AD-A047 949 WESTINGHOUSE DEFENSE AND ELECTRONIC SYSTEMS CENTER B--ETC F/G 19/5
F-4E AVIONICS UPDATE.(U)
AUG 77 A F WENK F33615-76-C-1340
UNCLASSIFIED AFAL-TR-77-91 NL

AFAL-TR-77-91

F-4E AVIONICS UPDATE

Westinghouse Defense and Electronic Systems Center
Baltimore, Maryland 21203

August 1977

TECHNICAL REPORT AFAL-TR-77-91

Technical Report for Period 15 June 1976 - 30 September 1976

Approved for public release; distribution unlimited.

AIR FORCE AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This technical report has been reviewed and is approved for publication.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFAL-TR-77-91	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) F-4E Avionics Update		5. TYPE OF REPORT & PERIOD COVERED Final Report. 15 June 76 - 30 Sept 76
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A.F. Wenk et al		8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-1340 P0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS Westinghouse Defense and Electronic Systems Center Baltimore, Maryland 21203		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 698DF, Task 01, Work Unit 29
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Avinoics Laboratory (RWT-1) Air Force Systems Command Wright-Patterson AFB, Ohio 45433		12. REPORT DATE August 1977
		13. NUMBER OF PAGES 43
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Digital Computers
Heads Up Displays (HUD)
Digital Weapon Control Technology
Fire Control Simulator
Avionics Software
Display Symbology
Digital ALCOSS Gunnery and Tracer Gunnery (Avionics)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

1. This report covers the final phase of the previous F-4E Austere HUD Program AFAL-TR-76-190, dated December 1976. This report covers live aerial gun firing performance support that Westinghouse provided for the gunsight mechanization previously incorporated in test aircraft No. 304 at AFFTC.
2. The report also covers SEAFAC support work and transformers delivered to SEAFAC.

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FOREWORD

Contract F33615-74-C-1173 did the necessary modifications to result in an integrated weapons system on F-4E aircraft tail number 304 at the Air Force Flight Test Center. Air-to-air missilery, air-to-air gunnery, and air-to-ground gunsight modes algorithms were mechanized by a software program in an installed GFE computer aboard the aircraft, including integrating a GFE (Texas Instruments and General Electric) Austere HUD.

This final report covers the efforts of contract F33615-76-C-1340, in which the Air Force tested out the previous contract mechanization for the gunsight modes. The Tracer and Air Force Digital Lead Computing Optical Sight routines were flight tested with real firings against airborne-towed targets.

This final report was submitted by Westinghouse Electric Corporation under Contract F33615-76-C-1340, Project 69DF, Task 01, Work Unit 29, contract data requirements, sequence no. 1 for the U.S. Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio 45433. Skip Wenk was the Westinghouse Program Manager.

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SECTION I

INTRODUCTION

The F-4E Avionics Update Program was a follow-on to the previously concluded Austere HUD Program which covered the period of May 1974 through the latter part of 1975.

The Austere HUD Flight Test Program was flown at the Air Force Flight Test Center, Edwards Air Force Base, California; its basic goals being to verify the accuracy and performance of the F-4E Austere Heads Up Display air-to-air gunsights by the integrated Westinghouse AN/AYK-8 computer and software package with the Texas Instruments/General Electric Heads Up Display and the Honeywell Aerial Gunnery Software routines. This integrated system was then installed in an Air Force F-4E aircraft and flown by Air Force test pilots and Tactical Air Command pilots to evluate and optimize the system in a simulated combat environment. Some 60 flights were flown and each pilot's comments (likes, dislikes and suggestions for improvement) were noted and discussed. These discussions resulted in modifications to the switchology, symbology, algorithms and software.

The Austere HUD Program ended with the general agreement that an optimum, operational system had been produced for the mechanized gunnery modes.

The F-4E Avionics Update Flight Test Program then followed in which this optimized system was evaluated in a simulated combat environment with the actual firing of live bullets at towed targets.

SECTION II

FLIGHT TEST SUMMARY

June 1976 through July 1976

The F-4E Avionics Update Program got underway with the reinstallation of the HUD system into F-4E aircraft number 304, which had returned from Hill Air Force Base where it has been extensively modified to bring it up to the latest F-4E operational configuration.

Initially, some problems were encountered in getting the system operational and the first 17 flights were only partially successful due to the fact that, after 10 to 40 minutes of flight, the system automatically shut down and could not be restarted. Poor operation was experienced with many of the avionic subsystems. The cause of these shutdowns was not immediately determined. The very hot and dry weather conditions at the Edwards Air Force Base locale made isolating the problem extremely difficult.

The problem was finally isolated to a failure in the aircraft equipment cooling system, which caused the introduction of very cold air into the electronics equipment, resulting in ice and/or moisture condensation at higher altitudes. The lost time and data as a result of this failure clearly demonstrated the definite need for low temperature and/or moisture detection devices in future avionics equipment operating at high altitudes.

During the remainder of the June/July 1976 period, aircrews consisting of: Majors Milam, McDonnald, Meschko and Capts. Casper, Gardner, Crimmel and Mulane, flew 25 additional missions. Verified hits were scored during 13 of these 25 flights. The target was missed on only three flights. The tow target was lost on four flights, the gun jammed on one, two were aborted for tow aircraft problems and two were test flights in which no gunfire was attempted.

Major Dave Milam had the distinction of being the first pilot to hit the target using the tracer (hotline) gunnery mode.

Westinghouse Field Representative, Bruce Klinger, designed at the test sight and installed circuitry in the AN/AYK-8 computer for interfacing the airborne time code generator with the HUD system. This made possible the display of mission-elapsed time on the Heads Up Display and the recording of elapsed time on the airborne digital tape recorder. This greatly facilitated correlation of the gunsight film, digital instrumentation data and analog instrumentation data for on-site analysis purposes.

An interface problem between the GFE Digi-Data recorder and the Air Force CDC 6500 computer system was discovered in July 1976. The problem being that the CDC 6500 computer ATAGAS software would not accept flight data instrumentation tape produced by the Digi-Data recorder. Further analysis of the situation revealed that both hardware and software problems were involved. The hardware problems were determined to be previoulsy established logic problems which should have been corrected by the Digi-Data Corporation as modifications. These modifications, however, had not been installed in the Austere HUD Digi-Data recorder at the time of its purchase by the Air Force. These hardware problems were corrected, on site, by the Westinghouse field personnel.

The software problem was a result of the unnecessarily strict requirements of the particular CDC 6500 computer Air-to-Air Gunnery Analysis System (ATAGAS) software program and other complications created by previous modifications made to the CDC 6500 operating system. These software problems were referred to the Westinghouse software personnel in Baltimore for a solution. The recording of digital tapes continued so that flight data would not be lost pending a solution to the problem.

Aircraft number 304 was unavailable for flying a total of 12 days during this period due to mechanical problems.

August 1976 through September 1976

This period of the program began with a concentrated effort to isolate and correct the suspected inaccuracies in the system indicated by the analysis of data obtained during the previous test flights. To prove the existence of these suspected inaccuracies, it was decided to fly some night missions in which live tracer ammunition was fired while executing combat maneuvers.

Analysis of the gunsight camera film data obtained during these flights indicated that the system was very accurate during steady-state aircraft conditions, but aircraft attitude changes introduced some inaccuracies at ranges of 2 to 3 thousand feet. Further analysis of the data by Westinghouse and Honeywell systems personnel revealed some scale factor and position errors in the Honeywell and Westinghouse software, and some inaccuracies in the inputs from the McDonnell-Douglas accelerometers and gyros. Adjustments were made to minimize the input inaccuries and to correct and optimize the scale factors. Subsequent night tracer flight data confirmed that the system was now accurate over the desired range.

An inaccuracy in the range data information to the AN/AYK-8 computer from the AN/APQ-120 radar was also discovered from the analysis of test flight data. The Westinghouse software personnel devised a method in which an in-flight range bias correction would be introduced into the AN/AYK-8 computer. This procedure greatly decreased the time required to accurately determine the magnitude of and correct this range error. The Westinghouse software personnel, at the request of the Air Force, also incorporated a "lag line" display feature into the Digital Air Force Lead Computing Optical Sight (DALCOS) gunnery mode. These corrections and modifications greatly increased the accuracy and ease of operation of the system which was demonstrated by the very impressive results obtained throughout the remainder of the program.

During the August/September 1976 period, aircrews consisting of Majors Meschko and Howard, and Captains Gardner, Crimmel, Pomeroy and Sizemore, flew 48 missions - 43 of which were gunnery flights. Verified hits were scored on 22 of the 43 attempts. The target was missed on only five flights. The tow target was lost on six flights, five were aborted for aircraft number 304 mechanical problems, five were aborted for tow aircraft problems and five were data flights where no attempt was made to hit a target.

Some very impressive gunnery scores were achieved during this period. Some of the verified target hits were made under the following conditions:

MODE	RANGE	Shooter G's	ASPECT ANGLE	ROUNDS FIRED	TARGET
Tracer	3000'		$20^o - 30^o$	50	Banner
DALCOSS	2000'	2	$20^o - 30^o$	50	Dart
DALCOSS	2200'	5	$20^o - 30^o$	50	Dart
Tracer	1800'	4/5	$20^o - 30^o$	50	Dart
DALCOSS	2500'	3/5	$20^o - 30^o$	50	Figat
Tracer	3200'	4	$20^o - 30^o$	50	Figat
DALCOSS	2200'	2	$20^o - 30^o$	50	Figat
Tracer	1200'	3	20^o	50	Banner
DALCOSS	1500'	5	$20^o - 30^o$	50	Dart

MODE	RANGE	Shooter G's	ASPECT ANGLE	ROUNDS FIRED	TARGET
Tracer	1000'	5	$20^{o} - 30^{o}$	50	Dart
Tracer	1500'	6	90^{o}	50	Banner
DALCOSS	1600'	4.4	80^{o}	50	Banner
DALCOSS	1600'	5.5	90^{o}	50	Banner
Tracer	1000'	4	70^{o}	50	Banner
Tracer	1200'	3.5	90^{o}	50	Banner
Tracer	1000'	4	100^{o}	50	Banner
DALCOSS	800'	3	130^{o}	50	Banner
Tracer	800'	2.5	160^{o}	50	Banner

During these flights, several extremely difficult gunnery feats were performed by Major Tom Meschko and Captain Guy Gardner. Two of these being: hitting a target at 6 G's with a 90^{o} aspect angle using only a 50 round gun burst and hitting a target at 2.5 G's with an aspect angle of 160^{o}, also with a 50 round burst.

Westinghouse Field Representative, Bruce Klinger, designed and installed circuitry in the AN/AYK-8 computer for interfacing the airborne Distance Measuring Equipment (DME) with the HUD system. This allowed the DME range to be recorded on the airborne digital instrumentation equipment and numerically displayed in the aircraft cockpit.

During the August/September 1976 period, aircraft number 304 was unavailable for flying a total of five days due to mechanical problems and two flying days were lost due to inclement weather.

The successful flights produced data required for the evaluation of the system and 25 reels of digital instrumentation magnetic tape of the flight data were generated for further analysis by the Air Force personnel as input data to the Air to Air Gunnery Analysis System (ATAGAS) computer program.

The flight test logs showed 188 flights with no computer failures to the An/AYK-8 computers. The total flight hours involved were 197 hours. It is of particular note that both AN/AYK-8 computers, used during the Austere HUD/F-4E Avionics Update Program, operated almost continuously for 28 months without a single failure.

The Air Force was very pleased with the results of the program and consider it to be a highly successful flight test program.

The following is an individual flight scoring chart.

Flight #	Hot Passes	Hits Confirmed	Mode
20	Not Available	Yes	DALCOSS
22	8	Yes	DALCOSS
23	9	Shot Target Off Cable	DALCOSS
25	2	Destroyed Target	DALCOSS
26	1	Shot Target Off Cable	DALCOSS
27	8	Shot Down Target	Tracer
28	3	Shot Target Off Cable	
32	7	Yes	DALCOSS
33	6	Yes	DALCOSS
34	4	Yes	
35	6	Yes	Tracer
38	2	Shot Target Off Cable	Tracer
40	7	Yes	Tracer
42	5	Yes	Tracer
43	6	Yes	Tracer
44	3	Yes	Tracer
45	7	Yes	Tracer
58	12	Yes	Tracer
60	10	Yes	DALCOSS
61	6	Yes	DALCOSS
62	2	Disintegrated Target	Tracer
64	4	Shot Target Off Cable	DALCOSS
65	10	Shot Target Off Cable	Tracer
67	5	Destroyed Target	1 Tracer, 1 DALCOSS
69	3	Unknown - Destroyed	DALCOSS
70	Not Available	Yes	DALCOSS
73	18	Yes	8 Tracer, 10 DALCOSS
74	2	Destroyed Target	DALCOSS
75	1	Yes	
78	11	Yes	1 Tracer, 3 Tracer
89	8	Yes	3 Tracer 1 DALCOSS

TIME CODE GENERATOR MODIFICATIONS

A GFE time code generator was installed in aircraft 304 by the Air Force and interface between it and the AN/AYK-8 computer had to be designed and installed in the field. The software was changed such that the program would read the timer and then record the coded time on the Raymond tape handler along with the 65 program and status parameters of the wepons modes. This greatly facilitated locating and reducing the snap shot programs.

The design and wiring list follows:

Action	From	To	Sig Name
Delete	XA504/5	XA504/8	504 µ 5.2 V
Delete	XA504/5	XA504/3	504 µ 5.2 V
Delete	XA504/8	XA504/37	504 µ 5.2 V
Delete	XA504/13	XA504/43	504 µ 5.2 V
Delete	XA504/13	XA504/44	504 µ 5.2 V
Delete	XA504/17	XA504/21	504 µ 5.2 V
Delete	XA504/17	XA504/47	504 µ 5.2 V
Delete	XA504/21	XA504/55	504 µ 5.2 V
Delete	XA504/27	XA504/31	504 µ 5.2 V
Delete	XA504/37	XA504/43	504 µ 5.2 V
Delete	XA504/44	XA504/47	504 µ 5.2 V

These pins should now be empty 504/3,5,8,37,13,47,21,31

Action	From	To	Sig Name
ADD	XA504/27	XA504/56	504 µ 5.2 V
ADD	XA504/55	XA504/44	504 µ 5.2 V
ADD	XA504/44	XA504/43	504 µ 5.2 V
ADD	XA504/43	XA504/17	504 µ 5.2 V
ADD	XA504/55	XA504/56	504 µ 5.2 V

These pins should now be connected B09/001, XA504/27,55,56,44,43,17

Action	From	To	Sig Name
ADD	XA502/59	XA504/59	5.2 V
ADD	XA502/59	XA502/58	5.2 V
ADD	XA502/58	XA502/23	5.2 V
ADD	XA502/23	XA502/32	5.2 V
ADD	XA502/32	XA502/35	5.2 V
ADD	XA502/35	XA502/55	5.2 V
ADD	XA502/55	XA502/47	5.2 V
ADD	XA502/19	XA502/48	DGND
ADD	XA502/48	XA502/30	DGND
ADD	XA502/30	XA504/30	DGND
ADD	XA502/20	XA502/49	.8 sec - Ret
ADD	XA502/45	XA502/46	.8 sec -
ADD	XA502/46	XA502/3	.8 sec -
ADD	XA502/3	XA502/2	.8 sec -
ADD	XA502/4	XA502/34	.8 sec
ADD	XA502/36	XA504/5	1 sec TCG
ADD	XA502/52	XA502/51	Reset Ret
ADD	XA502/57	XA502/56	Reset time
ADD	XA502/57	XA502/12	Reset time
ADD	XA502/12	XA502/13	Reset time
ADD	XA502/13	XA502/5	Reset time
ADD	XA520/45	XA502/14	Software reset
ADD	XA502/14	XA502/15	Software reset
ADD	XA502/16	XA502/6	Reset S
ADD	XA502/7	XA502/8	Reset FF
ADD	XA502/7	XA502/10	Reset FF
ADD	XA502/9	XA502/31	Reset FF -
ADD	XA502/11	XA504/8	Zero Time
ADD	28J5/53	XA502/50 } TP	.8 sec - IN
ADD	28J5/54	XA502/49 } TP	.8 sec - RET IN
ADD	28J5/55	XA502/53 } TP	Reset
ADD	28J5/56	XA502/52 } TP	Reset Ret

59 - 55 - 47 - 23 - 58

ADD	XA502/23	to	XA502/55
ADD	XA502/55	to	XA502/47
ADD	XA502/4	to	XA502/35
ADD	XA502/35	to	XA502/17
ADD	XA502/36	to	XA502/18
ADD	XA502/22	to	XA502/40
ADD	XA502/38	to	XA504/5
ADD	XA502/31	to	XA502/44

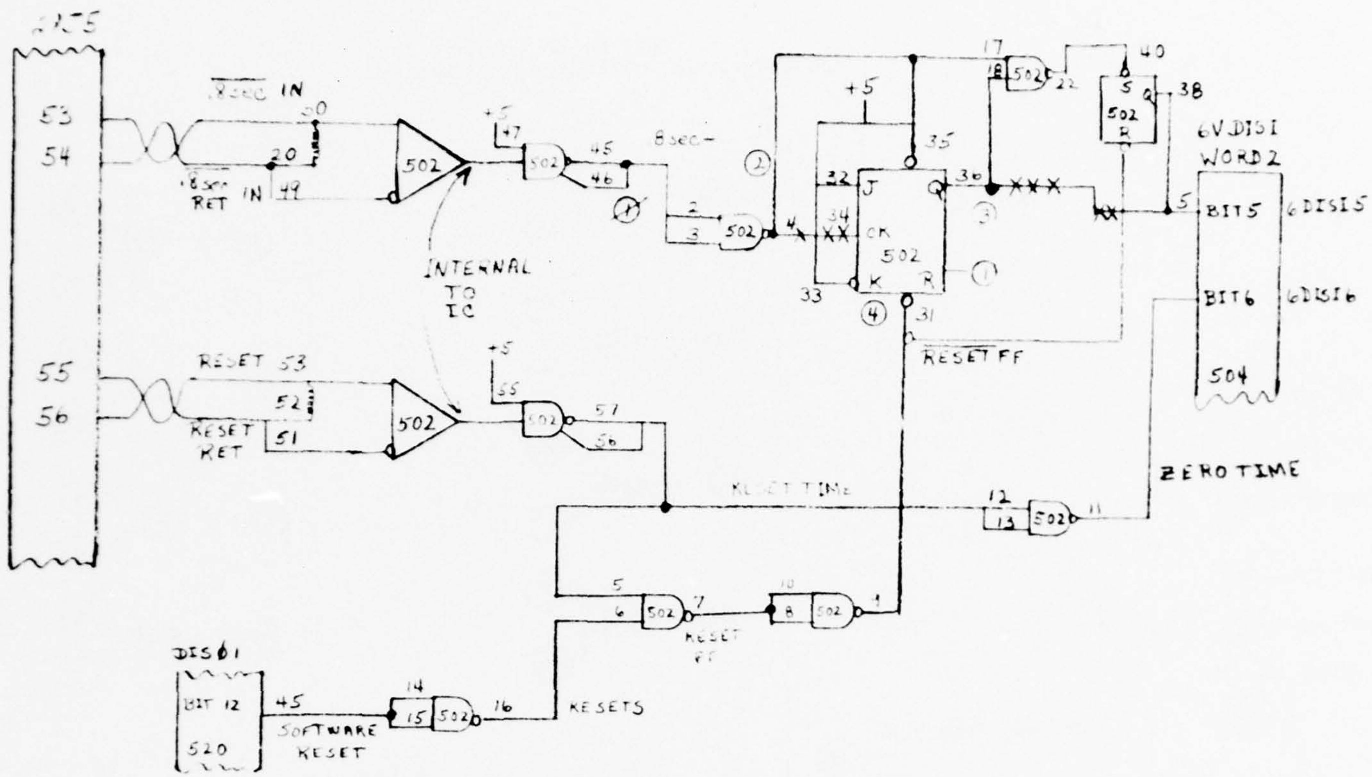
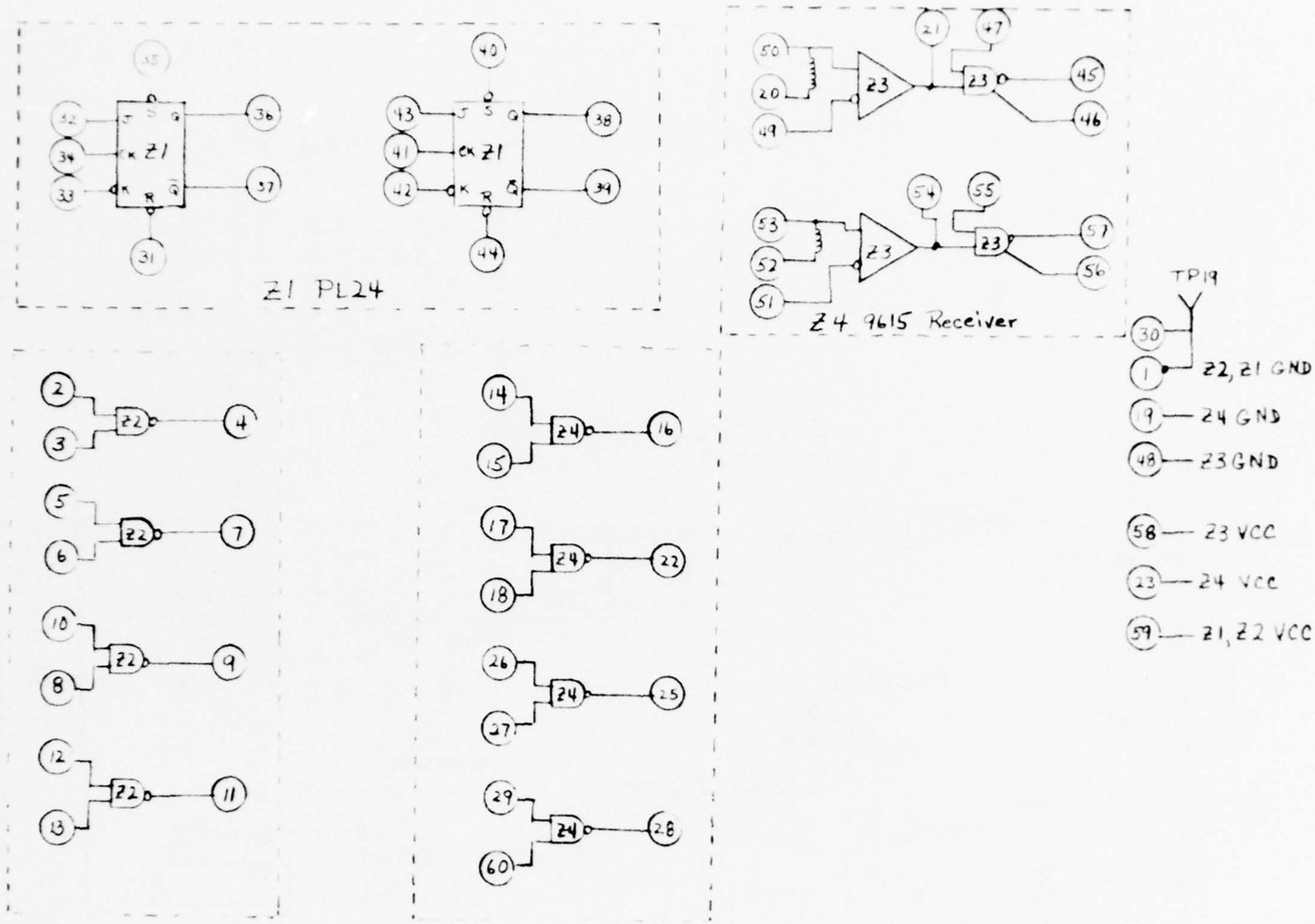


Figure 1. TCG Interface Modification - LRU-28



TIME CODE GENERATOR INTERFACE BOARD
LRU-28 A502

Figure 2. Time Code Generator Interface Board - LRU-28 A502

A. Digital Readout for Time Code Generator

The Air Force decided that it needed an on-the-spot display of the time code generator, and installed a digital readout meter on top of the code generator. The AN/AYK-8 was again modififed, both hardware and software, to drive the display and present the time in appropriate time digits.

The wiring modes are shown in figure 3.

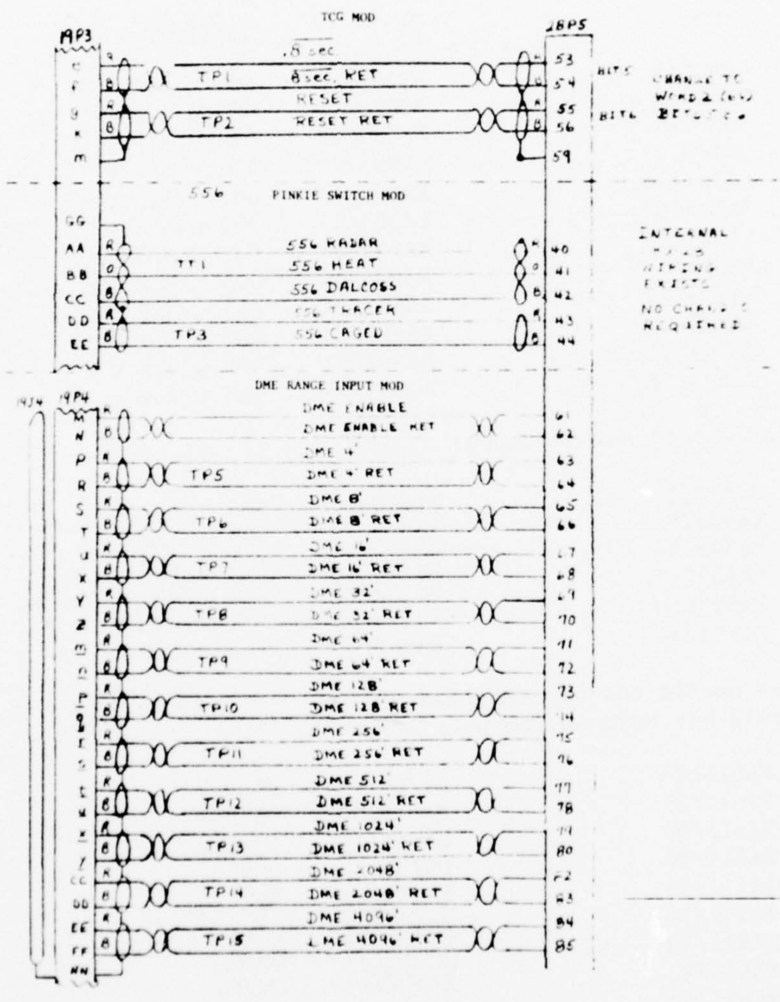


Figure 3. Wiring Modes - TCG, Pinkie Switch, DME Range Input

B. Distance Measuring Equipment

The range measuring system described in Appendix 1 had to be interfaced to the AN/AYK-8 computer, as mentioned previously.

The interface wiring modifications installed at the Air Force Flight Test Center are as follows:

Action	From	To	Sig Name
Delete	XA503/3	XA503/5	503 μ 5.2 V
Delete	XA503/3	B08/001	503 μ 5.2 V
Delete	XA503/8	XA503/37	503 μ 5.2 V
Delete	XA503/37	XA503/43	503 μ 5.2 V
Delete	XA503/44	XA503/13	503 μ 5.2 V
Delete	XA503/13	XA503/17	503 μ 5.2 V
Delete	XA503/17	XA503/47	503 μ 5.2 V
Delete	XA503/47	XA503/46	503 μ 5.2 V
Delete	XA503/20	XA503/21	503 μ 5.2 V
Delete	XA503/21	XA503/55	503 μ 5.2 V
Delete	XA503/58	XA503/31	503 μ 5.2 V
Delete	XA503/58	XA503/29	503 μ 5.2 V

These pins should now be empty: 3, 37, 13, 47, 21, 31

ADD	B08/001	XA503/5	503 μ 5.2 V
ADD	XA503/8	XA503/43	503 μ 5.2 V
ADD	XA503/44	XA503/17	503 μ 5.2 V
ADD	XA503/17	XA503/46	503 μ 5.2 V
ADD	XA503/20	XA503/55	503 μ 5.2 V
ADD	XA503/44	XA503/20	503 μ 5.2 V

These pins should now be connected B08/001,5,7,8,43,44,17,47,20,55,56,27,29 58. XA611 should not have any connections.

ADD	XA611/59	D9/001	+5.2 V
ADD	XA611/59	XA611/50	+5.2 V
ADD	XA611/50	XA611/24	+5.2 V
ADD	XA611/30	D9/002	DGND
ADD	XA611/31	XA504/47	DME ENA
ADD	XA611/10	XA504/21	DME4
ADD	XA611/33	XA504/37	DME8
ADD	XA611/8	XA504/13	DME16
ADD	XA611/40	XA504/3	DME32
ADD	XA611/49	XA504/31	DME64

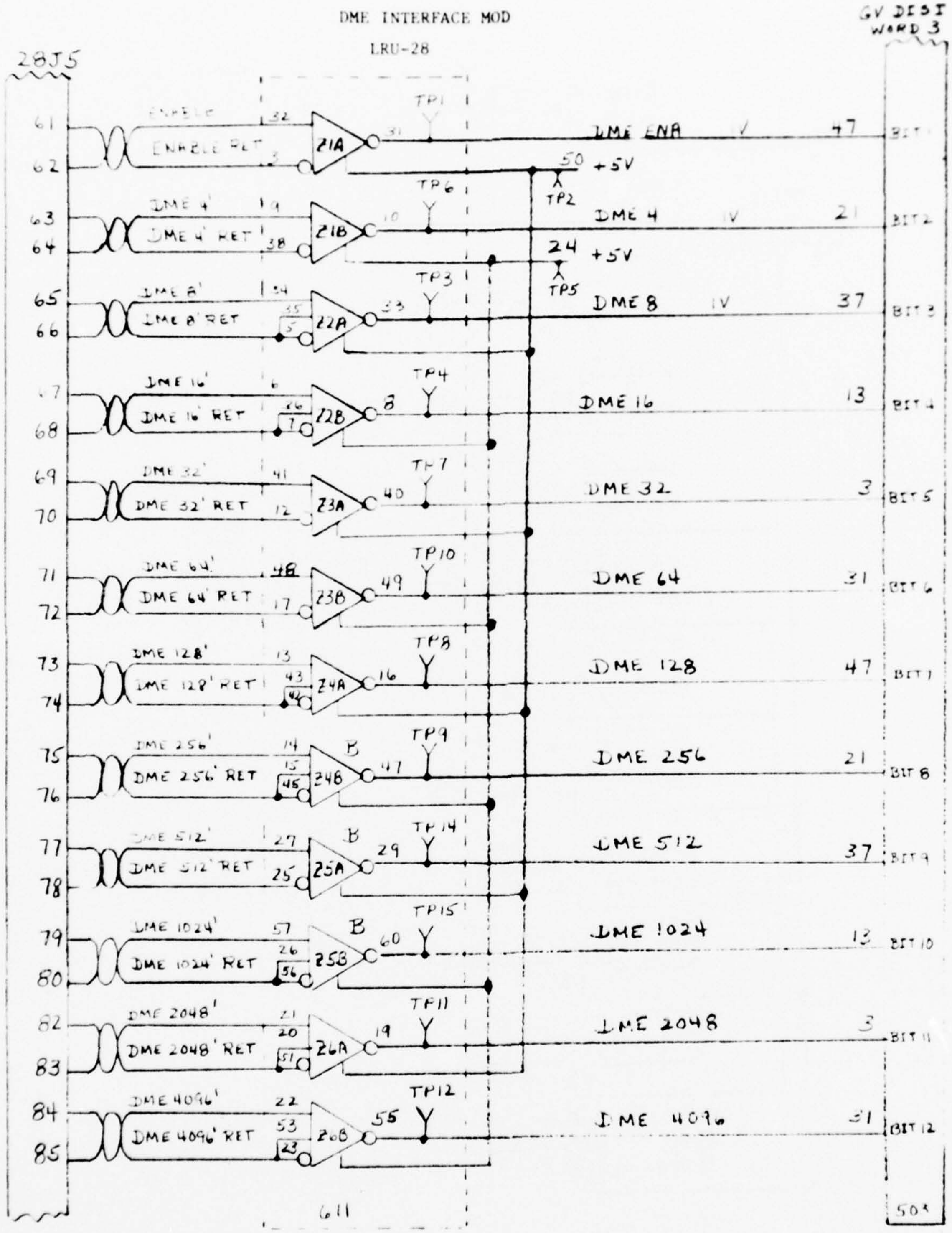


Figure 4. DME Interface Mod - LRU-28

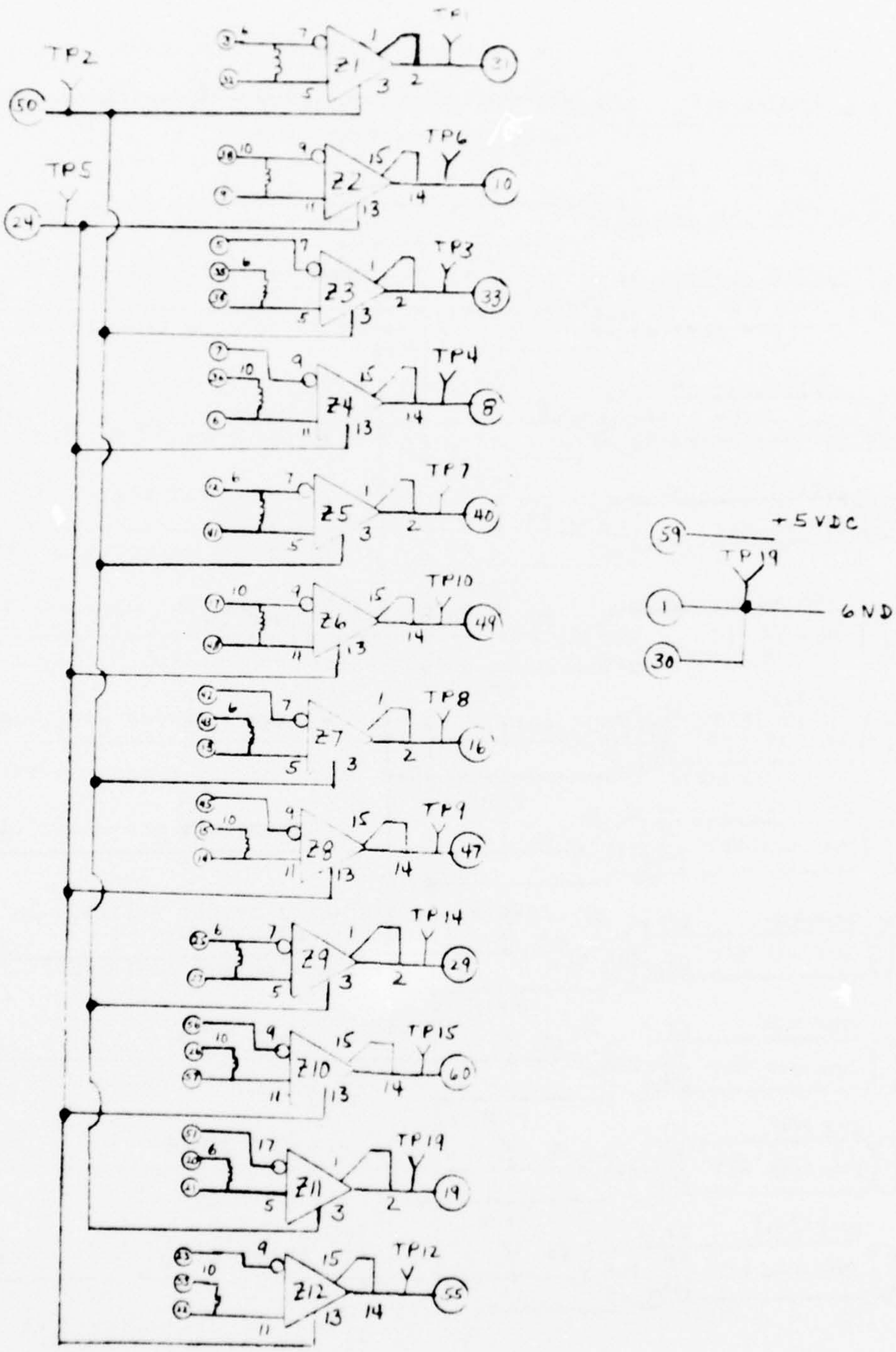


Figure 5. Receiver Board - LRU-28, XA611

Action	From	To		Sig Name
ADD	XA611/16	XA503/47		DME128
ADD	XA611/47	XA503/21		DME256
ADD	XA611/29	XA503/37		DME512
ADD	XA611/60	XA503/13		DME1024
ADD	XA611/19	XA503/3		DME2038
ADD	XA611/55	XA503/31		DME4096
ADD	XA611/35	XA611/5		DME8'R
ADD	XA611/36	XA611/7		DME16'R
ADD	XA611/42	XA611/43		DME128'R
ADD	XA611/15	XA611/45		DME256'R
ADD	XA611/26	XA611/56		DME1024'R
ADD	XA611/51	XA611/20		DME2048'R
ADD	XA611/23	XA611/53		DME4096'R
ADD	28J5/61	XA611/32	TP	ENABLE
ADD	28J5/62	XA611/3		ENA RET
ADD	28J5/63	XA611/9	TP	DME4'
ADD	28J5/64	XA611/38		DME4'R
ADD	28J5/65	XA611/34	TP	DME8'
ADD	28J5/66	XA611/35		DME8'R
ADD	28J5/67	XA611/6	TP	DME16'
ADD	28J5/68	XA611/7		DME16'R
ADD	28J5/69	XA611/41	TP	DME32'
ADD	28J5/70	XA611/12		DME32'R
ADD	28J5/71	XA611/48	TP	DME64'
ADD	28J5/72	XA611/17		DME64'R
ADD	28J5/73	XA611/13	TP	DME128'
ADD	28J5/74	XA611/42		DME128'R
ADD	28J5/75	XA611/14	TP	DME256'
ADD	28J5/76	XA611/15		DME256'R
ADD	28J5/77	XA611/27		DME512'
ADD	28J5/78	XA611/25		DME512'R
ADD	28J5/79	XA611/57	TP	DME1024'
ADD	28J5/80	XA611/26		DME1024'R
ADD	28J5/82	XA611/21	TP	DME2048'
ADD	28J5/83	XA611/20		DME2048'R
ADD	28J5/84	XA611/22	TP	DME4096'
ADD	28J5/85	XA611/23		DME4096'R

C. Digidata Recorder Modifications

Upon discovery of an interface problem between the AN/AYK-8 and the GFE Digidata recorder. (Changes were made in the field to alleviate this problem.)

SEAFAC SERVICES

Engineering services and consultation was provided to the ASD/ENA SEAFAC facility to service the AN/AYK-8 computers and computer maintenance bench at Building 485 at Wright-Patterson Air Force Base. Fifty brassboard pulse transformers were fabricated and delivered to SEAFAC where the transformers were tested and installed into the SEAFAC hot bench by the Air Force personnel. The SEAFAC facilities were used on occasion to update the Air Force Flight Test Center's total software package to ensure that the Westinghouse-supplied support software package was functioning properly on the Air Force's CDC 6000 computer. During the course of the flight tests at the Air Force Flight Test Center, a neutral power ground opened in flight and subjected the avionics equipment in Bay 19 of aircraft number 304 to more than 2 times rated voltage. SEAFAC shipped a replacement AN/AYK-8 system which was used during the repair of the damaged aircraft system. SEAFAC also supplied needed cards (standard computer modules) which were needed to interface the mentioned time code generator and distance to other aircraft measuring equipment.

The SEAFAC facility proved to be a very valuable facility for supporting the Air Force Flight Test Center's efforts.

GENERAL SUMMARY OF FLIGHT TEST SOFTWARE CHANGES

AFFTC-TR-76-45 report presents a very accurate description of the F-4E Austere HUD/Gunsight Flight Test Program for Phase B. The report gives a system description, changes made for this specific flight test and a summary of the flight test results.

The HUD symbol changes made for this program were as follows:

Target Designator Option:

A target designator circle identical to the one available in the air-to-air missile mode was optionally selectable in both air-to-air gun modes through the CCP. It was selected to aid the pilot in visually acquiring the target during the roll in for the firing pass when a radar lock on was available. The target appeared within the designator circle if the target was in the HUD field of view (FOV). It was a significant aid to the pilots.

Point Pipper:

A one-mil dot programmed into the HUD symbology for use as a more precise aiming reference in DALCOS. The dot was located in the center of the six-mil pipper circle which indicated expected bullet dispersion. The pipper point allowed more accurate tracking by the pilot and more accurate film reading.

Changes for Detected Discrepancies:

The operational program was modified to clear up discrepancies which were detected during the flight test, especially in the Tracer program. A complete log of the software configuration was kept on site. Master listings of the operational program was kept on site.

Lagline Incorporation:

A lagline was incorporated in the DALCOS to indicate when the sight was settled. The lagline was Air Force supplied equations and was scaled to be representative of the rate of movement and direction of movement. Whenever the magnitude was less than the radius of the bullet dispersion pattern, the lagline was not displayed. Since the lagline indicated when the sight was in solution, it helped the pilot to tell when to fire.

Range Correction:

A range correction change for in-flight adjustment, by software, was made to correct a radar range error discovered by comparing ground radar range calibration data.

Throttle Mode Selection:

HUD mode selection was interfaced with the throttle switches of the TCTO-IF-4E-556 modifications which enabled automatic display of the HUD modes corresponding to the weapons selected. This helped evaluate the value of HUD mode selection with hands on the flight controls.

Appendix B gives a flight test summary.

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APPENDIX A

NEW TRANSPONDER

RANGE MEASURING SYSTEM INSTALLED

BY AIR FORCE FLIGHT TEST CENTER

ON AIRCRAFT NUMBER 304

1.0 SYSTEM DESCRIPTION

1.1 Introduction

The following describes how the standard YG1054 Proximity Warning System can be modified to allow it to function as a precise distance measuring device. Separation distances can be continuously monitored to within an accuracy better than ± 10 feet and virtually independent of the actual separation distance.

In addition to the computation of separation distance, the pulse coded signal format is designed to accommodate the exchange of altitude or similar information. As a result, the basic YG1054 transponder, with relatively simple module interchange, can be modified to provide range, range rate and altitude relative to a target (responder location).

1.2 Background - The YG1054 Proximity Warning System

The YG1054 is a C-band pulsed transponder system designed to provide warning to student helicopter pilot whenever other similarly equipped training aircraft penetrate a preselected protective envelope. Development of the YG1054 began in 1967, and the first installations of production models were made in early 1969. The systems proved to be reliable and effective in preventing mid-air collisions with the result that more than 3000 of the systems have been ordered to date by the U.S. Army.

The system warns the pilot of possible collision situations by sounding an audio alarm and illuminating an intruder altitude position display on instrument panel whenever another similarly equipped aircraft penetrates the protected airspace. The protected airspace for the Army application extends 300 feet above and below the aircraft and can be selected to have a radius of up to one mile.

The system consists of a receiver-transponder unit and two quarter-wave stub antennas. The components of the receiver include the display, digital signal processor, transmitter, receiver, barometric sensor, and power supply. The package is designed for standard control-panel console mounting, weighs 5 lbs. and occupies 120 cu. in.

The information flow in the system consists of sequential time events. Consequently, most of the processing is handled by sequential coincidence logic. Essentially, there are two modes of operation; an interrogation mode and a response mode - with each device serving both functions.

Altitude information is derived from a self-contained barometric sensor and is coded and transmitted continuously and omnidirectionally as a series of pulse pairs with the delay between the pulse pairs being proportional to altitude.

Other equipped aircraft, within communication range, receive and process the altitude data, compare it to their own altitude, and determine if the interrogating aircraft is within the altitude band of concern. If it is, a response is transmitted omnidirectionally (back to the interrogating aircraft). The interrogating aircraft then determines the length of time which elapsed between its transmission of altitude data and the receipt of the reply. The fact that a response was received at all indicates that another aircraft was within the altitude band of concern and its separation distance is determined by clocking the round-trip transit of the pulses. In the YG1054, the actual separation distance is not actually measure - but rather it is established whether or not the intruder aircraft is within a maximum selected range of concern such as 2000 or 5000 feet.

1.3 Modification of the YG1054 to Perform a Precision DME Function

1.3.1 The Problem

Provide digital range data with an accuracy of ±10 feet relative to a target aircraft which may be maneuvering, be as far away as two (2) miles and whose relative range may be changing as fast as 2000 feet per second.

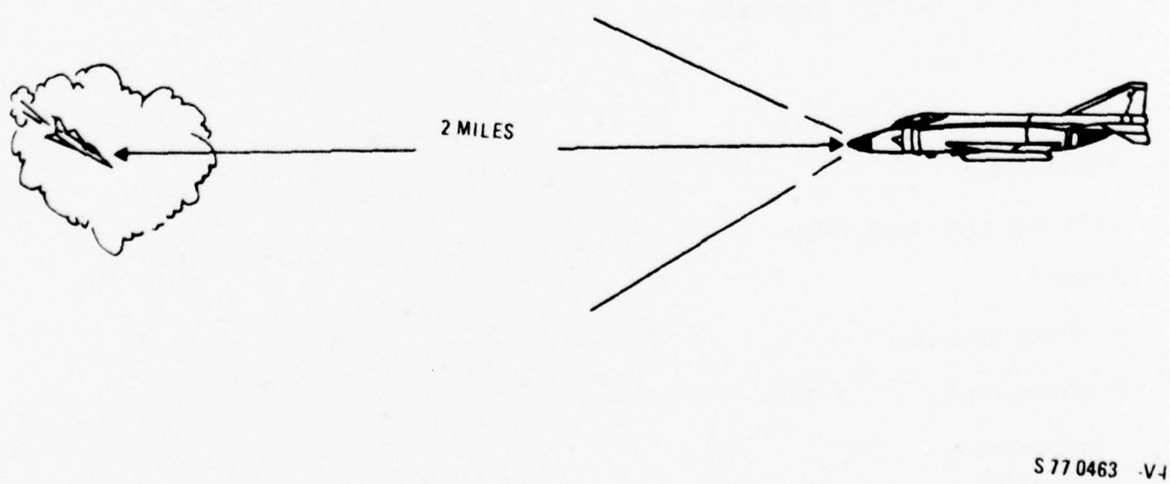

Figure 6.

1.3.2 The Solution

Modify two (2) standard YG1054 Proximity Warning devices as follows:

Unit #1 Chase Aircraft (Interrogator/Processor)	Unit #2 Target Aircraft Responder
• Remove barometric sensor	• Remove barometric sensor
• Remove front control panel and digital display logic - replace with blank panel containing an in-track indicator light and a power-on/off switch and indicator is possible.	• Remove prox-warning interrogation logic
• Replace digital prox-warning signal processor with a standard altimeter type 2nd order closed loop leading edge tracker and time/digital converter. Digital output to format specified.	• Replace front control panel

Figure 1 depicts the general physical appearance of the modificed devices. Different mounting configurations can be accommodated.

Primary Parameter Summary

• Transmitter Carrier Frequency	C-Band 5.08 GHz
• Modulation Type	Pulse Coded
• Transmitter Peak Power	200 Watts
• Pulse Width	50 + 20 nanoseconds
• Interrogation Rate (PRF)	2000 pulse pairs/second
• Range	2 miles
• Accuracy (Static)	$\pm$10 feet
• Environmental	
Temperature	0 to 75°F
Vibration	MIL-E-5400, Curve III

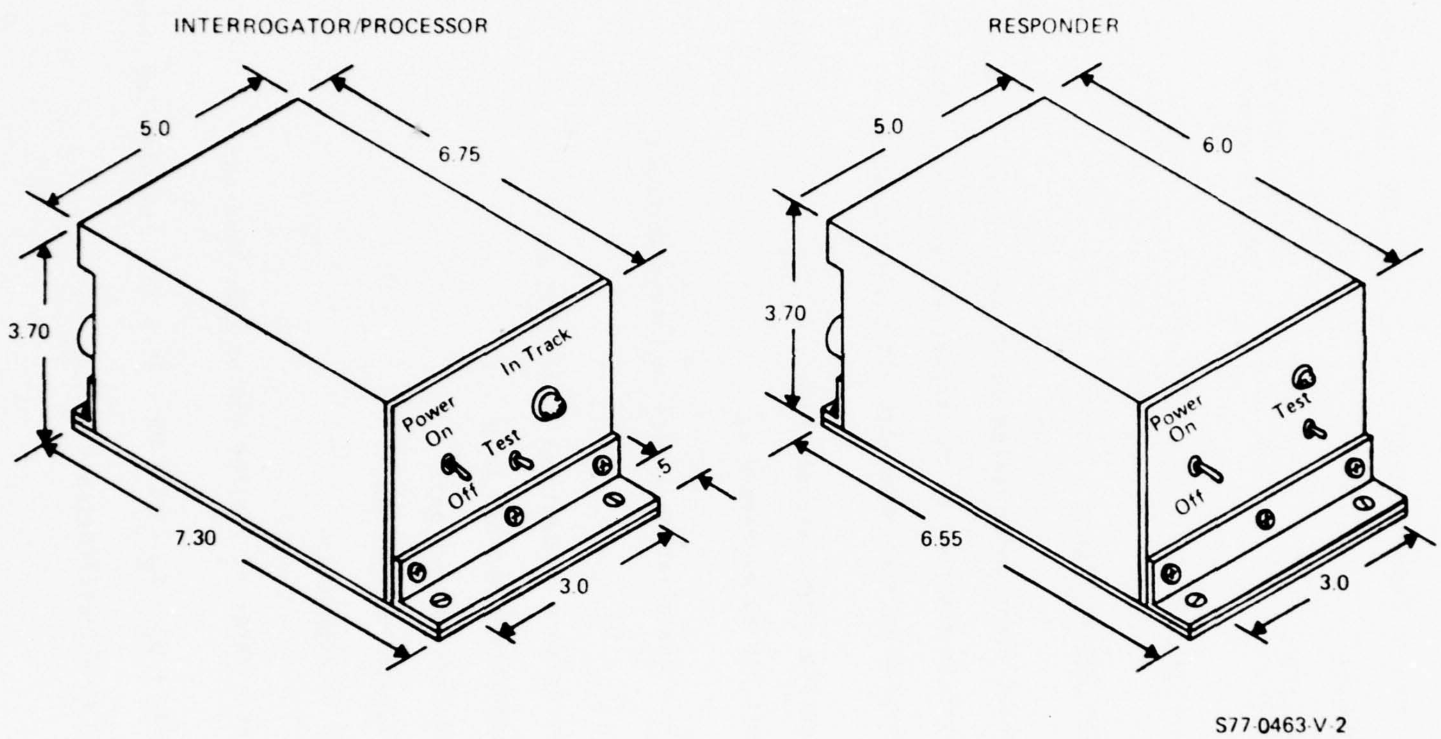

Figure 7. Range Measurement System - Proposed Configuration

- Power Requirements (Each Device) — 28 VDC, approximately 1 amp
- Antenna Coverage

Chase Aircraft	Forward Quadrant
Target Aircraft	Omnidirectional

1.3.3 Performance Analysis

Target Acquisition Sensitivity

In the proposed transponder system the maximum separation range which can be accommodated is governed by the target aircraft responders ability to receive and respond to the chase aircraft's interrogation.

The interrogation signal strenth received (P_{r2}) by the responder in the target aircraft can be expressed as:

$$P_{r2} = \frac{P_t G_1 G_2 \lambda^2}{16\pi^2 R^2} = \text{installation losses in target aircraft}$$

where: P_t = Interrogators transmitter power (+53 dBm)

G_1 = Interrogators antenna gain

G_2 = Responders antenna gain

λ = Wavelength at 5.08 GHz

R = Range of separation

as a result, P_{r2} at a range of 2 miles can be expressed as:

$$P_{r2} = +53 \text{ dBm} + G_1 + G_2 - 34.7 \text{ dB} - 80.5 \text{ dB} - \text{Installation loss}$$

$$= -62.2 \text{ dB} - \text{Installation} + G_1 + G_2$$

The installation loss in the responder aircraft due to cables, connectors, etc., can be assumed to be less than 4 dB.

The antenna gain associated with the responder aircraft (G_2) must be assumed to be near 0 since omnidirectional coverage must be provided to accommodate any maneuver executed.

It would seem reasonable that during the period of concern - that period when range data is desired - the target aircraft would be located in the chase aircraft's forward quadrant. As such an antenna gain of approximately 7 dB can be realized.

Therefore, the interrogation signal strength received by the target's responder, P_{r2}, is equal to:

$$P_{r2} = .62 \text{ dB} - 4 \text{ dB} + 0 + 7 \text{ dB}$$
$$= -59 \text{ dBm}$$

The receiver sensitivity of the responder system is better than -68 dBm, providing an approximate 9 dB margin at a range of 2 miles.

Responder

The responder unit will be a modification of the Honeywell YG1054 C-band transponder. The unit will only function in the respond mode and have no interrogation or range computation capability. A functional block diagram of the responder is shown in figure 2.

Antenna Pair and Power Divider

1. The antenna system will consist of the existing pair of 1/4 wave stub antennas, power divider and coaxial cables currently used on the VEGA 302C-2 transponder system.

Internal Functions

2. The received input and transmitted response will be routed to and from the antenna system via a hybrid duplexer.

3. The responder receiver input will be a weak R.F. pulse pair separated by 450 nanoseconds. The center frequency will be 5.08 GHz.

4. The receiver consists of a balanced mixer and local oscillator operating at 5.06 GHz. The receiver provides super heterodyne mixing of the received signal which results in a pulse pair signal return at a center frequency of 20 mc.

5. The I.F. amplifier detects the receiver output signal to pair of video pulses and amplifiers the weak input (-70 dBm) to a 10 Volt level. The I.F. amplifier also contains a pulse pair decoding network. The decoding network only passes the video signals if a pulse pair exists and the separation between the pulse is 450 $\pm$ 50 nanoseconds.

6. The two video pulses from the I.F. amplifier are fed to a delay network. This delay network consists of a precision ramp and a comparator. The video input triggers a precision ramp which is fed to a blocking oscillator comparator. A D.C. reference voltage is also fed to the comparator.

The comparator output is a very narrow pulse which occurs at the point in time when the ramp voltage and D.C. reference voltage are equal. The result is a stable, precision delay which can be adjusted to maintain a fixed turn-around time for the responder. The total time delay will be 2 μsec for the responder unit.

7. The delayed trigger pulse controls the firing of the transmitter. The transmitter consists of a pulse modulator and a transmitter cavity. The output of the transmitter will be a single pulse, 500 Watt peak power, delayed by precisely 2 μsec from the initial received signal.

8. The transmitter output is sent via the duplexer to the antenna system for the reply to the chase aircraft interrogation.

Interrogator Unit

The interrogator unit will also be a modification of the Honeywell YG1054 C-band transponder, but will also contain an automatic analog range tracking network and time digital converter to provide the range measurement into a 13-bit parallel signal with an accuracy of ±10 feet. A block diagram of the interrogator unit is shown in figure 3.

1. The range measurement is initiated by the transmitter which produces a pair of pulses, 200 Watts peak amplitude, 60 nanoseconds wide, and separated by 450 nanoseconds. The PRF is nominally 3 kHz. The pulse pair is routed to the antenna system via a duplexer and power divider located in the receiver head.

2. In addition to generating an R.F. pulse pair to the antennas for transmission, the transmitter also provides a "time of transmission" reference pulse (TΦ) to the analog tracker and digital processor. The TΦ pulse is the digital start pulse for the range measurement and occurs at the exact time of transmission of the first pulse of the pulse pair.

3. After transmission, the received signal from the responder unit is a single pulse at a level of -70 dBm or greater and a time delay representative of the range to the responder plus the 2 μsec responder turn-around time.

4. The received signal is heterodyned by the receiver mixer and local oscillator. The local oscillator of the interrogator unit has a frequency of 5.08 GHz which is the same as the received signal. This results in a detected video output of the mixer or a "zero intermediate frequency".

5. The I.F. amplifier is therefore truly a video amplifier with a bandwidth of approximately 200 mHz. The I.F. amplifier has an overall gain capability of 90 dB and has full AGC control over a dynamic range of 60 dB. The output of the I.F. amplifier is a single video pulse which is held constant in amplitude (8 Volt peak) to ensure continuous tracking.

6. The analog tracker is a closed loop tracking system which maintains a gate pulse on the leading edge of the video return. The gate position

is therefore a true representation of the earliest return or straight line path to the target. Multipath returns are thus eliminated and are not averaged in the range computation.

The purpose of the analog tracker is to maintain the tracking gate on the leading edge of the video return during the track mode. The track gate is a true representation of the time delay of the return signal. The tracking gate is therefore used as the digital stop pulse. Since only gate position is determined by the tracker, no analog errors or non-linearities which may exist can affect the range accuracy of the digital range signal.

The analog tracker also provides a discrete "validity" command when the system is tracking properly. The discrete signal is used to light the "TRACK" light on the interrogator unit.

7. The time digital converter provides a range signal in 13-bit parallel form. The method of computation is similar to a start-stop counter. The Tϕ pulse (transmission reference) initiates a flip-flop into the high state and the flip-flop is reset by the track gate (video return position). The flip-flop output then representative of the range delay.

The open gate is used to pass 25 mHz clock pulses into an accumulator during each PRF period. The digital system samples 100 periods and averages them to produce a highly accurate digital signal which is updated at a .1 second rate. The 100 pulse averaging reduces errors

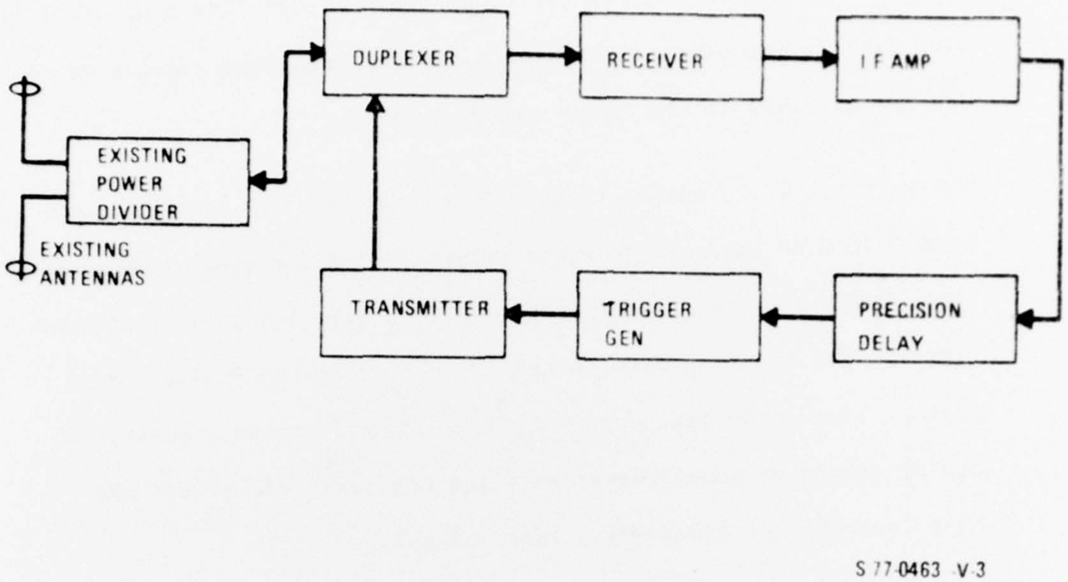

Figure 8. Target Aircraft Responder

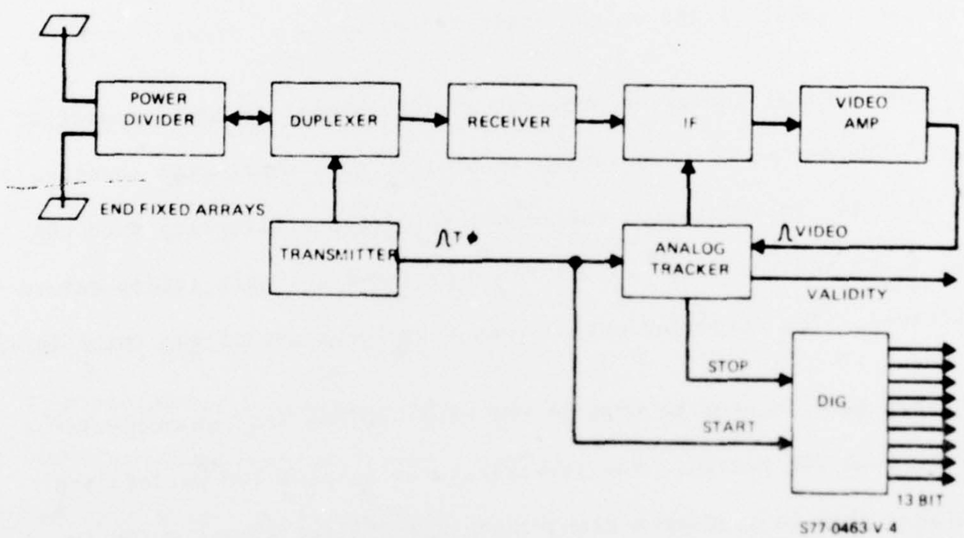

Figure 9. Chase Aircraft Interrogator

due to jitter and the uncertainty of an extra clock pulse (20 foot period) being accepted by the accumulator. The uncertainty of one clock pulse exists because the clock is not synchronized to the initial opening of the gate by the Tϕ pulse. The 100 pulse average technique thus reduces to uncertainty of one clock pulse from 20 feet (one clock period) to .2 feet since 100 periods are averaged.

The output signal will be compatible to the HDAC-13 digital to analog converter manufactured by ILC Data Devices Corporation.

1.4 Proposed Antenna Installation

1.4.1 Target Aircraft

The existing installation of the VEGA Radar Transponder Model 302C-2 would be utilized on the target aircraft. The antenna system, composed of two quarter wave stubs, power splitter and existing cables can be used by the Honeywell system directly with no changes anticipated. The bandwidth of the VEGA antenna system is sufficiently broad to work with no degradation at 5.08 GHz.

The antenna installation on the target aircraft will amount to removing the existing VEGA transponder and replacing it with the Honeywell unit. The Honeywell responder unit will have a single antenna port connector to connect directly to the existing antenna system.

1.4.2 Chase Aircraft

The system requirements of chase aircraft dictate that the antenna system provide a nominal 60 degree cone of coverage looking forward along the boresight of the aircraft.

To achieve this coverage and provide adequate antenna gain, several types of antennas at various locations were considered. Among the antennas considered were the following:

Quarter Wave Stub - The quarter wave stub is small but does not provide the directivity required to meet system requirements. Several locations were considered but none provided a clear view forward without shielding from other portions of the aircraft. Locations on the instrument pod were unsatisfactory because of aircraft noise shading the upper half of the forward look sector.

Directive Blade Antenna - An aerodynamic blade with directive elements could be developed to obtain a 6 to 7 dB gain in the forward quadrant. The location of the blades would have to be in the forward portion of the aircraft ahead of the cockpit to achieve the coverage required. A pair of blade antennas located at 45 degrees with respect to vertical would provide adequate coverage and reduce effects of cross polarization when the chase aircraft is in a roll maneuver. The blade antenna requires a fairly rigid mounting surface because of aerodynamic stress and therefore is limited to locations on the forward fuselage, where existing panels or access plates exist.

Honeywell is therefore considering the blade antenna as an alternate approach if the end fired array is not acceptable to the U.S. Air Force from an installation standpoint.

Standard Horn or Array - The standard horn or array antenna would require a location in the forward nose of the aircraft. It has been determined that space or access to the forward nose compartment does not exist because of the existence of the fire control radar. A standard horn or array in the nose cone of the instrument pod would not provide adequate coverage because the forward fuselage blanks the upper antenna pattern thus preventing coverage above the aircraft boresight.

A small array antenna located in the cockpit behind the plexiglass windshield was considered. The plexiglass windshield is approximately 9/16 inches thick and slopes at a 30 degree angle with respect ot the aircraft boresight. The 30 degree incident angle and the 9/16 inch thickness would cause pattern distortion, refraction and severe signal attenuation at 5.08 GHz because the thickness is almost exactly a quarter wave length at the operating frequency of the system.

1.4.3 The End Fired Array

A pair of END FIRED MICRO STRIP ARRAY antennas located at 45 degrees with respect to the aircraft vertical plane is the proposed solution. The antennas could be located at either the upper or lower half of the forward fuselage as shown in figure 4 (A and B).

The end fired array is a modification of a standard micro-strip array. The individual element of the array are fed via a phase network which results in a tilting of the E plane in a forward direction. The resultant tilt places the peak of the main lobe approximately 10^{o} above the plane of the antenna as shown in figure 5 (B).

The antenna is dimensionally 2 inches by 4 inches and 1/16 inches thick. This results in a "patch" like antenna which is easy to install.

A small hole in the fuselage or access plate will be required to have access to the antenna connector which pertrudes from the back of the antenna. The antennas can be bolted, riveted to the fuselage or secured to a removable access panel via an EPOXY ADHESIVE if panels exists at the proper location.

1.4.4 Orientation and Cross Polarization

The target aircraft antennas will have an orientation where the E plane is vertical by virtue of the quarter wave stub antennas. The chase aircraft will have a resultant E plane orientation in the vertical plane via two antennas mounted at 45^{o} with respect to vertical. The result is a loss of approximately 3 dB in sensitivity if both aircraft are flying straight and level.

If the chase aircraft is maneuvering at severe roll angles, one antenna will increase in signal as the other antenna fades in signal due to cross polarization.

The result of this orientation is that the system will have an initial 3 dB signal loss due to pattern polarization, but the signal will remain

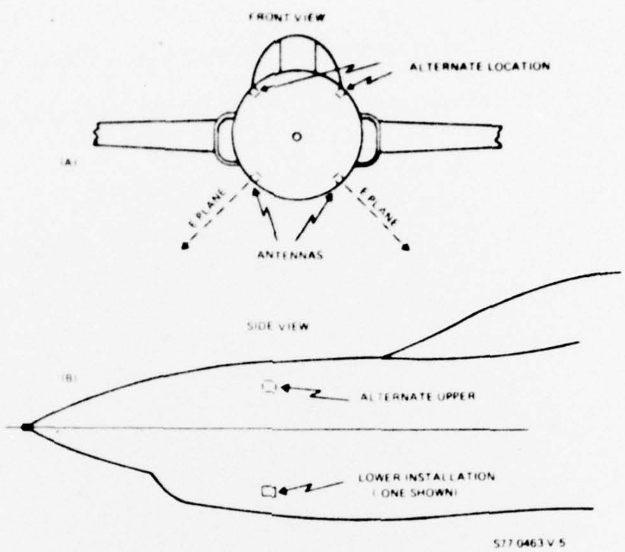

Figure 10. Antenna Installation

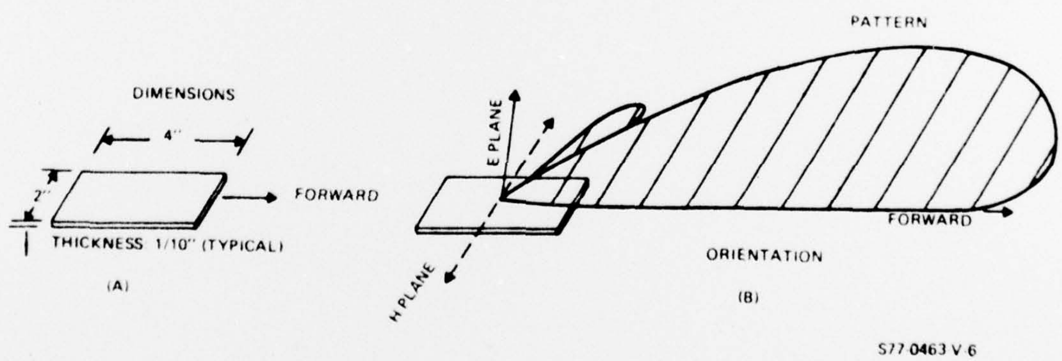

Figure 11. Antenna Parameters

relatively constant at all roll angles during maneuvers. This will increase the ability of the system to maintain track or "LOCK ON" during severe maneuvers.

APPENDIX B

FLIGHT TEST SUMMARY

Flight Number	Date (1976)	Flight Time (hr.)	Test	Target	Crew
1*	27 Feb	1.4	Acoustic scorer/double sighter burst	FIGAT	Meschko/McDonald
2	10 Mar	1.3	Systems check/tower flyby	-	Casper/Crimmel
3*	16 Mar	1.0	Systems check	F-4	Casper/Crimmel
4*	18 Mar	1.0	Systems check	F-4	Meschko/Crimmel
5*	22 Mar	0.5	Systems check	-	Casper/Crimmel
6*	9 Apr	0.5	Systems check	F-4	Gardner/Crimmel
7	12 Apr	0.7	Systems check	F-4	Gardner/Crimmel
8*	14 Apr	0.5	Systems check	F-4	Gardner/Crimmel
9*	19 Apr	0.9	Systems check	F-4	Marsk/Gardner
10*	23 Apr	1.1	Systems check	F-4	Casper/Crimmel
11*	26 Apr	0.5	Systems check	-	Gardner/Crimmel
12*	28 Apr	0.4	Systems check/power check	-	Gardner/Crimmel
13*	29 Apr	1.1	Systems check/target for F-15	-	Gardner/Crimmel
14*	29 Apr	1.0	Systems check/target for F-15	-	Casper/Crimmel
15*	20 May	0.6	Systems check	-	Casper/Crimmel
16*	21 May	1.1	Systems check/target for F-4G	-	Gardner/Crimmel
17*	25 May	1.2	Systems check	-	Meschko/Crimmel
18	28 May	1.1	Systems check	-	Casper/Crimmel
19	2 Jun	1.2	Systems check	-	Gardner/Crimmel
20	4 Jun	1.2	Tracking/Acoustic scorer check	FIGAT	Casper/Meschko
21*	7 Jun	0.7	Target destroyed on takeoff	FIGAT	Gardner/McDonald
22	14 Jun	1.2	Tracking with DALCOS	FIGAT	Gardner/Crimmel
23	17 Jun	1.5	Tracking with DALCOS	FIGAT	Aitken/Meschko
24*	18 Jun	0.7	Target lost prior to range	FIGAT	McDonald/Crimmel
25	21 Jun	1.1	Tracking with DALCOS	FIGAT	McDonald/Crimmel
26	24 Jun	1.5	Tracking with DALCOS	FIGAT	Caspter/Crimmel
27	24 Jun	1.7	Tracking with HLGS	FIGAT	Milam/McDonald
28	25 Jun	1.7	Tracking with HLGS	FIGAT	Casper/Crimmel
29*	28 Jun	0.7	Lost banner on takeoff	Banner	Casper/Crimmel
30*	29 Jun	0.4	Air abort/tow aircraft	Banner	Casper/Crimmel

FLIGHT TEST SUMMARY (Continued)

Flight Number	Date (1976)	Flight Time (hr)	Test	Target	Crew
31	30 Jun	1.4	Tracking with DALCOS	Banner	Meschko/Crimmel
32	1 Jul	1.5	Tracking with DALCOS	Banner	Casper/Crimmel
33	2 Jul	1.5	Tracking with DALCOS	Banner	Meschko/Crimmel
34	10 Jul	0.7	Functional check flight	-	Marks/Crimmel
35	12 Jul	1.5	Tracking with DALCOS	Banner	Gardner/Crimmel
36	13 Jul	1.7	Snapshoot with HLGS	Banner	Casper/Mullane
37*	14 Jul	0.9	DME calibration	F-4	Casper/Crimmel
38	16 Jul	1.3	Tracking with HLGS	Banner	Casper/Crimmel
39*	19 Jul	1.4	Gun jammed	Banner	Gardner/Crimmel
40	23 Jul	1.5	Tracking with HLGS	Banner	Casper/Crimmel
41*	26 Jul	1.1	Lost target in flight	Banner	McDonald/Casper
42	29 Jul	1.7	Tracking with HLGS	Banner	McDonald/Crimmel
43	30 Jul	1.8	Tracking with HLGS	Banner	McDonald/Crimmel
44*	2 Aug	1.0	Air abort/shooter aircraft	Banner	Gardner/Crimmel
45	4 Aug	1.7	Tracking with DALCOS	FIGAT	Meschko/Gardner
46*	5 Aug	1.4	Air abort/tow aircraft	Banner	Gardner/Meschko
47	6 Aug	1.5	Radar range calibration	F-4	Meschko/Gardner
48	9 Aug	1.2	Night tracer firings	-	Meschko/Crimmel
49*	10 Aug	0.7	Air abort/tow aircraft	Banner	Gardner/Crimmel
50	11 Aug	1.0	Night tracer firings	-	Meschko/Crimmel
51*	12 Aug	0.7	Air abort/tow aircraft	Banner	Gardner/Crimmel
52	16 Aug	1.0	Night tracer firings	-	Meschko/Crimmel
53*	17 Aug	0.4	Air abort/tow aircraft	Banner	Meschko/Crimmel
54*	18 Aug	0.9	Lost target in flight	Banner	Meschko/Crimmel
55	18 Aug	1.2	Night tracer firings	-	Meschko/Pomeroy
56	19 Aug	1.3	Tracking with DALCOS	Banner	Meschko/Pomeroy
57*	20 Aug	0.5	Lost target in flight	Banner	Meschko/Sizemore
58	23 Aug	1.5	Tracking with HLGS	Banner	Gardner/Sizemore
59	25 Aug	1.3	Tracking HLGS	Dart	Gardner/Pomeroy
60	26 Aug	1.5	Tracking with DALCOS/HLGS	Banner	Gardner/Sizemore
61	27 Aug	1.3	Tracking with DALCOS	Banner	Meschko/Pomeroy
62	30 Aug	1.1	Tracking with HLGS	Dart	Gardner/Pomeroy
63*	30 Aug	0.4	Air abort/shooter aircraft	Dart	Gardner/Pomeroy
64	31 Aug	1.3	Tracking with HLGS	Dart	Meschko/Sizemore
65	1 Sep	1.0	Tracking with DALCOS/HLGS	Dart	Gardner/Pomeroy

FLIGHT TEST SUMMARY (Continued)

Flight Number	Date (1976)	Flight Time (hr)	Test	Target	Crew
66*	1 Sep	0.8	Lost target on takeoff	Dart	Gardner/Sizemore
67	7 Sep	1.3	Tracking with DALCOS/HLGS	FIGAT	Meschko/Pomeroy
68*	8 Sep	1.0	Lost target in flight	FIGAT	Gardner/Crimmel
69	8 Sep	1.1	Tracking with DALCOS	FIGAT	Gardner/Crimmel
70	13 Sep	1.6	Tracking with DALCOS	FIGAT	Meschko/Pomeroy
71*	14 Sep	0.4	Air abort/tow aircraft	-	Meschko/Crimmel
72	15 Sep	1.2	Tracking with DALCOS/HLGS	Dart	Meschko/Crimmel
73	16 Sep	1.6	Tracking with DALCOS/HLGS	FIGAT	Gardner/Crimmel
74	16 Sep	1.2	Tracking with DALCOS	FIGAT	Meschko/Crimmel
75*	17 Sep	1.0	Lost target in flight	Dart	Meschko/Gardner
76	20 Sep	1.1	Tracking with HLGS	Dart	Gardner/Crimmel
77	20 Sep	1.1	Tracking with HLGS	Dart	Meschko/Crimmel
78	20 Sep	1.1	Tracking with HLGS/DALCOS	Dart	Gardner/Crimmel
79	22 Sep	1.2	Tracking with HLGS/DALCOS	Dart	Howard/Crimmel
70*	23 Sep	1.3	Lost target on takeoff	Banner	Meschko/Pomeroy
81	23 Sep	1.4	Operational utility	Banner	Meschko/Pomeroy
82	24 Sep	1.4	Operational utility	Banner	Meschko/Pomeroy
83	24 Sep	1.4	Operational utility	Banner	Meschko/Pomeroy
84	27 Sep	1.4	Operational utility	Banner	Gardner/Pomeroy
85	27 Sep	1.4	Operational utility	Banner	Gardner/Pomeroy
86*	28 Sep	0.8	Air abort/shooter aircraft	Banner	Gardner/Pomeroy
87	28 Sep	1.5	Operational utility	Banner	Meschko/Pomeroy
88	29 Sep	1.5	Operational utility	Banner	Meschko/Pomeroy
89	29 Sep	1.3	Operational utility	Banner	Gardner/Pomeroy
90*	30 Sep	0.7	Air abort/shooter aircraft	FIGAT	Gardner/Pomeroy
91*	30 Sep	0.7	Lost target on takeoff	FIGAT	Meschko/Pomeroy
92	30 Sep	1.2	Operational utility	FIGAT	Meschko/Pomeroy

Total Flight Hours - 103.0
Effective Sorties - 54
*Noneffective Sorties - 38

A noneffective sortie was one where the flight objective could not be met due to system malfunctions, target malfunction, or air abort.

Target Utilization
- FIGAT flights - 19
- Dart flights - 12
- Banner flights - 34