FINAL REPORT

MODIFICATION OF 16.5 GHz SIDE-LOOKING

RADAR SYSTEM FOR NASA C-130 AIRCRAFT

CONTRACT NO. NAS9-9116

PHILCO Ford

PHILCO-FORD CORPORATION
Aeronutronic Division
Newport Beach, California

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Prepared for: NASA Manned Spacecraft Center
Houston, Texas 77058

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Submitted by: R. E. McCain
R. E. McCain
Program Engineer

Approved by: J. N. Sherwood
J. N. Sherwood
Program Manager

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PHILCO Ford

PHILCO-FORD CORPORATION
Aeronutronic Division
Newport Beach, Calif. • 92663

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SECTION 1

INTRODUCTION

This final report covers the modification of a 16.5 GHz Side-Looking Radar (SLAR) for installation in a C-130 Aircraft in support of the NASA Earth Resources Program. The delivered Radar System consists of a modified AN/DPD-2 Radar Electronic Assembly (GFE), Multiple Polarized Antenna, Control Panel and Antenna Pressurization System. Special test equipment in the form of a System Preflight Calibrator and Recorder Calibrator was fabricated and delivered to support the alignment, checkout and calibration of the Radar System. In addition, component and assembly spares were procured, fabricated and delivered to support the Radar System during the flight test program.

The basic AN/DPD-2 Electronic Assembly had been modified to the NASA configuration under previous Contracts NAS9-7240 and NAS9-7835 and was GFE to support this program. In addition, the Multiple Polarized Antenna, Control Panel and Antenna Pressurization System are identical/similar to hardware previously delivered on those referenced contracts. The reader is referred to Aeronutronic Publication No. U-4281,"Final Report, Phase I, Modification of 16.5 GHz Side-Looking Radar System, Contract No. NAS9-7240," dated 30 November 1967, and Aeronutronic Publication No. U-4281, "Final Report, Phase II, Modification of 16.5 GHz Side-Looking Radar System, Contract No. NAS9-7835," dated 23 September 1968 for a description of the modifications performed on the basic hardware items. This report primarily discusses the modifications required to effect the C-130 installation/application and those hardware items not previously supplied.

This program also provided the installation design and associated mounting hardware to interface with the aircraft mounting racks as detailed by LTV

Electrosystems, Inc. Interface Specification, IFS No. 69-IFS-20001, dated 20 February 1969, which was prepared for NASA and approved by Philco-Ford.

Intra-system cabling and connectors to support the aircraft cabling in accordance with LTV Drawing No. 8471-60220, "16.5 GHz SLAR Interconnect Block Diagram," dated 21 February 1969 were provided. A complete set of system cables to permit testing in the laboratory without the necessity of removing cables from the aircraft installation was also provided under this contract.

SECTION 2

TECHNICAL DISCUSSION

The following is a discussion of the required modifications and description of hardware items delivered under the subject contract.

2.1 MODIFIED 16.5 GHz RADAR ELECTRONIC ASSEMBLY

This unit is a basic AN/DPD-2 Electronic Assembly modified for the intended NASA application. The basic modifications were performed under Contracts NAS9-7240 and NAS9-7835, described in the final reports on these contracts as referenced herein, and the modified unit was GFE to this program to support the overall system integration and test requirements.

In the process of completing the system integration tests several problems were encountered with the GFE Electronic Assembly which required fault isolation and subsequent re-alignment or repair of major subassemblies. The problem areas and the subsequent repair action are briefly discussed in the succeeding paragraphs.

2.1.1 LOW VOLTAGE POWER SUPPLY

As received, the +200 VDC supply was inoperative and the ripple on the +5.7 VDC supply was excessive. The +200 VDC supply required the replacement of rectifier diodes and the +5.7 VDC supply required replacement of a filter capacitor in the regulator assembly.

During the course of completing overall system integration test, it was noted that the power supply short-circuit protection functions were not operating properly. The supply has the capability of sensing "over-current" load conditions due to shorts or non-catastrophic intermittent failures, and isolating the supply from the load. The protective circuitry also has an automatic reset feature which periodically reconnects the supply to the load to determine whether the problem was of an intermittent or catastrophic nature. Final analysis of the situation indicated the basic problem to be faulty operation of the reset circuitry which also limits the duty cycle on those circuit components associated with the load isolation feature. However, before the problem had been completely analyzed, several semiconductor components in various of the individual supply sections had been damaged and required replacement.

2.1.2 TRANSMITTER/MODULATOR

During the system integration test phase, it was noted that the Transmitter was periodically being disabled via the overload protective circuitry in the Modulator. The problem was random in nature and was determined to result from "spurious" triggering of the thyratron switch tube. Several changes were required to eliminate the problem -- the most significant of which were the incorporation of a diode(s) in series with the modulator trigger input circuitry which effectively raised the triggering threshold levels and thereby rendered the circuitry less susceptible to spurious triggering on noise, transients, etc, and the incorporation of a diode across the Film Used Counter in the Control Panel to suppress the "inductive" transient resulting from the periodic triggering of the Counter, as actuated by the Film Drive mechanism. These modifications appear to be "uniquely" required dependent upon the system configuration in terms of cabling, grounds, etc. and were not required in basic AN/DPD-2 Radar configuration.

2.1.3 RECEIVER

As received, the Preamplifier in the Vertical Receiver Channel was inoperative. The problem was traced to a shorted decoupling capacitor on the Preamp B+ line which probably was the initial cause for the inoperative status of the +200 VDC supply in the Low Voltage Power Supply. The capacitor was replaced and operation returned to normal.

During the course of completing the system integration tests, intermittent losses of signal/gain in the Vertical Hi-Res IF Channel was noted. The problem was traced to an intermittent connection (internal to the capacitor case) in an interstage coupling capacitor which was subsequently replaced and operation returned to normal.

2.1.4 RECORDER

The Film Drive Motor failed during the system integration test. Disassembly of the gearhead assembly from the basic motor indicated the problem to be the bearing in the motor assembly. This is a special motor and replacements are not readily available. The required replacement was made using the motor, Kearfott-type CM10360410 being procured as spares, Item No. 10, under the subject contract. This was done with the concurrence of the Contract Technical Monitor. It is recommended that consideration be given to the procurement of two (2) spare motors to support the P3V and C-130 installations as the motor represents a long-lead procurement item.

2.1.5 DATA PROCESSOR

Insufficient target build-up at the output of the Video Sweep Integrator (VSI) section of the Data Processor was noted during the system integration tests. The symptoms indicated excessive signal attenuation through the VSI channel which could be related to high insertion loss in the quartz delay line and/or marginal gain performance in either the line driver or Post Delay Amplifier (PDA). Detailed RF impedance measurements indicated failures in both the input and output transducers to the 1072 μsec quartz delay line. The problem is one of attachment (bonding) the transducer to the quartz delay line elements and has been a recurring problem over the life of the AN/DPD-2 Systems. These units are non-repairable as the original vendor is currently considered to be a non-qualified source for this assembly. Currently qualified sources are available; however, their techniques in fabricating the delay line and transducer elements are not compatible with the repair of other vendor supplied units. The delay lines are custom packaged specifically for the AN/DPD-2 Data Processor application and are not readily available off-the-shelf.

A spare Data Processor (Item #1) and a spare Delay Line Assembly (Items 16, 25, 26, 27) were being procured under the subject contract. In the interest of program scheduling and compatibility with the C-130 Aircraft installation schedules, it was decided (with the concurrence of NASA Program Technical Monitor) to install the spare Data Processor in the Electronic Assembly, complete the system integration testing and deliver the system.

The spare Delay Line Assembly was installed in the GFE Data Processor and delivered as an assembly rather than as a component spare.

2.2 MULTIPLE POLARIZED ANTENNA

This unit is essentially identical to the antenna delivered under Contract NAS9-7835 (described in the final report previously referenced) and flight tested on the NASA P3V Aircraft. Some minor changes to the design were made particularly in the area of the line feed assembly which was structurally "beefed-up" in the lens mounting flange area to provide a more rigid surface on which to effect the "O" ring pressure seal.

Some unanticipated problems were encountered in achieving the desired pattern characteristics. In the original design, dielectric plugs were used to cover each radiating slot to achieve the required slot coupling for a "near uniformly" weighted aperture. Initial testing of this antenna with the dielectric plugs installed indicated a high sidelobe condition ($\approx$ -6 db) for the vertical polarization case. The design specification for the antenna is -10 db minimum. Selective removal of the dielectric plugs on the first 20 slots of the line source resulted in sidelobe improvements. This empirical selection was terminated with a sidelobe level of -9.5 db as the condition representing the best compromise between gain, beamwidth and sidelobes. Sidelobe levels are not of first order importance in this type system as the synthetic aperture will provide in excess of 20 db discrimination.

Irregularities in the elevation patterns were noted as being similar to those evidenced on the original antenna fabricated under Contract NAS9-7835. The installation of RF absorbent material within the antenna mounting enclosure and the addition of a strip of dielectric material approximately three feet in length, along both top edges of the lens reduced the spurious reflections sufficiently to minimize the noted regularities. It was also noted that the gain of this antenna assembly including the radome enclosure was in the order of 1 db less than the previous model. This can be primarily attributed to the increase in radome thickness for structural integrity. The thicker radome design was implemented in the field on the previous models after pattern tests with the original (thinner) radome had been completed.

The following is a summary of the final antenna test data:

Parameter	Vertical Pol.	Horiz. Pol.	Design Goal
Az. Squint Angle	1.8°	1.7°	$1.5^{\circ} \pm 0.5^{\circ}$
Az. Beamwidth	0.6°	0.75°	0.75° max.
Az. Sidelobe	-9.5 db	-14.2 db	-10 db max.
Gain	29.2 db	29.8 db	30 db min.
VSWR	1.33	1.38	1.4 max.
Pressure Leakage	0.1#/min		1.0 #/min.
Cross-Talk	-21 db		-15 db min.
*Elev. Squint Angle	$+3^{\circ}$	$+3^{\circ}$	not specified

*Measured at upper tilt position limit

Parameter	Vertical Pol.	Horiz. Pol.	Design Goal
Elevation Pattern			
Ref	0	+0.7 db	0 db
$+8^{o}$	-2.3 db	-0.4 db	- 1 db min.
-4^{o}	0	+0.2 db	- 1 db min.
-16^{o}	-3.6 db	-4.6 db	- 6 db min.
-28^{o}	-12.2 db	-13.0 db	-11 db min.
-40^{o}	-11.5 db	-15.2 db	-16 db min.
-46^{o}	-15.7 db	-17.2 db	-19 db min.
-52^{o}	-20.9 db	-19.7 db	-23 db min.

There are some minor deviations to the elevation pattern coverage design goals. However, this antenna is very similar in that respect to the model being flown in the NASA P3V Aircraft which has flight demonstrated adequate elevation coverage. The antenna patterns are shown in Figures 1 through 3.

The range of tilt control, referenced to "steering reference" point on the antenna elevation pattern, in terms of depression angle is 0^{o} to -24^{o} which should be more than adequate. The range of depression angles required by the aircraft mission profiles is -4^{o} to -19^{o}.

2.3 CONTROL PANEL ASSEMBLY

The Control Panel delivered under this contract is essentially identical to that designed and delivered under Contract NAS9-7835. Two (2) minor modifications have been incorporated to facilitate ground testing and to accommodate the interface with the C-130 Navigation System.

Operation at altitudes in excess of 10,000 feet MSL require pressurization in the high power waveguide sections of the system to prevent electrical breakdown. In the basic system, waveguide pressure integrity is maintained from the magnetron output flange through the antenna line source. A low pressure interlock switch is included to prevent the application of high voltage to the Transmitter/Modulator section in the absence of and/or low waveguide pressure. Therefore, the Transmitter cannot be operated without the waveguide pressure or manual (hard-wired) bypassing of the interlock. To facilitate system testing on the ground or in the laboratory where the pressurized waveguide is not required, an interlock bypass switch has been added to the Control Panel Assembly. The switch is located on top of the main chassis and is inaccessible to the operator with the Control Panel mounted in place. However, the Control Panel is mounted on slides which allows it to be pulled out of the mounting rack for operator accessibility.

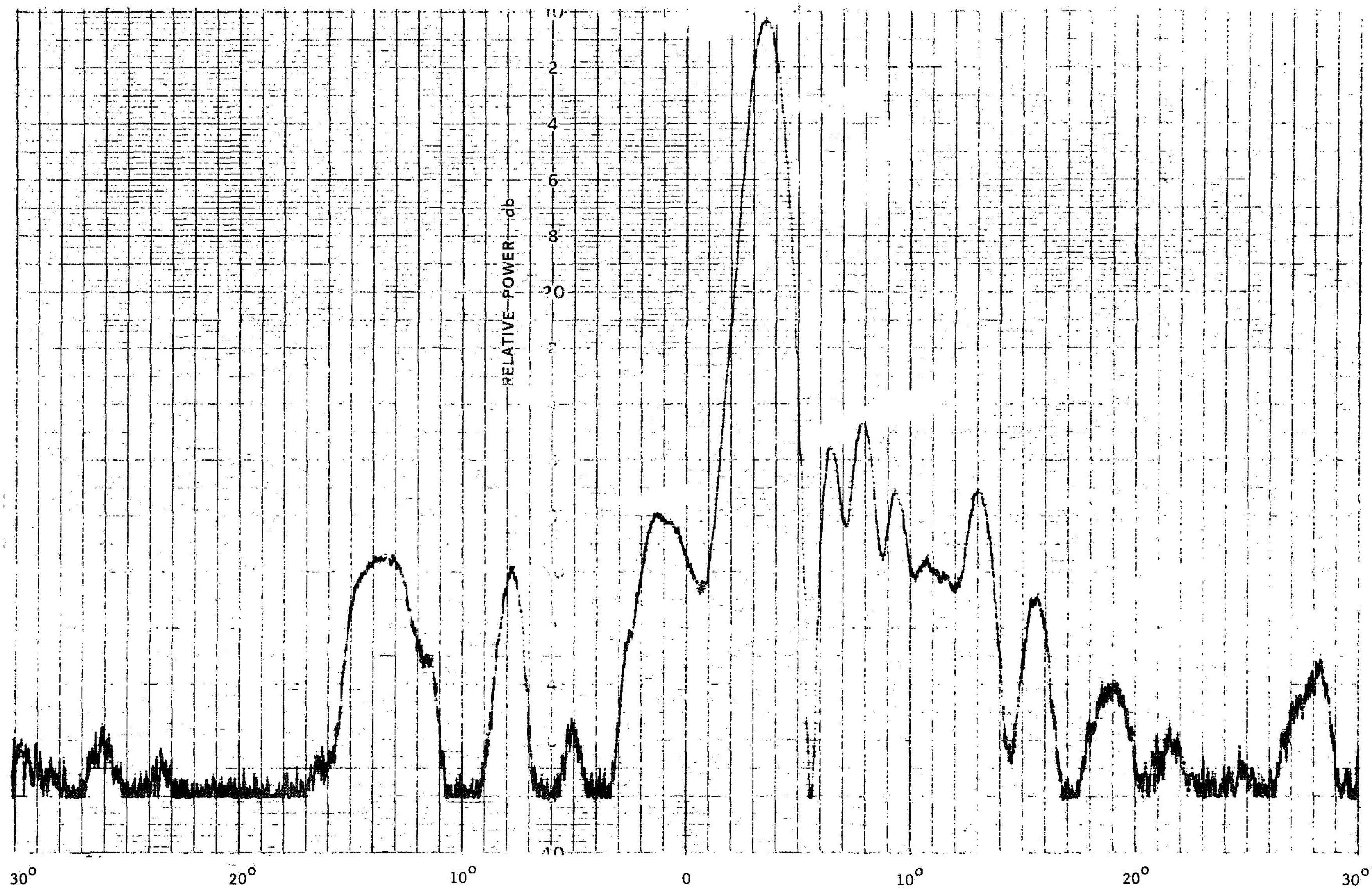

FIGURE 1. AZIMUTH PATTERN FOR HORIZONTAL POLARIZATION

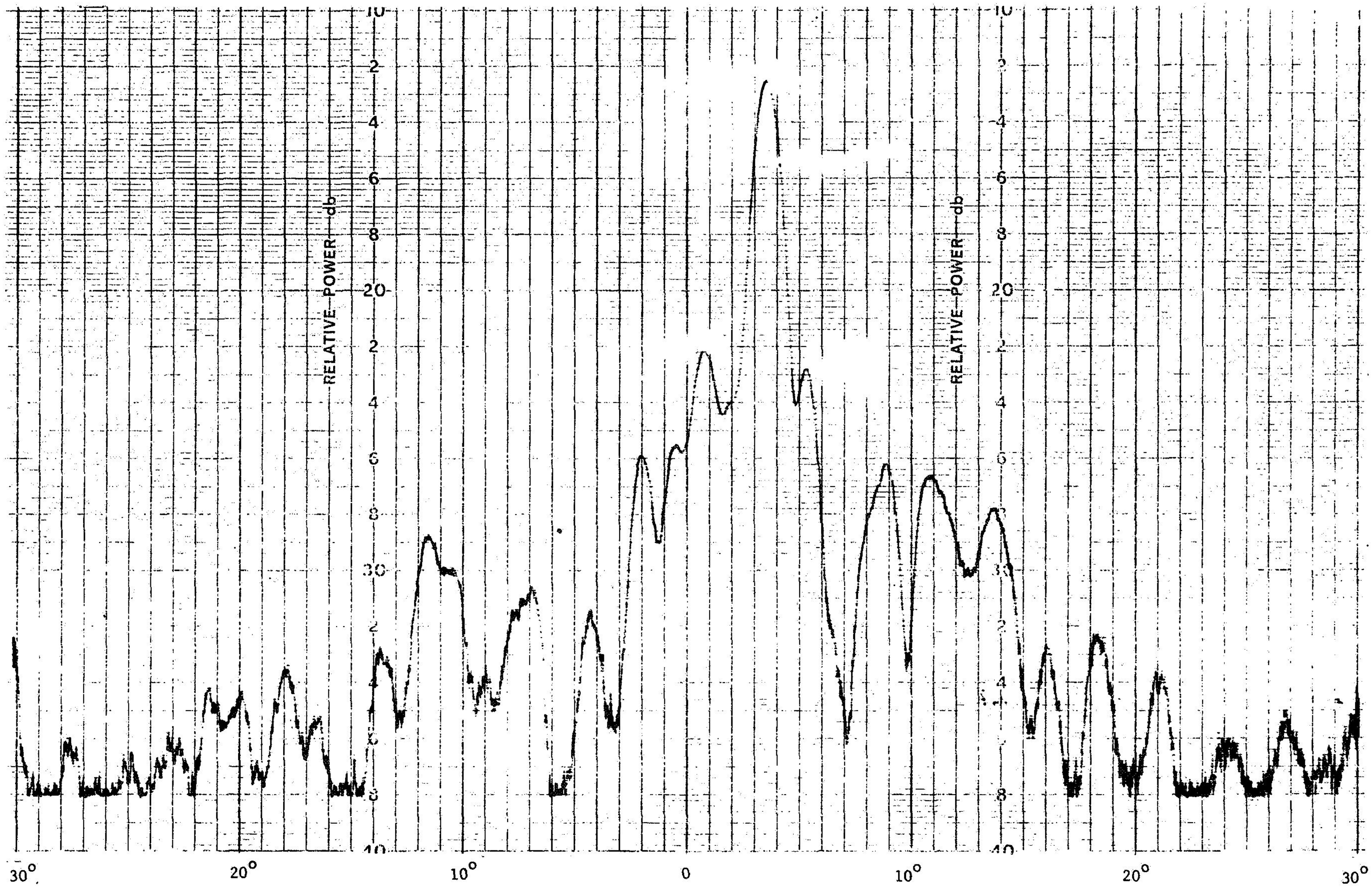

FIGURE 2. AZIMUTH PATTERN FOR VERTICAL POLARIZATION

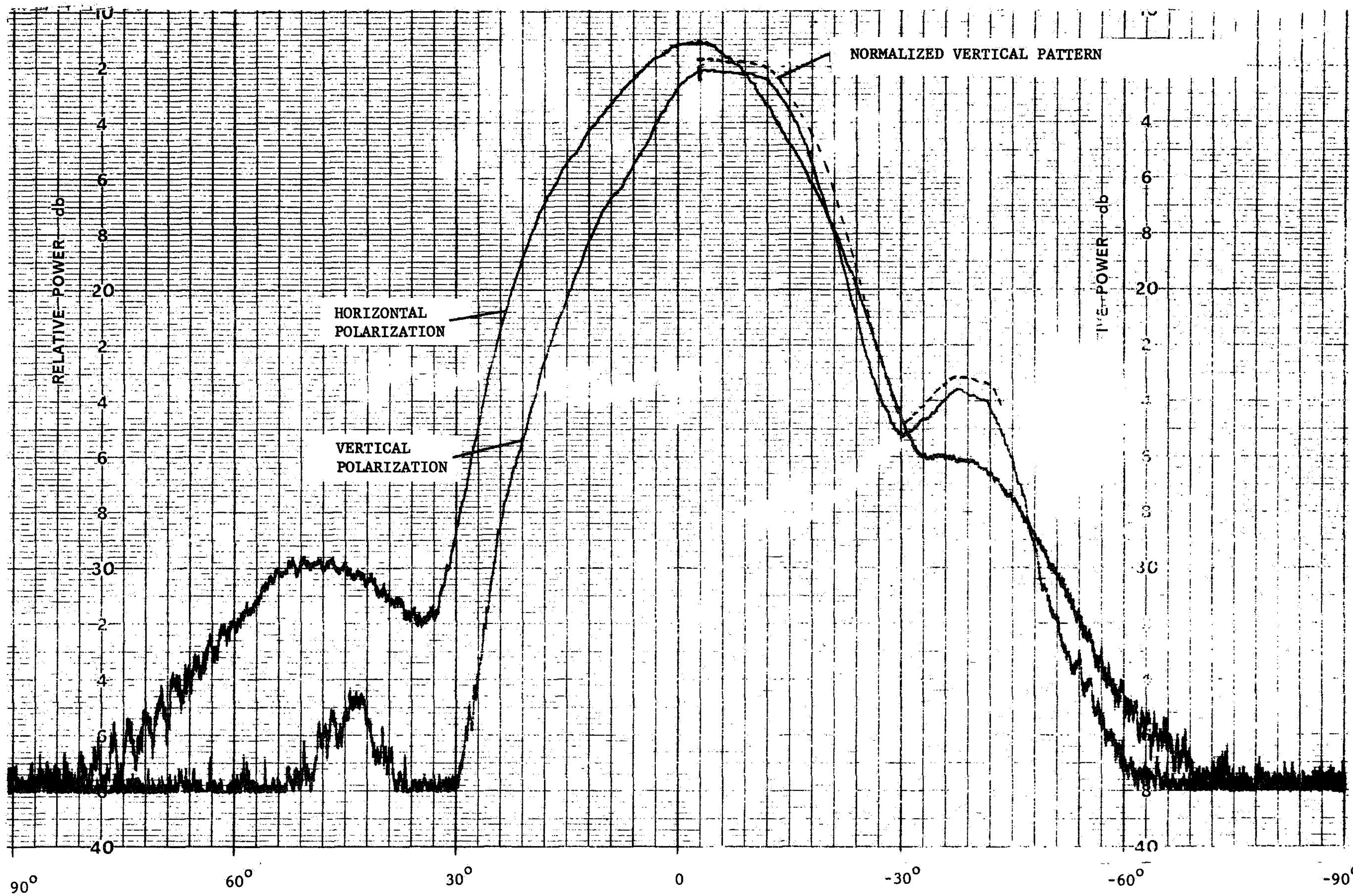

FIGURE 3. ELEVATION PATTERNS OF MULTIPLE POLARIZED ANTENNA

In the "NORMAL" bypass switch condition, the switch is completely removed from the circuitry and the transmitter firing capability and low pressure indicator are controlled by the Low Pressure Interlock Switch. In the "By-Pass" condition, the added switch completely bypasses the Low Pressure Switch relative to controlling the transmitter firing capability. In this position, the Low Pressure Warning Light is also activated to preclude operator error from attempting to fire the transmitter in the airborne application.

The Control Panel also includes those functions necessary to interface the modified 16.5 GHz System with the aircraft navigation systems. The radar requires V_G (aircraft ground speed) and D_A (aircraft drift angle) inputs to maintain geometric fidelity of the recorded ground maps. These inputs are required in DC analog voltage format with a specific scaling. For example, V_G scaling requirements are .0213 volts per feet per second. D_A scaling requirements are dependent upon V_G (drift angle pot is energized by V_G voltage) and for V_G = 500 feet per second are 0.133 volts per degree of drift.

For the P3V Aircraft installation under Contract NAS9-7835, the aircraft navigation system provided D_A and V_G inputs in the form of 3-wire synchro outputs. Conversion to the required DC analog outputs was accomplished by including two (2) synchro follow-up servos with the appropriate scaling factors derived from potentiometer output follow-up shafts. When in the manual D_A and V_G positions, the aircraft 3-wire synchros were replaced by identical synchros on the Control Panel.

For the C-130 application, the Navigation System is an LN-12D which provides D_A information as a 3-wire synchro output with a 1:1 ratio which is identical to the P3V configuration and the same type synchro follow-up servo is included in the Control Panel. However, the LN-12D provides V_G information in a DC analog form with a scaling of 0.0066 volts per feet per second. The system requires DC analog signal at a scaling of 0.213 volts per feet per second. Therefore, the synchro follow-up servo has to be replaced with an operational amplifier with a gain of 3.23 to provide the proper scaling interface. Also, the synchro previously used for manual V_G functions has to be replaced by a potentiometer with an output scaling of 0.0066 volts per feet per second.

In all other respects, the Control Panel delivered under this contract is identical to that delivered under Contract NAS9-7835.

2.4 SYSTEM PREFLIGHT CALIBRATOR

The System Preflight Calibrator designed and delivered under this contract is similar in functional characteristics to the AN/DPD-2 System Preflight Calibrator being utilized to support the P3V Aircraft System. Basically, the unit is a self-contained test set which provides a metered voltage monitoring system for GO/NO-GO indications of equipment operability status and a coherent target generator which can be utilized in the set-up and calibration of system performance.

There are functions within the basic AN/DPD-2 Radar which have been removed from the system for the NASA applications. Correspondently, in the interest of simplicity and costs, those test functions not required by the NASA radar configuration were deleted. The packaging design has been completely modified to accommodate mounting in a standard 19-inch equipment rack. Auxiliary dust covers are also provided to be installed to allow the Calibrator to be used as a bench instrument in a laboratory environment.

2.5 RECORDER CALIBRATOR

The Recorder Calibrator delivered under this contract is identical to the AN/DPD-2 Recorder Calibrator being utilized to support the P3V Aircraft System with the exception of the prism drive motor utilized to optically transmit the light output of the standard light source to the photomultiplier aperture. The drive motor used in previous models is no longer available as a standard part and has been replaced in the current model with a motor of approximately twice the speed. In use this results in the pulse waveform depicting the photomultiplier output from the standard light source occurring at twice the repetition rate as on previous models. The repetition rate is not a critical parameter.

The Recorder Calibrator and associated masks are used to adjust the position and intensity of the CRT sweeps in the Recorder Assembly.

2.6 SPARES

Component and assembly level spares were delivered in accordance with the detailed spares list in the subject contract with the following exceptions:

1. Failure of the Film Drive Motor in the Recorder Assembly (GFE) required the expending of Spares Item No. 10, Motor-Generator, P/N CM10360410 to effect the necessary repairs.

2. Failure of the 1072 μsec quartz delay line in the Data Processor (GFE) required the expending of Spares Item No. 16, Inner Oven Assembly, SM-D-533056, No. 25, Line Drivers (2), SM-D-533226, No. 26, CPS Post Delay Amplifier, SM-D-533223 and No. 27, VSI Post Delay Amplifier, SM-D-533229 to effect the necessary repairs.

2.7 LABORATORY INTERFACE CABLES

A set of system cables which would allow testing of the complete 16.5 GHz SLAR System in a laboratory environment was fabricated and delivered under this contract.

The set of laboratory cables consists of the following cables with reference to LTV Electrosystems, Inc. Coordination Drawing No. 8471-60220, "16.5 GHz SLAR Interconnect Block Diagram," dated 21 February 1969.

Cable No. Designation	Cable P/N	From	To	Qty/ Set
1	40271	Primary Power (no connector)	SLAR Control Panel (P1)	1
2	40272	SLAR Control Panel (P2)	SLAR Electronics Unit (P20)	1
3	40273	SLAR Control Panel (P3)	SLAR Pressure Unit (P31)	1
4	40274	SLAR Control Panel (P4)	SLAR Electronics Unit (AP2, P13, P14, J25)	1
5	40275	SLAR Control Panel (P5)	SLAR Accelerometer (P22)	1
6	40276	SLAR Control Panel (P6)	SLAR Electronics Unit (P21) & Preflight Calibrator (P9)	1
7	40277	SLAR Electronics Rack (P25)	SLAR Antenna (J30)	1
8	40278	Preflight Calibrator (P8)	SLAR Electronics Unit (P10)	1
9	40295	SLAR Directional Coupler (P38)	Preflight Calibrator (P37)	1
J-Box (1-2)	40279	N/A	N/A	1

2.8 AIRCRAFT INSTALLATION CONNECTORS

This contract provided that Philco-Ford supply the connectors (cable end which interfaces with Philco-Ford delivered hardware only) to support the fabrication of the aircraft cabling system by LTV Electrosystems, Inc.

The set of aircraft installation connectors consists of the following connectors with reference to LTV Electrosystems, Inc. Coordination Drawing No. 8471-60220, "16.5 GHz SLAR Interconnect Block Diagram," dated 21 February 1969.

Ref. Symbol	Part No.	Qty/Set
P1	DM9728-37-3S	1
P3	DS07-27-8P-059	1
P5	DSM07-12-14PW-059	1
P7	CK6F18-55S	1
P25	CK6F14-31S	1
P29	KPSE06-F-18-32S	1
J29	KPTB-18-32P	1
P31	MS3116E-12-10S	1
P22	DSM07-12-14SW-059	1

2.9 ANTENNA PRESSURE SYSTEM

The Antenna Pressure System for the C-130 Aircraft configuration is identical to that provided for the P3V installation with the exception of the mounting location for the low pressure sensing - transmitter interlock switch.

In the P3V installation the pressure switch is remotely located from the basic Pressure Unit and mounted to the rear of the Electronics Assembly mounting rack. The result is a somewhat complex installation in terms of the required pressure tubing routing to the waveguides, with a "tee" connection to accommodate the additional tubing run to the pressure switch. For the C-130 configuration, the low pressure sensing switch is mounted as an integral part of the Antenna Pressurization Unit which results in a much simpler interconnection installation.

SECTION 3

RELIABILITY ANALYSIS

A reliability prediction for the basic AN/DPD-2 Radar System was performed for an ambient temperature of 25°C under Contract DA-28-043-AMC-00211(Y) and the results included in the Contract Final Report, Technical Report ECOM-002," dated July 1966. These predictions were made in accordance with the procedures of MIL-HDBK-217, "Reliability Stress and Failure Rate Data for Electronic Equipment," 8 August 1962. These data were modified to reflect the deletions and addition of parts necessitated by the NASA modifications under Contract NAS9-7835 including the additional failure rate data generated for the Multiple Polarized Antenna and Control Panel which are unique to the NASA radar configuration. The inherent reliability in terms of MTBF was predicted at 620 hours for the Modified 16.5 GHz SLAR from these calculations.

The subject contract provides for similar type data on the special AN/DPD-2 test equipment, System Preflight Calibrator and System Recorder Calibrator, which were designed concurrently with the basic AN/DPD-2 Radar System under Contract DA-28-043-00211(Y). Many of the components in the test equipment design are common to the Radar System and the failure rates from the referenced report were used accordingly. Failure rates for the new components were derived from MIL-HDBK-217A and FARADA.

At an ambient air temperature of 25°C, the inherent MTBF of the System Pre-Flight Calibrator and System Recorder Calibrator has been calculated to be 2280 hours and 5740 hours, respectively. Individual subassembly contributions to these failure rates are tabulated as follows:

System Preflight Calibrator	Failures/10^6 hrs
Power Supply	8.80
Panel & Cable Assembly	297.76
IF Preamplifier	13.01
IF Processor	43.45
Meter Panel Assembly	75.53
TOTAL	438.55
System Recorder Calibrator	173.81

The estimated MTBF's relate only to the inherent reliability capability. The MTBF in operational use may be expected to be lower. MIL-STD-756 recommends a failure rate multiplier of 6.5 for adjusting MIL-HDBK-217 failure rates to an airborne application.

SECTION 4

AIRCRAFT INSTALLATION

The installation design for the SLAR System in the C-130 Aircraft was the subject of several coordination meetings between NASA, LTV Electrosystems and Philco-Ford early in the program. The installation design specifications are documented in LTV Electrosystems, Inc. Interface Specification IFS No. 69-IFS-20001 dated 20 February 1969, which was prepared for NASA and approved by Philco-Ford.

Philco-Ford delivered to NASA the following drawings which define the detailed mounting interface requirements.

Drawing No.	Title
42073	System Preflight Calibrator Mounting Interface
42074	SLAR Electronics Mounting Interface
42072	Control Panel Mounting Interface
42042	Antenna Enclosure Mounting Interface
40101	Outline and Mounting, Pressurization Set
42081	Electronic Unit, 16.5 GHz SLAR
40086	Accelerometer Installation

SECTION 5

DOCUMENTATION

A documentation package describing the Modified 16.5 GHz SLAR for the NASA applications consisting of approximately 300 drawings and various other documents (acceptance test procedures, etc.) were provided under Contract NAS9-7835.

An additional package consisting of approximately 60 drawings providing details unique to the C-130 Aircraft configuration, and reflecting additional hardware and spares not previously procured have been provided under the subject contract.

The level of documentation provided is sufficient to support the SLAR installation and maintenance of the radar system.