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CONTRACT M-48068

LUNAR IMPACT TV CAMERA (RANGER III, IV, V)

FINAL ENGINEERING REPORT

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared for the

JET PROPULSION LABORATORY
OF THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

By the

ASTRO-ELECTRONICS DIVISION
DEFENSE ELECTRONIC PRODUCTS
RCA RADIO CORPORATION OF AMERICA
PRINCETON, NEW JERSEY

AED R-2076

November 15, 1963

ABSTRACT

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This report presents a description of the development and testing phases of a Lunar Impact TV Camera for inclusion in the Ranger III, IV, and V Spacecrafts. The Lunar Impact TV Camera, designed to take and transmit a series of detailed pictures of the surface of the moon during the descent of the spacecraft to the moon, was limited to a read-out time of 10 seconds per picture with horizontal and vertical resolution requirements of 200 lines each, due to the 2-kc bandwidth restriction. Other limitations were imposed upon the design of the Camera by the maximum weight and power permitted, the optical systems available, the anticipated light levels, and the environmental requirements. Design of the image sensor was performed within these limitations and necessitated significant advances in the state of the art for slow-scan TV camera systems in three areas: (1) rapid-erase techniques, (2) dark-current compensation, and (3) the use of a subcarrier frequency video signal to improve video amplifier capabilities. The final image sensor configuration comprised an electrostatically deflected and focused vidicon containing a special slow-scan photoconductor storage surface with rapid-erase capabilities. The mechanical design evolved integrated the electronic circuitry into the general cylindrical configuration required for the optical telescope and image-sensor tube; this arrangement also was designed to withstand the vibration, shock, and temperature environments anticipated, within the restrictions of weight and volume.

Author

PREFACE

This Report was prepared by the Astro-Electronics Division (AED) of RCA for the Jet Propulsion Laboratory (JPL) of the California Institute of Technology under Contract No. M-48068. The Report describes work performed by AED from March 25, 1960 to November 1, 1961 and is supplied in accordance with Modification No. 6 (Supplemental Agreement) of the aforementioned Contract.

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SECTION I

INTRODUCTION

The work described in this Report concerns the development of a Lunar Impact TV Camera for inclusion in the Ranger Spacecrafts III, IV and V. The Camera is designed to produce a series of high-definition pictures of the surface of the moon for transmission back to earth before the impact of the Spacecraft with the moon.

The work is divided into various sections, each dealing with a specific phase of the project.

Section II is the design-study phase for the determination of general parameters, selection of an image sensor, lens-image sensor relationships, and the description of advances in camera system techniques.

Section III concerns itself with the selection and evaluation of an image sensor vidicon tube.

Section IV describes the mechanical considerations involved in the design of the Camera System.

Section V covers the fabrication and evaluation of a prototype model.

Section VI is a description of the Camera System.

Section VII describes the circuit components employed in the camera system, including some problems encountered and their solutions.

Section VIII is concerned with the field engineering phase of the work.

Section IX is a summary of the results of the project.

SECTION II

DESIGN STUDY AND BREADBOARD PHASE

A. GENERAL

The purpose of the television (tv) camera (Figure II-1) of the Lunar Impact Mission is to begin taking a series of pictures of the surface of the moon as soon as the spacecraft is within optical range. These pictures, taken during the descent of the spacecraft, are expected to provide greater detail than those obtained from earth-based telescopes under optimum environmental conditions. The pictures will be transmitted back to earth, with the transmission terminating before the impact of the spacecraft with the moon. Such pictures, providing topographical information such as land features, altitudes, and slopes of surfaces, would furnish enough combined information to aid in the selection of landing sites for future manned lunar excursions.

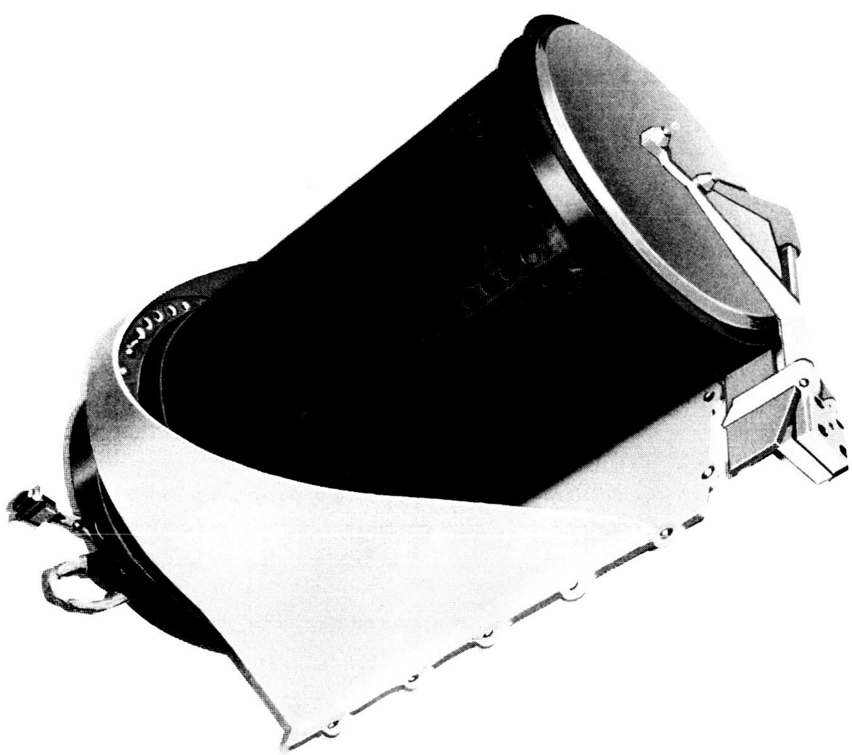

Figure II-1. Lunar Impact Camera Subassembly

These same pictures, in conjunction with other scientific data obtained from the flight, should indicate the type and position of the surface upon which a seismometer capsule will land. The Ranger Spacecraft is designed to carry such a capsule, which consists of a large balsa ball containing a seismograph and transmitter, and which will be ejected at an elevation of approximately 24 km above the moon. The ejection of this capsule is expected to disturb the orientation of the spacecraft to the extent that no further usable pictures could be obtained from the camera. Thus, one factor that determines when the last useful picture will be transmitted from the (tv) system is the time at which the seismograph equipment is ejected from the spacecraft.

Before the ejection of the capsule, the TV camera will produce a series of pictures that encompass a decreasing area, thus providing accurate data regarding the location on the moon where the capsule will land and of the surrounding territory. The number of pictures taken during a given interval is determined by the scan time, which in turn is determined by the video bandwidth of the data link and the resolution required. The power available in the communications link limits the video bandwidth to 2 kilocycles; for a resolution of 200 lines, the scan time must be 10 seconds. Under these conditions, the optimum system takes pictures at intervals of 13 seconds, which includes time for residual-picture erasure. Picture taking begins when the system comes within optical range of the moon (approximately 4000 km away) and the final complete picture is taken when the spacecraft is at a lunar altitude of about 47 km, in order to allow sufficient time for the readout cycle for this last picture before the ejection of the seismograph at 24 km. The readout time is the second factor that determines the time at which the final complete picture is taken. The final picture must be taken at least 10 seconds before the ejection of the seismographic equipment, since this much time is required to read the picture image off the faceplate in order to transmit it back to earth. The interval between the ejection of the seismographic equipment and the impact of the spacecraft with the moon is 6 seconds. Therefore, the final picture must be taken at least 16 seconds before the lunar impact of the spacecraft. The optics of the system are arranged to provide a final resolution of 10 feet (approximately 3 meters) or better.

The nominal trajectory of the Lunar Impact Flight includes a nearly vertical descent to the lunar surface. The optical axis of the television camera will be fixed in the vehicle-body coordinate system. When the spacecraft reaches the vicinity of the moon, but is not yet within optical range, it will perform a command terminal maneuver to align the optical axis of the television camera with the spacecraft velocity vector for descent to the lunar surface.

B. DETERMINATION OF GENERAL PARAMETERS

Several definite constraints were placed upon the final design for the basic camera system, of which the primary parameter of interest was the constraint imposed by the weight limitations. The total weight of the lens, shutter, camera, and power supplies associated with the camera system was required to be less than 13 pounds.

It was also planned that the readout time for each frame would be 10 seconds and that 3 more seconds would be available during which the camera system would establish an "erase" mode in order to remove the residual image from the previous picture.

The shutter time also played a leading role. The rate of stabilization of the spacecraft (which determines the accuracy with which a pointing axis may be maintained along the velocity vector of the vehicle) was the deciding parameter in the choice of a shutter-opening time; this shutter time was chosen in order to minimize picture "smear" induced by any modulations along the velocity vector. It was finally concluded that the shutter time could not exceed 20 milliseconds.

A further limitation was imposed by the use of a telescope having an aperture rating of f/6. This telescope, which was designed and furnished by the Jet Propulsion Laboratory (JPL), has a focal length of 40 inches and was required to be extremely lightweight in order that the weight specifications of 13 pounds for the total system would not be exceeded. The limitation imposed by the use of a 40-inch focal length was due to the relationship between the focal length of the telescope to the area of the scanned surface and therefore to the sensitivity of the sensor.

Another item of importance was the requirement that the entire camera package be sterilized, which necessitated that the camera withstand a baking temperature of 125 degrees C for 24 hours.

Thus, the design-study phase of the TV Camera System for the Lunar Impact Mission was based upon the following criteria: (1) the resulting camera system must weigh less than 13 pounds; (2) it must have a sensitivity compatible with the light levels anticipated on the moon and compatible with the f/6. lens system to be used in the telescope; (3) it must also operate satisfactorily within the restriction of a 20-millisecond shutter speed, and (4) it must survive the sterilization treatment requirements.

C. SELECTION OF THE IMAGE SENSOR

1. Types of Image Sensor Surfaces Evaluated

The image sensor surfaces that were initially selected by RCA to be evaluated for applicability to the Lunar Impact Camera were the ASOS* surface (slow-scan photoconductor storage surface), the ASOS surface coated with an insulating layer of polystyrene (electrostatic storage surface), the Westinghouse Permachon surface and the Westinghouse slow-scan surface. The Westinghouse slow-scan and Permachon surfaces were eliminated as a possibility for future use early in this surface-evaluation program since the selenium compound which is used in the slow-scan surface was unable to withstand sterilization temperatures, and the Permachon surface did not meet the requirements of the mission (especially that of sensitivity).

The two items that remained for consideration were the ASOS surface and the ASOS-polystyrene surface. A systematic and thorough approach for evaluating both types of faceplates was put into effect. The reason for the dual effort was the limited amount of data available on both a sealed-off ASOS polystyrene tube and on the storage characteristics of the ASOS surface. In order to ensure uniformity of testing conditions (i.e., the same type of electron gun), a one-inch GEC** vidicon was used with both the uncoated ASOS (slow-scan) surface, and with the ASOS surface with a layer of polystyrene on the inner surface.

2. Frame Time for Faceplate Testing

Although the final frame time was specified at 10 seconds, it was not practical to evaluate the selected surfaces at this frame rate, since the variations in the results of the tests could have been functions of either the surfaces being tested, the frame time, or both. To eliminate at least one of these variables, the frame time at which these surfaces were tested was fixed at two seconds to eliminate the variable of frame time, and to make all the tests dependent solely upon the properties of the surfaces. This time of two seconds is employed in the TIROS Camera System and there exist at RCA large amounts of data with which to compare all new tests; thus, all the properties attributable to the two-second frame time could be eliminated from the existing experimental data and the remaining results would then be a function of the surface being tested. Table II-1 lists the sensitivity characteristics of an ASOS target.

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*Antimony Sulfide Oxysulfide
**General Electrodynamic Corporation

TABLE II-1. SENSITIVITY OF ASOS TARGET

Target Potential (Volts)	"f" Stop	Faceplate Illumination (Ft-Candle-Sec)	Signal Current μA	Dark Current μA
29	0.95	4.80	0.01	0.0133
29	1.4	2.40	0.012	0.0133
29	2.0	1.20	0.011	0.0133
29	2.8	0.60	0.0097	0.0133
29	4.0	0.30	0.0077	0.0133
29	5.6	0.15	0.0057	0.0133
29	8.0	0.075	0.0033	0.0133
29	11.0	0.0375	0.0023	0.0133
29	16.0	0.0188	0.0013	0.0133
29	22.0	0.0094	0.00073	0.0133
39	0.95	4.80	0.015	0.02
39	1.4	2.40	0.016	0.02
39	2.0	1.20	0.016	0.02
39	2.8	0.60	0.013	0.02
39	4.0	0.30	0.0093	0.02
39	5.6	0.15	0.0067	0.02
39	8.0	0.075	0.0047	0.02
39	11.0	0.0375	0.0025	0.02
39	16.0	0.0188	0.0013	0.02
39	22.0	0.0094	0.0008	0.02

Note 1: 10-Second Scan, 26-ms Shutter Speed, 870-Ft-Lambert Light Source

Note 2: Faceplate Illumination (Ft-Candle-Sec) =

$$\frac{\text{(Scene Brightness) (Lens Efficiency) (Exposure Time)}}{4f^2}$$

Sample Calculation: Light Source = 850 Ft-Lamberts
f No. = 2.0
Lens Efficiency = 0.85
Exposure Time = 26.0 ms,

So:

$$\text{Faceplate Illum.} = \frac{(870)\ (0.85)\ (0.026)}{16} = 1.20 \text{ Ft-Candle-Sec.}$$

3. Comparison of 1-Inch Electrostatically Deflected Vidicon and ½-Inch Magnetically Deflected Vidicon

Since the most stringent restriction placed upon the system was that of weight, the selection of an image sensor was limited to either a 1-inch electrostatically deflected vidicon or a 1/2-inch magnetically deflected vidicon. (A 1-inch, magnetically deflected vidicon was not considered because of the weight and power limitations.)

It was originally decided to use the 1/2-inch, magnetically deflected tubes to make the experimental 1/2-inch tubes with the polystyrene layer. The initial problem with the electrostatic storage tube was to determine the optimum thickness of the polystyrene layer in relation to the ASOS photoconductor layer that, in turn, would determine the capacitance of each surface. A number of sample tubes were tested, each with a different relative thickness of materials. The basic conclusion drawn was that the capacity of the polystyrene layer (C_i) should be approximately equal to the capacity of the ASOS photoconductor layer (C_p) for optimum sensitivity.

4. Theory of Operation of the Electrostatic Storage Surface

The reason for equating C_i and C_p is found in the theory of operation of an electrostatic storage surface.

The electrostatic storage surface requires "prepare," "expose," and "develop" cycles (PED) for normal operation as outlined in the following. Figure II-2 illustrates the equivalent circuit of the electrostatic storage surface and Figure II-3 is a timing chart of the PED cycles.

a. "Prepare"

During "prepare," the following conditions are imposed upon the vidicon:

Electron Beam: Fully "on"

V_{mp} ("Prepare"): Switched to a more positive voltage than the mesh readout voltage

Floodlights: "On"

Deflection Mode: Rapid-scan on vertical deflection plates.

The purpose of the "prepare" cycle is to charge the gun side of the polystyrene to a uniform potential. This is accomplished by turning on the floodlights which tend to shunt C_p by decreasing αR_p. With the beam fully "on" and being deflected at a rapid rate, the secondary electrons which are knocked off the polystyrene surface are collected by the more-positive mesh until equilibrium occurs between the mesh and the polystyrene surface. At equilibrium, the gun-side surface potential of the polystyrene equals the mesh potential, and a voltage approximately equal to $V_m - V_t$ is achieved across C_i.

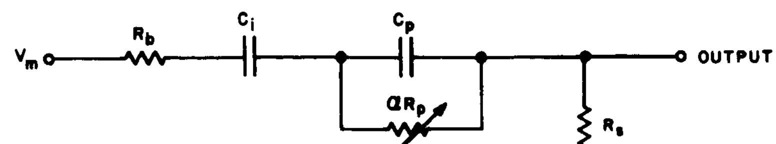


Figure II-2. Electrostatic Storage Surface Equivalent Circuit

b. "Expose" (Figures II-4, II-5)

The expose cycle is accomplished under the following conditions:

Beam: Fully "on"

V_{me} ("expose"): Switched to a more negative voltage than V_{mp}

Floodlights: "Off"

Shutter: Open

Deflection Mode: Rapid-scan on vertical deflection plates.

Only with the polystyrene elemental capacitance equal to the photoconductor elemental capacitance (i.e., $C_i = C_p$) and a voltage V_{me} on the mesh will a voltage equal to

$$\frac{V_{mp} - V_{me}}{2}$$

be present across C_p and a voltage of

$$V_t - \frac{(V_{mp} - V_{me})}{2}$$

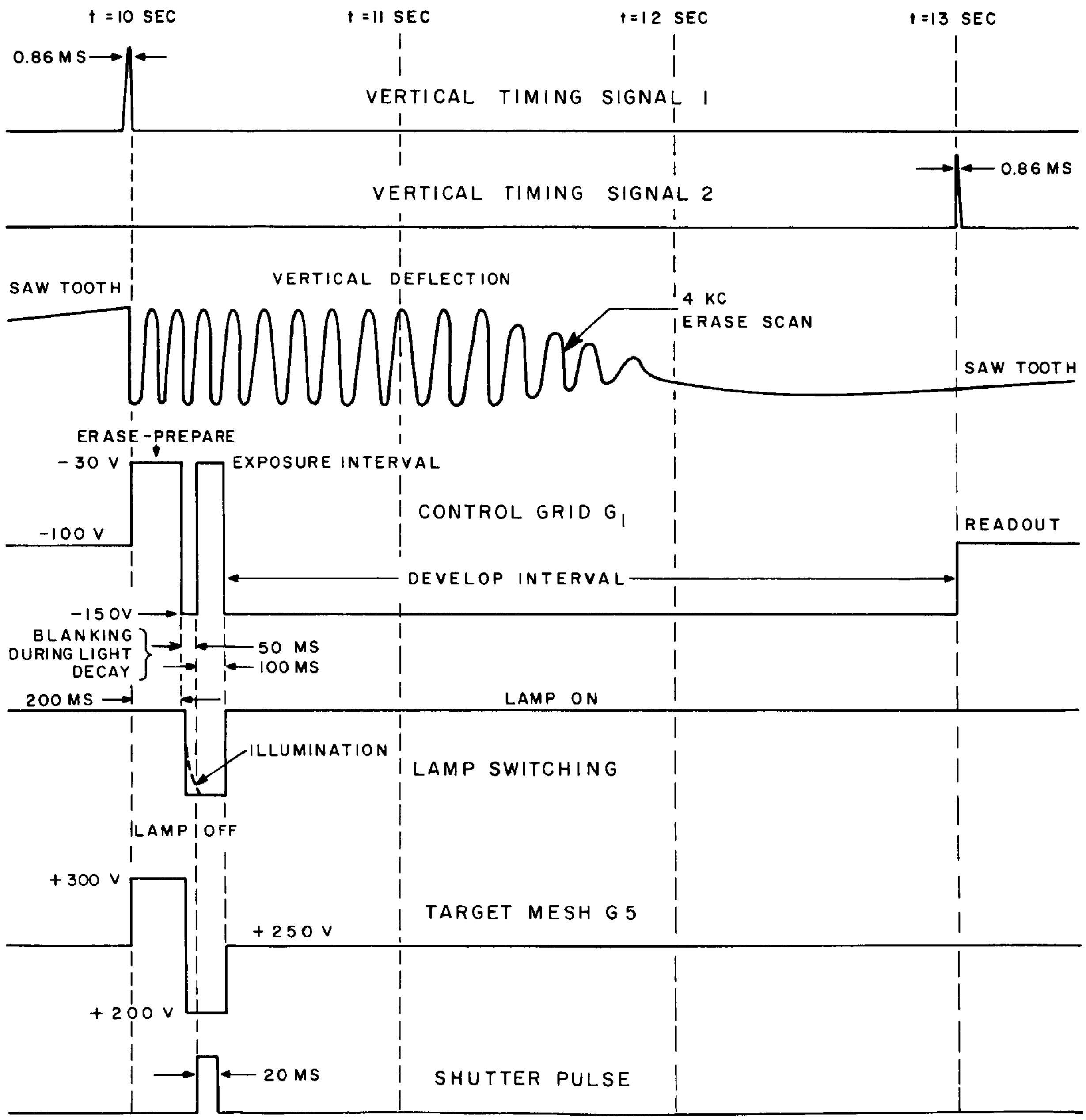


Figure II-3. "Prepare", "Expose", "Develop" Timing Cycles for Polystyrene Storage Tube be placed at C_i. This division of $V_{mp} - V_{me}$ occurs before the shutter is open and these equal potentials across each surface occur only as a result of C_i equalling C_p.

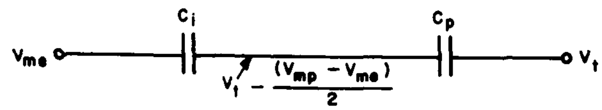


Figure II-4. Distribution of Potential Across C_i and C_p During "Expose" Cycle

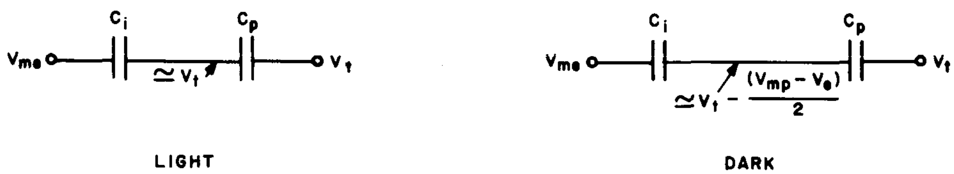


Figure II-5. Distribution of Potential Across C_i and C_p After "Expose" Cycle

With the shutter open, an optical image is focused on the photoconductor and the photoconductor is discharged through R_p in proportion to the amount of light falling upon each photoconductor element. Therefore, at the end of the "expose" cycle, the following conditions exist: (1) the gun side of the polystyrene is at V_{me} potential; (2) the interface of the polystyrene and the photoconductor is at a potential whose range is from approximately zero to

$$V_t - \frac{(V_{mp} - V_{me})}{2} .$$

c. "Develop" (Figure II-6)

Conditions:

Beam - "Off"

V_m - Not an influencing parameter since beam is "off"

Deflection - Not an influencing parameter since beam is "off"

Floodlights - "On".

The purpose of the "develop" cycle is to transfer the charge pattern (at the interface of the photoconductor and the polystyrene) to the gun side of the polystyrene. By turning the beam current "off", there can be no change in the voltage across the polystyrene and with the floodlights on, the photoconductor is uniformly discharged, transferring the voltage pattern to the gun side of the polystyrene.

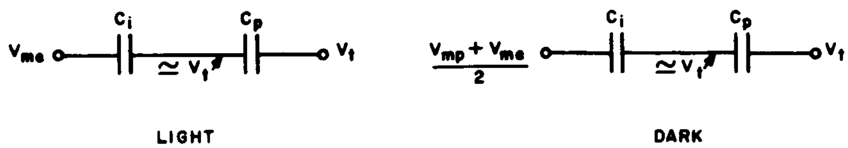


Figure II-6. Distribution of Potential Across C_i and C_p After "Develop" Cycle

5. Sensitivity Measurements of the Electrostatic Storage Surface

A number of measurements recorded from the tests supported the theory that a 4-to-1 loss in the sensitivity would result from the use of a polystyrene faceplate. This loss occurred because it was necessary to first place the signal on the photoconductor, then to transfer it to the dielectric storage medium, and then to transfer it (on "readout") back to the photoconductor. The sensitivity was therefore reduced since an energy loss of 2-to-1 occurs each time a capacitor is discharged into another capacitor.

Until the cause of the loss in sensitivity was found, it appeared that the image sensor selected would be the 1/2-inch magnetically deflected tube with a polystyrene storage layer on the back surface of the photoconductor. During the initial phase of the program, a camera system was designed to use the electrostatic storage surface in the 1/2-inch tube. While the design was being formulated, definite confirmation was made that the 4-to-1 loss in sensitivity was due to the double transfer; this effect could not be eliminated.

6. Slow-Scan Photoconductor Surfaces

Concurrent with the previous effort, a study of the behavior of both 1/2-inch and 1-inch ASOS photoconductor surfaces was made.

As a result of previous experience with the ASOS surface, it was felt that storage might be a problem with the 1/2-inch tubes; as expected, some of these tubes were found to be capable of storage while others were not. The other parameters of the test were sensitivity, maximum-temperature performance, and dark current.

For the 1-inch ASOS tube, the results of the tests on storage time were very encouraging, and efforts were continued toward evaluating this surface. A gun was not available from the RCA Electron Tube Division (Lancaster, Penna.) where the ASOS faceplate was manufactured, necessitating the consideration of a hybrid tube made with an RCA evaporated ASOS photoconductor and an electrostatically deflected gun made by the General Electrodynamic Corporation. The results of the testing of these sensors were quite encouraging and it was felt that the final selection of an image sensor could be made on this basis.

7. Selection of an Image Sensor

All the results of the continuing test of various image sensors were thoroughly investigated at a meeting between representatives of JPL and RCA. The principal parameters examined were sensitivity, maximum temperature, storage time and reliability. (Results of the meeting were based on data presented in Table II-2.)

The reliability of the 1/2-inch magnetically deflected tube had been well proven in TIROS, but the reliability of the 1-inch electrostatic tube in a launching environment was not known and had to be considered. Other considerations were the low sensitivity of the 1/2-inch ASOS-polystyrene tube, and difficulties that might result when a hybrid tube was made partially in one plant and partially in another. The decision was finally made to discontinue the work being done on the polystyrene 1/2-inch tube and to concentrate on the 1-inch electrostatically deflected ASOS vidicon. The configuration of the tube selected is shown in Figure II-7.

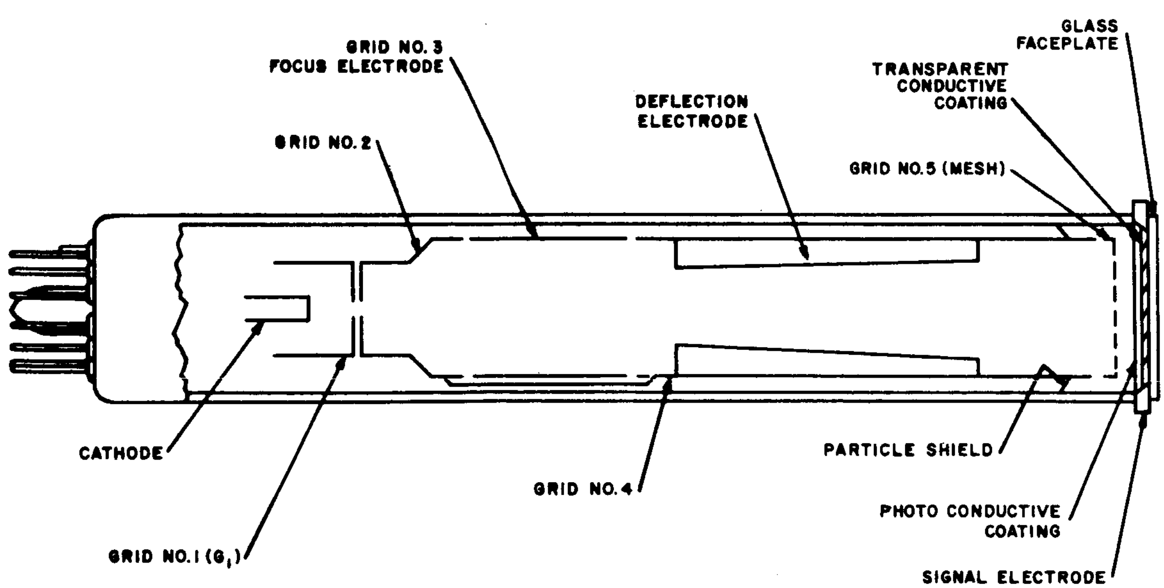


Figure II-7. Image Sensor Tube Construction

TABLE II-2. SUMMARY OF IMAGE SENSOR EVALUATIONS FOR 10-SECOND FRAME TIME

Sensor	Camera System Weight	Camera System Power	Dark-Current Pulse	Shading	Maximum Temp. for Signal Storage	Ease Of Operation	Estim. Relia-bility	Delivery For Reliable Tubes	10-Sec. Storage	Sensitivity	Secondary Redistribu-tion Effects
			(5)		(4)	(6)	(2)		(3)	(1)	(7)
One-half inch poly-storage	9 lbs.	9.5 W	Controlled	Good	+55°C	Difficult	Good	At once	Good	Just Barely Enough	Yes
One-inch poly-storage	9 lbs.	9.3 W	Controlled	Good	+55°C	Difficult	Needs to be proven	2-3 mos.	Good	Adequate	Yes
One-half inch vidicon	9 lbs.	8.7 W	Auto clipping circuits required	Top to Bottom	+40°C	Normal	Good	At once	Need to Select Tubes	Adequate	No
One-inch vidicon	9 lbs.	8.3 W	Auto clipping required	Top to Bottom	+40°C	Normal	Needs to be proven	2-3 mos.	Need to Select Tubes	More than Adequate	No

NOTE: Numbers ( ) indicate the estimated order of importance. Since power and weight do not differ very much, they are not designated.

8. Chronological Procedure for Slow-Scan Photoconductor and Electrostatic-Storage Evaluation

a. Initial testing of the sensitivity, reciprocity, signal-to-noise, and resolution on the GEC electrostatically deflected slow-scan vidicons was performed at the 2-second frame time.

b. After eliminating all parameters due to the two-second frame rate and evaluating these surfaces, the same tests and measurements were done at a 10-second frame rate. It was found that some of the 1/2-inch tubes were capable of storage and others were not; but in general, the record for the 1-inch tube was very good.

c. The test which followed was that of a GEC, electrostatically deflected slow-scan vidicon using the subcarrier system at a 10-second rate. The sensitivity for these tests, made with an open shutter, was excellent.

d. The next sequence in testing procedure was the comparison of the sensitivity of the ASOS target with the polystyrene surface. A 1-inch tube was fabricated with half of the target having a polystyrene layer on the ASOS surface, and with the other half having an uncoated ASOS surface. The results of these tests showed the electrostatic surface (polystyrene coated) to be approximately one fifth as sensitive as the slow-scan photoconductor (uncoated) surface.

e. The next series of tests was conducted with the fast-erase technique, and the sensitivities were again measured. These sensitivities initially ranged from 0.025 to 4 foot-candle-seconds, and finally from 0.006 to 2 foot-candle-seconds. These pictures were all taken with an opening of f/6 and a 20 ms exposure, in order to duplicate anticipated lunar illumination. The pictures also showed a satisfactory signal-to-noise ratio. Table II-1 lists the results of a typical sensitivity measurement test with ASOS target, 10-second scan, and 26 ms shutter speed.

f. During the previously described tests, the electrostatic storage surfaces were tested first at the 2-second frame rate and then (after problems which arose at this rate were solved) at the 10-second frame rate. Excessive leakage developed across the polystyrene, and the sensitivities measured with the best surfaces, and under expected lunar conditions were only 0.018 foot-candle-second.

The above tests ran from May 1960 to November 1960. A decision to use an electrostatically deflected vidicon with the slow-scan photoconductor was made by JPL on the basis of data from these tests.

9. Summary of Reasons for Decision

The ASOS photoconductor surface afforded the highest sensitivity and was capable of storage for the 10-second period required. The storage capabilities of the ASOS-polystyrene electrostatic storage tube were very good and satisfied this requirement of the mission, but the effective reduction in sensitivity by approximately 4-to-1 was sufficient to outweigh this advantage and to eliminate its use. The configuration of the image sensor surface selected is shown in Figure II-8.

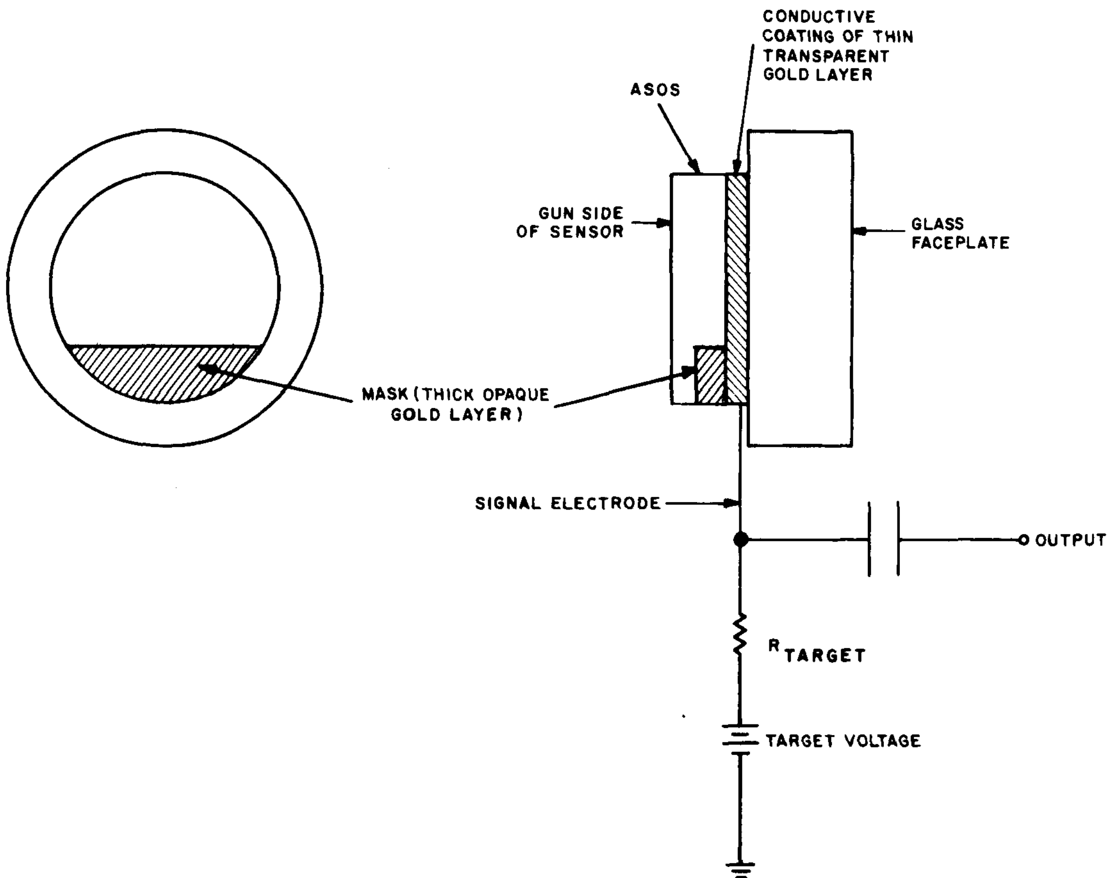


Figure II-8. Image Sensor Surface Configuration

This decision was based upon studies of the lunar mission indicating that the maximum sensitivity from the image sensor would be required, thus the 1-inch ASOS tube was chosen.

D. RELATIONSHIP OF LENS FOCAL LENGTH TO THE SCANNED AREA ON THE IMAGE SENSOR

A focal length of approximately 40 inches was chosen for the telescope at the beginning of the program. This choice was made early because the lead time in lens procurement by JPL is quite long. This selection limited the image sensor surface selection because of its effect upon sensitivity; the focal length is an extremely important parameter due to the low light level expected in the lunar environment.

1. Theory

The sensitivity of a 1/2-inch vidicon is proportional to the sensitivity of a 1-inch vidicon as to the respective areas scanned. This occurs because the capacitance of each individual element is proportional to its area and the charge (q) stored is proportional to this capacitance, i.e.:

Capacitance is proportional to area	$C \propto A$,
Charge is proportional to capacitance	$q \propto C$,
The sensitivity is a function of the charge stored upon it	$S = f(q)$,
Thus, the sensitivity is proportional to the area.	$S \propto A$.

Therefore, since a 1-inch surface has four times the area of a 1/2-inch surface, it will have four times the amount of charge stored upon it. Since the current is equal to the rate of change of the charge with respect to time (i.e., $I = dq/dt$), and sensitivity is a function of the output current of the vidicon surface, the surface which stores four times the charge per unit time for the same illumination will be four times as sensitive.

2. Comparison of Sensitivity of ½-Inch Image Sensor with f/3 Lens with that of 1-Inch Image Sensor with f/6 Lens

An ASOS vidicon of the 1/2-inch size using a lens with 20-inch focal length instead of one with a 40-inch focal length would have a speed of f/3 instead of f/6, provided that the diameter of the lens is unchanged. Thus the same sensitivity could have been obtained with the system, using a 1/2-inch ASOS tube with the f/3 lens. The reason that a 1/2-inch tube could have been used with a faster lens (f/3) and achieved the same sensitivity as a 1-inch tube with a slower lens (f/6) is that the 1/2-inch tube would have permitted the use of a lens of shorter focal length. The shorter focal length lens (20-inch), having the same diameter as the 40-inch lens, provides the capability of gathering 4 times the amount of light. Therefore the two effects, 4 times the light absorption and 1/4 the surface area, cancel each other.

3. Conclusion

If the selection of the optics had not already been made early in the program, the optimum solution for this mission would appear to have been the 1/2-inch ASOS tube, which would have achieved the required sensitivity without necessitating the use of a hybrid tube.

E. ADVANCES IN CAMERA SYSTEM TECHNIQUES

Three areas were unique in the design of the TV Camera System for the Lunar Impact Mission. These areas, comprising rapid-erase techniques, dark-current compensation and the use of a subcarrier-frequency video signal, were all advances in the state-of-the-art for slow-scan TV camera systems.

1. Rapid-Erase Techniques

The need to take and transmit a picture every 13 seconds with a readout time of 10 seconds required that erasure of the residual image upon the faceplate must occur within 3 seconds. Existing techniques of erasing the faceplate utilized the same 10-second sweep rate in readout, and entailed scanning the faceplate at least 5 times, thus taking 50 seconds. The new rapid-erase technique was obtained by (1) biasing the control grid in a more positive direction to enable more beam current to flow; (2) switching the vertical deflection rate to 4 kc in order to scan faster; and (3) switching the flood-lights "on" in order to discharge the photoconductor during the initial period of erasure, which has the effect of destroying the previous picture. Figure II-9 illustrates the accompanying increase in sensitivity as a result of the use of the "erase" lights.

A photoconductor surface such as ASOS can be compared to a simplified equivalent circuit where

C_p is the elemental photoconductor capacitance,

α is a function of the light striking the surface ($0 < \alpha < 1$), and

R is the photoconductor impedance,

as shown in Figure II-10.

The target containing the residual picture image is exposed to a floodlight that causes α to become zero, thereby discharging the capacitor. The floodlight is then switched off, and the beam, with its faster scan rate and higher beam current (as compared with readout conditions), scans the gun side of the photoconductor, charging it to uniform potential.

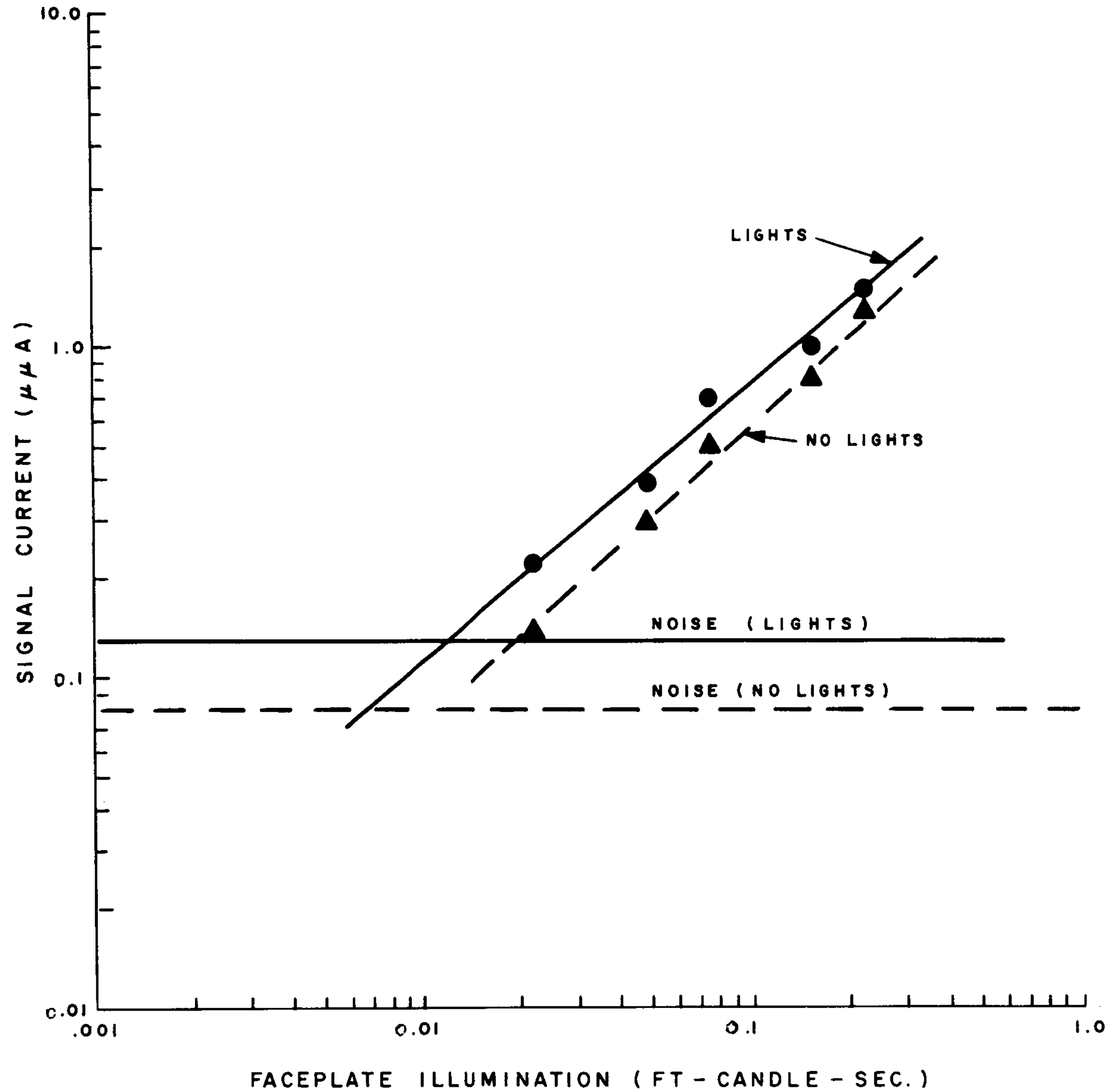


Figure II-9. Sensitivity of Image Sensor with and without "Erase" Lights

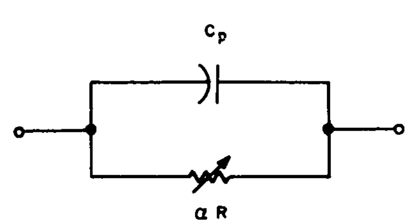


Figure II-10. Photoconductor Surface Equivalent Circuit

A problem developed in the limited beam current (i) available. Although the scanning rate increased and the control grid was biased in such a manner as to turn the beam current on "harder", the aperture arrangement of the GEC electrostatically deflected vidicons limited the beam current.

Since the resolution requirement for this mission was not severe, (200-lines), it was practicable to increase the aperture size of the GEC gun (see Section III A 2). The resulting increases in beam current were sufficient to allow enough charge to reach the ASOS photoconductor, while the increase in beam diameter did not cause a reduction of the 200-line limiting resolution requirement.

The problem of edge effects (non-uniform charge at edges) which became pronounced, was a result of rapid erasure; the scanned area was affected by the charges developing around it on the photoconductor. The solution involved an increase in the "erase" cycle amplitude to cover a larger area than that actually scanned during the "read" cycle. This provided a suitably charged buffer area around the readout area, minimizing the occurrence of transients at the edge of the scanned area.

The rapid scanning of the photoconductor with a 4000-cycle scan rate and with a high beam current was sufficient to bring the residual image down to less than 10 percent, which was an important requirement in obtaining useful pictures for this particular mission.

2. Dark-Current Compensation

After the selection of the ASOS faceplate, it was necessary to develop an automatic system for clipping the large dark-current pulse resulting from the slow-scan TV system. At the slow-scan rate (t=10 seconds) and at high temperatures, the dark-current (semiconductor leakage) pulse was large compared to the useful signal. If this entire signal were transmitted, it would have been necessary to reduce the amplification to remain within the linear or dynamic range of the system. This reduction would have resulted in reducing both the effective signal-to-noise ratio of the system and the reproduced gray levels.

To prevent this, a video reference signal corresponding to black (i.e., no light) was established from the vidicon. The clamp circuit designed for this application clamped the video signal to this reference at the beginning of each horizontal line, and then clipped the dark-current pulse. Relationships of the various voltage levels are shown in Figure II-11.

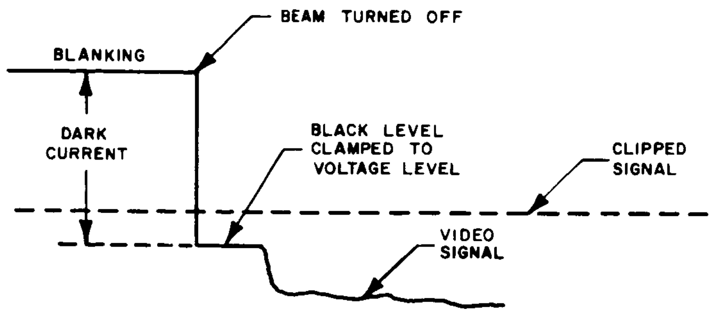


Figure II-11. Diagram of Voltage Levels for Dark-Current Compensation

The principal problem was the determination of the d-c reference level corresponding to black. The solution appeared to be the use of a black reference mask on the face of the vidicon; this provided an optical black reference within the vidicon, but produced numerous problems. The black mask on the outside of the vidicon resulted in an out-of-focus edge, causing the loss of a portion of the picture. In the early tests a mask on the outside of the vidicon was used, but because of the poor results (out-of-focus edge) the mask was put on the inner surface next to the photoconductor, which was found to be a satisfactory location (see Section V B 3). The optimum width of the mask was determined by the amount of shading found at the edges of all pictures obtained by vidicon cameras. The black mask was made wide enough so that during scanning it extended out of the severely shaded area of the raster, i.e., into the linear region of the image sensor surface. The width of the mask also was determined by the possibility that a change might occur in the combined horizontal-deflection size and centering.

The clipping of the dark-current pedestal, using the black reference described, proved successful.

3. Subcarrier-Frequency Signal

An advancement in the state-of-the-art of the camera system was accomplished in the application of a subcarrier on the cathode of the vidicon to eliminate the need for a video amplifier with extremely low frequency response and to replace it with a band-pass amplifier. In this design, the subcarrier frequency of 100 kc caused the beam current to be "chopped" (modulated) at this carrier rate. The beam current was then modulated by the video information on the vidicon target. The resultant output across the target load was an amplitude-modulated carrier that was fed into a tuned amplifier.

The use of a subcarrier for video information resulted in numerous advantages: (1) it eliminated the need for building a video amplifier which would require a maximum response of less than one cps without loss; (2) it eliminated the need for a tube or Nuvistor in the preamplifier and therefore eliminated a constant-current drain for the filament. (A transistor could now be used because the passband is well above the 1/f noise region for semiconductors.); (3) the use of stagger-tuned interstage-coupling networks resulted in higher gain with fewer transistors; (4) video peaking in the amplifier was not required, since the usual high-frequency video loss was replaced by only a slight attenuation across the passband at the output of the vidicon; (5) the vidicon output lead was shielded in this case, since the parasitic capacitance of the shield was made part of the tuned circuit of the input stages of the preamplifier. This also greatly reduced interference problems in this system.

SECTION III

VIDICON PROCUREMENT, TESTING AND EVALUATION

Three problems developed during testing in connection with the flight-model vidicons to be used in the TV camera system:

(1) Mottling of the photoconductor occurred,

(2) Secondary emission occurred at low voltage, and

(3) Insufficient beam current was produced for adequate erasure.

A. SIGNIFICANT PROBLEMS

1. Mottling of the Photoconductor

Mottling, which resulted in a spurious background signal because of photoconductor irregularities, was a result of the hybrid tube that was manufactured from an evaporated ASOS photoconductor made by RCA, and an electrostatic gun made by GEC. The first 11 tubes delivered by GEC all exhibited this mottling and the effect increased with operation.

Investigation by RCA indicated that the mottling of the faceplate was due to either (1) improper evaporation of the ASOS photoconductor, (2) deterioration due to subsequent storage, (3) the copper screen used in the GEC gun, or (4) contamination resulting from sealing of the stem.

A faceplate which was taken from an unused tube, and one which had never been previously used in a tube, were arranged in a demountable vacuum pump setup. The new faceplate was observed and did not immediately show mottling, but definite mottling occurred after it was scanned four to five minutes. This indicated that the source of trouble was faceplate evaporation or subsequent storage. The RCA tube division then sealed one of the unused faceplates onto a selected tube (which had not been exposed to air) in order to determine if exposure to air for a number of days was the cause of mottling; the plate exhibited the mottling effect. Concurrently an RCA designed electrostatic tube, also with an unused faceplate from the same evaporation group (without exposure to air), was tested. This tube operated satisfactorily with no evidence of mottling.

The final conclusion drawn was that mottling was caused mainly by the accumulation of minute amounts of water vapor during the time the faceplates were shipped from the RCA Tube Division to GEC, where they were sealed to the tube. All faceplates were subsequently shipped in vacuum bottles.

2. Insufficient Beam-Current Erasure

The problem was adequately solved by increasing the aperture size from 1.2 to 2.0 mils in order to furnish sufficient beam current (see Paragraph II-C-1 for a discussion of erasing techniques).

3. Secondary Emission at Low Voltage

Several of the image sensors tested during the vidicon procurement period showed secondary-emission ratios of greater than one. The tubes possessing this property evidenced a loss of sensitivity due to insufficient storage of charge upon the image surface. This was accompanied by a breakdown effect to the photoconductor surface. With the cathode at ground potential, the target at plus 15 volts, the screen grid (mesh) G_5 at plus 250 volts, and the image-sensor surface exhibiting a secondary-emission ratio of greater than one, the inner surface of the photoconductor tended to charge up to the mesh potential. This resulted in excessive potential difference across each elemental increment of the surface, causing breakdown to the photoconductor surface.

Since the system voltages were already firmly established by system design, the most expedient solution was to test several image sensors and to find one that exhibited a secondary-emission ratio of less than one at the established voltages.

B. EFFECT OF STERILIZATION ON DESIGN

The environmental specifications for the camera system, as stated in "Spacecraft Environmental Specification, Flight Equipment" (JPL Specification No. 30201 and subsequent revisions) did not impose any requirements which were not immediately attainable other than the sterilization requirements. It was necessary to submit the complete camera system to a temperature of 125 degrees C for 24 hours, in accordance with the NASA policy of sterilizing all spacecraft that have a high probability of lunar impact.

Circuit elements were chosen that were capable of being baked in the required manner. In general, no difficulties were anticipated in these elements and after testing, none existed. The image sensor tube might have presented a problem in this area, inasmuch as there was no evidence that the photoconductor surface could withstand the baking. However, the camera system exhibited no degradation of system parameters following the sterilization procedure.

SECTION IV

MECHANICAL CONSIDERATIONS

A. GENERAL

During the first phase of the design program, RCA received the contract for the "hardware" portion of the project. This entailed meeting reliability and quality control standards together with packaging concepts established by JPL. Until the final selection of an image sensor and the associated electronics, a dual effort was required of the Mechanical Design Group to produce a system that would accommodate either the 1/2-inch or 1-inch tube, in order that a prototype model would be readily available. When the selection of the 1-inch, slow-scan, electrostatically deflected image sensor was accomplished, RCA was able to supply a finished, packaged unit with no delays.

B. PACKAGING CONCEPT

1. "Doughnut"-Type Construction

The packaging concept that was developed satisfied the initial requirements established by JPL. It consisted of mounting the circuitry on cylindrical modules with hollow centers and with a diameter large enough to contain the image sensor tube. This "doughnut"-type construction was planned so that the outer diameter of the electronics modules would be the same as that of the telescope, and would result in an over-all package of (constant-diameter) cylindrical shape. This technique enabled optimum utilization of the available space, since the chassis also served as the external surface of the telescope. Figure IV-1 illustrates a typical circular module, and Figure IV-2 is a photo of a complete cylindrical assembly.

2. Power-Supply Module

In addition to the space available for the electronic circuitry in the telescope-vidicon doughnut-type package, space for a module of approximately 36 cubic inches was originally made available in the spacecraft bus for the power-conversion equipment. This power equipment converted the 2400-cycle, sine-wave, input power to the various d-c levels required by the tv camera system.

As a result of the initial mechanical design effort, the 1-inch by 6-inch by 6-inch space provided for this Transformer-Rectifier Package was found to be insufficient,

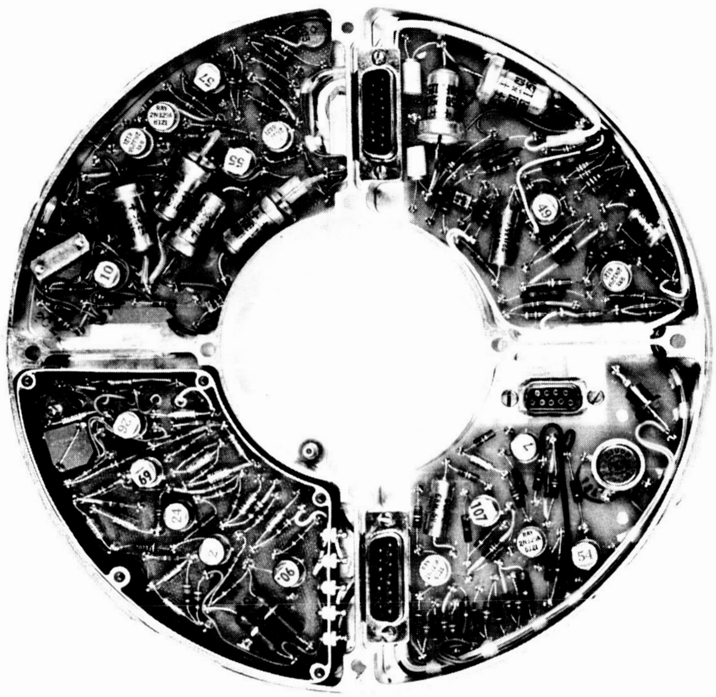


Figure IV-1. Typical Circular ("Doughnut") Module

Figure IV-2. Cylindrical Package

and in order to provide a more suitable packaging condition, the package was increased to 72 cubic inches in volume (2 inches by 6 inches by 6 inches). The advantage which resulted was that changes in the circuitry would not affect the mechanical design considerations, since components that might have to be replaced were now readily accessible.

3. Optical Telescope and Shutter

The two independent design efforts for the optical telescope and shutter portions of the TV camera system resulted in additional requirements upon the mechanical design effort. The electronic packaging and vidicon mounting was required to be readily capable of being integrated and compatible with either the primary optical design by the Te Co. or the alternate optical design by JPL.

The basic design objective was to place the shutter in the focal plane of the optical telescope, which is situated within a cylindrical package containing the circuitry. This required establishment of a common reference compatible with both optical designs for the plane of the target.

The telescopic optical system that was finally used was developed by JPL and was a conventional astronomical telescope of the Cassegrain configuration. This system employed a primary concave parabolic mirror, and a secondary convex hyperbolic mirror that in turn reflected the lunar image (picked up by the primary mirror) to the image sensor surface 0.5 inch in front of the primary mirror. An aperture 7 inches long having an equivalent focal length of 40 inches was provided by this astronomical telescope. Figure IV-3 is a schematic diagram of the arrangement.

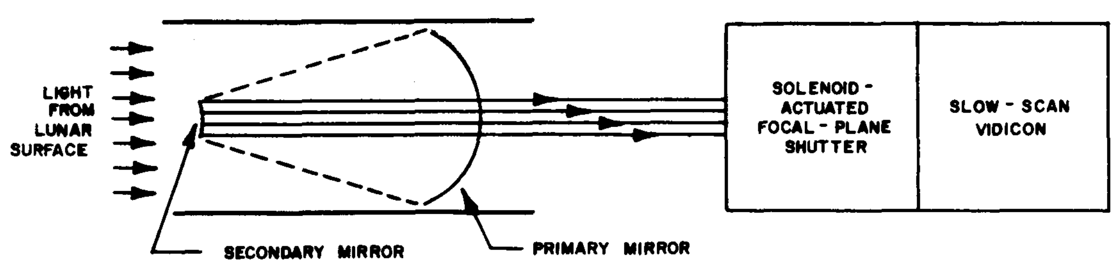


Figure IV-3. Optical System of Telescope, Schematic Diagram

The initial optical resolving power was 5 seconds of arc or 40 optical line-pairs per mm over the 1-degree telescope field-of-view. This resolving power was deteriorated by the image-sensor scan to approximately 34 seconds of arc or 6 optical line-pairs per mm resolution.

The mechanical shutter, which was placed in the focal plane, was a rotary-type shutter whose operation resulted from the inertia of motion produced by the actuation of a solenoid. The shutter required a pulse to send a small eccentric rotor through a 360-degree excursion. This drove a blade with a slot in it, to produce the required 20-millisecond exposure, and a uniformly illuminated field on the faceplate of the image sensor tube resulted.

4. Resonance Restrictions

The doughnut-shaped module housings that were designed initially consisted of two plates of cast magnesium. These housings contained "I"-shaped brackets for mounting the electronic modules to the plates on standoffs, for increasing the strength and rigidity, and for reducing the mechanical resonance of this unit. The inner and outer surface dimensions of these plates were determined by the outer diameters of the image sensor tube and the optical telescope assembly respectively; the width was determined by the thickness of the electronic circuitry modules. These modules, which were mounted in a back-to-back fashion in each housing, were secured to the "I" shaped brackets. These plates were then mounted to the baseplate supplied by JPL. The unit was tested on the vibration table and found to be satisfactory. At this stage, JPL mechanical engineers felt that the mechanical resonance specification of 500 cps was not high enough, but should encompass a frequency range of 500 to 2000 cps to eliminate all possibilities of mechanical resonance. Although this represented a change in contractual requirements, RCA agreed to the new design requirement. The change consisted of a solid shelf cast into the housing and positioned at the center of each unit (as shown in Figure IV-1). This rigid control member in the package unit gave the electronics modules more support, since the boards were now firmly cemented to each side of the shell. The change effectively raised the mechanical resonance frequency above the highest frequency anticipated from the spacecraft.

5. Weight and Volume

Throughout the program, the general problem of weight and volume was always under consideration, since rigorous requirements existed for both. Continuous effort was expended in search of lighter components and in attempting to alter the spacing of the components so as to reduce the total number of boards and interconnecting plugs.

The weight limit of the telescope-image sensor equipment was set at 13 pounds. The allowance of 6 pounds for the optical telescope left only 7 pounds for the camera, associated electronics, and power supplies.

6. Summary

In summation, the mounting for the image sensor tube with its associated electronics and the optical elements within the telescope structure was carefully designed to withstand the vibration, shock, and temperature environments that were anticipated. Weight and volume were also considered in order to meet the over-all system requirements.

SECTION VI

SYSTEM DESCRIPTION

The camera system includes an image sensor (vidicon) with electrostatic deflection and focus which combines a special high-storage-capability image-sensor target with rapid-erase capability. During operation, the faceplate of the vidicon is exposed to the subject for 20 milliseconds by the shutter and the resultant, slowly decaying image is subsequently scanned at a horizontal rate of 20 cps and a vertical rate of 0.1 cps. The resultant system provides a picture with 200 lines per frame and a readout time of 10 seconds per frame. The bandwidth of this system for equal vertical and horizontal resolution is 2.0 kc.

The horizontal deflection circuit is triggered from a 20-cps generator, which in turn is synchronized with the 400-cps spacecraft clock; the vertical deflection circuit is triggered from a 0.1-cps generator synchronized with the two sync inputs provided by JPL. Commands for shutter operation and erasure are obtained from the vertical sync generator and supplied to the shutter delay and driver circuits. The shutter commands terminates the "erase" cycle, triggers the shutter-solenoid drive, and (following a fractional-second delay) causes initiation of the frame sweep. The "erase" command terminates the frame sweep and initiates the "erase" cycle which consists of (1) illumination of the target by six filamentary lamps about the periphery of the gun-side of the target, (2) switching of a 4-kc sine wave to the vertical deflection plates to accelerate the beam scan rates over the target surface, and (3) adjustment of the control grid bias to increase the beam current.

An averaging technique cannot be employed for background shading or d-c restoration, since each frame is different. Instead, the beam current of the image sensor tube is modulated at a 100-kc frequency, which "chops" the target (image-sensor-surface) current and creates an amplitude-modulated signal. The d-c level is set by clamping the video signal at the beginning of each horizontal scan line with the level determined by a black (optical) mask.

This modulation technique enables the generation of an amplified video signal with a stabilized base. The signal is then mixed with blanking pulses in order to form the composite video signal, which is finally presented to the telemetry system for transmission to earth. A block diagram representing the system is presented in Figure VI-1.

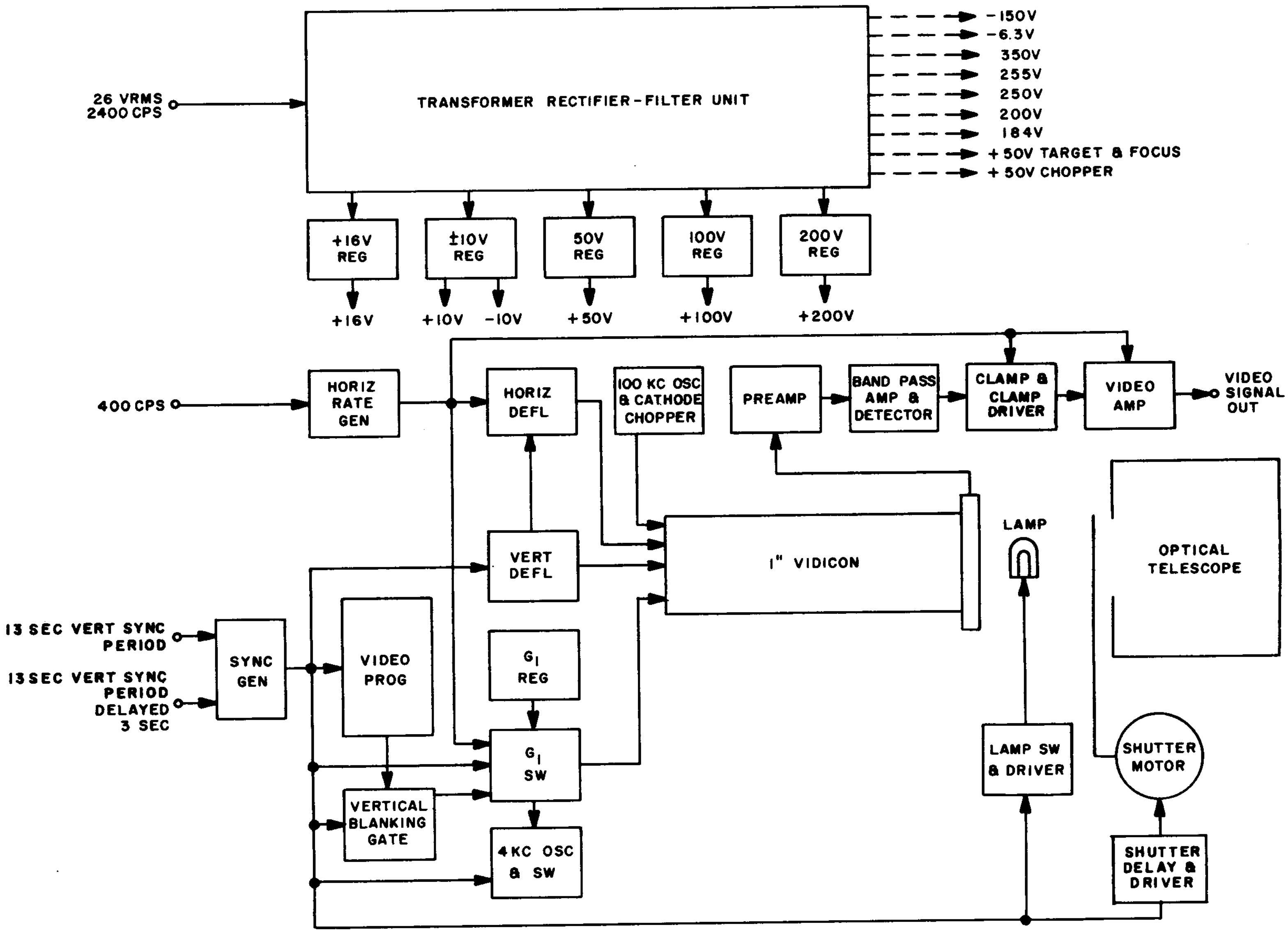


Figure VI-1. Camera System Block Diagram

SECTION V

FABRICATION OF PROTOTYPE MODEL

A. EVALUATION OF PROTOTYPE MODEL

The general approach in evaluating the prototype model was to test (at room temperature) for all the various voltage levels and their corresponding timing cycles as set forth in the slow-scan vidicon timing charts, shown in Section VII.

After the requirements of the timing chart were met, the image sensor was then ready for evaluation. During this part of the test, voltages for G_1, G_2, the mesh (G_5), and the target were all varied to arrive at the best combination for optimum values of the operating parameters for each camera system.

B. PROBLEMS DURING THE EVALUATION PHASE

During this phase of the program, the following problems were discovered and solved as indicated.

1. Transformer Noise

The original design of the TV camera system required one transformer which supplied the required potentials from its secondary windings. In order to reduce the noise on the deflection circuits, video amplifiers, etc. (due to coupling capacitance of the secondary windings of this transformer) the single transformer was replaced by four separate units.

2. Ripple Voltage in Power Supply

The initial testing of the prototype model, after replacing the power transformer, still disclosed the pickup of interference from the power supply. The power to the system was furnished by JPL in the form of a 2400-cps sine wave at 26 volts rms. The problem resulted from the appearance of this 2400-cycle voltage as interference in the video signals. The transformer-rectifiers were used to convert the 2400-cps sine wave to the d-c voltage at the levels necessary for operation, but a portion of the 2400-cycle wave was still observed in the video output. The final solution was achieved by filtering out these ripple voltages. This solution was complicated by the requirements of low-impedance sources from the power supply.

3. Erasure

Initially the vertical-deflection signal was a sawtooth wave of 80 volts peak-to-peak and of 10 seconds duration with a "flat-top" (d-c level) of 3 seconds duration, as shown in Figure V-1.

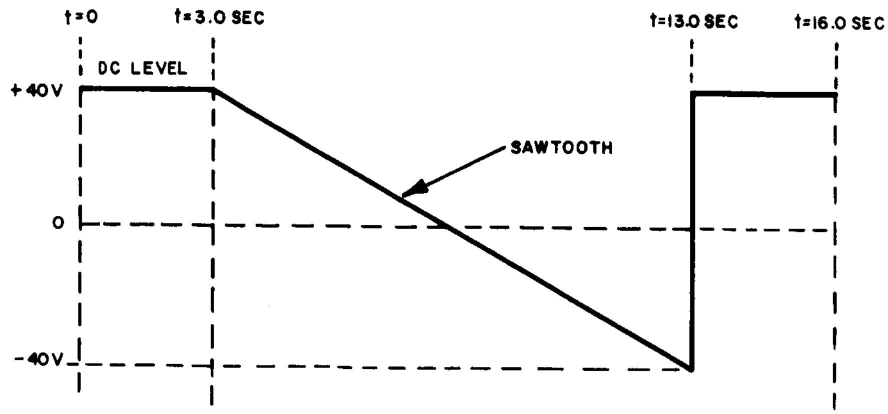


Figure V-1. Initial Vertical-Deflection Timing Cycle

The 4-kc "erase" sine wave was superimposed on this d-c level; and as a result of its d-c level, it was unable to sweep the entire photoconductor surface during the "prepare" cycle. This was corrected when the d-c level was adjusted so that the 4 kc sine-wave voltage was centered. This d-c level adjustment is shown in Figure V-2.

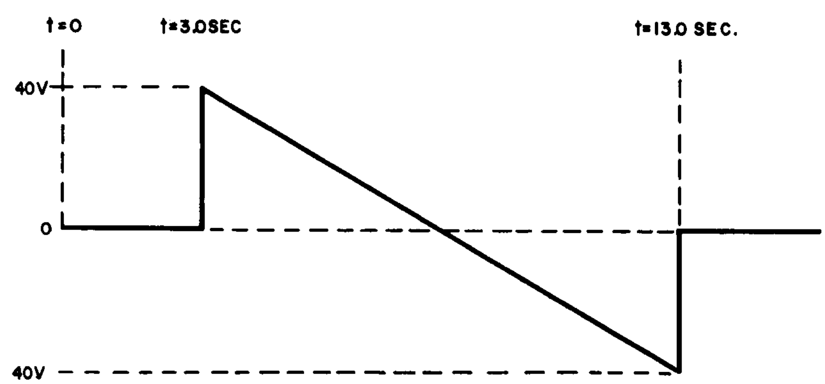


Figure V-2. Vertical-Deflection Timing Cycle with d-c Level Adjusted

During the 1.8-second "erase" period, the amplitude of the vertical 4-kc sine wave from the oscillator decayed due to the capacitive coupling between the oscillator and the vertical-deflection amplifier; this is shown in Figure V-3.

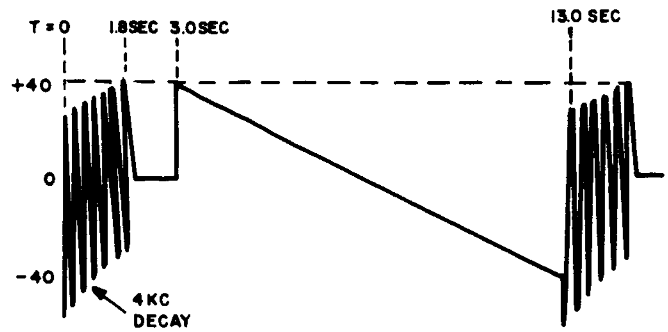


Figure V-3. Effect of Decay on 4-kc "Erase" Voltage

In order to eliminate the effects of this decay due to the capacitive coupling, increased feedback was applied in the 4-kc oscillator to increase the output amplitude. The decay still existed, but since the amplitude of the oscillator was increased, the decay portion of the "erase" cycle was in a region that did not scan the faceplate. The improvement is seen in Figure V-4.

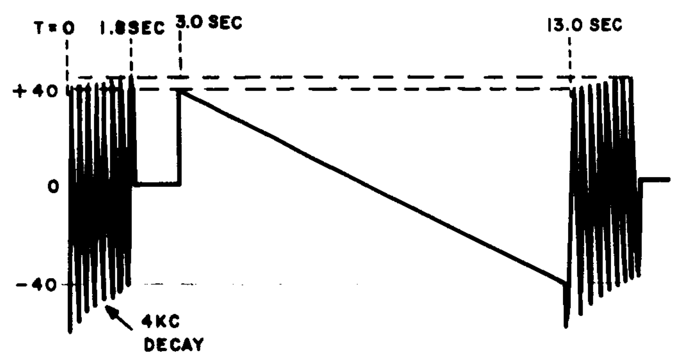


Figure V-4. Improvement of "Erase" Cycle Due to Increase of 4-kc Amplitude

Another change in the "erase" cycle was an increase in the amplitude of the horizontal-deflection voltage. The increase in amplitude of both the vertical and horizontal deflection (as shown in Figure VII-5) eliminated the edge effects caused by charges developing around the edges of the photoconductor.

Since the beam current in the image sensor is limited by its characteristics, thereby making it difficult to prepare the target, lights were initially placed in front of the slow-scan photoconductor to discharge it. Test showed that the black mask appeared blacker than the black bars placed in front of the slow-scan surface. This caused the dynamic excursion of the amplifiers to exceed the range for linear operation as shown in Figure V-5 (a).

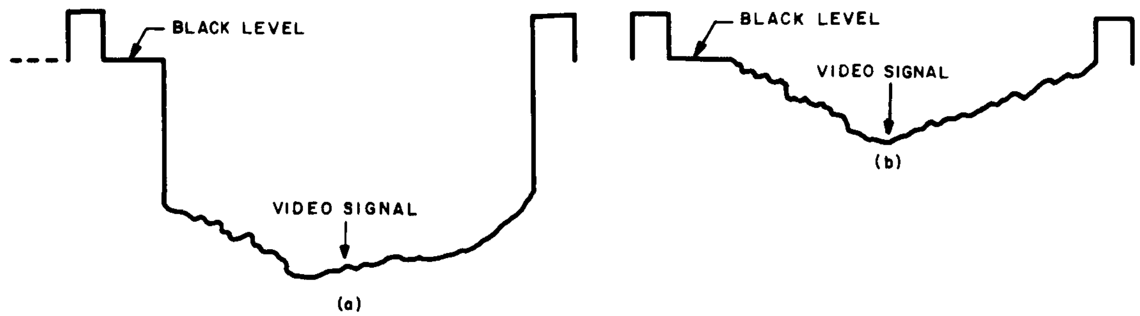


Figure V-5. Change in Signal Voltage Relationships Due to Position of "Erase" Lamps

Since the lights were placed in front of the target, the area behind the mask was not brought to the positive target voltage as was the rest of the faceplate, since the resistivity of the photoconductor decreases in proportion to the amount of light striking it. Since the mask effectively blocked the light, the resistance of the area behind the mask remained high; as a result this surface area was not brought up to the target-supply voltages, but remained lower. When the inner surface of the photoconductor was rapidly scanned, the potential of the surface behind the mask was brought toward the electron gun potential faster than the rest of the photoconductor surface, which was already at a less-positive potential. This had the effect of causing the area behind the mask to be more negatively charged than the rest of the faceplate. During readout this more negatively charged area appeared "blacker" than the actual "black" level.

To remedy this, the lights were placed behind the target in order to illuminate the surface of the photoconductor uniformly. This uniform illumination enabled the entire inner surface of the photoconductor to be brought to the same target voltage, resulting in the signal-voltage relationship as shown in (b) of Figure V-5.

4. Noise on the Clamped Signal

A noise voltage was superimposed on the dark-current pulse from the black mask, and since the video was clamped to this dark-current pulse, it was also clamped to the noise on it. This caused the signal level to fluctuate according to the level of the noise. The initial solution consisted of two approaches:

(1) The clamping response time was increased in order to make the period of the clamping time greater than the period of the noise.

(2) The high-frequency noise superimposed on the dark current was eliminated.

The optimum solution was achieved by redesigning the "one-shot" monostable multivibrator that controlled the clamping time, in order to make the period of the clamping time larger than the period of the noise.

5. Pincushion Effect

A "pincushion" effect was also found, which was the secondary effect of an electrostatic field set up by the grid-to-target potentials. This field caused the signal to be curved inward at the centers of each edge. The effect was greatly reduced when the target voltages were adjusted for a minimum effect for each image sensor.

SECTION VII

CIRCUIT COMPONENTS

Components of the Lunar Impact Camera TV System are described in the following sections in detail. Block diagrams and timing charts are provided for illustration; the over-all circuit is shown in Figure VII-1.

A. POWER SUPPLY

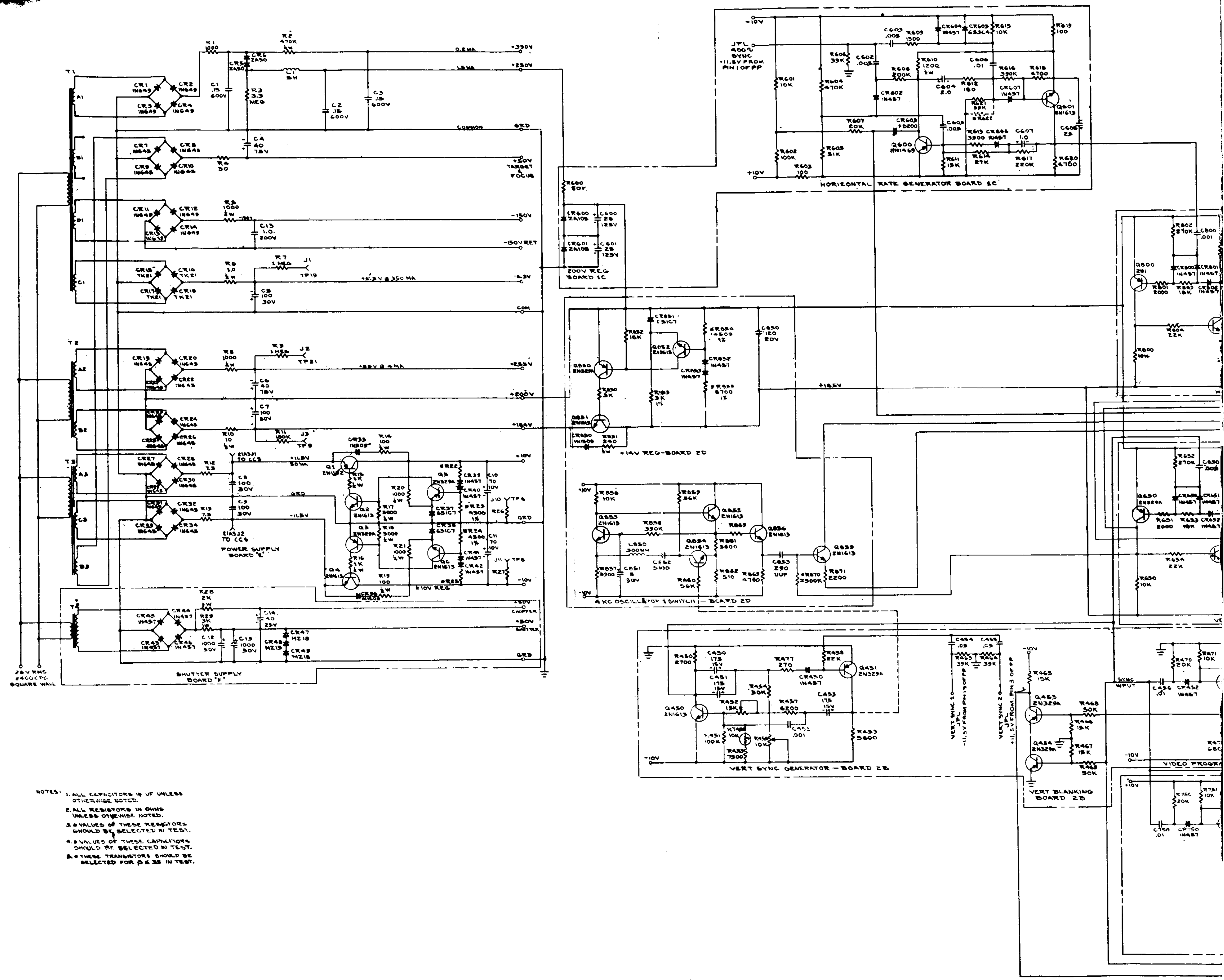
The 26-volt, 2400-rms power supplied to the system is fed into four transformers. The outputs of these transformers are rectified by 9 full-wave bridge rectifiers, which with their respective filters provide the system with the d-c voltages required for circuit operation. The voltage regulators (which provide a stabilizing effect, so that the output voltage is independent of load variations and input-voltage changes) are of two types: temperature-compensated transistor regulators (the junctions of the three series transistors of which are temperature-compensated by diodes), and Zener-diode regulators. Figure VII-2 is a block diagram of the Power Supply Subassembly.

B. TIMING CIRCUITRY

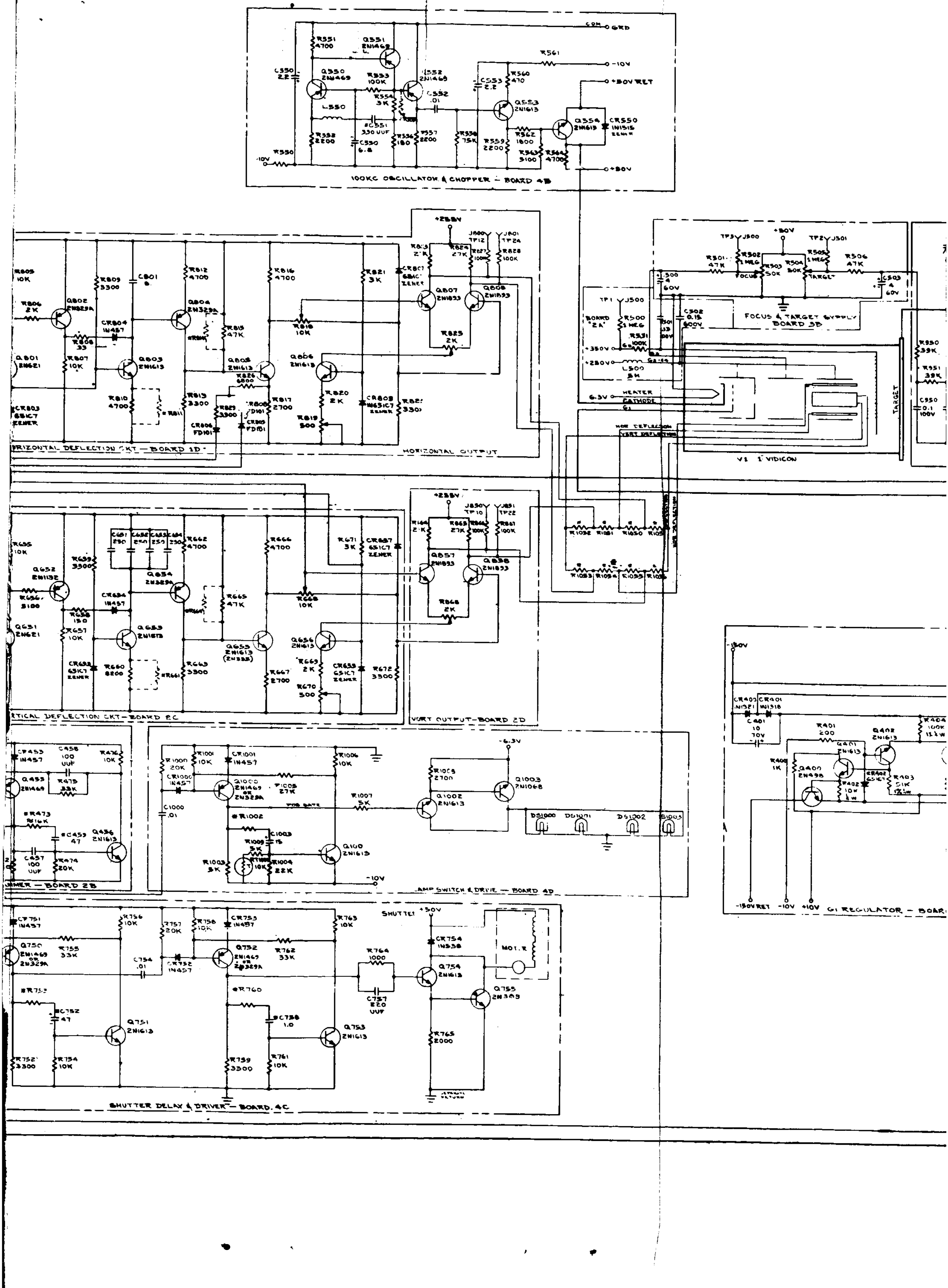
The timing cycle for the slow-scan, photoconductive, 1-inch image sensor is dependent upon the three input timing signals supplied by JPL: (1) a 400-cps square-wave synchronizing signal; (2) a negative-going pulse of 0.86 ms duration, with a period of 13 seconds; and (3) a positive-going pulse of 0.86 ms duration, with a period of 13 seconds, and a delay of 3 seconds with respect to the first pulse. These signals are shown in the timing diagram of Figure VII-3. Components of the timing circuitry are described in following paragraphs.

1. Horizontal Rate Generator

The 400-cps timing signal (which is "locked" to the vertical sync) is applied to the horizontal rate generator and is used to supply timing signals to the horizontal deflection amplifier, the control grid (G_1) switch and the transistor switches at the black-level clamp, and at the video amplifier. These are all shown in detail in Figures VII-3 and VII-5; a block diagram of the circuit is presented in Figure VII-4.



NOTES: 1. ALL CAPACITORS IN UF UNLESS OTHERWISE NOTED.
2. ALL RESISTORS IN OHMS UNLESS OTHERWISE NOTED.
3. * VALUES OF THESE RESISTORS SHOULD BE SELECTED IN TEST.
4. * VALUES OF THESE CAPACITORS SHOULD BE SELECTED IN TEST.
5. * THESE TRANSISTORS SHOULD BE SELECTED FOR $\beta \leq 35$ IN TEST.


100KC OSCILLATOR & CHOPPER — BOARD 4B
HORIZONTAL DEFLECTION CKT — BOARD 1D
HORIZONTAL OUTPUT
FOCUS & TARGET SUPPLY BOARD 3B
V1 1" VIDICON
VERTICAL DEFLECTION CKT — BOARD 2C
VERT OUTPUT — BOARD 2D
LAMP SWITCH & DRIVE — BOARD 4D
G1 REGULATOR — BOARD
SHUTTER DELAY & DRIVER — BOARD 4C

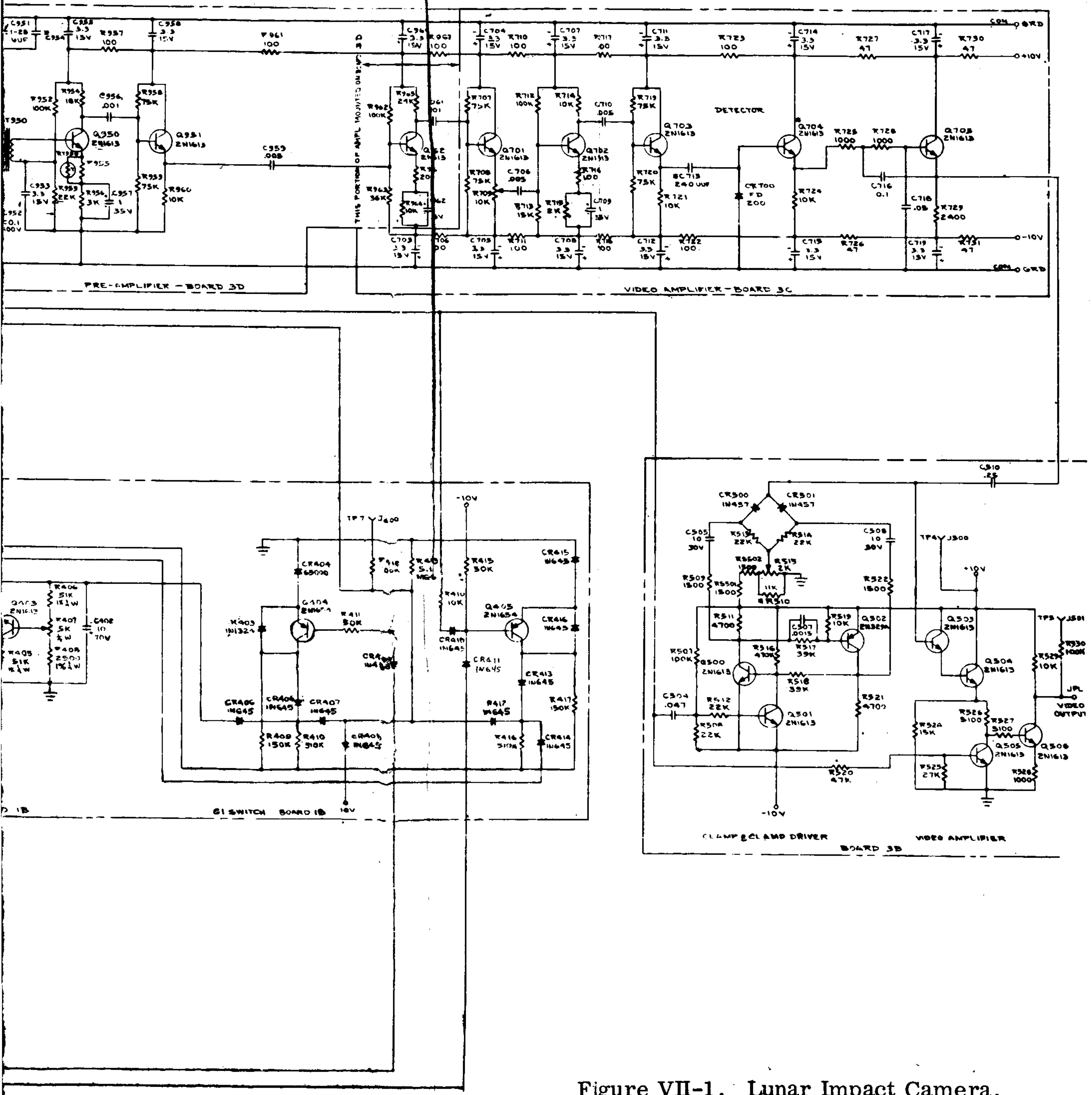


Figure VII-1. Lunar Impact Camera, Schematic Diagram

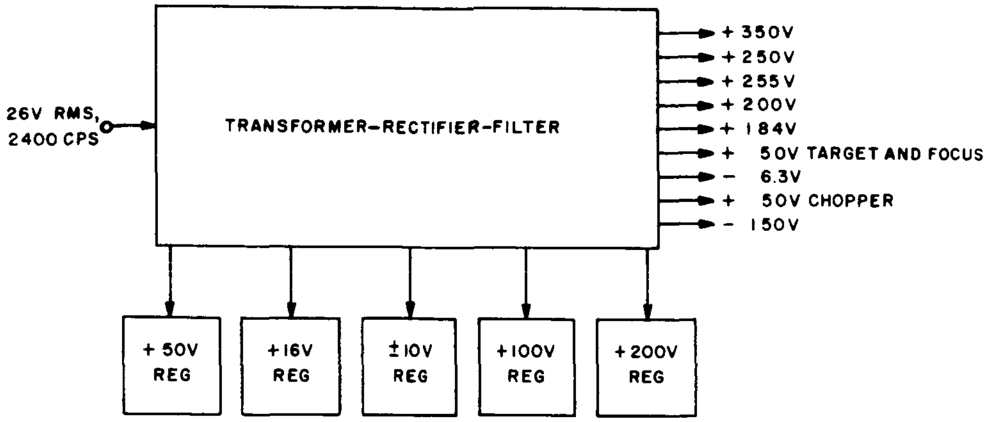


Figure VII-2. Power Supply Block Diagram

The horizontal rate generator was designed so that it will operate regardless of whether the 400-cps input timing signal is received. Thus, a failure in the "clock" supplying the input signal will not render the system inoperative, as the horizontal rate generator would then go to the free-running mode of operation with the output timing signal generated by the horizontal rate generator itself.

The circuit used is based upon this principle of a dual mode of operation; although the actual switching of the transistor (and therefore the output timing signal) is primarily dependent upon the 400-cps square-wave input, it will still generate a timing signal if the 400-cps input is not received. This 400-cps input is first differentiated by an RC network and is then gated to the base transistors Q600 and Q601 in order to pass only the positive pulses. When transistor Q601 is off, the base to emitter voltage is as shown in Figure VII-6, with the positive pulses of a 2.5 ms period superimposed on this voltage and with the twentieth pulse turning transistor Q601 on.

This occurs since this twentieth pulse reaches the threshold voltage needed to turn the transistor "on," causing a minus-20-volt excursion in the input to the base of pnp transistor Q600 and turning transistor Q600 "on" until the next positive pulse occurs. This positive pulse, which occurs 2.5 ms later, is applied to both bases; it switches pnp transistor Q600 "off" but does not affect the state of Q601 since it is already "on." The result of switching Q600 "off" is a minus-20-volt excursion across the capacitor on the collector which is coupled to the base of Q601. The minus-20-volt excursion applied to the base of Q601 switches it "off." The reason for the use of the input trigger (400-cps square-wave) is to compensate for drift in the RC timing elements due to temperature and tolerance variations. In the original design, the RC timing constants were chosen to allow the switching time to occur within one-half of 2.5 ms (1.25 ms) from the time of the twentieth pulse. This allowed for a ±2.5 percent margin for the RC elements,

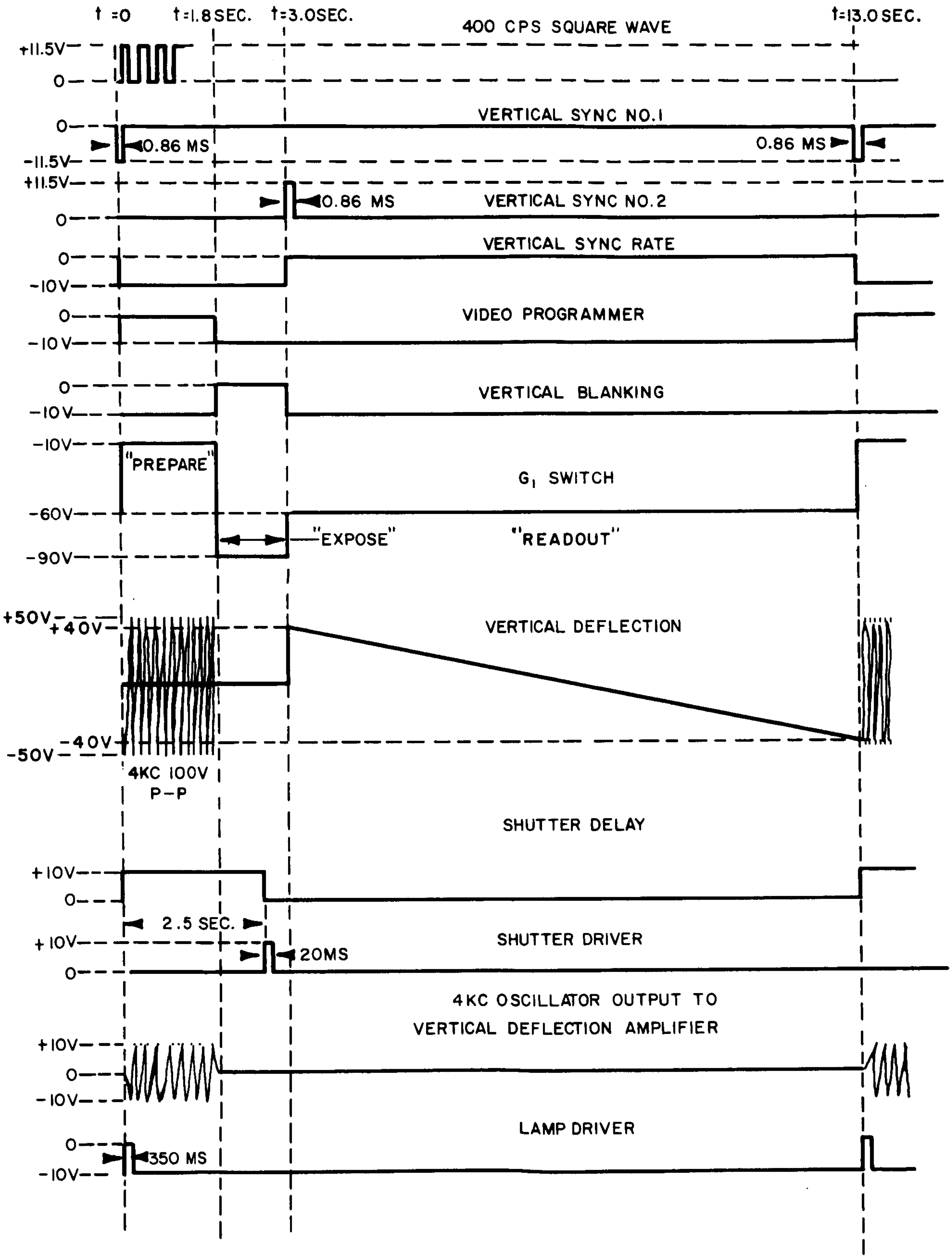


Figure VII-3. Vertical, Prepare, Expose, and Readout Timing Diagram

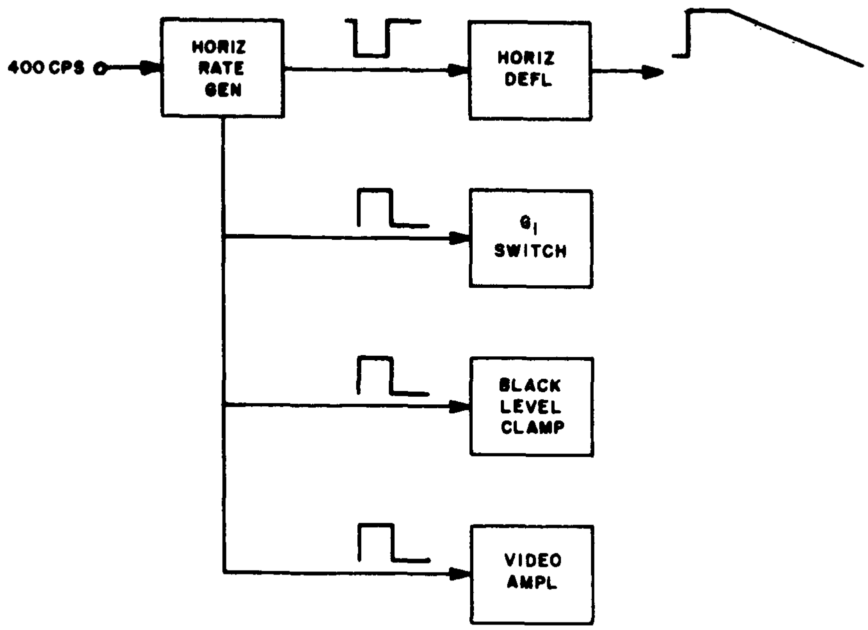


Figure VII-4. Horizontal Rate Generator Block Diagram

while still maintaining the same switching time, and resulted in the generation of a very accurate timing signal from the horizontal rate generator. In the free-running mode, the threshold voltage required to turn transistor Q601 on is obtained from the base-to-emitter voltage-level change; in a similar manner, Q600 is also energized to turn Q601 "off."

2. Horizontal and Vertical Deflection Circuits

The output signal from the horizontal rate generator is gated into the horizontal deflection circuit (shown in Figure VII-1) with the 2.5 ms negative pulse that switches transistors Q800, Q801, and Q802 to the "on" state. By switching transistor Q802 "on," the collector of this transistor is brought to 200 volts which, through diode 1N457, charges the 8 μf capacitor to the 200-volt level. When the input signal is positive for 50 ms, the transistors (Q800, Q801, Q802) are turned "off" and the constant-current source supplied from the collector of transistor Q803 linearly charges the 8 μ f capacitor in a negative direction to the 185-volt level, providing an extremely linear sawtooth output.

The voltage across this capacitor is then amplified through two common-emitter stages and a difference amplifier, with the output of the difference amplifier going to the horizontal deflection plates of the vidicon. Waveforms of these circuits are shown in Figure VII-7.

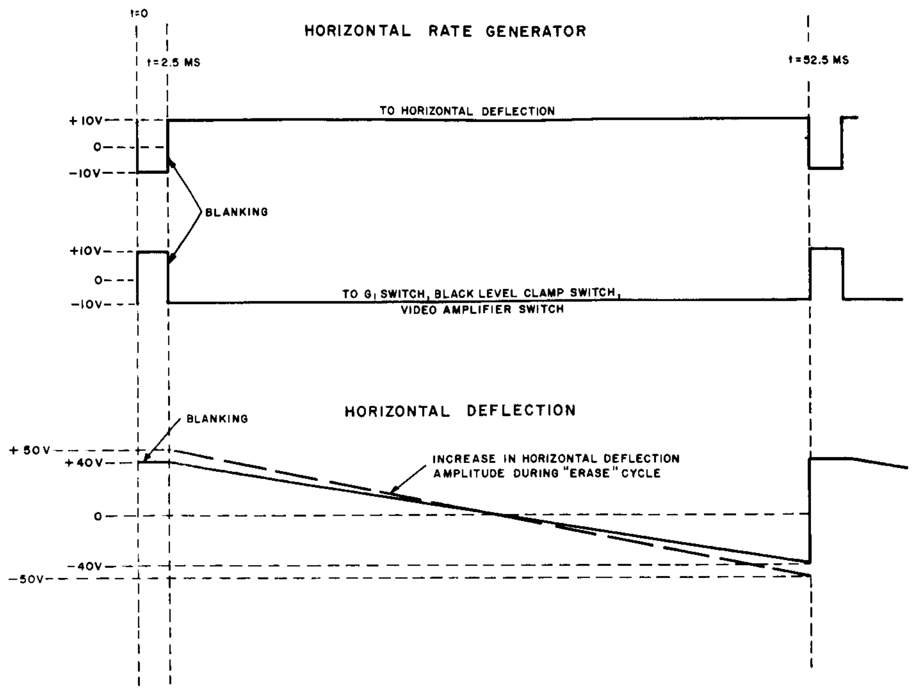


Figure VII-5. Horizontal Timing Diagram

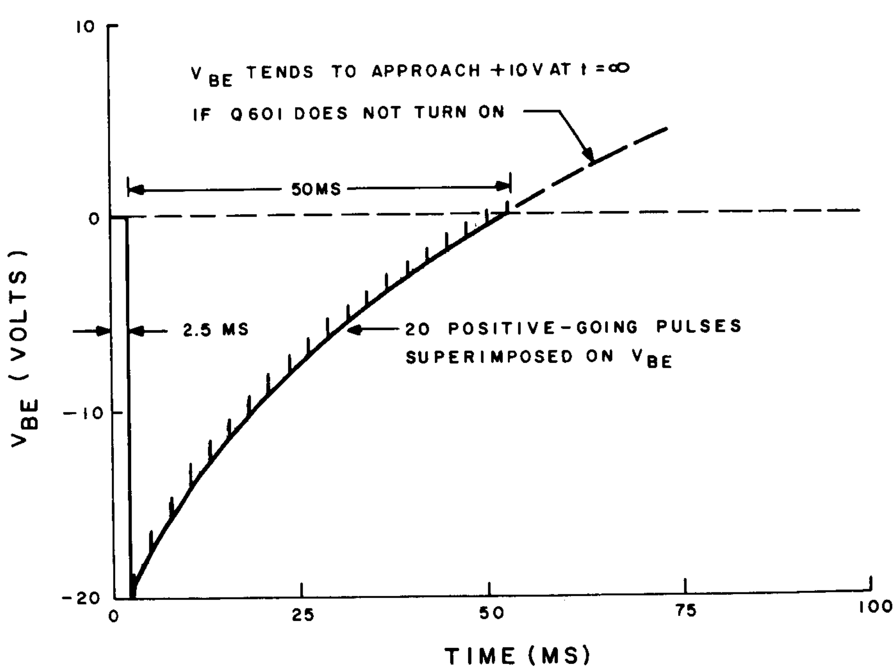


Figure VII-6. Horizontal Rate Generator Timing Signals

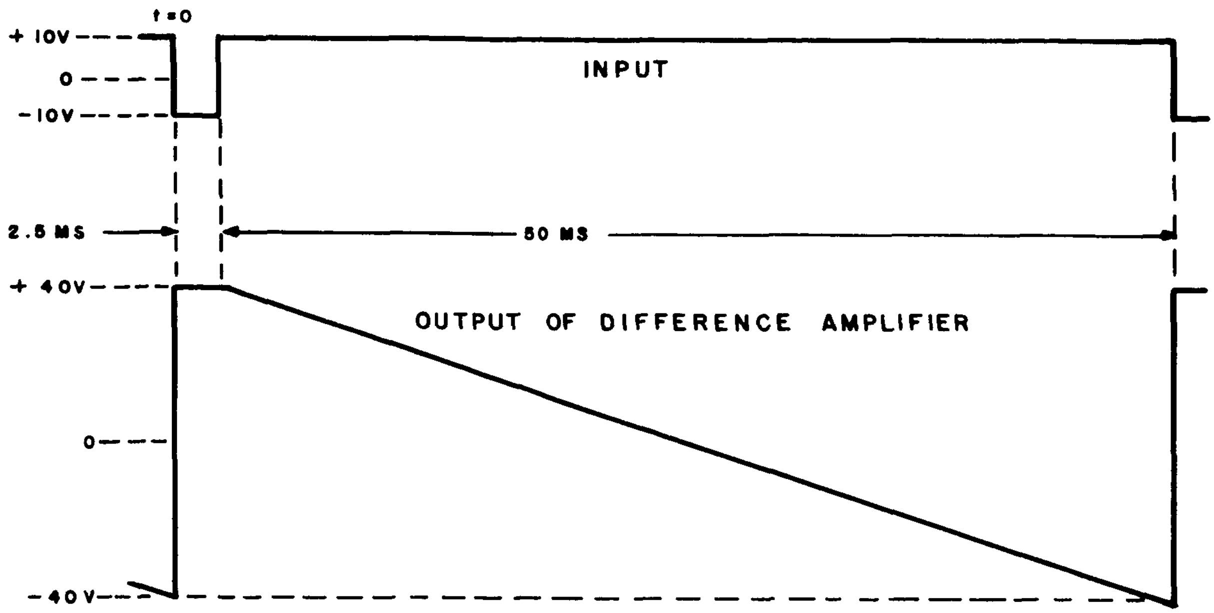


Figure VII-7. Horizontal-Deflection Circuit Waveforms

The vertical deflection circuit is similar to the horizontal deflection circuit except for (1) the timing circuit, which is required to produce a sawtooth wave of a different period (10 seconds rather than 50 ms), and (2) the switching circuit used to produce a d-c voltage level of 3 seconds duration upon which the 4 kc, 100-volt peak-to-peak potential is superimposed in order to erase the residual picture image. This voltage level is adjusted so the erasing beam is "centered," in order to scan the entire image sensor surface during the erase cycle.

Two possibilities existed in the design of the horizontal deflection circuitry, with respect to the biasing voltages and the d-c level upon which the sawtooth output would be superimposed. In the final design, the entire circuit "floats" at a plus-200-volt level. This is done since the electrons which must be deflected are approximately at this d-c level when they are under the influence of the deflection plates, and the deflecting sawtooth voltage must also be at this d-c potential in order to influence the electrons. The other possibility was to have the cathode at a minus-200-volt potential with the sawtooth deflecting voltage at zero d-c potential level, since the electrons would now pass the deflecting plates at zero potential level. This would have resulted in severe design requirements for the cathode and control grid. The same analysis was applied to the vertical-deflection circuitry in establishing the voltages and the d-c level up on which the alternating voltage wave is superimposed.

The signal output from the horizontal rate generator to the control grid is also used to switch the control grid during the horizontal blanking period. This is accomplished by switching transistor Q405 of the G_1 switch "off," causing the grid to be biased to minus 90 volts, which is sufficient to cut off the electron beam. The same signal output from the horizontal rate generator is also used to drive the clamp driver in the clamping circuit in order to clamp the video signal to the voltage determined by the black mask level before every horizontal sweep.

3. Vertical Sync Generator

The vertical sync generator (shown in Figure VII-8) produces a vertical synchronizing signal, which is used to supply timing signals to the video programmer, the vertical blanking circuit, the switch of the 4-kc oscillator, the vertical deflection circuit, the control grid (G_1), the shutter delay and shutter driver, and the lamp switch. Waveforms produced by this circuit are shown in Figure VII-9.

The vertical sync generator design is similar to that of the horizontal rate generator in that it also employs a dual method of operation, i.e., (1) the input signals from JPL trigger the circuitry to produce the required timing outputs, or (2) in case of a failure in the input signals, the circuit would operate in a free-running mode with the output signal dependent solely upon the RC time constants. The only difference between the mode of operation of the horizontal and vertical generators is in the type of input trigger timing signals supplied to each.

4. Video Programmer and Vertical Blanking

The video programmer is used to supply a timing signal, which is fed into the vertical blanking circuit. This timing signal is gated with the timing signal from the vertical sync generator by the use of an AND gate.

The video programmer makes use of a monostable multivibrator to supply the required signal to the AND gate of the vertical blanking circuit. The normal state of transistors Q455 and Q456 is the "off" position with the voltage from the collector of transistor Q455 at minus 10 volts. At time t_0, a negative pulse of 3 seconds duration from the sync generator is differentiated by the $0.01 \mu f$ capacitor, which is in parallel with a 20,000-ohm resistor, to produce a negative and a positive pulse. Diode CR452, which is in series with these pulses and the base of pnp transistor Q455, passes only the negative pulse that is used to turn both transistors "on". This negative pulse is used to generate a larger pulse, whose width is determined by the RC time constant of the monostable multivibrator. The collector of transistor Q455 is now at zero potential where it remains for 1.8 seconds. Figure VII-10 illustrates the relationships of the various signals in this circuit.

The timing signal for vertical blanking is obtained by AND gating the output signals of the sync generator and the video programmer. The AND gate consists of two pnp transistors in parallel, and is in the "on" position when negative signals are

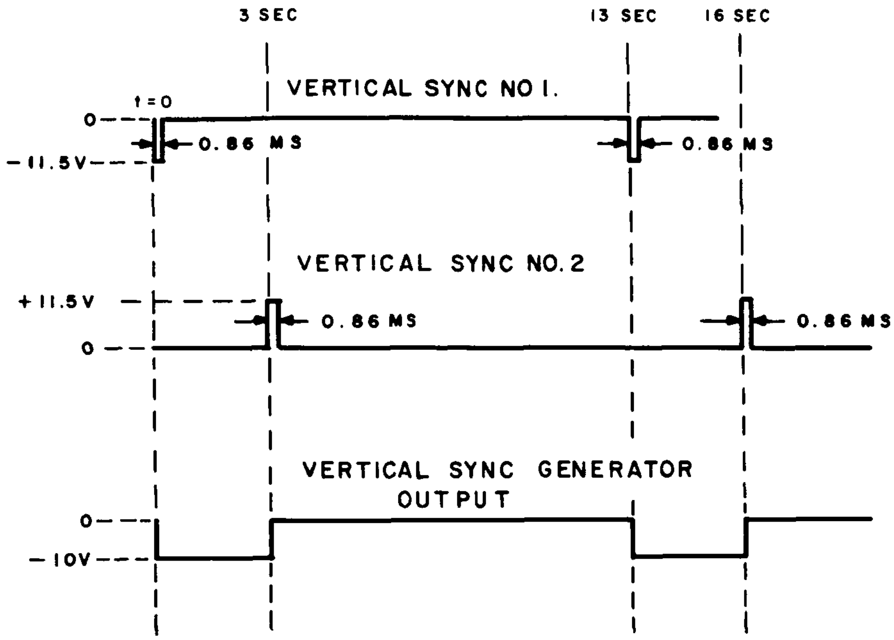


Figure VII-9. Vertical Sync Generator Waveforms

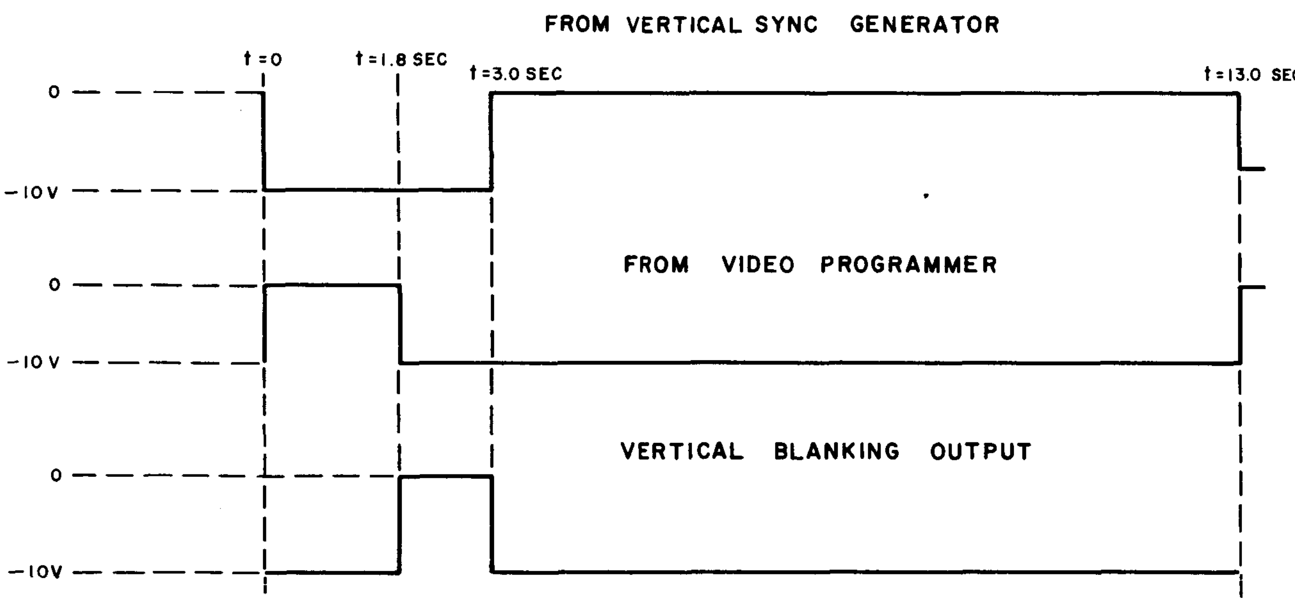


Figure VII-10. Programmer and Blanking Circuit Waveforms

simultaneously applied to the bases of these transistors. When this occurs, the output signal, which is normally at minus 10 volts, switches to zero potential. Due to the input timing signals, this condition occurs at time t of 1.8 seconds and lasts until t is 3 seconds for a pulse of 1.2 seconds duration.

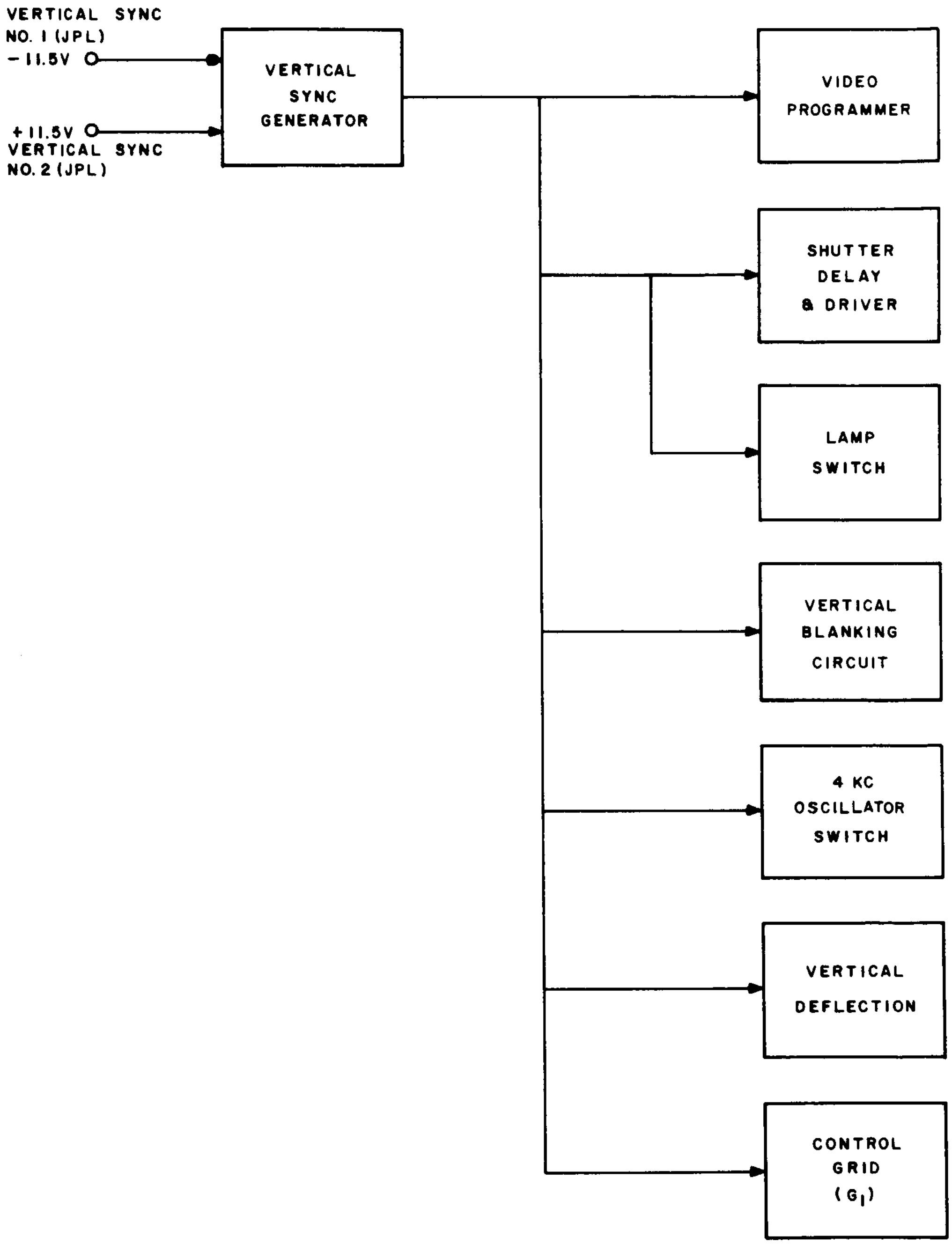


Figure VII-8. Vertical Sync Block Diagram

5. G_1 Switch

The control grid is used to regulate the beam current of the image sensor during the "prepare", "expose", and "readout" cycles for each picture and during horizontal blanking as follows:

(a) "Prepare" The control grid is biased in such a manner that the electron beam is turned on "hard."

(b) "Expose" The control grid is biased in such a manner that the electron beam is turned completely "off."

(c) "Readout" The control grid is biased in such a manner that the electron beam deposits electrons on the inner surface of the photoconductor corresponding to the charge pattern which has formed during exposure. The control grid is also turned completely off during the "readout" cycle whenever horizontal blanking occurs.

The G_1 switch is designed to supply the required voltage levels to the control grid by the use of switching transistors Q404 and Q405 and the accompanying diodes as shown in the schematic of Figure VII-1. Figure VII-11 illustrates the relationships of the various waveforms involved in the circuit.

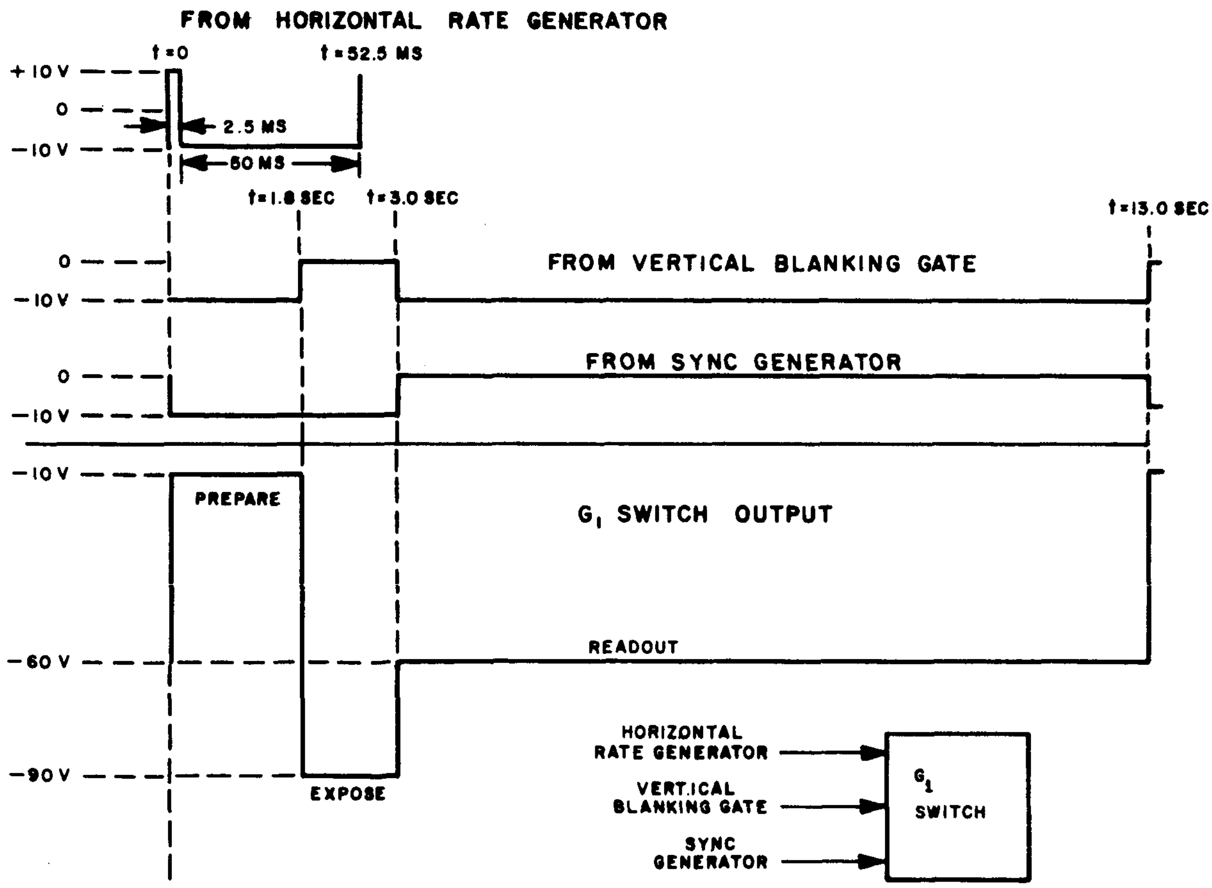


Figure VII-11. G_1 Switch Waveforms

At time t_o, diodes CR407 and CR412 are reverse-biased due to the collector voltages of both switching transistors and because of the minus-10-volt potential supplied by the G_1 regulator. This condition exists for 1.8 seconds and the G_1 output, which is OR-gated from these two diodes and the minus-10-volt supply, will be at the minus-10-volt potential during this period of time. The vertical blanking pulse at t of 1.8 seconds to t of 3.0 seconds for the "expose" cycle cuts off transistor Q405 and thereby sets its collector potential at minus 90 volts. This minus-90-volt level is determined by the resistance network and the minus-150-volt supply of the G_1 circuitry.

The output of the G_1 switch will then be minus 90 volts, since diodes CR407 and CR408 are reverse-biased and diode CR412 is forward-biased, which when OR-gated together provides this negative output voltage. At time t of 3.0 seconds to t of 13.0 seconds for the "readout" cycle, the timing signal from the sync generator switches Q404 "off" while the timing signal from the vertical blanking gate switches Q405 "on". The output of G_1 is determined in the same manner as for the "expose" cycle, the only difference being in that the output voltage level is determined by the resistance network from the collector of transistor Q404 to the control grid.

The horizontal blanking pulse, which occurs for 2.5 ms every 52.5 ms, is analagous to the vertical blanking pulse in its effect upon the control-grid potential level.

6. 4-KC Oscillator, Switch, and Vertical Deflection Amplifier

The 4-kc oscillator is used during the "prepare" cycle to erase the residual image on the image sensor surface after the readout cycle occurs. This oscillator provides a 4-kc signal to the vertical deflection amplifier, whose d-c level is adjusted during the "prepare" cycle to center the erase beam on the image sensor surface. The amplitude of the 4-kc erase beam, determined by the difference amplifier of the vertical deflection amplifier, is also adjusted so that the entire photoconductor surface is scanned. The switching time of the 4-kc signal to the vertical deflection circuit is determined by the 3-second vertical sync pulse applied to switching transistor Q854 in the oscillator circuit.

The frequency of the oscillator is determined by the values of capacitor C852 and inductor L850.

Figure VII-12 is a block diagram of the oscillator-amplifier; the waveforms of the various signals are shown in the timing diagram of Figure VII-2.

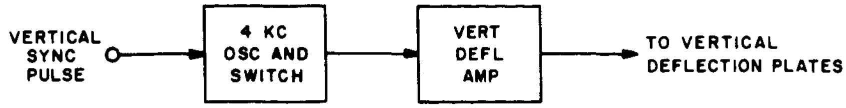


Figure VII-12. Oscillator-Amplifier Block Diagram

7. 100-KC Oscillator and Chopper

The 100-kc oscillator produces a signal which is used as the subcarrier on the cathode of the image sensor as shown in Figure VII-13. This subcarrier frequency causes the beam current to be chopped (modulated) at this carrier rate. The output of the oscillator goes to a "chopper", where a square wave of the same frequency with voltage levels of 0 and plus-18-volts is generated by the positive and negative cycles of the 100-kc oscillator. The output of the chopper is then applied to the cathode of the vidicon. The frequency of the oscillator is determined by the values of capacitor C551 and inductor L550.

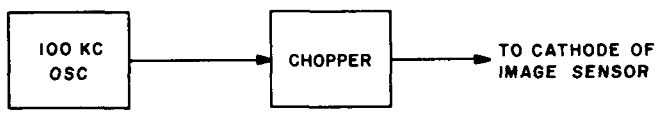


Figure VII-13. 100-kc Oscillator-Chopper Block Diagram

8. Lamp Switch and Driver

During the initial period of the "prepare" cycle, the image sensor surface is exposed to light from the "erase" lamps in order to remove the residual image on this surface. The length of time that these lamps are "on" is determined by the Lamp Switch and Driver, which consists of a monostable multivibrator and a transistor switch driven by the output of the multivibrator as shown in Figure VII-14 and in the appropriate portion of Figure VII-1.

9. Shutter Delay and Driver Circuits

The shutter time of 20 ms determines the length of exposure of the image sensor surface and occurs at time t of 2.5 seconds.

The vertical sync rate triggers a monostable multivibrator to produce the shutter delay time required. This positive pulse from the shutter delay circuit is then differentiated by an RC network and the negative pulse occurring at 2.5 seconds is gated into another monostable multivibrator, that produces a pulse of 20 ms duration. This positive pulse of 2.5 seconds delay and 20 ms duration is used to drive the shutter motor. The timing circuits and block diagram are shown in Figure VII-15; electronic circuitry is found in the appropriate portion of Figure VII-1.

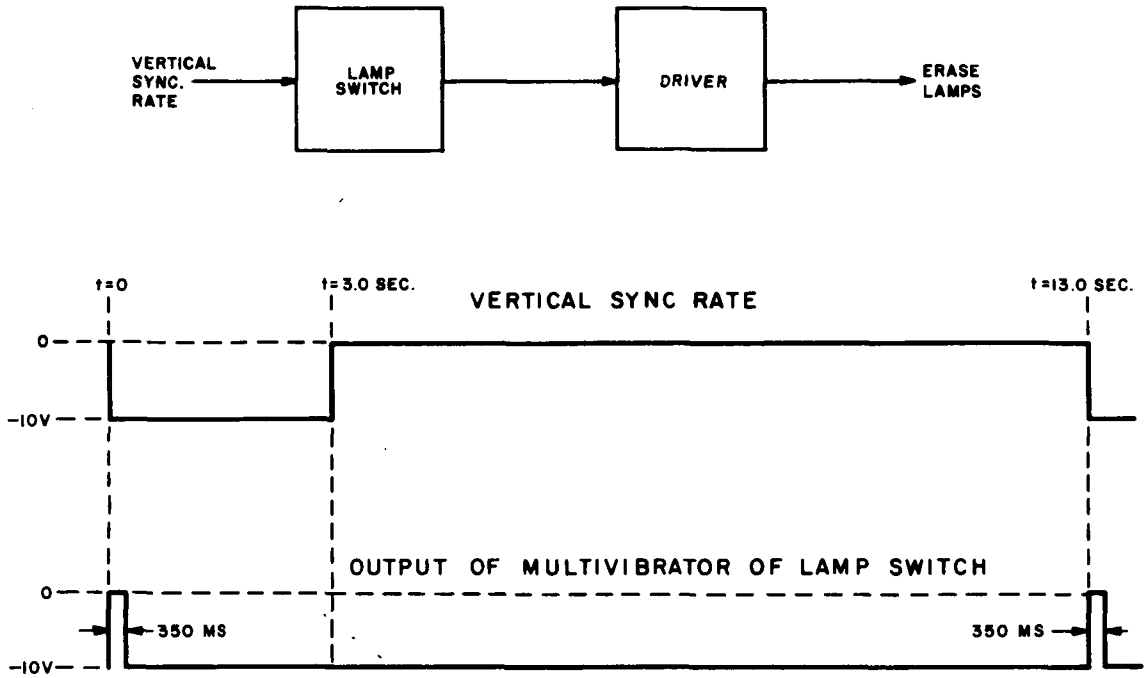
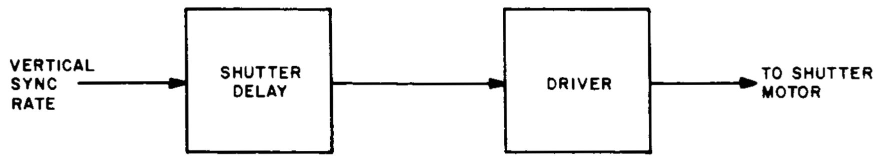


Figure VII-14. Lamp Switch-Driver Block Diagram and Timing

C. VIDEO CIRCUITRY

The video signal output across the target load is an amplitude-modulated carrier (2 kc bandwidth) whose frequency is 100 kc. The video signal is fed into the shielded toroidal transformer of the preamplifier, where the inductance of the transformer is utilized, with capacitors C951 and C954, to form a tuned circuit for the 100-kc carrier. This tuned signal is amplified in the preamplifier and the resulting output signal is a-c coupled into the bandpass amplifier. The bandpass amplifier contains four stages: two are common-emitter amplifiers and are used for voltage amplification; one is an emitter-follower stage whose output is variable for gain adjustment; and the fourth is an emitter-follower amplifier that drives the output stage of the bandpass amplifier to the detector. Both the preamplifier and the bandpass amplifier contain high-pass RC filters.

The input signal to the detector is rectified by a diode and coupled by an emitter-follower amplifier into the detector stage, where the 100-kc signal is detected by an RC circuit. The resulting video signal is a-c coupled into the clamp and video amplifier circuits. The detector uses an RC integrating network to detect the 2-kc video signal from the amplitude-modulated carrier. Figure VII-16 is a block diagram of the circuitry shown in the appropriate area of Figure VII-1.



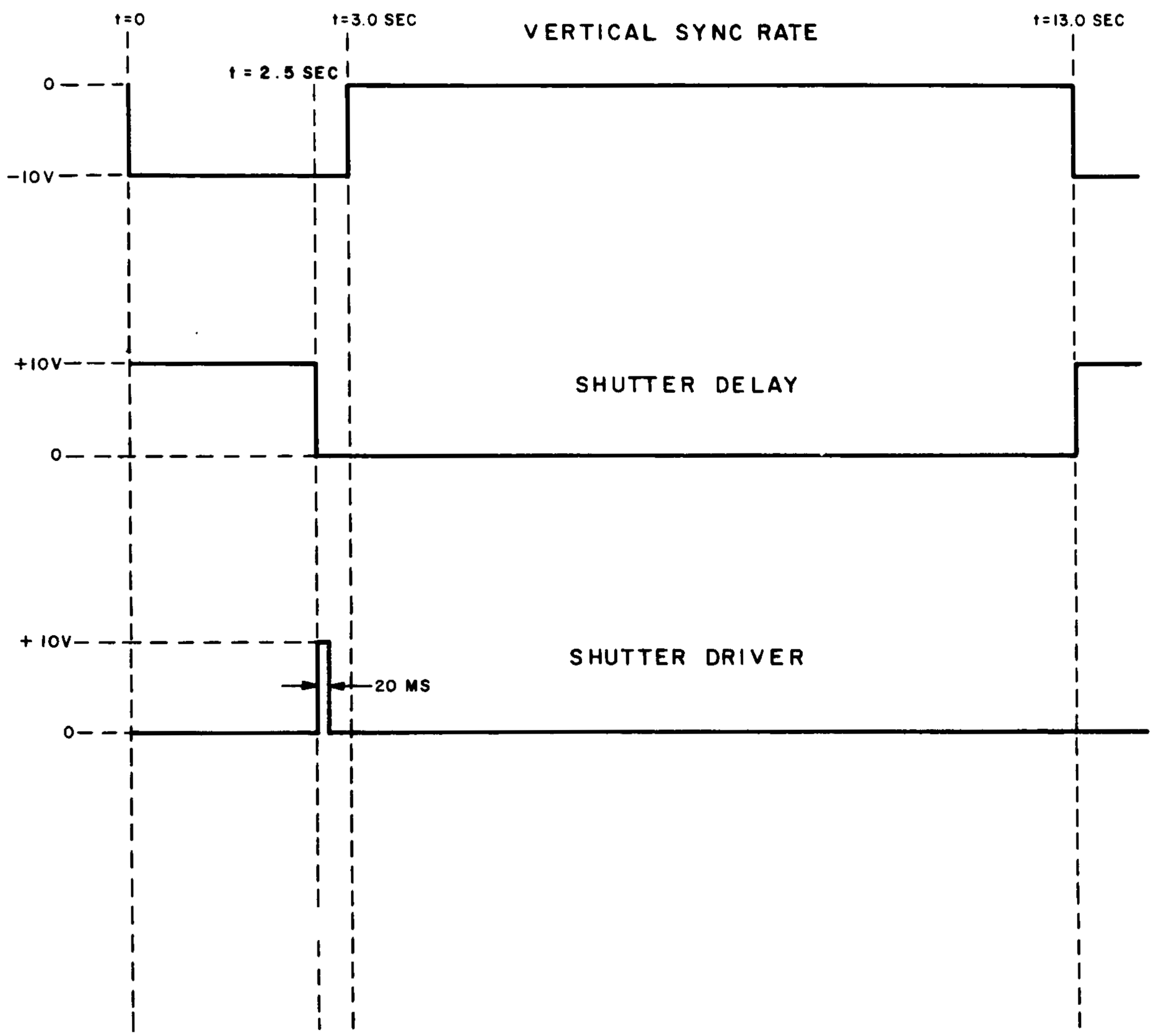


Figure VII-15. Shutter Delay-Driver Block Diagram and Timing

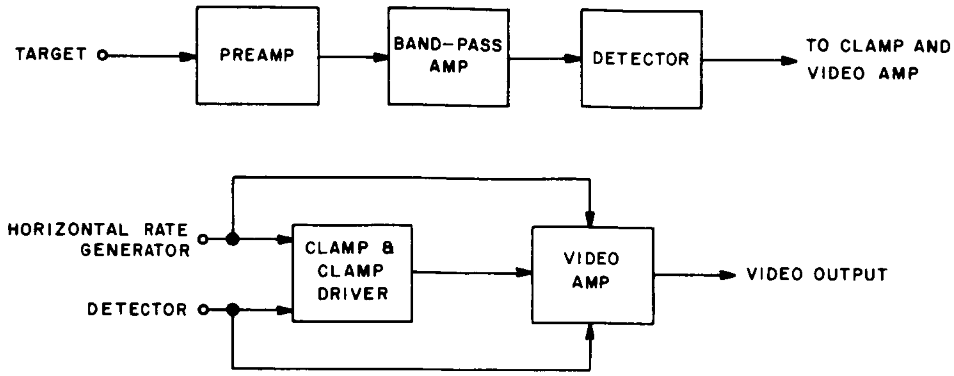


Figure VII-16. Image Sensor Output Circuitry Block Diagram

The video signal, which is a-c coupled into the clamp circuit, has 5 percent of each line of the signal (2.5 ms) clamped in such a fashion that "scene black" corresponds to a voltage generated when the electron beam scans the portion of the photoconductor that is masked from light. By clamping each video line to this level, vertical shading is minimized and automatic compensation for varying dark current over the operating temperature range is provided. The clamping switch Q502 is activated by the timing signal from the horizontal rate generator. The same timing signal is also used to switch the video amplifier "off" in order that the clamped signal will be the only video output signal during the 2.5-ms clamping time. After 2.5 ms, the clamp switch opens and the video amplifier is switched "on," as the video signal bypasses the clamping circuit and is now a-c coupled into the video amplifier. The output of this amplifier is the video signal which is transmitted back to earth.

SECTION VIII

FIELD ENGINEERING

A. GENERAL

The final phase of the contract required that the environmental tests be conducted by RCA in order to qualify the Camera System before its integration and qualification with the rest of the spacecraft. The original plan required the shipment of a lens and shutter from JPL to RCA, in order that the environmental tests could be conducted at RCA. This was never done for the following reasons:

(1) The lens was delayed in delivery.

(2) The shutter model was behind schedule and could not be delivered on time.

(3) A delay occurred in the delivery of the image sensors because of their hybrid nature.

In order to avoid jeopardizing the launching date, the flight model Camera Systems were sent to JPL at Pasadena, California, where they were environmentally tested. All five flight models and one prototype model were tested at JPL with RCA personnel present to assist and witness, so that any necessary design changes could be immediately effected.

Upon receipt at JPL, the flight models were all subjected to the same series of tests until they were qualified. The general procedure of testing for the first flight model for qualification is typical of that for the other flight models and is outlined in the next subparagraph. (These were the Flight Acceptance Tests.)

B. TEST PROCEDURE FOR THE FIRST FLIGHT MODEL

The following steps were performed for the first flight model.

1. The camera system was first checked at RCA before shipment in accordance with temperature requirements of JPL Specification 30201.

2. After shipment, the System was again checked using the RCA power supply for all the specification requirements (except that of sterilization) as listed in Table VII-1. This Table lists the results of an actual test performed at JPL.

TABLE VIII-1. TYPICAL FLIGHT-MODEL TEST

Test	0^oC	RT	50^oC
Primary + Voltage	25	25	25
Primary - Voltage	-26	-26	-26
Bias Voltage	12.4	12.4	12.4
Mesh Voltage	450	450	450
Target Voltage	18.5	18.5	18.5
Focus Voltage	25.0	25.0	25.0
+10 V	9.1 V	9.1 V	9.1 V
G_1 Voltage	-58	-58	-58
-10 V	-9.1	-9.1	-9.1
-16 V	-15.5 V	-16.5 V	-15.5 V
55 V	47 V	46 V	47 V
-6.3 V	-5.0 V	-5.0 V	-5.0 V
200 V	195 V	200 V	195 V
G_2 and G_4 Voltage	250	250	260
Clamp Level (Volts)	1.8	1.6	2.3
Hor. Defl. Total Time (ms)	52.2	52.5	52.7
Blanking Time (ms)	2.78	2.81	2.89
Vert. Defl. Readout Time (sec)	10.26	10.33	10.29
Prepare-Expose Time (sec)	3.24	3.13	3.09
Clamp Gain	5.3	7.0	7.15
Erase Time (sec)	1.80	2.00	1.65
Shutter Delay (sec)	2.3	2.4	2.0
Shutter Pulse (ms)	125	140	100
Lamp Pulse (ms)	360	360	355

3. The Power Package, supplied by JPL, was now used with the Camera System for the first time. The System power output was lower than expected and the RCA Transformer-Rectifier Package, which was designed for 26 volts rms, required redesign in order to function at the lower voltage level. This was accomplished by changing the voltage-regulation diodes in the power package to others with different voltage characteristics.

4. After the modification had been made, the camera was adjusted (i.e., centered, focussed, etc.) in order to test the shutter and optical telescope as a complete unit with the Camera System for the first time. At this point, the shutter-drive power transistor Q755 failed due to the unexpected shutter load. This was remedied by replacing the transistor with one that had a higher power rating.

5. The system tests revealed that ground problems existed in the electronics, the shutter, and the optics. These problems, discussed later in this section, required the greatest amount of effort by the Field Engineers during this phase of the contract.

6. A temperature test was run on the system without the shutter and the optics. This step was necessary, inasmuch as the shutter and the optical telescope obstructed access to necessary adjustments in the electronics. Difficulty in the clamp circuit discovered at this point was caused by the transistor switch, which was unsatisfactory at low-temperature due to the low β of the transistor. A transistor with higher β was selected for this application.

7. The optical telescope and the shutter were then mounted, and the System was again tested in accordance with the temperature specifications.

8. Final spot "potting" was now done, since earlier performance of this operation would have prevented checking of the circuitry and accomplishment of any necessary changes.

9. The complete Camera System (electronic circuitry, shutter, and optics) was tested in the main JPL environmental laboratory in accordance with the JPL specification (30201). The principal tests involved shock and acceleration in each of the three directions of an orthogonal system; a sequence of band-limited, Gaussian-noise vibration tests; a combined Gaussian-noise and sinusoidal vibration test; and the spaceflight temperature tests, which were to verify that the Camera System would perform satisfactorily in a temperature-vacuum environment with a suitable safety margin. A failure in the coil of the preamplifier transformer T950 occurred during the thermal-vacuum test. The cause was ascribed to excessive

potting around the coils, which resulted in severe pressure during the tests. When the amount of potting used was reduced, the pressure was relieved.

10. The system was then returned to the JPL temperature chamber where it was subjected to a thermal sterilization treatment for 24 hours at 125 degrees Centigrade.
11. The complete system was checked in the JPL environmental laboratory to determine the effects of the sterilization. These tests revealed no degradation in the system.
12. At this point, the final centering and the focussing (alignment) of the Camera System was accomplished.
13. Etching (of reticle marks on the image sensor surface) was originally not planned and was therefore performed at JPL. These marks were placed at each of the four corners of a 0.44-inch-square area on the surface of the 1-inch vidicon to indicate the distortion-free area of the image sensor surface.
14. The Camera System was now assembled in the Space Vehicle, and all the harnesses were completely checked.
15. Complete integration of the units associated with the Camera System was performed.
16. The system was turned on and checked by means of monitor racks supplied for this phase by JPL. The complete vehicle was then run through a simulated flight test for 60 hours, which was the estimated duration of the flight.
17. After this last test, the system was packaged and sent to Cape Canaveral, where the spacecraft was externally gas-sterilized and and given the last complete system test.

The prototype model that was sent to JPL was also subjected to a series of the same type of tests and was qualified. (These tests were the prototype acceptance tests and were more rigorous than the flight acceptance tests.) It was then used at JPL to check out the image sensors to be used in the flight models.

C. PROBLEMS DURING FIELD ENGINEERING

1. Grounds

a. Shutter-Camera

The principal difficulty resulted from the presence of too much noise on the over-all system ground as compared with the RCA ground. If the shutter ground were not insulated from the RCA ground, the RCA ground would have picked up all the system noise, which would then have been picked up by the target lead.

The first solution was to insulate the shutter assembly from the optics and the RCA Camera System. A thin nylon tape was first employed to insulate the systems, but the tape thickness was too great and would have required that the shutter case be ground down or that the optics be made larger. It was therefore decided that it would be more feasible to shield the target lead from the shutter and optics (this would isolate the input to the preamplifier); this was accomplished by "floating" the shield of the target lead at plus-10 volts instead of at ground potential. As a result, the RCA ground was isolated from the system ground; the ground-loop pickup, which was previously fed with the signal into the preamplifier, was eliminated.

b. Transformer-Rectifier Package

Pin 14 of the Transformer-Rectifier Package connector was disconnected because it also tied the RCA ground to the system ground. This connection had introduced noise from the JPL system into the Transformer-Rectifier box by means of ground loops.

2. Image Sensor Tubes

Considerable time was spent selecting suitable vidicons for the following reasons:

(1) Potentials for the mesh (G_5) and the accelerating electrode necessary to produce a good, flat field were critical and required adjustment.

(2) "Erase" was sometimes poor due to poor target characteristics.

(3) Twisted guns or misalignment of the faceplate, mask, and gun necessitated changes in the vertical and/or horizontal balance resistors.

(4) Certain of the tubes failed to exhibit a sufficiently flat field at the temperatures of zero and 50 degrees Centigrade.

(5) Some tubes failed to meet the required temperature and vacuum conditions.

(6) Masks were displaced (rotated) with respect to their required positions.

Measures taken to provide image sensors capable of satisfying the specification requirements included the following:

(1) In order to achieve a flat field, the mesh and accelerating-electrode potentials for each tube were carefully adjusted by providing suitable Zener voltage-regulating diodes and the necessary associated circuitry.

(2) Image sensors were selected by bench testing, using a lamp box as a light source to determine the presence of a flat field and the absence of spots and shading.

(3) The image sensor tubes were subjected to temperatures of zero and 50 degrees Centigrade, each stabilized for one hour, and then tested to determine whether their characteristics were affected by the temperature extremes.

SECTION IX

SUMMARY

The study portion of the program resulted in the selection of an image sensor and associated circuitry capable of producing pictures of the moon under the environmental conditions imposed by the requirements of the mission. During this phase, advances in the Camera System electronics were made in connection with rapid erasure, dark-current compensation, and subcarrier-frequency techniques. The selection of a hybrid arrangement for the production of the image sensor vidicon resulted in manufacturing and testing problems, but all the difficulties were ultimately overcome and a sufficient quantity of image sensors was produced.

The mechanical design of the system enabled it to fulfill readily the requirements of all the environmental tests performed by JPL. The weight and volume restrictions were satisfied, and the mechanical interface of the camera system was readily adaptable to that of the optical telescope and shutter. Sterilization of the electronic circuitry and image sensors produced no adverse effect upon the system. As a result of the careful mechanical design, an extremely small amount of rework was required during the prototype and field engineering phases.

The fabrication of the prototype resulted in an efficiently functioning system with only minor shortcomings in the matters of "noise" in the power supply and clamped signal, and need for an improvement in the "erase" portion of the "prepare" cycle. Several minor problems arose in the final phase of the program during Field Engineering, mainly those which occurred in the course of the system integration, thermal-vacuum, and vibration tests; solutions for these were immediately provided by the RCA Field Representative. The Flight Models tested at JPL in Pasadena, California provided satisfactory pictures and were entirely acceptable by JPL.

All three cameras were launched toward the moon, but two of them were never put into operation. The first Camera System in the Ranger satellite did produce pictures from space in the vicinity of the moon; the reticles, added by JPL external to the face of the image sensor, were discerned in the pictures. It was known that the camera was pointing in the general direction of, but apparently not directly at the moon. As a result, the pictures presented showed only light, presumably from the flare of the lens.