Interim Radio Spectrum Surveillance Station

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Radio frequency interference at NASA's deep space stations has become a serious problem. A radio spectrum surveillance capability at these stations is needed to determine the sources of interference so that preventative measures can be taken. The first phase of a program to develop this capability was the development of a low-cost surveillance station now in operation at the Goldstone Deep Space Communication Complex near Barstow, California. This interim surveillance station is described and findings from the use of this equipment are presented.

I. Introduction

In recent years there has been a significant increase in the number of occurrences of radio frequency interference (RFI) at the NASA deep space tracking stations. The interference in some cases degraded telemetry received from deep space spacecraft and in a few cases has caused the receivers to lose lock on the spacecraft carrier signal. Attempts to identify the sources of the interfering signals have been severely handicapped because the stations have no means of determining the direction of the interfering source and very limited capability to view the interfering signal spectrum. Further, since the prime function of the station is to provide spacecraft data, the major activities of the station operators at times of signal degradation are to verify that a malfunction of station equipment has not occurred; to reacquire the spacecraft signal, if necessary; and to improve the quality of the spacecraft data.

To facilitate the identification of RFI sources so that preventative measures can be taken, a radio spectrum surveillance station has been developed and installed at the Goldstone Deep Space Communications Complex near Barstow, California. Because of the immediate need for RFI surveillance, a low-cost system using mostly off-the-shelf equipment was developed to provide surveillance capability. Later, a more sensitive and sophisticated system will be implemented. Its development will be influenced by the observations of this low-cost system.

The purpose of this presentation is to describe the interim surveillance system and to present findings from field use of this equipment.

II. Background

Before describing the surveillance station, a brief discussion of the interference protection criteria for the deep space stations will point out the difficulty in providing them with interference protection. For brevity, the discussion is limited to the 64-m antenna stations.

Also some motivating factors for implementing the surveillance station and a general overview of the equipment cost and schedule are presented.

A. Interference Criteria

There are three major interference criteria for the deep space stations. These criteria were established to prevent receiver saturation and degradation of carrier tracking and telemetry performance.

Power levels of -120 dBW or stronger in the band of 2290 to 2300 MHz will produce saturation of the DSN receiver. This condition causes an increase in the receiver-system noise temperature because of gain compression of the maser and can cause spurious signals to be introduced in the receiver because of operation in a nonlinear region of one or more stages of the receiver. Assuming that a signal source producing a -120-dBW signal level at the receiver is 2 deg off the main beam axis of the station's antenna, the power flux density (pfd) at the antenna corresponding to this power level is -116 dBW/m^2, using an off-axis antenna gain of:

$$G = 32\text{-}25 \log \phi \quad 1 < \phi < 48$$

$$G = -10 \quad \phi \geqslant 48$$

where ϕ is the angle from the main beam axis in degrees and G is in dBi (Ref. 1). For the source having angles equal to or greater than 48 deg from the main beam axis, a pfd of -81 dBW/m^2 is required to saturate the receiver.

The second criterion is a continuous wave (CW) signal no greater than -212 dBW in any 10-Hz band between 2290 and 2300 MHz. This amplitude of interfering signal will induce phase modulation on the desired carrier signal of approximately 10-deg amplitude, when the frequency separation between the two signals is comparable to, or less than, the carrier tracking loop bandwidth (assumed to be 10 Hz at receiver threshold). Using target locations of 2 deg and 48 deg off the antenna main beam axis, as above, the maximum allowable power flux densities are -208 dBW/m^2 and -173 dBW/m^2.

The third criterion is a power spectral density for noise-like interference no greater than -222 dBW/Hz. A -222-dBW/Hz amplitude interfering signal will cause approximately 1-dB degradation in telemetry performance. Both this and the second criterion are based upon C.C.I.R. Recommendation 365-3 (Ref. 2) which assumes a 16-K system noise temperature and an antenna elevation angle of 30 deg. Corresponding power flux densities at 2 and 48 deg off pointing angles are -218 dBW/m^2-Hz and -183 dBW/m^2-Hz.

B. Motivating Factors

At the time of considering the feasibility of a surveillance station at the Goldstone facility, there was evidence that aircraft in the vicinity of the stations produced the most detrimental radio frequency interference. Calculations show that an aircraft at a 160-km range and radiating 1-mW CW towards a deep space station can produce -145 dBW/m^2 at the station's antenna. Comparing this value with pfd values calculated from the interference protection criteria, it can be seen that emissions from aircraft can (and do) cause very serious interference.

Of particular concern is the possibility that communications with a spacecraft will be interrupted during critical operations such as a planetary encounter or trajectory change maneuver. At these times, it is very desirable to perform radio frequency surveillance of the spacecraft downlink frequency band. At the time of the decision to implement the surveillance station, the two upcoming encounters were the Pioneer-Venus spacecraft with Venus and the Voyager spacecraft with Jupiter.

In July 1977, it was decided that, in the 18 months remaining before the Pioneer-Venus encounter, a surveillance station suitable for detecting aircraft emitters could be developed for reasonable cost. This station would provide protection against the major source of interference and yield radio environment information valuable for the development of future surveillance stations.

C. Schedule and Cost

The work on the development of the station began in July 1977, and postinstallation testing was completed in November 1978. Hardware costs were approximately $50,000, and slightly over 3 manyears of effort were expended. Much of the equipment such as power supplies, the equipment rack, and digital recorder were on hand and not purchased.

The surveillance station did support both Pioneer-Venus spacecraft encounters and the Voyager 1 encounter.

III. General Description

The surveillance station is located on a mountain peak central to the three deep space stations and is normally unattended. In the unattended configuration, it monitors the frequency band of 2290 to 2300 MHz while scanning through 360 deg of azimuth in approximately 1 min. The receiver sensitivity allows detection of power flux densities of -137 dBW/m^2 or greater at the antenna of the surveillance station. Upon detecting a signal, a photograph is made showing the signal spectrum, spectrum analyzer control settings, time, and antenna azimuth. At the same time, the equipment provides a notification signal via landline to the Goldstone Radio Spectrum Coordinator.

The surveillance station is normally operated continuously and serves a very useful function in aiding deep space station operators to determine if a radio frequency interferer is external or internal to their station. Upon occurrence of interference, the station operators may call the Radio Spectrum Coordinator to determine if a signal was detected by the surveillance station. If so, the signal source is known to be external to the deep space station. If it was not detected by the surveillance station, however, it can not be concluded that the source is internal to the deep space station for it may be an external signal too weak to be detected by the surveillance station.

The surveillance station can also be operated manually. In this mode the operator has full control of the spectrum analyzer settings, the antenna pointing direction, antenna rotation rate, and operation of the camera and digital recorder. The maximum frequency range of the equipment in this mode is 2250 to 2320 MHz and, by use of the narrowest resolution bandwidth (10 Hz) of the spectrum analyzer, sensitivites as high as −177 dBW can be achieved.

The manual mode is used primarily for real-time identification of interferers. Because the operator can determine the received signal characteristics and the direction of the source almost immediately, other agencies can be contacted while the source is still in the vicinity of Goldstone, thereby greatly facilitating the identification of the source.

A third mode of operation, in which the spectrum analyzer is removed from the surveillance station and used with a hand-held antenna, is also provided. This mode is used for investigating radio frequency sources at locations other than the surveillance station site, for example, searching for radio emissions internal to one of the deep space stations.

IV. Functional Description

Figure 1 shows a functional block diagram of the surveillance station. The heart of the system is an analog spectrum analyzer (Hewlett Packard 8568A). Requisite features of this instrument are very high frequency stability, annotation of the display with important analyzer control settings and provision to display user-supplied information. The user-supplied information in this application is time, antenna-rotation rate, and antenna azimuth. The frequency range of the analyzer is 100 Hz to 1.5 GHz, and down conversion of the S-band received signals is necessary.

The down conversion is performed by the Microwave Assembly which contains the mixer and local oscillator circuits. To maintain high frequency stability, the local oscillator signal is generated by coherently multiplying a highly stable reference signal supplied by the spectrum analyzer.

The surveillance antenna is a standard gain horn having a maximum gain of 17.2 dBi. Its half power beamwidths are 28 deg in azimuth (H plane) and 26 deg in elevation. The mounting bracket for the antenna allows the antenna elevation angle to be wrench-adjustable from −10 to +70 deg. Since the primary goal of this equipment is to detect the presence of aircraft emitters and sources at ground level, the antenna elevation is currently set to +5 deg.

To achieve a useful receiver sensitivity at moderate cost, two uncooled, low-noise amplifiers [gallium arsenide field-effect transistor (GAs FET)] are used as a preamplifier to amplify the antenna output signal. The noise figure of the preamplifier is 1.2 dB. A bandpass filter is used before the preamplifier to protect it from degradation by transmissions from a nearby deep space station and to restrict the number of mixer product terms out of the first mixer. A CW signal having a power level of −153 dBW (corresponding to a pfd of −138 dBW/m^2) will produce a barely discernible signal on the spectrum analyzer (12-dB signal-to-noise ratio) when the station is configured for unattended operation. The resolution noise bandwidth in this mode is 4400 Hz.

Automatic recording of the received signal spectra is performed by a 35-mm camera triggered by a signal-to-noise ratio detector. Detecting the signal-to-noise ratio instead of the absolute signal level eliminates the problem of receiver gain variation with temperature (approximately 2 dB).

The presence of a signal-to-noise ratio which exceeds a present threshold value, in addition to actuating the camera, also:

(1) Produces a printed record of the time and azimuth at the end of the sweep during which the signal was detected.

(2) Notifies the Radio Spectrum Coordinator of the detection.

(3) Increments counters at both the surveillance station and at the Radio Spectrum Coordinator's position.

Figure 2 is a photograph of the spectrum analyzer display taken by the recording camera. Time, antenna azimuth, and antenna rotation rate displayed at the top of the display are updated at the end of each spectrum analyzer sweep. With these parameters and the analyzer sweep time (displayed at the end of the bottom line), the antenna azimuth at which the signal was received and the time of occurrence of any signal seen on the analyzer trace can be determined by interpolation. The Display Controller controls the timing of the equipment sequences, performs the antenna rotation rate calculation, and performs the data formatting necessary for communicating with the spectrum analyzer.

The antenna motor is a DC motor with the field and armature separately excited. A switch is used in series with the armature to start, stop, or reverse the antenna rotation, and the motor speed is controlled by adjusting the armature power supply.

An S-Band signal source located 7.4 km from the surveillance station is provided for assessment of equipment performance. The source may be turned on from either the Radio Spectrum Coordinator's position or the surveillance station thereby providing a test signal whose amplitude, direction, and frequency are accurately known.

For transportable operation, the spectrum analyzer, the microwave assembly, and a hand-held antenna are used. The hand-held antenna assembly consists of a 12 dBi gain horn and a preamplifier having a noise figure of 3.1 dB. The preamplifier power supply is contained in the microwave assembly.

The performance parameters of the equipment are listed in Table 1.

Photographs of the major station elements are shown in Figs. 3 through 5.

V. Operational Findings

Since installation of the equipment in November 1978, there have been several hundred photographs taken by the equipment of radio spectra having frequency components in the deep-space-station downlink receive frequency band (2290 to 2300 MHz). Although cataloging of these photographs is just beginning and many of the radio frequency sources have not yet been identified, some important facts have been learned.

The results to date indicate that the number of detections correlate with military exercises in the vicinity of the Goldstone Deep Space Station Complex with the greatest number of detections associated with the use of FAA airspace R2508. During periods of critical deep space spacecraft operations, such as planetary encounters or spacecraft emergencies, military agencies are requested to impose radio silence on frequencies near the deep-space receive band and, during these periods, no sources have been detected. Further, it has been found that the weekends and evening hours, the hours not usually used for military exercises at the aircraft gunnery ranges, have the fewest number of detections. It should be pointed out, however, that, because of the large amount of effort required to identify potential interference sources, only sources which are considered as having a high RFI potential have been investigated. Of those investigated, approximately 65 percent have been identified. The identified sources are all military aircraft.

As an example of the benefit of the surveillance station at the Goldstone Deep Space Station Complex, it was learned by use of this equipment that a usual practice on board certain Air Force aircraft is to test some electronic equipment for a few minutes shortly after takeoff. The emissions from this equipment were first detected by the surveillance station at a range of approximately 170 km. From the surveillance-station photographs, the Air Force by very conscientious efforts identified the aircraft involved and modified operational procedure to eliminate this potential interference source.

VI. Room for Improvement

Although the unattended operating mode has satisfied the original requirements levied upon it to provide records showing the spectra and azimuth of potential interferers, there is a clear need to incorporate additional features which will facilitate the identification of the interferers.

Identifying radio frequency sources is much like fighting a fire, the sooner you get to it the better are your chances. To solicit help from other agencies in identifying a radio frequency source, the Radio Spectrum Coordinator must have time, azimuth, and a description of the signal spectrum. With the present design, time is available to him, if he notes the time upon hearing the audible alarm. If he is not present at the time of detection, time is printed at the surveillance station (approximately 20 minutes away). Azimuth is not supplied to the Radio Spectrum Coordinator's position, but this too is printed at the surveillance station.

The most serious delay is that he must wait for development of the camera film to see the received signal spectrum. This can require from 6 hours to several days, depending on the quantity of film to be processed and to which facility it is sent for processing.

A real-time display containing time, azimuth, and spectrum at the Radio Spectrum Coordinator's position is the obvious solution. Since this position is not staffed on a 24-hour basis, the display device should be capable of making a permanent record.

Another deficiency is that the fixed spectrum-analyzer control settings used in the unattended mode do not always provide an optimum display of the received signal spectrum. In several instances, the interfering signal carrier was outside the 2290- to 2300-MHz range used and only sidebands falling within this range were photographed. Increasing the operating range results in lower frequency resolution and violates other requirements of the station.

This problem can best be solved by providing adaptive control of the spectrum analyzer either by the Radio Spectrum Coordinator, by software routines in the Display Controller, or by both.

VII. Conclusion

The surveillance station described is providing highly useful experience in surveillance system requirements and techniques. It has identified several particular interferers and is yielding spectral signature data which, after cataloging, will serve as a library for rapid identification of frequently seen interference.

It has helped deep-space station operators to determine whether or not RFI sources are external to their station. It has aided the designers of a more sophisticated surveillance station, employing fast Fourier transform techniques, in developing processing algorithms for their system.

References

1. International Radio Consultative Committee (C.C.I.R.) Report 391-2, "Radiation Diagrams of Antennae for Earth Stations in the Fixed Satellite Service for Use in Interference Studies," *Fixed Service Using Communications Satellites,* Vol. IV, XIII Plenary Assembly, Geneva, 1974, Published by the International Telecommunication Union, Geneva, 1975.
2. International Radio Consultative Committee (C.C.I.R.) Recommendation 365-3, "Frequencies, Bandwidths and Interference Criteria for Manned and Unmanned Deep Space Research," *Space Research and Radio Astronomy,* Vol. II, XIVth Plenary Assembly, Kyoto, Japan, 1978, Published by the International Telecommunication Union, Geneva, 1979.

Table 1. Performance parameters

Parameter	Operating Mode			Conditions
	Unattended	Manual	Transportable	
Frequency coverage, MHz	2290-2300	2250-2320	2250-2320	
Antenna rotation rate, RPM	≃1	0-4	N/A	
Receiver sensitivity, dBW	⩽−153			4.4-kHz resolution noise B.W.
		⩽−177		14-Hz resolution noise B.W.
			⩽−156	400-Hz resolution noise B.W.
Detection sensitivity, dBW/m^2	⩽−137	⩽−164	⩽−142	90% confidence with above resolution bandwidths
Source azimuth accuracy, deg	±20 at −135 dBW/m^2	±7 at −140 dBW/m^2	±12 at 138 dBW/m^2	95% confidence stationary target
Frequency readout accuracy, MHz	±0.2	±0.06	±0.06	
Amplitude accuracy, dB	±5	±4	±4	
Time of detection accuracy, s	±1	±1	N/A	
Permanent record capacity (records)	>720	>720	N/A	100-ft camera roll
False-alarm rate	⩽1 per day	N/A	N/A	SNR threshold setting 12.5 dB

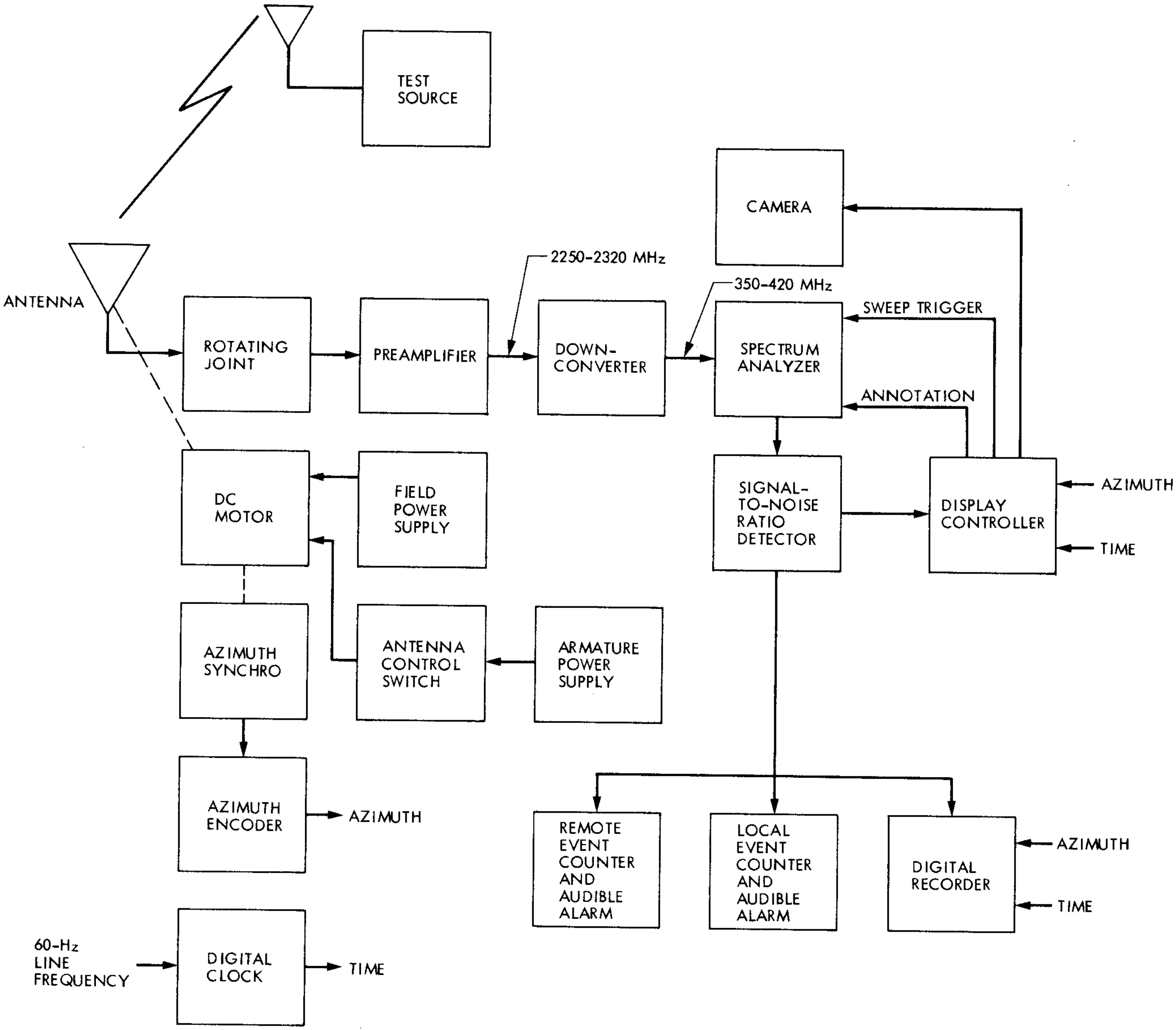

Fig. 1. Block diagram

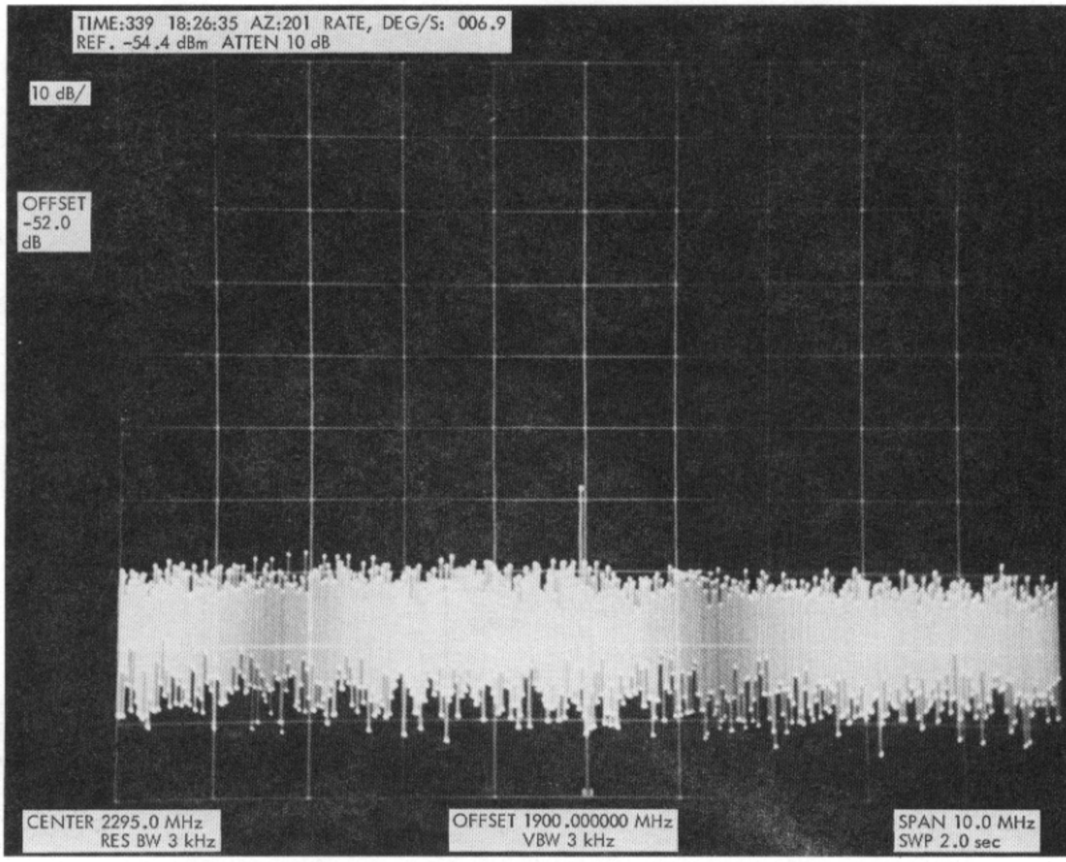

Fig. 2. Recorded spectrum

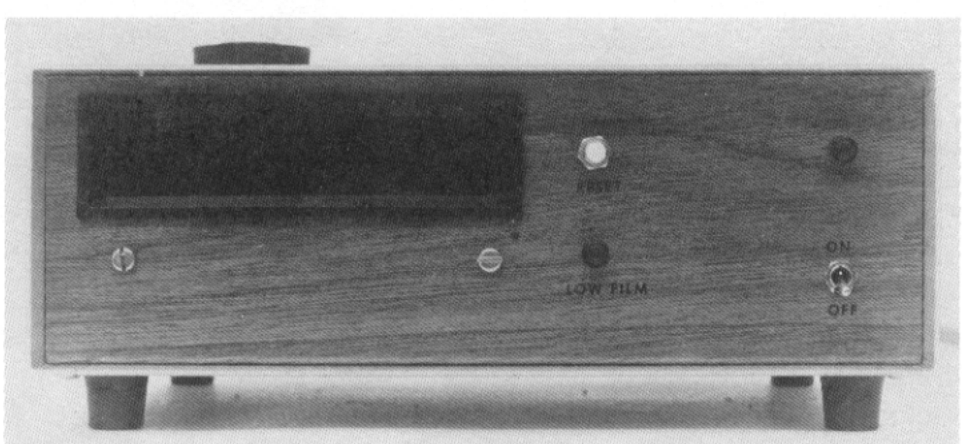

Fig. 3. Radio spectrum coordinator's display

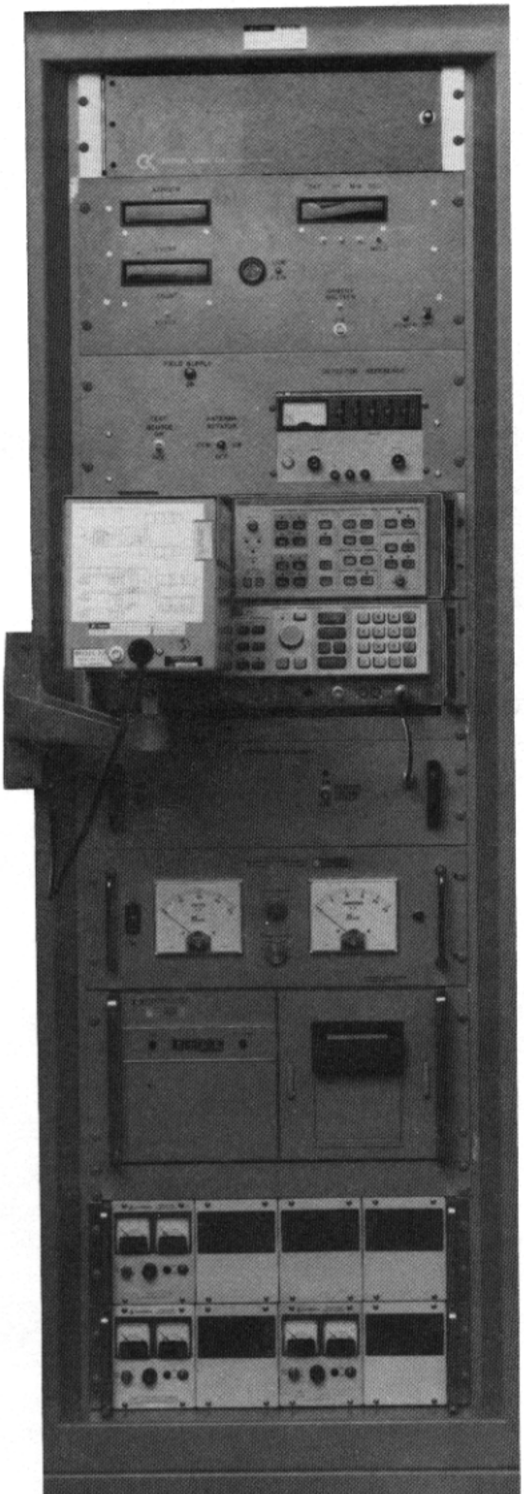

Fig. 4. Operator's console

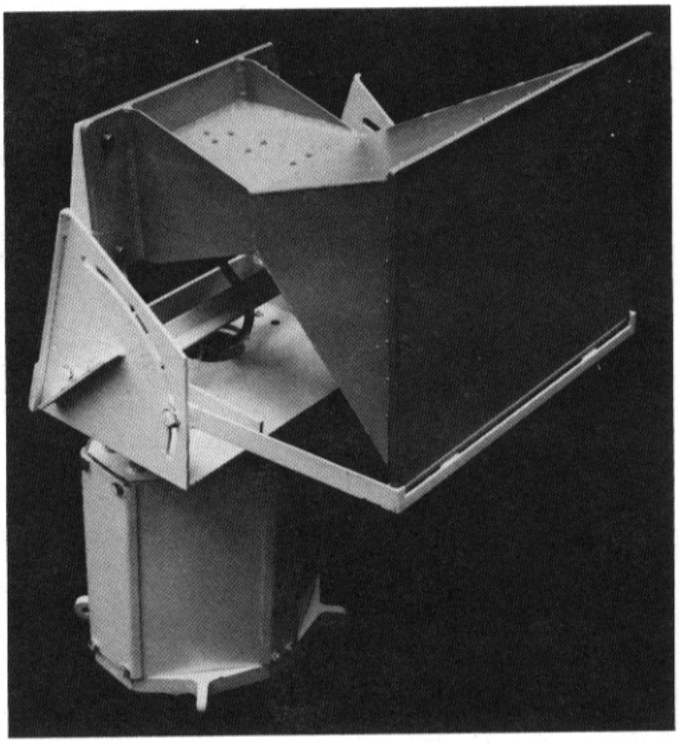

Fig. 5. Surveillance antenna