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VOYAGER

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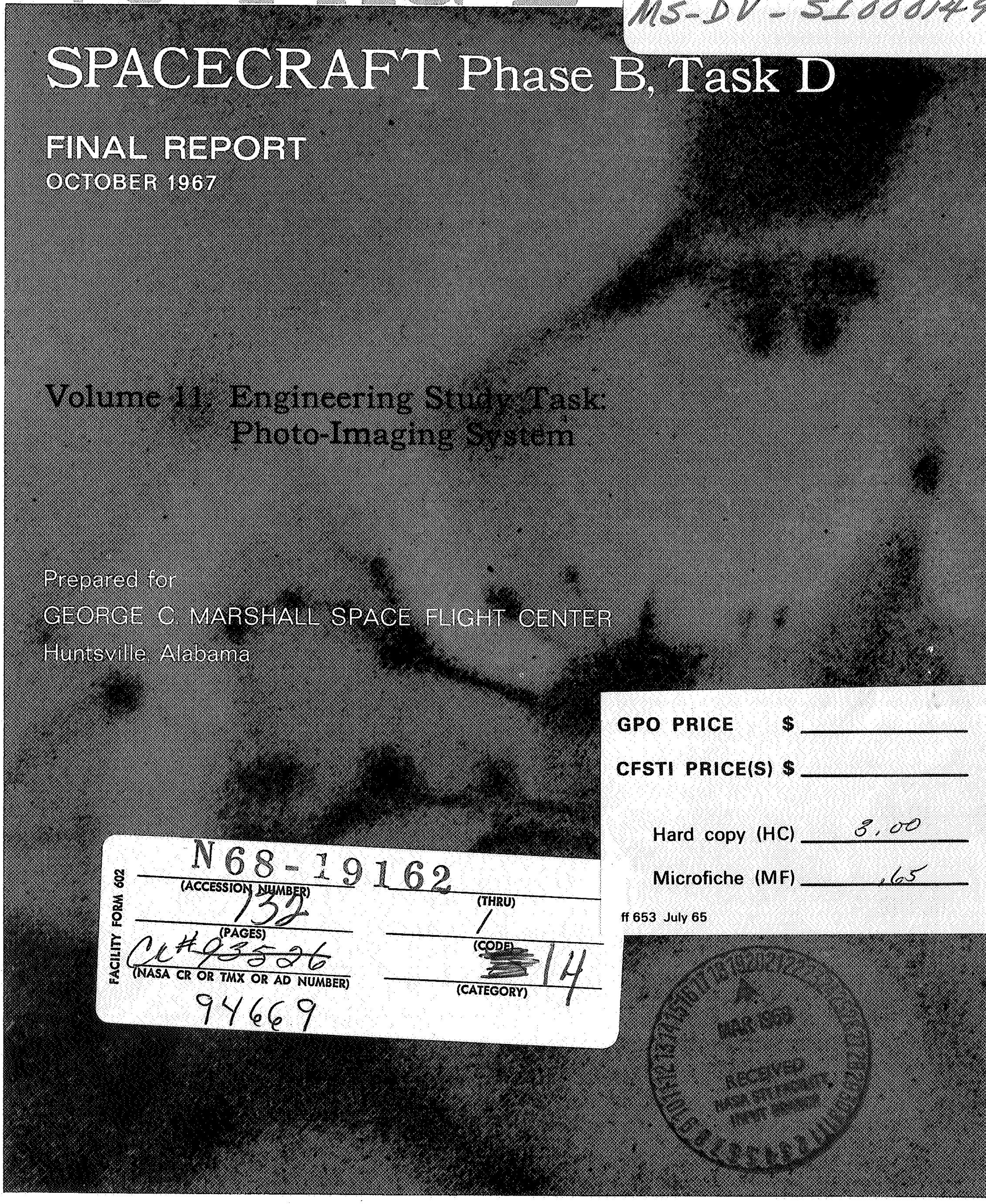


SPACECRAFT Phase B, Task D

FINAL REPORT

OCTOBER 1967

Volume 11, Engineering Study Task: Photo-Imaging System

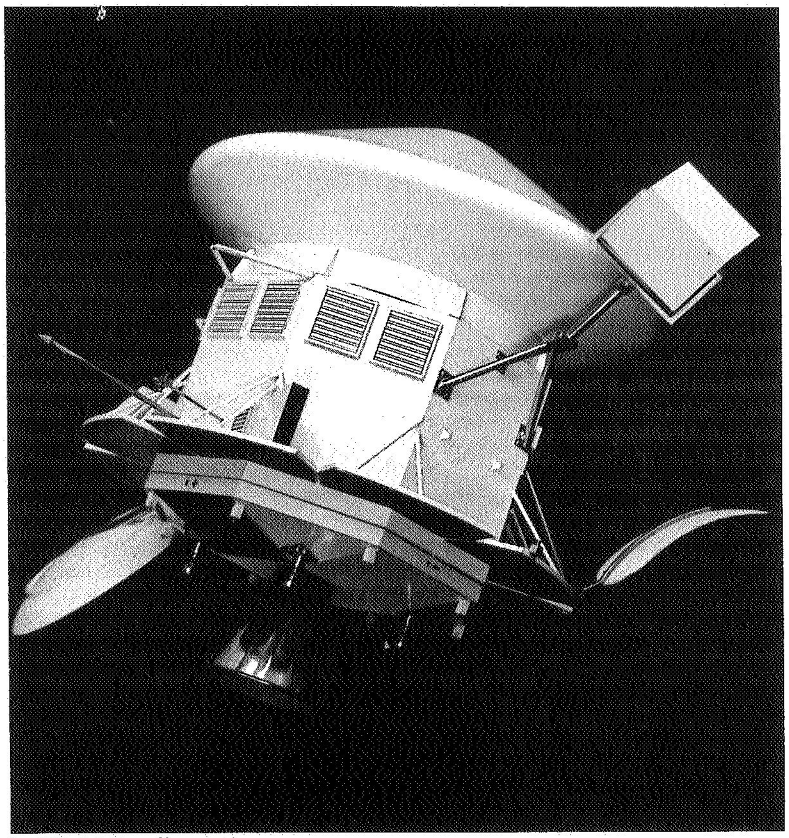
Prepared for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

Voyager Operations
Space Vehicles Division

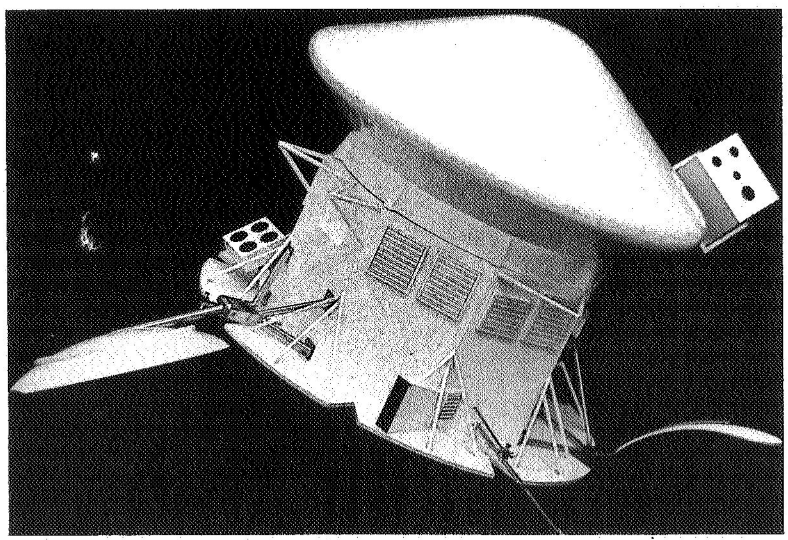
TRW SYSTEMS GROUP

One Space Park, Redondo Beach, California

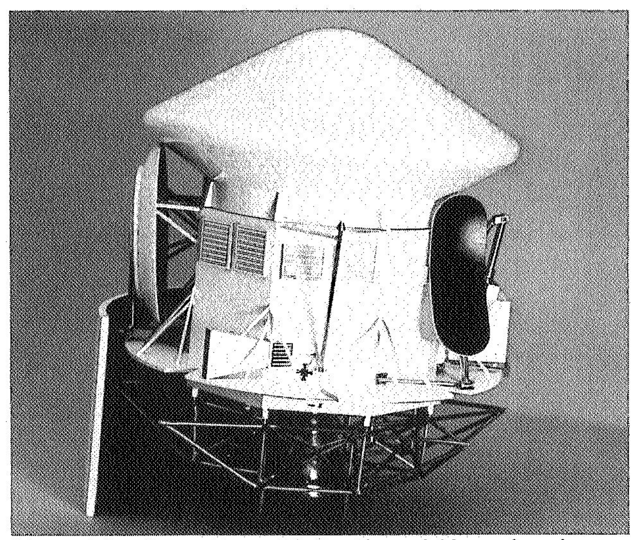
MODEL OF **TRW** RECOMMENDED **VOYAGER SPACECRAFT**



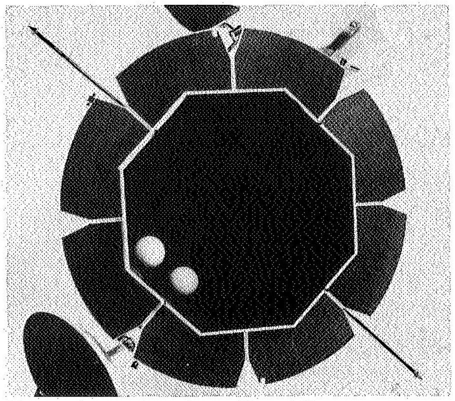
In-Flight Configuration



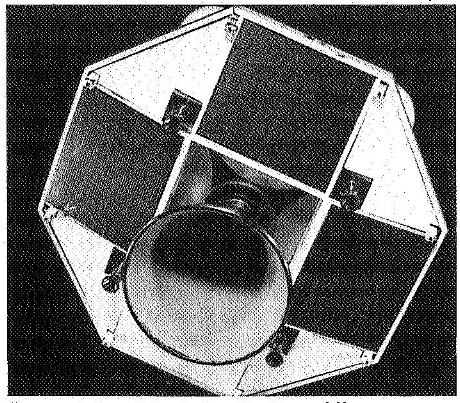
Opposite View In-Flight Configuration



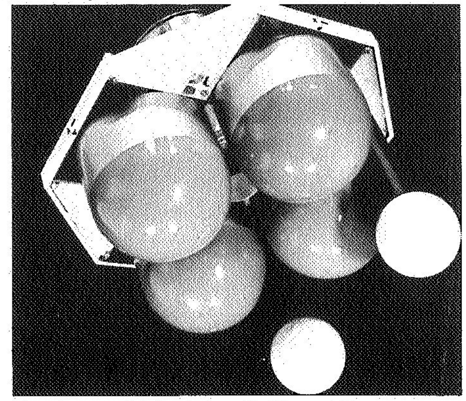
Stowed Configuration with Section of Shroud and Planetary Vehicle Adapter



Propulsion Module, Top View



Propulsion Module, Bottom View



Equipment Module, Bottom View

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VOYAGER

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CONTENTS

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ILLUSTRATIONS

ILLUSTRATIONS (Continued)

1. INTRODUCTION AND SUMMARY

In order to provide optimum photographic coverage of Mars, the most efficient use possible must be made of the taking capabilities of the photo-imaging system itself and of the characteristics and capacity of the communications system. This requires taking and recording pictures whenever the spacecraft position provides the best opportunities with respect to altitude, solar phase angle, and interest of area overflown. In addition, the data communication link must be used to capacity at all times when transmission is possible, since this link ultimately limits the amount of information which can be returned to earth.

In view of the fact that the photo-information sent from the spacecraft to the earth is in the form of a video signal, the use of TV sensors at first seems especially appropriate. However, photo-imaging is possible during only about 6 percent of the time at most, as will be seen when the mission constraints are discussed. Real-time transmission of TV-sensed imagery would therefore require short bursts at very high data rates, about 48 minutes in each 13.7-hour orbital period, with rates in excess of 1.4 Mbits/sec. This is completely incompatible with the communication system. Consequently, some means for recording and storing the video data must be provided so that it can be read out to the transmission system at an appropriate rate spread out over as much of the orbital period as possible. Once the requirement for data storage is introduced, the apparent special advantage of TV systems disappears. Rather, those systems having an inherent large storage capacity are more favorable from this standpoint.

In the detailed presentation which follows, three general types of systems are considered. The first is an all-TV system, designated as the hypothetical system The second system is that recommended by TRW and comprises a dual-framing film camera based on Lunar Orbiter concepts for medium and high resolution coverage, along with a TV camera for broad low resolution mapping in either color or black and white. The third system is designated as the alternate system and consists of a dielectric tape camera for medium-resolution coverage along with the low-resolution TV color camera which is common to all three configurations. No high resolution camera is included in the alternate system. The dielectric tape camera can in principle be fitted with an imaging system of sufficiently long focal length to provide high resolution ground coverage, but this is not an attractive approach because the resulting long exposure time imposes severe image motion compensation (IMC) requirements. A high resolution TV camera such as described in the hypothetical system could of course be added.

The possible variations of the alternate system just discussed illustrate the general situation that an almost unlimited number of combinations of sensor types and sizes could be considered. However, it is felt that the three discussed herein cover essentially all of the basically different implementations sufficiently applicable in concept and far enough along in development to be considered for the 1973 Voyager mission. Modifications in the combinations of types, exact optical parameters, and modes of operation can easily be made and understood in terms of the characteristics given for these systems.

2. REQUIREMENTS AND CONSTRAINTS

The requirements and constraints used in the selection and discussion of the photo-imaging systems are based on the general specification for the 1973 Voyager mission developed by JPL. However, because of the very general nature of that specification, considerable interpretation by TRW has been necessary. In addition, particular values of the orbit parameters have been chosen for definiteness. It should be emphasized that the design concepts discussed are not inherently dependent on the exact orbital parameters. In fact, the adjustment of the parameters for optimal Mars surface coverage has not been taken into account in the nominal values chosen, so slightly different values would in fact be optimum.

2.1 MISSION REQUIREMENTS

The mission requirements for the 1973 Voyager mission emphasize development of capabilities and gaining experience in the use of these capabilities as well as the actual collection and transmission to earth of information. These requirements are of course completely compatible in terms of instrumentation with the shifting emphasis in later missions to gathering of specific data in the light of information already received and analyzed. Differences will occur principally in modes of operation, relative allocations of transmission time, and total amount of information recorded and transmitted.

For the 1973 mission the first photo-imaging requirement is for fairly complete coverage of the Martian surface at rather low resolution. TRW feels this can be accomplished effectively by providing monoscopic coverage at a resolution of about 1 kilometer (for imaging from periapsis, with somewhat poorer resolution for imaging away from periapsis) in either color or black and white of all of the surface overflown with adequate lighting conditions. Color information can be obtained by imaging the same area successively through red, green, and blue filters; the same camera can provide black and white coverage by using a clear filter. The use of about this level of resolution is suggested for several reasons:

a) Photographic observations of the moon from earth are limited to about this resolution by atmospheric inhomogeneities. Such photography has provided a satisfactory starting point for planning and carrying out more detailed photography from lunar spacecraft. On the other hand, 1000-meter resolution pictures would reveal details on the Martian surface 200 or more times smaller than can be observed from earth. Thus, photo-imaging at 1000-meter resolution would provide information significantly better than that we now have, known to be useful as a basis for more detailed observations, and at a level with which astronomers have already had considerable experience in lunar work.

b) Only about 5×10^9 data bits are required to describe the entire surface of Mars in one color at this resolution. This would take about 27 hours total transmission time at 51.2 kbits/sec. Thus, 1000-meter surface resolution imaging is compatible with returning to earth information on broad coverage of Mars during the very early part of the mission when decisions need to be made about the landing site for the capsule, future modes of data gathering, and the like.

c) After initial rapid mapping has been substantially completed, repeated coverage in monochrome or full color can be obtained with reasonable allocations of transmission time. Color information can provide data useful in deducing rock or soil types. Repeated coverage can give information on seasonal or other temporal changes in the appearance of the Martian surface.

In addition to the low resolution coverage, as much imagery as possible providing significantly greater detail should be obtained. Since the S-band radio data rates limit the amount of information that can be sent to earth, some compromise must be made between resolution and coverage. As will be shown in Section 6, the highest resolution obtainable consistent with mission constraints is about 10 meters. At this resolution only a small fraction of the Martian surface can be obtained, but it is clear that some coverage should be obtained at this level of detail. The choice of 100-meter ground resolution for medium resolution imaging is somewhat arbitrary, but as the geometric mean of the high and low levels, and one at which data on one quarter to one half of Mars' surface can be sent to earth, it seems to be a reasonable choice. For the medium resolution mapping, the instrumentation and mode of use should be chosen so that contiguous or overlapping frames can be taken. Stereoscopic coverage of selected areas will probably be desired, and this should be obtainable by using overlapping vertical frames, frames taken at appropriate fore and aft angles, or frames taken on different orbital passes. Flexibility in this capability is highly desirable. In order to locate areas of high resolution imagery with respect to the Martian surface as a whole, the camera must be boresighted with the lower resolution systems and/or very accurate pointing must be provided. The same requirements arise when duplicate coverage for stereo pairs is desired, and at least a few high resolution stereo pairs should be obtained.

2.2 MISSION CONSTRAINTS

2.2.1 Illumination

In the absence of strongly marked color or brightness variations, photo-imaging with large solar phase angles is necessary to provide shadows showing the surface detail. The moon offers a striking example of this situation, and the surface of Mars is probably in this respect similar to that of the moon. The range of solar aspect angles suitable for lunar photography is from 50 to 80 degrees. For Martian photography it is advisable to decrease this range to about 55 to 75 degrees. The desirable minimum is increased since Mars apparently exhibits less relief than the moon, and the maximum is decreased since Mars does not have as high a surface brightness as the moon because of its greater distance from the sun. Color photography requires somewhat different conditions from black and white. On the one hand, smaller phase angles can be tolerated, since the detail desired is provided by color differences; and on the other hand, more light is required because of the restricted spectral band used for each color component (filter factors up to four, at least, will be encountered) so the range needs to be restricted to avoid large solar phase angles. The requirements for black and white photography with shadow relief and for color are thus not completely compatible, but they do have a large region of overlap. The actual choice of orbit characteristics should probably be governed primarily by the black and white requirements. Figure 2-1 illustrates the relationships between subsatellite trace and optimum photo-imaging zones for an orbit optimized for medium resolution photography. Considerations the same as, or similar to, those leading to Figure 2-1 have been used in calculating maximum orbital

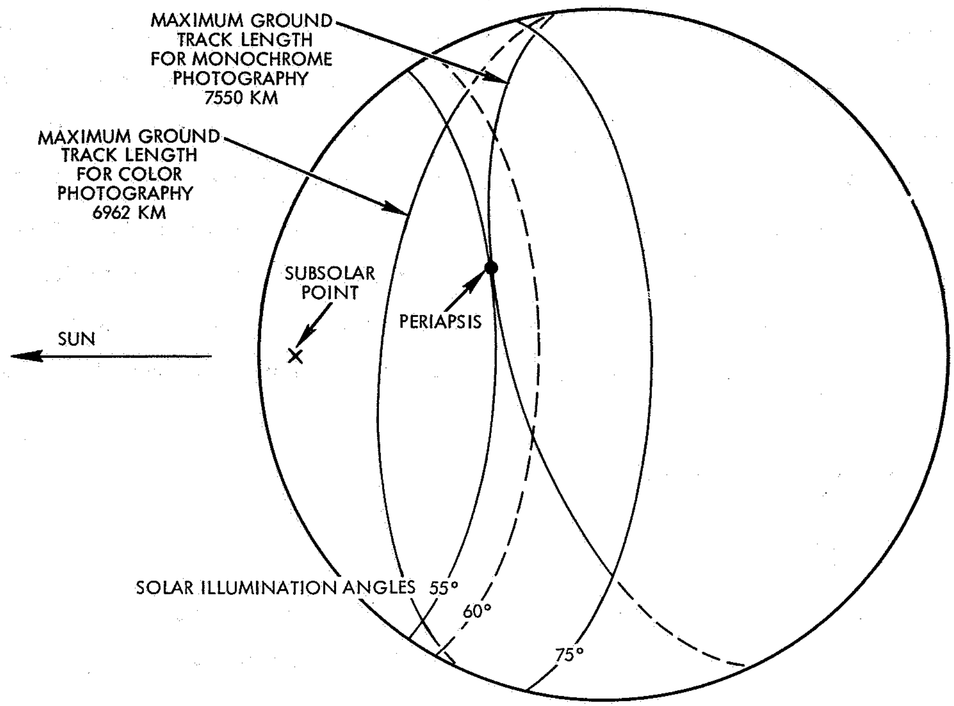


Figure 2-1
ILLUMINATION ANGLE AND GROUND TRACK GEOMETRY. Three photo-imaging systems configured in this study provide continuous low resolution coverage over solar illumination angles from 0 to 60 degrees and continuous medium resolution coverage over solar illumination angles from 55 to 75 degrees. The maximum length of ground track for low resolution color photography and medium resolution monochrome photography are illustrated.

coverage for the photo-imaging systems. The figure does not specify orbit inclination nor the latitude of the subperiapsis point. In general a considerable range of latitudes are available for this point, depending on the inclination chosen. It should be observed that the optimum location of the orbit trace relative to the desired illumination zone cannot be maintained over a long period of time as a result of precession of line-of-apsides.

Since Mars is a superior planet (i.e., its orbit is outside that of earth), we can never observe it from earth under illumination with large solar phase angles. For this reason, the relationship between surface brightness and solar phase angle must be extrapolated from a narrow range of observations with the help of some reasonable assumptions. The actual relationship should fall between that for a Lambertian surface and that for the moon. Even if Mars' surface were as strongly non-Lambertian as the moon, which is not likely, the presence of a thin, but appreciable, atmosphere would mitigate the reduction of brightness with solar angle to some extent. The best estimate available to TRW for the Mars photometric curve is given in Figure 2-2. Both Lambert and lunar surface curves, normalized to the same subsolar brightness, are included for comparison. The brightness values given are based on the standard visibility curve; therefore, the effective brightness for a particular sensor will vary somewhat according to its spectral sensitivity. The overall reddish appearance of Mars occurs because the spectral albedo of Mars is low in the blue (about 0.08) and high in the red (about 0.29). This means lower effective brightnesses for relatively blue-sensitive materials and higher effective brightnesses for relatively red-sensitive materials. In particular, a panchromatic emulsion such as SO-243 has better relative red sensitivity than the eye and thus will be somewhat benefitted by the reddish color of Mars. For the sake of uniformity, all exposure times presented in the performance characteristics of the photo-imaging systems have been based on a brightness of 260 foot-lamberts (before filter factors, if any).

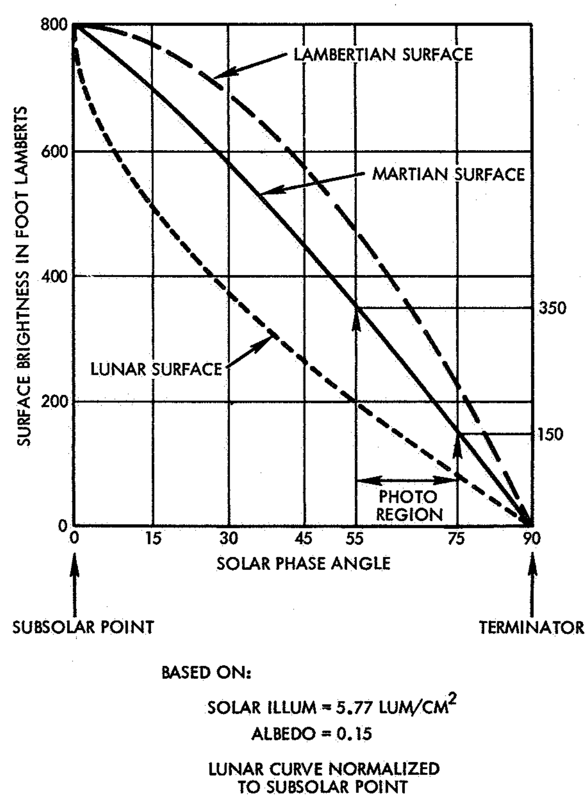


Figure 2-2

PHOTOMETRIC CURVE FOR MARS. Due to the structure of the Martian surface, the reflectance is lower than that of a perfect Lambertian reflector. However, the Martian surface approximates a Lambertian reflector to a higher degree than the Lunar surface.

2.2.2 Orbit Configuration

For the purpose of configuring the photo-imaging systems in this study, a nominal orbit has been selected with an altitude of 1000 kilometers at periapsis and an altitude of 20,000 kilometers at apoapsis, giving a period of 13.7 hours. Because of this highly elliptical orbit, the effects of orbit geometry on ground coverage, resolution, framing interval, planetary scan platform pointing rate, and IMC rate must be considered.

From Figure 2-1, the maximum length of the ground track attainable within the desired range of solar illumination angles for monochrome photography is 7550 kilometers, corresponding to an angular range of ±63 degrees from periapsis. For color photography, the maximum length of ground track within the desired range of solar illumination angles is 6962 kilometers, corresponding to an angular range of ±60 degrees from periapsis.

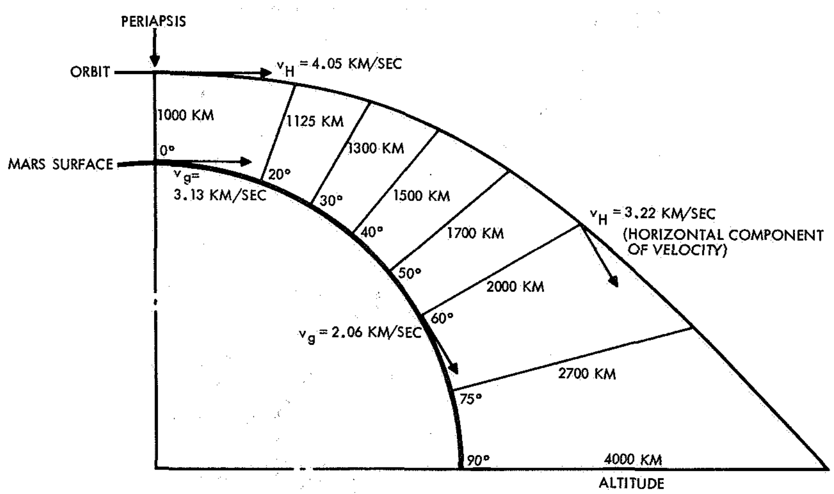


Figure 2-3

GEOMETRY OF ORBIT WITH RESPECT TO MARTIAN SURFACE (1000 x 20,000 KM ORBIT). Due to the use of an elliptical orbit, altitude increases and velocity decreases with increasing time from periapsis. These nonlinear effects are considered in the design of the photo-imaging systems presented in this study.

The orbit geometry is illustrated in Figure 2-3. Note that over the desired range of photographic coverage from periapsis the altitude increases from 1000 to 2000 kilometers and the velocity of the spacecraft subpoint decreases by one-third. For the purposes of discussion, the ground coverage obtained by the proposed low resolution color television camera (included in each of the three proposed systems) is shown in Figure 2-4. With a ground coverage per frame of 500 x 500 kilometers at periapsis, this increases with altitude to a value of 955 x 955 kilometers at 57 degrees from periapsis, with a corresponding degradation in resolution from 1 to 1.9 kilometers. However, the nominal value of resolution of 1 kilometer can be maintained within 10 percent over a range of ±20 degrees from periapsis. Also, the interval between consecutive frames becomes larger with increase in the value of the true anomaly, increasing from 2.5 to 7.2 seconds over the specified ground track length. Thus programmed framing will be required, a function of orbit geometry.

Figure 2-5 shows the variation in planetary scan platform pointing rate with true anomaly. This will require either continuous pointing of the planetary scan platform to the Martian vertical during the photographic interval with a horizon tracker, or use of an inertial reference during this interval in the conjunction with a programmed variable rate, with the variation in rate being a function of orbit geometry and the spacecraft position in orbit.

In order to achieve IMC with a high resolution camera, compensation must be provided for variation in the apparent rate of planetary surface velocity with orbit geometry. This is also illustrated in Figure 2-5. If IMC is provided by programming the angular positions of the planetary scan platform gimbals, this variation again is a function of orbit geometry and spacecraft position.

In summary, the effects on the photo-imaging systems imposed by the use of an elliptical orbit are as follows:

- Increase in mapping coverage with increase in length of ground track from periapsis.
- Degradation of resolution with increase in length of ground track from periapsis.
- Programmed framing is required in order to prevent excessive overlap of adjacent photographs.
- Programmed planetary scan platform pointing rates, and/or programmed IMC rates must be provided.

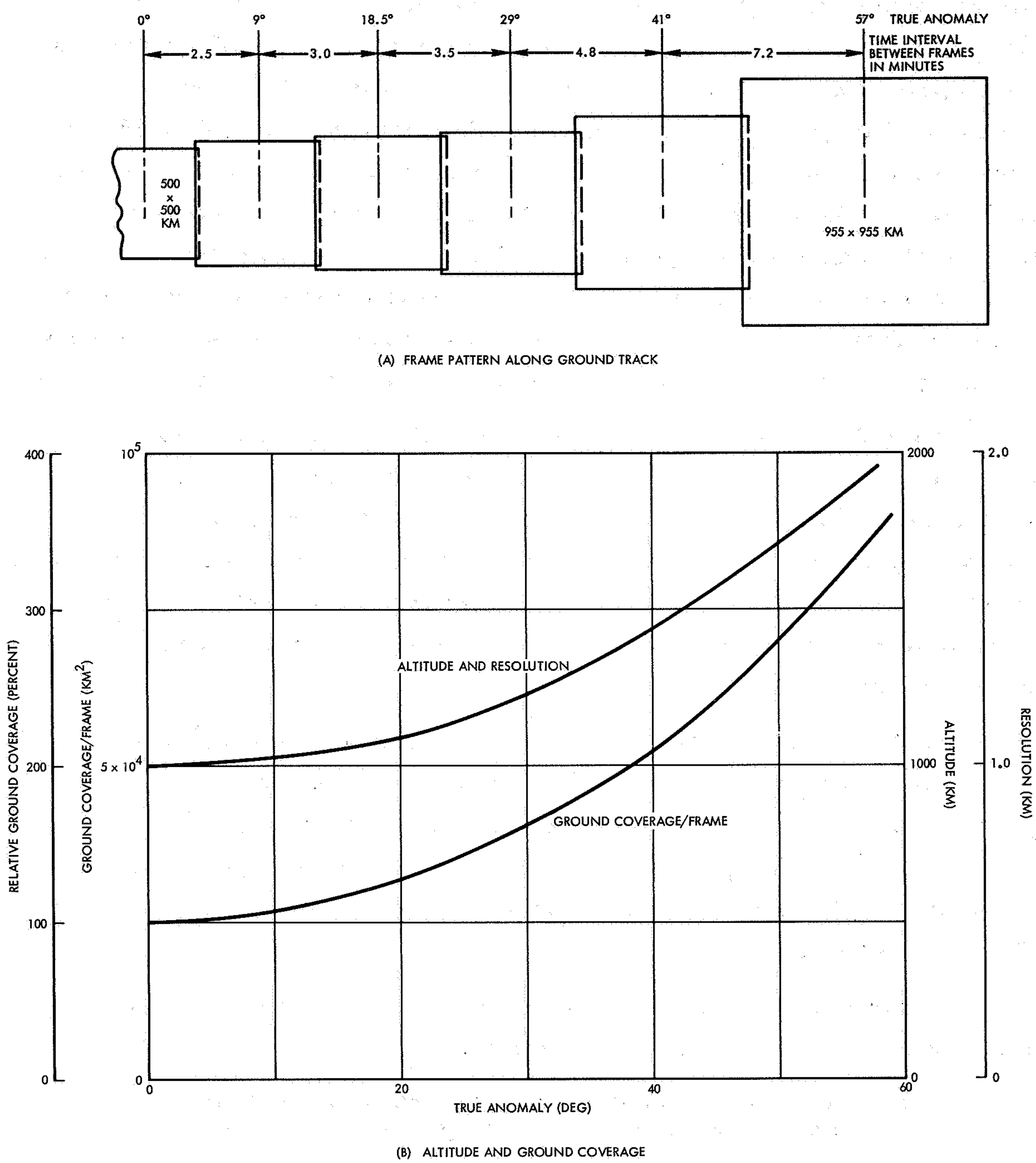


Figure 2-4

GEOMETRY OF GROUND COVERAGE-LOW RESOLUTION TV MAPPING SYSTEM. The increase in ground coverage of the low resolution photo-imaging subsystem increases as the true anomoly increases. Also, the time interval between consecutive frames must be increased to prevent excessive overlap of photographs.

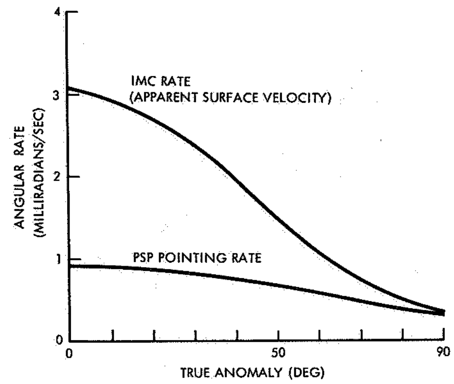


Figure 2-5
PSP POINTING RATE AND IMC RATE VERSUS TRUE ANOMALY. The nominal value of thre rate used for image motion compensation is approximately three times as great as the PSP pointing rate at periapsis. Both decrease with increase in the true anomaly.

2.3 DESIGN CONSTRAINTS

2.3.1 Transmission

The photo-imaging system requires considerably more communications capability than all the rest of the telemetry and science functions of the spacecraft together, in fact, over 80 percent of the total. Even so, the capability of the photo-imaging system is in general limited by the total amount of information which it is possible to transmit during a 6-month mission lifetime. The total data transmission estimates used for the 1973 Voyager mission are based on an initial rate of 51.2 kbits/sec, followed consecutively by 25.6 kbits/sec and 12.8 kbits/sec as the distance between Mars and the earth increases. Figure 2-6 shows an example of the changing data rates. The curved line shows the data rate that can be supported by the communications link at any time, based on rather pessimistic assumptions. The detailed analysis of transmission capability is given in Volume 4 of this report. The allocation to the photo-imaging system amounts to a total of 2.64×10^{11} bits during the 6-month period. The highest bit rate is, fortunately, available in the early part of the mission, when it is especially important to collect and transmit as much data as possible. Therefore, the photo-imaging system must be capable of exploiting the highest bit rate, not merely the average.

A second consideration also makes it important for the photo-imaging system to be able to collect and record information rapidly enough to keep the communication link full at its highest capacity. This is the

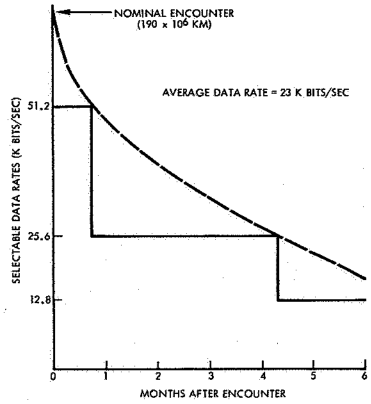


Figure 2-6
PERFORMANCE OF COMMUNICATIONS LINK. After nominal encounter, the initial data rate is maintained for approximately 3 weeks. The data rate is then reduced to 50 percent of the initial value for a period of approximately 4 months. The final data rate is 25 percent of the initial value.

fact that the times when it will be necessary to reduce the bit rate have been calculated on a very conservative basis. There is a good chance that operation at the higher bit rates will be possible for longer times than indicated by the nominal values, and the photo-imaging system should be able to exploit this capability.

2.3.2 Weight and Power

Nominal baseline allocations for the photo-imaging system have been 150 pounds of weight and 120 watts of power (maximum). At this stage it has been necessary to regard these as standards against which to measure the systems investigated rather than as rigid requirements. The all-TV hypothetical system is markedly over the weight (302 pounds) and there is little hope for improvement without drastically reducing the system capabilities. Lighter storage devices than tape recorders, requiring less power, can be expected some time in the future, but none is near to space qualification at the present time and so cannot prudently be considered for the 1973 opportunity. Moreover, even complete elimination of the tape recorders would not bring the weight within nominal limits. The recommended combination film camera and TV system is somewhat overweight but has relatively modest power requirements (218 pounds, 59 watts). The weight budget includes a rather conservative estimate for shielding; some saving may eventually be achieved in this area, but it is doubtful if the 150-pound value can be reached. The dielectric tape camera and color TV, as presented, appear to be within the limits (150 pounds, 50 watts) but this is without a high resolution capability, the addition of which would increase the weight and power by at least 45 pounds and 1.1 watts, respectively. In summary, it appears that the power allocation is satisfactory, but that the weight must be increased a bit.

2.3.3 Image Motion Compensation

It is desirable to eliminate the requirement for image motion compensation (IMC), or at least to keep it as modest as possible. Four levels of IMC of increasing complexity can be distinguished:

1) No IMC: This obviously simplifies design, reduces weight and complexity, and increases reliability.

2) IMC based on calculated velocity/height (V/H) values: The rate of platen movement or camera tilt needed to compensate for image motion depends on the ratio of velocity to altitude; therefore some determination of V/H is necessary. For modest IMC accuracies (3 to 5 percent) an open-loop determination of VH from orbital data is satisfactory, eliminating the need for a special V/H sensor.

3) IMC based on state-of-the-art V/H sensors: IMC accurate to about 1 percent can be achieved with space-proven V/H sensors operating closed-loop with respect to the IMC mechanism; although whether they will work as well over the Martian surface as over the earth or the moon is not certain.

4) Very high accuracy IMC: For IMC accuracies significantly better than 1 percent considerable developmental work on the V/H sensor-IMC mechanism is required.

There is an important breakover point between levels 2 and 3. Level 4 should be avoided entirely in realistic planning for 1973, while level 3 involves weight and reliability penalties sufficiently great to be avoided if possible. Actually, V/H can be calculated from orbital data to a very high accuracy, but other factors enter into open-loop application of this quantity to an IMC device. Two important ones are attitude rates of change, which can produce image smears similar to those caused by orbital velocity, and errors in the control by open-loop command of the IMC drive. When the significant factors are taken into account, an

IMC accuracy of about 3 percent can be established as achievable with open-loop control. This has been taken as a working design constraint for the photo-imaging system.

The exact way in which smear resulting from uncompensated image motion combines with other causes of image degradation is extremely complicated. Fortunately, a sufficiently accurate estimate of the effects of image smears of all kinds can be made by combining them in a rms evaluation. Therefore, if the allowable smear is taken as $\sqrt{10}/10$ times the desired optical resolution element, a degradation of the resolution amounting to about 5 to 10 percent, will result. This criterion is actually somewhat more severe than that commonly used; it therefore represents a conservative approach to the IMC requirements. Table 2-1 summarizes the relationship between IMC requirements and resolutions and effective exposure times of interest in the Voyager mission. The values given in the table are for periapsis at 1000 kilometers. For any points away from periapsis the IMC requirements are less severe.

Table 2-1. IMC Requirements versus Resolution and Exposure Time

		IMC Accuracy Required		
Resolution (meters)	Allowable Smear (meters)	1 msec Exposure	10 msec Exposure	100 msec Exposure
1000	320	None	None	None
100	32	None	None	10 percent
10	3.2	None	10 percent	1 percent

Note: Image motion compensation requirements are more severe with increased resolution and longer exposure intervals.

3. HYPOTHETICAL TV PHOTO-IMAGING SYSTEM

3.1 SUMMARY

The first photo-imaging system which has been examined for use in the Voyager spacecraft consists of five television cameras, fulfilling the requirements of low and medium resolution mapping coverage, and high resolution imaging of selected areas. All three types of imaging may be obtained simultaneously or sequentially.

3.1.1 Low Resolution Camera

The low resolution television camera will provide either monochrome or color coverage with resolution of 1 kilometer from the altitude of 1000 kilometers at periapsis. The use of color coverage will be of benefit in the identification of vegetation on the surface of Mars and in determining the seasonal variations in cloud formations and dust storms. When used in the color mode with a field of view of 500 x 500 kilometers at periapsis, 11 color pictures (33 monochrome frames – red, green, and blue in sequence) will provide coverage of approximately 6.25×10^6 km^2 or 4.3 percent of the total area of Mars in one orbit. The lateral coverage of the optical field of view increases to 1120 kilometers at an angle of 65 degrees from periapsis. A 1-1/2 inch RCA type 8521 electromagnetic vidicon has been chosen for this camera having adequate resolution, size of format, and moderate power requirements. In order to permit slow-scanning, an ASOS photoconductive target will be used in conjunction with a quartz storage layer. This target and storage layer combination has been developed by RCA for use in the APT (automatic picture taking) system for the Nimbus meteorological satellite program.

3.1.2 Medium Resolution Cameras

For medium resolution coverage, three return-beam vidicon cameras are proposed with a resolution of 100 meters from the altitude of 1000 kilometers at periapsis. The requirement for three cameras is dictated primarily due to the limitation in the data acceptance rate of the associated digital tape recording equipment. The cameras are used in sequence, resulting in a continuous flow of digital video information to the tape recording equipment at the rate of 700 kb/sec. During one orbit, 27 frames of information may be obtained (9 frames per camera), permitting continuous coverage over a ground track length of 4480 kilometers. The number of frames which may be obtained in one orbit is limited by the data capacity of the digital tape recording equipment. The lateral ground coverage at periapsis is 150 kilometers, increasing to 225 kilometers at 37.5 degrees from periapsis. The 2-inch return beam vidicon has been selected for this application, primarily from the standpoint of high resolution and relatively large format. The resolution of this tube is presently 3100 TV lines at 10 percent response, permitting the use of a nominal resolution of 3000 x 3000 resolution elements on a 1-inch square raster. Again, the use of the slow-scan ASOS photoconductive target, in conjunction with a quartz storage layer, is proposed in order to accommodate the frame rate of 110 seconds, permitting the use of an acceptably low data rate to the digital tape recorders.

3.1.3 High Resolution Camera

For high resolution imaging, one SEC vidicon camera is proposed. From an altitude of 1000 kilometers at periapsis, a resolution of 10 meters will be obtained with 10 x 10 kilometer ground coverage per frame. The primary basis for selection of the SEC vidicon for high resolution imaging has been the characteristic of high luminous sensitivity which permits an extremely short exposure time (1 millisecond), eliminating the requirement for image motion compensation. During one orbit, 18 frames of information may be obtained over a ground track length of 4480 kilometers, with a minimum spacing between frames of 220 kilometers along the ground track (at periapsis). The minimum distance between adjacent frames is determined by the rate of acceptance of data by the digital tape recorder used with the SEC camera which is configured to accept data at a rate of approximately 700 kb/sec. The SEC vidicon which is proposed for this camera is the Westinghouse type 5419B. The resolution at this time is 1000 TV lines. In order to obtain the required 2000 TV line resolution, additional development will be required in the design of the electron optical system in order to reduce the diameter of the electron beam which scans the photoconductive target.

3.1.4 Equipment Configuration on Planetary Scan Platform

The equipment configuration and preliminary specifications for the photo-imaging system are defined in Figure 3-1. One low resolution television camera, three medium resolution return beam vidicon cameras, and one high resolution SEC vidicon camera will be mounted on the planetary scan platform (PSP) and boresighted. If stereo photography is desired, this may be accomplished by fore and aft pointing of the PSP, or by obtaining overlapping coverage on sequential orbits. The total weight of the camera equipment on the PSP will be 230 pounds, and the average power for all five cameras is estimated to be 11.3 watts. An additional 72 pounds and 80 watts will be required for the four tape recorders in this system, which will not be mounted on the planetary scan platform.

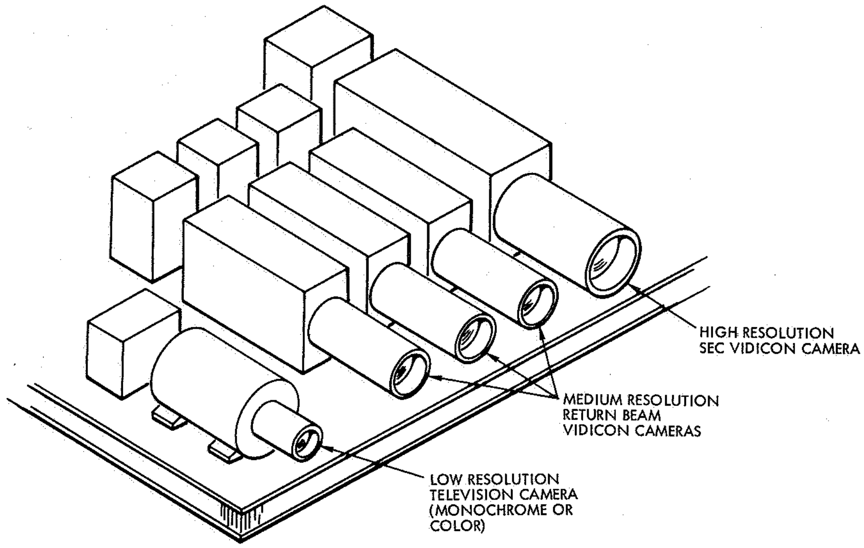
3.1.5 Data Storage

The configuration of the data recording equipment for the photo-imaging system is defined in Figure 3-2. Four tape recorders are used to accept the digitally encoded video data from the five cameras. Through the use of a redundancy switch, the recorders may be interchanged to accommodate a particular orbital recording sequence. Each of the four recorders will have a total data capacity of 9×10^8 bits using a tape speed of 50 inches per second. Data will be accepted at the nominal rate of 700 kb/sec. This data stream will then be converted from serial to parallel form and recorded on six parallel tracks at the rate of 116 kb/sec per track, with a recording density of 2300 bits/inch. Each recorder has a total tape length of 3000 feet. After filling one length of tape with six parallel tracks of video information, the tape may be reversed to permit utilization of an additional six parallel tracks.

The maximum data which may be obtained in one orbit by the low resolution television camera (2.8×10^8 bits) will utilize only one-third the capacity of one tape recorder. However, the data obtained by one of the three return beam vidicon cameras (9 frames over a ground track

PRELIMINARY SPECIFICATION

Hypothetical Photo Imaging System



Purpose

To provide complete photographic coverage of the planet Mars at low resolution (1 kilometer) in color, mapping of large areas of Mars at medium resolution (100 meters), and imaging of selected areas at high resolution (10 meters)

Performance Characteristics

LOW RESOLUTION CAMERA

Sensor	RCA 1-1/2 inch vidicon with slow-scan target
Field of View	29 x 29 degrees
Ground Coverage per frame	500 x 500 kilometers
Nominal Ground Resolution	1 kilometer
Number of Frames per Orbit (maximum)	33 frames (11 color pirtures)
Photography duration/orbit	48 minutes (maximum)

MEDIUM RESOLUTION CAMERAS

Sensor	RCA 2 inch return beam vidicons with slow-scan target
Field of View	8.6 x 8.6 degrees
Ground Coverage per frame	150 x 150 kilometers
Nominal Ground Resolution	100 meters
Number of Frames per Orbit (maximum)	27 (9 per camera)
Photography duration/orbit	26 minutes (maximum)

HIGH RESOLUTION CAMERA

Sensor	Westinghouse 3 inch SEC vidicon
Field of View	35 x 35 arc-minutes
Nominal Ground Resolution	10 meters
Number of Frames per orbit (maximum)	18
Ground Coverage per frame	10 x 10 kilometers
Photography duration/orbit	26 minutes (maximum)

Physical Characteristics

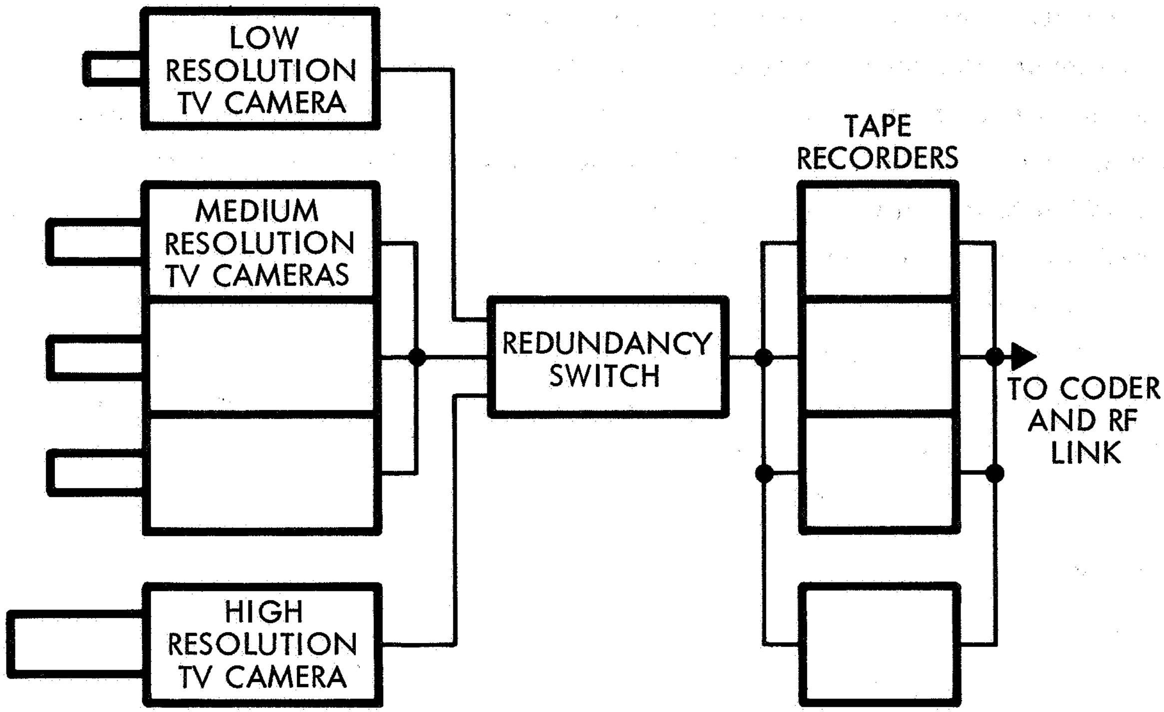
CAMERA EQUIPMENT MOUNTED ON PLANETARY SCAN PLATFORM

Weight:	230 pounds
Size:	3.64 cubic feet
Power:	195 watts maximum) 11.3 watts (average)

TOTAL SYSTEM - INCLUDING 4 TAPE RECORDERS

Weight:	302 pounds
Size:	5.2 cubic feet
Power:	275 watts (maximum) 29.3 watts (average)

FIGURE 3-1



RECORDER SPECIFICATIONS

● CAPACITY	9×10^8 BITS (EACH)
● TAPE SPEED	50 IN/S
● NUMBER OF TRACKS	14 (6 + 6 FOR VIDEO)
● TAPE LENGTH	3000 FEET
● INPUT DATA RATE	700 KB/S

Figure 3-2
DATA HANDLING CONFIGURATION-HYPOTHETICAL PHOTO-IMAGING SYSTEM. The low resolution camera will utilize one tape recorder. The medium resolution cameras will utilize three tape recroders. The high resolution camera will utilize one tape recorder. Recorders may be selected by the redundancy switching network, depending upon the mode of photography desired.

of 4480 kilometers, ±37.5 degrees from periapsis) completely utilizes the capacity of one recorder, including the usage of additional tape to accommodate the increasing dead time between recording of adjacent pictures as the altitude of the orbit increases. Thus three recorders are required to permit the recording of 27 adjacent frames (a total of 2.1×10^9 bits of data). The high resolution camera will not provide continuous coverage, as time must be permitted for data recording between consecutive frames. Utilizing one tape recorder for storage of high resolution imaging data, as many as 18 frames of data may be obtained during one orbit. If the locations of the selected areas of which high resolution imaging is desired are widely spaced, this recorder may be stopped between consecutive recordings to conserve tape utilization.

3.1.6 Mapping Coverage

The mapping coverage obtained by the photo-imaging system in one orbit is defined in Figure 3-3. Note that the lateral coverage of the three subsystems increases with increasing displacement from periapsis due to the corresponding increase in altitude. The maximum coverage obtained by the low resolution television camera in one orbit will be determined by the range of solar illumination angles permissible for color photography rather than by tape recorder capacity. However, the maximum coverage which will be obtained in one orbit by the medium resolution return beam vidicon cameras is limited by the storage capacity of the tape recording equipment. For high resolution imagery, one tape recorder is allocated permitting as many as 18 selected areas, each 10 x 10 kilometers, to be imaged within one orbit.

During a 6-month lifetime in orbit, with a total data transmission capacity of 2.64×10^{11} bits, the coverage of Mars which may be obtained is defined in Table 3-1. Note that complete coverage may be obtained with the low resolution camera in color. The percentage of Mars which may be mapped with medium resolution is 36.0 percent, and 0.11 percent

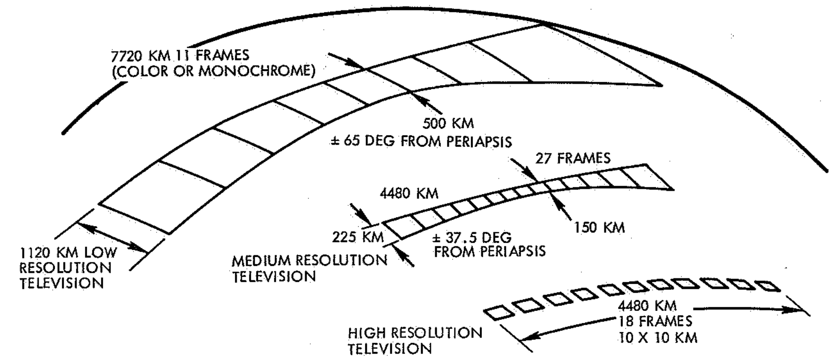


Figure 3-3

MAPPING COVERAGE PER ORBIT (MAXIMUM)-HYPOTHETICAL PHOTO IMAGING SYSTEM. The low and medium resolution television cameras will obtain continuous coverage over a ground track distance of 7720 and 4480 Kilometers, respectively. The high resolution television camera can photograph as many as 18 frames over a ground track distance of 4480 Kilometers. The ground coverage traces of the three cameras are displaced laterally on the diagram for purposes of illustration.

may be imaged with the high resolution camera, assuming that 1600 selected areas are viewed.

The values presented in Table 3-1 are based upon the nominal values of ground coverage of each of the three television subsystems at periapsis. Note that the coverage obtained will increase as the photographic interval is increased beyond periapsis due to the increase in altitude inherent in the elliptical orbit (see Figure 3-4).

3.2 COLOR TV SYSTEM

The color TV system comprises a low resolution (1 kilometer) TV camera equipped with a rotating filter wheel permitting acquisition of restricted spectral band pictures (blue, green and red, from which colored imagery can be derived) or normal black and white imagery. The black and white capability can be used as a low resolution backup system. The camera is equipped with a 1-1/2 inch vidicon (RCA 8521) operated with a 1000 line scan and a readout time picture of either 12 or 25 seconds (Figure 3-5).

Table 3-1. Coverage of Mars Obtained With Low, Medium, and High Resolution Television Cameras

	Low Resolution TV (color)	Medium Resolution TV	High Resolution TV
Nominal Ground Resolution	1 km	100 m	10 m
Nominal Coverage/Frame (at periapsis)	500 x 500 km	150 x 150 km	10 x 10 km
Bits/Frame (6-bit encoding)	8.58×10^6	77.04×10^6	34.32×10^6
Frames/Orbit (maximum)	11 color pictures (33 frames)	27 (9 per camera)	18
Data/Orbit (maximum)	2.83×10^8 bits	2.08×10^9 bits	6.17×10^8 bits
Ground Coverage/Frame (nominal)	2.5×10^5 km^2	2.25×10^4 km^2	100 km^2
Area of Mars	1.46×10^8 km^2	1.46×10^8 km^2	1.46×10^8 km^2
Data Allotment (Total data link capacity = 2.64×10^{11} bits/6 months)	1.52×10^{10} bits	1.94×10^{11} bits	0.55×10^{11} bits
Number of Frames	585 (color pictures) 1755 frames	2620	1600
Percentage of Mars Area Covered	100	36	0.11

*The table presents the ground coverage obtained by the three television camera subsystems over a 6 month period with a total data link capability of 2.64×10^{11} bits. This estimate is based upon nominal values of ground coverage at an altitude of 1000 kilometers.

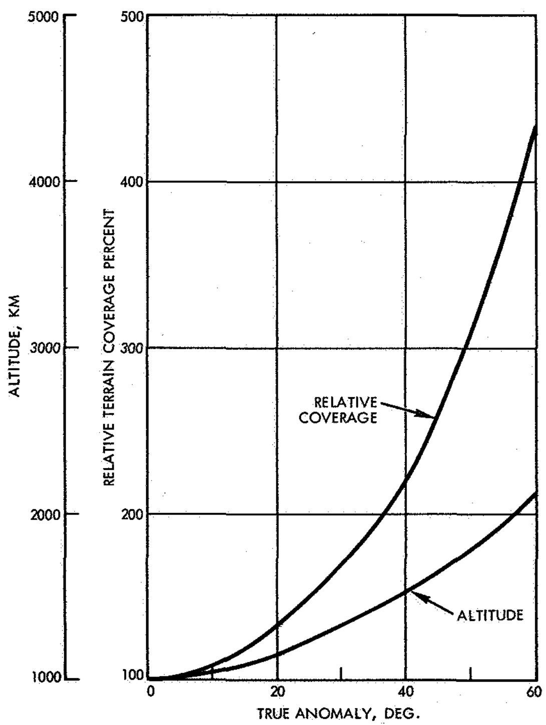


Figure 3-4

INCREASE IN TERRAIN COVERAGE versus true anomaly (1000 x 20,000 KM elliptical orbit).

PRELIMINARY SPECIFICATION

Color TV Camera

Purpose

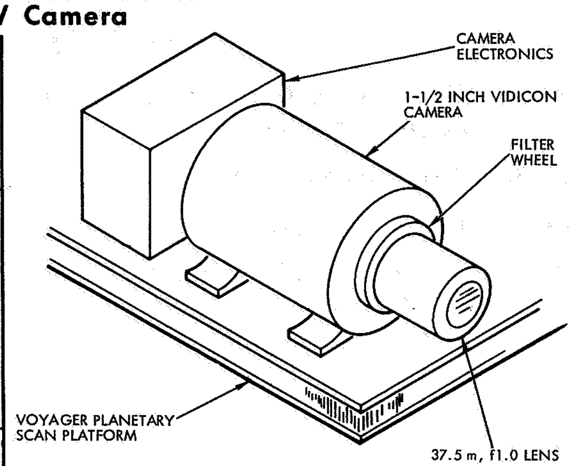
This 1-1/2 inch slow scan color television camera provides global mapping of Mars to a resolution of 1 kilometer. For more rapid coverage it can also be operated in the black and white mode.

Performance Characteristics

Nominal Resolution	1000 TV Lines
Exposure Time	40 msec
Dynamic Range	10^{-2} to 10^{-4} FCS
IMC	None Required
Raster Format	18.5 x 18.5 mm
Frame Scan Time	12 or 25 sec
Frame Base/Prepare Time	20 or 26 sec
Nominal Scene Brightness	260 ft C
Shutter	Mechanical

Electrical Characteristics

Sensor	RCA 1-1/2 inch vidicon
Focus and Deflection	Electromagnetic
Vidicon Target	ASOS with quartz storage layer
Scan Lines/Frame	1430
OPTICS	
Lens	Carl Meyer 37.5 mm, f1.0
Optical Field of View	29° x 29°
Color filters	Red, Green, Blue and Neutral



Physical Characteristics

Weight	20 pounds
Power	25 watts (maximum) 1.5 watts (average)
VOLUME	
Optics	3.0 in. x 2.5 in. dia
Camera Head	10 in. x 6.0 in dia
Control Electronics	5 in. x 5 in. x 4 in.

FIGURE 3-5

3.2.1 Preliminary Specifications and Principal Performance Parameters

The preliminary specifications and the anticipated performance of this subsystem are given in Tables 3-1 and 3-2. A total of 11 frames in each of the three colors can be acquired per orbit, each frame with a ground coverage of 500 x 500 kilometers at periapsis and ground distance between adjacent frames of 160 kilometers. The acquiring of color pictures can be performed ±65 degrees from periapsis with a maximum swath width of 1120 kilometers near both ends of the swath. The minimum swath width at periapsis is 500 kilometers. A total strip length of 7720 kilometers can be obtained and recorded either in color or monochrome during each orbit. The geometry of ground coverage is illustrated in Figure 3-3. The data transmission time at 50 kb/sec is 1 hour 34 minutes for this ground strip.

3.2.2 Functional Description

The sensor of the TV camera is the vidicon tube. The observed scene is focused on the photoconductive target. The spectrum of the

Table 3-2. Principal Performance Parameters, Color TV Camera

	Anticipated Performance
Ground Resolution/Optical Line-Pair (at periapsis)	1 km
Sensor Resolution/Horizontal Scan Line	1000 TV lines
Optical Line-Pair/Horizontal Scan Line	500 line-pair
Ground Coverage/Horizontal Scan Line (at periapsis)	500 km
Ground Coverage/Frame (at periapsis)	500 x 500 km
Format	18.5 x 18.5 mm
Optical Field of View	$29^{\circ} \times 29^{\circ}$
Scan Lines/Frame (Kell Factor = 0.7)	1430
Resolution Elements/Frame	1.43×10^{6}
Bits/Frame (6-bit encoding)	8.58×10^{6}
Readout Time/Frame	*12 seconds with system 1, 25 seconds with systems 2 and 3
Data Rate/Frame	*0.715×10^{6} b/sec with system 1, 0.343×10^{6} b/sec with systems 2 and 3
Erase Time/Frame	*20 seconds with system 1, 26 seconds with systems 2 and 3
Ground Distance Between Adjacent Frames	100 km with system 1 160 km with systems 2 and 3
Frames/Orbit (average)	11 frames in each of 3 colors 33 frames total
Total Data/Orbit (average)	2.83×10^{8} bits
Data Transmission Time at 50 kb/sec	1 hour 34 minutes
Photographic Interval/Orbit	48 minutes (maximum)

*These parameters are determined by the related recording equipment. The system designation is as follows:
System 1 is the hypothetical all-TV system
System 2 utilizes the color TV and dielectric tape camera
System 3 is the recommended color TV-film system.

acquired picture is restricted by inserting an optical filter (green, blue or red) in the light path as sketched on Figure 3-6. The spectral responses of the filters are sketched on Figure 3-7.

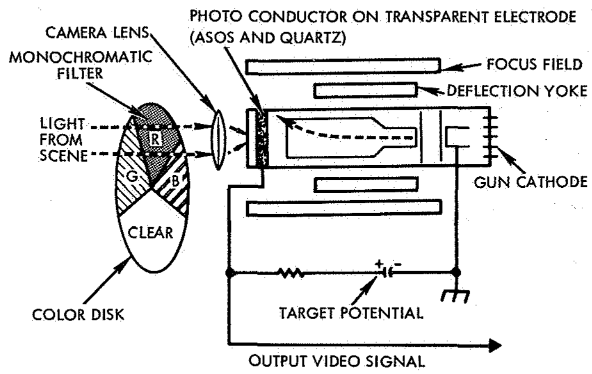


Figure 3-6
SCHEMATIC REPRESENTATION OF THE COLOR TV CAMERA VIDICON AND COLOR WHEEL. Sequential three color photography will be accomplished by utilizing green, red, and blue filters in front of the vidicon faceplate on consecutive frames.

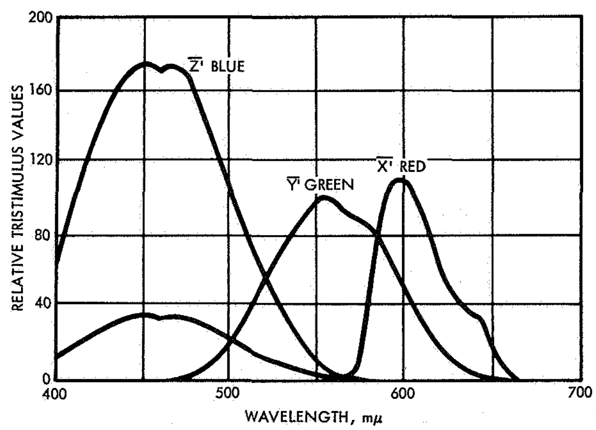


Figure 3-7
SPECTRAL RESPONSE OF THE COLOR FILTERS. The spectral response curves of the three color filters are illustrated above. The vidicon response peaks at approximately 500 mu, approximately the same as the human eye.

The most important difference between this camera and a commercial TV camera is the fact that this space camera takes single frames rather than a continuous scan of the same scene. Not shown in Figure 3-6 is a shutter mechanism. Its function is to let the light from the scene stimulate the vidicon target for a short time. This short exposure (40 msec) reduces the smear due to the motion of the camera over the terrain. An image orthicon tube would require even less exposure time but in the present state of the art image orthicon tubes are bulky, heavier and not as reliable as the vidicon tubes already successfully used in many space missions.

The shutter is opened, either by ground control or by an automatic sequencer, for a time interval in the order of 40 msec. This exposure will vary as a function of the illumination. The light coming from the ground scene, filtered by the color wheel, is focused by the lens system and imaged onto the transparent electrode of the vidicon target. This electrode, an efficient conductor, is extremely thin. The light focused on it passes through to the photoconductive target. The photoconductive material, a good electrical insulator when dark, becomes a good conductor when exposed to light. Before the shutter is opened, it is "primed" by an electron beam. This deposits a uniform layer of electrons (negative charges) on its back surface. The transparent electrode has a fixed positive charge. When an image falls on the photoconductive layer, its electrons leak to the conductor in bright areas in proportion to the brightness of the image elements. In the dark areas, the electrons remain. This charge pattern can be stored for several seconds in ordinary vidicons, and up to several hours on specially designed targets such as the ones made with the ASOS quartz combination.

The next operation is to read out the stored image. The effective target size is 18.5 x 18.5 mm and the target has a linear resolution of 500 line-pairs in the direction of the horizontal scan. In order to preserve 500 line-pairs in the other direction and assuming a Kell factor of 0.7, an effective scan of 1430 TV lines is necessary. The total number of picture elements per frame will be 1.43×10^6. The dynamic range of the vidicon in response to light excitation is 40 decibels. In order to fully exploit this range, a quantization in $64(2^6)$ gray levels is indicated, i.e., a 6 bit quantization per picture element. The total number of bits per frame becomes 8.58×10^6. After conversion of the analog data to digital form, the video data is recorded on a single magnetic tape recorder.

After a frame has been scanned and read into the tape recorder, the photoconductive layer of the vidicon is "flooded" to remove any remaining electron charge, reprimed and is ready for another picture taking sequence. The color wheel rotation can be accomplished as soon as the iris is closed to prepare the system to take the next picture in a different color. A total of 33 successive frames can be acquired per orbit. This requires a tape recorder capacity of 2.83×10^8 bits.

For an exposure time of 40 milliseconds the smear due to motion is in the order of 100 meters, the required resolution being 1 kilometer. No image motion compensation is needed.

To ensure maximum scientific information from a photograph, it is necessary to have precise information on the camera that obtained the photograph in terms of those parameters that describe the quality of the image. To insure such precise information, a calibration will be performed prior to launch with all subsystems functioning. Each calibration will use the entire telecommunication system of the spacecraft so as to include those factors of the modulator, transmitters, tape recorders, encoders, etc., that influence overall image transfer characteristics. The factors, or parameters, of the camera that control the first-order effects in the resulting images are: the dynamic range or light-transfer characteristics, the modulation transfer or spatial frequency response, the geometric distortion, the shading, and the vignetting of the lens/vidicon combination. These parameters will be calibrated on the color TV camera prior to launch.

Calibration stimuli will consist of test slides, sinewave slides to determine the modulation transfer or spatial frequency response, gray scale wedges to determine the vidicon erasure characteristics, a grid pattern to allow nonlinearities, and distortions to be removed from each image. Light transfer characteristics and shading measurements will be obtained by exposing the camera to a series of uniform light fields, each progressively brighter, until a saturation point is obtained. Representative data of this type are shown on Figures 3-8, 3-9, and 3-10.

3.2.3 Physical Description

The color TV camera differs most significantly from the other TV cameras in that it has a filter wheel. The filter wheel contains red, green and blue filters; the fourth section contains a clear element for black and white observations. Segments of the filter wheel are placed

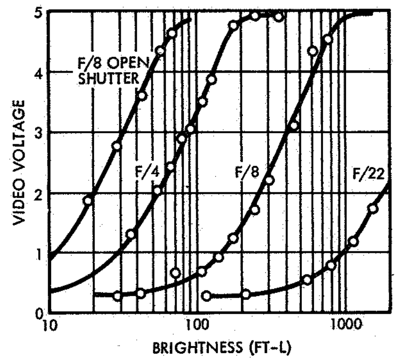


Figure 3-8

THE VIDICON response to illumination as a function of lens f-number will be calibrated prior to launch

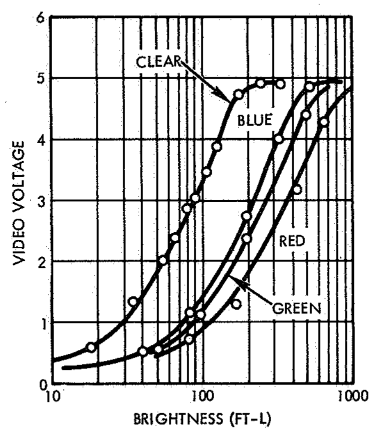


Figure 3-9

THE VIDICON response using each of the color filters, and the neutral filter, will be calibrated prior to launch

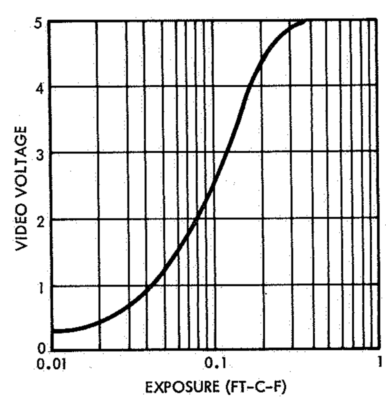


Figure 3-10

THE VIDICON response as a function of the product of illumination and time of exposure is illustrated sequentially in the field of view of the camera following receipt of the proper (preprogrammed or earth-originated) command.

The optical formation of the image is performed by means of a lens system of focal length equal to 37.5 mm and a variable aperture from f/1.0 to f/8 varying in half f/numbers. The shutter mechanism permits three exposures: 0.15, 0.04 and 0.01 second. While the most effective iris control is accomplished by command operations, a servo type automatic iris is also available to control the aperture area in proportion to the average-scene luminance. Potentiometers are geared to the iris to allow ground determination of these functions. A beam splitter, integral to the lens assembly, provides a light sample for automatic iris operation.

The mechanical focal-plane shutter is located between the lens assembly and the vidicon image sensor. Upon receipt of the appropriate command, rotary solenoids drive the shutter blades sequentially across an aperture in the shutter baseplate, thereby allowing light energy to reach the image sensor. The time interval between the initiation of each blade determines the exposure intervals, nominally 40 msec.

Electronic circuitry for timing, power and amplification functions of the camera will be constructed of solid-state circuitry. This circuitry comprises five functional groups, consisting of (1) the drive circuit for the shutter, iris mechanism and color wheel positioning, (2) the video amplifier, (3) the horizontal and vertical sweep circuits for the scanning raster, (4) the synchronization circuitry for ground recording and reproduction purposes, and (5) an electronic conversion unit to provide voltages and regulation from the spacecraft central power source. Thermal control devices are within the camera—surrounding the vidicon faceplate and on selected electronic modules—to provide and maintain operational temperatures when the camera experiences environment conditions that could be detrimental.

The camera will have an estimated weight of 20 pounds, will take 2 watts of power (average).

The volume of the optics assembly will be 2.5 inch diameter x 3.0 inch. The volume of the camera head will be 6 inch diameter x 10 inch, and the electronics assembly will occupy 5 x 5 x 4 inch.

3.2.4 Interfaces

The input commands and outputs to telemetry are summarized in Table 3-3.

Table 3-3. Color Television Camera Input Command and Telemetry List

Input Commands (Representative)		
Turn-On and Warmup	Digital	1 bit
Operate Shutter	Digital	1 bit
Scan and Record	Digital	1 bit
Erase and Neutralize Target	Digital	1 bit
Set Iris Opening (6 pos.)	Digital	3 bit
Internal Calibration Test	Digital	1 bit
Filter Wheel Position (4 pos.)	Digital	2 bit
Outputs to Telemetry (Representative)		
Target Temperature	Digital	
Heater Current	Digital	
High Voltage	Digital	
High Light Level	Digital	
Shutter Position	Digital	
Filter Wheel Position	Digital	
Power Transformer Temperature	Digital	
Power Supply Voltages	Six Digital Measurements	
Time Reference	Digital	
Power-On Command	Digital	
Shutter Command	Digital	
Scan/Record Command	Digital	
Erase Command	Digital	
Iris Command	Digital	
Calibrate Command	Digital	

3.3 MEDIUM RESOLUTION CAMERA

Medium resolution coverage will be provided by three return-beam vidicon cameras. From an altitude of 1000 kilometers, the nominal resolution of this system will be 100 meters. Although continuous coverage could be provided by a single camera, the rapid readout time which would be required (in the order of 40 seconds) would result in a high output data rate. After conversion to digital form, this would result in a digital data rate in the order of 2.1 Mb/sec, which is beyond the state of the art in digital tape recording. Therefore three cameras are proposed, each taking pictures at a third of the rate that would be required by a single camera. This results in an output data rate which is believed to be within the state of the art of tape recording within the anticipated developmental time period.

The mapping coverage which can be obtained with these three cameras has been previously defined in Section 3.1 and in Figure 3-3. Over an angular range of ±37.5 degrees from periapsis, a total of 27 frames of data may be obtained, with 9 frames being obtained by each of the three cameras.

A preliminary specification for the return-beam vidicon cameras is defined in Figure 3-11. The anticipated performance of the combination of the three cameras is defined in Table 3-4.

PRELIMINARY SPECIFICATION

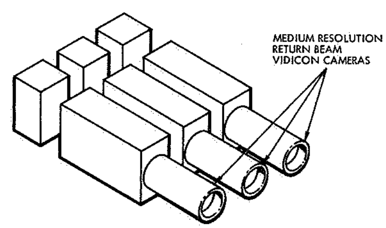
Medium Resolution TV Cameras

Purpose

To provide mapping coverage of large areas of the Martian surface at medium resolution (100 meters from an altitude of 1000 kilometers)

Performance Characteristics
(for each of three cameras)

Type of Sensor	RCA-23061 Two-Inch Return Beam Vidicon
Type of Target	ASOS – Quartz Storage Target
Resolution	3100 TV Lines at 10% Response
Raster Format	25 x 25 mm
Nominal Resolution	3000 TV Lines
Scan Lines/Frame (Kell Factor = 0.7)	4280 TV Lines
Frame Scan Time	110.5 sec
Frame Erase/Prepare Time	25 sec
Nominal Scene Highlight Brightness	260 FT-L
Optical System	T 1.5, 6.6 in. f.l.
Exposure Time	10 msec
Shutter	Mechanical
Dynamic Range	10^{-2} to 10^{-4} FCS
Percent IMC Required	None
S/N (Pk. Sig/RMS Noise)	34 db
Photography Interval/Orbit	26 minutes



Physical Characteristics
(for each of three cameras)

VOLUME (ESTIMATED)	
Optics	7 inch diameter x 5 inches long
Camera Head	6 x 6 x 12 in.
Control Electronics	6 x 6 x 10 in.
POWER (ESTIMATED)	50 watts (maximum)
	2.9 watts (average)
WEIGHT, LB (ESTIMATED)	
Optics	20
Camera Head	20
Control Electronics	15
Total	55

FIGURE 3-11

Table 3-4. Performance of Medium Resolution Return Beam Vidicon Cameras

Anticipated Performance	Medium Resolution TV No. 1	Medium Resolution TV No. 2	Medium Resolution TV No. 3
Ground Resolution/Optical Line-Pair (at periapsis)	100 m	Same as MRTV No. 1	Same as MRTV No. 1
Sensor Resolution/Horizontal Scan Line	3000 TV lines		
Optical Line-Pair/Horizontal Scan Line	1500		
Ground Coverage/Horizontal Scan Line (at periapsis)	150 km		
Ground Coverage/Frame (at periapsis)	150 x 150 km		
Optical Field of View	8 deg 36 min. x 8 deg 36 min.		
Scan Lines/Frame (Kell Factor = 0.7)	4280		
Resolution Elements/Frame	3000 x 4280 = 12.84×10^6		
Bits/Frame (6 Encoding)	77.04×10^6		
Readout Time/Frame	110.5 sec		
Data Rate/Frame	0.697 Mb/sec		
Frame/Orbit (max) ±37.5 deg from periapsis	9		
Total Data/Orbit (max)	6.93×10^8 bits	Same as MRTV No. 1	Same as MRTV No. 1
Readout Time (at 50 kb/sec)			
Each camera	3.85 hr	3.85 hr	3.85 hr
Total - 3 cameras		11.6 hr	

3.3.1 Functional Description

Each of the three return-beam vidicon cameras will utilize a 6.6 inch diameter T/1.5 Schneider-Cogswell type catadioptric optical system, with a field of view of 8 degrees 36 min. square on the 25 x 25 millimeters raster of the vidicon. This field of view results in a ground coverage of 150 x 150 kilometers from an altitude of 1000 kilometers. With a nominal exposure interval of 10 milliseconds used for exposure of the vidicon target, scanning of the vidicon target will be performed over an interval of 110.5 seconds. With a nominal resolution of 3000 resolution elements per horizontal scan line, a raster of 4280 lines will be used (assuming a Kell factor of 0.7). The number of resolution elements per frame will be 12.84×10^6, resulting in a digital data rate of 0.697 Mb/sec after 6-bit encoding. This data stream will be then converted from serial to parallel form. Using 6 kb/sec parallel tracks for data recording, at the rate of 116 kb/sec, the data will be recorded on a digital tape recorder.

The scan time of 110.5 seconds has been selected to permit an acceptably low rate of data to the tape recording equipment. With an additional 26 seconds of time to erase and neutralize the vidicon target, the minimum time between consecutive frames for one camera will be 136.5 seconds, corresponding to a ground track distance of 427.5 kilometers, (at periapsis).

In order to obtain continuous coverage, three cameras are used, with each being exposed at 45.5 second intervals (at periapsis), giving continuous ground coverage of 150 x 150 kilometers per frame, with 5 percent overlap between frames.

As the altitude of the spacecraft increases with increasing time from periapsis, the ground coverage of each frame increases directly with altitude. This, in conjunction with the decreasing horizontal component of spacecraft velocity, will dictate that the exposure interval between frames be increased to prevent excessive overlap of adjacent frames. The interval between exposures will be programmed as a function of the location of the spacecraft in orbit. The nominal exposure time of 10 milliseconds has been calculated for a scene brightness of 260 foot-lamberts. Inasmuch as the brightness of the Martian surface varies between 350 and 150 foot-lamberts over the desired range of solar illumination angle (55 to 75 degrees), and will be 800 foot-lamberts at the subsolar point, a variable shutter interval will be provided. This will necessarily be preprogrammed, depending upon the anticipated scene brightness (Figure 3-12). Six shutter exposure intervals (3.5, 5.0, 7.5, 10, 15, and 20 milliseconds) will cover the anticipated range of scene brightness.

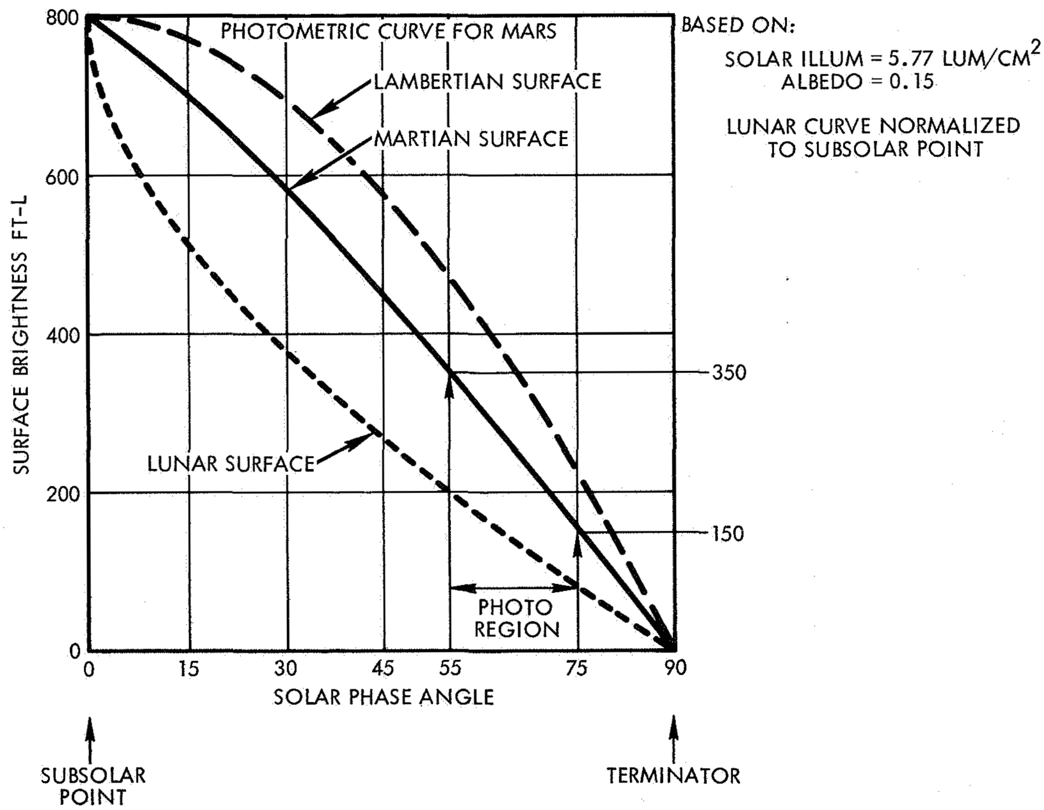


Figure 3-12

MARTIAN SURFACE BRIGHTNESS. The reflectance of the Martian surface is less than that of a pure Lambertian reflector, but higher than that of the Lunar surface.

Referring to the functional block diagram (Figure 3-13), the image of the scene is focused upon the photoconductive target of the 2-inch return beam vidicon. Upon receipt of the command to actuate the shutter, the vidicon target will be exposed for an interval between 3.5 and 20 milliseconds determined by the estimated brightness of the terrain and the corresponding shutter exposure interval command. After exposure of

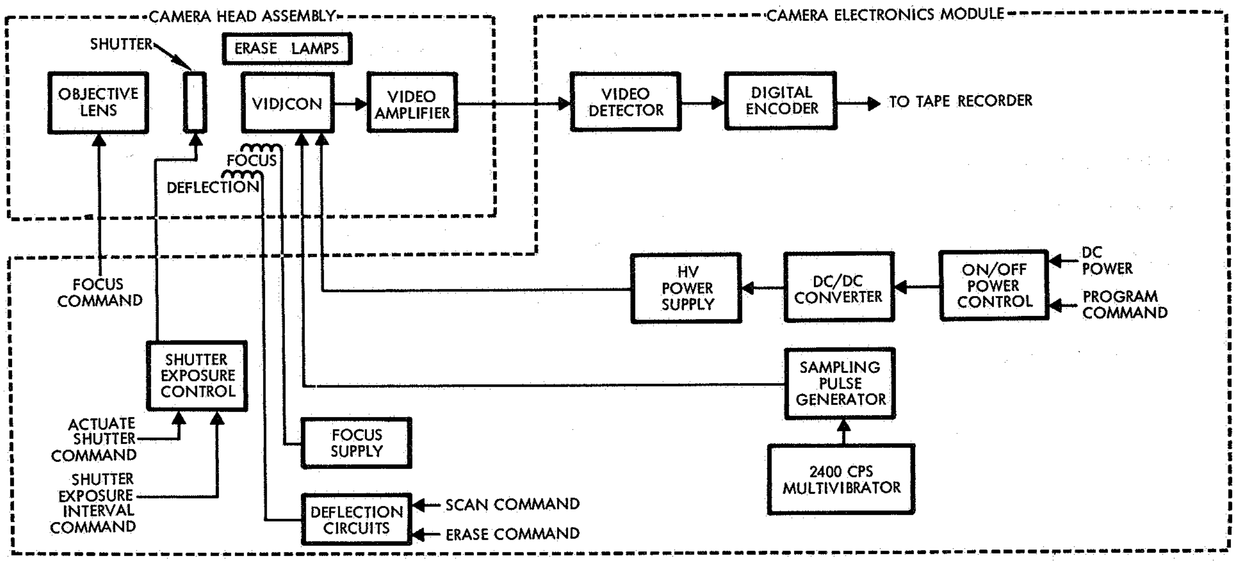


Figure 3-13
FUNCTIONAL BLOCK DIAGRAM RETURN BEAM VIDICON CAMERAS.

the target, upon receipt of the scan command, the target will be scanned by the electron beam over a frame time of 110.5 seconds. Due to the very slow scan rate of the vidicon, the video signal will be pulse-modulated at the rate of 2400 pps by applying pulses to the vidicon photocathode. This prevents loss of video signal amplitude at the slow scanning velocity. A peak detector is used following the video amplifier. After detection of the analog video signal, digital encoding will be accomplished to a 6-bit level, after which the video signal will be recorded on the digital tape recorder.

After the scanning mode is completed, the erase mode is initiated. During this interval, 26 seconds in duration, the photoconductive target is scanned by the electron beam to eliminate all residual electron charge from the previously recorded scene, and is recharged to target potential to permit recording of the next scene.

The input commands for the camera system are defined in Table 3-5. In addition, a number of telemetry outputs will be required to monitor significant control voltages, command voltages, and the environmental state of each camera. These are also defined in Table 3-5.

Table 3-5. Input Commands and Telemetry Outputs—Medium Resolution TV Cameras

	Medium Resolution TV No. 1		Medium Resolution TV No. 2	Medium Resolution TV No. 3
Input Commands (Representative)				
Turn-On and Warmup	Digital	1 bit	Same as MRTV No. 1	Same as MRTV No. 1
Operate Shutter	Digital	1 bit	↑	↑
Scan and Record	Digital	1 bit		
Erase and Neutralize target	Digital	1 bit		
Focus Lens	Digital	3 bit		
Exposive Interval (6 intervals)	Digital	3 bit		
Internal Calibration Test	Digital	1 bit		
Filter Wheel Position	N/A			
Outputs to Telemetry (Representative)				
Target Temperature	Digital			
Heater Current	Digital			
High Voltage	Digital			
Photocathode High Voltage	N/A			
High Light Level	Digital			
Shutter Position	Digital			
Filter Wheel Position	N/A			
Photocathode Pulsewidth	N/A			
Power Transformer Temperature	Digital			
Power Supply Voltages	Six digital measurements			
Timing Reference	Digital			
Power-On Command	Digital			
Shutter Command	Digital			
Scan/Record Command	Digital			
Erase Command	Digital			
Focus Command	Digital			
Shutter Command	Digital		↓	↓
Calibrate Command	Digital		Same as MRTV No. 1	Same as MRTV No. 1

The physical characteristics of each of the three cameras - weight, volume, and power, are defined in Figure 3-11.

3.3.2 Discussion of 2-Inch Return Beam Vidicon

Emphasis is being placed on the development of this tube by the RCA Electronic Components and Devices Division, Lancaster, Pennsylvania. Although the 4-1/2 inch vidicon, type C-74137, developed under Air Force funding, has a higher resolution capability (6500 TV lines at 10 percent response), the 2-inch vidicon offers a considerable saving in weight and power requirements for space applications.

The primary advantage of the 2-inch type C-23061 vidicon is high resolution (3800 TV lines at 10 percent response) in an envelope of moderate size, and with moderate power requirements. The resolution of this tube which has been obtained in experimental tests in the laboratory is defined in Figure 3-14. The envelope used is the same as that used for 2-inch image orthicons, permitting use of a relatively large raster size of 25 x 25 millimeters (Figure 3-15). The tube may be used in either the direct or return beam scanning mode, the latter having the advantage of signal amplification by the multiplier dynode structure of the electron gun.

High resolution is obtained by utilizing a very strong magnetic focus field of 150 to 160 gauss, with four loops (5 nodes) in the electron beam and 5 pi sections in the focus coil. The weight of the deflection components is 9 pounds, and 15 watts of focus and deflection power are required for operation at 30 frames/per sec. The deflection power will be reduced at slower frame rates. Magnesium oxide dynodes are used in the dynode multiplier which has a nominal gain of 200.

Although operation in the return beam mode will not increase the sensitivity to incident illumination, the signal level for a given amount of faceplate illumination will be increased by the gain of the dynode multiplier. This feature is of advantage in a system which is preamplifier noise limited, and will increase the perception of objects of low illumination which might otherwise be obscured by preamplifier noise.

The present tube utilizes the ASOS (antimony sulfide-antimony oxide) slow-scan target which has been used in the vidicons for the Tiros meterological satellite. This surface is suitable for slow-scanning with frame times up to 20 seconds. In this application a frame time of 110.5 seconds will be required. This can be accomplished by utilization of a

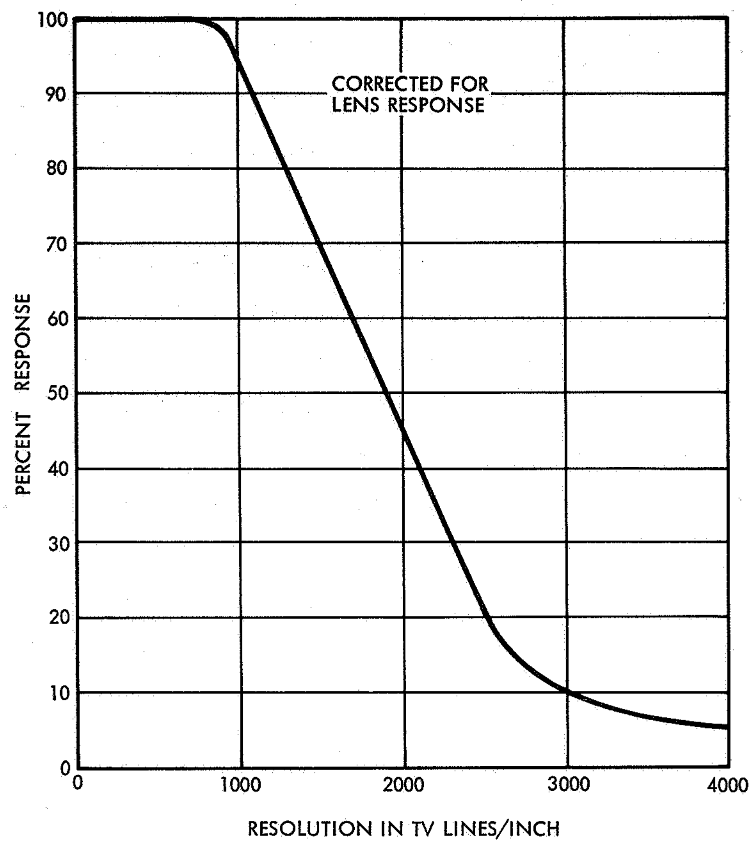


Figure 3-14
RESOLUTION-RCA 2 INCH TYPE C-23061 RETURN BEAM VIDICON.

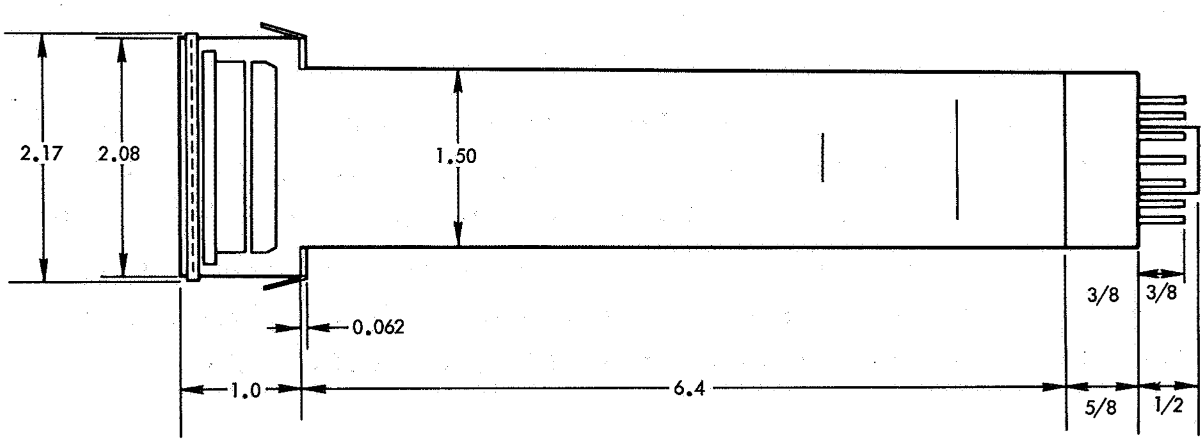


Figure 3-15
ENVELOPE OUTLINE RCA 2 inch type C-23061 return beam vidicon.

quartz storage layer on the ASOS photoconductive target. This process has previously been used by RCA on one-inch tubes developed for the APT cameras for the NASA Nimbus meteorological satellite. The quartz layer permits storage times as long as several hours without loss of signal resolution. The thickness of the quartz layer is adjusted to equalize the capacitance of the quartz layer and the ASOS photoconductive target. As a result, the signal amplitude from a vidicon using this storage layer is one-half of that using the normal ASOS target. However, as the sensitivity of the ASOS layer is eight to ten times higher than conventional photoconductive target materials (antimony trisulfide, selenium, etc.), this effect is not significant.

In order to utilize the 2-inch return beam vidicon in this application, some development effort will be required. This will consist of development of processing techniques for deposition of the quartz storage layer on the larger target, and space-qualifying the tube. Both of these efforts are well within the state-of-the-art having been accomplished on 1/2 and 1-inch vidicons used in previous space programs.

3.4 HIGH RESOLUTION CAMERA

High resolution imaging of selected areas of the Martian surface will be provided by one SEC vidicon camera. From an altitude of 1000 kilometers, the nominal resolution of this system will be 10 meters. The coverage which can be obtained with this camera has been previously defined in Section 3-1 and Figure 3-3. A preliminary specification for the high resolution SEC vidicon camera is defined in Figure 3-16. The anticipated performance of the camera is defined in Table 3-6.

3.4.1 Functional Description

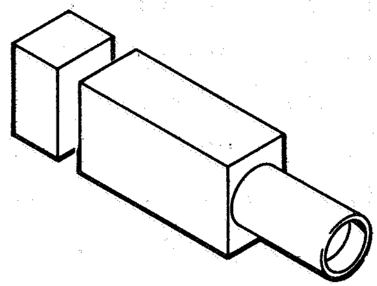
The high resolution SEC vidicon camera will utilize a Ritchey-Chretien type optical system with a 100 inch focal length and a F-number of 16, with a field of view of 35 x 35 arc-minutes on the 25 x 25 millimeters photocathode area of the SEC vidicon. This field of view results in a ground coverage of 10 x 10 kilometers from an altitude of 1000 kilometers. With a nominal exposure interval of 1 millisecond obtained by electronically pulsing the image section of the SEC vidicon, scanning of

PRELIMINARY SPECIFICATION

High Resolution Sec Vidicon Camera

Purpose

To provide imaging of selected areas of the Martian surface at high resolution (10 meters from an altitude of 1000 kilometers)



Performance Characteristics

Type of Sensor	Westinghouse Type WX 5419 B SEC Vidicon
Type of Target	S-20 Photocathode and Al_2O_3-KCl Target
Resolution	2000 TV Lines (Projected)
Raster Format	25 x 25 mm
Nominal Resolution	2000 TV Lines
Scan Lines/Frame (Kell Factor = 0.7)	2860 TV Lines
Frame Scan Time	50 sec
Frame Erase/Prepare Time	20 sec
Nominal Scene Highlight Brightness	260 FT-L
Optical System	T 16, 100 in. f. l.
Exposure Time	1.0 msec
Shutter	Electronic
Dynamic Range	10^{-5} to 10^{-7} FCS
Percent IMC Required	None
S/N (Pk. Sig/RMS Noise)	34 db

Physical Characteristics

VOLUME (ESTIMATED)	
Optics	8 inch diameter x 22 inches long
Camera Head	7 x 7 x 20 in.
Control Electronics	6 x 6 x 10 in.
POWER (ESTIMATED)	20 watts (peak) 1.2 watts (average)
WEIGHT, LB (ESTIMATED)	
Optics	15
Camera Head	15
Control Electronics	15
Total	45

FIGURE 3-16

Table 3-6 Performance of High Resolution SEC Vidicon Camera

Anticipated Performance	
Ground Resolution/Optical Line-Pair (at periapsis)	10 m
Sensor Resolution/Horizontal Scan Line	2000 TV lines
Optical Line-Pair/Horizontal Scan Line	1000
Ground Coverage/Horizontal Scan Line (at periapsis)	10 km
Ground Coverage/Frame (at periapsis)	10 x 10 km
Optical Field of View	0° 35' x 0° 35'
Scan Lines/Frame (Kell Factor = 0. 7)	2860
Resolution Elements/Frame	2000 x 2860 $= 5.72 \times 10^6$
Bits/Frame (6 Bit Encoding)	34.32×10^6
Readout Time/Frame	50 sec
Data Rate/Frame	0. 686 mb/sec
Frames/Orbit (max) $\pm 37.5^{\circ}$ from periapsis	18
Total Data/Orbit (max)	6.17×10^8 Bits
Readout Time (at 50 kb/sec)	3. 43 hr

the SEC vidicon target will be performed over an interval of 50 seconds. With a nominal resolution of 2000 resolution elements per horizontal scan line, a raster of 2860 lines will be used (assuming a Kell factor of 0.7). The number of resolution elements per frame will be 5.72×10^6, resulting in a digital data rate of 686 kb/sec after 6-bit encoding. This data stream will then be converted from serial to parallel form. Using six parallel tracks for data recording at the rate of 114.5 kb/sec, the data will be recorded on a digital tape recorder.

The scan time of 50 seconds has been selected to permit an acceptably low rate of data to the tape recording equipment. With an additional 20 seconds of time to erase and neutralize the target of the SEC vidicon, the minimum time between consecutive frames will be 70 seconds, corresponding to a ground track distance of 219 kilometers (at periapsis). The duty cycle of the high resolution camera has been scaled to match the capacity of the magnetic tape recorder, resulting in the capability of obtaining 18 frames of data over a ground track distance of 4480 kilometers, covering an angular range of ±37.5 degrees from periapsis.

As the altitude of the spacecraft increases with increasing time from periapsis, the ground coverage of each frame increases directly with altitude. This increase in coverage is defined in Figure 3-4. At 37.5 degrees from periapsis, the field of view will have a ground coverage of 14 x 14 kilometers.

The nominal exposure time of 1 millisecond has been calculated for a nominal scene brightness of 260 footlamberts. Inasmuch as the brightness of the Martian surface varies between 350 and 150 foot-lamberts over the desired range of solar illumination angle (55 to 75 degrees), and will be 800 foot-lamberts at the subsolar point, variable exposure intervals will be provided. The exposure interval will necessarily be preprogrammed, depending upon the anticipated scene brightness (Figure 3-12). Six exposure intervals (0.3, 0.5, 0.7, 1.0, 1.5, and 2.0 milliseconds) will cover the anticipated range of scene brightness. Image motion compensation will be required only at the longest exposure interval of 2.0 milliseconds. With this exposure interval, only 50 percent IMC will be required.

Referring to the functional block diagram of the camera (Figure 3-17), the image of the scene is focused upon the photo-emissive photocathode of the SEC vidicon. Upon receipt of the command to record the scene, the image section will be pulsed for an interval between 0.3 and 2.0 milliseconds, determined by the estimated brightness of the terrain and the corresponding exposure interval command. After the image section has been pulsed, the accumulated charge of the SEC vidicon target will be scanned by the electron beam over a frame time of 50 seconds. Due to the very slow scan rate employed, the video signal will be pulse-modulated at the rate of 2400 pps by applying pulses to the SEC vidicon cathode. This prevents loss of video signal amplitude at the slow scanning velocity. A peak detector is used following the video amplifier. After detection of the analog video signal, digital encoding will be accomplished to a 6-bit level, after which the video signal will be recorded on the digital tape recorder.

After the scanning mode is completed, the erase mode is initiated. During this interval, 20 seconds in duration, the photoconductive target is scanned by the electron beam to eliminate all residual electron charge

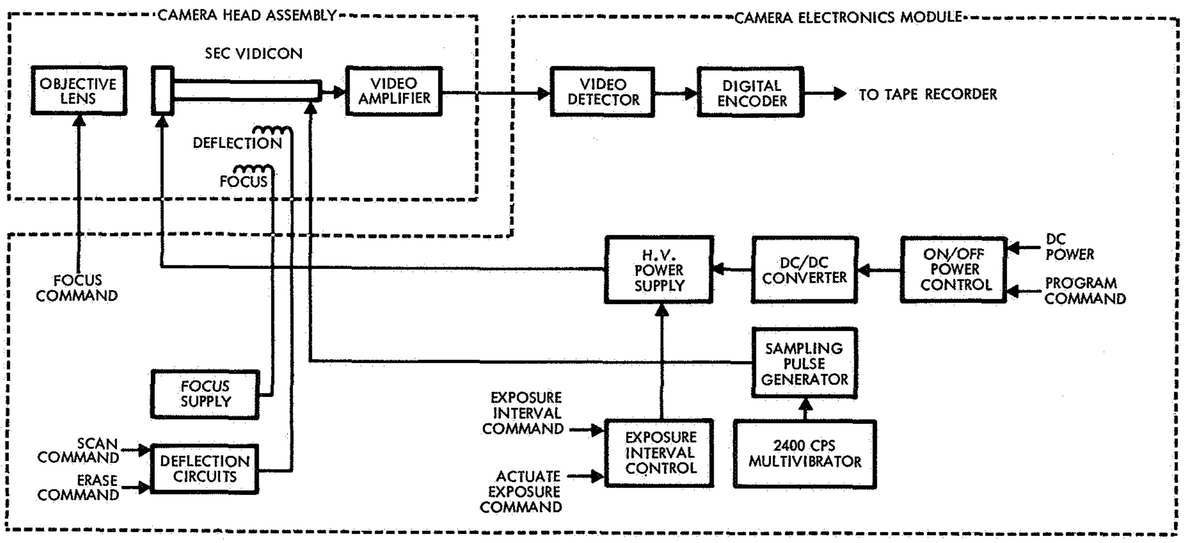


Figure 3-17
FUNCTIONAL BLOCK DIAGRAM - SEC VIDICON CAMERA.

from the previously recorded scene, and is neutralized to permit recording of the next scene. The input commands for the camera system are defined in Table 3-7. In addition, a number of telemetry outputs will be required to monitor significant control and command voltages as well as the environmental state of the camera. These are also defined in Table 3-7.

The physical characteristics of the camera weight, volume, and power, are defined in Figure 3-16.

3.4.2 Discussion of SEC Vidicon

The SEC vidicon is a newly developed camera tube which is quite similar in construction to an image orthicon, except that it does not need an electron multiplier. In essence, it combines the best features of the image orthicon with the simplicity of the vidicon. Figure 3-18 is a schematic representation of the SEC vidicon. Its primary advantage is an order of magnitude increase in the secondary electron emission yield of the target when using low-density insulator materials rather than solid materials.

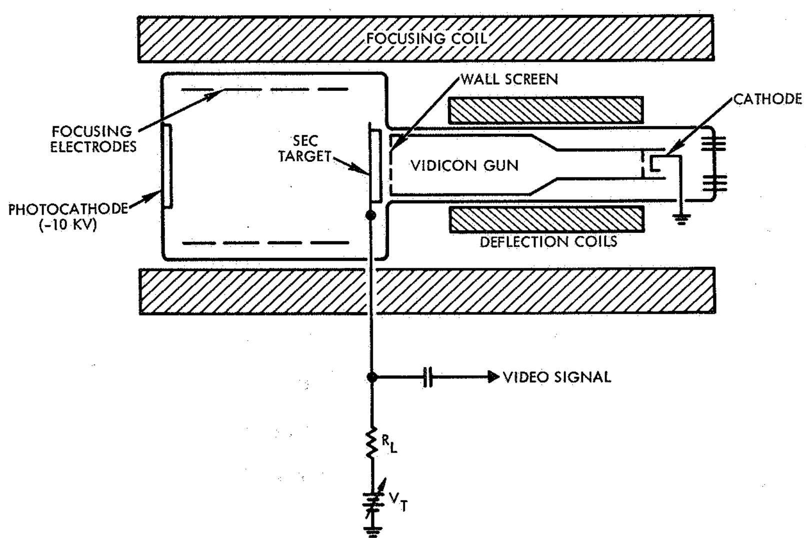


Figure 3-18

SEC VIDICON CROSS SECTION SCHEMATIC. The SEC vidicon has high sensitivity to incident illumination, resulting from secondary electron conduction of the target when subjected to electron bombardment at a high energy level.

Table 3-7. Input Commands and Telemetry Outputs High Resolution SEC VIDICON Camera

Input Commands (Representative)		
Turn-On and Warmup	Digital	1 bit
Operate Shutter	Digital	1 bit
Scan and Record	Digital	1 bit
Erase and Neutralize Target	Digital	1 bit
Focus Lens	Digital	3 bit
Set Exposure Interval (6 intervals)	Digital	3 bit
Internal Calibration Test	Digital	1 bit
Filter Wheel Position	N/A	
Outputs to Telemetry (Representative)		
Target Temperature	Digital	
Heater Current	Digital	
High Voltage	Digital	
Photocathode High Voltage	N/A	
High Light Level	Digital	
Shutter Position	Digital	
Filter Wheel Position	N/A	
Photocathode Pulsewidth	N/A	
Power Transformer Temperature	Digital	
Power Supply Voltages	Eight Digital Measurements	
Timing Reference	Digital	
Power-On Command	Digital	
Shutter Command	Digital	
Scan/Record Command	Digital	
Erase Command	Digital	
Focus Command	Digital	
Iris Command	Digital	
Calibrate Command	Digital	

The distinguishing features of the SEC target are that it uses free electrons for multiplication and charge storage and that conduction due to electrons in the conduction band or ionic conduction can be avoided. It is, therefore, possible to obtain a high speed of response, limited ultimately only by the transit time of free electrons across the target thickness under the action of the applied polarizing voltage. This time is very short and negligible in comparison to standard frame times. Thus, the target can be read out completely within one frame. Because these secondaries are produced in a layer which is an exceptionally good insulator, essentially no current flows in the absence of the exciting signal, and the film has nearly an ideal memory between scans of the reading beam. For this reason, SEC tubes are superior to both the orthicon and vidicon in slow scan applications. Because the SEC target possesses a large charge storage capabity, it can also handle a wide range of input signals without requiring changes in operating voltages. Beam noise is negligible and a very wide range of operating conditions can be accommodated without adjusting the beam current.

3.4.2.1 Operating Characteristics

Referring to Figure 3-18, the scene to be televised is focused on the flat semi-transparent photocathode on the inside of the faceplate of the tube, while the photocathode is held at about minus 10 kilovolts. The emitted photoelectrons are then electrostatically focused on the SEC target which consists of a 700 Å supporting layer of aluminum oxide (Al_2O_3), a 500 A layer of aluminum (Al), and a low-density (2 percent bulk density), 25μ layer of potassium chloride (KCl). The target backplate is maintained at a slight positive potential and the KCl side is stabilized at gun cathode potential (ground potential) by the low energy electrons of the scanning beam. Figure 3-19 schematically illustrates the currents involved in the operation of the target.

Photoelectrons with an energy of about 10 kev designated by the current I_p, penetrate both the Al_2O_3 and Al, and dissipate most of their energy in the KCl, thereby creating many low-energy secondary electrons.

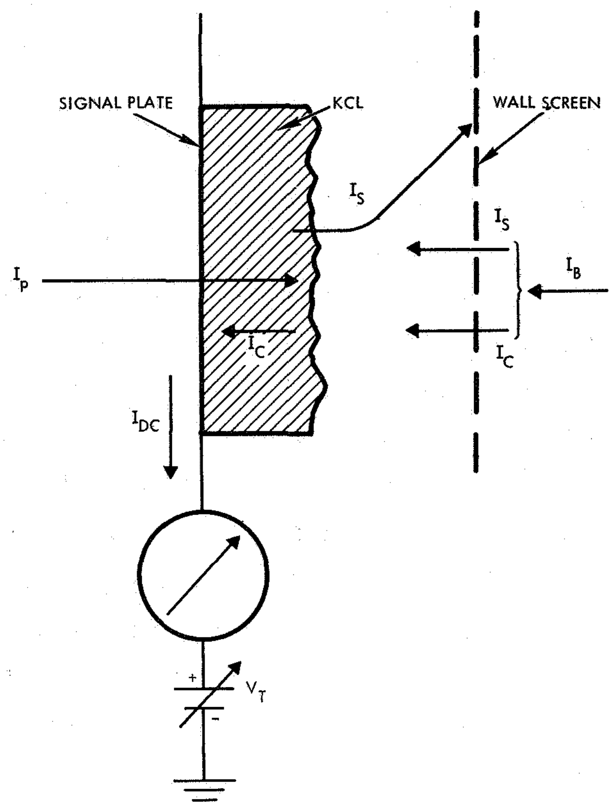


Figure 3-19
SCHEMATIC DIAGRAM OF CURRENTS involved in SEC Target Operation.

Due to the electric field across the layer established by the previous polarization, initially most of these electrons are collected by the signal plate causing the KCl layer to charge to more positive values. The conduction through the layer is represented by the current I_c. The process continues until the KCl layer reaches the potential of the signal plate. At this point, the current I_s, due to transmitted secondary electrons, becomes significant. These emitted electrons are collected by the wall screen and continue to charge the KCl layer to even more positive values. The charging process is interrupted by the scanning beam which then returns the potential of the charged area to ground. This capacitive discharge results in a current pulse which produces a video signal voltage across the load resistor.

Although this process is in many respects quite similar to that taking place in the standard vidicon, it should be emphasized that conduction through the target is achieved by free electrons traveling in the interparticle volume of the layer rather than electrons in the conduction band.

The contribution of those electrons which are excited into the conduction band is insignificant at normal target voltages due to the many interparticle barriers across the layer thickness. With increasing voltage on the signal plate, conduction due to electrons in the conduction band will take place and the observed gain is increased by this third component. If the gain contribution of solid-state conduction is appreciable, the target shows the typical time lag that is characteristic of electron bombardment induced conductivity. This effect, however, does not occur at normal target voltages. Solid-state conduction seems to take place only after a certain threshold voltage is exceeded on the target. This threshold voltage lies between 30 and 40 volts, depending on target thickness and structure.

Figure 3-20(a) gives a qualitative description of the instantaneous gains due to secondary electron conduction and transmission secondary electron emission as a function of the target surface potential V_s which, in turn, is a function of exposure time and light level. The gain is defined as the ratio of the charge generated on the target surface to the photoelectron charge. V_T denotes the target signal plate potential. Initially when the target surface is at ground potential, the conduction gain is at its maximum. It steadily decreases as the target surface discharges toward the potential of the signal plate. When the target surface potential equals V_T, and therefore no electric field exists across the target, the conduction gain becomes zero. The transmission secondary emission gain, which has been steadily increasing during this process, continues to raise the target surface potential and will eventually drive it beyond the signal plate potential, causing the electric field across the layer to reverse polarity. Conduction again takes place; however, now in the reverse direction, and neutralizes some of the charge created by emitted secondary electrons. Providing the process is not interrupted by the scanning beam, the target surface will stabilize at an equilibrium potential V_E determined by the voltage at which the number of secondary electrons leaving the surface equals the number conducted through the KCl layer. At this point, the total instantaneous gain goes to zero and further signal integration is not possible. Figure 3-20(b) shows the integrated charge as a function of the surface potential. The ordinate is the integral of the sum of the instantaneous currents shown in Figure 3-20(a).

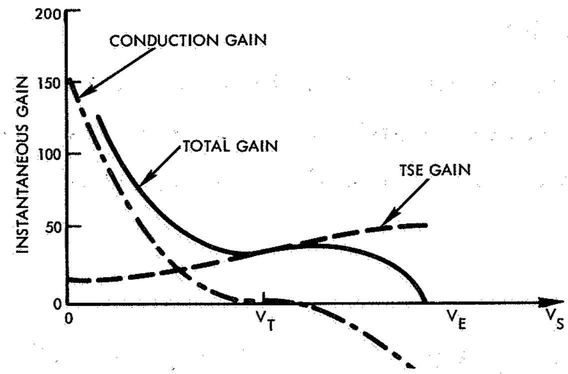
The equilibrium potential is generally higher than the first crossover potential for secondary electron emission in reflection. This means that if the target has been charged beyond crossover potential due to high input current densities or long integration times, the reading beam will not return the target surface to ground but will stabilize it at the potential of the wall screen. The scanning sequence is therefore interrupted until the target is returned to its normal mode of operation. This problem can be overcome by inserting an additional grid at a potential below first crossover between the target and the wall screen.

The total target gain, averaged over the exposure time, increases approximately linearly with increased signal plate voltage V_T. The maximum voltage that can be applied to the signal plate is limited to about 40 volts by the onset of solid-state conduction through the target. At a target voltage of 30-40 volts the total gain, the sum of conduction and transmitted secondary emission gains, reaches a value of 200. It is interesting to note that the SEC target, due to its transmission secondary emission gain component, exhibits gain at zero and even negative voltages, contrary to the behavior of a photoconductive target.

Because the SEC target possesses a large charge storage capacity, it can also handle a wide range of input signals without requiring changes in operating voltages. Beam noise is negligible and a very wide range of operating conditions can be accommodated without adjusting the beam current.

3.4.2.2 Physical Characteristics

The SEC vidicon is one of the larger camera tubes being 17.5 inches long and 3 inches in diameter (Figure 3-21). It weighs approximately 5 pounds, consumes 3 watts when operating and 1 watt on standby. No mechanical shutters or iris are necessary except as protection from direct solar exposure. The exposure of the SEC vidicon target can be controlled by electronically gating the accelerating potential in the image section of the image tube.



(A) CONDUCTION GAIN, SECONDARY ELECTRON GAIN AND TOTAL GAIN AS A FUNCTION OF TARGET SURFACE POTENTIAL, V_S

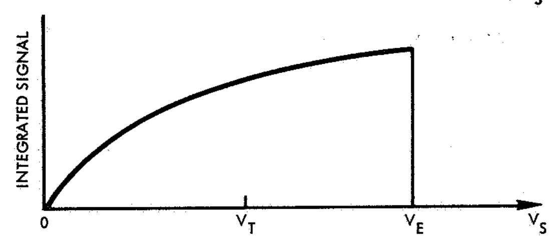


Figure 3-20
(B) ACCUMULATED "SIGNAL" AS A FUNCTION OF TARGET SURFACE POTENTIAL, V_S.

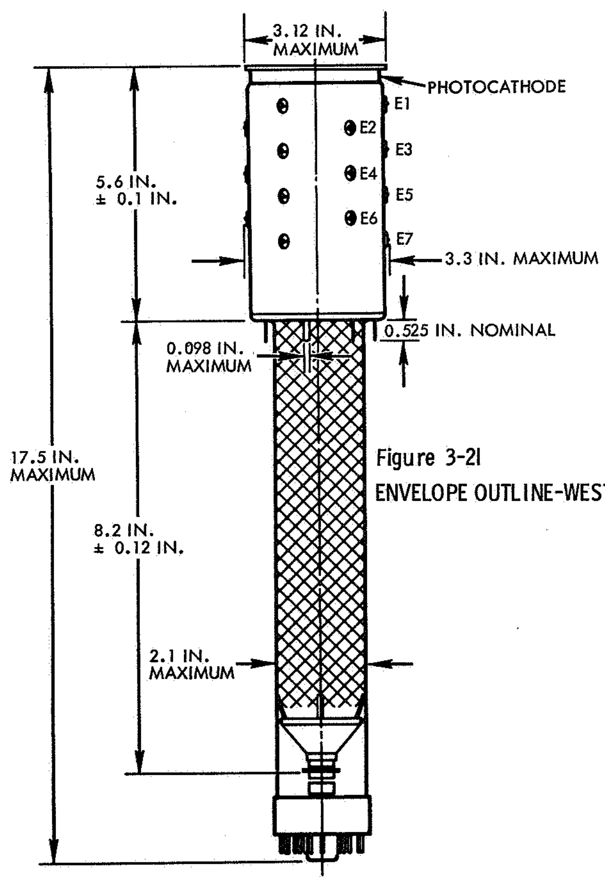


Figure 3-21
ENVELOPE OUTLINE-WESTINGHOUSE TYPE 5419B SEC VIDICON.

3.4.2.3 Dynamic Range

The dynamic range of the SEC vidicon is limited by the amount of light scattered in the faceplate and internal tube structure, and a value about midway between the vidicon and the image dissector is quoted as approaching 10^5 to 1.

3.4.2.4 Sensitivity

The SEC vidicon tubes primarily employ an S-20 photocathode surface. The SEC vidicon sensitivity comes within a factor of ten of that of an image orthicon which requires the added complexity of return-beam readout.

The SEC vidicon target has very good storage properties; therefore, there is negligible loss of signal charge or resolution during long frame times (up to several hours). There is no additive noise which remains constant with decreasing reading rate, as in the vidicon, and the limiting noise in the SEC vidicon system is amplifier noise. Thus, the signal to noise ratio of the SEC vidicon can be maintained so long as excess amplifier noises are negligible by simply reducing the amplifier bandwidth and increasing the amplifier input load impedance.

The SEC vidicon possesses low light level sensitivity almost comparable to the thin-film image orthicon (down to 10^{-5} foot-candles photocathode illumination).

3.4.2.5 Resolution

The limiting resolution (5 percent response) of the SEC vidicon is about 800 TV lines. Figure 3-22 shows the typical amplitude response characteristics of the SEC vidicon tube.

In laboratory tests resolutions of 1000 TV lines/inch have been achieved and the limiting factors were the tube and equipment parameters. Because of the high resistivity of the target, it appears likely that the ultimate resolution capability will be limited primarily by scattering of primary electrons to about 3500 TV lines/inch.

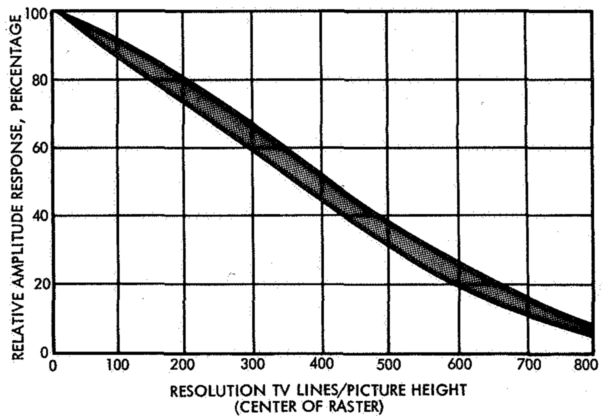


Figure 3-22

RESOLUTION-WESTINGHOUSE TYPE 5419B SEC VIDICON. The limiting resolution of the present Westinghouse SEC vidicon is 800 TV lines at 10 percent response. Further improvement is possible with improvement of the electron optical system, which will result in a smaller size of the scanning beam.

3.4.2.6 Format

Square or rectangular formats within a useful 1.6-inch diameter target area are presently available. Any rectangular shape adhering to the maximum useful diameter (maximum diagonal) dimensions are allowable.

3.4.2.7 Reusability

The rapidity of reuse due to the tube lag characteristics is relatively quick because 95 percent of the image charge pattern is read out in one scan of the target surface. This amount of residual signal will not interfere with the reproduction of eight shades of gray in the image. If this is not satisfactory, an additional scan will reduce the residual signal to 1/400 its original value, or for greater rapidity, a faster scan with a higher and defocused reading beam current could be employed. The SEC vidicon useful operating life is comparable to a regular vidicon with no deleterious effects due to the low density target structure.

3.4.2.8 Environmental Restrictions

Rugged SEC vidicon TV cameras are being produced under contract with NASA for the lunar program. Chief restrictions are that the allowable faceplace temperature is 55°C to protect against photocathode damage by evaporation and the maximum allowable sustained photocathode illumination is about 10 foot candles.

3.4.2.9 Developmental Effort Required

The design of the high resolution television camera has been based upon the use of the Westinghouse type 5419B SEC vidicon. As defined in previous pages, the limiting resolution of this sensor is 800 TV lines at 5 percent response. For this application a resolution of 2000 TV lines will be required. As stated previously, Westinghouse believes that resolution in the order of 3500 TV lines can be achieved. As in the case of vidicons, improvement in the electron optical system (in order to obtain a smaller electron beam diameter) is one of the major modifications which result in a resolution increase. Therefore, in order to achieve the required resolution of 2000 TV lines, it is recommended that a developmental effort be initiated by NASA to upgrade the resolution of the type 5419B SEC vidicon to meet this goal.

A second approach may be considered. In the survey trips which were conducted to obtain the latest state of the art information on TV sensors, it was determined that the General Electric Tube Department at Syracuse, New York, has developed experimental models of a 2-inch SEC vidicon using the electrostatic FPS (Deflectron) deflection system. Resolution of 750 lines has been achieved in initial experimental models. By scaling up this tube to a diameter of 3 inches, increased resolution is possible. Investigation is recommended to determine if a resolution of 2000 lines is realistic. The advantage of utilizing the General Electric tube with the electrostatic deflection system would be reduced power requirements, significant in this space application.

4. RECOMMENDED FILM/TV PHOTO-IMAGING SYSTEM

4.1 SUMMARY

The photo-imaging system which is recommended for use in the Voyager spacecraft consists of a television camera which may be used in either color or monochrome mode for low-resolution mapping coverage and a film system for medium and high resolution mapping coverage. This combination of dual frame film and TV cameras can provide the most flexibility of any photo-imaging system. A preliminary specification for the photo-imaging system is defined in Figure 4-1.

PRELIMINARY SPECIFICATION

Photo-Imaging System

Purpose

To provide complete photographic coverage of the planet Mars at low resolution (1 kilometer) in color, mapping of large areas of Mars at medium resolution (100 meters), and imaging of selected areas at high resolution (10 meters).

LOW RESOLUTION CAMERA

Sensor - RCA 1-1/2 inch vidicon with slow scan target
Field of View - 29 x 29 degrees
Ground coverage - 500 x 500 kilometers (per frame)
Nominal ground resolution - 1 kilometer
Number of frames per orbit (maximum) - 33 frames (11 color pictures)
Photography time/orbit - 48 min (maximum)

MEDIUM AND HIGH RESOLUTION CAMERA

Sensor - Eastman Kodak 70 mm film camera

	Medium	High
Lenses- f.l.	100 mm (4 inches)	1000 mm (40 inches)
Format	60 x 60 mm	60 x 60 mm
Ground resolution	100 meters	10 meters
Frames per orbit	10	10
Ground track length per orbit (maximum)	7550 kilometers	
Photography time/orbit	48 min (maximum)	48 min (maximum)

CAMERA EQUIPMENT MOUNTED ON PSP

Weight 220 lb
Size 14.7 ft^3
Power 50.6 watts (average)

TOTAL SYSTEM INCLUDING ONE TAPE RECORDER

Weight 238 lb
Power 58.6 watt average

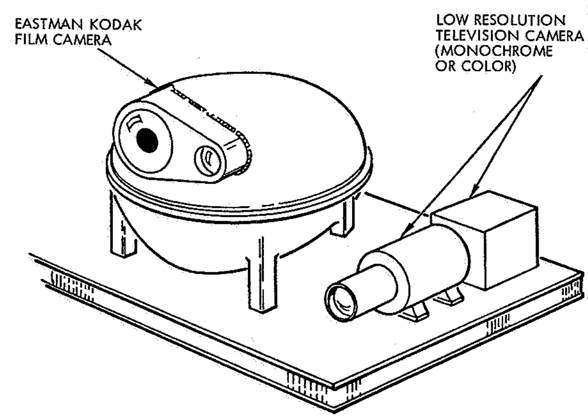


FIGURE 4-1

4.1.1 Low Resolution Camera

The low resolution television camera will provide either monochrome or color coverage with resolution of 1 kilometer from the altitude of 1000 kilometers (at periapsis). The use of color coverage will be of benefit in the identification of vegetation on the surface of Mars and in determining the seasonal variations in cloud formation and dust storms. When used in the color mode, with a field of 500 x 500 kilometers, 11 color pictures (33 monochrome frames - red, green, and blue in sequence), will provide coverage of approximately 6.25×10^6 km^2 or 4.3 percent of the total area of Mars in one orbit. Note that the lateral coverage of the optical field of view increases to 1120 kilometers at an angle of 65 degrees from periapsis. A 1-1/2 inch RCA type 8521 electromagnetic vidicon has been chosen for this camera, having adequate resolution, size of format, and moderate power requirements. In order to permit slow scanning, an ASOS photoconductive target will be used in conjunction with a quartz storage layer. This target and storage layer combination has been developed by RCA for use in the automatic picture taking system for the Nimbus meteorological satellite program.

The configuration of the low resolution television camera has been described in detail in Section 3.2 of this volume and therefore is not repeated in this section.

4.1.2 Medium and High Resolution Film Camera

A dual framing Eastman Kodak film camera is recommended, similar to the camera developed for the Lunar Orbiter program. For medium and high resolution, two separate lens systems will be used. With lenses of 4- and 40-inch focal length the resolution will be 100 and 10 meters, respectively, from an altitude of 1000 kilometers (at periapsis).

The camera system provides medium and high resolution frames on the same roll of 70 millimeter film. The two lenses (4- and 40-inch focal length) are boresighted, so that with simultaneous exposures the high resolution frame covers the area at the center of the medium resolution frame. The lateral ground coverage will be 600 and 60 kilometers, respectively. During one orbit, 10 frames of information may be obtained in either or both of the modes on a 60 x 60 millimeter film format.

The Voyager film camera system will differ from the Lunar Orbiter in those respects dictated by differences in the missions. The lenses will be considerably different in focal lengths and design types, a new Bimat processing formulation appropriate to the Voyager mission duration will be used, additional radiation shielding will be added, and the readout system will be designed to permit continuous transmission of photographic information during the lifetime of the spacecraft in Mars orbit. A preliminary specification for the film camera is shown in Figure 4-2.

PRELIMINARY SPECIFICATION

Recommended Film Camera Systems

Purpose

To provide medium and high resolution photographic coverage of the Martial surface. Contains integral film processor and data readout system.

Performance Characteristics

SENSOR

Eastman Kodak film camera modified to incorporate 40 inch and 4 inch focal length lenses, increased radiation shielding, improved "Bimat" film and processor.

FILM FORMAT

70 mm (60 x 60 mm) Type SO-243, length 100 feet (usable)

OPTICAL SYSTEM

	Medium Resolution	High Resolution
Lens -	- Refractive	Catadioptic
E.F. -	- 100 mm f2.8	1000 mm f.4.0
Exposure -	10-140 msec	10-40 msec
Frame Rate	1 frame/2 sec maximum	1 frame/2 sec maximum
IMC	None	5 percent

PROCESSING

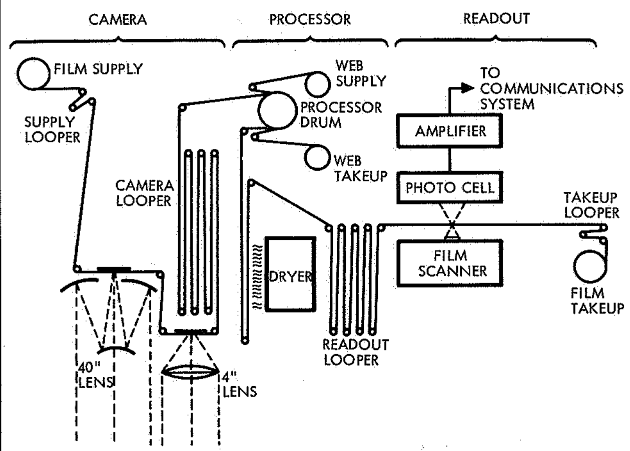
Eastman (new) "Bimat", web application transfer type. 120 feet, approximately 2.5 inches/min speed.

READOUT

Flying spot scanner with optical and mechanical scan. Rate changeable as bit rate is changed. GRE compatible.

Physical Characteristics

Size 14.1 ft^3
Weight 200 lb (including radiation shielding)*
Power 49.2 watts (average)



*NOTE: The weight estimate includes 30 gm/cm^2 of radiation shielding for the film casette, a total of 65 pounds. This shielding reduces the effect of solar cosmic rays to a low level, in the order of 2 or 3 rad per year. The predominant radiation will be galactic cosmic radiation of high energy level, against which shielding is not effective. The level of this radiation is estimated to be from 6 to 20 rads per year. 100 rad causes 50 percent fog level on S0-243 film.

FIGURE 4-2

4.1.3 Equipment Configuration on the Planetary Scan Platform

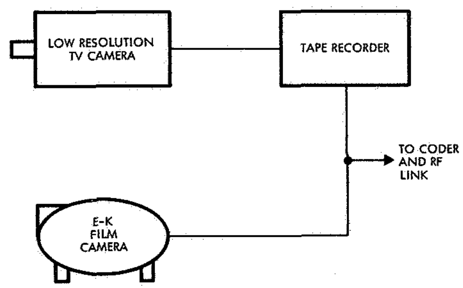
The film camera and the low resolution television camera will be mounted on the planetary scan platform and boresighted. The film camera will be contained in its own pressure vessel and will be provided with internal heating elements.

The total weight of the equipment mounted on the planetary scan platform will be 220 pounds with an average power consumption of 50.6 watts.

The total system weight, including the tape recorder for the television camera, will be 238 pounds, with an average power consumption of 58.6 watts.

4.1.4 Data Storage

The configuration of the data recording equipment for the photo-imaging system is defined in Figure 4-3. One tape recorder is used to accept the digitally encoded video data from the low resolution television



RECORDER SPECIFICATIONS

CAPACITY	4.5×10^8 BITS
TAPE SPEED	25 IN/SEC
NO. OF TRACKS	14 (6 + 6 FOR VIDEO)
TAPE LENGTH	3000 FT
INPUT DATA RATE	350 KB/SEC

Figure 4-3
DATA STORAGE REQUIREMENTS - RECOMMENDED FILM AND TV PHOTO IMAGING SYSTEM. A single tape recorder is required for handling the video data from the color television camera. The film camera does not require the use of a tape recorder, as the film is the medium for storage of data.

camera. The recorder will have a total data capacity of 4.5×10^8 bits, using a tape speed of 25 inch/sec. Data will be accepted at the nominal rate of 350 kb/sec. This data stream will then be converted from serial to parallel form and recorded on six parallel tracks at the rate of 28.3 kb/sec per track, with a recording density of 2300 bits/inch. The recorder will have a total tape length of 3000 feet. After filling one side of the tape with six parallel tracks of video information, the tape may be reversed to permit utilization of an additional six parallel tracks.

Note that the maximum amount of data which will be obtained in one orbit (2.8×10^8 bits) will utilize only 60 percent of the capacity of the tape recorder. With the tape running continuously, there will be increasing gaps in the recording as the satellite departs from periapsis, due to the increase in altitude which results in increased ground coverage, permitting greater intervals in recording of adjacent frames.

4.1.5 Mapping Coverage

The mapping coverage obtained by the photo-imaging system in one orbit is defined in Figure 4-4. Note that the lateral coverage of the two subsystems increases with increasing displacement from periapsis, due to the corresponding increase in altitude. The maximum coverage obtained by the low resolution television camera in one orbit will be determined by the range of solar illumination angles permissible for color photography, rather than by tape recorder capacity. The coverage of the film camera during one orbit is also limited only by the range in solar illumination angles desired for monochrome photography.

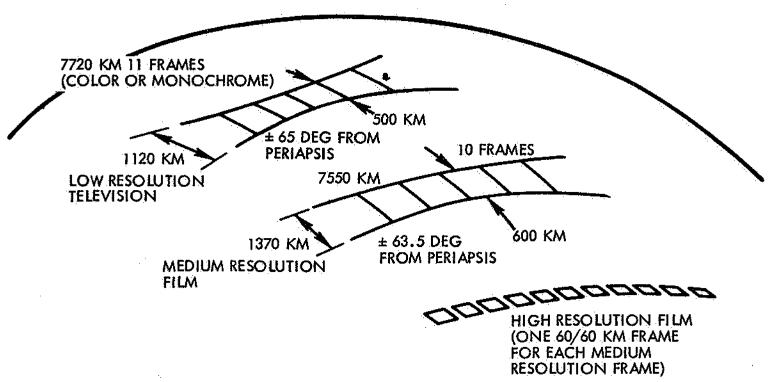


Figure 4-4
MAPPING COVERAGE-RECOMMENDED FILM AND TV PHOTO IMAGING SYSTEM. Both the color television and film cameras will obtain continuous ground coverage over the maximum range which is determined by the desired solar illumination angles. One high resolution film frame may be taken for each medium resolution film frame. The tracks of ground coverage which are illustrated are displaced for clarity.

During a 6-month lifetime in orbit, with a total data transmission capacity of 2.64×10^{11} bits, the coverage which may be obtained is defined in Table 4-1. Note that 100 percent coverage may be obtained with the low resolution camera in color. The percentage of Mars which may be mapped with medium resolution is 26 percent.

Table 4-1. Coverage of Mars Obtained with Low Resolution Television Camera and Medium and High Resolution Film Camera*

	Low Resolution TV (color)	Medium Resolution Film	High Resolution Film
Nominal Ground Resolution	1 km	100 m	10 m
Nominal Coverage/Frame	500 x 500 km	600 x 600 km	60 x 60 km
Bits/Frame (6-bit encoding)	8.58×10^6	1.24×10^9	1.24×10^9
Frames/Orbit (maximum)	11 color picture (33 frames)	10	10
Data/Orbit (maximum)	2.83×10^8 bits	12.4×10^9 bits	12.4×10^9 bits
Ground Coverage/Frame (nominal)	$2.5 \times 10^5 km^2$	$3.6 \times 10^5 km^2$	$3600 km^2$
Area of Mars	$1.46 \times 10^8 km^2$	$1.46 \times 10^8 km^2$	$1.46 \times 10^8 km^2$
Data Allotment (Total Data Link Capacity = 2.64×10^{11} bits/6 months)	1.52×10^{10} bits	1.25×10^{11} bits	1.25×10^{11} bits
Number of Frames	585 (color pictures) 1755 frames	100	100
Percentage of Mars Area Covered	100%	26%	0.26%

*This estimate of coverage of the Martian surface which will be obtained in low, medium, and high resolution is based upon a data link capacity of 2.64×10^{11} bits over a period of 6 months. Equal portions of the total data capacity are assigned to medium and high resolution photography. This estimate is based upon the ground coverage obtained at the nominal altitude of 1000 kilometers.

The coverage indicated is limited by the data transmission rate, not by camera capabilities. For example, if a higher data rate were available, a camera loaded with 500 feet (less than 5 pounds) of film could gather about 2.6×10^{12} bits of data, or 260 percent Mars coverage at 100 meters resolution plus 2.6 percent Mars coverage at 10 meters resolution.

The camera has a demonstrated capability to locate position on the film to less than 0.1 inch, so that readout, or re-readout of selected portions of the permanent record, can be programmed to suit either original or changed mission requirements. Mosaicking problems are less severe than with other systems because of the large angular coverage of each frame.

4.2 FILM CAMERA AND GROUND RECONSTRUCTION EQUIPMENT — GENERAL DESCRIPTION

The film camera system proposed for the Voyager spacecraft consists of the photo system in the spacecraft and a ground reconstruction system which includes reassembly processing of prints on the ground. Most of the components have been previously qualified for many special space and aircraft uses. A functional diagram of the camera and ground reconstruction equipment is illustrated in Figure 4-5.

The spacecraft camera will be capable of several different modes of picture-taking. Vertical photographic frames can be spaced to give sufficient overlap to permit stereo viewing. Fore and aft pointing of the system may also be considered for stereo coverage. The system may also be programmed to take successive pictures in a given area with overlap and to repeat frames on succeeding orbits. The lens systems are focused on separate vacuum platens which hold the film flat during the exposures which are controlled by focal plane shutters. The various operating parameters, such as exposure, frames per sequence line scan tube focus, and gain of the video will be provided by the ground control. The performance of the film camera is defined in Table 4-2.

The 70 millimeter film (Kodak SO-243) is a special film with high resolution and good contrast. Because of its very slow emulsion speed the film has relatively high resistance to damage of the emulsion by radiation. The film will be developed by a diffusion process called the Bimat process. After exposure a chemically impregnated web is pressed against the SO-243 film and development is achieved by diffusion of chemicals into the film. Once the film has been processed and dried, it is ready for readout.

The readout uses a high-intensity electron beam generated by a CBS line scan tube. The beam does not scan the entire frame at a time but rather a series of vertical adjacent strips which must later be reassembled on the ground. Transmitted through the emulsion, the beam is picked up by a photo-multiplier tube which converts its varying intensity to equivalent voltage variations. This electrical signal will be processed and sent to the high-gain dish antenna for transmission to the Deep Space Instrumentation Facility (DSIF) station.

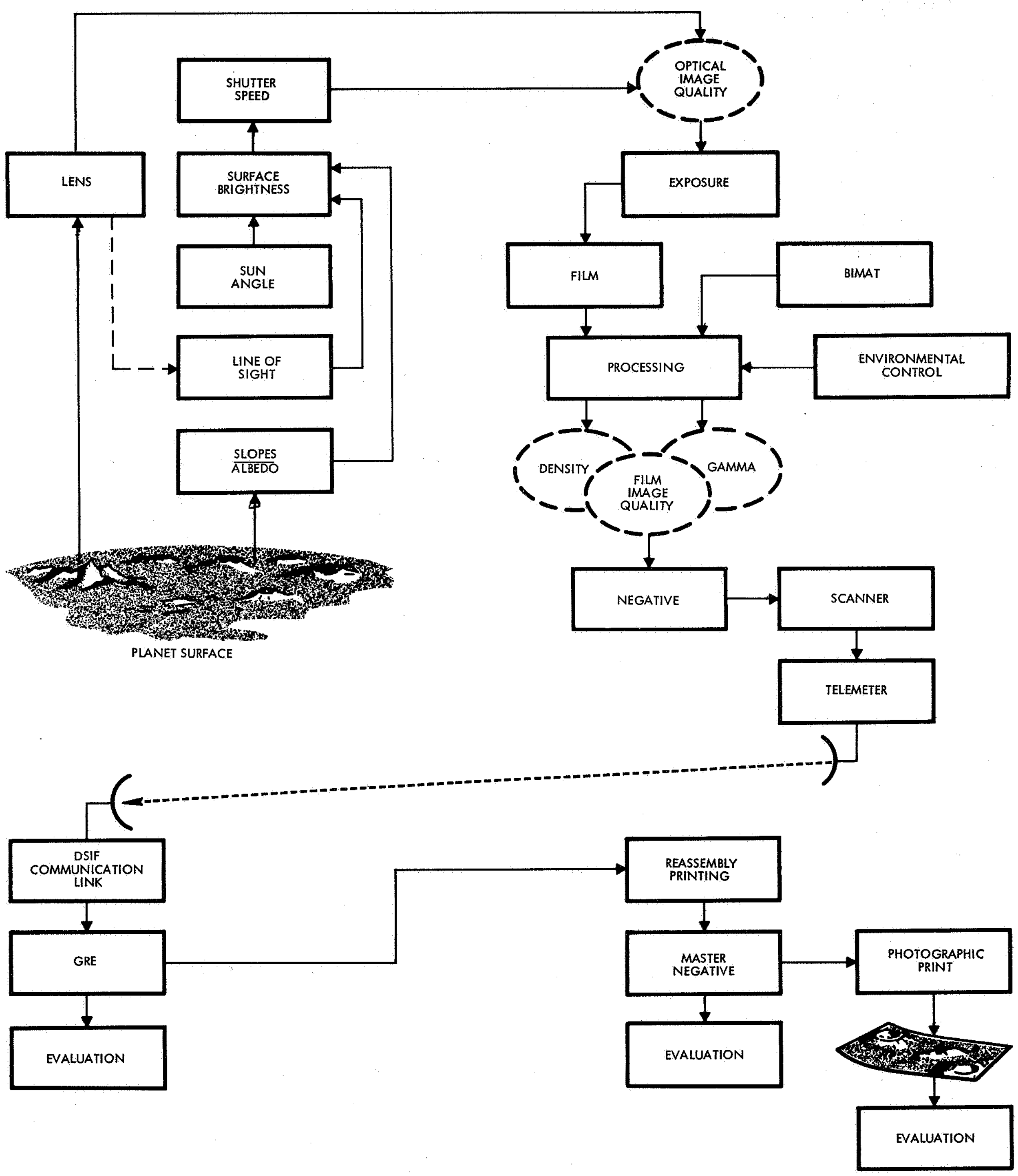


Figure 4-5

FILM CAMERA SYSTEM AND GROUND RECONSTRUCTION EQUIPMENT FUNCTIONAL DIAGRAM. This functional diagram illustrates the flow of information from the photographic camera in the spacecraft through the data transmission link to the ground reconstruction equipment.

Table 4-2. Anticipated Performance of Film Camera

Anticipated Performance	High Resolution	Medium Resolution
Ground Resolution/Optical Line-Pair (at periapsis)	10 m 100 line pair/mm	100 m 100 line pair/mm
Sensor Resolution	60 x 60 mm	60 x 60 mm
Format		
Ground Coverage/Frame (at periapsis)	60 x 60 km	600 x 600 min.
Optical Field of View	3 deg 27 min. x 3 deg 27 min.	33 deg 27 min. x 33 deg 27 min.
Scan Lines/Frame (Kell factor = 0. 7)	17, 160	17, 160
(TV) Resolution Elements/ Frame	2.06×10^8	2.06×10^8
Bits/Frame (6-bit PCM coding)	1.24×10^9	1.24×10^9
Frame/Orbit (Max)	10	10
	(Limited by areas of ground track with proper sun phase angles)	
(±63 deg from periapsis)		
Total Data/Orbit	12.4×10^9 bits	12.4×10^9 bits
Frames/6 months (Assuming 2.9×10^{11} total bits communication capability)	100	100
Coverage of Mars (Monoscopic, no overlap)	0.26%	26%

At the ground station the signal is processed and used to modulate a kinescope to convert the electrical impulses back to a light beam. The resulting image is photographed on 35 millimeter film which is developed and sent to a reassembly facility. Here the 35 millimeter strips are mated to reconstruct the original photograph. The assembly is then re-photographed on a 9.5 inch film from which final prints are made.

4.3 FILM CAMERA — FUNCTIONAL DESCRIPTION

Principal subassemblies of the film camera are the camera, processor-dryer, readout group, and the camera control assembly. The outputs from the camera system are exposed film and instrumentation data. The picture format includes time and frame data in digital form as well as a set of format edge marks to be used for accurately locating details on the picture with respect to the center of the picture.

4.3.1 Camera—Optical and Film

The lens for the high resolution system will be an f4.0 catadioptric type of 1000 millimeter focal length. The medium resolution lens is an f2.8 refractor type of 100 millimeter focal length.

Discrete frames of 60 x 60 millimeter format will be taken simultaneously through both lenses. Figure 4-2 shows simple schematics of the camera system. The film supply is 70 millimeter wide Kodak SO-243 (100 feet usable) which passes through the film supply looper. This looper controls tension to the 100 millimeter film platen through a set of rollers to the 1000 millimeter film platen. They will have vacuum systems to control film flatness during exposures. The film will then enter the storage looper.

Control of the camera will be accomplished by the spacecraft command and sequencing system. The logic level signals supplied will be amplified in the camera by a central camera control box. Thermal control will be accomplished by an enclosure of the whole camera system by using thermal tapes and thermal panels. Temperature will be held to $60 \pm 10^{o}F$ and pressure to 1.0 to 1.9 lb/sq in. A closed thermal door in the spacecraft will protect the windows and lenses.

The SO-243 negative film material will be about 100 feet in length with a leader material of about 30 feet for thread-up and other expansion. Radiation shielding will be provided to protect the undeveloped film during periods of long potential exposure to the expected environment.

4.3.2 Film Processor-Dryer

The Kodak Bimat transfer film processing system is a "silver halide diffusion transfer" process diagrammatically shown in Figure 4-6. In this system the processing chemicals and moisture (termed imbibant) are presoaked into a thin hydrophilic layer which is coated on an ESTAR

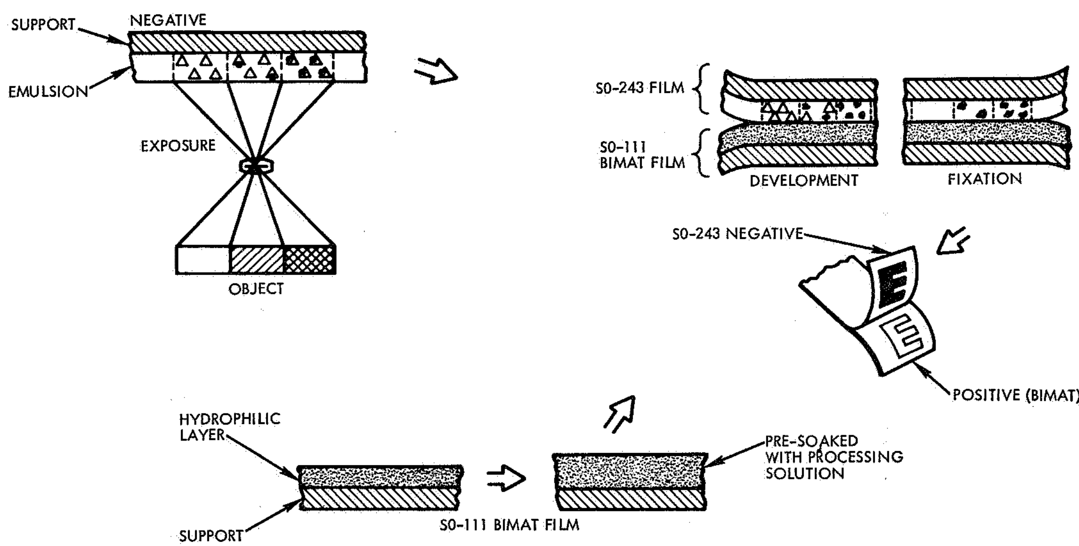


Figure 4-6
BIMAT PROCESSING METHOD. The Bimat processing method permits rapid processing of the film negative at the rate of 2.5 inches per minute. After processing, the Bimat positive is discarded.

film base support. During film processing, Kodak dry Bimat transfer film (ESTAR base), Type SO-111, imbibed with the processing chemicals, is laminated into intimate physical contact with the exposed photosensitive film, and the imbibant solution immediately begins to diffuse into the negative film emulsion layer. All exposed silver halide grains are rapidly developed within the negative film while the unexposed halide is simultaneously starting to be dissolved. By diffusion, most of the dissolved halide is moved from the negative film into the Bimat film, where it is reduced to silver by nuclei present in the hydrophilic layer. The silver deposited in the Bimat film forms a positive image; however, this image is of no interest since the photographic system is designed to use only the film negative image. Although, in the Kodak Bimat transfer film process, image development is completed rapidly, the fixing action continues for a longer period. Processing speed will be about 2. 5 in. /min.

In the spacecraft processing operation, about 6 grams / sq ft of Bimat imbibant are absorbed in the hydrophilic layer of the Bimat film. Typical sensitometric processing results are shown in Figure 4-7 for the Kodak high

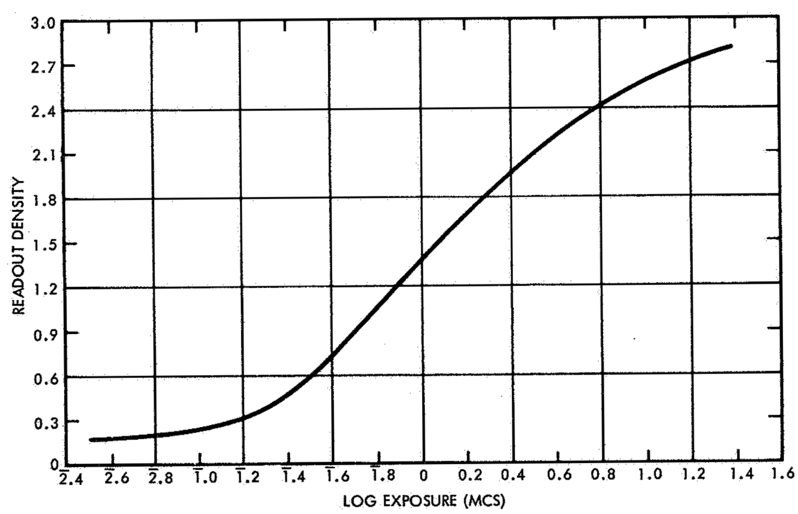


Figure 4-7

CHARACTERISTIC CURVE, TYPE SO-243 FILM BIMAT PROCESS. The density range of the photographic negative obtained with Bimat processing is illustrated above, as a function of exposure in meter-candle-seconds.

definition aerial film (gray base), Type SO-243 Number 2, processed for 3.5 minutes at 85°F using Kodak Bimat dry transfer film type 1 (ESTAR base), Type SO-111, imbibed with the Kodak PS 485K Bimat imbibant.

It will be necessary to control relative humidity of the processor-dryer to 50°F ±20 percent to prevent Bimat from drying out. The temperature control system will maintain the Bimat film at about 60°F at all times. After processing, the film takeup compartment will be maintained at 80°F maximum. The processor drum will be controlled at 85 ± 2°F during processing. The dryer drum will be controlled at 95 ± 2°F during processing.

4.3.3 Film Readout Group

The readout portion of the photo-system will be used to convert the planet images from the processed and dried film into amplitude-modulated video signals. Figure 4-8 shows the line scan tube. A 6.5 micron image of the light spot will be focused on the film by the scanner lens. The lens

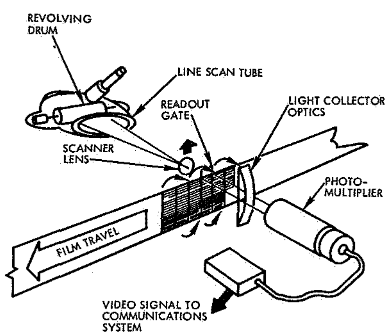


Figure 4-8
PHOTO SYSTEM READOUT SCHEMATIC. A CBS line scan tube is used to generate a moving spot of light by means of an electron gun which scans a drum coated with a phosphor. The drum is rotated to prevent fatigue of the phosphor. This spot is then focussed on the film. The intensity of the light received by the photomultiplier tube is a function of the density of the portion of the film being scanned.

will move at right angles to the film following each scan. A "framelet" will result comprising about 17,000 lines, each 2.67 millimeters long, across about 60 millimeters of the 70 millimeter frame of film. Following one framelet completion, the film will be moved 2.54 millimeters to begin its next framelet. The scanner lens moves in the opposite direction for this framelet. A complete dual exposure frame 120 millimeters) would require 47 such framelets.

Light passing through the film, modulated by image density, will be sensed by the photo-multiplier tube through light collection optics. An analog electrical signal proportional to the intensity of the transmitted light will be generated and amplified. Timing and synchronization pulses will be added to form the composite video signal which is fed to the spacecraft's video transmitter.

4.3.4 Camera Control Assembly

The camera control assembly will have three functions:

1) Converting the logic level signals from the command, control, and programming electronics box in the photo system into usable power level voltages to control the automatic cycling of the camera.

2) Converting the logic level command from the spacecraft programmer into power level voltages to control the exposure setting of the two cameras.

3) Converting the binary data signals from the spacecraft command and sequencing system into time-oriented voltages to illuminate the data lamp (or lamps) in order to expose the digital time data on the film.

The power level voltages are generated by transistorized switches. Switches are saturated during the operation of their respective clutch, brake or motor, in order to achieve the maximum power efficiency. Reversal of the film drive motor during readout will be accomplished by means of a latching relay.

The command received from the spacecraft programmer will be a single pulse which, upon successive applications, results in one of three exposure settings. This will be accomplished by the use of steering networks and a four-position stepper motor. The mechanism of the 100 millimeter shutter may utilize this sequential four-position rotation in such a way that the exposure cycle is that of ABCBAB... etc., i.e., one of three exposure settings. By coupling a shaft encoder directly to the stepper motor shaft, it is possible to obtain an exposure control signal for the 1000 millimeter shutter which effectively locks the two into exposure synchronization.

The last function of the camera control assembly is that of recording of a digital time code. The readout is intended to be serially exposed along the edge of the film as it advances. Since the 20-bit code used may be obtained from the spacecraft command and sequencing system on the broadside basis, this means that data storage and destructive serial readout, synchronized to motion, will be needed.

Instrumentation of the shutter exposure setting will be provided by an extra pair of tracks on the encoder which is used to drive and synchronize the exposure settings of the 1000 millimeter shutter to the 100 millimeter shutter. Since the exposure change command only steps the shutter aperture from any one setting to the next rather than to a particular setting, this information is necessary to verify whether correct exposure has been achieved.

Measurement of the camera storage looper film content will be achieved through a potentiometer geared to the shaft of one of the two negator springs of the looper. The looper content information can be used as an indicator of how many frames were advanced through the camera as well as how many frames have been processed.

4.4 INTERFACES — RECOMMENDED PHOTO-IMAGING SYSTEM

Command and telemetry interfaces of the recommended photo-imaging system (including both the color television and film cameras) are shown in Tables 4-3 and 4-4, respectively.

Command information is channeled through the PSP decoder and switching assembly from the spacecraft command and sequencing subsystem. Telemetry is handled through the PSP remote multiplexer from the telemetry and data handling subsystem.

Table 4-3. Recommended Photo-Imaging System Interface Commands*

1) One low resolution, wide angle television camera for continuous color or monochrome mapping coverage.

Function	Commands: Power	Commands: Discrete
Turn on and warm up	1	
Operate shutter on/off		2
Scan and record on/off		2
Erase and neutralize target on/off		2
Set iris opening (6 positions)		6
Internal calibration test on/off		2
Filter wheel position (4 positions)		4

2) One Eastman-Kodak film camera for continuous medium resolution mapping and selected high resolution imaging.

Function	Commands: Power	Commands: Discrete
System power on/off	1	
Camera film drive forward		1
Draw vacuum and clamp film		1
Small shutter		1
V/H relay state (if required)		1
Camera film drive on/off		2
Bimat cut		1
Camera film drive, reverse		1
Large shutter		1
Relay state, readout electronics		1
R/O forward release		1
Supply brake on/off		2
Supply motor on/off		2
Takeup forward/reverse		2
Takeup on/off		2
± 20 and + 6.3 volt converter on/off		2
Heater inhibit, day/night		2
High voltage converter on/off		2
Processor dryer heater on/off		1
Large shutter motor		1
Scanner motor		1
Bimat motor		1
IST annode motor		1
Internal calibration test on/off		2

*Two quantitative command lines each with 7-bit resolution will be provided directly from the computer and sequencer to the photo-imaging system. Digital to analog conversion will be accomplished within the photo-imaging system as required for these two functions.

Table 4-4. Recommended Photo-Imaging System Interface Telemetry

1) One low resolution Color Television

Function		Analog	Digital
Target Temperature		1	
Heater Current		1	
High Voltage		1	
High Light Level		1	
Shutter Position		1	
Filter Wheel Position		1	
Power Supply Voltages		6	
Time Reference (18 bits)			3
Power-On Command	(1 bit)		1
Shutter Command	(1 bit)		
Scan/Record Command	(1 bit)		
Erase Command	(1 bit)		
Trio Command	(1 bit)		
Calibrate Command	(1 bit)		
	Totals	12	4

2) One Eastman Kodak Film System

Function	Analog	Digital
Take-up Contents	1	
Camera Looper Contents	1	
Readout Looper Contents	1	
V/H Ratio (if required)	1	
Shutter Operation	1	
Platen Operations	1	
V/H Temperature	1	
Camera Temperature	1	
Window Temperature	1	
Processor Temperature	1	
Dryer Temperature	1	
+10 Converter Output	1	
LST Cathode Current	1	
PM Voltage	1	

5. ALTERNATE DIELECTRIC TAPE AND TV PHOTO-IMAGING SYSTEM

5.1 SUMMARY

The alternate photo-imaging system which has been selected for use in the Voyager spacecraft consists of a television camera which may be used in either the color or monochrome mode for low resolution mapping coverage, and a dielectric tape camera for medium resolution mapping coverage. High resolution imaging is not provided in this system although this capability can be provided by redesign of the dielectric tape camera.

5.1.1 Low Resolution Camera

The low resolution television camera will provide either monochrome or color coverage with resolution of 1 kilometer from the altitude of 1000 kilometers at periapsis. The use of color coverage will be of benefit in the identification of vegetation on the surface of Mars and in determining the seasonal variations in cloud formations and dust storms. When used in the color mode, with a field of view of 500 x 500 kilometer(s) at periapsis, 11 color pictures (33 monochrome frames — red, green, and blue in sequence), will provide coverage of approximately 6.25×10^6 km^2 or 4.3 percent of the total area of Mars in one orbit. Note that the lateral coverage of the optical field of view increases to 1120 kilometers at an angle of 65 degrees from periapsis. A 1-1/2 inch RCA type 8521 electromagnetic vidicon has been chosen for this camera, having adequate resolution, size of format, and moderate power requirements. In order to permit slow scanning, an ASOS photoconductive target will be used in conjunction with a quartz storage layer. This target and storage layer combination has been developed by RCA for use in the APT (automatic picture taking) system for the Nimbus meteorological satellite program.

The configuration of the low resolution television camera has been described in detail in Section 3 of this volume, and therefore is not repeated in this section.

5.1.2 Medium Resolution Dielectric Tape Camera

For medium resolution coverage, one dielectric tape camera is proposed, with a resolution of 100 meters from the altitude of 1000 kilometers at periapsis. During one orbit, 32 frames of information may be obtained in either a framing or panoramic mode, permitting continuous ground coverage over a ground track length of 7550 kilometers and an angular range of ±63.5 degrees from periapsis. When used in the panoramic mode, in which frames are obtained by scanning orthogonally to the ground track, the dielectric tape camera offers the widest swath width of any of the three medium resolution systems proposed. In this mode, the lateral ground coverage will be 1000 kilometers (nominal value at periapsis). The dielectric tape camera proposed is based upon the design of the prototype equipment which has been recently space-qualified for the Nimbus meteorological satellite program, with one primary modification. This modification consists of replacement of the present 1-inch vidicon electron gun with a 4-1/2 inch return beam image orthicon electron gun in order to obtain the desired resolution of one line-pair per 100 meters. No auxiliary tape recording equipment is required for the dielectric tape camera as the dielectric tape is the recording medium. However, one tape recorder will be required for use with the low resolution television camera.

5.1.3 Equipment Configuration on the Planetary Scan Platform

The equipment configuration and preliminary specifications for the photo-imaging system are defined in Figure 5-1. The dielectric tape camera and the low resolution television camera will be mounted on the planetary scan platform (PSP) and boresighted. If medium resolution stereo photography is desired, this may be accomplished by more rapid framing (in the panoramic mode) of the dielectric tape camera. Stereo photography may be obtained with the low resolution color television camera by fore and aft pointing of the planetary scan platform, or by obtaining overlapping coverage on sequential orbits.

The total weight of the equipment mounted on the planetary scan platform will be 132 pounds, with a power consumption of 48.5 watts. To these specifications must be added 18 pounds and 2 watts for the single tape recorder which is not mounted on the planetary scan platform, resulting in a total system weight of 150 pounds and total system power of 50.5 watts.

PRELIMINARY SPECIFICATION

Alternate Photo-Imaging System-Dielectric Tape and TV Cameras

Purpose

To provide complete photographic coverage of the planet Mars at low resolution (1 km) in color, mapping of large areas of Mars at medium resolution (100 m), and imaging of selected areas at high resolution (10 m)

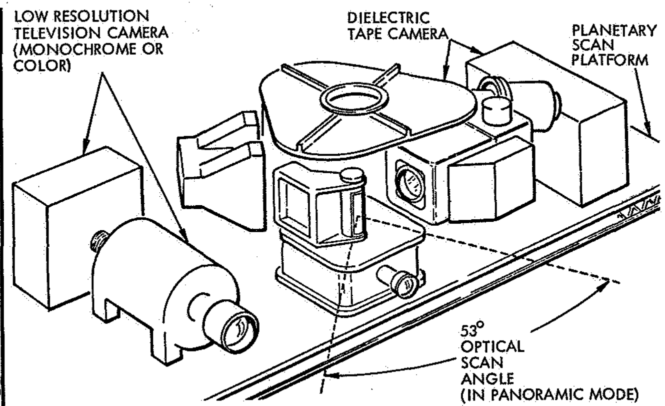
Performance Characteristics

LOW RESOLUTION CAMERA

- Sensor: RCA 1-1/2 inch vidicon with slow scan target
- Field of view: 29 x 29 degrees
- Ground coverage per frame: 500 x 500 km
- Nominal ground resolution: 1 km
- Number of frames per orbit (maximum): 33 frames (11 color pictures)

MEDIUM RESOLUTION CAMERA

- Sensor: RCA 35 mm dielectric tape camera
- Field of View: 10° 35 min. x 10° 35 min. (framing mode)
  10° 35 min. x 53° (panoramic mode)
- Nominal ground resolution: 100 m
- Number of frames per orbit (maximum): 32
- Ground Coverage per Frame: 184 x 184 km (framing mode)
  184 x 1000 km (panoramic mode)



Physical Characteristics

CAMERA EQUIPMENT MOUNTED ON PLANETARY SCAN PLATFORM

Weight:	132 lb
Size:	1.92 ft^3
Power:	75 watts (maximum) 48.5 watts (average)

TOTAL SYSTEM INCLUDING ONE TAPE RECORDER

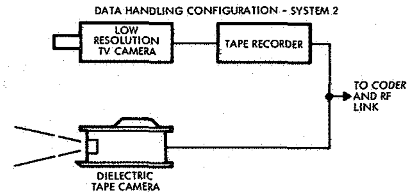
Weight:	150 lb
Size:	2.3 ft^3
Power:	95 watts (maximum) 50.5 watts (average)

FIGURE 5-1

5.1.4 Data Storage

The configuration of the data recording equipment for the photo-imaging system is defined in Figure 5-2. One tape recorder is used to accept the digitally encoded video data from the low resolution television camera. The recorder will have a total data capacity of 4.5 x 10^8 bits using a tape speed of 25 in./sec. Data will be accepted at the nominal rate of 350 kbits/sec. This data stream will then be converted from serial to parallel form and recorded on six parallel tracks at the rate of 58.3 kbits/sec per track, with a recording density of 2300 bits/in. The recorder will have a total tape length of 3000 feet. After filling one side of the tape with six parallel tracks of video information, the tape may be reversed to permit utilization of an additional six parallel tracks.

Note that the maximum amount of data which will be obtained in one orbit (2.8 x 10^8 bits) will utilize only 60 percent of the capacity of the tape recorder. With the tape running continuously, there will be increasing gaps in the recording as the satellite departs from periapsis due to the increase in altitude which results in increased ground coverage, thus permitting greater intervals in recording of adjacent frames.



RECORDER SPECIFICATIONS

CAPACITY	4.5×10^8 BITS
TAPE SPEED	25 IN./SEC
NO. OF TRACKS	14 (6 + 6 FOR VIDEO)
TAPE LENGTH	3000 FT
INPUT DATA RATE	350 KB/SEC

Figure 5-2
DATA HANDLING CONFIGURATION-ALTERNATE PHOTO-IMAGING SYSTEM. Only one tape recorder is required for the low resolution color television camera. The dielectric tape camera does not require a tape recorder, as the dielectric tape is a storage medium.

5.1.5 Mapping Coverage

The mapping coverage obtained by the photo-imaging system in one orbit is defined in Figure 5-3. Note that the lateral coverage of the two subsystems increases with increasing displacement from periapsis due to the corresponding increase in altitude. The maximum coverage obtained by the low resolution television camera in one orbit will be determined by the range of solar illumination angles permissible for color photography rather than by tape recorder capacity. The coverage of the dielectric tape recorder during one orbit is also limited only by the range in solar illumination angles desired for monochrome photography.

During a 6-month lifetime in orbit, with a total data transmission capacity of 2.64×10^{11} bits, the coverage which may be obtained is defined in Table 5-1. Note that complete coverage may be obtained with the low resolution camera in color. The percentage of Mars which may be mapped with medium resolution is 52 percent.

5.2 DIELECTRIC TAPE CAMERA

The dielectric tape camera system is intended to provide medium resolution (100 meters) mapping coverage of Mars. The Mars surface is imaged by means of a scanning mirror and a lens system onto the dielectric tape through a narrow rectangular aperture. The 35-millimeter tape is moved past the aperture slit at a rate that corresponds to the rate of motion of the optical image. The image motion, and consequently the tape motion, is in a direction approximately perpendicular to the direction of satellite motion. Two modes of operation are possible: the frame mode, where the image format on the tape is a square; the panoramic mode, where the

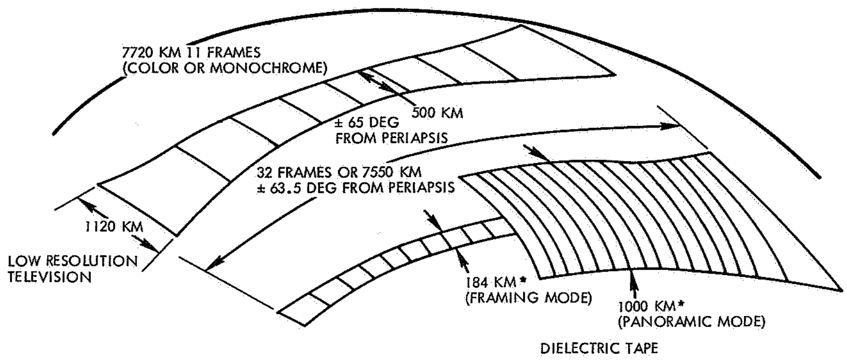


Figure 5-3

MAPPING COVERAGE PER ORBIT ALTERNATE PHOTO-IMAGING SYSTEM. The low resolution television camera will obtain continuous coverage over a ground track length of 7720 Kilometers. The dielectric tape camera will obtain continous coverage over a ground track length of 7550 Kilometers, with a nominal swath width (at periapsis) of either 184 Kilometers or 1000 Kilometers, depending upon whether the framing or panoramic mode is used. The ground tracks are displaced laterally in the illustration for clarity.

Table 5-1. Coverage of Mars Obtained With Color TV and Dielectric Tape Camera*

	Low Resolution TV (color)	Dielectric Tape Camera (Framing Mode)	Dielectric Tape Camera (Panoramic Mode)
Nominal Ground Resolution	1 km	100 m	100 m
Nominal Coverage/Frame	500 x 500 km	184 x 184 km	184 x 1000 km
Bits/Frame (6-bit encoding)	8.58×10^6	1.16×10^8	6.3×10^8
Frames/Orbit (maximum)	11 color pictures (33 frames)	32	32
Data/Orbit (maximum)	2.83×10^8 bits	3.7×10^9 bits	2.02×10^{10} bits
Ground Coverage/Frame (nominal)	2.5×10^5 km^2	3.38×10^4 km^2	1.84×10^5 km^2
Area of Mars	1.46×10^8 km^2	1.46×10^8 km^2	1.46×10^8 km^2
Data Allotment (total data link capacity = 2.64×10^{11} bits/6 mo.)	1.52×10^{10} bits	2.49×10^{11} bits	2.49×10^{11} bits
Number of Frames	585 (color pictures) 1755 frames	1070	198
Percentage of Mars Area Covered	100%	52%	52%

*The ground coverage obtained with the low resolution television camera and the dielectric tape camera over a 6-month period with a total data link capability of 2.64×10^{11} bits is estimated in this table, based upon nominal values of ground coverage at a 1000-kilometer altitude.

image format on the tape is rectangular, providing a swath perpendicular to the satellite motion which is ten times larger than in the frame mode.

5.2.1 Preliminary Specifications, and Principal Performance Parameters

Figures 5-4 and 5-5 give the preliminary specifications and the performance parameters of the dielectric tape camera.

5.2.2 Functional Description

The dielectric tape camera combines the sensor and storage medium and therefore has several important system advantages. It is capable of obtaining more data by an order of magnitude than other TV systems. Compared with photographic systems, the dielectric tape is immediately available for readout without processing, is reusable, and is an order of magnitude more radiation resistant.

5.2.3 Dielectric Tape

A cross-sectional view of the 35-millimeter dielectric tape is shown in Figure 5-6. The base material employed is Cronar, a specially processed Mylar having good optical properties. The edges of the Cronar are folded to prevent contact of the center area of adjacent layers when the tape is rolled on takeup reels. A very thin metallic layer is evaporated on the base material. At the edges of the tape the metallic coating is made relatively thick to permit electrical contact to one side of the photoconductor. The photoconductor, which may be of a conventional type, is evaporated on the thin portion of the metallic coating and is, in turn, overcoated with a thin polystyrene insulating layer. (Polystyrene has been chosen as the insulator since it combines the desirable properties of long information storage time and relatively straightforward processability.)

The photoconductor may be exposed through the insulator, which is transparent, or through the base material and metallic coating, which is semitransparent. In this camera, exposure takes place through the insulator. Exposure, or writing, consists of the transferring of the optically induced array of varying photoconductor resistance into an equivalent electrical charge pattern on the insulator. In summary, writing is accomplished by the simultaneous exposure to both light and electrons.

PRELIMINARY SPECIFICATION

Dielectric Tape Camera System

Purpose

To provide medium resolution photographic coverage of the Martian surface. Can be used in either the framing or panoramic mode.

Performance Characteristics

SENSOR

RCA space qualified Nimbus dielectric tape camera upgraded to incorporate an RCA 4-1/2 inch I-O gun.

FORMAT

35 mm dielectric tape 100 ft long image format (framing) mode 18.4 mm x 18.4 mm) (panoramic mode 18.4 mm x 100 mm)

Tape resolution:
100 lp/mm (1840 lp/width)

Optics:
Focal length 100 mm, f/2.5

Resolution elements/frame
Framing mode:
$1.9^4 \times 10^7$ (3680 samples/lines; 5260 lines, using a Kell factor of 0.7)

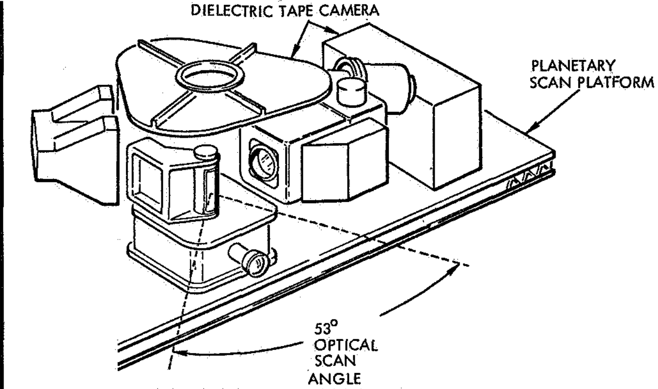
Panoramic mode:
1.05×10^8 (3680 samples/line; 28,500 lines, using a Kell factor of 0.7)

Bits/Frame (6 bit encoding)
Framing mode: 1.16×10^8
Panoramic Mode: 6.3×10^8

Bits/inch of tape: 8×10^7

Effective exposure time: 35 msec

Tape writing speed: 1.345 in./sec (18×10^6 ,elements/sec)



Tape reading speed - Adjustable to communications link capability; at 18,000 bits/sec this would be 1.8 hr/frame or 18,800 sq km coverage/hour

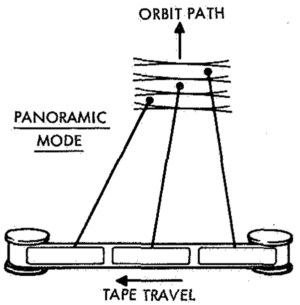
Tape dynamic range: 0.003 to 0.1 ft-c-sec

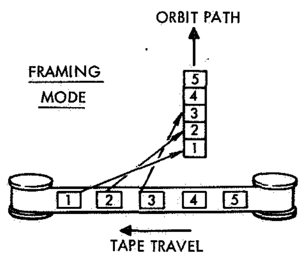
IMC requirement: 30 percent accuracy; IMC value calculated from orbital data.

Physical Characteristics

Size:	camera enclosure	24 x 15 x 7.5 in.
	electronics	13 x 6 x 6 in
Weight:	camera enclosure	91 lb
	electronics	19 lb
Power:	picture taking	25 watts
	read-out	50 watts
	stand-by	6 watts

FIGURE 5-4





GENERAL DESCRIPTION

CONFIGURATION: DIELECTRIC TAPE CAMERA TO BE MOUNTED ON THE PLANETARY SCAN PLATFORM AND BORE-SIGHTED WITH A COLOR TELEVISION CAMERA. OPTICS INCLUDE A SCANNING MIRROR. THE SCANNING MIRROR CAN ALSO PROVIDE IMC. THE TAPE MOTION IN THE FRAMING MODE CAN BE USED FOR COARSE IMC. STEREO COVERAGE CAN BE OBTAINED BY TAKING TWO PICTURES OF THE SAME AREA AT APPROPRIATE FORE AND AFT ANGLES

ANTICIPATED PERFORMANCE

	FRAMING MODE	PANORAMIC MODE
• GROUND RESOLUTION/OPTICAL LINE-PAIR (AT PERIAPSIS)	100 M	100 M
• SENSOR RESOLUTION	100 LINE PAIR/MM	100 LINE PAIR/MM
• GROUND COVERAGE/HORIZONTAL SCAN LINE (AT PERIAPSIS)	184 KM	184 KM
• GROUND COVERAGE/FRAME (AT PERIAPSIS)	184 × 184 KM	184 × 1000 KM
• FORMAT	18.4 × 18.4 MM	18.4 × 100 MM
• OPTICAL FIELD OF VIEW	10°35' × 10°35'	10°35' × 53°
• SCAN LINE/FRAME (KELL FACTOR = 0.7)	5260	28,500
• RESOLUTION ELEMENTS/FRAME	$1.9A \times 10^7$	1.05×10^8
• BITS/FRAME (6-BIT PCM CODING)	1.16×10^8	6.3×10^8
• FRAMES/ORBIT (NOMINAL)	32	32
(LIMITED BY AREAS OF GROUND TRACK WITH PROPER SUN PHASE ANGLES)		
• TOTAL DATA/ORBIT	2.32×10^9 BITS	1.51×10^{10} BITS
• TRANSMISSION TIME (50K BITS/SEC)	18.5 HRS	112 HRS
• TOTAL STORAGE CAPACITY (100 FT OF TAPE)	9.6×10^{10} BITS	9.6×10^{10} BITS

Figure 5-5
DIELECTRIC TAPE CAMERA SYSTEM-PRINCIPAL PERFORMANCE PARAMETERS.

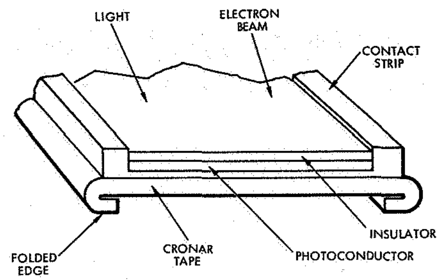


Figure 5-6

CROSS SECTION OF THE DIELECTRIC TAPE. The Dielectric tape consists of a photoconductor deposited upon a Cronar base. The photoconductor is charged with an electron beam. The charge pattern is modified by the incident illumination, due to the leakage due to photoconductivity. Scanning of the resultant electron image is performed by an electron beam.

The writing process is shown schematically in Figure 5-7. A rectangular slit defines the area of both optical and electron exposure. The slit also establishes the desired potential gradient in the immediate vicinity of the tape. As the tape is exposed optically, it is flooded with a 500-volt electron beam. Secondary electrons in excess of the number of primary beam electrons (the ratio of secondary to primary electrons is about 1.3) are emitted and collected by the slit which is operated at a potential positive with respect to the tape. The insulating surface of the tape then incurs a net loss of electrons and charges positively with respect to the metallic backing. The areas of the tape exposed to relatively bright light charge more positively than the low light areas. The potential difference established on the tape is of the order of 3 to 5 volts.

The cross section of tape used is 0.76 inch, some 34 mils of this dimension being reserved for optically inserted black information. The width of simultaneous electron and optical contact is 12 mils. Since the tape moves at 0.357 in./sec, the exposure time is 34 milliseconds.

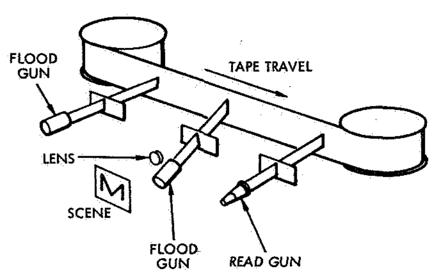


Figure 5-7

DIELECTRIC TAPE OPERATIONAL PROCESS. Three electron guns are used in the camera. The first neutralizes the Dielectric tape. The second scans the tape as the electron charge on the tape is modified by photoconductivity resulting from the incident illumination. Scanning is performed by a finely focused reading gun.

The reading process consists of converting the charge pattern on the insulator into an electrical output signal. A finely focused electron beam, from a 4 1/2-inch image orthicon gun, is employed for this purpose. As the beam strikes the insulator surface with relatively high velocity (about 350 volts), secondary electrons will be emitted with a range of initial velocities. The bulk of the secondary electrons will have a velocity spread in the order of 5 to 10 volts. Superimposed on the velocity spread will be the velocities attributable to the charge pattern on the tape. A collecting slit close to the tape is employed to separate the electrons according to their velocities and thus provide the output signal.

A somewhat idealized transfer function which may be employed to mathematically describe the readout mechanism is shown in Figure 5-8. If the collecting slit is made sufficiently positive, all secondary electrons will be collected. The slit current is then given by δI_b, where I_b is the primary beam current and δ is the secondary emission ratio. If the collecting slit is sufficiently negative, all secondary electrons will be repelled and the slit current will be zero. Between these two extremes, some portion of the secondary electrons will be collected. The output signal i_o is then given by

$$i_o = \frac{\delta I_b \, \Delta V}{k}$$

where ΔV is the difference of potential of two areas of the tape and k is a constant determined by the efficiency of the readout mechanism. For this camera, where the peak value of ΔV is 5 volts and k is about 13 volts, a beam current of 100 nanoamperes produces an output signal of about 50 nanoamperes.

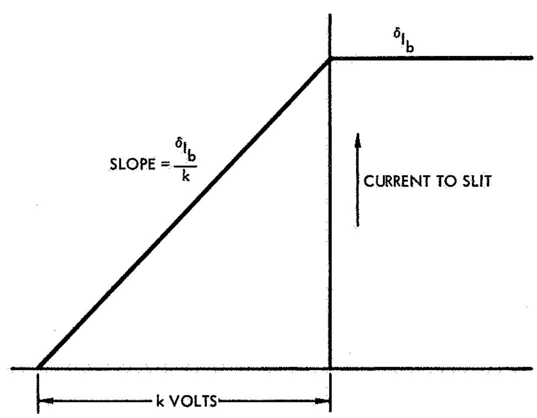


Figure 5-8

IDEALIZED TAPE TRANSFER FUNCTION. The output signal of the Dielectric tape is a linear function of the differential voltage of the electron charge pattern on the tape.

The output signal is accomplished by an output noise component of about 0.3 nanoampere composed of noise due to the secondary emission process and to primary beam noise. In addition, the preamplifier employed in the camera contributes about 0.5 nanoampere of noise. The total rms noise is therefore about 0.6 nanoampere resulting in an output signal-to-noise ratio (peak-to-peak signal to root-mean-square noise) of about 38 decibels.

A third process is required for tape operation. Prior to writing new information, a uniform tape potential must be established. This is accomplished by contacting the tape with a relatively uniform beam of electrons. The electron flooding is accompanied by exposure to light to hasten the prepare process. As is the case for both writing and reading, exposure takes place through a disk containing a rectangular aperture which, together with the tape speed, defines the prepare-exposure time. Since preparation is accomplished just prior to writing, the tape is moving at the write speed of 0.357 in./sec. The slit dimension is 40 mils, resulting in a prepare time of 110 milliseconds.

An additional difference exists between prepare and write. During prepare, the disk potential is made negative with respect to the initial tape potential. This results in a charging current equal to the beam current. As the tape approaches the disk potential, the charging current approaches zero. At equilibrium, the secondary electron current collected by the disk is equal to the primary beam current. By contrast, the disk potential is positive for writing and equilibrium is not reached. Consequently, the charging current is given by ($\delta I_b - I_b$) the difference between the secondary and primary current.

5.2.4 Electron Guns

The two flood guns used for writing and preparing are structurally identical. The gun used is the special 4.5-image orthicon return beam gun specially developed by RCA. This gun and the necessary deflection coils weigh 27 pounds and consume 20 watts of power. This combination of components is able to produce the resolution of 100-line-pair/mm.

An innovation involving the use of a directly heated cathode has been employed in these guns. The usual indirectly heated oxide cathode exhibits poor life under the relatively dirty vacuum conditions in the tape camera (high temperature bakeout of the camera is prevented by the low tolerance to heat of Mylar and other materials used in tape fabrication). The cathode consists of a tungsten-rhenium wire 2 mils in cross section by 0.3 inch in length. The power required for the cathode is less than 1 watt. At a nominal operating temperature of $2100^{\circ}K$, the computed life is in excess of 10,000 hours. Several experiments have been performed which tend to confirm the computations for the expected operational cycling.

The light which is produced by the directly heated cathode is adequate to serve as the light source for the prepare process. The exposure during prepare is in excess of 3 footcandle-seconds, some 30 times greater than the normal highlight exposure during writing. The light from the cathode is undesirable during writing, and the beam is deflected by an angle sufficient to eliminate any possibility of interference with the desired optical exposure.

The flood gun structure has been strengthened, employing many of the techniques previously applied to electron guns intended for space applications.

The read gun is similar to the strengthened gun used in the Ranger and Nimbus cameras. The primary difference is in the cathode where the directly heated tungsten-rhenium wire is employed. The positional accuracy necessary for this cathode is significantly more stringent than that of the flood guns. In order to obtain the desired accuracy, the cathode wire is spring-loaded and fired prior to positioning in the grid cup assembly.

The gun is otherwise operated in rather conventional fashion with an electromagnetic deflection and focus yoke. However, the beam lands with high velocity (about 350 volts), so that the beam alignment coils are not necessary. In addition, the vertical deflection winding is employed for centering only, the equivalent of vertical deflection being supplied by the tape velocity.

5.2.5 Circuit Functions

A functional block diagram of the camera electronics is shown in Figure 5-9. The major circuit functions employed for the two normal operational modes are included in this diagram. The circuits operative during the write mode (dark shading in the figure) include command and control, motor drive, logic and time code, and electron gun circuitry. A portion of these circuits are shared, in time sequence, during the read mode (shown partially shaded). In addition, the circuits required to operate the read gun and amplify the video output signal are activated during the relatively short read cycle.

Starting with a write command, which may be either obtained from information in the spacecraft or issued from a ground station, the time sequence is as shown in Figure 5-10. During the first 30-second interval, power is supplied to the filaments of the prepare and write guns, the iris motor is connected to the motor drive amplifier, the iris servo is actuated and the iris is adjusted to provide the desired exposure, and all write circuits achieve stable operation conditions. At the conclusion of the 30-second warmup interval, the picture-taking cycle commences with the turn-on of the tape and mirror motors by the control circuitry.

Frame synchronization commences as the mirror reaches the end of the scan interval. Coincident with the end of scan, an electro-optical switch S2 is activated. This switch initiates shutter closing (to block the main optical path), turn-on of the iris servo, and mirror flyback. The instrumentation pattern is written on the tape between the actuation of the switch and the beginning of the time-code interval. Time-code writing starts with the beginning of the next 1-second time-code sequence as determined by the spacecraft clock. A second instrumentation interval follows the completion of time code, lasting until 2 seconds have elapsed since switch activation.

During the 2-second interval, the mirror will have returned, been reversed to a reference position, stopped for a brief interval, and (coincident with a precise timing signal) started in the forward direction. The

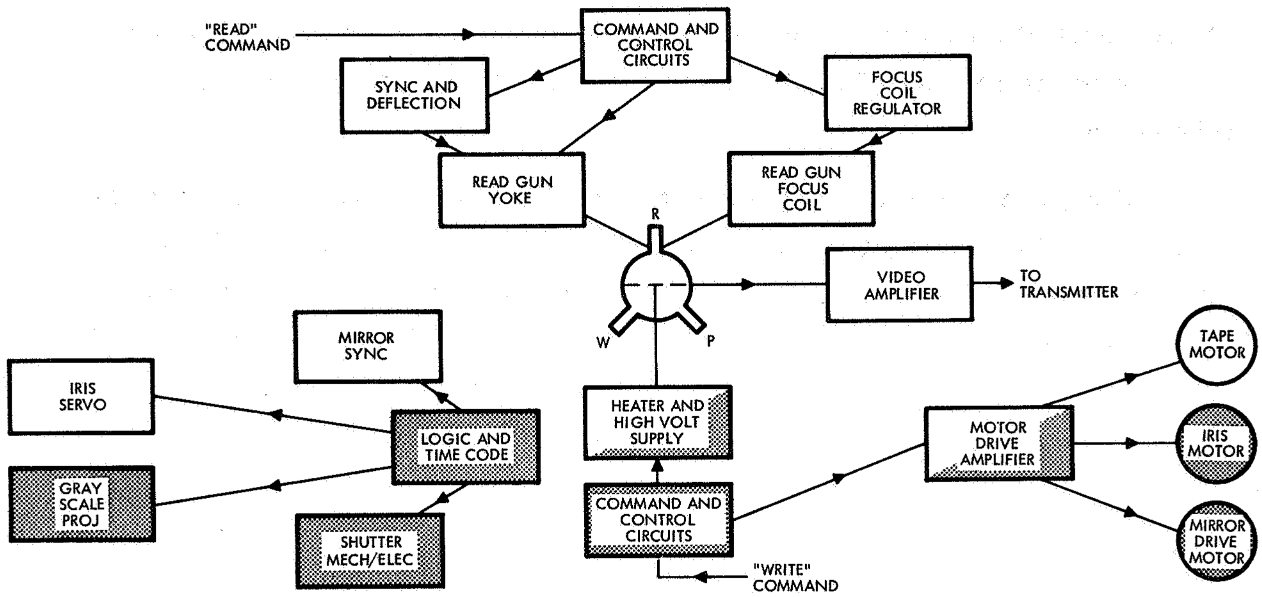
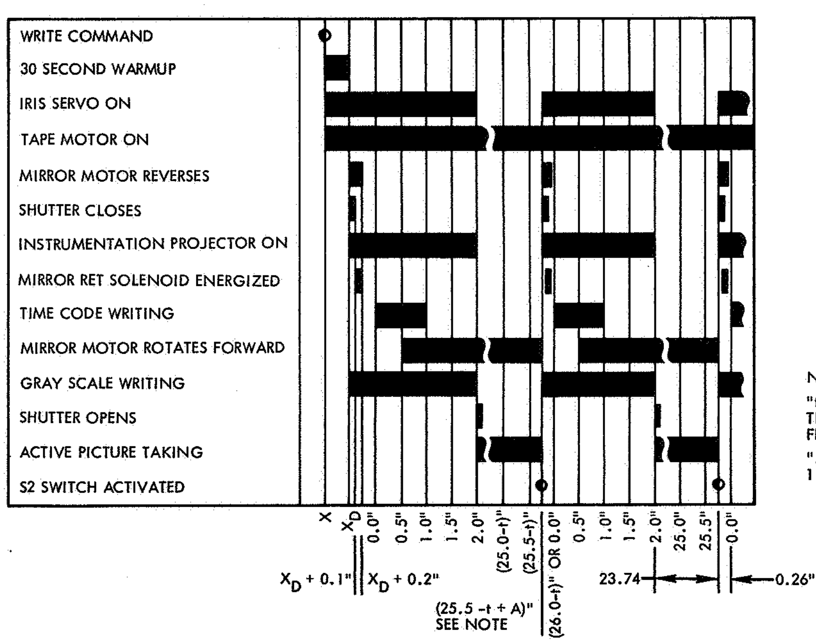


Figure 5-9
FUNCTIONAL BLOCK DIAGRAM OF CAMERA ELECTRONICS.



NOTE:
"t" IS THE TIME REQUIRED FOR THE MIRROR TO ROTATE FROM THE REFERENCE STOP TO THE POSITION WHERE THE FIRST FRAME BEGAN IN THE ABOVE WRITE MODE.
"A" IS A VARIABLE RELATED TO THE TIMING BETWEEN S2 AND 1 CPS

Figure 5-10
WRITE MODE TIMING DIAGRAM.

start of mirror scan precedes the start of picture taking to allow the mechanism to reach the desired velocity and initial angle. The opening of the shutter then starts the picture-taking interval. Shutter opening also marks the turn-off of the projector and the deactivation of the iris servo.

The picture-taking sequence will ordinarily continue until the spacecraft nears the daylight-to-dark transition. At about the transition time, information will be fed, via the logic, to the control circuitry to turn off the camera. Alternatively, the picture-taking cycle will continue until actuation of an end-of-tape sensor on the transport mechanism. This sensor generates the proper signal for camera turn-off.

The readout of information stored on the tape will be initiated by command, issued by the ground station. As in the case of a write command, the first 30 seconds are employed for filament warmup. During this interval, power is applied to all read-mode circuitry: timing circuitry, read-gun power supply and deflection, preamplifier and processing amplifier, motor power amplifier, and appropriate logic and control circuitry.

One additional circuit function is active only during the 30-second warmup interval. A calibration pulse, fed to the video preamplifier, serves as a check on video channel performance independent of the camera output signal. This check provides information on frequency response and overshoot as well as video channel gain.

A functional block diagram of the read-mode electronics is shown in Figure 5-11. For simplicity, the logic and control and the switching circuitry is not shown. Synchronization of the appropriate circuitry, including the chopper supplies, is derived from the precise 5-kilocycle clock signal, via the self-contained interface and pulse generator circuitry. The choppers are synchronized at one-half the 2500-cycle scan rate. Transitions in the power-supply circuits then occur during the video blanking interval. The effect of stray feed from these circuits on the video signal is thereby minimized.

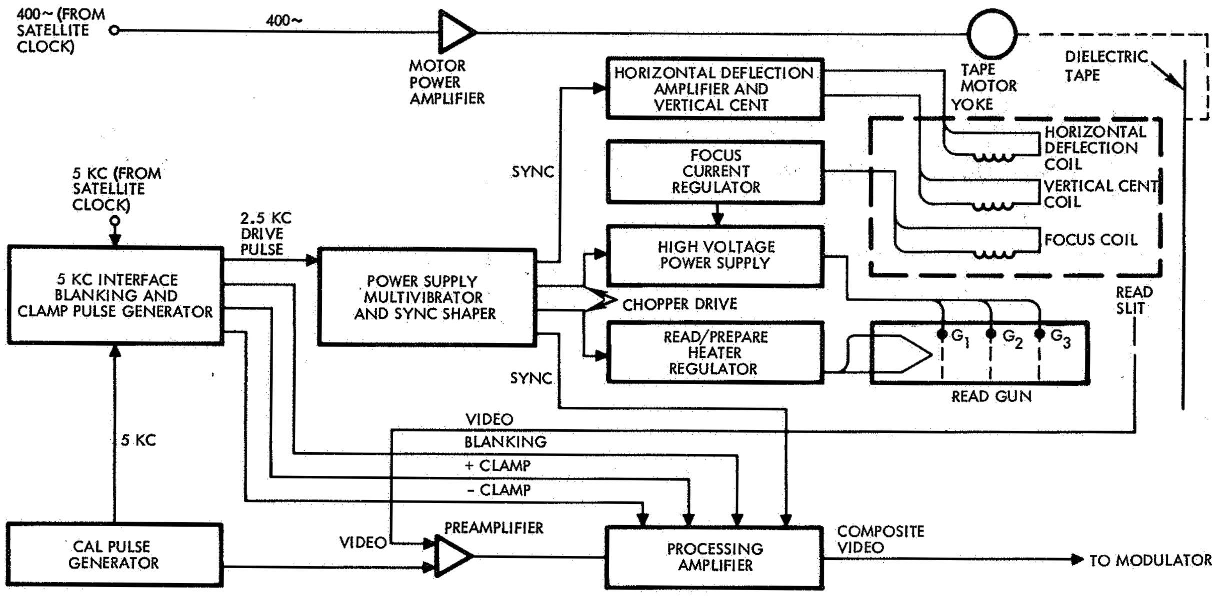


Figure 5-11
READ MODE FUNCTIONAL DIAGRAM

The focus current regulator, the high-voltage supply, and the read-gun filament regulator are all precision DC supplies. These circuits have been checked and performance-proved under varying temperature and supply voltage and are relatively immune to interfering signals on the input supply line.

During the read mode, the tape is scanned at a rate of 2500 lines per second. Of the 400 microseconds per line, 85 percent is devoted to picture information. The video signal from the read slit, as shown in Figure 5-12, is fed to the video preamplifier. In addition to video information, this signal contains black information (optically inserted) at the start of each scan-line interval. After preamplification, the signal is fed to the processing amplifier where DC is reinserted by a symmetrical keyed clamp. Blanking and sync are then added to the signal which is DC-coupled to the output. The composite video also contains a front and back porch interval to assure noise-immune operation at the ground station. White and black level clippers are also incorporated to prevent any spurious signal from extending beyond the normal black-to-white video excursion.

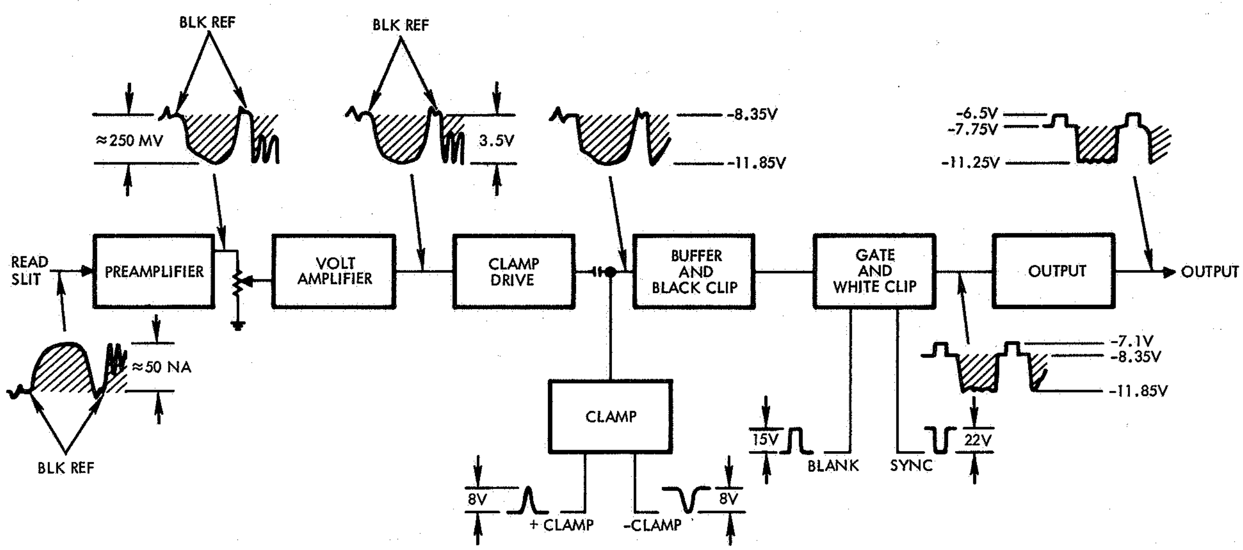


Figure 5-12
VIDEO CHANNEL BLOCK DIAGRAM.

The preamplifier is mounted on the camera enclosure close to the read slit to provide reduced susceptibility to stray pickup. Sufficient gain is provided in the preamplifier so that the signal may be fed to the processing amplifier, located in the electronics modules, at a level high enough to assure noise-free operation. The preamplifier output signal is approximately 0.25 volt from a 50-ohm source impedance.

5.2.6 Physical Description

5.2.6.1 Electronic Components

The electronics are packed in modules. The assembly consists of 6 1-inch frames with a structural separation in the center of each frame. The boards are mounted back-to-back in each frame, with components on the outside and wiring on the inside of each board. Each frame contains four boards plus four connectors. Some large components such as transformers extend through more than one module frame. Interconnection wiring between boards located on different frames is accomplished via the connectors on each frame and do not extend through the internal portion of the package. Therefore, the frames are readily separable for measurement or debugging.

Components are mounted in conventional fashion with terminals and hand wiring. All wiring and components are fastened with epoxy or urethane for mechanical strength and are conformally coated.

5.2.6.2 Mechanical Components

The camera enclosure is machined from solid-stock aluminum. The enclosure is roughly triangular in outline and consists of three compartments. The largest of the three compartments contains the tape transport and dielectric tape. This compartment, which must sustain vacuum during camera operation, is sealed on the large opening side by a machined cover and O-ring. The O-ring sits in a contoured groove in the cover and is mounted against a ground seat on the enclosure.

The openings in the sides of the enclosure provide access and mounting surfaces for the optical input and electron guns, the vacuum pump, and the combination roughing-port and seal-off tube mount. The magnetic coupling is mounted on the wall separating the large compartment and the small compartment directly below. This coupling provides the means for transmitting torque through the vacuum wall. The high-speed components of the transport mechanism are located on the lower side of this wall in the small pressurized compartment.

The third enclosure compartment is also pressurized. This compartment contains the lens, the lens mount, iris drive mechanism, and shutter. The scanning-mirror mechanism is mounted on a precision-machined surface in front of the lens compartment. The reflected light from the scanning mirror passes through glass sealing windows in the entrance and exit side of the compartment. The third and major opening in the compartment is sealed with a machined cover, contoured groove, and O-ring.

5.2.6.3 Optical Components

The dielectric tape camera employs two optical systems: a picture-taking system and a calibration-instrumentation system. The picture taking system functions to image a section of Mars on the dielectric tape. The function of the calibration-instrumentation system is to place an image of gray scale and bar pattern on the tape. These are used as an aid in system calibration and to monitor systems operations, and to provide synchronizing information to the ground station. The elements which make up the picture-taking system are shown in Figure 5-13. The optical arrangement of the calibration-instrumentation system is shown on Figure 5-14. The approximated required focal length F of the lens is computed from the relationship

$$F = H. \frac{N_R}{R_G}$$

where

H is the orbiting altitude

N_R is the dimension of a tape resolution element

R_G is the dimension of a ground resolution element

The camera would employ a lens of F = 100 millimeters with a maximum aperture of f/2.5.

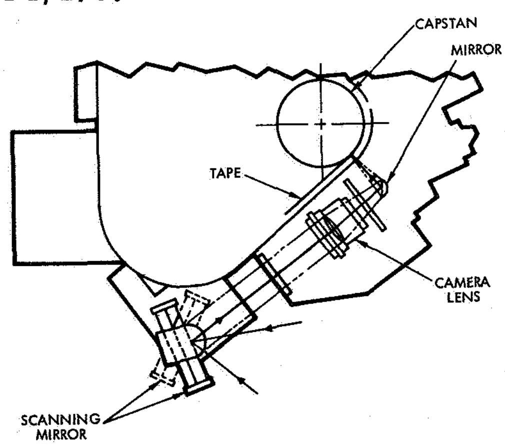


Figure 5-13
ELEMENTS OF PICTURE TAKING SYSTEM for framing photography, the scanning mirror may be used for pointing. For panoramic photography, the scanning mirror would be used in a lateral scanning mode.

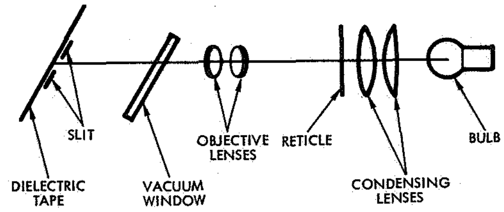


Figure 5-14
OPTICAL ARRANGEMENT OF CALIBRATION-INSTRUMENTATION SYSTEM. An internal gray scale is used for calibation of the photometric response of the dielectric tape in conjunction with photography of the Martian surface.

The tape sensitivity, the tape rate, the scene brightness range (150 - 800 foot-lamberts) combine to determine the range of lens aperture employed. The maximum aperture employed will be f/2.5, the minimum f/19.3. This design allows picture taking over a 25 to 1 range in scene brightness and should provide good quality coverage near periapsis for most of the orbits envisioned in the mission.

The shutter is located adjacent to the lens in the same pressurized compartment. Pressurization here eliminates concern for lubrication of moving components in vacuum.

The shutter consists of a thin aluminum leaf, pivoted and counterbalanced so as to be easily moved by opposing solenoids. A common plunger is employed, being alternately attracted by the appropriate solenoid. A very light detent maintains the shutter in the desired position.

The shutter serves to block the main optical path for the 2-second period between active mirror scans. For one half of this time, time-code information is written on the tape. For the other half of the interval, the instrumentation optical system images the gray scale and bar pattern on the dielectric tape. The optical arrangement for this system, shown in Figure 5-14, consists of a back-to-back doublet of 4-inch focal length, a patterned reticle, a condensing lens system, and lamp.

5.2.6.4 Tape Transport

The 35-millimeter folded-edge tape is stored on and exchanged between two coplanar reels as shown schematically in Figure 5-15. During passage between the two reels, the tape passes around the tape drive system and one idler roller. Although it is generally desirable to minimize the number of elements which contact the tape (the two reels and capstan representing the minimum), inclusion of the idler roller appears to be well justified. The roller is desirable for three main reasons. First, it increases the angle of wrap around the capstan and provides sufficient traction to eliminate the need for pressure rollers. Second, it provides a constant angle of tape approach to the capstan, despite the changing tape radius on the reel. Third, it allows a rolling mechanism to contact the raised metal edges of the tape. (The thin metallic strip is

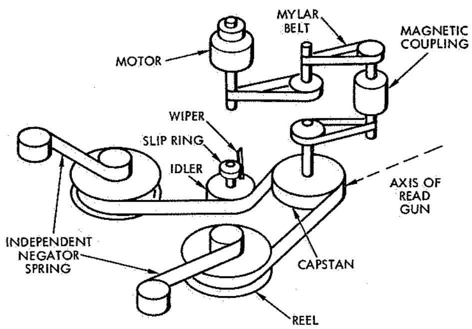


Figure 5-15
TAPE TRANSPORT MECHANISM. The motor drive mechanism is magnetically coupled to the tape transport mechanism through the vacuum wall interface.

thereby not exposed to the abrasive action of sliding brushes.) The roller is electrically isolated from the transport, contact being made by multiple wipers on a surface especially designed for this purpose.

The coplanar reels are torqued by independent tapered negator springs. These springs maintain constant positive tape tension, independent of electrical power, providing continuous traction between the capstan and the dielectric tape.

The capstan shaft is driven by a Mylar belt from the vacuum side of a vacuum-wall interface coupling. After consideration of various interface drives, a magnetic coupling was selected as most suitable for this application. On the opposite side of the vacuum wall, the input shaft of the coupling is also Mylar-belt-driven by the transport drive motor.

All the components on the outer side of the vacuum wall are contained in one of the sealed, pressurized compartments. The sealing techniques employed for these compartments represent a conservative design. Starting with one atmosphere absolute pressure and based on measured leakage rates of less than 1×10^{-4} cm^3/sec, a predicted acceptable compartment pressure of more than 0.1 psia will be maintained for more than 20 years.

5.2.6.5 Scanning-Mirror Mechanism

The operating components of the mirror mechanism are illustrated in the schematic of Figure 5-16. As in the case of the tape transport, the high-speed components of the mechanism are maintained at atmospheric pressure to ensure satisfactory lubrication. The prime mechanical power source is a synchronous gearhead motor. Further speed reduction is

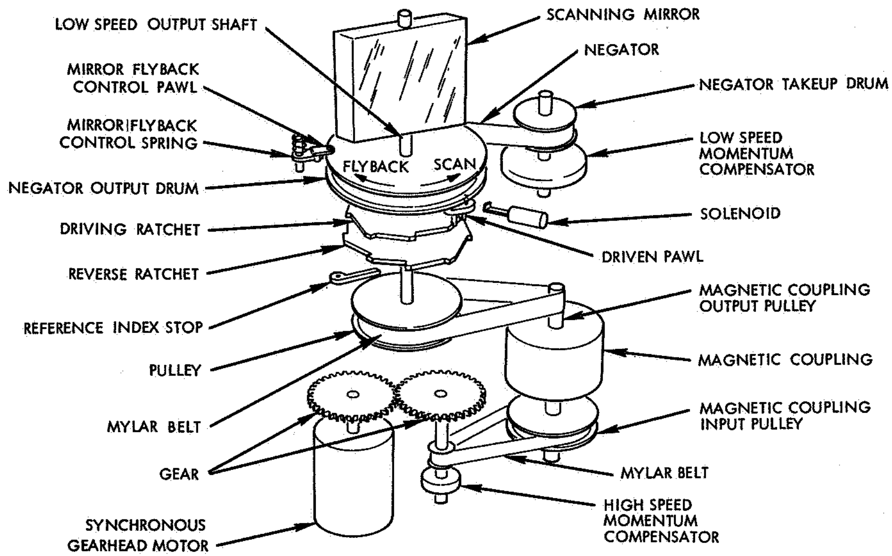


Figure 5-16
SCANNING MIRROR MECHANISM.

obtained from one precision gear mesh and an initial Mylar-belt stage. The driven pulley of this belt stage is on the input shaft of a magnetic coupling. A final speed reduction is obtained by a second Mylar-belt stage at the output of the magnetic coupling.

The components on the output side of the magnetic coupling form the low-speed section and will be subjected to space environmental conditions. The belt drive of the low-speed section rotates a pair of directly coupled opposite-faced ratchets. The seven-toothed drive ratchet rotates the mirror shaft by means of a pawl which is radially spring-loaded against the ratchet teeth. The mirror shaft, itself, is torsionally spring-loaded in a direction opposite to the drive-ratchet scanning motion by a constant-torque negator spring. As the drive ratchet turns, the mirror shaft is rotated through its required scanning angle of 26.5 degrees, intermittent motion being obtained by decoupling the mirror shaft from the drive ratchet. Upon disengagement, the negator-spring torque rotates the mirror shaft in the reverse direction, thus returning the mirror to its starting position where it will be reengaged by the next drive-ratchet tooth.

The decoupling of the mirror shaft from the drive ratchet is accomplished by withdrawing the spring-loaded pawl from engagement with the ratchet tooth. An electrical impulse derived from the mirror-shaft positional information activates a solenoid, retracting a plunger, which pulls the pawl out of engagement. The velocity of mirror flyback is controlled by opposing the constant-torque negator with a torsion spring. The torsion spring is decoupled near the end of flyback and is not connected during active scan.

Synchronization of the mirror to the clock-reference time base is achieved by interrupting the ratchet forward motion and restarting at a known reference angular position. At the time that the mirror has reached its extreme scanning position, the synchronous motor reverses the drive ratchet so that the reverse ratchet comes to rest on a reference stop. This reverse motion is not be be confused with the mirror flyback motion. Although both reversals of motion occur at approximately the same time, they are completely independent. The ratchet reversal involves a fraction of a degree while the mirror flyback encompasses 26.5 degrees. The reversal of the drive ratchet is achieved by applying a brief reversal signal to the synchronous motor. A satellite clock signal is used as a reference for restarting the motor in the forward direction, thus synchronization is achieved once each mirror scan.

5.2.6.6 Magnetic Coupling

The two magnetic couplings used in the camera system represent particularly important mechanical components. The need for transmitting torque through a vacuum wall is essential for maintaining long-lived components within the enclosure, as well as in the pressurized compartments. Satisfactory operation of cathodes and dielectric tape depends on the vacuum environment, while outgassing of motor components (even if nondestructive) could present an intolerably high pump load. In addition, the uniformity of motion of both the transport and the mirror mechanism, and consequently the picture quality, depend in part on the performance levels of their respective couplings.

The magnetic configuration of the coupling consists of a radial array of eight pairs of magnetic poles. Both inner and outer magnets are single pieces of Alnico V, cast integrally with their salient poles. The wall material separating the poles is 10-mil stainless. It is, of course, desirable that this separating cylinder be magnetically transparent.

The stiffness of the magnetic configuration, together with the pulley reduction from capstan to coupling output shaft, results in an average load of less than 2 percent of the slippage load. The angular displacement between input and output shaft due to variations in loading are estimated to be extremely small. In effect, then, the output shaft is "locked" to the input shaft.

5.2.6.7 Vacuum Pump

The camera system contains an integrally mounted Vac-ion pump. This pump maintains vacuum during prelaunch testing and is intended to maintain vacuum during orbit. In-orbit operation is necessary because of present uncertainty as to the vacuum level in the immediate vicinity of the spacecraft. Outgassing of the spacecraft structure and components may cause the pressure level to exceed the desired camera pressure of 10^{-6} Torr. In addition, the nature of the gas molecules, unless carefully controlled, might cause contamination of the tape and gun cathodes. (Some random interchange of molecules takes place in both directions when an opening exists between volumes having a pressure differential.)

The high voltage supply which powers the pump is mounted adjacent to the pump. The supply provides 3000 volts at no-load, with a short-circuit current of 25 milliamperes. Except for starting and bakeout, the supply capacity is significantly in excess of the pump requirement. At 25 degrees Celsius, the pump draws about 50 microamperes and increases with temperature to about 1 milliampere at 55 degrees Celsius.

Both the pump and power supply are strengthened and have been tested successfully under severe environmental conditions. However, the combined weight of approximately 9 pounds and the normal power drain of 6 watts represent a significant portion of the total weight and power of the system. It is anticipated that, as more data is accumulated on the pressure environment in the vicinity of the spacecraft, both components may be replaced by a suitable controlled aperture for orbiting operation.

5.3 INTERFACES, DIELECTRIC TAPE CAMERA

The input commands and the telemetry channels are given in Table 5-2. The corresponding data for the color television camera has been defined in Section 3.2.

Table 5-2. Dielectric Tape - Input Commands and Telemetry Channels*

Input Commands (representative)

Turn-on and warmup	Digital 1 Bit
Operate shutter	Digital 1 Bit
Scan and record	Digital 1 Bit
Erase and neutralize tape	Digital 1 Bit
Focus lens	Digital 1 Bit
Set iris opening (6 positions)	Digital 3 Bits
Internal calibration	Digital 1 Bit
Change mode (frame/panoramic)	Digital 2 Bits
Tape speed	Analog - equivalent to about 7 bits
IMC	Analog - equivalent to about 7 bits

Telemetry Channels

Output Number	Function
1	Peak White Monitor
2	Sync Tip Monitor
3	Focus Current Monitor
4	Presence of Time Code
5	Presence of -24V on Y Bus
6	At Read End of Tape
7	Presence of -24VD
8	Sync Signal Monitor
9	Blanking Signal Monitor
10	Vac-ion P.S. Current Monitor
11	Follow Pot Position
12	Presence of -24VC
13	Horizontal Output Monitor
14	Temperature of Camera Housing
15	Temperature of Power Supply Housing
16	Temperature of MPA Heat Sink
17	P-P Video Monitor
18	-10V Monitor
19	S2 Lamp Current Monitor
20	Presence of 1 Hz
21	Presence of -24V on X_D Bus
22	At Write End of Tape
23	Presence of -24VB
24	Solar Pot Position
25	Heater Voltage Monitor
26	P.S. Multiplexer Output Monitor
27	Clamp Monitor
28	Presence of 5 kHz
29	3 kv Monitor
30	Presence of either 100 or 400 Hz
31	Horizontal Sawtooth Monitor
32	Temperature of Horizontal CRT Area
33	MPA 60V Output Monitor
34	Indicates that 8-pole Field of Tape is in Circuit
35	Presence of -24V on YD Bus

*The preceding telemetry outputs are provided for in the present tape camera system. The telemetry data handling system should have the following characteristics:

1) Readings will be required twice per operating cycle, i.e., once during write and once during readout.
2) The minimum sampling rate can be once per 16 seconds.
3) The accuracy of measurement can be ±5 percent.

6. COMPARISON OF PHOTO-IMAGING SYSTEMS

The performance characteristics and capabilities of the photo-imaging system described in Sections 3, 4, and 5 have been limited by different kinds of constraints for different system configurations and different performance characteristics. A direct comparison of the performance figures, therefore, does not fully indicate the relative advantages and disadvantages of the systems with respect to specific performance criteria. This section analyzes the performance characteristics of the systems with respect to some of the more important of these criteria.

6.1 COVERAGE AND RESOLUTION

Coverage and resolution are intimately related in that, for the same total number of data bits, coverage is proportional to the square of the resolution length. This relationship is illustrated in Figure 6-1. The total area of the surface of Mars is 1.46×10^8 km^2. It takes about 5×10^9 bits to cover the area of Mars at a resolution of 1000 meters, about 5×10^{11} bits to cover it at a resolution of 100 meters, and 5×10^{13} bits

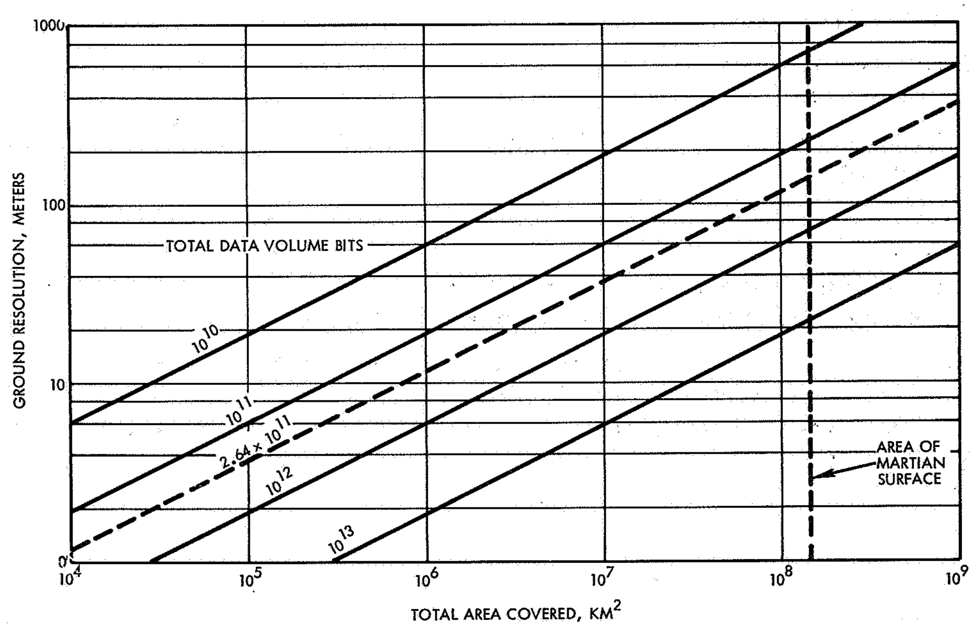


Figure 6-1
RESOLUTION VERSUS AREA. The area covered is proportional to the square of the resolution.

at 10 meters. A more subtle relationship also exists in the fact that broad coverage implies imaging from orbital positions appreciably away from periapsis. The higher altitudes involved result in poorer resolution. All the performance figures given previously have been based on periapsis photo-imaging, with no redundancy and no overlap. The effects of off-periapsis photo-imaging will probably about balance realistic amounts of overlap as far as coverage is concerned. It is evident from Figure 6-1 that the total amount of data that can be transmitted will limit the possible coverage in many cases. In Table 6-1, which is a recapitulation of data given in the individual descriptions of the photo-imaging systems, this is true for the medium and high resolution coverage of the recommended and alternate systems, but not for the other cases. This is discussed in more detail in the succeeding paragraphs.

Table 6-1. Percent Photo Coverage of Mars

		Total Coverage	
	Hypothetical System (%)	Recommended System (%)	Alternate System (%)
Low Resolution Color Mapping (1000 m)	100	100	100
Medium Resolution (100 m)	33	26*	52*
High Resolution (10 m)	0.074	0.26**	Not proposed

*Medium and high resolution coverage is limited by transmission capability for the recommended and alternate systems.

**Equal transmission time has been assigned to medium and to high resolution. If only medium resolution photography were transmitted, as in the alternate system, the medium resolution coverage would also be 52 percent.

6.1.1 Low Resolution

The low resolution (color) imaging system is the same for all the cases considered. The (periapsis) resolution of 1000 meters chosen for this system is about the same as that obtained of the lunar surface by terrestrial photography. It is at the same time over 200 times as good as the resolution of Martian photographs obtained from earth. The amount of coverage indicated in the performance tables was chosen as a nominal amount more or less representative of mission requirements. It is not dictated by either data gathering or data transmission limitations. Considerably greater coverage could be obtained without seriously encroaching on the communication allocations for medium and high resolution imaging. Color information appears to be desirable at this resolution; the estimates of coverage were made considering three pictures of each area, in red, green, and blue, as constituting single coverage. This is accomplished with sequential use of appropriate filters with a single camera. The resulting displacement of the frames complicates the ground data reduction procedures somewhat, but adequate color information can be recovered. Truly simultaneous color imaging would require three cameras in the spacecraft for this purpose with a very considerable weight and power penalty. Stereo coverage at this resolution would provide little, if any, additional information over monoscopic viewing, since the vertical resolution would be so poor as to reveal only the very largest features, i.e., those exhibiting altitude differences of over 1000 meters.

6.1.2 Medium Resolution

Imaging at the medium resolution of about 100 meters on the surface is readily accomplished by all three systems with optics of moderate size, weight, and performance requirements. The differences lie on the coverage capabilities. The hypothetical system has been configured with three return beam vidicon cameras and three tape recorders in order to be able to obtain contiguous framing in the images obtained in one orbit, and to exploit the transmission capability fairly well. Even with these three cameras (with weight and power requirements over the nominal limits) the performance is not completely satisfactory. In the early stages of the mission the system cannot keep a 51.2 kb/sec data link full; it more nearly matches the 25.6 kb/sec rate. With the nominal transmission rate profile, this at first glance does not appear to be too serious, since the 51.2 kb/sec rate is available for only a short time. However, it is particularly during this period that it is important to gather and transmit as much information as possible. Moreover, the transmission rate profile has been estimated conservatively; it is even possible that with good fortune the highest rate could be maintained during most or all of the mission. The medium resolution TV camera system could not exploit such good fortune. Finally, the system provides very little flexibility in mode of operation. If photo-imaging is not accomplished on a given orbit, the opportunity to send information to earth during that orbit is irretrievably lost, except possibly in the last phase of the mission, since the storage capacity is not sufficient for more than perhaps two orbits' transmission at the lowest data rate.

The coverage of both the recommended and alternate systems is limited by the transmission rate and not by the inherent capabilities of the systems themselves. There are, however, definite differences between the two systems. The film camera provides a permanent record; this means of course that the film is not reusable for new information storage, but it also means that the imagery on the film can be re-read as often as is desired. The limitation of total capacity is not really serious. The amount of film specified for the recommended system will record over twice as much imagery as can be transmitted to earth during the nominal mission. Increasing the film supply to about 500 feet, at a total weight of about 10 pounds, including processing web, would provide a storage capability of over 2.6×10^{12} bits of data, or 10 times the 1973 mission total. On the other hand, the ability to re-read the imagery, along with the capability of locating any desired position on the film very accurately, offers a number of advantages. One possibility would be to read out a frame at low resolution, with corresponding economy of transmission, and then make a decision on earth as to whether the frame were worth transmitting at its maximum potential resolution. Another mode would be to repeat the transmission of all or part of a frame because the original transmission was defective in some way, or because something on the frames was so interesting or unexpected that verification was desirable. Another, perhaps lesser, consideration is the fact that the developed film is less subject to damage than any other storage medium, including radiation damage or inadvertent erasure.

The 100 feet of dielectric tape provided in the dielectric tape camera have a total capacity of about 9×10^{10} bits. This is adequate to provide buffer storage between widely varying read-in and read-out rates and give considerable flexibility in the imaging modes employed. The capacity amounts to about one-third of the 1973 mission requirements, so the tape would have to be reused twice. Since hundreds of reuses are possible with no performance degradation there is no problem of total capacity, even in an upgraded system. Readout is destructive, however, so that recall and retransmission of previously transmitted material is not possible. Also the ability to locate precisely at a given place on the tape is not at present included in the camera, but this is not an inherent limitation of the concept.

6.1.3 High Resolution

Obtaining a surface resolution of 100 meters is quite practical with any of the three types of sensors considered, as has been seen. For a resolution of 10 meters or better on the surface it becomes more difficult, and in fact, high resolution photography is not recommended with the dielectric tape camera.

To determine the maximum practical resolution achievable with a given sensor one must start with the minimum size of an optical resolution element on the sensor (width of a line-pair, in TV nomenclature). For a given resolution, the focal length must be adjusted to make the geometrical image of the desired surface element match this size. The relationship is expressed by the equation

$$f = H \frac{\ell_s}{\ell_g}$$

where

- f is the focal length
- H is the altitude (distance from camera to object)
- ℓ_s is the length of the resolution element on the sensor
- ℓ_g is the length of the resolution element on the ground

It is then necessary to determine whether a feasible lens of the required focal length can provide satisfactory resolution performance, i.e., can actually resolve an image element of the desired size. Diffraction by the aperture of the lens (or other imaging system; for simplicity the term "lens" will be used to include reflective and catadioptric systems) sets an absolute limit to resolution performance by the Rayleigh criterion

$$\phi = \frac{1.22\lambda}{D}$$

where

ϕ is the minimum resolvable angle
λ is the effective wavelength of the light
D is the aperture of the lens

In terms of sensor resolution

$$\ell_s = \phi f = 1.22\lambda \left(\frac{f}{D}\right)$$

Thus for a given focal length and sensor resolution a minimum aperture for a diffraction limited system is specified. However, there is no guarantee that a diffraction limited system can be achieved; in general this performance is possible only for very small fields of view. Finally, it is necessary to determine whether an otherwise satisfactory system has enough light-gathering power, considering the sensor sensitivity, to allow acceptable exposure times. Aperture sizes may need to be increased for this reason if for no others. In orbital photography, the acceptable length of effective exposures is governed almost exclusively by the necessity of reducing image motion smear to an amount consistent with the desired resolution, certainly no more than the length of the resolution element desired. Image motion smear on the sensor is given by

$$S_s = V/H \; t_e$$

where

V = velocity of suborbital point
H = altitude
t_e = effective exposure time

This smear can be reduced by making the exposure time as short as possible, or cancelled by introducing image motion compensation (IMC) proportional to -V/H. IMC can be achieved by either swinging the camera during exposure so that it always points at the same place, or by moving the sensor surface (e.g., the photographic film) so that the same image points fall on the same film locations throughout the exposure. IMC of better than 1 percent accuracy is difficult to obtain, not only because of basic problems in V/H sensing and mechanical drives, but also because precise IMC cannot be achieved over an entire moderate sized field of view with any single motion.

The three factors affecting resolution described in the preceding paragraph—sensor resolution, lens resolution, and motion smear—combine in approximately root-mean-square fashion to produce the final resolution. Therefore, each must be somewhat better than the limits indicated in any real system. In particular, an empirically satisfactory allocation to motion is about $\sqrt{10}/10$ (= 0.316) times the desired resolution length.

The foregoing considerations have been applied to image tube, film, and dielectric tape systems to determine their suitability for high resolution photo-imaging. The results are summarized in Table 6-2. In appropriate cases lens diameters larger than the minimum required by diffraction effects have been included. Of possible imaging tubes, a SEC vidicon with 2000 TV lines on a 1-inch raster has been chosen as the

Table 6-2. High Resolution Photo-Imaging Possibilities

Ground Resolution (meters)	Focal Length (in.)	Lens Diameter (in.)	Exposure t_e (msec)	Ground Distance in t_e (meters)	Allowable Smear (meters)	Allowable IMC Error (%)	Field of View
			SEC Vidicon				
10	100	2.63	6.4	20	3.2	15	35' x 35'
	100	6.7	1	3.1	3.2	None	35' x 35'
3.16	316	8.3	6.4	20	1	5	11' x 11'
1	1000	26.3	6.4	20	0.32	1.6	3.5' x 3.5'
			Film (SO-243)				
10	40	2.63	290	910	3.2	0.35	3° 27' x 3° 27'
	40	10	20	62	3.2	5	3° 27' x 3° 27'
3.16	125	8.3	290	910	1	0.1	1° 5' x 1° 5'
	125	26.3	29	91	1	1	1° 5' x 1° 5'
1	400	26.3	290	910	0.32	0.035	21' x 21'
			Dielectric Tape				
10	40	2.63	1260	3950	3.2	0.08	1° 3' x 1° 3'
	40	10	90	280	3.2	1.1	1° 3' x 1° 3'

best candidate. (This tube does not exist at present, but can reasonably be expected to be available for a 1973 spacecraft.) The higher sensitivity of the SEC vidicon makes it preferable over other types, since rather short exposure times can be used. The 100-inch focal length, 6.7-inch diameter system is satisfactory for the 1973 Voyager mission although the field of view is smaller than one would prefer. Higher resolutions can be seen to be technically possible, but they suffer from even smaller fields of view and further require optical systems of weight and volume incompatible with Voyager allocations.

The film system for 10 meters ground resolution with the minimum diameter lens requires very accurate IMC; moreover, it is doubtful that diffraction limited lens performance could be obtained over the entire field of view. The 40-inch focal length, 10-inch diameter system is about as fast (large aperture) an imaging system as can be made with the required performance, but it is feasible. The field of view available is six times as large as that with the SEC vidicon, but IMC must be provided. IMC accurate to 5 percent can be achieved with an open-loop system using V/H values calculated from orbital data, so this is not an extremely difficult requirement. On the other hand, for a 3.16 meters ground resolution with minimum aperture, a completely unrealistic IMC accuracy is required. Even with a very large and heavy optical system of 26.3 inches aperture (it would weigh several hundred pounds), the IMC requirement is stringent, calling for a closed-loop system. Thus 10 meters ground resolution is feasible and attractive with a film camera, but any significantly better resolution is impractical.

A dielectric tape camera with 40-inch focal length, 10-inch diameter optics can just achieve 10 meters ground resolution with very good IMC. Nothing else is at all suitable. In view of the better characteristics of the SEC vidicon and film systems, a high resolution dielectric tape system was not further considered. The alternate photo-imaging configuration could best be made to include a high resolution capability by adding a SEC vidicon camera.

6.2 POINTING AND STABILITY REQUIREMENTS

The pointing and stability requirements for the three photo-imaging systems which have been configured are determined primarily by the optical fields of view and the desired values of resolution. Prior to defining the requirements for the three systems, the modes of operation will be discussed.

During the photographic interval, the planetary scan platform must be driven with precise rate and position control. The slewing and image motion compensation rates which will be required have been previously defined in Section 2.2.2 of this volume. Two types of operation are envisioned: a) vertical photography, in which continuous low and/or medium resolution photographs will be obtained, with high resolution imaging at selected intervals; and b) off-vertical photography, in which low or medium resolution stereo photographs may be desired, as well as selected high resolution imaging, either monoscopic or stereo.

In vertical photography, two methods of pointing may be employed. The first consists of utilizing the Mars horizon tracker as a primary reference in a closed-loop mode, with the planetary scan platform servo system utilizing the output signal of the horizon tracker as a control signal. This method offers the advantage of requiring no programmed rate information to maintain the planetary scan platform oriented to the vertical, as the required rate signal will be obtained from the horizon tracker. For offset pointing at relatively small angles from the vertical, a bias may be applied to the position signal from the horizon tracker.

The second method would consist of pointing the planetary scan platform in an open-loop mode, utilizing the spacecraft as a primary reference. This will require determination of the spacecraft position and velocity in orbit, which, in conjunction with the spacecraft attitude (determined by the celestial sensors) will enable computation of the direction in which the planetary scan platform must be pointed. During the photographic interval either the spacecraft structure or the inertial reference may be used as the reference coordinate frame from which pointing angles are determined. This second method has several disadvantages: a) a variable rate must be programmed to maintain the orientation of the planetary scan platform at the local vertical, and b) the pointing accuracy will be decreased by the cumulative errors from the spacecraft to the planetary scan platform—primarily errors in alignment and in the planetary scan platform gimbal drive system.

For off-vertical photography at angles considerably displaced from the vertical, use of the second method will be required where the desired angular displacement from the vertical exceeds the offset biasing capability of the Mars horizon sensor in the closed-loop mode.

Using either method of control a programmed rate will be required to provide image motion compensation where required by the photo-imaging system. This variable rate will be dependent upon the spacecraft velocity and altitude in orbit and the spacecraft position in orbit with respect to Mars.

6.2.1 Pointing and Stability Errors in Closed-Loop Operation

Using the Mars horizon as the primary reference in closed-loop operation the principal sources of pointing errors will be

- Boresight alignment of the horizon tracker and the planetary scan platform.
- Boresight alignment between cameras on the planetary scan platform.
- Alignment of camera optical axes to the reference coordinates of the planetary scan platform.
- Orthogonality of the gimbal axes of the planetary scan platform.
- Alignment of encoders and torquers to the gimbal axes.
- Thermal deformation in the planetary scan platform and its gimbal structure.

The primary source of stability error will be the limit cycle motion of the planetary scan platform servo system.

6.2.2 Pointing and Stability Errors in Open-Loop Operation

If the inertial reference unit in the spacecraft is used as the primary reference, the following will be additional sources of pointing errors:

a) Alignment of the planetary scan platform gimbal structure with respect to the coordinates of the inertial reference unit.

b) Thermal deformation in the spacecraft structure.

c) Drift, during the photographic interval (up to 48 minutes), of the gyros in the inertial reference unit.

The primary source of stability error in this case will a gain be the limit cycle motion of the planetary scan platform servo system.

Using the spacecraft as a primary reference, with the attitude controlled by celestial (sun and Canopus) sensors, item (c), above, would be replaced by the bias in the spacecraft attitude control system, rather than by gyro drift. The sources of stability errors will be the limit cycle motion of both the spacecraft attitude control system and the planetary scan platform servo system.

It is not the purpose of this discussion to define the magnitude of the above errors, but rather to define the bounds upon them dictated by the requirements of the several photo-imaging systems. It may be concluded, however, that closed-loop operation, using the Mars horizon tracker as the primary reference, will offer the greatest accuracy in pointing. In both closed- and open-loop operation, the primary source of stability error will be the planetary scan platform servo system.

6.2.3. Pointing Accuracy Requirements

In Table 6-3 the optical fields of view are defined for the three photo-imaging systems configured in this study. The fields of view for low and medium resolution imaging in all three systems are quite large and dictate no stringent requirement in pointing accuracy. However, for high resolution imaging, the hypothetical photo-imaging system utilizing the SEC vidicon camera poses the most stringent requirement. With a field of view of 0 deg 35 min. square, the pointing accuracy of the planetary scan platform must be maintained to a fraction of this value if specific areas on the Martian surface are to be observed with high resolution. However, if only general high resolution photography is desired, not of areas at a specific location on the planetary surface, the accuracy in pointing can be several times larger than the size of the optical field of view. The definition of the objectives of high resolution imagery is therefore of considerable importance, as the impact on the design of the spacecraft (from the standpoint of alignment and boresighting requirements) is considerable from the standpoints of cost and complexity.

Note that the recommended photo-imaging system, utilizing the Eastman-Kodak film camera, has a high resolution field of view (3^{o} 27') six times larger in linear dimension than the hypothetical system utilizing the SEC vidicon. In this case the tolerances required in spacecraft alignment are considerably less stringent. Again, however, the requirement for pointing with an accuracy smaller than the size of the optical field of view will be dictated by the objectives of the high resolution imagery—observation of areas at a specific location, or general high resolution imagery without regard to the specific location of the area being observed.

6.2.4 Stability Requirements

The ground resolutions for the several sybsystems of the three photo-imaging systems are shown in Table 6-3. The exposure interval has been calculated, considering the brightness of the scene (nominal value = 260 ft-l), optical system T-number, and sensitivity of the sensors (in meter-candle-sec). The allowable smear due to image motion has been arbitrarily established as 0.316 times the desired resolution, resulting in a root-mean-square contribution of approximately 5 percent to the value of the resolution. The apparent movement of the terrain during the exposure interval was then calculated, and where larger than the permissible smear, appropriate image motion compensation has been specified. The linear value of allowable smear has been converted to angular form (in deg/sec) based upon the nominal altitude of 1000 kilometers and the specified exposure interval. The allowable uncompensated angular rate of the planetary scan platform has arbitrarily been established as 0.316 times that which would produce a smear equal to the nominal resolution.

Table 6-3. Parameters Determining Pointing Accuracy and Stability*

	Hypothetical Photo-Imaging System			Recommended Photo-Imaging System			Alternate Photo-Imaging System		
	Low Resolution Color TV	Medium Resolution R-B Vidicon	High Resolution SEC Vidicon	Low Resolution Color TV	Medium Resolution Film	High Resolution Film	Low Resolution Color TV	Medium Resolution Dielectric Tape	Medium Resolution Dielectric Tape
Optical field of view	$29^\circ \times 29^\circ$	$8^\circ 36' \times 8^\circ 36'$	$0^\circ 35' \times 0^\circ 35'$	$29^\circ \times 29^\circ$	$33^\circ 27' \times 33^\circ 27'$	$3^\circ 27' \times 3^\circ 27'$	$29^\circ \times 29^\circ$	$10^\circ 35' \times 10^\circ 35'$ (framing mode)	$10^\circ 35' \times 53^\circ$ (panoramic mode)
Optical system	37.5 mm F/1.0	6.6 in. T/1.5	100 in. T/16	37.5 mm F/1.0	100 mm F/2.8	1000 mm F/4	37.5 mm F/1.0	100 mm F/2.5	100 mm F/2.5
Ground Resolution	1000 m	100 m	10 m	1000 m	100 m	10 m	1000 m	100 m	100 m
Allowable smear	320 m	32 m	3.2 m	320 m	32 m	3.2 m	320 m	32 m	32 m
Exposure interval	40 msec	10 msec	1 msec	40 msec	10 msec	20 msec	40 msec	35 msec	35 msec
Ground distance during exposure	125 m	31 m	3.1 m	125 m	31 m	62 m	125 m	110 m	110 m
Allowable IMC error	100%	100%	100%	100%	100%	5%	100%	30%	30%
Allowable ground smear (angular rate) during exposure interval	0.48 deg/sec	0.19 deg/sec	0.19 deg/sec	0.48 deg/sec	0.19 deg/sec	0.19 deg/sec	0.48 deg/sec	0.18 deg/sec	0.18 deg/sec
Allowable planetary scan platform uncompensated angular rate	0.16 deg/sec	0.06 deg/sec	0.06 deg/sec	0.16 deg/sec	0.06 deg/sec	0.06 deg/sec	0.16 deg/sec	0.06 deg/sec	0.06 deg/sec

*Requirements for hypothetical, recommended, and alternate photo-imaging systems.

From Table 6-3, it may be seen that for all three systems, the angular stability requirements (allowable planetary scan platform uncompensated angular rates) for all three systems are identical for both medium and high resolution photography. The angular stability of the planetary scan platform, determined primarily by the planetary scan platform servo system, must be in the order of 0.06 deg/sec during the photographic interval. This rate, which corresponds to a value of 216 deg/hr, does not impose a severe requirement on either the spacecraft attitude control system or the planetary scan platform servo system.

6.2.5 Estimated Performance

The above discussion has defined the pointing and stability requirements of the three photo-imaging systems. An analysis of the estimated performance of the spacecraft subsystems in pointing the planetary scan platform is contained in Volume 5 of this study.

6.3 DATA HANDLING

The actual picture-taking function is performed very rapidly with any of the applicable sensors, and the fraction of the time when the spacecraft is in a position suitable for surface imaging is very small—about 6 percent of the time for the nominal orbit considered. These facts, combined with the limitations of the communications system, make it mandatory to store the photo-imaging data and later to transmit it at a rate very different from that at which it was taken. The fundamental requirement for on-board data handling is thus that it will permit the gathering of pictorial information under the best conditions as independently as possible of transmission requirements, while providing the data to the communications link at a rate and in a form compatible with the S-band radio and with the ground reconstruction equipment.

6.3.1 TV Sensors

None of the sensors used in the hypothetical all-TV system have the inherent capability to store more than one frame of pictorial information per imaging tube. Consideration was given to using enough tubes with very slow scan readout to accomplish the required storage function. This approach is unsatisfactory, however, not only because of the weight and volume penalty for a large number of image tubes, but also because of very difficult stability problems in the electronics associated with the extremely long scan times involved. Of other storage devices, several types show some promise for future use (e.g., thermoplastic tape, core-type storage), but only magnetic tape recorders have yet been fully developed for spacecraft operation. Therefore, tape recorders have been chosen. The data will be stored in digital form, ready for transmission to earth. While the total storage capabilities of tape recorders tends to limit the amount of information which can be stored, this is not as serious a limitation for the present application as the rate at which data can be read into them. Reading in with six parallel channels at 116 kb/sec can provide a maximum read-in rate of 700 kb/sec, allowing for as much improvement of the present state-of-the-art as can be forecast with reasonable confidence. This establishes the vidicon scan time, hence the number of frames that can be taken by a single camera while the spacecraft is over the zone of acceptable photographic conditions, and thus finally the maximum taking rates given in Section 3.

The amount of pictorial data that can be obtained by the hypothetical system is about enough to keep the S-band radio link filled at its maximum capacity when optimum imaging conditions exist. There is, however, very little operating flexibility. No sizeable backlog of data can be built up either to take advantage of especially good imaging conditions or to provide material to transmit in the absence, for any reason, of current new data. Moreover, the necessity of reusing the tapes for the data from each new orbit will generally preclude the possibility of retransmitting any of the data, as might sometimes be desirable.

The format in which the material is sent to earth can be made completely compatible with ground receiving and reconstruction equipment used for Mariner missions, so no problem exists on that account. Further ground data handling and processing can follow well established procedures.

6.3.2 Film Camera

The recommended system includes a vidicon camera for low resolution color imaging identical to that used in the hypothetical system, and data handling for this camera is consequently also the same. Medium and high resolution photography is obtained with a film camera based on Lunar Orbiter concepts. The film camera inherently involves creation of a permanent record stored on the film. The stored information is of course in analog form. When the imaging data are to be transmitted to earth the film is read out with a flying spot scanner at a rate appropriate to the transmission rate. A composite video signal containing the necessary calibration and sync pulses is generated, converted into PCM coded digital form, and sent to the transmitter.

Photographic film, considered as a data storage medium, provides the highest information density storage available at the present time. It provides a completely permanent record, with the advantages and disadvantages of permanency. For the present application, the disadvantages are very slight.

Since photographic imaging is an irreversible operation, silver halide film is not reusable after one picture has been taken on any particular section of the film. When a camera has been loaded with a specific amount of film, this does mean that there is an absolute limit, set by the film supply, to the amount of photography which can be done. However, because of the very high data packing density of film, enough capacity for any contingency can be provided with a modest amount of film. In the recommended photo-imaging system there is enough film for over twice as much photographic data as can be sent to earth during the entire mission, and if this margin is not considered sufficient, more film can easily be added. Table 6-4 compares the storage capacity of the three systems. While the other systems have a potential for collecting more data than film, this potential is beyond the capability of the rest of the spacecraft subsystems' ability to exploit. On the other hand, all the information on film is available throughout the mission, which is not true with the other systems.

Table 6-4. Storage Capabilities*

	Storage Density (bits/in.)	Maximum Storage Capacity (bits)	Ultimate Maximum Data Capacity (bits)
Hypothetical (All-TV System)	2.5×10^4	3.6×10^9 (4 tape recorders)	Indefinite (Tape is reusable)
Recommended (Film Camera System)	5×10^8	6×10^{11} (100 ft of film + 30 ft for leader)	6×10^{11}
Alternate (Dielectric Tape Camera System)	1×10^8	1.2×10^{11} (100 ft of tape)	Indefinite (Tape is reusable)

*The film system has an absolute limit for a given amount of film, but much more flexibility within that limit.

A permanent record of all the photographic data gathered permits a number of very valuable modes of data handling:

1) Medium or high resolution imagery can be read out first at a lower resolution to allow a decision to be made as to whether there is likely to be any information on the frame worth examining at higher resolution. This can be accomplished with the expenditure of a rather small amount of transmission time. If something interesting is detected or suspected, then the frame can be read out again at its maximum potential resolutinn.

2) Unusual or unexpected image forms can be read out a second time, or as many times as desired, in order to verify the reality of the image and to insure that it is not an artifact of the transmission.

3) Garbled or interrupted transmission can be repeated so that no photographic data is lost from transmission problems.

4) For especially valuable frames of imagery, poor picture quality resulting from transmission deficiencies can be improved by multiple transmissions.

Another important advantage of film over magnetic tape is the speed with which the data is entered, 10^4 to 10^5 times as fast for film as for the tape recorders. This means that the choice of number of frames to take per orbit or where they are to be located, depends on other factors than the time required to read in to the tape recorders. This, coupled with the capacity to store a large amount of data for a long time allows exploiting favorable orbital and illumination conditions to the maximum extent. For example, complete longitudinal coverage of Mars can be accomplished in about a month. During this length of time the location of the subperiapsis point, if chosen carefully at the start, will not depart too much from its optimum location. Thus a one-month period of very good photographic conditions is likely to be followed by a much longer less favorable period. Of the three systems considered, the film system is much the best for getting the maximum out of this type of situation, while the dielectric tape camera is not quite as good, and the TV sensors extremely poor.

Because of the similarity of the Voyager film camera to the Lunar Orbiter camera, the format is compatible with the ground reconstruction equipment used for the Lunar Orbiter. Ground handling and processing of the data will also be essentially the same. The receiving equipment will have to be modified to receive PCM coded data instead of the analog (FM) transmission by Lunar Orbiter. A more detailed discussion of pertinent OSE and MDE is given in Volume 7.

6.3.3 Dielectric Tape Camera

The dielectric tape camera, like the film camera, contains its own storage medium. Since the storage capacity at one time (see Table 6-3) is equivalent to about 50 orbits of maximum transmission, almost the same flexibility in data handling with regard to taking times and rates versus sending times and rates exists as for the film camera. The camera was designed to be compatible with Lunar Orbiter GRE, so that in this respect it is also very similar to the film camera, and neither of them presents any major problems.

The storage capacity of the dielectric tape camera, although sizable, is still less than half the amount of data gathered in the total mission. An extreme case of collecting photo information early in the mission could demand more than this capacity, even taking into account the reusability of the tape. The example of exploiting favorable orbital conditions during the first month cited in Section 6.3.2 might prove to be such a case. However, it is possible that a longer dielectric tape could be provided in the camera to account for this posisbility.

In other respects the dielectric tape camera does not provide as much data handling flexibility as the film camera. These are partly inherent in the concept and partly the result of details of the present design. The latter could be corrected for Voyager applications. The principal inherent shortcomings derive from the destructive nature of the readout. After one readout, only about 10 percent of the information remains, so that multiple readouts are almost useless. Preliminary readout of a frame at low resolution is possible by scanning only a fraction of the lines, say every tenth line. The following high resolution readout, if desired, will however exhibit deficiencies in the lines previously scanned so that a completely faithful representation of the original imagery is not obtained.

6.4 RELIABILITY

It is assumed that the photo-imaging system will be supplied to the spacecraft contractor as government-furnished equipment. Therefore, an extensive analysis of the reliability of the three photo-imaging systems has not been conducted. However, the following general statements may be made pertaining to the anticipated reliability of the photo-imaging systems.

6.4.1 Vidicon Cameras (used in hypothetical, recommended, and alternate systems)

The most critical element in the vidicon camera, from the standpoint of wearout, is the thermionic cathode. In industrial use, the RCA Electron Components and Devices Division has reported that the average lifetime of vidicon tubes is in excess of one year, in continuous operation. In space applications, the most significant data has been obtained from the Tiros program. In the Tiros program, improvements have been incorporated into the 0.5-inch vidicon tubes as the program has progressed, primarily the incorporation of the dark (low power) cathode. As of January 31, 1966, 10 Tiros satellites have been orbited and operated successfully, providing an aggregate total of 3890 days of operation and transmitting over 609,000 television photographs to ground stations. The performance of the individual satellites is summarized in Table 6-5. The basic configuration differences between each of the satellites are summarized in Table 6-6. From this data, it can be concluded in general that vidicon camera systems may be expected to perform satisfactorily for periods of continuous operation in excess of 1 year.

Representatives of the RCA Astro-Electronics Division were contacted by TRW regarding the mean lifetime of the camera equipment used in the Tiros program. Based upon the three most recent Tiros flights, RCA estimates the mean lifetime of an individual camera, including electronics, to be 2000 days, with intermittent operation in space.

Scaling this information to the proposed equipment, the low and medium resolution TV cameras are estimated to be of the same complexity as the Tiros camera, and the high resolution SEC camera is of somewhat greater complexity. A camera lifetime of 1650 days is assumed. Assuming a total mission lifetime for Voyager of 284 days, the probability of success for the three camera subsystems is as follows:

$$p_s \text{ (low resolution camera)} = e^{-284/2000} = 0.868$$

$$p_s \text{ (medium resolution camera)} = e^{-284/2000} = 0.868$$

$$p_s \text{ (high resolution camera)} = e^{-284/1650} = 0.842$$

The effects of the radiation levels anticipated during the duration of the Voyager mission are not expected to significantly affect the operation of the vidicon tubes. Information published by RCA* states that with total doses of radiation in excess of 10^4 rads, browning of the crown glass (Corning Type 7052 or 7056) occurs, resulting in a loss of optical transmission and corresponding reduction in signal amplitude. Quartz faceplates, however, remain relatively clear under this level of radiation. However, total dose of radiation anticipated during the Voyager mission will be several orders of magnitude below those specified in the above tests.

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*"Vidicons for Space Applications", R. E. Hoffman, Journal of the Society of Motion Picture and Television Engineers, August 1967, pp 780-782.

Table 6.5 Tiros Orbital Performance

TIROS Satellite	Launch Date	Useful Life (days)	Pictures Transmitted	Storm Bulletins
I	4/1/60	89	22,952	___
II	11/23/60	376*	36,152	___
III	7/21/61	230	35,033	70
IV	2/8/62	161	32,593	102
V	6/19/62	321	58,226	395
VI	9/18/62	389	66,557	275
VII	6/19/63	959**	122,500	630
VIII	12/31/63	773**	101,720	794
IX	1/22165	378**	70,000	896
X	7/1/65	216**	63,800	795
		3890	609,553	3957

*Limited use after 7 months in orbit.

**Still operational as of January 31, 1966.

Table 6-6. Tiros Configuration Summary

Spacecraft	Tiros I	Tiros II	Tiros III	Tiros IV	Tiros V	Tiros VI	Tiros VII	Tiros VIII	Tiros IX	Tiros X	Tiros XI*
Weight (lb)	263	278	285	286	287	281	299	260	300	290	290
Camera 1	NA	NA	WA	WA	WA	WA	WA	WA	WA[1]	WA	WA[1]
Camera 2	WA	WA	WA	MA	MA	MA	WA	APT	WA[1]	WA	WA[1]
Beacon Frequency (MC)	108	108	108	136	136	136	136	136	136	136	136
Magnetic Attitude Control		X	X	X	X	X	X	X	MBC QOMAC MASC	MBC QOMAC	MBC QOMAC MASC
Timers for Beacon Turn-Off						X	X	X			
Selective Address Unit							X	X	X	X	X
Additional Experiments											
Scanning IR	X	X	X				X				
Wide-Field IR	X	X	X								
Omnidirectional IR		X	X				X				
Electron Probe							X				

*Designated ESSA-1

Notes:

Camera Code (Picture Area - 400-nautical miles altitude):

- NA = Narrow Angle (12.5 deg lens); 5,000 square miles
- MA = Medium Angle (78 deg lens); 250,000 square miles
- WA = Wide Angle (104 deg lens); 500,000 square miles
- WA[1] = Wide Angle (104 deg lens); Camera Tilted 26.5 deg; 1,000,000 square miles
- APT = Automatic Picture Transmission; 1,000,000 miles

Magnetic Attitude Control Code:

- MBC = Magnetic Bias Control
- QOMAC = Quarter Orbit Magnetic Attitude Control
- MASC = Magnetic Spin Control

6.4.2 Eastman Kodak Film Camera

The proposed film camera system is based upon a modification of the design of the camera developed by Eastman Kodak for the Lunar Orbiter program. The design of the Lunar Orbiter camera, in turn, resulted from a number of programs conducted under military sponsorship.

At the initiation of this study, the primary concerns regarding the use of the Eastman camera were a) lifetime of the Bimat developer (for the extended duration of the Voyager mission), and b) shielding from the radiation levels anticipated during the extended mission.

TRW representatives visited the Eastman Kodak Comapny on July 27, 1967, to discuss the application of this equipment to the Voyager program. At that time representatives of Eastman Kodak stated that the lifetime of the Bimat developer is in excess of one year if proper storage constraints are observed (primarily temperature). In regard to radiation, the amount of shielding used to protect the film casette on the Lunar Orbiter camera was 2 g/cm^2. For the Voyager program, TRW proposes that 30 g/cm^2 of shielding be used, a total weight of 65 pounds. Utilizing the specifications furnished by the Marshall Space Flight Cenetr on radiation in the Mars environment, this amount of shielding will reduce the effect of solar cosmic rays to approximately 2 or 3 rad/yr (integrated dose). The predominant radiation will be galactic cosmic radiation, of high energy level, against which shielding is not effective. The level of this radiation is estimated to be from 6 to 20 rad/yr. 100 Rad results in 50 percent fog level on SO-243 film. Thus it may be roughly estimated that the recommended amount of shielding would provide sufficient protection for 5 years of operation, with the integrated dosage over that period resulting in 50 percent fog level on the SO-243 film.

In regard to the reliability of the overall camera system, a firm statement cannot be made at this time regarding the probability of success, as the equipment will require some modifications for the Voyager mission. The primary modification will be that of permitting exposure, processing, and transmission of data from only a portion of the film supply at any time, rather than exposure and processing of the entire supply prior to transmission. However, the performance of the present equipment in the Lunar Orbiter program has been most satisfactory. In only one of the five flights performed in the program did a malfunction occur: in the first flight, a defective shutter resulted in blurred high resolution photographs. In the additional four flights performance of the camera was highly satisfactory.

6.4.3 Dielectric Tape Camera

The dielectric tape camera has been developed by the RCA Astro-Electronics Division for the NASA Goddard Space Flight Center for use in the advanced Nimbus meteorological satellites and is also being considered for use in the Apollo applications program. At this time one prototype camera has passed space qualification tests of thermal humidity, vibration, acceleration, and thermal vacuum. However, data is not available regarding the estimated MTBF, nor is operational data available.

6.5 RADIATION RESISTANCE

The radiation environment to which the Voyager spacecraft will be exposed includes contributions from the Van Allen belts near earth, Martian trapped radiation belts, if any, galactic cosmic radiation (GCR), and solar cosmic radiation (SCR). The effects of all of these sources of radiation on electro-optical imaging tubes, such as used in the hypothetical photo-imaging system, or on the dielectric tape camera, are substantially less than they are on the film camera. The only part of the film camera which is subject to appreciable radiation damage from sources such as these is the undeveloped film, whether exposed or not. The principal concern, therefore, is whether adequate measures can be taken to protect the film until after it has been processed. It will be seen that sufficient shielding can be provided with moderate amounts of material. After it is processed, the film is considerably less susceptible to radiation damage than TV imaging tubes, the dielectric tape camera, or other electronic components.

The total radiation dosage, in radians, for a mission consisting of 6 months in transit and 6 months in Mars orbit, is given in Table 6-7, for shielding levels of 10 and 30 g/cm^2. In the film camera, only the film supply must be protected, as already indicated, so the total weight of shielding required is not excessive, even for 30 g/cm^2.

Galactic cosmic radiation is fairly constant in intensity and nearly indpendent of shielding. Because of the very high energies of the GCR particles, predominantly in the 10^3 to 10^7 MeV range, small amounts of shielding have no appreciable effect on dosage from GCR. At some point, moderate shielding could produce secondary radiation, through production of cascade particles, with greater effects than the undisturbed primary radiation. The amount of shielding at which this effect might become significant is not well determined. However, below 30 g/cm^2 secondary effects should be small, while somewhere above this they could begin to be noticeable. Thus 30 g/cm^2 is a safe upper limit to put on the shielding level; it is quite possible that greater amounts would not be harmful, but of course the extra weight is undesirable anyway. The yearly dosage is estimated as 6 to 20 rad; the higher value has been used in the table.

Table 6-7. Nuclear Radiation Dosage*

Type of Radiation	Shielding Level	
	10 g/cm^2	30 g/cm^2
Galactic Cosmic Rays (independent of shielding)	20 rad	20 rad
Van Allen Belts	1	0.1
Martian Radiation Belts (effective 3 months, at 10^{-3} times Van Allen Belts)	6	0.1
Solar Cosmic Rays (based on 1959 occurrence)	48	0.6
At Earth: 83 rad/yr with 10 g/cm^2; 1 rad/yr with 30 g/cm^2		
At Mars: 36 rad/yr with 10 g/cm^2; 0.4 rad/yr with 30 g/cm^2		
Total	75 rad	21 rad

*Based on 6 months in transit and 6 months in orbit about Mars

Van Allen belt radiation is quite intense, but the time spent in the Van Allen belts is so short that the total dosage is negligible even with very little shielding. It is now known that there is no appreciable radiation trapped by the Martian magnetic field outside 4 Mars radii. Since Mars' magnetic dipole moment is less than 10^{-3} that of earth, Martian radiation belts inside 4 radii can confidently be assumed to be less than 10^{-3} as intense as the Van Allen belts. With an effective times in the belts of about 3 months, the resultant integrated dosage is probably less than the values given in the table.

Solar cosmic radiation is associated with major flares, the rate of occurrence and intensity of which can be predicted only statistically. However, since the year 1959 produced the greatest integrated total solar proton flux on record, it provides a convenient and conservative basis for estimation. Solar cosmic radiation amounts observed at earth should be corrected for the greater distance of Mars from the sun. The solar proton flux values do not follow a simple inverse distance squared law because the protons are largely confined in "magnetic bottles." However, the statistical average at any particular distance from the sun still follows the same law.

It is generally true that slow emulsions are less sensitive to nuclear radiation damage than faster ones. So-243 in particular is one of the best films in this respect. An integrated dose of 100 rad results in about a 50 percent fog level on the film. Thus the estimate of 75 rad for 10 g/cm^2 shielding is within limits that could be tolerated, while the 21 rad for 30 g/cm^2 (essentially all from Galactic cosmic radiation) presents no problem.

6.6 DEVELOPMENT REQUIRED

In configuring the three photo-imaging systems for the 1973 Voyager mission, the various sensors used in the three systems have been selected primarily from the standpoints of: a) meeting the requirements of resolution, large size of format, and sensitivity in order to obtain the desired ground resolution, ground coverage, and to permit elimination (where possible) of IMC requirements; and b) availability with a reasonable time period, consistent with the schedule requirements for a 1973 launch. The developmental efforts associated with the three photo-imaging systems are defined in Table 6-8.

Table 6-8. Developments Required for Photo-Imaging Systems

	Hypothetical Photo-Imaging System	Recommended Photo-Imaging System	Alternate Photo-Imaging System
Low Resolution Sensor	RCA 1-1/2 Inch Type 8521 Vidicon a) ASOS-quartz target b) Dark heater (low power) c) Vibration damping spacers	RCA 1-1/2 Inch Type 8521 Vidicon a) ASOS-quartz target b) Dark heater (low power) c) Vibration damping spacers	RCA 1-1/2 Inch Type 8521 Vidicon a) ASOS-quartz target b) Dark heater (low power) c) Vibration damping spacers
Medium Resolution Sensor	RCA 2-Inch Type C-23061 Vidicon a) ASOS-quartz target b) Dark heater (low power) c) Vibration damping spacers	Eastman-Kodak Film Camera a) Modify optical systems for desired resolution and field of view b) Increase radiation shielding c) Increase buffer storage capability d) Modify to read forward from buffer storage unit e) Provide for coarse-scan readout for "quick look" examination f) Provide for readout at 3 scan rates to be compatible with communication system	RCA Dielectric Tape Camera a) Modify optical system for desired resolution and field of view b) Modify to incorporate 4-1/2 inch image orthicon electron gun for high resolution
High Resolution Sensor	Westinghouse WX 5419B Vidicon a) Improved resolution (smaller electron gun aperture) (increased focus field strength) b) Target ruggedization		

6.6.1 <u>One and One-Half-Inch Vidicon Development</u>
(Required for all three photo-imaging systems)

The sensor for the low resolution color TV camera of the three photo-imaging systems has been selected primarily from the standpoints of adequate resolution and format size, consistent with moderate power requirements. The RCA type 8521 1-1/2 diameter vidicon, with modifications, is specified. The size of the photosensitive target (1.0 inches diagonal), when used in conjunction with a lens of 37.5 millimeter focal length, is adequate to obtain the desired ground coverage of 500 x 500 kilometer from an altitude of 1000 kilometer. The resolution (1000 RV lines at 10 percent response) is adequate for the desired ground resolution of 1 kilometer. The size of the tube, 1.59 diameter x 7.75 inches in length, results in a camera with reasonable weight and power requirements. The vidicon is currently used in industrial television pickup equipment.

The primary modifications which will be required are

- Incorporation of a slow-scan target
- Incorporation of a "dark" (low-power) heater
- Incorporation of damping spacers for resistance against environmental vibration during launch.

The target which will be required for use at the slow-scan rate (12 seconds in the hypothetical photo-imaging system, and 25 seconds in the recommended and alternate photo-imaging systems) will require use of the ASOS (antimony sulfide-antimony oxide) target which has been employed in the Tiros meteorological satellite program. This slow-scan photoconductor is approximately eight to ten times more sensitive than the standard fast-scan photoconductor used at standard TV rates, and has the capability of utilizing scanning rates as long as 10 seconds per frame. However, at this scan rate, a loss of signal of approximately 45 percent is encountered with a corresponding loss of resolution in the order of 25 percent, due to lateral leakage within the photoconductor.

In order to improve the performance at the desired scan rates (12 or 25 seconds), the use of a quartz storage layer over the ASOS photoconductive target is recommended. This quartz layer of extremely high resistivity permits storage of the electronic charge pattern, induced by photoconductivity of the ASOS target, over periods as long as several hours. This eliminates the effect of loss of signal level and resolution in the ASOS target, as the charge pattern is transferred from the ASOS target to the quartz storage layer at the instant of exposure to scene illumination.

This ASOS-quartz thin-film process has been previously developed by RCA for use in 1-inch vidicons for the APT (Automatic Picture Taking) system for the Nimbus meteorological satellite program. Only minor developmental effort will be required to adapt this process to the larger (1-1/2 inch) target.

A second modification which will be required for application of this vidicon to the space environment is the incorporation of a "dark" (low-power) cathode. In order to obtain sufficient current in the electron beam, vidicons require a thermionic cathode operating at a temperature greater than 1000°K. Standard vidicons use a heater rated at over 3.5 watts, but for space use a heater assembly rated at approximately 0.5 watt is normally used. With a new heater material, rhenium-tungsten, and a new dark insulating coating which radiates more power and permits cooler operation, this structure has proven to be extremely rugged and well suited for use in satellite launch environments. This heater configuration has been utilized in previous vidicons developed for space applications, and does not present a significant development problem.

In order to resist the vibration level of 10 to 20 g's normally associated with the launch environment, damping spacers of indium or Teflon are normally provided between the electron gun and the envelope of the vidicon. This modification, also, is customary in vidicons used for the space environment and does not present a significant development problem.

6.6.2 Two-Inch Vidicon Development
(required for the hypothetical photo-imaging system)

For the medium resolution cameras of the hypothetical photo-imaging system, the RCA C-23061 return-beam vidicon has been selected. The primary basis for selection of this component is the large format size (25 x 25 millimeter) which permits the use of a wide optical field of view (8 deg, 36 min with a lens of 6.6-inch focal length), resulting in a ground coverage per frame of 150 x 150 kilometer. In addition, the extremely high resolution (3000 TV lines at 10 percent response) permits the desired ground resolution of 100 meters to be obtained. This component was selected after an extensive survey of available television pickup tubes. The 2-inch tube offers the highest line density, in terms of TV lines per photosensitive area, of all the available pickup tubes currently available or in development, with the exception of the RCA 4-1/2 inch type C-74137, which was not considered for this application due to the extremely large weight, volume, and power requirements.

The modifications which will require incorporation into this tube are essentially the same as for the 1-1/2 inch vidicon, namely:

- An ASOS photoconductive target with a quartz storage layer
- A low-power "dark" heater
- Damping spacers for resistance against environmental vibration.

In this case the use of the ASOS target with the quartz storage layer is justified by the extremely long scan time required (110.5 seconds per frame), which is required to produce an acceptably low data rate to the digital magnetic tape recorders which will be used with this subsystem.

6.6.3 SEC Vidicon Development
(required for the hypothetical photo-imaging system)

The Westinghouse type WX 5419B SEC vidicon has been selected as the high resolution sensor for this subsystem primarily from the standpoint of high sensitivity to incident illumination. With a secondary electron conduction gain of 200, an extremely short exposure interval may be used to eliminate the requirement for image motion compensation. The SEC vidicon has a significant advantage over the image orthicon type of sensor, which could also be considered for this application, in simplicity of both the sensor and associated camera control electronics.

For this application, the primary requirement will be improvement of the resolution, in order to obtain the desired ground resolution of 10 meters within the area of ground coverage of 10 x 10 kilometers of the optical field of view. The tube currently has a resolution of 800 TV lines at 10 percent response. A resolution of 2000 TV lines at 10 percent response is desired. Information obtained from the Westinghouse Corporation indicates that a resolution of 3500 TV lines is theoretically possible. By improvement of the electron optical system a resolution of 2000 TV lines may be attained. Two modifications will be required. The first is reduction of the diameter of the electron gun aperture from 0.0018 to 0.001 inches to reduce the electron beam diameter, which is permissible at reduced scanning velocities. (At standard TV scanning rates the larger electron gun aperture is required to supply sufficient electrons to discharge the target). The second modification would be to increase the strength of the focus field (presently 80 gauss), in conjunction with modification of the accelerating voltages, in order to obtain an electron beam which is more finely focused at arrival on the vidicon target. Additional effort may also be required in ruggedization of the aluminum oxide target supporting structure to withstand the anticipated levels of launch vibration.

A second approach may be considered. In the survey trips which were conducted to obtain the latest state-of-the-art information on TV sensors, it was determined that the General Electric Tube Department at Syracuse, New York, has developed experimental models of a 2-inch SEC vidicon, using electrostatic FPS (Deflectron) deflection system. Resolution of 750 lines has been achieved in initial experimental models. Resolution may be increased in three ways:

- By scaling the tube up to 3 inches in diameter, resulting in a larger target area.
- By reduction of the aperture of the electron gun to 0.001 inches, reducing the beam diameter.
- The slow scan velocity required in this application (50 seconds per frame compared to 1/30 sec at standard TV rates) will reduce electron beam current by a factor of 150, resulting in a more sharply defined electron beam.

Investigation is recommended to determine if a resolution of 2000 lines is attainable. The advantage of utilizing the General Electric tube, with the electrostatic deflection system, would be radically reduced power requirements, significant in this space application.

6.6.4 Eastman Kodak Film Camera (recommended photo-imaging system)

Several modifications will be necessary to the design of the Eastman Kodak film camera, presently configured for use in the Lunar Orbiter program.

The first modification will consist of replacement of the present optical systems (3- and 24-inch focal length) with optical systems of 4- and 40-inch focal length, to meet the medium and high resolution photo-imaging requirements of the Voyager mission.

For the Mars mission, an increase in the amount of radiation shielding will be required due to the long duration of the mission. In order to provide adequate shielding from the solar cosmic radiation and the galactic cosmic radiation, 65 pounds of shielding are estimated. This will provide 30 g/cm^2 of shielding for the 130 feet of film required for the recommended photo-imaging system. This film capacity will provide complete utilization of the data link at an average data rate of 23 kb/sec over the 6 months of orbital lifetime (a total data capacity of 2.64×10^{11} bits).

Increase will be required in the capacity of the camera for storage of film after processing. At present the storage capacity in the loopers is approximately 4 feet of 70 millimeter film. In the Mars mission, 10 frames each of medium and high resolution photography may be obtained in one orbit. The length of the film exposed in one orbit will be 4.7 feet, corresponding to 20 frames on the 70 millimeter film. With a total amount of data per orbit of 24.8×10^9 bits, the time required to transmit this data at a rate of 50 kbits/sec will be 70 hours, equivalent to approximately five orbits. It may be desirable to photograph a large percentage of the planetary surface during the early portion of the mission, or during an interval when the orbital subtrace lies within the zone of desired solar illumination angles. In either of these cases it would be desirable to expose, develop, and store a considerable amount of film prior to transmission.

The Lunar Orbiter camera exposes all of the film prior to transmission, with the film being then rewound on the supply reel during readout, with readout being accomplished in the reverse mode. For the Voyager mission it is desirable to expose only a portion of the film prior to transmittal, with readout being accomplished in a forward mode.

It is also desirable to provide a coarse-scan readout for quick-look examination of the photography obtained in selected areas. If the results of this photography are not satisfactory, the film would not be scanned in the fine mode, thus conserving the limited capacity of the data link.

Due to the increase of the earth-Mars distance after encounter, the data transmission rate must be reduced throughout the 6 month orbital lifetime. A reduction of the data rate in three steps is proposed (51.2/25.6/12.6 kb/sec). This will require a corresponding modification of the CBS line-scanner used to interrogate the film, to permit scanning of the film at three scan rates.

All of the above modifications to the existing camera design are feasible, and are considered necessary for the Voyager mission.

6.6.5 RCA Dielectric Tape Camera (Alternate Photo-Imaging system)

The present dielectric tape camera, configured for use in earth orbit, utilizes an optical system with an 8 degree field of view (defined by the width of the tape), which is panoramically scanned through an angle of 98 degrees by the scanning mirror.

For the Voyager mission, only a minor modification will be required to the optical system to change the field of view from 8 degrees to 10 degrees and 35 minutes. If it is desired to use the equipment in a panoramic mode, a minor modification will permit reduction of the 98 degree panoramic scan angle to the desired value of 53 degrees.

The primary modification to the existing camera is that of replacement of the present one-inch vidicon readout electron gun, with a resolution of 27 line-pair/mm, with a 4-1/2 inch image orthicon electron gun, with a resolution of 100 line-pair/mm (with 50 percent response). This modification is feasible, as the 4-1/2 inch electron gun has been used in a prototype model of the camera previously developed by RCA for the Air Force Avionics Laboratory.

6.7 GROWTH POTENTIAL

Growth in the capability of a photo-imaging system can occur primarily in the areas of increased coverage or increased resolution. A secondary growth area, less important than these, is in the field of view of individual frames. Within the time period under consideration, up to the final decision dates for spacecraft to exploit opportunities in the mid-1980's, growth will be limited more by other spacecraft subsystems than by the photo-imaging instrumentation itself. Increased coverage is obviously meaningful only if the information obtained can be sent to earth, and any significant increases in this area thus are paced by improvements in the communications system. Increased resolution can be achieved by closer approach to Mars, but this depends on the spacecraft guidance and navigation systems certainly, with perhaps propulsion and communications as well, but not on the photo-imaging equipment at all. High resolution can also be obtained by increasing the focal length of the optics primarily, with perhaps some modest increases in sensor resolution per se. Larger optics require larger size and weight allocations; thus growth in the propulsion subsystem area is at least as important as in the photo-imaging area.

6.7.1 TV Sensors

The photo coverage potential of image-tubes for the 1973 Voyager mission has been shown to be limited by data storage devices. The same is true *a fortiori* for later missions. There is little hope for marked improvement of magnetic tape recorders beyond the performance predicted to be available for 1973. Growth must therefore be sought in other storage media, such as thermoplastic tape or core-memory type devices. It seems reasonable to expect that space qualified instrumentation using such concepts will be available in a few years.

Some improvement in the resolution of image tubes, perhaps by a factor of two or so, can be expected. This can be exploited either for increased field of view or for higher ground resolution. High sensitivity tubes like the SEC vidicon offer probably the best hope for very high resolution cameras (1 meter or better ground resolution) of all the sensors considered. This is primarily because they can use large focal ratio (f-number) optics without incurring long effective exposure times and hence stringent IMC requirements. The ability to operate satisfactorily with large f-numbers is very important with long focal length optics, since otherwise design becomes very difficult and weight increases very rapidly. The main deficiency of such systems is a very small field of view.

6.7.2 Film Camera

The ultimate coverage capability obtainable with a film camera (other than transmission limitations) is set by the amount of film which can be loaded into the camera. Since 70-millimeter film weighs less than 1 pound per 100 feet, and the processing web weighs only a little more, the weight of a large film supply is not excessive. It would be quite easy to provide up to 1000 feet of film, weighing less than 20 pounds and even more could be added if necessary. 1000 feet of film would have a storage capacity of about 6×10^{12} bits, or over 20 times that estimated as required for the 1973 Voyager mission.

The achievement of very high resolution with film carries a greater weight penalty than the SEC vidicon cameras because larger aperture imaging systems must be used. It would seem that a reasonable limit for the ground resolution of photography taken from an altitude of 1000 kilometers is about 3 meters (refer to Table 6-2). Beyond this, weight and IMC requirements rapidly become very difficult if not impossible to meet.

6.7.3 Dielectric Tape Camera

The dielectric tape camera has a practically unlimited capability to obtain photographic coverage in its present form. If a larger field of view is desired, a 70-millimeter wide dielectric tape version of the camera can be developed in perhaps 2 to 4 years. For high resolution photography, however, the growth potential is very limited. As discussed in Section 6.1.3, the dielectric tape camera is not recommended even for 10-meter ground resolution for the 1973 Voyager spacecraft. Greater improvements than can reasonably be anticipated must be achieved in both the intrinsic sensor resolution and in its sensitivity before resolutions of better than 10 meters on the ground can be obtained.