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94/183 GHz AIRCRAFT RADIOMETER SYSTEM FOR PROJECT STORM FURY

J. A. Gagliano, J. A. Stratigos, R. E. Forsythe,
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Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

Under

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April, 1980

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

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16. Abstract

A design study was performed to recommend a radiometer design suitable for use in NASA's WB-57F aircraft to collect data from severe storm regions. The design recommended was a 94/183 GHz scanning radiometer with 3 IF channels on either side of the 183.3 GHz water vapor line and a single IF channel for a low-loss atmospheric window channel at 94 GHz. The design study phase of this project was followed by the development and construction of the 94/183 GHz scanning radiometer known as the Advanced Microwave Moisture Sounder (AMMS). The AMMS was packaged to mount on an instrument pallet onboard the WB-57F aircraft. The radiometer scans the scene below the aircraft over an angle of ± 45 degrees with the beamwidth of the scene viewed of approximately 2 degrees at 94 GHz and 1 degree at 183 GHz. The AMMS data collection system consists of a microcomputer used to store the radiometric data on the flight cartridge recorder, operate the stepper motor driven scanner, and collect housekeeping data such as thermistor temperature readings and aircraft time code (IRIG B). WB-57F data flights include: Project SESAME, Florida Thunderstorm, and Winter Snow missions.

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Foreword

This final report was prepared by the Electromagnetics Laboratory of the Engineering Experiment Station, Georgia Institute of Technology under Contract NAS5-23710. The contract was initiated by the Applications Directorate of NASA Goddard Space Flight Center, (GSFC), Greenbelt, Maryland. The contract was administered by J. Larry King of the Earth Observations Systems Division.

The period of performance was 20 September 1976 to 30 April 1980. Report authors are J. A. Gagliano, J. A. Stratigos, J. M. Welch, R. E. Forsythe, J. M. Schuchardt, and D. O. Gallentine.

The views and conclusions in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of NASA/GSFC or the U. S. Government.

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Preface

The primary objectives of this program include: the design, development, and fabrication of a multichannel 94/183 GHz scanning radiometer referred to as the Advanced Microwave Moisture Sounder (AMMS); the integration of the AMMS into the WB-57F aircraft pallet; the airborne collection of radiometric data during the Project Severe Environmental Storms and Mesoscale Experiment (SESAME), the Florida Thunderstorm Mission, and the Winter Snow Mission. Components from previous NASA contracts NAS5-23603 (refer to Georgia Tech Final Technical Report A-1866) and NAS5-24480 (refer to Georgia Tech Final Technical Report A-2132) were augmented by the addition of the following: a microprocessor controlled scanner reflector, onboard hot and cold calibration loads, two solid state Gunn diode local oscillators, X2 subharmonic mixer at 183 GHz, IF matching network for the 94 GHz channel, low noise preamplifier for 5 GHz IF channel, improved video amplifiers/phase sensitive detectors with integrate/dump or low pass filter output selection, onboard dual cartridge recorder with flight data storage capability of up to 12 hours; onboard microcomputer to operate the AMMS unattended throughout the entire flight; and two separate packages (containing the AMMS electronics) designed to integrate into the WB-57F pallet, with one of the packages pressurized to approximately 7.5 psi differential to protect the flight recorder, and both packages are temperature controlled to provide system gain stability and prevent moisture damage to the AMMS during aircraft descent.

In addition ground support equipment was provided to perform three main functions immediately following each data flight: provide a hard copy printout of the day's flight log that includes radiometric minimum and maximum brightness temperatures per channel per scan, system gain for each channel in degrees Kelvin per volt, 94 GHz mixer dc bias current, and critical RF components' operating temperatures; provide a display of four channels of radiometric images (using a color video monitor) of calibrated brightness temperatures for each scan; and perform the transfer of the data from the flight cartridge to a computer compatible nine-track reel-to-reel tape for more detailed data analysis.

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The purpose for the design, development, and construction of the 94/183 GHz multichannel scanning radiometer was to provide an instrument for recording imaged data of the upper atmospheric water vapor concentrations near 183 GHz and lower atmospheric rain near 94 GHz. The sensor was packaged for installation on the instrument pallet onboard the WB-57F aircraft based at Johnson Space Flight Center (JSC) near Houston, Texas. Integration of the AMMS with the WB-57F pallet was accomplished at NASA/GSFC in May 1979. The first data flights on the WB-57F aircraft were on Project SESAME in which data was taken during severe storms over Oklahoma and Texas in June 1979. The Florida Thunderstorm Mission followed in September 1979 during which severe storm data was taken over south Florida for a period of about three weeks. The latest data flights occurred in February 1980 during the Winter Snow Mission in which the radiometer was used for the mapping of rain, water vapor, and snow precipitation.

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1.0 Introduction

The first phase of the program consisted of a design study to recommend a radiometer design suitable for use in NASA's WB-57F aircraft to collect data from severe storm regions. The design study was reported in the June 1977 system design study report (Project No. A-1902) entitled "94/183 GHz Aircraft Radiometer System for Project Storm Fury" prepared for Goddard Space Flight Center under Contract NAS5-23710. The 183 GHz portion of the radiometer was designed to operate on the peak of the atmospheric water vapor line to yield information on the total water vapor content of the atmosphere and clouds. The 94 GHz portion was designed to provide data on the surface brightness temperature and lower level precipitation brightness temperatures. Figure 1 depicts the radiometer channel allocation desired for the measurements.

The design study included recommendations for the critical components and subassemblies for the 94/183 GHz scanning radiometer. Necessary criteria were established for the selection of vendor components. The recommended system included a scanning planar reflector, driven by a microprocessor controller, viewing the scene through a lens antenna. Figure 2 shows the lens mounted in the package with the scanning reflector attached. Antenna design involved the analysis and selection of various candidate lenses and corrugated feedhorns. Alignment of the feed beams at 94 GHz and 183 GHz was designed using a reflecting surface oriented at 45° to permit simultaneous viewing of the feeds on alternate cycles of the chopping intervals. The Dicke chopper approach chosen was a reflective blade driven by a speed regulated motor at high speeds to alternately view the scene and a reference load on successive chops. This chopper design was first implemented during the June 1978 data flights onboard NASA's Convair 990 research aircraft as reported in the January 1979 Final Report (Project No. A-2132) entitled "94/183 GHz Multichannel Radiometer for Convair Flights" prepared for Goddard Space Flight Center under Contract NAS5-24480. Other components utilized on that program

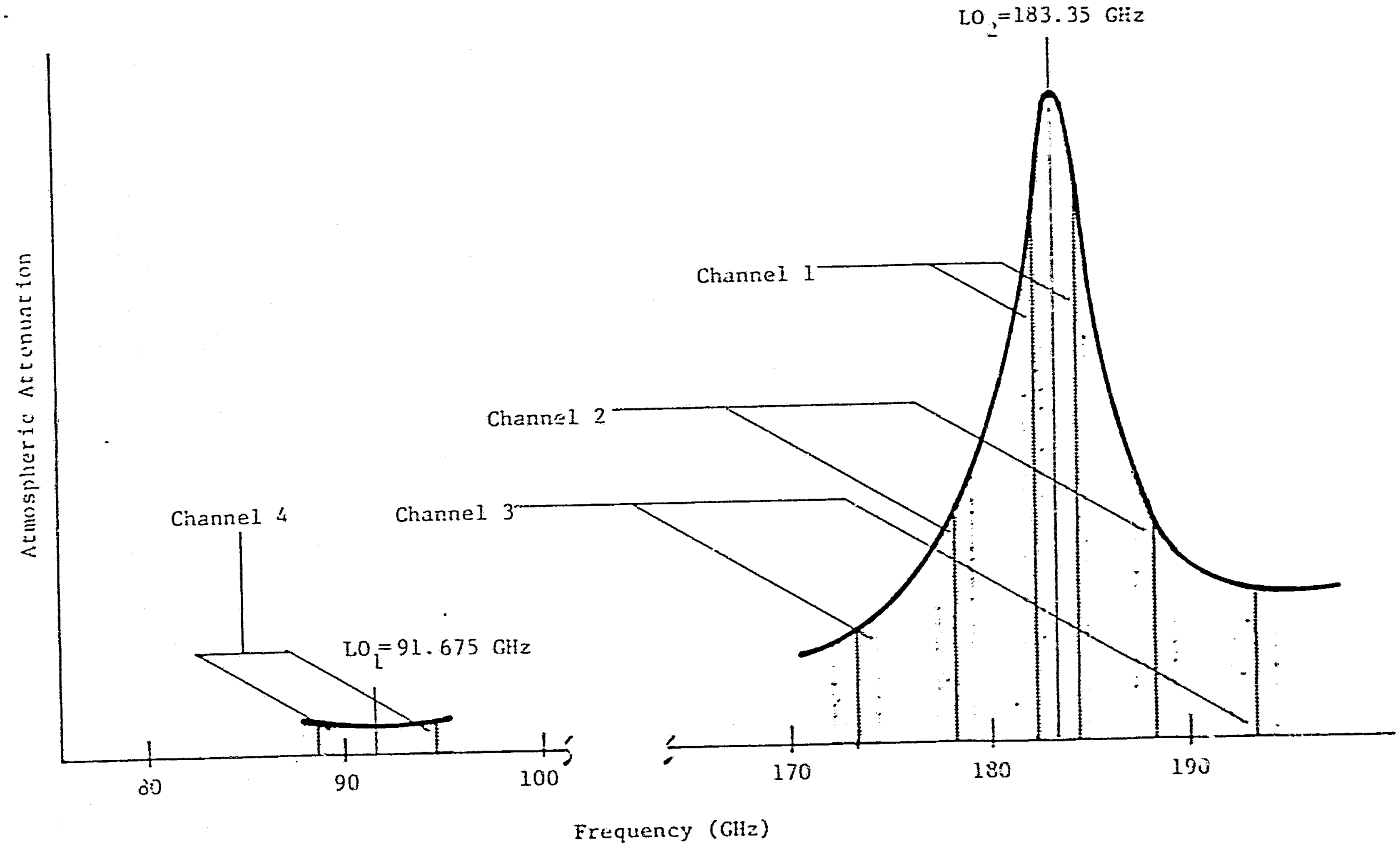


Figure 1. 94/183 GHz WB-57F Radiometer Channel Allocation.

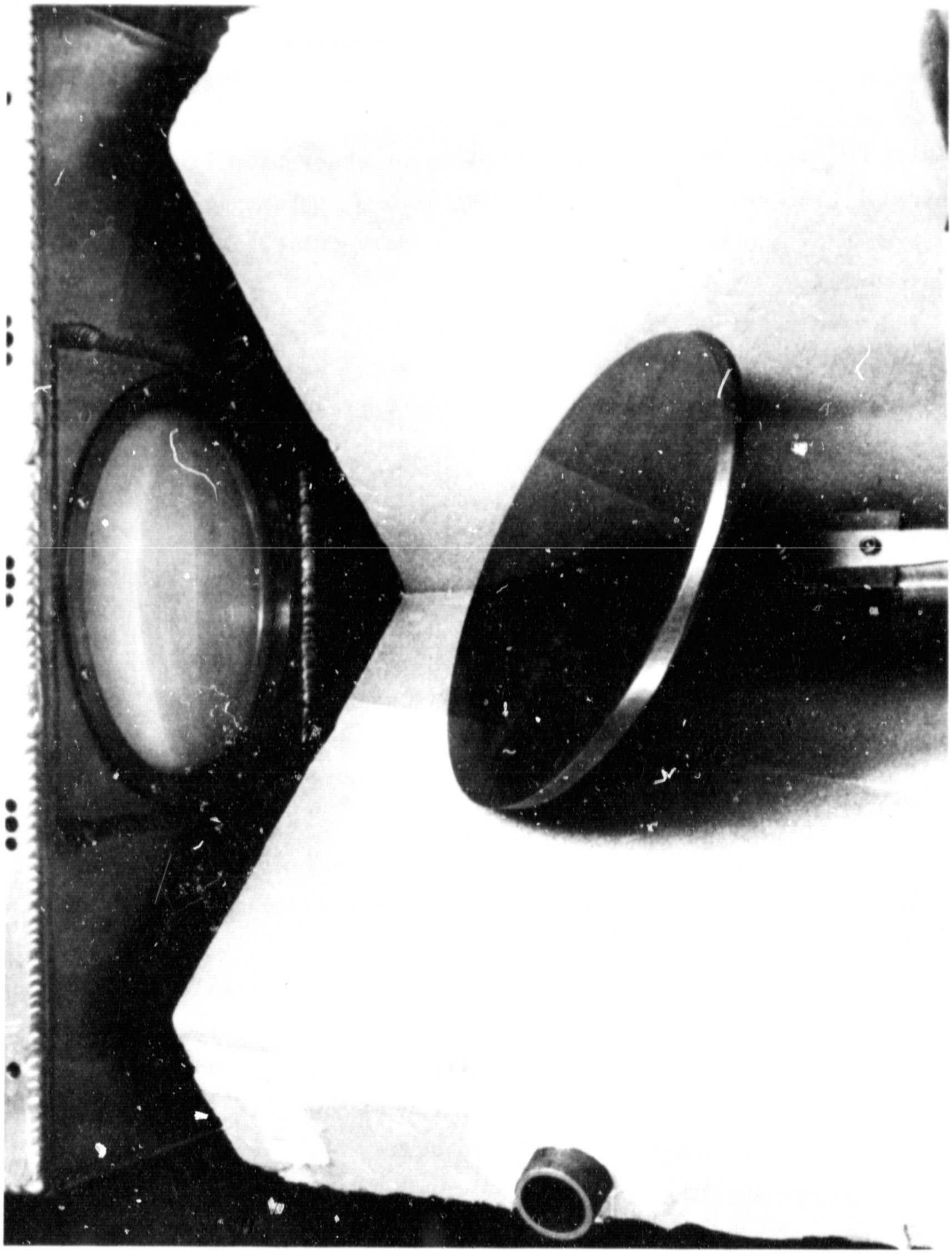


Figure 2. Radiometer Antenna and Scanner Configuration.

included: a split-block mixer at 183 GHz, designed to allow wider IF bandwidths, which was flown on the 1978 Convair 990 flights as well as the WB-57F Project SESAME flights in June 1979; a mixer at 94 GHz using a GaAs Schottky barrier diode mounted in a Sharpless-type mount; a four-port microstrip triplexer with the capability of applying dc bias to the 183 GHz mixer diode; three IF channels at center frequencies of 1, 5, and 8.75 GHz about the 183.3 GHz water vapor absorption line; a single IF channel centered at 2.32 GHz for the 94 GHz system; and expanded microprocessor control and display of the data collected onboard the Convair 990.

The next phase of the program consisted of developing and constructing the 94/183 GHz scanning radiometer known as the Advanced Microwave Moisture Sounder (AMMS). Figure 3 is a block diagram of the system designed to fly on the WB-57F aircraft. Significant improvements in a number of critical areas were implemented during this phase of the program. Additional work above that recommended in the design study report was performed to provide features for improved radiometer performance and for enhanced radiometric data handling during the WB-57F missions. The specific items incorporated in the AMMS include: a X2 subharmonic mixer at 183 GHz having lower losses which allowed an all solid state Gunn diode local oscillator to be used; a new IF preamplifier at 5 GHz to improve the radiometer sensitivity in that channel; an expanded on-board data collection system to permit recording for a full 6 hour flight; and an expanded internal microcomputer to provide totally hands-off preprogrammed operation when airborne (the WB-57F backseat instrument operator now only turns the unit on and off).

Table 1 provides a summary of the radiometer's specifications which were met during the development phase of this program. The AMMS final configuration packaging was designed with the RF and IF systems contained in a single package sharing a common baseplate. The digital electronics were housed in a separate package which was pressurized to protect the digital flight recorder. Figures 4 and 5 are views of the RF and IF components respectively, while Figure 6 depicts the digital package.

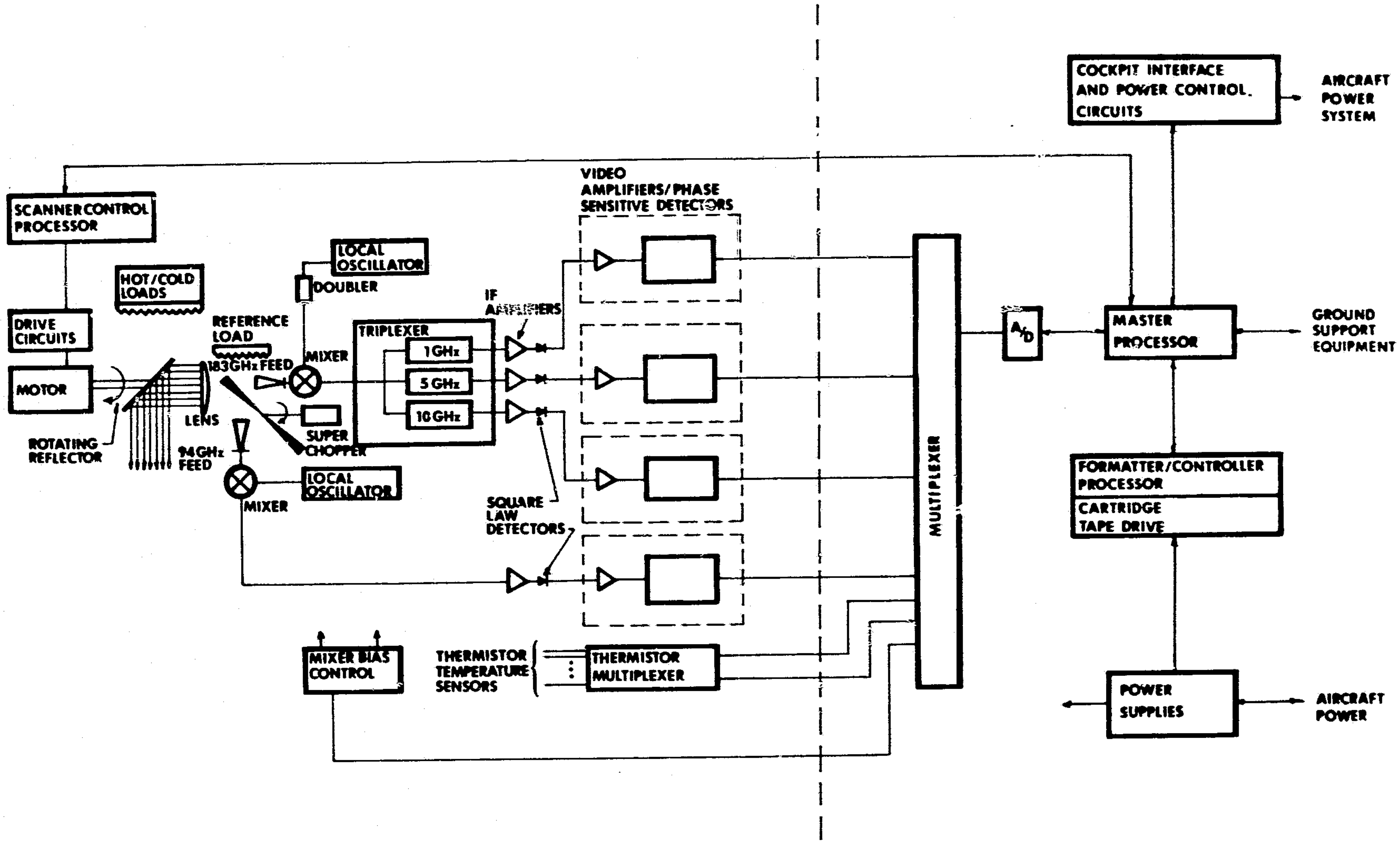


Figure 3. WB-57F 94/183 GHz Radiometer Block Diagram.

Table 1

94/183 GHz RADIOMETER SPECIFICATION SUMMARY
PRIOR TO SEPTEMBER 1979 FLORIDA THUNDERSTORM MISSION

Radiometer Type	Multichannel Scanning Type with Super-Chopper
RF Center Frequencies	94 GHz (93.5 to 94.5 GHz) and 183.3 GHz (173.3 to 193.3 GHz)
IF Bandwidths	
94 GHz:	2.32 $\pm$ 0.50 GHz
183 GHz:	1.00 $\pm$ 0.25 GHz 5.00 $\mp$ 0.50 GHz 8.75 $\mp$ 1.25 GHz
Temperature Sensitivity	ΔT_{min} for 60 msec integration time
Fundamental mixer 94 GHz:	0.5 to 1.0°K at 2.32 GHz IF
Subharmonic mixer 183 GHz:	0.9 to 1.4°K at 1.00 GHz IF 1.1 to 1.6°K at 5.00 GHz IF 2.3 to 3.3°K at 8.75 GHz IF
Fundamental mixer 183 GHz:	1.4 to 2.2°K at 1.00 GHz IF 2.0 to 3.2°K at 5.00 GHz IF 5.2 to 8.2°K at 8.75 GHz IF
Temperature Measurement Range	0 to 500°K
Radiometer Operational Temperature	0 to +50°C
Radiometer Output Scale Factor	50°K/volt or 20 mV/°K
Calibration Mode Duty Cycle	25%
Chopper Switching Rate	350 Hz
Integration Time	15 to 60 msec
Recorded Data Format	ANSII Standard on 3-M 450 Foot Cartridge Tapes
Input Voltage Requirements	115 Vac, 400 Hz
Power Consumption	920 watts, nominal; 1380 watts, maximum
Overall Weight	300 lbs.

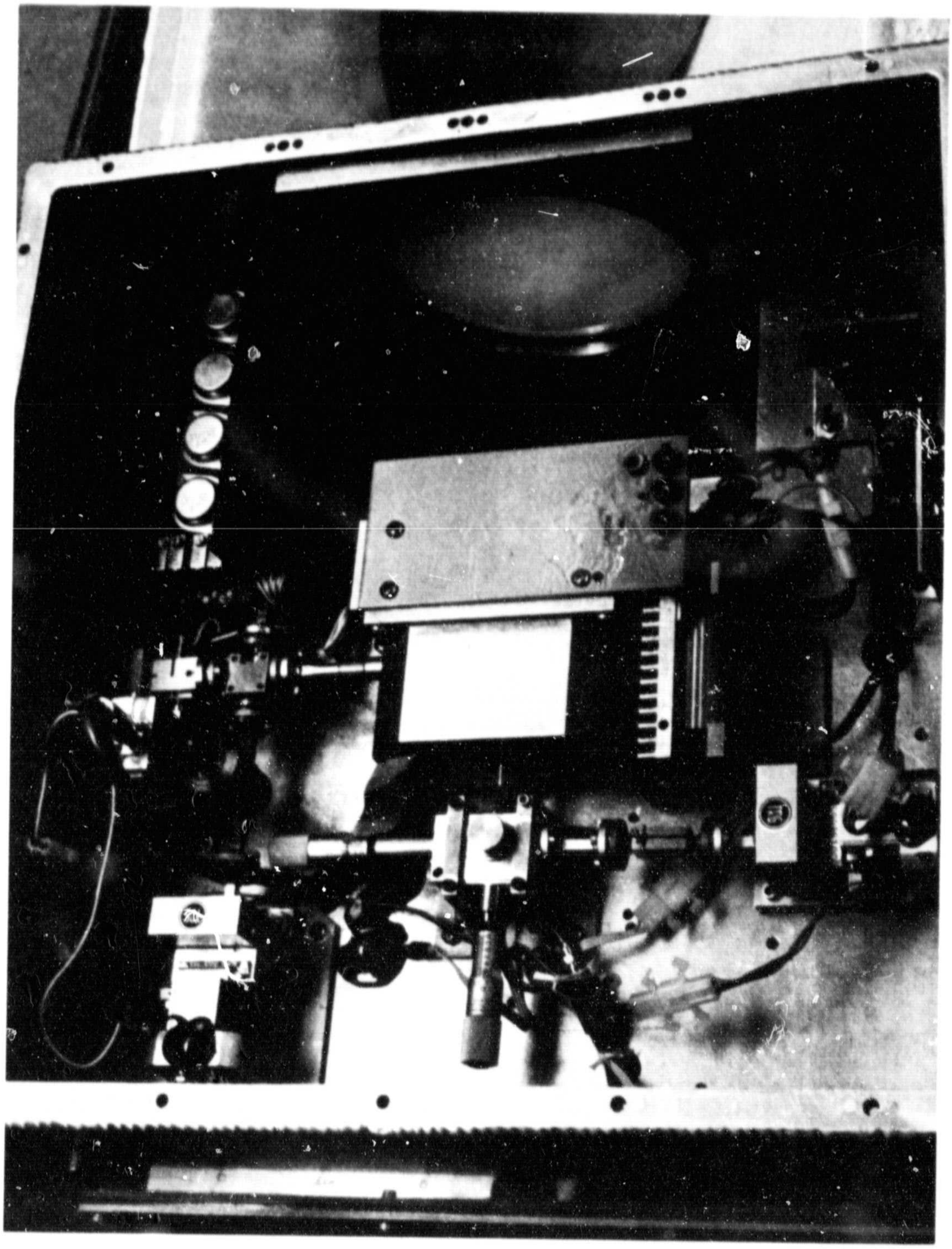


Figure 4. AMMS RF Package Components View.

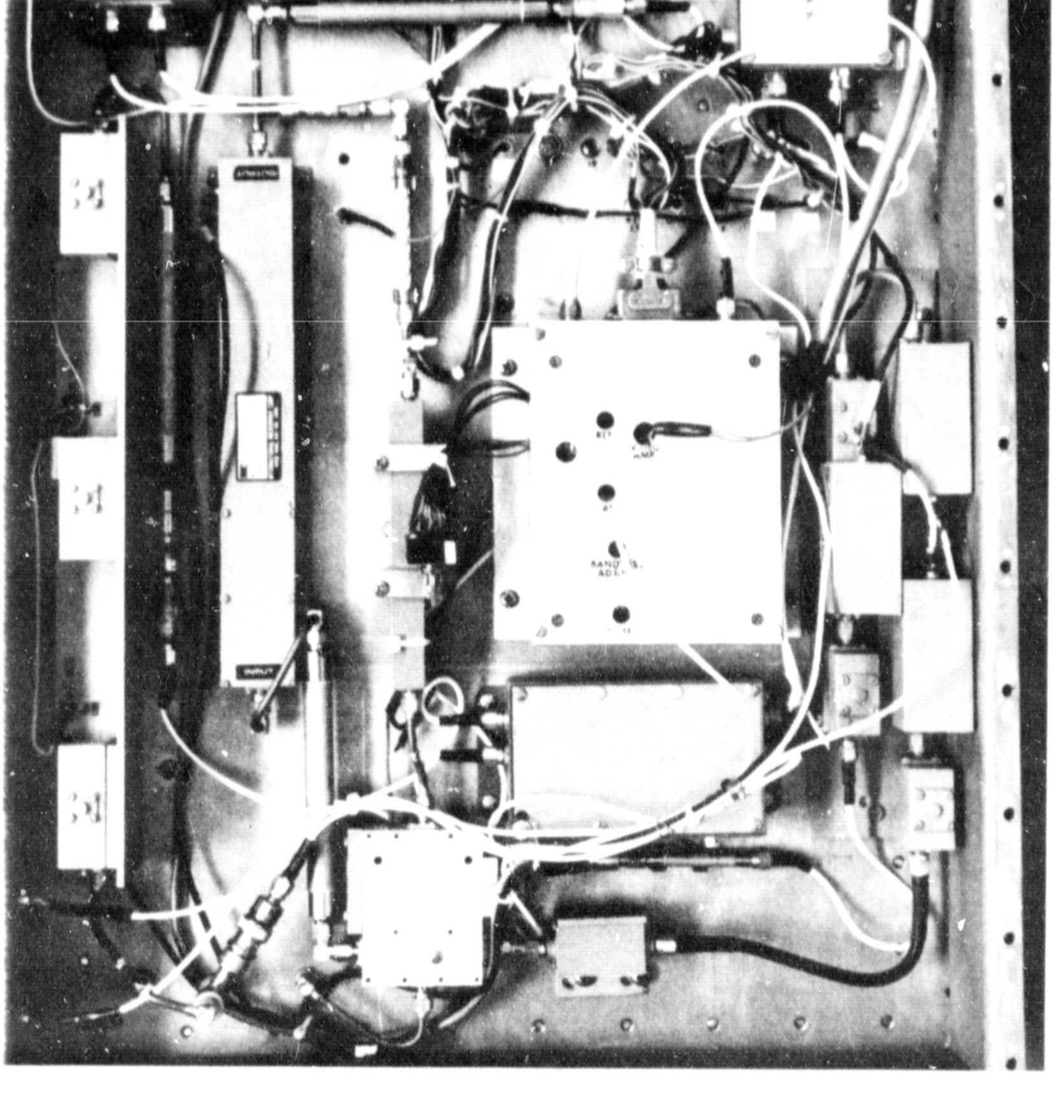


Figure 5. AMMS IF Package Components View.

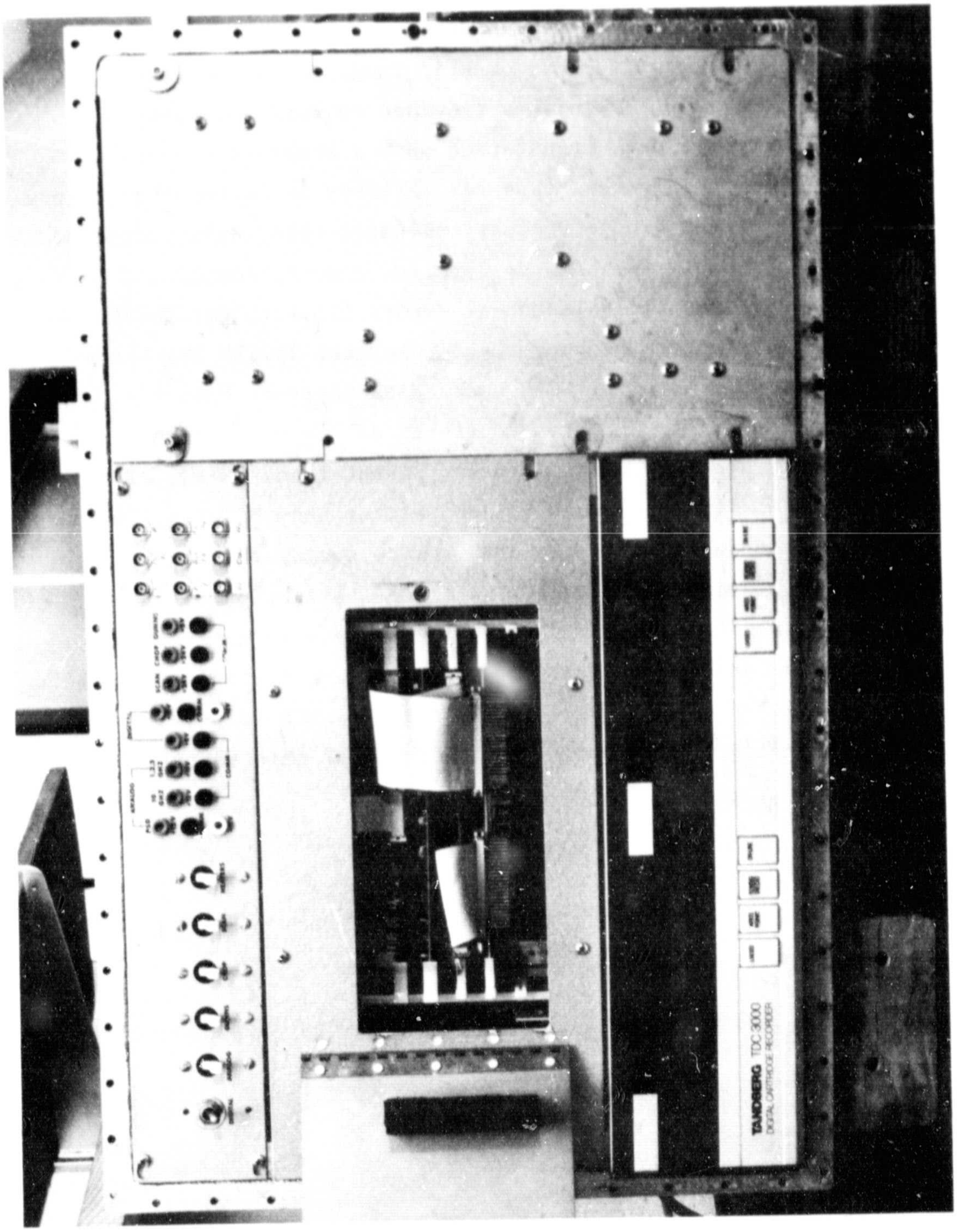


Figure 6. AMMS Digital Package with Flight Recorder.

In addition a portable ground support system was developed to allow the data recorded in flight to be examined immediately upon landing of the WB-57F aircraft and also to permit changes in the AMMS control software between data flights. Radiometric images at 94 GHz and 183 GHz data were displayed, flight logs were provided on hard copy printout, and the flight cartridge data transferred onto a standard nine-track computer compatible reel-to-reel tape for delivery to NASA/GSFC. Figure 7 is a photograph of the ground support equipment (GSE) constructed for the quick look data analysis. A more detailed description of the AMMS is provided in the August 1979 Technical Report (GIT Project No. A-1902) entitled "Operations and Maintenance Manual for the 94/183 GHz Scanning Radiometer System" prepared for GSFC under NASA Contract NAS5-23710.

The final phase of the program consisted of the data flights onboard the WB-57F aircraft during Project SESAME (June 1979), Florida Thunderstorm Mission (September 1979), and Winter Snow Mission (February 1980). The basic objectives of the AMMS system during the WB-57F flights were to experimentally investigate the applications of radiometry at 94 and 183 GHz for the mapping of rain in severe storm regions, measuring atmospheric water vapor, snow precipitation, and snow cover. More detailed plans on the WB-57F data flights is provided in the "WB-57F Data Flight Experiments" Section 4.0 of this report.

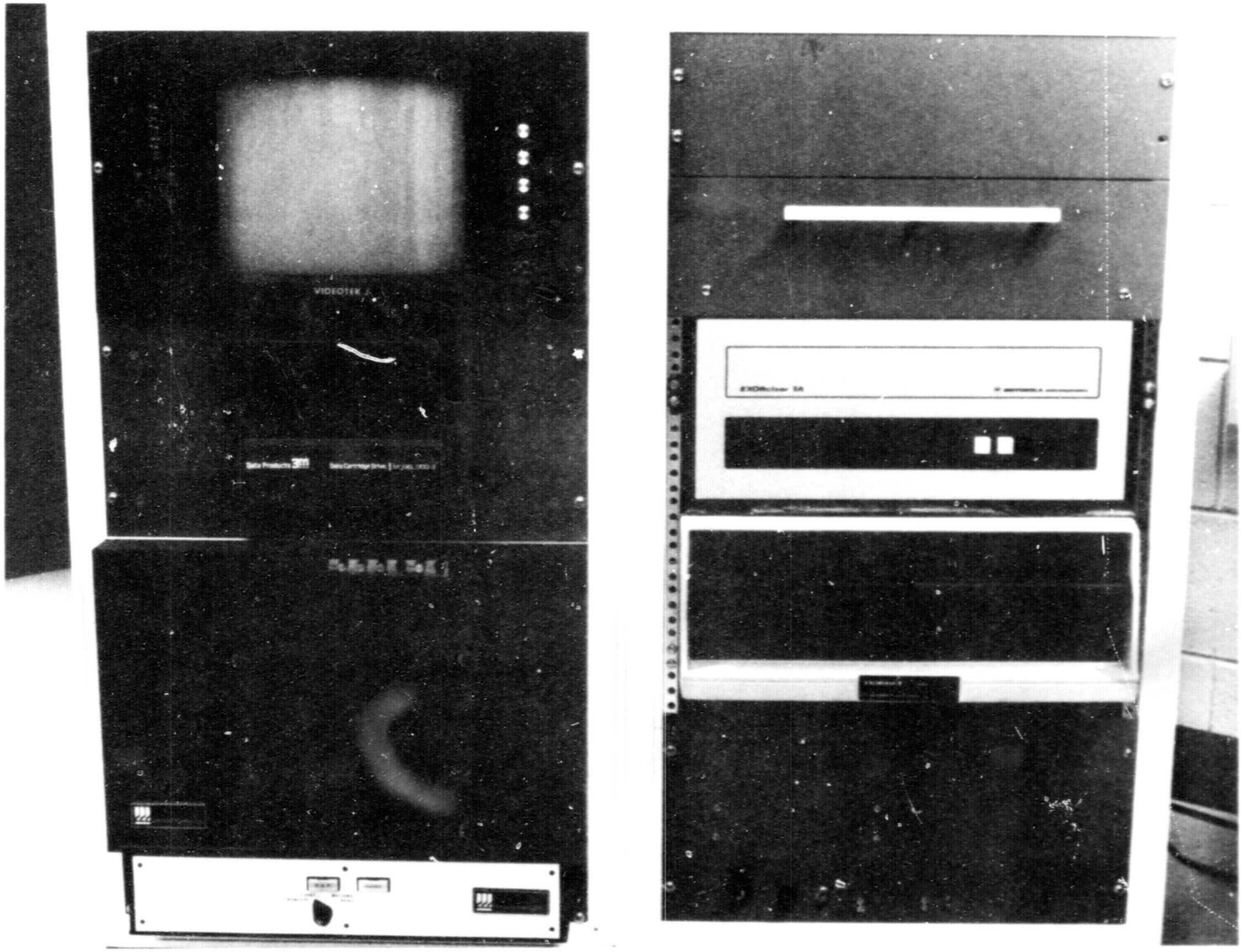


Figure 7. AMMS Ground Support Equipment.

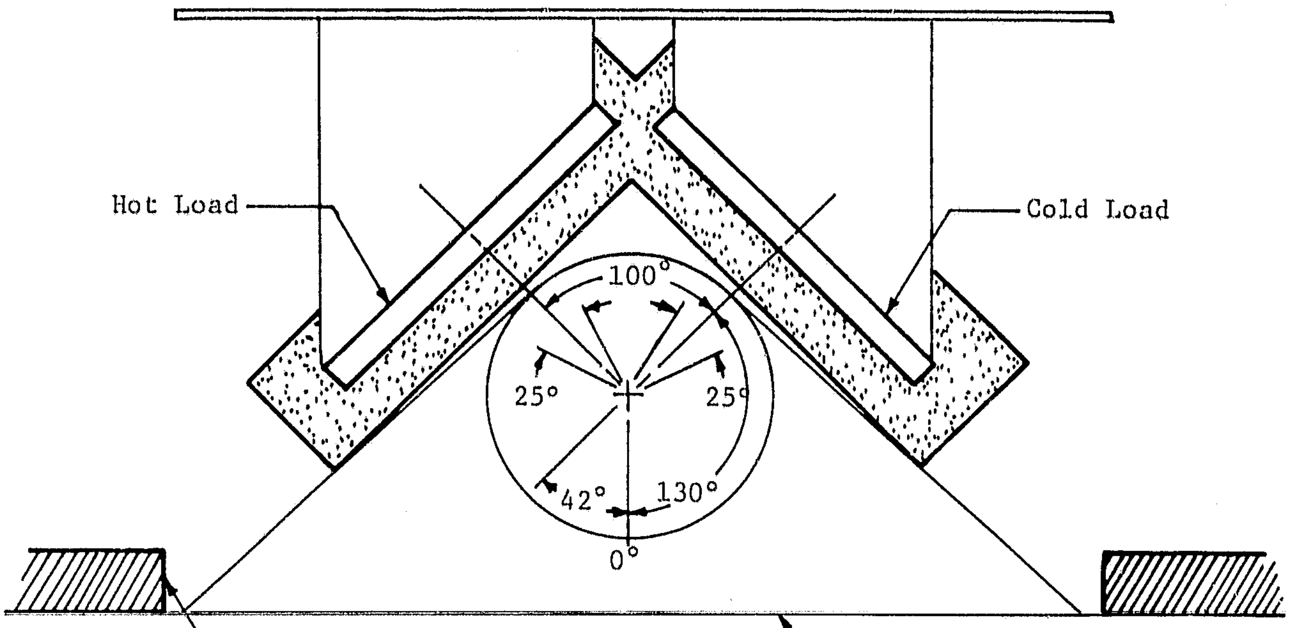
slot position so that the 94 GHz antenna views the reference load and the 183 GHz antenna looks out the lens to the scene. The chopper speed during the flights was 3500 rpm which, for a blade with 6 notches, resulted in a Dicke chopper reference signal of 350 Hz.

The 94 GHz and 183 GHz beams were scanned $\pm$ 45° through nadir by the planar reflector which was driven by a stepper motor under microprocessor control. Parameters set by the microcomputer include: scan, retrace and calibrate speeds, the scan angular width, and the number of scans per calibration cycle. Figure 9 depicts the relative location of the scanner with respect to the hot and cold calibration loads and the pallet window below. The view shown is along the direction of flight of the WB-57F. Below is a summary of the scan parameters used during the flight missions.

scan width = $\pm$ 45°
No. of scans/calibration = 6
scan speed = 33.2 deg./sec.
retrace speed = 278.5 deg./sec.
calibrate speed = 83.7 deg./sec.

Therefore, the scan period is 90/33.2 = 2.71 seconds. The retrace period is 90/278.5 = 0.32 seconds and the calibration period is 270/83.7 = 3.23 seconds. The total scan/retrace time for each map is (2.71 + 0.32) = 3.03 seconds. After 6 scans/retraces (18.18 seconds), a calibration cycle of 3.23 seconds occurs.

The hot and cold calibration loads are part of the scanner assembly as shown in Figure 10. The hot and cold loads were manufactured from cast lossy dielectric materials having machined grooves at the Brewster angle of the dielectric. The surfaces of both loads were covered with low loss RF foam to protect the surfaces as well as provide thermal stability during the flights. The hot calibration load's temperature was maintained at 60°C using a temperature controller to regulate the 115 Vac power to heater strips mounted on the backplate of the load. Following the Florida Thunderstorm WB-57F mission, the cold calibration load was modified by adding a compartment behind the load which was connected to an external air scoop on the pallet. This modification reduced the cold load temperature to about − 22°C during most of the flights.



Scan Angles*			
	Sweep	Begin	End
View Outside	84°	318°	42°
Reference Load (Hot)	25°	117.5°	142.5°
Reference Load (Cold)	25°	217.5°	242.5°

*Angles measured from 0° reference straight down (clockwise). View is from motor side of radiometer.

Figure 9. Radiometer Scan Angle Geometry.

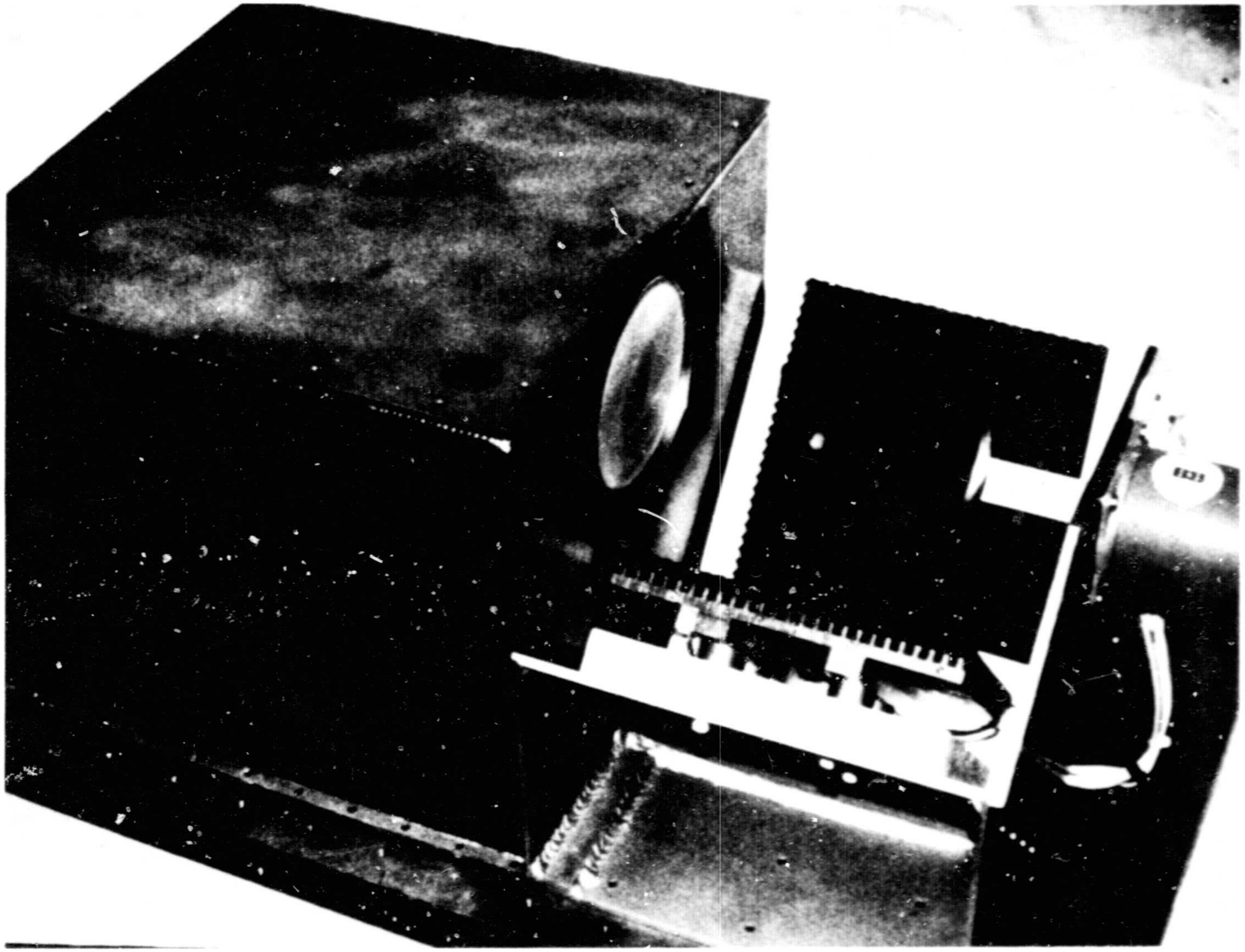


Figure 10. AMMS Calibration Loads Mounted on a Scanner Assembly.

2.1.2 Scanner Processing System

Motion of the scanner is controlled via a stepper motor and microprocessor controller. Figure 4, Section 1.0 shows the scanner assembly which consists of a 45° elipsoidal alluminum plate mounted on the end of the stepper motor shaft. Shaft position information is derived from a two-track incremental encoder. Encoder pulses are decoded by the scanner processing unit (SPU) which provides TTL level direction and step pulses to the translator module which in turn provides the four phase current pulses to drive the stepper motor field coils. Figure 11 shows a block diagram of the scanner system. Load resistors R1 and R2 are remotely located on a heat sink to prevent warming of the calibration loads. Test switches S1-S4 are provided to enable the RPU to operate the scanner in four different modes for testing when the radiometer processor is disconnected.

The Radiometer Processing Unit (RPU) controls scanner motion via the CW and CCW step lines. Each pulse of either line moves the stepper motor in 0.9° increments. This is known as the half-step mode and is set by a jumper on the translator module. Position of the scanner is derived from the outputs of the incremental encoder. One track contains a single 0° reference slot and produces the "HOME" signal which is low when the scanner is at the nadir position. The second encoder track produces 200 pulses per revolution. Two phase quadratures signals from this track are converted into CW and CCW pulses by a phase detector in the RPU. SPU operation is controlled by software in two 2048 byte Eproms that is executed by a 6802 microprocessor. The RPU programs are written in BASIC and assembly language. The SPU software has three basic functions: 1) provide properly timed pulses to the translator module to move the scanner in the described direction to a desired angle; 2) communicate with the RPU and perform various fundamental operations such as go to an angle, retrace, etc., and execute internally stored scan patterns; and 3) provide a pulse-damped operation mode which reduces scanner jitter by applying four forward and two reverse pulses to the scanner in order to move a full step (1.8°) smoothly.

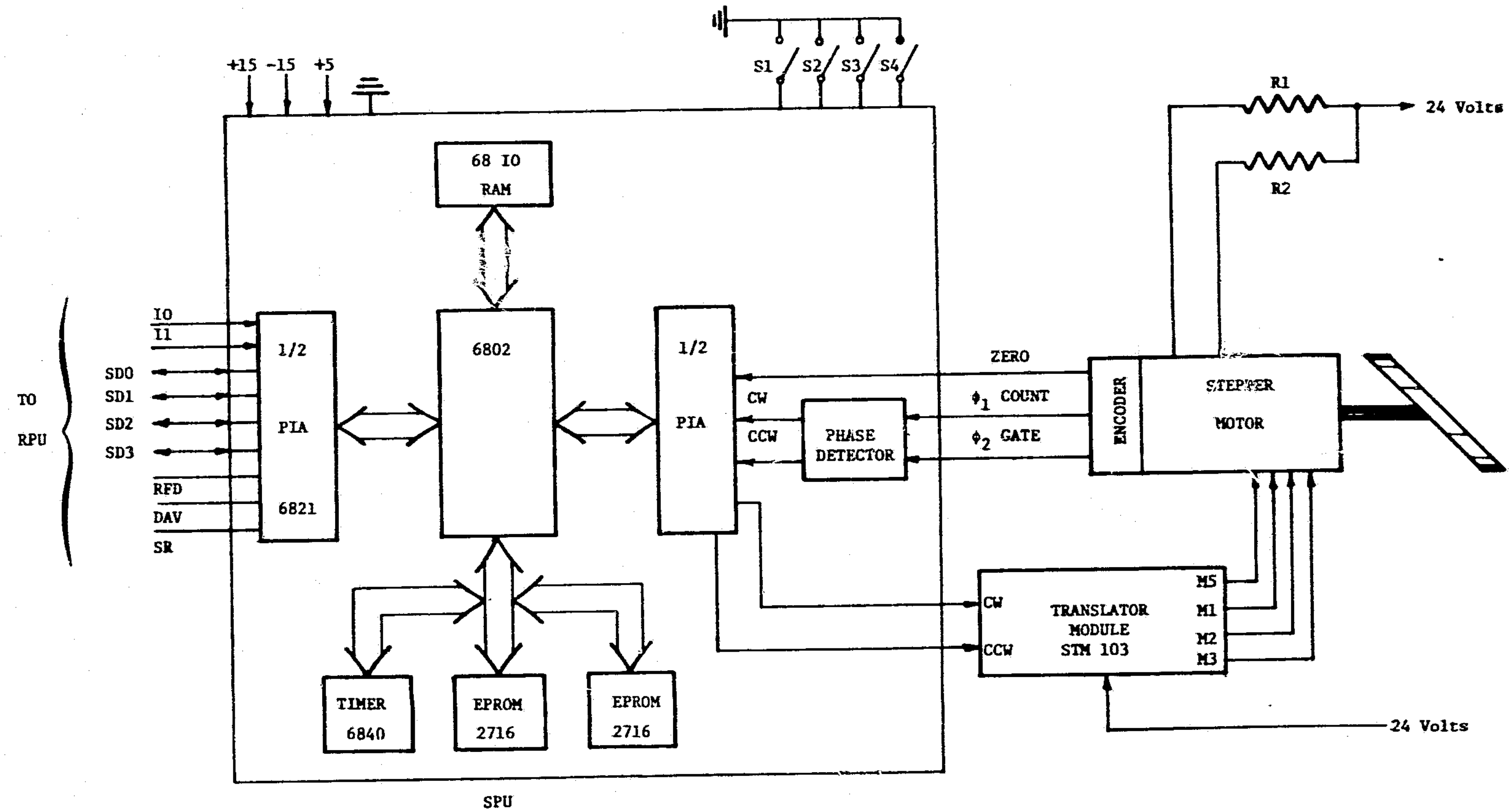


Figure 11. AMMS Scanner Processing System Block Diagram.

The RPU communicates with the SPU via four data lines, two instruction lines and three handshaking lines. Table 2 lists the various scanner functions available to the RPU. During normal operation the set start of scan command is used to program a starting angle of 45° (step no. 25). The damped step command is used 50 times to move the scanner 90° (50 steps) followed by a retrace command. After six scans, go-to-hot load and go-to-cold load commands are issued for calibration followed by a home command and a retrace. This sequence then repeats.

Execution of the SPU software is initiated by reset logic which holds the 6802 reset line low during power up. A reset can also be generated by the RPU by asserting I0 and I1.

2.1.3 Mixers/Local Oscillators

The 94 GHz mixer is a single-ended mixer using a Schottky barrier diode mounted in a Sharpless wafer. A directional filter cavity is used for LO injection to get the signal and local oscillator energies into the mixer. The mixer is tuned with a variable micrometer backshort and operates at a dc bias level of about 0.9 mA and requires about 1.0 mW of LO power at 91.65 GHz. The bias is applied through a Microlab/FXR bias tee and is supplied by an automatic biasing network that uses a long time constant RC circuit to prevent large voltage transients which might damage the mixer diode. The IF is 1.8 to 2.8 GHz and is matched to the mixer diode using a two stage quarter-wave transformer in microstrip. The mixer is connected to the IF box with a 14 inch low loss semi-rigid cable of 0.25 inch diameter.

The 183 GHz mixer is a subharmonic mixer using two antiparallel mounted diodes in the signal waveguide as shown in Figure 12. The LO (91.65 GHz) is injected via a GHz substrate stripline low pass filter launched onto the substrate with a waveguide to stripline transition. The IF filter blocks the LO but passes the IF frequencies (0.5 - 10 GHz) to the IF port. Tunable backshorts are used in both the LO and signal waveguides to tune the mixer. This mixer operates with about 10 to 20 mW of 91.65 GHz LO power. It is connected to the IF box with a 14 inch long low loss 0.25 inch diameter semi-rigid cable.

Table 2

SUMMARY OF SCANNER CONTROLLER COMMANDS

COMMAND	ACTION
RUNCW, XXXX	Rotate continuously clockwise at speed XXXX in steps/sec.
RUNCCW, XXXX	Same except counter-clockwise
OSCL, XXXX	Oscillate at speed XXXX between ϕ_1 and ϕ_2
SETANG1, XXX	Set ϕ_1 to XXX degrees
SETANG2, XXX	Set ϕ_2 to XXX degrees
RUN2CW	Rotate with speed V_1 between ϕ_1 and ϕ_2 and speed V_2 between ϕ_2 and ϕ_1 clockwise
RUN2CCW	Same except counter-clockwise
STOP	Halts motor at present location
HOME	Move to nadir and stop

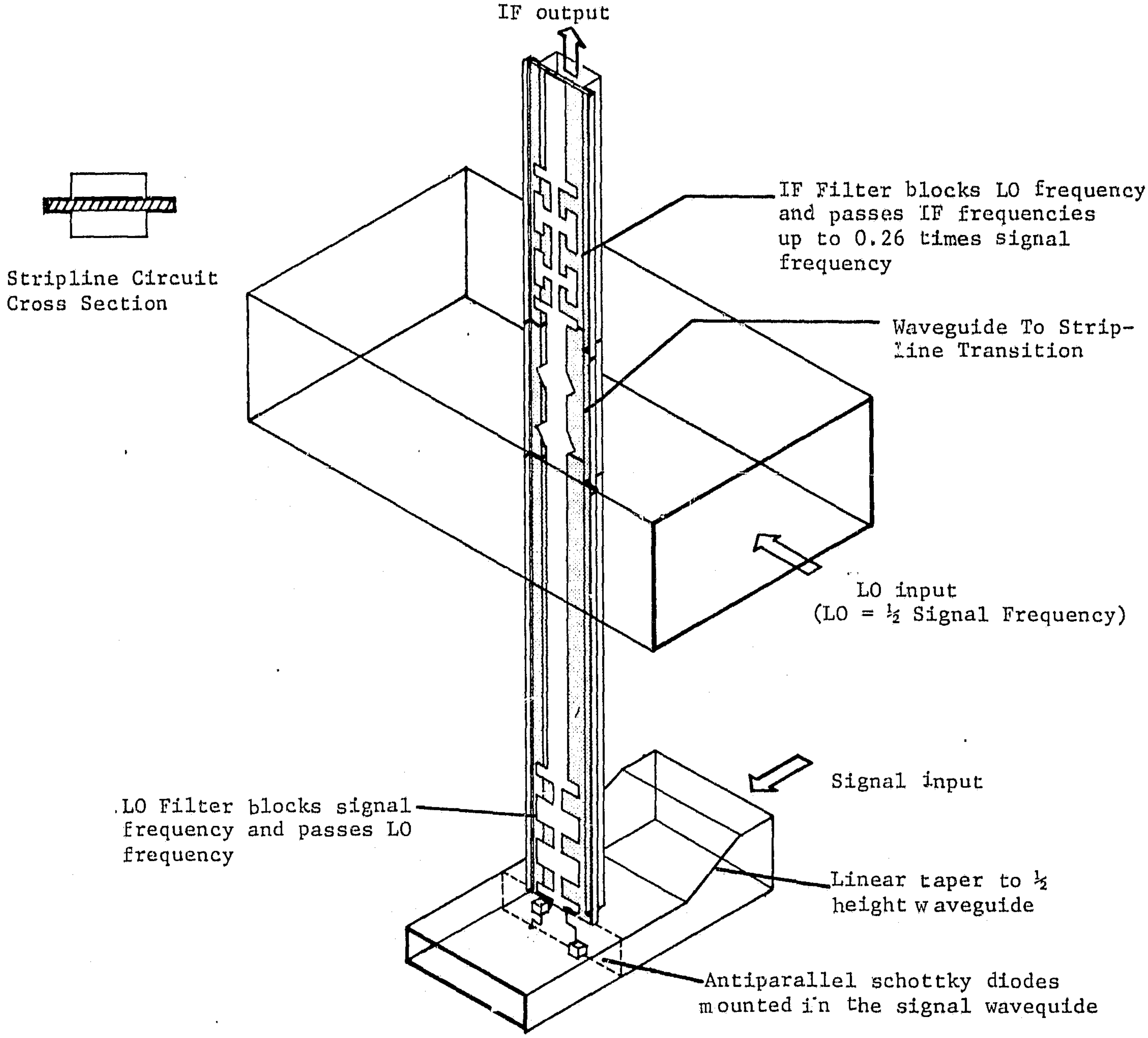


Figure 12. Functional Schematic of Subharmonic Mixer.

The local oscillators were purchased (GFE) from Alpha/TRG. These are 45 GHz Gunns driving varactor doublers. The 94 GHz mixer LO is currently generating about 9 mW of power and the 183 GHz mixer LO is generating about 30 mW of power at 91.65 GHz. A back up local oscillator (a Central Microwave Gunn unit) is now available and has about 25 mW of power at 91.65 GHz. Both local oscillators are attenuated with variable attenuators to the optimum power level.

The local oscillator injection cavity used for the 94 GHz system is a waveguide directional filter which uses two rectangular waveguides operating in the TE_{10} mode connected by means of a cylindrical direct-coupled cavity resonator operating in the circularly polarized TE_{11} mode. The bandwidth of this type filter is typically only a fraction of a per cent wide. This device is shown in Figure 13. This filter allows the use of low power oscillators because of the low LO injection loss (1.5 dB) achieved with it. Low signal losses are also achieved (0.4 dB). For comparison a 10 dB directional coupler has 10 dB LO loss and about 1.0 dB signal loss at these frequencies. The insertion loss of this filter has been measured using a 75-100 GHz IMPATT sweeper and is shown in Figure 14.

2.2 IF System

During the development of the IF system, efforts were made to improve the temperature sensitivity ΔT_{min} on all four radiometric channels. The most noteworthy efforts include the following: design of an IF matching network between the 94 GHz mixer and the 2.32 GHz IF amplifier; addition of a low noise preamplifier in the 5 GHz channel of the 183 GHz system; reduction in the losses associated with the 94 GHz LO injection cavity filters; improved design of the microstrip triplexer resulting in lower losses in all three 183 GHz IF channels; and the use of low loss semi-rigid cables in the IF package. The ΔT_{min} of each channel was measured just prior to the February 1980 Winter Snow flights for a 30 ms integration time with the following results: 2.0 °K maximum for 94 GHz system, 3.0°K (183/1GHz), 4.5°K (183/5GHz), and 5.5°K (183/10GHz). The IF system components were shown in Figure 5, Section 1.0. The 94 GHz portion of AMMS has a single IF channel centered at

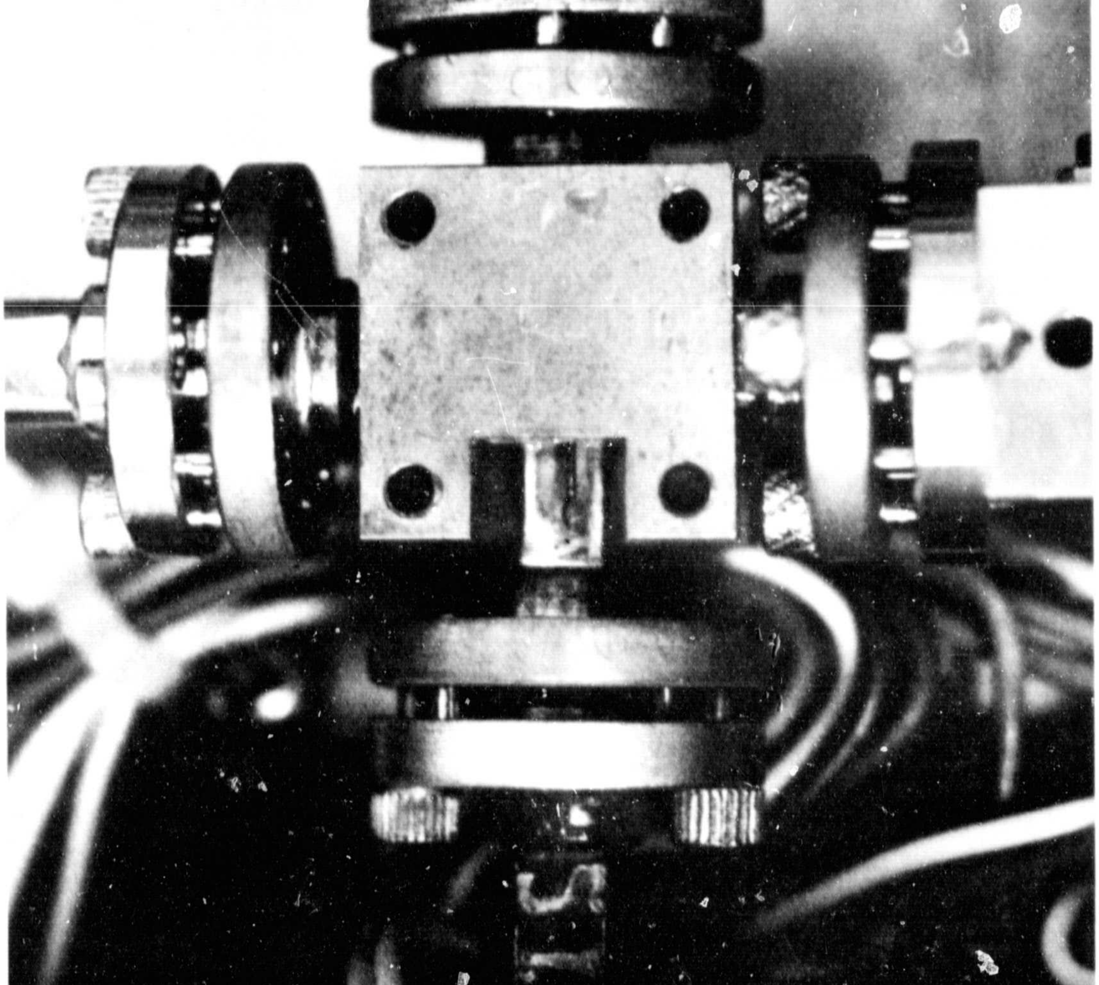


Figure 13. View of 91.65 GHz LO Injection Cavity Filter.

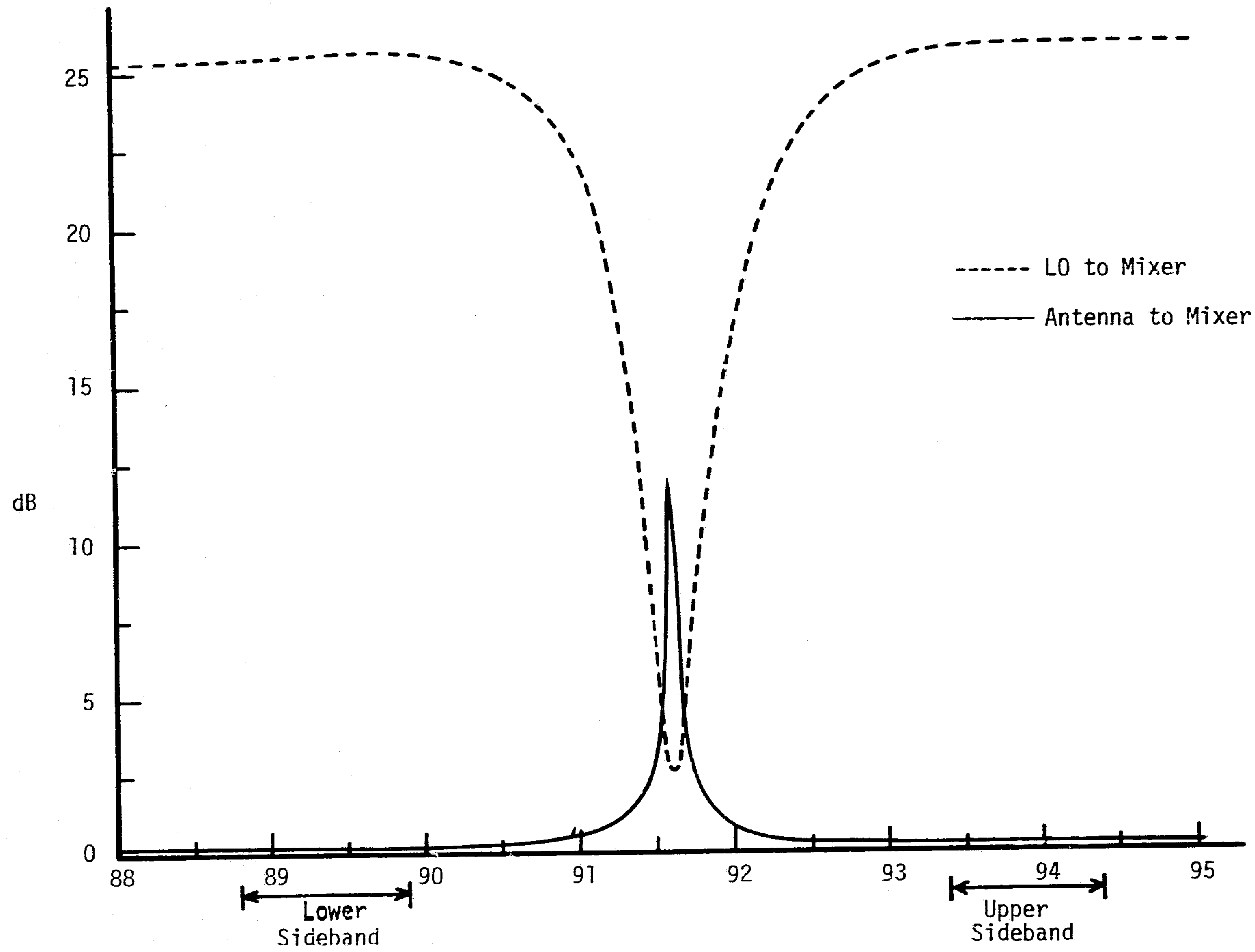


Figure 14. Measured Insertion Loss vs. Frequency for a Cavity Waveguide 91.65 GHz LO Injection Mixer

2.32 GHz and the 183 GHz system has three IF channels centered at 1.00 GHz, 5.00 GHz, and 8.75 GHz. Summaries of the RF losses, and system noise figures are given in Tables 3 and 4 respectively.

The triplexer used for separation of the three IF channels of the 183 GHz portion of the system, shown in Figure 15, consists of a series of two diplexers built on 1/16" low loss Duroid®. A labeled diagram is shown in Figure 16. The first diplexer consists of a parallel connection of a high pass and a low pass filter specifically designed to work when their inputs are connected in parallel. The high pass portion passes 3 to 10 GHz using a single series connected lumped element capacitor and a semi-lumped element as a shunt inductor. The low pass filter is a high impedance, low impedance filter which passes 0 to 3 GHz. The second diplexer is a parallel combination of two band stop filters. The filter that is in the mid frequency port blocks 7.5 to 10.0 GHz and passes 4.5 to 5.5 GHz. The other filter blocks 4.5 to 5.5 GHz and passes 7.5 to 10.0 GHz. This device also has EMI/RFI gasket shielding. The computed and measured responses of this triplexer are shown in Figures 17 and 18. The entire IF portion of the IF/RF package is shielded to prevent interference from transmitters that operate in the IF frequency range. All inputs and outputs to this portion of the system are either low pass filtered or are SMA feed through connectors which come directly from the two mixers.

2.3 Video Processing Electronics

The video electronics portion of AMMS provides the interface between the radiometer's square-law detected IF amplifier outputs and the multichannel analog-to-digital converter input. The video processing circuitry was described in the Operations and Maintenance Manual for the 94/183 GHz Scanning Radiometer System (August 1979) and the electronics remains the same except for the addition of the integrate/dump output from the phase sensitive detectors. This design change was incorporated into the phase sensitive detectors following the May 1979 Project SESAME WB-57F flights and was a result of the radiometer's scanner operating in a step-stop mode. The scanner steps 1.8° and then stares at the scene below for 30 ms while the phase sensitive detector's output integrates. At the end of 30 ms the

Table 3

SUMMARY OF AMMS SYSTEM NOISE FIGURES
AS OF FEBRUARY 1980 WINTER SNOW MISSION

Channel (RF/IF)	94/2.32 GHz	183/1.00 GHz	183/5.00 GHz	183/8.75 GHz
Lens Loss (dB)	0.50	1.0	1.0	1.0
Feedhorn (dB)	0.40	0.75	0.75	0.75
LO Injection (dB)	0.40	---	---	---
DSB Mixer Losses (dB)	7.55	7.05	9.00	9.55
Triplexer Loss (dB)	---	0.40	0.75	1.20
Cable Losses (dB)	0.75	0.60	1.00	1.30
IF Amplifier Noise Figure (dB)	3.00 +	3.00 +	3.50 +	5.00 +
System Noise Figures (dB)	12.60	12.80	16.00	18.80

Table 4

SUMMARY OF AMMS SYSTEM PERFORMANCE
AS OF FEBRUARY 1980 WINTER SNOW MISSION

Channel (RF/IF)	System Noise Figure (dB)	T_{system} (^oK)	System Bandwidth (GHz)	ΔT_{min} (^oK) (for 30 msec integration time)
94/2.32 GHz	12.60	4,980	1.0	2.0
183/1.00 GHz	12.80	5,281	0.5	3.0
183/5.00 GHz	16.00	11,203	1.0	4.5
183/8.75 GHz	18.80	21,650	2.5	5.5

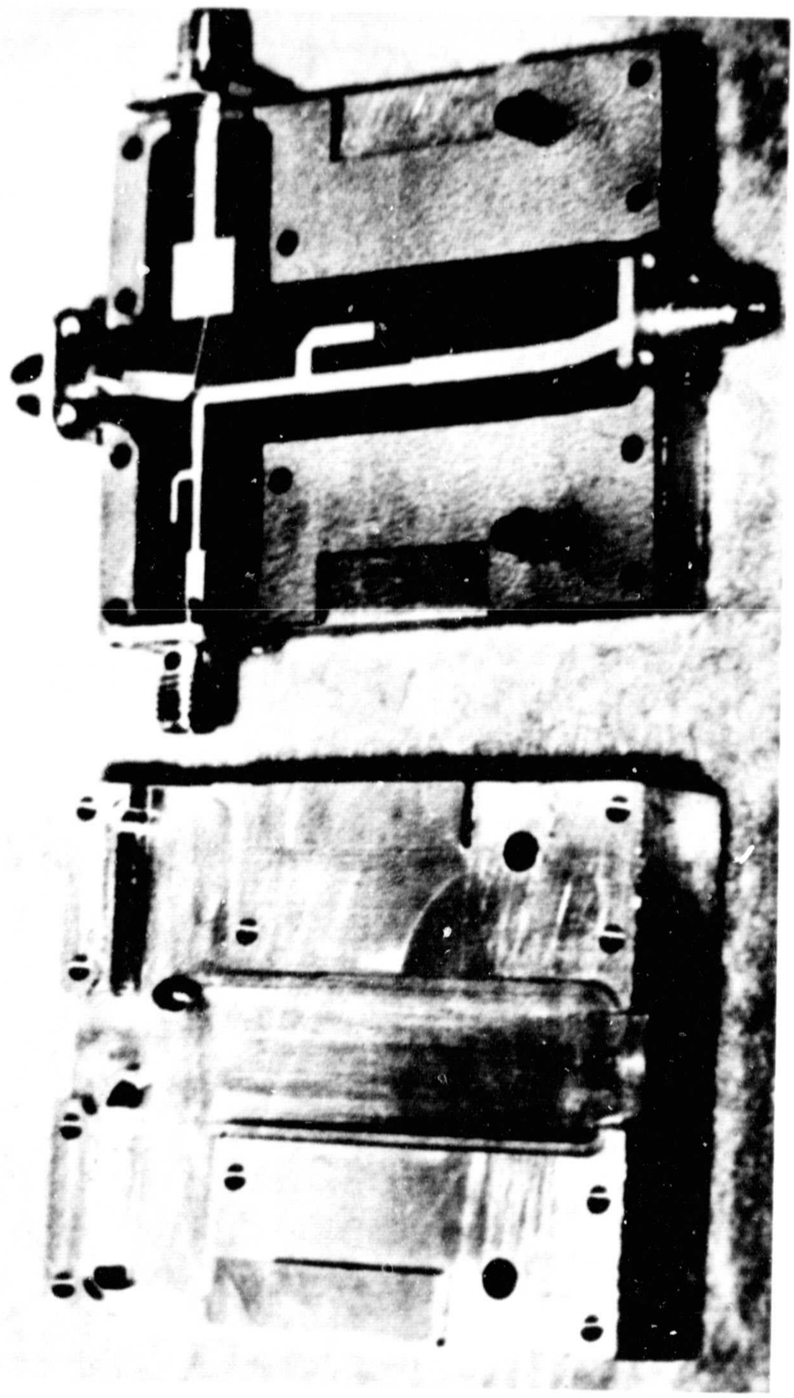


Figure 15. View of Microstrip Triplexer.

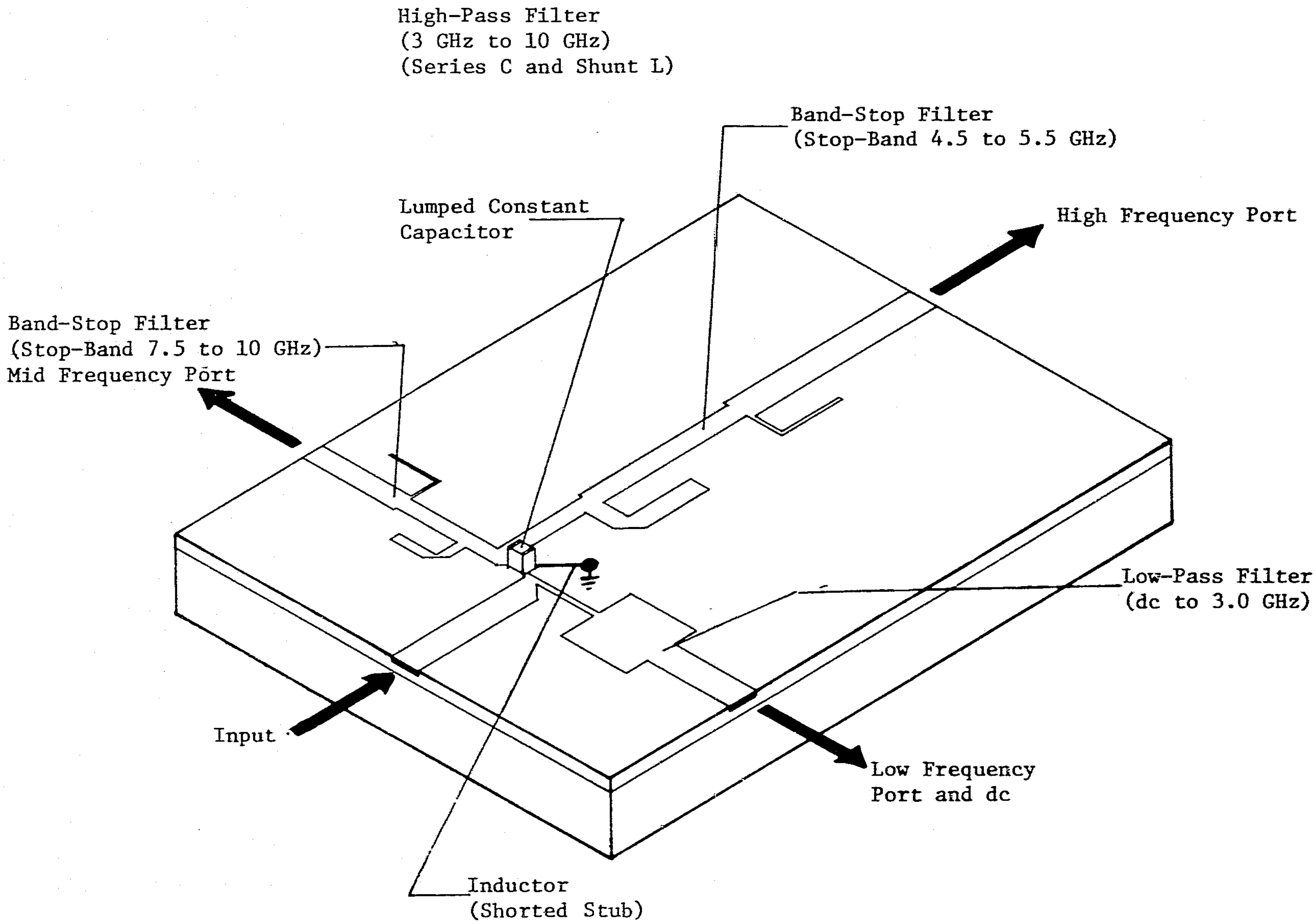


Figure 16. Revised Improved Triplexer (With dc Port) Concept.

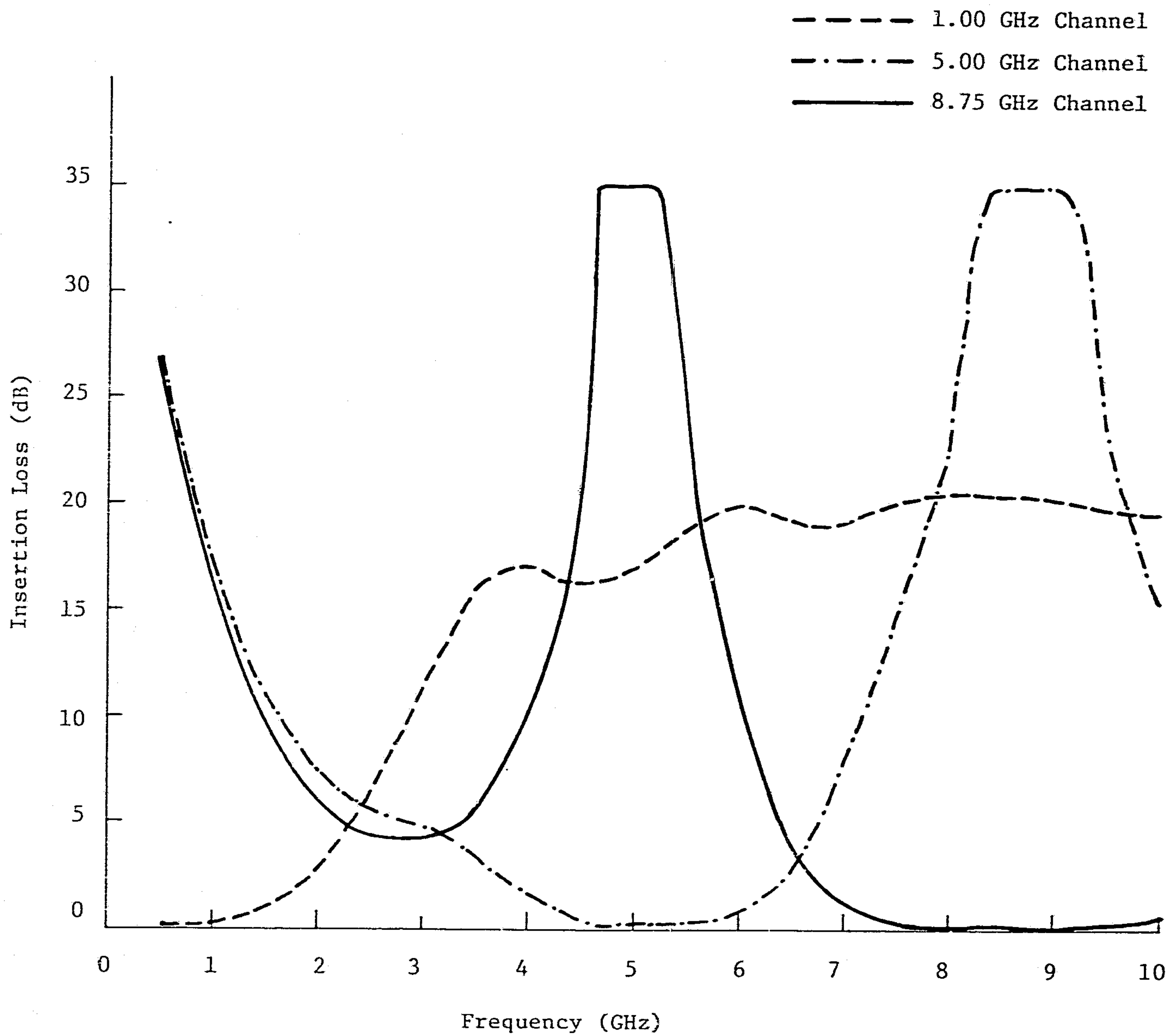


Figure 17. Computed Insertion Loss of IF Triplexer.

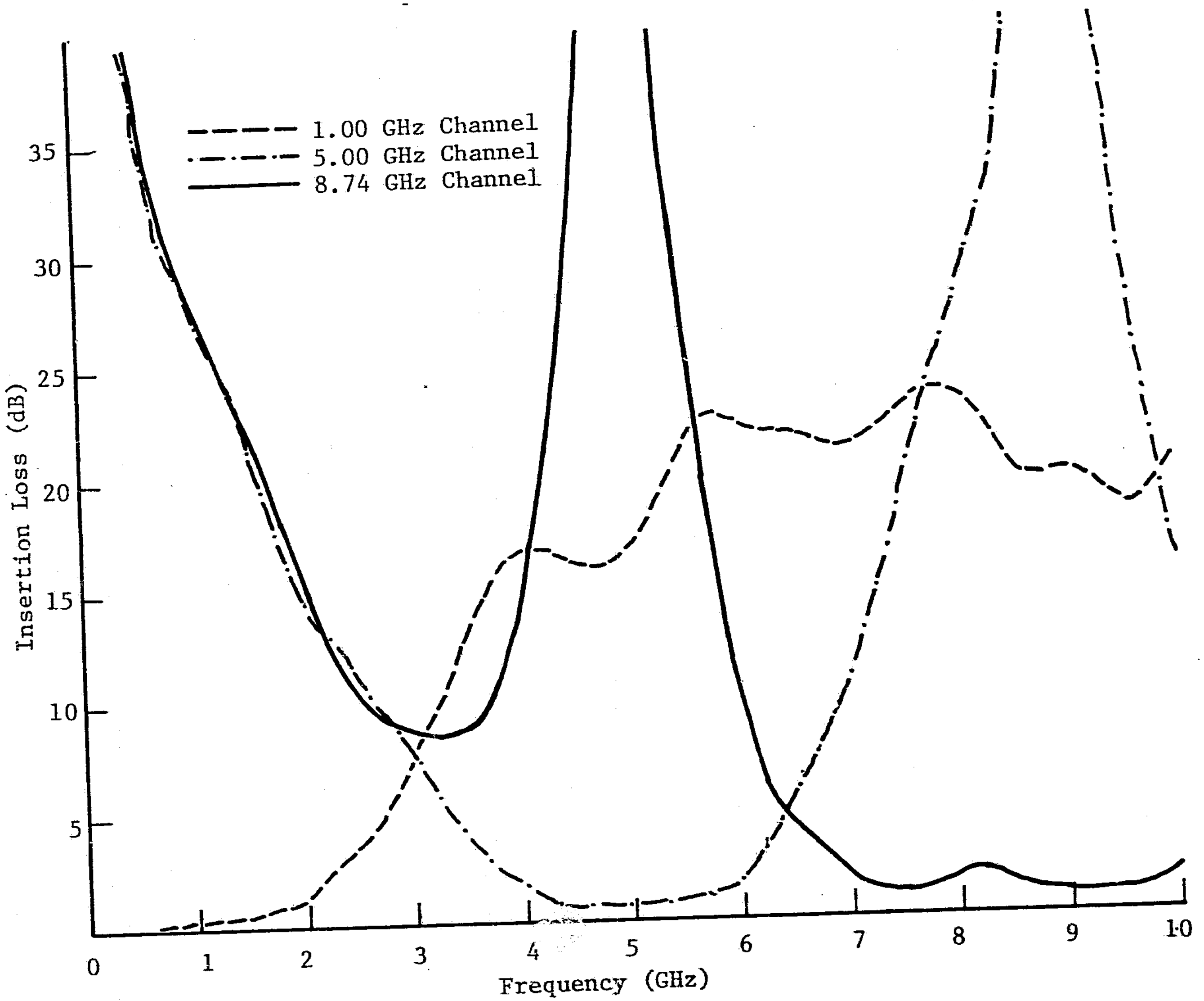


Figure 18. Measured Insertion Loss of IF Triplexer.

microcomputer samples the detector's output and stores the resulting data on tape. The integrator output is then dumped (discharged to zero) while the scanner moves to the next 1.8° step position. This integrate/dump design provides for discrete data cell measurements at each stepped position.

Other video circuits utilized in the AMMS include the following: four high-gain, low-noise video amplifiers used to boost the radiometer's signal levels; a 16 channel multiplexed thermistor amplifier which monitors critical temperatures such as calibration loads, Dicke reference load, mixers, and local oscillators; three temperature controller circuits to independently regulate the operating temperatures of the hot calibration load, the Dicke reference load, and the RF components baseplate; four line driver buffer amplifiers whose outputs are routed to the backseat operator's oscilloscope in the WB-57F cockpit; and the chopper reference circuit which converts the optoisolator signal from the radiometer's chopper to a standard logic level signal which drives the reference input stage of all four phase sensitive detectors.

The ac/dc power supplies for the AMMS are housed in the digital package adjacent to the flight recorder. The power supplies run off of the 115 Vac, 400 Hz aircraft power and supply the following: +20 Vdc to the scanner's motor; +24 Vdc to the chopper's motor; +4 Vdc (two separate power supplies) to the two Gunn diode oscillators; +15 Vdc to the 1 GHz, 2.32 GHz and 5 GHz IF amplifiers; +12 Vdc to the 8.75 GHz IF amplifier; 1.0 mA maximum dc bias current for the 94 GHz mixer; ± 15Vdc to the analog electronics; +5 Vdc and ±15 Vdc to the digital electronics. A fan is provided to cool the power supplies when the radiometer is undergoing ground tests.

2.4 Airborne Data Collection System

The data collection system in the AMMS radiometer consists of two major elements: 1) a microcomputer with a CPU, RAM, ROM, parallel and serial I/O, time code demodulator, and A/D converter, and 2) a dual digital cartridge tape recorder. The microcomputer portion of the system is referred to as the Radiometer Processing Unit (RPU). In operation the RPU has five major functions: 1) collect radiometer data via the A/D converter from the four phase sensitive detectors, 2) operate the integrate/dump circuits, 3) send motion commands to the Scanner Processing Unit (SPU), 4) collect housekeeping data from thermistor temperature sensors and an IRIG B time code demodulator, and 5) record data on cartridge tape. All of these functions are under control of the radiometer operating system software (RADSYS) which is read into RAM from the cartridge tape drive upon power-up reset and executed by a 6800 microprocessor.

The RPU consists of five circuit boards in a Motorola Micromodule card cage housed within the pressurized digital package. All signal connections are made via 25 pin female DB-25 connectors located on the card cage side panel. Connection for the IRIG B signal is via a BNC jack on the same panel. Power (+5, ±15 Vdc) is applied through a Molex connector on the mother-board. Circuit boards are accessed through a hinged front panel. Figure 19 shows a block diagram of the RPU and indicates major functional interconnections. A list of detailed schematics is included in Appendix A - List of Electronic Schematics.

CIRCUIT BOARD 1

A Motorola Micromodule 1A CPU board is the heart of the RPU. This board contains a 6800 microprocessor, a RS232 serial interface, two parallel I/O ports, 1 K bytes of RAM, 8 sockets for up to 8K bytes of Eprom and all necessary clock and bus interface logic. Eight data bus and 16 address bus lines are supplied to other boards via a 86 pin card edge connector. Connections to the serial and parallel I/O ports is made via 20 and 50 pin edge connectors on the top of the board.

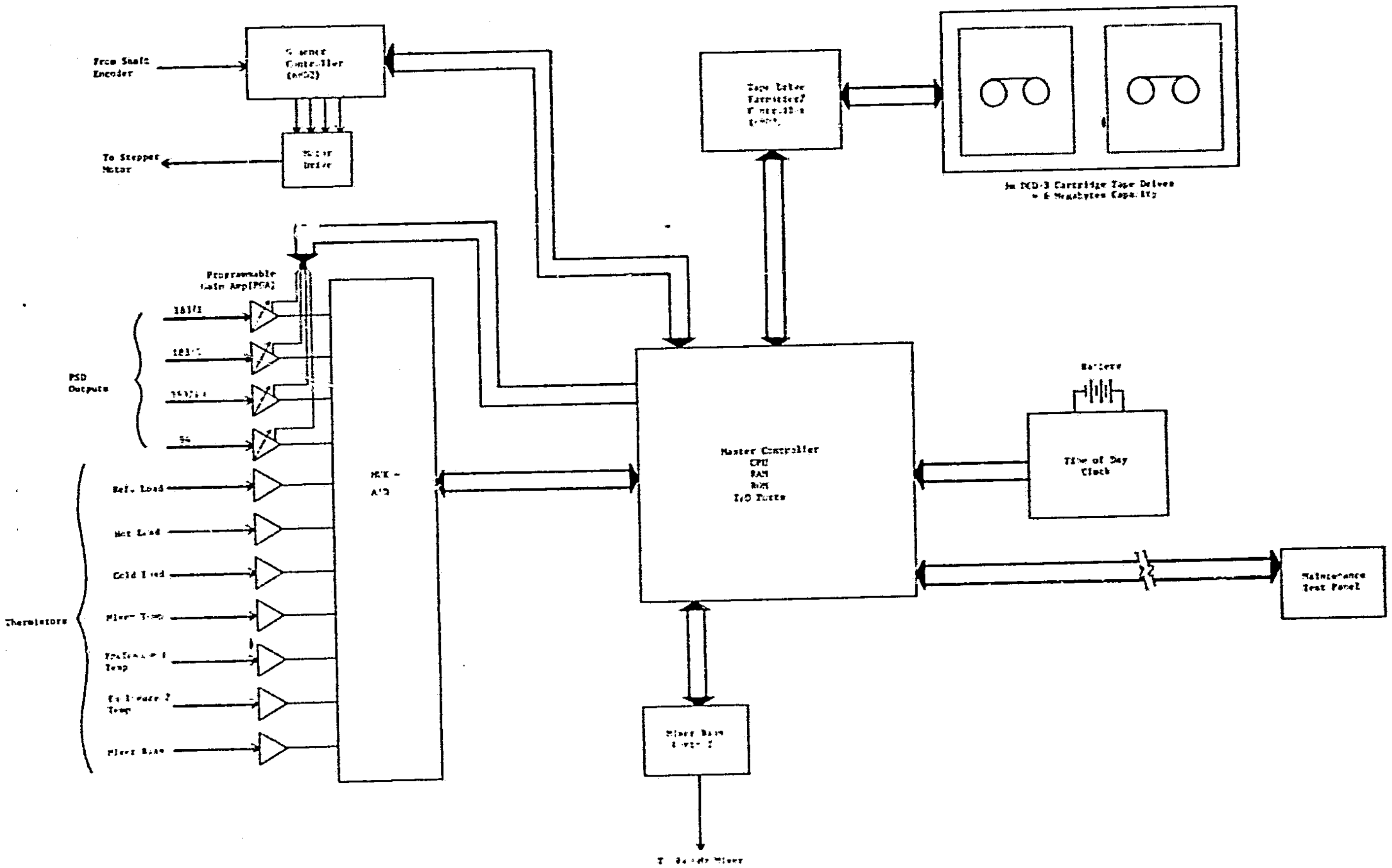


Figure 19. Radiometer Processing System Block Diagram.

CIRCUIT BOARD 2

A Chrislin Industries CI-6800 16 K-byte RAM board is used to store the radiometer operating system and various buffers. This board's starting memory address location is hexidecimal 1000 and ending address is hexidecimal 5000. The only modification made to this board was the removal of the RAM/ROM switch.

CIRCUIT BOARD 3

Analog data from the radiometer and housekeeping sensors is digitized with an Analog Devices RTI-1231S analog I/O subsystem. This board contains a 12 bit A/D converter, 8 channel differential multiplexer, and two 12 bit D/A converters (not used). Wire wrap jumpers have been installed per the Analog Devices instruction manual for the 8 channel differential input mode, 0 - 10 vdc range, and polled status operation. Also two jumpers were added to connect $\pm$ 15 vdc from the RPU card bus to the power connector. The eight analog inputs are connected via card edge connector. Note that although a cable is installed on the D/A output connector it is not presently used in the radiometer.

CIRCUIT BOARD 4

A wire-wrap circuit board in the RPU card cage contains miscellaneous interface and control circuits. Each circuit is briefly described below.

1) Cart drive interface - A RS232C serial interface composed of a 6850 ACIA and its associated buffers and drivers is used to communicate with the cart drive. The data rate is set to 9600 baud via a baud rate clock from the CPU board. No handshaking signals are used.

2) SPU interface - All I/O lines from PIA2 on the CPU board are brought onto the I/O board via a 50 pin ribbon cable. Nine of these lines are appropriately buffered to generate the SPU interface signals; IØ, I1, SD0, SD1, SD2, SD3, SR, DAV, RFD. SD0-SD3 are buffered by a tri-state bi-directional bus transceiver.

3) Watchdog circuit - This circuit is designed to generate a RPU reset should any transient problem cause the RPU software to fail. This is accomplished by having the RPU generate a periodic pulse via CB2 of PIA2 which keeps a retriggerable one-shot from timing out. The software to generate the watchdog pulse is inserted in the scanner retrace and cart tape command routines. Failures that could activate the watchdog circuit are: software "crashes" in the SPU or RPU, cart drive lockup due to multiple tape errors, momentary power failures of the scanner, chopper or RPU power supplies. Any problem which causes pulses to be absent on CB2 for at least 15 seconds will trigger the watchdog circuit. When this occurs, U17 Pin 4 will go high causing U17 Pin 10 to oscillate, flashing the "FAILURE" light. U18 is set to a 10 second astable mode and will trigger U19 every 10 seconds. U19 Pin 10 will generate a 100 ms reset pulse to the RPU bus. When a pulse is received that triggers U16 the failure light will go out and the "OPERATE" light will come on. During a power-up sequence the watchdog circuit will receive trigger pulses from the RPU software while the software searches for a blank track. Normally the power-up reset circuit on the CPU board will generate a reset signal when power is turned on causing the tape bootstrap to operate. Should this not occur, the watchdog circuit will generate a reset pulse in 15 seconds. Plugging in the GSE will disable the watchdog timers via the CTS line from the CPU serial interface and the timer reset lines.

4) Internal clock - A Mostek M5009 programmable timer divides the 1 MHz RPU clock by 10^6 to provide a 1 Hz pulse to CA1 of PIA1. This PIA is programmed to interrupt the RPU software at a 1 Hz rate in order to maintain the internal time in hours, minutes and seconds.

5) Chopper reference - A square wave is provided by an opto-isolator to CB1 of PIA2 via the I/O board connector. This signal is used to time the integrate/dump command.

6) Miscellaneous I/O - The remaining lines of PIA2 are used to provide the integrate/dump command, and the test, erase and step inputs. These last three signals are generated by buttons on the radiometer test box and are not used in the current software versions (Boot 2.0 and RADSYS 3.0). They are designed to be utilized as self test and special function inputs to reduce the radiometer's dependence on the GSE for normal operation. In particular the "ERASE" button was intended to allow both cart tapes to be prepared for flight by erasing the first block following the operating system on track ØØ and the first block of tracks Ø1 - Ø7. This function can be easily added by adding the appropriate software to either the bootstrap Eprom or to RADSYS. The "OPERATE" light could be used to signal when the erase operation is completed.

7) Thermistor selection - Address data to the thermistor multiplexer is provided by PIA lines PB0-PB3 on the I/O board. Inverting buffers are used to generate lines MUX0 MUX3.

CIRCUIT BOARD 5

Conversion of the serial IRIG B time code signal into parallel BCD data is performed by a Datum IRIG decoder (part no. 17261-13) which is mounted on a plug-in card in the RPU card cage. Input to the board is through a short coax cable with a two pin connector which mates to a second connector attached to the card cage. Parallel BCD data is multiplexed onto 8 data lines with 74367 buffers on the mounting card. Data is read via PIA1 on the CPU card through a 50 pin ribbon cable connection to the top of the board. The Datum demodulator board has no adjustments and only requires an input signal in the range of 100mv - 10Vac.

2.5 Ground Support Equipment

The ground support equipment (GSE) currently used for analyzing the flight data taken with AMMS has three main functions:

1) Flight tape cartridge to reel-to-reel transfer of the data for the transcription of the radiometer's cartridge tapes onto computer compatible 9-track reel-to-reel tapes;
2) Radiometric data display to allow the recorded flight data to be examined immediately upon aircraft landing by giving either a "flight log" output or by displaying an image of color coded pixels representing calibrated brightness temperatures; and
3) Radiometer software modifications to permit changes in the AMMS software control programs before the next scheduled flight.

The GSE used during the WB-57F flight missions was shown in Figure 7, Section 1.0. A block diagram of the GSE is shown in Figure 20. A description of each GSE subassembly follows.

The microcomputer used by the GSE is a Motorola EXORciser 1A containing an 8 bit microprocessor (M6800), 48K bytes of random-access-memory, an operating system stored in read-only-memory, and appropriate interfaces to drive the display system, tape and disk systems. The Motorola EXORdisk II dual floppy disk drive supplies 500K bytes of mass storage capacity for data and program storage. The EXORdisk is compatible with the EXORciser and supports a disk operating system with text editors, assemblers and compilers for Fortran, Basic, and assembly languages.

Operator communication with the system for operation and software editing is via a Texas Instruments Model 735 printing terminal. This unit is equipped with an integral keyboard, printer, and modem for telephone line communication. Two magnetic tape drives are interfaced to the system. One drive is a 3M DCD-3 Data Cartridge Drive, which is compatible with the flight tapes used by the radiometer. This allows data to be retrieved from the radiometer tapes and software enhancements to be made to the radiometer's microcomputer operating system. The other drive is a Digi-Data Model 1130. It is a 9-track reel-to-reel

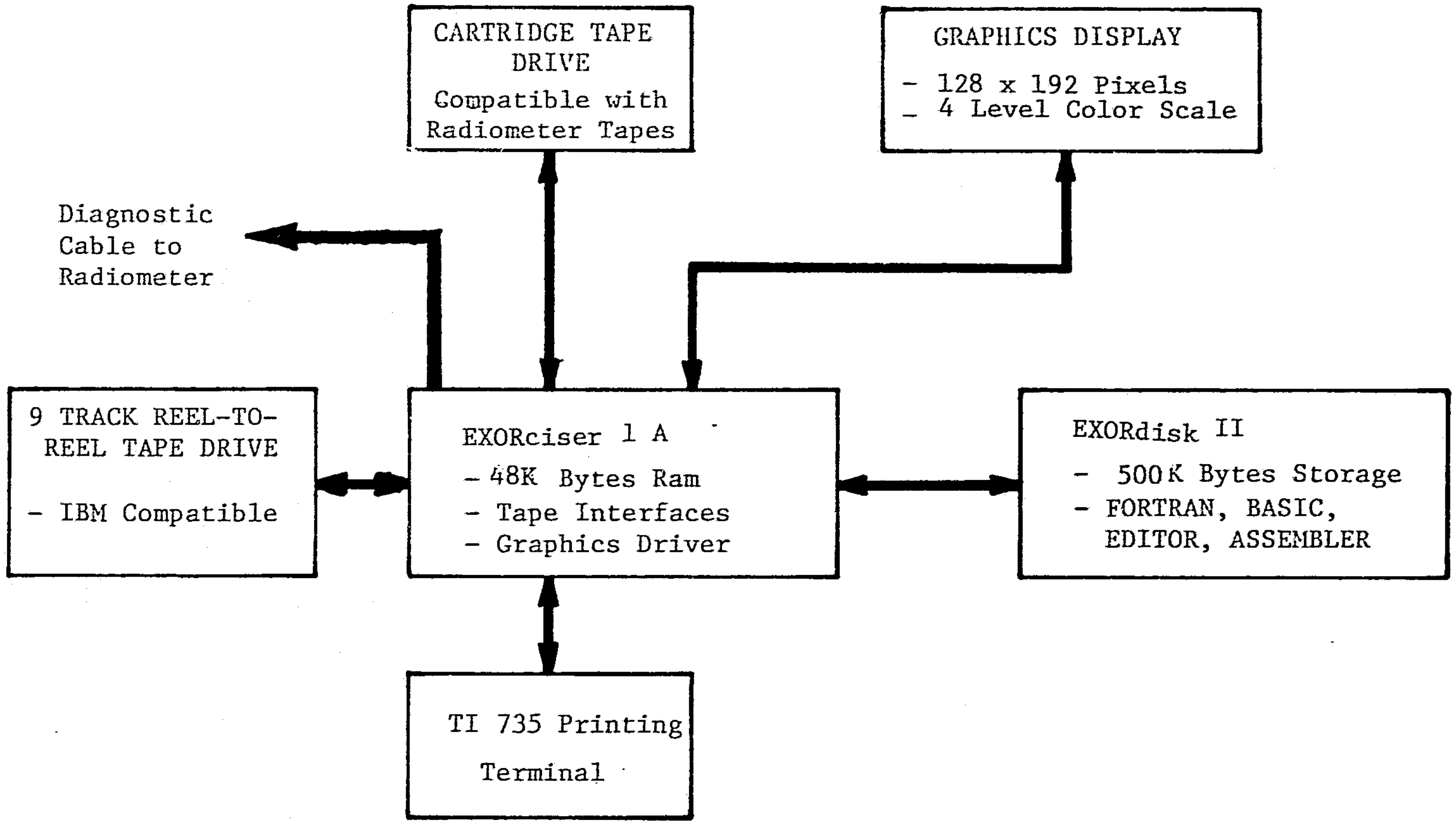


Figure 20. AMMS Ground Support Equipment Block Diagram.

digital tape recorder which produces tapes with an IBM compatible 800 BPI NRZI format on an 8 1/2" reel. Approximately 12 megabytes of storage capacity are available per each 8 1/2" reel. These tapes can be read by any computer system capable of reading IBM compatible tapes.

Graphical representations of radiometric images are displayed on a color video monitor driven by a graphics generator. The format of the display is controlled by software in the GSE microcomputer. A resolution of 128 x 192 points with a 4 level color scale is provided. Data are displayed such that each color represents a calibrated brightness temperature.

2.6 Mechanical Packaging

The radiometer system is packaged in two separate pressurized containers and is located in the WB-57 pallet directly above a new opening which was added in the bottom of the pallet. The RF portions of the system including the waveguide components, antenna horn, 5 inch diameter lens, and RF amplifiers are housed in a pressurized container. Bleed air from the engine intakes is used to pressurize this container in order to prevent condensation during aircraft descent. Additional heating elements powered by the 115 volt/400 Hz power are installed within the package to maintain a stable temperature. A pressure relief valve is also installed in the package to maintain approximately 1.5 pounds per square inch differential pressure within the RF package. This prevents large pressures from being applied against the 5 inch diameter Rexolite lens.

The hot and cold calibration loads and the scanner with its stepper motor are a part of this package. A compartment located behind the cold load is connected to an external air scoop to use outside air to maintain a lower cold load temperature of approximately -22°C. The surface of the loads is covered with low loss RF foam for thermal stability and surface protection. The structure supporting the calibration loads and the scanner motor is designed for high stiffness to minimize relative motion between the scanner, lens and antenna horn caused by engine vibrations. This entire package is mounted on rails located near the rear of the pallet.

The tape recorder and digital electronics portion of the system are housed in a container approximately 16 inches wide by 15 inches high by 32 inches long. This package is designed to withstand full 10 psi pressure and uses cabin air, which has a moderate amount of moisture, for pressurization to and in the tape recorder operation. A 7.5 psi relief valve is also installed in this package.

Internal heating elements, powered by the 115 V/400 Hz source, are also installed in the digital package in order to maintain a stable temperature. The design is based on chassis-panel type construction with a gasket sealed cover. Access to the flight recorder tapes is through a small opening. All connectors and removable covers are gasketed to minimize the leakage of cabin air. A fan is also installed in the package to be operated when testing on the ground. Figure 21 is a photograph showing both packages located in the WB-57F pallet as configured during the February 1980 Winter Snow Mission. Appendix B is a list of mechnical drawings on the AMMS.

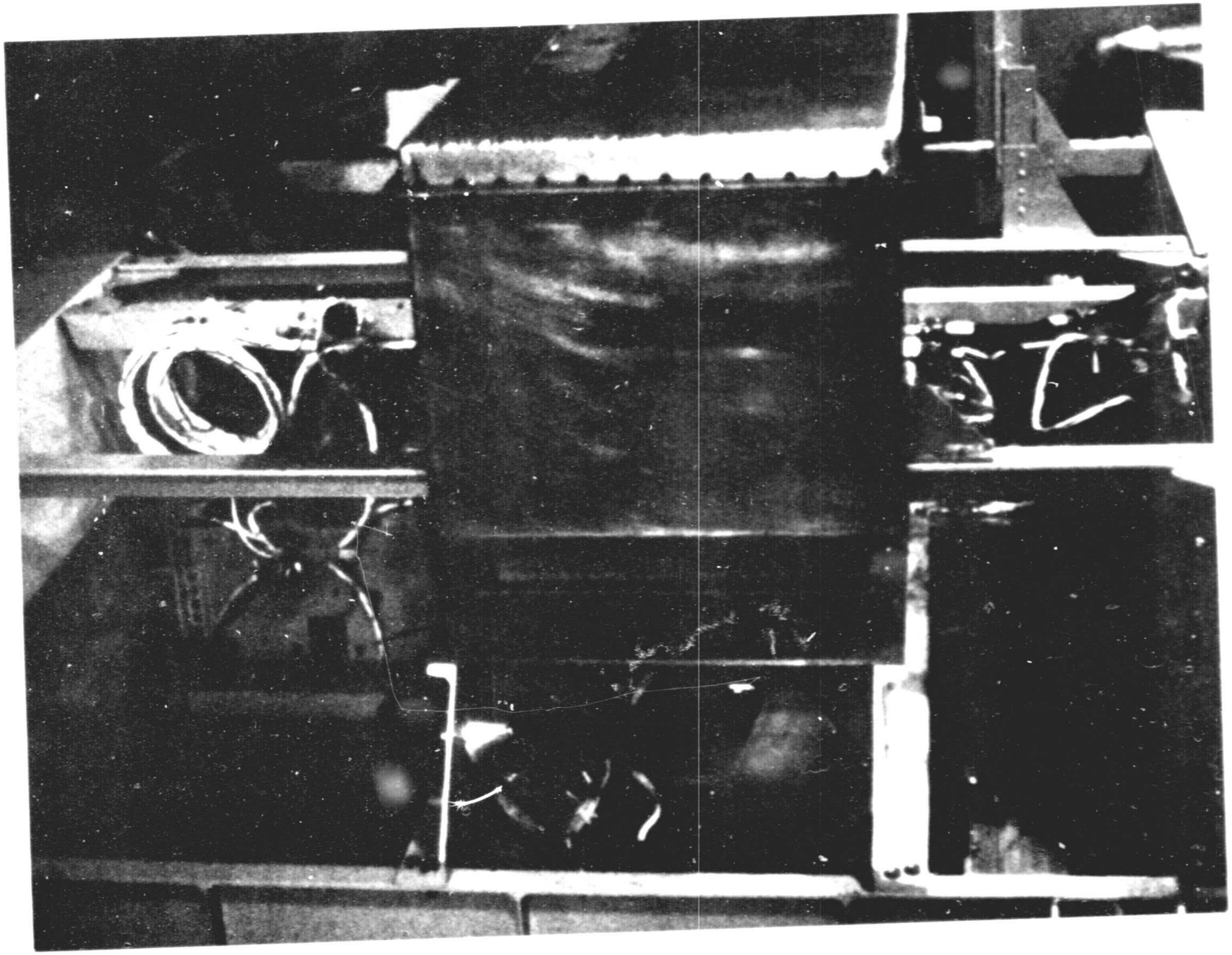


Figure 21. AMMS Located in WB-57F Pallet During February 1980 Mission.

3.0 Revised AMMS Operating Procedures

3.1 AMMS Flight Operation

Two control switches were required to operate AMMS from the WB-57F backseat control panel during the Project SESAME and Florida Thunderstorm missions. Figure 22 shows the control panel used during these flights. One switch, labeled "AMMS HTR" supplied 110 Vac power via pallet remote-control-circuit breaker (RCCB) to the AMMS internal and hot calibration load heaters and to the Radiometer Processing Unit (RPU). The second switch "AMMS POWER" was not connected to a RCCB but went directly to an input port of the RPU. When the RPU sensed that this switch was closed it supplied a signal to close another RCCB that supplies 110 Vac to the tape drive and radiometer power supplies. When it was necessary to power-down the radiometer the "AMMS POWER" switch was opened causing the RPU to rewind the tapes and turn off the radiometer RCCB. This two-switch operation was designed to allow the heaters to be operated without the radiometer taking data and to allow the tape drive to rewind the tapes prior to being powered-down to prevent possible damage to previously recorded data.

After the May and September 1979 flight series it was found that possible confusion with two switches caused an unexpected loss of data. It was decided to change the backseat control panel to allow one switch to operate both RCCB's and to convert the "AMMS HTR" button to an indicator light only that can be controlled by the RPU. Figure 23 shows the new control panel which was used for the February 1980 Winter Snow WB-57F flights.

Following the September 1979 WB-57F flights the AMMS flight software was modified to primarily improve the reliability of the data collection process. One change involved adding a self-checking program that periodically checked to see if the scanner was operating and that data was being written on tape. In the event of a problem, an automatic reset sequence was initiated which automatically reloaded the flight software operating system from tape as in the normal AMMS power-up sequence. The AMMS switch mounted on the WB-57F backseat control panel

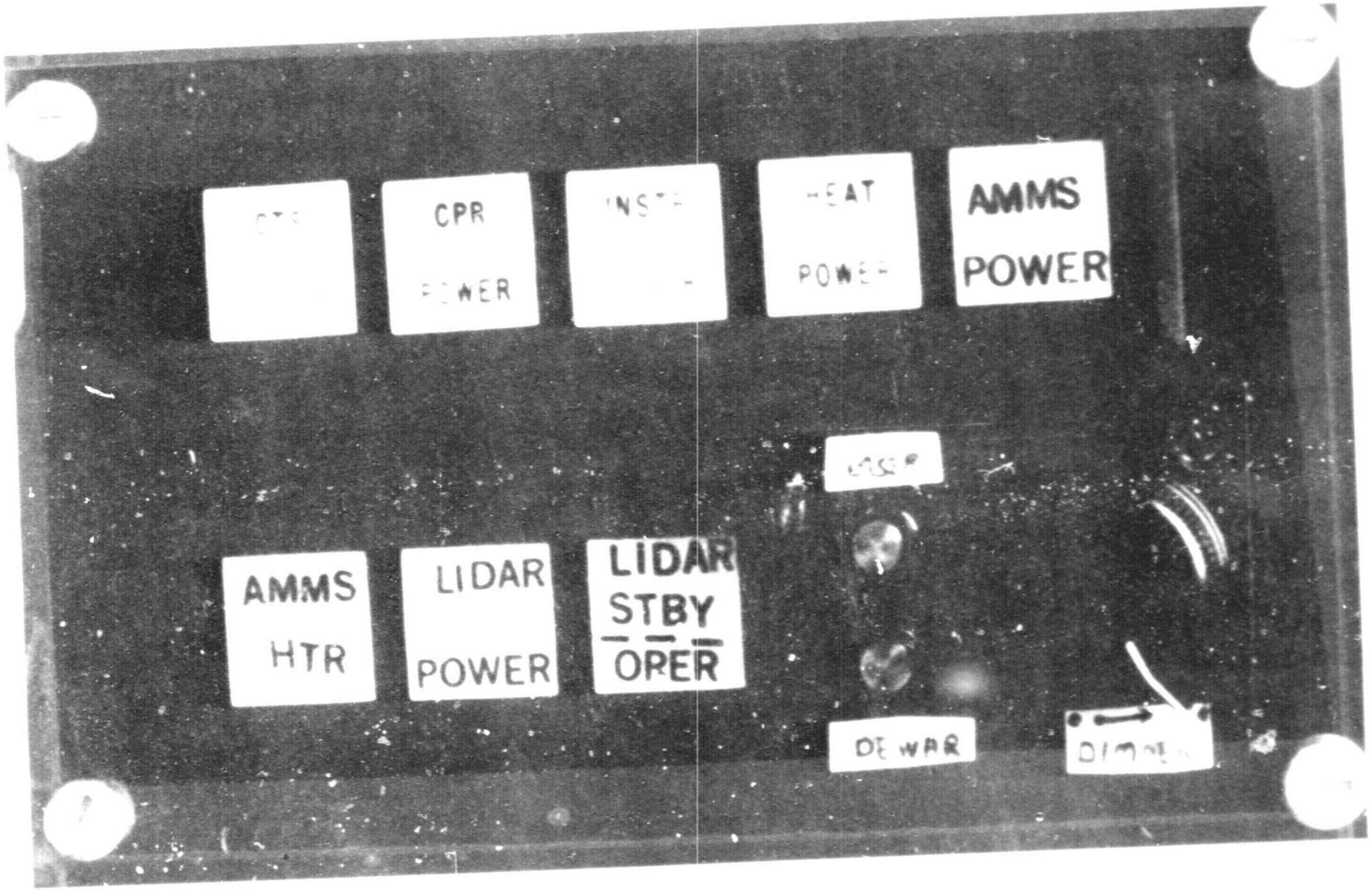


Figure 22. WB-57F Backseat Operator Control Panel.
(May/June and September 1979 Flights)

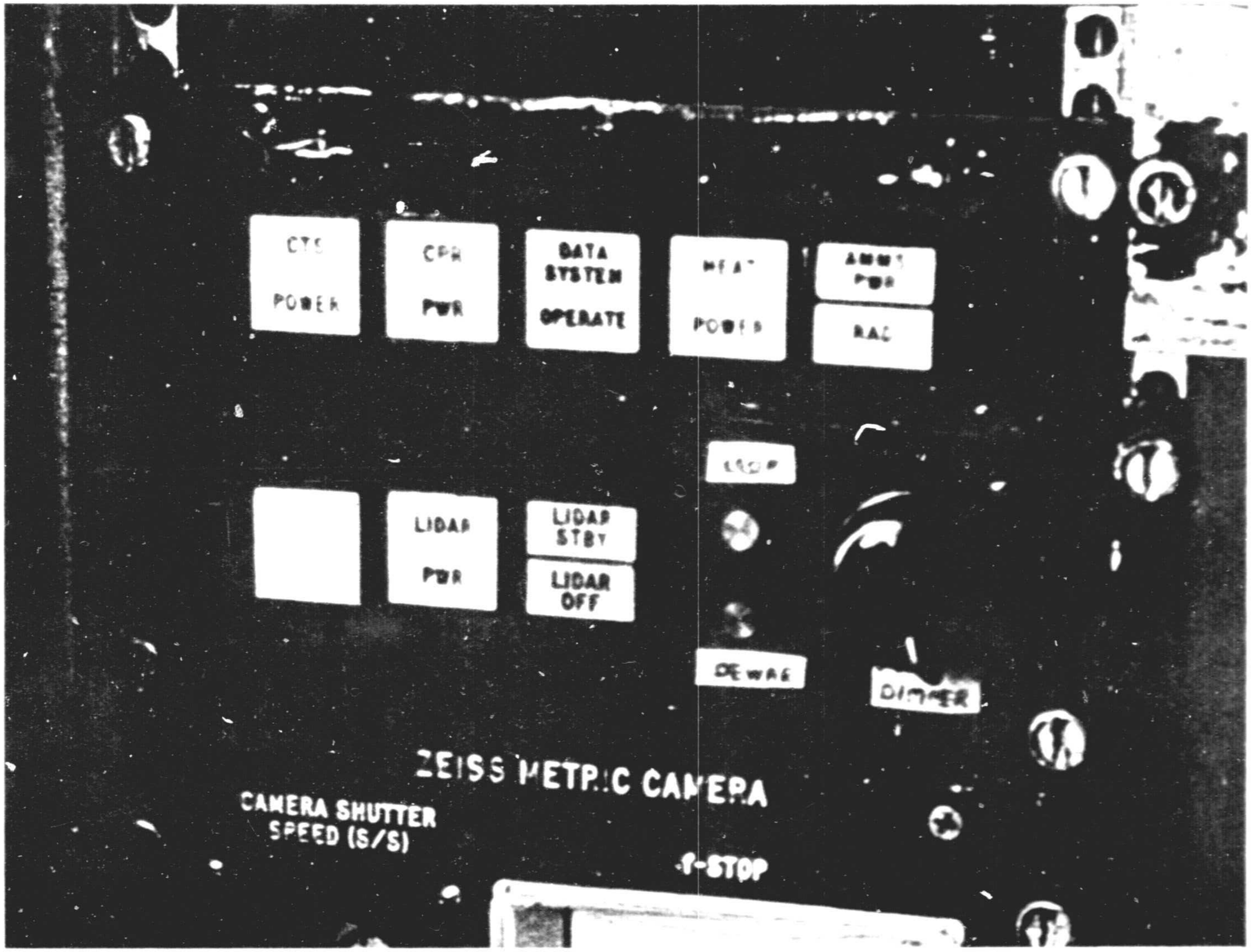


Figure 23. WB-57F Backseat Operator Control Panel (February 1980 Flights).

contained an indicator light which was used to signal the backseat operator in the event of a problem.

Another significant change in the RPU software incorporated after the September 1979 flights involved operating the AMMS flight recorder on an interrupt driven basis. This resulted in eliminating two seconds of dead time which occurred during a tape write by sharing the RPU's processing feature during the periodic idle times of scanner motion and integration. This software change did not alter the AMMS data collection process but simply made use of presently unused processing time.

The Scanner Processor Unit (SPU) software was modified following the Florida Thunderstorm Mission to eliminate a periodic skew in the imaged data of about 10 degrees which was occurring following each radiometer calibration cycle. The modification involved programming the scanner to recycle through nadir position after each calibration cycle. This resulted in the SPU logic being re-initialized to a zero reference state, thus causing the scanner to return to the retrace position before starting the next scan cycle.

In order to link the AMMS data with aircraft navigation data it was necessary that both the radiometer and aircraft data sets contain a common time reference. This was provided by the IRIG B time code signal generated by a master clock in the WB-57F. This signal was in the form of an AM modulated 1 kHz sine wave. In order to record the time of day information on the AMMS flight tape this signal was decoded. Prior to the February 1980 flight series this was accomplished by a combination of hardware and software in the RPU. Two problems with this method of time code demodulation occured during the September 1979 flight series. First, noise on the WB-57F IRIG B signal caused occasional false decoding due to the lack of noise immunity in the demodulation technique used, and secondly, the RPU was totally occupied for up to 2 seconds during the demodulation process resulting in a 2 second "dead" time following each calibration cycle. The best remedy for both of these problems was to purchase a commerical IRIG B demodulator from Datum Inc.

and add it to the RPU. It consisted of a 5.5 in. by 7.8 in. circuit board that accepted an IRIG B input from the WB-57F and produced parallel BCD date and time. Adding this to the RPU required mounting the decoder board within the RPU card cage and adding two parallel I/O chips to the RPU to read in the BCD information. Appendix C describes the flight cartridge tapes data format used during the most recent WB-57F flights.

3.2 GSE Post-flight Data Analysis

Significant additions and changes to the post-flight data analysis have occurred since the May 1979 Project SESAME flights as reported in the before mentioned "Operations and Maintenance Manual for the 94/183 GHz Scanning Radiometer System" (see Table 3 of that manual). All the changes have served to enhance the quick look analysis capabilities of the ground support equipment. Additional software development has resulted in the ability to change the airborne software program between data flights. The following data analysis routines were available during both the Florida Thunderstorm (September 1979) and the Winter Snow (February 1980) WB-57F missions.

Following each data flight the GSE was used to produce quick-look images and a summary flight log of each mission in order to identify events involving large changes in brightness temperature, such as scattering from rain or ice in thunderstorms. Color images of interesting events were produced on the GSE's four-color display. When viewed as a radiometric image, rain events produced sharp contrasting areas of low temperature surrounded by warmer areas. Although the color display generator on the GSE is only capable of producing four colors, this is sufficient for identifying rain events. In addition, the 183 GHz channels produced similar images with enough sensitivity to detect the same events.

Figure 24 is a black and white reproduction of the color video output currently available with the "quick-look" analysis program. The quadrants of the reproduction are images constructed from the data of

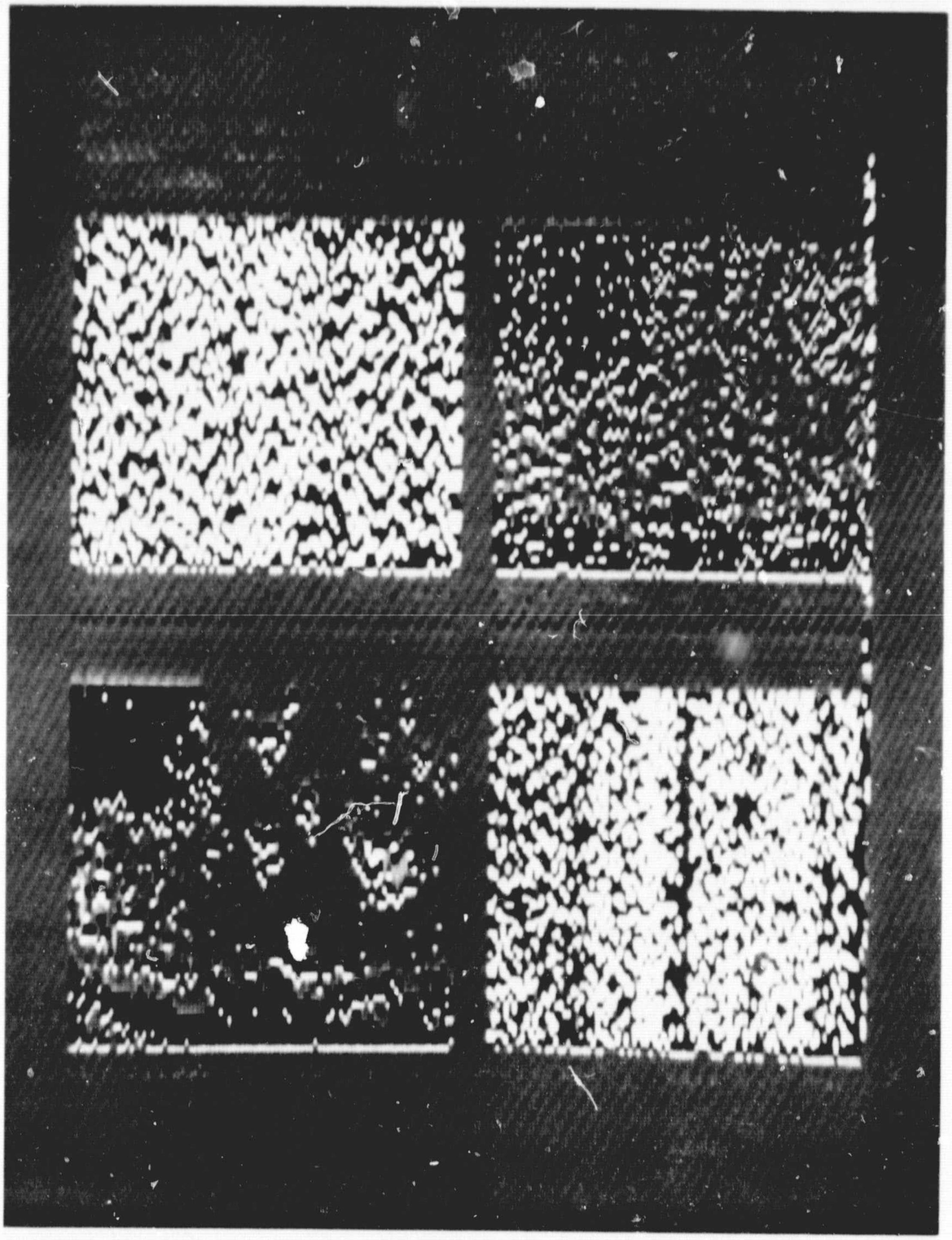


Figure 24. AMMS 4 Channel Radiometric Images Displayed.

the four radiometer channels. They are - clockwise from upper left - 1) 94 GHz, 2 GHz IF channel; 2) 183 GHz, 1 GHz IF channel; 3) 183 GHz, 10 GHz IF channel; and 4) 183 GHz, 5 GHz IF channel. The four colors used for the color video output correspond to actual calibrated brightness temperature ranges: yellow < 210°K, 210°K < blue < 240°K, 240°K < green < 270°K, and red > 270°K.

Each channel's image has a resolution of 50 x 64 pixels, each pixel representing an actual data sample point. The scanner's back-and-forth motion is represented in the left and right directions on the screen, and the airplane's motion is represented in the downward direction on the screen. Each row on the screen for each channel represents a ± 45° scan from nadir by the scanner or about 3 seconds worth of data (total time for taking all four channels concurrently). When the airplane is at 60,000 feet, the ground distance scanned is approximately 25 miles. Each row is made up of 50 pixels so each pixel horizontally represents a distance of about 2500 feet. After every 6 scans, there is almost 3.5 seconds of data "dead" time while a radiometer calibration is performed. There are 92 rows of data displayed for each channel, or about 5.65 minutes of flight time.

The GSE printing terminal was used to provide a hard copy printout of each day's flight to identify events involving large drops in brightness temperature. The log contains pertinent housekeeping information as well as minimum and maximum brightness temperatures covering each six scans of the radiometer data cycle. Figure 25 is a typical flight log from the September 1979 Florida Thunderstorm Mission. A description of each column heading is given below:

<u>Column #1: "BLK"</u>: This number is the decimal block count that is recorded at the beginning of each 1 K byte data block. Since a complete scan/calibration cycle produces 2 blocks, only even block numbers are printed in this column. The block counter starts at Ø following power on and is reset to Ø each time the tape track is changed or power is cycled. Track change occurs automatically after block 819 is recorded. If this number resets to Ø before block 819 it indicates that power was cycled off and on for some reason.

FLIGHT: 9 DATE: 9/24/79

BLK	TIM	IRIG	CD	HT	RF	D1	D2	BIS	G2	G1	G5	G0	MA2	MI2	MA1	MI1	MA5	MI5	MA0	MI0
404	117	1749	14	62	29	32	35	916	32	37	52	56	284	261	422	162	289	242	311	229
406	117	1749	14	62	29	31	35	917	33	28	70	78	285	261	391	174	282	226	318	206
408	118	1749	14	62	28	31	35	917	33	60	66	94	292	252	469	***	288	233	332	190
410	118	1750	14	62	28	32	35	917	33	39	55	71	292	256	403	118	297	243	338	201
412	119	1750	14	62	28	31	35	917	32	89	72	63	289	241	521	***	290	227	322	222
414	119	1751	14	62	28	31	35	917	34	127	57	75	287	229	669	***	289	189	327	153
416	119	1751	14	62	28	31	35	917	33	47	59	62	279	186	427	43	278	178	271	143
418	120	1751	14	62	28	31	35	918	33	33	68	67	268	159	[illegible]	143	250	147	265	118
420	120	1752	14	62	28	31	35	917	33	28	66	55	285	146	[illegible]	167	275	130	311	144
422	120	1752	14	62	28	31	35	917	33	121	62	58	283	131	645	***	267	86	294	96
424	121	1753	13	62	28	31	35	917	32	34	68	72	267	160	352	125	234	113	247	81
426	121	1753	13	62	28	31	35	917	34	39	66	55	270	154	354	74	226	113	250	114
428	122	1753	13	62	28	31	35	917	33	90	62	57	273	134	526	***	239	127	286	114
430	122	1754	13	62	28	31	35	917	34	40	69	60	271	166	396	80	255	138	276	116
432	122	1754	13	62	28	31	35	918	31	53	73	68	268	135	397	4	209	91	219	33
434	123	1754	13	62	28	31	34	917	33	66	66	48	264	141	417	***	221	99	273	95
436	123	1755	13	62	28	31	35	917	33	97	75	60	232	116	375	***	155	51	184	45
438	123	1755	13	62	28	31	34	917	33	59	61	58	244	111	349	***	195	66	221	73
440	124	1756	13	62	28	31	34	917	33	33	76	79	225	111	405	114	163	27	155	1
442	124	1756	13	62	28	31	34	917	32	65	61	67	265	137	365	***	202	124	199	75
444	125	1756	13	62	28	31	34	917	34	41	74	55	285	121	363	61	253	120	290	141
446	125	1757	13	62	28	31	34	917	33	49	74	56	276	211	468	1	272	154	293	180
448	125	1757	13	62	28	31	34	918	32	85	69	58	281	246	676	***	281	216	310	197
450	126	1757	13	62	27	31	34	917	32	658	68	59	285	244	***	***	282	220	319	209
452	126	1758	13	62	27	31	34	918	32	71	61	61	277	216	554	***	295	237	295	186
454	127	1758	13	62	27	31	34	917	31	51	63	73	280	256	497	8	282	225	304	185
456	127	1759	12	62	27	31	34	918	31	318	60	75	275	251	***	***	284	234	289	176
458	127	1759	12	62	27	31	34	917	32	40	65	68	271	248	480	72	270	213	323	186
460	128	1759	12	62	27	31	34	917	32	39	74	63	276	256	451	116	272	216	298	203
462	128	1800	12	62	27	30	34	917	34	63	69	66	275	255	558	***	283	225	334	217
464	128	4080	12	62	27	30	34	918	32	29	79	66	280	258	446	151	291	219	318	207
466	129	1801	12	62	27	30	34	917	33	60	63	63	276	253	563	***	289	241	331	213
468	129	1801	12	62	27	30	34	917	32	***	61	54	278	254	127	400	288	236	327	229
470	130	1801	12	62	27	30	34	917	33	53	71	81	276	253	459	8	284	221	314	193
472	130	202	12	62	27	30	34	917	32	28	65	49	279	255	401	163	279	230	313	236
474	130	1802	12	62	27	30	34	917	30	117	62	80	275	257	797	***	286	237	306	191
476	131	1802	12	62	27	30	34	918	32	64	73	84	275	253	535	***	280	223	329	190
478	131	1803	12	62	27	30	34	918	32	***	56	69	277	256	417	400	287	241	320	206
480	132	1803	12	62	27	30	33	918	32	58	70	69	272	256	547	***	284	232	323	215
482	132	1804	12	62	27	30	34	918	33	58	66	109	270	250	520	***	287	227	335	139
484	132	1804	12	62	27	30	34	918	33	35	64	80	270	254	461	108	286	232	309	187
486	133	1804	12	62	27	30	33	917	34	55	68	55	270	253	535	***	286	225	308	218
488	133	1805	12	62	27	30	33	917	32	45	74	61	272	254	375	28	277	217	307	223
490	133	1805	12	62	27	30	33	917	31	115	69	61	279	258	598	***	275	222	309	214
492	134	1806	11	62	27	30	33	918	33	36	70	68	273	254	460	125	283	223	305	197
494	134	1806	11	62	26	30	33	917	34	47	64	67	271	247	468	54	283	221	298	197
496	135	1806	11	62	26	30	33	918	33	51	59	86	268	248	492	81	273	225	272	152
498	135	1807	11	62	26	30	33	918	32	62	74	85	267	249	529	***	265	204	259	116
500	135	1807	11	62	26	30	33	917	31	50	74	65	265	246	490	118	257	184	257	147
502	136	1807	11	62	26	30	33	918	33	36	69	77	257	236	402	98	269	194	263	138

Figure 25. September 1979 WB-57F Typical Flight Log Output.

Column #2: "TIM"" This column contains the internal clock time which is maintained by a crystal derived interrupt in the Radiometer Processor Unit (RPU). This information is recorded as BCD hours, minutes and seconds. Only hours and minutes are printed. This clock is started at Ø hrs Ø mins upon application of power to AMMS. Numbers of 1 or 2 digits are minutes: i.e. "32" = 32 minutes, and 3 digit numbers are hours and minutes: i.e. "132" = 1 hour 32 minutes.

Column #3: "IRIG": This column contains the Zulu hours and minutes from the IRIG B time code demodulator. This time is recorded in BCD hours, minutes and seconds.

Column #4: "CD": This is the temperature of the cold calibration load in degrees centigrade. The three cold load thermistors are averaged to produce this temperature.

Column #5: "HT": Temperature of the hot calibration load in degrees centigrade. Due to the placement of heating strips on the back of the hot load the middle thermistor was weighted by a factor of 2 and averaged with the two outside thermistors.

Column #6: "RF": This is the temperature in degrees centigrade of the Dicke reference load.

Column #7 and #8: "01", "02": 01 is the temperature of the 94 GHz Gunn local oscillator for the 94 GHz channel and 02 is the temperature of the 94 GHz Gunn used to provide LO injection for the 183 GHz subharmonic mixer.

Column #9: "BIS"" This is the value in microamps of the dc bias applied to the 94 GHz mixer. Quiescent bias set to 900 microamps LO power, typically resulted in 915-926 microamps of bias.

Columns #10, #11, #12, #13: "G2", "G1", "G5", "G0": These are the computed radiometric gains in degrees per volt of the 94 GHz channel and the 1, 5 and 10 GHz IFs of the 183 GHz channel respectively. The gain of each channel is calculated by averaging the ten hot load samples to give the quantity "HOT_{AVG}" and the nine cold load samples to yield "$COLD_{AVG}$". Gain is then calculated via the equation:

$$G = \frac{T_{HOT} - T_{Cold}}{HOT_{AVG} - COLD_{AVG}}$$

where T_{Hot} and T_{Cold} are the hot and cold calibration load temperatures. Values of gain less than Ø or greater than 999 result in *** due to print format overflow.

Columns #14 through #21: These columns contain the maximum and minimum scene temperatures found in each 6 scan cycle for the four channels. These temperatures are in degrees Kelvin and are the result of finding the maximum and minimum voltages for each channel every scan cycle and converting these numbers to temperatures via the equation:

$$T_S = T_H - \left(\frac{T_H - T_C}{V_C - V_H}\right)(V_S - V_H)$$

where T_S is the scene temperature and V_S is the radiometer PSD voltage while observing T_S. The 94 GHz channel produced the most stable and reliable maximum and minimum temperatures due to its low ΔT_{min}. MA2 values of approximately 335°K are due to reflections of the hot load from the closed pallet door. Typical MA2 values with the door open at altitude are 270°K-300°K. Typical MI2 temperatures are 240° over water. Unusual or extreme values for the 183 GHz channels are due to RFI induced calibration errors and problems with power and frequency drift in the local oscillator.

4.0 WB-57F Data Flight Experiments Summary

4.1 May/June 1979 - Project SESAME Flights

The first flights with the Advanced Microwave Moisture Sounder (AMMS) occurred on the WB-57F flights for Severe Environmental Storms and Mesoscale Experiment (SESAME) during May-June 1979. These flights originated from Ellington Air Force Base in Clearlake, Texas. These were the first data flights on the WB-57F and were used to demonstrate confidence in the surviability of the hardware during extended high altitude operation. Several operational problems were encountered during the flights and were either corrected in the field or at Georgia Tech following the flight series. The most significant problem was the failure of the 183 GHz mixer prior to the first flight which resulted in no useful data being recorded from any of the three 183 GHz IF channels. The 94 GHz RF hardware portion of the instrument operated properly for the May/June 1979 flights.

Operation of AMMS was controlled by three microcomputers. One microprocessor controlled the operation of the digital cartridge recorder and was fully tested and debugged prior to the flights. A second microprocessor, the Scanner Processing Unit (SPU), controlled all scanner motion. Both of these processors were interfaced to a master processor, the Radiometer Processing Unit (RPU). The RPU software underwent several changes during the course of the flights to correct problems that were encountered. For this reason and problems encountered with the SPU, data was recorded asynchronously with scanner motion.

During normal operation the RPU operating system was read from the tape when power was applied to the system. Upon execution, the RPU software transmited scan parameters to the SPU. These parameters set the scan, retrace and calibrate speeds, the angular width of the scan and the number of scans per calibration cycle. Following initialization of the SPU, the RPU began collecting data from the radiometer and recording data on magnetic tape. It is important to note that the data collection process and scanner motion are totally independent. Data was sampled at a rate of one sample every 30 ms without synchronization to scanner position. Thus there is no absolute indication of scan, retrace or calibration data contained within the tape records. However, since the scanner speeds were constant throughout a flight, the locations of particular events are periodic.

The scanner consists of a 45° aluminum reflector rotated by a microprocessor controlled stepper motor. Figure 9 in Section 2.1.1 depicts the scanner geometry relative to the calibration loads and the pallet window. For the flights of interest (May 30, June 5, 7, 8) the following scan parameters were used:

Scan Width - ± 45°
Scan Speed - 33.2 deg/sec
Retrace Speed - - - - - - - - - - - - - - - - - - - 278.5 deg/sec
Calibrate Speed - - - - - - - - - - - - - - - - - - 83.7 deg/sec

Thus the scan period was 93/33.2 = 2.7 seconds. The retrace period is 90/278.5 = 0.323 seconds and the calibration period is 270/83.7 = 3.23 seconds.

During flight operation a crystal derived clock timed all data collection operations of the RPU by interrupting the RPU every 10 ms. This interrupt was used to increment an internal time of day clock which was initialized to zero upon power application in flight. Every 30 ms the outputs of the radiometer channels were sampled by a 12 bit A/D converter and placed in a temporary 1024 byte buffer. The first 28 bytes of the buffer contain housekeeping data. Table 5 lists the housekeeping data format and locations. Note that all data following the time is in packed 12 bit format. Radiometer data is placed in the buffer beginning at byte 28. For flights 4, 5, 6 and 7, only 2 of the 4 channels were recorded due to problems with the 183 GHz channels. The 94 GHz data is recorded first, followed by one of the 183 GHz channels. Thus every other 12 bit number following the housekeeping data is 94 GHz data. A dual buffer system was used so that there were no gaps in the data between blocks. At 30 ms per sample (both channels were sampled simultaneously) and with 996 bytes of data (or 664 12 bit numbers) each block represents 664 x 30/2 = 9.96 seconds.

Table 5

HOUSEKEEPING DATA FORMAT
(May/June 1979 Flights)

Byte No.	Data	Comments
0	Block Number HI	Range is 0000-0352$_{16}$
1	Block Number LO	in Binary
2	Date HI	0530$_{16}$, FF05$_{16}$, FF06$_{16}$
3	Date Lo	or FFo7$_{16}$ for Flights 4-7
4	Hours	BCD time since turn on
5	Minutes	
6	Seconds	
7	94 GHz mixer bias	12 Bit Binary Data (Packed)
8	-----------------	
9	183 GHz mixer bias	
10	183 GHz Gunn Temp	
11	-----------------	
12	94 GHz Gunn Temp	
13	94 GHz Mixer Temp	
14	-----------------	
15	183 GHz Mixer Temp	
16	Reference Load Temp	
17	-------------------	
18	Cold Load #1 Temp	
19	Cold Load #2 Temp	
20	-----------------	
21	Cold Load #3 Temp	
22	Hot Load #1 Temp	
23	-----------------	
24	Hot Load #2 Temp	
25	Hot Load #3 Temp	
26	----------------	
27	Digital Package Temp	
28	94 GHz Data	
29	----------------	
30	183 GHz Data	
⋮	94 GHz Data	
1023	"	

The cartridge tape system used on the radiometer was organized as 4 tracks with 850 blocks per track. Thus the block number will reset to 0000 after each track.

The block number is simply a binary number with a range of 0000-0352_{16}. The date bytes contain the actual date of 0530 for the May 30 flight (flight no. 4) and contain FF05, FF06 and FF07 for flights 5, 6 and 7. The time of day clock is in BCD and reads normally.

The two bias words represent the DC bias in microamps applied to the 94 and 183 GHz mixers. The range is 000-FFF_{16} with a full scale current of 1000 microamps. There are thus 0.244 microamps/count. The 183 GHz bias was usually close to zero and nominal values for the 94 GHz bias were in the range of 900-930 microamps.

All of the temperatures in the housekeeping data were recorded as voltages in the range of 0 to 10 volts. In order to convert to temperature the following formula was used for all but the cold load:

$$T(°C) = (-10 \text{ deg/volt} \times V) + 100 \text{ deg}$$

Where V = 0.00244 volts/count

For the cold load temperatures:

$$T(°C) = (-10 \text{ deg/volt} \times V) + 50 \text{ deg}$$

Thus a hot load reading of 138_{16} = 0.00244 x 312 = 0.76 volts = 92.4°C.

Radiometric data words also represented voltages and were recorded from the outputs of the phase sensitive detectors. These voltages were linearly related to brightness temperature. The constants for converting these numbers to temperature was obtained from the calibration data. Bascially a point-slope equation of the calibration line was obtained by measuring the radiometer output while it was viewing two known temperatures. With the two voltages V_H and V_C and the actual hot and cold load temperatures (from the housekeeping data) T_H and T_C, the following formula resulted:

$$T_R(°K) = \left(\frac{T_H - T_C}{V_H - V_C}\right)(V_R - V_H) + T_H + 273$$

where T_R is the brightness temperature in degrees Kelvin, and V_R is the recorded voltage. T_H and T_C were obtained from the average of the three load temperatures. The number of samples recorded for V_H and V_C depended on the calibration speed, angular extent of the load and time constant of the system. The calibration speed was chosen so that at least five samples could be averaged.

The flight data was transferred from cartridge to reel-to-reel tape which was turned over to NASA/GSFC. The reel-reel tape contains data from the WB-57F flights of May 30, June 5, June 7 and June 8. The flights are separated by End of File (EOF) marks with two EOF marks after the last data block. All data is organized into 1024 byte blocks. The range of block numbers for each flight and the total block count and approximate flight hours of data are listed in Table 6.

4.2 September 1979 - Florida Thunderstorm Mission

During deployment at Homestead AFB, Florida from 10 September to 25 September, 1979, the AMMS was flown on the NASA WB-57 for 10 flights. AMMS returned useful data from 7 of these flights. Various problems with Georgia Tech equipment, and in-flight operational procedures resulted in no useful data from flights 1, 5 and 7. AMMS data from these flights were originally recorded on standard 3M DC-300XL (450' length) cartridge tapes. A copy of all data was made on a single 10-1/2" reel of standard 9-track 800 BPI computer tape and sent to GSFC.

A complete set of flight data summary logs were printed by the ground support equipment terminal. These logs contain pertinent housekeeping information as well as min and max brightness temperatures covering each 6 scan data cycle. A description of each print item on the flight log is given in Section 3.2. Following are comments on some of these print items as pertains to these flights.

Column #2: "TIM": The internal clock timer was operational on all flights with the exception of flight #2.

Table 6

WB-57F MAY/JUNE 1979 FLIGHT DATA SUMMARY

DATE	FLIGHT NO.	BLOCK COUNTS	TOTAL BLOCKS	FLIGHT TIME (hrs)
5/30/79	4	0-849 0-784	1635	4.5
6/5/79	5	0-849 0-98	949	2.6
6/7/79	6	0-849 0-849 0-228	1929	5.3
6/8/79	7	0-849 0-849 0-363	2064	5.7
		TOTAL BLOCKS	6577	
		TOTAL DATA	6.73 megabytes	
			TOTAL FLIGHT TIME	18.1

Column #3: "IRIG": Problems with the demodulation software and noise on the time code line caused periodic mis-reading of the code especially in flight #2. Most flights contained enough valid codes to locate any particular block accurately in time. In the case of flight #2, the only valid code was recorded in block 2 at 17:32 Z. Reference to the aircraft flight logs and using the constant 23 seconds/cal cycle should enable any block to be located within a few seconds.

Column #5: "HT": Problems with the temperature controller caused the hot load temperature reading to exceed 99°C on flight #6.

Columns #10, #11, #12, #13: "G2", "G1", "G5", "G0": Nominal values of gain G2 for flights 2 through 5 were from 50-70 degrees per volt. Prior to flight #6 G2 was adjusted to the range of 25 to 35. Sudden changes in gain were probably the result of RFI in flight. Due to the high ΔT_{min} of the 183 GHz channels large swings in G1, G5 and G0 occurred during most flights. The 5 GHz channel provided the most consistant gain values of the three 183 GHz channels. Values of gain less that Ø or greater than 999 result in *** due to print format overflow.

Table 7 is a summary of the flight data that was recorded. The 7114 blocks of recorded data represent 22.7 hours of radiometer operation. Of these 7114 blocks, 6660 were actually recorded during flight time for a total of 21.3 flight hours of data. Each group of contiguous blocks represent data either from one track of the cartridge tape (2.6 hours) or operation until power failure if less than 820 blocks. Note that each cartridge tape contains the operating system software in the first two blocks of track Ø. These blocks are not analyzed by the flight log program and are not included in the block totals. They are, however, recorded on the 9-track tape. Data from each flight is separated by an EOF mark. Two EOF marks are recorded at the end of the 9-track tape.

Table 7

WB-57F SEPTEMBER 1979 FLIGHT DATA SUMMARY

Flight No.	Date	Contigous Blocks	Total Blocks	Comments
2	9/14/79	849	849	Did not switch tracks
3	9/15/79	820	820	Recorded over data on Track Ø
4	9/17/79	820		Flight Data
		598	1418	Flight Data
5	9/18/79	88	88	Ground test only
6	9/21/79	20		Ground Test
		12		Ground Test
		162		Flight Data
		28		Flight Data
		406	628	Flight at 45,000'
7	9/22/79	216	216	Ground test only
8	9/23/79	26		Ground Test
		820		Flight Data
		544	1390	Flight Data
9	9/24/79	820	820	Flight Data
10	9/25/79	92		Ground Test
		8		Flight Data
		786	886	Flight Data

4.3 February 1980 - Winter Snow Mission

The objectives of this WB-57F mission was to experimentally investigate the application of radiometry at 94 GHz and 183 GHz for the mapping of rain, water vapor, and snow precipitation. The AMMS was the only instrument mounted on the pallet during this mission. A minor modification was made to the AMMS digital package cover to allow easier access to the flight tapes. Figure 26 is a photograph taken of the AMMS cover with the access port shown right above the flight recorder tapes. Appendix D is a description of the procedures used to perform pressurization and vacuum tests on the modified digital package.

Five full data flights on the WB-57F were performed during the time period of February 11, 1980 to February 28, 1980. The WB-57F was based at Ellington AFB, Texas during this mission. Target requirements in order of priority as established by NASA were: stratiform rain over land, snowfall over land, and snow on the ground. Target areas were synoptic scale fronts within 1000 nautical miles of Houston, Texas and snow surface truth areas near Steamboat Springs, Colorado.

The WB-57F data flights field support effort required Georgia Tech personnel at Ellington for pallet integration, routine maintenance/ operation of the AMMS, quick-look data imaging, and hard copy flight log printouts using the GSE. Table 8 provides a summary of the flights 1 - 7 in which data was recorded using AMMS and subsequently analyzed using the GSE. Flights 1 and 2 were shortened flights (each less than 2 hours) due to problems with the WB-57F aircraft. Flights 3 through 7 were of approximately five hours duration each during which the AMMS recorded data on flights over Colorado for snow truth, Georgia for rainstorm activity, Great Lakes region for snow/ice measurements, and near Washington D. C. for snowstorm activity.

Figure 27 is a typical flight log printout of 50 blocks of data recorded from flight 06 on 27 February 1980. A definition of each column heading shown in the printout is listed in Table 9. Some observations of the flight log are worth noting. The MA2 and MI2 temperatures shown in Figure 27 are within 40°K of each other until

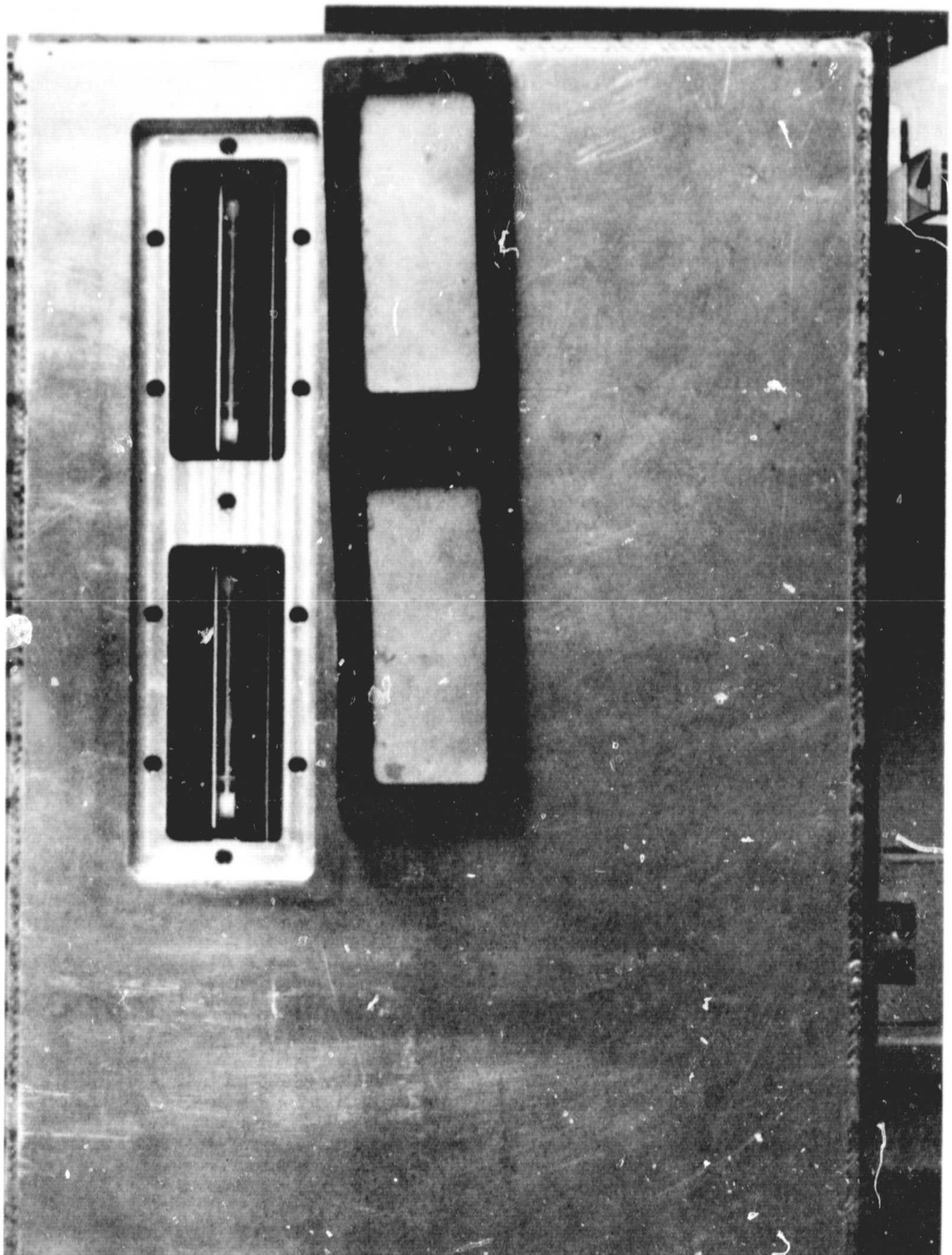


Figure 26. AMMS Modified Digital Package Cover.

Table 8

FEBRUARY 1980 WB-57F DATA FLIGHT LOG SUMMARY

Data Flight	Date	Take Off	AMMS ON	Door Open	Sky Calib.	AMMS Off	Touch Down
1	2/11	2029	2045	2034	2117	2139	2207
2	2/12	1635	1632	1643	1807	1833	1835
3	2/14	1725	1736	1730	2204	2208	2235
4	2/15	1655	1647	1657	none	2131 (tape out)	2245
5	2/22	1635	1629	1636	2052	2101	2120
6	2/27	1700	1656	1711	2201	2230	2235
7	2/28	1630	1622	1640	2127	2138	2155

FLIGHT: 06 DATE: 2/27/80 DAY: 6015

BLK	TIM	IRIG	CD	HT	RF	BIS	G2	G1	G5	G0	MA2	MI2	MA1	MI1	MA5	MI5	MA0	MI0
2	0	1656	17	49	27	922	-64	-96	-816	-49	318	287	404	220	321	279	327	271
4	0	1656	17	49	27	923	-67	-87	-751	-68	320	287	432	226	327	283	339	272
6	1	1656	17	49	27	923	-69	-83	-841	-50	321	285	398	227	323	278	326	271
J	1	1657	17	49	27	923	-61	-67	-882	-52	319	288	400	246	328	274	323	276
10	1	1657	17	49	27	923	-65	-58	-812	-57	322	287	381	249	325	282	326	270
12	2	1657	17	50	27	923	-66	-71	-875	-64	323	287	408	240	341	281	335	274
14	2	1658	17	50	27	921	-67	-75	♦♦♦♦	-64	322	285	412	220	342	274	334	270
16	2	1658	17	50	27	921	-65	-65	-883	-56	321	284	398	240	331	277	328	274
18	3	1658	17	50	27	920	-70	-63	-962	-55	325	285	397	240	331	277	324	27[illegible]
20	3	1659	17	50	27	919	-69	-57	-866	-66	323	287	389	243	326	276	331	271
22	3	1659	17	51	27	920	-71	-78	-988	-50	323	288	429	231	331	270	324	276
24	4	1659	17	51	27	920	-72	-84	-900	-51	324	285	441	224	336	277	332	276
26	4	1700	17	51	27	921	-65	-68	♦♦♦♦	-63	321	287	410	233	335	274	336	276
28	4	1700	17	51	27	920	-64	-77	-903	-54	323	290	402	226	335	275	330	276
30	5	1700	17	51	27	920	-67	-54	-777	-57	325	286	388	256	328	277	328	274
32	5	1701	17	51	27	920	-68	-60	-779	-75	322	287	391	243	336	283	336	267
34	5	1701	17	52	27	920	-65	-87	-858	-57	322	287	434	223	329	277	335	273
36	6	1701	17	52	27	919	-67	-83	♦♦♦♦	-57	320	284	418	233	339	255	326	277
38	6	1702	17	52	27	921	-64	-76	-912	-63	322	287	393	239	337	272	331	265
40	6	1702	17	52	27	920	-71	-56	-878	-64	325	286	370	242	333	275	329	274
42	7	1702	17	52	27	919	-66	-64	-877	-71	323	287	381	255	336	249	341	269
44	7	1703	17	52	27	920	-63	-70	♦♦♦♦	-53	322	287	371	245	352	230	335	285
46	7	1703	17	52	27	919	-66	-54	-869	-64	323	289	369	259	334	241	344	276
48	8	1703	17	53	27	919	-67	-58	-993	-74	323	289	348	268	333	272	338	270
50	8	1704	18	53	27	919	-64	-72	-791	-70	323	288	359	269	329	280	337	270
52	8	1704	18	53	27	920	-64	-96	-852	-54	325	288	379	245	324	274	331	280
54	9	1704	18	53	27	920	-66	-58	-974	-60	325	289	355	274	339	273	330	270
56	9	1705	18	53	27	921	-62	-77	-751	-52	322	286	410	179	330	251	330	279
[illegible]	9	1705	17	53	27	920	-64	-78	-898	-49	323	287	411	247	329	272	326	277
60	10	1705	17	53	27	921	-69	-64	♦♦♦♦	-59	327	287	369	275	336	271	337	276
62	10	1706	17	53	27	920	-67	-67	-799	-58	324	288	356	252	330	271	328	27[illegible]
64	10	1706	17	54	27	920	-66	-75	-856	-69	326	288	354	263	329	279	335	269
66	11	1706	17	54	27	920	-68	-64	-944	-62	323	286	341	263	335	275	335	275
68	11	1707	17	54	27	921	-70	-64	-797	-67	325	287	335	270	336	284	326	264
70	11	1707	16	54	27	922	-66	-68	-788	-70	325	285	350	269	329	277	326	262
72	12	1707	16	54	27	921	-64	-87	-876	-55	325	288	365	236	339	273	330	276
74	12	1708	16	54	27	921	-65	-80	-822	-55	324	287	356	248	334	279	329	275
76	12	1708	15	54	27	921	-69	-68	-997	-56	324	284	368	259	333	272	331	275
78	13	1708	15	54	27	921	-66	-89	-915	-61	324	285	362	245	331	269	331	266
80	13	1709	14	54	27	921	-70	-73	-794	-64	324	282	374	253	329	275	336	277
82	13	1709	14	55	27	921	-69	-75	-888	-63	325	285	413	248	329	249	334	266
84	14	1709	13	55	27	921	-67	-77	-868	-54	323	286	405	252	336	276	332	267
86	14	1710	13	55	27	922	-71	-70	-904	-67	324	283	420	196	335	251	340	265
88	14	1710	12	55	27	921	-68	-75	-801	-69	327	285	449	134	336	248	340	264
90	15	1710	12	55	27	921	-65	-104	♦♦♦♦	-56	324	279	501	♦♦♦	347	219	331	274
92	15	1711	11	55	27	920	-65	-44	-592	-60	294	255	393	176	318	249	305	264
94	15	1711	11	55	27	916	-71	-42	♦♦♦♦	-51	286	245	391	172	327	197	302	265
96	16	1711	10	55	27	916	-70	-61	-813	-59	287	250	432	131	345	261	303	260
98	16	1712	9	55	27	914	-67	-162	-913	-62	288	234	622	♦♦♦	297	208	301	259
100	16	1712	9	55	27	921	-66	-59	-967	-54	288	243	417	♦♦♦	306	199	303	261

Figure 27. February 1980 WB-57F Typical Flight Log Output.

Table 9

Definition of February 1980 Data Flight Log Parameters

Column Heading in Flight Log	Definition
BLK	Block number on cartridge in which data is stored
TIM	Internal time generated by AMMS
IRIG	External time code generated by WB-57F
CD	Cold calibration load temperature in °C
HT	Hot calibration load temperature in °C
RF	Dicke reference load temperature in °C
BIS	94 GHz mixer dc bias current in μa
G2	94 GHz radiometer channel gain in °K/volt
G1	183/1 GHz radiometer channel gain in °K/volt
G5	183/5 GHz radiometer channel gain in °K/volt
GO	183/10 GHz radiometer channel gain in °K/volt
MA2	Maximum 94 GHz radiometric temperature in °K recorded on block
MI2	Minimum 94 GHz radiometric temperature in °K recorded on block
MA1	Maximum 183/1 GHz radiometric temperature in °K recorded on block
MI1	Minimum 183/1 GHz radiometric temperature in °K recorded on block
MA5	Maximum 183/5 GHz radiometric temperature in °K recorded on block
MI5	Minimum 183/5 GHz radiometric temperature in °K recorded on block
MAO	Maximum 183/10 GHz radiometric temperature in °K recorded on block
MIO	Minimum 183/10 GHz radiometric temperature in °K recorded on block

time IRIG 1711 when the AMMS pallet door opens. At this time the observed temperature drops on the MI2 column indicating that the radiometer is now scanning the scene below the aircraft. The cold calibration load temperature (CD) begins to drop as the aircraft ascends. Since the aircraft takeoff was approximately 1705 one observes that the CD temperature is already down to 9°C approximately seven minutes into the flight. CD temperatures of -20°C were reached on most flights within one hour of aircraft takeoff. The gain of the 183/5 GHz radiometer channel (G5) was significantly higher than the other three gains (G2, G1, G0) as shown in Figure 27. This was because the 5 GHz IF amplifier's gain was reduced in the field due to amplifier problems. This resulted in low output voltage swings at the AMMS phase sensitive detector output which caused the calibration gain (G5) in °K/volt to go up. The **** which appear in the G5 column are an indication that the gain was greater than 999°K/volt.

The reliability of the AMMS with the exception of IF amplifier problems at 1 GHz and 5 GHz was greatly improved over previous WB-57F flights in May and September 1979. Both Gunn diode oscillators remained stable throughout the mission with no obvious changes in frequency or power output observed. The AMMS scanner performed reliably with no lockup problems occuring during any of the data flights. The 183 GHz subharmonic mixer gave good performance with ΔT_{min} of approximately 6°K, for 30 ms integration time, on the 10 GHz channel. The AMMS data collection system reliably stored data on all flights as reported by the WB-57F backseat operator. Quick-look analysis of the data was performed following each flight using the GSE to provide simultaneous images of all four radiometric channels. A complete log of each flight was printed out using the GSE computer terminal and sent to NASA/GSFC.

The 1 GHz IF amplifier was severely interferred with by the WB-57F aircraft transponder which transmits at 1090 MHz continuously. Upon request from Georgia Tech, NASA/JSC agreed to shut off the transponder for brief periods of less than five minutes during selected flights. One such occurrance was during flight 04 on 15 February 1980 beginning at IRIG 1724 and ending at IRIG 1731. The gain (G1) was relatively constant during the transponder off time.

The 5 GHz IF amplifier continued to perform in an erratic mode during the early flights. Field tests revealed a bad internal connection on an FET lead in the mid-stage of the IF amplifier. Efforts to repair the circuit were unsuccessful so the stage was bypassed, thus reducing the amplifier's gain from 70 dB to approximately 50 dB. The amplifier was re-installed in the AMMS for the remaining flights 5 - 7 with poor performance because of the reduced gain.

Table 10 is a summary of the flight data that was recorded. The data from the flight cartridges was transferred to reel-to-reel tape and forwarded to NASA/GSFC. Data from each flight is separated by an EOF mark. Two EOF marks are recorded at the end of the 9-track tape.

Table 10

WB-57F FEBRUARY 1980 FLIGHT DATA SUMMARY

Date	Flight No.	Contiguous Blocks	Total Blocks	Comments
2-11-80	1	326	326	shortened flight (54 min. data)
2-12-80	2	660	660	shortened flight (1 hr.-50 min. data)
2-14-80	3	217 538 534	1289	flight data
2-15-80	4	482 540 537	1554	flight data (tape out at 2131)
2-22-80	5	498 540 536	1574	flight data
2-27-80	6	445 540 540 362	1895	flight data
2-28-80	7	438 540 540 252	1770	flight data

5.0 Conclusion

The 94/183 GHz scanning radiometer has demonstrated successfully on the WB-57F data flights the capability to collect data from severe storm regions during the Project SESAME and the Florida Thunderstorm missions in 1979. In addition the Ground Support Equipment offered a quick-look data analysis following each flight including: a four channel display of radiometric images of calibrated brightness temperatures for each scan cycle, a hard copy printout of the day's flight log, and the transfer of the flight data to a computer compatible tape for future detailed analysis.

Even though Georgia Tech was not tasked with any long term data analysis of the 1979 WB-57F flights, some time was spent analyzing selected portions of the flight data to improve system performance before the February 1980 Winter Snow Mission. A computer program was written for the ground support processor in order to produce tapes with calibrated brightness temperature data that was read by Georgia Tech's Earth Resources Data Analysis System (ERDAS). This resulted in a higher resolution display of the data and produced pseudo-color and black and white radiometric images. By using non-linear color transfer functions available with ERDAS, the visibility of desired temperature ranges (such as in a rain cell) were enhanced.

Georgia Tech could improve the performance of the radiometer ground support equipment by rewriting the analysis software. A different BASIC compiler would be used which produces faster executing code. It would increase by a factor of two the speed of the quick-look data analysis process including both the flight log generation and the creation of the four channel display. Additional capabilities could be added at that time such as an individual pixel temperature printout.

As a result of the successful measurement programs to date, NASA has asked for Georgia Tech to participate in the September 1980 hurricane flights with the AMMS onboard the WB-57F aircraft. Prior to these flights Georgia Tech will be improving the performance of the AMMS by replacing the 1 GHz and 5 GHz IF amplifiers with improved devices to provide better temperature sensitivities on these channels. The microstrip triplexer will be replaced due to a shift in the 1 GHz channel frequency away from aircraft RFI such as TACAN and the WB-57F transponder. The new triplexer will result in lower losses in all three 183 GHz IF channels. The LO injection cavity for the 94 GHz system will be reworked to reduce the LO injection loss and the signal loss of this channel. Work is continuing on improvements to the mixers. Matching networks are being developed for the 183 GHz IF system. A lower loss lens will be fabricated using a less lossy material (TPX). RFI absorbing material will be added to the interior of the IF box to improve shielding.

Appendix A

94/183 GHz Scanning Radiometer Revised Electronic Drawings List

Drawing No.	Title
A-1902-C132	Stepper Motor Controller Processor Bus/Motor Interface Logic
A-1902-C133	Scanner Processor Assembly: Internal Connection
A-1902-D134	3M DCD-3 Cart Drive Interface
A-1902-D135	Radiometer Processor Assembly: Connector Cabling
A-1902-D136	Exorciser to Digi-Data DBTS Interface
A-1902-D137	RPU I/O Board
A-1902-C138	Thermistor Multiplexor/Amplifier
A-1902-C143	PSD Line Driver Module
A-1902-C144	Dual Channel Video Amplifier
A-1902-D147	Dual Channel Phase Sensitive Detector
A-1902-B148	Four Channel Integrate/Dump Control
A-1902-C156	94/183 GHz Mixer DC Bias
A-1902-B157	Lamp Driver Module
A-1902-D158	Radiometer Digital Package Wiring Diagram
A-1902-B159	Chopper Reference Circuit
A-1902-C161	Test Cable for Scanner Processor
A-1902-D164	RF Box Wiring Diagram
A-1902-C168	IF Box Component Schematic
A-1902-B169	RF and Scanner Component Layout
A-1902-C170	Test Box Schematic
A-1902-C171	Radiometer Interconnect Diagram

Appendix B

94/183 GHz Scanning Radiometer Revised Mechanical Drawings List

Drawing No.	Title
A-1902-B025	Corrugated Antennas for NASA Flight Radiometers
A-1902-C037	94 GHz Directional Filter
A-1902-C038	183 GHz Directional Filter
A-1902-D044	Revised Triplexer
A-1902-C072	Reference Hot Load
A-1902-C073	Reference Cold Load
A-1902-D075	Revised Radiometer Location Relative to Pallet
A-1902-B082	Five Inch Lens With Seven Inch F.L.
A-1902-D084	RF Housing With Lens Holder Detail
A-1902-D095	Digital Package Lower Half
A-1902-D096	Digital Package Upper Half
A-1902-B113	RF Breather Valve Mounting Detail
A-1902-D116	AMMS Package Configuration
A-1902-D139	Reference Cold Load Cooling Chamber
A-1902-D142	RF Housing Access Layout
A-1902-D151	Fan and Power Supply Layout
A-1902-C160	Cartridge Access Door
A-1902-D162	Layout of Cartridge Access Door on Digital Package Cover
A-1902-C163	Cartridge Access Port Doubler

Appendix C

Cartridge Tapes Data Format

(Feb. 1980 Winter/Snow Mission)

Block	Byte No. (HEX)	Byte Contents (Left Nibble / Right Nibble)	Data Type
Even	0	Block No. (MSB)	Binary
	1	Block No. (LSB)	Binary
	2	IRIGB Day (MSB)	Packed BCD
	3	IRIGB Day (LSB)	
	4	Internal Time Hours	
	5	Internal Time Minutes	
	6	Internal Time Seconds	
	7	IRIGB Time Hours	
	8	IRIGB Time Minutes	
	9	IRIGB Time Seconds	Packed BCD
	A	94 GHz Bias Current	Packed HEX Digits
	B	94 GHz Bias Current/183 GHz Bias Current	
	C	183 GHz Bias Current	
	D	183 GHz Gunn Temp.	
	E	183 GHz Gunn Temp./94 GHz Gunn Temp.	
	F	94 GHz Gunn Temp.	
	10	94 GHz Mixer Temp.	
	11	94 GHz Mixer Temp./183 GHz Mixer Temp.	
	12	183 GHz Mixer Temp.	
	13	Ref. Load Temp.	
	14	Ref Load Temp./Cold Load #1 Temp.	
	15	Cold Load #1 Temp.	
	16	Cold Load #2 Temp.	
	17	Cold Load #2 Temp./Cold Load #3 Temp.	
	18	Cold Load #3 Temp.	
	19	Hot Load #1 Temp.	
	1A	Hot Load #1 Temp./Hot Load #2 Temp.	
	1B	Hot Load #2 Temp.	
	1C	Hot Load #3 Temp.	
	1D	Hot Load #3 Temp./Digital Box Temp.	
	1E	Digital Box Temp.	Packed HEX Digits
	1F	FF(EOD/Begin Scan 1 Flag)	2 HEX Digits
Even	20	5 GHz Data - Pixel 1, Scan 1	Packed HEX Digits

Table Cont.

Block	Byte No. (HEX)	Byte Contents (Left Nibble / Right Nibble)	Data Type
Even	21	5 GHz Data/10 GHz Data - Pixel 1, Scan 1	Packed HEX Digits
	22	10 GHz Data - Pixel 1, Scan 1	
	23	2 GHz Data - Pixel 1, Scan 1	
	24	2 GHz Data/ 1 GHz Data - Pixel 1, Scan 1	
	25	1 GHz Data - Pixel 1, Scan 1	
	26	5 GHz Data - Pixel 2, Scan 1	
	27	5 GHz Data/10 GHz Data - Pixel 2, Scan 1	
	28	10 GHz Data - Pixel 2, Scan 1	
	29	2 GHz Data - Pixel 2, Scan 1	
	2A	2 GHz Data/ 1 GHz Data - Pixel 2, Scan 1	
	2B	1 GHz Data - Pixel 2, Scan 1	
	≈	≈	
	146	5 GHz Data - Pixel 50, Scan 1	
	147	5 GHz Data/10 GHz Data - Pixel 50, Scan 1	
	148	10 GHz Data - Pixel 50, Scan 1	
	149	2 GHz Data - Pixel 50, Scan 1	
	14A	2 GHz Data/1 GHz Data - Pixel 50, Scan 1	
	14B	1 GHz Data - Pixel 50, Scan 1	Packed HEX Digits
	14C	FF(EOD/Begin Scan 2 Flag)	2 HEX Digits
	14D	5 GHz Data - Pixel 1, Scan 2	Packed HEX Digits
	14E	5 GHz Data/10 GHz Data - Pixel 1, Scan 2	
	14F	10 GHz Data - Pixel 1, Scan 2	
	150	2 GHz Data - Pixel 1, Scan 2	
	151	2 GHz Data/1 GHz Data - Pixel 1, Scan 2	
	152	1 GHz Data - Pixel 1, Scan 2	
	≈	≈	
Even	278	1 GHz Data - Pixel 50, Scan 2	Packed HEX Digits

Block	Byte No. (HEX)	Byte Contents (Left Nibble / Right Nibble)	Data Type
Even	279	FF(EOD/Begin Scan 3 Flag)	2 HEX Digits
	27A	5 GHz Data - Pixel 1, Scan 3	Packed HEX Digits
≈	≈	≈	≈
Even	3A5	1 GHz Data - Pixel 50, Scan 3	Packed HEX Digits
Odd	0	Block No. (MSB)	Binary
	1	Block No. (LSB)	Binary
	2	5 GHz Data - Pixel 1, Scan 4	Packed HEX Digits
	3	5 GHz Data/10 GHz Data - Pixel 1, Scan 4	
	4	10 GHz Data - Pixel 1, Scan 4	
	5	2 GHz Data - Pixel 1, Scan 4	
≈	6	2 GHz Data/1 GHz Data - Pixel 1, Scan 4	≈
	7	1 GHz Data - Pixel 1, Scan 4	
	8	5 GHz Data - Pixel 2, Scan 4	
	≈	≈	
Odd	12D	1 GHz Data - Pixel 50, Scan 4	Packed HEX Digits
Odd	12E	FF(EOD/Begin Scan 5 Flag)	2 HEX Digits
Odd	12F	5 GHz Data - Pixel 1, Scan 5	Packed HEX Digits
≈	≈	≈	≈
Odd	25A	1 GHz Data - Pixel 50, Scan 5	Packed HEX Digits
Odd	25B	FF(EOD/Begin Scan 6 Flag)	2 HEX Digits
Odd	25C	5 GHz Data - Pixel 1, Scan 6	Packed HEX Digits
≈	≈	≈	≈
Odd	387	1 GHz Data - Pixel 50, Scan 6	Packed HEX Digits
Odd	388	FF(EOD Flag)	2 HEX Digits

Block	Byte No. (HEX)	Byte Contents (Left Nibble / Right Nibble)	Data Type
Odd	389	FF(Start Hot Calib. Flag)	2 HEX Digits
	38A	5 GHz Calib. Data - Hot Sample 1	Packed HEX Digits
	38B	5 GHz Calib./10 GHz Calib. Data - Hot Sample 1	
≈	38C	10 GHz Calib. Data - Hot Sample 1	
	38D	2 GHz Calib. Data - Hot Sample 1	≈
	38E	2 GHz Calib./1 GHz Calib. Data - Hot Sample 1	
	38F	1 GHz Calib. Data - Hot Sample 1	
Odd	390	5 GHz Calib. Data - Hot Sample 2	Packed HEX Digits
≈	≈	≈	≈
Odd	3C5	1 GHz Calib. Data - Hot Sample 10	Packed HEX Digits
	3C6	FF(Start Cold Calib. Flag)	2 HEX Digits
	3C7	5 GHz Calib. Data - Cold Sample 1	Packed HEX Digits
	3C8	5 GHz Calib./10 GHz Calib. Data - Cold Sample 1	
≈	3C9	10 GHz Calib. Data - Cold Sample 1	
	3CA	2 GHz Calib. Data - Cold Sample 1	≈
	3CB	2 GHz Calib./1 GHz Calib. Data - Cold Sample 1	
	3CC	1 GHz Calib. Data - Cold Sample 1	
Odd	3CD	5 GHz Calib. Data - Cold Sample 2	Packed HEX Digits
≈	≈	≈	≈
Odd	3FC	1 GHz Calib. Data - Cold Sample 9	Packed HEX Digits
	3FD	5 GHz Calib. Data - Cold Sample 10	
≈	3FE	5 GHz Calib./10 GHz Calib. Data - Cold Sample 10	≈
Odd	3FF	10 GHz Calib. Data - Cold Sample 10	Packed HEX Digits

Appendix D

Pressurization and Vacuum Test Procedures
On the AMMS Digital Package

VACUUM TEST OF AMMS DUAL CARTRIDGE RECORDER MOUNTED IN DIGITAL PACKAGE

The recorder was mounted inside the digital package and the gasketed cover was installed. AC power to the recorder was provided and the data link was connected so that the recorder could operate (data transfer to external terminal) under vacuum test.

The 7 psi release valve on the digital package was removed and the opening in the package was covered so that the test could be performed at 11 psi maximum differential (4 psi inside the digital package). The recorder performed without any problems during the test duration of approximately 1 hour. No problems were observed following the test when the pressure was returned to normal.

A deflection of approximately 1/4 in. was observed in the cover of the digital package during the vacuum test. As a result it was decided to weld stiffener ribs (0.5 in. thick aluminum) on the inside of the cover. A repeat of the vacuum test revealed only 1/16 in. deflection at 11 psi differential.

Figure 1 shows the test set-up for the vacuum test operation.

PRESSURE TEST OF AMMS DIGITAL PACKAGE

The gasketed cover was installed and the package was pressurized to 7 psi differential (22 psi inside the package). No problems were encountered and the release valve operated properly.

The release valve was removed and the opening covered so that the package could be tested to a differential pressure higher than 7 psi. The package was pressurized to 10 psi differential (25 psi inside the package). No leaks in the gasketed cover were detected.

Figure 2 shows the test set-up for the pressure test operation.

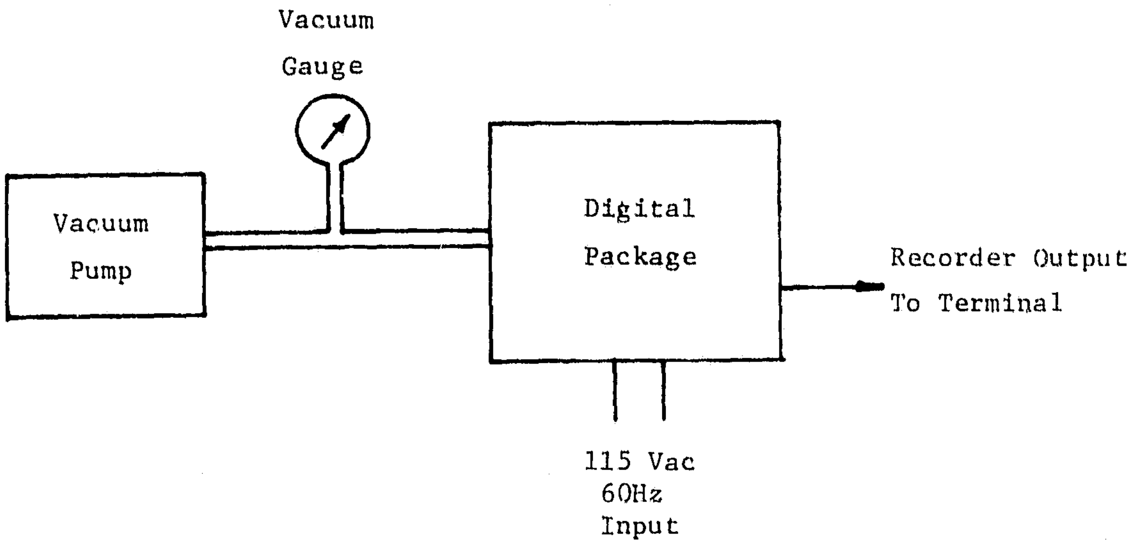


Figure 1. Dual Recorder Test At 4 psi Absolute

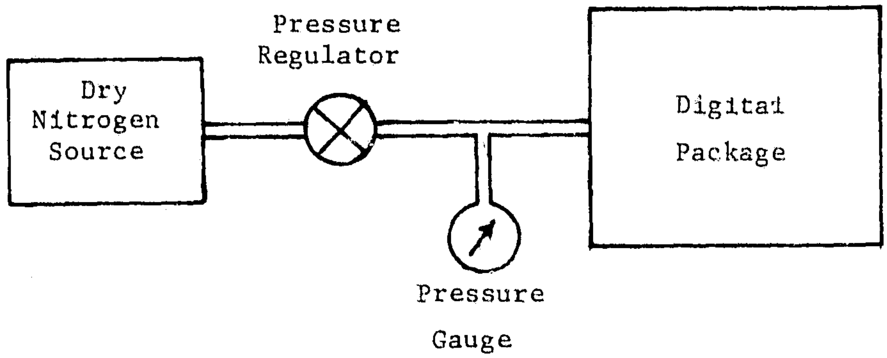


Figure 2. Digital Package Test at 25 psi Absolute