APOLLO COLOR TELEVISION CAMERA

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INTRODUCTION

During the Apollo 10 flight a compact SEC color television camera was used to communicate with the earth by providing real-time color scenes of the earth, the moon, spacecraft maneuvers, and interior scenes. The performance of the camera under these abnormal and adverse conditions was excellent, as may be attested to by millions of viewers of this color television camera first from space. This camera was designed and developed for the NASA Manned Spacecraft Center by the Westinghouse Aerospace Division in Baltimore, Maryland.

The camera is unique in its concept as associated with the total system and as a television camera in its configuration and performance. As part of a system, it generates a field sequential color signal using a single image tube and a rotating filter wheel. A ground station color converter later changes the sequential color signal to a standard NTSC color signal. This approach is new in that a simple and reliable method is used in the camera where it is most important and relegates the complexity of generating a compatible broadcast signal to the ground where it is readily handled.

The Apollo 10 color television camera is shown in figure I. It is 17 inches long including the zoom lens, weighs only 13 pounds (weightless in space) and is completely self-contained. A small four wire cable containing a single dc input voltage and a composite video output suitable for modulating the transmitters was the only connection required. During the space flight a small viewfinder monitor, occupying a volume of only 85 cubic inches and using 2.5 watts of power, was used to assist the astronaut in aiming and focussing the camera.

Besides providing real-time communications useful to NASA ground personnel and the public, another scientific feature should not be overlooked. The particular configuration using the calibrated color filter wheel allows true color information to be obtained by proper data reduction of the recorded video transmission.

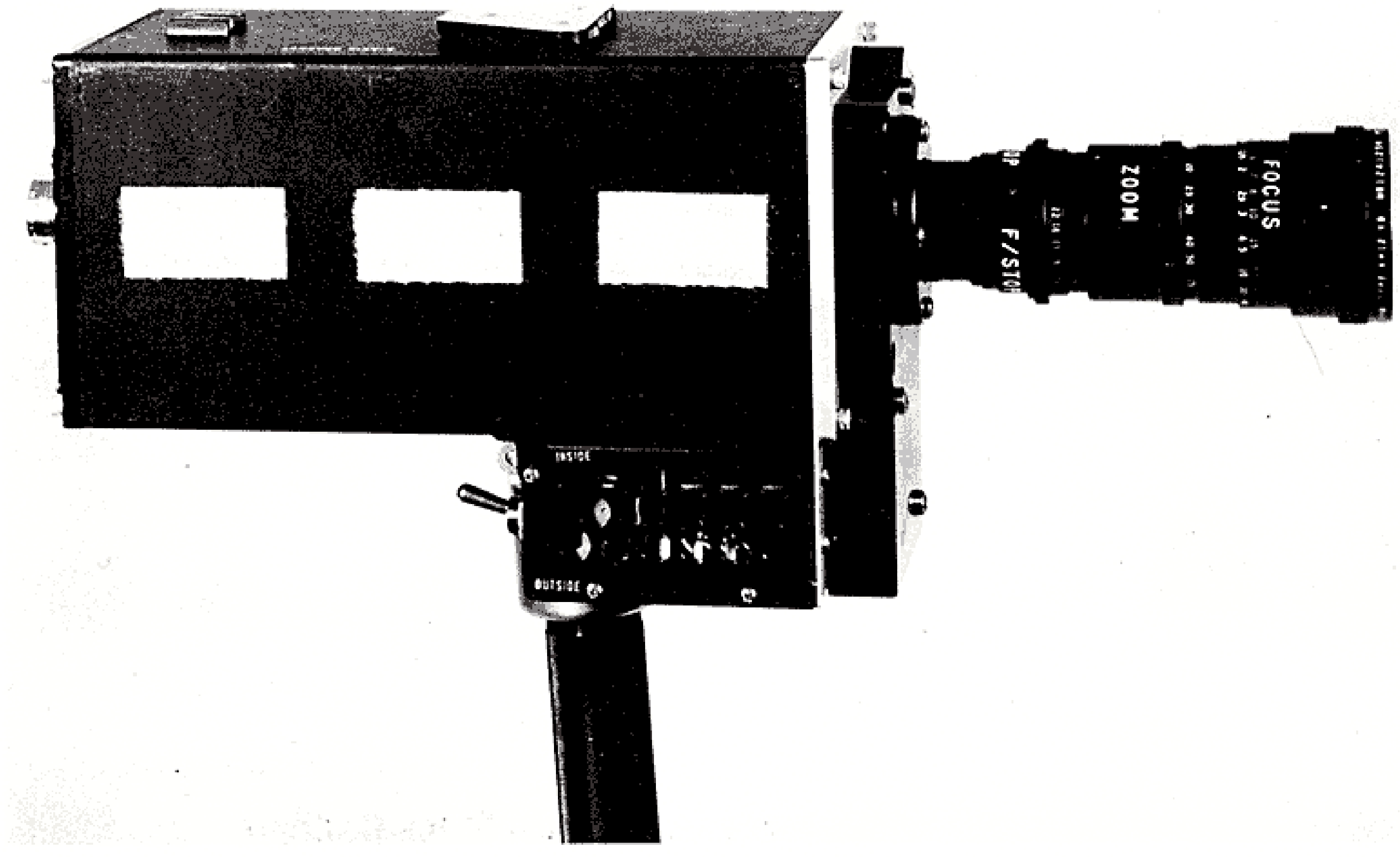


FIG. 1 APOLLO COLOR TELEVISION CAMERA

THE SYSTEM

A general diagram of the system is shown in figure 2. The image is focussed by the lens through the filter wheel onto the faceplate of the image tube. As the wheel positions a red filter in the field, the image tube stores the red information of the scene being viewed and then reads it out. This information is processed by the electronics of the camera and is sent to the Mini Monitor and to the transmitter. The same is true for the green and blue filters, and since the wheel is rotating at the field rate the color information is generated at a field sequential rate.

The field sequential color signals are transmitted to the earth from the command module spacecraft in the S-band region. The received signal is placed into a series of two tape recorders for the purpose of compensating for Doppler shift and presenting real-time information. This is accomplished by recording the information as it occurs in the first unit and driving the second unit with the subcarrier standard (frequency) which corrects the tape speed for any errors introduced by the Doppler shift. One tape recorder could have been used, but the transmission would have to be complete before performing the second operation thereby delaying the presentation at least that long. As it now stands, there is only an approximate 10-second delay from input to output.

The sequential color information is then put into the scan converter. The scan converter is a storage and readout device holding the two previous fields in memory and presenting the three fields at once at the output on the incidence of the third field. As the new field is placed into memory the oldest field is erased, updating the information at the field rate.

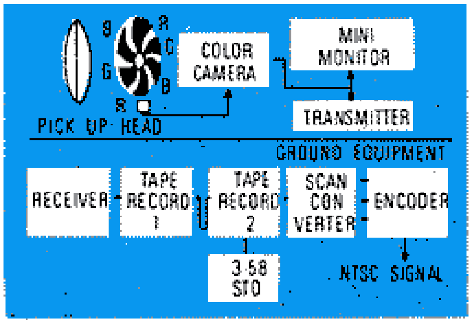


FIG. 2 APOLLO COLOR TELEVISION SYSTEM

THE APOLLO COLOR CAMERA

A block diagram of the color camera is shown in figure 5, where portions of it are shaded to give a representation of the amount of integrated circuits used. As can be seen, almost 70 percent of the functional blocks are integrated circuits exclusive of the power supplies.

An internal view of the color camera is shown in figure 3. It consists of three sections, the first being a monochrome camera with the addition of synchronization, pulse forming, and drive circuitry for the color adaptation. The second section is attached to this camera forming the housing for the transformer and motor, and finally, the section containing the motor, gearing, and filter wheel assembly which also serves as the mounting for the lens.

An internal view of the predecessor to the color camera, the monochrome camera, WTC-13, is shown in figure 4 with one circuit board open. This is the sync/sweep board displaying the three techniques of packaging with modules, medium scale integration, and conventional printed circuit wiring.

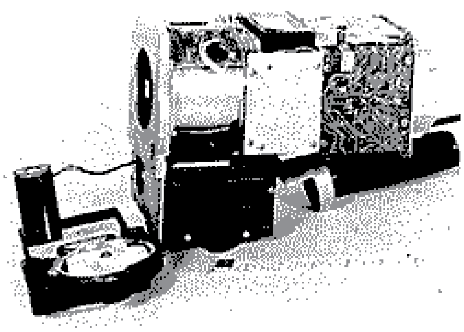


FIG. 3 COLOR CAMERA-INTERNAL VIEW

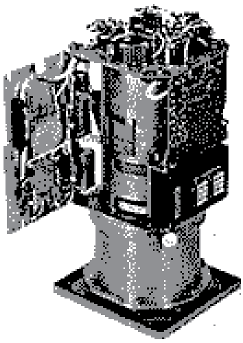


FIG. 4 MONOCHROME CAMERA-INTERNAL VIEW

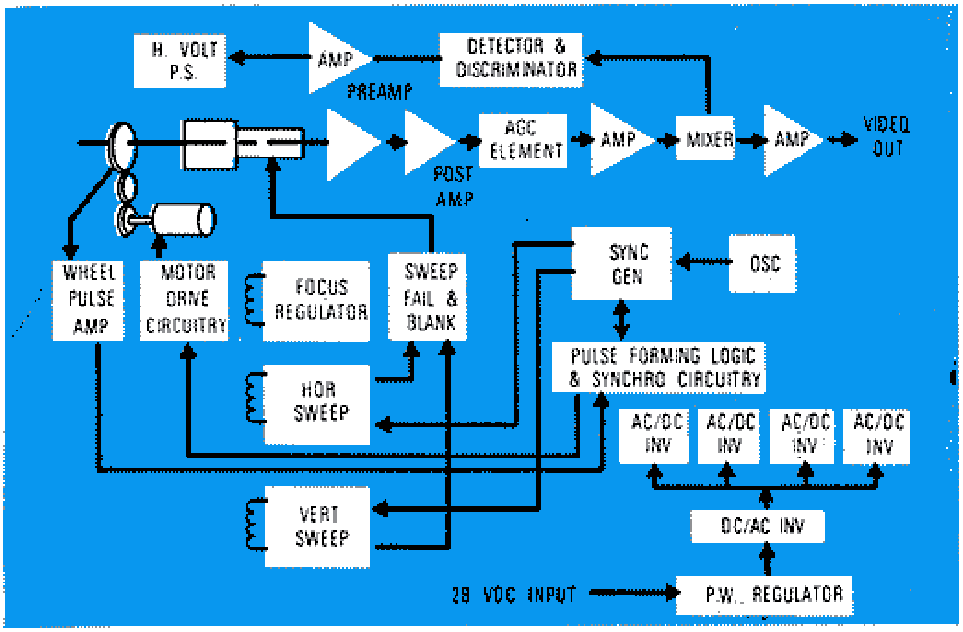


FIG. 5 BLOCK DIAGRAM APOLLO COLOR TELEVISION CAMERA

On both cameras the printed circuit boards are mounted with the tracks to the outside, projecting the modules and components in around the cylindrical housing that holds the deflection assembly. This is done to conserve space.

The large flat package in the center of the board is the synchronizer which has a 5-Vdc and oscillator input. It delivers horizontal drive, vertical drive, mixed blank, and mixed sync at its outputs into 500 ohms. Figure 6 shows the interior of this 1 "square by ⅛" package having 22 integrated circuit chips of which 14 are dual bistable multivibrators and 8 are gate circuits. The synchronizing generator is completely bistable, has no adjustments, and was ideally suited for medium scale integration.

The camera input voltage is 28 ± 4 volts dc using 20 watts nominally. Its output is a standard EIA format at color standard frequencies with the exception that it does not carry the color burst which is added on the ground. It is a black negative signal from -0.75 to $+2.75$ volts into 100 ohms constrained within 20 percent to prevent over-deviation of the transmitter.

The bandpass of the camera is 4.5 megahertz with a 20 dB/octave roll-off, therefore having a theoretical limiting horizontal resolution of 360 TV lines/vertical dimension. Due to the fact that the S/N is high and that the roll-off is finite, more extensive calculations and experience has shown the resolution to be in excess of 425 TV lines/vertical dimension. The limiting vertical resolution fixed by the number of scan lines and Kell factor is approximately 350 TV lines/vertical dimension.

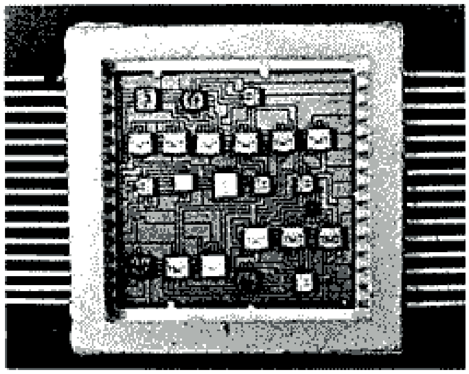


FIG. 6 SYNC GENERATOR

The system limiting horizontal resolution is set by the bandpass of the Command Module transmitter and is less than 2 megahertz, resulting in slightly more than 200 horizontal TV lines referenced to the vertical dimensions, which again exceeds the theoretical limit because of an even higher S/N and finite roll-off. Since the S/N was high, approximately 40 dB for a broad scene, it was decided to include aperture correction to boost the image tube 200 TV line response by 40 percent, which also improves the resolution.

The Apollo color camera controls are limited to one switch associated with the electronics and the common lens adjustments of focus, iris, and zoom. The switch is used to change the automatic light control detector from an averaging type for "inside" scenes to a peak detector type for "outside" scenes. A typical scene for the "outside" mode would be the earth subtending one-third of the vertical field of view.

The lens is a standard Cine commercial lens that has been extensively modified. The most significant modifications were to the format, adjusting it from a 12.7mm to 25mm, and to space qualify it.

The lens has the following characteristics:

T – 5:1
Zoom Ratio – 6:1
Focal Length – 25-mm to 150-mm
Field of View
  Wide Angle – 43° horizontal
  Narrow Angle – 7° horizontal

	Near Focus	f#
Wide Angle	20"	4.4
Wide Angle	1"	44
Narrow Angle	3"	4.4
Narrow Angle	2"	44

The color camera was designed environmentally to meet military specifications. The delivery schedule did not permit sufficient time to evaluate the camera performance as set forth in those military specifications and therefore the testing was limited to the command module environmental conditions.

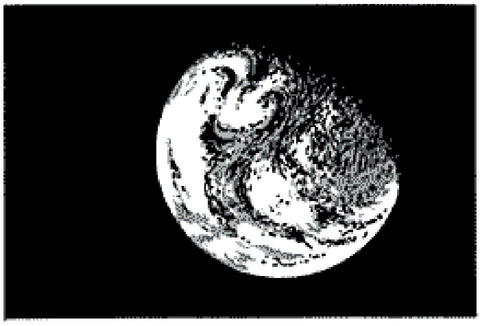
Shock and vibration at lift-off and splash down was accommodated by testing to determine a safe level that the camera could stand and one that could be acquired by typical storage techniques. This level was set as a limit and was achieved by appropriate packaging.

The thermal picture in the Command Module while it is in space is unusual. The atmosphere, O_2, is reduced to 5 psia and is weightless, presenting a question of efficiency in cooling. Convection would depend on forced flow only under this condition. The amount of forced flow is an unknown; therefore, it was necessary to ensure that the camera was passively cooled by radiation.

Evaluation of the design indicated it could be used indefinitely in the Command Module. This evaluation was borne out during the long uninterrupted transmissions.

Another requirement was that the camera be subjected to a vacuum in a nonoperating condition and survive the test.

Although testing in other areas was limited, the camera, lens monitor, and cables were thoroughly tested for the vacuum transition and for complete operation in the Command Module environment.



THE SENSOR

The color camera uses a Westinghouse type WL30691 SEC image tube. The SEC has been recognized for some time as ideally suited for space applications because of its size, weight, power requirements, ruggedness, stability, and simplicity of operation. It has in addition the features of wide dynamic range, tolerance to high saturation levels, and an electrical gain mechanism. The two latter features are necessary for a portable camera such as this one with little or no operational controls to handle changing or uncontrolled scene lighting.

Two outstanding characteristics of this image tube for a color camera are its low-light level capability and lack of lag. The low-light level capability comes from the noiseless gain mechanism and general noiseless performance of the tube. The lack of lag is due to the conduction process and low relative capacitance. Lag is a problem when viewing a moving scene, generally resulting in a loss of resolution for a monochrome system and in addition an edge color breakup in a field sequential color system. In most image tubes such as the vidicon or image orthicon this characteristic becomes more severe at low light levels. The lag characteristic of the SEC at low light levels is quite good and therefore its performance remains useful in that region.

The need for a low-light level capability arises from two basic conditions: the command module lighting and the color wheel mechanism.

In the case of the Command Module, it has a wide spread of light levels from spectral reflections of the sun to levels less than 1 footcandle. Special lighting for the purpose of television is not a practical consideration because of power, space, weight, and layout problems; therefore, the entire light range extending to the low levels needs to be detected by the image tube. The color wheel losses are not unusual, as in any television camera losses of light are experienced through lens systems and filters for color signals. This is overcome in a studio by simply turning on more light. The losses were kept to a minimum for the Apollo Color Camera but they did exist. The lens in a wide-open position was a T = 5:1, or a 100:1 loss. The ratio of the photocathode area to the product of filter and photocathode area is approximately 5:1 for all filters, and the ratio of field time to transmission time is 2.5:1; therefore, the total loss is approximately 1300:1. For a 1.3 footcandle scene illumination with unity reflectivity, the image tube would receive approximately 10^{-3} footcandles faceplate illumination, a level well below the capability of a standard vidicon. The SEC image tube at the 2-megahertz bandpass in this color camera has a S/N of approximately 30 dB at this light level, which is a signal more than acceptable.

A brief explanation of how the SEC image tube functions is as follows, with a basic layout shown in figure 7. The light image is focussed by a lens on the image faceplate. This light image causes the photocathode to emit photoelectrons which are focussed by the geometry and an electrostatic field to the SEC target. The photoelectrons have enough energy to penetrate through the ALO and AL layers to the KCL where they strike a particle causing secondary electrons. Since the AL layer is positive, these electrons move to it where they position with respect to the positive particle. If there is no electron beam they will remain there, and if the light continues to enter the faceplate the charge continues to build up; thus, the target is an integrator. As the electron beam is scanned across the target the beam discharges these positive areas causing a current in the load resistor which is amplified for the video signal.

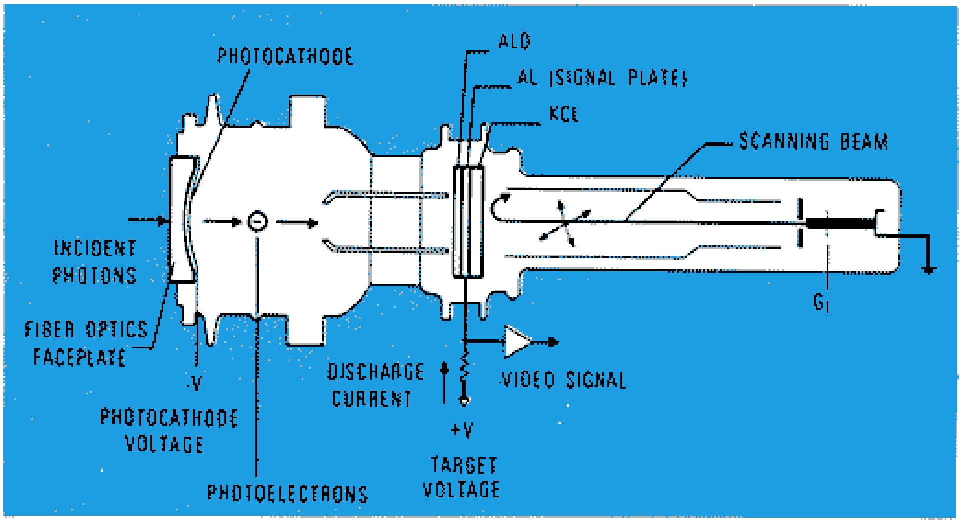


FIG. 7 SEC IMAGE TUBE LAYOUT

THE COLOR WHEEL AND MOTOR

The color wheel is a compromise of size, transmission efficiency, and uniformity. If it could have been very large and rotated stably, its transmission would have approached 100 percent with no deviation in uniformity. Size was however a primary consideration and it was necessary to make those compromises and include some innovations to minimize these losses.

As seen in figure 3, the color wheel has six sections comprised of two sets of red, green, and blue filters. This configuration is dictated by the speed of the motor, 1,798.2 rpm, and the gear ratio, 3:1. The color wheel then rotates at 599.4 rpm or 9.99 rps to yield six fields per revolution at the standard vertical color frequency of 59.94 hertz.

Interspersed between the filters are opaque regions, a compromise accompanying the use of the 3″ color wheel. Its necessity is explained as follows. As a red filter rotates past the image tube faceplate this light information is integrated by the target. Before the green filter arrives it is necessary to read the information off the target to prevent color mixing; therefore, the electron beam must follow the red filter and precede the green filter. This is most readily facilitated by using an opaque region between the two, the size and shape of which is determined by the wheel size and stability of the scanning beam and wheel rotation. After the opaque region is determined, it is necessary to ensure the scanning electron beam is within its confines during readout. This is accomplished by knowing the relative position of the wheel and using that information to set the scanning beam. This principle is shown in the block diagram. A pickup device senses the wheel position, the signal is amplified and sets the synchronizing generator which controls the sweep circuits and causes the beam to be in the right position.

The ability of this system to keep the scanning beam in the opaque region depends to a large extent upon the stability of the synchronous motor which is only as good as its input frequency. For that reason, it is necessary to maintain a motor drive frequency whose stability is excellent.

As a result of frictional load shifts and motor hunting, the filter wheel suffers some erratic motion. To compensate for this, the size of the opaque region is increased.

The input power to the motor is approximately 11 watts at nominal input voltage. If a class A driver were used to drive it, the total power would have exceeded 30 watts; therefore, it was decided to drive it with a pulse input resulting in a total power consumption of approximately 12 watts.

The filters are dichroic depositions selected for maximum transmission and spectral response. When modified by the spectral response of the S2O photocathode and a daylight source their response closely matches that of the P22 phosphor. These filters are deposited on one piece of glass and sealed by another.

ALC/AGC

The gain mechanism of the SEC is well known and is achieved by varying the high voltage on the photocathode from 2.5 to 8 kV. This is accomplished by sampling the video and deriving a signal to vary the high voltage accordingly. This is an effective method enabling the SEC to handle a light range greater than 1000:1 and deliver a minimum S/N of 32 dB for the color camera.

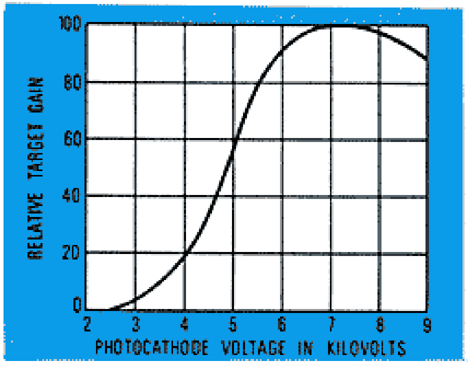
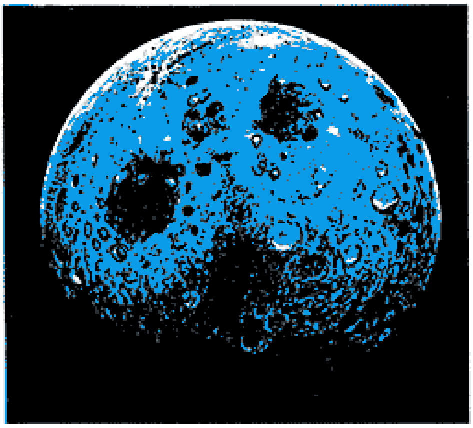


FIG. 8 COLOR CAMERA GAIN CURVE

An additional consideration has been given to the color camera as follows. The gain curve, in figure 8, shows it to be nonlinear and having little gain above 5.5 kV. Also, it can be shown that the damage levels of an SEC image tube is proportional to the photocathode high voltage for a fixed time. The color camera is programmed to take advantage of the lack of gain above 5.5 kV and buy the safety factor needed to prevent the image tube from being damaged. This approach also simplified the circuitry by eliminating the number of break points. This is achieved by allowing photocathode to rise to 8 kV at very low-light levels to achieve maximum sensitivity. As the light level rises and the S/N is above 25 dB, the high voltage drops immediately to 5.5 kV, where a 20 percent decrease in S/N is not detectable. At this point the amplifier AGC comes in and maintains the voltage level constant until the signal level is reached where it becomes necessary to reduce the high voltage again at which time the reduction becomes linear since the gain curve is reasonably linear. As the high voltage is dropped before the signal levels rise to any significant level no damage is possible, and since the nonlinear portion of the curve is avoided, no circuitry is required to track it.

The effectiveness of this method was demonstrated as the camera was panned around the Command Module from dark to bright scenes and while viewing scenes containing spectral reflections.



Preamplifier

The preamplifier is made up of discrete components, primarily to acquire a low noise device. The input is an FET stage with a tube load resistor of 300 Kohms. This is followed by a feedback pair. The equivalent input noise current is approximately 1 nanoampere for 2 megahertz.

Postamplifier

The postamplifier as indicated in the block diagram includes all the circuitry from the preamplifier to the high voltage driver. The majority of this circuitry is made up of hybrid integrated circuits. The output is a current source delivering a 3.5-volt swing into 100 ohms.

Deflection Circuits

The vertical deflection circuit is of the Miller run-up variety using a total of two integrated circuits and a dual transistor for the active components. The size of the scan is varied by adjusting the feedback resistor and the centering is adjusted by offsetting the input operational amplifier.

The horizontal deflection circuit is a high efficiency reaction type with a 1 percent linearity.

Power Supply

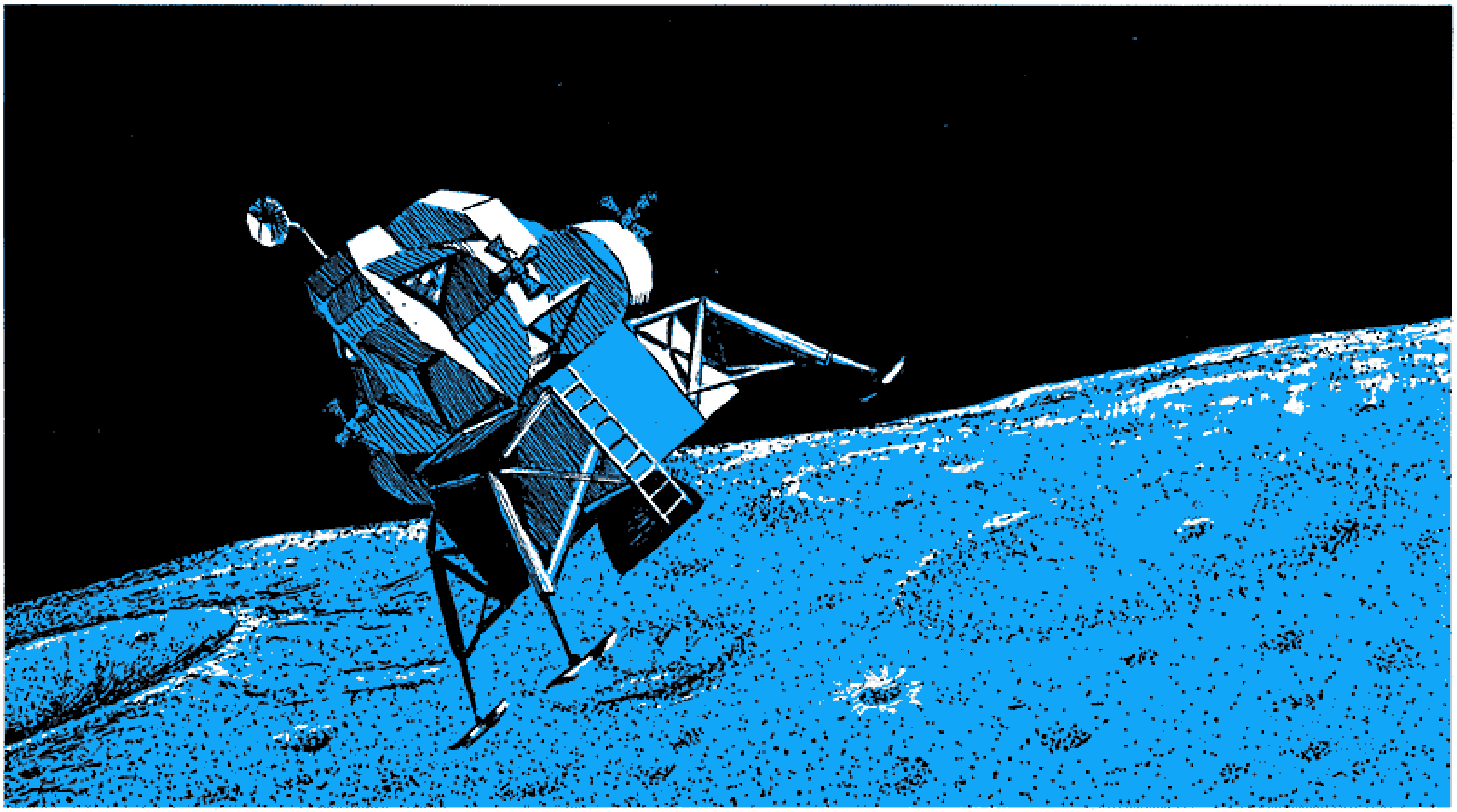
There are two power supplies in the color camera, a high voltage one driven by the ALC loop and the low voltage one receiving the primary power from the spacecraft.

The low voltage power supply develops all the voltages for operating the circuitry and the image tube with the exception of the image section. Its efficiency is approximately 60 percent at the nominal input voltage. Its configuration may be seen in figure 4.

CONCLUSION

The feasibility of using color television aboard a spacecraft has been proved beyond all doubt, and the public interest generated by its use has been similarily indicated. The question now arises as to its practical application. During the Apollo 10 flight the astronauts showed some of these applications when they televised the crew, indicating their condition, and when they televised the instrumentation, and also the unusual condensation in the tunnel for ground support evaluation. There are a multitude of other applications, most of which may be classified under the one heading of remote viewing and this may be further broken down into viewing at inaccessible points because of position and because of a hostile environment. For the present these are the most likely conditions for television applications in the space program since the spacecraft has limited viewing positions and outer space is at least a hostile environment for man.

The spectacular aspect of color television seemingly passed a peak with the splashdown of Apollo 10 It is expected that this will be repeated many times but it may never be exceeded.



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