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Report No. FAA-RD-75-223

FAA WJH Technical Center
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TIME/FREQUENCY COLLISION AVOIDANCE SYSTEM EQUIPMENT PHASE I - DEVELOPMENT MODEL GROUND STATION AND ASSOCIATED AIRBORNE FEASIBILITY MODELS

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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16. Abstract

This report summarizes the work accomplished by McDonnell Douglas Electronics Company (MDEC) under contract with the FAA for Phase I development of Time/Frequency Collision Avoidance System (CAS) items. The procurement was for equipment, analysis, documentation and for services performed at the National Aviation Facilities Experimental Center (NAFEC).

Work performed at MDEC is described and includes: system analysis, design and development, fabrication and assembly, integration and test, and documentation.

Activities at NAFEC are also described and include: field training, preliminary functional tests, installation, and field acceptance test.

Equipment delivered to NAFEC is described and includes: a dual channel ground station, airborne fly-by synchronization equipment, and feasibility models of airborne CAS units for both air carrier and general aviation.
A complete list of references relating to contract documentation is included.
Appendices present the results of antenna measurements and reliability/maintainability studies.

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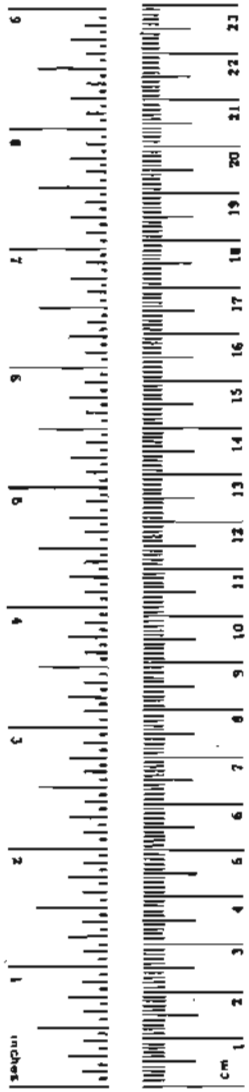
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

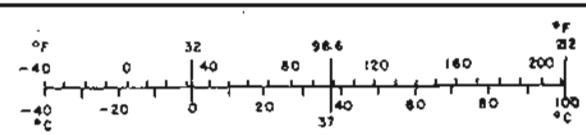
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

AFC	Automatic Frequency Control
ANTC	Air Navigation/Traffic Control (Division of ATA)
ARINC	Aeronautical Radio, Incorporated
ATA	Air Transport Association of America
ATCRBS	Air Traffic Control Radar Beacon System
BIT	Built-In-Test
BUM	Back-Up Mode
CAS	Collision Avoidance System
CAU	Collision Avoidance Unit
dB	Decibel
dBm	Decibels relative to one milliwatt
$\Delta R/\Delta T$	Delta Range divided by Delta Time (range rate)
DMS	Data Message Slot
FAA	Federal Aviation Administration
FBS	Fly-By Synchronization
Ft	Feet
GHz	Gigahertz
G/S	Ground Station
Hz	Hertz
IF	Intermediate Frequency
kHz	Kilohertz
KW	Kilowatt
MDEC	McDonnell Douglas Electronics Company
MHz	Megahertz
MI	Maneuver Indicator
NAFEC	National Aviation Facilities Experimental Center
n.mi.	Nautical Mile(s)
OMS	Own Message Slot
PFU	Precision Frequency Unit
PPS	Pulses Per Second
RF	Radio Frequency
Sync	Synchronization or Synchronized
T/F	Time and Frequency
VSI	Vertical Speed Indicator
VSWR	Voltage Standing Wave Ratio

1. INTRODUCTION

1.1 Scope

This is the final report on the work accomplished under contract DOT-FA73WA-3239 for Phase I (developmental) items. The procurement was for equipment, analysis, documentation, and services as set forth in the engineering requirement FAA-ER-240-016 and as amended by contract modifications (No. 1 through No. 7). The primary purpose of the basic contract was to develop and test a Time/Frequency (T/F) Collision Avoidance System (CAS) Ground Station and airborne synchronization equipment which operates to disseminate precise time required by the system. Contract modification No. 5 provided for several items of deliverable CAS airborne equipment and the loan of instrumentation. The purpose of the additional equipment is to allow test and evaluation of compatible general aviation and air carrier type CAS which employ a new, less expensive technique for range rate processing. All of the ground and airborne equipment was built by McDonnell Douglas Electronics Company (MDEC) and delivered to the FAA test facility at NAFEC where it successfully passed the field acceptance tests.

The intent of this report is to describe the work accomplished under the basic contract for the ground station and airborne synchronization equipment. A separate final report covers the results and conclusions derived from the field acceptance test of the MINI-CAS (MDEC feasibility model of the general aviation CAS). For the purpose of self-containment, however, this report includes a brief description of the additional airborne equipment and a summary of test results.

During the program, monthly progress reports, analyses, test plans and procedures, and detailed instruction manuals were formally submitted. These

documents are referenced herein for the reader who desires more detailed descriptions of the equipment or program activities through final acceptance.

Inasmuch as the overall objectives of the Phase I procurement are: 1) to validate or appropriately modify, ER-240-016 to reflect the needs of a Phase II ground station prototype; and (2) to evaluate the latest version of the airborne T/F CAS, the reader should also refer to FAA-NAFEC reports which will follow this report upon completion of the field evaluation tests. This report and its companion "MINI-CAS" report document only MDEC activities and the preliminary findings obtained during the factory and field acceptance test stages of the Phase I program. Detailed NAFEC flight test results are not included nor available at this stage of the program.

1.2 System Description

The time/frequency collision avoidance system is a cooperative time division multiplex radio frequency system designed to protect equipped aircraft against the threat of collision with any other similarly equipped aircraft. In dense traffic areas, the T/F concept provides interference free data exchange for nearly 2,000 participants. The technique requires precise time synchronization and controlled frequency switching of air and ground equipment.

Ground stations, synchronized to a single source of master time, provide first order synchronization support to all airborne units within communication range. Extension of ground station time is provided through time-hierarchy relay chains to all users by scheduled airline users equipped with ARINC Characteristic 587 Collision Avoidance Units. Provisions are made in ARINC Characteristic 590 and ANTC Report No. 117 for limited level classes of cooperative equipment intended for use by small commercial, airline, general

aviation, and military users. One of the major simplifications in the limited level systems is the omission of the time-hierarchy function. These systems can obtain T/F synchronization from hierarchial systems but cannot relay it to others.

In less dense traffic areas, not covered by ground stations and beyond the reach of the aircraft sync relay, CAS protection is provided by a secondary asynchronous mode (Back-Up Mode).

1.3 Equipment Summary

The following CAS evaluation equipment was delivered to NAFEC. Table 1-1 lists the major items and functions.

Development Model Ground Station

The development model CAS Ground Station was supplied as part of the equipment to be used in the evaluation of the T/F CAS concepts and to develop production design data. Primary functions are to provide master timekeeping and synchronization service for airborne CAS. Secondary functions include test and monitoring of both air and ground subsystems.

Collision Avoidance Units

Two identical airborne Collision Avoidance Units (C.A.U.s) were provided for use in the FAA T/F CAS evaluation program. These units are refurbished Engineering Model 2000 equipments which conform to ARINC Characteristic No. 587. The logic of both units is new and has been redesigned to incorporate new functions required for the evaluation program.

The new functions include: 1) Fly By Sync (for air-to-ground synchronization of the ground station), 2) Extended Range Sync (for nearly doubling the start-up and resync range of the ground-to-air link), and 3) $\Delta R/\Delta T$ Interface (permits C.A.U. to use range rate data from external $\Delta R/\Delta T$ Unit instead

TABLE 1-1. CAS EQUIPMENT DESCRIPTION SUMMARY

EQUIPMENT	MAJOR FUNCTIONS	MAJOR ITEMS
Ground Station (G/S)	System Timekeeping Synchronization Service Monitoring/Flight Following Test	Master Channel Slave Channel Antennas (3)
Fly-By-Sync (FBS)	Obtain U.S.N.O. Time Transfer Sync to G/S Monitor G/S Calibration Monitor G/S Performance Operate as CAS Provide Hierarchy Sync	"Flying Clock" Freq. Std. Clock Stby Pwr. Sup. Control Panel C.A.U.
Model 2000 CAS	Commercial Airline CAS Provide Hierarchy Sync Provide Ground Beacon CAS Operate with FBS	C.A.U. Maneuver Indicator Antennas (2) $\Delta R/\Delta T$ Unit
$\Delta R/\Delta T$ Unit	Provide Digital Range Rate for C.A.U. instead of Doppler	Packaged as external unit for evaluation
MiniCAS	General Aviation CAS with $\Delta R/\Delta T$ and TAU Logic	Pilot's Display is integral with Unit. Antenna (1)
Instrumentation (Photopanel)	Real Time Displays Photographic Recording Monitor G/S Performance Monitor C.A.U. Performance Monitor MiniCAS Performance Provide Range/Altitude for Join-up and Stationkeeping	Own Slot Display Data Slot Display Controls.

of internal Doppler measurement). All previously tested functions are retained, with a few improvements, in the new logic design.

ΔR/ΔT Units

Two identical ΔR/ΔT Units were provided as "add-on" boxes for each C.A.U. and are intended for use in evaluation of the ΔR/ΔT concept. The C.A.U. will operate normally (using Doppler-derived range rate) without the ΔR/ΔT unit. When the unit is interfaced with the C.A.U. and ΔR/ΔT mode is selected (switch provided on unit), the C.A.U. utilizes the digitally-derived range rate for TAU (time-to-collision) computations. The digital range rate is computed by differencing successive range measurements (ΔR) and dividing by elapsed time (ΔT).

Fly-By Sync Equipment

One set of Fly-By Sync equipment was provided for evaluation of the air-to-ground fly-by synchronization technique. The equipment is designed to obtain master time by means of a portable clock from the U.S. Naval Observatory, maintain time while enroute, and transfer time to CAS ground stations via an RF link. Since the equipment utilizes one of the C.A.U.'s, it also operates cooperatively in the normal CAS environment with other CAS-equipped aircraft. Timekeeping is provided by a Hewlett Packard "Flying Clock" which consists of a Cesium Beam Frequency Standard and Clock (with an improved beam tube) and a Standby Power Supply (with nicad batteries). The Fly-By equipment is packaged on a special pallet and cabinet which includes a Fly-By Sync Control Panel (simplified by contract modification to FAA Engineering Requirement).

Mini CAS

Two identical airborne Mini CAS units were provided for evaluation of "limited level" CAS concepts for general aviation users. These units

are modified versions of McDonnell Micro CAS feasibility models. The logic has been redesigned to include TAU-threat logic based on the $\Delta R/\Delta T$ range rate concept. The new logic has been packaged as a flight-worthy breadboard in the Mini CAS assembly. No attempt has been made to miniaturize the design for flight test and evaluation of the Mini CAS concepts.

McDonnell CAS Instrumentation

Two identical sets of instrumentation were provided on loan by McDonnell for the FAA CAS flight test. Each set is provided with cables to interface with either the C.A.U. or Mini CAS. The instrumentation contains various digital displays and status lights for real-time monitoring of system performance.

Figure 1-1 is a photograph of all deliverable equipment.

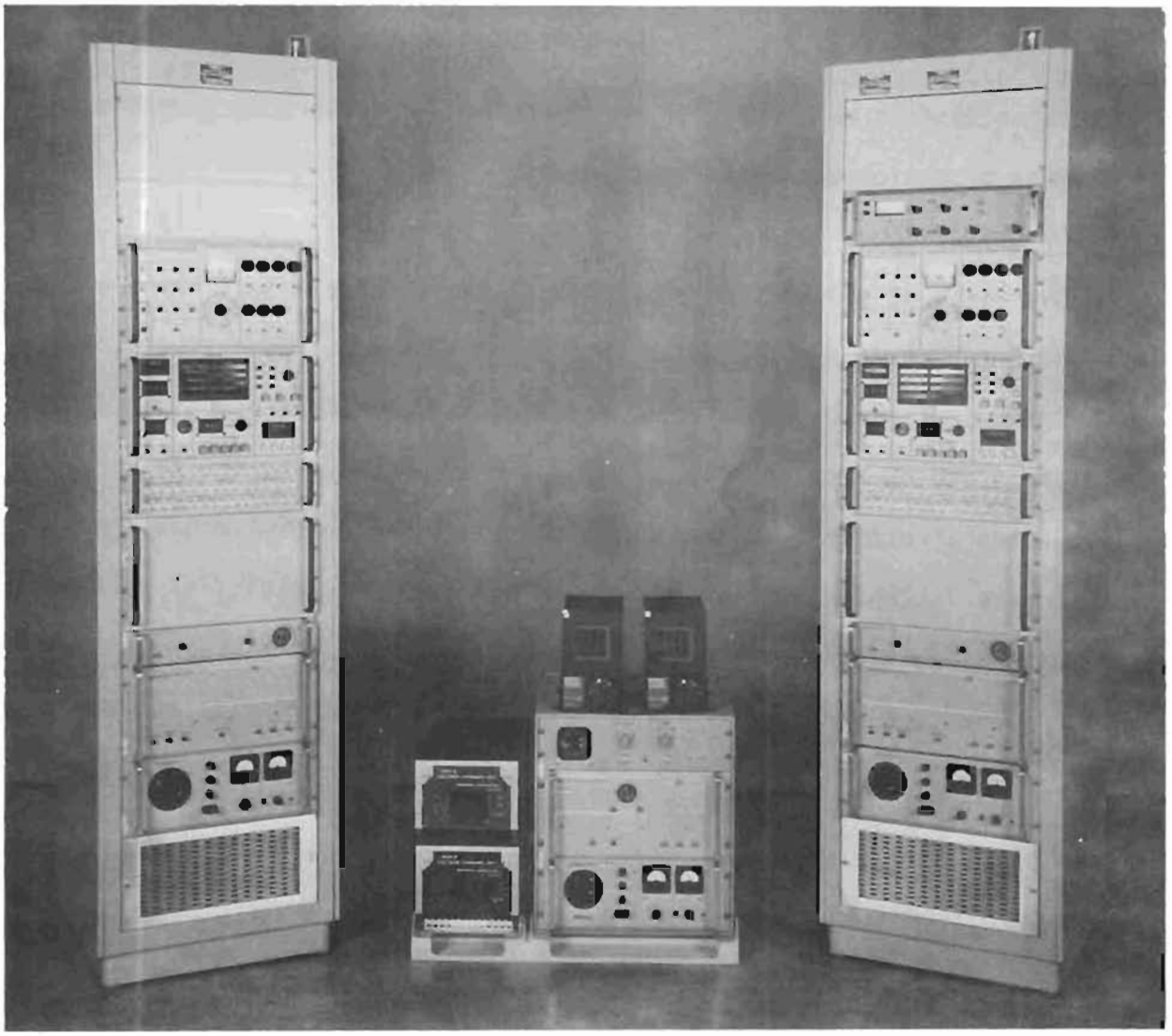

FIGURE 1-1. CAS EQUIPMENT

1.4 Program Summary

The schedule of activities, depicted in Figure 1-2, summarizes the work accomplished by McDonnell from award of contract, 29 June 1973, to field acceptance, 13 December 1974. All work, including design, documentation, factory acceptance testing, delivery, installation, and field acceptance testing was completed on schedule. There were no unresolved equipment or performance discrepancies.

1.5 Organization of Report

Overviews of all work accomplished at the McDonnell facility and the FAA-NAFEC test area are presented in Sections 2 and 3, respectively. Brief descriptions of the ground station and airborne equipment are given in Sections 4 and 5, respectively. Sections 6 and 7 describe the factory and field acceptance tests. General conclusions, based on preliminary test results are listed in Section 8. Appendix A includes results of reliability/maintainability studies performed in accordance with the engineering requirement. Appendix B contains ground station antenna test results not previously documented.

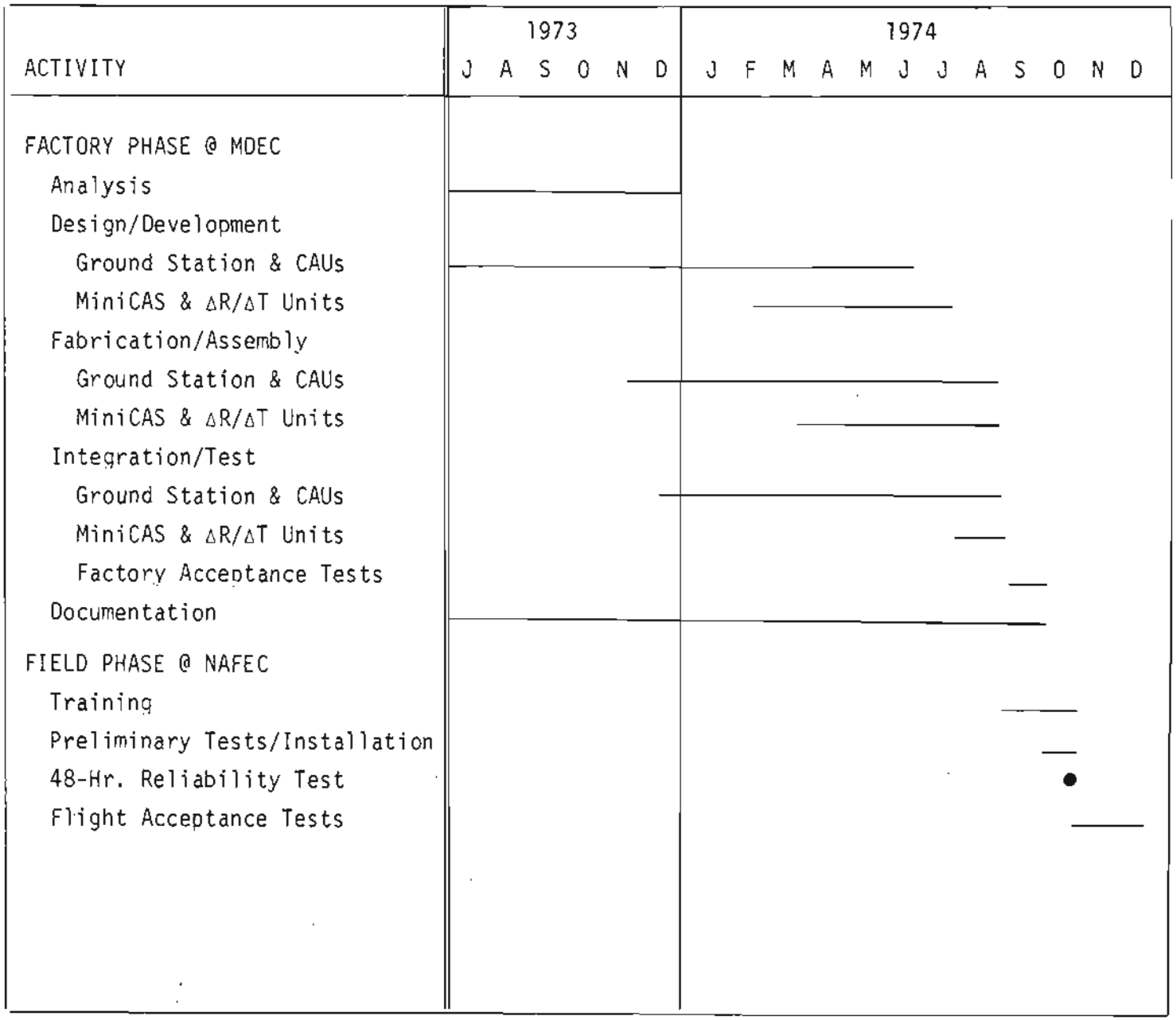

FIGURE 1-2 PROGRAM SUMMARY SCHEDULE

2.0 WORK ACCOMPLISHED AT MDEC

2.1 General

This section describes the work accomplished during the first stage of the Phase I FAA CAS Program. This stage covers the time period from award of contract, 29 June 1973, to delivery of equipment, 10 October 1974. All work was performed at the McDonnell Douglas Electronics Company (MDEC) facility located in St.Charles, Missouri.

The activities are divided into five general categories:

(1) Systems Analysis

(2) Design and Development

(3) Fabrication and Assembly

(4) Integration and Test

(5) Documentation

Detail monthly progress reports and a PERT diagram were prepared to describe the status of these activities. These reports covered schedule, current status, meetings, problem areas, and proposed solutions, and future scheduled An overall summary of the requirements and final accomplishments for each category is presented below.

2.2 Systems Analyses

FAA-ER-240-016 required engineering systems analyses in five areas. A contract modification (No.5) deleted the requirement for two of these in exchange for additional hardware. The deleted analyses concerned the subjects of "Fly-By Synchronization" and "Extended Range Synchronization". These features of the CAS were, however, incorporated into the equipment to the extent that the basic concepts could be evaluated during flight test.

The remaining three analyses were performed, submitted on 28 December 1973, and approved.

The report, reference (6), is divided into three independent sections:

(1) Ground Station Clock Requirements;

(2) Loran-C Accuracy and Comparison to Other Time Dissemination Services; and

(3) CAS Monitoring Requirements.

Although the results and conclusions derived from the analyses were not intended to be translated into hardware requirements for the developmental ground station, many of the present design features are included in the analyses. The results of extended field tests are required before final recommendations can be made for future prototype equipment. Section 7 of this report presents some preliminary findings concerning the station clocks, time dissemination, and overall CAS monitoring.

2.3 Design and Development

2.3.1 General Requirements

The general design requirements of the basic contract and FAA-ER-240-016 were for both ground and airborne equipment. The equipment included:

(1) A developmental model dual channel CAS ground station, including one Loran-C receiver, and with the capability of being time-synchronized by overflying aircraft;

(2) A modified McDonnell Model 2000 airborne CAS, including a Cesium frequency standard and clock, with the capability of synchronizing the ground station by the Fly-By-Sync technique; and

(3) A second airborne CAS, but without the Cesium standard, clock, and Fly-By-Sync equipment. (The capability to interface with the additional equipment was retained in the basic CAS unit.)

The objective of the basic contract was to develop production data for T/F CAS ground stations and associated synchronization equipment.

In early 1974, a contract modification was negotiated which deleted certain less essential tasks and items (analysis, more elaborate Fly-By-Sync equipment, etc.) in exchange for additional airborne hardware. The intent of the modification was to permit the FAA to evaluate advanced versions of both general aviation and airline type CAS which incorporate circuits for digital computation of range rate (delta range/delta time). The additional equipment, delivered concurrently with the above three items, was:

(1) MiniCAS - 2 units which are modified versions of original "MicroCAS" general aviation models. The MiniCAS employs delta range (ΔR), and delta time (ΔT) range rate logic and full TAU threat logic. The earlier MicroCAS was a range-altitude only system.

(2) $\Delta R/\Delta T$ Units - 2 units which interface with the Model 2000 air-carrier type CAS to provide the capability of comparing the new $\Delta R/\Delta T$ concept with the original Doppler method of deriving range rate.

(3) Instrumentation - 2 units, loaned by MDEC, which provide real time displays and photographic recording. The instrumentation operates with either Model 2000 CAS or MiniCAS units and substitutes for the deleted Fly-By-Sync Display Panel.

None of the fundamental design features of the original three equipment items were deleted as a result of the modification.

2.3.2 Ground Station Requirements

Certain basic requirements were specified by FAA-ER-240-016 for the ground station. Inasmuch as this is a developmental model, many of the specific design details were developed only as the program progressed through final system integration and test. The final developmental model design (functional and physical) is described in detail in the ground station instruction manual, reference (7). A summary is presented in Section 4 of this report.

The basic requirements specified for the baseline design of the developmental model are restated below:

(1) A dual channel station is required for operational availability.

(2) Separation of the station into two independent station (channels) is required to permit interference and time transfer experimentation. (This feature would not be required in a production system.)

(3) The general equipment design must be in accordance with FAA-G-2100 which sets forth standardized requirements for FAA ground electronics equipment relative to environment conditions, workmanship, processes, safety, electrical circuits, finishes, ventilation, wire, marking, selection of parts and materials, and quality assurance. (In effect, the developmental model design was to be completely representative of a preproduction prototype in its physical characteristics.)

(4) Functionally the dual channel station must: (a) accept time synchronization from a master source, (b) maintain time within 0.5 microseconds relative to the master source (between resynchronization periods), (c) disseminate time to airborne CAS, (d) radiate test signals for ground test of aircraft CAS, and (e) monitor operational parameters of both air and ground systems.

2.3.3 Airborne Synchronization Equipment Requirements

The basic requirements specified for the original procurement of airborne CAS equipment are restated below:

(1) The equipment is not required to meet any specific configuration or form factor; however, the equipment must be suitable for installation in a test bed aircraft.

(2) The equipment design shall use best commercial parts and practices.

(3) Each airborne CAS shall operate as a full air-carrier type CAS, in accordance with ANTC-117. See reference (4).

(4) One of the airborne CAS units, when interfaced with the Fly-By-Sync equipment shall obtain master time, maintain it by means of a Cesium clock and transfer master time to specific CAS ground stations via an RF link. The same equipment shall be used to monitor ground station operation.

The specific design details (functional and physical are documented in the airborne equipment instruction manual, reference (8). A summary description is presented in section 5 of this report.

2.3.4 Additional Airborne Equipment Requirements

The additional airborne equipment provided under contract modification No. 5 is not specified by the basic engineering requirement, reference (2). McDonnell's "Technical Description, MiniCAS, Modified CAU's and Instrumentation", dated 18 March 1974, prepared in response to RFPWA6R-4-5144 governs to the extent provided by the articles of the contract modification.

The additional equipment, listed in paragraph 2.3.1 of this report, required no formal documentation and was to be designed and built to best commercial practices. No attempt was to be made to physically incorporate the $\Delta R/\Delta T$ logic into the Model 2000 CAS or to redesign the existing "MicroCAS" unit to add the TAU-threat logic for MiniCAS. The new logic units for both versions of airborne CAS were to be packaged as flight-worthy breadboards to be used for evaluation of the $\Delta R/\Delta T$ range rate concept.

General design details are documented in the airborne equipment instruction manual, reference (8). A summary description is presented in Section 5 of this report.

2.3.5 Design Activities

All design activities for the ground station and airborne synchronization equipment required by the basic contract proceeded in parallel starting in July 1973. Essentially all design was complete by June 1974 with the formal release of the last set of ground station logic drawings.

Design activities for the additional equipment did not start until mid-February 1974, but were completed by July 1974.

The following paragraphs summarize the design activities for each type of deliverable equipment and include major accomplishments as well as problems encountered.

2.3.5.1 Ground Station Design

Before starting detail design, the basic requirements of FAA-ER-240-016 (see paragraph 2.3.2) were reviewed. In those areas where the detailed characteristics were not specified, such as mechanical configuration and monitoring and display function, a design concept was created. This effort resulted in a preliminary document entitled: "Technical Description, FAA CAS T/F Ground Station", dated 28 September 1973. This document contained detail descriptions of the selected design approach and included: block diagrams; layout drawings of the cabinets and displays; estimates of power, size, and weight; identification of modules (make and buy items); McDonnell performance specifications for the various subassemblies; and a detailed description of the built-in-test features.

After reviewing the design approach with the FAA technical personnel, suggested changes were incorporated such as completely automatic channel switchover, instead of manual, after a failure is self-detected. Detailed interface signals were defined so that the circuit designers could proceed.

Concurrent with the detailed electrical design effort, a support program was initiated to insure that the equipment would meet the specified reliability and maintainability. Specific tasks of the engineering specialists were to assist in the selection of parts, participate in design reviews, analyze failures, recommend corrective action, and perform equipment MTBF and MTTR calculations. The results of these analyses are presented in Appendix A.

The most difficult part of the design involved compliance with the standardization requirements of FAA-G-2100, reference (3). The final

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design is, for the most part, compliant. However, because of the developmental nature of the equipment, a number of requests for approval of suitable non-standard parts were submitted as cost-effective and were approved. In a large number of cases, these "non-standard" parts were in the category of special devices not covered by FAA-G-2100. These included, for example: RF circulators, couplers, isolators and low loss cable; light emitting diodes (LED's) and sockets; high voltage components; special parts used on ceramic substrates in microstrip circuits such as PIN diodes, chip capacitors, and microwave transistors; and a group of "off-the-shelf" commercial equipments such as the Hewlett Packard frequency standards, clocks and power supplies, the Austion Loran-C receiver, the Fluke frequency synthesizer, and the ACDC power supplies.

The logic design, considered the critical path in the development program, was especially restricted by the requirements of FAA-G-2100. Since sockets and wire-wrap techniques, normally used for development work were not permitted, a complete breadboard of the logic and display sections had to be fabricated and tested before the design could be finalized and fabrication of the deliverable assemblies started. Approval was obtained, however, to use MDEC standard stitch wire weld printed circuit boards for the developmental model. The integrated circuits (I.C.'s) are soldered on these boards which contain a standard grid for power and ground and plated-thru holes for the I.C.'s. Signal paths are provided by welded wire connections made on the rear to pins inserted in the board. The wiring is then protected by attaching a rear protective cover plate. This construction technique permits design changes to be made much more easily than could otherwise be done using production double-sided or multilayer printed circuit boards.

The total scope of the design task is probably best illustrated by the number of drawings generated. Table 2-1 summarizes the effort.

TABLE 2-1. DRAWING SUMMARY

Engineering Drawings*	Number
Layouts	44
Artwork	140
	188 (Total)

Formal Drawings	Number
Spec Control	4
Film	44
Detail	156
Assembly	80
Schematics	56
	340 (Total)

*Engineering drawings are highly accurate working drawings and are not generally released for manufacturing.

2.3.5.2 Basic Airborne Equipment Design

The McDonnell Model 2000 Collision Avoidance Unit (CAU) engineering model design served as the starting point for design of the airborne synchronization equipment. The Model 2000 CAU's were originally built in full compliance with ARINC Characteristic No. 587, reference (5), as demonstration and test units. To satisfy the requirements of FAA-ER-240-016, the entire logic section of the CAU was redesigned to incorporate the new functions. These included:

(1) Fly By Synchronization (for air-to-ground synchronization of the ground station),

(2) Extended Range Sync (for nearly doubling the start-up and resync range of the ground-to-air link), and

(3) $\Delta R/\Delta T$ Interface (added by contract modification to permit CAU to use range rate data from external $\Delta R/\Delta T$ Unit instead of internal Doppler measurement).

All previously tested functions were retained, with a few improvements, in the new CAU logic design.

The original contract required one set of Fly-By Synchronization (FBS) equipment with a special control and display panel. This panel was to include controls for ground station slot, a manual entry of special down-link data messages, and displays of status, sync transfer error and up-link messages. Contract modification No. 5 deleted most of these requirements. All of the FBS functions, except the special data link, were incorporated, however, into a modified FBS design. A pallet containing the Cesium beam frequency standard and clock, standby power supply, simplified FBS panel, and one of the CAU's was designed to work with one set of MDEC-loaned instrumentation to provide the FBS capability.

No significant design problems were encountered in the development of the basic airborne equipment.

Approximately 40 drawings were generated to document the new portions of the design. This count, of course, does not include some 300 drawings for the existing Model 2000 CAU developed prior to award of contract.

2.3.5.3 MiniCAS and $\Delta R/\Delta T$ Unit Design

The design of this additional airborne CAS evaluation equipment was authorized by contract modification No. 5. Design activities for both MiniCAS and the $\Delta R/\Delta T$ Unit (for CAU interface) were started in parallel in February 1974.

The McDonnell Model 2002 MicroCAS feasibility models served as the starting point for the MiniCAS design. These units were originally built as general aviation versions of the T/F airborne CAS. They were tested by the Air Force, with ARINC Research Corporation providing assistance, during March 1973.

The MicroCAS threat logic, evaluated by ARINC, was based on fixed range alarm boundaries. It was concluded that the full TAU-threat logic used in the air-carrier CAS would be more suitable for all classes of users. TAU-threat logic requires measurement of range and range rate to derive TAU (time to closest approach). Up until recently range rate was derived from the Doppler shift on the carrier frequency of the 200 microsecond CAS range signal. This requires highly accurate and stable (spectrally pure) frequency generation throughout the entire transmitting and receiving subsystems. The cost of this type of frequency control for the general aviation CAS would be prohibitive. However, with the development of inexpensive medium scale integrated circuits for digital logic, the previously discarded approach of measuring range rate by range differencing became practical. This technique, called $\Delta R/\Delta T$ (delta range divided by delta time), therefore, makes full TAU-threat logic practical for general aviation MiniCAS.

Likewise, the $\Delta R/\Delta T$ concept, when used for the air-carrier type CAS, allows a significant reduction in the complexity of the RF subsystem.

For the FAA evaluation program, no attempt was made to redesign the RF sections of the Model 2000 CAU or to modify the coherent transmitter employed by the MicroCAS. A separate $\Delta R/\Delta T$ Unit was designed to interface with the CAU so that it could operate in either Doppler or $\Delta R/\Delta T$ mode. The MicroCAS threat logic was redesigned to use $\Delta R/\Delta T$ range rate processing and TAU threat logic. Since the resulting "MiniCAS" retained coherent transmissions suitable for Doppler processing by the CAU, both types of range rate processing could be simultaneously compared during flight testing. (Preliminary evaluation by ARINC Research and McDonnell reveals that the $\Delta R/\Delta T$ method should be equal to or better than the Doppler technique. This conclusion was based on comparison of measured Doppler data with $\Delta R/\Delta T$ data obtained by mathematically differencing measured range data obtained during the same test flights. (Actual $\Delta R/\Delta T$ hardware was not available, however, during the 1973 flight test program.)

No significant design problems were encountered in the MiniCAS logic and $\Delta R/\Delta T$ Units for the CAU.

Formal drawings were not required by contract; however, engineering schematics and assembly drawings were generated to document the designs.

2.4 Fabrication/Assembly Activities

Fabrication of detail mechanical parts and printed circuit boards for the ground station and airborne synchronization equipment (modified CAU's) started in November 1973. Essentially all purchase orders for parts and materials were written by the year end. Assembly operations started in February 1974 after initial receipt of purchased parts. Final assembly and wiring tasks continued through August 1974 as a result of delays in delivery of purchase parts. (Six month delivery times for certain

"standard" connectors and integrated circuits were typical of the electronics industry in 1974.) In spite of these delays, all the equipment was built; debugged; tested and ready for delivery on schedule, October 1974.

Fabrication and assembly activities for the additional equipment (Mini-CAS, $\Delta R/\Delta T$ Units and modified MDEC Instrumentation) started in March 1974 and continued through August. Working to a compressed schedule, with similar parts delivery problems, the equipment was also built, debugged, tested and ready for delivery concurrently with the ground station and basic airborne hardware.

The following paragraphs summarize the fabrication and assembly activities for each type of deliverable equipment and include major accomplishments as well as problems encountered.

2.4.1 Ground Station Fabrication/Assembly

The ground station was fabricated and assembled under the scrutiny of both McDonnell quality control and the resident FAA Quality/Reliability Officer (QRO). The FAA Q.R.O. was in residence from November 1973 through delivery in October 1974. The full quality assurance program began, of course, during the development stage with participation in design reviews, drawing check, supplier/subcontractor evaluation, and procurement control. During the fabrication/assembly stage, in process inspection was extensive. This included: approval of work orders, incoming inspection of purchased part, complete visual inspection of all fabrication and assembly operations, mechanical inspection of detailed parts, process inspection, and chronological documentation of each operation. All rejected items were recorded and held for disposition and corrective action.

The major problem encountered during the assembly stage was parts procurement and delivery. Although the design was based on the "standard parts" requirements of FAA-G-2100 (except for certain waivers discussed in paragraph 2.3.5.1), many of the parts, selected during the design phase and called out in the assembly drawings, were difficult to procure. Problem areas generally related to long lead times (e.g. 36 weeks); minimum buy situations (e.g. 2-required, minimum order - 100); and the non-availability of QPL sources (i.e., no vendors were fully qualified to furnish certification that certain parts met all the requirements of the applicable military specifications.)

In order to maintain the program schedule and budget on the development model ground station, McDonnell submitted and the FAA approved a parts substitution list. These parts substitutions do not affect form, fit, or function of the equipment and in most cases the parts are specified as "equivalent" to the military types. The production drawing parts list retains the military part number in all cases and indicates that the substitute part number is applicable to the develoment model only.

The overall scope of the fabrication and assembly activity is presented in Table 2-2. This table summarizes the task in terms of number of printed circuit cards, ceramic substrates, replaceable modules, etc., constructed for the dual channel ground station. The two channels are essentially identical and are housed in standard 19-inch cabinets. One of the channels differs in that it also contains a Loran-C receiver and a commercial Frequency Synthesizer used for test. Both channels, however, contain mounting provisions and wiring for these two items. (See Section 4 for complete description and illustrations of the equipment.)

TABLE 2-2. FABRICATION/ASSEMBLY SUMMARY

GROUND STATION

Items Assembled:	Total Quantity (2-Channels)
Major Assemblies	12
Plug-in RF Modules	28
Antennas	2
Circuit Cards:	
Logic (Stitch welded)	32
RF (double-sided)	40
Display (double-sided)	8
RF Cerimic Substrates	24
Detail Machine Shop Parts	1600 (Approx.)
Connectors (multipin and coaxial)	600 (Approx.)
Major Purchased Items:	
Frequency Standard/Clock	2
Standby Power Supply	2
Frequency Synthesizer	1
Loran Receiver	1
Blower	2
DC Power Supplies	12

2.4.2 CAU/FBS Fabrication/Assembly

Two McDonnell Model 2000 Collision Avoidance Units (CAU's) were modified and one set of Fly-By Sync (FBS) interface equipment was built under the same type of quality assurance program as described for the ground station. Since the airborne equipment design and construction did not have to conform to FAA-G-2100, there were fewer problems associated with parts procurement. Military grade parts were used, however, whenever possible to provide reliability.

The logic sections of the CAU's were removed and replaced with completely new logic, designed to provide the new function (see paragraph 2.3.5.2). In addition part of the receiver was replaced with an improved low noise Log I.F. Amplifier. The remaining subassemblies of the CAU (power supply, exciter, transmitter, oscillator and buffer modules) were retained in their original form but were reinspected for workmanship.

For the FBS equipment, a pallet was fabricated to mount one of the CAU's and the "Flying Clock" units. This equipment consisted of a refurbished Hewlett Packard Model 5061A Frequency Standard and Clock with a K02-5060A Standby Power Supply. A simple panel was also fabricated to house the FBS controls, a test switch, and a CAS Maneuver Indicator.

Overall scope of the fabrication and assembly activity is presented in Table 2-3. (See section 5 for complete description and illustrations of the equipment.)

TABLE 2-3. FABRICATION/ASSEMBLY SUMMARY

CAUs & FBS

New Items	Total Quantity
Logic Assembly	2
Receiver	2
Buffer Module (FBS)	1
Circuit Cards	
RF (double-sided)	5
Logic (double-sided)	6
Logic (multilayer)	10
Logic (motherboard)	2

2.4.3 MiniCAS and $\Delta R/\Delta T$ Unit Fabrication/Assembly

This additional airborne CAS evaluation equipment was also built under the surveillance of MDEC and FAA Quality representatives. All material and parts were of best commercial quality for these "feasibility" models. No significant problems, other than an extremely tight schedule, were encountered in the fabrication and assembly stages.

Two McDonnell Model 2002 MicroCAS units were refurbished with all new logic. The existing RF assemblies and power supplies were repackaged in the bottom half of the new MiniCAS Units. The logic, built on five standard stitch wire weld cards with sockets for the I.C.'s, was added as a card rack on the upper half of each unit. No attempt was made to miniaturize the design. The existing MicroCAS indicator was attached to the front for control and threat display. A new, more stable, voltage-controlled oscillator replaced the original 5 MHz source.

Two $\Delta R/\Delta T$ Units, one for each CAU, were built. Each new unit consisted of two plug-in logic cards, similar to the MiniCAS cards, and a power supply, housed in a small modular case. Again, no attempt was made to incorporate this logic into the CAU assembly.

In addition to these deliverable units, MDEC modified two sets of CAS Instrumentation used on previous programs. The instrumentation, provided on a loan basis, interfaces with either CAU or MiniCAS to provide real-time displays and has provisions for photographic recording by a pulse-operated camera (provided by NAFEC).

A set of interconnecting cables were fabricated to complete the assembly tasks. (See section 5 for complete description and illustrations of the equipment.)

2.5 Integration and Test

Test activities at MDEC were in four general areas:

(1) Breadboard

(2) Unit Design Verification

(3) System Integration

(4) Factory Acceptance

A brief description of the work accomplished is given in the following paragraphs.

2.5.1 Breadboard Tests

2.5.1.1 Ground Station Logic/Display

A complete operating breadboard of one channel of the ground station logic (card rack assembly) and the display panel was constructed using commercial parts, stitch wire weld boards and sockets for the digital integrated circuits. This was necessary to insure that the completely new design was debugged to the extent possible before proceeding

with the final deliverable design. Major changes to the deliverable units would have been difficult because of rigid quality control requirements and long procurement times involved in getting standard parts per FAA-G-2100.

An MDEC Test Set, designed for previous company-funded CAS programs, was used to exercise the breadboard by simulating signals typical of airborne CAS units.

During integration testing of the deliverable logic assemblies, through August 1974, the breadboard was used as a substitution tester.

2.5.1.2 RF Circuits

Although the RF circuit design for the ground station was based on the earlier Model 2000 CAU design, most of the circuits had to be redesigned to meet the special requirements of FAA-G-2100. Some of the design was completely new. In these cases, partial breadboards were built and tested to minimize the unknown in the deliverable RF hardware designs. Essentially, all of the RF breadboard tests were completed by December 1973. A model of the ground station antenna was also built and tested with 2-inches of radial ice. See Appendix B.

2.5.2 Unit Design Verification Tests

These test activities were initiated by MDEC design engineering to complement the formal quality and factory acceptance test programs. After each major functional subassembly or module was assembled, the "unit" was subjected to a semi-formal test by engineering to debug, align, and show design verification to the extent possible at this level prior to integration into the major equipment end item (ground station, CAU, MiniCAS, etc.).

Although not required by the FAA Engineering Requirement, most of the module tests included temperature tests to insure that the development

model ground station meets production design requirements. Each unit was then subjected to a formal quality inspection (and "sealed") after completion of the design verification tests to insure that any design "fixes" were properly installed and documented.

McDonnell retains a complete file of these informal unit test procedures and data sheets.

2.5.3 Systems Integration Tests

Upon completion of design verification tests for a related set of "units" (e.g., transmitter modules, exciter modules, receiver modules, CAU logic, etc.), the group was installed in the appropriate assembly and tested as an integrated set. As additional sets were installed and tested, the integration proceeded in logical order until a complete assembly (ground station channel, CAU, MiniCAS, etc.) was ready for final systems integration (ground station-to-airborne stations). All deliverable equipment was completely integrated and ready for the formal factory acceptance test by 26 August 1974, on schedule.

2.5.4 Factory Acceptance Tests

These tests were performed by MDEC at the St.Charles, Missouri, facility and witnessed by MDEC Quality, the resident FAA Q.R.O. and observers from FAA-NAFEC. The tests were performed in accordance with the approved Factory Acceptance Test Procedure, reference (10), to demonstrate compliance with engineering requirements and the contract.

The scheduled tests covered a five-week period during which each end item (ground station, two CAU's with $\Delta R/\Delta T$ units and FBS, and two MiniCAS) were first individually tested and then cooperatively tested. A total of thirteen major system tests were performed. Section 6 of this report

summarizes the results of this major activity. All equipment was accepted and ready for delivery on schedule by October 1974.

2.6 Documentation

In accordance with contractual requirements the following documentation was generated by MDEC to support the developmental program:

(1) Analysis (reference 6)

(2) Ground Station Instruction Manual (reference 7)

(3) Airborne Equipment Manual (reference 8)

(4) Factory Test Plan (reference 9)

(5) Factory Test Procedure (reference 10)

(6) Field Test Plan (reference 11)

(7) Field Test Procedure (reference 12)

In addition, approximately 400 formal drawings were released to MDEC Drawing Control files. Most of these were supplied as a drawing package for use at FAA NAFEC during the field and flight test programs.

3.0 WORK ACCOMPLISHED AT NAFEC

3.1 General

This section describes the work accomplished during the second stage of the Phase I FAA CAS program. This stage covers the time period from start of field training, October 7, 1974, to the final acceptance flight, December 13, 1974. Essentially all work, excent planning tasks, was performed at the National Aviation Facilities Experimental Center (NAFEC) located near Atlantic City, New Jersey.

The activities are divided into three general categories:

(1) Field Training

(2) Preliminary Functional Tests/Installation

(3) Field Acceptance Tests

Detailed monthly progress reports were prepared to describe the status of these activities. These reports covered schedule, current status, meetings, problem areas and proposed solutions, and future scheduled tasks. An overall summary of the final accomplishments for each category is presented below.

3.2 Field Training

3.2.1 Orientation Course

After completion of the factory acceptance tests at MDEC, the FAA requested that a CAS orientation course be held at NAFEC for personnel who would be involved in the field test program. This course was held from October 7 to October 11, 1974. Subject matter included a review of system concepts and the general requirements of ANTC-117 (reference 4), technical requirements of the current FAA contract (references 1 and 2), and

technical descriptions of the delivered CAS ground and airborne equipment. The field test plan (reference 11) was also discussed in preparation for the upcoming tests.

3.2.2 Equipment Familiarization

After the equipment arrived at NAFEC, technical personnel were instructed in the operation of each item of ground, airborne, and instrumentation hardware. The various methods of measuring equipment performance parameters (e.g., receiver sensitivity, transmitter power, oscillator drift, etc.) were demonstrated. As the field test phase progressed, NAFEC personnel were able to conduct the formal acceptance tests with minimum assistance from MDEC.

3.3 Preliminary Tests/Installation

In accordance with the FAA request for delayed shipment (to allow completion of ground station building facility at NAFEC), all of the equipment was shipped from MDEC on October 10, 1974. The shipment was delayed in-route and did not arrive at NAFEC until October 22, but was off-loaded and received in good condition with no damage. After the equipment was unpacked and determined to be operable, it was reassembled and brief GO/NO-GO power-on checks were performed. Both channels of the ground station were set in place in NAFEC Building 156, located about one mile east of the main hanger. The two ground station CAS antennas were installed atop two fifty-foot telephone poles, located opposite ends of the building, approximately fifty feet apart. Low loss semi-rigid cable was connected to each antenna and run to the respective channel cabinets. The Loran-C receiver antenna was also mounted on one of the poles and connected to the receiver in Channel No. 1.

During the preliminary functional tests and subsequent 48-hour ground station acceptance test, preparations were made for installation of the airborne equipment in NAFEC Gulfstream test-bed aircraft (N-376 and N-377). These installations were completed by November 10, 1974.

3.3.1 GO/NO GO Checks

Initial bench checks indicated that all the airborne equipment was operating properly; however, it was determined that the ground station did not properly display the MiniCAS slot number, although displayed information from the CAU was correct. The problem was identified and corrected prior to start of the preliminary functional tests (abbreviated repeat of factory tests) and final acceptance tests. (Problem was caused by a late modification at the factory which inadvertently caused all zeroes to be loaded into slot number display for received signals without biphase modulation.)

3.3.2 Functional Tests

Before the formal field acceptance tests were started, all equipment was subjected to preliminary functional tests. There tests consisted of selected portions of the Factory Acceptance Test Procedure, reference 10, which was performed in its entirety at the MDEC facility. The approved Field Test Procedure, reference 12, specified those tests which were to be repeated in the field to establish a reasonable level of confidence that the equipment was operating properly after delivery.

Tests were performed on each CAU with interfacing $\Delta R/\Delta T$ Units, MiniCAS, and on each channel of the ground station separately and together. Then system-to-system tests were repeated to recheck CAU-to-CAU, CAU-to-MiniCAS, MiniCAS-to-MiniCAS, Ground Station-to-CAU/FBS, and Ground-to-MiniCAS cooperative operation.

3.3.3 Equipment Radiation Tests

Prior to installation at NAFEC, all tests had been performed with the equipment transmitters and receivers terminated into dummy loads. System-to-system RF communication links were simulated using hardline (coaxial cable interconnections) and suitable RF plumbing (couplers, hybrid junctions and attenuators) to control path losses. This technique eliminates the uncontrollable effects of multipath propagation normally encountered when antennas are allowed to radiate.

Although the CAS design, based on extensive practical experience with real-world multipath conditions, incorporates many techniques for coping with the effects of multipath, certain conditions can cause signal contamination to the extent that it should not be used. Rather than process such signals, which probably would result in highly erroneous data, it is rejected by the signal verification circuits.

For baseline functional testing, it is, therefore, desirable not to introduce multipath into the data gathered in the laboratory. During flight testing, of course, multipath-corrupted data is unavoidable.

To ascertain the effects of multipath prior to the start of formal acceptance tests, two checks were made: 1) the ground station was connected to its dual antenna system, and 2) the airborne units were installed in the aircraft, parked on the ramp, and permitted to communicate with the ground station and each other via normal antenna-free space paths. The following results were reported:

3.3.3.1 Ground Station Radiation Test

Initial transmissions by ground station Channel No. 1 into its antenna resulted in a biphase modulation built-in-test (BIT) failure in

that channel. Transmission by Channel No. 2 into its antenna resulted in normal operation. As an experiment, the antennas were cross cabled such that Channel No. 1 used Channel No. 2's antenna, and vice versa. This resulted in a biphase BIT failure in Channel No. 2, indicating a problem with No. 1 antenna. Measurements were made of cable and antenna VSWR. Both antenna systems were well below the 1.5:1 limit. (in fact, the "good" antenna system had a higher or worse VSWR than the "bad" antenna system.)

Oscilloscope observations revealed that Channel No. 1 antenna system was experiencing more multipath reflections from the surrounding terrain than the other channel. It was also noted that the "bad" antenna was slightly tilted on its mount atop the pole. The antenna was straightened slightly and the multipath interference was reduced sufficiently, for the moment, to allow the biphase BIT to pass without failure. However, the next day, under different weather conditions, the multipath again caused random BIT failures in Channel No. 1. Due to the non-predictable nature (phase and amplitude) of the multipath, it was decided to permanently inhibit the biphase modulation BIT circuit to prevent nuisance-type failure alarms.

Earlier analysis, reference 6, revealed that this particular BIT function was of questionable value and probably should be eliminated from the production design. The success of the BIT depends upon the biphase decoding logic to "read" correctly each data bit of the biphase message as transmitted by the channel in own slot. Since biphase data transmission is a "secondary" data link function, not essential for CAS or ground station synchronization support to airborne stations, and since the operator can easily determine proper operation by observation of ground channel displays, disabling the BIT seems justified.

Another manifestation of multipath return in Channel No. 1 was an intermittent failure alarm generated by the range BIT circuit. This was traced to strong radar-like reflection following transmission of the ground station range pulse. These reflections, as observed in the No. 1 channel receiver, continued for over 100 microseconds and occasionally were above the processing threshold long enough (approximately 25 microseconds) to be treated as a "second" range pulse in the same slot. Although the "first" range pulse always passed all verification tests for both presence and absence of video, the false start of the "second" ghost range pulse caused the BIT circuit to reject both signals by declaring them to be co-slot occupants. This design error was corrected (one wire was removed) and the range BIT now functions properly in spite of the multipath.

A third problem was discovered when both channels were connected to their respective antennas: the Master-Slave loop BIT was observed to fail erroneously. This was not caused by multipath, however. The Master-Slave loop test requires that the transmitted signals radiated by the Master Channel be received by the Slave, via the antenna link, demodulated and verified, passed back to the Master, via hardline, and compared to the original logic modulation for proper time-of-arrival (within path delay tolerances). The BIT failure was traced to an error in the stitch-wire list used to weld the logic. A mis-wired capacitor in the line receiver circuit caused a foreshortening of the receiver switch control signal in the Slave Channel. The function of the control signal during the loop BIT is to attenuate the high power signal, transmitted by the Master, so that it appears weak at the Slave's receiver. With the mis-wired capacitor, the control signal allowed leakage from the Master Channel transmitter RF pregate to be seen by the Slave. Even though this weak pregate is about 100 dB below the

main high power signal (approx. 63 dBm), the pregate as seen by the Slave was still at the receiver threshold of -88 dBm. Due to the short distance between channel antennas (50 feet) and the high gain (6dB per antenna), the calculated and observed pregate signal at the Slave was about -88 dBm. Consequently, when the pregate leakage preceded the normal signals, the Slave logic could not verify the Master's transmissions and the loop BIT would fail. The problem was corrected by properly reconnecting the capacitors in both channels. Now, with the receiver switch (PIN diode attenuator) gated on during the entire pregate and signal time, the BIT test functions as it should.

3.3.3.2 Aircraft CAS Radiation Tests.

Initial radiation tests with the CAU and MiniCAS units installed on the aircraft were completely successful. During these tests, the aircraft were parked on the NAFEC flight ramp about 0.6 miles from the ground station. Good CAS communications were established between the station and each aircraft CAS and between each aircraft. In spite of severe ground-to-ground multipath, the aircraft CAS were able to synchronize and pass the ground station ramp test sequence of simulated threat signals. The ground station displays of both aircraft CAS were solid, as were airborne instrumentation displays of each other and of the ground station.

Later tests, however, did reveal an instrumentation problem, aggravated by multipath. This did not affect CAS operation. The range display intermittently read 196.1 n.mi. although the correct range was being measured by the CAU. The "bad" range number is a preset used in the instrumentation. A logic "race" in the CAU-Instrumentation interface circuit caused the display to erroneously reset to this number after a valid range was measured but was followed by multipath or other interference. The interface circuit

was modified to correct the display problem.

3.4 Field Acceptance Tests

The final field acceptance tests were performed after completion of the preliminary bench checks and functional tests. The acceptance activity was divided into three phases:

(1) 48-hour ground station test

(2) Installation of airborne equipment in aircraft

(3) Four 2-hour flight tests (minimum requirement)

The tests were conducted at NAFEC in accordance with the approved test procedure, reference 12, by NAFEC personnel, assisted by MDEC.

The scheduled activity started on November 6, 1974, with the 48-hour continuous test of the T/F Dual Channel Ground Station (exercised by all of the airborne equipment setup nearby on benches). This test was successfully completed without interruption or malfunction.

All airborne CAS equipment and instrumentation was installed and functionally checked out in the FAA test bed aircraft (N-376 and N-377 Gulfstreams) by November 10th.

The flight acceptance tests covered the period from November 12 to December 13, during which six flights were made. Since one of the aircraft was grounded by an alternator problem, the first scheduled flight was used only to check-out and demonstrate operation of an airborne CAU with the ground station. Four more "official" flights were made per the formal procedures. The sixth and final flight was made to recheck operation of one CAU which was experiencing intermittent built-in-test failures and to gather more data on CAU to MiniCAS threat encounters.

Total flight time (take-off to touch-down) was approximately 14 hours. Total operating time, including preflight checkout, exceeded 30 hours. The

ground station was operated in support of all the preflight checkouts and flights. Except for the CAU automatic built-in-test (BIT) shutdown, there were no CAS equipment failures, ground station or airborne. (The CAU BIT shutdown was later identified as a valid self-detection of improper CAU operation. The cause was traced to an intermittent connection between a wire and crimp type terminal within the Exciter module of the CAU.)

Section 7 of this report summarizes the results of the field acceptance tests in more detail. (Subsequent tests, performed by NAFEC, during the Flight Test Evaluation Program, scheduled to start in January, 1975, are beyond the scope of this report and will be reported by NAFEC in a future document.)

4.0 DESCRIPTION OF GROUND STATION

4.1 General

This section contains a brief description of the development model time/frequency (T/F) collision avoidance system (CAS) ground station. Detailed descriptions, theory, operating procedures, and maintenance information are included in the instruction manual, reference 7, provided under the contract work.

The ground station consists of two channels which contain all required functions. The channels may be separated, physically and/or functionally, to permit interference and time transfer experimentation with independent operation. When separated, both stations retain most of the major time-keeping, communication, monitoring, and test functions of the dual channel system. Only secondary monitoring functions are inactivated. Both channels communicate with the CAS airborne stations which are described in Section 5 of this report.

Photographs of Channel No. 1 of the ground station are shown in Figures 4-1 and 4-2. Both channels are identical in construction and wiring. Since two channels are normally located side-by-side, only Channel No. 1 is equipped with the Loran-C Receiver and Frequency Synthesizer. Complete mounting and wiring provisions are made in Channel No. 2, however, for both these items.

4.2 Ground Station Functions

A simplified functional block diagram is given in Figure 4-3. When configured as a primary ground station, the two channels are divided into "Master" and "Slave". Either channel may perform either function but not both simultaneously. Both share the station clocks and Loran-D time

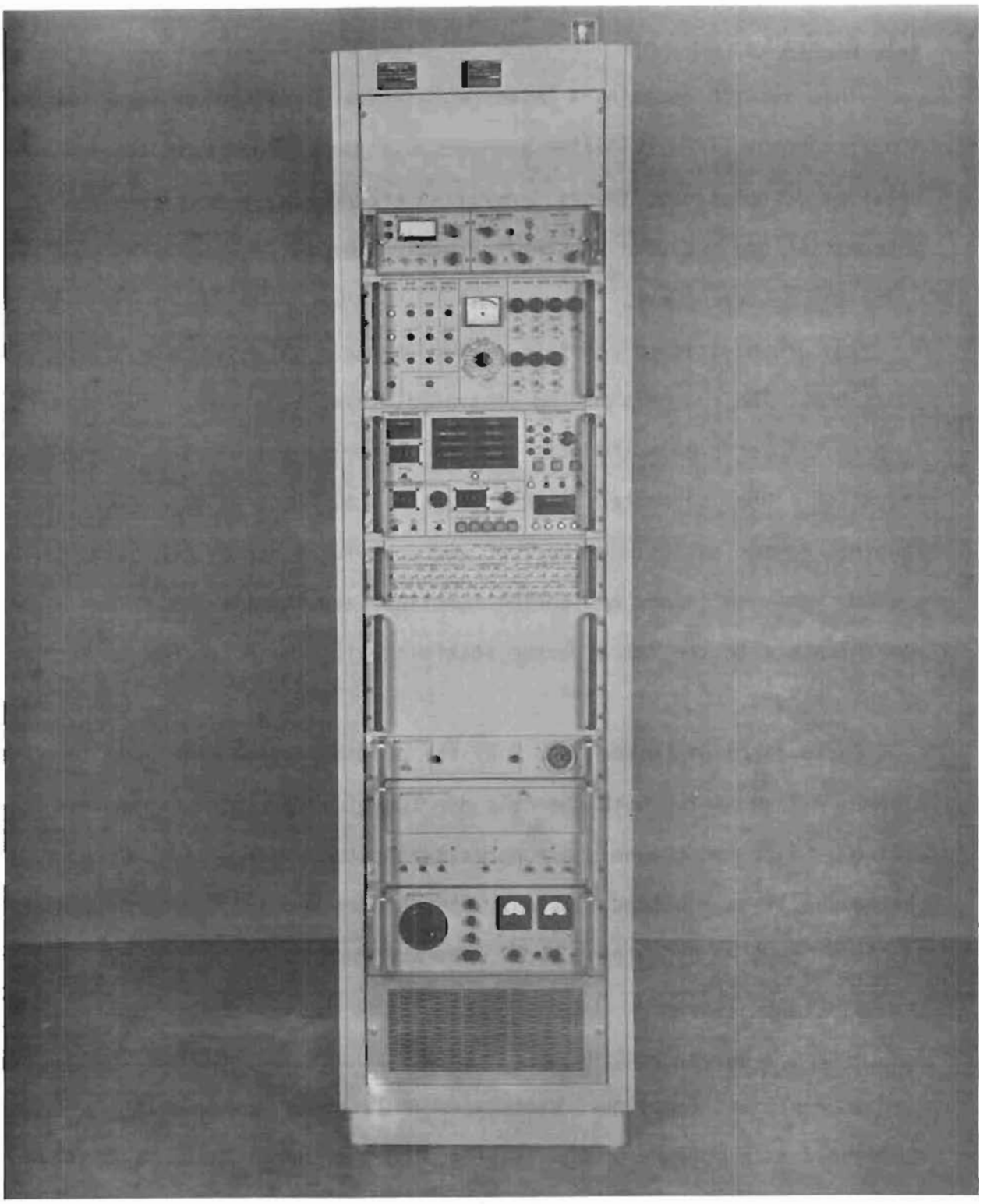


FIGURE 4-1. GROUND STATION CHANNEL NO. 1 (FRONT VIEW)

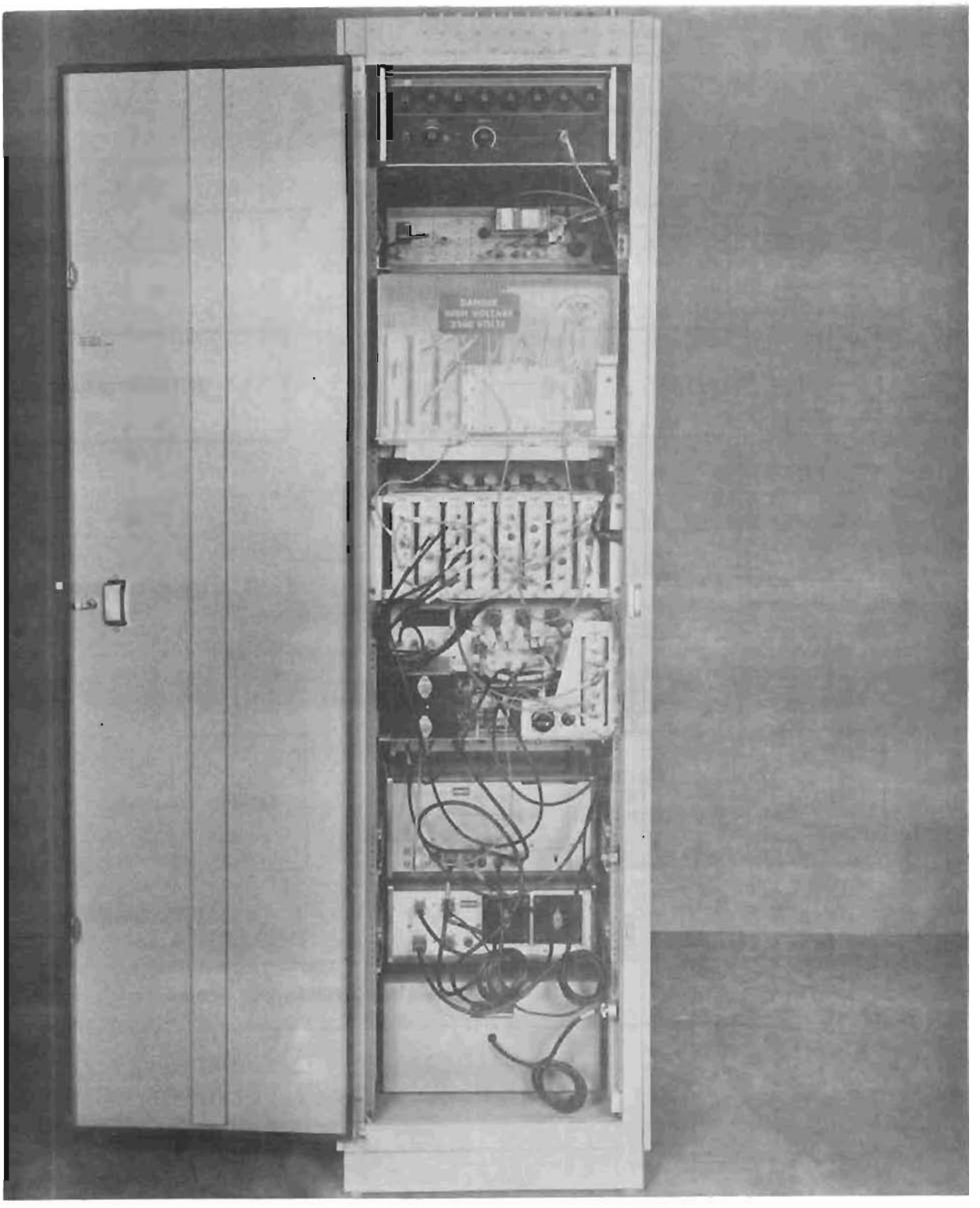


FIGURE 4-2. GROUND STATION CHANNEL NO. 1 (REAR VIEW)

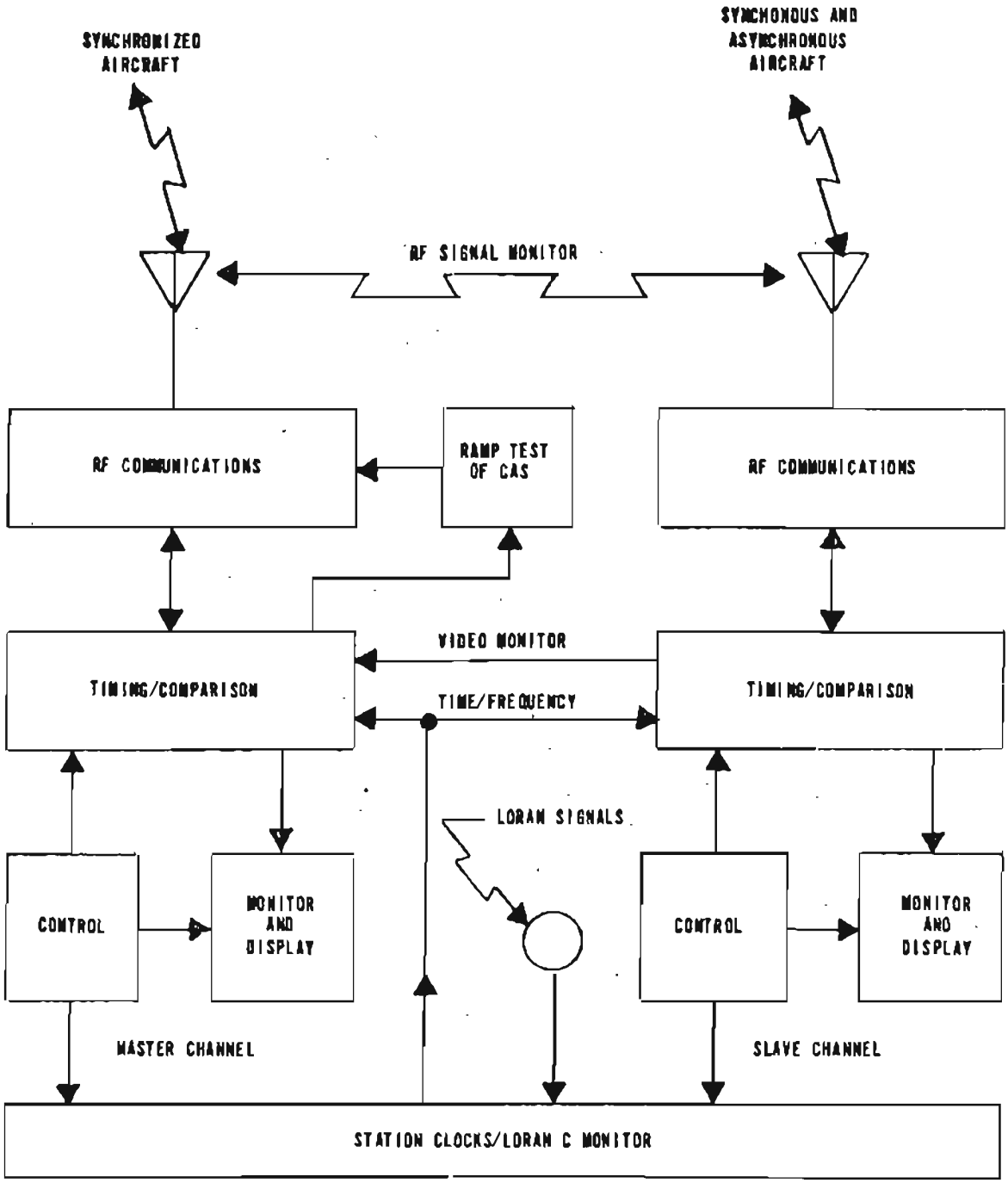


FIGURE 4-3. DUAL CHANNEL GROUND STATION SIMPLIFIED BLOCK DIAGRAM

monitor receiver. In general, the master channel communicates with synchronized aircraft and monitors their performance. The slave channel monitors the master and detects aircraft which may be operating asynchronously. The slave channel is slaved only in the sense that it accepts initial synchronization from the master. After that it maintains time independently. The slave channel will automatically assume the role of the master if the master channel fails.

The general contents and purpose of each block on Figure 4-3 are as follows:

RF Communications - contains the transmitter and exciter-receiver. The exciter provides biphase modulated RF to the transmitter which amplifies and sends the RF to the antenna. The receiver converts received RF into IF, measures the Doppler frequency shift of the received RF, and demodulates the data stream.

Ramp Test - This logic generates test messages which are used in the aircraft to verify threat logic.

Timing/Comparison - This logic generates timing signals, establishes the time to transmit and format of all messages, compares time/frequency accuracy of the frequency standards (including the Loran-C receiver) and performs self tests to assure proper operation.

Control - provides means to turn power on/off and control sequence of self tests.

Monitor and Display - contains light emitting diode numeric displays to monitor received messages, lamps to display the results of self tests, and a meter for checking internal power supply voltages.

Station Clocks/Loran-C Receiver - generates precision 5 MHz for station time/frequency reference; monitors Loran-C transmissions to provide an independent time/frequency check.

Specific functions for each channel are listed below and summarized in Table 4-1. Ground Station characteristics are summarized in Table 4-2. Functions of the master channel are to:

(1) Accept initial time synchronization or update from a UTC time disseminating service (e.g., fly-By Sync/CAS, Loran-C, WWV, portable clock);

(2) Maintain time synchronization, within $\pm$ 0.5 microseconds (3 sigma) relative to UTC between ground station time update intervals;

(3) Synchronize CAS aircraft within range;

(4) Radiate test signals for ground test of aircraft CAS;

(5) Monitor time agreement among (a) the internal frequency standard, (b) the external frequency standard, (c) ground epoch start triad transmitted by the master (RF received by the slave; demodulated, verified and hardlined back to the master, when co-located); and (d) the epoch count derived from Loran-C receptions (if available);

(6) Communicate with CAS aircraft to test both ground and airborne stations' ability to communicate, as well as to cross check the accuracy of the timekeeping and time transfer services;

(7) Passively monitor performance of synchronized aircraft (identify and display selected CAS range, altitude, and biphase data);

(8) Passively monitor slave transmissions;

(9) Perform continuous integrity monitoring in the form of Built-In-Test (BIT) of all master channel functions;

(10) Automatically inhibit master transmissions when a failure is detected; and

(11) Provide suitable alarms and indications.

Functions of the slave channel are to:

(1) Accept initial time synchronization or update from the master channel;

(2) Independently maintain time synchronization within $\pm$ 0.5 microseconds, 3 sigma, relative to UTC (between master channel time update intervals);

(3) Continuously and independently monitor time agreement among the selected "on-line" station clock, the hot standby station clock, and the epoch count derived from Loran-C receptions;

(4) Receive ground epoch start triads radiated by the master channel, decode them, and hardline a verification signal back to the master.

(5) Display the CAS test signals radiated by the master channel;

(6) Display master ground slot transmissions;

(7) Search for, detect, display information, and communicate with aircraft operating with asynchronous CAS (apparently skewed by more or less than one slot, or actually skewed in time or frequency cycle);

(8) Perform continuous integrity monitoring in the form of Built-In-Test (BIT) of all slave channel functions.

(9) Automatically inhibit slave transmissions (interrogation of skewed aircraft) when a failure is detected;

(10) Provide suitable alarms and indications for the operator so that he may take corrective action;

(11) Automatically assume the function of the master if master fails.

TABLE 4-1. DUAL CHANNEL T/F GROUND STATION FUNCTIONS

	MASTER	SLAVE
Accept Initial Time and Update	X	X
Maintain Time to Within 0.5 μs, 3σ	X	X
Monitor Time Between Clocks	X	X
Integrity Monitor (BIT)	X	X
Inhibit Transmissions if Failure is Detected	X	X
Generate Failure Alarm	X	X
Synchronize CAS Aircraft	X	
Radiate Test Signals	X	
Communicate with Fly-By Sync Aircraft	X	X
Monitor Performance of Synchronized Aircraft	X	X
Monitor and Display Slave Transmissions	X	
Decode Ground Epoch Start Triads and Route Verification Pulse to Master		X
Monitor and Display Master Ramp Test Signals		X
Monitor and Display Master Slot Signal		X
Detect Skew		X
Function as Master when Other Channel is Not		X

TABLE 4-2. GROUND STATION CHARACTERISTICS

Equipment Type: Development Model T/F CAS Ground Station

Equipment Function: Timekeeping, Synchronization, and Monitoring Service for Airborne CAS.

Equipment Use: FAA Test and Evaluation.

Assigned Frequency Band: 1592.5 MHz to 1622.5 MHz.

Operating Frequencies: 1600 MHz, 1605 MHz, 1610 MHz, and 1615 MHz, normally time division multiplexed.

Frequency Control: Cesium Beam.

Modulation: Pulse (1.6 microseconds to 200 microseconds) and Biphase (NRZ Space, 1 Megabit/second burst rate for 120 microseconds within each 200 microsecond pulse).

Modulation Duty: Up to sixteen 200 microsecond pulses per 3 second epoch, plus up to 2000 1.6 microsecond resync triads per 3 second epoch at intermittent duty.

Power Output: 2000 watts $\pm$ 3 dB.

Receiver Type: Superheterodyne, double conversion.

IF Frequencies: 45 MHz and 160 or 165 or 170 or 175 MHz.

Local Oscillator Frequencies: 1440 MHz and 205 or 210 or 215 or 220 MHz.

Receiver Noise Figure: 8 dB.

Receiver Sensitivity: -88 dBm.

Antenna: Vertical array of nine half-wave dipole elements.

Power Requirements: 15 amperes, single phase 60 Hz 120 VAC.

Major Assemblies of Master/Slave Channels: Frequency synthesizer, Loran-C receiver, transmitter, power control/monitor panel, exciter-receiver; display panel, test point panel, logic, cesium frequency standard, standby power supply, blower, digital clock, and antenna.

5.0 DESCRIPTION OF AIRBORNE EQUIPMENT

5.1 General

This section contains a brief description of the airborne equipment and instrumentation provided for the FAA CAS evaluation program. Detailed descriptions, theory, operating procedures, and maintenance information are included in the instruction manual, reference 8, provided under the contract work.

Photographs of the Collision Avoidance Unit (CAU), Fly-By Synchronization, and MiniCAS equipment are shown in Figures 5-1, 5-2, and 5-3, respectively.

5.2 Airborne System Configurations

The McDonnell Model 2000 Collision Avoidance System (CAS) conforms to ARINC Characteristic No. 587 which defines the basic requirements for CAS specifically designed for installation in commercial transport aircraft. A complete airline CAS installation includes at least one electronics unit, designated the Collision Avoidance Unit (C.A.U.), two antennas, at least one maneuver indicator, and an optional Precision Frequency Unit (P.F.U.). Figure 5-4 illustrates normal operational configurations for commercial airlines.

The McDonnell MiniCAS equipment is intended for use on general aviation aircraft. A typical configuration is shown in Figure 5-5.

For the FAA evaluation program, the configurations are modified to accommodate the additional requirements for flight test, instrumentation, and evaluation of new concepts (fly-by-sync and $\Delta R/\Delta T$ threat logic).

Figures 5-6 and 5-7 depict configurations for installation in two flight test aircraft. Figure 5-6 configuration is intended primarily for test of the Fly-By-Sync (F.B.S.) equipment with a C.A.U. and $\Delta R/\Delta T$ Unit.

FIGURE 5-1. MODEL 2000 COLLISION AVOIDANCE UNIT

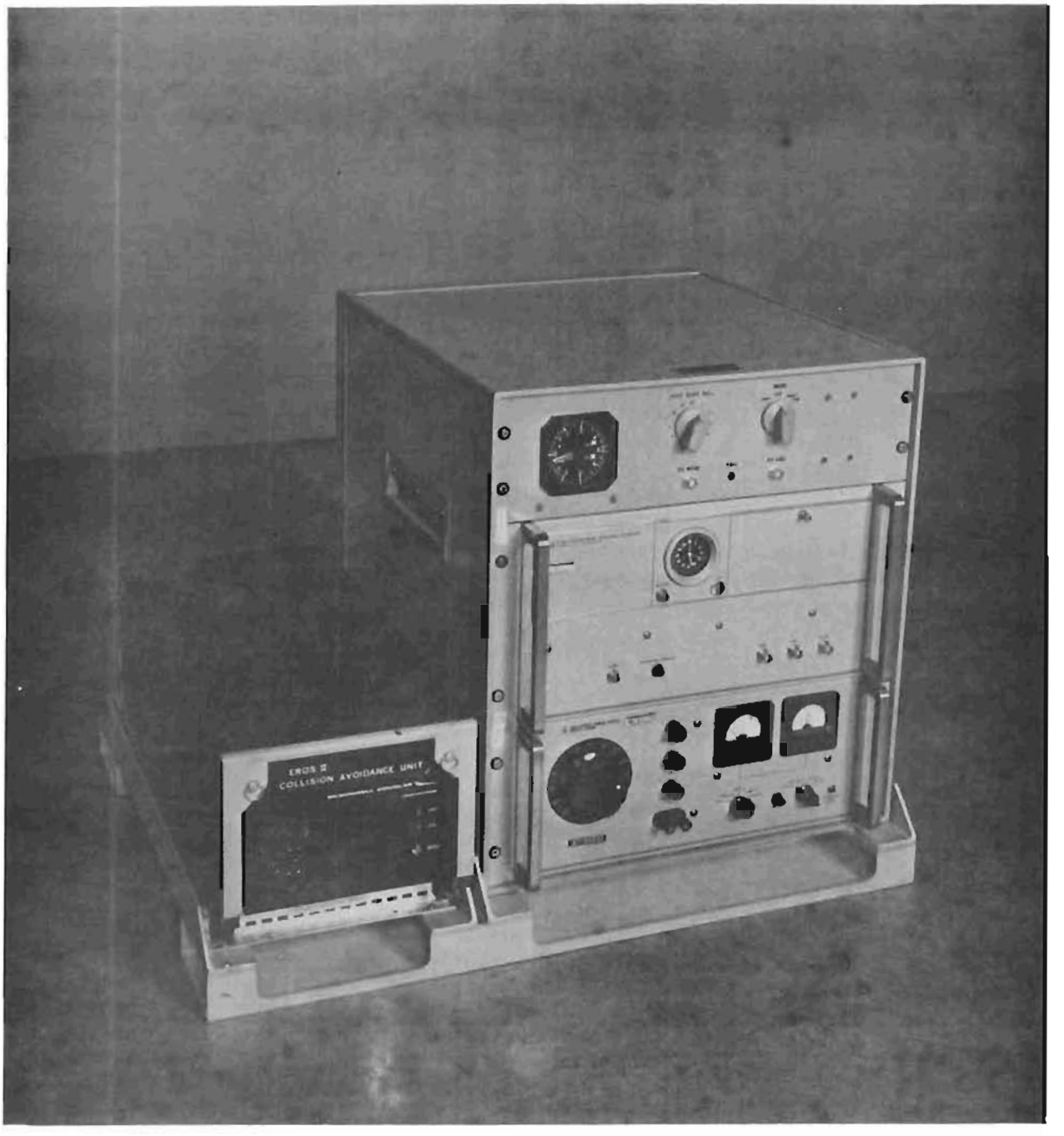


FIGURE 5-2. FLY-BY SYNCHRONIZATION EQUIPMENT

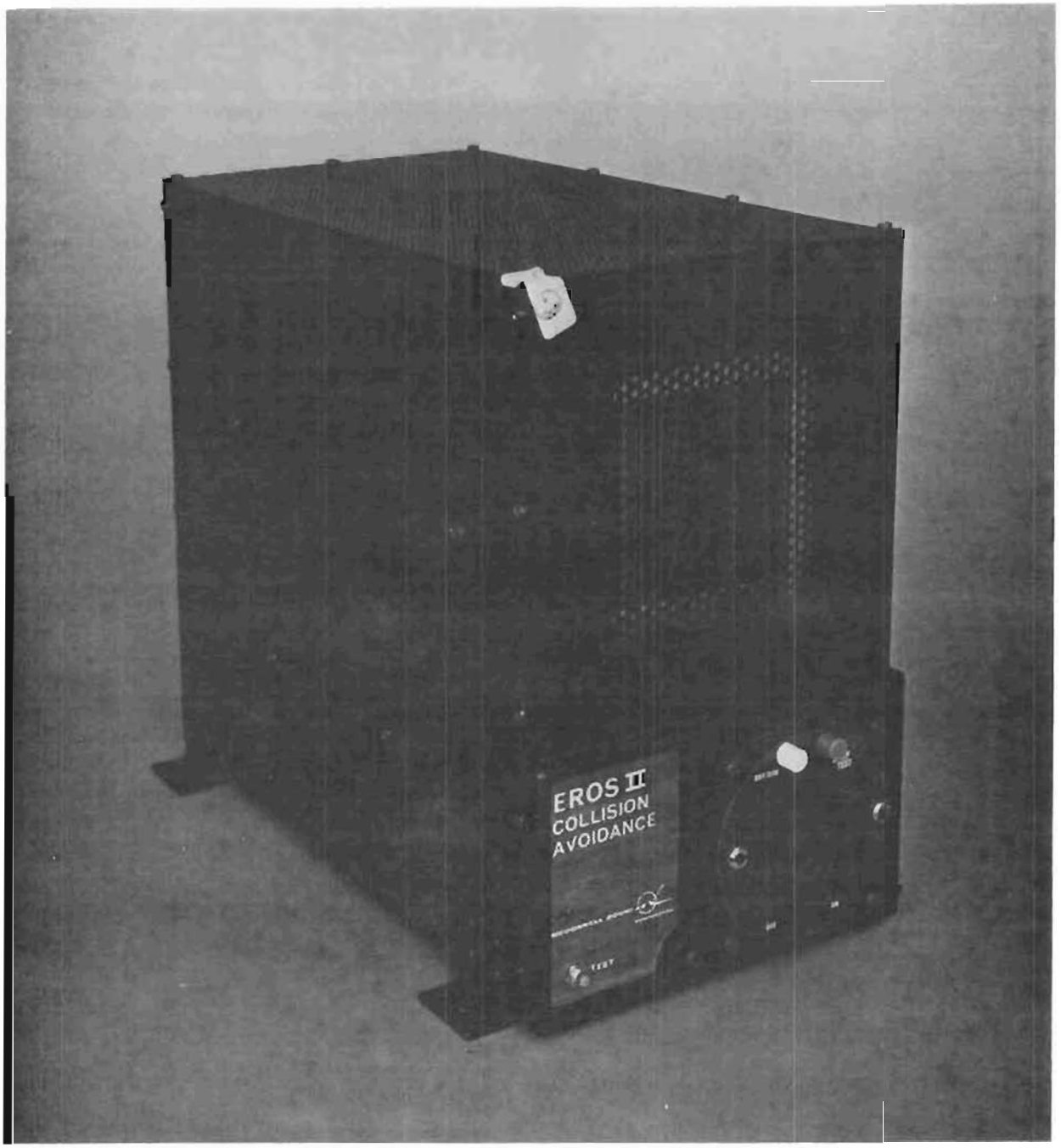


FIGURE 5-3. MINICAS

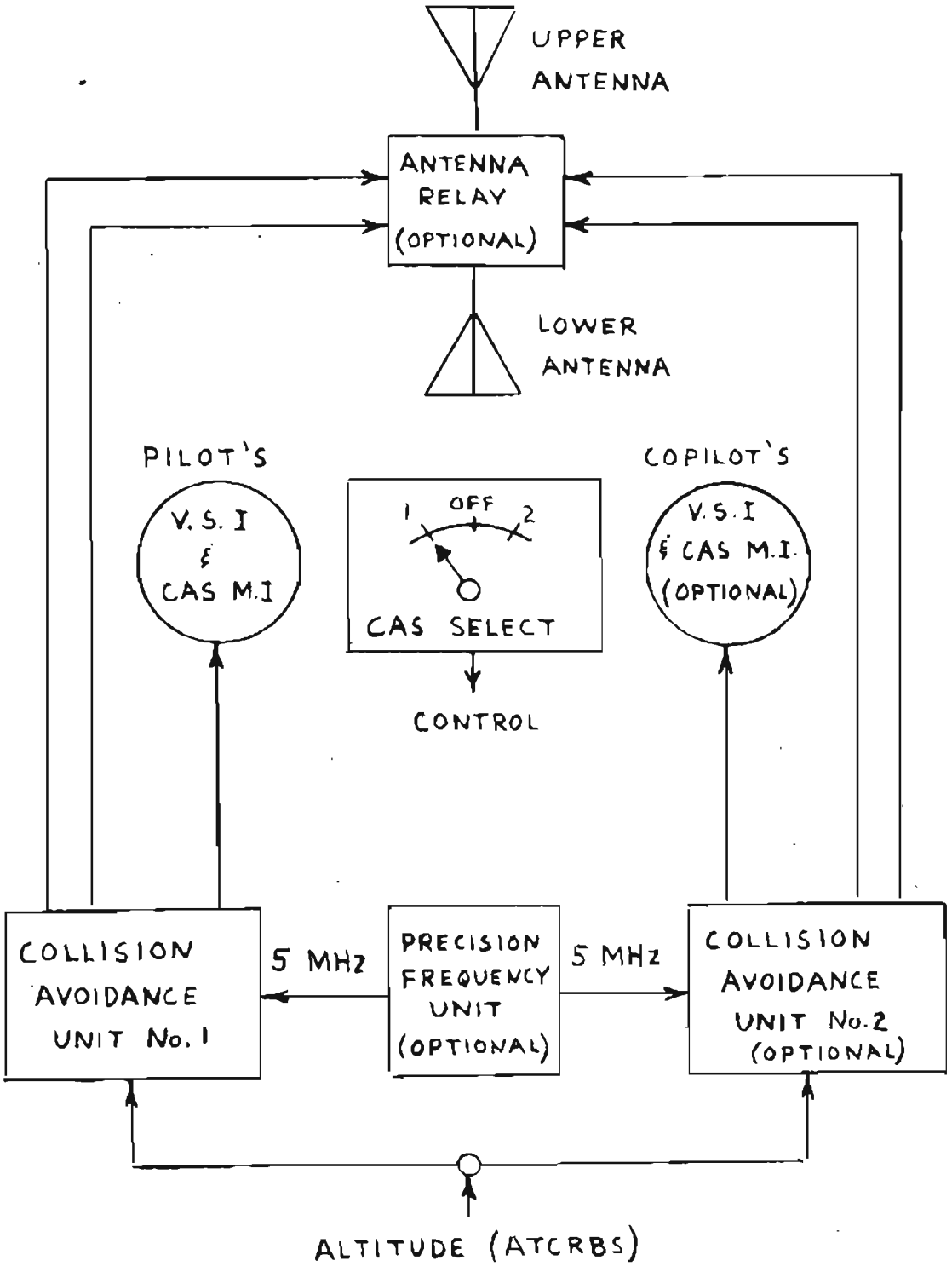


FIGURE 5-4. COMMERCIAL AIRLINE CAS CONFIGURATION

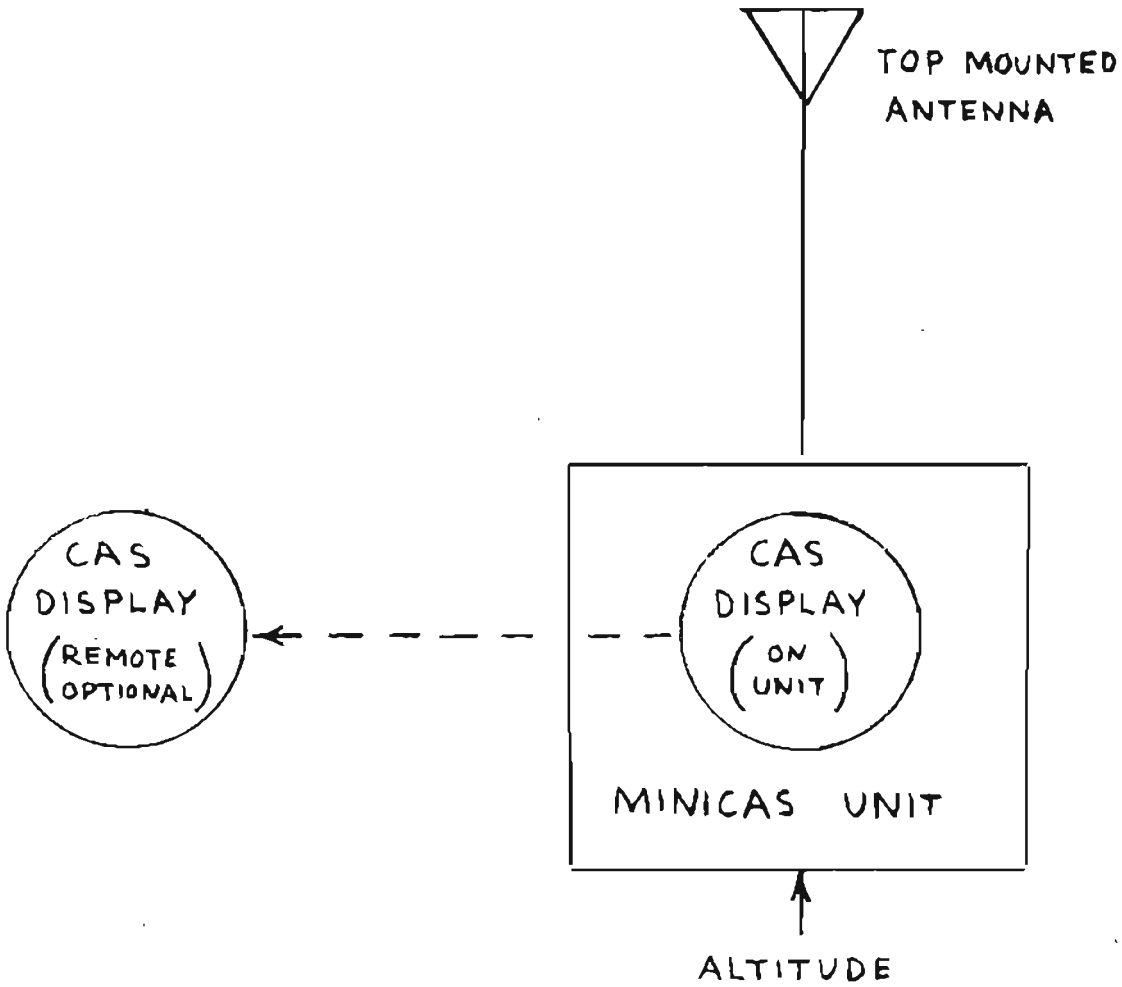


FIGURE 5-5. GENERAL AVIATION MINICAS CONFIGURATION

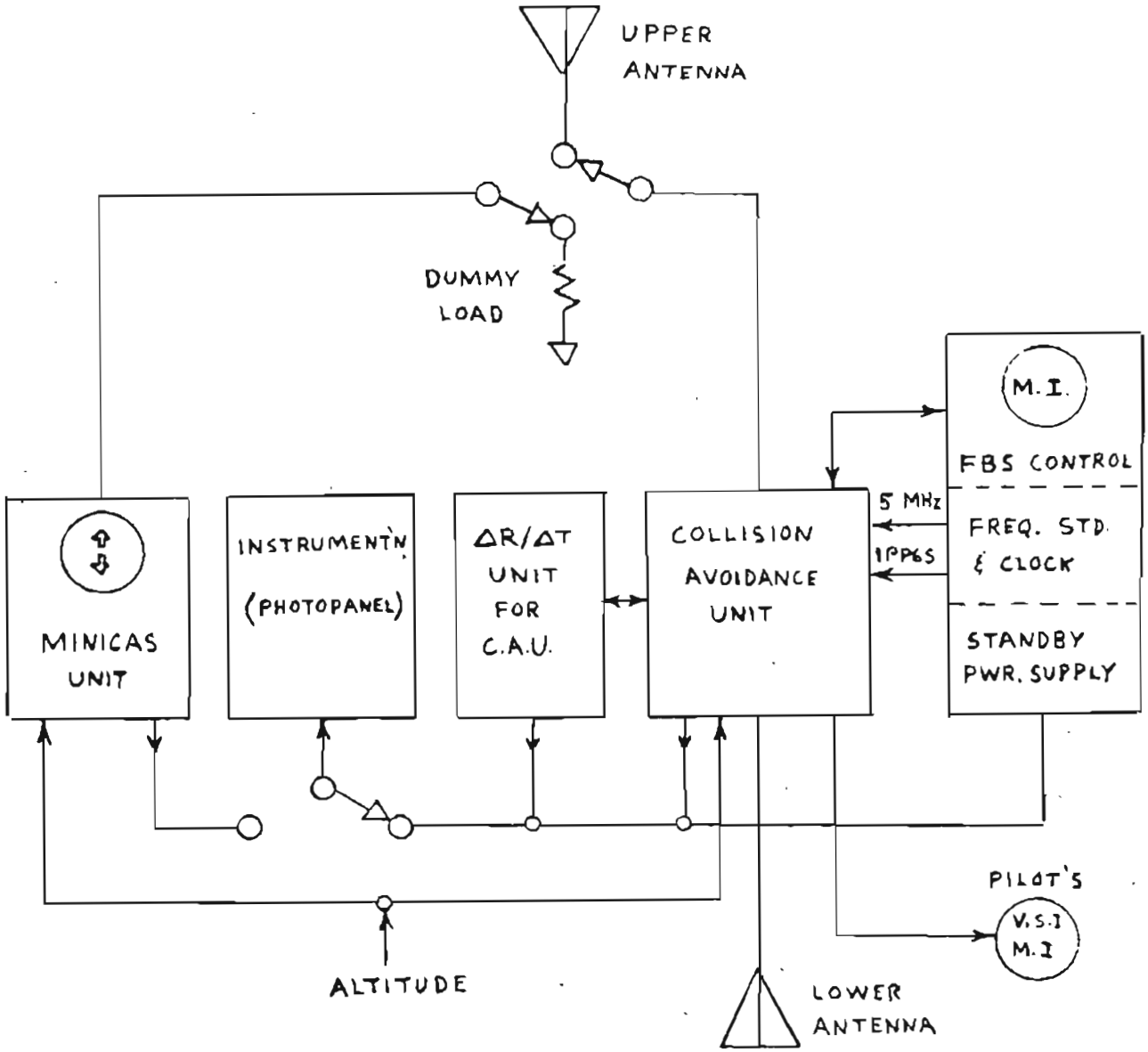


FIGURE 5-6. TEST AIRCRAFT NO. 1 EQUIPMENT CONFIGURATION

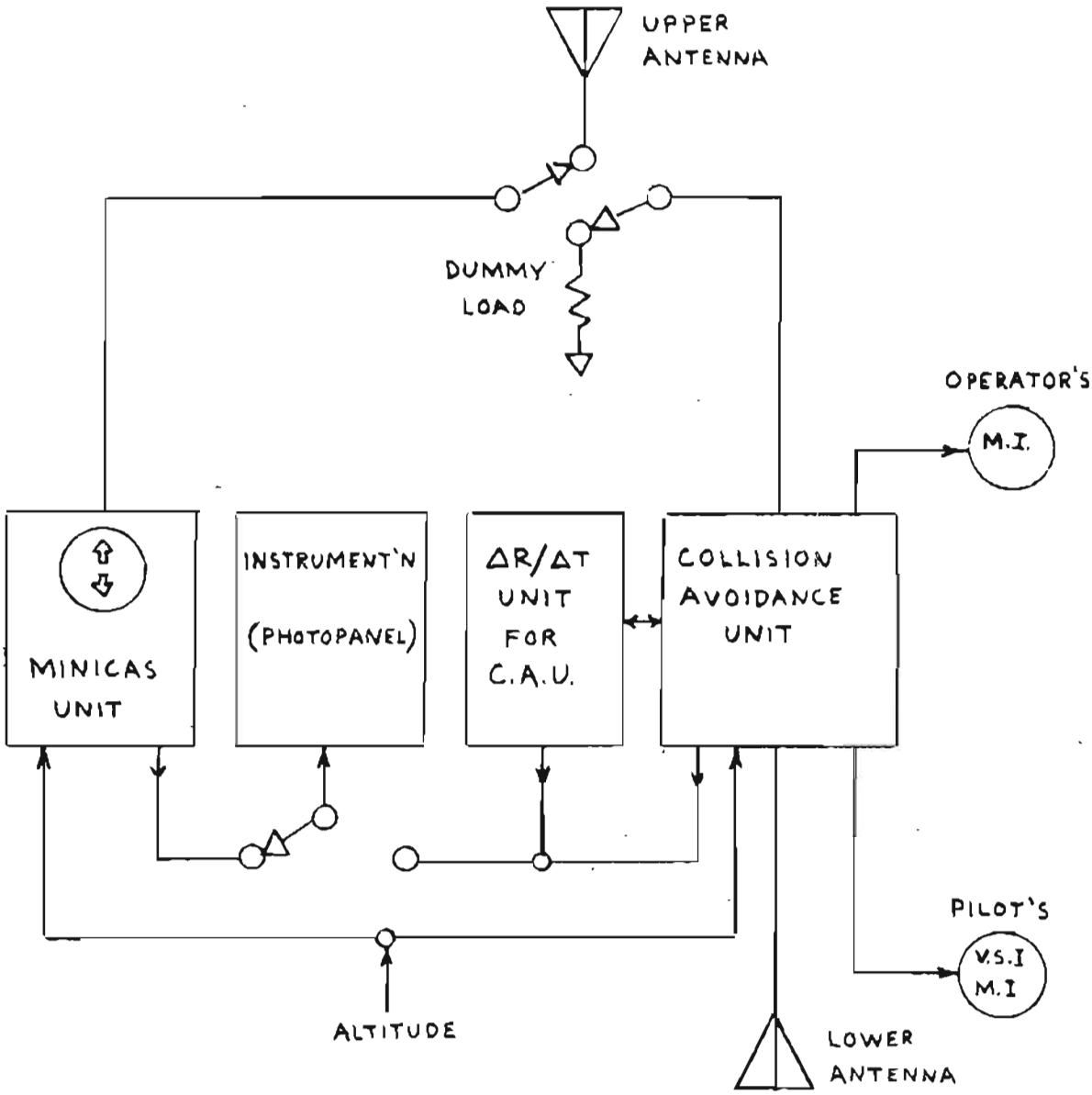


FIGURE 5-7. TEST AIRCRAFT NO. 2 EQUIPMENT CONFIGURATION

Instrumentation, antennas, and aircraft interfaces are connected to the C.A.U. The MiniCAS is normally "off" or in "standby" with transmission inhibited. (The MiniCAS in the second aircraft would normally be "on" with the second C.A.U. "off.") The standby MiniCAS may be used by turning the C.A.U. off and reconnecting the instrumentation, upper antenna, and aircraft interfaces to the MiniCAS.

Figure 5-7 configuration is intended primarily for test of the MiniCAS which is shown connected to the upper antenna, instrumentation, and aircraft interfaces. The C.A.U. is normally "off" but can be used instead of the Mini CAS by reconnecting the appropriate interface equipment. Fly-By-Sync equipment is not provided for the second aircraft.

5.3 Fly-By-Sync Operation/Functions

The airborne fly-by synchronization equipment (Flying Clock and simplified Control Panel), when operated with a C.A.U. and one set of instrumentation, enables the operator to control and monitor the initial synchronization and periodic calibration of the CAS ground station. Specifically, the CAS/FBS performs the following functions:

(1) Obtains UTC time synchronization from a master time source (such as the Naval Observatory) by means of a portable clock, or alternately via an RF link using a CAS T/F ground station (master channel);

(2) Maintains master time while flying from the master source to specific CAS ground stations, and while returning to the source for closed loop checks;

(3) Transfers master time (initial start or update) to the specific CAS ground station(s), normally via an RF link;

(4) Operates cooperatively as a full airborne CAS in accordance with ANTC 117 and ARINC 587, in the normal CAS environment, while performing FBS duty;

(5) Monitors the operation of CAS ground station master channels, specifically checking all two-way communication functions including dynamic range of the links and the timekeeping and synchronization process;

(6) Performs continuous integrity monitoring in the form of built-in-test (BIT) of all CAS functions;

(7) Automatically takes itself out of service when a failure is detected; and

(8) Processes ground station ramp test signals, when on the ground and test mode is selected. Displays the simulated threat responses on the maneuver indicator and the test data on the instrumentation.

5.4 Model 2000 CAS Operation/Functions

The McDonnell Model 2000 CAS may be operated with or without the FBS equipment. On the FBS aircraft this is accomplished simply by selecting either CAS/FBS or CAS-ONLY mode on the Control Panel. In the CAS/FBS mode the C.A.U. uses the precision frequency (5 MHz) of the Flying Clock to maintain time and is initially synchronized to the epoch time of the clock. The C.A.U. remains in time-hierarchy 01 throughout its FBS mission. In the CAS-ONLY mode, the C.A.U. continues to use the precision frequency of the Flying Clock (simulating operation of the ARINC 587 P.F.U.); however, the epoch time of the clock is not used. Instead, the C.A.U. must achieve

time sync via the normal ground-to-air or air-to-air hierarchal resync process. In this mode the C.A.U. demotes in hierarchy at the normal "slow" rate of one step per 834 epochs (41.7 minutes) in the absence of a resync update.

On the aircraft without FBS equipment the C.A.U. always operates in the normal CAS mode using its internal crystal oscillator. In the absence of resync update, the hierarchy demotes at the normal "fast" rate of one step per two epochs (six seconds).

The C.A.U.s are interchangeable and perform identical CAS functions which are:

(1) To encode and transmit CAS signals to convey range, range rate, altitude, and time synchronization information to receiving stations.

(2) To receive and decode CAS signals transmitted by participating stations.

(3) To provide two basic modes of CAS operation: Sync Mode, using time hierarchy, four frequency multiplexing and one-way threat evaluation; and Back-Up Mode (BUM), using special interrogate-respond threat evaluation techniques when operating asynchronously. Obstacle avoidance is also provided since it is an integral part of the existing design.

(4) To determine the extent of the collision hazard with respect to cooperating aircraft and to generate maneuver and advisory information (visual and aural) for the pilot.

(5) To maintain time synchronization with respect to the most accurate source of time within communication range.

(6) To transfer accurate time synchronization to other stations requiring such service.

(7) To provide for automatic selection of the ARINC 587 Precision Frequency Unit (PFU) 5 MHz, when available, for the generation and protection of a more accurate time base, permitting longer operation in the sync mode in the absence of time update from other stations (not required when the "Flying Clock" is used).

(8) To provide continuous integrity monitoring (BIT); to provide outputs to an airborne integrated data system (AIDS), when available; to provide data to a flight data recorder (FDR), when available; and, to send commands to the maneuver indicator and Fly-By Sync Panel to indicate status, degradation and failure.

(9) To provide outputs for automatic test equipment (ATE) for use in fault isolation in the maintenance shop. These signals are used also for interface with the instrumentation.

5.5 C.A.U. Operation with $\Delta R/\Delta T$ Unit

The operation and functions of the C.A.U., when connected to the $\Delta R/\Delta T$ Unit, are unchanged from those described in the previous paragraph. The only difference is the technique by which rate information is derived.

In the basic C.A.U., range rate is obtained by measuring the Doppler-shift of the radio carrier frequency. This requires highly accurate and stable frequency generation throughout the entire transmitting and receiving subsystems (in addition to precise timekeeping logic for ranging and resync).

Using the $\Delta R/\Delta T$ concept, in which range rate is digitally derived by range differencing, the requirements placed on the RF subsystems are greatly relaxed.

For the FAA evaluation program, no change has been made to the RF hardware. However, the $\Delta R/\Delta T$ concept can be tested by turning on the $\Delta R/\Delta T$ unit connected to the C.A.U. (Switch provided on $\Delta R/\Delta T$ unit.) In the $\Delta R/\Delta T$ mode, the C.A.U. utilizes the digitally-derived range rate, instead of the internal Doppler measurement, for TAU-threat computation.

When connected to the instrumentation, both types of range rate data are displayed for simultaneous comparison and evaluation. Threat displays and maneuver commands, however, are based only on the selected range rate measurement technique.

5.6 MiniCAS Operation/Function

ANTC-117 and ARINC characteristic No. 590 provide for limited level Collision Avoidance Systems that omit as many complexities as possible while permitting use by aircraft flying at jet altitudes and speeds. The McDonnell MiniCAS provides a compatible system for subsonic aircraft whose performance constrains them to an altitude below 10,000 feet and altitude rates less than 1,000 feet per minute.

The MiniCAS units, provided for the FAA evaluation program, are modified versions of early model Micro CAS equipment. MicroCAS threat logic was based on range and altitude computations only. However, the transmitted signal was controlled to the extent that receiving aircraft equipped with Doppler measurement circuits could compute TAU-threats based on both range and range rate information. The modified MiniCAS retains this so-called "coherent" transmission feature for use with the C.A.U. which can process either Doppler or $\Delta R/\Delta T$ range rate.

MiniCAS incorporates the new $\Delta R/\Delta T$ concept permitting it to use full TAU computations in the threat decision logic. Functionally, the MiniCAS provides the essential characteristics of the ANTC-117 Limited Level 2 system. Specifications for the Level 2 system have been revised slightly to reflect the performance of the MiniCAS.

5.7 Instrumentation Operation/Functions

The McDonnell instrumentation may be operated with either the C.A.U. (with or without FBS) or the MiniCAS. Both real-time displays and photographic recording are provided. The instrumentation package, Figure 5-8, is arranged such that the display may be viewed directly while the camera photographs the display.

When the instrumentation is connected to the C.A.U., the operator may monitor both own slot and one data slot (other participating airborne or ground station) on the display. Own message slot number is identified to the operator by a four-digit display (OMS SLOT NO.). Unknown data slot numbers are identified in a roll call manner on the BOGEY SLOT NO. readout. The operator may select one of the active data slots for display by dialing-in the number on the DMS SELECT thumbwheel switches.

The following information is displayed on the own message slot section of the panel:

1) Own Message Slot Number
2) Hierarchy (00 through 63)
3) Sync Address (Slot Number)
4) Transmitted Altitude (Feet)
5) Received Resync (Time)

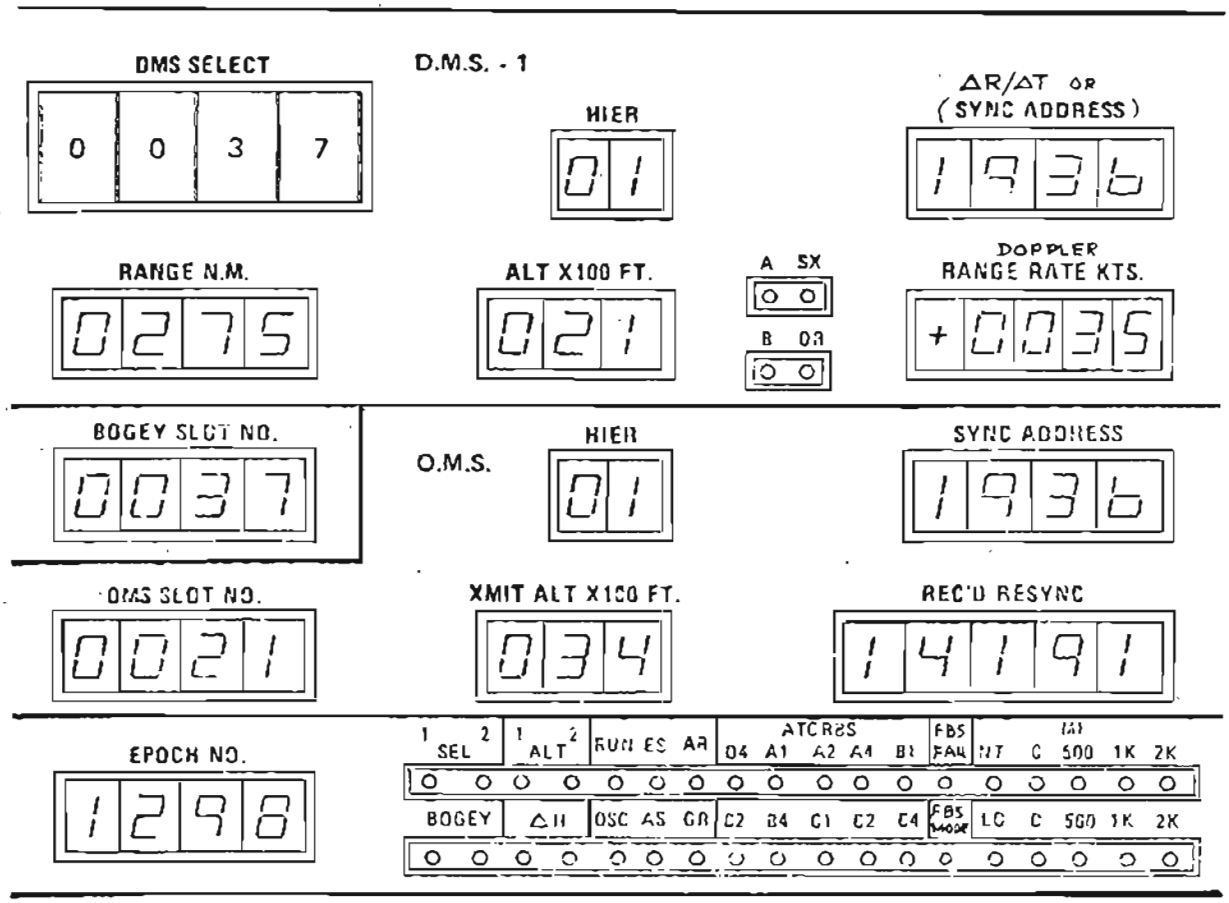


FIGURE 5-8. MCDONNELL INSTRUMENTATION DISPLAY

In the data message slot section the following bogey or selected slot information is displayed:

1) Range (Nautical Miles)

2) Altitude (Feet)

3) Hierarchy (00 through 63)

4) Doppler Range Rate (Knots)

5) $\Delta R/\Delta T$ Digital Range Rate (Knots) or Sync Address (Slot Number) when selected by a switch.

Other useful switches and status display lights included on the panel include ATCRBS code (altitude encoder) readout, maneuver indicator repeater lights, and a resettable four-digit counter (Epoch Number) for time correlation.

When operated with the integrated CAS/FBS equipment, the real time displays may be used to monitor performance of the Fly-By-Sync calibration process as well as the normal C.A.U. parameters described above. After the initial sync has been transferred from the FBS aircraft to the ground station, the accuracy of the process may be verified by monitoring the OMS RESYNC number readout. This readout is a five-digit number that indicates the fine sync time as calculated from time of receipt of a fine sync triad. The nominal value is 1419.2 microseconds. The difference between the displayed value and the nominal value is the amount and direction that the C.A.U. normally corrects its time base in the CAS ONLY mode. In the CAS/FBS mode, however, the airborne C.A.U. is already aligned to the Flying Clock with master time (from the U.S.N.O.), and the time base is not adjusted to agree with any received resync. The RESYNC readout in the case of FBS operation, therefore, indicates how well the ground station time base and transmitted resync signals

agree with the airborne. Normal quantizing errors and scatter due to the RF link are expected, but the average of the readings should approach 1419.2 as the number of samples increases. A significant bias (non-zero average difference) would indicate the need for recalibration of the ground time base.

When the C.A.U. is on the ground and test mode is selected, the instrumentation may be used to monitor the test message transmissions from the ground station. (Doppler range rate must be used to obtain the proper maneuver indicator threat displays.)

MiniCAS operates with the instrumentation in much the same manner as the C.A.U. However, since MiniCAS does not use Doppler range rate nor biphase data, the associated displays are not activated.

5.8 Summary of Equipment Characteristics

Table 5-1 summarizes the major characteristics of the airborne equipment.

TABLE 5-1. AIRBORNE EQUIPMENT CHARACTERISTICS

GENERAL INFORMATION

Equipment Type: Airborne Communication, Navigation and Identification

Equipment Function: Airplane Collision Avoidance

Equipment Use: FAA Test and Evaluation

Procurement Specification: Department of Transportation, Federal Aviation Administration Engineering Requirement, "Collision Avoidance System Ground Station," FAA-ER-240-016, 1 October 1971 (includes partial specifications for airborne equipments, modified by changes to Contract DOT-FA73WA-3239).

TABLE 5-1 (Continued):

Major Equipment Items:

McDonnell Model 2000 CAS (Modified)

Hewlett Packard "Flying Clock" (Modified)

Fly By Sync Control Panel (Simplified)

MiniCAS (Modified MicroCAS)

Instrumentation (Photopanel)

Assigned Frequency Band: 1592.5 MHz to 1622.5 MHz

Operating Frequencies: 1600 MHz, 1605 MHz, 1610 MHz, and 1620 MHz, normally time division multiplexed.

Frequency Control: Cesium Beam or Crystal

Modulation: Pulse (1.6 microseconds to 200 microseconds) and Biphase (NRZ Space at 1 Megabit/second burst rate for 120 microseconds within the 200 microsecond pulse).

Modulation Duty: One 200 microsecond pulse per 3 seconds minimum; 0.0002 typical maximum; 0.003 lockout.

SPECIFIC EQUIPMENT INFORMATION:

1) McDonnell Model 2000 CAS (Modified)

Major Items:

Collision Avoidance Unit (C.A.U.)

Upper and Lower Antennas

Maneuver Indicator

$\Delta R/\Delta T$ Unit

Function: Commercial Airline CAS

Airline Specification: ARINC Characteristic No. 587

Special Modifications: Fly-By-Sync, Extended Range Resync, $\Delta R/\Delta T$ Unit for digital range rate, and instrumentation interface outputs.

TABLE 5-1 (Continued):

System Frequencies Used: All (transmit and receive)

Frequency Control: External Cesium Beam or Internal Crystal.

Modulation: Pulse and Biphase

Power Output: 1000 Watts $\pm$ 3 dB

Receiver Type: Double Conversion Superheterodyne

Receiver Sensitivity: -88 dBm, nominal

Receiver Noise Figure: 8 dB maximum

Antenna: Vertically Polarized Stub

Displays: CAS Status Flag and CAS Command/Advisories

Power Requirements: 115V, 400 Hz, 3 amps, maximum and Standby Timekeeping 28 VDC, 2 amps, maximum (C.A.U.).

Note: $\Delta R/\Delta T$ Unit requires 115V, 400 Hz, 1 amp, maximum

2) Hewlett Packard "Flying Clock" (Modified)

Major Items:

Standby Power Supply Model K02-5060A

Cesium Beam Frequency Standard Model 5061A, with Standard Options 002 (30 minute battery) and 004 (improved beam tube, and special option H59 (001 clock option with special 1PP6S output.)

Function: Master Clock for Fly-By-Sync Service

H.P. Specifications: (Also see HP Manuals)

Accuracy: $\pm 7 \times 10^{-12}$

Settability: $_ 1 \times 10^{-13}$

Long Term Stability: $\pm 3 \times 10^{-12}$ (for life of tube)

TABLE 5-1 (Continued):

H.P. Specifications (Continued):

Warm-up Time: 30 minutes

Standby Battery Operation: 30 minutes without main standby supply, 6 hours with main supply.

Outputs: 5 MHz, 20 milliwatts, minimum, into 50 ohms, 1 pulse/6 seconds, 4.7 volt ± 5%, (CAS Epoch Pulse).

Power Requirements: 115V, 400 Hz, 1.5 Amperes, maximum. (Aircraft input to Standby Power Supply)

3) Fly-By-Sync Control Panel (Simplified)

Function: Mode Control and Display for FBS C.A.U.

Mode Selection: TEST, CAS-ONLY, and CAS/FBS

Displays: CAS Maneuver Indicator and FBS "FAIL" light.

Interface: C.A.U. and Instrumentation

Power Requirements: Provided by interfaces (aircraft power input not required)

4) MiniCAS (Modified MicroCAS with $\Delta R/\Delta T$)

Function: General Aviation CAS

Specification: McDonnell Proposal, 18 March 1974

Special Modifications: $\Delta R/\Delta T$ and TAU Threat Logic

System Frequencies Used: Transmit 1605 MHz; Receive All

Frequency Control: Internal Crystal

Modulation: Pulse Only (no biphase)

Power Output: 150 watts ± 3 dB

Receiver Type: Single Conversion Superheterodyne

TABLE 5-1 (Continued):

SPECIFIC EQUIPMENT INFORMATION (CONTINUED):

Receiver Sensitivity: -78 dBm, nominal

Receiver Noise Figure: 13 dB, maximum

Antenna: Vertically Polarized Stub

Displays: Standby/Sync light and CAS Command/Advisories

Power Requirements: 13 ± 1 VDC, 5 amos, maximum.

5) Instrumentation (Photopanel)

Function: Real Time Data Display and Photographic Recording

Interfaces: C.A.U. or MiniCAS, and Aircraft

Capacity: Two Data Slots (own aircraft and intruder)

Display Update Rate: Once per CAS 3-second Epoch

Recording Rate (Camera): One Frame per Epoch

Displays:

Own Message Slot Number

Own Hierarchy Status

Own Sync Address

Own Transmitted Altitude

Own Received Resync Time

Bogey Message Slot Number (non-selected slot)

Intruder Range

Intruder Transmitted Altitude

Intruder Hierarchy Status

Intruder Doppler Range Rate

Intruder $\Delta R/\Delta T$ Range rate } (shared)

Intruder Sync Address }

CAS Input/Output Status Lights

TABLE 5-1 (CONTINUED):

SPECIFIC EQUIPMENT INFORMATION (CONTINUED):

Controls:

Data Slot Selector Switches

Oleo Switch (simulates aircraft strut switch)

Approach/Departure Switch (simulates flap switch)

Transmit Inhibit Switch

Camera ON/OFF Switch

Power Requirements: 28 VDC, 2 amps maximum

6.0 FACTORY ACCEPTANCE TEST

6.1 General

This section describes the Factory Acceptance Test performed by McDonnell to demonstrate compliance with the Engineering Requirement, FAA-ER-240-016 (reference 2) and the contract, DOT-FA73WA-3239 (reference 1), for the Development Model T/F CAS Ground Station and associated airborne equipment. The tests were performed at the MDEC, St.Charles, Missouri facility from August 26 to October 2, 1974. All tests were performed in accordance with the approved procedure (reference 10) and were witnessed by the resident FAA Quality/Reliability Officer. Tests results were recorded and approved.

6.2 Summary of Tests Performed

The factory acceptance tests were divided into two groups: 1) single system tests, and 2) system-to-system tests.

Single system tests were those performed on single end-item equipments. Measurements were limited to those which did not require use of a cooperative system or special test set. Tests in this group were:

1) CAU Test (each unit)
2) MiniCAS Test (each unit)
3) Ground Station Test (each channel)

System-to-system tests were those which required use of two or more cooperative equipments or systems to establish communication links and to demonstrate compatibility. Tests in this group were:

1) CAU-to-CAU Test
2) MiniCAS-to-MiniCAS Test
3) MiniCAS-to-CAU Test (each unit)
4) Ground Station-to-CAU/FBS Test (each unit)
5) Ground Station-to-MiniCAS Test (each unit)
6) Ground Station-to-All (four) Airborne Test

6.3 Test Objectives

All tests were selected to provide a reasonable level of confidence in the performance and compatibility of the individual equipments and systems operating as a cooperative T/F CAS system under laboratory conditions. Specific parameters (e.g., pulse characteristics, transmitter power, receiver sensitivity, altitude encoding accuracy, etc.) were recorded and compared with specified tolerances.

All tests were performed with hardline (coaxial cable) interconnections between equipments to eliminate the uncontrollable effects of multipath and signal strength variation. The resulting measurements and indicated responses (displays, alarms, etc.) thus became the baseline data for later bench and flight tests in the field.

6.4 Single System Tests

6.4.1 CAU Tests

The following tests were performed on both Collision Avoidance Units, MDEC Part No. A05A0211:

1) Transmitter and Pulse Characteristics (power output, droop, leakage, spurious radiation, rise time, fall time, overshoot, undershoot, backswing, return swing, pulse widths, pulse, spacing, and biphase modulation characteristics).
2) Receiver Characteristics (tangential and threshold sensitivity, dynamic range, adjacent CAS frequency response, spurious out-of-band response, and recovery time).
3) Oscillator Characteristics (warm-up time and drift rate without AFC)
4) Built-In-Test (operation of CAU and Antenna BIT circuits)

See paragraph 6.6 for summary of results.

6.4.2 MiniCAS Tests

The following tests were performed on both MiniCAS units, MDEC Part No. A05A0214.

1) Transmitter and Pulse Characteristics (same parameters listed for CAU, except biphase).
2) Receiver Characteristics (same parameters listed for CAU).
3) Oscillator Characteristics (same parameters listed for CAU).

No discrepancies were noted.

6.4.3 Ground Station Tests

Each channel of the dual channel station was tested individually for the following:

1) Transmitter and Pulse Characteristics (same parameters listed for CAU).
2) Receiver Characteristics (same parameters listed for CAU).
3) Standby Power Operation
4) Power Line Voltage Variation
5) Built-In-Test Functions.

No discrepancies were noted in either channel. During the test, however, two logic elements in one of the channels were inadvertently "blown-out" by a high voltage transient introduced by an item of test equipment. The two I.C.'s were replaced and the rework inspected.

Upon completion of the single channel tests, the ground station was tested in the dual channel configuration. Tests were made with Channel No. 1 as Master and Channel No. 2 as Slave. Then all tests were repeated with the Master/Slave functions reversed in each channel.

The following operations were demonstrated:

1) Time Base Alignment (alignment of both station clocks to agree with an external source, internal logic, Loran-C and ability of monitoring subsystem to automatically detect out-of-tolerance conditions).
2) Cross Channel Monitoring (Master/Slave loop BIT, and Slave monitor of Master ramp test functions).
3) Automatic Switchover (automatic detection and switchover from failed clock to good clock and of Master function from failed channel to good channel).

No discrepancies were noted during the factory tests. During the preliminary functional tests in the field, however, it was discovered that the automatic switchover did not function properly for all possible combinations of failed conditions. A minor design change was incorporated and all known failure-mode combinations were rechecked for correct automatic switchover action.

6.5 System-to-System Tests

6.5.1 CAU-to-CAU Tests

The following tests generally required the use of the $\Delta R/\Delta T$ Units, the Hewlett Packard "Flying Clock", the Fly-By Sync (FBS) panel, and CAS Maneuver Indicators in addition to the CAU assemblies. Tests included the following:

1) Back-Up-Mode Threat Evaluation
2) Sync Mode Tests (sync triad formats, hierarchy and fine sync process, oscillator automatic frequency correction, Doppler accuracy, $\Delta R/\Delta T$ accuracy, altitude encoding/decoding accuracy, CAS threat evaluation and reciprocity, and check of FBS interfaces).

See paragraph 6.6 for summary of results.

6.5.2 MiniCAS-to-MiniCAS Tests

These tests primarily exercised the threat evaluation logic of each MiniCAS which were checked for proper response and reciprocity of commands. Other items rechecked in this test included

1) Start-Up (from donor, CAU or Ground)
2) Fine Sync (from donor)
3) Oscillator Automatic Frequency Correction
4) $\Delta R/\Delta T$ Accuracy
5) Altitude Encoding/Decoding Accuracy

See paragraph 6.6 for summary of results.

6.5.3 MiniCAS-to-CAU Test

Both MiniCAS units were tested for compatible operation with both CAU's. The following items were checked:

1) Start-Up (from CAU)
2) Fine Sync (from CAU)
3) MiniCAS Oscillator Correction (by CAU)
4) $\Delta R/\Delta T$ Accuracy (each system)
5) Doppler Accuracy (MiniCAS transmitting, CAU receiving)
6) Altitude Encoding/Decoding Accuracy (each system)
7) CAS Threat Evaluation and Reciprocity

See paragraph 6.6 for summary of results.

6.5.4 Ground Station-to-CAU/FBS Test

These tests required full operation of the ground station with each channel tested in both Master and Slave modes. Both CAU's were tested with the FBS/Flying Clock configuration for correct operation with the ground station.

Tests included:

1) FBS Operation (CAU/FBS sync G/S)
2) Normal Operation (G/S sync CAU)
3) Master Channel Monitoring of CAU
4) Slave Channel Monitoring of CAU
5) Ramp Test (G/S test message generation and CAU response)
6) SKEW Test (purposely skew CAU time base and demonstrate capability of G/S to detect conditions).

No discrepancies were noted.

6.5.5 Ground Station-to-MiniCAS Tests

These tests were performed to demonstrate the ability of the ground station to operate with both MiniCAS units. Tests included:

1) G/S sync MiniCAS
2) Master Channel Monitoring of MiniCAS
3) SKEW Test (capability of Slave channel to detect MiniCAS time base skew).

No discrepancies were noted.

6.5.6 Ground Station-to-All Airborne Systems Test

These tests were performed to demonstrate the ability of the dual channel ground station to operate with all deliverable airborne CAS equipment (two CAU's and two MiniCAS units) simultaneously. Tests included:

1) G/S Sync (to all airborne units)
2) G/S Monitoring (of all airborne units)
3) Effect of G/S Failure and Recovery

No discrepancies were noted.

6.6 Summary of Test Results and Discrepancies

The Factory Acceptance Tests for all equipment was satisfactorily completed. Failure reports were written on all discrepancies noted during the tests where limits specified in the approved test procedure were not met by the equipment. With the exception of three minor discrepancies, all out-of-tolerance conditions noted during the acceptance tests were corrected. After the corrective action was performed, selected portions of the acceptance tests were repeated to verify the fix and to verify that all related circuits and measurements retained their previous characteristics.

McDonnell Douglas Electronics Company submitted a formal request for waiver on the three discrepancies not resolved inasmuch as the conditions noted were caused by inconsistencies within ANTC-117, reference 4. The waivers were granted and it was agreed that none of the conditions reported will in any way affect the operation of the CAS for the purpose procured.

The three discrepant conditions associated with the formal MDEC Failure Reports are summarized below:

Item 1 Failure Report 05420 and Failure Report 05423

After applying power to a cold Collision Avoidance Unit (CAU), the Collision Avoidance Unit will start operation in back-up mode (BUM) before an oscillator accuracy of 1×10^{-8} is achieved.

There is no specification in ANTC-117 or ER 240-016 for time-out prior to start of operation in the back-up mode (BUM). Both Collision Avoidance Units do not achieve the required oscillator accuracies within the time specified in the Factory Acceptance Test Procedure. However, on each unit (within one minute of specification) the oscillator achieves an order of magnitude better accuracy than is required by specification. Since warm up time is not specified and considered a market place item, McDonnell Douglas Electronics Company recommended acceptance of the Collision Avoidance Unit as is since the temporary inaccuracy will have no affect on system operation.

Item 2 Failure Report 05425 - Failure Report 05428 and Failure Report 05429

Steady state TAU 1 threats at the boundaries between altitude bands sometimes shift from one band to the other momentarily, always in the direction to provide an early alert of a potential threat.

The second basic discrepancy is related to the mechanization of the altitude threat logic in both the Collision Avoidance Unit and Mini CAS. Altitude input to the CAS is in a special gray code format with the least significant bit equal to 100 ft. Altitude is pulse position encoded for transmission at a rate of 0.4 usec per 100 feet input increment with reference to the leading edge of the range signal. Upon reception, the altitude is decoded with reference to the range pulse in the same manner as encoded for transmission.

If the 5 MHz oscillator in the transmitting system is exactly in phase with the oscillator in the receiving system, the Altitude encoded in one system will be perfectly decoded in the other system. However, as the phase of one oscillator shifts with respect to the other, the decoded altitude can vary by one least significant bit in the decoder which results in a change of 100 feet in the decoded altitude. Therefore, the only way ANTC-117 requirements incorporated in the Factory Test Procedure can be achieved is if the oscillator of the participating units remain perfectly in phase, which is impossible. McDonnell Douglas Electronics Company therefore allowed for the shift of 100 feet from one band to the next at the altitude band boundary limits such that they only occur at the extreme of the phase differences, and the majority of the threats were correctly detected in the altitude band occupied by the TAU 1 threats. Due to the inconsistency in ANTC-117 McDonnell Douglas Electronics Company has assured that threats will be detected at the earliest point in time. On this basis, MDEC requested waiver of failure reports written on this discrepant condition and acceptance of the units "as is".

Item 3 Failure Report 05426

On one of the two Collision Avoidance Units (CAU) the first to third pulse spacing of the resync triad is out of tolerance by 20 nanoseconds.

During the Factory Acceptance Test of one of the two Collision Avoidance Units provided under the subject contract, a measurement of the RF signal at the antenna revealed that the time between the first and third pulses of the resync triad was 20 nanoseconds greater than the tolerance (50 nanoseconds) specified in ANTC-117 and the Factory Acceptance Test Procedure. Considering this very tight tolerance on the signal in space and the major retuning and rework that would have been required, McDonnell Douglas Electronics Company requested waiver of the Failure Report covering this discrepancy inasmuch as the system operation is not affected in any way and the correction of this discrepant condition would not improve operation of the Collision Avoidance Unit.

There were no unresolved discrepancies of any type for the Dual Channel Ground Station. There were no equipment part failures in any of the ground or airborne hardware during the entire five week period of the factory acceptance tests.

7.0 FIELD ACCEPTANCE TEST

7.1 General

This section describes the Field Acceptance test performed to demonstrate that: all subsystems, ground and airborne, were operable; adjustments to the equipment were optimized; and the equipment complies with the Engineering Requirement, FAA-ER-240-016 (reference 2), and the contract, DOT-FA73WA-3239 (reference 1), for the Development Model T/F CAS Ground Station and associated airborne equipment. The tests were performed at the FAA NAFEC facility, New Jersey, by NAFEC personnel with assistance from MDEC.

A description of all work accomplished at NAFEC from October 7, 1974 through December 13, 1974 is given in section 3 of this report, and includes field training, preliminary functional tests, and installation. This section is devoted only to the formal Field Acceptance Tests which were conducted from November 6 through December 13, 1974. All tests were performed in general accordance with the approved procedure (reference 12). As noted in the procedures, flight test portions of the field acceptance tests were modified as necessary to provide additional testing as time permitted.

Test results were recorded and approved for the purpose of equipment acceptance. However, no attempt will be or should be made to perform a complete evaluation of the T/F CAS concepts or accuracy based on this data. Final evaluation will be the objective of further testing to be performed by NAFEC on instrumented ranges. This activity is scheduled to start in early 1975 and will be the subject of a future report to be prepared by NAFEC.

7.2 Summary of Acceptance Tests Performed.

The formal field acceptance tests were divided into two groups: 1) 48-hour ground station test, and 2) flight acceptance tests.

The 48-hour test was essentially a reliability test, during which both channels of the ground station were operated for 48 consecutive hours without a failure. All airborne equipment was used in a bench test set-up to exercise the various ground station functions and to monitor operation.

The flight acceptance tests required, as a minimum, two successive 2-hour flights without a failure for each of the two basic type of airborne CAS equipments (CAU's and MiniCAS units). Thus, a minimum of four 2-hour flights were scheduled. Six actual flights were made, including a preliminary check flight and a final flight to recheck operation of one CAU which had earlier experienced automatic in-flight shutdown. The sixth flight was also used to demonstrate additional two aircraft encounters between the CAU and one of the MiniCAS units.

The ground station was operated in support of all the preflight check-outs and flights of the airborne CAS equipment. Specific tests of the ground and airborne CAS included:

1) Ramp Test
2) Fly-By-Sync
3) Extended Range Resync
4) Flight Following (by ground)
5) Communication Range (all links)
6) CAU-to-CAU Threat Encounters

7) CAU-to-MiniCAS Threat Encounters

8) MiniCAS-to-MiniCAS Threat Encounters.

In threat encounters involving the CAU, both BUM and Sync Mode were tested and both Doppler and $\Delta R/\Delta T$ range rate processing were employed.

Total flight time (take-off to touch-down) was approximately 14 hours for aircraft N-377 and 12 hours for aircraft N-376. Total operating time, including preflight checkout, exceeded 30 hours for each aircraft and the ground station.

7.3 Test Objectives

The single major objective of the "Field Test", performed at NAFEC, was completion of the Field Acceptance Test. This test required only that MDEC demonstrate that all ground and airborne subsystems were operating properly for the specified number of hours. The objective of the Field Acceptance Test was not to evaluate any of the T/F CAS concepts nor to evaluate accuracy of any of the CAS parameters. This type of evaluation is considered to be the major objective of the Flight Test Program which follows the Field Acceptance Test. Responsibility for the Flight Test Program, including plans, procedures, independent instrumentation systems, data reduction, analysis, and reports, is the FAA's.

Certain specific test objectives were recommended by MDEC for the Field Test. These objectives were necessarily in the category of a qualitative performance demonstration since means for quantitative data collection were limited. The various tests formulated to accomplish the specific demonstration objectives are described in the following paragraphs.

Some quantitative data was collected using MDEC-loaned photo-panel instrumentation with NAFEC cameras. Most of the photo-data was unuseable, however, because of technical difficulties experienced with the camera and film processing. These problems have since been corrected by NAFEC. Provisions are also being made by NAFEC for digital tape recording which should simplify future data reduction task.

7.4 48-Hour Ground Station Test

Both channels of the Collision Avoidance System Ground Station were operated for 48 consecutive hours without a failure of the equipment in any respect. The tests started at 3 P.M. on November 6, 1974 and continued until 3 P.M. November 8, 1974. NAFEC personnel attended the station continuously during the two-day test.

All airborne equipment was connected in a bench test setup via hard-lines (coaxial cables) and RF plumbing (couplers, hybrids, attenuators, etc.) to both channels of the ground station. The setup duplicated the "Ground Station-to-All Airborne Systems" configuration used in the final Factory Acceptance Test. (See paragraph 6.5.6). The setup allowed the ground station to operate with any or all of the airborne equipments simultaneously.

Specific ground station functions exercised during the 48-hour test were:

1) Fly-By-Sync: CAU with FBS was used to perform initial start-up and calibration routine to synchronize the ground station prior to placing it in the normal automatic Master/Slave mode of operation.

2) Normal Sync: The ground station was used to synchronize all four airborne CAS units.

3) Monitoring: All ground station displays were checked for proper readouts in all display modes while all airborne units continued to operate for four hours. Thereafter, at least one airborne unit was used to verify correct operation every two hours for the first 24 hours. During the next 8 hours, operation was verified every hour. Checks were then made at two hour intervals for the final 16 hours.

4) Ramp Test: During the final hour, the ramp test functions of the Master Channel were rechecked.

5) Skew Test: Also in the final hour, the ability of the Slave Channel to detect asynchronous operation of airborne units was rechecked.

6) Effect of "Failed" Channel: At the end of the 48th hour, the Master channel was intentionally caused to "fail" by turning off the high voltage power supply in that channel. The "failed" status of the channel was detected by built-in-test circuits and the other channel automatically switched from the Slave to Master mode of operation. In this mode sync service was immediately restored without measurable error to all airborne units. Then the "failed" channel was "fixed" and checked for proper operation in the Slave mode.

7.5 Flight Acceptance Tests

After completion of the 48-hour ground station test, the airborne equipment was installed in the two test bed aircraft (NAFEC Gulfstream, N-376 and N-377). Brief functional checks were performed to insure that

all systems were operable and ready for the flight acceptance test phase. These activities, completed by November 10, 1974, included the equipment radiation tests described in paragraph 3.3.3.

The dual channel ground station was employed throughout the flight acceptance tests to provide synchronization and flight following, and to further demonstrate its ability to operate with the airborne CAS in the aircraft flight environment at various ranges and altitudes.

The following paragraphs summarize the objectives and results of each flight.

7.5.1 Check Flight

The first two-aircraft flight (CAU-to-CAU) scheduled for November 12, 1974 was cancelled due to a problem with the aircraft alternator on N-376. Since N-377 was operable, a two hour check flight was made with CAU No. 1 equipment operating in that aircraft.

Ramp tests were successfully performed prior to takeoff, demonstrating the CAU's ability to process test messages and simulated CAS threat encounters. These test signals were radiated by the ground station located approximately 0.6 n.miles from the flight ramp.

During the flight, CAS communications were maintained between the ground station and the CAU on aircraft N-377 to approximately 140 n.miles. At this range aircraft altitude was 20,000 feet. Maximum reliable range at this altitude is limited more by radio line of sight than by the RF link power budget which can theoretically accommodate a ground-to-air link of 280 n.miles, provided aircraft altitude is greater than 50,000 feet.

Assuming a 4/3 earth model (equivalent earth radius to compensate for bending of a radio beam under standard atmospheric conditions), the

maximum theoretical ground-to-air range for an aircraft at 20,000 feet is approximately 175 n.miles. This requires, however, that both ground and airborne antennas have satisfactory patterns and an unobstructed view at near zero elevation angles relative to the far horizon. Although the ground station antenna pattern is known to have sufficient gain at zero elevation (see Appendix B), few aircraft antennas (top or bottom) have smooth patterns at low elevation at all azimuths. Most exhibit good forward gain (toward the nose) with rear nulls (toward the tail). Further, at low grazing angles, few line-of-sight paths are completely clear of obstructions.

Typical link calculations assume that one degree elevation angle provides reliable range performance. At one degree, the maximum theoretical communication range between the ground station and an aircraft at 20,000 feet is only 110 n.miles. To achieve 140 n.miles range, the elevation angle would be approximately 0.5 degree. Hence, the range observed during this check flight appears reasonable.

Relative to aircraft antenna switching, it was observed at the ground station that signals from the upper antenna were in general stronger and less multipath-corrupted than signals from the lower antenna. This was true for both outbound and inbound legs of the flight. Signals were generally stronger during the inbound leg probably because of better aircraft antenna patterns in the forward direction. Directly overhead, signals from the upper antenna were very weak. This is to be expected when the antenna is completely shadowed by the aircraft fuselage.

Displays of aircraft range, altitude, and biphase data link information (hierarchy, sync address, identification, and slot number)

were good as observed on the ground station flight-following monitor panel. Doppler range rate, as measured by the ground station exhibited the typical scatter about the true mean. (Future ground equipment should use $\Delta R/\Delta T$ measurements if range rate displays are desired.)

The CAU on aircraft N-377 stayed in sync with the ground station throughout the 2-hour check flight. The "extended range resync" mode was automatically employed beyond the normal resync range of approximately 90 n.miles. This was the first time this new function had been demonstrated in a flight environment.

7.5.2 First Acceptance Flight

The first two aircraft flight per the formal acceptance test procedure was flown November 14, 1974. CAU No. 1 was again operated with the "Flying Clock" in aircraft N-377. CAU No. 2, operating on the internal crystal oscillator, was aboard N-376. The ground station was fully operational throughout the test mission which was designed to demonstrate the following:

1) Ramp test preflight checkout
2) Airborne CAS operation in close flight formation
3) Normal sync mode operation
4) Extended range resync
5) Long range startup and resync
6) Back-Up-Mode (BUM) operation
7) Maximum ground-to-air range
8) Ground station flight following
9) Simple CAS threat encounters in all modes

Both aircraft systems successfully passed the preflight ramp tests (using Doppler range rate processing). The aircraft took off together in Sync Mode, joined up wingtip-to-wingtip and calibrated altimeters at 21,000 feet. Reciprocal Climb/Dive threats were properly displayed in each aircraft. All instrumentation displays were correct.

Both aircraft proceeded outbound in close flight-formation at 21,000 feet to determine maximum resync and communication range to the ground station. The aircraft displayed range to the ground out to 97 n.miles, beyond which the CAU logic automatically inhibits its range processing circuits (per ANTC-117 rules). The ground station continued to monitor both aircraft out to approximately 160 n.miles. Extended range resync from the ground to both aircraft was provided to about 150 n.miles, which is the approximate logic limit for the process. These ranges are reasonable for the altitude involved. (See paragraph 7.5.1)

After the ground station lost contact, the aircraft proceeded outbound to about 190 n.miles and both CAU's were forced to BUM. The aircraft turned around, rejoined to check altimeters and properly displayed reciprocal Climb/Dive commands based on the BUM threat logic.

Heading inbound, the aircraft remained in close formation displaying BUM threats while attempting long-range start-up (a new function incorporated in both CAU designs). Although the logic permits long-range start up to approximately 80 n.miles, the CAU's did not regain sync until they were within 65 n.miles of the ground station. The explanation for this is that while both CAU's are in a threat command situation, the logic rules (per ANTC-117) prohibit the CAS from changing operational mode. At 70 n.miles, when the aircraft finally opened

air-to-air range beyond 0.5 n.miles, they extinguished the BUM commands and were able to synchronize. Since the maximum startup range without long range startup logic is 45 n.miles, the new logic was successfully demonstrated.

After sync was regained, both CAU's were switched to employ $\Delta R/\Delta T$ range rate processing instead of Doppler. A brief racetrack pattern was flown in which both CAU's received proper avoidance commands during a head-on encounter.

Time did not permit a return to maximum range for recheck of performance as suggested by the procedure. The aircraft returned to NAFEC after nearly three hours flight time. (Procedure required only two hours).

Problems uncovered during the flight included:

1) Instrumentation intermittently read 196.1 n.mi.
2) Momentary "Timing Fail" occurred in ground station when received signal arrives approximately 1230 microseconds into time slot.
3) NAFEC 16 mm camera and film processing produced less than satisfactory results.

None of these problems were considered to affect the results of the flight test since all objectives were satisfactorily demonstrated. The above problems, discussed in paragraph 7.6, were eventually solved.

7.5.3 Second Acceptance Flight

The second two-aircraft CAS acceptance test flight was flown on November 20, 1974. MDEC-loaned instrumentation was modified to fix the intermittent 196.1 n.mile readout problem reported during the first mission. CAS equipment configuration was the same as used on the first flight with

both CAU's operating in CAS-only mode during the first outbound run. For the remainder of the flight CAU No. 1 on aircraft N-377 operated in the Fly-By Sync mode. Again, the ground station was employed in the mission which was designed to demonstrate the following:

1) Ramp test
2) Normal sync mode operation
3) Extended range resync
4) Air-to-air start-up and sync
5) Maximum ground-to-air range
6) Maximum air-to-air range
7) Fly-By sync of ground station
8) Ground station flight following
9) $\Delta R/\Delta T$ Mode CAS threats

Both CAU's successfully passed the preflight ramp check. The aircraft took off together in Sync Mode. They did not join up for altimeter calibration and minimum range CAS threat checks because of inclement weather. Proper threats were displayed, however, while the aircraft were side by side on the ramp (with altitude pulse turned on). The aircraft headed outbound from the ground station on diverging radials to determine maximum air-to-air and air-to-ground range.

The ground station tracked CAU No. 1 in aircraft N-377 flying at 22,000 feet to 122 n.miles. CAU No. 2 in aircraft N-376 was tracked to 161 n.miles at the same altitude. Both CAU's measured range to the ground station up to 97 n.miles, beyond which the display is logically inhibited.

Air-to-air communications between both aircraft was maintained to the 97 n.mile limit.

Extended range resync was provided by the ground station to both CAU's. After the ground station lost contact, CAU No. 1 with the "Flying Clock" supplied normal resync to CAU No. 2 with the crystal oscillator.

After the aircraft were separated over 100 n.miles, both CAU's were forced to BUM. Then CAU No. 1 was placed in Fly-By-Sync Mode, using the time base of the "Flying Clock". The ground station placed in Standby Mode with its time base no longer in sync with the FBS CAU.

Both aircraft turned and headed inbound toward the ground station. The FBS aircraft (N-377) started and resynchronized the BUM aircraft (N-376) at 74 n.miles. Since normal maximum air-to-air start-up/sync range is limited to 45 n.miles, the new long-range start-up logic was successfully demonstrated for the first time over an air-to-air link. Maximum possible long-range start-up is approximately 80 n.miles.

As the FBS aircraft continued inbound the ground station operators performed the FBS calibration of both ground channels. After initial sync was obtained from the FBS CAU, a ten sample average of air-to-ground sync error showed less than 15 nanoseconds time difference as computed from the ground display. The FBS CAU operator reported correct ground-to-air resync time on the aircraft instrumentation display for final verification of the FBS process.

Since the weather was still bad, the aircraft did not attempt a planned join-up while over the ground station. Instead, they switched radials and again proceeded outbound in opposite directions. Altitude for the run was changed from 22,000 feet to 8,000 feet to determine maximum range performance at lower altitude.

The ground station tracked both CAU's to 105 n.miles which is only 5 miles less than the theoretical maximum for zero elevation angle (ground station antenna) using the standard 4/3 earth model. The last observed ranges to the ground station on aircraft instrumentation were 91.3 and 94.8 n.miles.

Air-to-air ranges were displayed to 79 n.miles which was the maximum aircraft separation before they turned around and headed inbound at 8,000 feet.

As in the first inbound run, CAU No. 2 was forced to BUM and the ground station was placed in Standby Mode. CAU No.1 remained in FBS mode and resynchronized both ground station channels at 42 n.miles. Sync accuracy was computed to be within 25 nanoseconds (two samples), at the ground station and verified by the FBS operator. CAU No. 2 again synchronized to the FBS aircraft; however, since the operator was monitoring the ground station, the exact start-up range was not determined.

Prior to landing, the weather cleared enough to permit the aircraft to join-up for a simple CAS encounter in $\Delta R/\Delta T$ mode. Proper threats were displayed and all one-way ranges were compared to demonstrate that all three equipments (CAU No. 1, CAU No. 2, and the ground station) were still synchronized to a common time at the conclusion of the mission. Total flight time was approximately 3.5 hours. (Acceptance procedure required only two hours).

There were no new problems uncovered during the flight. The momentary "Timing Fail", reported in previous flights, again occurred and the film quality was still poor. However, the flight was considered acceptable since all objectives were satisfactorily demonstrated.

7.5.4 Third Acceptance Flight

The third two-aircraft CAS flight was flown on November 21, 1974. MiniCAS No. 1 was operated on aircraft N-376 and MiniCAS No. 2 was on N-377. The CAU's were not involved. Flight following and sync service was provided by the ground station. Mission objectives to be demonstrated were:

1) Ramp Test
2) Normal sync mode operation
3) Airborne CAS operation in close flight formation
4) Maximum ground-to-air and air-to-air ranges
5) Ground station flight following
6) Simple CAS threat encounters in $\Delta R/\Delta T$ mode
7) Start-up and resync to ground station

Preflight ramp tests were passed by the MiniCAS units. Both aircraft took off with the MiniCAS synchronized to the ground station. Instead of joining up at the assigned altitude and proceeding outbound together during the first run, the test plan was modified by NAFEC to accommodate local weather conditions. Two runs were made on split radials (215 and 250 degrees) to determine maximum range performance. To demonstrate MiniCAS threat encounters, the aircraft joined briefly prior to landing. (More extensive encounters were performed in the next flight. See paragraph 7.5.5).

During the first outbound run MiniCAS No. 1 on N-376 was tracked by the ground station to 81 n.miles at 8000 feet altitude. The airborne operator on that aircraft reported ground ranges up to 93 n.miles. MiniCAS No. 2 on N-377 was tracked to 95 n.miles at 8700 feet by the ground operator. The airborne operator reported ground ranges up to 91 n.miles. Maximum reported air-to-air range was 55 n.miles.

After both MiniCAS units reverted to standby mode, the aircraft turned around and headed inbound. MiniCAS No. 1 reacquired sync from the ground station at 45 n.miles, which is the maximum possible range since MiniCAS does not employ the long-range start up logic. MiniCAS No. 2 regained sync at 41 n.miles.

The aircraft switched radials and headed outbound again at approximately 8000 feet altitude. Maximum communication ranges of nearly 95 n.miles were reported by both ground and airborne operators. MiniCAS No. 2, however, reverted to standby at a range of 74 n.miles from the ground. As observed on a monitor oscilloscope at the ground station, the signal from MiniCAS No. 2 was seen to be in a deep fade zone from about 60 to 75 n.miles. Since the time spent in this zone exceeded the demote (sync mode-to-standby mode) time of approximately 3.2 minutes, the ground station was unable to update MiniCAS No. 2. At 74 n.miles, the ground station received a strong signal and replied with resync but it was apparently not processed by the MiniCAS as it reverted to standby. From 75 n.miles to 95 n.miles the signal was again useable; however, the MiniCAS cannot restart at this range. (In normal operation, the MiniCAS could have been kept synchronized by any air-carrier type CAS within 90 n.miles. Also, the MiniCAS demote time could probably be increased to 10 minutes since the present 3.2 minute is very conservative considering the stability of the timing oscillator.)

On the second inbound run, start-up ranges of 44 and 37 n.miles were achieved for MiniCAS No. 1 and No. 2, respectively. Air-to-air CAS communication ranges of 41 n.miles were reported by the airborne operators.

Before landing, the aircraft joined up at low altitude (approx. 4000 feet) for a brief check of the MiniCAS threat logic. All displays were correct. Total mission time was about 2.5 hours. (Procedure required two hours, minimum.)

In addition to the momentary "Timing Fail" and camera/film problems experienced in all flights, it was noted that the transmitted altitude of the MiniCAS on N-376 was erroneous above 5000 feet. The cause was traced to a bent pin on the connector at the end of the aircraft cable from the ATCRBS altitude source. (A2 bit was open) The pin was straightened after the flight. Operation was rechecked by simulating various altitude input codes to exercise each input bit.

None of these problems prevented satisfactory demonstration of all flight objectives.

7.5.5 Fourth Acceptance Flight

This flight was held November 26, 1974. The formal test procedures were modified by NAFEC to include additional MiniCAS-to-MiniCAS threat encounters with tracking by photo theodolites over the NAFEC range during the first portion of the flight. The second portion of the flight test was designed to check compatibility between a CAU on one aircraft and a MiniCAS on the other. Specific objectives to be demonstrated were:

1) Ramp Test of MiniCAS
2) MiniCAS-MiniCAS threat encounters
3) CAU-MiniCAS threat encounters in Doppler and $\Delta R/\Delta T$ modes
4) Maximum ground-to-air range
5) Ground station flight following
6) CAU sync support of MiniCAS beyond range of ground station

After successful preflight ramp checks, both aircraft, equipped with MiniCAS, took off, joined-up for altimeter calibration at 7000 feet, and checked for proper CAS displays. Then two racetrack patterns were flown over the NAFEC theodolite range. Both produced co-altitude head-on encounters of approximately 400 knots. Satisfactory alerts and maneuver commands were generated by both MiniCAS using the new $\Delta R/\Delta T$ range rate processing. (A separate final report covers the detail results and conclusions derived from the field acceptance test of the MiniCAS.)

Following the MiniCAS encounters, the unit on N-377 was turned off and CAU No. 1 on that aircraft was turned on. The CAU, however, repeatedly failed its automatic built-in-test (BIT) and could not be used for this flight. Therefore, the aircraft CAS were quickly reconfigured to utilize MiniCAS No. 2 on N-377 and CAU No. 2 on N-376. (The opposite configuration, MiniCAS No. 1 and CAU No. 1 were flown in the final flight. See paragraph 7.5.6).

Both aircraft flew outbound in close formation at approximately 8000 feet while performing simple opening and closing maneuvers to check out CAS threat response and instrumentation displays. The CAU operated in Doppler mode during the outbound leg.

The ground station provided sync to both airborne systems. Last resync to the MiniCAS was reported at 83 n.miles, although it was tracked by the ground out to 95 n.miles. The CAU, operating on the internal crystal oscillator, demoted as low as Hierarchy 18 at 100 n.miles but continued to keep the MiniCAS in sync via the air-to-air link.

During the inbound leg, the CAU operated in $\Delta R/\Delta T$ mode while several vertical and parallel and turn-in encounters were flown against the MiniCAS.

While inbound the CAU was immediately updated to Hierarchy 01 status and the MiniCAS remained in sync during the entire flight. All CAU-MiniCAS threat encounters and instrumentation displays were satisfactory.

Total flight time for the combined MiniCAS-MiniCAS and CAU-MiniCAS missions was about three hours. (Procedure required two hours, minimum.)

7.5.6 Fifth Acceptance Flight

The fifth and final acceptance flight was flown on December 13, 1974. Between the fourth and fifth flight all known problems, including the ground station "Timing Fail" and the photo-recording difficulties, were corrected. The intermittent BIT-fail problem in CAU No. 1 was thought to be fixed by replacing a questionable coaxial connector. Although the CAU operated throughout the fifth flight without failure, the real cause of the BIT-failure was not isolated until February 1975. (See paragraph 7.6 for discussion of problems.)

The major objective of the fifth flight was to demonstrate compatibility between CAU No. 1 and MiniCAS No. 1. Since there was no formal procedure for this extra flight, it was patterned much like the fourth flight relative to specific objectives and flight profiles.

After preflight ramp checks, both aircraft took off, joined-up at 6500 feet and flew outbound in close formation to exercixe the minimum range threat logic. Both aircraft turned around about 50 n.miles from the ground station, still maintaining good air-ground communications. While inbound one aircraft varied altitude slowly to exercise the vertical threat logic of both CAS units. Over NAFEC, head-on encounters were performed to test the TAU-threat logic using both Doppler and $\Delta R/\Delta T$ range rate processing in the CAU. (MiniCAS transmits stable frequencies for Doppler but processes only $\Delta R/\Delta T$ information.)

While in the area of the ground station several "vertical scissors" and "tail chase" maneuvers were performed to further demonstrate CAS compatibility.

Heading outbound again, N-377 with the CAU flew level at 6200 feet while N-376 with the MiniCAS slowly varied altitude from 2900 feet to 9500 feet. Slant range was maintained within 1.8 n.miles so that all ANTC-117 altitude caution bands (Limit Climb and Descent Rates) were checked out. The ground station was able to follow the entire flight of both aircraft at all altitudes out to 75 n.miles (6200 feet altitude at this range) where the aircraft turned and headed inbound. Again synchronization was provided by the ground station to both CAS units during the entire run.

Heading inbound, both aircraft flew parallel slightly beyond threat range to check for proper absence of threat displays. Then one aircraft attempted to turn-in toward the other. The proper "NO Turn" commands were immediately displayed.

Finally, to demonstrate the altitude rate threat logic employed by the CAU, aircraft N-377 climbed to 8300 feet and dove down toward N-376 at 6200 feet. The CAU generated the "Level-Off" command and MiniCAS displayed "Aircraft Below".

This concluded the final mission. Flight time was approximately 2.5 hours. No problems of any type were reported by ground station or airborne operators.

7.6 Summary of Test Results and Problems

The Field Acceptance Tests for all equipment was satisfactorily completed. Relatively few problems were encountered during the tests

and none of them prevented the accomplishment of the test objectives. All of the problems were corrected.

There were no equipment failures of any type in the dual channel ground station, either MiniCAS unit, or the MDEC-loaned instrumentation. The only failure in CAU No. 1 was automatically self-detected by BIT circuits. The cause was traced to a poor wire crimp connection in the exciter unit. The only failure in CAU No. 2 occurred prior to start of flight testing and was also self-detected by the CAU. A shorted RFI filter pin in the standard ARINC-type rack and panel equipment connector prevented the CAU from transmitting an altitude pulse. This pin (LTP-26) normally provides the oleo strut switch signal (air-ground) input to the CAU. Since no spares or replacements were available, the circuit was rewired with a short jumper and an alligator clamp was provided for manual control of the air/ground function.

The momentary "Timing Fail" problem experienced during each of the first four flights was traced to a logic design error. Whenever signals from long range aircraft were detected in the time slot between 1227 and 1235 microseconds, a momentary time base "glitch" occurred in the ground station. The logic would immediately (within one slot) self-detect its own time base error, inhibit all sync service, and ring the alarm. Within 30 seconds, the logic would then automatically correct its time base error by resetting to one of the station clocks, both of which retained proper time, and resume normal operation. A minor modification was made to the A6 logic cards in each channel. The fix was verified by retesting under controlled conditions, using MiniCAS signals delayed to arrive at these times in the slot.

The photo-recording problems were corrected by NAFEC by changing to 35 mm cameras and film and providing a hood for the displays. MDEC also modified the normal flashing CAS command signals (Climb, Dive and Level) so that they are now displayed continuously during a threat. In the normal flashing mode, the camera often missed the display due either to improper trigger timing or shutter drag.

Unfortunately, much of the photo-recording data was unuseable for detailed analysis of acceptance test results. However, preliminary reports from NAFEC indicate that satisfactory photo-data was obtained during their flight test and evaluation program which began in January 1975. Results of that program will be reported by NAFEC.

8.0 CONCLUSIONS

8.1 Development Model Ground Station

Based on the analysis, design and development work accomplished at McDonnell Douglas Electronics Company, and on the preliminary results obtained from the factory and field acceptance tests, it is concluded that:

1) The ground station provides all of the basic functional requirements of the FAA-ER-240-016.
2) The design and construction conform to the standardized requirements set forth by FAA-G-2100 for ground electronic equipment.
3) The performance, based on measured data, meets all basic technical characteristics specified by ANTC-117.
4) Specifically, the new cooperative CAS functions of the ground station, including Fly-By Sync, extended range resync, flight following, skew detection, and automatic test and self-monitoring, were satisfactorily demonstrated.
5) The dual channel equipment with automatic switchover has been shown to be reliable and capable of providing high operational availability.

Final evaluation should be based on more extensive field tests which will be performed by the FAA at NAFEC during 1975. If the T/F CAS becomes an operational system, the manner in which the secondary functions of the ground station are implemented and used should be reviewed. For example, questions remain to be answered relative to remoting of mode controls, failure alarms, and flight following displays.

Timekeeping and synchronization service for the CAS airborne community are the primary ground station functions and must be provided, of course, by the equipment near the antenna installation.

Finally, in light of other McDonnell studies (reference 13) which show that only a few master ground stations are required to provide adequate synchronization coverage for airborne CAS, the deployment of simple slave type hierarchal ground stations should be considered. These stations could be synchronized by overflying air-carrier CAS and subsequently provide sync service and/or test and monitoring at airports not served by a master station.

8.2 Airborne Equipment

Based on the preliminary results obtained from the factory and field acceptance tests of the feasibility model airborne equipments, it is concluded that:

1) The new functions of fly-by sync, long range start-up, and extended range sync, incorporated in the air-carrier version of CAS, were satisfactorily demonstrated.
2) The new digital range rate processing logic ($\Delta R/\Delta T$) employed by both air-carrier and general aviation versions of CAS appears equal to or better than the former Doppler technique. If further evaluation by NAFEC proves the concept, the complexity and cost of future airborne T/F CAS can be reduced by eliminating the requirements for precise carrier frequency control and measurement.

3) Both air-carrier and general aviation CAS communication ranges, air-to-air and air-to-ground, are sufficient to allow additional functions such as flight following, DME, stationkeeping, data link, and navigation, to be optional for each member of the T/F CAS network.

APPENDIX A

CAS RELIABILITY/MAINTAINABILITY STUDY RESULTS

A.1 Summary of Results

The results of detailed analyses indicate that both the CAS Ground Station and associated airborne CAS/Fly-By-Synchronization equipment meet the reliability, maintainability, and mission availability requirements. Mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) were calculated for each line replaceable unit (LRU) and appropriately combined to derive total subsystem and system reliability and maintainability. Since the ground station is dual channel equipment operating in the "hot standby" mode with automatic switchover, the data were also used to compute mission availability.

The following results were obtained:

Dual Channel Ground Station:

Channel MTBF	=	400 hours
Channel MTTR	=	21.5 minutes
Station Mission Availability	=	0.999420 for 168 hours
Station Equivalent MTBF	=	289,571 hours

Airborne CAS/FBS: (Model 2000 CAU with HP Flying Clock):

System MTBF = 247 hours

System MTTR = 9.4 minutes

The MTBF results are based on maximum specified temperatures ($50^{o}C$ plus calculated heat rise) and average part stress ratios.

A.2 Maintainability

A.2.1 Maintainability Estimates

A quantitative analysis of the developmental CAS indicates that the design meets specified maintainability requirements. These requirements are:

a) CAS Ground Station

1) The mean-time-to-repair (MTTR) shall not be more than 30 minutes.

2) The mean-preventative-maintenance time (MPMT) shall not exceed 30 minutes in 168 hours.

b) Airborne Fly-By Synchronization Equipment

1) The MTTR for the system shall not be more than 30 minutes.

2) The MPMT shall not exceed 60 minutes in 168 hours.

The MTTR estimates, which are summarized in Tables A-1 and A-2, indicate an MTTR of 21.5 minutes for the CAS Ground Station and 9.4 minutes for the airborne CAS. As no scheduled maintenance is required, the analysis does not include any preventative maintenance time data and specified requirements are met. Routine inspection of the ground configuration, pre-flight inspection of the airborne configuration, and cleaning as required is adequate for the system.

A.2.2 Analysis Criteria

The following conditions or assumptions provided the basis for development of the estimates.

a) The maintenance concept applicable to the analysis basically consists of:

1) Fault isolation to a line-replaceable-unit (LRU). This was performed using built-in monitor and fault indicators, and general test equipment as required.

2) Repair by replacement of assemblies identified as LRU's. Tables 1 and 2 identify these assemblies as applicable to the ground or airborne configuration.

3) Test for satisfactory operation using operational functions of the equipment.

b) Maintenance times indicated consist of only time during which active maintenance is being performed. Administrative, supply, and similar delay times were not included.

c) Maintenance technicians utilized were considered to be experienced and proficient in the maintenance of similar equipment and had received training in operation and support of this system.

d) Support facilities and resources (spares, tools, test equipment, etc.) were considered available as required for the performance of corrective maintenance.

e) The applicable ground or airborne system MTTR is based on applying the assembly failure rate data in a series design configuration with continuous operation of each assembly.

f) Access time which may be required on the aircraft due to obstructions or removal of other installed equipment is not included.

TABLE A-1. MTTR ESTIMATE - CAS GROUND STATION

LRU Ref	Nomenclature	MAINTENANCE TASK TIME (MINUTES) Trouble Shoot	Repair/ Replace	Adjust/ Check	Total	Failure Rate ($\times 10^{-5}$)	Time x FR(10^{-5})
A1	Frequency Synthesizer	6.0	14.8	2.0	22.8	9.980	337.544
A2	Loran-C Receiver	7.0	4.6	1.0	12.6	20.000	252.000
A3	Transmitter	-	-	-	-	-	-
A3A1	Pulse Modulator	18.0	4.0	2.0	24.0	0.904	21.696
A3A2	Transmitter Monitor	2.0	4.2	1.0	7.2	4.943	35.590
A3A3	Receiver Monitor	9.5	4.4	1.0	14.9	4.050	60.345
A3A4	Power Amplifier	18.0	10.6	2.0	30.6	24.823	759.584
A3A5	H.V.P.S.	8.0	26.4	2.0	36.4	4.613	167.913
A3A6	L.V.P.S.	6.0	25.4	2.0	33.4	2.702	90.247
AT1	Attenuator	7.0	9.2	2.0	18.2	0.010	0.182
CR1	Detector	7.0	7.2	2.0	16.2	4.350	70.470
CR2	Detector	6.0	7.2	2.0	15.2	4.350	66.120
DC1	Coupler	11.0	24.2	2.0	37.2	0.001	0.037
HY1	Circulator	11.0	21.2	2.0	34.2	2.000	68.400
A4	Power Monitor Panel	7.0	7.0	1.0	15.0	2.893	43.395
A5	Exciter/Receiver	-	-	-	-	-	-
A5A1	1st Receiver	16.0	2.2	1.0	19.2	9.665	185.568
A5A2	Log.I.F. Amplifier	16.0	2.6	1.0	19.6	1.252	24.539
A5A3	Video/Bio Demodulator	10.5	3.2	1.0	14.1	5.906	86.818
A5A4	Discriminator	16.5	2.6	1.0	20.1	15.423	310.002
A5A5	5 Freq. Generator	13.5	3.0	1.0	17.5	6.495	113.663
A5A6	Bio Mod/Freq.Converter	19.5	2.8	1.0	23.3	6.941	161.725
A5A7	Freq. Multiplier	16.5	2.4	1.0	19.9	10.223	203.438
A5A8	UHF Upconverter	16.5	2.0	1.0	19.5	16.906	329.667
A5A9	Rec. Power Supply	7.0	17.0	2.0	26.0	2.702	70.252
A5A10	Exciter P.S.(+5 + 12V)	7.0	17.0	2.0	26.0	2.702	70.252
A5A11	Exciter P.S.(+28V)	5.0	15.0	2.0	22.0	2.815	61.930
A6	Logic Display Panel	6.0	6.4	2.0	14.4	22.220	319.968
A7	Test Point Panel	-	-	-	-	-	-
A8	Logic Assy.	-	-	-	-	-	-
A8A1	Logic Card Rack Assy.	13.5	13.0	2.0	28.5	34.414	980.799
A8A2	Logic P.S. (+5V)	6.0	7.2	2.0	15.2	4.892	74.358
A8A3	Logic P.S. (+28V)	6.0	7.0	2.0	15.0	2.815	42.225
A8A4	Buffer/Multiplier	12.0	2.6	2.0	16.6	1.524	25.298

TABLE A-1. MTTR ESTIMATE - CAS GROUND STATION (Continued)

LRU Ref	Nomenclature	MAINTENANCE TASK TIME (MINUTES) Trouble Shoot	Repair/ Replace	Adjust/ Check	Total	Failure Rate ($\times 10^{-5}$)	Time x FR(10^{-5})
A8B1	Phase Shifter	9.0	5.6	4.0	18.6	0.935	17.391
A9	Cesium Standard	5.0	13.6	2.0	20.6	4.000	82.400
A10	Stby Power Supply	8.0	10.4	2.0	20.4	6.000	122.400
A11	Blower Assy.	3.0	8.4	1.0	12.4	0.130	1.612
	1 MHz Oscillator	7.0	3.8	1.0	11.8	1.000	11.800
	Loran Antenna	10.0	30.0	1.0	41.0	2.688	110.208
	CAS Antenna	7.0	30.0	2.0	39.0	2.688	104.832
TOTAL						249.955	5374.668

$$\text{MTTR} = \frac{\sum(\text{FAILURE RATE} \times \text{MAINTENANCE TIME})}{\sum \text{FAILURE RATE}} = \frac{5374.668}{249.955} = 21.5 \text{ MINUTES}$$

TABLE A-2. MTTR ESTIMATE - AIRBORNE FLY-BY SYNC EQUIPMENT

Nomenclature	MAINTENANCE TASK TIME (MINUTES)				Failure Rate ($\times 10^{-5}$)	Time x FR(10^{-5})
	Trouble Shoot	Repair/ Replace	Adjust/ Check	Total		
CAU Assy.	2.0	4.0	2.0	8.0	378.787	3030.296
Flying Clock Assy.	3.0	15.0	12.0	30.0	12.459	373.770
Maneuver Indicator (2)	3.0	10.0	2.0	15.0	7.092	106.380
CAS Antenna (2)	7.0	45.0	2.0	54.0	5.376	290.304
TOTAL					403.714	3800.750

$$\text{MTTR} = \frac{\sum(\text{FAILURE RATE} \times \text{MAINTENANCE TIME})}{\sum \text{FAILURE RATE}} = \frac{3800.750}{403.714} = 9.4 \text{ MINUTES}$$

A.3 Reliability

A.3.1 Reliability Estimates

A quantitative analysis of the developmental CAS indicates that the design meets the specified reliability and mission availability. These requirements are:

1) CAS Ground Station: The mean-time-between failure (MTBF) of the dual channel ground station shall not be less than 1000 hours. For reliability calculations the mean-preventative-maintenance-time (MPMT) interval of 168 hours shall be used as the operating (mission) time. The station shall be a dual channel system, as required to meet operational availability.

2) Airborne CAS: The MTBF for the fly-by synchronization system shall not be less than 100 hours.

Tables A-1 and A-2 of the maintainability estimates, respectively, list the failure rates for each of the line replaceable units (LRU's) of the ground and airborne equipment. Total airborne failure rate is 403.714×10^{-5} which is equivalent to an MTBF of 247 hours. Total failure rate for a single channel of the ground station is 249.955×10^{-5}. This is a channel MTBF of 400 hours. In normal operation, however, dual channel redundancy with automatic switchover is provided. Also, two-out-of three redundance with automatic switchover is provided for the station clock network. Reliability is theoretically reduced (MTBF = 400/2 = 200 hours) if all equipment is required to be fully operational at all times; whereas, in normal operation, the availability of the primary functions of a Master channel-to keep time and supply sync service- is significantly increased (MTBF>>400 hours) by the dual channel/automatic switchover concept.

Figure A-1 illustrates the concept in block diagram form. Each contributing line replaceable unit (LRU) of the on-line Master channel and station clock network is shown. The Test Point Panel (A7) and Standby Power Supply (A10) LRU's are not included since they are not required for normal operation. (In fact, they effectively increase overall availability by, respectively, reducing fault isolation time and providing carryover power for the clock network during power interruptions.) Although units of the clock network are physically located in the channels for convenience, they are treated separately in the model which indicates 2-out-of-3 redundancy. The two channels operate in hot standby paralled redundancy with an MTBF of approximately 464 hours per channel, exclusive of the clock network.

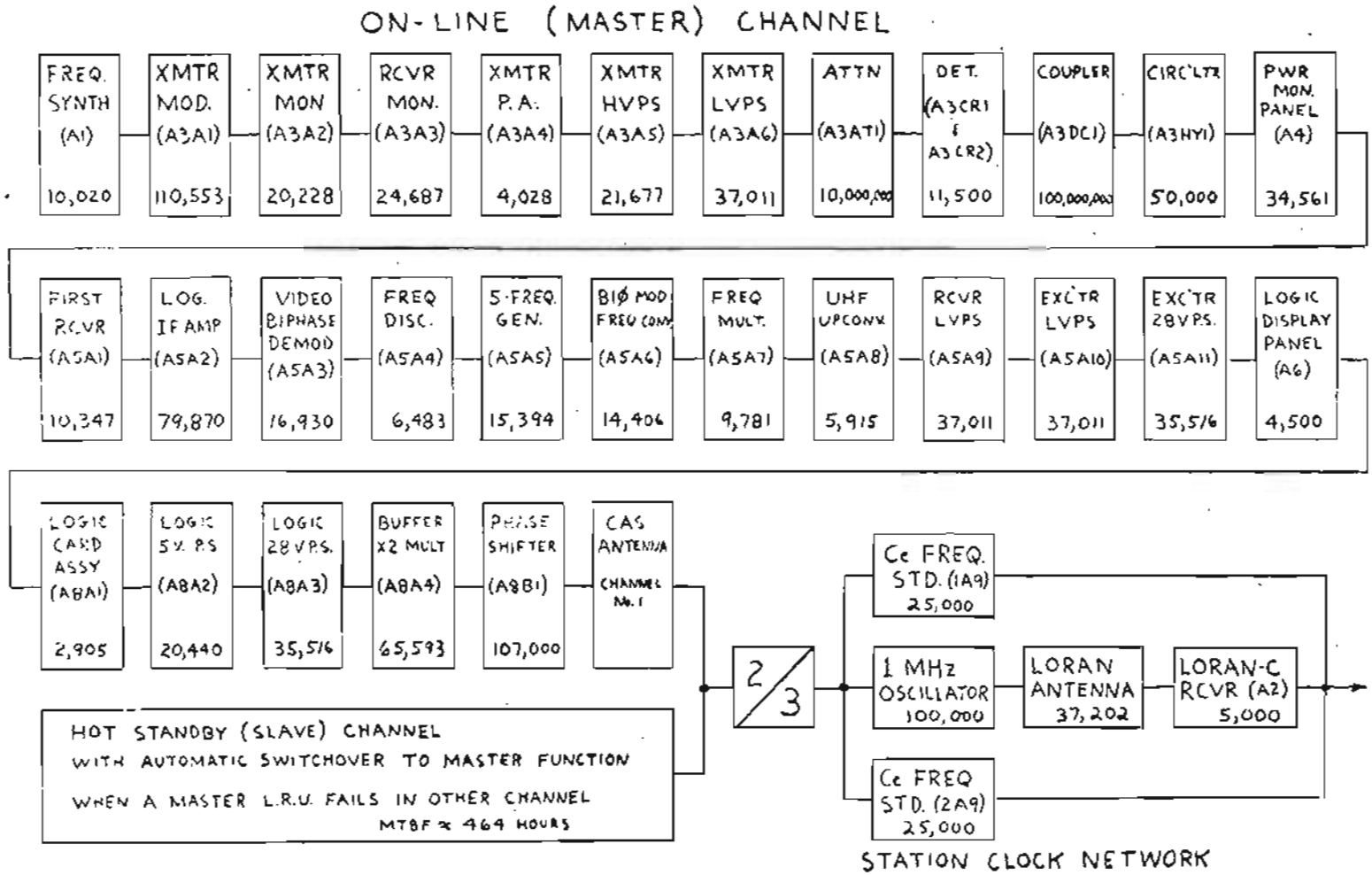
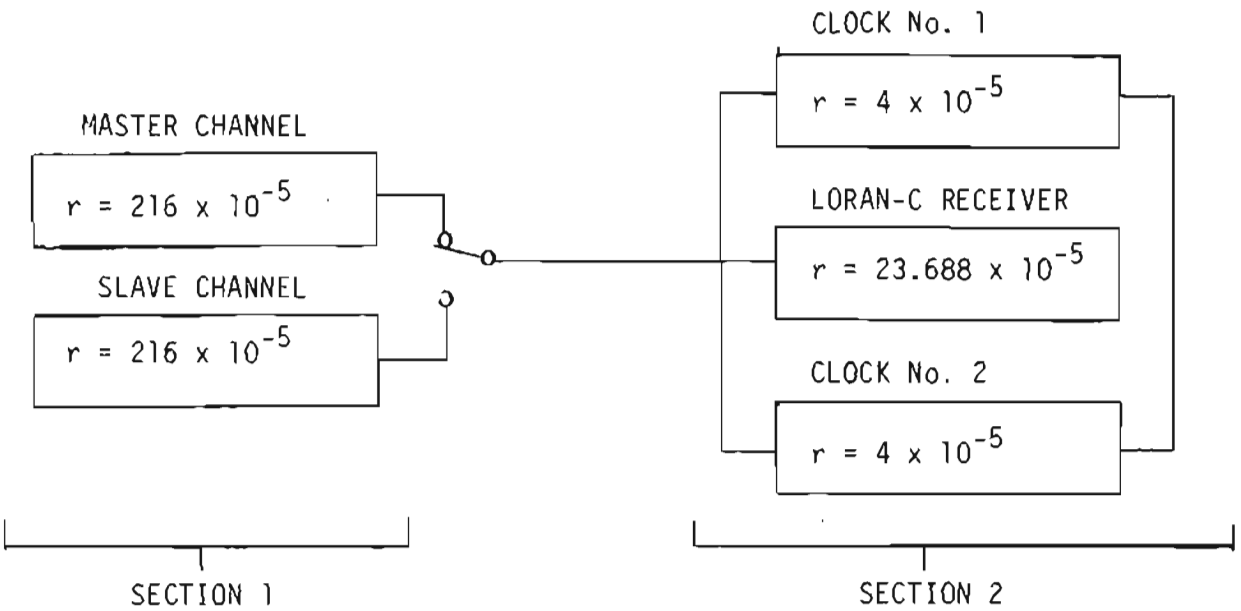


FIGURE A-1. GROUND STATION RELIABILITY MODEL

A.3.2 Mission Availability

The reliability model of Figure A-1 may be simplified to the one shown in the figure below:



1 channel required for success

2 out of 3 branches required for success

Availability of each section is calculated from the following equation:

$$A_M = \mathrm{EXP}\left[\frac{-n \quad r^n \quad T}{n\left(\sum_{i=1}^{n}\right)\frac{1}{i} \quad r^{n-1} + \mu^{n-1}}\right] \qquad \text{Eq. (9-30)}$$

n = Number of channels

r = Failure rate/channel

T = Mission time period

μ = Maintenance action rate

Equation (9-30) from Calabro, S.R.; Reliability Principles and practices; McGraw-Hill Book Co., Inc.: New York 1962.

<u>Section 1 Availability for 168 hours operation:</u>

$$n = 2 \text{ channels}$$

$$r = 216 \times 10^{-5} \text{ failure/hour}$$

$$T = 168 \text{ hours}$$

$$\mu = \frac{1}{MTTR}$$

$$MTTR = 22 \text{ min. or } \frac{22}{60} \text{ hour}$$

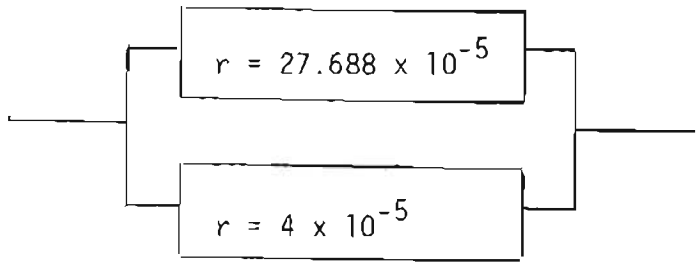
$$\mu = \frac{1}{\frac{22}{60}} = \frac{60}{22} = \frac{30}{11} \text{ Actions/hour}$$

$$A_{M1} = EXP \frac{-2\,(216 \times 10^{-5})^2\,(168)}{2(\frac{3}{2})\,(216 \times 10^{-5}) + \frac{30}{11}}$$

$$A_{M1} = .9994267$$

Section 2 Availability for 168 hours of operation:

Since 2 out of 3 branches are required for success, this may be treated as a dual channel equivalent to the following:



Section 2 availability is then at least:

$n = 2$ channels

$r = 27.688 \times 10^{-5}$ Failure/Hour

$T = 168$ hours

MTTR - 15.5 min. or $\frac{15.5}{60}$ hour

$$\mu = \frac{1}{\frac{15.5}{60}} = \frac{60}{15.5} \text{ hours}$$

$$A_{M2} = \text{EXP}\left[\frac{-2\ (27.688 \times 10^{-5})^2\ (168)}{2(\frac{3}{2})\quad (27.688 \times 10^{-5}) + \frac{60}{15.5}}\right]$$

$$A_{M2} = .9999933$$

Total system availability for 168 hours:

$$A_{MT} = A_{M1} \times A_{M2}$$

$$= .9994267 \times .9999933$$

$$= .9994200$$

EQUIVALENT MTBF

Reliability is the probability of success for a given mission time.

Availability is the probability of success for a given mission time.

If one wishes to think in terms of an equivalent MTBF for this multiple channel, repairable system, equate availability to reliability, R.

$$R = \varepsilon^{-rT}$$

or

$$R = \varepsilon - \frac{T}{MTBF_{EQ}}$$

or

$$\ln R = - \frac{T}{MTBF_{EQ}}$$

$$MTBF_{EQ} = - \frac{T}{\ln R}$$

$$\text{Let } R = A_{MT}$$

$$MTBF_{EQ} = - \frac{T}{\ln A_{MT}}$$

$$MTBF_{EQ} = - \frac{168}{\ln .99942}$$

$$MTBF_{EQ} = 289{,}571 \text{ hours}$$

APPENDIX B

GROUND STATION ANTENNA TEST RESULTS

B.1 Summary

The dual channel CAS ground station employs two independent antenna subsystems. Each antenna radiates and receives vertically polarized electromagnetic waves in the 1592.5 to 1622.5 MHz frequency band. The radiation pattern provides maximum communications range in a horizontal plane without excessive pattern multi-lobing which could result from low angle radiation. The beam elevation angle is low enough to provide maximum communications range and communications with aircraft on the ground, but not so low as to allow excessive multipath reception. The mean antenna gain in the horizontal plane at the beam center is 8 dB greater than that of an isotropic radiator. The difference between maximum and minimum gain in this plane is less than 1 dB. The radiation pattern has a vertical beam width of about 13 degrees and the lower half power point is about one degree above the horizon. The VSWR is less than 1.5:1 over the operating frequency band.

B.2 Description

The antenna consists of a vertical array of collinear-mounted dipole elements. The sections have an effective length of one-half wavelength and have their inner and outer conductors transposed at each junction. The top section of the antenna contains a quarter wavelength short, which is extended to provide protection against lightning. An inverted choke is positioned one-half wavelength below the first gap to eliminate the

need for a ground plane and to keep unwanted RF currents from traveling down the feed cable. The elements are covered and supported by a fiberglass radome.

B.3 Test Data

The results of pattern measurements and VSWR tests are presented in Figure B-1 through B-9. Figures B-1 through B-6 are the vertical radiation patterns at various frequencies encompassing the passband. CAS frequencies are 1600 MHz, 1605 MHz, 1610 MHz, and 1615 MHz.

Figure B-7 is the horizontal pattern indicating 0.9 dB circularity and Figure B-8 indicates midband gain measurements resulting in 8.4 dB gain.

Figure B-9 is a plot of antenna VSWR over the operating frequency band.

A breadboard model of the antenna was subjected to an ice-load test. Figure B-10 shows the antenna encased in approximately two-inches of radial ice. The measured VSWR remained less than 1.5:1 over the CAS frequency band.

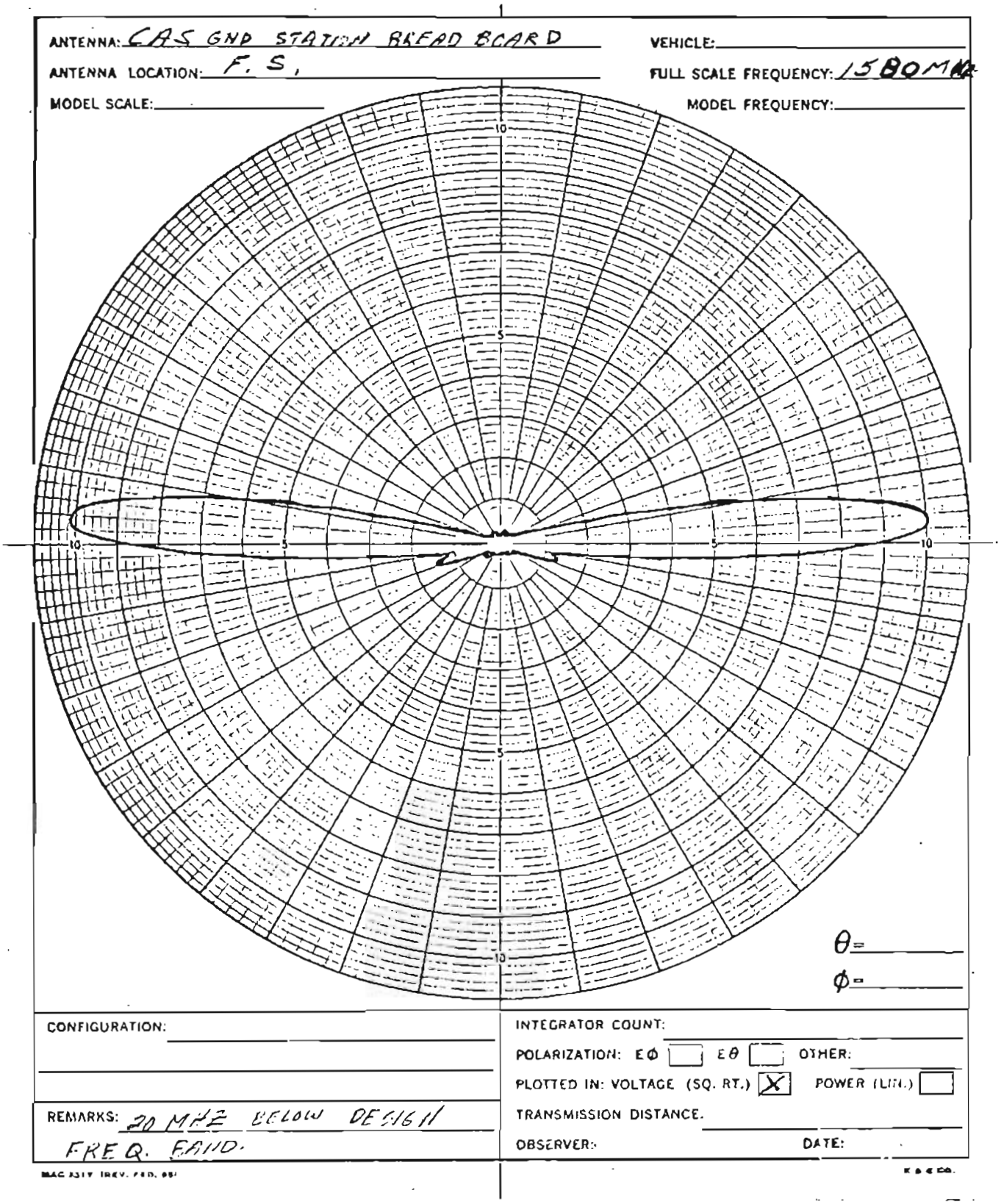


FIGURE B-1. VERTICAL PATTERN 1580 MHz

ANTENNA: CAS GND STATION BREADBOARD

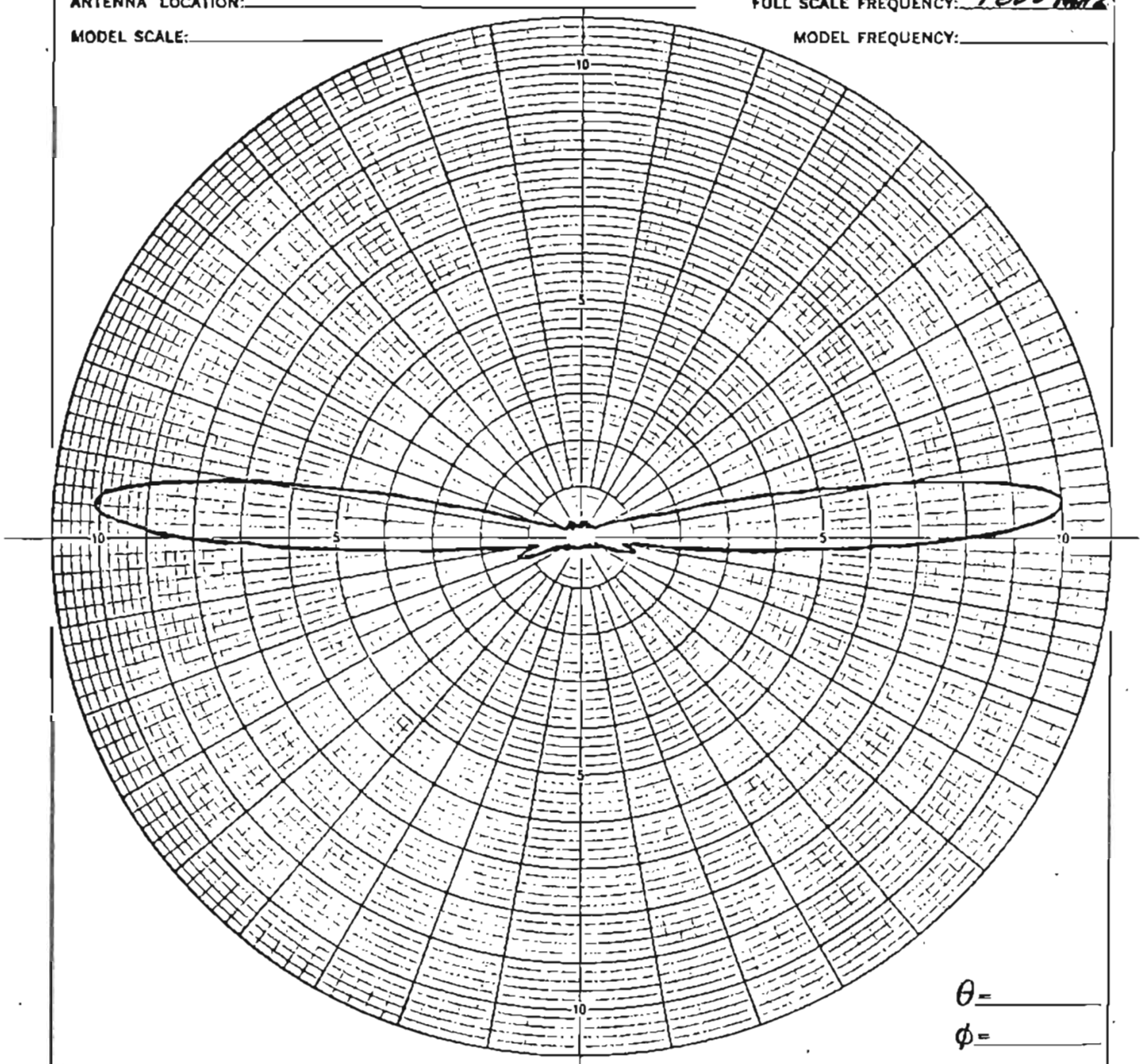
VEHICLE:

ANTENNA LOCATION:

FULL SCALE FREQUENCY: 1600 MHz

MODEL SCALE:

MODEL FREQUENCY:



θ =

ϕ =

CONFIGURATION:

INTEGRATOR COUNT:

POLARIZATION: Eϕ [ ] Eθ [ ] OTHER:

PLOTTED IN: VOLTAGE (SQ. RT.) [X] POWER (LIN.) [ ]

REMARKS: LOW FREQ. END OF BAND

TRANSMISSION DISTANCE:

OBSERVER: DATE:

FIGURE B-2. VERTICAL PATTERN 1600 MHz

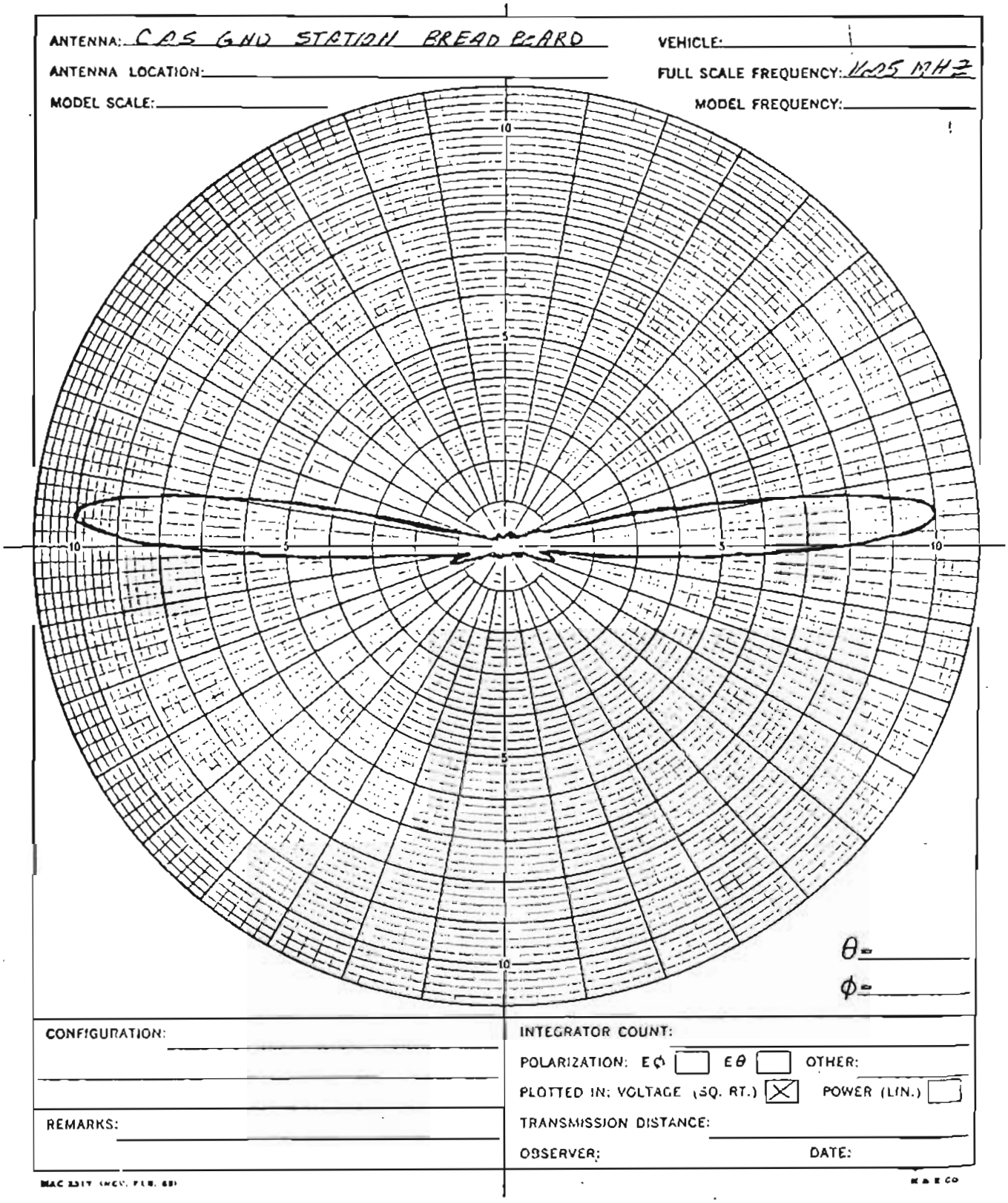


FIGURE B-3. VERTICAL PATTERN 1605 MHz

ANTENNA: CAS GND STATION BREADBOARD

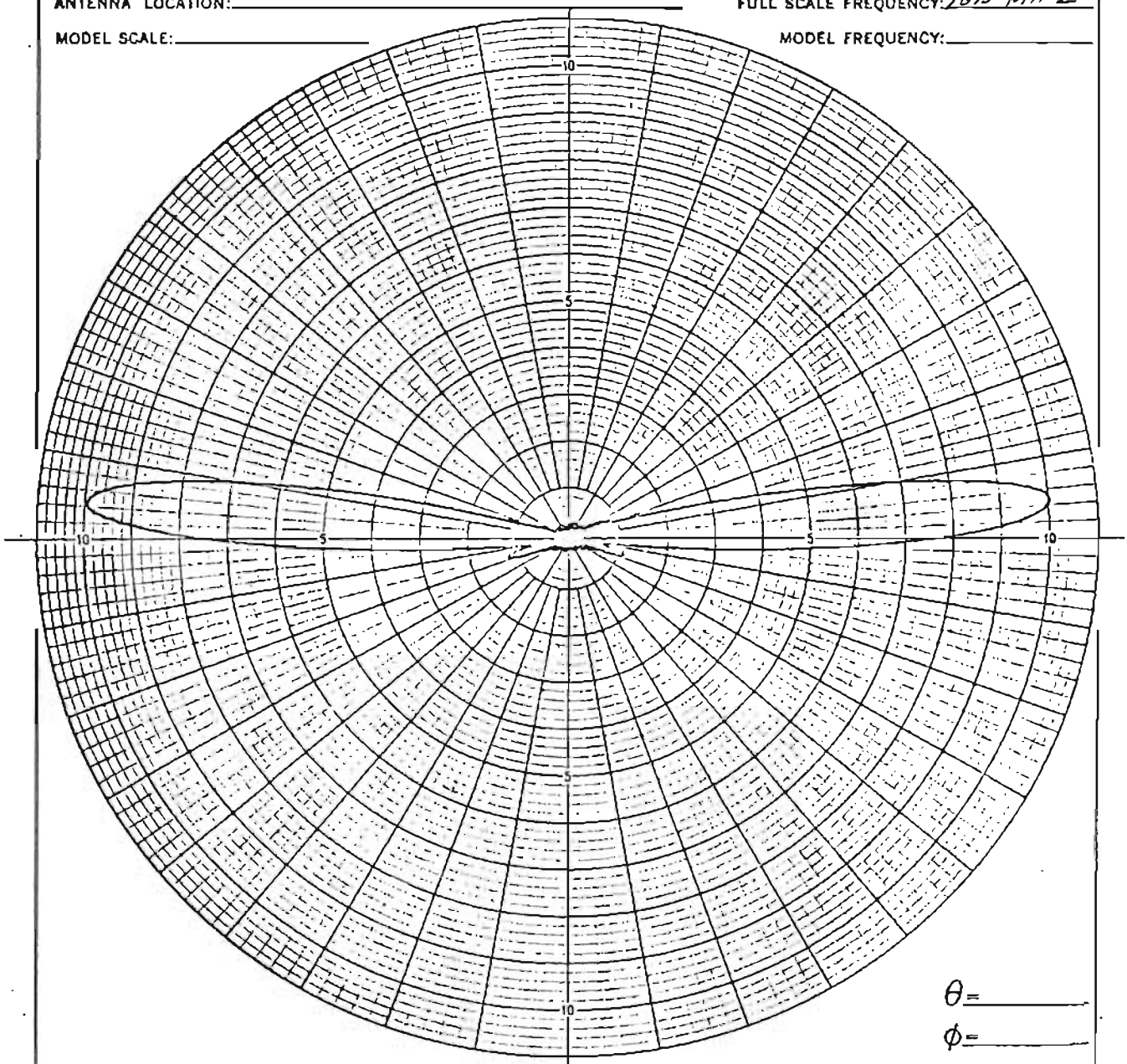
VEHICLE:

ANTENNA LOCATION:

FULL SCALE FREQUENCY: 1610 MHZ

MODEL SCALE:

MODEL FREQUENCY:



CONFIGURATION:

INTEGRATOR COUNT:

POLARIZATION: Eφ [ ] Eθ [ ] OTHER:

PLOTTED IN: VOLTAGE (SQ. RT.) [X] POWER (LIN.) [ ]

REMARKS:

TRANSMISSION DISTANCE:

OBSERVER:

DATE:

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FIGURE B-4. VERTICAL PATTERN 1610 MHz

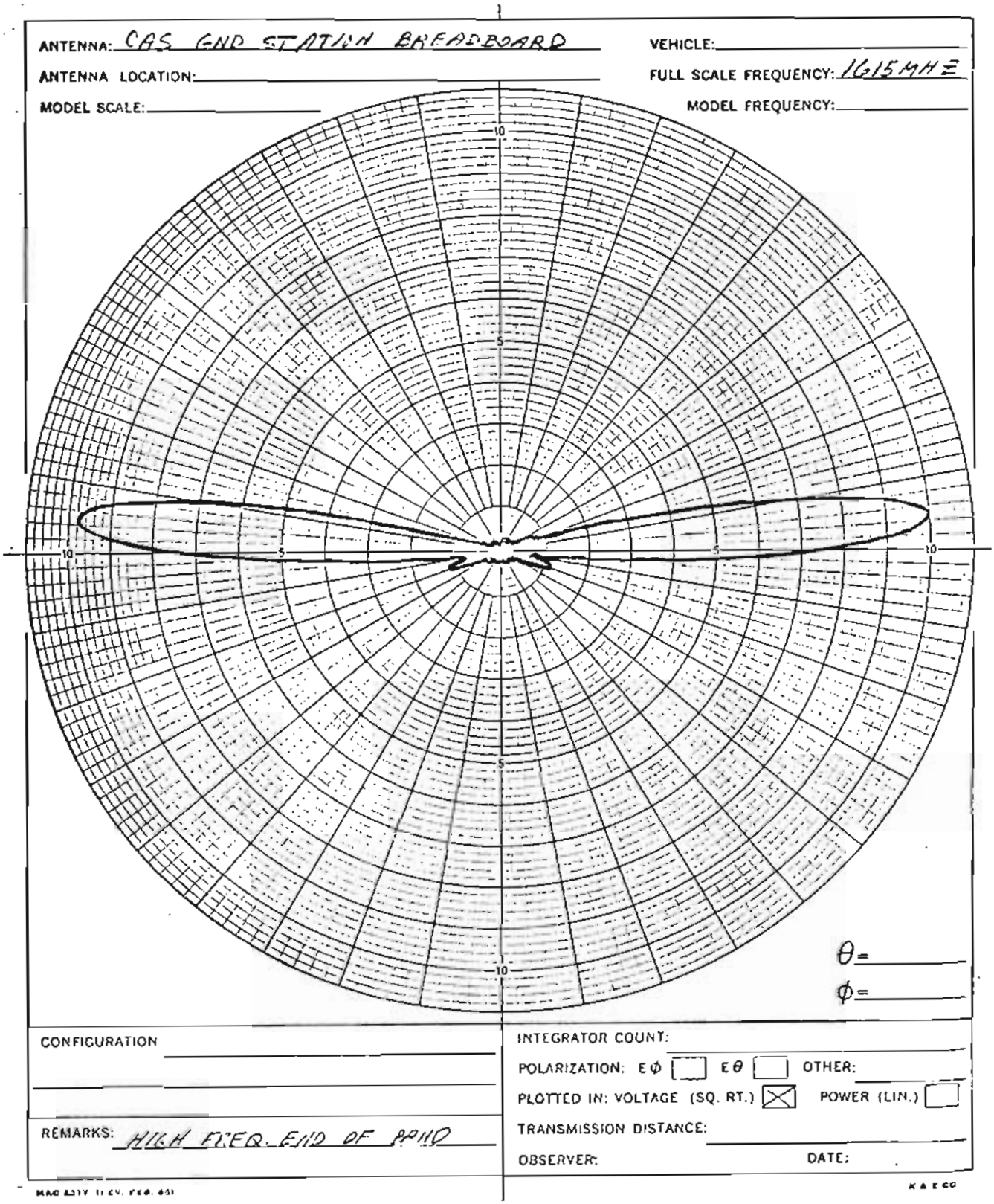


FIGURE B-5. VERTICAL PATTERNS 1615 MHz

ANTENNA: CAS GND STATION BLENDBOARD

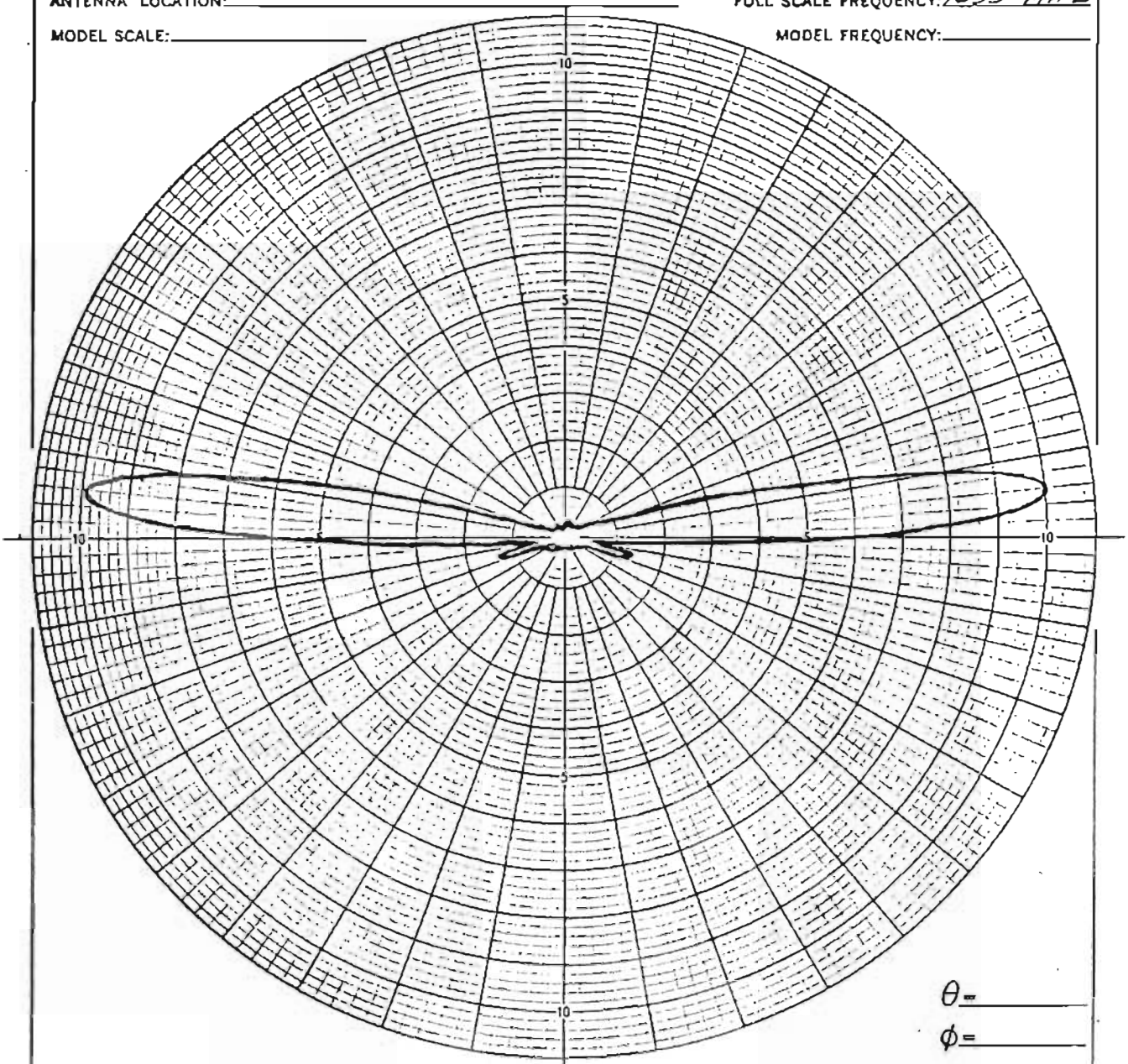
VEHICLE:

ANTENNA LOCATION:

FULL SCALE FREQUENCY: 1635 MHZ

MODEL SCALE:

MODEL FREQUENCY:



CONFIGURATION:

REMARKS: 20 MHZ ABOVE DESIGN BAND

INTEGRATOR COUNT:

POLARIZATION: Eφ ☐ Eθ ☐ OTHER:

PLOTTED IN: VOLTAGE (SQ. RT.) ☒ POWER (LIN.) ☐

TRANSMISSION DISTANCE:

OBSERVER: DATE:

FIGURE B-6. VERTICAL PATTERN 1635 MHz

ANTENNA: CNS GND STATION BREADBOARD

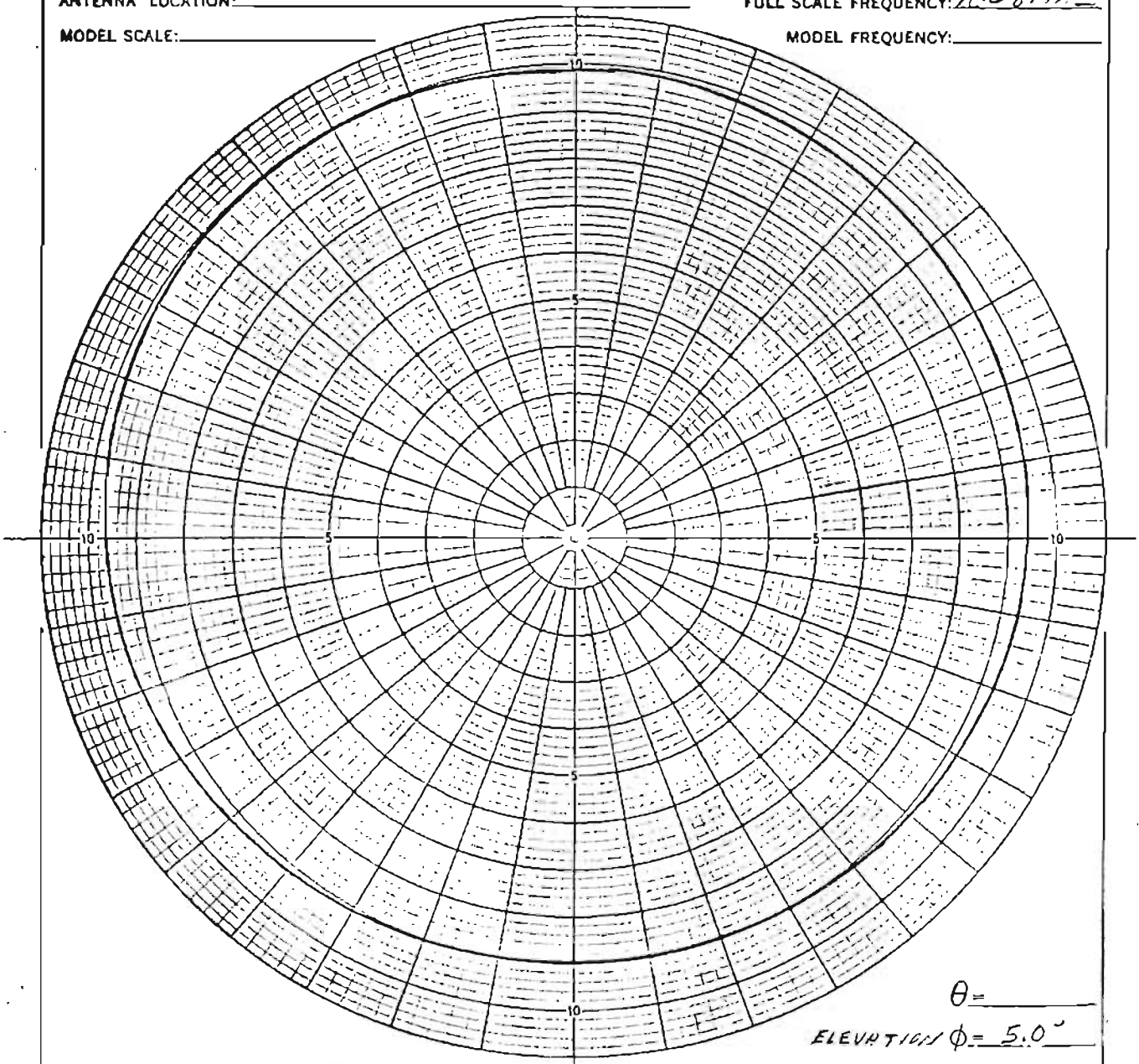
VEHICLE:

ANTENNA LOCATION:

FULL SCALE FREQUENCY: 1608 MHZ

MODEL SCALE:

MODEL FREQUENCY:



CONFIGURATION:

INTEGRATOR COUNT:

POLARIZATION: Eφ ☐ Eθ ☑ OTHER:

PLOTTED IN: VOLTAGE (SQ. RT.) ☑ POWER (LIN.) ☐

REMARKS: CIRCULARITY = .9 dB

TRANSMISSION DISTANCE:

OBSERVER:

DATE:

FIGURE B-7. HORIZONTAL PATTERN 1608 MHz

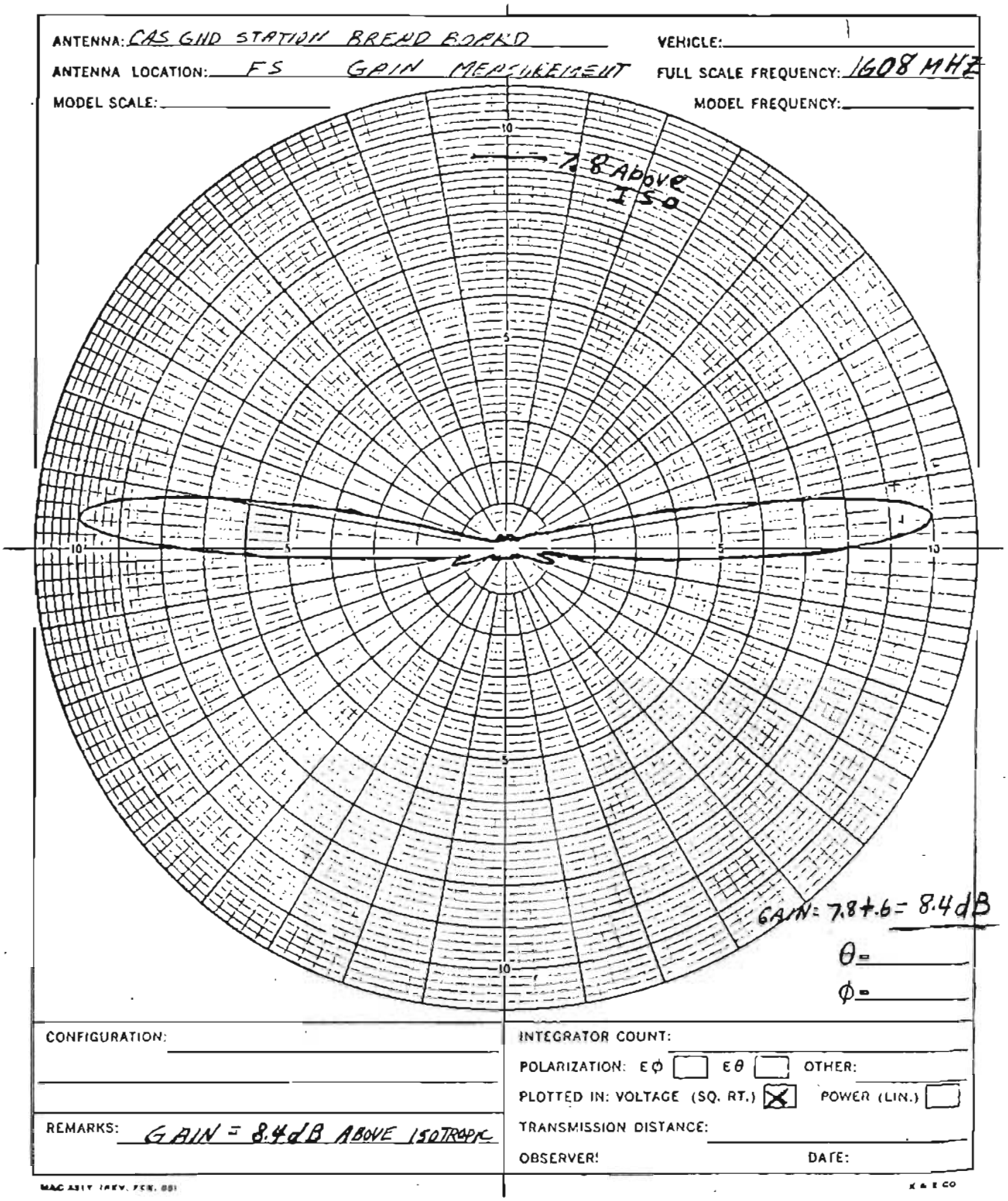


FIGURE B-8. VERTICAL PATTERN 1608 MHz

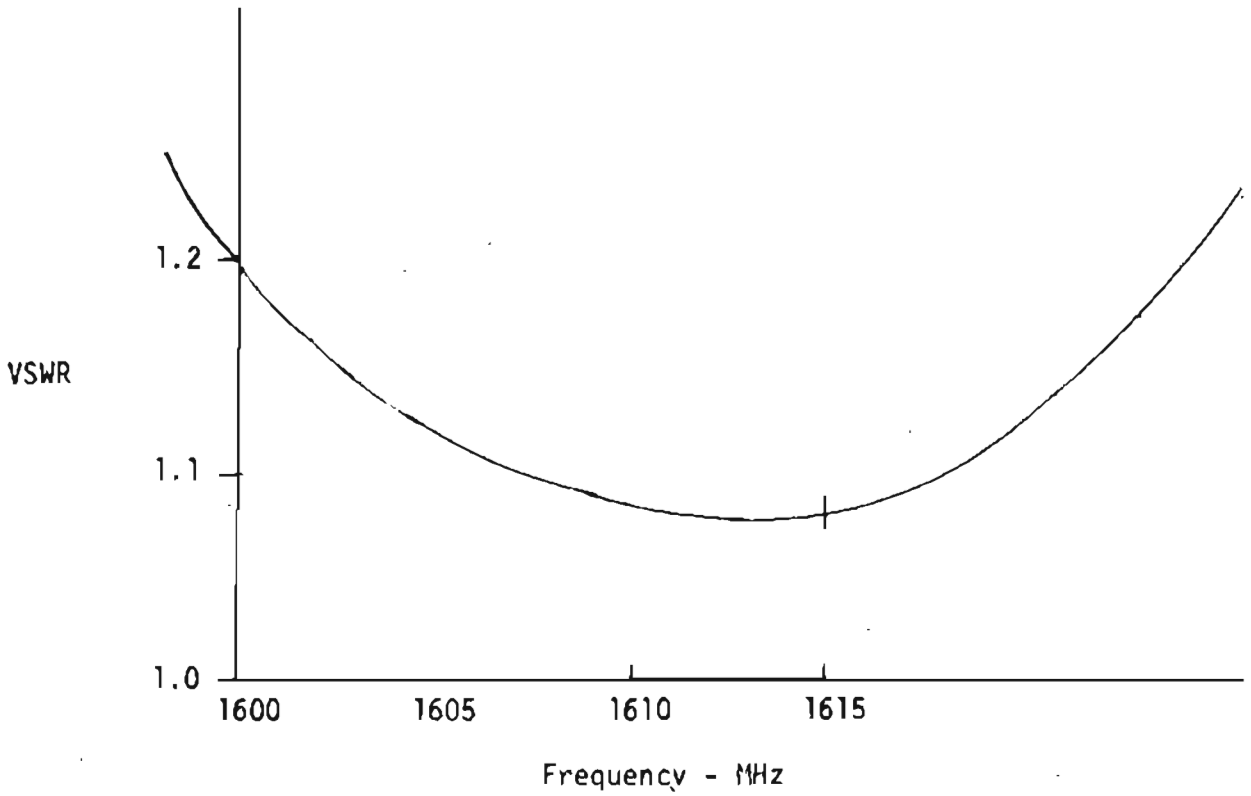


Figure B-9. ANTENNA VSWR

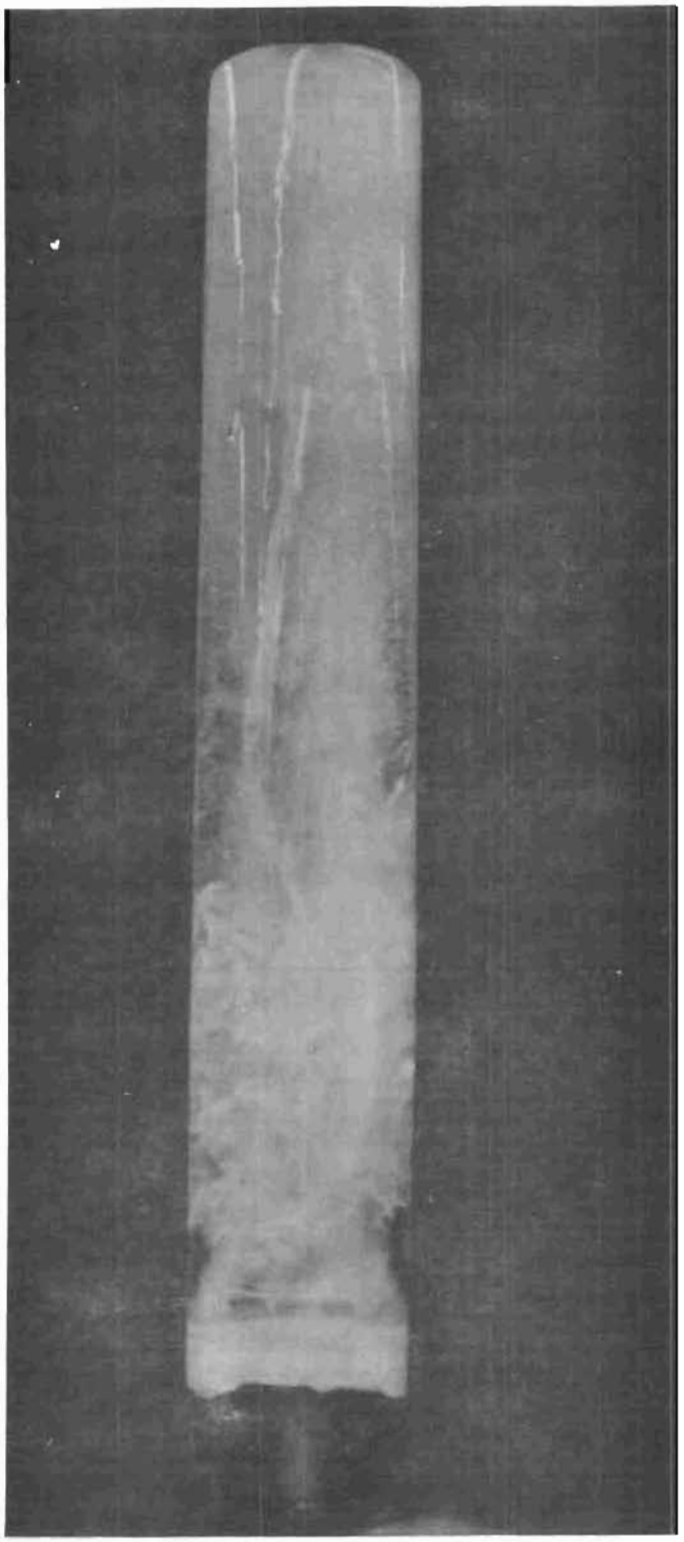


FIGURE B-10. ANTENNA ICE LOAD TEST

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2. "Collision Avoidance System Ground Station", Department of Transportation, Federal Aviation Administration Engineering Requirement; FAA-ER-240-016, 1 October 1971.

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4. "Airborne Collision Avoidance System Statement of Airline Policy and Requirements and a Technical Description of the System", ANTC Report No. 117, Revision 10, March 24, 1972.

5. "Air Transport Time-Frequency Collision Avoidance System"; ARINC Characteristic No. 587, September 1970.

6. "Collision Avoidance System Ground Station Analysis", Department of Transportation, Federal Aviation Administration; Final Report FAA-RD-74-44, March 1974.

7. "Collision Avoidance System Ground Station", McDonnell Douglas Electronics Company; Instruction Manual No. A12G1230.

8. "Collision Avoidance System Airborne Equipment", McDonnell Douglas Electronics Company; Instruction Manual No. A12A0701.

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10. "Collision Avoidance System", McDonnell Douglas Electronics Company; Factory Test Procedure No. A12G1231.

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