LUNAR ORBITER: A PHOTOGRAPHIC SATELLITE

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Langley Station, Hampton, Va.

Presented at the Spring Convention of the Society of Motion Picture and Television Engineers

Los Angeles, California
March 28-April 2, 1965

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ABSTRACT

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Beginning in 1966, NASA will put a series of unmanned photographic spacecraft into orbit around the moon. These will photograph fairly large areas of the lunar surface at high resolution. Exposure is on film, which is processed onboard and then read out for transmission to earth. These received signals are recorded on film by means of kinescopes at the tracking stations. The general design and operation of this photographic system are described.

Author

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Purpose

The Lunar Orbiter is one of three NASA programs for the unmanned exploration of the moon in advance of Project Apollo. The Ranger program, carrying television cameras, has given man his first close views of the lunar surface. It now remains for the Surveyor and Lunar Orbiter programs, working as a team, to provide some specific types of information about selected areas of the lunar surface in order to make a safe manned landing possible.

Surveyor must make a soft landing so that its instruments can measure important surface properties (for example, bearing strength) at a selected point. Eye-level television cameras will give visual information about conditions at that point. If the data supplied at one such point by a Surveyor spacecraft are favorable, the area surrounding that point is a potential landing area for the Apollo mission.

It is the job of the Lunar Orbiter to examine such areas photographically, so that the Surveyor data can be extrapolated over a full-sized landing site, with all the topographic features of a significant size measured and located. Since protuberances only half a meter high are significant and the area to be examined is over 8,000 square kilometers per mission, very heavy demands are made on the Orbiter's data-gathering capacity (fig. 1).

Typical Mission

The spacecraft (fig. 2), which weighs about 840 pounds, will be launched from Cape Kennedy by an Atlas-Agena vehicle. During its coast toward moon rendezvous, as well as later in lunar orbit, the spacecraft will be stabilized in yaw and pitch, so that its solar panels face the sun, and in roll, so that its star sensor points at the star Canopus. This keeps the parabolic antenna facing the earth. The spacecraft will depart from this attitude only to point its rocket engine for velocity changes and to point the camera for photography.

The one or two velocity changes in midcourse will correct for slight variations in launch vehicle performance (fig. 3). When the spacecraft arrives at the orbit injection point, the rocket will be pointed against the direction of flight and fired, thus slowing the spacecraft enough to make it a satellite of the moon. In its initial orbit, the minimum altitude will probably be greater than 250 kilometers. After the spacecraft is tracked in orbit long enough to locate the orbit accurately and to estimate its perturbations, the rocket engine will be fired for the last time. This additional slowing will bring the minimum altitude (perilune) of the final elliptical orbit down to a nominal 46 kilometers (the maximum altitude (apolune) will probably remain about 1,850 km).

Because the final orbit is the one from which the photographs are to be taken, it must satisfy several conditions. The perilune of the orbit must be at the lunar latitude of the primary targets, to provide the necessary scale and ground resolution. The lighting angle at this point must fall within rather narrow limits which will be described later. The inclination of the orbital plane to the lunar equator must also fall within certain limits, to control the pattern of coverage.

Having attained this orbit, the spacecraft will simply wait for the moon's rotation to bring the target areas under the orbit. It will maintain its sun-Canopus orientation in the meantime, even when it is in the moon's shadow. During the first orbital pass on which pictures are to be taken, the spacecraft will be reoriented so that the camera is vertical over the center of the first target area. At the time which has been designated by ground command, the camera will make the first exposure. The interval between exposures will be controlled automatically to provide the selected overlap between successive photos. The number of exposures for that pass will also be set by command. After the last exposure of each pass, the spacecraft will return to its sun-Canopus orientation.

Coverage of the larger target areas will be built up by the lateral overlap of photos exposed on successive orbital passes (fig. 4). Since the moon's rotation rate is fixed, as are the camera dimensions, the lateral overlap is a function of the orbital period and inclination. The coverage will be explained in greater detail later.

The onboard film processor is designed with enough capacity to complete the processing of 20 exposures (the maximum which can be made on one pass) during that pass. The processed film is then stored on the takeup spool until it can be read out for transmission to earth. Although a few exposures can be read out whenever pictures are not being taken, the major portion of the film footage will be read out only after all exposures have been made. It takes about 40 minutes to read out one exposure, and it can only be accomplished on those portions of the orbit where the spacecraft sees the sun and the earth simultaneously.

Within 30 days after launch, all the film should have been exposed and read out. The spacecraft will remain in orbit, and is expected to operate in a low-gear mode for up to a year. It will function mainly as an object to be tracked in orbit, by means of its transponder. Reduction of the tracking data will then permit the determination of the shape of the moon's gravity field. In addition, the spacecraft will make limited long-term measurements of micrometeoroid impacts and solar flare radiation.

The project is being carried out by The Boeing Company, under the management of the NASA Langley Research Center.

Photographic Coverage

A more detailed examination of the Lunar Orbiter's coverage capabilities must begin by noting that it carries a dual framing camera. Each exposure puts two images on different portions of the single roll of film. At the nominal altitude of 46 kilometers, with the camera vertical, the wide-angle image covers a rectangular area of 31.6 km by 37.4 km, at an effective ground resolution of 8 meters. The central portion of this coverage, a narrow rectangle of 4.2 × 16.6 km, is also covered by a high-resolution image at a 1-meter effective ground resolution, as shown in figure 5.

A choice of two overlap modes is available for building up coverage in the line of flight. In the high-repetition exposure mode, the exposure interval provides a 5-percent forward overlap between successive high-resolution exposures, so that there will be no gaps in this coverage.

Since there is always a simultaneous wide-angle exposure, the latter are overlapped some 87 percent. In the Low Repetition mode, the exposure interval provides an overlap of slightly over 50 percent on the wide-angle exposures to insure uninterrupted steroscopic coverage. This mode leaves gaps between successive high-resolution exposures.

In either mode, the number of successive exposures to be made in one pass can be selected among four choices.

Lateral overlap of the high-resolution strips from successive passes is insured by the correct inclination of the plane of the orbit. If lateral overlap is required only on the wide-angle coverage (as a logical extension of the Low Repetition mode), this can be accomplished by photographing only on alternate passes.

The total coverage capability of each mission is required to be at least 8,000 square kilometers at 1-meter resolution and at least 40,000 square kilometers of stereoscopic coverage at a resolution of 8 meters. Since the film capacity permits up to 194 exposures, there is a considerable margin over these requirements. There is considerable flexibility in apportioning the coverage capability among large and small target areas. In general, we anticipate that a number of separate target areas will be photographed in one mission. The number is limited less by film capacity than by the attitude-control gas available for reorientation maneuvers.

Ground Resolution

The preceding discussion of photographic coverage freely used numbers for effective ground resolution, without defining the term. The definition used here is entirely operational; i.e., it is based on the primary use that we expect to make of the high-resolution photography. This requires some additional explanation.

Remember that the Lunar Orbiter photographs are to be used to produce topographic information. Since the wide-angle coverage will all be stereoscopic, topographic information will be extracted from those photos by photogrammetric means. Unfortunately, the information will be too coarse for direct use in the detailed examination of Apollo landing sites. This requires the use of the high-resolution coverage, which is not stereoscopic. The basic means for extracting topographic information (slopes and heights) from this coverage is photometric analysis. When the lunar surface is obliquely illuminated, slopes which face the sun reflect more light to the camera than do level surfaces, and slopes which are averted from the sun reflect less. The function expressing this relationship, which is definitely peculiar to the moon, will be discussed in a later section. The way we will go about extracting topographic information, then, will be to run microdensitometer traces on the photographs, scanning parallel to the sun-camera-ground plane. After making corrections to the density values based on photometric calibration data, we will have ground slopes in the direction of scan. By integrating these slopes into profiles, it is possible to generate a surface.

For the purpose of evaluating Lunar Orbiter performance, the ground resolution is defined in terms of the photometric detection of a standard shape; i.e., a circular cone 1/2 meter high with a 2-meter base diameter (fig. 6). When this is photographed under the operational illumination conditions and transmitted through all of the data links and picture reconstruction equipment and subsequently scanned by a densitometer having a scanning aperture of effective 1/2-meter diameter, the resulting signal-to-noise ratio must be at least one in order to demonstrate a 1-meter ground resolution.

Photo System Description

The external shell of the photo system is visible in figure 2. It is a pressure vessel containing the camera, processor, and readout apparatus. It has two quartz windows through which the dual camera photographs the lunar surface. It controls the ambient temperature, pressure, and humidity within which all the equipment is to operate.

Figure 7 is an artist's rendition of the photo system. A schematic diagram (fig. 8) shows the functional relations of its components. The photo system is being built by the Eastman Kodak Company, which is responsible for all of its components. It will weigh about 135 pounds. Let us examine the main components individually, starting with the camera.

Being a dual camera, it has two lenses, two platens, and one film-transport mechanism. The wide-angle lens (the term is comparative in this case) is a commercially manufactured 80-mm Xenotar, of f/2.8 aperture, made by the West German firm of Schneider. The only important modifications made to the lens are the substitution of a fixed Waterhouse stop of f/5.6 aperture in place of the iris diaphragm and changes in the intra-lens shutter which limit the exposure speed selection to 1/25, 1/50, and 1/100 second. Tests of sample lenses procured commercially show that they meet the performance requirements and can withstand environmental conditions within the photo system enclosure. The platen, in contrast, is very much of special design. With the aid of a mechanical clamp, it holds the film flat by vacuum, despite the fact that the ambient pressure within the enclosure is only one pound per square inch. The platen moves during exposure to provide image motion compensation. The pattern of edge marks exposed by the platen mask is designed to facilitate the accurate reconstruction of the pictures after readout, since the wide-angle pictures are to be used in photogrammetric analyses.

The high-resolution lens is a 24-inch f/5.6 especially designed and built by the Pacific Optical Company. Although it weighs less than 16 pounds, it provides the outstanding performance required by the nature of the Lunar Orbiter's mission.

In order to minimize the size of the camera, the design uses a mirror to fold the optical path from the 24-inch lens to the platen. The focal plane shutter provides the same choice of exposure speeds as the wide-angle camera shutter. The platen moves during exposure to provide image motion compensation.

The performance required of the image motion compensation apparatus is particularly exacting in the case of the Lunar Orbiter's high-resolution camera, as can be seen from the following figures. The design exposure speed is 1/25 second, because of the very low exposure index of the film used (Kodak S.O. 243 film, with exposure index about 3). The spacecraft's orbital velocity at the low point of the orbit is around 2 kilometers per second, so that it moves 50 meters across the target area during an exposure. In order to achieve 1-meter ground resolution, the uncompensated image motion must be no more than the scale equivalent of 1/2 meter. The allowable error in image motion compensation is thus 1 percent, which must be allocated between the mechanical limitations of the platen servomechanism and the errors in the information supplied to it by the velocity/height (V/H) sensor.

The V/H sensor is thus a vital component of this camera. It is basically (fig. 9) an image tracker which scans a portion of the image formed by the 24-inch lens. It compares the outputs derived from successive circular scans to measure the rate and direction of image motion. The direction information is used to control the spacecraft yaw attitude. The rate information is supplied to the image motion compensation servomechanism and also to the exposure interval controller.

The film supply consists of a 260-foot roll of unperforated 70-mm film. The supply spool is lightly shielded against ionizing radiation from solar flares. The Kodak Special High Definition Aerial Film, Type SO-243, is relatively immune to fogging at the ambient levels of radiation in space, but some flare shielding is required. The film carries pre-exposed data along one edge. These are mainly resolving power charts and sensitometric gray scales, which are later read out along with the photographic images. The gray scales thus provide the photometric calibration which makes it possible to estimate ground slopes from the measurement of film densities.

Since the camera may make as many as 20 exposures on one pass over the target area, while the processor operates slowly and continuously, a buffer is required between the camera and the processor. The mechanism provided is a "looper," consisting essentially of two pulley blocks which can be separated to store film without slack. As much as 20 feet (enough for 20 exposures) can be stored in this way. The processor speed is sufficient to clear a full looper within one orbital period.

Processor

The film processor (fig. 10) is quite simple in construction, thanks to the convenience of the Bimat Process.

In the last 2 or 3 years Eastman Kodak has been able to disclose details of the process. Dr. L. W. Tregillus reported on it as "A Diffusion-Transfer Process" at the May 1962 meeting of the Society of Photographic Scientists and Engineers, and R. G. Tarkington gave a paper on "The Kodak Bimat Process" at the March 1964 meeting of the American Society of Photogrammetry. Since Tarkington's paper has now been published,* the description here will be very brief.

Bimat film is a processing web whose gelatin layer has been presoaked in a monobath solution. It is slightly damp to the touch, but very little free liquid can be squeezed from it. Once the web has been laminated to exposed negative material, the development of the negative image proceeds along with the diffusion-transfer of undeveloped silver ions to the web, where they are reduced to a positive image. The process goes to completion, in that all of the silver halide is reduced to silver in a few minutes. After that, it does not matter how long the two films remain in contact.

In the Lunar Orbiter's processor, the two films are delaminated after a sufficient time, with the web being wound up on a takeup spool. No use is made of the positive images on the web. The negative film is dried by an electric heater, and is then stored pending readout.

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*Tarkington, R. G., "The Kodak Bimat Process." Photogrammetric Engineering, Vol. 31, No. 1, January 1965.

Readout

In the readout process, the film is scanned to convert a sequence of image densities into electrical signals suitable for transmission to earth. The high information density on the Lunar Orbiter's film (a ground resolution of 1 meter corresponds to 76 line pairs/mm on the film) imposes stringent requirements on the film scanner. These are met by looking at small segments of the photo with a flying spot that is demagnified down to a 5-micron diameter (fig. 11).

The flying spot comes from a Line Scan Tube of the kind that was developed by CBS Laboratories some years ago for film scanning application. The electron beam is deflected in only one direction, so that it produces a single line on the phosphor. At the beam intensities required, the phosphor would burn if it did not keep moving. In this tube, the phosphor is coated on the outer surface of a metal drum which rotates continuously. The scan period is 1,250 microseconds, and the scan is about $2\frac{1}{2}$ inches long at the phosphor.

The light emitted by the Line Scan Tube is focused on the film by a scanning lens. The scanning lens demagnifies the line to a length of 1/10 inch. The motion of the scanning lens moves the scanning line across the film. The 57-mm scanned width of the film is covered by nearly 17,000 horizontal scans of the beam. The time required for this is 20 seconds. The film is then advanced 1/10 inch, and the lens scans the next segment in the reverse direction. It takes 40 minutes to read out the 11.6 inches of film that correspond to a single exposure.

The film is read out backwards; i.e., it advances from the takeup toward the supply spool. The purpose of the readout looper is to permit the reading out of a few selected exposures between photographic sequences without backing the film into the processor. Most of the exposures, in any event, will not be read out until the completion of photography. At that time the Bimat web is cut and removed, so that the film can be pulled backward through the processor without damage.

Collecting optics lead the transmitted light into a photomultiplier. The signal is then conditioned by a video amplifier to make it compatible with the spacecraft communications modulator. A separate synchronization package provides spot sweep voltages to drive the line scan tube and synchronization pulses for the ground equipment.

Figure 12 shows the composite video output as it leaves the photographic system.

Video Transmission

The spacecraft has two communications antennae, operating in the "S" band at 2295 megacycles (fig. 13). Communication is normally through the low-gain antenna at low transmitter power, except when photographic data are being transmitted. Whenever pictures are to be sent, the photo system readout mechanism and the traveling wave tube amplifier are turned on by command from earth. The photographic data, mixed with the performance and environmental telemetry data, are then transmitted via the 3-foot-diameter parabolic high-gain antenna.

Figure 14 shows the RF baseband structure for the composite telemetry and video transmission mode, and serves to illustrate the somewhat unusual modulation technique employed for the video data. The 50 bit/second telemetry data train is phase modulated onto a 30-kc subcarrier, which is then combined with the video data that have been transformed to a vestigial sideband signal. That signal is created by amplitude modulating the data on a 310-kc subcarrier by means of a double balanced modulator. This suppresses the carrier and produces two equal sidebands. An appropriate filter is then superimposed on the double sideband spectrum, essentially eliminating the upper sideband.

Since the mission subcarrier must be reinserted on the ground for the proper detection of the vestigial sideband signal, provision for deriving such a subcarrier signal is made by transmitting a pilot tone of 38.75 kc. That pilot tone is exactly 1/8 of the original 310-kc subcarrier frequency, and is derived from the same crystal oscillator. Multiplying the received pilot tone by 8 in the ground equipment provides a proper subcarrier for reinsertion. This composite baseband of telemetry, pilot tone, and video signals is phase modulated into the 2295-megacycle RF carrier.

The use of the vestigial sideband modulation technique permits the use of a large modulation index to obtain noise-improvement without exceeding the allotted $3\frac{1}{3}$- mc RF bandwidth.

Ground Photo Reconstruction

Communication with the spacecraft is maintained by NASA's Deep Space Instrumentation Facility. Three of the Facility's Deep Space Stations will be equipped to receive video data from the Lunar Orbiter. Located at Goldstone in California, Madrid, Spain, and Woomera in Australia, they will provide uninterrupted coverage while the spacecraft is transmitting.

At each station, the RF carrier will be received by the antenna-receiver system and demodulated (fig. 15). The subcarrier containing the telemetry data will be routed to the performance telemetry equipment and recorded on magnetic tape. The photographic data subcarrier will be demodulated and routed to the Ground Reconstruction Equipment. Here the video data will be displayed line by line on a kinescope face. The displayed image will be recorded on a continuously moving 35-mm film strip to create a permanent film record.

The current plans call for three film records to be exposed at each Deep Space Station. One record will be processed at the station and rapidly evaluated so that picture quality can be determined and commands sent to the spacecraft for the remotely controlled adjustment of the camera or readout mechanism. The other rolls will be forwarded, unprocessed, to the lunar data processing laboratory.

The images on the 35-mm film are approximately sevenfold enlargements of the spacecraft film segments. They run lengthwise on the film, and alternate segments are reversed end-for-end, due to the reciprocating travel of the spacecraft readout mechanism's scanning lens. The Reassembly Printer at the processing laboratory makes a composite print of sets of 14 of these segments, accomplishing the reversal of the alternate segments and edge-matching adjacent segments. The 9- by 14-inch composite is slightly reduced from the scale of the 35-mm film, being about $6\frac{1}{2}$ times the scale of the spacecraft film. It takes seven of these composites to reproduce a single high-resolution frame. Figure 16 shows the geometry of the various formats at different stages of the process.

Photometric Considerations

Plans to photograph the moon, as well as plans for using the photographs, must take into account its peculiar properties as a reflective surface. Far from being a uniformly diffusing surface (a Lambert reflector), the moon is a highly directional backscatterer of incident light. This is seen in the everyday observation that a full moon reflects 12 times as much sunlight to the earth as a half moon does. In addition, the moon is a very poor reflector, whose normal albedo averages about 7 percent. The normal albedo is measured where the angles of incidence and emittance to the surface normal are zero, and it is the ratio of the measured luminance to that of an ideal white surface. The photometric function expresses the variation in luminance with the geometry of the illumination and viewing situation.

The photometric function at a point can most usefully be described in terms of two variables, g and α, where g is the phase angle (the angle between the line of sight and the sun line) and α is the angle between the surface normal and the line of sight when projected to the plane of g. These angles are shown in the upper diagram of figure 17.

In the case of the Lunar Orbiter's high-resolution camera, the relationships are simplified. Since the camera is nominally vertical and its angular coverage is quite limited, the line of sight is approximately the local vertical. This means that the phase angle g is about the same as the sun's zenith distance (the complement of the solar altitude), and α is the component of the ground slope in the direction of the sun.

In order to extract the most ground slope information from the photos, we wish to choose the range of phase angles at which the photometric function is most sensitive to departures of α from zero. The lower portion of figure 17 is a plot of photometric function versus α for constant values of g. The selected operating range corresponds to solar altitudes between 15° and 40°.

The general method for extracting topographic information from the photography was outlined in the section on Ground Resolution. It involves the complementary use of the wide-angle and high-resolution coverages of the same area. As employed, the two types of photographs are affected in different ways by photometric considerations. A somewhat more detailed examination of these effects will provide an understanding of the method.

The accuracy of stereoscopic height and slope measurements on the wide-angle photographs depends primarily on the geometry (the base/height ratio), provided that they show fine ground details in sufficient contrast. Without the latter, stereoscopic vision is difficult, or even impossible. Fine-detail contrast in the lunar scene may be produced by small areas of shadow, by local variations in the normal albedo, or by the effect of the photometric function on surface roughness. It does not matter what causes the contrast in the scene, and it is not important that its reproduction be linear or even regular.

On the other hand, slope determination from the high-resolution photographs is completely dependent on the faithful reproduction of the scene's light values. The first step in the use of a picture is to perform the calibrations necessary to convert each density level on the picture to a relative scene luminance. The next step is to scan the photo with a microdensitometer in lines parallel to the sun-ground-camera plane.

Since the solar altitude and camera orientation will be known, the phase angle can be calculated for each portion of the scan. The photometric function then becomes a function of the single variable α which is convertible to ground slope in the sun-line direction.

Unfortunately, the calculated luminance at a point is always ambiguous, since it varies as the product of the normal albedo and the photometric function. In order to make that experimental model from the Ranger VII photo, it was necessary to assume that the normal albedo was the same all over the area. That assumption cannot be made with the Lunar Orbiter's photos, both because they cover very much larger areas and because important decisions will be based on the calculated slope values.

It is here that the stereoscopic wide-angle photos complement the high-resolution photos. Wherever a slope has sufficient horizontal extent to be clearly seen at a ground resolution of 8 meters, its inclination can be measured stereoscopically. This independent measurement will permit the determination of the normal albedo at many places on each photo. If local differences in the normal albedo are found, they are probably due to differences in the nature of the surface material. The wide-angle photos should, in addition, provide a visual indication of the surface boundaries between the different materials.

At this stage, it is possible to integrate the slopes over the length of a scan to produce a ground profile. Since the photometric method can provide no information about slope components perpendicular to the sun line, adjacent profiles cannot be precisely tied together to form a surface without recourse to the stereoscopic information. The plan for the reduction of the Lunar Orbiter photographic data includes the production of topographic base maps by photogrammetric methods at a contour interval appropriate to the precision of stereoscopic height determination. To produce larger scale maps showing the finer relief details, the elevations of the ends of each photometrically derived profile will be adjusted to fit the contours of the base maps.

Conclusion

If one looks at the overall Lunar Orbiter program from the photographer's point of view, he sees a remarkable anachronism. We will be stretching Space Age technology to new levels in putting a spacecraft into a selected orbit around the moon. We will be using the most modern communications technology in getting the video information back to earth. Yet the camera we are sending to the moon is a recognizable descendant of the one which Matthew Brady used to photograph the Civil War.

There are, of course, several ways to pick up visual information in a form directly compatible with the required video transmission. The real-time television camera systems used in Ranger and Surveyor, which are certainly more direct ways of getting moon pictures, are not available to the Lunar Orbiter. Because we have to acquire visual information in orbit faster than we can transmit it, we need a storage buffer. There are also several electronic and magnetic ways to store video data. The program schedule, which is based on the urgent requirement for the photography, requires the use of proven processes.

The fact is that at present, as in the past, there is no proven way of storing information which can compare in compactness with an image composed of silver grains in a gelatin emulsion.

1. PHOTOGRAPHIC
   (A) APOLLO SITE CERTIFICATION
   (B) APOLLO SITE SELECTION
   (C) LANDMARK MAPPING
   (D) GEOLOGIC SURVEY

2. NON PHOTOGRAPHIC
   (A) GRAVITATIONAL FIELD
   (B) MICROMETEORITE FLUX
   (C) HIGH ENERGY PARTICLE FLUX

NASA

Figure 1.- Lunar orbiter mission objectives.

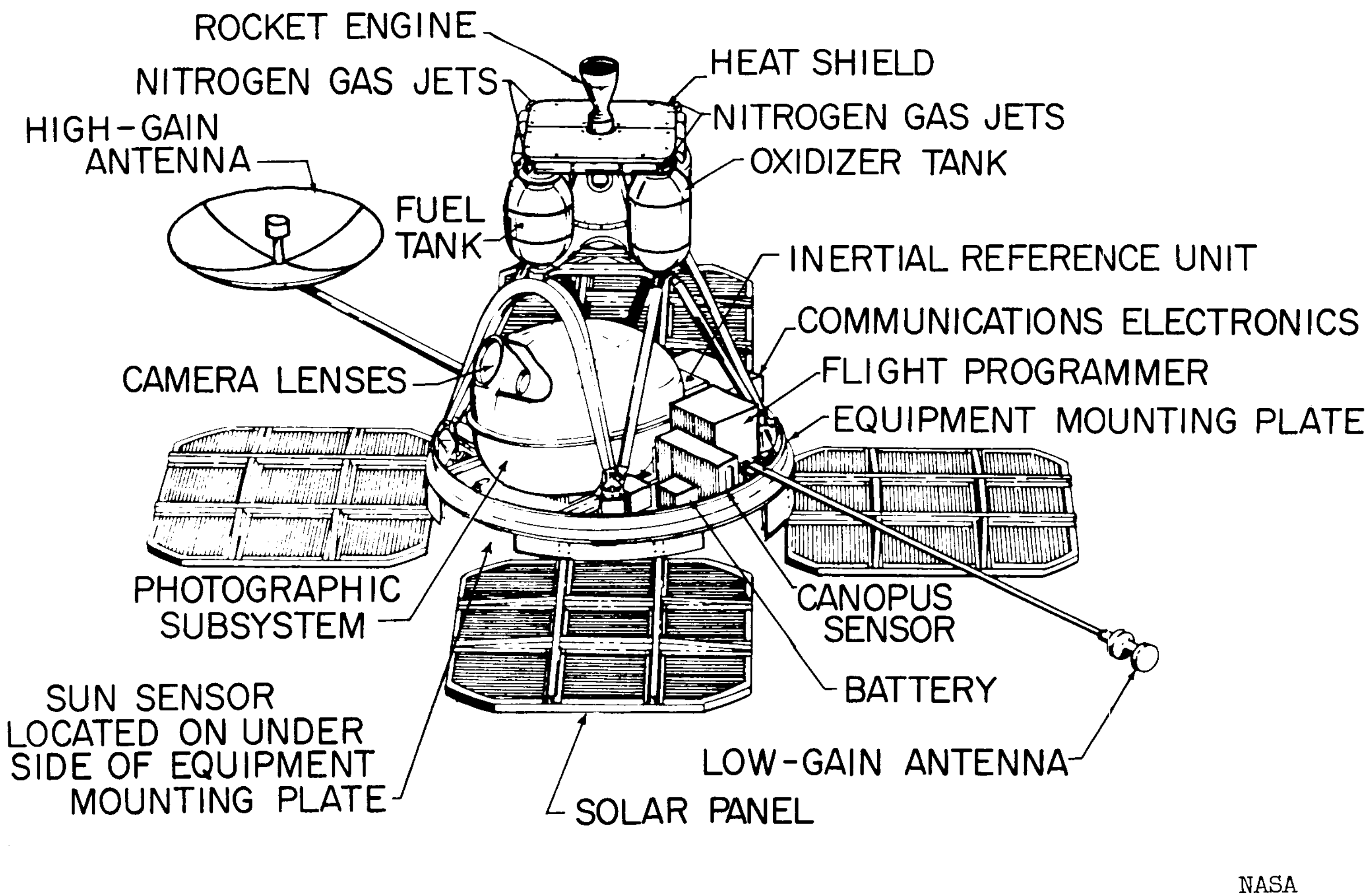


Figure 2.- Spacecraft configuration.

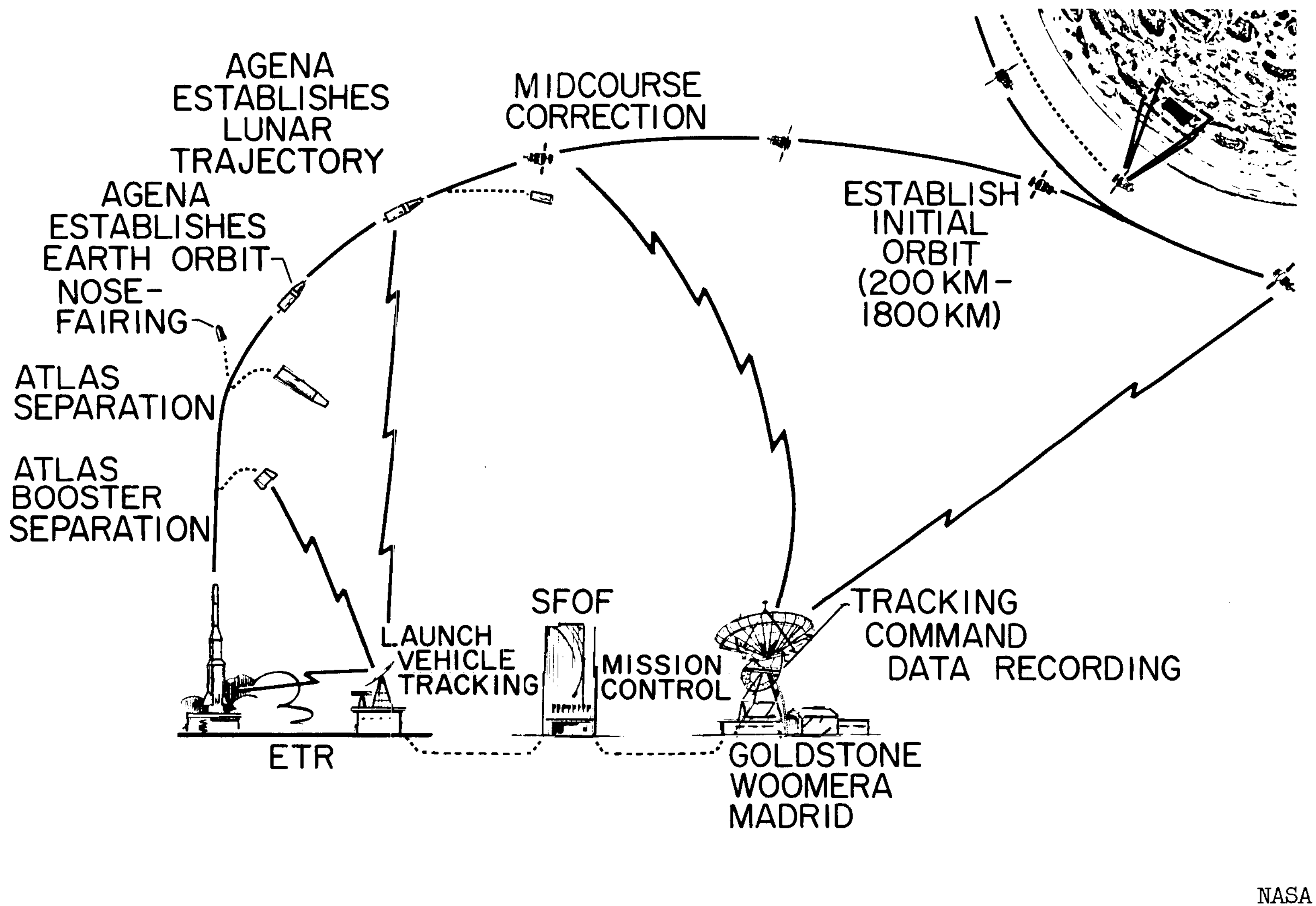
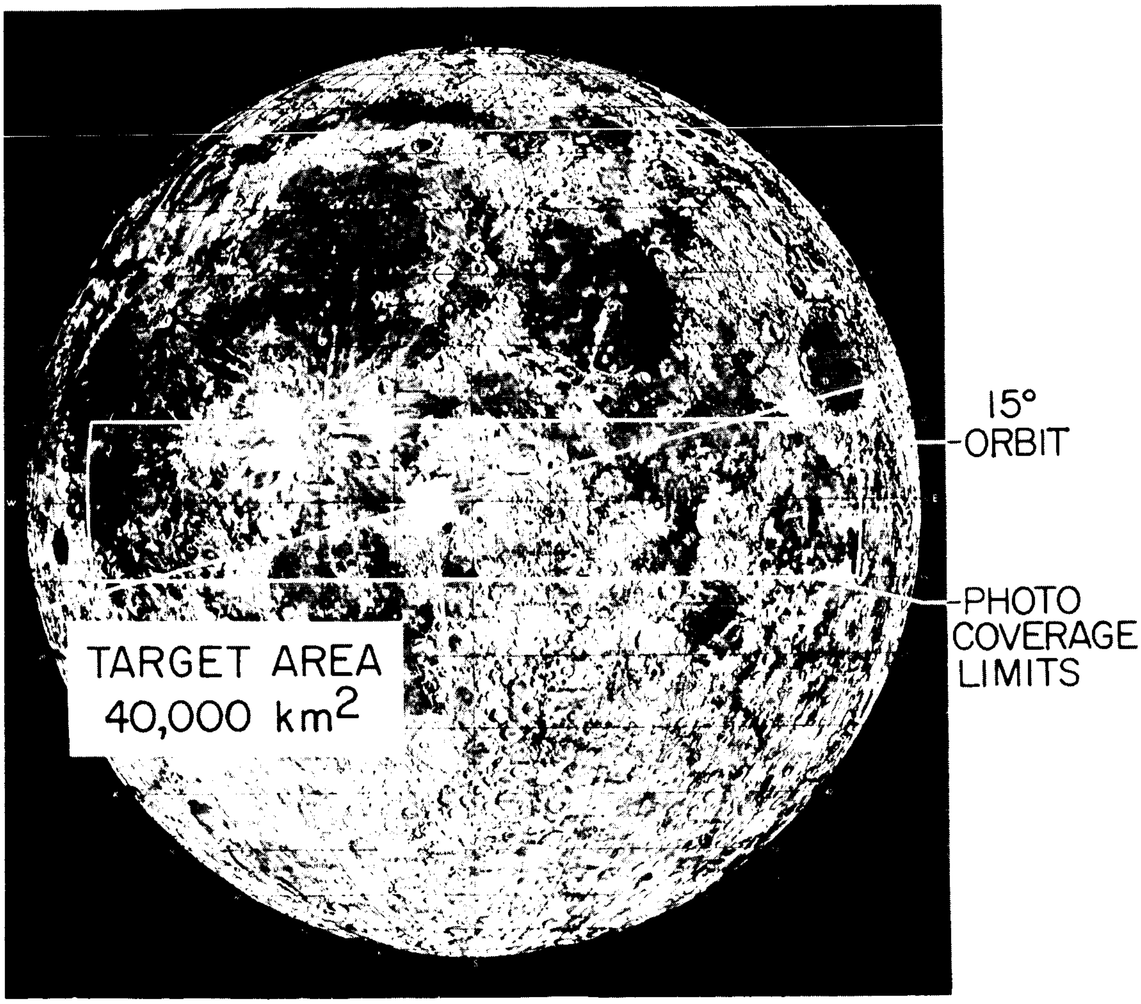
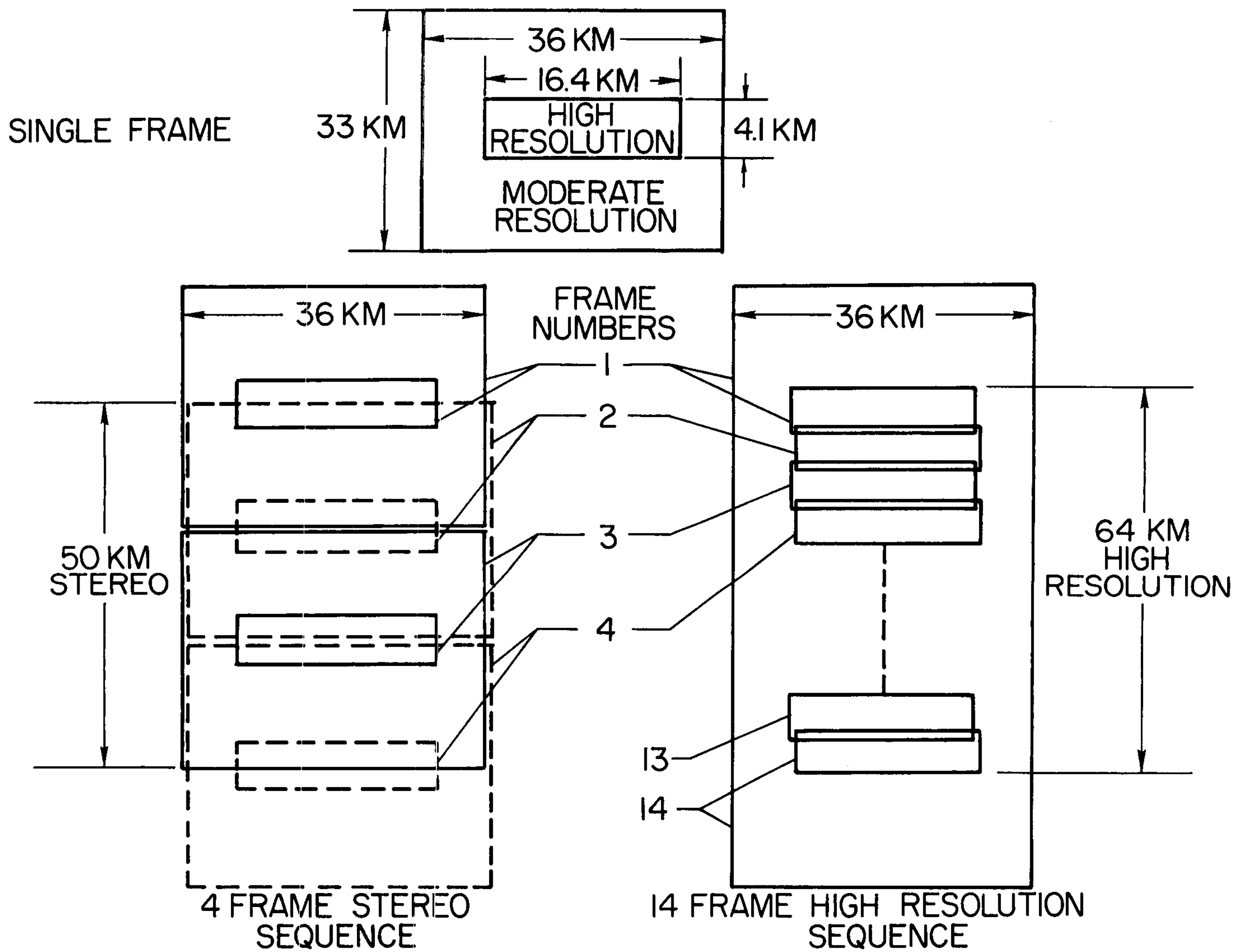


Figure 3.- Mission operations.



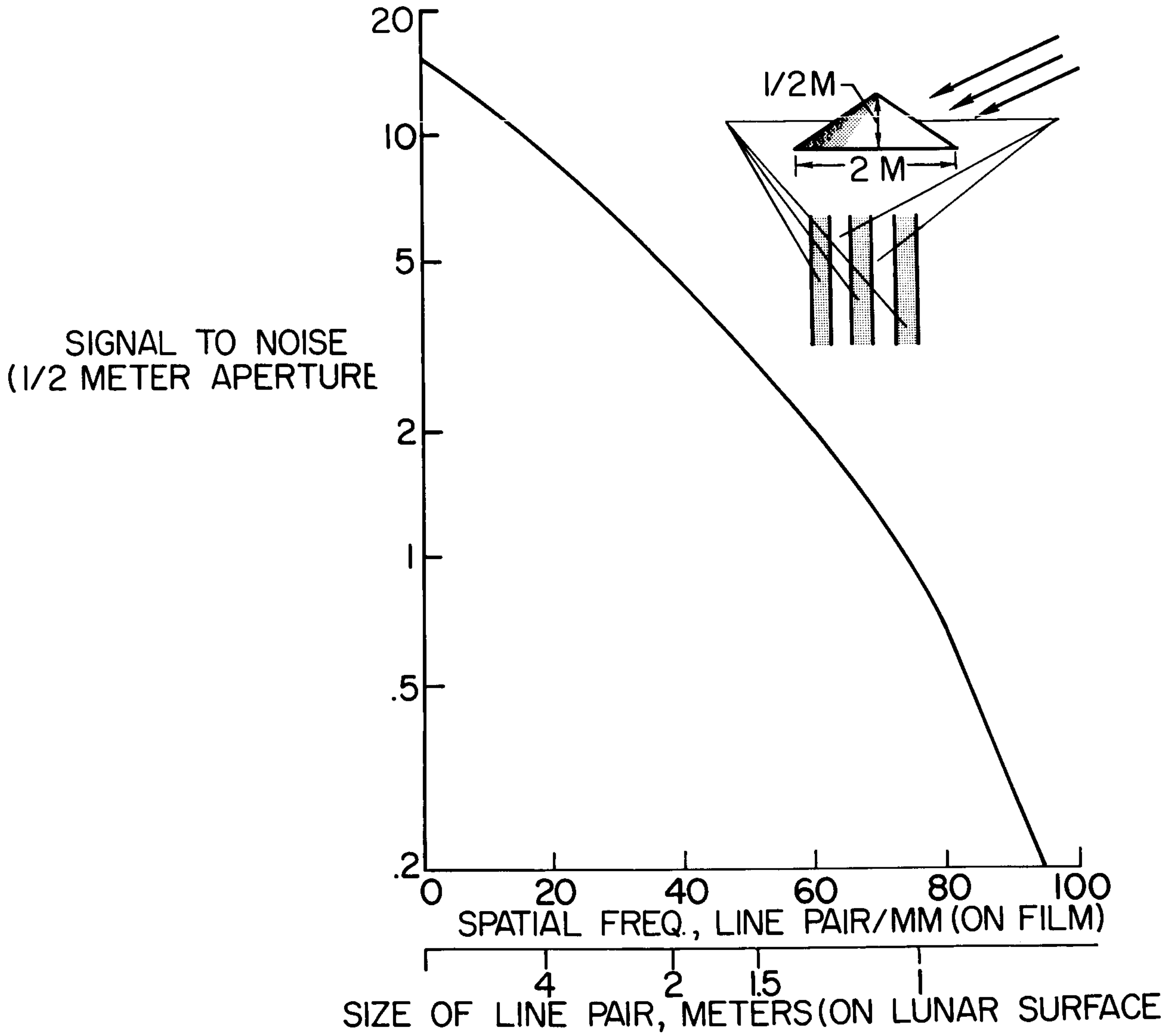
NASA

Figure 4.- Photographic coverage and representative orbit track.



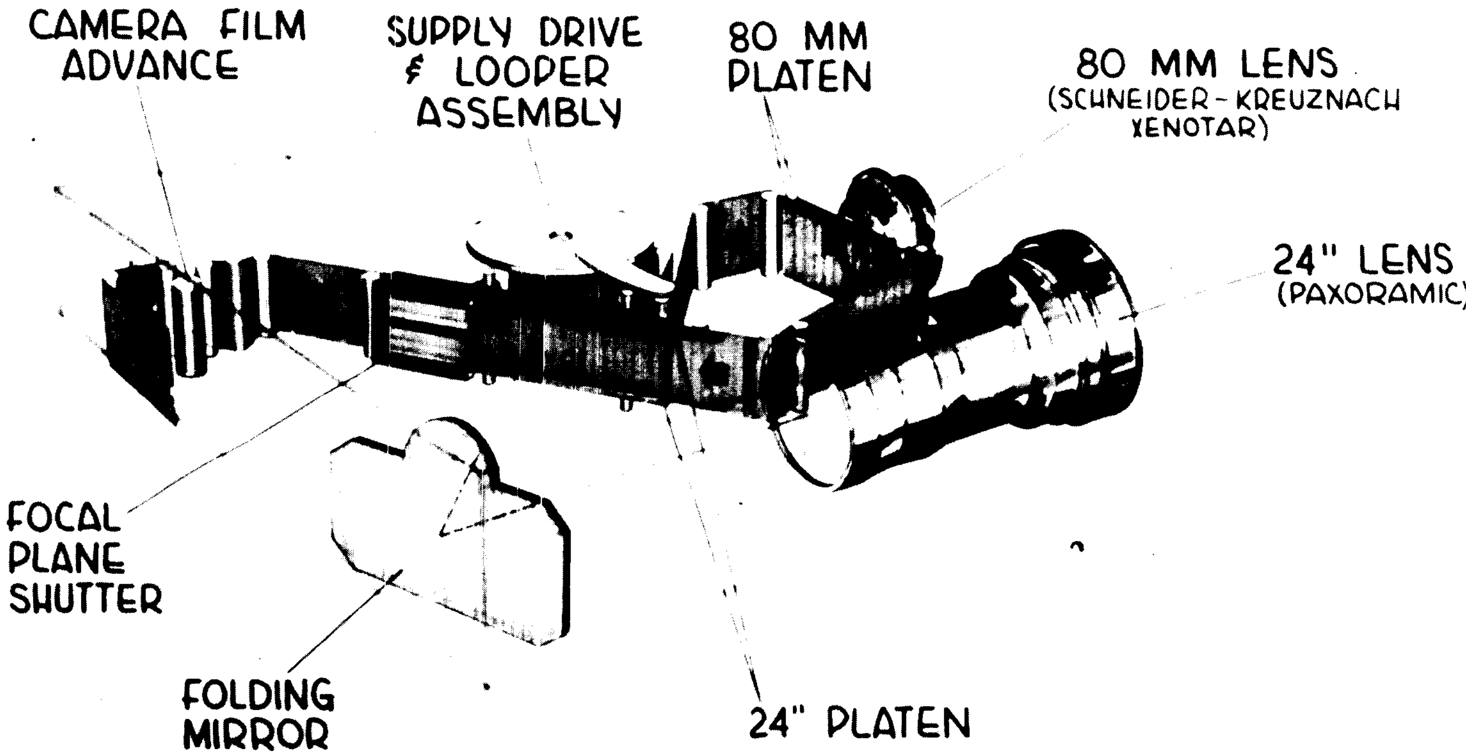
NASA

Figure 5.- Frame format and typical sequences.



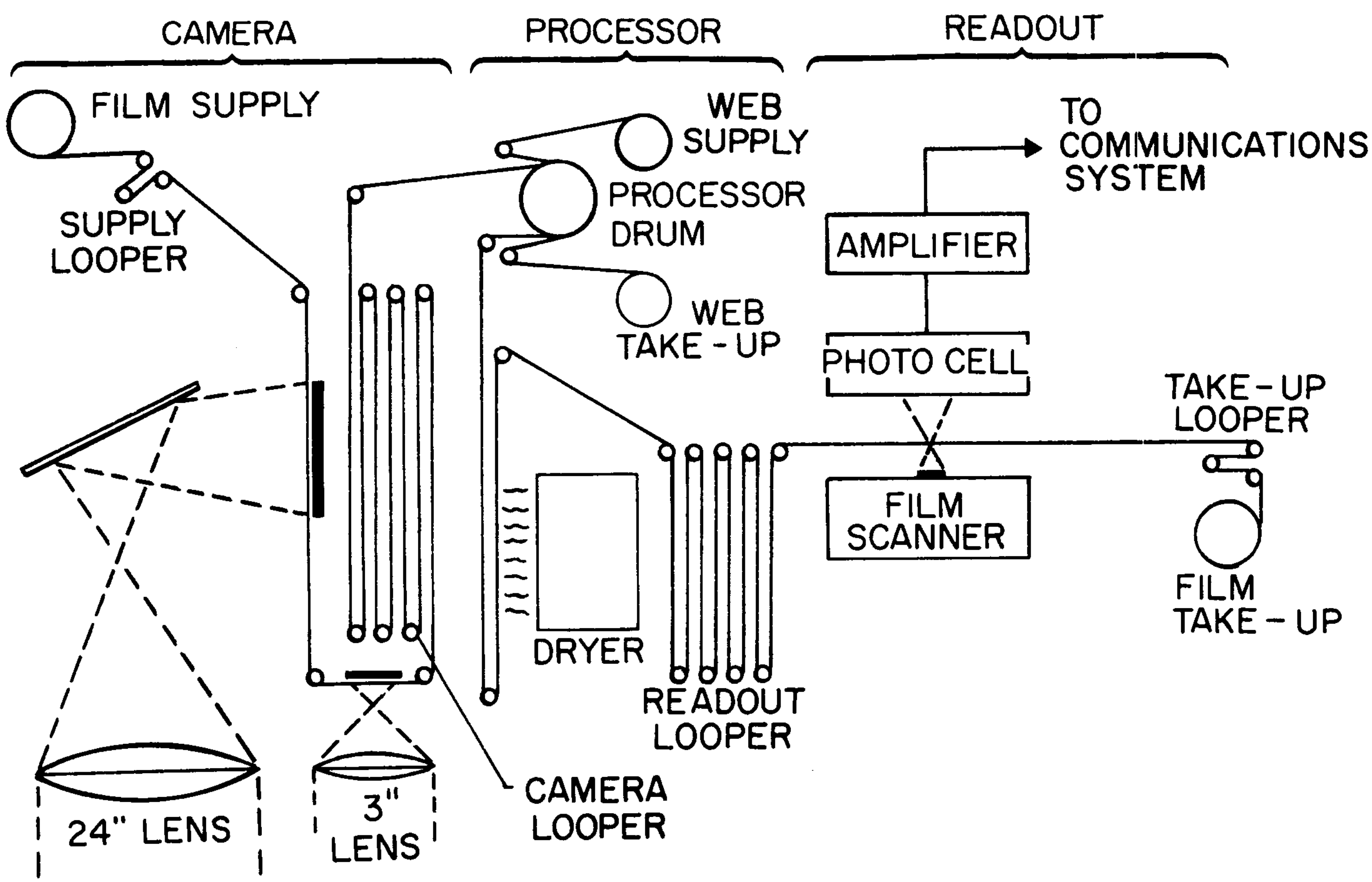
NASA

Figure 6.- System signal-to-noise ratio.



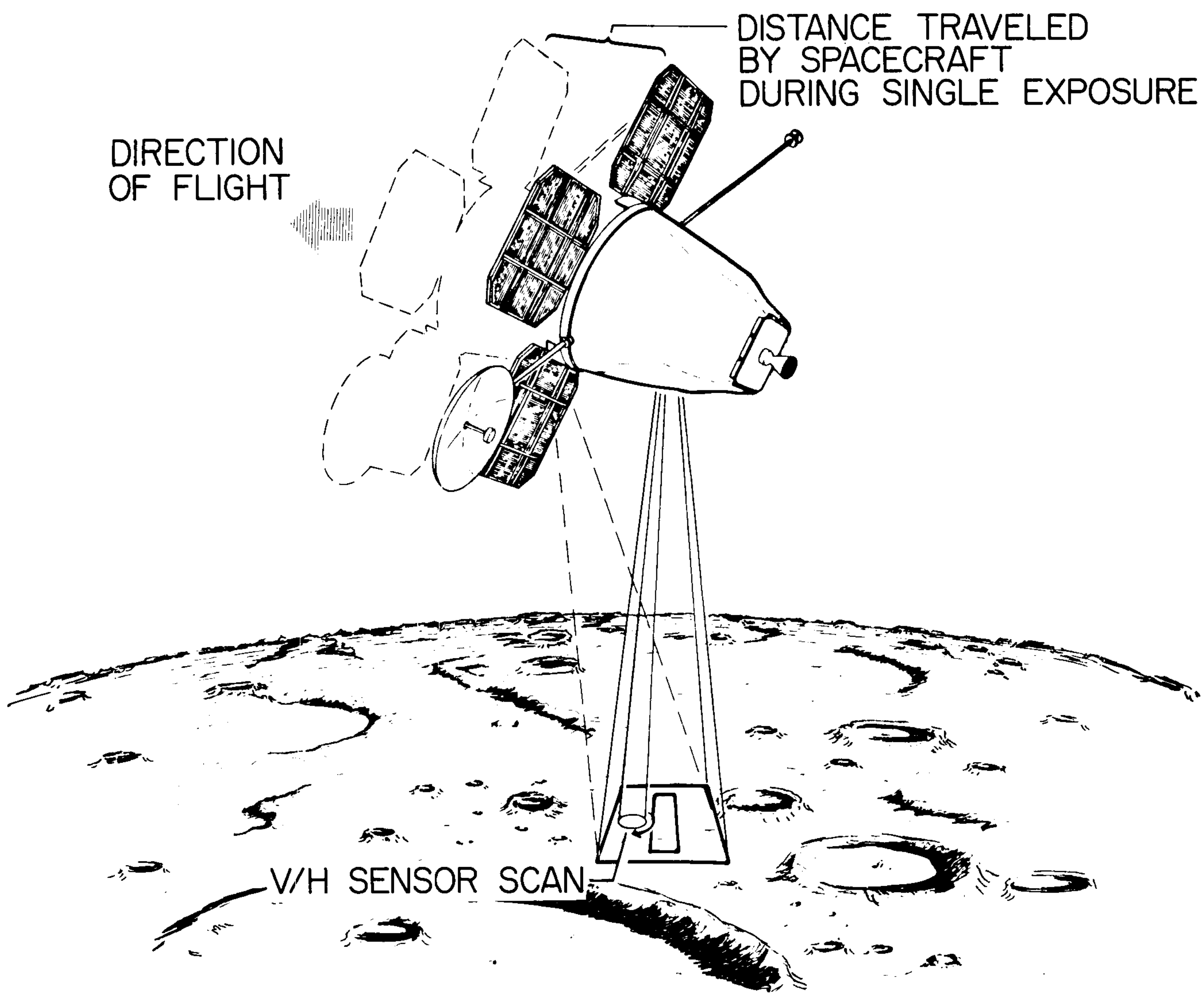
NASA

Figure 7.- Spacecraft photographic system - artist's rendition.



NASA

Figure 8.- Spacecraft photographic system.



NASA

Figure 9.- V/H sensor geometry.

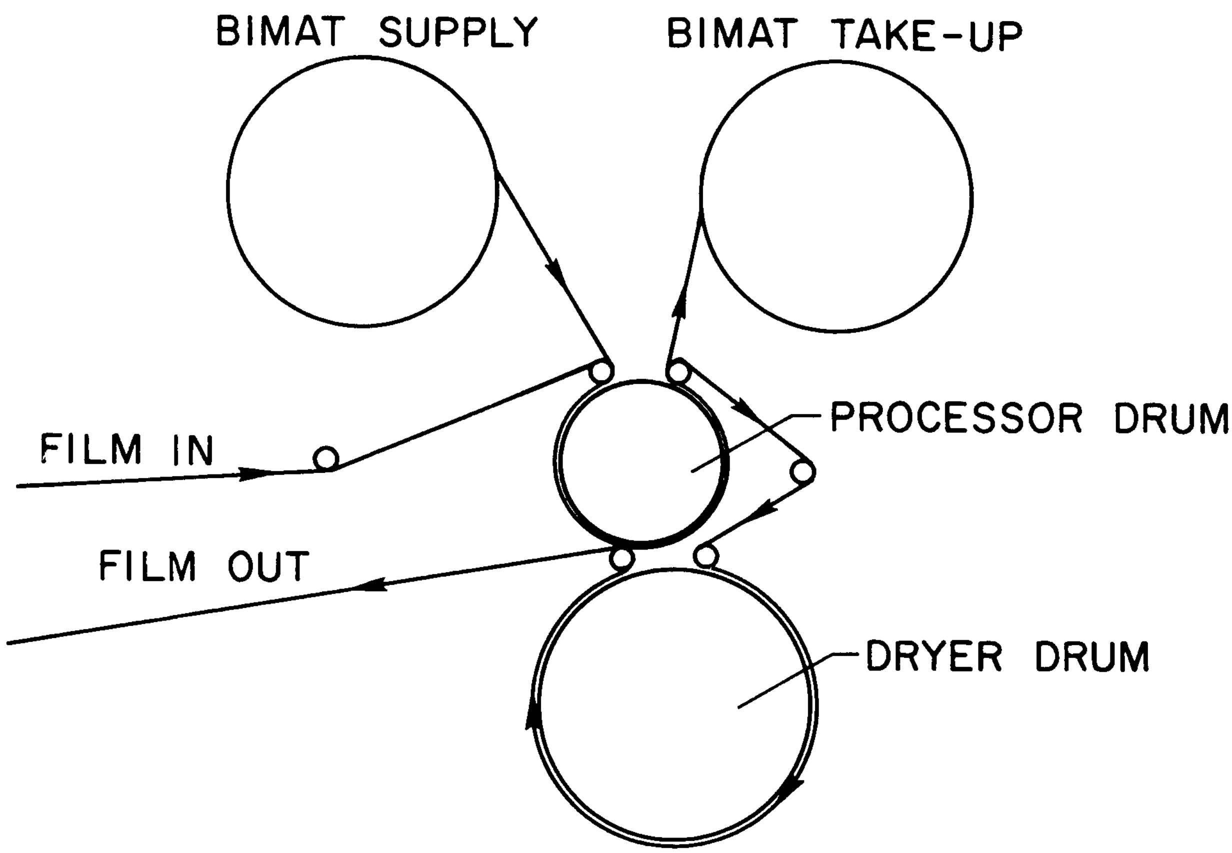


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Figure 10.- Processor-dryer.

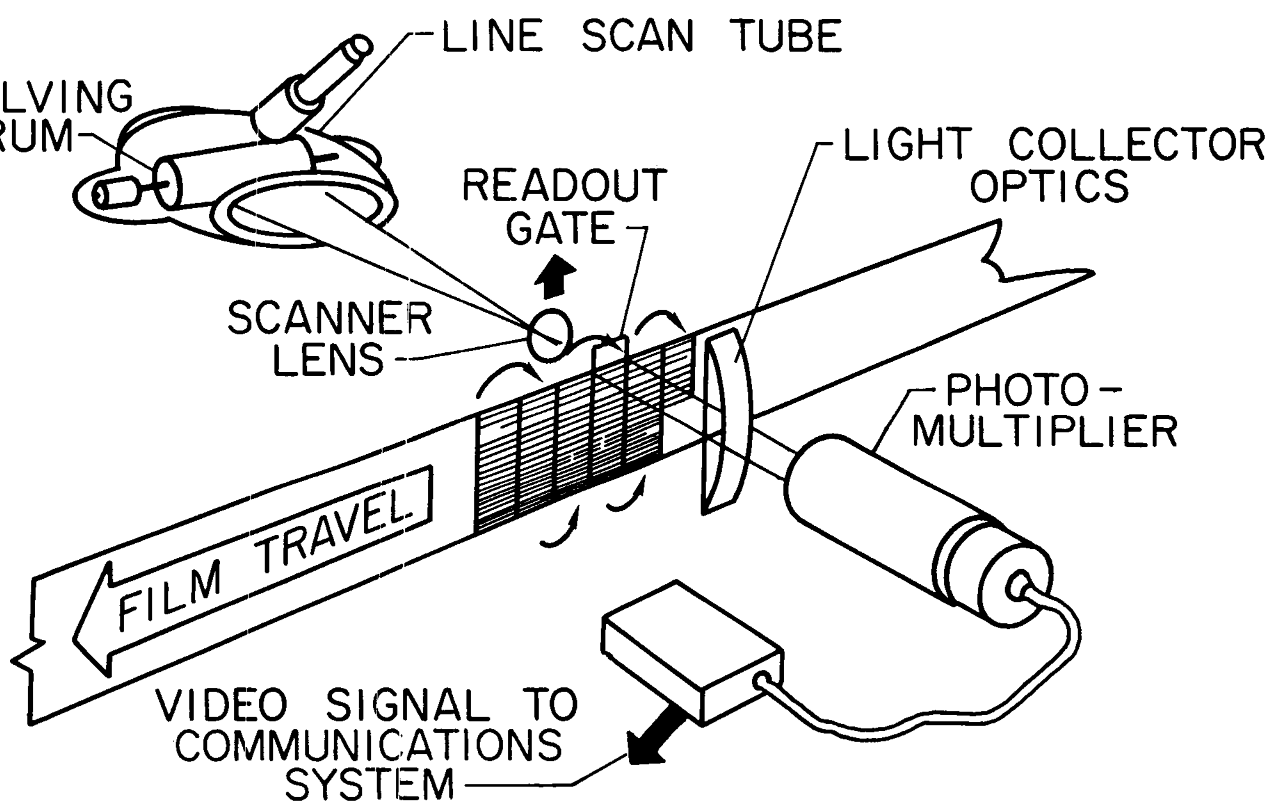

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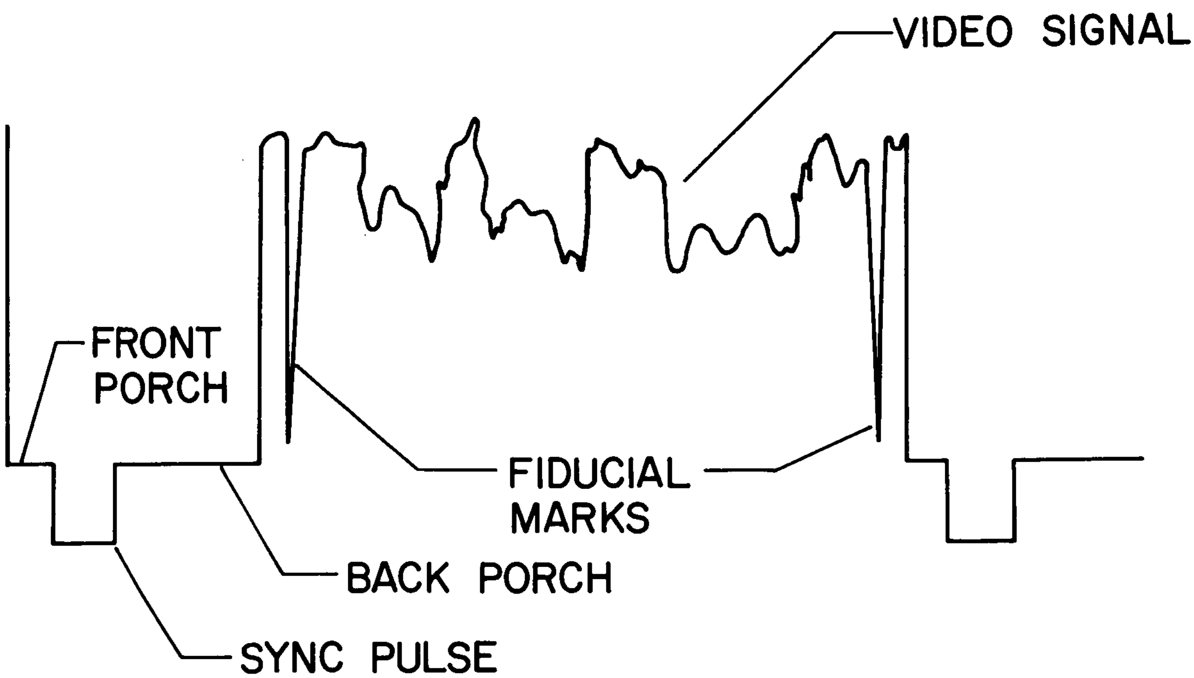
Figure 11.- Photographic system readout schematic.



NASA

Figure 12.- Composite video signal.

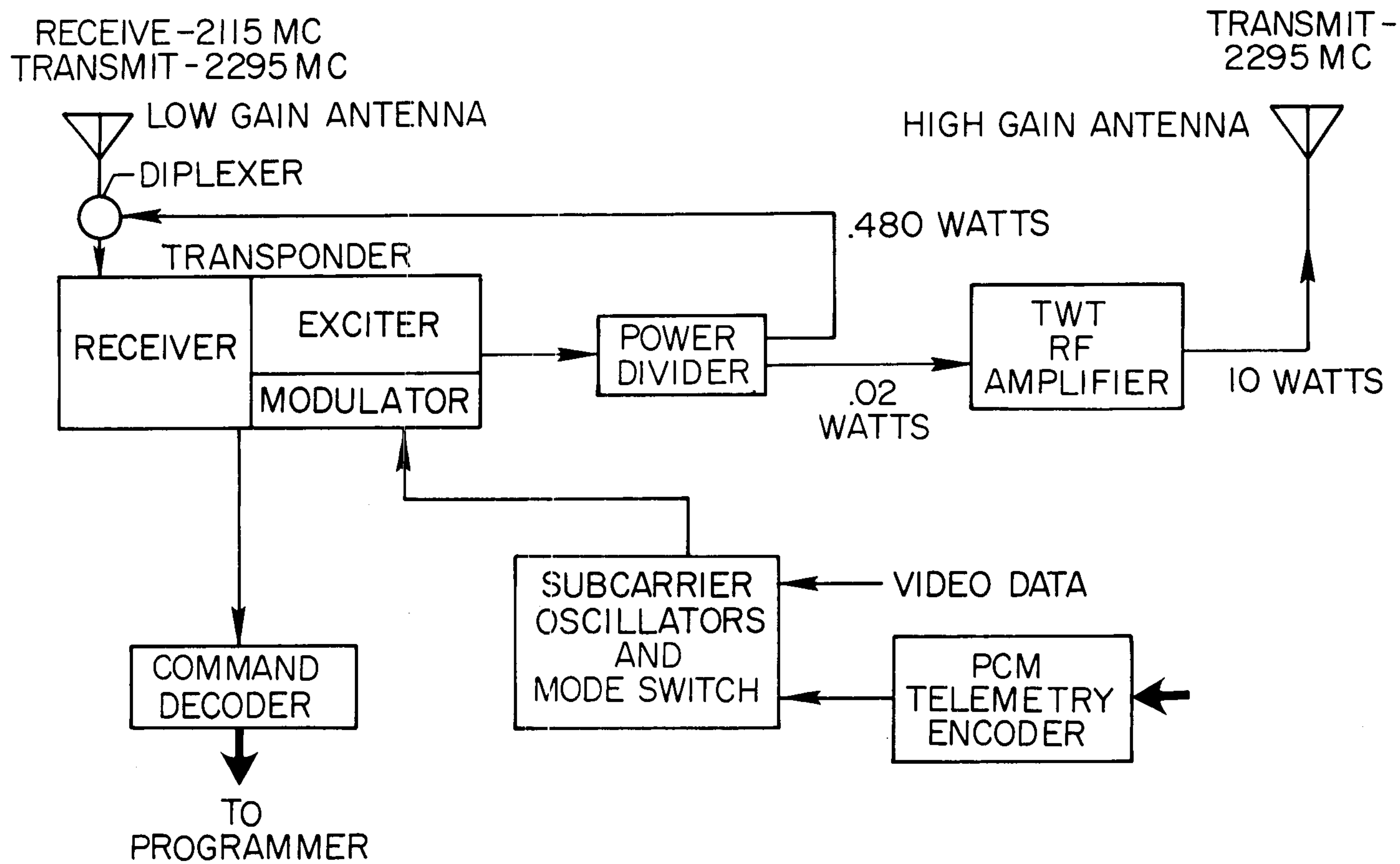


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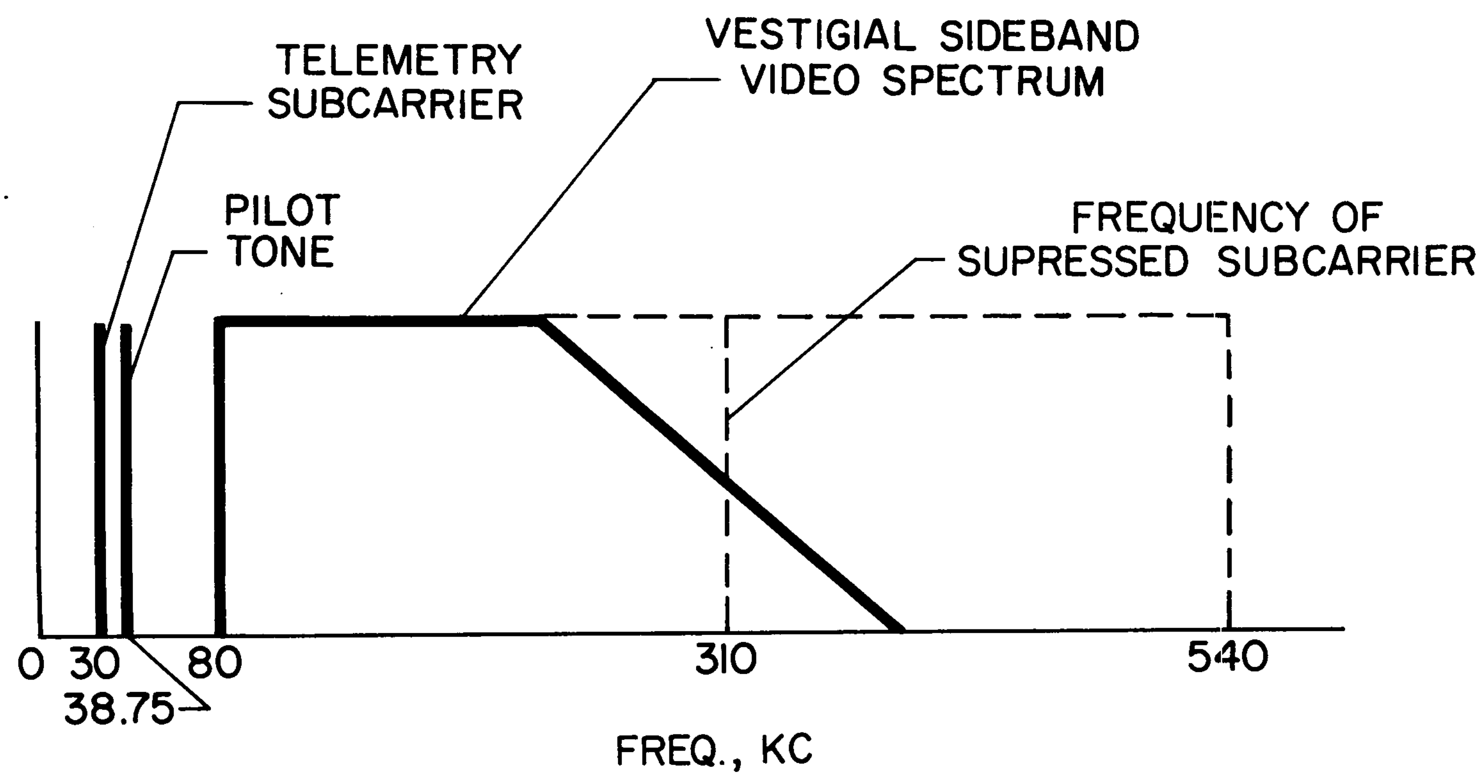
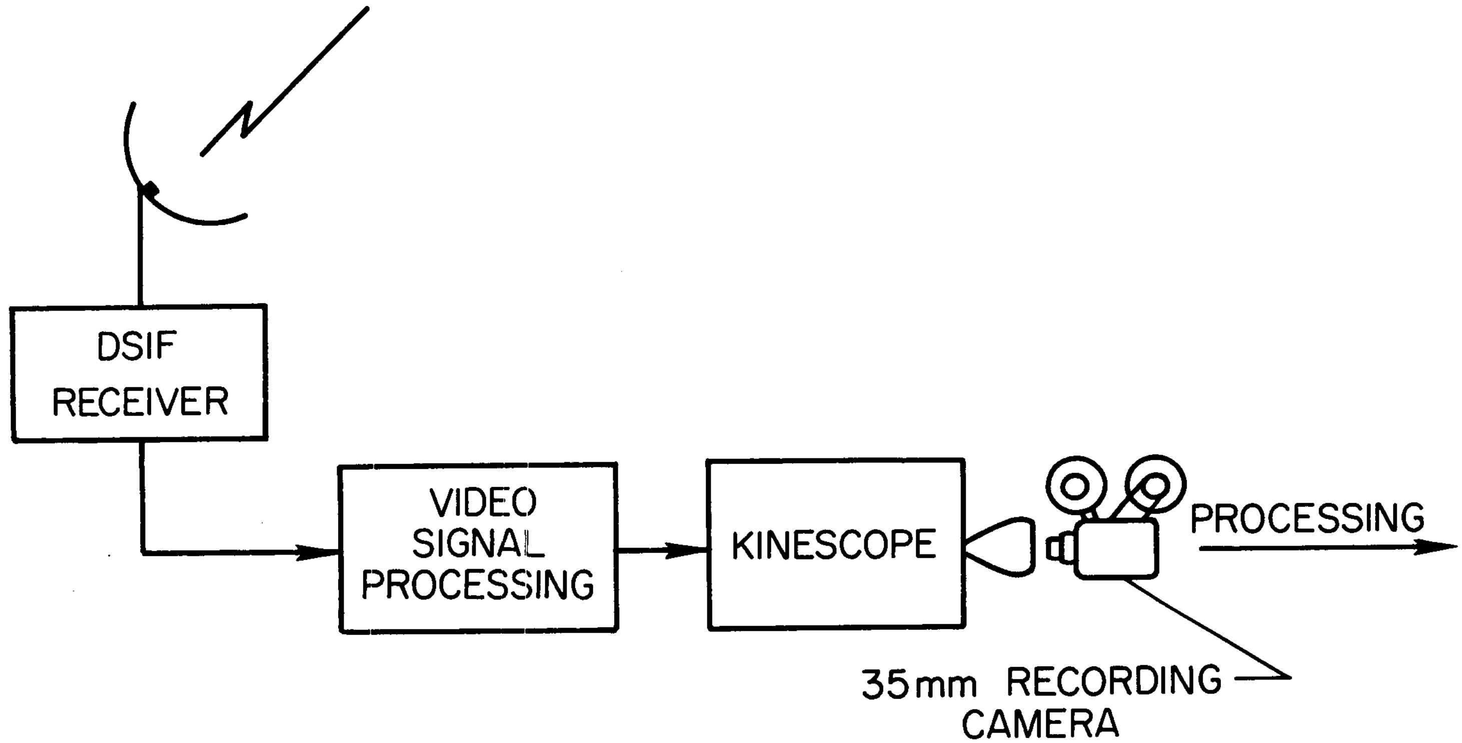
Figure 13.- Spacecraft communications system.



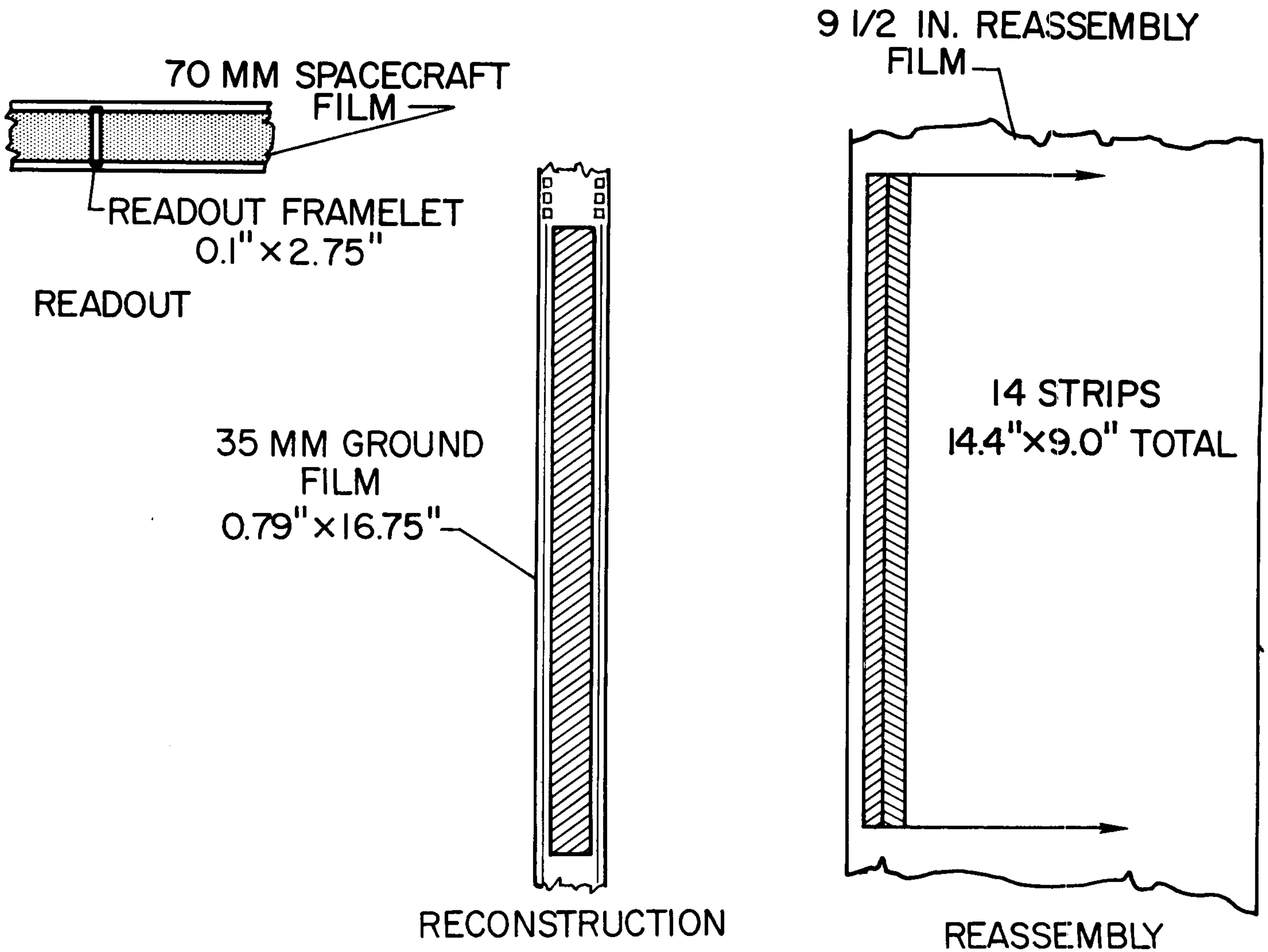
NASA

Figure 14.- RF baseband structure.



NASA

Figure 15.- Ground data recording.



NASA

Figure 16.- Reassembly geometry.

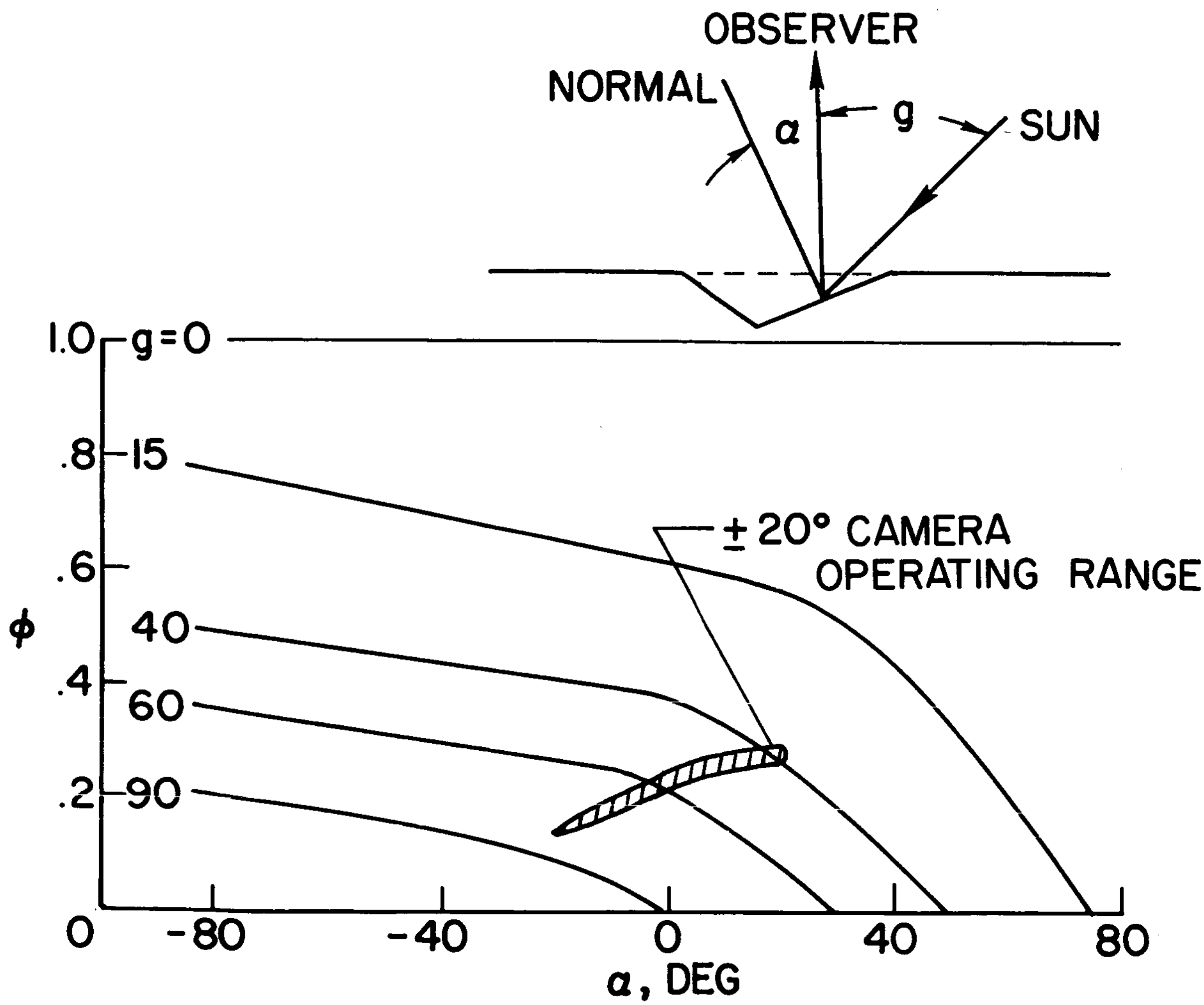


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Figure 17.- Lunar photometric function.

NASA-Langley, 1965