A Review of the Image Dissector Meteorological Cameras and a View of Their Future

Edward W. Koeing
ITT AOD

Gilbert A. Branchflower
NASA, GSFC

A REVIEW OF THE IMAGE DISSECTOR METEOROLOGICAL CAMERAS AND A VIEW OF THEIR FUTURE

Edward W. Koenig
ITT Aerospace/Optical Division
Fort Wayne, Indiana

Gilbert A. Branchflower
NASA Goddard Space Flight Center
Greenbelt, Maryland

SUMMARY

During the Fourth Space Conference, a paper was presented entitled "The Image Dissector Camera, A new Approach to Spacecraft Sensors". This is a continuation of that paper. Two daylight cloud cover cameras were discussed in the earlier paper. They were the Applications Technology Satellite III Image Dissector Camera (ATS III IDC) and the Nimbus Image Dissector Camera System (NIMBUS IDCS). Since the ATS III IDC was initially activated in orbit on November 7, 1967, it has sent back to earth more than 1300 cloud cover pictures with near full earth disk coverage per picture. The first Nimbus IDCS flew aboard the illfated Nimbus B which had to be destroyed immediately following booster lift-off, but launch of the backup camera aboard Nimbus B-2 is scheduled within a few weeks.

Development studies are presently being funded by NASA Goddard Space Flight Center on two other image dissector camera applications. The first is a 5000 TV line camera that is scheduled to be flown aboard ATS-F. The major objective of this high resolution system is to supply cloud photographs of the full earth disk from which cloud motion studies can be made. The second study involves a three aperture image dissector which is being developed as the sensor for a multi-spectral camera for earth resources applications. The resolution capability of this system is 2600 TV lines.

REVIEW OF IMAGE DISSECTORS

The Image Dissector Cameras are based on a simple camera tube that is related to multiplier phototubes, with the added capability of high resolution electronic scanning. A diagram of the components of this tube is given in Figure 1, showing the photocathode, scanning components, defining aperture, and electron multiplier section. The electron scanning is accomplished by deflecting the continuously emitted field of electrons from the photocathode past the defining aperture. Choice of aperture size in relation to photocathode size determines the sensor resolution. Noise in the system is a function of the number of electrons passing through the aperture in a sampling time interval so is also a function of the resolution. All of the cameras described here have been designed to use the optimum size tube elements and scan methods to attain signal-to-noise ratios of 30 to 40 db, with essentially no sensor related noise in the dark image areas. Two tubes are shown in Figure 2, the smaller tube, one inch diameter, having been used in the ATS-III and Nimbus B cameras, and the large tube, 2 1/4 inches diameter, used in the ATS-F and ERTS programs.

The ATS-III and Nimbus-B cameras are shown in Figure 3, emphasizing the compact nature of such a system, since the Nimbus camera is only 12 pounds and required but 12 watts input for all tube, video, scan and signal processing requirements. Electronic scanning permits adaptive operation of an imaging system with full control of image quality without mechanical shuttering or iris control mechanisms. Reliability of such systems has been demonstrated by the ATS-III operation of 16 months orbital activity.

ATS-III IDC

This camera was flown aboard ATS-III not so much as a scientific experiment as a technological experiment. The ultimate intent, of course, as with all remote earth sensors, is to supply the scientific community with additional information about the earth and its environment, but the prime objective of this first camera was to demonstrate the capabilities, and possibly discover unknown limitations, of the image dissector as the nucleus of cloud cover cameras. A review of the ATS-III IDCS requirements is given in Table I. Performance of the camera has been extremely good. Sensitivity has not degraded by more than 5% since initial turn-on, and resolution is also unchanged. The satellite was launched November 5, 1967, and the camera turned on November 7. Camera operation and system tests were performed regularly. The camera was used extensively from March 10 through April 14, 1968, in support of tornado watch activities for ESSA. One of the first pictures of hurricane Abby was obtained from the IDC. The camera was also used for weather observations in support of the Apollo 7 and Apollo 8 missions. Starting in mid-October 1968, cloud cover pictures from the IDC have been sent in near real time (within 25 minutes of receipt from the satellite if desired) to ESSA's Suitland, Maryland facility through the use of a WEFAC scanner and telephone lines. Figures 4 through 8 show IDC pictures obtained at various times and from various satellite locations (ATS-III has ranged from 46° W longitude to 95° W longitude).

The prime ground station for the IDC is located at NASA's Goddard Space Flight Center. Wideband video from the satellite is received at the Rosman, North Carolina CDA station and sent in real time via microwave to GSFC where the data is displayed on hard copy and recorded on tape for later off-line processing.

To date no efforts have been made to digitize the data for later expansion and video enhancement. The Spin Scan Camera on ATS-III already had that capability and it was felt that the additional cost required to gain that redundant capability was not worthwhile. ESSA scientists at Suitland have, though, made cloud motion movies of the IDC pictures and have stated that the photographs are stable enough on a picture-to-picture basis to allow meaningful cloud motion studies to be made from them.

Since the IDC was described in detail in the Fourth Congress paper, and also in the papers mentioned in the bibliography, no detailed circuit description will be given here. A simplified block diagram is shown as Figure 9. Inputs from the spacecraft are power, command, and clock. The camera contains the image dissector, a sun sensor for spin rate, and the electronics required to synchronize camera timing and operation with spacecraft spin and to retain proper phasing for earth viewing once initial phasing has been commanded from the ground. The camera generates one line of video each time the spacecraft rotates. A full picture contains 1328 lines. North-to-south coverage is 14.7 degrees which cuts off the polar regions, but full earth coverage is provided in the west-to-east or line scan direction. Resolution is limiting at 1600 TV lines across the earth.

The camera composite output contains frame sync, line sync, sun pulse, and video amplitude modulated onto a subcarrier whose frequency varies in proportion to the spacecraft spin speed. The IDC is, therefore, unique from the Spin Scan Cameras not only in that it is an electronic scan device versus a mechanical scanner, but in that the IDC output contains all of the frame and line sync information required to display the video with a minimum amount of special ground support equipment.

NIMBUS IDCS

The Nimbus IDCS has an output format identical to that of the Nimbus and ESSA APT cameras. It is an eight hundred TV line system with a line rate of 4 hz and a video bandwidth of 1800 Hz. The video from the camera will be transmitted to earth in real time AM/FM with an AM subcarrier of 2400 Hz and simultaneously recorded on spacecraft recorders. The recorder playback is speeded up 32 to 1 to yield playback at AVCS rates over the Nimbus Ground Stations. Camera resolution is 25% at 800TV lines and the output video has a highlight signal-to-noise of 38 db (p-p/rms).

Average image dissector photocathode loading for both the ATS and Nimbus Cameras is the same, but the Nimbus application should be a more severe test of sensor sensitivity with loading because the camera will be operating 48% of the time (daylight portion of every orbit) as opposed to an operating time of roughly 5% of the time for the ATS-III camera (averaged over the first year).

The Nimbus camera was initially to be a true line scan system, similar to the HRIR, but due to the need for wide angle coverage and the desire to retain APT rates, a complimentary scan was conceived. The camera will supply full east-west or horizontal scan and complement spacecraft motion to provide the south-to-north or vertical coverage. By using this method, each picture will image 1600 n mile on a side with a 1 to 1 aspect ratio, while picture overlap will be approximately 50%. Ground resolution at the subsatellite point will be 1.78 n mile.

NEW PROGRAMS

The completion and operation of the two basic Image Dissector cameras in the ATS-III and Nimbus B spacecraft indicate the performance and quality of these unique sensors for cloud cover imaging.

The major factors contributing to the usefulness of this camera approach are:

- Reliability
- Wide dynamic range
- Optimized resolving capability
- Photometrically useful output
- Long term stability
- Adaptability to spacecraft conditions

Each of these characteristics may be extended to increased capability for future camera systems. The availability of a fully controlled electronic scanning sensor has led to consideration of two advanced camera systems; one, for ATS-F, using a significantly increased resolution for high quality images from synchronous orbit, and another using the flexibility of tube design to provide a multi-spectral image from a low orbiting satellite. Both applications use the full set of characteristics given above, but the approach for each camera is so different as to be worth consideration.

HIGH RESOLUTION CAMERA

A contract was received by ITT Fort Wayne in October 1968 to determine a realistic upper limit of resolution for an Image Dissector Camera. Based on the results of the previous camera programs and tube developments now in progress, it was estimated that a camera having 5000 television lines limiting resolution could be developed. This camera would necessarily require a larger tube and commensurate improvements in the electronic systems, but is within the achievable state of the art. Results of the study and experimental work on improved sensor tubes indicate that this goal may be met. The resulting camera is expected to have the general characteristics given in Table 2. The approach was based on the requirements for an earth imaging sensor for the ATS-F satellite shown in Figure 10. This satellite is primarily for communications experiment but has room available for a visible spectrum camera and an infrared camera. The availability of a stabilized earth-oriented satellite at synchronous altitude allows the camera unit to be optimized for a trade-off of picture taking interval, resolution, and signal to noise ratio, resulting in the characteristics given below.

Since the completion of the Nimbus and ATS-III development programs, the capability of the sensor tubes have improved dramatically. In particular, the photocathode, originally an S11 with an average sensitivity of 30 microamperes per lumen, was considered to have a lifetime of one year with a loading factor (average continuous current emitted) of 3 microamperes per square centimeter. We have now established techniques of forming multi-alkali photocathodes with low resistivity that provide sensitivities of more than 150 microamperes per lumen and will operate for a year with 10 microamperes per square centimeter. At the same time, these surfaces have greatly improved red response, allowing better haze filtering for higher contrast earth scenes. Other improvements in quality of construction and better electron multiplier structure add to the space worthy nature of the sensor system. The size of tube to be used in this program is shown in Figure 2. Activities in the use of the information from the High Resolution Camera have grown also. For the past experiment Mr. Branchflower of NASA Goddard Space Flight Center acted as the technical investigator. In the present program, Mr. Branchflower and Mr. Werner of NASA will remain Technology Co-Investigators, but Mr. Lester F. Hubert, Chief, Synoptic Meteorology Branch, NESC, will be Principal Scientific Investigator for the program. Data from the camera will be used for cloud motion studies and other experiments under their control.

Of the various requirements, characteristics of most concern are resolving power and stability. Resolution of 5000 elements in 1.5 inches requires 3300 elements per inch. The test patterns in Figure 11 demonstrate the achievement of 3200 television lines per inch at greater than 10% modulation at the center of the tube and approximately 2600 lines per inch at the position corresponding to the edge of the earth image. It is anticipated that these figures will be maintained or improved upon during the development of an operational system.

Perhaps just as important to the meteorologist is the stability of the image as it is translated from an optical input into the transmitted signal and finally received and used as the ground station. In order to make use of the one mile resolution of a cloud element, and to make possible cloud motion studies, it is desirable to maintain geometric positions to this accuracy over a significant time period. The maximum requirement in this case would, therefore, suggest a stability of one element in 5000 over a twelve hour period. The motion of the satellite itself will not be this constant, nor will the combined effects of power source and electronic component drift. We anticipate that the one element stability may be maintained over a one picture frame interval, giving accurate geometrical relationships to each image. The electronic systems will have a goal of one element stability over an eight hour period. Matching techniques similar to those used on Spin Scan and IDC images in the past will have to be applied to obtain successive photographic image registration suitable for cloud motion studies.

The versatility of the Image Dissector Camera is expected to be used for an added purpose in this application as a means to adapt to ground display equipment having more typical resolving capacity. This will be achieved by controlling the electronic scan of the camera to cover less than the complete earth disc. Since the scan system is completely digital in nature, it is possible to command the camera to start scanning at pre-selected points in the image and scan a raster of 100 elements on a side in a shorter time interval than the nine minutes used for full earth scanning. These images, arriving at the 20 seconds per frame, would show typical cloud cover over half of the US in one image and be immediately available for meteorological analysis.

The combining of optics and electronics for a self contained camera that may be installed in the ATS-F spacecraft results in a package that will weigh forty pounds or less and require a power input of twenty watts or less. Although the camera uses a 2 1/4 inch diameter tube compared to the one inch tubes of the present cameras, the total package size is still only half of a cubic foot in volume. The absence of motorized scanning or iris control and the absence of mechanical shutters maintains the stability of the spacecraft. It is anticipated that the camera will meet or exceed the goals given and provide high quality images suitable for cloud cover analysis and a continuing meteorological program.

MULTI-SPECTRAL CAMERAS

Perhaps one of the more interesting applications of the Image Dissector camera is its potential use as an Earth Resources sensor. Calling on the adaptive nature of the basic tube concept, it is possible to generate continuous output signals corresponding to three colors of the scene. This is possible using a single sensor tube with the approach shown in Figure 12. From the earth stabilized ERS satellite the Multi-Spectral Camera scans the scene in a line scan, generating a continuous strip image of the earth over which the satellite passes.

Color information is generated from the image as it is focused on the photocathode of the two inch sensor tube. Since the sensor converts all light input into an electron image, it is able to view a continuously changing scene without smear, being exposed only during the short time interval in which an element of the scene is sampled by the electron aperture. Separation of output signals is performed by the three sampling apertures that replace the single aperture of the high resolution camera. Each aperture has its own electron multiplier, completely separating its signal from the others. Spacing of the apertures is critical since it is the separation distance that determines the registration of the three looks. We predict an effective spacing of only 0.015 inches between apertures, the equivalent of 20 scan lines. To give each aperture an individual color identity, the tube and scanning methods are set such that one aperture scans the area slightly ahead of vertical, one scans vertical, and one slightly behind, the off-axis angles being only 2.5 minutes of arc.

Color filters on the faceplate of the camera tube provide the separate inputs to the three apertures. Strip filters only .015 inches wide may be used to restrict the light activating the photocathode for the regions sampled by the apertures. This is possible only in a line scan system, since the image is being broken into strips along which the detection process takes place.

In the normal Image Dissector process, the electrons from all parts of the photocathode are accelerated to the aperture plane simultaneously. Since the three apertures are spaced to receive the electrons from the three respective bands, the electron beam is deflected along the direction of the filter bands so that each aperture reads only its respective color signal. No orthogonal scan is required since the flight of the spacecraft moves the images across the bands in turn.

Although the process appears complex, it is really simple and particularly promotes a high degree of stability between the look angles of the various apertures. All information generated by the sampling apertures is controlled by a single lens and a single set of deflection and focus coils. The position of the three apertures remains fixed in the field of view, such that constant corrections can be applied to make element by element registration. By keeping the aperture separation small, misregistration due to spacecraft attitude motion can generally be ignored. Comparing this color registration stability to that of a three tube system, such as used in normal color television, becomes most important as the resolution increases to the figures used for this program. Resolution of color images having over 2500 elements per line could be severely degraded by loss of registration stability and require nearly impossible demands on ground station equipment for compensation, if possible at all.

The value of the equipment is lost if the images are not consistent from image to image. The Image Dissector Camera can provide this stability since it uses a single lens, and a single optic system with no intermediate color separation filters, wedges, or mirrors. The stability of the color separation bands as three adjacent strips mounted directly on the tube faceplate eliminates disturbance caused by thermal or structural changes. The absence of mechanical shutters is made possible by the instantaneous action of the photoemitting surface. The only smear is that caused by movement of the scene in the 2 microseconds during which one element is being sampled. This motion is less than one foot, so it is negligible. In the same sensor, using the wide dynamic range of the sensor tube, it is possible to maintain extremely accurate photometric information by varying the amplifier gain, eliminating the need for a motor driven iris.

From the tube output the image data will be simultaneously amplified and provided as parallel outputs to the transmitter. Simple multiplex techniques will insure accurate time referencing of the data such that display systems receiving the data in real time can be recording the color image at the precise time that the camera is viewing the scene. Since the vodeo bandwidth for recording or transmission is only 150,000 Hz per channel, the total signal can be carried over a 1MHz or less transmission bandwidth without channel interference.

Studies of the Multi-Spectral Camera show that these characteristics can be provided in a camera that is compact and reliable. The reliability of the approach has been generally demonstrated by the flight of ATS-III in which a similar camera has operated very well for over 15 months. Since the ERS camera will have only a single sensor tube, no mechanical activators and relatively simple electronics, we can anticipate nearly the same lifetime performance. In mechanical structure, the camera will be an enlarged version of the Nimbus B Camera shown earlier, having dimensions of approximately five by eight by thirteen inches. Since the camera uses a single lens, this will be as large as practical to provide maximum sensitivity. A lens as large as ten inches diameter may be used. Total weight of the camera sensor and electronics is only thirty pounds, while the lens itself may exceed this weight.

CONCLUSIONS

The predictions made at the Fourth Space Congress of the technical feasibility and potential future use of the Image Dissector Camera appear to be coming true. Results from the first program have been dramatic in the lifetime in orbit of the ATS-III IDCS and its steady output of useful meteorological pictures. Global coverage of cloud pictures are now readily available to potential users. An increased resolving capability and multispectral output are possible with the use of improved sensor tubes and equipment technology. The ability to apply such information has grown also during this period, allowing such experiments to become increasingly significant. The combined effort of NASA, ESSA, and industry to capitalize on improved sensor technology will aid major areas of environmental research and application.

ACKNOWLEDGEMENT

The effort reported was performed under direction of Systems Branch, NASA Goddard Space Flight Center on contracts NAS5-9619, NAS5-9671, NAS5-11617, and NAS5-11618. Reports available on these programs include:

Branchflower, G. A., and Koenig, E. W., The Image Dissector Camera, A New Apporach to Spacecraft Sensors, Proceedings of Fourth Space Congress, April 3-6, 1967.

Branchflower, G. A., Foote, R. H., and Figgins, D. A., The Applications Technology Satellite Image Dissector Camera Experiment, NASA TN D-4186.

Branchflower, G. A., Image Dissector Camera Experiment, Applications Technology Satellite Technical Data Report, Section 8.5, (NASA/GSFC).

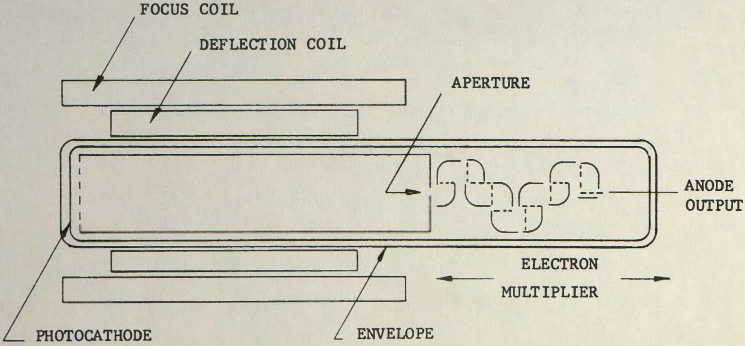

Figure 1 Image Dissector Component Parts.

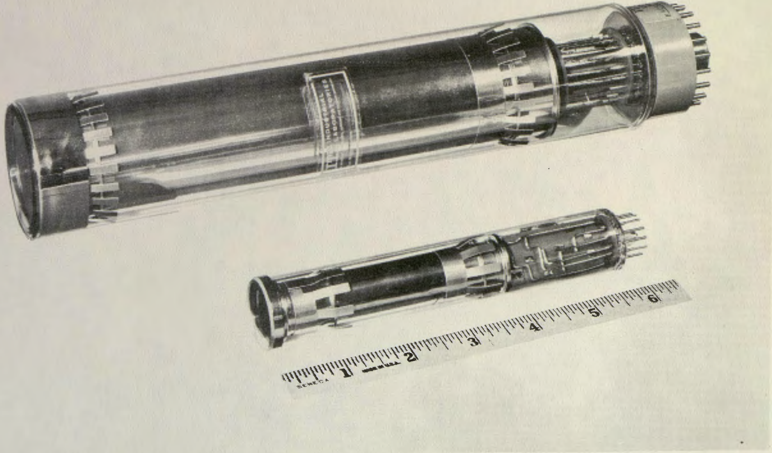

Figure 2 Image Dissector Tubes.

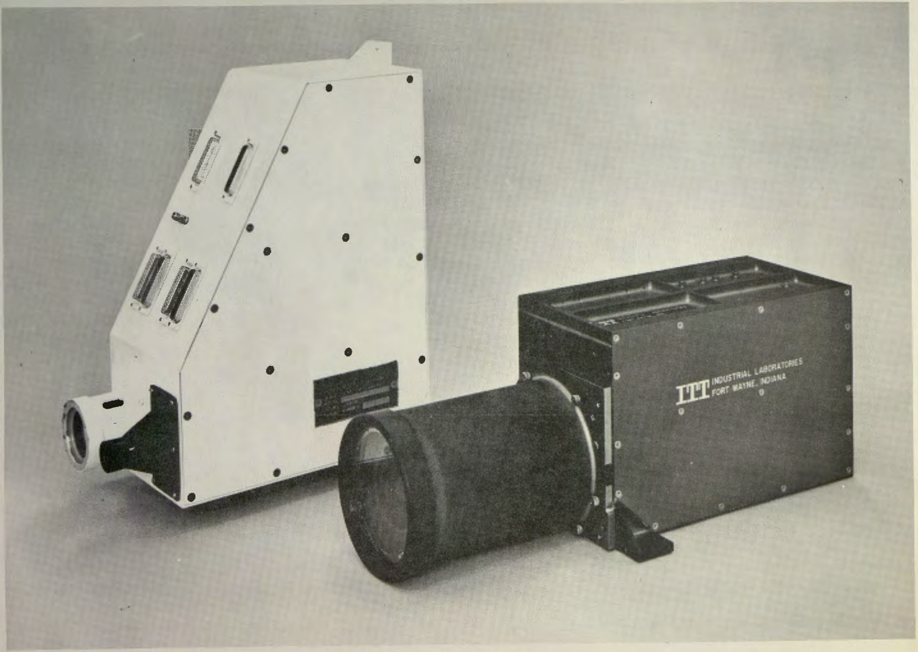

Figure 3 Nimbus B and ATS-III Cameras.

Figure 4

IDC Picture Taken On the Day of Initial Activation, 7 November 1967, Spacecraft at 47° W Longitude.

Figure 5 IDC Tornado Watch Picture, 12 March 1968, Spacecraft at 85° W Longitude.

Figure 6 IDC Tornado Watch Picture, 18 March 1968.

Figure 7 IDC Picture Showing Hurricane Abby, 3 June 1968, Spacecraft at 60° W Longitude.

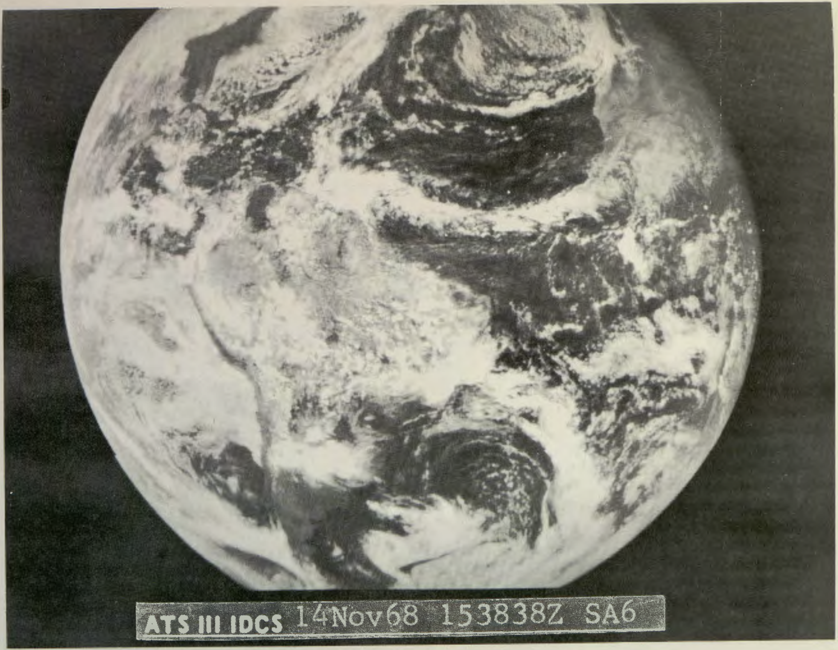

Figure 8 IDC Picture Taken One Year and One Week After Initial Activation, 14 November 1968, Spacecraft at 47° W Longitude.

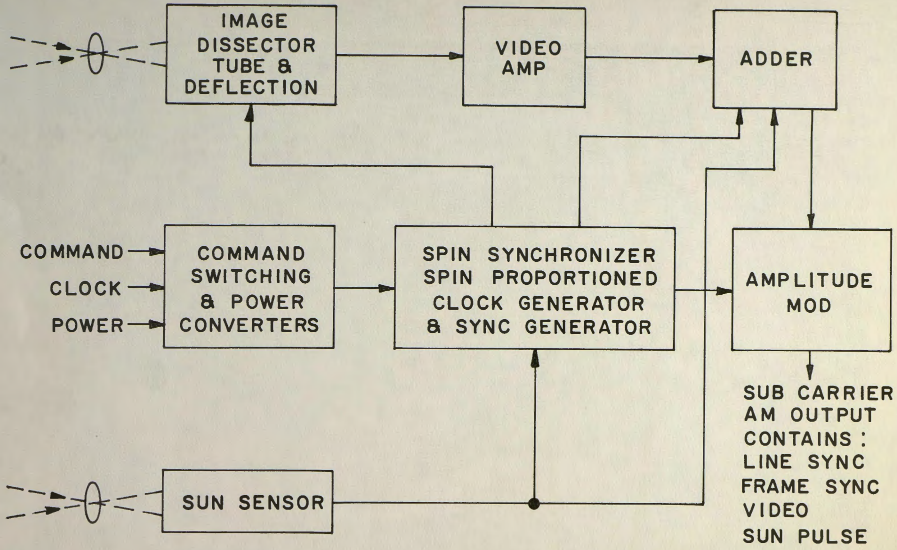

Figure 9 ATS IDC Block Diagram

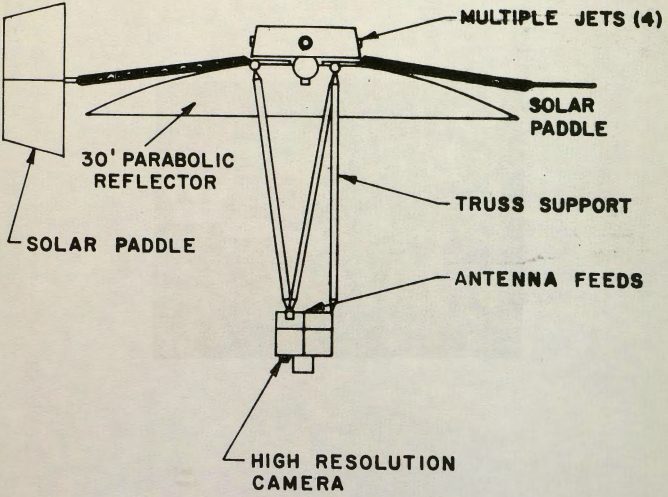

Figure 10 ATS-F Satellite

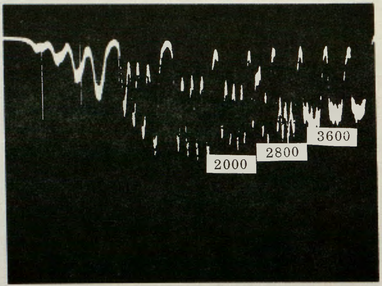

Figure 11

Video Response Pattern

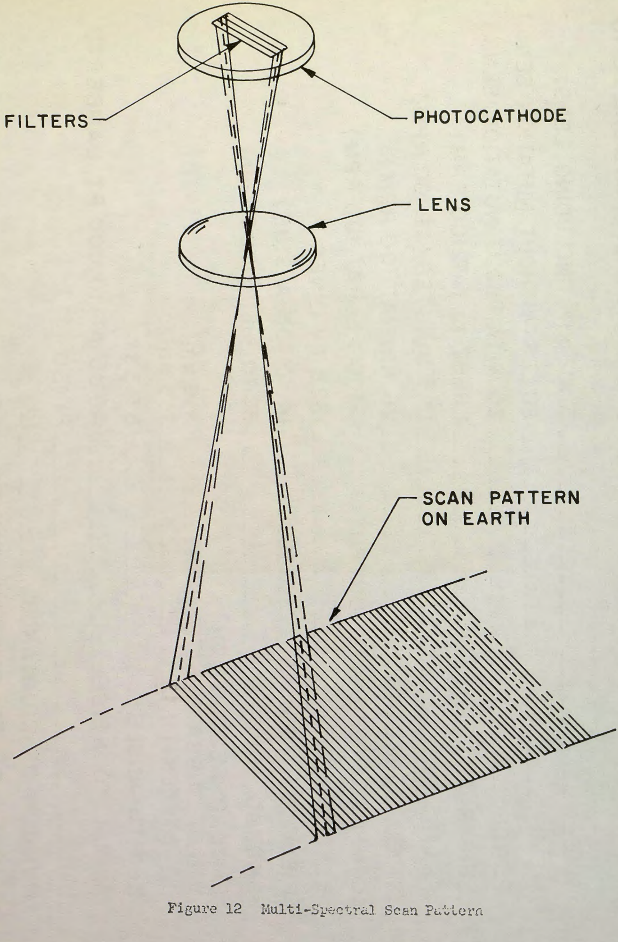

Figure 12 Multi-Spectral Scan Pattern

IMAGE DISSECTOR CAMERA SYSTEM LIST OF PARAMETERS

SIZE	5"x12"x11" (INCLUDING LENS)
WEIGHT	20 LBS (WITHOUT NUTATION SENS.)
POWER	20 W (WITHOUT NUTATION SENS.)
LINE RATE	1.6667 hz (AT 100 RPM)
FRAME RATE	13.3 MINUTES (AT 100 RPM)
VIDEO BASEBAND	28 Khz (AT 100 RPM)
COMPOSITE WIDEBAND OUTPUT	>100 Khz (AT 100 RPM)
RESOLUTION	1328 TV LINES
FIELD OF VIEW	14.6° (ON A SIDE)
GROUND COVERAGE	6040 nmi x 6040 nmi
GROUND RESOLUTION	
AT SUBSATELLITE POINT	3.8 nmi
AT ZENITH	7.5 nmi
ZENITH ANGLE	57.53°
SIGNAL TO NOISE	40 db AT 10,000 FT. LAMBERT
IRIS	FIXED
NUMBER OF COMMANDS	12
NUMBER OF TELEMETRY POINTS	25

ATS-F HIGH RESOLUTION CAMERA PARAMETERS

SENSOR	ITT F4052, S25 PHOTOCATHODE
SPECTRAL RANGE	MONOCHROME, .49 TO .95 MICRONS
FIELD OF VIEW	17.6°
LENS	123 mm, T/5
RESOLUTION	5000 TV LINES PER EARTH DIA. 1.1 n mi. GROUND RESOLUTION
SCAN, PRIMARY MODE	FULL EARTH
SECONDARY MODE	SELECTED 1000 MI SQUARE AREAS
SCAN RATE	9.5 SCANS / SEC
FRAME TIME	8.75 MIN PRIMARY MODE 20 SEC SECONDARY MODE
VIDEO	COMPOSITE VIDEO, 24 KHZ BANDWIDTH
SIGNAL TO NOISE RATIO	30 DB (PEAK SIG/RMS NOISE)

16-41