TV Show of the Century: A Travelogue with No Atmosphere

Reprinted from March 6, 1967 Issue of ELECTRONICS

Produced by Westinghouse Technical Information
Reprint 6437

Aerospace Division
Westinghouse Electric Corporation
Defense and Space Center
P. O. Box 746
Baltimore, Maryland 21203

Tv show of the century: A travelogue with no atmosphere

Apollo astronauts will use a lightweight television camera to send back pictures of their trip and of the moon's surface

By Stanley Lebar and Charles P. Hoffman

Aerospace Division, Westinghouse Electric Corp., Baltimore

More "vast wasteland" is in store for television viewers—the surface of the moon. Apollo astronauts will use a highly sensitive, lightweight camera to send tv signals from their spacecraft and the moon back to earth, where some of the scenes will be retransmitted by conventional television stations to a living-room audience. Also, scientists and engineers viewing live, real-time tv images will follow nearly every phase of the three-man mission.

Integrated circuits make up 80% of the camera's electronics. A rugged unit, small enough to be held in one hand, the camera uses an improved version of a recently developed tube to operate in the brightness of the lunar day and in near-darkness, when the only illumination is light reflected from the earth—a light range from 0.007 to 12.600 foot-lamberts. The lower limit of this range would be equivalent on earth to the light from a quarter-moon, the highest limit to the light from an overhead sun on a clear summer day. Although lenses will be interchanged to optimize light sensitivity, the camera won't require any internal adjustments.

Only one camera will be taken on the trip, a unit designed for a 99.9% probability of success over the 360-hour duration of the mission. Completed models have already been delivered to the National Aeronautics and Space Administration. They are built to operate in the severe vacuum environment of the moon at temperatures ranging from 250° to —300° F; passive cooling will hold camera temperature between 0° and 116° F. The camera is also designed to operate in the humid and corrosive atmosphere of the spacecraft without endangering the astronauts.

Making the scene

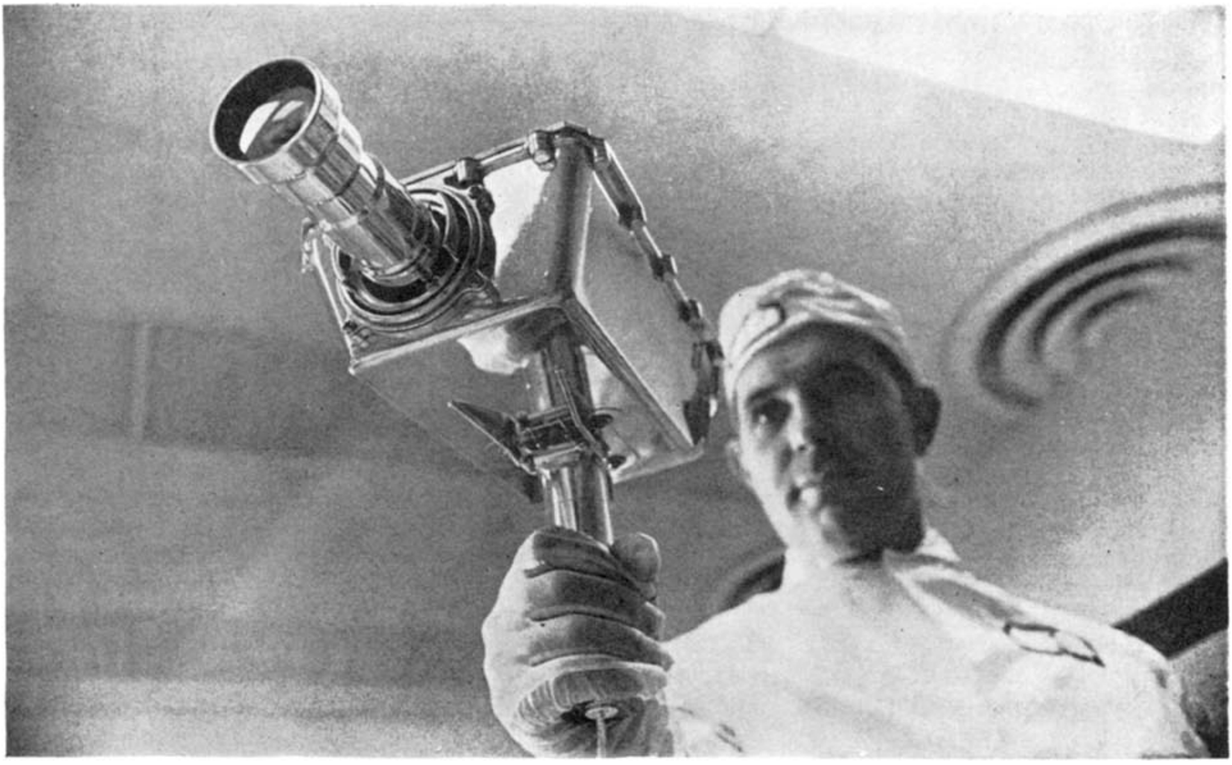
The only external camera control is a switch to change operation from slow to fast scan. For high-resolution scientific studies, the camera will be mounted on a tripod and will scan the scene at a rate of ⅝ frame per second with 1,280 lines per frame. Where lower resolution is needed—for example, to monitor the astronauts' movements—the camera can be hand-held and will scan the scene at 10 frames per second with 320 lines per frame. Unlike the conventional broadcast television format, the lines won't be interlaced.

After touchdown on the moon's surface and erection of an S-band antenna, the astronauts will connect a combination handle-electrical connector to the camera; the handle can be engaged or disengaged in a vacuum without the contacts welding together. The handle is hooked up to a 100-foot cable that will supply the camera with d-c power from the Lunar Excursion Module (LEM) and will

The authors

Stanley Lebar manages the Apollo lunar tv program. A 14-year veteran with Westinghouse, he has worked in the fields of optical instrumentation, waveguide and antenna systems, missile fuzes, and space systems. The manager of several programs over the past 10 years, he received his BSEE degree from the University of Missouri in 1950.

Charles Hoffman, engineering manager of the Apollo camera program, has been active in the design of radar and electro-optical systems. For his work on an integrated-circuit version of an infrared search-track system he received the "Outstanding Engineer Award" from the Maryland IEEE chapter. He received a BEE degree from Johns Hopkins University.



Apollo television camera with telephoto lens attached is held by Westinghouse engineer. Handle also serves as an electrical connector that can be engaged and disengaged without the contacts welding in the moon's vacuum environment. Cable in handle carries d-c voltages to camera and video output to transmitter in the spacecraft. All the electronics are mounted on the top plate. Bottom pan is an enclosure. Thick casing is for protection from meteors.

also connect the camera's video output with the module's S-band transmitter. After selecting a lens appropriate to the light conditions and the scene to be viewed, an astronaut will switch to the desired scan mode. He will use the edges of the camera as an aiming sight.

The heart of the Apollo camera is a sensitive image tube that combines a variable-gain light intensifier with a secondary electron conduction (SEC) target.[1, 2] This target produces gain and stores the image that is subsequently scanned by the tube's electron beam gun. Although the tube is slightly less sensitive than an image orthicon, the electronics for reading out the stored image are as simple as those of a vidicon tube. With fast response, the SEC tube's video output signal at low light level reproduces objects in motion without smearing—unlike the video output of vidicon and image orthicon tubes. At the same time, the SEC target can store and integrate signal information over a relatively long time period, a factor that contributes to the tube's slow-scan capability and sensitivity.

Optical system

The Apollo camera, built by the Westinghouse Electric Corp.'s Defense and Space Center, is provided with four interchangeable lenses of fixed focal length. A wide-angle lens will be used primarily for pictures inside the command module, while a telephoto lens will be used to view the earth and moon during the trip back and forth. Two general-purpose lenses will be used on the moon's surface, one during the lunar day and the other during periods of darkness.

The lenses focus light onto the electrostatic diode image intensifier's photocathode, which emits electrons in proportion to the incident light level. A faster lens—one with a larger aperture—collects more light and thus increases the number of emitted electrons. S-20 photocathode material is used in this tube because its quantum efficiency is relatively high and uniform over visible wave lengths.

The potential difference between the photocathode and the SEC target accelerates the emitted electrons and the intensifier's electronic optics focus the image onto the SEC target.

Depending on the incident light level, an automatic control circuit varies the accelerating potential so that electrons hitting the target have energies ranging from 2,000 to 8,000 electron volts, with the higher energy level corresponding to low light levels. In this way, the tube is able to accommodate a wide range of illumination while maintaining a relatively constant signal output.

The SEC target releases secondary electrons in proportion to the number and energy of the impinging electrons. These secondary electrons are collected by a thin aluminum plate that is at a higher potential than the target material. As a result, each point on the face of the target becomes positively charged in proportion to the incident light level.

The operation of reading the stored image out of the SEC target is similar to that in a vidicon tube. When the electron gun scans across the target, it

Apollo camera's system parameters

Power consumption	6.5 watts with 24- to 32-v d-c primary source
Weight	7.25 lbs.
Video bandwidth	2 hz to 500 khz
Scene illumination (requires lens change)	0.007 to 12,600 foot-lamberts
ALC/AGC control range	Greater than 1,000:1
Scan parameters	
Mode 1	10 frames/sec, 320 lines/frame noninterlaced
Mode 2	0.625 frames/sec, 1,280 lines/frame noninterlaced
Aspect ratio	4:3
Faceplate image size	0.5 x 0.375 inch
Resolution (limiting)	500 tv lines in picture height
Signal-to-noise ratio	28 db, minimum
Operating temperature	0° to +116F with passive cooling
Linearity	2%

neutralizes the charge and brings the target potential back to ground level. This change in charge results in a current pulse that is coupled to an external resistor. The voltage developed across the resistor is the video signal.

The tube's image intensifier and 1-inch hybrid vidicon gun are especially rugged but are otherwise of conventional design. Because the gun is electrostatically focused, it requires only simple external circuitry. Although a magnetically focused gun would improve the tube's resolution, the focus coil would appreciably increase weight and power requirements.

Thermally balancing the package

Except for the unregulated d-c supply from the spacecraft, the camera is a self-contained unit. The SEC tube and deflection surface provide the basic conversion from optical to electrical signals, while a combined automatic light-level control and gain control (ALC/AGC) maintains a constant video output even as light levels change. Video amplifiers boost the signal and mix it with sync signals and blanking pulses developed in the synchronizer.

The amount of surface area needed to maintain thermal balance at lunar noon determines the camera's size and weight. Besides having the appropriate cooling properties for lunar operation, the surface finish must withstand the corrosive atmosphere of the spacecraft. The finish used will hold the camera's surface-temperature below 120° F during lunar day if the top surface can reflect into deep space. For night operations on the moon, camera temperature may drop as low as —44° F. However, 27 square inches of silver shields can be attached to the unit's top surface to prevent radiation of heat outward and hold the low temperature to 0° F, improving reliability.

Integrated circuits for reliability

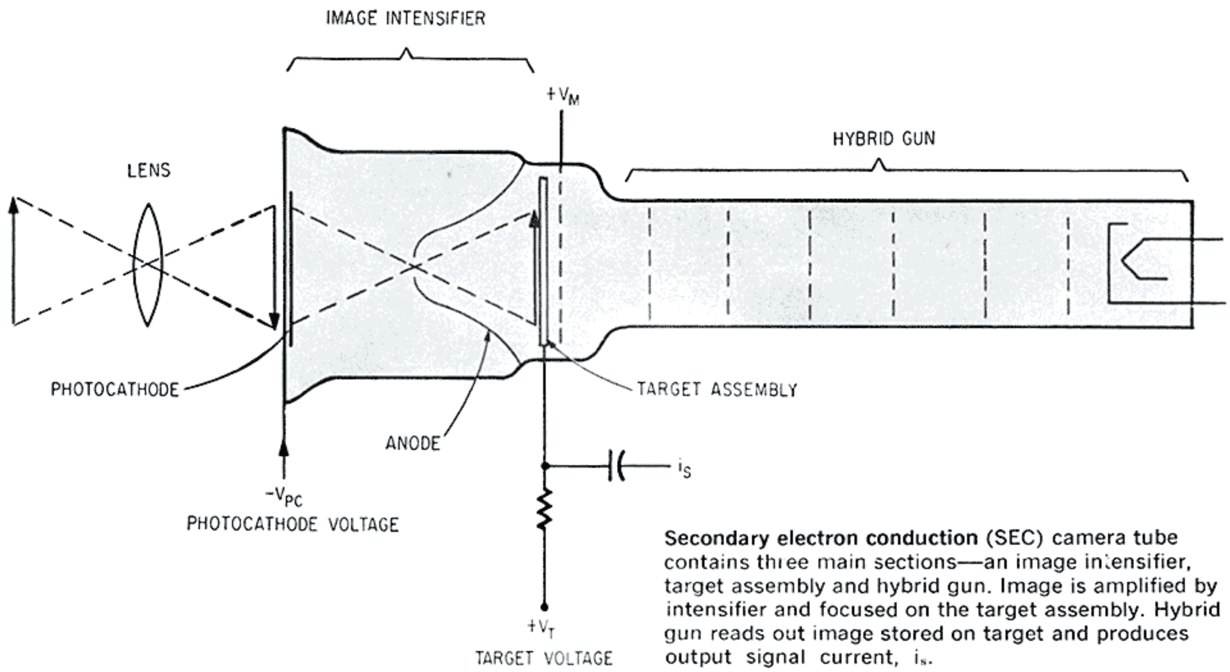
Reliability was also the prime factor directing the choice of integrated circuits for most of the camera's electronics, though size, weight, power-consumption and cost reductions were also considerations. Of the 43 integrated circuits used, 24 are of different types and 19 of these types were designed especially for the camera.

The custom circuits are of both monolithic silicon and multiple-chip hybrid designs. Of the 19 custom units, Westinghouse built 11—the ones deemed most likely to change with improvements in the SEC tube. A monolithic silicon chip contains all the active components except for pnp and field effect transistors. Those components that couldn't be built with integrated circuits—large capacitors and chokes, for example—had to be wired in.

Since the synchronizer requires the largest number of integrated circuits—12 flip-flop packages and 7 gate packages—it was essential to use devices with low power-switching capability. Two higher-power AND-gate units form the interface between the synchronizer sweeps and the mixer in the video

Comparison of tv cameras

	SEC	Vidicon	Image orthicon
Low light level in foot-lamberts (for S/N = 20 db	10^{-3}	10^{-1}	10^{-5}
Lag	No	Yes	Yes
Power	6.5 watts	6.5 watts	15 watts
Weight	7.25 lbs.	4.5 lbs.	25 lbs.
Size	160 in.^{3}	80 in.^{3}	400 in.^{3}
Complexity	Slightly more than vidicon	Simple	Complex
Dynamic range	40 db	40 db	30 db



Secondary electron conduction (SEC) camera tube contains three main sections—an image intensifier, target assembly and hybrid gun. Image is amplified by intensifier and focused on the target assembly. Hybrid gun reads out image stored on target and produces output signal current, i_s.

circuit. Hybrid circuits were used in the mixer, sweeps and power supply.

Whether made by Westinghouse or purchased from outside vendors, the circuits have had to meet specifications far in excess of the environmental stresses they are liable to encounter.

Design constraints

For transmission of pictures back to earth, the camera's video output frequency-modulates the S-band transmitter. The signals will be transmitted in analog form because NASA studies have shown that such a system requires only one fourth the bandwidth of a digital transmission scheme. Since power is limited, the bandwidth has to be restricted to 500 kilohertz.

To prevent excessive deviation of transmitter frequency, the video signal must be less than 2.1 volts when working into 100 ohms. The sync burst format used puts both the sync amplitude and the video signal above a reference black level. In this way, both the sync and picture information can have a full 2-volt swing and thus deviate the transmitter the full 500 khz. In comparison, the amplitude-modulated format of commercial tv would prevent full deviation because video information is on one side of a fixed black level and the sync information is on the other.

As in commercial tv, the vertical sync pulses in the Apollo system are serrated at the horizontal line frequency to maintain horizontal sync in the receiver during the vertical sync pulses.

Scan modes

The 10-frames-per-second, 320-line scan format —the primary mode in the Apollo camera—affords good vertical resolution and adequate display of motion. In telecasting fast actions—a man quickly raising his arm, for instance—there is breakup or smear at frame rates below 15 frames per second, and this breakup is quite pronounced at 10 frames per second. However, because the astronauts will move slowly in the spacecraft and on the lunar surface, the rendition of motion at the slower rate is acceptable.

The resolution is actually lower than the number of lines. A 500-khz transmitter bandwidth would theoretically limit the maximum resolution to 210 lines, but because the filter in the video amplifier section has a frequency response that rolls off gradually, the resolution is equivalent to that of a 250-line system.

The high resolution offered by the slower scan mode—⅝ frame per second with 1,280 vertical lines—is limited by the camera's aperture response.

Signal controls

The combined control of the photocathode and video gain by the ALC-AGC circuit compensates for a 65-db change in light level in about 2 seconds. Over this wide dynamic range, the signal-to-noise ratio will change only about 20 db. Not shown in the schematic diagram on page 185 are transistors that electronically switch the input level, detector time constants and threshold levels when changing operation modes.

The first step in controlling the signals is to produce a d-c signal proportional to the video signal. This conversion starts in detector Z_1. D_1 and C_1 will clamp to a fraction of a positive voltage (black level) that is generated by the blanking pulse at the end of each sweep. In this camera, R_1 is usually set so that the clamping level is about 1.5 volts. This fixes the minimum peak-to-peak video signal that must appear before D_2 begins to conduct. The video output (white signal) is a negative-polarity

The target

The Apollo camera's advantages are related to the unique characteristics of the tube's secondary electron conduction (SEC) target. The target consists of three sections:

- A thin supporting layer of aluminum oxide.
- A thin conducting layer of aluminum that acts as the signal plate and which becomes more transparent to accelerated electrons as their energies exceed 2,000 electron volts.
- A layer of an insulating material such as low-density potassium chloride (KCl) to produce the secondary electrons.

The signal plate is held at positive potential with respect to the KCl target material, which is at ground potential when there is no charge on it. Therefore, there is a field across the KCl.

When the signal-plate voltage isn't too high, it is characteristic of such materials as KCl that conduction involves secondary electrons traveling through the interparticle volume of the material, rather than electrons moving in the conduction band. Under the influence of the electric field, therefore, most of the secondary electrons pass through the KCl and are collected by the signal plate, resulting in a large charge distribution on the target's surface. Thus the target has high gain, where gain is defined as the ratio of the charge produced on the target to the total charge of the incident electrons.

Furthermore, the slow decay of conduction-band electrons isn't a factor in neutralizing the charge during the readout process. There is no lag, therefore, as in the semiconductor targets employed in vidicon tubes; the target is almost completely neutralized in every scan.

At the same time, the target has a high resistivity—usually greater than 10^{17} ohm-cm. Although the target's capacitance is only a few hundred picofarads, the resulting RC time constant for a charge to leak off the target allows the target to accumulate charge during long exposure times.

The resistivity isn't a factor in readout, because the time constant during this process is determined by the "beam resistance"—typically on the order of 10^6 ohms.

Because of the target's high resistivity, there is no measurable dark current to contribute noise. That is, if no light is incident on the tube, there is no current flow in the target. System noise is determined by the noise figure of the preamplifier stage at the tube's output and by how well the system is shielded from spurious internal signals and external noise sources.

To maximize the charge buildup, and thus increase sensitivity, the tube is operated with the highest target voltage—about 25 volts—producing high-quality images. The granularity of the SEC target becomes apparent at very high target voltages.

Because the target has capacitance, the peak signal current varies directly with the exposure time. The longer the time, the greater the charge buildup and the greater the output current. Similarly, the larger the target area, the greater the signal output.

The signal current, which will vary inversely to the readout time, is approximated by

$$i_s = \frac{\Delta Q}{\Delta t_r}$$

where i_s is the signal current, ΔQ is the charge and Δt_r is the readout time. If the scan rate is reduced, the readout time increases at every point on the target and the peak signal current decreases.

waveform and will thus make D_2 conduct when the absolute value of the negative level is greater than the voltage established by R_1. Signals passed by D_2 are smoothed in the integrator circuit R_3, R_2 and C_2.

Since reflections from the LEM will produce wide variations in light level, the ALC/AGC loops must respond very rapidly to bright spots. The loops' time constant—2.2 seconds—is fast enough to correct the gain for bright spots as small as 5% to 10% of the over-all picture area.

After integration, the d-c voltage is divided and amplified to control the photocathode and AGC attenuator loops. The control element in both these loops isn't activated until a certain threshold is reached; the threshold level in the AGC portion of the tube is close to 0 volts.

When the light level is about 4 db below the saturation point of the tube, the ALC threshold is exceeded. As the light level increases, the ALC circuit reduces the d-c supply voltage into the photocathode supply from 15 to 3 volts. This changes the photocathode voltage from −8 kilovolts to −2 kilovolts, extending the tube's range.

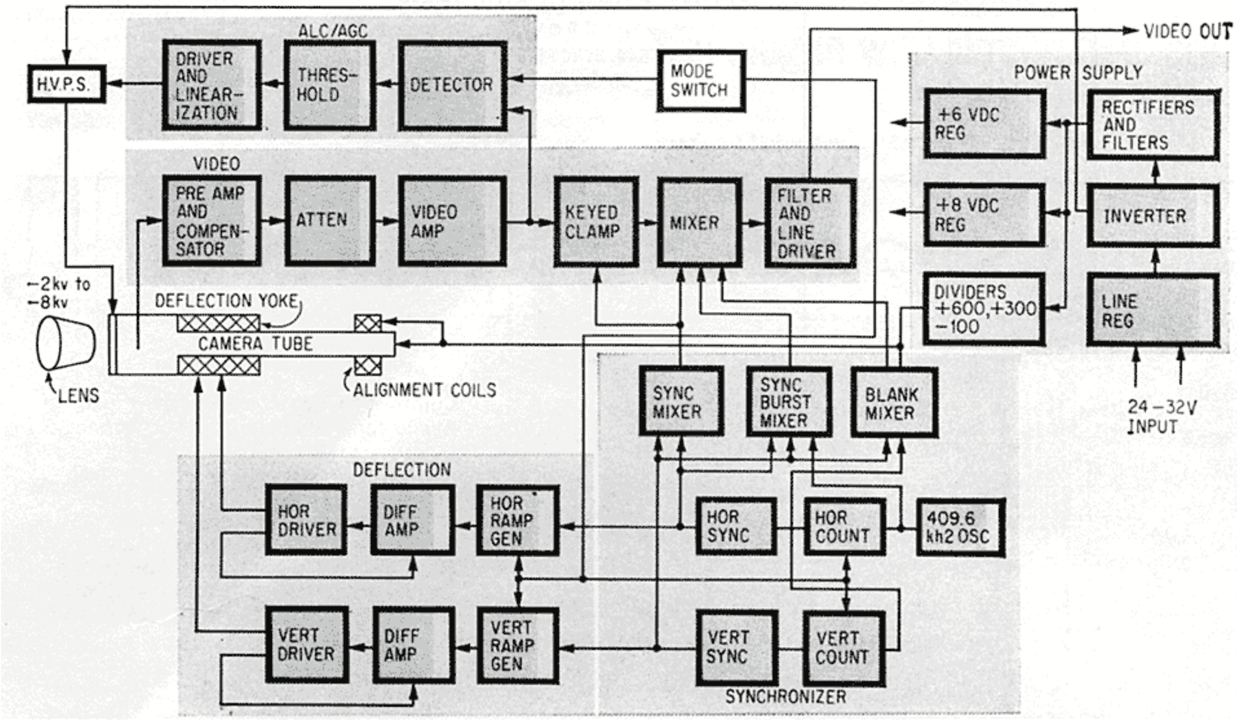
The ALC threshold is exceeded when diode D_3 starts to conduct. The point at which this happens is determined by the voltage on C_2 and the settings of potentiometers R_4 and R_5. R_5 is set to activate the AGC loop near 0 volts, while R_4 is set to actuate the ALC loop when the AGC regulation starts to deteriorate, and to provide a smooth transition between the two control loops.

Of the other integrated circuits, Z_4 includes components to set the threshold for the ALC circuit and the resistors needed for the three differential amplifiers. A correction network, Z_4, supplies differential amplifier Z_5 with a nonlinear signal that corrects for the nonlinear characteristic of the photocathode. Amplifier Z_6 is a low-output impedance circuit that drives the high voltage supply.

Video amplifiers

The video unit consists of the preamplifier that boosts the camera tube's output, two post-amplifiers, and the mixer that combines the video with the sync and blanking pulses. The mixer is a high-impedance source that produces 2 ± 0.1 volts across 100 ohms or 1 ± 0.05 volts across 50 ohms. The final output is the composite video waveform shown on page 186.

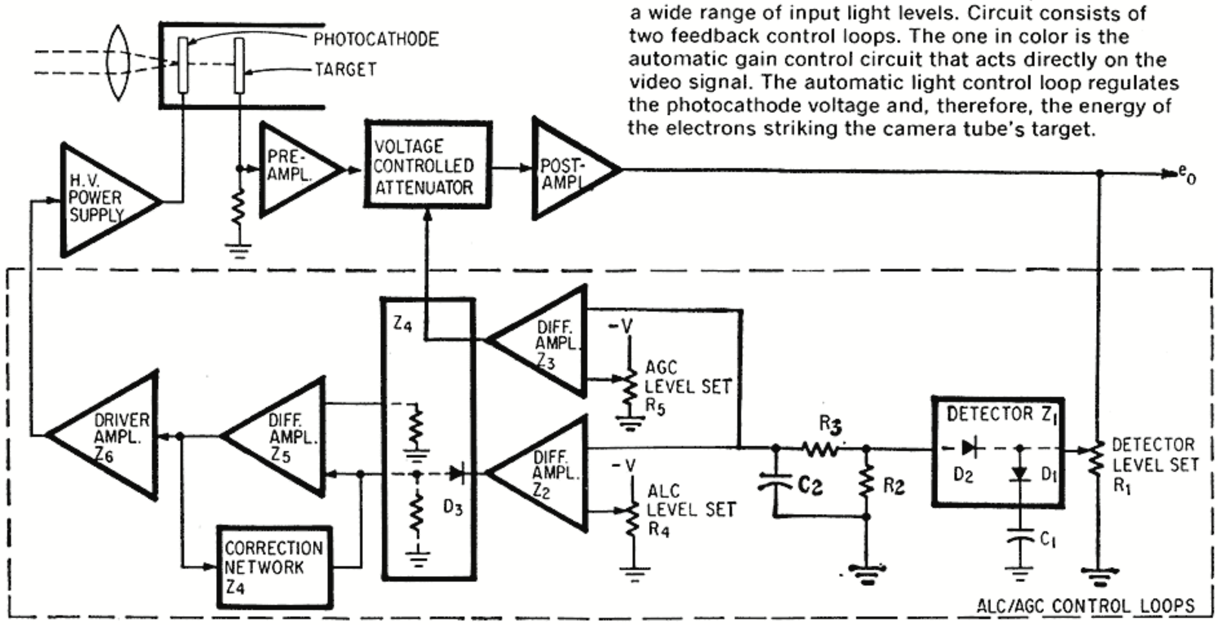
The over-all bandwidth is 2 hertz to 500 khz, with the upper frequency limit being the result of power allocations in the S-band transmitter. A filter between mixer and output stages reduces the signal 20 db per octave at frequencies above 500 khz.



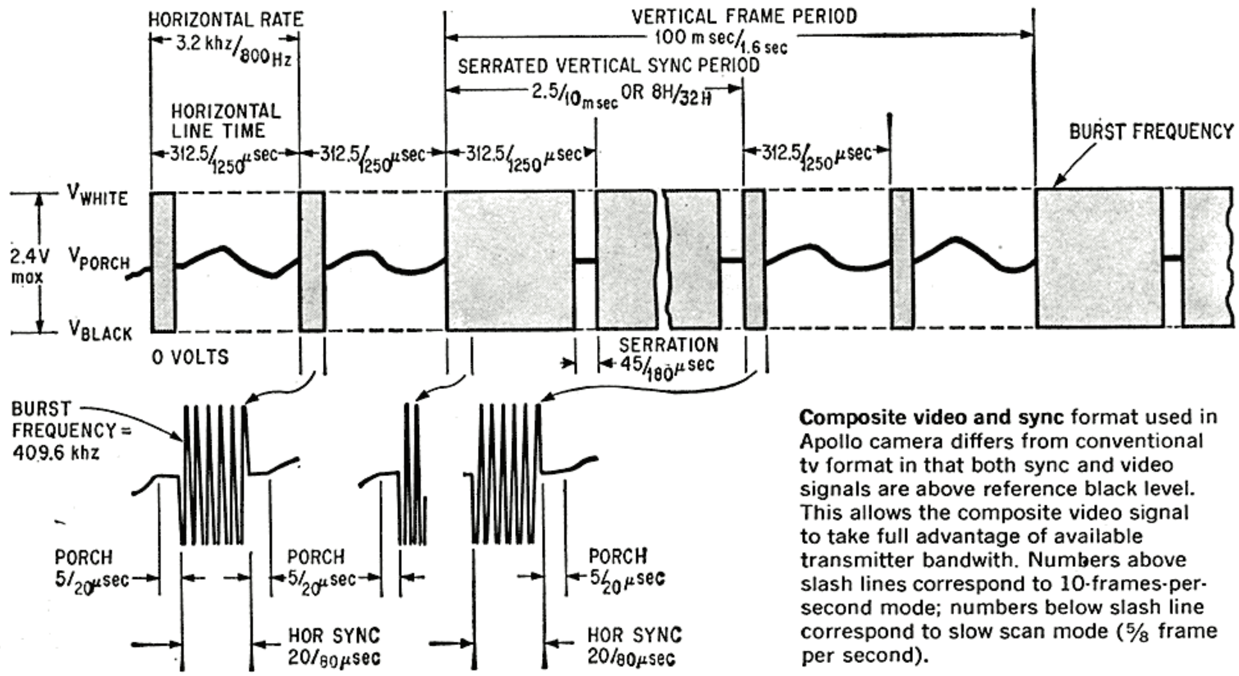
Camera's five major sections are shown in color in the block diagram above. Shaded portions indicate the percentage of integrated circuitry. Deflection circuits generate the waveforms to scan the tube. Camera's signal is controlled by the automatic light control and automatic gain control (ALC/AGC) circuit. Video signal is fed to S-band transmitter after amplification and mixing with synchronizing and blanking signals.

The 2-hz limitation is fixed by the amount of "droop" allowed in the slow scan mode. Droop is a change in amplitude caused by the loss of low-frequency components in the brightness signal; when viewing a uniform white scene, droop will cause the picture to have varying shades of gray. The 2-hz limitation is a compromise between acceptable droop and the increased size of the coupling capacitors that the amplifiers would otherwise require to improve the low-frequency response.

Three basically similar monolithic integrated circuits are used for the preamplifiers and post-amplifiers. The preamplifier is designed to compensate for the reduced frequency response that would be caused by the capacitance in the camera's target. The SEC camera tube has no detectable dark current, so low-noise performance is improved by reducing the noise in the preamplifier. A discrete



ALC/AGC control circuit holds video output constant over a wide range of input light levels. Circuit consists of two feedback control loops. The one in color is the automatic gain control circuit that acts directly on the video signal. The automatic light control loop regulates the photocathode voltage and, therefore, the energy of the electrons striking the camera tube's target.



Composite video and sync format used in Apollo camera differs from conventional tv format in that both sync and video signals are above reference black level. This allows the composite video signal to take full advantage of available transmitter bandwith. Numbers above slash lines correspond to 10-frames-per-second mode; numbers below slash line correspond to slow scan mode (5/8 frame per second).

field effect transistor is added to the input of the preamplifier to increase the input impedance and to reduce the equivalent-noise current from 0.5 nanoamperes to below 0.3 na.

Deflection circuits

Vertical and horizontal synchronizing pulses trigger ramp generators in the deflection circuits. The resulting sawtooth waveform drives one side of a differential amplifier stage while a feedback voltage developed by passing the yoke current through a small resistor drives the other. This amplifier drives a Class-B amplifier, which in turn drives the deflection yoke.

In conventional cameras, a resonant circuit drives the deflection yokes. This is possible at the higher scan rates of conventional units because the resonant circuits are small and economical. For slow scan applications, however, the reactance components would become excessively large and difficult to stabilize with temperature.

The Class-B amplifier in the Apollo camera can operate over a wide range of scan frequencies and is exceptionally good for slow scanning. The circuit has good stability and linearity, and the output is independent of temperature variations because a feedback circuit provides a low closed-loop gain of about 1.5-to-2 for the driver-differential amplifier combination. By changing a few components that control the timing and the output loading, the basic design serves for both horizontal and vertical sweeps.

To achieve great stability, the camera's synchronizer utilizes a crystal-controlled binary counter with gating and feedback to provide outputs for both the slow and fast scan modes. The oscillator, which operates at 409.6 khz ± 0.02%, utilizes a custom-designed monolithic circuit. Flip-flops or gates are contained in 13 other monolithic circuits.

The synchronizing pulse to the deflection circuits is a negative-going one of 4 to 5 volts. For the 10-frames-per-second mode, the horizontal sync pulses are 20 microseconds wide at a repetition rate of 3.2 khz; for the slower mode, the pulses are 80 μsec wide at 10 hz or 40,120 μsec wide at 5/8 hz.

Sync bursts of 409.6 khz with serrations, blanking pulses and sync pulses are also supplied to the mixer in the video circuit to produce a composite video signal that modulates the transmitter.

Other applications

A natural extension of the initial lunar-landing application would be the combination of an Apollo-type camera with a telescope to provide an unmanned lunar observatory. Signals from the earth could control the direction of the telescope.

Further, the SEC tube is available at this time for commercial uses. Among the applications being considered are:

- A rugged portable color camera for commercial broadcasting.
- A surveillance camera for security or industrial applications where there are fluctuating or extremely low light levels.

The camera may also find a place aboard ships and aircraft and at observatories and laboratories.

References

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2. A series of papers on SEC, advances in electronics and electron physics, Vol. 22A, 1966, Academic Press, pp. 219-291.

The Apollo lunar tv camera has been developed for the National Aeronautics and Space Administration under contract NAS 9-3548 out of the Manned Space Center, Houston, Texas.