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New electronic and magnetic systems have been developed to handle huge quantities of data during each Nimbus orbit

Data storage for meteorological satellites

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Huge quantities of data will be stored and readout from advanced weather satellites, such as Nimbus. Data storage thus becomes a critical feature of design. This paper discusses some of the advanced research being conducted by the Goddard Space Flight Center (GSFC) in the field of electronic and magnetic data storage of video information in meteorological satellites.

Electrostatic storage is the basis for two unique TV systems being developed by RCA for GSFC. Two basic processes characterize these systems:

1. An optical image is converted to an electrical charge pattern that can be stored for relatively long periods of time (writing process).
2. The transformation at will of this charge pattern into a video signal (reading process).

The storage vidicon is the heart of the Automatic Picture Transmission System (APTS) which will be flown on Nimbus. This system provides wide-angle cloud-cover pictures from a satellite and transmits them in real time on a narrow-band channel to a local ground station for recording on facsimile equipment.

The storage vidicon resembles a conventional vidicon except for the addition of a thin, high-resistance polystyrene storage layer on the photoconductive surface. A cutaway view of the front end of the vidicon is shown on page 49. The tube is operated by holding the target potential constant and raising or lowering the mesh potential with respect to the target during the prepare, expose and readout sequences. The vidicon photoconductor is optically exposed by means of a mechanical shutter, and is then electronically "developed," that is, the charge image is transferred from the photoconductor layer to the polystyrene storage layer. The readout cycle follows for 200 sec, during which picture information is readout at the rate of 4 lines per sec.

Experimental evidence indicates that the polystyrene surface suffers radiation damage under prolonged electron bombardment, resulting in reduced lateral resistance and loss of storage capability. Research is being conducted to improve radiation resistance of the polystyrene by increasing the purity of the materials. The addition of a flood gun is being investigated to reduce the electron bombardment. In addition, other materials are being investigated.

On readout, the video signal amplitude modulates a 2400 cps subcarrier which in turn frequency modulates a 5-w transmitter as indicated in the block diagram on page 49. The requirement for the system to pass very low-frequency video signals was a difficult problem, solved by pulsing the cathode with a 4800 cps subcarrier. This subcarrier signal causes the readout electron beam to be chopped at the 4800 cps rate. The charge pattern on the polystyrene storage layer amplitude modulates the subcarrier. The video modulated subcarrier is A.C. coupled to a bandpass amplifier and detector.

Video data is continuously transmitted during the daytime portion of the satellite orbit. The system has a linearity of 0.5% and a limiting resolution of 700 TV lines. System linearity was achieved through special yokes, vidicons, and digital sweep circuits. Highlight sensitivity is 0.7 foot-candle sec. Signal-to-noise ratio is 26 db, giving approximately 7 grey scales. A grey-scale calibration wedge, consisting of 11 known levels, is located at the top of each picture, parallel with the horizontal scan. A flash tube illuminates the wedge each time the shutter is activated, giving a calibrated scale on each picture. The angular coverage is 108 deg, which, for a 500-n. mi. altitude satellite, yields approximately 1150 by 1150 n. mi. ground coverage per picture.

The storage vidicon thus permits slow scan readout, and a narrow bandwidth permits use of simple ground-station equipment. The APTS ground station can be assembled from inexpensive, off-the-shelf commercial components. The ground station consists of a helix antenna and a preamplifier mounted on a pedestal, a narrow-band FM receiver, and a commercial facsimile recorder modified for automatic start and stop, employing the airborne subsystem control signals, and thus permitting any local weather station to obtain direct cloud-cover pictures

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of the immediate area whenever the satellite is in view.

With an investment for a ground station of approximately $30,000, meteorological groups throughout the world will receive local real-time cloud pictures at least once a day for immediate use.

A second television system under development for Nimbus which utilizes the electrostatic storage is the Dielectric Tape Camera. The storage medium is a thin flexible tape coated with suitable materials which permits storage of an electric-charge pattern on an outer insulating layer.

The writing process consists of exposure of the tape to an optical image through a lens system in a manner similar to photography. However, in this process, the tape is also exposed to a uniform electron beam that deposits an electric charge on each elemental area of the tape in proportion to the amount of light falling on that area. Optical and electrical exposures both occur from the insulating or dielectric side of the tape.

To convert this charge image to a video signal, the portion of tape on which the image is stored is moved to a location where it can be scanned by the electron beam that performs the readout process. In this process, the polystyrene surface is scanned by the read beam in much the same manner as an image orthicon target is scanned by the electron beam. The result is that in the scanning process, the return beam is modulated by the charge pattern on the insulation.

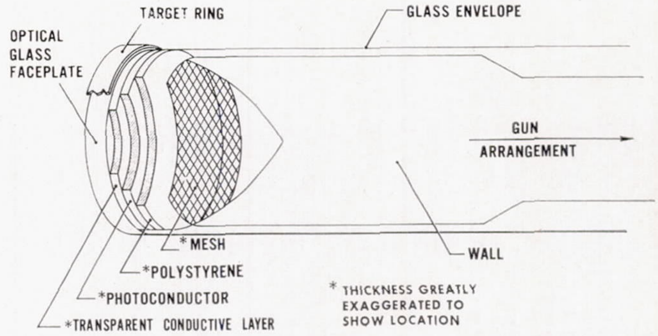
The tape itself is 35 mm wide and consists of three layers on a base material, as shown at the right. The base material is optical quality nylon called "Cronar." These optical properties were important in early development, when the tape was exposed optically through the base material. Research into the basic process indicates that it may be advantageous to make the base from an opaque material since optical exposure can be performed directly on the dielectric material, rather than through the base.

Three layers are superimposed on this base in sequence using vacuum deposition techniques. These layers are deposited on a continuous basis, with the tape moving at a constant rate of speed. Lengths as long as 50 ft have been processed on this laboratory tape machine.

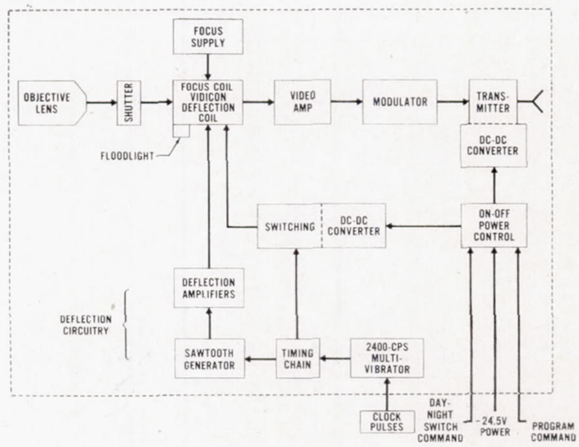
The first layer is a gold-and-copper combination approximately 0.01 microns thick which forms a transparent conducting coating that serves as the electrical connection to one side of the photoconductive layer.

The photoconductive layer is simi-

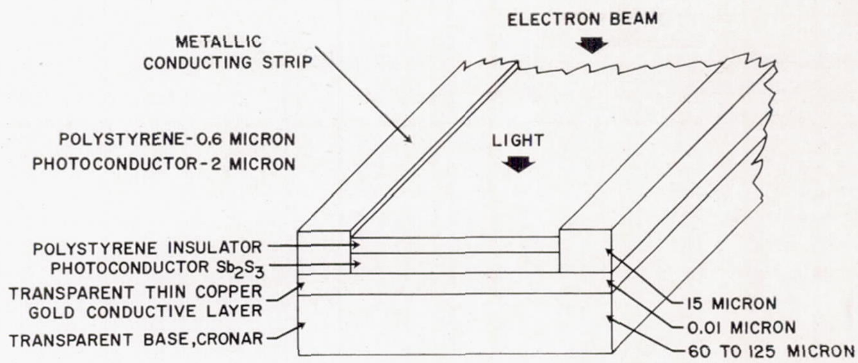
POLYSTYRENE STORAGE VIDICON



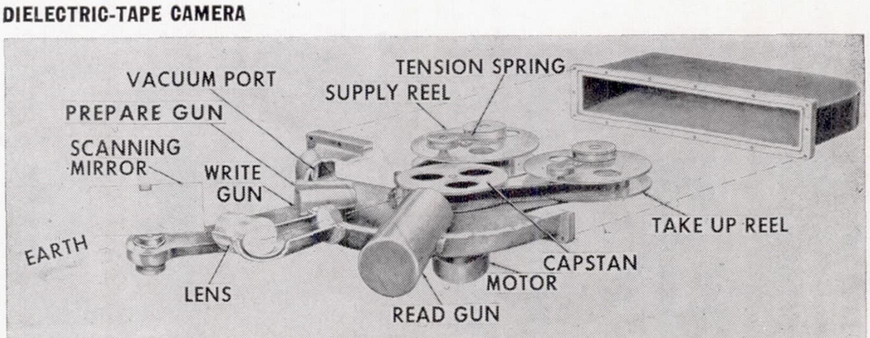
APTS DIAGRAM FOR SATELLITE



DIELECTRIC-TAPE CONSTRUCTION



DIELECTRIC-TAPE CAMERA



lar to the photosensitive layer of commercial vidicons, and the spectral response of the system is determined by this layer. The material used at present is arsenic trisulphide.

The final layer is an extremely thin uniform coating of polystyrene approximately 0.6 microns thick. This is the insulating layer that acts as a capacitor for holding the electric charges forming the charge pattern equivalent to the optical image.

A laboratory camera has been developed which has demonstrated the feasibility of utilizing the dielectric tape principles for observing the storing cloud-cover pictures from a satellite. The tape camera performs the combined function of observation and storage, replacing both the vidicon camera and the tape recorder. An advanced model is now under development which will closely approximate the flight configuration. This is shown on page 49. A number of problems remain to be solved, since the entire enclosure must be evacuated for proper operation.

The electrostatic camera possesses the following inherent capabilities:

1. Higher packing density per pound than the conventional camera/tape recorder configuration.

2. Limiting resolution comparable with the best image orthicons. 1200–1500 TV lines is currently achievable, with a target of 2500 TV lines in the foreseeable future.

3. Slit camera type operation, which permits wide angular coverage with low distortion.

4. Sensitivities comparable to currently available airborne vidicons, and low light sensitivities of the order of 0.01 ft-candle sec.

5. Variable resolution readout capability.

The present camera configuration can store on tape two complete orbits with horizon-to-horizon coverage with 0.2 mi. ground resolution.

The present Tiros and initial Nimbus spacecraft contain conventional vidicons with magnetic tape as the storage medium. The same is true of the infrared scanning system.

Simple calculations indicate that 10^7 infrared information bits and 5 $\times$ 10^8 TV informations in 96 pictures must be stored per orbit. These data are presented in analog or binary coded form. Data storage without mechanical movement is, of course, attractive. However, development of large memories with size, weight, and power comparable to magnetic tape recorders does not appear feasible within the next few years. For this reason, the imrpovement of magnetic-tape storage devices is constantly being investigated in-house at Goddard Space Flight Center.

A medium capacity endless-loop tape recorder has been successfully developed for satellite applications. The recorder utilizes 120 ft of 1/4-in. tape, and records for 1 1/2 hr. Playback is at 30 times the record speed. The recorder consumes 2 w of power on record and 10 w on playback.

Recorder development has emphasized flexibility so as to serve as many applications as possible. Momentum compensation has also been of prime importance. Stabilized spacecraft are controlled by small torques so that even the small unbalanced momentum generated by the recorders become major disturbances. Long-life applications require a sealed pressurized container; the lower section of the container houses drive-amplifiers for 100-cps synchronous motors, a pressure transducer, and auxiliary electronics. Inherent ruggedness of these units makes direct mounting on the container feasible with standard encapsulation employed.

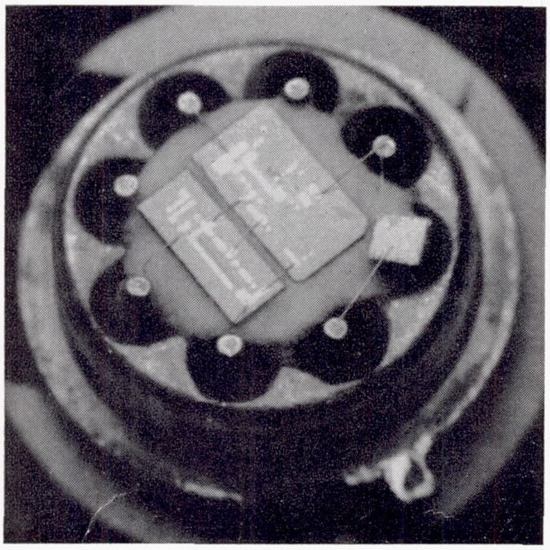
An analog version of the recorder has the endless-loop cartridge in the center of the container, partly covered by plugs, and the record and playback motors in the form of two cylinders to one side. A single capstan drives the tape across the head, held firm by a pressure pad. By single substitution, an eight-track digital head is mounted with the electronic record and playback amplifiers alongside.

Since the tape drive is a delicate mechanism, it must be mounted so as to survive the large range of vibration environments encountered in different structures. In general, resonance of these structures occurs at low frequencies, so the mount itself can be designed for resonance at higher frequencies. The tape drive is mounted between two plates tied to two shelves of the container by means of miniature dampers, and up to 20 *g*'s rms of random noise vibration can be applied, or an equivalent sinusoidal sweep, without failure.

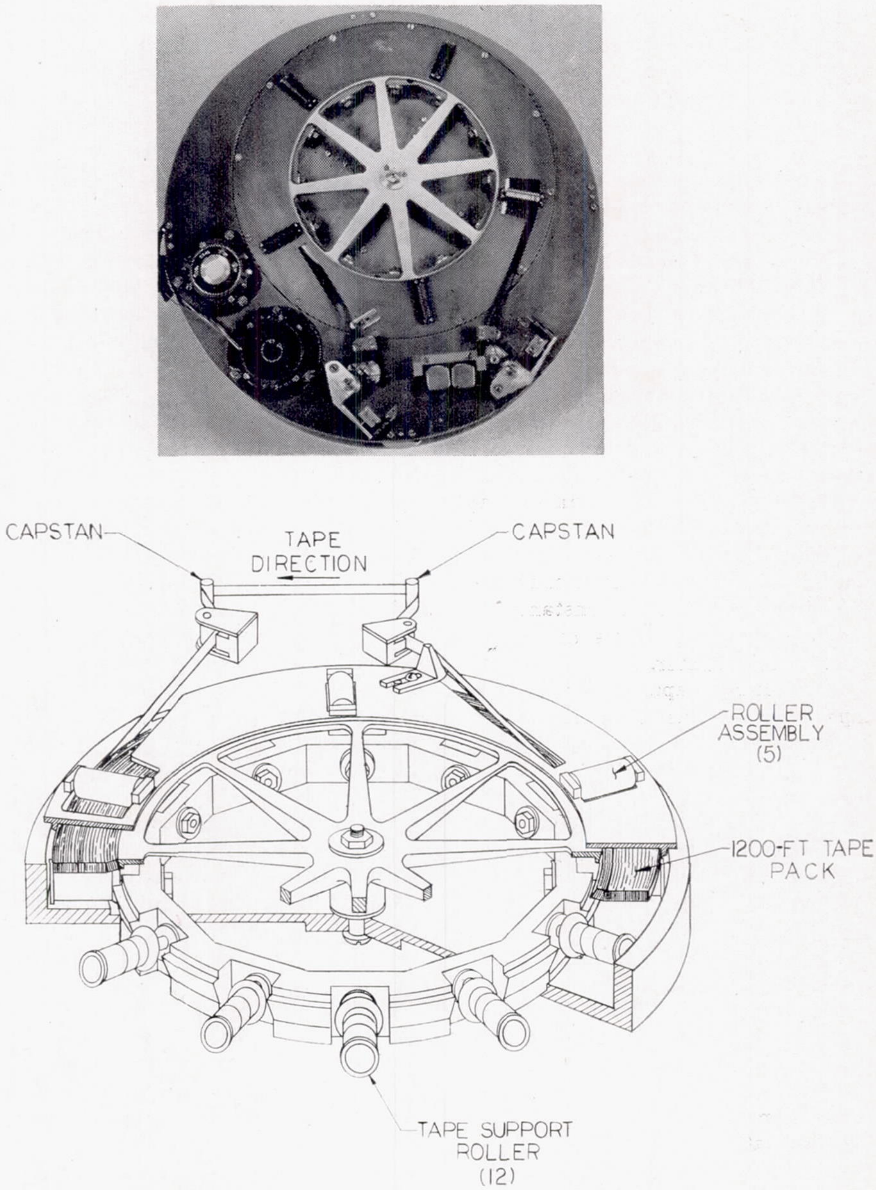
The record and playback amplifiers for analog units are inherently more reliable than the drive mechanism. Conventional analog amplifiers are being used. Digital amplifiers, however, lend themselves more readily to design by integrated circuits. The high reliability of these circuits when silicon planar transistors are used, and their small size, makes it practical to include an eight record/playback amplifer package in the recorder since it can be built with a volume equal to that of the recorder head. Such circuits can be operated at power levels of one microwatt per stage so that thermal dissipation of an assembly is negligible. Thus, these circuits run at low temperatures and are extremely reliable.

Each record amplifier consists of four transistors which can be mounted with its associated resistors in a standard transistor can. Conventional non-return-to-zero recording is used in which zeros and ones magnetize the tape in opposition. Separate erase is thus not needed. A microphotograph of the amplifier is shown at the left. The small square is a field-effect transistor preamplifier; the next larger square a silicon crystal with load and coupling resistors etched on the surface which serves as the next transistor stage. The longest crystal contains two direct coupled transistors and associated circuitry.

Similarly, playback amplifiers have been developed where the head output is amplified and the wave-shape re-



Single Digital Record Amplifier is shown in this microphotograph. Small square is a field-effect transistor; larger silicon crystals contain other circuitry.



1200-ft-tape Endless-loop Recorder now looks as shown in the photo at top, a laboratory model. The drawing below shows details of its endless-loop cartridge.

constructed by a multivibrator so that conventional or microminiature logic circuitry can process the pulse train. The power levels and small volume of these circuits permit selective redundance at small cost in terms of weight and volume.

Redundant logic circuitry can readily be designed to achieve long-life recorders. A contribution toward this end is the development of an analog-to-digital converter sufficiently small and of sufficiently low power that digital recorder techniques become comparable with analog.

Analog-to-digital converters can also be built according to any of the standard techniques using integrated circuits for the logic. The speed required for the conversion often determines the techniques used. A compromise between complexity and speed in an analog-to-digital converter leads to a design where the input signal is compared sequentially to a number of binarily related voltages, setting appropriate flip-flops. Readout can be serial or parallel as desired, since the flip-flops hold their positions until recycled. For most meteorological applications, seven bits or 128 levels is adequate. For infrared sensing, it is sufficient to operate this converter at a 40 microsec per bit rate, with total conversion requiring 280 microsec. Logic for such a converter has been microminiaturized and operates at less than 5 microwatts for this logic, with an additional 50 microwatts needed for the error amplifier and weighing network.

The requirement for large storage capacity led to the development of an endless-loop recorder having 1200 ft of 1/4-in. tape. Playback speed is 30 ips, and record speed is either 30 cps or 3 3/4 cps. The unit will record analog video whose subcarrier is frequency modulated. Initially, infrared scanner signals will be recorded. Later models will record TV frames when a fast start and stop is perfected.

The advantages of endless-loop recorders over more conventional two-reel types lie in their convenient readout capability. Since the tape moves in the same direction for record and playback, no recycling time is lost and a complicated high-speed recycle mechanism is not needed. Readout can be commanded at arbitrary times and, since erase can be performed immediately prior to record, only the oldest information will be erased regardless of how many readouts are performed within a given time.

A view of a laboratory-model recorder and a cross-section of the tape cartridge are shown at the left. Loops of a few hundred feet or shorter can be pulled without additional guide. The differential velocity between tape layers demands good tape lubrication, particularly in view of wide temperature requirements and attendant tension changes. These side effects became predominant when long loops were designed. Regular mylar magnetic tape cannot be used in untreated form. Preshrinkage at high temperatures creates good dimensional stability so that drive forces stay within tolerable limits. Tape lubrication has a direct influence on speed constancy, and the lubricant must be perfectly smooth. Low flutter and wow can only be achieved in long loops when tape support rollers are used, thus helping to overcome the velocity differential between the inner and outer radius.

Better performance has been achieved with long loops than with short ones, with flutter and wow of 0.17% rms up to 1000 cps and 0.102% rms up to 300 cps measured on a laboratory model. The general layout of the tape drive is an outgrowth of the short loops. Around the spoked wheel, retained by rollers, is the tape loop which is driven by two capstans from the innermost portion of the tape to the outer. As in other recorders, Mylar belts are used for speed reductions and a clutch engages the capstans to the record or playback drive chain, respectively.

The same drive principle can be applied to multiple track 1/4- and 1/2-in. tapes and to digital recorders, thereby generating a family of equipment for a variety of meteorological satellite requirements. ••