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James A. D'Arcy

Electrical Engineer, Radio Corporation of America, Astro-Electronics Division, Princeton, New Jersey

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PHOTO-DIELECTRIC TAPE CAMERA SYSTEMS

James A. D'Arcy
Electrical Engineer
Radio Corporation of America
Astro-Electronics Division
Princeton, New Jersey

Summary

A photo-dielectric tape camera is a type of television camera which combines the features of an image sensor and an electrostatic tape recorder in one package. Photo-dielectric tape (usually abbreviated to phototape or dielectric tape) is the essential part of a dielectric tape camera; it includes both the photosensitive medium and the storage medium. Optical images sensed by the camera are stored directly on the dielectric tape in the form of a charge pattern. The stored information can be retrieved immediately or retained for as long as several months.

Two types of dielectric tape camera have already been built by the Astro-Electronics Division of RCA as a result of programs sponsored by the National Aeronautics and Space Administration and the Air Force. One type, a 35-mm, panoramic, slit camera has been developed and space qualified for the Goddard Space Flight Center of NASA under Contract No. NAS-5-2503. Another type, a 70-mm, high-resolution camera, has been built as a laboratory model for the Air Force Avionics Laboratory of Wright-Patterson Air Force Base under Contract No. AF 33(657)-11485. These cameras are shown in Figure 1 and 2, respectively. In addition, several other types of dielectric tape cameras are in conceptual form.

The purpose of this paper is (1) to describe the dielectric tape and its use; (2) to describe the different types of dielectric tape cameras; and (3) to indicate some of the applications of these cameras.

Dielectric Tape

Description

Dielectric tape can be considered a reusable type of electronic film; thus far, it has been manufactured in two widths, 35 mm and 70 mm. As shown in Figure 3, the base of this tape is "cronar", a transparent, flexible, synthetic polyester about 5 mils thick. The edges of the cronar are folded to protect the central portion of the tape from contact with adjacent layers when the tape is wound on take-up reels. Three layers of material are evaporated on to the base, one on top of the other. The layer placed next to the base is a transparent conducting layer of gold; it provides electrical contact with one side of the photoconductor. The gold is thicker at the edges in order to provide a means of external contact. The thin portion of the gold layer is coated with the photoconductor layer, which is in turn coated with a thin insulating layer of polystyrene. The polystyrene is the dielectric across which the charge pattern is stored. Each of these three layers is several microns thick.

Operating Procedure

The basic procedure for using dielectric tape involves three operations as shown in Figure 4: prepare, record, and playback. The prepare operation charges the tape to a uniform predetermined potential in order to remove any charge pattern which may exist and to prepare the tape for exposure. The prepare operation requires saturating light and an electron flood beam. The light effectively short-circuits the photoconductor resistance Rp (indicated in the schematic of Figure 5) while the flood beam charges the surface of the insulator C1 to a uniform potential. This operation (and the record operation) depends upon the insulator having a secondary electron emission ratio which is greater than unity.

The record operation places a focused optical image on the tape in the form of a charge pattern. This operation also requires light and a flood beam. In this case, the light consists of the focused optical image, which modulates the photoconductor resistance Rp while the surface of the insulator C1 is exposed to the electron flood beam. The optically induced array of varying photoconductor resistance is thereby transformed into an equivalent electrical charge pattern on the insulator.

The playback operation converts the charge pattern into an electrical signal, which is transmitted to the

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* In a slit camera, a continuous strip of dielectric tape (or film) is exposed by moving the tape past a narrow rectangular aperture or slit at the same rate as the optical image to be recorded.

** Cronar is the Dupont trade name for prestressed mylar having good optical qualities.

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* The electron flood beam and the dielectric tape are used in a vacuum of about $10^{-6}$ mm Hg.
ground station. A finely focused electron beam is required for this operation. In the case of the panoramic camera, the electron beam is generated using a gun similar to that of a 1-inch vidicon. The beam from this gun strikes the insulator with a relatively high velocity (about 350 volts), generating secondary electrons. These secondary electrons have velocity components attributable to the charge pattern. A separator structure placed close to the tape separates the electrons according to their velocities and thus provides the output signal.

It should be pointed out that the 1-inch vidicon type of gun is not the only type used for the playback operation; as an example, the Air Force Laboratory Model uses a 4.5-inch orthicon type of gun with dynodes. Nor is operation limited to the use of a high-velocity beam; a low-velocity beam can also be used.

Salient Features

Some of the salient features of dielectric tape are:

- High-density information storage,
- Extremely resistant to radiation,
- Flexible electronic processing,
- Reusable,
- No mechanical contact with insulator,
- Ability to record panoramic pictures, and
- Long-term image storage capability.

It has been extrapolated that dielectric tape is capable of storing information with detail in excess of 100 line pairs per mm at 70-percent response; however, the detail in the output signal is limited by certain factors, principally the response of the lens and the finite size of the playback electron beam. The curves in Figure 6 indicate the effect that some of the parts of a high-resolution dielectric tape camera have on the detail in the output signal. The curve in Figure 7 is a comparison of photographic film and dielectric tape. It shows that dielectric tape can withstand more radiation than film, by several orders of magnitude. Furthermore, radiation damage to film is a cumulative, irreversible effect, whereas dielectric tape is not permanently affected and may be used again without degradation in performance.

1. Existing Camera Systems

Space-Qualified 35-mm Panoramic Camera

Thus far, one type of dielectric tape camera (Figure 1) has been space qualified. Developed for use in the Nimbus satellite (600-nmi, sun-synchronous, polar orbit), the camera was designed to provide high-quality panoramic pictures of the earth's cloud cover.

In operation, a panoramic scanning mirror and a narrow-angle lens image the desired scene onto the dielectric tape through a narrow rectangular aperture. The tape is moved past this aperture (or slit) at a rate equal to the rate of motion of the optical image. The result, as shown in Figure 8, is a long, narrow-strip picture, or swath. After each picture has been recorded, the mirror returns to its starting position and begins to scan a new scene.

The width of a picture swath (92 nmi) and the rate at which the picture is taken (26 seconds per frame) were selected so that successive scans of the mirror would provide contiguous coverage at the center of the picture. The length of the swath (1600 nmi) was selected so that equator crossings in successive orbits would be contiguous at the edge of the picture. With a full load of dielectric tape (about 90 feet), the camera is capable of storing about 120 frames, thereby providing a total earth coverage of 1600 nmi by 11,000 nmi in one orbit. The specified ground resolution is 0.2 nmi, which corresponds to a camera resolution of 600 TV lines per inch (50-percent response); the limiting resolution of the camera is estimated to be about 1400 TV lines per inch. The dynamic range of the camera extends from 0.003 to 0.1 footcandle-second; this corresponds to ten $\sqrt{2}$ gray-scale steps.

The panoramic camera is constrained to play back all of the recorded information within 8 minutes through a bandwidth of 680 kHz (Nimbus transmitter bandwidth). Camera playback was planned to occur at the end of each orbit, enabling the camera to record another area of the earth on the succeeding orbit. This process provides complete earth coverage in 24 hours.

The weight of the panoramic camera is 83 pounds, including the electronics package. It requires about 25 watts of power during the record mode and about 30 watts during the playback mode. The camera, with cover removed to reveal the tape transport, is shown in Figure 9. A picture recorded by this camera is shown in Figure 10.

High-Resolution Camera—Laboratory Model

Another type of dielectric tape camera is shown in Figure 2. This camera was designed and fabricated in the form of a laboratory model, using both slit and frame format. It was developed on an Air Force sponsored research and development program whose goal was to further the state of the art in dielectric tape technology and to develop components for high-resolution imagery.

The basic components of this camera are:

- 70-mm dielectric tape,
- A gun with dynode multipliers similar to that used in 4.5-inch image orthicons,
- A tape transport, and
- A flood gun.
The 70-mm tape is similar to the 35-mm tape used in the space-qualified panoramic camera; however, the 70-mm tape has an active width of about 56 mm compared to an active width of 19 mm for the 35-mm tape. The playback gun is similar to those used in 4.5-inch image orthicons with dynode multipliers. This combination of gun and dynode multipliers provides a much higher system resolution, because a smaller diameter scanning beam is used. The resulting tape signal is first amplified in the dynode multiplier stages. The limiting resolution of a tape camera using a gun similar to that of a 1-inch vidicon is about 30 line pairs per mm, but a limiting resolution of about 90 line pairs per mm has been produced under ideal laboratory conditions using the high-resolution laboratory model. Thus, the laboratory model has produced the equivalent of about 10,000 TV lines across the active width of the tape.

A picture produced by the laboratory model is shown in Figure 11. The limiting resolution is 90 line pairs per mm. The tape format was 56 mm by 56 mm, and 18,000 scan lines were used to read out the information. The picture was read out in sections because of the display device limitations; a total of 210 individual readouts were required to construct the mosaic and preserve the resolution.

To illustrate the capability of a flight model of this 70-mm camera, consider such a camera (frame format) being placed in a 450-nmi orbit with 100 feet of tape and a 182-mm focal length lens; its characteristics would be as follows:

<table>
<thead>
<tr>
<th>Camera System Resolution</th>
<th>90 line pairs per mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tape Format</td>
<td>56 mm by 56 mm</td>
</tr>
<tr>
<td>Ground Coverage per Frame</td>
<td>138 nmi by 138 nmi</td>
</tr>
<tr>
<td>Ground Resolution</td>
<td>83 feet</td>
</tr>
<tr>
<td>Full Load Coverage</td>
<td>$8.95 \times 10^6$ square nmi</td>
</tr>
<tr>
<td>Playback Time per Frame</td>
<td>5.8 seconds</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>12 MHz</td>
</tr>
<tr>
<td>Weight (Approximate) of Camera and Electronics</td>
<td>150 pounds (excluding lens)</td>
</tr>
<tr>
<td>Power (Approximate)</td>
<td>300 watts (playback mode)</td>
</tr>
<tr>
<td></td>
<td>100 watts (record mode)</td>
</tr>
</tbody>
</table>

**Conceptual Camera Systems**

**High-Resolution Frame Camera**

During the past several years, a large amount of development effort has been expended in furthering the state of the art of dielectric tape technology. In addition, a parallel RCA-sponsored program has resulted in a new type of television camera; this camera uses 2-inch return-beam vidicon electron optics. Combining the outputs of these two efforts has resulted in another type of dielectric tape camera in conceptual form: the 35-mm frame-type dielectric tape camera. This camera, which is illustrated in Figure 12, has the resolution capability of the 70 mm high-resolution camera, but is similar in size to the 35-mm panoramic camera.

The basic components of the 35-mm frame-type camera are:

- 35-mm dielectric tape,
- A gun with dynode multipliers similar to that used in the 2-inch return-beam vidicon,
- A tape transport, and
- A flood gun.

The dielectric tape being considered for this camera has a nominal width of 35 mm and an active picture format of 25 mm by 25 mm. Plans call for sprocket holes along one edge of the tape in addition to the folds, so that accurate movement of the tape from the expose station to the playback station can be accomplished. About 100 feet of tape can be stored in the camera.

The playback gun with dynode multipliers designated for the 35-mm frame-type camera is similar to that used in the 2-inch return-beam vidicon. The operation of this gun is similar to that used in the 70-mm camera, and comparable resolution is anticipated. However, since the format of this camera is 25 mm by 25 mm, the realizable limiting resolution is 4500 TV lines across the width of the tape.

A relatively simple type of tape transport is planned for this camera. The most stringent requirement is accurate indexing; therefore, a precision advance mechanism would be used. It would be required to operate reliably in a vacuum for the orbital life of the camera.

The flood gun of the 35-mm frame-type camera would be used for both prepare and record. The gun is required to generate a flood of electrons that will uniformly cover the 25 mm by 25 mm format. A flight model of this type of camera would weigh about 70 pounds, including electronics, and would require about 50 watts of power during the playback mode.

This type of camera would be particularly useful in missions requiring high-resolution sensing and storage. Possible applications include an earth resources orbiting satellite and a moon or planetary orbiter. The camera could also be used on deep space missions and would serve best when sufficient transmission bandwidth, or time, was available to permit full use of its very large data storage capacity.
Drum-Type Camera

Another conceptual dielectric tape camera that would be applicable to a deep-space mission is shown in Figure 13. This camera is called a drum-type camera because it contains a faceted drum with a chip of dielectric tape attached to each facet.

The dielectric tape is in the form of 16-mm squares that are securely fastened to the facets. The camera is capable of holding 60 frames on an eight-inch diameter drum fabricated out of machined aluminum. The drum advance mechanism accurately transports a given tape chip to either the record or the playback station. The active area of the tape is dependent upon the type of playback gun used. Using a gun from a 1-inch vidicon would provide the lightest and smallest type (shown in Figure 13) of dielectric tape camera, but the active format size would only be about 6 mm by 6 mm. However, if a gun from a 1-inch vidicon were used, the active format size would be about 12 mm by 12 mm. A camera using either gun would be capable of providing a system limiting resolution of at least 30 line pairs per mm.

The cross-sectional area of the flood-gun beam depends upon the active format size. The smaller the tape format the smaller will be the flood gun. Only one flood gun is planned for the drum camera in Figure 13; this gun will be used for both the prepare and record cycles. Two possibilities have been considered for the prepare cycle: preparation of each tape chip just prior to being exposed, or preparation of all of the chips shortly before the start of the record cycle.

The drum camera is the lightest of the various dielectric tape cameras (about 30 pounds, including the electronics), requires the least power (about 15 watts), and is more readily sterilized. However, the format size and the storage capability are smaller in this camera than in the other cameras.

As an example of the use of a drum camera, consider such a camera placed in a Mars orbit 1000 kilometers above the surface; its characteristics would be as follows:

<table>
<thead>
<tr>
<th>Lens</th>
<th>16.6 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Playback Gun</td>
<td>1-inch vidicon gun</td>
</tr>
<tr>
<td>Format</td>
<td>6 mm by 6 mm</td>
</tr>
<tr>
<td>Tape Resolution</td>
<td>30 line pairs per mm</td>
</tr>
<tr>
<td>Ground Resolution</td>
<td>1000 meters</td>
</tr>
<tr>
<td>Ground Coverage per Frame</td>
<td>360 km by 360 km</td>
</tr>
<tr>
<td>Number of Storage Frames</td>
<td>60</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>5000 bits per second*</td>
</tr>
</tbody>
</table>

* Typical values for planetary missions.

Bits per Picture Element 6 bits per picture element
Readout Time per Picture 7.9 minutes
Total Readout Time 7.9 hours

Because of the slow readout speed, in the above example, a pulsed-beam type of readout has been assumed.

There are several areas in which the drum camera could be used effectively; it could be used for applications in which weight and power are prime considerations and large storage capability is not so important. One example is deep-space planetary missions, particularly if the camera must pass through a radiation field. A planetary lander mission is another possible application.

Conclusion

There are undoubtedly other dielectric tape camera configurations that can be described. However, the exact configuration of the camera depends upon the mission requirements, including the tradeoffs relating to weight, power and size. Several important considerations are:

- Tape resolution,
- Storage capability, and
- Picture format.

The tape resolution requirement determines the width of tape and the type of playback gun to be used. The storage capability is determined by the amount of time allotted for retrieving the stored information, the size limitation of the camera, the coverage to be stored, and other items. Establishing the picture format involves many considerations; it can be panoramic, frame-type, or the type of picture produced by a slit camera.

Because of their high-density and long-term storage, extremely high resistance to radiation, flexibility of processing, and reusable tape, phototape cameras are ideal for the following applications:

- Meteorological satellite for world-wide, high-resolution cloud and ground coverage.
- Deep space missions, such as a Mars Orbiter. The reusability and radiation resistance features of phototape make it particularly applicable to this type of mission.

Finally, it should be pointed out that cameras are not the only application for dielectric tape; it may also

* Typical values for planetary missions.
be used in scan converters and data storage devices. In these two cases, the dielectric tape is simplified by eliminating the photoconductor, and a read-in gun is used in place of the lens and flood-gun combination.

References


Figure 1. NASA Dielectric Tape Camera
Figure 2. Air Force Dielectric Tape Camera
Figure 3. Cross Section of Dielectric Tape
Figure 4. Operational Sequence
\[ R_p: \text{PHOTOCONDUCTIVE RESISTANCE} \]
\[ C_p: \text{PHOTOCONDUCTIVE CAPACITANCE} \]
\[ C_i: \text{INSULATOR CAPACITANCE} \]
\[ R_b: \text{INTERNAL RESISTANCE OF ELECTRON BEAM} \]
\[ E: \text{EFFECTIVE SUPPLY FOR CHARGING TAPE} \]

Figure 5. Dielectric Tape, Schematic Diagram
Figure 6. Response of Various Parts of High-Resolution Dielectric Tape Camera
**INFORMATION RETAINED**

- **PERMANENT FOGGING**
- **SINGLE IMAGE LOSS**

**RECEIVED DOSE (RADS)**

**A**
**PLUS - X AERIAL FILM**
FOG DENSITY INCREASED TO 1.8

**B**
**VAN ALLEN BELT**
ONE TOS ORBIT

**C**
**SOLAR FLARE**
18 MONTH MISSION, LUNAR ORBITER OR MARS ORBITER

**D**
**SOLAR FLARE**
"ONE GREAT FLARE"

**E**
**NUCLEAR BURST**
20 KT A-BOMB 1-10 MILES FROM CAMERA

**F**
**OPTICS DAMAGE**
GLASS LOSSES 50% TRANSMISSION

**G**
**VAN ALLEN BELT**
6-MONTH TOS MISSION

a. 750 NMI POLAR ORBIT, 1963 ENVIRONMENT. DOSE BEHIND 0.3" ALUMINUM
b. BEHIND 0.3" ALUMINUM, 1967
c. ORBIT AS FOR (a)

**Figure 7. Comparison of Film and Dielectric Tape for Resistance to Radiation**
Figure 8. Panoramic Coverage of NASA Dielectric Tape Camera
Figure 9. Interior View of NASA Dielectric Tape Camera
Figure 10. Panoramic Picture Produced by NASA Dielectric Tape Camera
Figure 11. Picture Produced by Air Force Dielectric Tape Camera
Figure 12. 35-mm High-Resolution Frame-Type Dielectric Tape Camera
Figure 13. 16-mm Drum-Type Dielectric Tape Camera