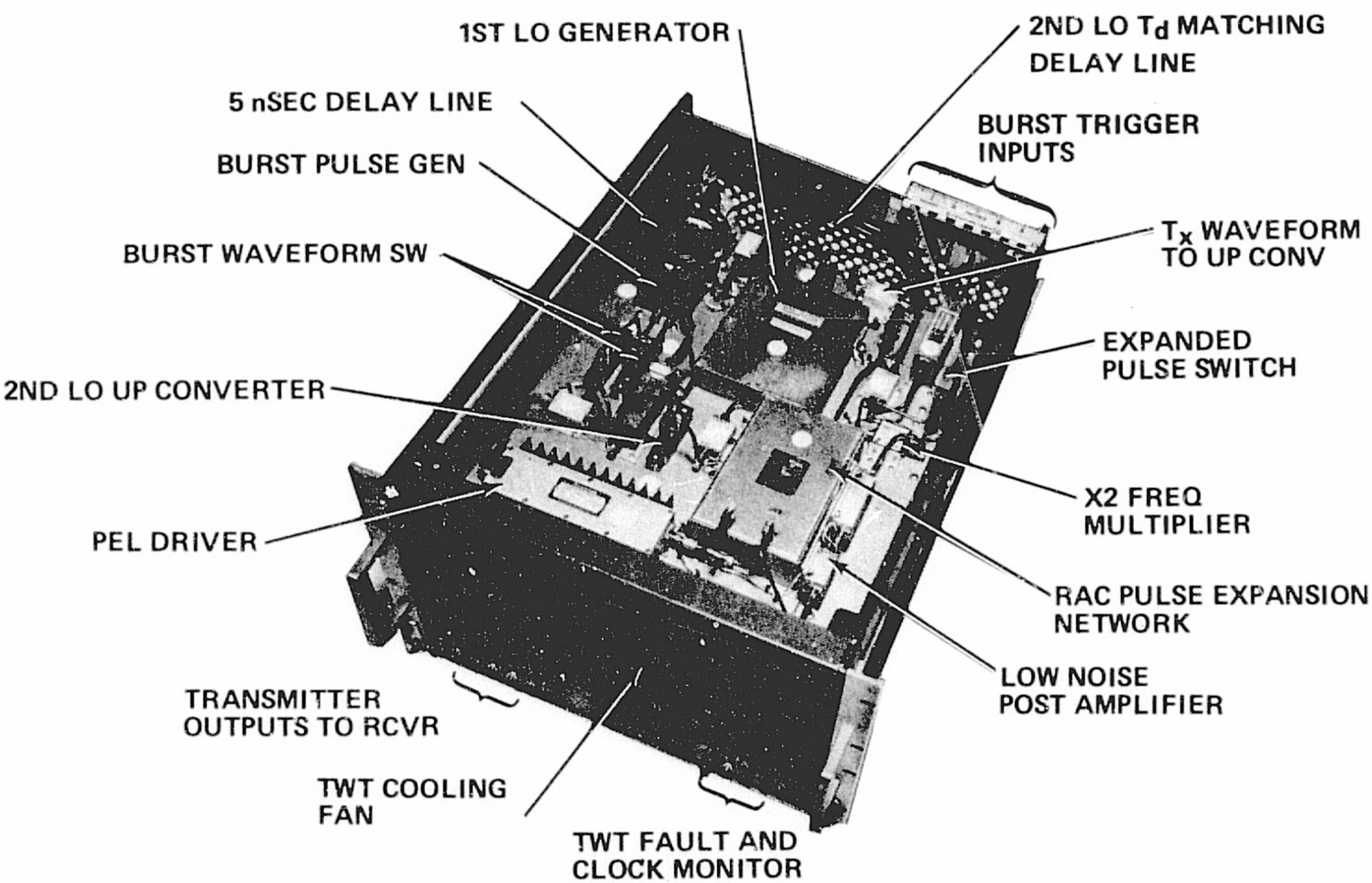
The Exciter and Transmitter equipments are packaged in a single removable slide-mounted drawer. Top and bottom views of the drawer are presented in figures (p. D-15, 16, 17). The Exciter and Transmitter are constructed primarily of enclosed modules connected with semi-rigid coaxial lines. The drawer is provided with a fan and front and rear panel vents for air cooling. The RAC line is contained in an enclosed module which is heated at a constant temperature of 75°C in order to provide stable operation.

Transmitter fault monitor indicator and test points are located on the front panel. Receiver LO and test target signal connectors are also located on the front panel and proved to be of great convenience during system test and integration; the Transmitter/Receiver connection is made with rigid coax which can be removed for signal test purposes. The ADS interface connections are located at the rear of the unit. The wave guide and antenna are connected to the duplexer which is also mounted on the rear panel.

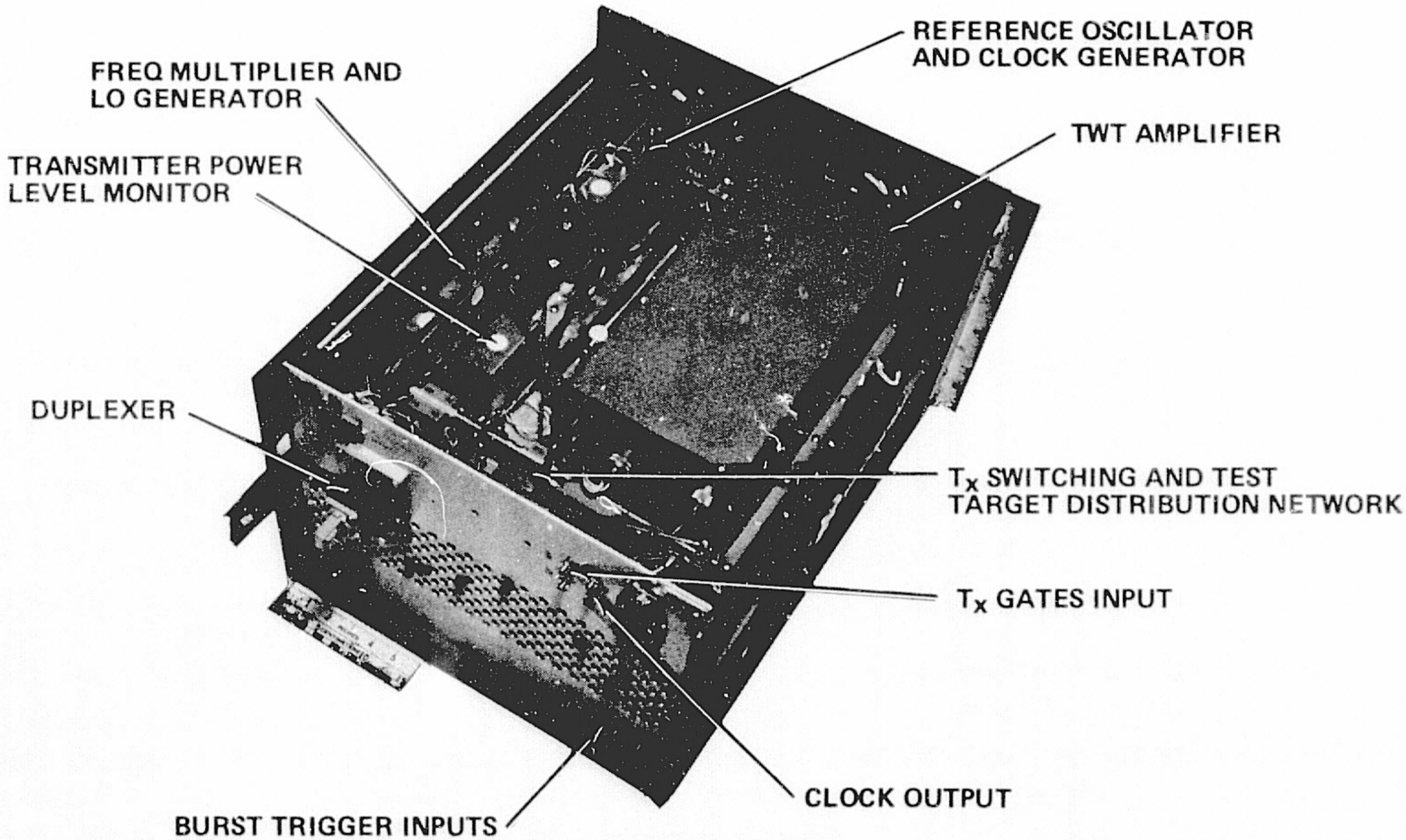
The Exciter, Transmitter, and Receiver power supplies are located in a single removable drawer as indicated on p. D-18. Power supply test points, breaker switches and an on/off switch are located on the front panel of this unit.

PRECEDING PAGE BLANK NOT FILMED

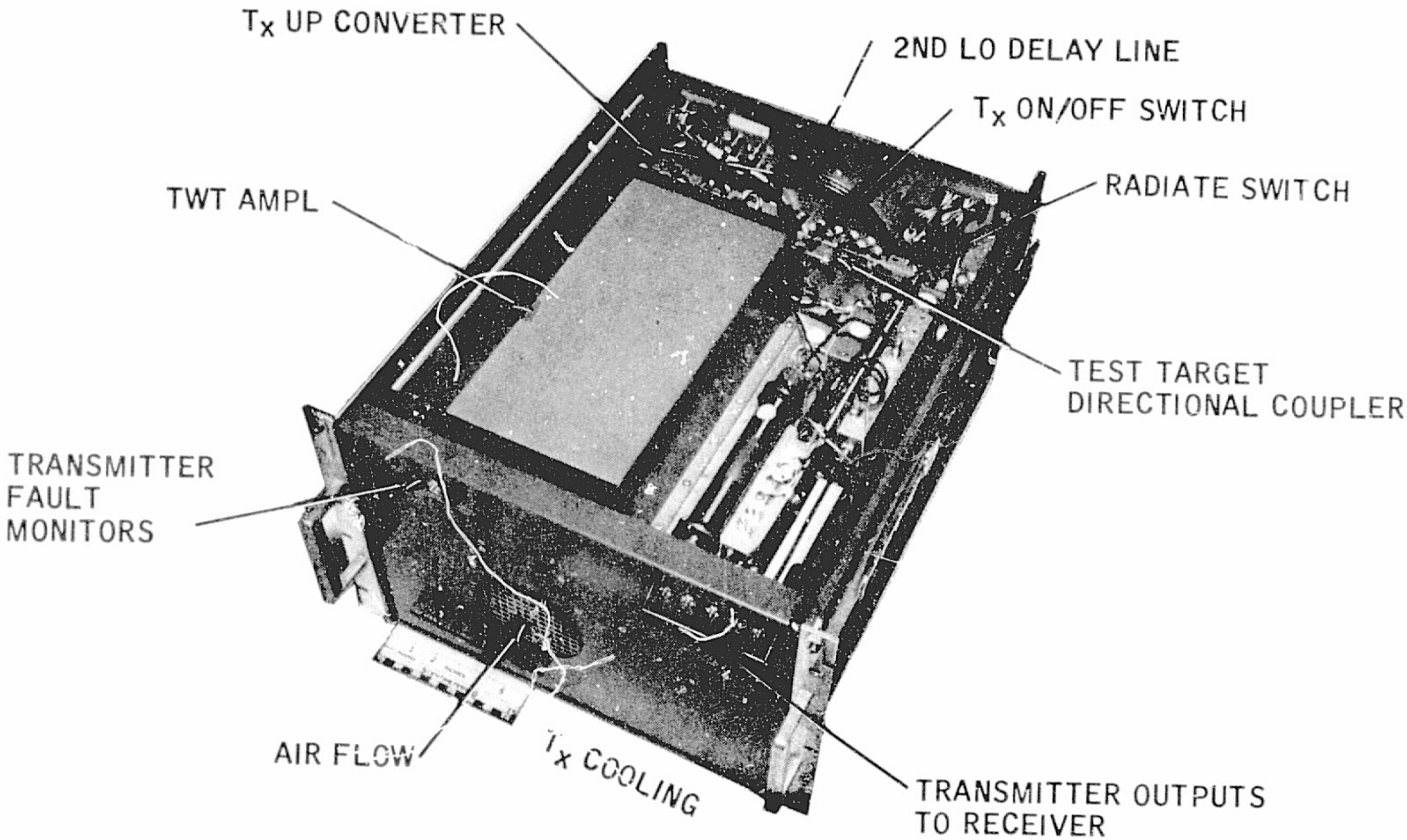
TRANSMITTER BOTTOM FRONT VIEW



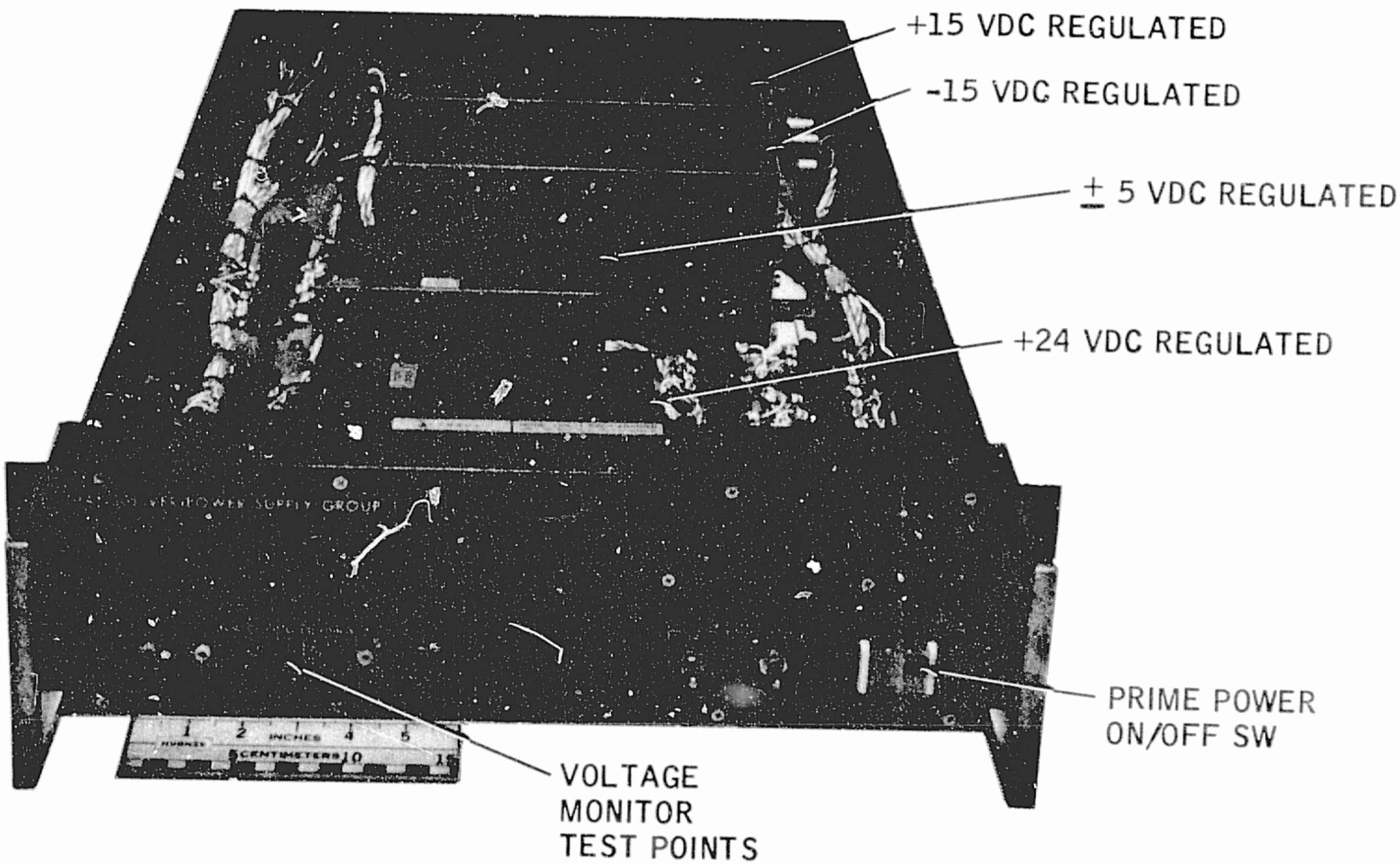
TRANSMITTER REAR TOP VIEW



TRANSMITTER FRONT TOP VIEW



TRANSCEIVER POWER SUPPLY GROUP



5. RECEIVER OVERVIEW

The Receiver provides the down-conversion, correlation and filtering or range gating of the sea return signals. The RF down-conversion and correlation are described below; signal levels and a block diagram of this portion of the Receiver are presented in the figures on p. D-22, D-23. Filter banks are described in the next topic.

Signals received from the antenna are echos of the sea return and are at the transmit frequency of 13.9 GHz. These returns have a pulse width of 3 usec, 1.5 usec or 0.75 usec depending on the radar operating mode. The normal mode return of 3 usec will have a 360 MHz linear F. M. chirp across the 3 usec time waveform while the shorter pulse widths will have a signal chirp bandwidth of 180 MHz and 90 MHz, respectively.

The signal returns are down converted in a WJ M-18 double balanced mixer to a center frequency of 1080 MHz by mixing the 13.9 GHz chirp signal with a CW local oscillator signal centered at 12.82 GHz. The mixer is followed by a 69 dB, 1 dB step, manual attenuator used to control the sea return signal level. The noise figure of the down-converter with 0 dB attenuation is 12.8 dB; total receiver noise figure is 13.3 dB.

A 30 dB directional coupler located at the mixer input allows injection of a test target. This signal is a sample of the Transmitter TWT output and is gate selected in the Calibrate submode. The test target level is approximately -65 dBm at the mixer input.

Two amplifiers which provide a total of 56 dB of gain follow the mixer and step attenuator. Mixer conversion loss and circuit losses set the overall converter gain to the required 41 dB. The 1st IF bandwidth is set by a linear phase filter with 3 dB bandwidth of 500 MHz.

Generation of test targets that will simultaneously fall in the Early gate and the Late gate is accomplished by use of the 102.77 nsec delay line. With the delay line selected, two targets are generated with one delayed from the other by 102.77 nsec, or 12.333 MHz. A buffer amplifier and linear phase filter following the delay network provide isolation and a solid termination to the chirp signal as it is applied to the 2nd mixer.

Dechirping of the 1080 MHz signals is accomplished in the 2nd mixer by mixing the signal with a chirp signal centered at 1620 MHz. This signal is a duplicate of the transmitted signal prior to its up-conversion to 13.9 GHz. If the dechirping local oscillator signal and the 1080 MHz sea returns are time coincident the chirp across the time waveform will be removed and a 3.0 μs (1.5 or 0.75 μs) pulse with a center frequency of 540 MHz will result. Time displacement of the two signals will result in an offset from the 540 MHz center frequency of 120 KHz per nanosecond of delay or 15 cm of range. Variations in range of the expected returns will produce signals occupying a band from approximately 517 MHz to 546 MHz. The second IF amplifier provides approximately 15 dB of gain to this signal prior to the band limit filtering which matches the expected limits of the sea return signals in all gate filter banks.

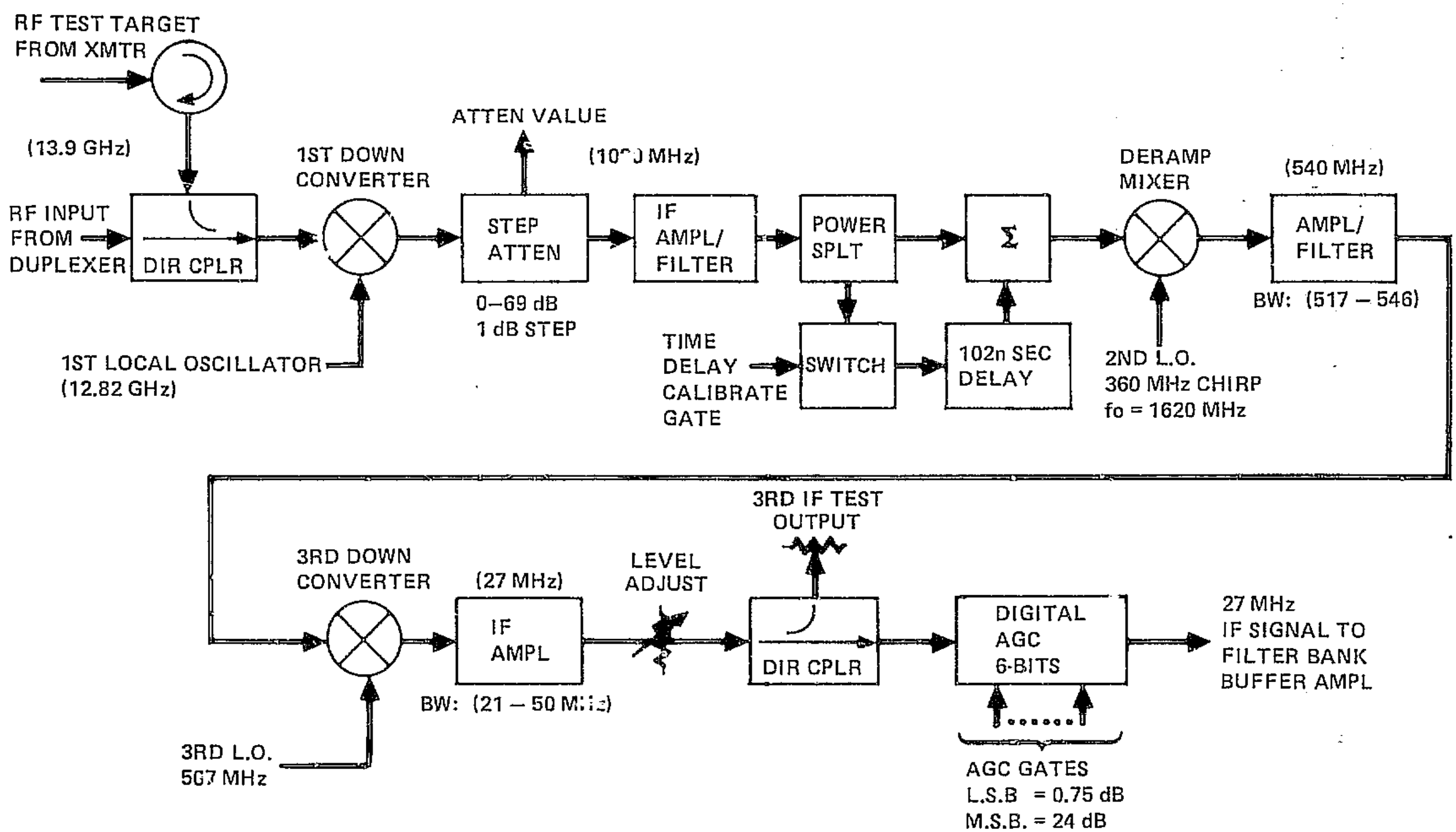
Conversion to a 3rd IF of 27 MHz occurs in the 3rd mixer. The expected signal frequency range at the 3rd IF output is 21.67 to 50 MHz. Manual setting of the IF chain gain is accomplished by a variable attenuator following the 3rd IF preamplifier. To insure that signals are maintained at the optimum level in the video chain and the A/D converter, automatic gain control (AGC) is utilized. This device consists of 6 gate selectable fixed attenuators with an LSB of 0.75 dB in a series configuration. Control of the AGC is by a T^2L signal from the ADS

PRECEDING PAGE BLANK NOT FILMED

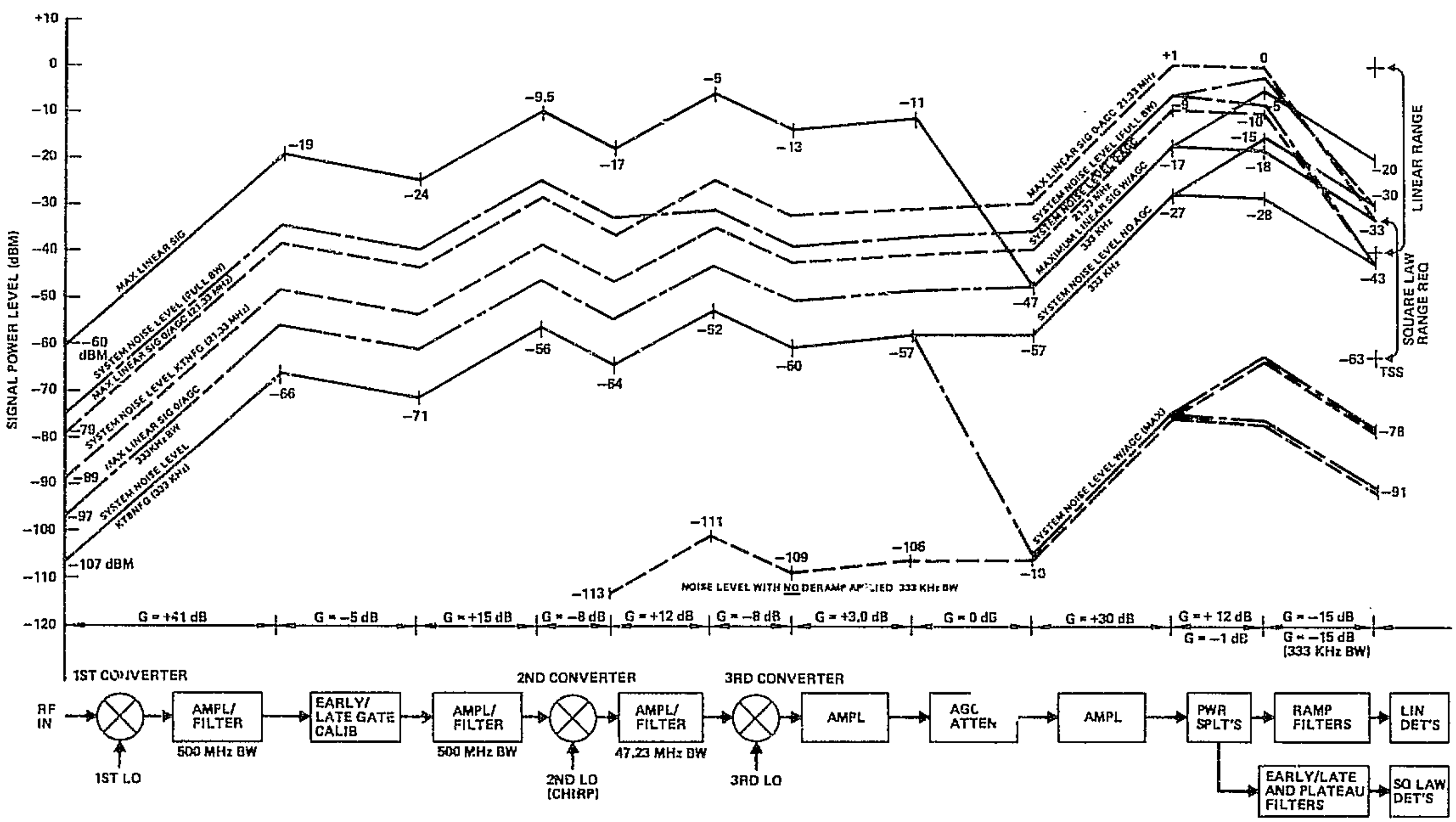
unit. An amplifier follows the AGC circuit with sufficient gain to overcome losses incurred in the filter bank input power splitter. The maximum linear signal corresponding to 0.1 dB compression is +1.0 dBm.

After power splitting the signals are sent to the Ramp Filters, the Early Gate Filters, and the Late Gate-Plateau Filter banks as described in the next topic.

RECEIVER RF AND IF SECTION BLOCK DIAGRAM



AAFE RADAR ALTIMETER RECEIVER SIGNAL AND NOISE POWER CONTOURS



6. RECEIVER FILTER BANKS

The third IF signals are filtered by 24 Ramp filters and Early, Late and Plateau gate filters. Because of the stretch process the filtering is equivalent to range gating where 120 KHz corresponds to one nanosecond or 15 cm in range.

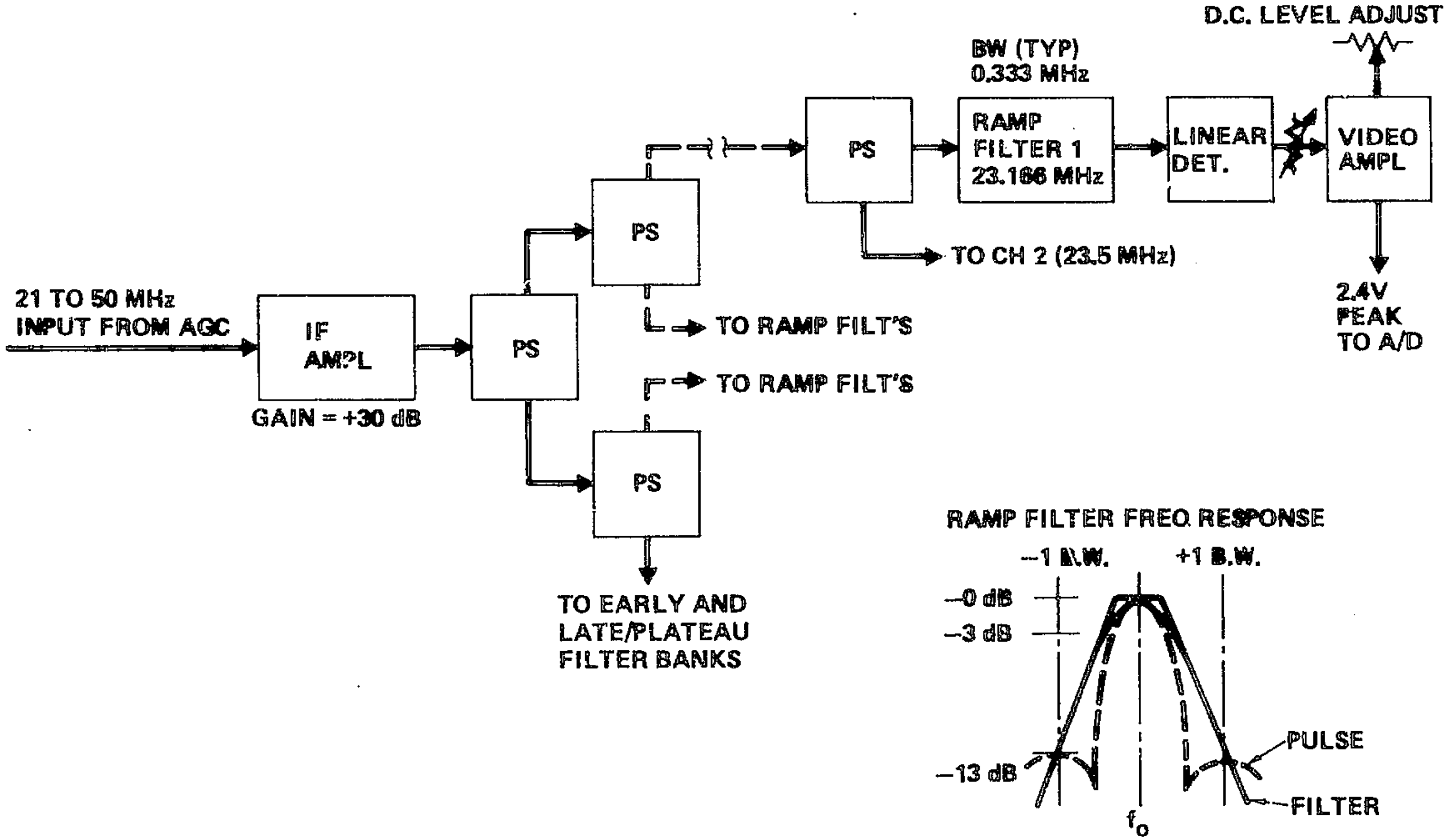
The Receiver has a bank of 24 Ramp filters which provide 8 MHz of frequency coverage or 10 m of range coverage in order to collect amplitude data from the leading edge of the sea return for 1-10 m significant wave heights. The Ramp filters are a set of contiguous 333 kHz bandwidth Butterworth three section passive filters. The center frequency of each filter is offset from the adjacent filters by 333 kHz or 2.777 nsec. The filters are designed to have matching -3 dB crossover points and adjacent filter center frequency rejection of greater than -13 dB; test data indicates that the center frequency rejection is approximately -19 dB. Filters 12 and 13 have the 3 dB crossover at the 27.000 MHz center frequency. A typical filter channel block diagram is presented in the facing figure. IF signals are supplied to each of the filters by a sequence of power splitters. After filtering, signals are detected in a linear detector. The output of each detector drives an operational amplifier that provides adjustable video gain and D.C. offset control. A current driver is used to buffer the video signals into the sample and hold circuits.

Block diagrams of the Early Gate, Late Gate and Plateau filters are presented in the next two figures. The filters are selected by T^2L signals which are dependent on Gate width and pulse width selected by the operator. The filter bandwidths of the Early Gate and Late Gate are multiples of the matched bandwidth of 333 kHz for 3 μsec. pulse width, 666 kHz for 1.5 μsec., and 1.33 MHz for 0.75 μsec. The design takes advantage of the bandwidth commonality of the Early gate selections; all 12 selections (4 gate widths x 3 pulse widths) are implemented by use of seven filters and output selection logic. Similarly, all required selections for the Late and Plateau gates are provided by seven filters; since the Plateau gate is always 16 cells the same filter is used and the output power split for generation of Late and Plateau gate signals when a 16 cell width is selected for the Late gate at the Radar control panel. The filter outputs for the three channels or gates are each switch selected into three identical square law detectors (one for each gate).

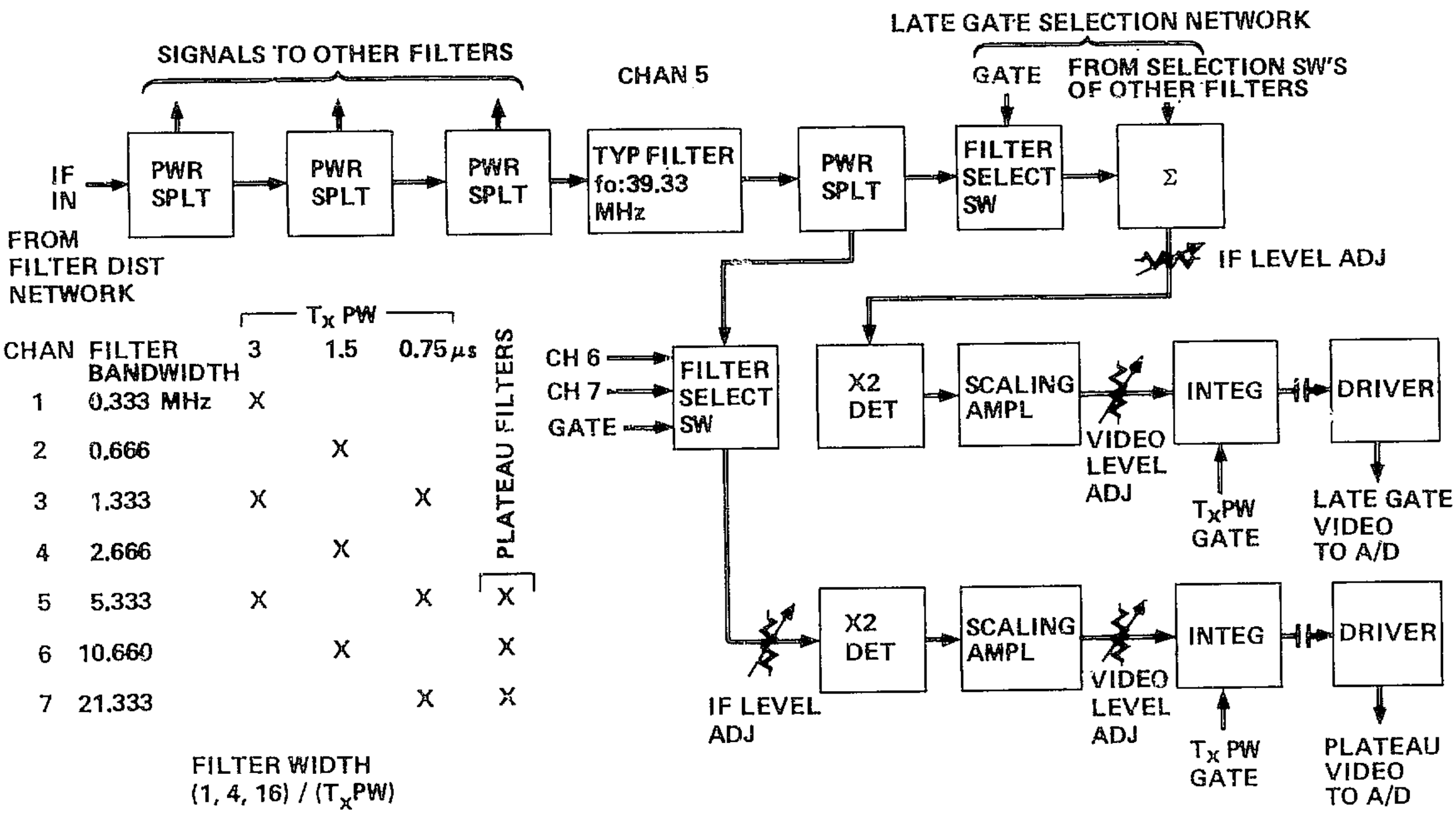
The output of the square law detector is applied to a video gain adjustment network, and scaled in a video amplifier with a voltage gain of 1.8. The output of the video amplifier is applied to a Prom containing the three video integrators. The Prom has a voltage gain of 49 and is gate selectable in accordance with the transmitter pulse width. The integrator is a low pass filter with a bandwidth which is matched to the video bandwidth or $1/2\tau$. This constitutes range cell-to-range cell integration. The output of the integrator is applied to the sample and hold circuit by a current driver.

The last figure (p. D-28) illustrates the relationship between the Ramp filters and the Early, Late and Plateau gates. The frequency scale can be converted to relative range by the 120 kHz/15 cm scale factor.

RAMP FILTER BANK



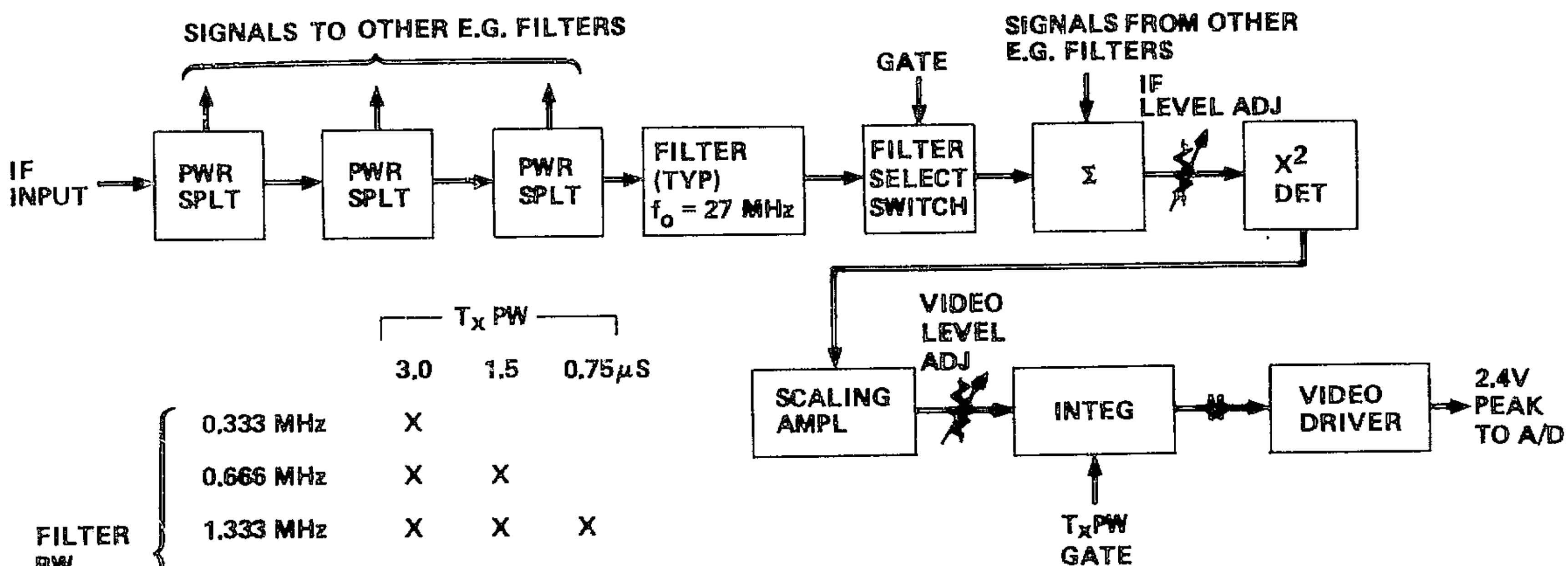
LATE GATE/PLATEAU FILTER BANK



CHAN	FILTER BANDWIDTH	T_X PW 3	1.5	0.75 μs	PLATEAU FILTERS
1	0.333 MHz	X			
2	0.666		X		
3	1.333	X		X	
4	2.666		X		
5	5.333	X		X	X
6	10.660		X		X
7	21.333			X	X

FILTER WIDTH
(1, 4, 16) / (T_XPW)

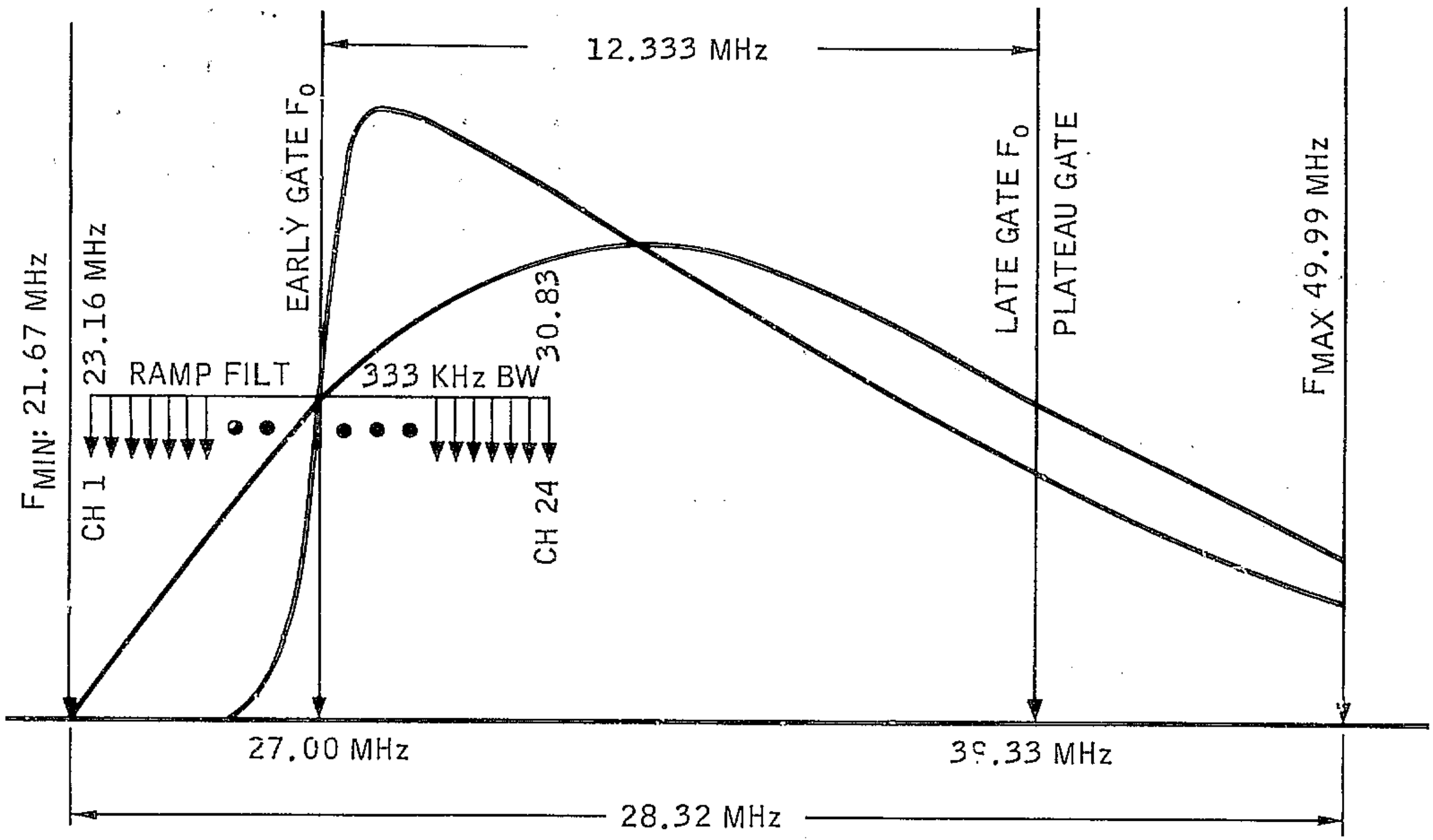
EARLY GATE FILTER BANK



		T_X PW		
		3.0	1.5	0.75μS
FILTER BW	0.333 MHz	X		
	0.666 MHz	X	X	
	1.333 MHz	X	X	X
	2.666 MHz	X	X	X
	5.333 MHz		X	X
	10.666 MHz			X

FILTER WIDTH =
(1, 2, 4, 8)/(T_X PW)

FILTER POSITION REFERENCED TO SURFACE RETURN



7. RECEIVER PACKAGING

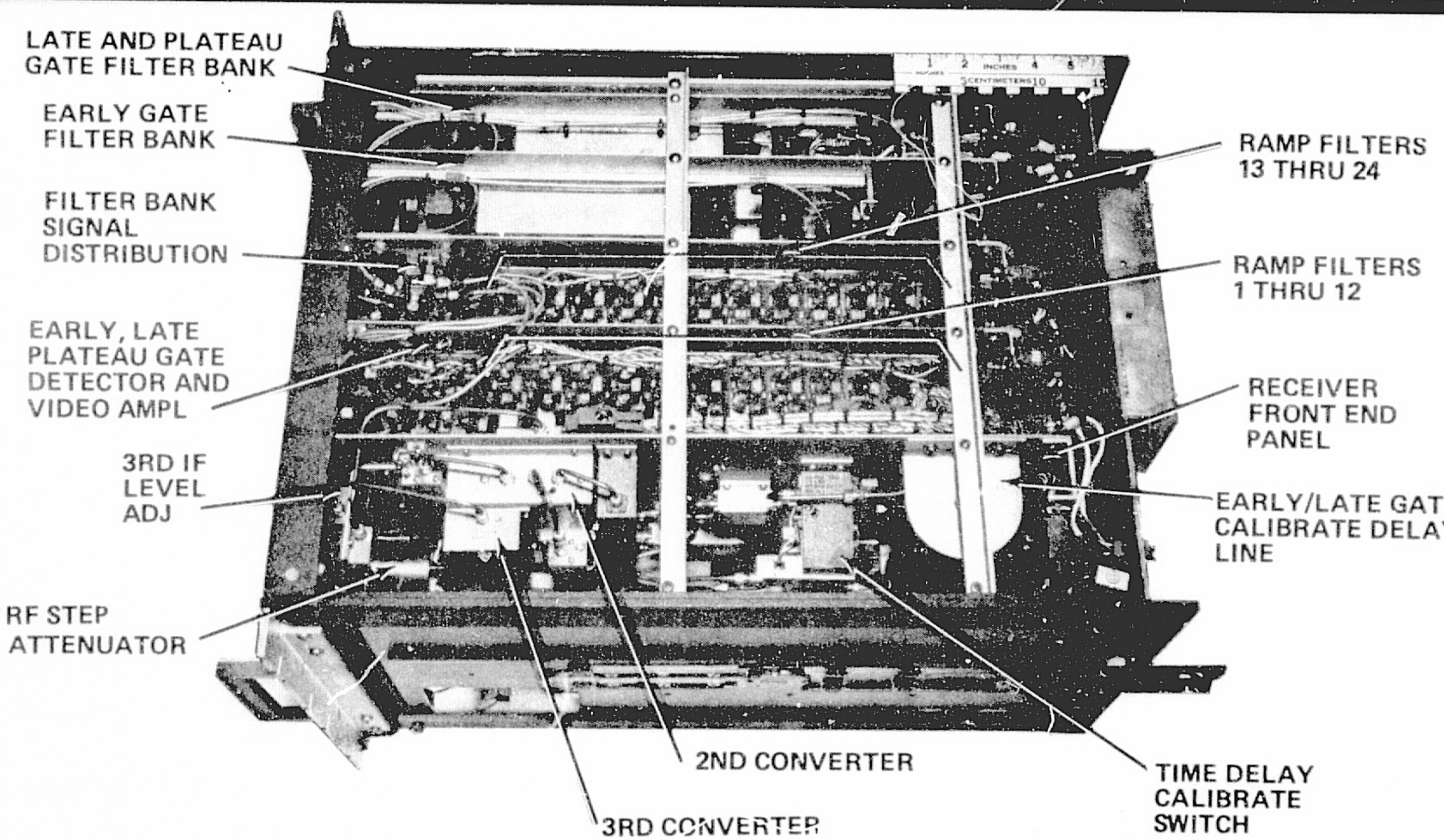
The Receiver equipments are contained in a single removable slide-mounted drawer as shown on p. D-31, 32. The Receiver unit consists of five circuit boards. RF and IF conversion circuits are mounted on a single board and the filters and video chains are located on the other four circuit boards. The filter circuits are packaged such as to provide easy access to the gain and bias adjustment controls. Packaging details of the Late/Plateau gate and the Ramp filters are presented in the figure on p. D-33.

Exciter/Transmitter signal connectors are located on the front panel of the Receiver (see Transmitter Packaging topic). ADS and RF signal connections are made at the rear panel. A number of test points including Early and Late gate signals, 3rd IF signal and gain control are located on the front panel.

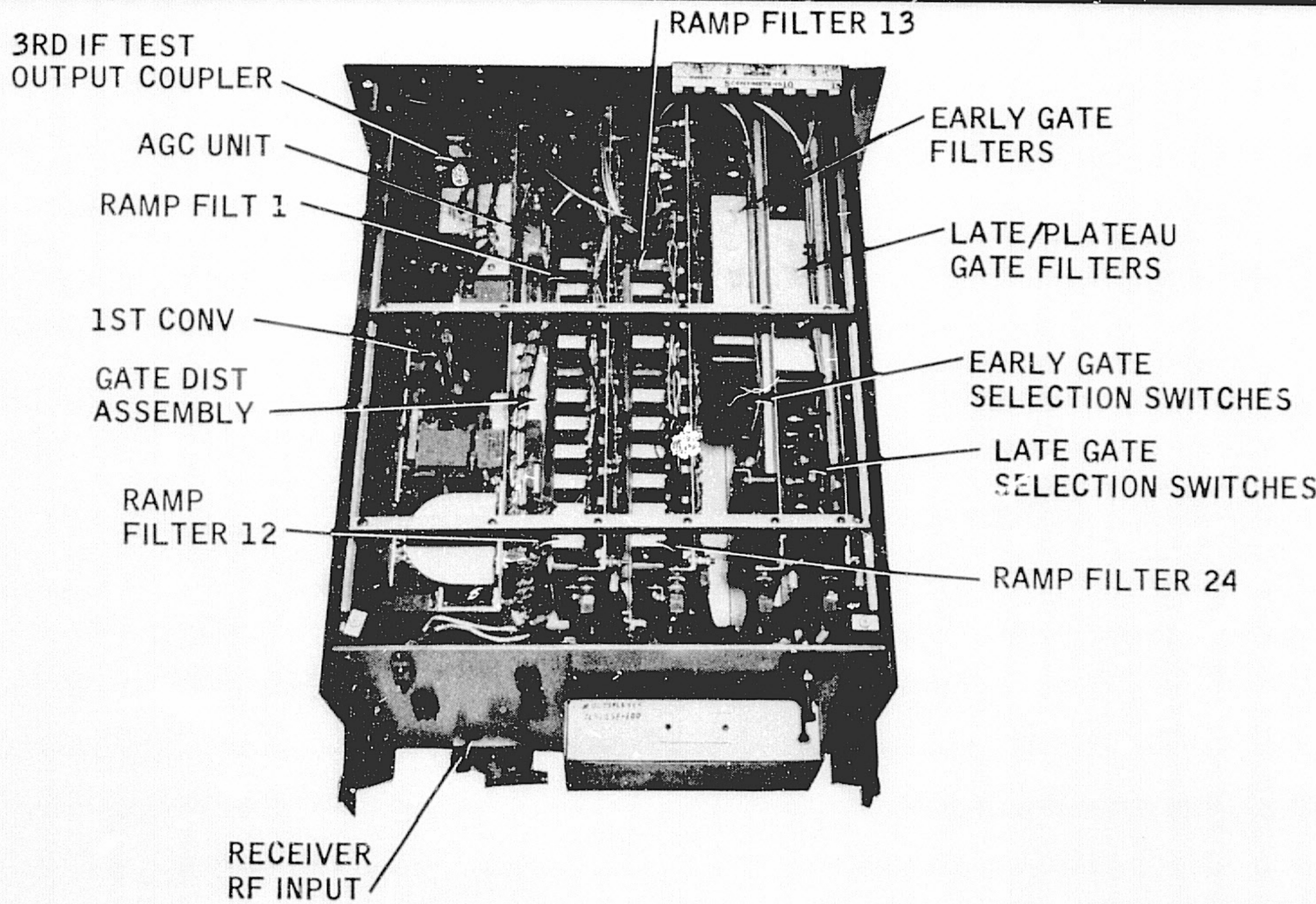
Temperature controlled heaters have been provided in order to reduce the filter warm-up time. No air or liquid cooling is necessary for this unit.

PRECEDING PAGE BLANK NOT FILMED

RECEIVER TOP SIDE VIEW

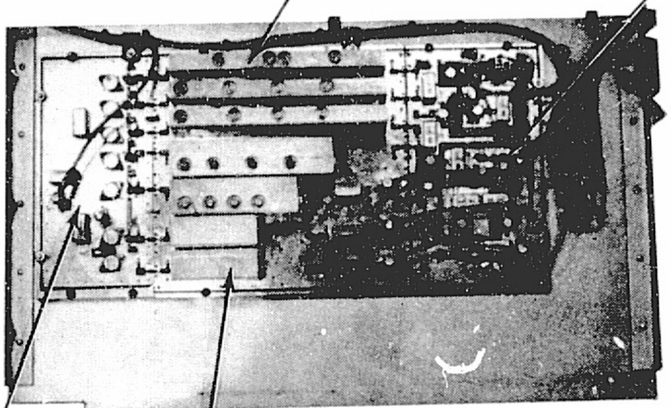


RECEIVER TOP REAR VIEW

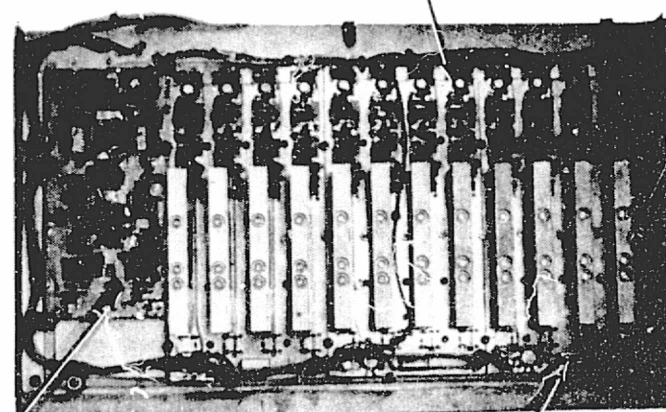


C-2

RAMP AND LATE/PLATEAU FILTER BANKS



EARLY/PLATEAU FILTER BANK



RAMP FILTER BANK 1-12 WITH LINEAR DETECTOR PANEL

8. TRANSCEIVER PERFORMANCE

This topic presents Transceiver performance as a stretch processor and video waveforms.

Stretch Processing

The figure on p. D-36 presents RF and IF spectra for a 3 μs pulse and describes the stretch process. The transmitted and received signal from a single scatterer (or test target) has a bandwidth of 360 MHz and a center frequency of 13.9 GHz as depicted in the upper photograph of the figure. Ideally this spectrum is flat; however, because of frequency dependent losses and RAC line induced amplitude variations, some deviations from the ideal spectrum exist. The signal is down-converted by 12.82 GHz in the first mixer resulting in a 3 μs pulse with a bandwidth of 360 MHz at a center frequency of 1080 MHz as indicated in the next photograph. A reference signal with the same bandwidth and a center frequency of 1620 MHz is generated at the estimated time of arrival of the backscattered signal; this reference is the 2nd LO signal shown in the left photograph. The reference signal is mixed or correlated with the incoming signal at 1080 MHz in the second mixer. If the reference signal and the backscattered signal are exactly coincident in time, the codes will correlate and a 3 μs uncoded pulse with a center frequency of 540 MHz will result at the output of the second mixer. Any time delay between the two signals will be translated to a frequency offset from 540 MHz at a rate of 120 KHz per nanosecond of time delay or 15 cm of range. The second mixer output, denoted as deramped (frequency) output is illustrated in the next photograph in the figure.

The third mixer is a down-conversion operation which mixes the inputs at the nominal center frequency of 540 MHz with a 567 MHz LO signal and translates the signals to a nominal center frequency of 27 MHz. This operation does not affect the signal spectral characteristics; the output is illustrated in the last photograph of the figure using an expanded 500 KHz/division frequency scale. The test data indicates that the peak sidelobe is approximately -12 dB below the peak (-13.2 theoretical). The data also indicates that the sidelobes fall-off to approximately -40 dB and the -4 dB width of the mainlobe is essentially equal to the theoretical value of 0.333 MHz. These frequency characteristics demonstrate good control of phase and amplitude errors throughout the system. As in other systems, a narrow mainlobe and low energy content in the frequency sidelobes is necessary in order to achieve fine range resolution.

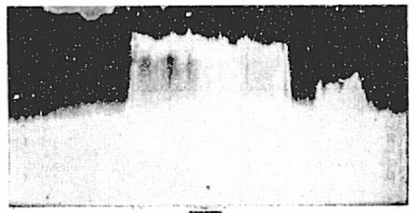
Video Waveforms

After the third mixer which down-converts the signals to the IF center frequency of 27 MHz, the signals are filtered, detected and sampled in order to determine signal amplitude as a function of range. Early, Late, Plateau and Ramp video channel outputs for a test target input are indicated in the next figure. In all cases a 3 μs test target centered in the respective filter was used.

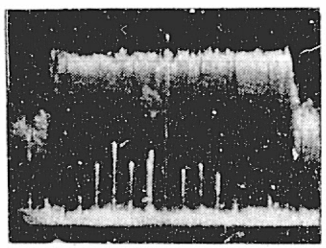
The Early, Late, and Plateau video chains consist of filtering, square law detection, and integration (low pass filtering). This is then followed by sampling and A/D conversion. The Early and Late gate filter bandwidths are selectable in multiples of 0.333 MHz; the Plateau gate filter bandwidth is 16 x 0.333 MHz or 5.333 MHz. The Video integrators are matched to the respective pulsewidths (3 μs in this case). The filter gains are set such that the average outputs of the video chains are equal when the input is system noise; this will result in equal levels when operating on constant amplitude sea returns since their amplitude fluctuation statistics are similar to noise. The Early and Late gate amplitude responses shown in the figure appear to differ for the different gate (filter) widths as a result of the narrow band (0.333 KHz) test target signal used in performing the test. Fine manual adjustment and signal amplitude correction by the software are employed on the basis of Receiver noise to insure signal gain alignment. All amplitude responses in the figure have a width of approximately 3 μs as a result of the 3 μs pulse. The Ramp filter video chains consist of a 0.333 MHz filter followed by a linear detection; i.e., integrators are not utilized.

The trailing edge of the 3 μs test target pulse is also an indication of the sampling time. For the narrow Early and Late gate widths the sampling time is offset by nearly 2 μs from the peak of the signal. Normally this would result in a substantial loss in S/N ratio, however, since the second mixer utilizes a gated reference signal, noise signals have no advantage in the time domain and the early sampling manifests in lower signal and noise amplitudes; thus S/N ratio is preserved. The lower amplitudes are compensated by higher filter gain and software corrections.

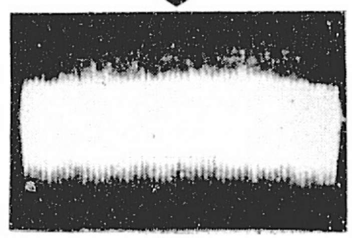
SPECTRAL CHARACTERISTICS OF RECEIVER WAVEFORMS



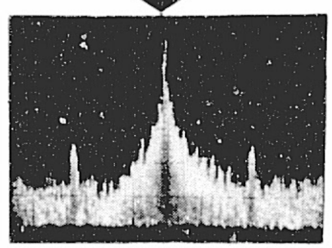
TRANSMITTED EXPANDED PULSE FREQ SPECTRUM AT TRANSMITTER OUTPUT
fo: 13.9 GHz
HORZ: 100 MHz/DIV
VERT: 10 dB/DIV



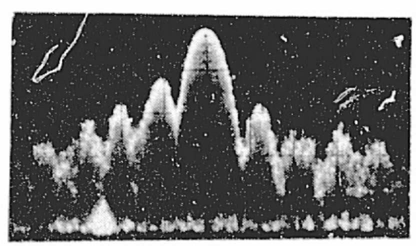
2ND LO EXPANDED PULSE FREQ SPECTRUM AT THE 2ND CONVERTER INPUT
fo: 1620 MHz
HORZ: 50 MHz/DIV
VERT: 10 dB/DIV



TRANSMITTED EXPANDED PULSE AT RECEIVER 2ND CONVERTER MIXER
fo: 1080 MHz
HORZ: 50 MHz/DIV
VERT: 10 dB/DIV



DERAMPED TRANSMITTER EXPANDED PULSE AT RECEIVER 2ND CONVERTER OUTPUT
fo: 540 MHz
HORZ: 5 MHz/DIV
VERT: 10 dB/DIV

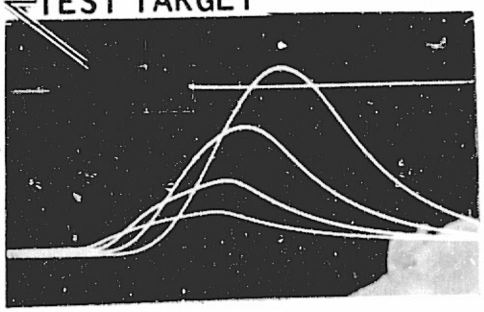


DERAMPED EXPANDED PULSE SHOWING SIDELOBE NULL POSITION
fo: 27 MHz
HORZ: 500 KHz/DIV
VERT: 10 dB/DIV
POSITION: RECEIVER 3RD IF TEST OUTPUT

RECEIVER FILTER BANK TIME WAVEFORMS FOR A TEST TARGET INPUT

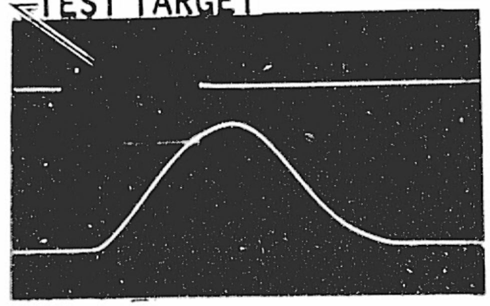
HORZ: 1 μSEC/DIV   VERT: 0.5 V/DIV

TEST TARGET

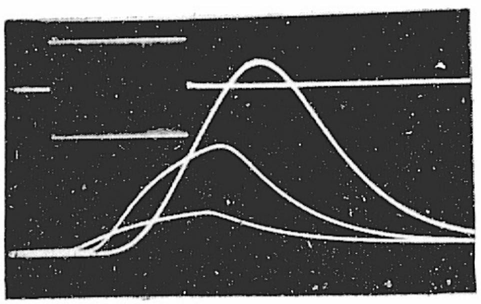


EARLY GATES
1, 2, 4, AND 8
FOR 3 μSEC
INPUT PULSE

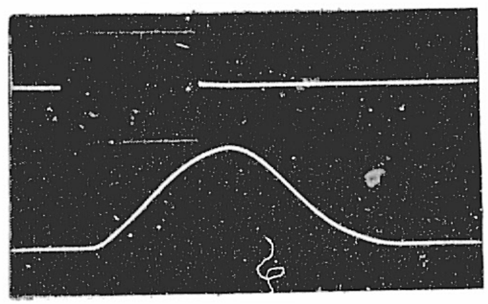
TEST TARGET



RAMP FILTER
NO. 1

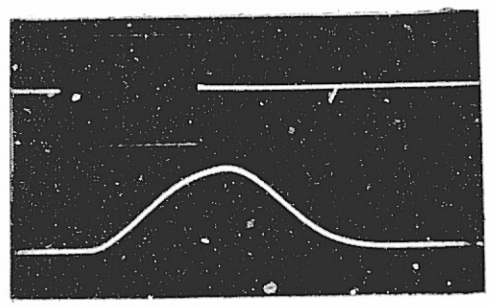


LATE GATES
1, 4 AND 16
FOR 3 μSEC
INPUT PULSE



RAMP FILTER
NO. 13

PLATEAU GATE
FOR 3 μSEC
INPUT PULSE



RAMP FILTER
NO. 24

SECTION E
ADS DESIGN

1. OVERVIEW OF THE ANALOG/DIGITAL SUBSYSTEM

The Analog/Digital Subsystem (ADS) consists of the four units indicated in the figure, the sample and hold and multiplexing circuits located in the Receiver, and the accelerometer mounted on the antenna. The ADS interfaces and equipments are represented in the simplified block diagram below. ADS basic functions consist of control, timing, analog sampling, analog to digital (A/D) and digital to analog (D/A) conversion, computer interface control, and the display function. A block diagram is presented on p. E-2.

The Control panel provides for manual control of all radar modes and indicates the current operating mode. A 4-digit light emitting diode array (LEA) is also provided to display several radar parameters calculated by the computer. See Topic B-5 for a detailed control panel description.

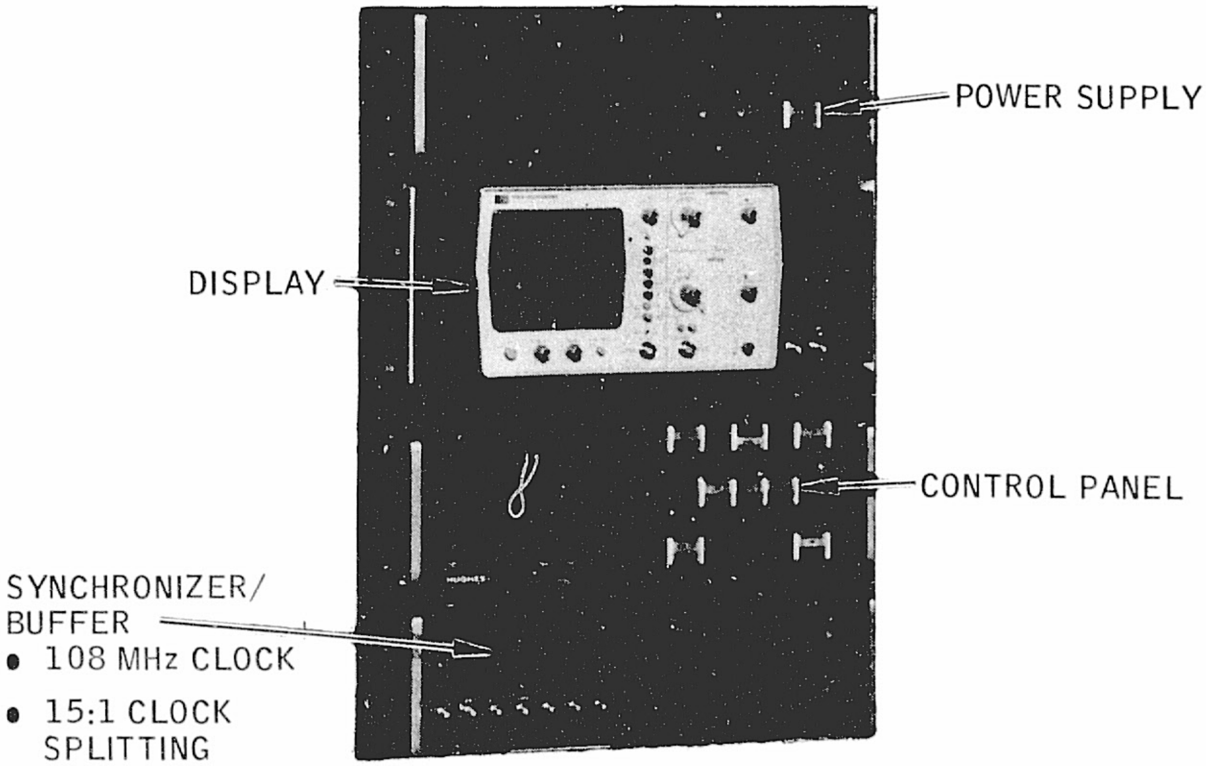
The timing function receives a 108 MHz reference clock from the Transceiver subsystem and develops timing and control signals required to synchronize the various Radar Subsystem functions. A delay circuit in the Synchronizer provides for 15:1 splitting of the clock signal; this, in effect, provides a 1.62 GHz clock capability and a range LSB of 0.62 ns (9.3 cm).

The sampling and data conversion function receives timing control and performs simultaneous sampling of all of the analog filter output signals from the Receiver. These signals are held in sample and hold circuits until each is processed through the 12-bit A/D converter at a 125 kHz (8 us/word) rate and sent to the computer interface unit for transfer to the computer; the 24 Ramp filter linearly detected outputs are squared by ADS and the 16 MSB's transmitted to the Computer.

The computer interface function controls the flow of data to and from the computer during each pulse period. Data transmitted to the computer is formatted and multiplexed on to the computer input lines and transferred without buffering. Output data is taken in sequence from the output data lines according to the output data word format, stored and distributed to the radar subsystem. Refer to the next topic for detailed interface timing and format descriptions. Digital data from the interface unit representing X and Y position is converted to analog in the D/A Converter and used to position the beam on the CRT display.

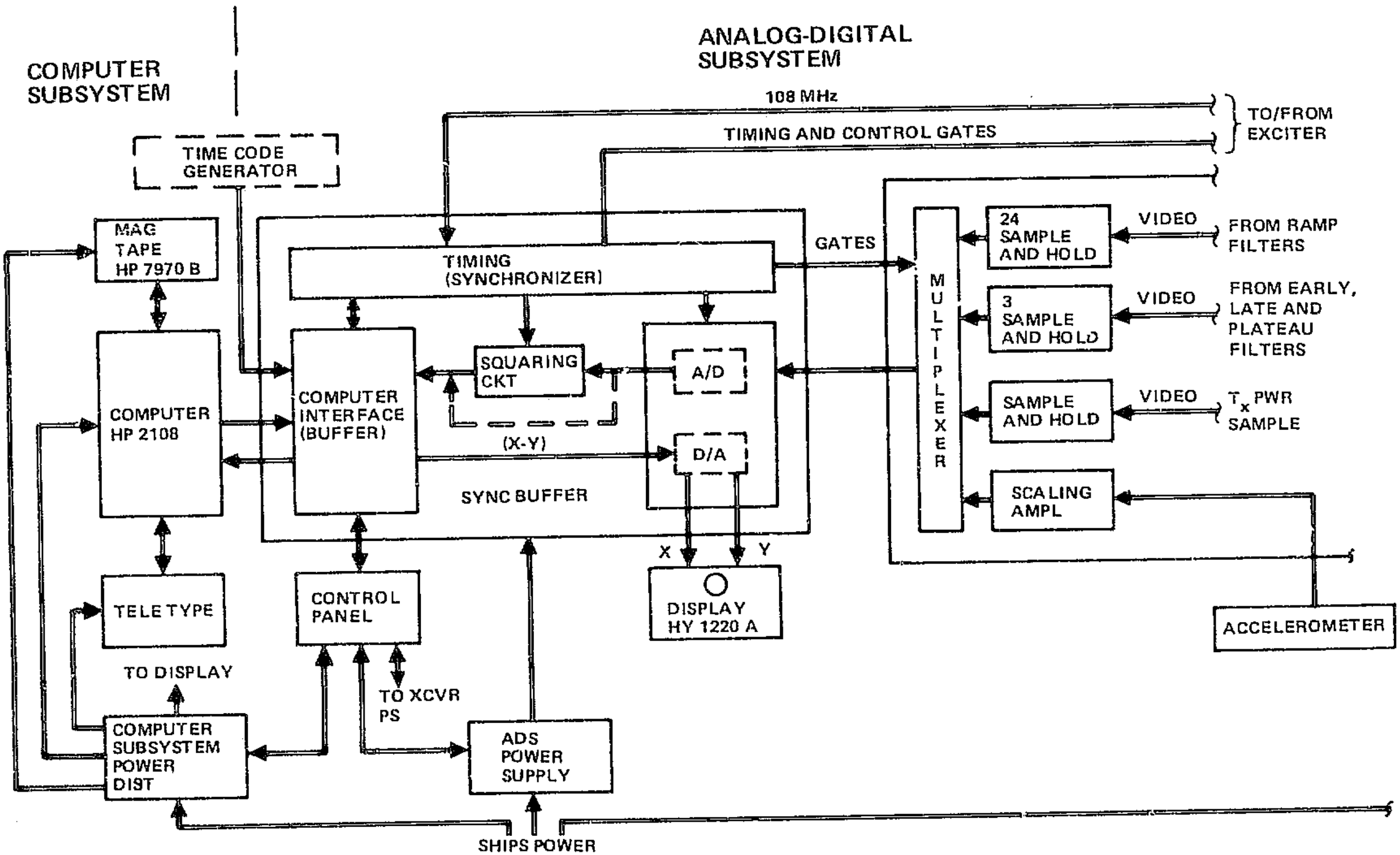
The vertical accelerometer provides acceleration measurements over a range of zero to +2g; its nominal accuracy is on the order of 0.05%. A 5Hz filter with 6dB/octave fall-off is implemented to exclude platform induced vibration effects.

ANALOG/DIGITAL SUBSYSTEM (ADS)



ORIGINAL PAGE IS OF POOR QUALITY

AAFE PULSE COMPRESSION RADAR ALTIMETER BLOCK DIAGRAM



2. RADAR/COMPUTER INTERFACE DESIGN

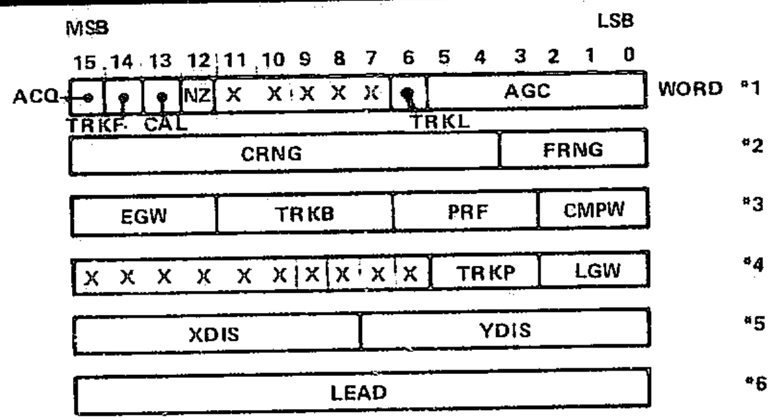
The ADS unit provides the Radar/Computer subsystem interface. This interface consists of a 16 bit data interface and control signals. The data formats are illustrated in the facing figure. The radar commands from the computer include 6 16-bit words and the radar output data to the computer consists of 36 words. The transfer of commands and radar data occurs each pulse. The 6 word radar command includes mode parameters, AGC, range, switch selections, and LEA and oscilloscope data. The 36 data words supplied by the radar to the computer include Transmitter power sample, Early, Late, and Plateau signal amplitudes as well as the 24 Ramp filter amplitudes. The words also include the operator selected switch settings, display selections and NASA time. Parameter selection and radar control are both determined at the Radar Control Panel. Switch selection codes are transferred to the computer which then stores them for internal use and re-transmits them as part of the 6 word radar command. Upon receipt of the 6 words, the ADS unit implements these commands and in addition lights the LED's corresponding to the selected switch position. This provides a wrap around implementation.

The next figure illustrates the timing for transferring of the radar commands and the radar data. The Transmitter power sample is the first radar data word to be transferred; its transfer occurs approximately 14 μs after the beginning of the pulse interval. Succeeding filter amplitudes of the Early, Late, Plateau and Ramp filters are transferred at the 8 μs A/D rate. The last 7 words of the radar data which consist of switch settings and time are transferred at the maximum rate of approximately 2 μs per word. Thus the total transfer time is approximately 240 μs. In order to be effective during the next pulse, the radar commands must be transferred prior to the Early Trigger (TE) which is approximately 25 μs before the Transmitter power sample. This six word transfer occurs at a maximum rate of 2 μs per word.

The ADS contains a counter which counts the number of successive pulses when command or data collection transfer initiation by the computer was late. A transfer fault indicator, which is manually resettable, is lighted at the Radar Control Panel when the count reaches 16. In the event that the command transfer is late, no data (36 words) is output by the ADS on that pulse; this insures that the data transmitted to the computer always corresponds to the commands sent by the computer. The Computer/Panel switch at the Radar Control Panel provides the ability to operate the radar in manual mode, using parameters selected by the operator at the panel. In this mode of operation, the Radar/Computer I/O can be inhibited by the Computer Transfer Inihibit switch which provides the capability to operate the Radar or Computer Subsystems on a stand-alone basis for trouble shooting purposes.

PRECEDING PAGE BLANK NOT FILMED

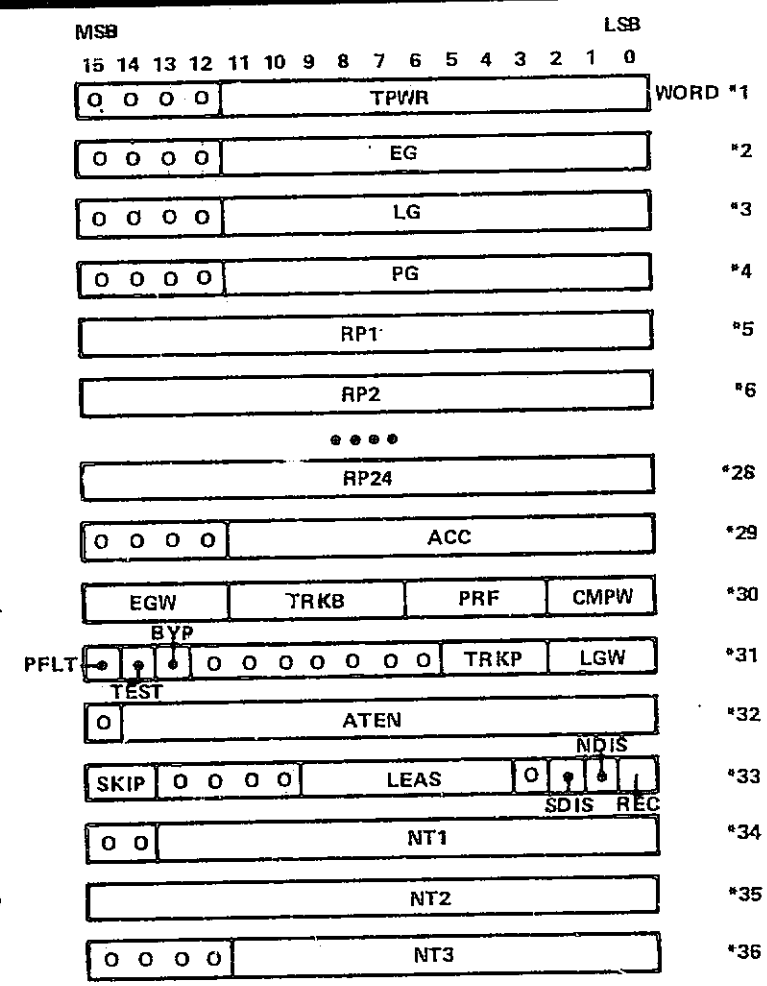
RADAR AND COMPUTER TRANSFER DATA FORMATS



CONTROL DATA OUTPUT
BY COMPUTER

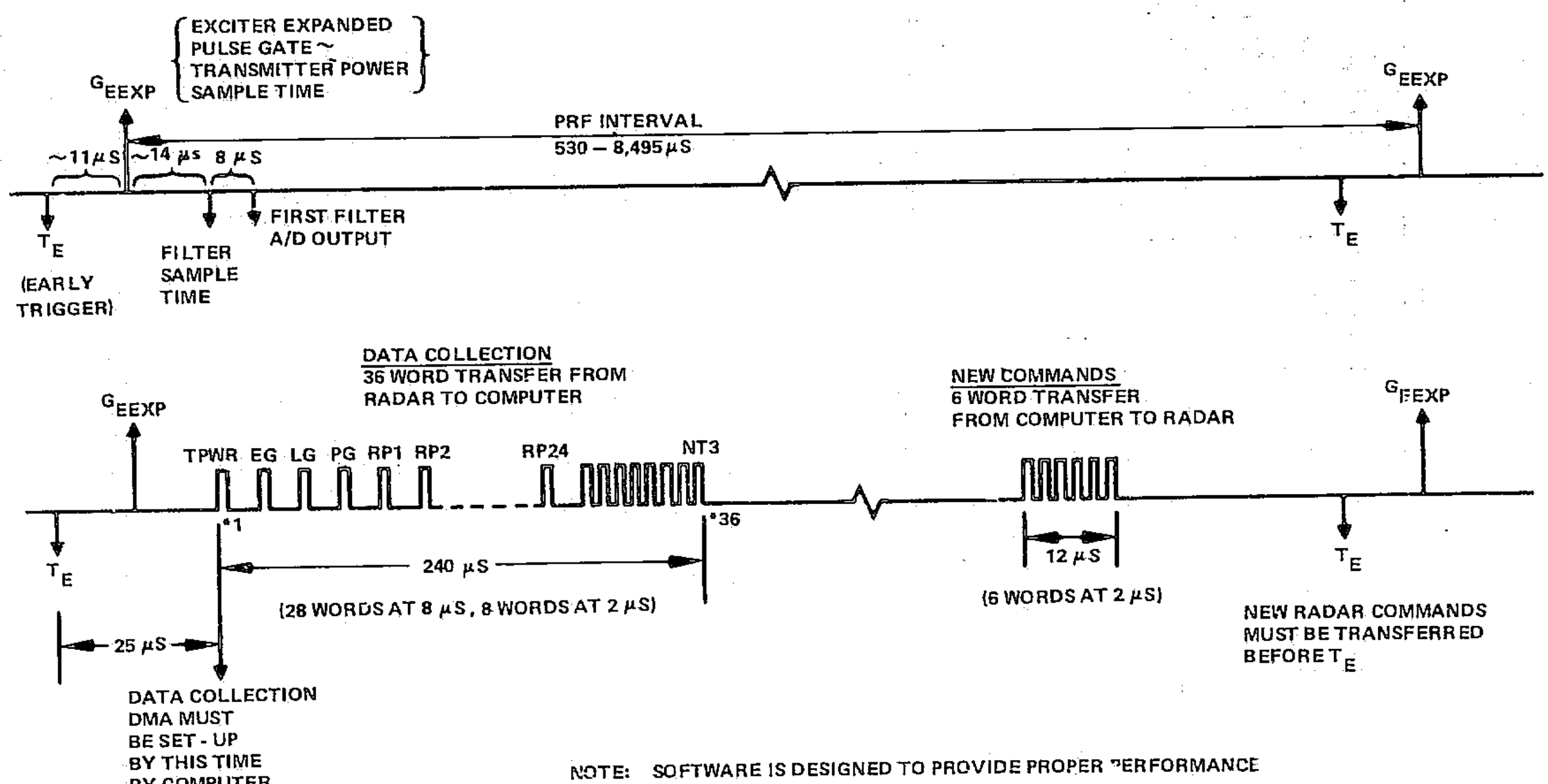
NOTE: O = ZERO

NOTE: X = ANY VALUE 0 OR 1



RADAR DATA
TRANSFERRED
TO COMPUTER

DATA SAMPLE AND TRANSFER TIMING



NOTE: SOFTWARE IS DESIGNED TO PROVIDE PROPER PERFORMANCE FOR PRF INTERVALS OF 1176 µS OR GREATER

3. CLOCK SPLITTING

The subnanosecond timing required by the Radar Altimeter is achieved by delaying the basic 108 MHz clock signal in multiple coax delay lines and selecting one of the incremental delay path outputs for use as the clocking source. The 15:1 subdivision of the 108 MHz signal results in an effective 1.6 GHz clock capability and a range command granularity of 0.62 ns or 9.3 cm.

The clock delay circuit is shown in the facing figure. It is implemented on an etched circuit board and receives its input clock reference signal (108 MHz) from the Transceiver. It also receives a four bit range word from the computer buffer, and a clock switching signal from the high speed timing logic located off the etched board.

Two outputs are generated by the clock delay circuit, one delayed and one undelayed 108 MHz clock. The undelayed clock (ref. clock output) is the input clock regenerated and delayed to align with the "zero delay" output of the delayed clock. The delayed clock output is coincident with the reference clock at all times except during receive or correlation time, when one of the 15 delayed (or zero delay) clocks is selected for output. The delays are implemented using miniature coax lines connected in series. This provides coarse staggering or delay of the signals which are then buffered with high speed gates for isolation and trimmed with another delay line in each path. The outputs of the trimmer delays are then gated in the output gating structure according to the computer range word, and one of the 15 delayed clocks is gated thru to the output. When the receive or correlation timing signals have been generated the delayed clock is switched back to the zero delay or reference clock position.

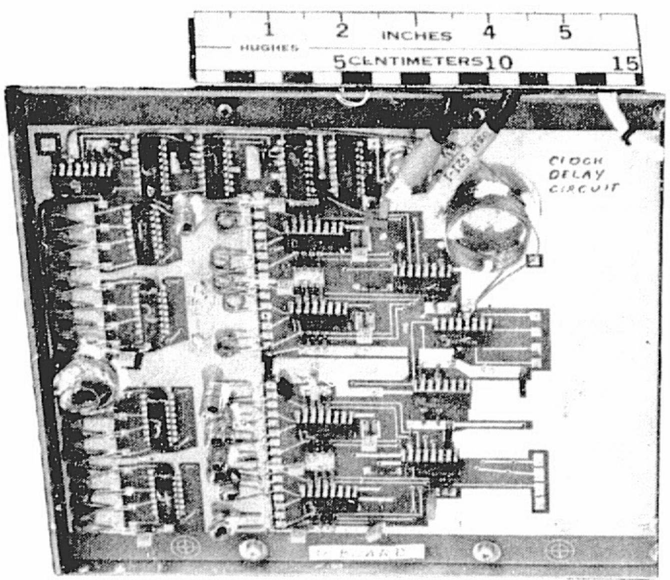
The adjacent figure illustrates the output signals from the delay circuit and verifies the 0.62 ns delay increments.

The circuit was initially designed for 16:1 splitting of the clock signals. Because of inaccuracies in test equipment at the high bandwidths the resulting delays yielded a ratio which was 15:1. Since this still resulted in an acceptable range LSB, the software logic was modified to utilize a 9.3 cm fine range LSB and only 15 of the 16 fine range states in range commands.

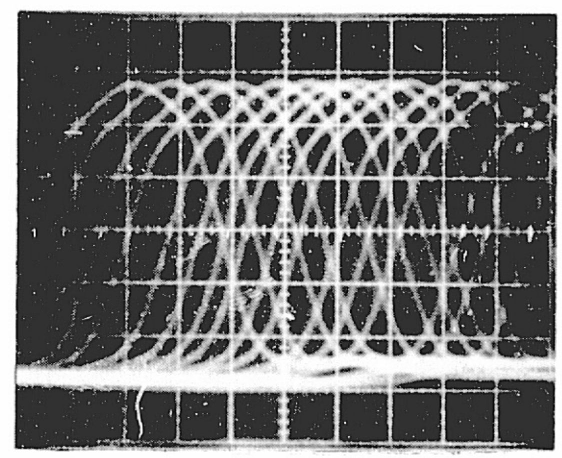
PRECEDING PAGE BLANK NOT FILMED

108MHz CLOCK 15:1 SPLITTER

CLOCK DELAY CIRCUIT



DELAYED SIGNAL OUTPUT



1 NANOSECOND PER DIVISION

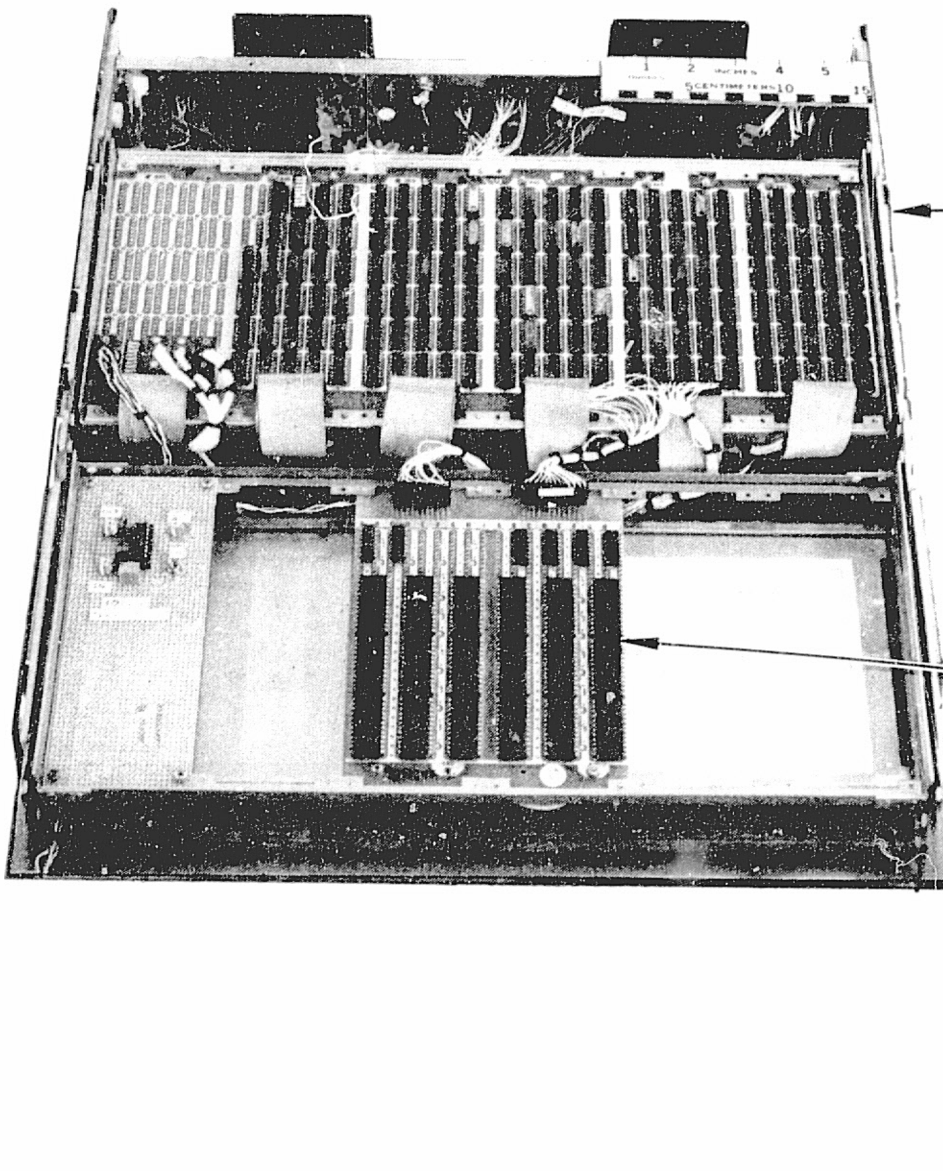
4. ADS PACKAGING

The ADS Subsystem implementation is of modular type with the equipments packaged in drawers. A power supply drawer contains the four power supplies and a circuit drawer contains four removable circuit panels. System controls and an oscilloscope display are mounted on separate panels. Sample/Hold circuits are located in the Receiver and the accelerometer is mounted on the antenna.

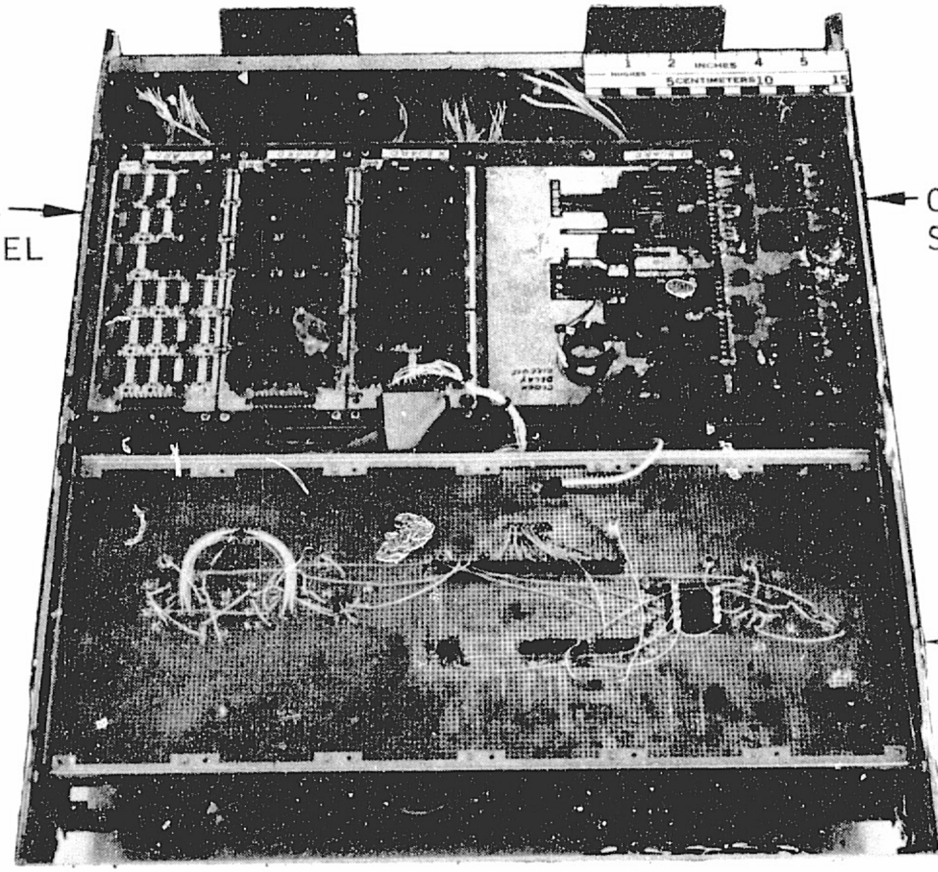
Packaging of the circuit drawer is shown in the next two figures where two of the four circuit panels are visible. Extensive use is made of dual in-line packaging (DIP). The four panels contained in the drawer are rotatable and removable for maintenance ease. The Synchronizer/Buffer drawer has two rear mounted fans for cooling and air exhaust perforations on the covers; the unit is designed to be operated with the covers attached (p. E-13). Seven externally mounted test points are provided and externally located control switches were added at a later date.

Both the Synchronizer/Buffer and the Power Supply (E-14) drawers are mounted on slides and are removable.

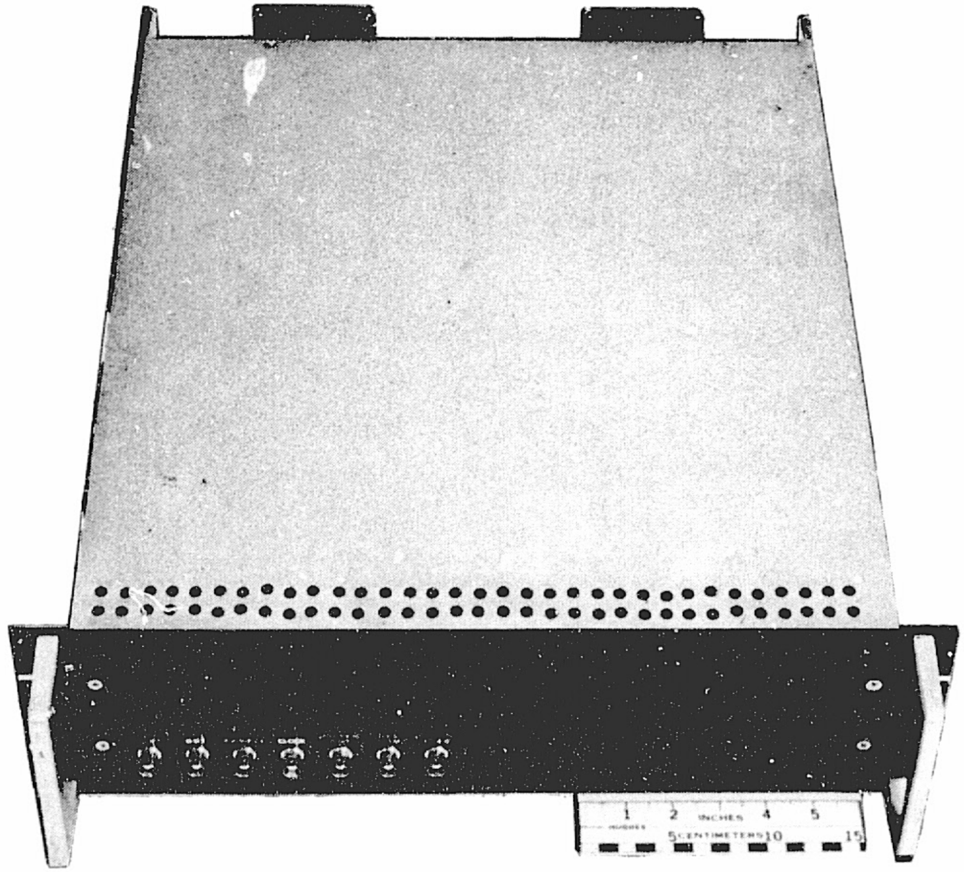
SYNCHRONIZER/BUFFER - TOP VIEW



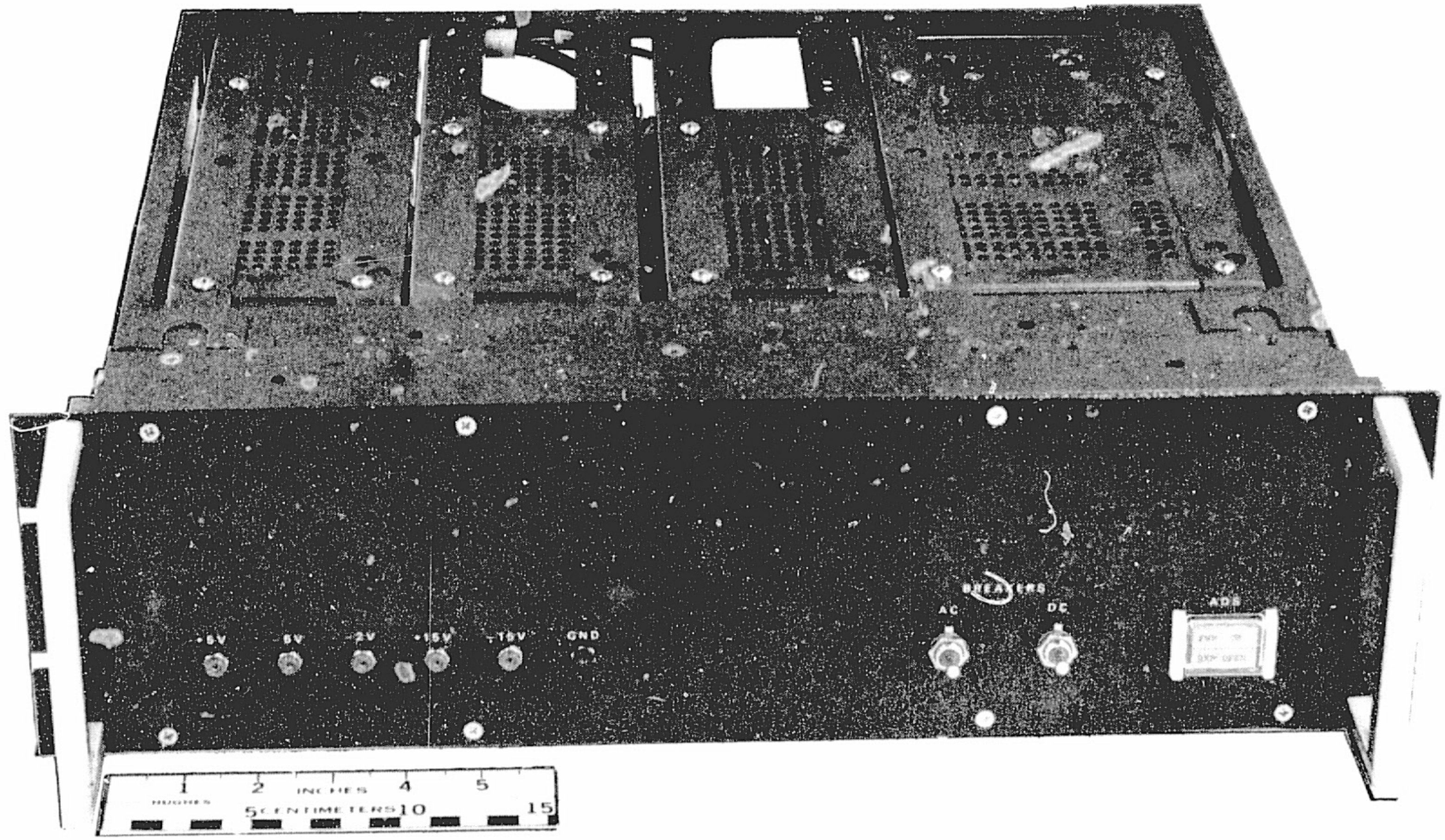
SYNCHRONIZER BUFFER - BOTTOM VIEW



SYNCHRONIZER/BUFFER



ANALOG/DIGITAL SUBSYSTEM POWER SUPPLY



SECTION F
COMPUTER AND PERIPHERALS

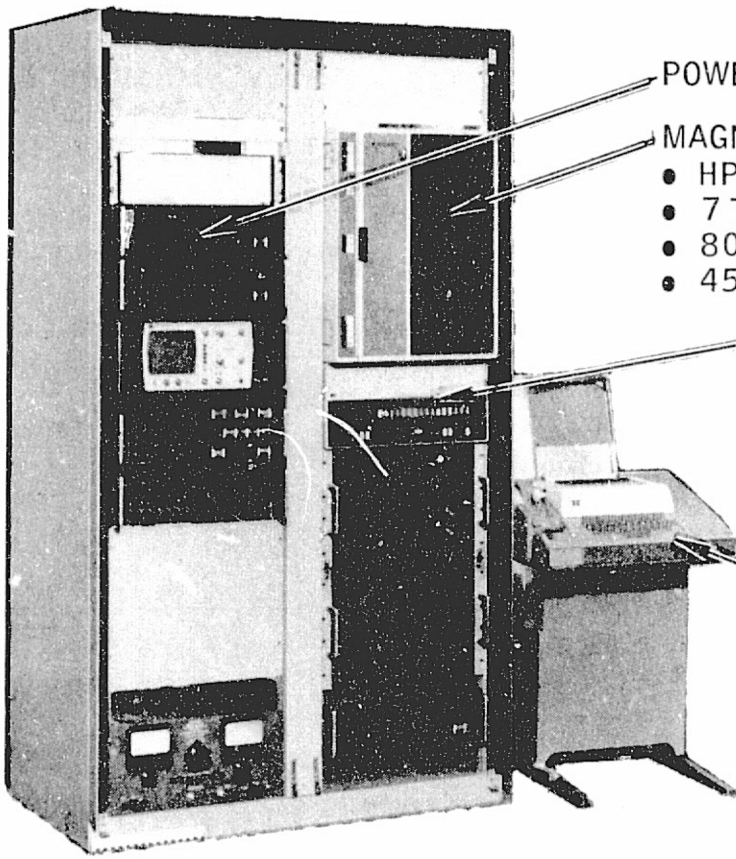
1. COMPUTER SUBSYSTEM DESCRIPTION

The AAFE Radar Altimeter Computer subsystem consists of four units as indicated in the facing figure. These units are: HP2108 Mini-computer, HP12971A Magnetic Tape System, ASR 33 Teletype, and the Power Distribution Unit. With the exception of the Power Distribution Unit which was developed specifically for the radar altimeter, all units of the Computer subsystem are commercial equipments. These units were selected on the basis of cost, performance, and operation in an aircraft environment. Ease of software development was also a significant factor in selection. Use of the HP3000 computer center at Hughes resulted in a significant cost saving during the development of the radar altimeter software.

Key computer characteristics are presented in the table (p. F-2). The HP2108 utilizes 16-bit words and has an integer add time of 1.9 μs. The relatively high speed integer arithmetic and the hardware floating point arithmetic were important factors in selecting this system. The computer has 16K of core and a number of functional features. Eight of the nine available I/O channels are used by the system to interface with other equipments and to provide special functions. The high speed interface with the radar subsystem is facilitated by use of direct memory access (DMA); the Microcircuit I/O card provides a 16-bit interface with the radar. By use of these devices a transfer rate of 616 kHz is achieved. The Breadboard card which consists of two signal lines is used for interface control. The power Fail Recovery unit consists of a battery which maintains the program in core during power failure or power off conditions; this feature has been valuable on a number of occasions. The Time Base Generator was purchased with the intent of using it in development of driver programs which were to be used in checking out the operational program. The Writable Control Store was procured to cover the possibility of processing time problems in the system; this card provides the ability to hard wire selected processing functions and thereby enables reduction of the processing time required by the computer software. The Time Base Generator and the Writable Control Store card are available but not used in the system.

Magnetic Tape System consists of a 7 track recording unit which operates at 800 bpi and 45 ips with a resultant capability of 12,000 16-bit words per second; it can also be operated at lower densities. The magnetic tape system is utilized for data recording as well as storage of operational and data reduction programs. Primary use of the teletype is in data reduction and program loading; the unit has also been useful in developing programs, paper tape patches and debugging. It contains a paper tape punch and reader in addition to the keyboard.

COMPUTER SUBSYSTEM



RADAR ALTIMETER COMPUTER CHARACTERISTICS

- HP 2108 MICROPROGRAMMABLE PROCESSOR
- WORD LENGTH ________ 16 BITS
- SPEED
  - CYCLE TIME ________ 0.65 μS
  - ADD TIME ________ 1.9 μS (MEMORY TO REGISTER)
  - HARDWARE FLOATING POINT ARITHMETIC
- INSTRUCTIONS ________ 128
- I/O
  - CHANNELS ________ 9
  - DMA TRANSFER RATE ____ 616 KHz
- OPTIONAL FEATURES INCLUDED
  - DMA - 2 CHANNEL
  - MICROCIRCUIT I/O CARD
  - BREADBOARD CARD
  - TIME BASE GENERATOR
  - POWER FAIL RECOVERY SYSTEM
  - WRITABLE CONTROL STORE

SECTION G
SOFTWARE DESIGN

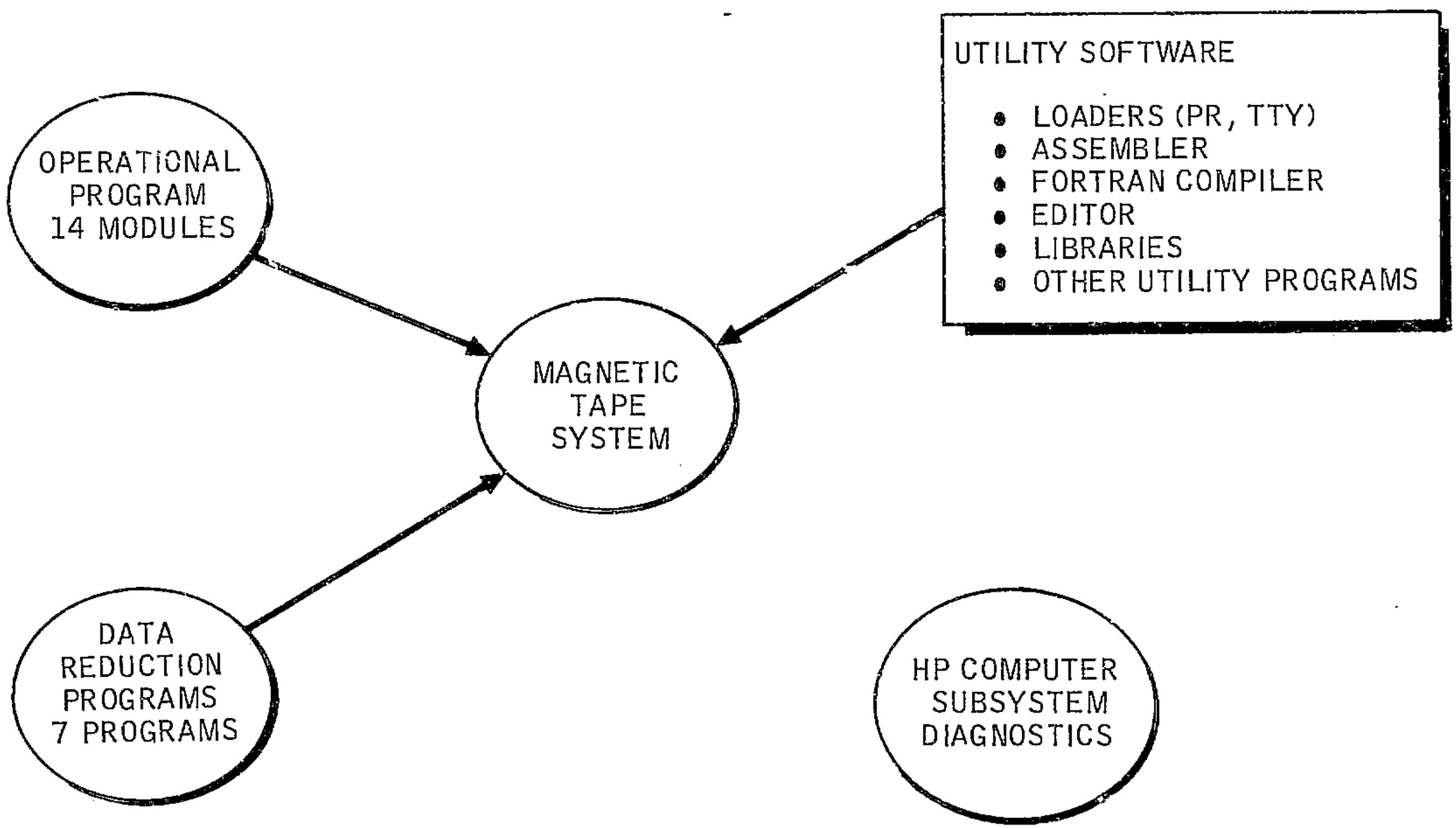
1. OVERVIEW OF SYSTEM SOFTWARE

The AAFE Radar Altimeter software consists of the Operational program, the Data Reduction programs, the diagnostics and utility software. The Operational program and the Data Reduction programs have been developed specifically for the radar altimeter system. The diagnostics and utility software are primarily standard Hewlett-Packard software. With the exception of the diagnostics, all software is stored on the Magnetic Tape System for convenience; original papertapes are also available. The Operational program or Data Reduction programs are accessed and loaded into core by means of master programs input from the teletype or a papertape photoreader. The Operational program contains all the software necessary to operate the altimeter, and the Data Reduction programs provide a basic but comprehensive stand alone data reduction capability.

The radar altimeter software development consisted of 14 Operational program modules which are coded in assembly language and eight Fortran programs as well as supporting programs. Most of this software has been developed by using the HP3000 computer center at the Hughes Aircraft Facility in Fullerton, California. However, program development is also possible with the radar altimeter computer subsystem. Assembly language and Fortran programs can be developed or updated using the assembler and Fortran compiler on the magnetic tape system. In most instances the development of the software can be accomplished by use of the teletype as input device; however, a photoreader was extensively utilized for program development, checkout and loading. Teletype and photoreader loaders are included in the Magnetic Tape System software.

Patches can be developed directly by use of the teletype punch unit and input to the computer by means of the HP Debug program. Also, patches can be entered directly via the computer control panel.

AAFE PULSE COMPRESSION RADAR ALTIMETER SOFTWARE OVERVIEW



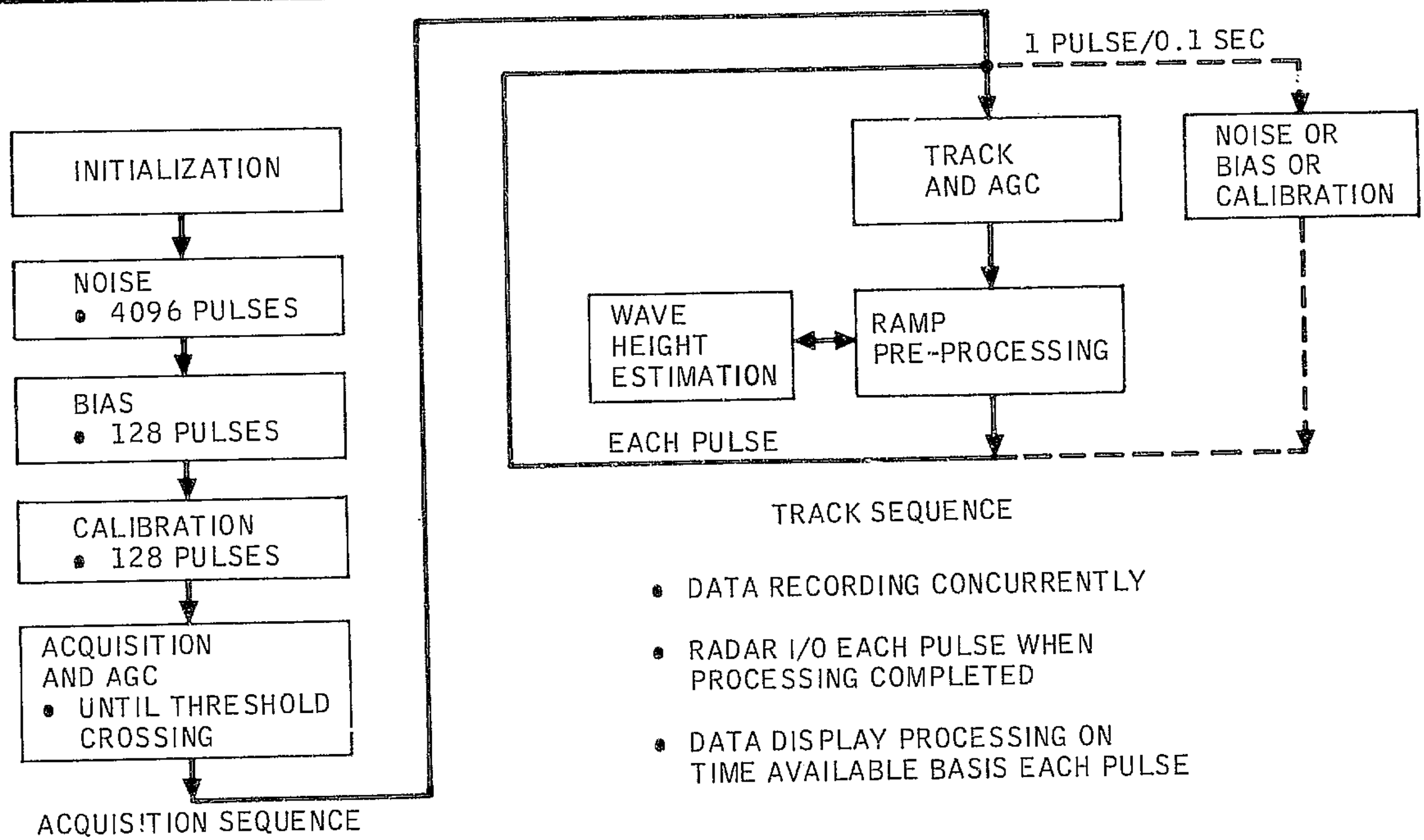
2. OPERATIONAL PROGRAM ARCHITECTURE

The Operational Program architecture is indicated in the facing figure. The Operational program processing consists of four sequences: Start, Acquisition, Track and Termination. During the Start sequence the computer obtains the first set of valid radar data which contains the switch setting information. The Initialization module of the Operational Program decodes these switch setting parameters and initializes other constants and values required by the program. It also prepares a 100 computer word subrecord for outputting to magnetic tape. The Acquisition sequence consists of executing Noise, Bias, and Calibration submodes and then the search for the sea surface. Processed data of these submodes provides average noise levels for extraction during tracking and waveheight estimation, filter bias levels, filter gain alignment factors and system delay data. The software is designed to initiate the search for the sea surface at 8,000 ft. or approximately 2400 meters. The Acquisition module logic steps the range starting at 2400 meters in approximately five meter steps until a Late gate threshold crossing is obtained, then the step size is reduced to one range LSB or approximately 9.3 cm and continues until a required number of Early gate threshold crossings is obtained. When both Late and Early gate threshold crossings have been obtained, the search process has been completed and lock-on and normal tracking commences.

In order to accelerate the acquisition process and provide quality data in minimum time, the Tracking sequence has been designed to include a high bandwidth lock-on mode. During the first two seconds, after completion of search, the tracking operation is performed with a bandwidth of 10 hertz; that is, smoothing is done every 1/10 of a second by the tracker. After 20 such intervals or 2 seconds the tracker logic continues tracking at the tracker bandwidth selected by the operator. The AGC bandwidth during search and during the high bandwidth tracker operation is also 10 hertz; afterwards the AGC bandwidth is 1/4 hertz. Noise, Bias and Calibration submodes are executed sequentially in the Track sequence by dedicating one pulse every 0.1 sec for these modes. Since these modes require 4096, 128, and 128 pulses respectively, the complete execution of these modes requires 435 seconds. In the track sequence, Ramp filter data is averaged and output for recording every 0.1 sec regardless of PRF. Thirty second averaged data are used by the Wave Height Estimation module to predict the sea wave height. Data recording, radar I/O, and data display processing are also performed concurrently with the above functions. The relative processing times of the operations are illustrated in the diagram on p. G-5.

The figure illustrates the approximate timing in the track sequence during a typical pulse. Position and velocity smoothing, change in AGC command, and ramp data averaging are not performed on the typical pulse. The software is designed such that these functions are performed at multiples of 0.1 sec intervals. When operating at a PRF of 850 pulses per second, the 0.1 sec intervals occur every 85 pulses; consequently, 84 typical pulses will occur before any extensive processing is performed. During extensive processing pulses may be skipped until the processing is completed. As indicated in the timing diagram, the initial computer processing and operation during the pulse period consists of inputting 36 new data words into the computer. Since these words are input at a rate of approximately 8 μs per word, the time between words is used to execute the Data Display program. Complete execution of that program may take several pulses. At the end of the 36 word transfer an interrupt occurs and causes processing to continue in the Track program. The interrupt processing after input of the 36 words consists primarily of checking the words containing switch setting data for changes. If a change has been made by the operator, the software terminates operation and restart is required. In the event that no changes were made, the Track program is executed, then the AGC module and afterwards the Executive issues new radar commands which consist of six computer words. These six words include the range, the switch settings, and the data display information. Afterwards the Ramp Pre-processing is executed where all filter outputs are accummulated. Although the data recording CPU time is shown as a single block, the computer magnetic tape I/O takes place in a dispersed manner during the pulse interval. After the Ramp Pre-processing program execution, the Executive prepares the interface for accepting 36 new radar words and then proceeds to execute the Data Display program. The Data Display program will be resumed at the last location where it was interrupted. Processing of the succeeding pulse periods is similar. Every 0.1 sec or 85 pulses when operating at PRF of 850 PPS, extended processing takes place and pulse skipping results; that is, the software programs are processed until completion. This usually requires one or more pulse intervals during which no data is collected from the radar and no radar commands issued. Testing has verified that the number of pulses skipped is less than 16; a transfer fault light indicator on the radar control panel is designed to go on in the event that 16 pulses are skipped.

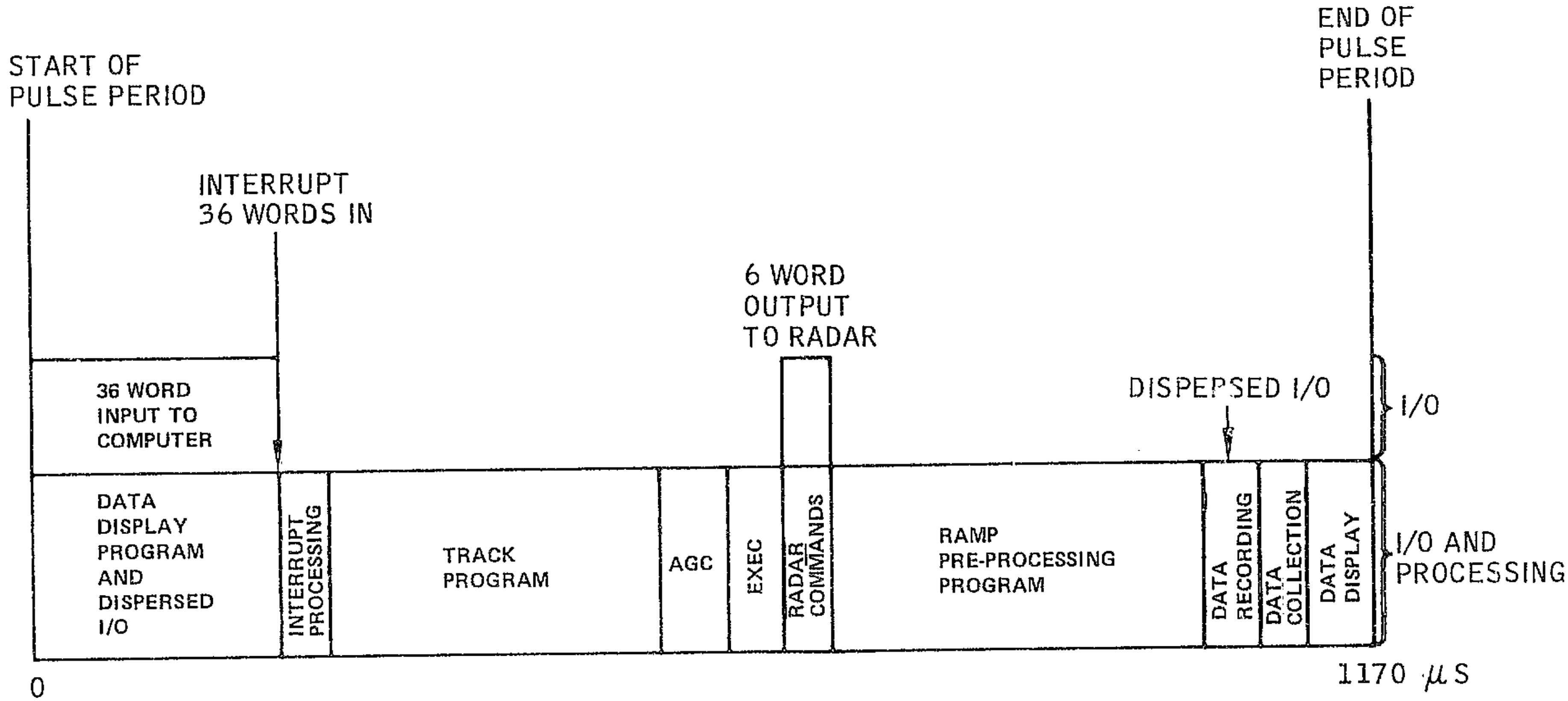
AAFE PULSE COMPRESSION RADAR ALTIMETER OPERATIONAL PROGRAM ARCHITECTURE



- DATA RECORDING CONCURRENTLY
- RADAR I/O EACH PULSE WHEN PROCESSING COMPLETED
- DATA DISPLAY PROCESSING ON TIME AVAILABLE BASIS EACH PULSE

SOFTWARE EXECUTION TIME FOR A TYPICAL TRACK SUBMODE PULSE

- POSITION AND VELOCITY SMOOTHING NOT PERFORMED ON THIS PULSE



3. DESCRIPTION OF OPERATIONAL PROGRAM MODULES

The radar altimeter Operational Program consists of fourteen functional modules. In addition, three off-line programs are stored in computer memory concurrently with the Operational Program for convenience. These programs and their brief functional descriptions are presented in the facing figure. The fourteen modules of the operational program occupy approximately 8,000 addresses in core. The additional off-line programs and HP supporting software occupy most of the remaining 8K of the 16K computer memory.

Executive

The Executive provides control of system operation and Operational Program module execution. It sequences system operation in Start or Initialization sequence, Acquisition sequence, Track sequence and Termination. It also includes logic for processing Radar I/O interrupts and properly terminating software and system operation in the event of faults or operator action.

Initialization Module

This module is executed only at the start of operation and processes the Radar Control Panel switch setting data contained in words #30 and #31 of the 36 word input. It decodes these words and determines the number of pulses in each 0.1 sec set (ISET) and the number of pulses to be used in AGC updates (JSET) and track smoothing (IBLK). It also derives and provides a number of other constants for various modules of the Operational Program and outputs a 100 word subrecord containing the switch setting codes and the constants for recording.

Noise Estimation Module

This module uses double precision integer arithmetic to provide average values of 4096 samples of the Transmitter power level and the noise levels of the Early, Late and Plateau gates and the 24 Ramp filters. It accumulates the signals during the execution of the Noise submode.

Bias and Filter Scaling Module

This module computes the average Transmitter power and average bias values of the Early, Late and Plateau gates and the 24 Ramp filters on the basis of the 128 pulses of the Bias submode. The Bias submode is essentially the same as the Noise submode except that maximum AGC is set. The module then accesses the average noise estimates provided by the Noise Estimation module and subtracts the biases from these values thereby deriving unbiased average noise levels. (It has been established by test that the bias removal is not effective for the 24 Ramp filters because of the use of linear detectors and squaring in ADS; biases of these filters should be set to less than 50mv prior to system operation.) The unbiased noise averages are then used to derive filter alignment scale factors; all Ramp filter noise levels are referenced to filter #12 and Early, Late and Plateau gate levels are referenced to the Plateau gate. In order to provide the necessary precision using integer arithmetic, the scale factors are expressed in units of 1/1024. This module outputs a 90 word subrecord which includes the bias levels, the unbiased noise levels and the filter scale factors.

AAFE RADAR ALTIMETER OPERATIONAL PROGRAM MODULES

NAME	DESCRIPTION
ON-LINE	
1. EXECUTIVE (EXM7)	CONTROLS SYSTEM OPERATION AND MODULE SEQUENCING
2. INITIALIZATION (INIT)	INITIALIZES PROGRAM BASED ON CONTROL PANEL SWITCH DATA
3. NOISE ESTIMATION (NOISE)	AVERAGES 4096 SAMPLES OF NOISE FOR EACH FILTER
4. BIAS (BIAS)	AVERAGES 128 SAMPLES OF BIAS FOR EACH FILTER, COMPUTES GAIN CORRECTIONS
5. CALIBRATION (CALIB)	COMPUTES INTERNAL RADAR TIME DELAY
6. ACQUISITION (ACQST)	STEPS RANGE FROM 8000 FT IN SEARCH FOR SEA RETURN
7. AGC (AGCAQ, AGCTK)	CONTROLS AGC
8. TRACK (TRACK)	PROVIDES RANGE CONTROL USING α-β TRACKER AIDED BY ACCELEROMETER
9. RAMP PRE-PROCESSING (RPROC)	PROVIDES 0.1 SEC AVERAGES OF RAMP FILTER OUTPUTS
10. WAVE HEIGHT ESTIMATION (WHGHT)	ESTIMATES WAVE HEIGHT, σ_0, PLATEAU GATE DROOP
11. RADAR COMMANDS (RCMDS)	TRANSMITS 6 COMMAND WORDS TO RADAR
12. DATA COLLECTION (DCOL1, DCOL2)	COLLECTS 36 WORDS OF DATA FROM RADAR
13. RECORDING (DAREC)	OUTPUTS DATA FOR MAGNETIC TAPE RECORDING
14. DATA DISPLAY (DISP)	PROVIDES DATA FOR OSCILLOSCOPE AND LEA
OFF-LINE	
15. DEBUGGING (DEBUG)	STANDARD HP PROGRAM; USED TO DUMP AND SET CORE
16. DECIMAL FLT. PT. CONVERSION (FLTOC)	CONVERT DECIMAL FLOATING POINT NUMBERS TO OCTAL
17. OCTAL FLT. PT. CONVERSION (OCTFT)	CONVERTS OCTAL FLOATING POINT NUMBERS TO DECIMAL

3. DESCRIPTION OF OPERATIONAL PROGRAM MODULES (Continued)

Calibration Module

This module is executed during the 128 pulses of the Calibration submode. It utilizes double precision integer arithmetic to provide averages of the Transmitter power and the Early, Late and Plateau gates and the 24 Ramp filters. In addition it determines the precise location of the test target with respect to the crossover of filters #12 and #13 and expresses this offset in centimeters. This function is performed by filter splitting. The module finds the two filters which contain the highest amplitudes, takes the ratio of the smaller with respect to the larger and enters this ratio as the independent variable in a quadratic equation which determines the offset of the test target within the filter containing the largest signal; this is then related to the crossover of filters #12 and #13 and converted to centimeters. The quadratic function is based on test data of filter response functions. The Calibration module outputs a subrecord of 42 computer words containing the filter average values and the range bias of the test target.

Acquisition Module

The Acquisition module processes the Early and Late gate signals and generates range commands during the search or acquisition submode and determines when acquisition has been completed. Initially the module determines the Early and Late gate thresholds by multiplying the noise levels of these two gates (provided by the Noise Estimation module) by constants (E = 3.5, L = 4.0) and the AGC value; these thresholds are recomputed at the AGC update rate. The Early and Late gate signals are thresholded each pulse period and the respective up/down counters are incremented or decremented accordingly. Initial step size in range is one coarse range LSB or approximately 5 meters; after a Late gate threshold crossing is obtained the step size is reduced to a fine range LSB or 9.3 cm. When the Early gate up/down counter value is 4, acquisition has been completed. The logic has provision for hard limiting the up/down counters and also range decrementing in the event of overshoot. This module outputs a 7 word subrecord each pulse.

AGC Modules

The Acquisition and Track AGC modules provide automatic gain control on the basis of the Plateau gate signal; the modules are separate but essentially identical. The modules compare the Plateau gate signal level with 128 A/D levels and increment or decrement the AGC command accordingly. In addition the modules compute a floating point numerical value of the attenuation corresponding to the AGC command code. The AGC is updated every 0.1 sec during Acquisition and high bandwidth Track and every 4 sec during normal tracking.

Track Module

This module performs the sea surface tracking using the Early and Late gate signals. The tracker logic is described in topic B-7; it utilizes an alpha-beta design and vertical accelerometer data. A 10 Hz high bandwidth mode is employed during the first two seconds and the normal selected bandwidth of 0.25 to 5 Hz is utilized subsequently. Altitude prediction utilizing velocity and accelerometer data is performed each pulse; estimation or smoothing is performed at the rate equal to the reciprocal of the bandwidth. Track quality is monitored

ORIGINAL PAGE IS
OF POOR QUALITY

automatically by checks of the late gate S/N ratio and the altitude error. Automatic termination may result also if the altitude limits or excessive vertical velocity are encountered. The Track module incorporates logic for accommodating the 15:1 clock splitting of the ADS. It outputs a 21 word subrecord after each estimation or smoothing operation.

Ramp Pre-Processing Module

This module provides 0.1 sec averages at any PRF of the accelerometer inputs, the Plateau gate amplitude and the 24 Ramp filters. In addition it provides an approximate count of the number of skipped pulses during the 0.1 sec period and provides individual 30 sec averages of Ramp filters #12 through #14 and the average of all the Ramp filters. This module is executed only during the Track submode. It outputs a subrecord of 33 computer words every 0.1 sec. The filter outputs are corrected for biases and re-scaled using the data provided by the Noise Estimation and Bias modules.

Wave Height Estimation

This module utilizes the Ramp Pre-Processing module outputs to compute the sea wave height, Plateau gate droop, and the sea reflectivity (σ_0). Wave height and droop estimation is based on computing a signal slope using Ramp filters #12 and #13 or #11 - #14 for higher sea states. This slope is then used in polynomials which predict the wave height and droop as described in the Wave Height Test topic in Appendix A. Sea reflectivity is computed by comparing the Plateau signal with the Plateau gate test target signal (Calibration module) and scaling the result by a constant; this approach is based on the range equation and system test data. The module outputs a 15 word subrecord every 30 seconds.

Radar Commands and Data Collection Modules

These modules control the computer I/O with the radar. The Radar Commands module transfers the 6 command words to the radar and the Data Collection modules collect the 36 data words from the radar. Module DCOL2 which is utilized after the initial exchange does not have a wait state for the interrupt and concurrent processing of other modules can be performed while the 36 words are input; the interrupt processing is contained in the Executive. All transfers are made on DMA channel #6.

Recording Module

The Data Recording Subroutine is designed to output data supplied by individual operational program modules on magnetic tape. This subroutine is called by other subroutines and modules which provide data for recording and it returns to these modules after transfer of the subrecord data into one of the two 1000 word buffers. The Data Recording subroutine uses a double buffer design which allows for concurrent data gathering and output without loss of data. Data to be recorded on magnetic tape is output on DMA Channel 7. This channel is dedicated for magnetic tape recording by virtue of a modification of the original magnetic tape driver software module D.25. In addition to output of radar data on magnetic tape, this subroutine writes single or double End of Files (EOF's) under operator control by means of the S-register.

3. DESCRIPTION OF OPERATIONAL PROGRAM MODULES (Continued)

Data Display Module

This module provides the oscilloscope display and LEA data. The logic checks the operator selections and provides noise or sea return amplitudes for the Early, Late and Plateau and the 24 Ramp filters for display on the oscilloscope. The module supplies one amplitude each pulse (or several pulses) and cycles through all 27 signals. The averaged amplitudes are obtained from the Noise Estimation, Track and Ramp Pre-Processing modules. For the LEA display it outputs a 4 digit BCD value of: wave height, reflectivity, altitude meters or cm, AGC, or tracker error. The module outputs the data in Radar Command words #5 and #6.

Off-Line Programs

The HP Debug program and floating point octal/decimal conversion programs are located in core concurrently with the Operational Program for convenience. This facilitates dumping core, entering patches, and performing octal/decimal conversions without the need to re-load programs.

4. DESCRIPTION OF THE DATA REDUCTION PROGRAMS

The radar altimeter data reduction software consists of seven programs as indicated on p. G-10. With these programs the Radar Altimeter Computer Subsystem provides a simple but comprehensive stand-alone data reduction capability. With the exception of Debug, all programs were specifically developed for the radar altimeter system by Hughes. The Debug program is a standard HP program for dumping or changing computer core. Sample outputs of some of the programs can be found in succeeding figures.

The Selective Access program was designed to provide the capability to extract any parameter of the nearly 300 parameters recorded on tape. This extraction is done in a chronological order. The program can extract five to ten different parameters simultaneously, depending on the format selected. It provides for octal, integer, floating point or exponential format outputs. A sample program output is given on p. G-11. As indicated in this sample, the user specifies a file number, the start and end record numbers and the start and end words within the record to define the extent of the search and the number of parameters and format of these parameters to be output. Having defined the number of parameters, he must then specify the subrecord type and the word number within the subrecord and a scale factor for each parameter. In the example, five parameters were selected from subrecord 21, which is the Track subrecord.

By use of subrecord format tables, one can select the proper words to be extracted. The words extracted in this sample (9, 11, 13, 15, 17) correspond Late gate amplitude, acceleration, altitude, tracker error, and tracker velocity. Because of the output format the range LSB for conversion to engineering units is 8.674550237 cm (not 9.3 cm). Generally, the program also outputs time from the beginning of the record; in this example Acquisition subrecords were located at the beginning of the record and no time data is available from these subrecords. Because of its flexibility, this program was extensively used during testing of the system.

The Altitude Resolution program was designed specifically for evaluating the altitude resolution capability of the system. A sample output of this program is provided in the next figure. The program is designed to operate on the altitude data output in the Track subrecords. The operator specifies the first point, number of points, and the start and end records within the file. The program searches the tape and extracts the specified number of altitude data points. The operator then can enter a scale factor which will scale the altitude data to engineering units or retain it in range LSBs. Next the operator specifies the type of processing to be performed by the program. The basic approach of evaluating the altitude resolution of the system consists of fitting a quadratic function to the tracker estimated altitude points. The differential between the quadratic and a selected data point is considered to be an error. A sliding fit is performed by the program and the errors are accumulated in an RMS manner. The end value of the accumulated RMS values is the altitude resolution over that data set. In the sample a 7 point quadratic was selected with fitting or error determination at the fourth or center point. Thus a quadratic was based on 7 raw data points and the error of the fourth point of the seven was computed. The next error, that of the fifth raw data point, was based on a quadratic fit over points 2 thru 8. The error of the sixth point was determined by a quadratic fit over points 3 thru 9, etc. The program has the capability of averaging successive errors before computing an RMS. This capability was introduced in order to provide the ability of generating or estimating the altitude resolution at lower data rates

PRECEDING PAGE BLANK NOT FILMED

or bandwidths than selected by the operator during the system test. In the sample, averaging of two adjacent errors was specified. The program also provides the ability to select summary printouts as well as detailed point by point printouts. In the sample, a printout of results every 10 points was selected in order to reduce the time required in generating the output. The five columns in the sample output give the following data: number of last point, the average altitude from the track subrecord over the 10 processed (20 raw) points, the average smooth altitude over 10 processed points, rms over the 10 points and the cumulative rms. This sample output indicates that the altitude resolution (CUM RMS) is 6.613 cm.

The Utility program is basically a dump program which can extract data from tape by file, record, or subrecord. Due to the limited octal format capability, its use was not extensive.

The Ramp program was designed to provide long term averages of a few selected parameters and the 24 Ramp filters. In addition, the program generates a print plot as shown on p. G-13. This program is useful in regenerating the type of data used in estimating the wave height during system testing. The Wave Height subroutine utilizes 30 second averages of the Ramp filter amplitudes. The basic Ramp data on magnetic tape consists of 0.1 second averages; the Ramp program can be used to average the Ramp data on tape over extended time intervals.

The Debug program is a standard HP program which was useful in entering patches as well as dumping core. Accessing computer core locations of the subrecords of the Operational program modules provided a convenient means of extracting average data without resorting to magnetic tape processing or manual extraction. The decimal floating point to octal conversion routine and its counterpart were developed for convenient conversion of floating point values.

ALTIMETER DATA REDUCTION MODULES

NAME	DESCRIPTION
1) SELECTIVE ACCESS (SELAC)	EXTRACTS ANY SELECTED PARAMETER(S) FROM MAGNETIC TAPE IN OCTAL, INTEGER OR FLOATING POINT
2) ALTITUDE RESOLUTION (ALTR)	ESTIMATES ALTIMETER ERROR BY SMOOTHING MEASURED RANGE DATA
3) UTILITY (UTIL)	DUMPS DATA FROM TAPE BY FILE, RECORD, OR SUBRECORD IN OCTAL
4) RAMP (RAMP)	AVERAGES AND PRINT-PLOTS RAMP FILTER DATA
5) DEBUG (DEBUG)	SELECTIVE DUMP OF CORE IN OCTAL
6) FLOAT-OCTAL (FLTOC)	FLOATING POINT TO OCTAL CONVERSION
7) OCTAL-FLOAT (OCTFT)	OCTAL TO FLOATING POINT CONVERSION

SELECTIVE ACCESS PROGRAM SAMPLE OUTPUT

```
NASA RADAR ALTIMETER SELECTIVE ACCESS PROGRAM

ENTER--FILE,STRT REC,END REC,STRT WRD,END WRD,N,FORMAT
5,1,100,1,1200,5,2
ENTER--SR TYPE,WRD NUM,SCALE
21,9,1.
21,11,867.4550237
21,13,0.08674550237
21,15,0.08674550237
21,17,8.674550237

 IREC=      3  IR1=  1030  IR2=      7  IR(L)=    304
    11028.67969        .00000    3106.34668       .25671       .15280

    11405.00000        .00097    3106.58496       .10878       .21836

    11277.00000       -.00012    3106.73389      -.03425       .19788

    11917.00000       -.00030    3106.74756      -.15265       .10677

    11021.00000       -.00036    3106.76660      -.07025       .06465

    11149.00000        .00048    3106.69775      -.12322      -.00829

    10893.00000        .00121    3106.71777       .02647       .00847

    11789.00000        .00066    3106.81982       .09477       .06545

    11405.00000        .00012    3106.92383       .04887       .09464
```

ORIGINAL PAGE IS
OF POOR QUALITY

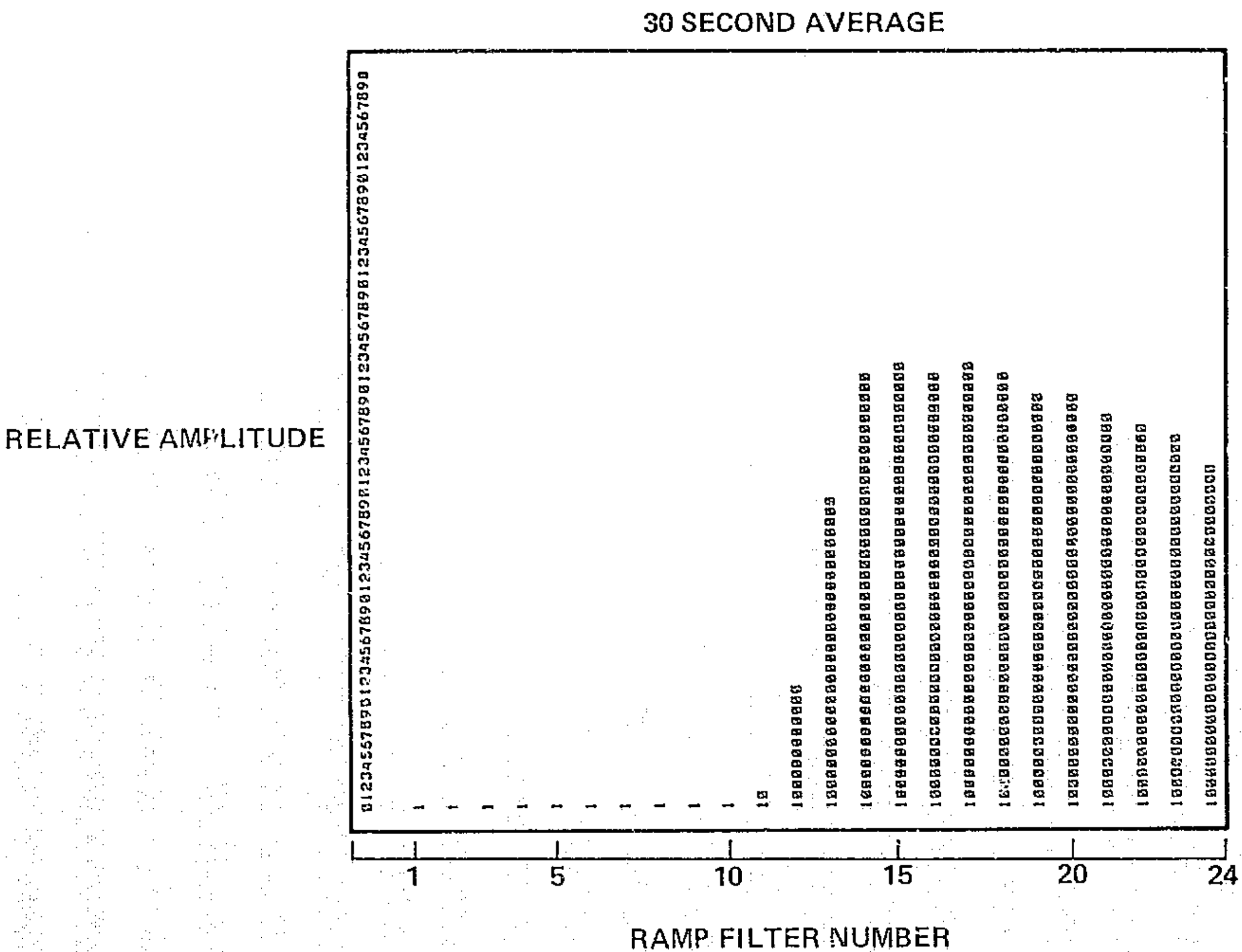
ALTITUDE RESOLUTION PROGRAM
SAMPLE OUTPUT

```
ALTITUDE RESOLUTION

ENTER--NFILE,NSTART,NPOINT,NREC1,NRECN
3,1,1000,1,1000
ENTER--SCALE
.08674550237
ENTER--NFIT,FITPOINT,NAVG=NUM OF PTS AVG BEFORE RMS
      PRINTOUT SPACING
7,4,2,10
```

POINT	AVGM	AVGS	RMS	CUM RMS
10	2656.53955	2656.53662	.04635	.04635
20	2658.32275	2658.32031	.04106	.04378
30	2656.73535	2656.73828	.02534	.03863
40	2654.91309	2654.91895	.05887	.04456
50	2661.54102	2661.53223	.05269	.04530
60	2662.71436	2662.71582	.04269	.04572
70	2657.83105	2657.82959	.07196	.05031
80	2651.67822	2651.68506	.09994	.05885
90	2650.98730	2650.97949	.04923	.05786
100	2648.54785	2648.55371	.05911	.05799
110	2645.35693	2645.35254	.08460	.06089
120	2649.18848	2649.19629	.10929	.06629
130	2650.17529	2650.17480	.05410	.06543
140	2648.15869	2648.15479	.05276	.06461
150	2646.10547	2646.10693	.10555	.06811
160	2647.26758	2647.27051	.05872	.06756
170	2647.27832	2647.26855	.03642	.06613

RAMP PROGRAM SAMPLE OUTPUT



APPENDIX A
ACCEPTANCE FLIGHT TEST RESULTS

Appendix A – Acceptance Flight Test Results

1. Altitude Resolution Test

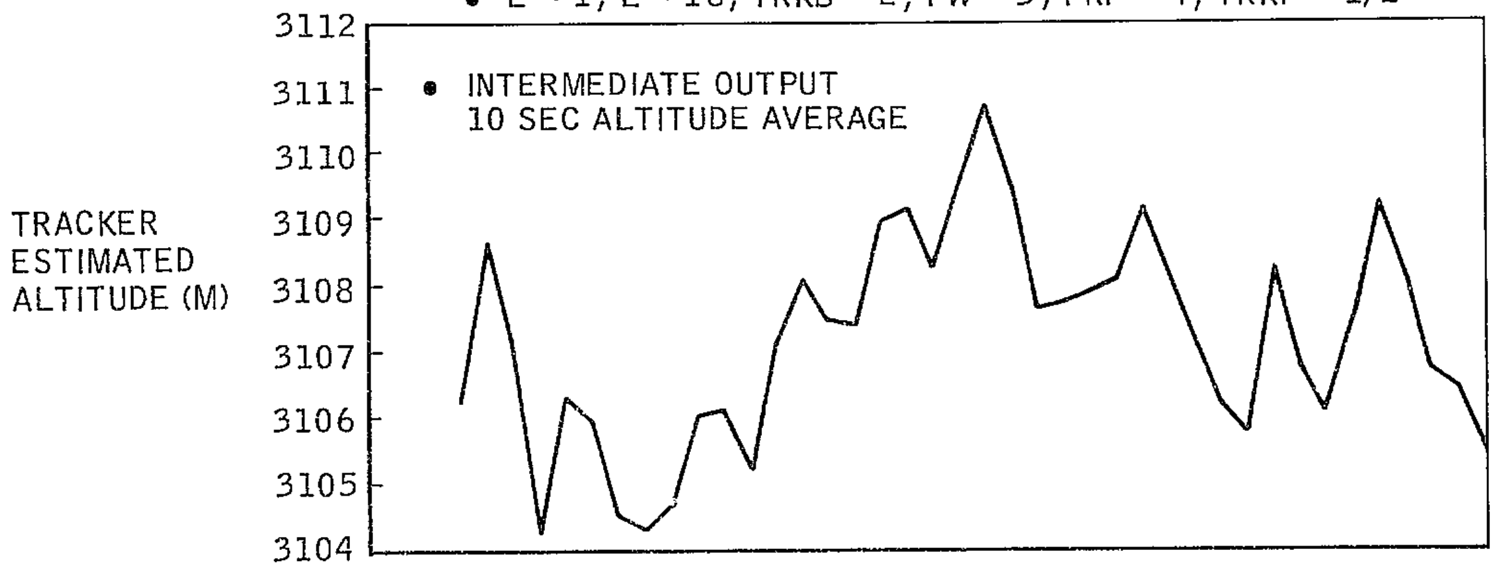
Acceptance flight tests were conducted on November 19, 1975. The C-54 aircraft platform was flown at 10 thousand feet due east 85 to 165 nautical miles from the NASA Flight Center at Wallops Island, Va. The aircraft ground speed was approximately 180 knots. The forecast significant wave height was one to two feet; actual wave height was on the order of 1 meter (3 feet). Smooth flight conditions prevailed throughout the flight test. The flight test consisted of two segments. The first segment involved the acquisition test and the second segment was dedicated to the altitude resolution and wave height estimation test.

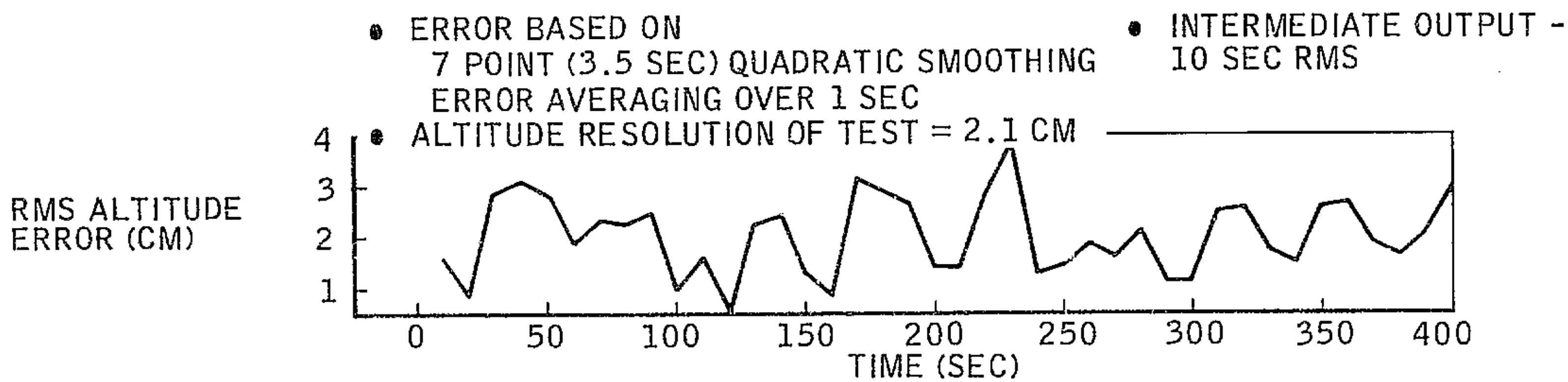
The altitude resolution test consisted of a ten minute data run. The results of the test are summarized in the facing figure. The upper diagram illustrates the average altitude estimated by the tracker as a function of time. This figure presents intermediate outputs of the Altitude Resolution data reduction program where the altitude data was averaged over ten second intervals. Since the selected tracker bandwidth was 2 hertz or response time of half a second, 20 such points were averaged and plotted in the above figure. The lower figure indicates the rms error of the tracker estimated altitude with respect to the smoothed altitude determined by the Altitude Resolution program. This plot also presents intermediate outputs over ten second intervals. It indicates that the rms error for any ten second interval is less than approximately 4 centimeters. The rms altitude error for the complete 10 minute data run was computed to be 2.12 centimeters. The data reduction was performed entirely by the use of the Altitude Resolution program. A 7 point center fit quadratic was used in smoothing of the tracker altitude data. Since the selected tracker bandwidth was 2 Hz, adjacent pairs of errors with respect to the smoothing quadratic were averaged to obtain errors for one second intervals. The 7 point (3.5 sec) smoothing was used on the basis of past NASA experience with the C-54 platform; longer windows tend to smooth out the platform motion whereas very short windows tend to follow the errors and yield optimistic results.

The 2.12 centimeter altitude resolution obtained during this test is considered to be an excellent result and is due to the low wave height conditions. This result may be near the ultimate capability of the system.

AAFE PULSE COMPRESSION RADAR ALTIMETER
ALTITUDE RESOLUTION TEST RESULTS

- ACCEPTANCE FLIGHT TEST
- E = 1, L = 16, TRKB = 2, PW = 3, PRF = 4, TRKP = 1/2





2. ACQUISITION TEST

The acquisition test consisted of 20 acquisition attempts. After each initiation of the acquisition process, the track was held for approximately 1 minute. In the 20 attempts, no failures or late acquisitions were encountered. All data was considered to be of good quality.

The acquisition process consists of searching in range from 8000 ft until the system locates signals from the sea surface. The initial search is conducted using coarse steps of approximately 5 meters.

After Late gate threshold crossings are obtained, the search step size is reduced to 1 fine range LSB or approximately 9.3 centimeters. The search continues with this step size until Early gate threshold crossings are obtained and the Early gate up/down counter registers a value of 4. At this time, the search has been completed and track lock-on is initiated. The track lock-on phase continues for 20 10Hz bandwidth intervals or 2 seconds. After that, tracking at the selected 0.5 sec or 2 hertz bandwidth is initiated. The basic acquisition requirement is that quality altitude resolution data be provided within 5 seconds after initiation of acquisition. Flight test results indicated that the system provides quality data within 4.5 seconds or less after the start of acquisition.

Data reduction consisted primarily of the use of the altitude resolution program and some manual calculations. Search time was determined to be approximately 0.5 second on the basis of the number of acquisition subrecords generated on tape before track. The next 20 track points were generated during the high bandwidth lock-on period and correspond to 2 seconds. Altitude resolution performance evaluation consisted of using points 20 through 26 and 21 through 27 which are spaced at 1/2 second intervals. A quadratic fit was generated for the 7 points and an error computed at the center points (i.e., the 23rd and 24th point); the two points correspond to 3.5 and 4.0 sec after track initiation or 4.0 and 4.5 sec after acquisition initiation. These errors were then averaged in order to obtain an equivalent output for 1 second or 1 Hz tracker bandwidth. The results of this processing for the 20 cases are indicated in the facing table. The maximum error is less than 5 centimeters. These values were rms'ed resulting in the 1.99 centimeter value at 4.5 seconds which exceeds the requirement.

In addition, the first 10 cases were individually plotted as shown in the next figure to verify that no residual oscillations existed beyond the 4.5 second point. Oscillations do frequently occur during the lock-on phase as illustrated in the figure, however, they have subsided at the point in question.

ACQUISITION TEST SUMMARY

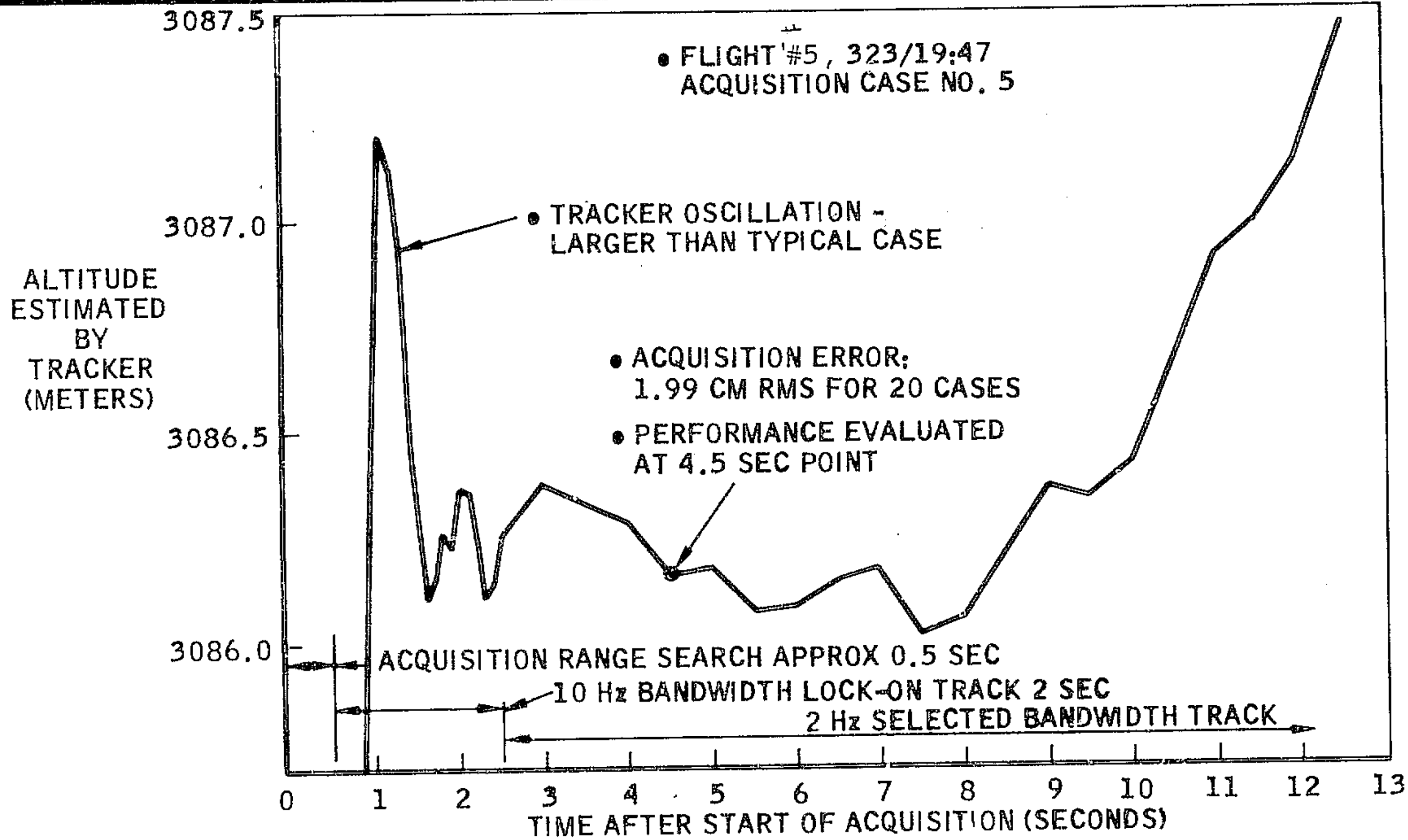
- ERRORS COMPUTED USING 7 POINT (3.5 SEC) QUADRATIC, CENTER FIT AND WITH ERROR AVERAGING OVER 1 SEC INTERVAL

- ERRORS FROM 20 ACQUISITION CASES AT 4.5 SEC AFTER START

CASE NO.	ERROR (CM)	CASE NO.	ERROR (CM)
1	3.56	11	2.76
2	1.34	12	0.93
3	0.49	13	4.86
4	3.52	14	1.00
5	1.73	15	0.61
6	1.49	16	0.66
7	1.02	17	0.81
8	0.10	18	0.68
9	1.69	19	2.59
10	0.93	20	0.39

- RMS ERROR = 1.99 CM AT 4.5 SEC
- REQUIREMENT = 10 CM AT $\leqslant$ 5 SEC

TRACKER ESTIMATED ALTITUDE DURING ACQUISITION



3. WAVE HEIGHT TEST

The wave height estimation test used data obtained during the altitude resolution test. The Wave Height Estimation program of the Operational program computes wave heights every 30 seconds on the basis of averaged Ramp filter amplitudes.

Although all 24 Ramp filters provide useful data for determination of wave height, the implemented logic utilizes only up to 4 of these filters to derive the wave height. For low wave height conditions, filters #12 and #13, which measure the amplitudes on the slope of the signal, are used. Using filter #12 and #13 average amplitudes, the Wave Height Estimation program computes a slope which it then normalizes by the average value of all the Ramp filters. The wave height is then computed using a quadradic function where the normalized slope is the independent variable. The quadradic function has been determined by use of theoretical and test data in-plant. A sample Ramp filter average such as used in the wave height calculation (in real time) but obtained after flight is indicated on p. G-13. The Ramp filter #12 and #13 amplitudes straddle the half-power point and provide the most sensitive estimation of the slope of the leading edge of the ramp.

Data reduction for this test consisted of extracting the wave height data computed by the Wave Height Estimation program and computing an average wave height and a standard deviation. Then the average value was compared with forecast and estimated observer data. The data is plotted in the facing figure. The mean value of the RMS wave height is 25.33 centimeters, and the fluctuation is 10.8 percent; the equivalent significant wave height is 101.3 centimeters. The forecast wave height before the flight was 1 to 2 feet which is approximately 0.5 meters; however post flight reports from observers indicated that swells of 1 meter did exist. Consequently, the estimated wave height was deemed to be within the required ±25% accuracy.

Furthermore, Flight #3 laser profilometer data which was reduced subsequently indicates that the system wave height measurement accuracy is approximately ±10%. On that flight, wave height measurements were made with the laser profilometer and the radar altimeter.

PRECEDING PAGE BLANK NOT FILMED

WAVE HEIGHT ESTIMATES FROM ACCEPTANCE TEST