



The Apollo Lunar TV Camera has been designed to operate either in the spacecraft or on the lunar surface with no adjustments except for lens changes.

On the first manned flight to the moon, a small low-power but very sensitive television camera will accompany the Apollo astronauts to send live television pictures back to earth. The camera was developed by the Westinghouse Aerospace Division under contract to NASA's Manned Spacecraft Center in Houston. Hand-held by the astronaut or mounted in the spacecraft, the camera will provide home television viewers with coverage of the Apollo exploration.

In several respects, the camera is unique among the rest of the Apollo electronics equipment. For example, it is one of the few items that must operate under all phases of mission environment—from launch pad to the moon, on the moon's surface, and back to earth. With more than 80 percent of its circuitry in the form of molecular integrated devices, the camera uses fully the most recent developments in solid-state devices. Today's most advanced sensor tube, the SEC camera tube, will enable the camera to operate under the low light level conditions that will be encountered during lunar night.

The main mission of the camera is to provide real-time television pictures of phases of the Apollo mission. A secondary mode of camera operation will provide high-resolution, slow-scan pictures for detailed scientific viewing.

To conserve transmission bandwidth, scanning parameters for the lunar camera are slower than those of standard broadcast television. When received on earth, the pictures will be converted to broadcast television rates for retransmission by commercial stations.

Operational Requirements

Mission environments and compatibility with other equipment place numerous constraints on camera design. As with all

space equipment, highly reliable operation is a prime requirement.

Environmental conditions that the camera must withstand are: vibration of 10 to 2000 cycles per second (up to 6 g) and shocks of more than 8 g during Apollo launch and lunar landing; pressure variation from sea level to 10^{-14} mm Hg; temperature extremes on the moon's surface from +250 degrees F during the lunar day to -300 degrees F at night; acoustical noise of 130 dB (above 0.0002 dynes/cm²). The camera may also be exposed to salt spray, 100 percent oxygen atmosphere, and meteoroid bombardment and particle radiation.

In a spacesuit, an astronaut does not have a great deal of dexterity. Ease of handling, holding, pointing, changing lenses, connecting and disconnecting, storing and carrying without danger of nicking his spacesuit place many constraints on the design of the camera package. Therefore, astronauts need only change lenses and switch scan modes. All other controls within the camera operate automatically. Since the camera will be hand-held, it must be small and lightweight.

Scenes will include views of astronauts moving in the spacecraft and on the lunar surface, the earth or moon from space, the lunar surface, and the LM vehicle on the lunar surface. Light levels for these scenes will vary from partial earthshine on the moon to full sunlight (0.007 to 12,600 foot-lamberts).

A lightweight stowage method is provided to hold the camera and lenses when not in use, within both the command module and the lunar module. It provides easy removal by the astronaut.

Scanning parameters for the camera were selected by NASA to best fulfill the overall mission. Several factors influenced the selection of the scan rates.

Motion rendition must be preserved to avoid breakup in pictures. Ten frames per second provide acceptable motion rendition. Although some motion breakup would occur in normal scenes, an astronaut cannot move quickly in a spacesuit; therefore motion breakup should not occur for the scenes that will be photographed during the Apollo mission.

Ease of scan conversion to 60 frames per second (standard rate) was another factor in determining the frame rate, since submultiples of 60 fps are most easily scan converted. Transmitter bandwidth and power is limited. Since the camera must share bandwidth with voice, biomedical, and other telemetry data, the camera is limited to a 500-kHz bandwidth.

A 320-line scan was chosen to obtain nearly equal horizontal and vertical resolution. Most home television sets reproduce about 300 TV lines from a 525-line scan and provide a pleasing picture. The 10-fps mode will provide a picture of about 250 discernible lines, which is still a satisfactory picture.

For scientific purposes, higher resolution pictures are needed. Since motion rendition is not required for these pictures, a slower scan rate can be used. A scan rate of $\frac{5}{8}$ fps with 1280 lines provides a camera in which the sensor becomes the limiting factor in resolution. This rate is also easily obtained from the circuitry that provides the 10-fps, 320-line scan.

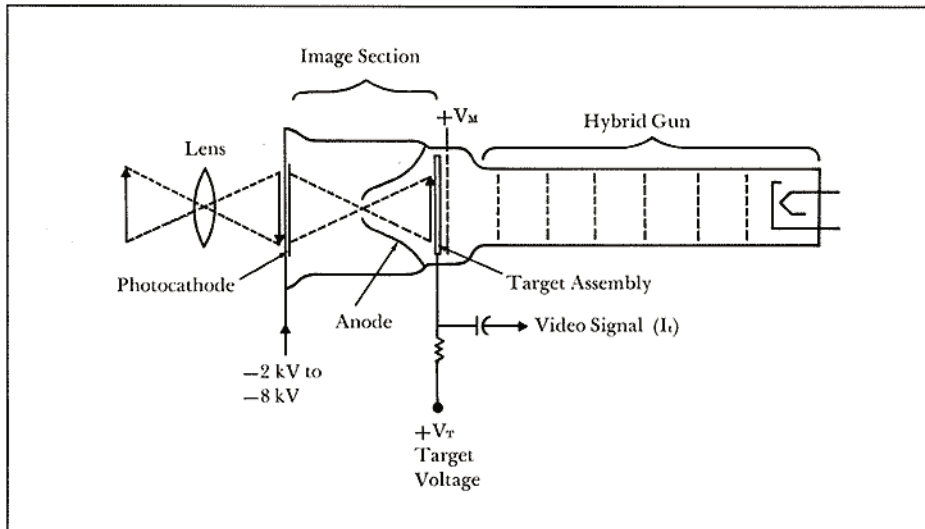
SEC Camera Tube

To satisfy the low light level requirements, the SEC (secondary electron conduction) camera tube¹ was chosen. A standard vidicon tube is not sensitive enough and an image orthicon is too large and heavy, and requires too much power. The SEC camera tube is comparable in sensitivity with the image orthicon, but it has the operational simplicity and the lower power requirements of the vidicon.

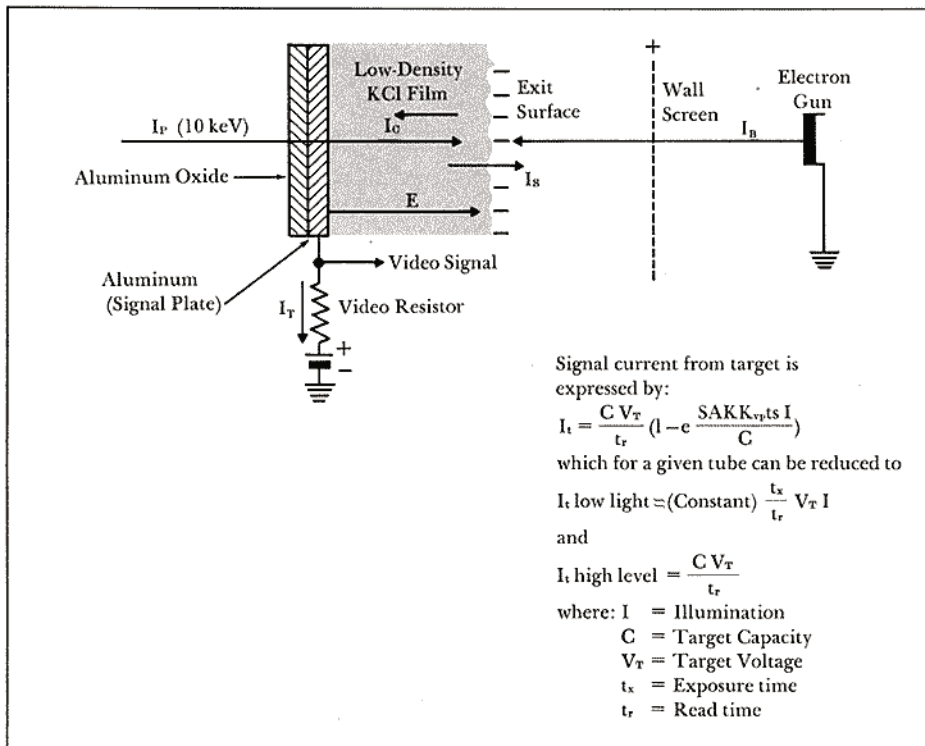
The SEC camera tube, shown in Fig. 1, consists of three main sections: image section, SEC target assembly, and hybrid gun. The scene is optically imaged on the photocathode, causing electrons to be emitted by the photocathode material (S-20). These electrons are accelerated by the high potential between the photocathode and the SEC target. This target, the unique feature of the SEC camera tube, consists of an aluminum oxide layer, a very thin layer of aluminum, and a low-density KCl film.

¹Goetze, G. W. and Boerio, A. H., "Secondary Electron Conduction for Signal Amplification And Storage In Camera Tubes," IEEE Vol. 52, Sept. 1964.

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1—The SEC camera tube consists of three main sections—an image section, target assembly, and hybrid gun.



2—Secondary electron conduction (SEC) in low-density film is demonstrated in this diagram. High-energy primary electrons (I_p) release secondary electrons in low-density film. The electric field (E) applied across the film causes a majority of the secondary electrons

to be transported through the low-density layer of KCl to produce secondary conduction current, I_c . A fraction of the secondary electrons escape from the exit surface as transmission secondary current, I_s . Gain is the ratio of $(I_s + I_c)$ to I_p .

When the accelerated electrons strike the target, they pass through the aluminum layer and strike the KCl film. Secondary electrons released by the KCl film are collected by the signal plate and the wall screen (Fig. 2), leaving a charge pattern in the KCl film. Since the resistance of the film is high, it can hold the charge pattern for long periods until discharged by the reading beam.

The reading beam is supplied by a vidicon-type gun, a hybrid arrangement with electrostatic focus and magnetic deflection (electrostatic focusing permits simple external circuitry and has low power requirements). As the reading beam scans the target, the beam current discharges the KCl film back to cathode potential. This discharging action produces the video signal (I_i).

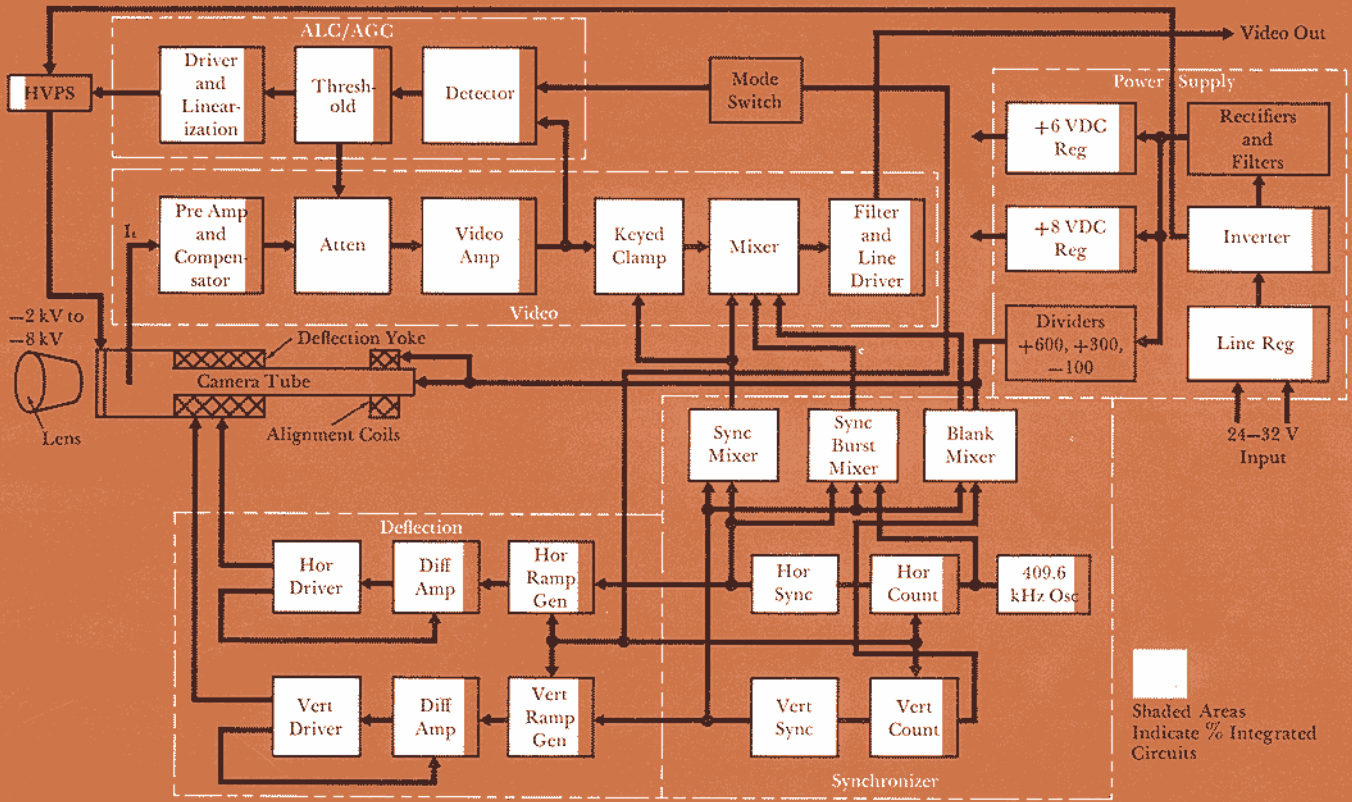
An important characteristic of the SEC target is that it is almost completely discharged by the beam, leaving negligible signal pattern for the next readout unless recharged by the scene. This eliminates the image smear problems that occur with vidicons and orthicons at low light levels. Of course, smear will occur if the image is moved within a frame period.

Electron gain of the SEC target provides target gains in excess of 100. With an S-20 photocathode, the combined sensitivity of the image section and the SEC target is typically 10,000 $\mu\text{A/lumen}$. Since target gain is a function of the accelerating potential, target gain is controlled by adjusting the accelerating potential (-2 kV to -8 kV).

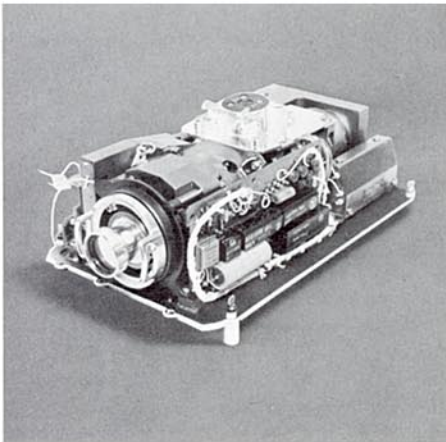
Camera Circuitry

Camera circuits can be divided into five major sections, as shown in the block diagram (Fig. 3).

The video output from the SEC camera tube is fed to the video section, which consists of a preamplifier, gain-control element (attenuator), amplifier stages, and a mixing stage. A minimum signal-to-noise (S/N) ratio of 28 dB is required to obtain useful pictures at the ground receiving stations; actually, an even higher S/N is desirable. The low-noise preamplifier is necessary to provide this minimum S/N at the lowest light level (noise equivalent current of the pre-



3—Simplified block diagram shows the five major sections of the lunar TV camera.



amplifier is 2.5×10^{-10} ampere). Overall video-current gain is about 10^6 . The mixer stage inserts sync information into the video signal.

The automatic control circuits (ALC/AGC section) are designed to provide the highest possible signal-to-noise ratio for a given light level, and at the same time maintain a constant signal level out of the camera for a wide range of light inputs. This is accomplished with two gain control paths that operate in sequence.

An automatic gain control (AGC) loop varies video gain at the attenuator to hold a constant output up to the *maximum operating point* (MOP) of the SEC camera tube. At maximum SEC signal current, the saturation level of the SEC target is approached and the picture begins to lose contrast. Therefore, the maximum operating point for the SEC camera tube is chosen just below this level.

When light levels would cause the tube to operate above this maximum operating point, photocathode potential must be reduced to reduce target gain. This is accomplished with the automatic light control (ALC) loop, which controls the high-voltage supply to the photocathode, thus regulating the energy of the electrons striking the camera tube target which in turn regulates target gain. Quality images can be obtained from the camera tube with accelerating potentials over a range of -8 kV to approximately -2 kV, which is the cutoff potential of the image section.

When the camera is operated in the slow-scan mode, the SEC camera tube has a much lower maximum operating point. This is because maximum signal current is proportional to the reciprocal of read time ($1/t_r$, as illustrated in Fig. 2); since slow-scan read time is 16 times longer, maximum signal current is reduced by 16. Therefore, the AGC control loop is switched out for the slow-scan mode and video output is controlled directly by the ALC loop. To provide ease of changing frame rates, all internal switching required is done electronically; a single-pole, double-throw switch, operated by the astronaut, provides the switch signal.

The AGC/ALC control loop arrange-

ment holds video output within a 3-dB variation over a 60-dB range in light level input.

A crystal-controlled oscillator in the synchronizer section provides a stable reference for all timing circuits within the camera. Digital countdown from the crystal frequency (409.6 kHz) generates all timing signals, such as synchronizing signals, blanking, vertical sync serrations, etc.

Linear sweep voltages for deflecting the SEC camera tube beam at the relatively slow scan rates are obtained with closed-loop driving circuits in the deflection section.

Power for the camera is obtained from the spacecraft 28-volt power source, which may vary from 24 to 32 volts. A switched line regulator provides a highly efficient regulation of this input to supply the inverter. All necessary voltages are obtained from the inverter. Two of these voltages— $+6$ volts and -8 volts used in the sweep, video, and automatic light control circuits—require further regulation because of their varying loads. The -8 kV photocathode supply consists of a separate inverter with a controllable input (for ALC) and a six-stage voltage multiplier, followed by additional filtering to provide extremely low ripple.

The connection to the camera, for bringing power in and the video signal out, must be easily connected or disconnected at any time during the mission. A special connector² was designed for the lunar camera since none was available that would operate in a vacuum, salt spray, humid, or explosive atmosphere.

Optical System

Several lenses are required because the anticipated scenes require different fields of view. Furthermore, the light level will vary from 0.007 to 12,600 foot-lamberts for the anticipated scenes. To cover both of these conditions, a set of four fixed-focus lenses were chosen in preference to a zoom lens or a turret system, because either of the latter would have been heavier and less reliable.

²Rushing, Frank, "Electrical Connectors for Outer Space Application," *Westinghouse ENGINEER*, March 1966.

4—(Top) A set of four fixed-focus lenses of the quick disconnect type can be easily handled by an astronaut in a spacesuit and provide various fields of view (Table I).

5—(Lower) Compact camera package provides for cooling, circuit shielding, electrical insulation, and protection from hostile environments.

Lenses are all quick disconnect type so that they can be handled by an astronaut in a spacesuit. They are listed with field of view and T-number in Table I. (T-number is the combination of f-number and effects of filtering). T-numbers were chosen to set the photocathode illumination within the dynamic range of the camera tube for the various scenes.

Maintaining optical focus for all lenses under all environmental conditions required careful selection of mounting materials and methods. For example, the lenses are mounted directly to the tube assembly rather than to the camera case, which permits closer mounting tolerances to be maintained.

Camera Package

Design of the camera package (Fig. 5) had to accomplish many tasks, such as cooling, shielding circuits from each other, insulating high voltages, preventing corona, and protecting circuitry from hostile environments.

One of the more critical problems was designing the camera to withstand the

thermal radiation from both the sun and the 250-degree surface of the moon during the lunar day—and also withstand the cold of the lunar night when the lunar surface drops to -300 degrees F. Limitations of the sensor, optical interfaces, and the electronic components preclude operation at these temperatures.

Passive cooling by radiation was chosen as the most reliable and lightest weight method. Heat generated within the camera circuitry must be conducted to the ground plane (heat radiating surface) since heat transfer by convection cannot occur in vacuum. For example, circuit components are mounted on boards with printed wiring on one side and a ground plane on the other. This ground surface not only serves as a heat conduction path, but also provides necessary shielding.

Thermal balance of the package requires sufficient surface area and a surface finish such that the heat generated by camera circuitry and the incoming thermal radiation can be offset by radiation and reflection from the camera's

surface into deep space. Therefore, circuits were designed for minimum power dissipation. Extensive use of integrated circuits helped accomplish this objective. As a result, temperature within the camera will be maintained between 0 and 130 degrees F. All circuits are designed to operate well beyond these temperatures to provide a further safety margin.

High voltages for the sensor plus the varied pressures encountered required special design to prevent insulation breakdown and corona. For example, power supply circuits are molded in epoxy for structural support and for protection against low pressure. The external surface of the power supply is plated and tied to ground to prevent surface charge buildup and corona, and to provide shielding.

A vacuum-tight pressure seal for the camera would have been unreliable and heavy, and therefore was not used. Rather, a seal between the camera covers will keep out humidity, but will allow pressure inside the camera to change slowly.

Camera Tests

Several cameras identical to the actual Apollo mission cameras were fabricated for environmental testing. Special manufacturing procedures were set up to fabricate the test cameras, and all assembly work was done in a clean room environment.

In addition to vibration, humidity, salt spray, and other environmental tests normally performed on space or airborne equipment, the cameras were tested for operation on a simulated lunar surface. Simulation of the lunar surface for both day and night was done in a large vacuum chamber, with a solar simulator for lunar day tests. After passing the tests for the mission environments, these cameras were then subjected to more stringent environments to determine the amount of safety margin available.

The final tests of the Lunar TV camera will be viewed by millions as they watch, on their home television sets, the exploration of the moon as seen by the Apollo astronauts.

Table I. Lens Characteristics

Scene	Light Level (ft-lamberts)	Lens Field of View (degrees)	Lens T-Number*
Lunar Surface—Night	0.007-1.2	30	1.15
Lunar Surface—Day	20-12,600	30	60
Earth and Moon	20-12,600	7	60
Spacecraft Interior	0.5-300	80	5

*T-number is the combination of f-number and the effects of filtering.

Table II. Camera Parameters

Power	6.5 watts, 24 to 32 volts dc input
Weight	7.25 lb
Video Bandwidth	2 Hz to 500 kHz
Scene Illumination	0.007 ft-lamberts to 12,000 ft-lamberts
Automatic Control Range	1000 : 1
Scan Parameters	10 frames/sec 320 lines/frame 5/8 frames/sec 1280 lines/frame
Aspect Ratio	4 : 3
Resolution	500 TV lines
Operating Temperature	0° to +130°F
Linearity	2%