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THE AUTOMATIC PICTURE TRANSMISSION (APT) TV CAMERA SYSTEM FOR METEOROLOGICAL SATELLITES

by Rudolf A. Stampfl and William G. Stroud

Goddard Space Flight Center

Greenbelt, Maryland

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SUMMARY

Nimbus, the second generation meteorological satellite which is the successor to TIROS, is a stabilized platform designed for global coverage of the earth's cloud cover and for future atmospheric research. A three camera TV system operating during daylight and an infrared scanner operating during the night store the cloud data on magnetic tape for later command readout.

This paper describes an additional camera system, designed for automatic and continuous real-time picture transmission during daylight. Although it is planned for trial on a TIROS satellite in a time-restricted mode, its operation on Nimbus will be continuous during daylight.

The camera uses an electrostatic storage vidicon which is exposed for 40 milliseconds, and read-out during the succeeding 200 seconds. The 800 line resolution and the 0.25 second scanning time per line are compatible with standard 240 rpm facsimile equipment which can be used for ground display. Full compatibility is achieved by amplitude modulation of a 2400 cps subcarrier and by transmission of a turn-on and phasing signal during the 8 seconds preceding actual picture transmission. The subsystem is independent of the spacecraft except for power and a frequency reference. A 5 watt transmitter broadcasts the signal in the 136 Mc space telemetry band. FM is used and this makes a large variety of standard mobile communication equipment readily adaptable.

The value of the system lies in its simplicity both in the spacecraft and on the ground. Neither command links nor storage are required. On the ground a manually tracked or even a fixed 10 db helix antenna, with a commercially available receiver and facsimile, is the only equipment required.

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INTRODUCTION

This paper describes a television system developed for the Nimbus meteorological satellite that takes pictures of the cloud cover over 1000 mile square areas and transmits the information directly to simple, inexpensive ground stations within sight of the spacecraft. The development of this equipment is a response to the local weather forecaster's need for current (real-time) data on the distribution of atmospheric parameters within his station's meteorological environment. It reflects a fundamental advantage of the weather satellite, i.e., its ability to collect atmospheric data *and* deliver it to the user on a global, regional, or local basis.

Nimbus is a second generation meteorological satellite following the less sophisticated, experimental, and quasi operational TIROS. In contrast to the spin-stabilized TIROS, it has been designed as a stabilized platform tailored to carry sensors for the measurement of a wide range of atmospheric phenomena. Primarily, the first Nimbus will provide global coverage of the earth's daytime cloud cover by using a three camera television subsystem which stores up to two orbits of sets of three frame pictures. The nighttime cloud cover will be obtained with an IR scanner sensitive in the 4 micron atmospheric window.

The value of cloud cover measurements has been demonstrated by the TIROS satellites, which have delivered pictures of daytime cloud cover when the camera geometry was favorable. Pictures have been analyzed routinely, nephanalyses prepared, and the results made available to the world meteorological network. The tracking of storms, such as the hurricanes and typhoons in 1961 and 1962, has been performed many times and a multitude of corrections have been applied to daily weather maps.

SPACECRAFT CONFIGURATION

The Nimbus spacecraft (Figure 1) is earth-oriented and stabilized in all three axes so that one area continuously faces the earth and has a fixed azimuth with respect to the spacecraft velocity vector. It consists of two rigidly interconnected structures. The upper, smaller structure contains the IR horizon sensors, gyros, pneumatics, inertia wheels, computer, inverters, and voltage and

*This report supersedes Goddard Space Flight Center Document X-650-63-77, published under the same title.

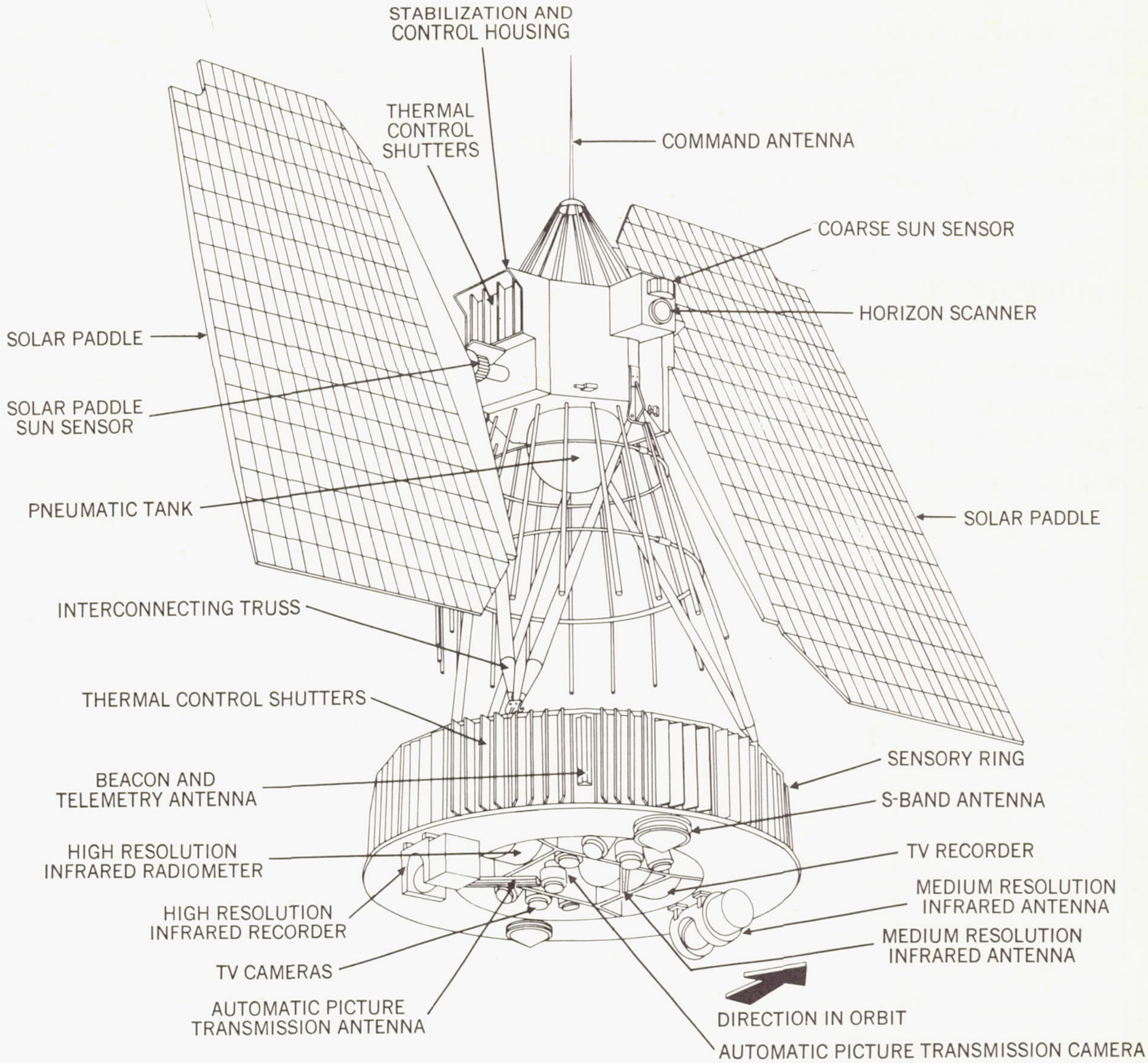


Figure 1—Nimbus spacecraft.

temperature regulators used to control the attitude of the satellite and keep it pointed to the local vertical. The solar array is attached to the control subsystem and is stabilized normal to the sun while in orbit. Launching the satellite into an 80 degree inclination retrograde orbit will cause the orbital plane to drift at the same rate as the earth moves around the sun thereby maintaining constant sun attitude for the entire spacecraft life. As a consequence, the solar power collectors need only rotate once per orbit around a single axis. The control system will stabilize to ± 3 degrees in yaw and roll, and to about ± 2 degrees in the pitch axis. Angular rates are less than 0.05 degree per second.

The low, larger structure houses the meteorological sensors. Full picture coverage of the daytime cloud cover of the entire earth will be obtained from a three camera vidicon TV system. This system, however, requires tape recorder storage, major ground station facilities to receive the wide-band transmitted picture data, and wide-band microwave links to relay the data from the command and data acquisition sites to the users. The lower structure also contains clocks, transmitters, and the telemetry, data storage, programming, command, and other electrical, electronic, and mechanical components required for the functioning of the meteorological subsystems.

THE AUTOMATIC PICTURE TRANSMISSION SYSTEM (APT)

Figure 2 is a block diagram of the APT system, both spacecraft-borne and ground components. In the spacecraft, appropriate optics focus the cloud map below the satellite on the face of a storage vidicon. This image is converted to an electric signal by electron beam readout; a subcarrier is modulated which in turn modulates the VHF transmitter. The signal passes through the antenna and receiver on the ground and the image is recreated directly on a facsimile unit in real time.

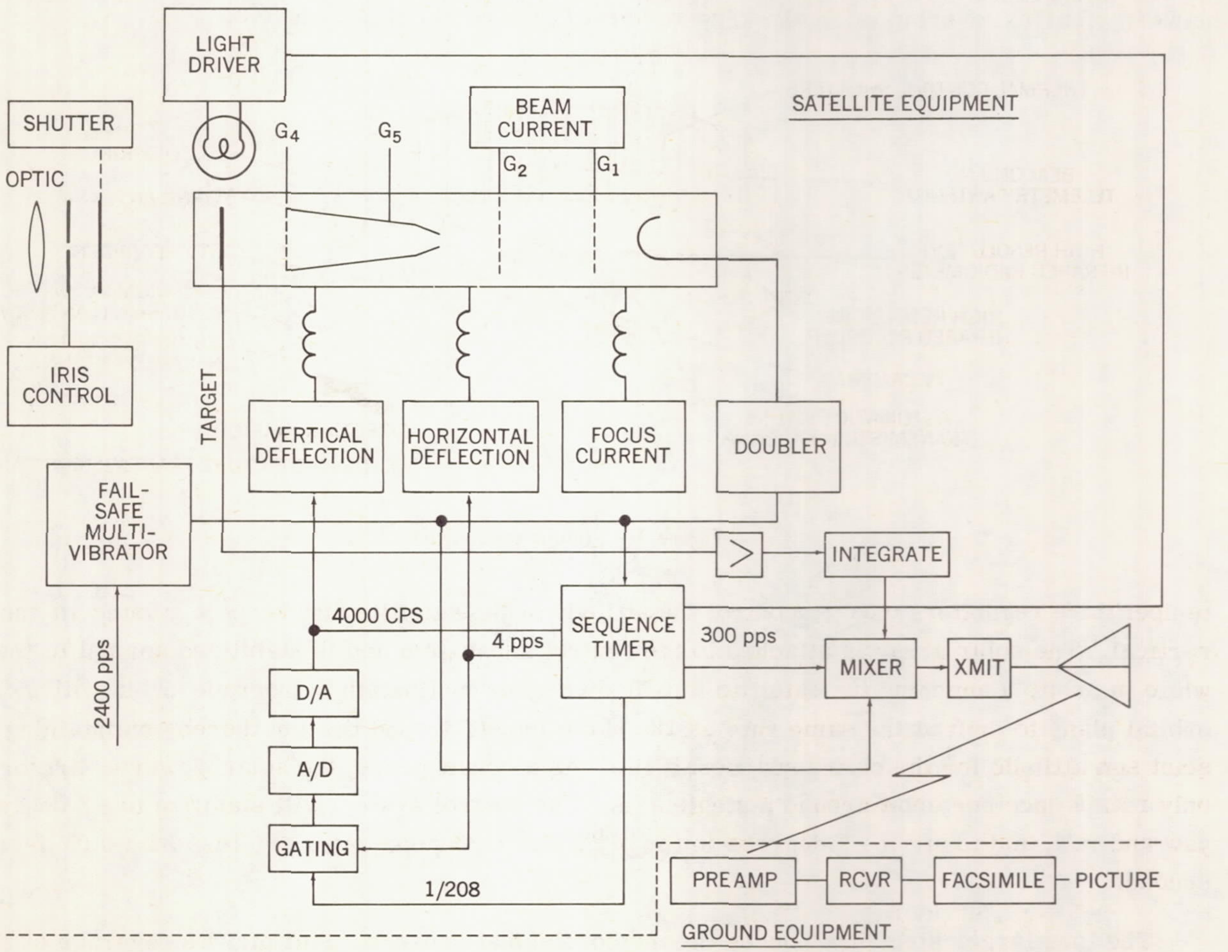


Figure 2—Block diagram of the APT system.

SYSTEM PARAMETERS

It is desirable, from the point of view of global cloud coverage, to provide users at least one cloud cover picture per day of their local areas. A compromise between satellite altitude, available lenses, and vidicon format resulted in the selection of a Kinoptic "Tegea" lens with the following characteristics:

1. Focal length — 5.7 mm
2. F-number — 1.8
3. Field of view — 107 degrees
4. Illumination at F/18 at 50 degrees — a half angle of 22 percent

This lens, used in an APT camera in a 900 km altitude circular orbit, produces a picture width of 1720 km on each side. Higher orbits may be used in later flights and a 1300 km altitude, for example, could yield a 2485 km picture width. Center-of-the-picture resolutions for an 800 line vidicon are 2.3 and 3 km, respectively, for the two altitudes. Picture overlap in the direction of flight will vary with altitude. Since Nimbus transverses approximately one picture width during the 208 seconds between pictures, overlap is small. The geometry is illustrated in Figure 3.

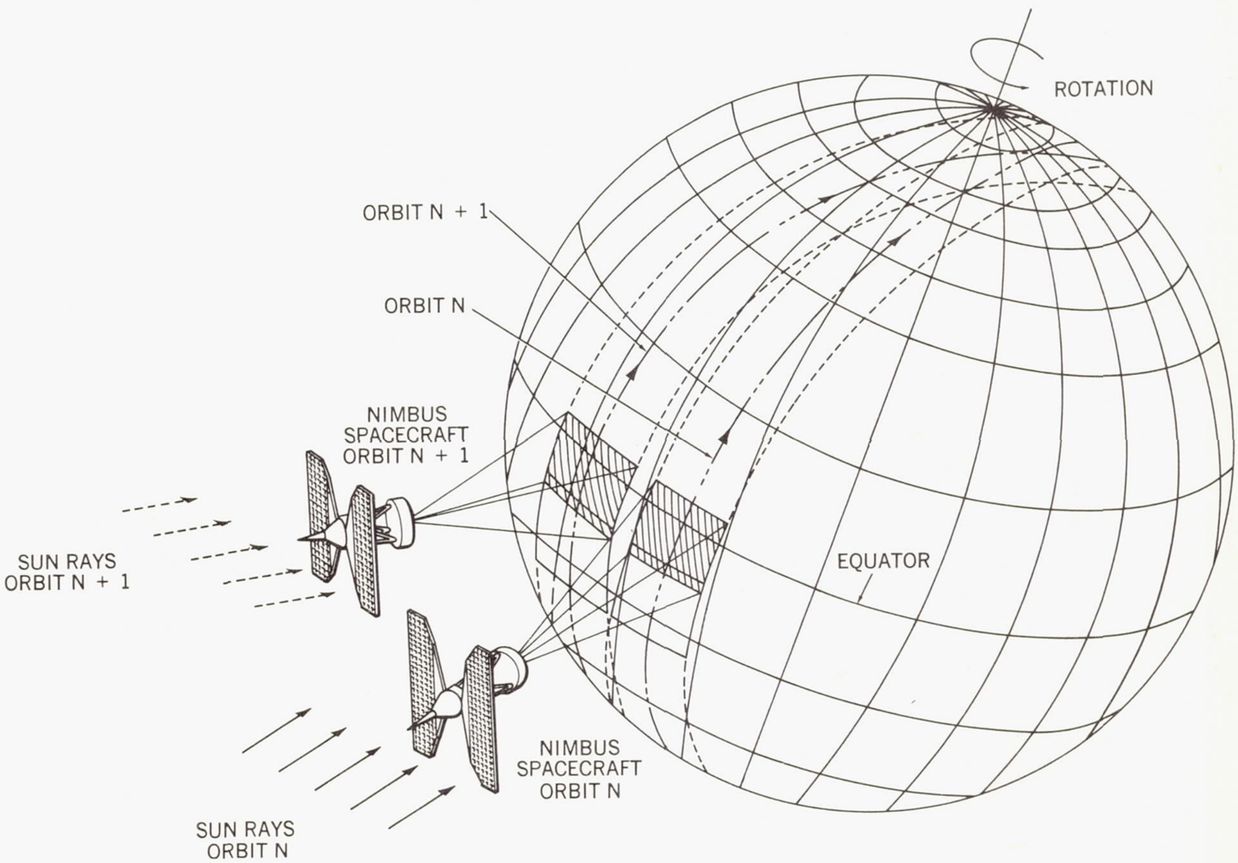


Figure 3—APT picture coverage.

Computations show that longitude coverage at points on the equator is incomplete. The area of gap is 1140 km at 900 km altitude and 600 km at 1300 km. Farther to the north or south, this gap decreases; it disappears at a latitude of 50 degrees. Optical exposure time is 40 milliseconds which is sufficiently small to avoid smear due to orbital velocity and residual angular velocities of the spacecraft (0.1 degree/sec). The smear is less than 10 percent of one picture element. A vidicon frame scanning time of 200 seconds was selected as compatible with the standard 240 rpm facsimile record speed, avoiding the need to develop special display equipment. In order to be compatible with facsimile transmission standards, the 2400 cps subcarrier is amplitude modulated and serves as the clock to drive the vidicon deflection circuitry. The subcarrier is modulated to the 80 percent level with white being maximum amplitude (positive modulation). A 3 second start tone followed by a 5 second phasing signal precedes readout.

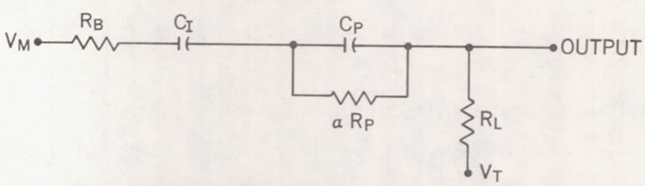
The subcarrier modulates the frequency of a 136 Mc, 5 watt transmitter, deviating it by ± 10 kc so that receivers with 30 kc IF bandwidth can be used. These receivers then drive standard facsimile equipment for display purposes. Full tonal reproduction can be achieved by a display medium which can resolve 800 elements per line with an aspect ratio of 1:1. Detailed considerations of the RF link will show that a 10 db gain receiving antenna and a receiver having a noise figure better than 7 db provide good quality pictures.

THE PREPARE, EXPOSE, AND DEVELOP CYCLE OF THE STORAGE VIDICON

The operation of the camera can best be explained by describing the operation of the storage vidicon itself. The APT vidicon is a conventional vidicon in which a polystyrene layer has been evaporated on the photoconductive layer. The high resistivity of the polystyrene permits an image to be stored as a distribution of electrostatic charges for a period of months. The tube therefore performs both the imaging function and the storage function. The charge distribution is created by exposure of the faceplate to light and flooding of the surface with electrons.

Operation of the camera requires the vidicon faceplate to follow an electrical sequence called the prepare, expose, and develop cycle, prior to readout. An equivalent circuit of a small faceplate element is given in Figure 4. As the figure shows, the photoconductor can be represented as an R_p-C_p network. The insulator capacitance C_I and the load R_L are in series with it.

The prepare operation is used to change the gun side of the polystyrene to a uniform potential in order to prepare the surface to receive image information. It also erases any residual charge from the preceding



C_I = ELEMENTAL POLYSTYRENE CAPACITANCE
C_P = ELEMENTAL PHOTOCONDUCTOR CAPACITANCE
R_B = BEAM IMPEDANCE
R_L = LOAD RESISTANCE
R_P = PHOTOCONDUCTOR IMPEDANCE
V_M = MESH VOLTAGE
V_T = TARGET VOLTAGE
α = FACTOR INDICATING VARIATION OF ELEMENTAL ILLUMINATION ON PHOTOCONDUCTOR $0<\alpha<1$

Figure 4—Equivalent network, APT vidicon faceplate.

picture. During this operation the electron beam and floodlights mounted around the faceplate are turned on and a rapid vertical sweep and normal horizontal sweep are in process. The floodlights are used to raise the conductivity of the photoconductor to a high value. The beam strikes the polystyrene surface ejecting secondary electrons which are attracted to the mesh (G_4 - see Figure 2) until the potential of the mesh and polystyrene are equal. The vertical scan assures that the beam strikes all parts of the polystyrene surface. At the completion of this operation, C_I still retains a net charge across the insulating layer. The floodlight is then turned off, so that R_p assumes a very high value. It is now necessary to transfer the charge from C_I to C_p and this is accomplished by changing electrode voltages appropriately.

During the expose operation the shutter opens and the photoconductor acquires a resistance corresponding to the illumination it receives. In order to maintain a very constant potential the electron beam remains on, and scan is active in both directions. The voltage across the photoconductor capacitance depends on the intensity of illumination at that point.

During the develop operation, the electron beam is off and the floodlights are again turned on. With the electron beam off, the polystyrene voltage cannot change; however, the photoconductor is driven to a low value. Simultaneously, grid potentials are chosen so that the charge pattern is transferred to the polystyrene layer (C_I). It is this charge pattern which is discharged through R_L by the beam during the readout process converting the image to a video signal.

PICTURE QUALITY

C_I and C_p are in the order of picofarads; consequently, the electrical charge is very small. The discharge current, of course, varies inversely with the dwell-time of the electron beam on the target. Since these small variations in beam current are the signal for readout, the beam must be very constant and the discharge time should be chosen as short as possible. These considerations led to pulsed operation of the beam. Conversely, the shorter the pulses, the wider the bandwidth requirement of the preamplifier with an increase in noise power. Empirically it was found that 25 microsecond pulses applied every 208 microseconds (4800 pps rate) to the cathode yield optimum results.

A low noise preamplifier amplifies the pulses and feeds a hold circuit which restores the video signal. Since 800 elements are scanned in 250 milliseconds, a 1600 cps video band is required. The preamplifier, however, must be designed to pass the 25 microsecond pulses and therefore is designed for a 25 kc bandpass. Peak signal to rms noise ratios of 20 db have been measured on an actual camera. A start code consisting of a 300 cps modulation of the subcarrier (100 percent amplitude) is sent for 3 seconds. Phasing pulses are then sent for 5 seconds at the regular line rate. A black pulse (12.5 milliseconds long) is sent at the beginning of each line. A measure of picture quality is contained in the number of gray levels which the eye can distinguish. This figure of merit depends on both noise and linearity of the system and is expressed as the dynamic range. Although this range exceeds 15 steps in very small areas of the picture and has been achieved in conventional vidicons, the storage vidicons produced so far show large variation over the entire picture area. This property makes brightness calibration of the picture impractical and judgment of relative brightness variations must be exercised. In general, six levels can be distinguished. Figures 2, 5, and 6 show a block diagram of the system and photographs of the camera and transmitter.

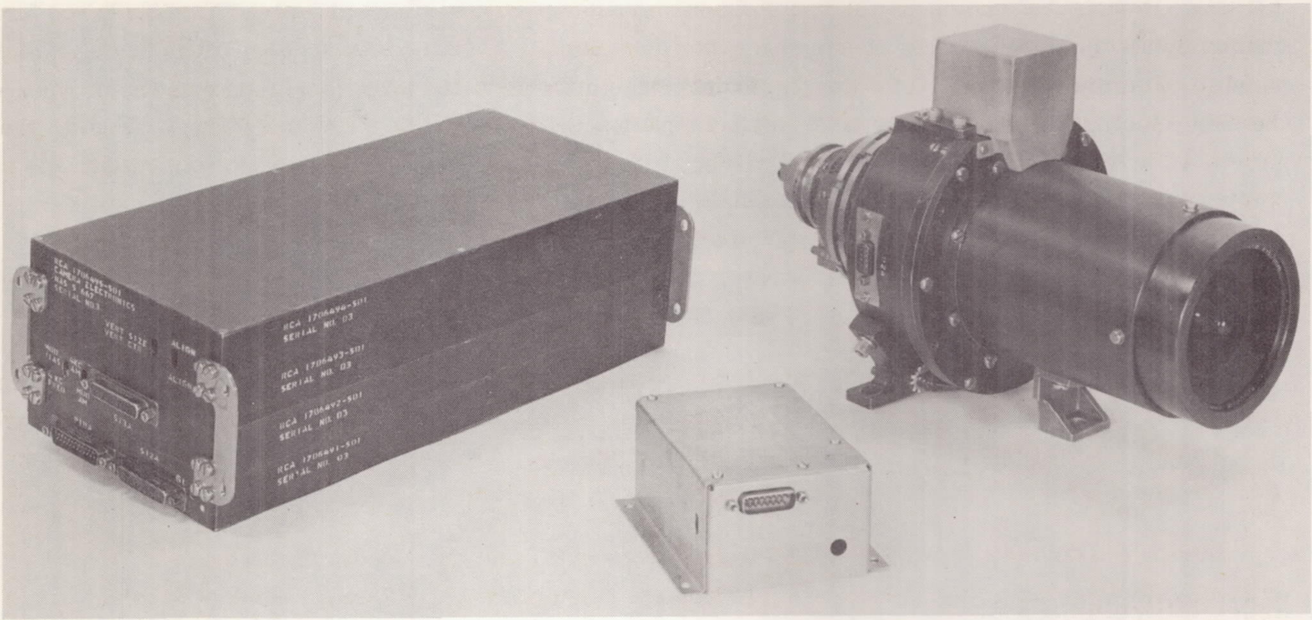


Figure 5—APT camera and electronics.

COMMUNICATIONS

The APT picture is communicated to an earth station in the space research band of 136-137 Mc. The video output, the turn-on, and the phasing code drive a modulator which amplitude modulates the 2400 cps subcarrier, thus requiring 4000 cps maximum frequency capability. The subcarrier is derived from the Nimbus master clock which is stable to 1 part per million. This stability is more than adequate for conventional facsimile receivers. The VHF carrier is deviated ± 10 kc, and with a 30 kc predetection bandwidth 5 watts must be transmitted from the spacecraft. The transmitter is a standard commercial unit which uses a 128 Mc fifth-overtone crystal oscillator. Modulation is applied to a 9 Mc voltage-controlled oscillator using a capacitor (varicap) as the variable element. A transistor mixer generates the upper sideband which is filtered and amplified in subsequent stages. An output stage designed with two TA2084 transistors operating in parallel develops more than 5 watts. Stability over the operating temperature of the transmitter is better than 0.01 percent and, since pre-aged crystals are employed, it is expected to stay within those limits over its projected lifetime of 6 months. The transmitter radiates through a small quadraloop antenna mounted on the base area of the spacecraft. The antennas have the appearance of a dielectric-loaded, shorted transmission line. Towards the open end of the line a tuning capacitor permits fine tuning. The feedpoint is removed from the shorted end for impedance match. The antennas radiate in a pattern similar to that on a dipole. Since the antennas are mounted on the base area, only small gain can be realized because the spacecraft acts as a reflector influenced by the position of the solar paddles. Figure 7 shows samples of the many patterns measured. Two mutually perpendicular components have been plotted demonstrating that the design objective of a gain larger than 1 was realized with a ±61 degree cone as measured from the spacecraft symmetry axis. This angular requirement stems from the fact that the horizon-to-horizon angle as viewed from the spacecraft is 122 degrees for a 1000 km altitude. Polarization components range from circular to linear and are dependent on the position of the solar panels. For the worst case of receiving station design, the best assumption is that the spacecraft antenna has a gain of 1 and emits a linearly polarized wave. Circular components emitted have right-handed polarization. In most cases ground reception below horizon angles of 10 degrees will not be practical. However, for design purposes the horizon distances of 4260 and 3480 km for the two altitudes mentioned should be considered. Path losses up to 148 and 146.2 db, respectively, are encountered. A ground receiving antenna having a gain of 10 db would receive -134 and -132 dbw for the two ranges.

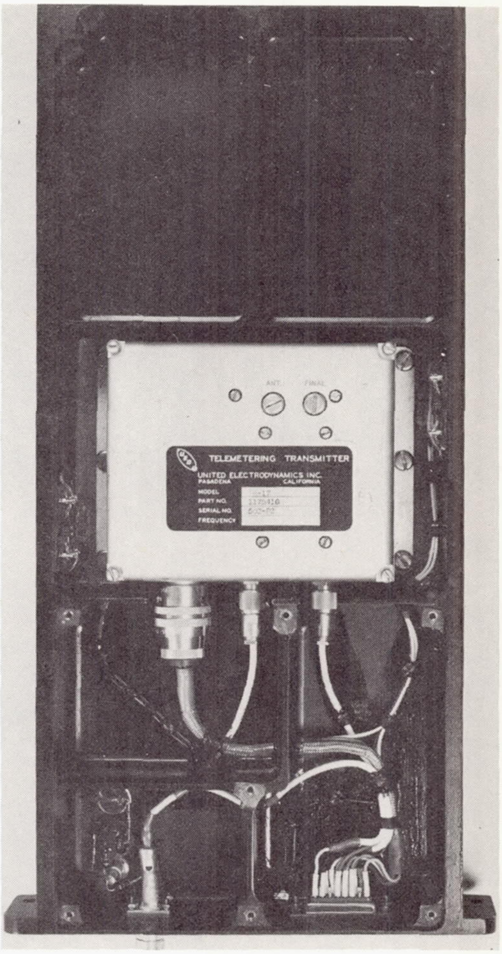


Figure 6—APT transmitter.

RECEIVING EQUIPMENT

The remaining parameters which determine the quality of the received picture depend heavily on the equipment chosen by an individual user. A set of ground equipment which is actually being used in various combinations at different locations is discussed here. In general, a helical receiving antenna yields good circularity with 10 db gain or better. The wide receiving angle avoids the necessity for autotrack. However, an azimuth and elevation pointing capability is necessary for effective use of the available transmission time.

Sky temperature at 136 Mc varies greatly, but is averaged over the wide antenna beam. A sky temperature of 1000°K can be expected around a wide angle centered approximately at the celestial equator.* However, users with more favorable celestial geometry can use receivers with higher noise figures. For the overall system a temperature of 1400°K can be assumed when a high quality preamplifier is employed. Preamps are available with noise figures of 3 to 6 db. The resulting carrier to noise ratio exclusive of the vidicon would be approximately 20 db. It is clear that this signal is at the threshold and postdetection signal-to-noise ratios of 30 db can be obtained from a variety of equipment. Mobile communication receiver equipment can be adapted for this application with only minor modifications. Noise properties of this type of equipment are higher than can be achieved, but operation can be satisfactory. As mentioned before, receiver output must be fed to a suitable facsimile recorder. Photographic and wet electrolytic papers are available on a variety of equipment. The four types in use at the present time will be described briefly.

*Ko, H. C., "The Distribution of Cosmic Radio Background Radiation," *Proc. IRE* 46(1):208-215, January 1958.

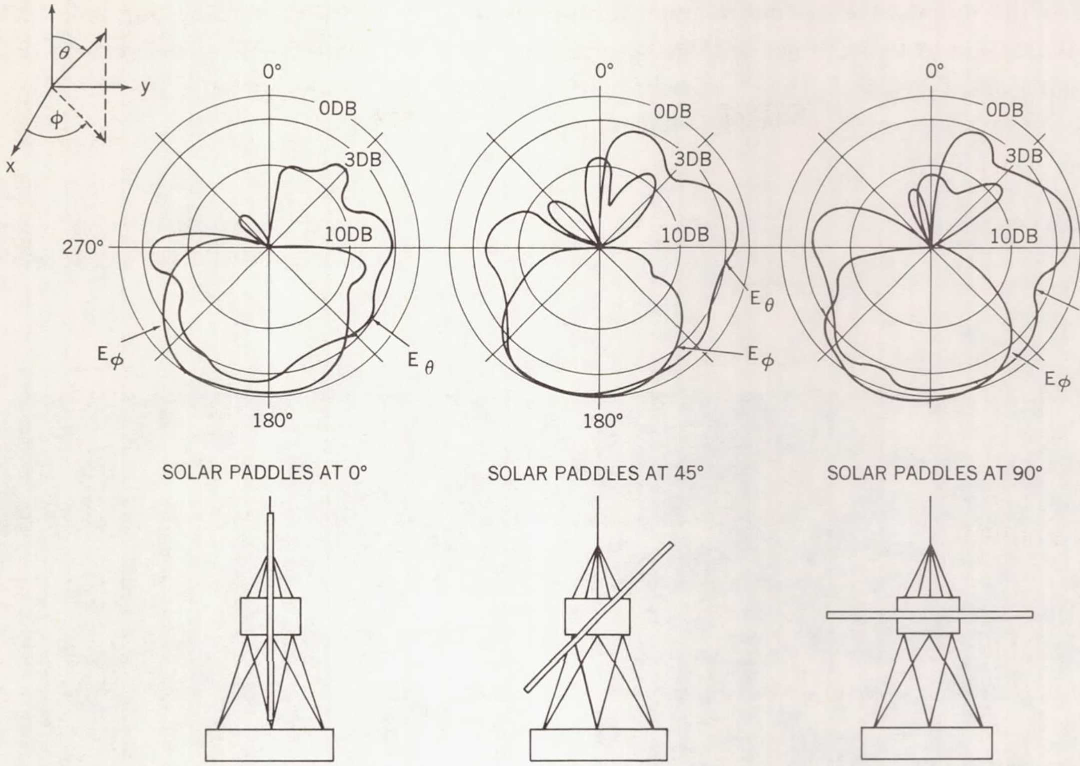


Figure 7—Antenna pattern.

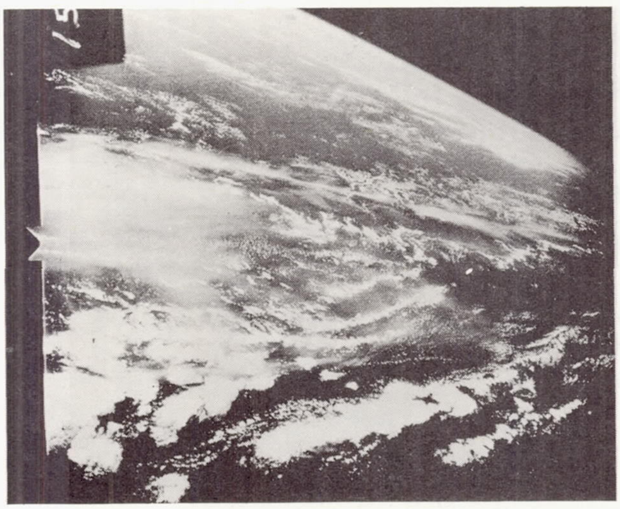
FACSIMILE EQUIPMENT

The Westrex Model 3030 TP is a photographic-type recorder designed for automatic turn-on and phasing. It remains synchronized over the duration of a frame through the use of a stable tuning fork oscillator. Polaroid film or paper can be exposed and both are available for immediate use. The use of appropriate paper permits a 70 mm picture to be inspected within 10 seconds. The light transducer is an R-1168 readout tube which illuminates an oscillating mirror for line scan. The scanning voltage driving this mirror is coherent with the paper or film advance drive moving the medium continuously.

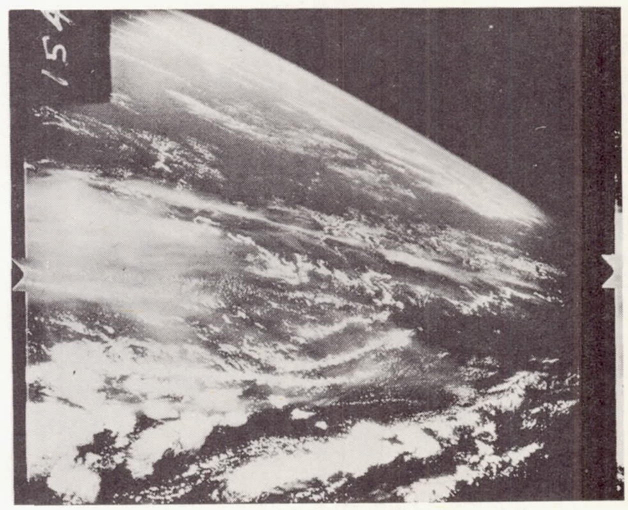
The Muirhead D700S is a photographic-type facsimile recorder. Eight inch film is wound around a drum which has a scanning speed of 240 rpm. The light transducer and optic are driven across the film at a synchronous speed providing the line advance. Automatic turn-on and phasing are provided and can be monitored.

Electrolytic paper recorders are less critical and more rugged in their operation, simpler in maintenance and less costly. On the other hand, the quality of the picture presentation is poorer than in the photographic units. The moist paper is driven by and pressed against a rotating cylinder. The cylinder contains a metallic, single turn, helical bar which provides one point contact between paper and cylinder. By turning the cylinder and advancing the paper, successive lines can be drawn on the paper. The electrolyte blackens in proportion to the current sent through it (actually in proportion to the current density for a small constant picture element), so that the moist paper and the cylinder alone are part of the video output circuit. Approximately 10 gray scales can be achieved with these machines. The Muirhead D900S and Fairchild Scan-a-fax are in use at the present time, the latter being used in APT ground stations now being installed throughout the world. A small modification of both is needed to obtain an aspect ratio of 1.

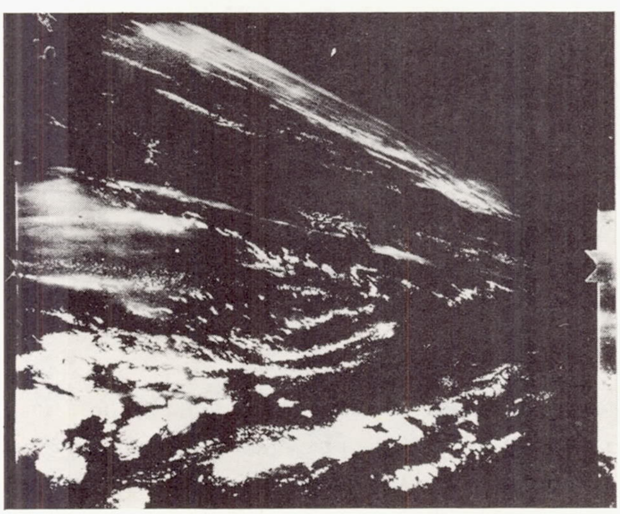
Figure 8 shows a comparison of picture quality. The original photograph, a photographic presentation reproduced by the Muirhead D700S, and a paper reproduction from the Fairchild Scan-a-fax are shown. Figure 9 pictures the manually controlled APT ground station and Figure 10 the antenna. Both of these were built for the NASA by the Fairchild Stratos Corporation.



Original Cloud Photograph



Muirhead D700S



Fairchild Scan-a-Fax

Figure 8—An original cloud photograph taken from a high altitude rocket and reproductions from the Muirhead D700S and the Fairchild Scan-a-Fax.

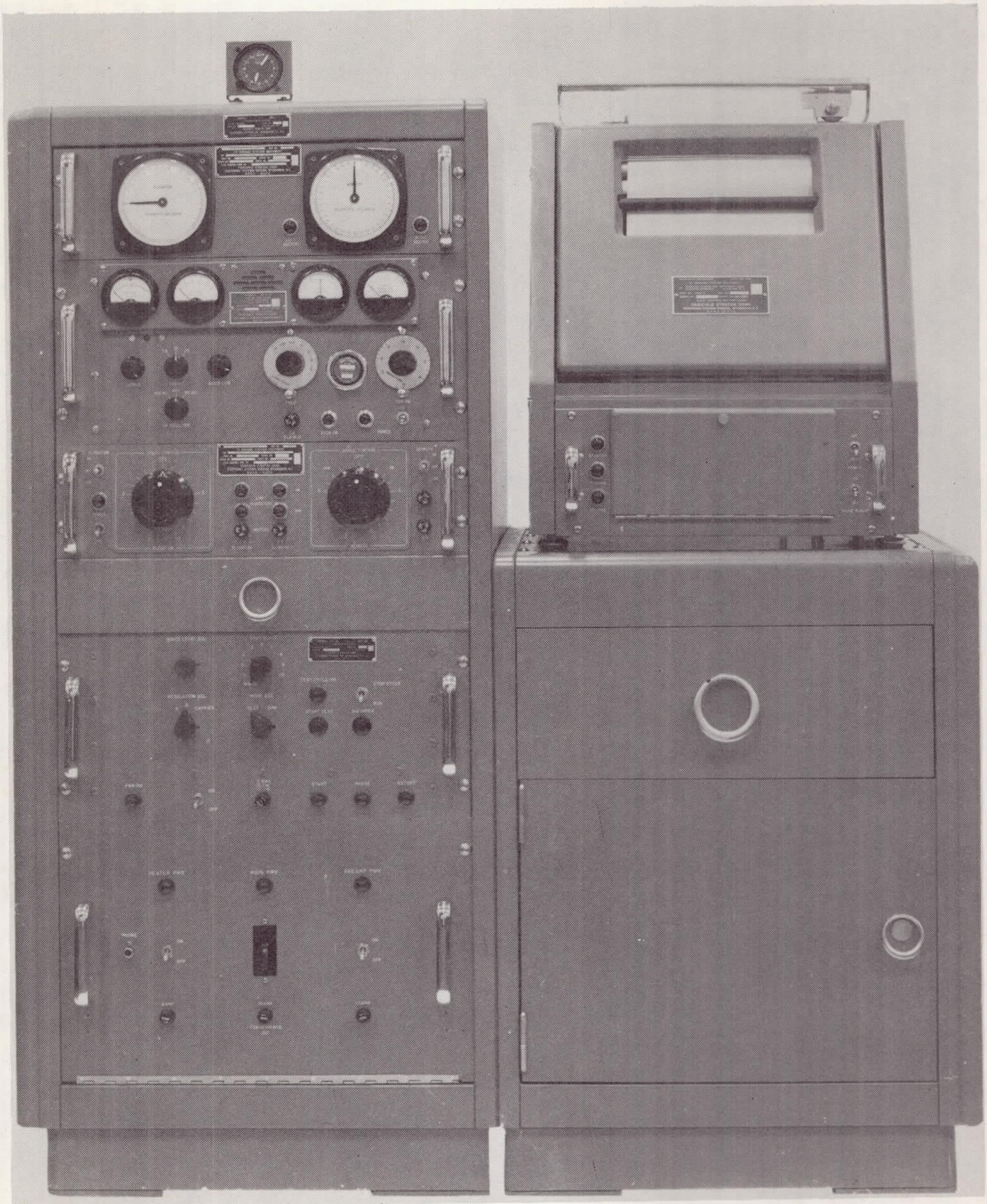


Figure 9—Photograph of the APT ground station showing antenna position indicators, receiver, antenna controls, facsimile calibrator, and power supply on left; facsimile is on right.

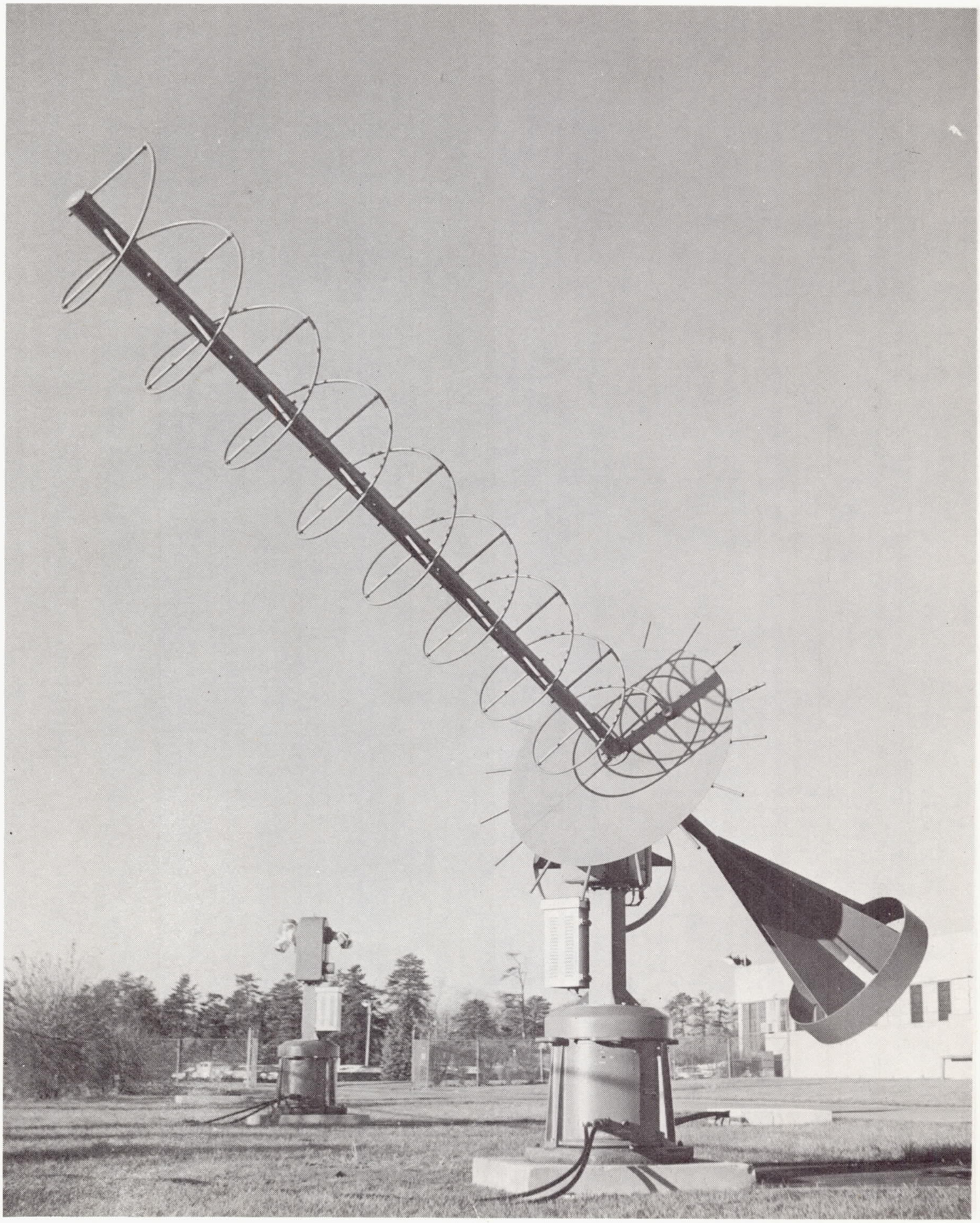


Figure 10—The APT antenna.

NASA-Langley, 1963 G-427