WALLOPS SEVERE STORMS MEASUREMENT CAPABILITY

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INTRODUCTION

Since its establishment in 1945, Wallops Flight Center has been a facility where both government research agencies and independent investigators from the United States and abroad can conduct a broad range of experiments. Over the years Wallops has installed a wide array of instrumentation systems and has assembled a highly trained group of personnel to support these experiments.

In this report we will discuss some of the instrumentation systems used in support of NASA's Storm Hazards Program. These systems include the Radar Atmospheric Research Facility (RARF) with its ultra-sensitive, high-resolution Space Range Radar (SPANDAR), a near real time display from the National Weather Service WSR-57 radar at NAS, Patuxent River, a Lightning Detection and Ranging System (LDAR), and a Ryan Stormscope.

We will first discuss the measurements that can be made with the systems that make them useful to the program and then describe the individual systems in some detail. Lastly, we will discuss modifications being made to prepare for the 1981 storm season.

MEASUREMENT CAPABILITIES

Wallops has available a combination of ultra-sensitive, high-resolution, multi-wavelength radar system that can detect, track, and quantify the properties of severe storms. Simultaneous measurements in the UHF (70 cm), S (10 cm), and C (5 cm) bands can be made of clouds and precipitation to deduce particle size and characteristics, including quantitive cross sections of individual hail-stones and raindrops. Relative attenuation at these wavelengths can be used to calculate path integrated rainfall and water content. The track of an instrument aircraft can be displayed on a S-band reflectivity map of the individual storm cells, thus correlating in situ aircraft measurements with the overall structure of the storm. The addition of doppler processing for the S-band radar, planned for 1981, will permit investigations of velocity fields associated with thunderstorms or coastal hurricanes.

The Lightning Detection and Ranging System (LDAR) and the Ryan Stormscope can be used to study the electrical properties of storms. The LDAR system can determine the location of lightning discharges in real time and measure and record the electric field waveform for further study. The Ryan Stormscope can detect and range lightning out to 320 kilometers (200 miles). The radars and the lightning detection systems should be able to detect the earliest phases of cloud electrification and precipitation.

Other weather phenomena which may be studied as precursors of storm systems or for their own interesting behavior are: sea breeze fronts, gust fronts, and tenuous regions of turbulence in the upper atmosphere.

As an integral part of any program, Wallops makes available operation meteorological support in the form of standard and special surface and upper atmosphere measurements, routine and special weather forecasting and weather briefing.

RADAR ATMOSPHERIC RESEARCH FACILITY (RARF)

The Radar Atmospheric Research Facility (RARF) consists of two separate research and development radar systems, one operating in the UHF (70 cm) band and the other in the S (10 cm) band. The facility was constructed in the late 1950's for a program involving atmospheric reentry of missile payloads. It originally included an X (3 cm) band radar which has since been dismantled. Since 1965 the facility has been used almost exclusively for atmospheric research projects. (See reference 1.) All of the ground based data collection instrumentation for the Storm Hazards Program are presently located at RARF for convenience of operation; however, in the future some may be located elsewhere.

Only the S-band radar (SPANDAR) is used in the Storm Hazards Program. It is used to survey any storm within a 100 nautical mile radius of Wallops in order to choose interesting storm cells as possible candidates for aircraft penetration, to monitor the aircraft's flight, and to display and to record radar reflectivity data from the storm the aircraft penetrates. The radar PPI scan is displayed on a 19-inch color television monitor along with the range time and the position of the aircraft. This real time PPI scan is also recorded on video tape. The PPI and RHI data scans are recorded both photographically and on digital tape.

As a supplement to the SPANDAR radar system, near real time presentation of the data from the National Weather Service WSR-57 weather radar, located at NAS, Patuxent River, Maryland, is displayed on another 19-inch color television monitor. These data are recorded when SPANDAR data are not available and at other times for documentation purposes.

A more detailed description of SPANDAR and the two display systems is given below.

SPACE RANGE RADAR (SPANDAR)

The Space Range Radar (SPANDAR) is a precision, long-range, S-band, conical scan, tracking radar. It was originally designed to collect missile reentry tracking data and deep space trajectory data. While it is still capable of performing these functions, it has been used most intensively since the middle 1960's in atmospheric research. Figure 1 is a block diagram of the SPANDAR. Table 1 gives the technical characteristics of the radar. Figures 2 and 3 are views of the SPANDAR antenna and tracking console.

The SPANDAR has two transmitters which differ only in power output. The high-power transmitter's peak power output is 5.0 megawatts with a 10 MHz bandwidth over a frequency band of 2700 to 2900 MHz. The low-power transmitter's peak power is 1.3 megawatts with a 10 MHz bandwidth over a frequency band of 2800 to 2900 MHz.

For meteorological measurements both transmitters are controlled by a frequency diversifier. The diversifier shifts the transmit frequency of each radar pulse by the reciprocal of the pulse width, thus making each pulse independent in frequency from every other pulse. The radar receiver is programmed in step with the transmitter so that echoes from each pulse are received in the proper range gate.

Frequency diversity allows for the accumulation of a large number of independent meteorological echoes at a much faster rate than normal, thus increasing the radar scan rate. It also rejects second-time around targets which fall outside the receiver bandwidth. Another advantage is that it inserts a calibration signal. In this way any receiver drift can be automatically compensated (reference 2).

The return signal from a precipitation volume is routed from the receiver to a Digital Video Integrator and Processor (DVIP) (reference 3). The DVIP is an intensity contouring device that continuously averages radar logarithmic video in range and direction to obtain quantitive estimates of mean detected precipitation returns. The accuracy of mean intensity estimates is improved over that of a logarithmic receiver by 1.0 db or less at range increments of 1 and 2 kilometers. Specifically, the DVIP (1) accepts logarithmic video over a maximum range of 80 db, (2) continuously integrates log video samples digitally in range and on a pulse-to-pulse basis in range increments of 1 and 2 kilometers, (3) provides a fixed range normalization function as part of the digital processing, (4) provides a contoured log video output of six contours of mean signal intensity to the radar PPI and to a 19-inch color television monitor, and (5) provides a separate digital output of one 8-bit binary word for each integrated video sample.

As stated earlier, the display of radar reflectivity data is used both for selection of storm cells and for investigation and for monitoring the aircraft position during flight. Aircraft position is tracked by a separate C-band tracking radar and superimposed on the SPANDAR display in real time. The position data are also recorded on digital tape for post-flight analysis.

WSR-57 DATA DISPLAY

The National Weather Service WSR-57 weather radar range normalized reflectivity is transmitted by a Radar Data Remoting System (reference 4) over a dedicated telephone line from the radar location at NAS, Patuxent River, Maryland, for display on a 19-inch color television monitor at the RARF site. The up-date time for this display is two minutes. Range time is superimposed on the display. It is possible to superimpose the aircraft track on this display; however, the ground track cannot be displayed simultaneously on the SPANDAR and the WSR-57 displays. The WSR-57 reflectivities are given in the same six discrete levels as the SPANDAR display. Figure 4 shows the TV monitors used to display weather data. The right one is normally used for SPANDAR data; the left one normally displays Pax River data.

LIGHTNING DETECTION AND RANGING (LDAR)

The LDAR was originally developed at NASA Kennedy Space Center to detect potential hazardous electrical activity that might impair missile launch operation (references 5 and 6). Wallops acquired it from Kennedy Space Center in 1979, but because of funding and manpower limitation could not put it into operation for the 1980 storm season. Our current plans are to have it operational for the beginning of the 1981 storm season.

LDAR measures the times of arrival of the pulsed RF radiation emitted by an electrical discharge. This RF radiation is detected by VHF antennas at outlying sites and relayed to a central station where the spatial location of the discharge is determined. The outlying sites normally are in a Y configuration with an antenna site at the extremities of the legs of the Y and a central site where each leg meets. The best configuration for accurate location of discharges is to have an azimuth of 120° between the baselines and with the central station located at the junction of each leg of the Y. At Wallops, geographical considerations and the availability of electrical power have caused us to deviate slightly from the 120° configuration. We have also relocated the central site to the extremities of one of the legs and placed it in the SPANDAR radar building. Figure 5 shows the layout as configured for Wallops.

Two basic measurements are made at each antenna site: the time of arrival of the pulsed RF signal and the electric field (E-field) waveform. The pulsed RF is detected by a vertically polarized, omnidirectional, 40 to 100 MHz antenna (figure 6), and the E-field signal is picked up by a circular flat plate antenna (figure 7). Signals from both antennas are transmitted to the receiving station over a 8 MHz bandwidth microwave link. At the receiving station the waveform of this lightning discharge is recorded on both digital and analog recorders. A mini-computer uses the time of arrivals to solve the hyperbolic equations to locate the position of the discharge. The range/azimuth position of the discharge is plotted as a dot on a PPI plot; the height of the discharge is plotted as a dot on two separate range/height indicators (RHI). Those discharges north of an east-west line passing through the central station are plotted on one RHI and those south of this line are plotted on another RHI.

An accuracy analysis of the LDAR system (reference 7) has shown that the symmetrical Y configuration produces a uniform low measurement error with an X, Y position accuracy within the baseline of the system of less than one percent. At distances greater than the baseline length, the accuracy decreases with distance; however, quite useable data can still be obtained at distances as far away as 110 nautical miles. Within the baseline, azimuth position can be measured with an error of less than 0.1 degree. Because of the planar orientation of the receiving stations, height is measured with a lesser accuracy than azimuth or range. Height is measured more accurately above 300 meters (1000 feet). Typically, the height error is less than 100 meters. Figure 8 shows the LDAR equipment in the SPANDAR control room.

RYAN STORMSCOPE

A Ryan Stormscope is installed in the RARF building for use in conjunction with LDAR (figure 9). The Stormscope is a four-component solid state receiving system which provides bearing and range information between aircraft and electrical discharges. Radio frequency signals, generated by electrical discharges, are picked up by a single flat-pack antenna which provides both the V and H direction loop antennas and an electrical sense antenna followed with a signal amplifier. The antenna signals are routed to the receiver where processing and control functions take place. The receiver is broadband tuned with a center frequency of 50 kHz. Azimuth of the discharge is determined from the ratio of the two crossed loop antenna inputs. Polarization of the fields is detected and processed. Signals from horizontal discharges are rejected. The range of the discharge is obtained by computer evaluation of signal strength, time to peak, decay time, spectral content, and comparison of electric and magnetic field amplitudes. (The details of the physical concept of this evaluation cannot be found in the open literature and are not provided by the company). Bearing information is displayed on a CRT monitor over 360°. Range is selected in three steps of 40, 100, and 200 nautical miles (NM). The system records and displays up to 128 individual electrical discharges, as small green dots on the CRT, and automatically updates the "oldest" discharge information with the "newest." In this manner, the display is constantly updated. If the dots are not replaced by new data, each is automatically erased after five minutes. Also, dots may be manually erased by the operator. Changes in heading and position of the aircraft will not affect data already displayed, so periodic clearing is necessary to maintain an accurate presentation with respect to the changing position of the aircraft in flight (references 6 and 8).

Several years ago, the Air Force Flight Dynamics Laboratory conducted an in-flight test program to evaluate the Stormscope performance in conjunction with a Bendix X-band airborne weather radar and a ground-based LDAR detection system operated at NASA Kennedy Space Center. The result of this comparison is given in reference 9.

PREPARATIONS FOR 1981

A major effort is being made to improve the instrumentation available for the 1981 storm season. We are cooperating with the Air Force Geophysical Laboratory, Cambridge, Massachusetts, in upgrading the SPANDAR radar to provide doppler information on the radial wind components within the storm cell. The AFGL equipment will be on the SPANDAR for only the first portion of the 1981 season. After the AFGL equipment is removed we will try to record the coherent SPANDAR signal for future processing.

Another major effort is to have the LDAR system fully installed and operating for the 1981 season.

REFERENCES

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3. Anon. - Digital Video Integrator and Processor (DVIP). February 1977, Enterprise Electronics Corporation.

4. Anon. - Radar Data Remoting System (RDRS). April 1979, Enterprise Electronics Corporation.

5. Poehler, H. A. and Carl L. Lennon: Lightning Detection and Ranging System LDAR System Description and Performance Objectives. NASA TM-74105, June 1979.

6. Corbin, John C., Jr.: Atmospheric Electricity and Lightning. Talk presented at the Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, March 25-27, 1980, University of Tennessee Space Institute.

7. Poehler, H. A.: A Preliminary Test of the Application of the Lightning Detection and Ranging System (LDAR) as a Thunderstorm Warning and Location Device for the FAA. NASA CR-154629, December 1978.

8. Ryan Stormscope WX-7A Weather Mapping System. Installation and Technical Manual. No. 377A200, Revision 2, January 1980.

9. Baum, R. K. and T. J. Seymour: In-Flight Evaluation of a Severe Weather Avoidance System for Aircraft. AFFDL-TM-79-45-EES, April 1979.

TABLE I.-SPANDAR TECHNICAL CHARACTERISTICS

Transmitter System:	
Frequency	2700 to 2900 MHz
Frequency Resolution	1 MHz
Peak Power Output	5 MW or 1.3 MW
Pulsewidth	1, 2, or 5 Microseconds
Pulse Repetition Rate (PRF)	160, 320, 640, and 960 PPS
Pulse Coding	1 to 3 Pulses
Receiver System:	
Type	Superheterodyne
Dynamic Range	70 db
Noise Figure	2.5 db
Sensitivity	-119 db
I. F. Frequency	30 MHz
Bandwidth	230 kHz, 480 kHz, 1.1 MHz
Tracking Gate	6 or 18 Microseconds
Antenna System:	
Reflector	18.3 m (60 ft) Parabolic
Beamwidth	0.39°
Beam Crossover	1.5 db
Gain	52.8 db
Polarization	Circular, Vertical, or Horizontal
Antenna Temperature	$30^{\circ}K$
Feed	NUTATING (Conical, 30 Hz)
Azimuth Coverage	360°
Elevation Coverage	90°
Tracking Rates (Az. and El.)	6° Per Second
Slew Rates (Az. and El.)	15° Per Second
Ranging and Tracking System:	
Measurement Range	910 m (1000 Yds.) to 25,000 NM
Range Precision	4.57 m (± 5 Yds.)
Angle Precision	0.06°

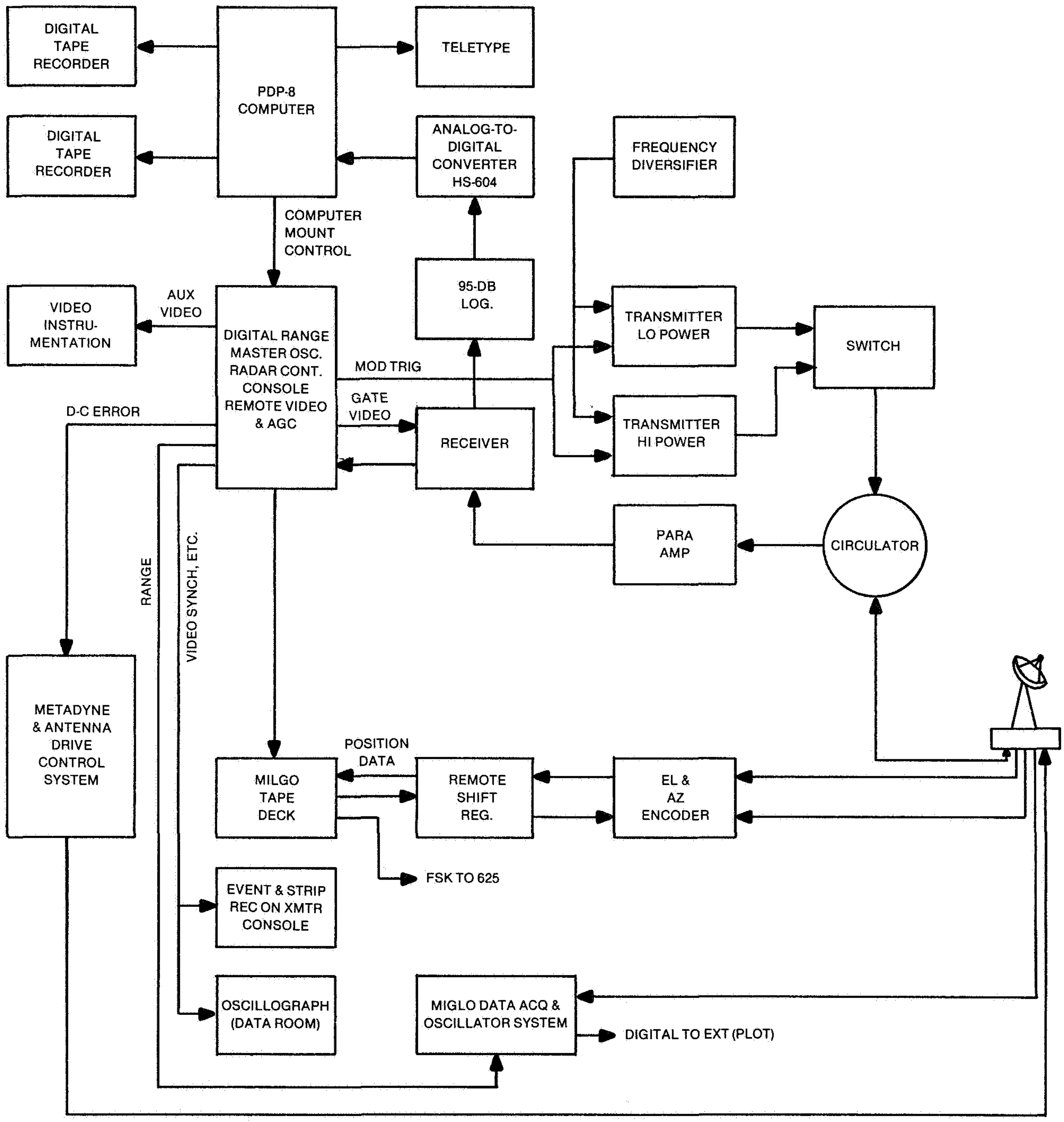

Figure 1.- Space Range Radar (SPANDAR) System block diagram.

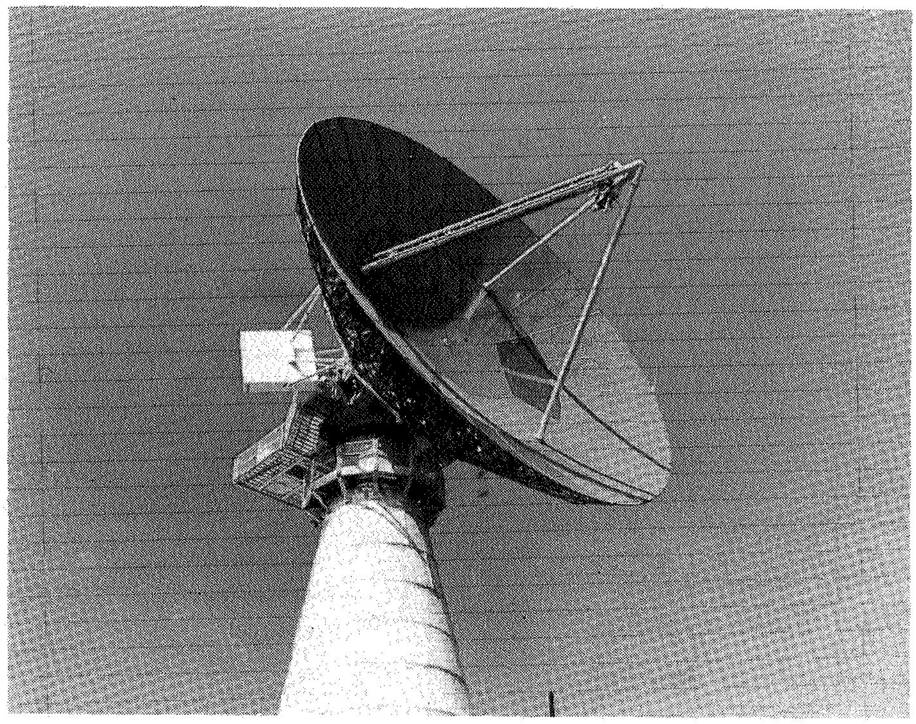

Figure 2.- SPANDAR antenna.

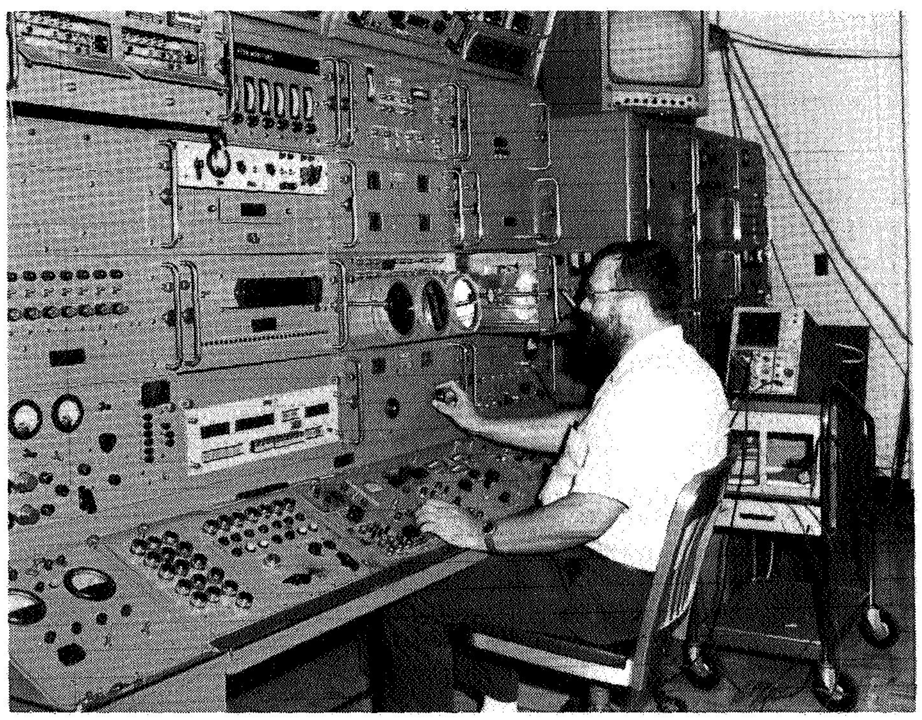

Figure 3.- SPANDAR tracking console.

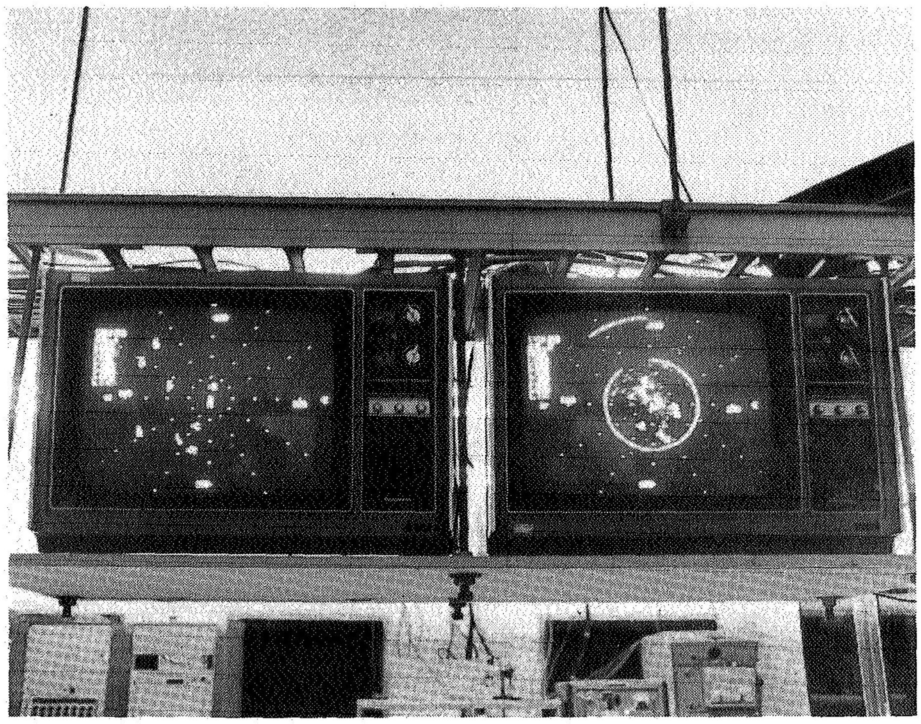

Figure 4.- Weather radar television monitors in SPANDAR control room.

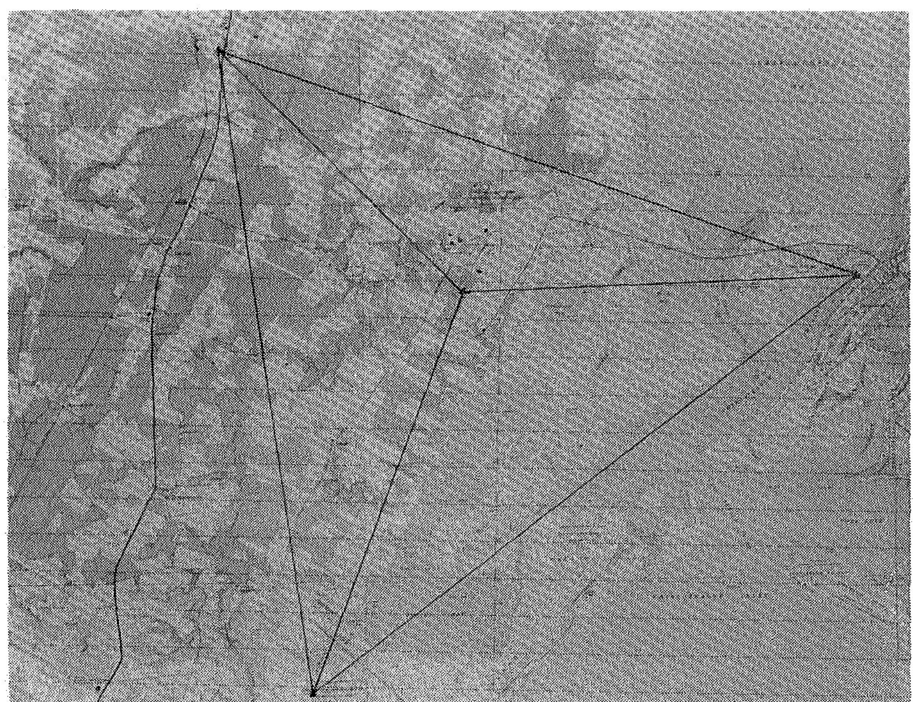

Figure 5.- LDAR antenna layout.

Figure 6.- LDAR RF antenna.

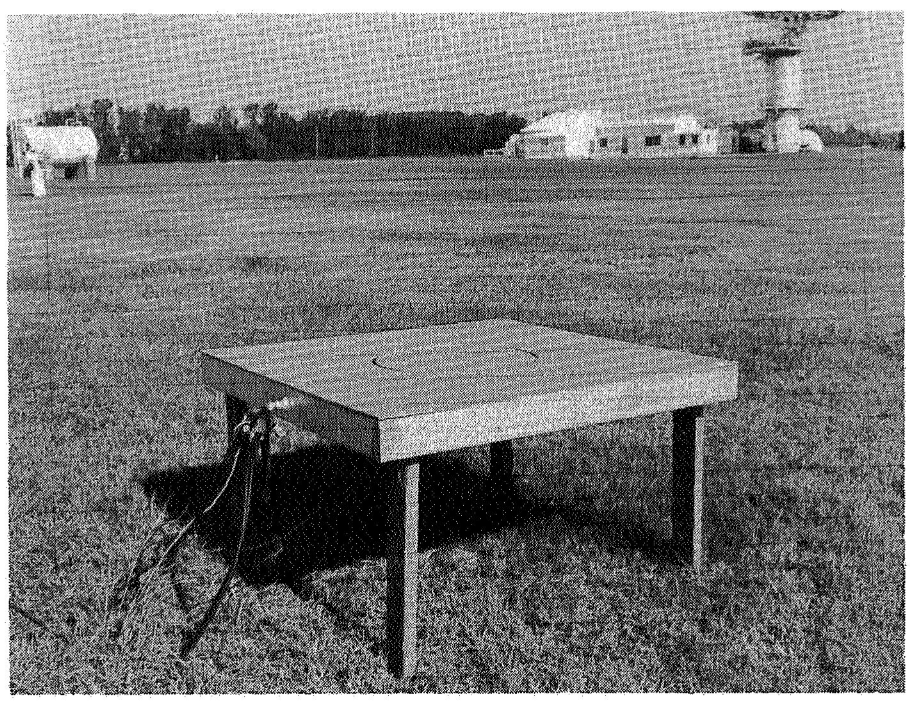

Figure 7.- LDAR e-field antenna.

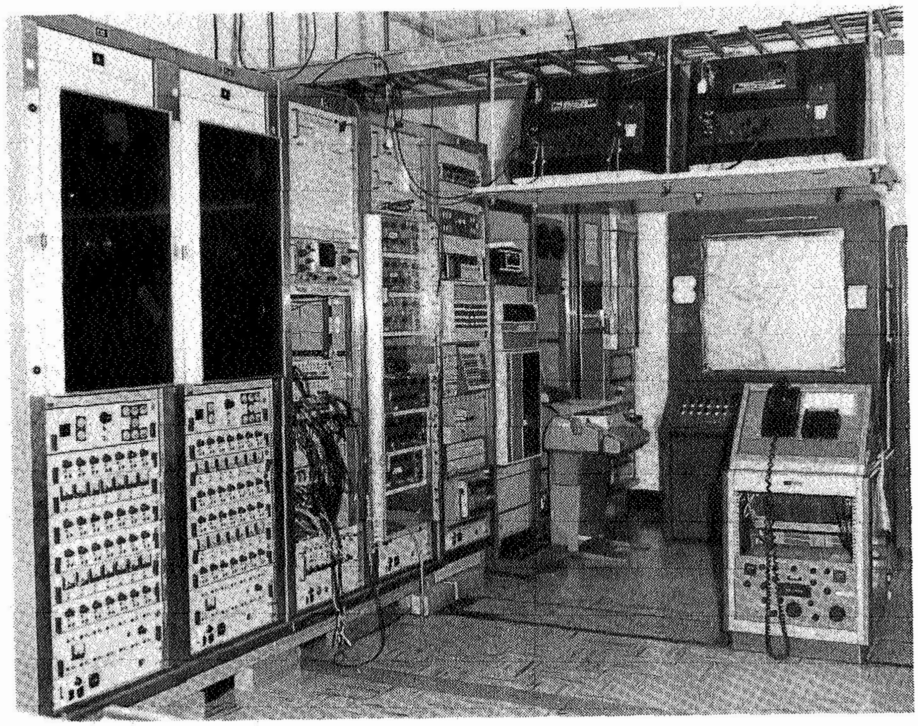

Figure 8.- LDAR receivers and data handling equipment.

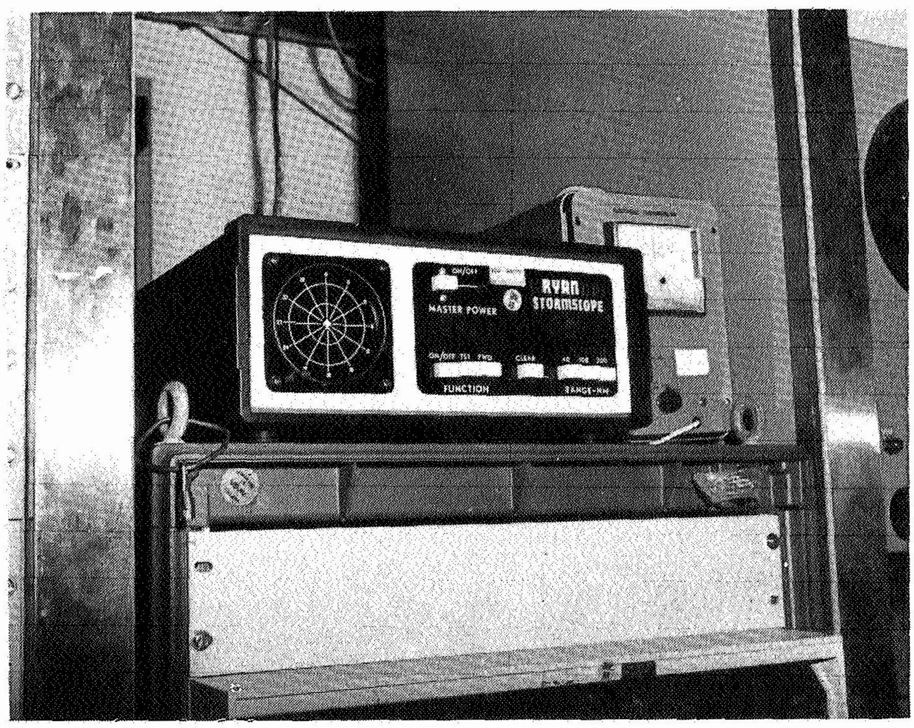

Figure 9.- Ryan Stormscope in SPANDAR control room.