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RESEARCH INSTRUMENTATION FOR TORNADO ELECTROMAGNETICS EMISSIONS DETECTION
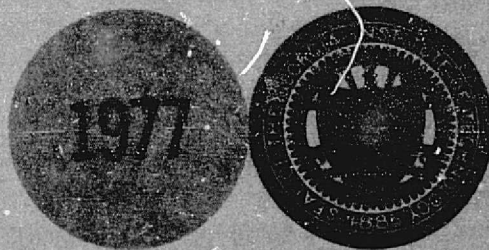
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Atlanta, Georgia 30332

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Final Technical Summary Report

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15. Supplementary Notes

16. Abstract

      Described is instrumentation for receiving, processing and recording HF/VHF electromagnetic emissions from severe weather activity. Both airborne and ground-based instrumentation units are described on system and sub-system levels. Design considerations, design decisions, and the rationale behind the decisions are given. Performance characteristics are summarized and recommendations for improvements are given.

      Presented are the objectives, procedures and test results of (1) airborne flight test in the Midwest U.S.A. (Spring 1975) and at the Kennedy Space Center, Florida, (Summer 1975), (2) ground-based data collected in North Georgia (Summer/Fall 1975), and (3) airborne flight test in the Midwest (late Spring 1976) and at the Kennedy Space Center, Florida (Summer 1976). The Midwest tests concentrated on severe weather with tornadic activity; the Florida and Georgia tests monitored air-mass convective thunderstorm characteristics. Supporting ground-truth data from weather radars and sferics DF nets are described.

      Approximately sixteen hours of magnetic tape recordings of sferics data were obtained during the 1975 experiment period and about thirteen hours of magnetic recorded data during the 1976 field operations.

17. Key Words (Selected by Author(s)) Severe Weather Research Tornado Detection Instrumentation Sferics Detection	18. Distribution Statement

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FOREWORD

This report was prepared by the Engineering Experiment Station at Georgia Tech under Contract No. NAS5-20956. The work described was performed in the Electronics Technology Laboratory, Mr. D. W. Robertson, Director, and was conducted under the general supervision of Mr. R. W. Moss, Head of the Communications Technology Group. Mr. H. H. Jenkins was the Project Director for phases of the work conducted during 1975, and Mr. C. S. Wilson was the Project Director for later phases of the work. The report summarizes the objectives, activities and results of a program to develop instrumentation for detection of electromagnetic emissions from tornadic weather activity.

The contributions of Messrs. B. J. Wilson and J. D. Kascak are acknowledged as is the overall guidance of Dr. D. M. LeVine of NASA.

PREFACE

The major objectives of this research effort were the design, development, installation and operation of instrumentation for data collection of severe weather electromagnetic (sferics) emissions.

This report describes the instrumentation for receiving, processing and recording HF/VHF sferics signals emanating from severe weather activity. Both airborne and ground-based instrumentation units are described at system and sub-system levels. Design considerations, design decisions, and the rationale behind the decisions are given. Performance characteristics are summarized, and recommendations for improvements are given.

Presented are the objectives, procedures, and test results of (1) airborne flight tests in the Midwest U.S.A. (Spring 1975) and at the Kennedy Space Center, Florida, (in Summer 1975); (2) ground-based data collection in North Georgia (Summer/Fall 1975); and (3) airborne flight tests in the Midwest (late Spring 1976) and at the Kennedy Space Center, Florida (Summer 1976). The Midwest tests concentrated on severe weather with tornadic activity; the Florida and Georgia tests monitored air-mass, convective thunderstorm characteristics. Supporting ground-truth data from weather radars and sferics DF nets are described.

Approximately sixteen hours of magnetic tape recordings of sferics data were obtained during the 1975 experiment period and about thirteen hours of magnetic recorded data during the 1976 field operations.

The capability of the sferics instrumentation was demonstrated on numerous airborne missions conducted in the midwestern states and at the Kennedy Space Flight Center and by ground-based monitoring in North Georgia. The 1975 airborne tests disclosed that several improvements are needed to optimize system performance. These improvements are: (1) an increased HF antenna efficiency, (2) a reduction in RF interference, (3) a more reliable time-of-day timing system, and (4) a system package reconfiguration for ease of operation and monitoring in an airborne environment. These improvements were incorporated into the instrumentation system prior to the 1976 field operations.

In addition to the main body of this report, three (3) appendices are included that provide additional information regarding the severe weather instrumentation and related systems. Appendix A provides a brief description of the Georgia Tech sferics network and weather radar which were used to provide supplemental data inputs to the Georgia ground-based field experiments. Appendix B provides information regarding the gain characteristics of the dual HF receiver and the four VHF receivers as the receivers were adjusted for normal operation during the 1975 field experiments. Appendix C contains a description of the additions and modifications to the severe weather instrumentation package that occurred prior to the start of the 1976 field operations.

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LIST OF FIGURES

1. INTRODUCTION

There exists an urgent need to improve tornado detection and warning systems; therefore, the National Aeronautics and Space Administration has initiated a program to determine the feasibility of using satellite monitoring techniques to contribute to improvements in tornado detection and warning systems.

A major portion of the program has been an effort devoted to identifying electromagnetic signal features which may be characteristic of severe weather phenomena and, in particular, delineate those features which may allow identification of tornadoes. A major aspect of this identification effort is to collect data on the electromagnetic emissions for a large class of severe storms and to examine the data for characteristics which distinguish tornadoes from other severe storm activity.

This report describes instrumentation developed to receive, process, and record electromagnetic emissions of severe storms from both airborne and ground-based facilities. The report contains several major sections. In the first section, the specific objectives are stated. This is followed by a description of the instrumentation system and various subsystems for both the ground-based and airborne configurations. The third major section discusses the design considerations, subsequent design decisions, and the rationale behind the decisions that were made. The fourth section presents a summary of the performance characteristics. The fifth section provides a summary of the field operations performed with the instrumentation. The last section deals with a general review of the instrumentation performance and recommended improvements.

Because of the need to be operational during projected severe weather periods, the instrumentation was developed on a quick-reaction basis. Work began in November 1974 and the instrumentation was operational by early April 1975.

There are five reports that may be considered supplemental reference material prepared under Contract NAS5-20956.

(1) "Operation and Instruction Manual. Research Instrumentation for Tornado Electromagnetic Emissions Detection," August 1975, H. H. Jenkins and C. S. Wilson.

(2) "Design Report. Research Instrumentation for Tornado Electromagnetic Emissions Detection," August 1975, H. H. Jenkins.

(3) "1976 Severe Local Storms Surveillance Experiment, Airborne Field Operation Data Log, 11-12 June 1976," C. S. Wilson, B. J. Wilson.

(4) "Thunderstorm II, Kennedy Space Center Florida, Ground-Based Field Operation Data Log, 3-19 July 1976," C. S. Wilson, B. J. Wilson.

(5) "Aircraft Antenna Measurements" February 1977, H. H. Jenkins, C. S. Wilson, B. J. Wilson.

Additional information on the Lightning Stroke Detector may be obtained from Dr. E. Philip Krider, The University of Arizona, Department of Atmospheric Sciences, Tucson, AR 85721.

Tornado Detector information may be obtained from Mr. W. L. Taylor, NOAA/ERL, Boulder, CO 80302.

2. OBJECTIVES

The _general_ objectives of the project were to design, develop, install, and operate instrumentation in support of airborne and ground-based severe weather experiments.

The _specific_ objectives were as follows:

(1) Design, develop, fabricate and test an HF/VHF multi-frequency, multi-polarization, broadband Severe Weather Data Acquisition System for receiving, processing, and recording electromagnetic emissions from severe weather. Certain desired performance characteristics were to be met.

(2) Integrate the Severe Weather Data Acquisition System, a Lightning Stroke Detector (supplied by the University of Arizona), and a Taylor Tornado Detector (supplied by NOAA/ERL) into an instrumentation package suitable for airborne and ground-based usage. The test aircraft was a Beechcraft Queen Air operated by Colorado State University. Certain weight/power/volume specifications had to be met.

(3) Provide the aircraft antennas and specify antenna placement on the aircraft. Perform the same function for the ground-based instrumentation package located in a mobile monitoring van.

(4) Install, align, calibrate and flight test the airborne instrumentation in the test aircraft. Train personnel on the operation of the instrumentation.

(5) Participate in airborne severe weather data collection experiments in the Midwest and at the Kennedy Space Center, Florida. The Midwest experiments concentrated on tornadic activity; the KSC tests were directed toward air-mass, convective thunderstorms, although some tornadic conditions were encountered during the tests.

(6) After the airborne tests, install the instrumentation in a mobile monitoring van and collect severe weather data in North Georgia with emphasis on severe thunderstorm activity.

(7) Support the ground-based experiments with ground-truth data from GIT and NWS weather radars and the GIT Sferics/DF Net, and provide summary reports from the ground-truth data.

(8) Provide supporting documentation including a Design Report, an Operation and Instruction Manual, and a Final Technical Summary Report.

3. DESCRIPTION OF INSTRUMENTATION

3.1 Introduction

The instrumentation consists of nine subsystems as follows:

(1) Antennas

(2) RF Distribution

(3) HF/VHF Receivers

(4) Post-Detection Signal Processors

(5) Magnetic Tape Recorder

(6) Timing

(7) Power Distribution

(8) Taylor Tornado Detector (supplied by NOAA)

(9) Lightning Stroke Analyzer (supplied by University of Arizona)

The following sections describe the overall system and the various subsystems.

3.2 Description of System

3.2.1 Airborne Unit

Figure 1 presents a functional block diagram of the airborne instrumentation unit which was installed and operated in a Beechcraft 80 Queen Air. The instrumentated aircraft is shown in Figure 2. Figure 3 depicts the physical configuration of the equipment for airborne usage. Figure 4 is a photograph of the instrumentation installed in the aircraft (Lightning Stroke Detector removed).

The Severe Weather Data Acquisition System consists of the RF Distribution Unit, the HF/VHF receivers, and the post-detection Signal Processors.

The RF Distribution Unit accepts the outputs from four aircraft antennas and amplifiers and diplexes these inputs into seven outputs as depicted in Figure 1. Please note that in this report 3, 30, 100, and 300 MHz are referred to as the test frequencies. These are nominal values. The HF frequencies are pre-set and switch selectable. The recommended VHF frequencies are 139 MHz and 295 MHz; however, these may

VERTICAL: 3 MHz VERTICAL: 30 MHz VERTICAL: VHF HORIZONTAL: VHF VERTICAL: LIGHTNING STROKE DETECTOR WWVB ANTENNA

A

RF DISTRIBUTION UNIT

300 MHz HORIZONTAL

3 MHz   B TAYLOR RECEIVER 3 MHz   30 MHz   100 MHz VERTICAL   100 MHz HORIZONTAL   300 MHz VERTICAL

3 MHz → LOWER HF RCVR. → SIGNAL PROCESSOR → 1, 2

30 MHz → UPPER HF RCVR. → SIGNAL PROCESSOR → 3, 4

100 MHz V → VHF RCVR. → SIGNAL PROCESSOR → 5

100 MHz H → VHF RCVR. → SIGNAL PROCESSOR → 6

300 MHz V → VHF RCVR. → SIGNAL PROCESSOR → 7

300 MHz H → VHF RCVR. → SIGNAL PROCESSOR → 8

DIRECT RECORD 1 2 3 4 5 6 7 8

TAPE RECORDER PR2200 FOURTEEN CHANNELS

EDGE TRACK   VOICE LOG

DIR OR FM   INTERNAL TIME REF.

FM   WWVB RCVR.

DIR / DIR   LIGHTNING STROKE DETECTOR → A

FM / FM   TAYLOR TORNADO DETECTOR → B

115V AC 60 Hz ← POWER DISTRIBUTION ← 28V DC A/C POWER

Figure 1. Tornado Electromagnetic Emission Instrumentation Functional Block Diagram.

6

A

B

Figure 2. Test Aircraft (Owned and Operated by Colorado State University).

CABINET 1

DC/AC INVERTER 2 RECORDER INVERTER

CABINET 2

VHF RCVR. 1
VHF RCVR. 2
VHF RCVR. 3
VHF RCVR. 4
RECORDER MONITOR PANEL
RF DISTRIBUTION
SPACE
TAYLOR'S TORNADO DETECTOR

WHVB RCVR.
LIGHTNING STROKE DETECTOR
DUAL HF SFERICS RCVR.
DC POWER DISTRIBUTION
DC/AC INVERTER 1 SYSTEM INVERTER

CABINET 3

MAGNETIC TAPE RECORDER

Figure 3. Instrumentation Configuration—Front View.

A

B

Figure 4. Depiction of Instrumentation in Test Aircraft (Lightning
Stroke Detector Removed).

be altered based on signal interference conditions. (We found that these VHF frequencies were optimum for transmission through the RF diplexers and with minimum interference reception for the specific tests performed during 1975.)

The HF/VHF RF outputs from the Distribution Unit are applied to six receivers - two HF and four VHF. The upper and lower HF receivers are special, wideband (600 kHz bandpass) tuned-radio-frequency (TRF) receivers developed by Georgia Tech especially for sferics reception.

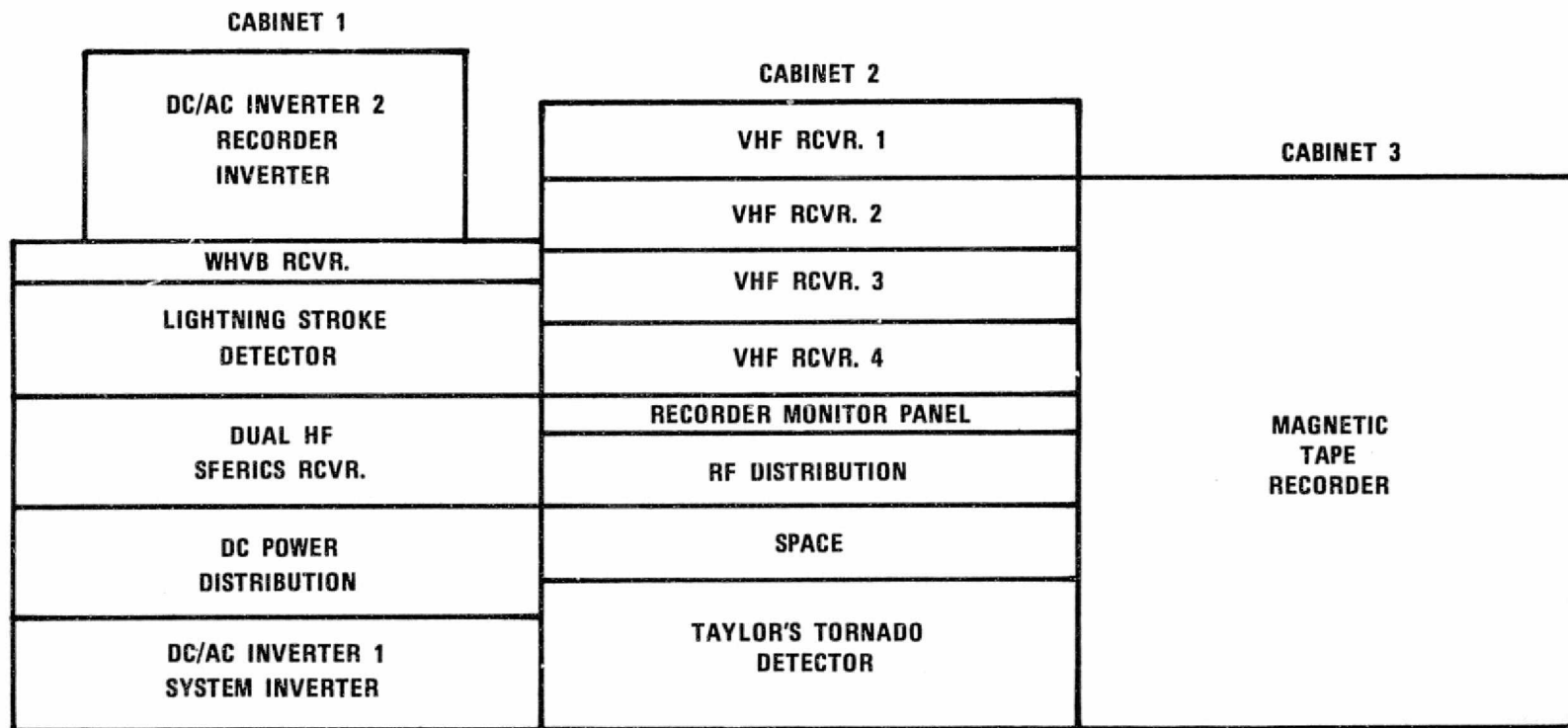Video outputs from the HF/VHF receivers are applied to the Post-Detection Signal Processors which amplify, filter, level, and process the video signals for input to the tape recorder. The Signal Processors are specially designed for sferics signal processing and include both linear and logarithmic amplifiers for HF video and linear for VHF video. The signal processor outputs are video, baseband signals with a nominal bandwidth of 300 kHz.

One lower HF output of the RF Distribution Unit goes to the Taylor Tornado Detector which is a broadband (10% bandwidth) TRF receiver tuned to 3.16 MHz. The two outputs are near-range and far-range video output signals representative of the detected sferics envelope.

The Lightning Stroke Detector is a wideband, low-frequency (<1 MHz) electric field sensor designed to respond to the low-frequency spectrum emanating from lightning strokes. When the external antenna is exposed to a transient electric field, e.g., a cloud-to-ground lightning stroke, a current flows on the conducting surface of the antenna. The integral of this current is proportional to the external E-field. The Lightning Stroke Detector simply integrates the E-field in a wideband current integrator. The integrator outputs are amplified linearly and logarithmically and then applied to the tape recorder.

Timing is obtained from a WWVB receiver in a IRIG H time code format. An internal time reference is also recorded. Early tests used a 10 kHz square wave clock. This was later changed to the internal tape recorder servo reference frequency. (100 kHz at 60 ips and proportionally lower at lower tape speeds).

The magnetic tape recorder (Ampex PR 2200) provides FM and DIRECT record capability for the sferics video signals, the timing signals, and the voice log (edge track recording).

The Power Distribution Unit converts the aircraft 28V DC research power into 115V AC 60 Hz power via use of two DC/AC inverters. This unit also controls and meters the primary power.

3.2.2 Ground-Based Unit

The ground-based, van-mounted instrumentation was similar to the airborne unit except that: (1) the DC/AC inverters were not used and all units were powered directly from 115V AC, 60 Hz; and (2) a portion of the RF Distribution Unit was not used as each receiving unit was provided with its own antenna, hence, precluding the need for RF power splitters and diplexers.

3.3 Description of Subsystems

3.3.1 Antenna Configuration - Airborne

The airborne antennas consist of five externally mounted antennas for sferics reception and one internally mounted ferrite loop antenna for WWVB timing reception. Two vertical stub antennas for upper and lower HF reception were located on top of the fuselage. These antennas are shown in Figure 5 between the VHF/UHF rams horn and blade antennas. A vertical blade antenna (Figure 6) was used for VHF vertical polarization reception; horizontal VHF polarization was received using a horizontal split loop antenna located aft beneath the tail (Figure 7). The Lightning Stroke Detector antenna was a vertical TEM-mode antenna located on the bottom of the airframe amid-ships (Figure 6).

3.3.2 Antenna Configuration - Ground-Based

For the ground-based operations, separate antennas were provided for each receiving unit in the system - including the Tornado Detector and the Lightning Stroke Detector. Presented below is a summary of the receiver/antenna configurations.
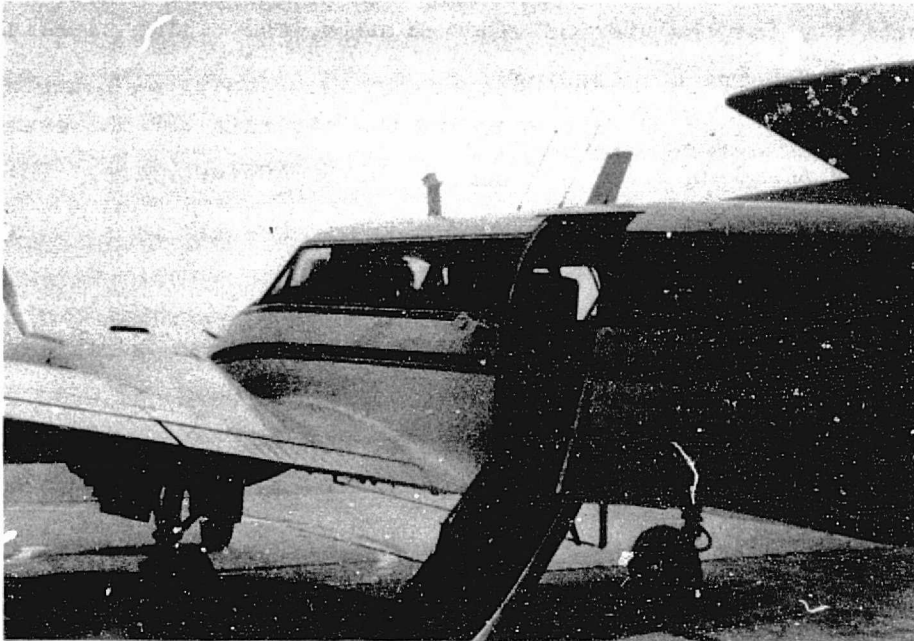
11

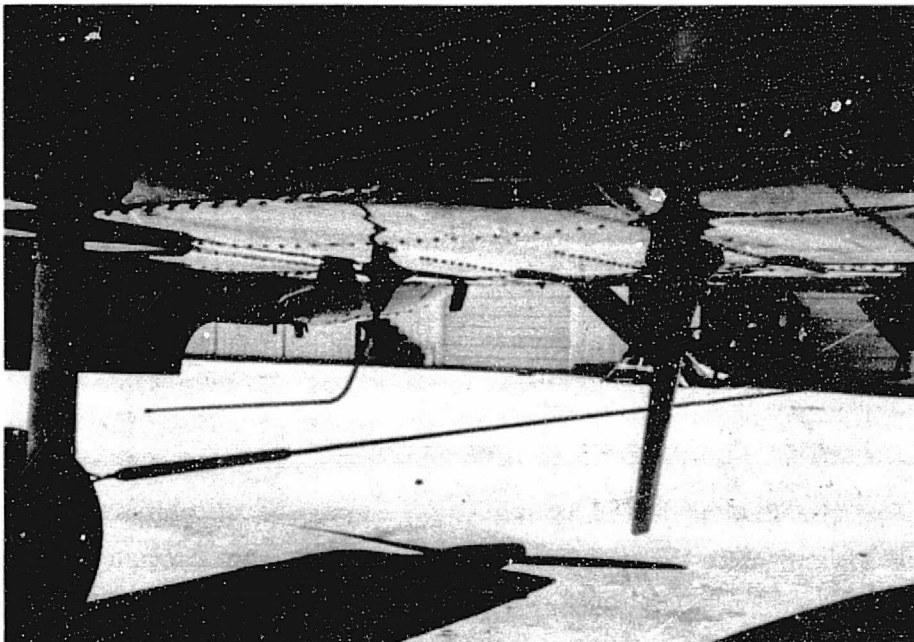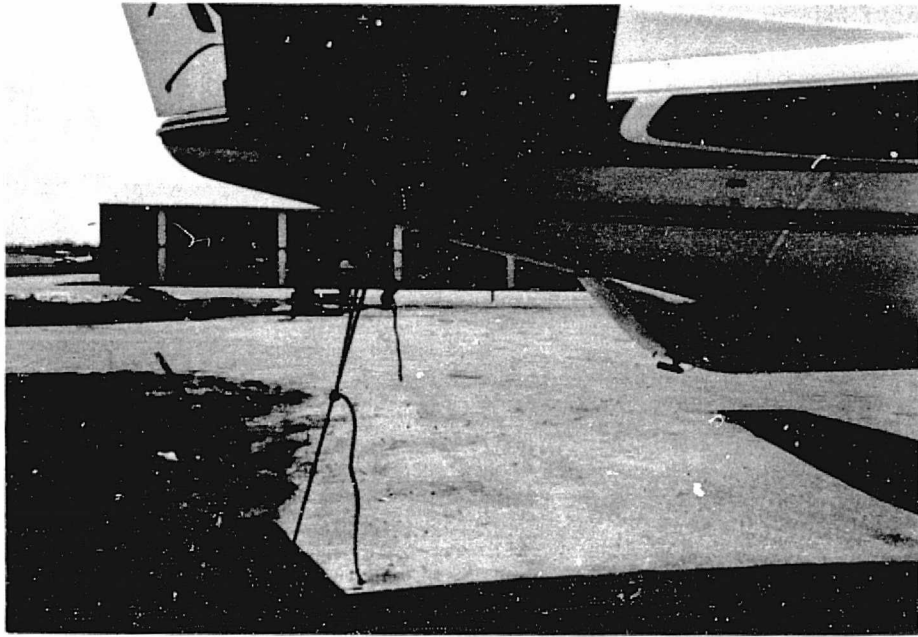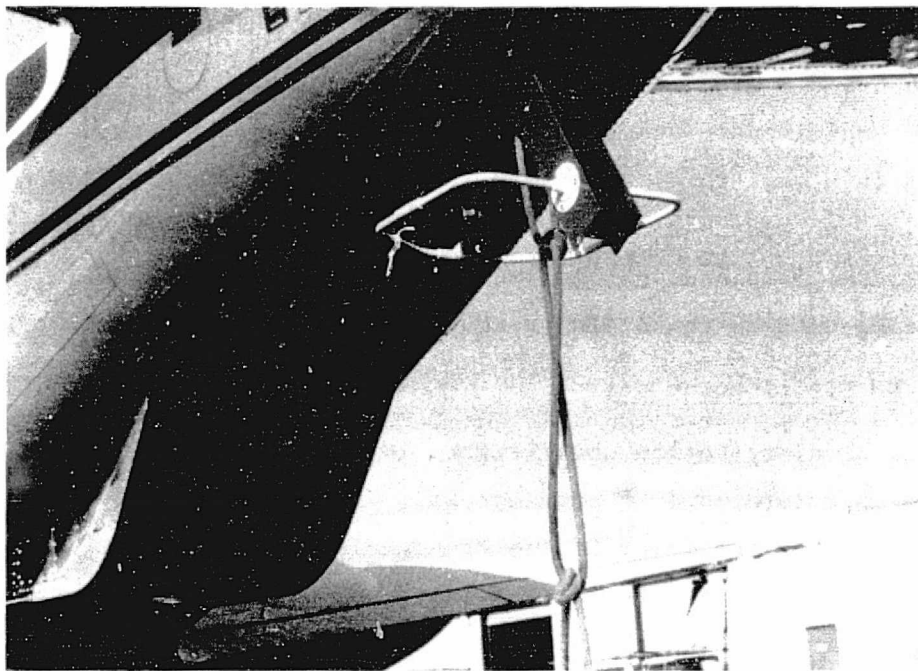Figure 5. View of HF Stub Antennas on Test Aircraft.

Figure 6. View of VHF Blade (Right) and TEM-Mode (Left) Antennas
on Test Aircraft. (ADF Long Wire Antenna Also Shown).

A

B

Figure 7. View of VHF Horizontal Split Loop Antenna. (Under Tail
to Rear of Doppler Radar Radome).

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Frequency/Unit	Type Antenna
Lower HF	Base-Loaded Monopole*
Upper HF	Resonant λ/4 Monopole*
139 MHz, Vertical	Resonant λ/4 Monopole*
139 MHz, Horizontal	Resonant Dipole
295 MHz, Vertical	Resonant λ/4 Monopole*
295 MHz, Horizontal	Resonant Dipole
Tornado Detection Unit	1.5 Meter Stub
Lightning Stroke Detector	Special Antenna Supplied by University of Arizona - Disc Antenna
WWVB Receiver	Ferrite Antenna

The antennas marked by an * were located on the roof of a monitoring van approximately 3 meters above ground. The dipoles were located about 5 meters above ground adjacent to the van. The Lightning Stroke Detector disc antenna was also located on top of the monitoring van.

Figures 8 and 9 are views of the antenna configurations for the ground-based experiments, which were conducted at the GIT Cobb County Test Site located in a semi-rural area some 26 km from the Georgia Tech campus. The monitoring van was co-located with one station of the GIT Sferics/DF Net. The crossed loop and vertical whip antenna assembly shown in Figure 8 (in the background on the building roof) is a part of this net.

3.3.3 RF Distribution Unit

The RF distribution unit (Figure 10) consists of diplexers, hybrids, preamplifiers, and RF attenuators. Its function is to distribute, amplify, and control the level of the RF signals prior to the HF/VHF receivers and the Tornado Detector. All antenna outputs (except the antenna output for the Lightning Stroke Detector) are routed through this unit. The unit outputs (the seven outputs on the left side) go to the receiving units.

The RF preamps are wide dynamic range units. The HF hybrids are broadband units functioning as power splitters.
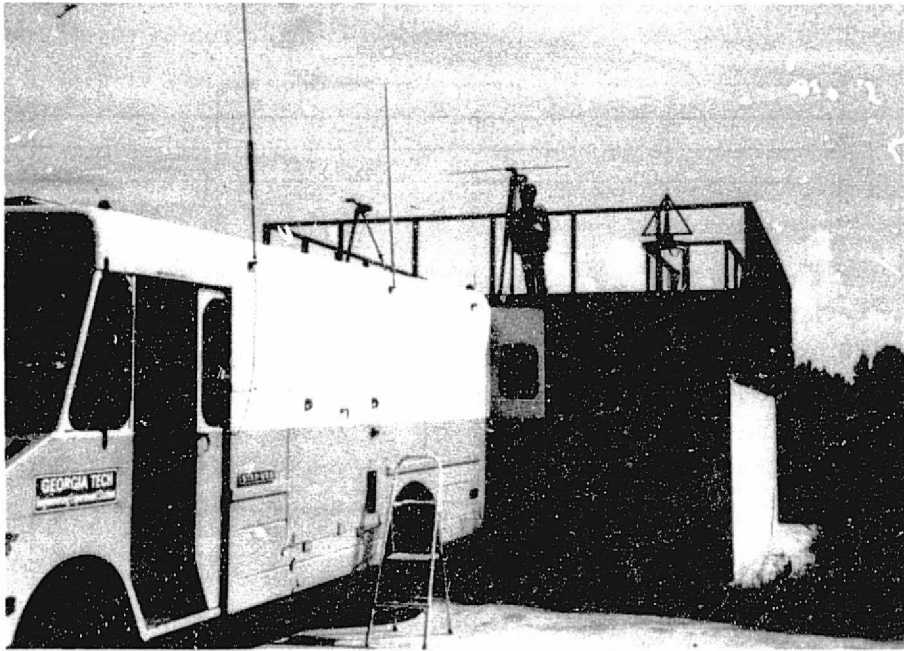
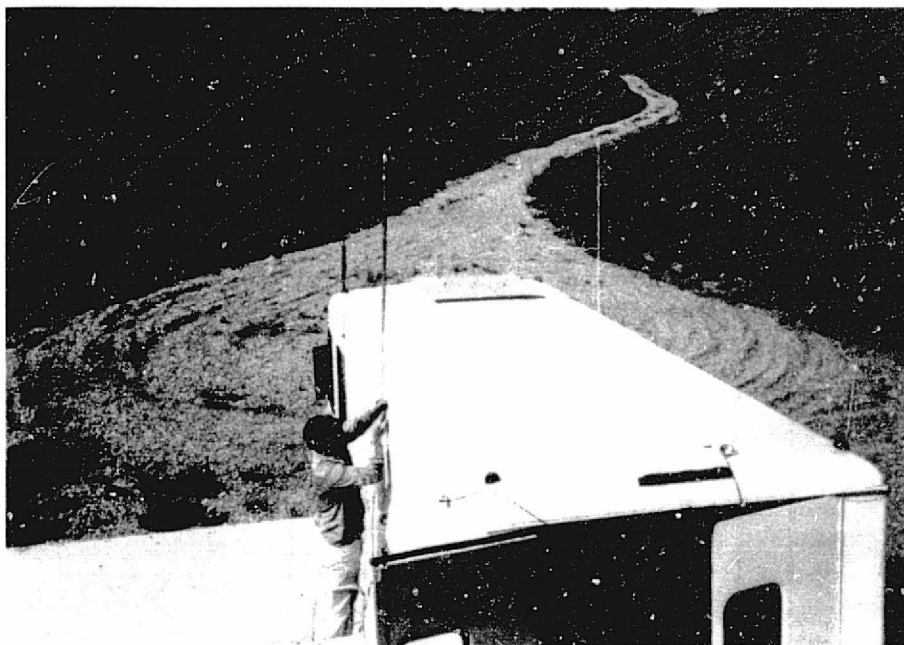Figure 8. View 1 of Ground-Based Monitoring Configuration.

Figure 9. View 2 of Ground-Based Monitoring Configuration Showing
Antenna Placements on Monitoring Van.
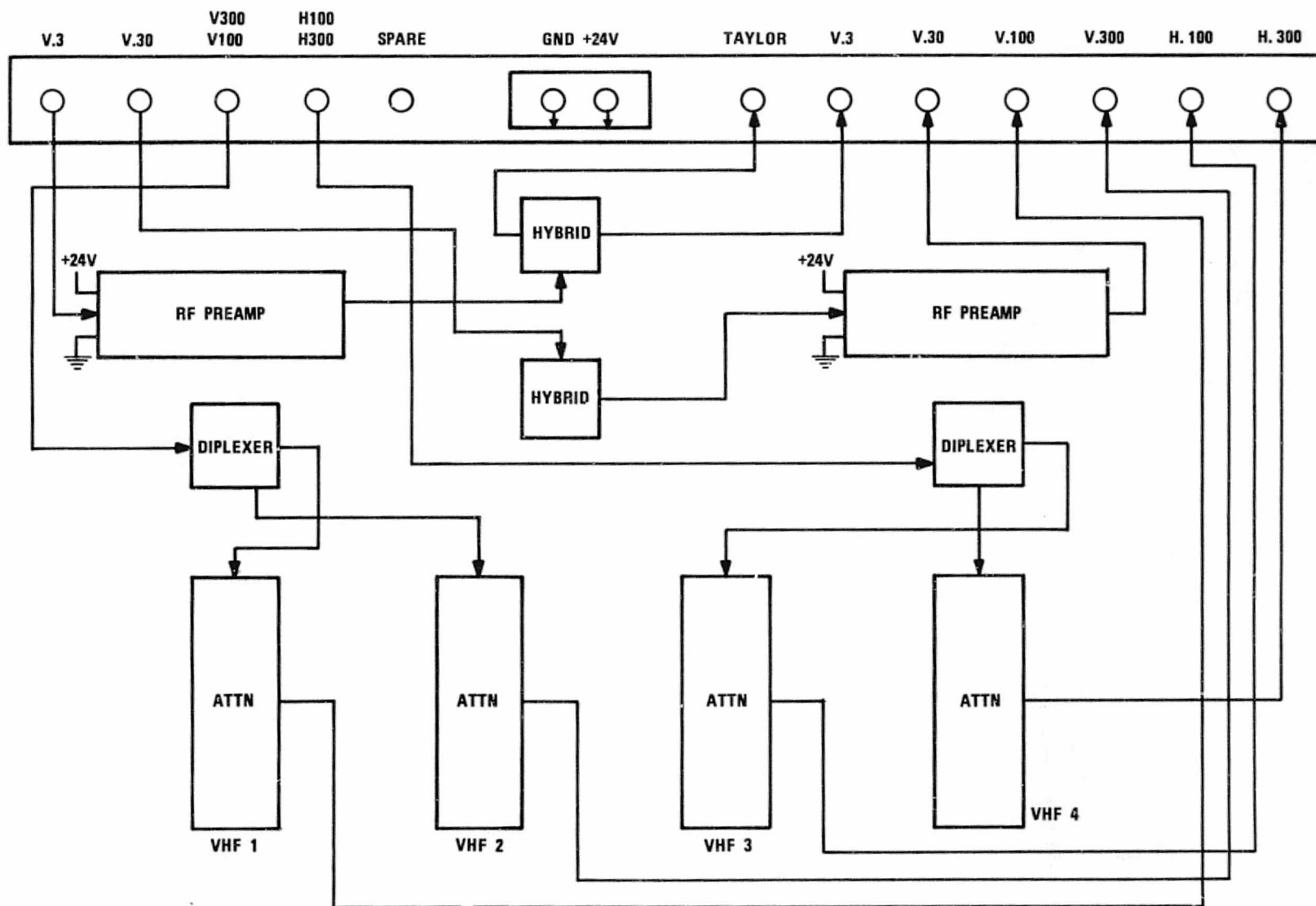
Figure 10. RF Distribution Unit-Block Diagram.

The diplexers separate the RF signals from the antennas into the 100 and 300 MHz components. The 100 MHz output is taken from the NAV/COMM port; the 300 MHz output from the glide slope port.

The four RF attenuators are for control of the VHF RF level prior to the receivers in order to prevent signal overload. RF gain is controllable in 10 dB steps from 0 to -120 dB. For ground-based operation, only the HF RF preamps were used.

3.3.4 Dual HF Sferics Receivers

The lower (3 MHz) and upper (30 MHz) HF receivers are wideband (600 kHz), tuned-radio-frequency (TRF) receivers developed by Georgia Tech especially for sferics reception. Figure 11 is a functional block diagram of the dual HF sferics receiver.

The receivers are TRF with RF bandpass filtering prior to the RF gain stages. The selectable center frequency of the bandpass filter sets the operating frequency. The RF step attenuators for the dual HF receiver also cover a 0 to -120 dB range in steps of 10 dB to provide RF gain control and prevent signal overload. They are operated manually by the operator based on the signal level meter indication.

The receiver contains: (1) selectable bandpass filters with a nominal bandwidth of 600 kHz; (2) RF gain stages; (3) an envelope detector; (4) signal level monitoring; (5) audio amplification; and (6) a video output buffer stage.

The upper HF unit contains five bandpass filters operating in the 30 to 40 MHz range and two RF gain stages. The lower HF unit contains three bandpass filters and three RF gain stages. A photograph of the dual HF sferics receiver is presented in Figure 12.

3.3.5 VHF Receivers

The four VHF receivers are commercial units as listed below:

VHF 1 (V, 100)*: Watkins-Johnson
                  WJ - 977

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*Georgia Tech owned.
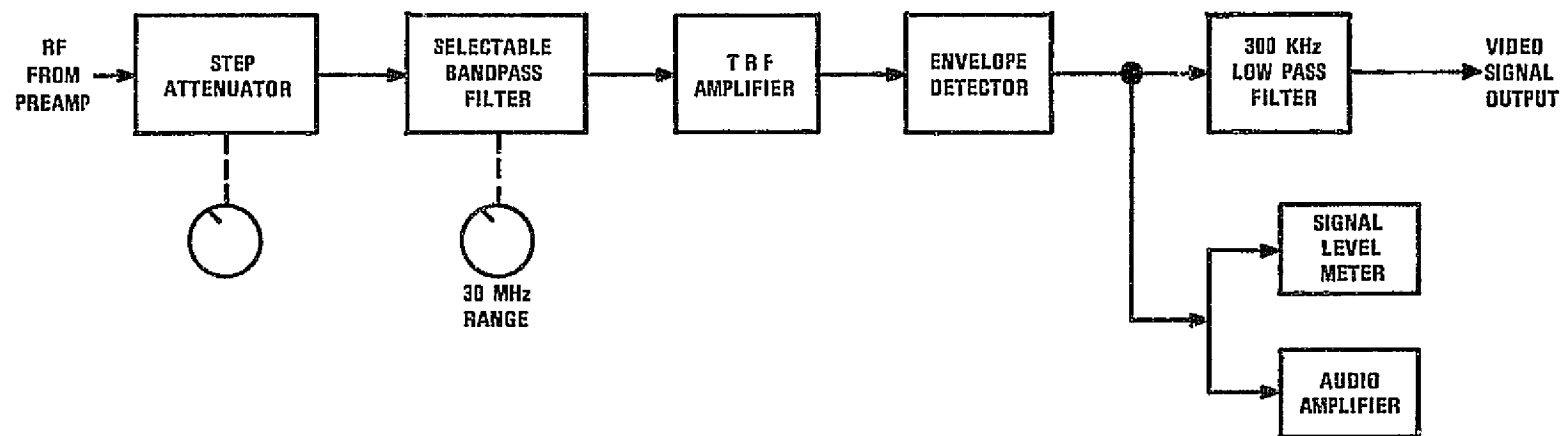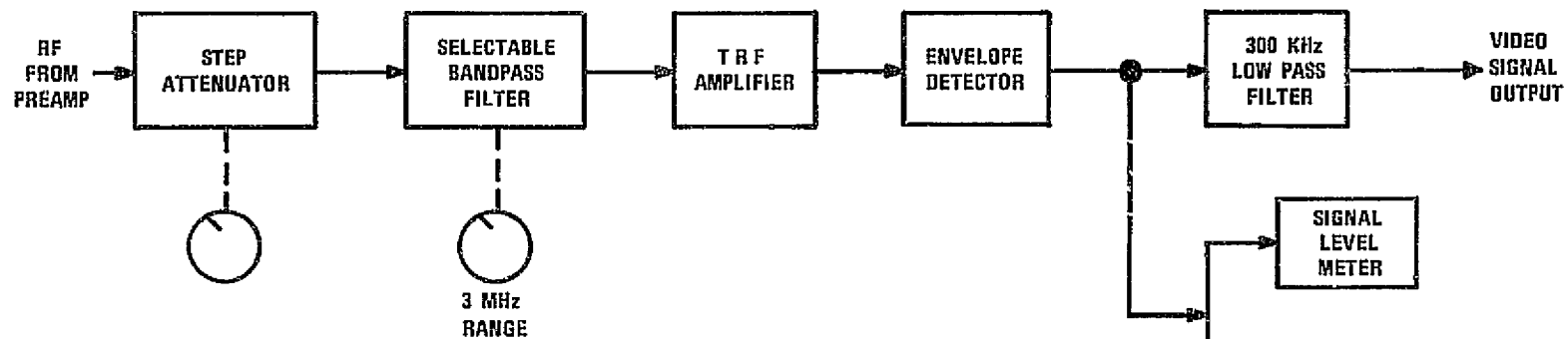
Figure 11. Functional Block Diagram of Dual HF Sferics Receiver.
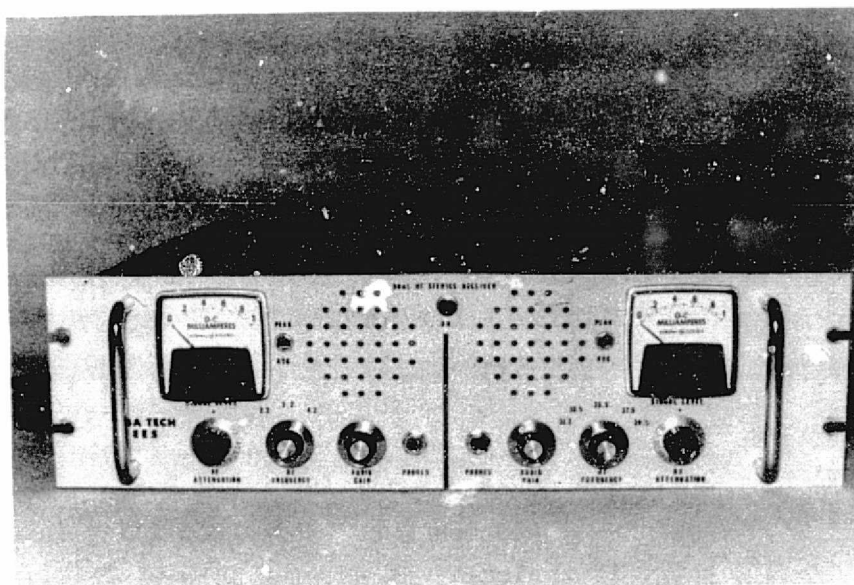
A
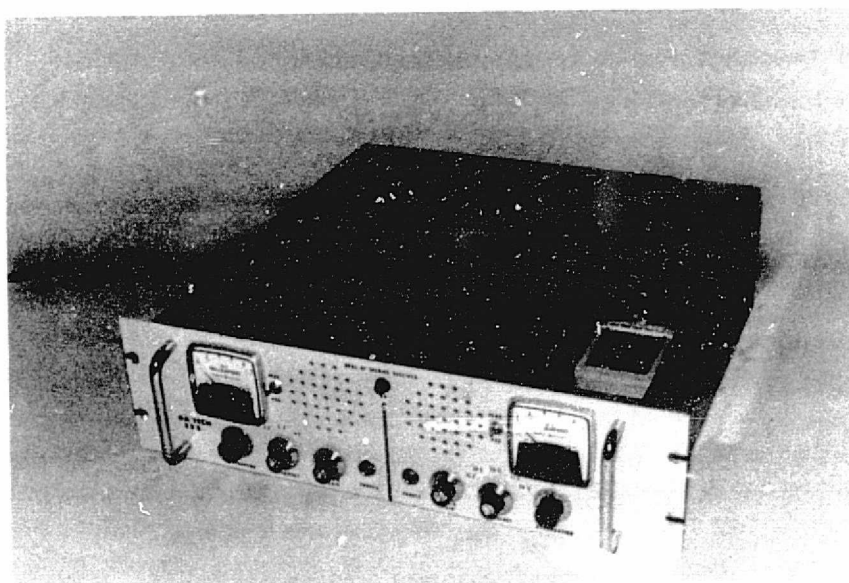
B

Figure 12.   Depection of the Dual HF Sferics Receiver.

```
VHF 2 (H, 100)*:   Watkins-Johnson
                   WJ - 977

VHF 3 (V, 300):    Watkins-Johnson
                   WJ - 8730
                   with WJ-9062
                   Tuning Head.

VHF 4 (H, 300):    Watkins-Johnson
                   WJ - 8730
                   with WJ-9062
                   Tuning Head.
```

All VHF receivers were operated with an IF bandwidth of 3 MHz in a non-AGC (AM Manual) mode.

The six video signal processors are all identical consisting of input and output buffer stages and linear and logarithmic amplifier intermediate stages. The dynamic range is typically 50 dB with linear amplification and 60 to 70 dB with logarithmic. The nominal video output level to the recorder is 2 volts peak-to-peak.

3.3.6 Magnetic Tape Recorder

The recorder was a fourteen channel Ampex PR 2200 with FM and DIRECT record capability. At 60 ips tape drive speed, the record capability is 300 Hz to 300 kHz (DIRECT) and DC to 40 kHz (FM – Wideband Group I). At 30 ips the upper frequency responses were halved. The usual record speeds were 60 and 30 ips for both airborne and ground-based tests providing a record time per reel of (3600 feet of 1" tape) 12 minutes and 24 minutes, respectively.

The table below shows the nominal tape recorder channel assignments that were used. Some variations in these assignments occurred from time-to-time depending upon mission requirements, equipment configurations, etc.

TAPE RECORDER CHANNEL ASSIGNMENTS

Recorder Channel	Record Mode	Signal Description
1	DIRECT	3 MHz, LIN
2	DIRECT	3 MHz, LOG

Recorder Channel	Record Mode	Signal Description
3	DIRECT	30 MHz, LIN
4	DIRECT	30 MHz, LOG
5	DIRECT	V-VHF 1 (139 MHz) LIN
6	DIRECT	V-VHF 2 (295 MHz) LIN
7	DIRECT	H-VHF 3 (139 MHz) LIN
8	DIRECT	H-VHF 4 (295 MHz) LIN
9	FM-Wideband	Internal Time Reference*
10	FM-Wideband	WWVB Time Code
11	DIRECT	LS-LIN
12	DIRECT	LS-LOG
13	FM-Wideband	Taylor-Far
14	FM-Wideband	Taylor-Near

3.3.7 Timing Subsystem

This subsystem consists of (1) a WWVB receiver providing an IRIG H time code output, and (2) an internally generated reference signal. Both signals are applied to the magnetic tape recorder (FM mode) for absolute (WWVB) and relative system timing.

3.3.8 Power Distribution Subsystem - Airborne

This subsystem provides AC (115 v, 60 Hz) via use of two DC/AC inverters which convert the 28 volt DC aircraft power to 115 volts, 60 Hz. Inverter 1 powers all equipment except the tape recorder; inverter 2 powers the tape recorder.

---

*Servo Reference Frequency of 100 kHz signal

4. DESIGN CONSIDERATIONS AND DECISIONS

The following is a summary of the design criterion for the Severe Weather Data Acquisition System. The major design considerations which are stated first are followed by the resultant design decisions

4.1 Operating Frequencies

Design Consideration

The operating frequencies, representatively spaced between 3 and 400 MHz, had to be selected to minimize interference and to obtain samples within the various, unique frequency bands that exist between 3 and 400 MHz. Practical factors also had to be considered. One was that the operating regions of commercially available, high-performance, flight-rated avionics antennas had to be accepted as the project schedule did not allow for the design, development, and approval of special aircraft antennas.

Design Decision

It was decided to choose frequencies in the lower HF band (2-4 MHz), upper HF band (30-40 MHz), lower VHF band, and upper VHF band.

Three switch-selectable frequencies were chosen for operation at lower HF. 2.2, 3.2, and 4.2 MHz. During the daytime hours, quiescent atmospheric noise is low within this frequency range; there is a very pronounced noise minima [1] between 2 and 3 MHz during the daytime hours which considerably enhances the ability to detect weak sferics signals originating from local storm cells. In addition, in this frequency region during daytime hours, ionospheric absorption is high and thus reduces the possibility of interference from long-range signal sources.

Also, the NOAA Tornado Detection Unit operates at a frequency of 3.16 MHz, and there was a desire to obtain sferics data at a frequency close to 3.16 MHz.

---

[1] "Reference Data for Radio Engineers," Fourth Edition, Federal Telephone and Radio Corporation, p. 763.

Three separate lower HF frequencies were chosen to minimize the probability of interference, and they were placed at discrete frequencies where no major activity exists, e.g., the standard WWV frequency at 2.5 MHz and the radio amateur band from 3.5 to 4.0 MHz were avoided.

Four switch selectable frequencies (31.2, 33.5, 35.5, 37.5, and 39.5 MHz) were chosen for underline upper HF operation. Above about 30 MHz, ionospherically propagated signal effects are nil, and atmospheric noise is not a major factor; therefore, the ambient conditions are quite different from those in the lower and middle HF band. Also, these frequencies have been allocated for radio astronomy usage and should be relatively free of interference. Further, these frequencies are just slightly above the Citizens Band allowing for the use of a commercially-available avionic CB antenna which could be shortened in order to establish a resonant condition in the 30 to 40 MHz range.

139 MHz was chosen as the underline lower VHF operating frequency because it is a dedicated space research frequency and close to the 118 to 136 MHz avionic band. This means that a standard avionics antenna could be used for 139 MHz reception.

295 MHz was chosen as the underline upper VHF frequency because it is quite close to the maximum upper tuning range for commercial VHF receivers and is located in a relatively quiet portion of the 225 to 300 MHz military avionics band.

4.2 Sensitivity

Design Consideration

The receivers in the Severe Weather Data Acquisition System had to be able to detect the expected sferics signal levels at the ranges of interest. A major parameter influencing sensitivity was the exceptionally wide IF bandwidth required (600 kHz) in order to obtain a 300 kHz baseband bandwidth.

Design Decision

Required receiver sensitivities are a direct function of the anticipated amplitude of the sferics signal at the receiver inputs. A literature

survey was performed to define the anticipated amplitudes at the selected operating frequencies and specified ranges. Overall, this search disclosed that definitive data on sferics amplitudes are sparse and, in general, must be extrapolated from test results obtained under specific conditions.

In general, it appears that sferics amplitudes lie in the 1-100 V/m range in the lower HF regions for severe weather conditions and decrease approximately as the reciprocal of frequency. Imyanitov [2] states that, at lower HF, the amplitude at a distance of 100 km can vary from 1 to 50 V/m. Taylor's data [3] indicate signal strengths in the order of 3 V/m at 3.16 and 10 MHz at distances of 30-100 km from severe storm cells. These data were obtained from ground-based facilities. Unfortunately, there have been very few airborne observations of sferics activity from severe storms. In fact, no mention of HF/VHF airborne experiments have been found in the literature; therefore, sferics levels in free-space above the earth "ground plane" are somewhat speculative. Indeed, the "free-space" levels may differ considerably from levels obtained on the surface of the earth above a "good" ground plane.

For design purposes, the following representative minimum sferics levels were postulated:

Frequency (MHz)	Sferics Level (V/m)
3	1
30	0.1
139	~0.02
295	~0.01

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[2] Imyanitov, I. M., et al., "Instrument for Detection of Close Thunderstorms," Metrological Equipment for Scientific Research, 1972, pp. 46-67.

[3] Taylor, W. L., "Review of Electromagnetic Radiation Data from Severe Storms in Oklahoma During April 1970," U. S. Department of Commerce, NOAA Technical Memorandum ERL-WPL-6, June 1971.

It should be noted that the above sferics levels greatly exceed the anticipated ambient noise levels [1]; and, hence, performance should not be externally-noise limited.

Calculations of received power for each frequency were made based on the above sferics levels and the characteristics of the airborne antennas. All of the airborne antennas were assumed to be resonant (50 ohms terminal impedance) except for the stub antenna used at the lower HF frequencies, which was treated as an electrically-short antenna with an effective electrical length of 0.1 meters. The resonant 30 MHz stub antenna was also assigned an effective length of 0.1 meters, and 0.2 meters was used as the effective length for the 139 MHz and 295 MHz antennas.

Based on the above conditions, the following sferics levels at the receiver inputs (assumed 50 ohms) were calculated:

Frequency (MHz)	Input Power (dBm)	Receiver Threshold Sensitivity (dBm)
3	−48	−67
30	−27	−70
139	−41	−92
295	−47	−92

The above indicates that the receiver sensitivities should be adequate for sferics detection based on the stated assumptions. It should be stressed that information on HF/VHF sferics levels in an airborne situation is virtually non-existent, and some prejudgements have been made concerning the nature of the phenomena which may or may not be correct.

4.3 Dynamic Range

Design Consideration

The Severe Weather Data Acquisition System had to have the dynamic range to accommodate the anticipated amplitude variations of the sferics signals within the range of interest and over the operating bandwidth.

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Design Decision

        Sferics dynamic range is another characteristic that is, in general, ill-defined; however, Taylor [4] does present a definitive statement as directly quoted below:

> "The total dynamic range of amplitude necessary to observe 90 percent of the impulses radiated during a lightning discharge over the frequency band from 10 kHz to 100 MHz and for distances extending to 100 km at greater than 2 degree elevation above the horizon is about 100 dB. This can be reduced in practice to about 50 dB by using separate equipment for different frequency bands and discarding the very small impulses at the greater ranges."

Conventional superheterodynes and TRF receivers can handle a 50 db dynamic range; however, a 25 to 30 dB dynamic range is the maximum capability of most wideband magnetic tape recorders. Hence, video logarithmic amplifiers with some 60 dB of dynamic range were used between the receiver video outputs and the tape recorder in order to accommodate the expected dynamic range.

Another design decision was to operate the receivers in a non-AGC mode and control any receiver overload conditions encountered via switchable RF attenuators between the antennas and the receivers.

4.4 Polarization Diversity

Design Consideration

        A decision had to be made as to which frequencies would have polarization diversity--vertical and horizontal.

Design Decision

        It was decided to provide both vertical and horizontal polarization for the VHF frequencies and vertical only for the HF frequencies.

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[4]Taylor, W. L., "Atmospherics and Severe Storms," Chapter 17 of Remote Sensing of the Troposphere, edited by R. E. Derr, August 15, 1972, Supt. of Documents, U. S. Govt. Printing Office, Washington, D. C.

This decision was based on the belief that polarization diversity with the electrically-small HF antennas would not be as meaningful as polarization diversity with the resonant VHF antennas. Also, it was anticipated that the VHF sferics signal levels may be smaller than the HF levels and that dual polarization may help in the reception of weak signals.

One antenna - a blade - was used for VHF vertical reception; another - a split loop - was used for VHF horizontal reception. Diplexers separated the VHF frequencies at the antenna outputs.

4.5 Receivers

Design Consideration

A "buy or build" decision had to be made relative to the sferics receivers. It was highly desirable to buy commercially available receivers - if possible - due to the limited time available for design and development. Major factors in the choice of receiver were the bandwidth, sensitivity, and dynamic range requirements. The exceptionally wide bandwidth (600 kHz) requirement was the major consideration.

Design Decision

A comprehensive review of commercially available HF/VHF receivers was performed. No suitable wideband HF receivers were found; therefore, it was decided to adapt an available Georgia Tech sferics HF receiver design for the Sferics Analyzer application. It was decided to use a tuned radio frequency (TRF) approach with frequency selection via switchable bandpass filtering directly at the RF input. Georgia Tech's experience with HF sferics reception, as well as the experience of other investigators, indicated that TRF receivers would be satisfactory for HF sferics reception, and that the sensitivity of a superheterodyne receiver was not required. (Here again it should be noted that essentially all experience was obtained from ground-based monitoring on the earth's surface, which could support and propagate surface waves.)

Commercial units were chosen for use at VHF. These are Watkins-Johnson Type WJ-8730 and WJ-977 units operated at a nominal IF bandwidth

of 3 MHz. It was determined that these units had adequate sensitivity, dynamic range, and tuning.

4.6 Signal Processing

Design Consideration

The type and degree of signal processing between the receiver outputs and the magnetic tape recorder was another design decision. The basic requirement here was simplicity with adequate processing for proper interfacing between the receiver and recorder.

Design Decision

Post-video processing was used to prepare the receiver video signals for magnetic tape recording. This circuitry consisted of logarithmic and linear video amplifiers for each receiver and buffer impedance matching amplifiers prior to the tape recorder inputs.

The VHF receivers were provided with 300 kHz low-pass filters directly at the video output ports prior to the log/lin amplifiers.

The dual log-lin amplifier capability was included to accommodate the full anticipated dynamic range of the sferics signals.

4.7 Tape Recorder

Design Considerations

The basic requirements for the magnetic tape recorder were:
(1) both FM and DIRECT record capability with DIRECT bandwidth to 300 kHz,
(2) fourteen-channel capacity, (3) voice log capability, (4) adequate record time, (5) low and high input impedance for both FM and DIRECT,
(6) selectable tape speed, (7) capable of operating from 28V DC, (8) low-weight volume for airborne usage, and (9) standard IRIG bandwidths for both FM and DIRECT.

Design Decision

The specifications of a number of commercial portable instrumentation recorders were reviewed in some detail. It was found that the performance characteristics for all candidate recorders are quite similar;

however, after considerable comparison and evaluation, it was decided to use an AMPEX PR-2200. Major factors were (1) excellent operability, and (2) similar recorders were used in Skylab with exceptional reliability. Further, a PR-2200 demonstrator was evaluated for several weeks, and excellent performance was observed.

4.8 Operating Format

Design Consideration

This consideration dealt with the magnetic tape recorder channel assignments and the type of recording – either DIRECT or FM – depending upon the specific bandwidths and structures of the signals being recorded.

Design Decision

The HF receiver's linear and logarithmic video outputs were recorded in a DIRECT mode on Channels 1 through 4. The VHF linear videos were recorded DIRECT on Channels 5 through 8. Logarithmic VHF video outputs were available, if needed; however, it was thought that the VHF sferics signal would have limited dynamic range and that linear video recording would be sufficient. This proved to be true.

DIRECT recording was employed for the sferics video in order to obtain the full bandwidth capability of 300 kHz at 60 ips. (Maximum FM bandwidth was 40 kHz.) The very low (100-300 Hz) frequency components are not passed in the DIRECT mode; however, this is not a significant factor since the post-recorder signal processing contains AC coupled video circuitry with a low frequency roll-off in the order of 100 Hz.

The tape timing information (WWVB time code and 10 kHz time marks) were FM recorded in order to preserve the DC baseline reference level.

The internal servo reference frequency was recorded DIRECT since it is 100 kHz at 60 ips and proportionally lower at the lower tape speeds.

The specific signal structure of the Lightning Stroke Detector outputs (linear and logarithmic) required DIRECT record capability whereas FM record was used for the NOAA Tornado Detector Unit.

The voice log used an edge track; therefore, all fourteen data channels could be devoted to the sferics and timing information.

5. SUMMARY OF TECHNICAL AND OPERATIONAL CHARACTERISTICS

Receivers

Six sferics receivers, a WWVB receiver, a Lightning Stroke Detector, and a Tornado Detector. Nominal receiving frequencies as below:

Lower HF: 2.2, 3.2, 4.2 MHz selectable

Upper HF: 31.2, 33.5, 35.5, 37.5, 39.5 MHz selectable

Lower VHF: 139 MHz

Upper UHF: 295 MHz

Lightning Stroke Detector: VLF/LF

Tornado Detector: 3.16 MHz

Polarization

Vertical: HF

Vertical and Horizontal: VHF

Vertical: Lightning Stroke Detector

Vertical: Tornado Detector

Typical Threshold Sensitivities (as measured at RF distribution Network Input)

Lower HF: −67 dBm

Upper HF: −70 dBm

VHF: −92 dBm

UHF: −92 dBm

Receiver Equivalent Bandwidth

600 kHz all channels for Sferics Receivers

300 kHz for Tornado Detector

Dynamic Range − Sferics Receivers

Typically 50 dB with linear video amplification

Typically 60 to 70 dB with logarithmic video amplification

System Impedance Level

50 ohms

Video Outputs - Sferics Receivers

Linear and logarithmic at nominal record level of 2 volts (peak-to-peak).

Maximum Record Bandwidth Capability (60 ips)

Direct: 300 Hz to 300 kHz

FM (Wideband Group I):   DC to 40 kHz

Record Time (60 ips)

Approximately 12 minutes with 3600 feet, 1" tape

Timing

WWVB IRIG H time code. 10 kHz time marks. Note: On some tests servo reference frequency signal was recorded instead of 10 kHz time marks. The servo reference frequency is 100 kHz at 60 ips and proportionally lower at lower tape speeds.

Power Consumption

Approximately 600 watts from 28 volt DC power source.

Weight

Approximately 400 pounds.

6. SUMMARY OF FIELD OPERATIONS

6.1 Midwest Airborne Tests - 1975

In mid-April 1975 the research instrumentation was transported to
Ft. Collins, Colorado, and installed and checked-out in the test aircraft,
which is owned and operated by Colorado State University, Department of
Atmospheric Sciences. The test aircraft also contained instrumentation
for meteorological observations of severe weather.

Specific efforts associated with the installation activity included
the following:

(1) Aircraft center of gravity computations were made for various
physical placements of the equipment; careful attention was
given to proper weight distribution of the aircraft.

(2) Modifications to the equipment were performed in order to meet
certain specific FAA requirements. For example, all of the
conventional three-prong AC connectors were changed to MS-
connectors in order to meet desired FAA practices for airborne
research equipment operated in an oxygen environment. Also,
certain modifications were made to wiring which carries large DC
currents.

(3) The instrumentation was calibrated and aligned in the aircraft
using RF signal injection at the antenna output terminals.
Georgia Tech assisted the University of Arizona and NOAA personnel
in the alignment and calibration of their equipment.

(4) Test flights were performed to evaluate the instrumentation
performance in an actual operational situation.

(5) Operator training was performed both on-the-ground and airborne.

During April and May, 1975, Georgia Tech personnel flew flight tests
in the Midwest. Missions were performed in Texas, Kansas, Colorado,
and Missouri. Approximately fifteen man-days were devoted to this effort.
Considerable experience and familiarization with the instrumentation
performance were obtained on these early missions.

Flight tests and data collection were performed at altitudes varying
from 6K to 18K MSL depending upon the specific cell build-up conditions

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and other meteorological characteristics. The cell towers were "boxed-in" by the test aircraft at a distance of approximately 2 to 5 kilometers. In some cases U-patterns and race-track-patterns were used rather than a complete box pattern when it was deemed infeasible - from a safety view-point - to fly a complete closed course around the cell tower. Nominal aircraft ground speeds were 150 to 180 knots.

The Midwest tests were part of a large, coordinated effort involving numerous aircraft and a variety of experiments probing the severe storm cells at different altitudes.

6.2 Kennedy Space Center, Florida, Airborne Tests - 1975

During June and July, 1975, the airborne operation moved to the Kennedy Space Center, Florida, where data were obtained on severe, convective, air-mass thunderstorms occurring over - or very close to - KSC.

During this time period, numerous airborne experiments were performed by other researchers studying the electrification of thunderstorms. These airborne experiments were supported by a considerable amount of ground-truth data such as the KSC weather radar, the ground electrical field mill network, and the lightning detection network.

These experiments, which were conducted prior to the Apollo-Soyuz launch, were designed to allow KSC personnel to more accurately predict lightning hazard during a launch.

The major effort occurred from 23 June 1975 to 10 July 1975. A total of six data collection missions were flown by the test aircraft on thunderstorm activity. One mission was conducted on the ground when a very large and severe thunderstorm occurred directly over Patrick Air Force Base where the aircraft was stationed. Another mission was flown in the early morning with no electrical activity from severe weather in the area in order to obtain "reference" tapes. A total of twenty-eight (28) magnetic tapes were obtained during the KSC tests. Tornadoes occurred during the flight tests of 28 June 1975 - approximately two hours of data were obtained in this mission.

The operational procedure was to box-in the cell towers at altitudes ranging from 2K to 14K feet MSL while maintaining a distance of roughly

2 to 5 km from the edge of the cell build-up. Typical aircraft ground speed was 150 knots.

In addition to obtaining a considerable amount of severe weather sferics data, the KSC tests conclusively demonstrated the value of having an experienced observer on board the aircraft during data collection. Detailed logs of visual observations were maintained affording a more complete and meaningful interpretation of the recorded data.

6.3   Georgia Ground-Based Tests - 1975

In late July, ground-based data collection began from a fixed site (the GIT Cobb County Test Site) in a semi-rural area some 26 km from the Georgia Tech campus. Figures 8 and 9 show views of the monitoring installation. Emphasis was on obtaining data on convective, air-mass thunderstorms occurring over or near the test site.

Supporting ground-truth data were obtained from the Georgia Tech weather radar on the Tech campus; the GIT Sferics DF Network, the NWS weather radar at Athens, Georgia, and the NWS weather wire.

The Georgia Tech weather radar provided data on individual cell location (azimuth and range), cell heights (ft. MSL) and cell frontal movements as well as general build-up conditions within 165 km of Atlanta, Georgia. The GIT radar was located relative to the monitoring site such that excellent resolution of thunderstorm structures over and near the monitoring site could be acquired.

The GIT Sferics DF Net provided data on sferics (2.88 MHz) burst rates and DF strobes on the electrically-active cells. One station was co-located with the sferics monitoring van; another was on the GIT campus; and a third, which was activated in early September, was located on the University of Georgia campus at Athens, Georgia, and operated by University of Georgia personnel.

The NWS weather radar data consisted of long-range (200 km or 400 km) PPI scope photographs acquired every ten minutes during periods of significant precipitation. These photographs provided excellent assessments of the large-scale, meteorological conditions existing within 160 to 320 km of the monitoring location.

The NWS weather wire provided detailed data on weather prediction and forecasts, and synoptic observations of surface and upper air conditions [temperature, dew point, cloudiness (amount, type, height), wind direction and speed, current weather, pressure tendency, and amount of precipitation]. Using the NWS weather wire data, we could obtain valuable test data such as freezing altitudes and the extent of weather activity.

The general procedure was to begin periodic monitoring of weather conditions during the morning. If conditions appeared favorable for weather to develop with electrical activity, continuous observations of the weather wire, the GIT radar, and the Sferics DF Net began around noon. When severe weather developed, sferics data collection began at the Cobb County Test Site and at the ground support facilities. The primary objective was to collect data for thunderstorms either over the test site or in the immediate vicinity.

Data collection was performed on August 5, 12, 18, 19, and 26 and September 10, 11, and 12. The passage of Hurricane Eloise on 23 September was also monitored. A total of twenty-three (23) data tapes were obtained during eight days of data collection.

On August 5 and 26, an excellent set of data were obtained on the life-cycle of single, isolated, severe convective thunderstorms which grew, matured, and dissipated very close (several kms) to the test site. These were classified as severe thunderstorms with heavy precipitation, high winds, some hail, and cloud-to-ground lightning. On August 26, there was an unconfirmed report of a tornado about 10 km west of the test site.

On August 18 and 19, the major sources of sferics activity were electrically active cells some 95 km from the test site. Sferics activity was relatively light.

On August 12, the GIT and NWS radars showed no build-ups or precipitation within 175 km of Atlanta. Sferics activity was very light, and no sferics DF strobes were observed. Data were collected at the test site in order to obtain "quiet", reference tapes indicative of the quiescent noise level existing on summer afternoons with no electrical activity within monitoring range.

The September 10, 11, and 12 data were related to cold front activity in North Georgia. A weak cold front moved through North Georgia on September 10 accompanied by widely scattered cell build-ups. All active cells were within 55 to 95 km of the test site, and slight-to-moderate sferics activity was present. On September 11, a weak cold front was situated over South Georgia and a very strong cold front over middle Tennessee. Therefore, North Georgia was under relatively unstable meteorological conditions, and wide-spread cell build-up was noted by mid afternoon. Numerous cells developed but none had tops exceeding the freezing level, and sferics activity was very light even though considerable precipitation existed.

On September 12, the strong cold front moved through North Georgia. The sferics data recorded pertain primarily to a severe thunderstorm which formed near the test site, matured, and moved to the East as a part of an extended squall since associated with the frontal passage.

Data summary reports were prepared for each of the ground-based observations and included the following:

(1) Summary of Test Conditions

(2) Tape Log and Summary

(3) Log of GIT Weather Radar Parameters

(4) Log of Visual Observations of Meteorological Activity

(5) Sferics Burst Rate and DF Data

(6) Edited NWS Radar Photographs

(7) Summary of Meteorological Conditions

To summarize, the Georgia ground-based monitoring produced sferics data on a wide variety of thunderstorm activity along with a considerable amount of radar and sferics supporting ground-truth data.

6.4 Midwest Airborne - 1976

The Spring of 1976 produced only a small amount of severe weather activity in the midwestern part of the United States. The majority of severe weather that did occur generally consisted of isolated storms

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rather than the large systems that often occur in this part of the country. Because of this irregular weather pattern, it was difficult to schedule the severe weather airborne missions, and as a consequence data were obtained on only two storms during the entire experiment period. The two airborne missions took place on concurrent days during the early part of June.

On 11 June the first airborne mission was conducted over North and South Dakota. This storm produced moderate sferics activity on the 3 and 30 MHz channels and very light activity on the VHF channels. The aircraft flew a number of box patterns in clear air on the west side of the storm at an altitude of 15 thousand feet. It was observed by other aircraft participating in the experiment that the cloud tops did not exceed 40 thousand feet. A total of six (6) data tapes were obtained during the course of this airborne mission.

On 12 June the second airborne mission was conducted over Minnesota in an area between the cities of Alexandria and Redwood Falls. The sferics activity during this period was significantly greater than that which occurred the previous day over North and South Dakota. The majority of the sferics activity was again on the 3 and 30 MHz channels with moderate to light activity on the VHF channels. The majority of the data were obtained with the aircraft again at an altitude of 15 thousand feet. A total of eight (8) data tapes were obtained during this mission.

6.5 Kennedy Space Center, Florida, Ground-Based Tests - 1976

During the period between 3 July and 19 July a ground-based field experiment was conducted at the Kennedy Space Center, Florida. This field operation was a part of the total Thunderstorm II project which consisted of a number of Principal Investigators from the atmospheric electricity community with each Principal Investigator conducting experiments related to his area of expertise. The primary objective of the Thunderstorm II program is to develop a better understanding of the structure, dynamics, and physical nature of thunderstorms.

The Georgia Tech/NASA role in this project consisted of obtaining ground-based sferics data at HF and VHF frequencies with the same instrumentation that was used during the Midwest airborne experiments. The instrumentation was mounted in a Georgia Tech owned van and driven from Atlanta to the Kennedy Space Center. At the Kenneay Space Center the van was located at camera site UCS-12 and all data were obtained from that location.

A number of large convective type thunderstorms occurred during the experiment period, and a total of twenty-two (22) reels of magnetic recorded data were obtained.

7. COMMENTS ON INSTRUMENTATION PERFORMANCE

The following are comments relating to the performance of the 1975 instrumentation package which could be improved.

It was determined that the efficiency of the airborne HF antennas should be improved. Additional tuning and matching are highly desirable, and it is recommended that a long-wire antenna be used in place of the lower HF stub antenna.

Operation of the WWVB timing system was intermittent during the flight tests and was a function of aircraft orientation. Signal drop-out occurred; therefore, it is recommended that future airborne timing be accomplished by internal digital clocks synchronized to a standard time transmission on the ground prior to a flight test. Ground-based timing reception in North Georgia was satisfactory.

External interference to the instrumentation receivers occurred at times for both airborne and ground-based tests with the most interference at HF. However, it was possible to find at least one interference-free channel on any given test. VHF transmissions from the test aircraft created a considerable amount of interference to each HF/VHF receiver. This was alleviated by exercising close control over the number and duration of the aircraft transmissions. Fortunately, no interference from the aircraft pulse doppler radar was observed.

Corona and P-Static interference were present for short periods of time, especially during airborne tests. However, the effects were of short-duration and very discernible to the airborne observer who noted the time period when the interference was present.

The size, weight and form factor of the airborne unit proved to be somewhat excessive. For future airborne experiments it is recommended that the equipment be reconfigured and the equipment cabinets be replaced with open-framing for size/weight reduction.

Prior to the start of the 1976 field operations, a number of system improvements and modifications were made to alleviate the problems mentioned above. A discussion of these improvements is contained in Appendix C.

8. CONCLUSIONS

Research instrumentation for detecting and recording electromagnetic emissions from severe weather has been designed, developed, and operated from airborne and ground-based facilities. The instrumentation receives HF and VHF emissions and records the detected sferics signals along with pertinent timing and test condition information. A Lightning Stroke Detector, developed by the University of Arizona, and a Tornado Detection Unit, designed by NOAA/ERL are integrated into the instrumentation package.

The initial capability of the instrumentation was demonstrated on numerous airborne flight tests in the Midwest U.S.A. and at the Kennedy Space Center and by ground-based monitoring in North Georgia during 1975. The airborne tests disclosed that improvements in system timing, HF antenna efficiency, and interference reduction were needed in order to optimize performance.

Approximately 16 hours of sferics data tape recordings were obtained from tests on a wide variety of severe weather phenomena during the 1975 experiment period.

Some problems and inadequacies were noted in the severe weather instrumentation system during the course of the 1975 field operations. These inadequacies were related to both data collection problems and to the physical compatibility of the instrumentation package with the aircraft environment. As a result, a number of modifications were made to the instrumentation system prior to the start of the 1976 experiment period for the purpose of improved operational performance.

During the 1976 field operations, airborne experiments were conducted in the Midwest and ground-based experiments were performed at the Kennedy Space Center, Florida. Approximately 13 hours of sferics data tape recordings were obtained during the course of these field operations.

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APPENDIX A

DESCRIPTION OF GIT SFERICS NETWORK
AND WEATHER RADAR

GEORGIA TECH SFERICS NETWORK

The Georgia Tech sferics network consists of three identical radio-direction-finding (DF) systems especially designed for the reception, processing and display of sferics emissions from severe weather activity. Each DF system consists of (1) a crossed loop antenna and associated monopole antenna (required for sense resolution), (2) a broadband, fixed tuned, HF receiver operating at a frequency of 2.8 MHz, (3) post detection signal processing to provide pertinent severe weather parameters and, (4) displays in the form of digital readouts and X-Y oscilloscope to provide visual outputs of the severe weather parameters.

In operation, the crossed loop antenna system is located remotely from the DF receiver with coaxial cables used for signal transmission between the antenna and receiver. Antenna mounted preamplifiers are used to provide RF gain and a low impedance driving source for the coaxial cables.

The DF receiver and all associated displays are housed within a single equipment enclosure suitable for use as a transportable, table-top unit.

One set of digital displays, which consists of four 8-digit registers, provides a count of the total number of received sferics pulses within a 90 degree sector, with one register assigned to each of the four quadrants. This set of counters can be preset to provide the total number of counts within either a 1, 10 or 60 second time frame or can be operated in a count-accumulate mode.

A second set of digital displays, which consists of three 4-digit registers, provides a readout of the sferics burst rate. The burst rate data is omnidirectional; that is, the receiver does not have the capability of distinguishing between a burst signal arriving from the west, for example, and a signal arriving from the east. Each of the three digital counters are designed to operate at three different levels of received signal field strength. In operation, as a storm approaches the location of the sferics receiver only one of the three digital counters will initially indicate burst count activity. Then as the storm moves closer a second counter will begin to indicate burst count activity; and

finally as the storm moves within close range all three counters will be operable. This set of counters can be preset to provide the total number of counts within either a 10 or 60 second time frame or can be operated in a count-accumulate mode.

The X-Y oscilloscope display is used to provide azimuthal information as to the location of the sferics activity. This directional information is obtained by applying the amplified 2.8 MHz RF signal directly to the X and Y inputs of the oscilloscope. The 180 degree ambiguity is resolved by blanking the oscilloscope display during the incorrect portion of the X-Y display. This sense resolution is achieved by appropriate processing of the monopole antenna signal with the crossed loop signals.

At the present time the sferics network consists of one receiver located on the Georgia Tech campus, a second receiver located at a field site in a semi-rural area of Cobb county (some 26 km from the Georgia Tech campus) and a third receiver located atop the journalism building on the University of Georgia campus at Athens.

Weather Radar Facility

The Radar Division of the Engineering Experiment Station has constructed a weather radar facility atop the Graduate Library on the Georgia Tech campus for the purpose of severe weather research. A 12 x 20 foot area has been partitioned off to house the facility. The partitioned area encloses a teletype weather wire installation, a 4 x 5 foot tracking/plotting board and the operating console for the weather radar.

The teletype is connected to the FAA weather circuit and receives information about general meteorological conditions in the southeastern United States and also weather warning data during times of severe weather. During periods of possible severe weather, the teletype is run and checked on a daily basis. The teletype is operated on a full-time basis during operational alerts.

The plotting board is used to track the movement of thunderstorms over a 165 km radius of Atlanta. The bearing, range and cell top height are recorded on the plotting board for all severe weather cells exceeding a

"t. " height of 30,000 feet. The tracking procedure used allows computation of speed, direction of travel, and time of arrival of severe weather. Additional data, such as azimuth strobes from a sferics radio direction finder network can be plotted and triangulated with the present plotting board arrangement. The dual plotting capability allows radar and sferics data to be compared on a real-time basis.

The weather radar was designed by the Radar Division. Certain features were included for the study of severe weather within a radius of 165 km of Atlanta. The radar can scan in azimuth and elevation simultaneously. The system will receive both the horizontal and vertical backscatter components simultaneously from meteorological targets of interest. The video and/or IF signals from both receive channels can be processed simultaneously or separately, depending on the processing needs.

The primary characteristics of the system are as follows.

Primary System Characteristics

Description	Characteristics
Indicators	PPI, A-scope, Digital Antenna Elevation Readout
Transmitter Power	250 kW
Pulsewidth	2.5 and .5 μs selectable
PRF	Selectable between (250 and 2500 PPS depending on duty cycle)
Frequency	Tunable 8.7 – 9.35 GHz
Antenna Type	4' Paraboloidal Dish
Antenna Gain	39 dB
Beamwidth (3 dB)	1.8°
Feed	Dual mode coupler
Polarization	Transmit vertical, receive vertical/ horizontal simultaneously
Recording Equipment	35 mm and 16 mm scope cameras

APPENDIX B

RECEIVER GAIN CHARACTERISTICS

RECEIVER GAIN CHARACTERISTICS

For the data collection experiments described in this report, the gain of both the HF and VHF receivers were preset to provide video signals of sufficient level to drive the Ampex PR2200 tape recorder. It was necessary to preset the receiver gains for a nominal video output level (based on the expected level of the received sferics signal) because of the difficulty of continuously monitoring all of the receivers and individually adjusting their gains for specific output signal levels. Signal monitoring would have been particularly difficult in the airborne environment.

Gain control for the dual HF receiver is accomplished solely by setting step RF attenuators, whereas gain control for the four Watkins-Johnson receivers is achieved by continuously adjustable RF/IF and video gain controls on each receiver.

For the airborne experiments, the RF attenuators at the inputs to the dual HF receiver were preset for zero attenuation; whereas for the Georgia experiments, the RF attenuators were occasionally set for a 10dB insertion loss as a result of the higher efficiency antenna used in these ground-based operations. The gain controls associated with the Watkins-Johnson receivers were nominally set the same for both the airborne and the ground-based experiments.

Table IB provides a tabulation of the video output signal levels as a function of the input RF signal levels for the dual HF receiver and the four VHF Watkins-Johnson receivers. The video signal levels, as tabulated, are the signal levels applied to the Ampex PR2200 tape recorder. For the dual HF reciever, the tabulated values were obtained with the step RF attenuators set for zero insertion loss. The values tabulated for the four VHF receivers were obtained by presetting the RF/IF and video gain controls to approximately the same positions as used during the course of the experiments. It is important to note, however, that because these gain controls are continuously adjustable that the signal levels tabulated in Table IB can be assumed to only approximate the signal levels obtained during the actual airborne and ground-based experiments.

DUAL HF RECEIVER

FREQUENCY (MHz)	INPUT SIGNAL LEVEL (dBm)	VIDEO OUTPUT SIGNAL LEVEL (VOLTS, PEAK-TO-PEAK)	FREQUENCY (MHz)	INPUT SIGNAL LEVEL (dBm)	VIDEO OUTPUT SIGNAL LEVEL (VOLTS, PEAK-TO-PEAK)
2.2	-80	0.13	31.2	-60	0.30
"	-70	0.46	"	-50	0.51
"	-60	1.75	"	-40	1.35
"	-50	6.00	"	-30	3.70
"	-40	16.50	"	-20	9.20
"	-30	SATURATED	"	-10	SATURATED
3.2	-80	0.058	33.5	-50	0.50
"	-70	0.21	"	-40	1.04
"	-60	0.96	"	-30	3.00
"	-50	3.5	"	-20	8.20
"	-40	11.6	"	-10	SATURATED
"	-30	15.0			
4.2	-80	0.125	35.5	-50	0.38
"	-70	0.34	"	-40	0.96
"	-60	1.40	"	-30	3.20
"	-50	4.60	"	-20	8.20
"	-40	12.50	"	-10	SATURATED
"	-30	SATURATED			
			37.5	-60	0.20
			"	-50	0.42
			"	-40	1.16
			"	-30	3.90
			"	-20	8.00
			"	-10	SATURATED
			39.5	-60	0.19
			"	-50	0.45
			"	-40	1.50
			"	-30	4.70
			"	-20	7.60
			"	-10	SATURATED

TABLE IB.   RECEIVER GAIN CHARACTERISTICS (A)

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FREQUENCY	RECEIVER DESIGNATION	INPUT SIGNAL LEVEL	VIDEO OUTPUT SIGNAL LEVEL	FREQUENCY	RECEIVER DESIGNATION	INPUT SIGNAL LEVEL	VIDEO OUTPUT SIGNAL LEVEL
(MHz)		(dBm)	(VOLTS, PEAK-TO-PEAK)	(MHz)		(dBm)	(VOLTS, PEAK-TO-PEAK)
139	V100	-110	0.24	295	V300	-90	0.12
"	"	-100	0.58	"	"	-80	0.44
"	"	- 90	1.75	"	"	-70	1.55
"	"	- 80	5.20	"	"	-60	5.25
"	"	- 70	15.20	"	"	-50	13.50
"	"	- 60	SATURATED	"	"	-40	SATURATED
139	H100	-100	0.44	295	H300	-80	0.03
"	"	- 90	1.35	"	"	-70	0.08
"	"	- 80	5.00	"	"	-60	0.30
"	"	- 70	15.25	"	"	-50	0.90
"	"	- 60	SATURATED	"	"	-40	3.50
				"	"	-30	8.00
				"	"	-20	11.00
				"	"	-10	SATURATED

TABLE IB. RECEIVER GAIN CHARACTERISTICS (B)

APPENDIX C

INSTRUMENTATION MODIFICATIONS FOR 1976

INSTRUMENTATION MODIFICATIONS FOR 1976

Prior to the start of the 1976 field operations, a number of additions and modifications were made to the severe weather instrumentation system. The purpose of these modifications were primarily (1) to improve the data collection capability and (2) to achieve an instrumentation package that was physically more compatible with the airborne environment than was the original package. Modifications and additions to the instrumentation included: (1) fabrication of an "open-frame" equipment rack specifically designed to contain the instrumentation in such a manner as to facilitate airborne operation; (2) design and fabrication of a calibration oscillator to permit the insertion of signals of known levels in place of the antenna signals: (3) addition of a time code generator/translator and associated WWV synchronizing receiver to provide absolute time-of-year in an IRIG B format for simultaneous recording with the sferics data; (4) design and fabrication of an operator's monitor (includes an oscilloscope) that permits the operator to continuously monitor and control the various system parameters; (5) modification of the four Watkins-Johnson VHF receivers for remote control of the RF/IF gain; and (6) addition of a long wire antenna and a new split loop antenna to the Queen Air aircraft.

Equipment Rack. The equipment rack for the previous year's operation consisted of three (3) individual racks with two of the racks for the various receivers and associated instruments and the third rack for the Ampex PR2200 tape recorder. The standard equipment racks were attached to the floor of the aircraft in an area normally occupied by the passenger seats. The racks were oriented such that all instruments including the tape recorder were facing the aisle. This configuration did not prove to be satisfactory because the equipment protruded into the aisle and caused a considerable congestion and, of major importance, prevented the operator from monitoring or controlling the instrumentation without getting out of his seat (an ill-advised practice in turbulent weather). Operation of the tape recorder, including changing tapes, could not be accomplished with the operator in his seat.

To eliminate this undesirable situation, an "open-frame" equipment rack was fabricated that specifically conformed to the aircraft environment. The rack was designed so that all equipment, excluding the tape recorder and the inverters, was mounted vertically in a "table-top" configuration rather than in the customary horizontal orientation. This arrangement eliminated the aisle congestion and provided for easier viewing and control of the instrumentation by the operator. The Ampex PR2200 tape recorder was mounted directly to the floor of the aircraft at one end of the equipment rack. The operator's position was such that the tape recorder was directly in front of him with the equipment rack behind the tape recorder. This configuration allowed easy access to the tape recorder and simultaneously provided the ability to observe the remaining instrumentation. The operator faced toward the rear of the aircraft. In addition to eliminating the aircraft aisle congestion, use of this open-frame equipment rack also provided some reduction in both weight and volume over the original multi-rack configuration.

Calibration Oscillators. Prior experience with the severe weather instrumentation package demonstrated the need for a technique to relate the level of a receiver video output signal to the level of the RF signal at the antenna terminal. By knowing both the antenna signal level and the gain characteristics of the antenna, the field strength of the received sferics signal could be determined.

The approach to this need was to locally generate a signal of known level which could be substituted for the antenna signal directly at the RF input terminal to the receiver.

The specific signal calibration technique devised for use with the severe weather instrumentation package consisted of having four crystal controlled oscillators with operating frequencies of 3.2 and 37.5 MHz (HF band) and 139 and 295 MHz (VHF band). These frequencies were the operating frequencies of the dual HF receiver and the four Watkins-Johnson VHF receivers.

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The signals from the four crystal controlled oscillators are fed to both fixed and voltage-controlled step attenuators that are series connected. The fixed attenuators reduce the level of the oscillator signals to that approaching the expected level of the antenna signals. The voltage-controlled step attenuators are designed to sequentially reduce the level of the calibration signals in four 10dB steps with a dwell time of approximately 2 seconds per step. As long as the oscillators remain active, this step attenuation process is iterative. In addition to the step attenuation sequence, the oscillator signals are pulse modulated at a frequency of approximately 10 KHz to provide a video output signal which simulates a sferics burst.

The processed calibration oscillator signals are connected to coaxial relays which provide a capability for connecting the RF inputs of the various receivers to either their respective antennas, for normal operation, or to the calibration signals. Operation of the calibration oscillators is accomplished by activation of a switch that is front-panel-mounted on the Operator's Monitor.

In operation, the calibration oscillators would generally be activated at the start and near the end of each reel of magnetic recording tape on the Ampex PR2200 recorder. In addition, if any system changes are performed during the data recording process, the calibration oscillators would be activated for a period of several seconds to re-establish system calibration.

Time Code Generator. For the purpose of correlating the received sferics data with data obtained by other sources on the same storm system, absolute time-of-year is a necessary input parameter to the severe weather instrumentation system. To provide this capability, the original instrumentation system included a LF receiver fixed tuned to WWVB at 60 kHz. Operated by the National Bureau of Standards, WWVB transmits time-of-year information in an IRIG H coded format with an accuracy of 1 part in 10^{11} of the primary standard maintained at Boulder, Colorado.

During field operations with the WWVB receiver, reliable reception of the 60 kHz signal was, at times, not possible. The reception problem was partic-

ularly noticeable in the airborne evironment. Often this important data parameter was not available for simultaneous recording with the sferics data.

Because of the reception problem, a decision was made to use a time code generator which could be initially synchronized to a known standard. The time code generator then maintains the required time-of-year accuracy for an extended period by virtue of its stable internal time base. The instrument selected to fulfill this need was a Datum Model 9300 Time Code Generator/Translator containing an internal time base with a frequency stability of $\pm$ 5 parts in 10^7. Time synchronization is accomplished by use of the "time ticks" derived from the resultant audio output of a receiver tuned to one of the time coded HF transmissions supplied by WWV. Synchronization accuracy of the time code generator is specified at less than $\pm$ 50 microseconds. To provide the required capability for time synchronization, a small superhetrodyne receiver, fixed tuned to WWV on 10 MHz, was designed and fabricated for inclusion in the instrumentation package. The audio output signal from the receiver was made available for connection to the time code generator to achieve synchronization.

The output signal from the time code generator is in a standard IRIG B format and thus is suitable for direct recording on an assigned channel of the Ampex tape recorder.

Operator's Monitor. During the airborne field experiments conducted in the Spring of 1975, it became apparent that a technique was needed whereby the operator could continuously monitor the status of the various elements of the instrumentation system while confined to his assigned seat. As a solution to this problem, an "Operator's Monitor" was designed and fabricated that would present to the operator the various system parameters and also provide the capability for the operator to alter parameters as required.

The Operator's Monitor accepts signals from (1) the dual HF receiver, (2) the four VHF receivers, (3) the NOAA Tornado Detector, (4) the University of Arizona Lightning Stroke Detector, and (5) the time code generator and associated WWV receiver.

System operating parameters are presented in the form of (1) signal strength meters, (2) signal overload indicator lamps, (3) NOAA receiver status lamps, and (4) an oscilloscope display. Two switch selectable meters (one meter for the dual HF receiver and a second for the VHF receivers) provide a relative measure of the peak signal strengths while signal overload lamps are used to immediately indicate an overload condition on any of the receivers. The oscilloscope is a small dual channel unit and is configured with the Operator's Monitor in such a manner that the two vertical inputs to the oscilloscope can be used to monitor, via operator controlled switches, any of the video signals from the various HF and VHF receivers as well as signals from the NOAA and Lightning Stroke receivers and from the time code generator.

Output signals from the Operator's Monitor are (1) receiver gain control signals for the four VHF receivers and (2) the calibration oscillator on-off control.

The Operator's Monitor is self-contained within a small (0.47 cubic feet) instrument case and in the aircraft is mounted atop the Ampex PR2200 tape recorder directly in front of the operator for easy viewing and control

Remote Receiver Gain Control. Prior field experiments using the VHF receivers have been conducted with both the RF/IF and the video gain controls determined by the setting of their respective front panel gain control potentiometers. As a result, repeatability and resetability of the receiver gains by use of these continuously adjustable controls is very difficult. To circumvent this problem, an incremental gain control technique was devised. When the receivers are interconnected with the Operator's Monitor, the RF/IF gain control function is transferred from the receiver to the monitor and the video gain function is removed from the front panel control to a preset potentiometer within the receiver. Because the RF/IF gain control within the VHF receivers is accomplished by use of a variable DC voltage, external or remote gain was easily implemented.

When the VHF receivers are interconnected with the Operator's Monitor, the receiver gains are controlled via four seven-position switches that provide low impedance DC drive voltages to the gain control lines within their respective receivers. The gain control lines are normally driven from a high impedance source within the receiver; thus external connection to these lines from the low impedance source within the monitor automatically disables the internal control. The voltages on the outputs of the seven-position switches are preset to produce a 10 dB receiver gain increment per step.

Antennas-Airborne System. During the 1975 airborne field operations the dual HF receiver and the NOAA receiver were fed from stub antennas mounted atop the fuselage of the Queen Air aircraft. These antennas proved to be very inefficient at HF, particularly for the lower HF portion of the band. Because of this sensitivity problem, the stub antennas were replaced with a longwire antenna prior to the 1975 airborne field operations. The longwire was mounted atop the aircraft fuselage and extended some 18.5 feet from near the top of the vertical stabilizer to a point just to the rear of the cockpit area. A comparison of the longwire antenna to the stub antenna demonstrated an increased sensitivity ranging from 25 dB at the lower portion of the HF band to some 13 dB at the upper HF frequencies. In addition to the dual HF receiver and the NOAA receiver, the WWV receiver that is associated with the time code generator was also connected to the longwire antenna.

In addition to the longwire antenna, the original VHF split loop antenna was replaced with a different split loop antenna mounted in a more suitable location on the aircraft fuselage. The original split loop antenna was mounted at the rear of the fuselage, in a horizontal position, directly under the tail. This mounting position placed the entire loop in proximity to the surface of the aircraft and resulted in a undesirable amount of capacitive loading on the antenna. The new split loop antenna was mounted on the vertical stabilizer of the aircraft, thus removing the capacitive loading effects and providing for improved performance.