Logic and Control Systems for a Panoramic Television Camera

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Introduction

The Dielectric-Tape Television Camera, including the subject logic and control system, is being developed for use in a meteorological satellite which will be placed in a polar orbit hundreds of miles above the surface of the Earth. This camera is being developed by the Astro-Electronics Division of RCA for the NASA Goddard Space Flight Center under contract NAS5-2503.¹

Dielectric tape is a 35-millimeter-wide, transparent plastic material which is covered with a transparent conducting layer of evaporated gold to provide electrical contact with one side of the photoconductor. The gold is coated with a photoconductive layer which is, in turn, coated with a thin, very uniform, insulating layer of polystyrene.²

The function of the camera, as depicted in Figure 1, is to provide high-quality panoramic pictures of the Earth's cloud cover. This is accomplished by recording the desired image on the dielectric tape in the form of a charge pattern. Later, when the satellite is over the ground station, the charge pattern is converted into an electrical signal which is transmitted to Earth where it will be permanently recorded on a graphic medium.

The camera is controlled primarily by three commands: Write (record), Read (playback), and Off. An additional eleven commands are used for peripheral and back-up operations. The commands are either transmitted from the ground station to the camera directly or they are stored in the satellite computer for a specified period of time.

The logic and control system has been designed to accept these commands and automatically direct the camera to perform the numerous functions characteristic of each mode of operation.

In the following sections, the operation of the camera is described in order to provide a general understanding of what is required of the control system. Particular emphasis is given to that part of the control system which synchronizes the retrace or "flyback" of the scanning mirror to the cycle of time code being recorded on the tape for identifying adjacent picture frames.

Control System

Record Mode

The camera has two primary modes of operation: record and playback. The record mode (see Figure 2) begins when the satellite computer sends a write command to the camera. Immediately, the playback mode

Figure 1. Representation of the Camera Coverage

100 STATUTE MILES
176 STATUTE MILES
1720 STATUTE MILES
Figure 2. Functional Block Diagram of the Write Mode

NOTE:
S₂ PROVIDES SCANNING MIRROR POSITIONAL INFORMATION.
circuits are deenergized if necessary; the electron-gun circuits are energized, together with the logic circuits, the iris servo, and the motor amplifier; and the tape motor is programmed (but is not energized at this time) to operate in the slow-forward mode.

The tape motor which is used for driving the dielectric-tape transport mechanism is a synchronous motor with two fields, a four-pole and an eight-pole. During the write mode, 100-cps power and the eight-pole field are used. During the read mode, the tape transport is driven eight times faster because 400-cps power and the four-pole field are used.

When the iris servo is energized, the iris is automatically adjusted to the proper opening. The iris opening is based on the position of the satellite over the Earth: minimum opening occurs over the equator; maximum opening occurs near the poles. The iris servo is programmed so that the iris will be readjusted during the 2-second mirror-retrace interval and during the 30-second interval between the write command and the start of the tape motor. Operation during the 30-second interval is provided in case the iris must be adjusted from maximum opening to minimum opening at the start of the write mode; this interval also provides stabilization time for the electron guns before actual recording begins.

During picture taking, adjustment of the iris is limited to the mirror retrace interval so that the aperture is not varied during the time that a picture is being recorded.

Thirty seconds after the write command is given, both the mirror and the tape motors are energized, and the actual recording of information on the tape begins. During the record mode, an optical image of the area under the satellite is focused by means of a scanning mirror and a narrow-angle lens system on the dielectric tape which is moving past a narrow rectangular slit at a rate equal to the rate of motion of the image. The image falling on the tape is converted into an electrical charge pattern which can be stored on the tape for a long period of time. When the scanning mirror reaches the end of its travel, it returns to its starting position.

There is approximately a two-second time interval (mirror retrace or synchronization interval, discussed in detail later) between successive pictures when time code, sync signal, and a gray-scale pattern are recorded on the tape. The mirror then scans a new scene and continues to scan for about 24 seconds until the next mirror-retrace interval begins. This results in a series of strip-pictures being recorded on the tape and continues until the camera is commanded to stop recording or until the end-of-tape is reached. The record circuits are then deenergized.

The aforementioned time code (NASA Minitrack, non-return to zero format) which is generated in the space vehicle will accompany the adjacent picture frames and will be used for time and geographical identification; the sync signal will be used to synchronize the ground equipment with the satellite camera; and the gray-scale test pattern is useful for monitoring the transfer characteristic of the entire system.

Playback Mode

When the satellite is over the ground station, a playback command is given. Immediately the write circuits are deenergized, if necessary; the read-gun circuits (see Figure 3) and the transmitter are energized; and the tape motor is programmed to operate in the fast-reverse mode (or in the fast-forward mode depending on the control system program). Simultaneously, a calibration pulse is connected to the video-amplifier input and transmitted to the ground station until playback begins. There is a 30-second delay before actual playback begins which allows time for the read gun to stabilize and for the gain of the video circuits to be checked using the calibration pulse.

Thirty seconds after the read-gun circuits are energized, the motor-power amplifier and the tape motor are energized. The playback cycle then commences and the charge pattern on the tape is converted into an electrical signal which is transmitted to the ground station. Playback continues until the end-of-tape is reached or until a command to stop reading is given. For an additional playback cycle, the required commands are sent to the camera; the resulting playback will be the same as previous playbacks except for the direction of motion of the tape and a finite amount of signal loss incurred for each successive readout.

Circuitry

The control system, with the exception of the mirror synchronization and iris servo sections, is an elaborate interconnection of latching relays. These relays are being used in applications where the anticipated number of operations is less than the minimum rating. In accordance with contract specifications they are also used as interface devices which accept external commands and direct the camera to perform the required operations.
Figure 3. Functional Block Diagram of the Read Mode

**Mirror Synchronization**

Time code is written on the tape for identifying adjacent pictures transmitted to the ground station. Three methods of writing time code on the tape were considered. The major advantage of the method selected is that it does not require the use of the read-gun circuitry during the write mode and, therefore, results in a conservation of power and an increase of reliability. The method consists of writing time code longitudinally on the tape during the retrace interval of the scanning mirror and requires that the scanning mirror be synchronized to the time code. This method, coupled with the specification that the total picture frame time must be 26 seconds, established the basic requirement for the mirror synchronization section.

**Scanning-Mirror Drive Mechanism**

In addition, the scanning mirror is required by orbital constraints to rotate through an angle of 49.05° in 24 seconds. The mechanism which has been designed to drive the scanning mirror utilizes a synchronous motor which drives a ratchet with seven equally spaced teeth (51.42° each). This ratchet wheel, in turn, drives the mirror mechanism. When the mirror reaches the end of its scan, an electro-optical switch (S2) is actuated and signals the beginning of the mirror synchronization interval. At the beginning of this interval, the mirror-return solenoid is energized and releases the mirror from the driving ratchet tooth. The mirror then returns to its starting position where it is intercepted by the succeeding ratchet tooth.
Since the mirror travels at the rate of 2.044° per second, an angular distance of 51.42° requires a travel time of 25.16 seconds, leaving 0.84 second of the 26-second period for synchronization. The logic circuitry utilizing the 1-cps time base available from the satellite clock is capable of supplying a start signal to the mirror motor at 0.5-second intervals. Since the actual travel time of the mirror motor during a frame should be less than 26 seconds and greater than 25.16 seconds, the motor must be energized 0.5 second after the beginning of the selected cycle of time code. It is desired that the mirror motor be de-energized 0.26 second (1% of 26 seconds) before the occurrence of the cycle of time code to be written. Therefore, the actual travel time of the mirror motor during a frame is 25.24 seconds. A criterion of synchronization requires the mirror motor to start from a reference position every frame. This implies the necessity of reversing the mirror motor every frame. Therefore, using a monostable multivibrator, a reversal time of 0.2 second is provided and takes into consideration motor acceleration and tolerances.

Mirror-Synchronization Logic

The system of mirror synchronization, developed to control the mirror mechanism, is included in the logic diagram on Figure 4. The relationship of the mirror-synchronization operations which occur during the mirror-retrace interval is indicated on the timing diagram on Figure 5. The retrace interval begins when the electro-optical switch (S2) is actuated, causing the shift register to select the next recurring cycle of time code. At the same time, the mirror motor stops rotating in the forward direction and reverses for 200 milliseconds. Actuation of S2 also causes the iris servo to turn on, the instrumentation projector to turn on, and the shutter to close. One hundred milliseconds after S2 actuates, the mirror-return solenoid actuates causing the mirror to return. During the retrace interval, gray-scale and frame sync are recorded on the tape by transmitting light from the instrumentation projector lamp through a reticle containing the desired pattern. The light pattern thus formed is projected onto the tape. With the aid of the electron beam, a charge pattern corresponding to the light pattern is then formed on the tape. Recording of gray-scale and frame sync continues until recording of time code begins.

Writing of time code begins when the next positive-going edge of the 1-cps square wave appears at the input of the synchronization circuitry. Time code is written by deflecting the write-gun beam to the auxiliary slit of the write slit assembly (a circular metal disk with two narrow slits) and allowing the selected time code signal to deflect the write beam on and off the auxiliary slit but always away from the main write slit. This causes a charge pattern corresponding to the selected cycle of time code to appear on the tape. After time-code writing is complete, the write beam is deflected away from both slits for 735 milliseconds so that the written time code passing under the write slit on the tape is not degraded by the write beam. One half second after the beginning of time code, high voltage (60-volt square wave for good starting characteristics) is applied to the mirror motor, which then begins to rotate in the forward direction.

When the write beam is deflected back to the write slit (1.735 seconds after the beginning of time code), gray scale and frame sync are once again written on the tape.

About two seconds after the beginning of time code, the shutter is opened, the iris servo is turned off, and the instrumentation projector is turned off. At the same time the voltage applied to the mirror motor is switched from high (60 volts) to low (42 volts) to conserve power.

When the shutter opens, active picture-taking begins and will continue for approximately 24 seconds, until switch S2 is actuated and directs the mirror-retrace interval to begin again.

Mirror-Synchronization Circuitry

Conventional Logic Elements. Most of the logic elements are conventional semiconductor circuits: bistable multivibrators, resistor-coupled-transistor-logic elements, and monostable multivibrators. In some cases, conventional diode-coupled-transistor-logic elements are used. However, a significantly different type of circuit is used to control the iris and mirror motors.

Motor Control Circuitry. The type of circuit used to control the iris and mirror motors must meet two major requirements: (1) It must be capable of reliably switching the motor on and off thousands of times in the specified environment, and (2) Its output must be completely isolated from the input.

The method selected is easily adapted to control by logic elements. The basic elements are a light-actuated silicon-controlled rectifier (photo-SCR) and an ultraminiature long-life incandescent lamp as shown in Figure 6.

When a lamp is energized, the corresponding photo-SCR's fire and complete the circuit for the flow of current through the motor coils. When the lamp is deenergized, the corresponding photo-SCR's present an open circuit to the flow of current. Therefore, with lamp No. 1 energized and lamp No. 2 deenergized, motor coil L1 is connected directly across the line and...
NOTES:
1. A HIGH INPUT OR OUTPUT INDICATES THE PRESENCE OF A SIGNAL
   WHEREAS A LOW INPUT OR OUTPUT INDICATES THE ABSENCE OF A SIGNAL.
2. CIRCLED NUMBERS CORRESPOND TO WAVEFORMS ON THE TIMING DIAGRAM
3. XD GOES HIGH 30 SECONDS AFTER A WRITE COMMAND IS GIVEN, (WHEN
   THE TAPE MOTOR STARTS)
4. S2 IS AN ELECTRO-OPTICAL SWITCH WHICH IS ACTUATED WHEN THE MIRROR
   REACHES THE END OF ITS SCAN.
5. THE SOLAR POT IS GEARED TO THE SOLAR PADDLES PROVIDING THE IRIS
   SERVO WITH SOLAR PADDLE POSITIONAL INFORMATION

Figure 4. Simplified Logic Diagram of the Mirror Synchronization Section
Figure 5. Timing Diagram of the Mirror Retrace Interval

Figure 6. Schematic Diagram of the Photo-SCR-Lamp Method of Motor Control

coll L2 is in series with the quadrature capacitor C1. The motor then rotates in a specified direction. If lamp No. 2 is energized and lamp No. 1 is deenergized, the motor will rotate in the opposite direction.

This explanation applies to the control circuits of both the iris motor and the mirror motor with one exception: An extra photo-SCR lamp combination is connected to the mirror motor in order to apply low voltage (42 volts) when the high voltage is disconnected.

Solenoid Single-Shots. The one-shot multivibrator that controls the various solenoids in the system is required to supply a two-ampere pulse (100-millisecond duration) when the corresponding solenoid is to be energized. The circuit being used is shown in Figure 7 and basically consists of two SCR's interconnected by a commutating capacitor. A trigger pulse causes CR1 to conduct and CR2 to turn off by commutating action. CR1 will turn off by commutating action when CR2 is turned on by a pulse from the time delay circuit connected to its gate.

Results

Testing of the synchronization section indicated that it performs according to specification. Using a Hewlett-Packard Electronic Counter, the measured elapsed time of 10 successive picture frames was measured and was 260.022 seconds or an average picture frame of 26.002 seconds. The interval in seconds between the end of the scan (S2) and the
beginning of time code was measured (nominal = 0.26 second) for fourteen successive intervals as follows:

<table>
<thead>
<tr>
<th>Interval</th>
<th>Elapsed Time</th>
<th>Interval</th>
<th>Elapsed Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.275</td>
<td>8.</td>
<td>0.274</td>
</tr>
<tr>
<td>2.</td>
<td>0.318</td>
<td>9.</td>
<td>0.313</td>
</tr>
<tr>
<td>3.</td>
<td>0.318</td>
<td>10.</td>
<td>0.315</td>
</tr>
<tr>
<td>4.</td>
<td>0.254</td>
<td>11.</td>
<td>0.254</td>
</tr>
<tr>
<td>5.</td>
<td>0.197</td>
<td>12.</td>
<td>0.197</td>
</tr>
<tr>
<td>6.</td>
<td>0.212</td>
<td>13.</td>
<td>0.225</td>
</tr>
<tr>
<td>7.</td>
<td>0.333</td>
<td>14.</td>
<td>0.335</td>
</tr>
</tbody>
</table>

Note that a particular interval repeats after seven frames indicating that the discrepancies are due primarily to angular variations among the ratchet teeth.

Peripheral and Back-Up Operations

When a satellite is sent into orbit for a specific length of time, it is essential that the various systems on board operate properly during the life of the satellite. One method of overcoming the possibility of component failure is to duplicate circuitry. An alternative to the use of redundancy is a method of back-up that utilizes alternate-path operations. This concept, which is used in the control system, allows the camera to continue operating even though portions of the synchronization circuitry have failed.

Mirror-Logic Override

Alternate-path operation is illustrated in the mirror-synchronization system. In this case, if a failure were to occur, the mirror motor would be disconnected (by command from the ground) from the logic circuit and would be directly connected to the motor power amplifier (essentially in parallel with the tape motor). A picture without time code and sync is better than no picture at all; this method is more than justified by the major savings in space that would otherwise be occupied by redundant circuitry.

Solenoid "Try-Again"

Another reliability innovation involves the various solenoids. As far as satellites are concerned, the solenoids require a tremendous surge of power to operate (2 amperes at 24 volts). Thus, if the electronics associated with a particular solenoid were to short circuit, the power drain on the satellite power supply would be disastrous, and the solenoid itself would become hot enough to melt solder in a matter of minutes. To protect against such a failure, a circuit has been designed which will detect, with the aid of thermostats, the characteristic rise in temperature and will cut off power to the solenoid circuits after insuring that the shutter is open. Recording of pictures will still continue even though the shutter mechanism is not operating.

A circuit has also been provided that will restore power to the solenoid circuits on command from the ground, in the event that the failure was temporary.

Other Peripheral Circuitry

The control system of the dielectric tape camera contains many other types of peripheral circuitry, such as:

- Mirror-lock circuitry which provides a means of securing the mirror during launch;
- Reread circuitry which provides a means of obtaining multiple playback;
- Iris auto/manual circuitry which provides a means of obtaining fixed aperture operation; and
- Rewind circuitry which provides a means of rewinding the tape toward the read end-of-tape without energizing any circuits but the tape motor circuits.

However, in general, the various peripheral circuits use latching relays to accomplish their...
required goals and are, therefore, considered simple circuits.

Conclusions

The circuits developed for the control system have been built and evaluated. These circuits have performed satisfactorily with a high degree of reliability; during testing, the measured average picture frame time was 26.002 seconds as mentioned previously. At present, vibration testing and thermal-vacuum testing of the system have been successfully completed. It is expected that more information will be gained as the environmental and operational evaluation programs continue.

Bibliography


