Apollo Black-and-White Television Scan Converter

By M. V. SULLIVAN

The communication system considerations of the Apollo space program limits the bandwidth available for TV signals to 0.5 MHz. Consequently, the Apollo black-and-white TV cameras operate at slow scan rates. The Command Module camera operates at ten frames/s and the Lunar Surveying camera produces one frame in 1.6 s. Both cameras are non-interlaced. The signals as received on the ground are not compatible with the standard broadcast rates, and scan conversion is required to convert to standard EIA format video signals suitable for transmission over commercial broadcast networks. The scan converter primarily consists of a kinescope which displays the slow-scan video, a vidicon camera which stores and converts the information to broadcast field and line rates, and a magnetic disc recorder which stores and repeatedly plays back the broadcast video. A detailed discussion of the various features and performance of the scan converter is presented, including incorporated image-enhancement techniques, pictures through the system, comments on actual performance and potential for improvement.

The early manned space flight missions had black-and-white television cameras on board to transmit real-time pictures of the mission to earth. Due to spacecraft power, weight and space limitations, the television-camera scanning rates and video bandwidth had to be reduced from those of the commercial standards. In order to provide pictures acceptable for direct public broadcasting, a scan converter was required at the ground receiving site to convert the received slow-scan television signals to scanning rates compatible with standard television.

Work on the scan converters for the Apollo program was supported by the NASA/Goddard Space Flight Center under Contract NAS5-10622.

Two television cameras were designed for the Apollo program: the Command Module camera, which operates at 10 frames/s and the Lunar Surveying camera, which operates at two rates: $\frac{5}{8}$ and 10 frames/s. In addition to having different scan rates, the slow-scan signals can be transmitted with pulse-amplitude sync or tone-burst sync. On the ground, the output format from the scan converter is the standard 30 frames/s, each frame consisting of two interlaced fields.

Three black-and-white scan converter units have been designed and built for the NASA Goddard Space Flight Center (GSFC) for use in the Manned Space Flight Network. One of these units is located at Cape Kennedy, Fla., one at Goldstone, Cal. and the third at Madrid, Spain. A fourth unit is being built, in order that deep-space signals can also be received at Canberra, Australia.

The television pictures of Apollo 8 (the mission that orbited the moon and provided the world with the Christmas-season TV spectacular) used the hand-held Command Module camera. On this mission, the 10-frames/s signals were received and scan-converted at the Deep Space Instrumentation Facilities at Goldstone and Madrid; each of these facilities employs an 85-ft receiving "dish." The Apollo 9 mission exercised the Lunar Excursion Module camera, operating at 10 frames/s. This mission orbited the earth and the signals were received at Cape Kennedy, where a 35-ft dish is used.

Early in the Apollo program, the advantages and disadvantages of a variety of methods of producing the television conversion were considered. The recent development of the video magnetic disc recorder enabled the NASA Manned Space Flight Center (MSFC) at Houston, Tex, to produce a breadboard model scan converter using the disc recorder. In this approach, the incoming slow-scan video is displayed on a kinescope; the displayed image is stored in a vidicon; the vidicon is read out at standard rates; the video is stored on the disc recorder; and the video is repeatedly read from the disc recorder until the next scene is ready for recording on the disc. A simplified block diagram of this system is presented in Fig. 1.

Following production of the breadboard, an engineering model of the disc-recorder type of scan converter was designed and built for the MSFC. Subsequently, improved versions of the converters have been built for the GSFC; the technical features of this improved model are those presented and described in this paper.

Input Signals

The video signals as received on the ground can have four different formats depending on the frame rate and mode of synchronization being used. The slow-scan cameras have a 4:3 aspect ratio, 0.5-MHz video bandwidth, and operate non-interlaced. The pertinent characteristics of each camera as well as those of standard television are presented in Table I.

The nominal level of the input composite video signal is 1 V peak-to-peak (p-p). However, provisions are included in the scan converter to handle a variation in input level from 0.15 to 2.5 V p-p. All slow-scan signals received on the ground are tape recorded as well as applied to the scan converter. These tape-recorded signals can in turn be applied to the scan converter. The flutter-and-wow associated with tape recorders puts an additional burden on the scan converter, for the output broadcast signal must meet the solid EIA timing

Table I. TV System Parameters.

Parameter	Command module camera	Lunar camera	Broadcast TV
Frames/s	10	0.625 or 10	30 (60 fields)
No. of lines	320	1280 or 320	525
Horiz. period	312.5 μs	1250 or 312.5 μs	63.5 μs
Lines/s	3200	800 or 3200	15,750
Bandwidth	0.5 MHz	0.5 MHz	4.5 MHz
Type of sync	Pulse	Pulse or tone	Pulse
Aspect ratio	4:3	4:3	4:3
Scanning	Non-interlaced	Non-interlaced	Interlaced

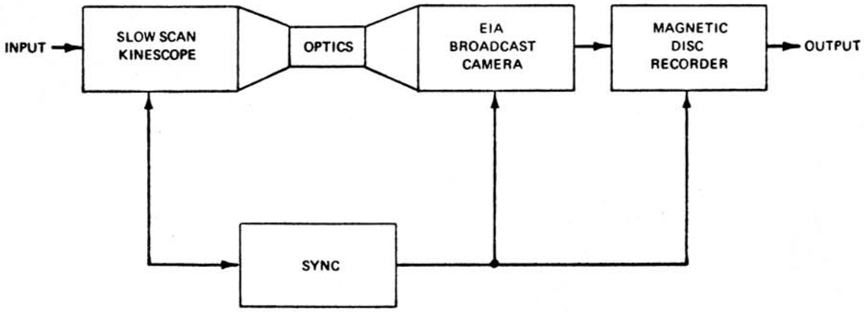


Fig. 1. Apollo Scan Converter, simplified block diagram.

Presented April 24, 1969, at the Society's Technical Conference in Miami Beach, FL, by Michael V. Sullivan, RCA Corp., Astro-Electronics Div., Box 800, Princeton, NJ 08540.
(This paper was received on September 29, 1969.)

requirements, while the input timing may have jitter.

The format of the input video with pulse-amplitude sync is presented in Fig. 2, and the format with tone-burst sync is presented in Fig. 3. In addition to the video waveforms, timing and amplitude information for each format is included.

The burst mode places the synchronization information within the dynamic range of the peak-to-peak video with no additional requirement for increased bandwidth. The reduction in dynamic range is a system consideration, for it is passed on as a subsequent reduction in transmitted power.

Conversion

While the incoming slow-scan video is written on the P-11 phosphor of the display tube, the electron beam of the vidicon camera is gated *Off*. The displayed scene is imaged on the photoconductor of the vidicon where it is stored as a charged pattern. As the slow-scan displayed frame is near completion, the vidicon beam is gated *On* and two fields of video are read from the stored charge at EIA standard rates. It is this technique that converts the video from slow-scan to standard-scan rates. The timing diagram of Fig. 4 illustrates how the EIA camera produces two interlaced fields for each frame of the 10-frame/s input.

With the gating of the vidicon beam *On* and *Off*, the output of the camera is at EIA rates but is not continuous. The first field of each frame is recorded on the disc recorder and is simultaneously applied as the output signal for the corresponding time period. The second field serves only to completely "erase" the vidicon and is discarded, for it contains an objectionable shading component different from that of the first field. The disc recorder plays the first field back, interlacing it with itself to produce the EIA frame format continuously at the output. Therefore, assuming the 10-frames/s input mode, each recorded field appears six times, once direct and five times played back from the disc recorder. In the $\frac{5}{8}$-frames/s mode, each field is used 96 times.

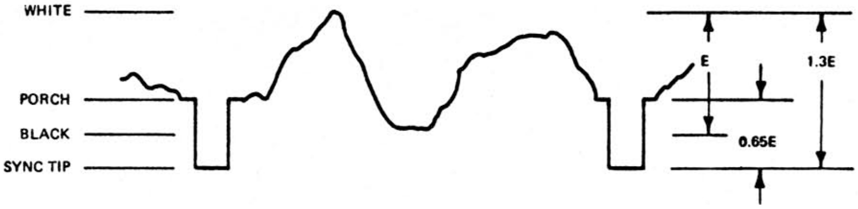
Scan Converter

The scan converter can be divided into three major groups:

(1) the slow-scan equipment, which is used to receive and display the video as it is received directly from an Apollo spacecraft or played back from a tape recorder;

(2) the EIA conversion equipment, which is used to convert the slow-scan video to commercial rates; and

(3) the built-in test equipment, which is used to calibrate, align and check the operation of both the slow-scan and EIA equipment.



Parameter	Format 1	Format 4
Line Frequency	320 LPF	1280 LPF
Frame Rate	10 FPS	0.625 FPS
Porch	5 ±1 μsec	20 ±4 μsec
Sync	20 ±10 μsec	1250 ±10 μsec

Fig. 2. Apollo pulse-type-sync video format.

Parameter	Format 2	Format 3
Line Frequency	320 LPF	1280 LPF
Frame Rate	10 FPS	0.625 FPS
Sync Burst Frequency	409.6 kHz 0.01%	409.6 kHz ±0.01%
Porch	5 ± 1 μsec	20 ±4 μsec
Burst Sync	20 μsec	80 μsec
Horizontal Line	3125 μsec	1250 μsec

Fig. 3. Apollo burst-type-sync video format.

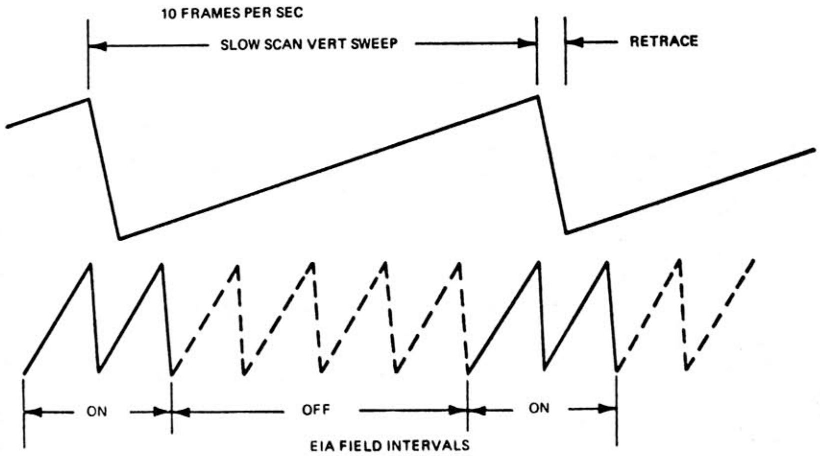


Fig. 4. Apollo scan converter timing diagram.

The major portions of the scan converter are presented in the block diagram of Fig. 5.

Slow-Scan Video

The video input signal is applied to the AGC and keyed-clamp circuits. The circuits are designed to accept any one of the four Apollo signal formats with input levels ranging from 0.15 to 2.5 V p-p and to produce a video signal with constant level. The AGC circuit operates on the sync portion of the signal. The sync pulse or tone is first detected, the amplitude is sampled, and the result is used to control the gain of the AGC amplifier accordingly. The detected sync pulses are also routed to the sync detector,

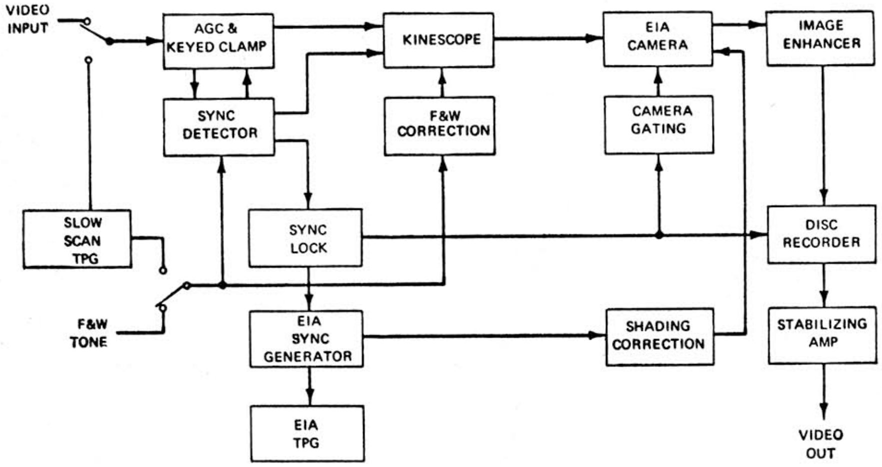


Fig. 5. Apollo TV scan converter block diagram.

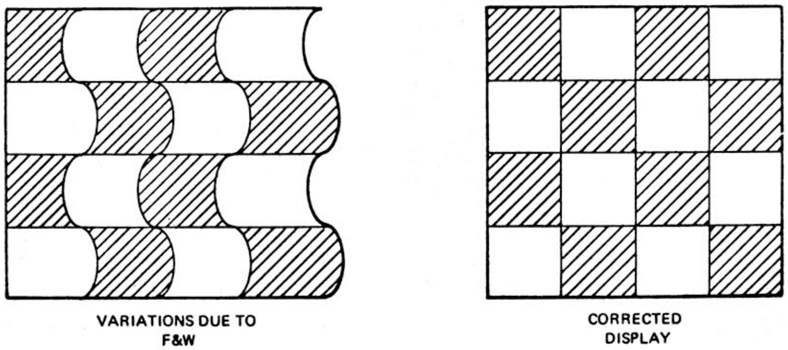


Fig. 6. Effect of flutter-and-wow on display.

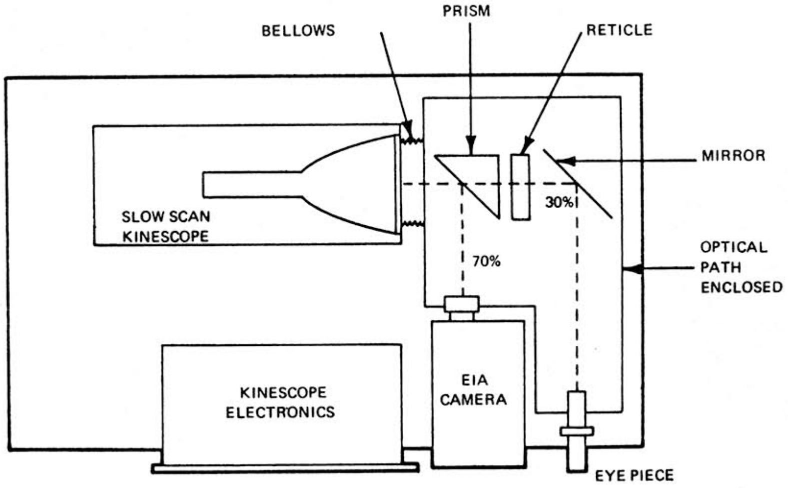


Fig. 7. Optical bench assembly.

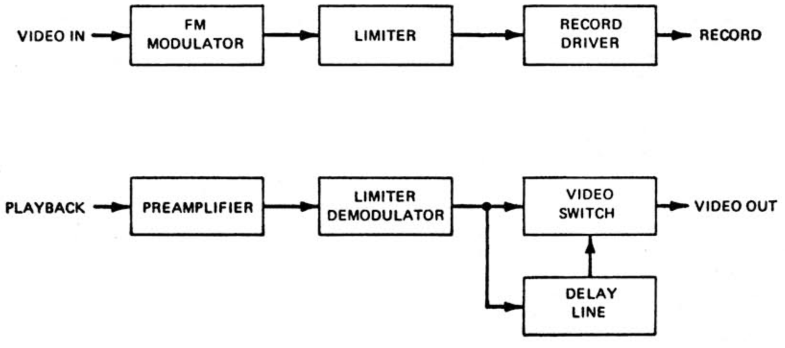


Fig. 8. Disc recorder video signal block diagram.

which generates two signals that control the keyed-clamp circuits once the scan converter acquires sync lock. The two signals (active clamp and composite narrow sync) are used to prevent noise from affecting the AGC loop.

The AGC-controlled composite video signal is routed to the gamma correction circuit. This circuit is designed to compensate for nonlinear transfer characteristics of the vidicon and kinescope. The corrected video is applied to the CRT display.

Sync Detector

The sync detector circuit receives composite video sync pulses in any one of the four Apollo slow-scan formats from the AGC circuit. The sync detector generates slow-scan horizontal sync pulses, slow-scan vertical pulses, and unblanking pulses for the kinescope. It does this by reshaping the input sync pulses and applying them to a phase-locked loop which drives horizontal and vertical counters. The horizontal counter, also part of the phase-locked loop, serves to open windows in the detector so that only the sync pulses are processed. Noise spikes that could be mistaken for sync pulses are blanked out.

Sync Lock

The sync-lock circuit employs a phase-lock loop to synchronize the EIA portion of the system to the slow-scan portion. The input signal is a 3200- or 800-Hz square wave, depending on the slow-scan frame rate. The input frequency is counted down to 50 Hz and applied to a phase detector, where it is compared with another 50-Hz signal counted down from a 1.008-MHz, crystal, voltage-controlled oscillator (VCO). After filtering, the output of the phase detector is a dc voltage, which is amplified and applied back to the VCO to complete the loop.

The 1.008-MHz oscillator signal is also counted down to 31.5 kHz, which is used to drive the EIA sync generator. Vertical synchronization is obtained by comparing the orientation of the vertical drive signal from the EIA sync generator with the slow-scan vertical sync. The EIA control logic makes this comparison, evaluates the situation, and may either advance or retard EIA vertical sync.

The gating logic circuit "looks" at slow-scan decoded vertical sync and EIA vertical drive, and generates gates which control the EIA camera timing and disc recorder timing.

Slow-Scan Display

The slow-scan kinescope display employs a 5-in, high-resolution, flat-face tube. It is a Beta Instruments unit that operates at both scanning rates. The tube is a type 5CKP11A with a fine-grain sifted phosphor. The spot size is 0.001 in at the center, and the video

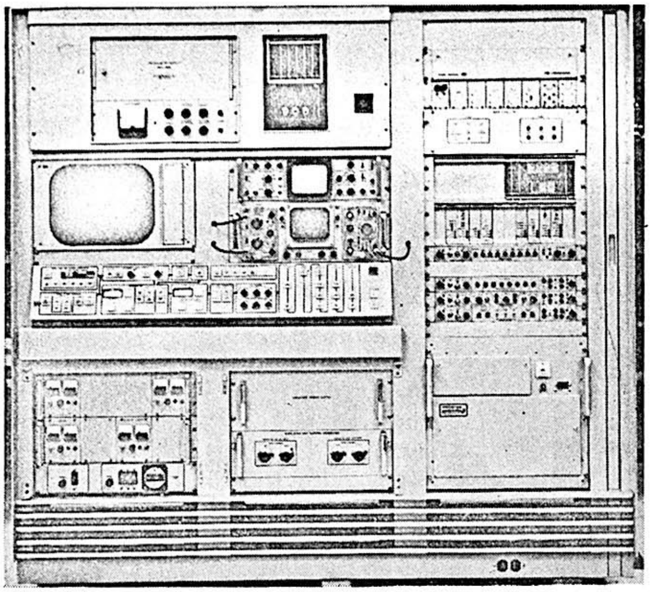


Fig. 9. Apollo TV scan converter.

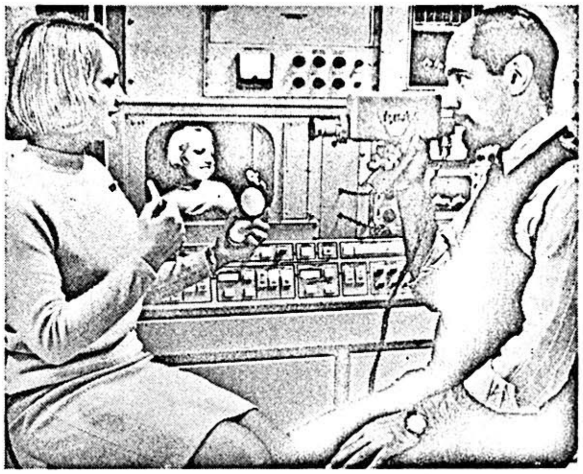


Fig. 10. Operation of Apollo system in laboratory.

Fig. 11. Astronaut Borman at controls of Apollo 8.

Fig. 12. Astronaut Anders checking Apollo 8 telephoto lens.

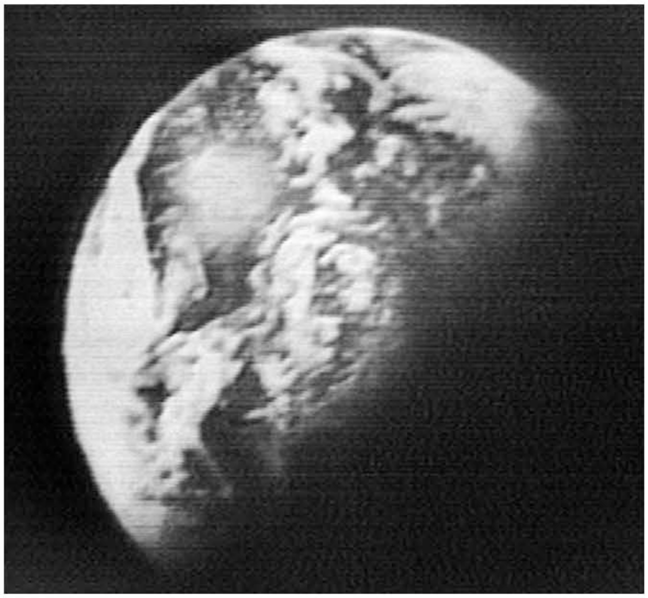


Fig. 13. View of Earth from Apollo 8.

bandwidth is flat from dc to more than 3 MHz.

To maintain high resolution over the entire raster area, dynamic focus is employed. Parabolic transfer functions in both axes are generated and used to maintain focus of the electron beam as it is deflected from the center of the CRT screen to the edges. Spot wobble, in which the spot is deflected (wobbled) slightly in the vertical direction at a 1-MHz rate, is used to remove the line structure of the display. Geometric sweep correction is incorporated in the display, as well as means to apply the flutter-and-wow correction to the deflection. Dual controls, such as contrast and brightness, are available for each frame rate.

Flutter-and-Wow Compensation

Flutter-and-wow correction circuits are switched into the display when the input signal is from a tape recorder. In the playback mode of operation, the tape recorder (external to the scan converter) furnishes 409.6 kHz flutter-and-wow tone along with the composite video. This tone signal is recorded on a separate tape channel at the same time the video signal is recorded. Any rate variations during record or playback produce deviations, which will frequency-modulate the recorded video and 409.6-kHz tone signals. Considering only the horizontal line component of a TV display, the picture produced from a tape recorder containing uncorrected flutter-and-wow signals introduced by the recorder might appear as shown in Fig. 6. The effect is produced by rate variations as the signal is taken from the tape, which alter the length of each horizontal line. The flutter-and-wow correction circuit senses the frequency variations in the flutter-and-wow tone signal during playback and produces correction signals to alter the sweep rates of the slow-scan kinescope, so that the horizontal lines are the same length. Similar correction signals are also generated to compensate the vertical size.

Optical Coupling

The slow-scan Apollo TV picture displayed on the kinescope is transferred through the optical system to the face of the EIA camera. A "peep-hole" eyepiece allows the operator to observe the display on the kinescope. Figure 7 is a top view layout of the kinescope and optical coupling to the vidicon camera. Mechanical, electrical and optical adjustments are available to align the system.

Camera

The EIA camera is a transistorized commercial unit (RCA TK-22 Vidicon Film Camera System) that consists of two parts: the camera and the camera auxiliary circuits. The camera portion converts the optical image to electrical signals, while the auxiliary unit accepts the sync and blanking signals from the scan converter system and then processes the camera video signals for the rest of the scan converter. The camera circuits were modified to include the camera-gating circuit, which allows the camera to be gated *On* or *Off* by the timing pulses from the sync-lock circuit. This permits the camera to be read out for a two-field period at EIA rates and blanks the camera for either the following four or ninety-four fields, depending on the input rates of 10 or $\frac{5}{8}$ frames/s.

Magnetic Disc Recorder

The magnetic disc recorder is an MVR unit. It is a single-channel, single-track, solid-state recorder, which records a field of video upon a command signal that precedes the vertical sync pulse. It plays back and interlaces this field with itself to produce a frame of information. The play-back is repeated until the next command signal calls for erasing the old video and updating the recording with a new field of video.

The recorder employs a 14-in, magnetically coated, disc rotating at 3600 r/min, with the speed servo-controlled. The EIA horizontal drive is used as the reference to be compared to the fixed number of pulses on the control track. A single record head and a single read head are used, physically located close to one another. In one revolution of the disc, a complete field of video is recorded at EIA rates. The incoming video is used to frequency-modulate a carrier in the range of 6 to 7 MHz, and the lower-side band information is recorded on the disc. During playback, proper timing is maintained by gating alternate fields of video through a $\frac{1}{2}$-line delay. A video signal block diagram is presented in Fig. 8.

Stabilization Amplifier

The stabilization amplifier is a standard TV commercial unit. It provides the means for removing the entire timing pedestal from the video as it comes from the disc recorder and inserting an entirely new timing pedestal.

Test Pattern Generators (TPG)

In order to have the capability to thoroughly check out the performance of the scan converter and transmission links prior to receiving pictures, the ability to generate slow-scan and standard-rate test patterns is included in the scan converter unit.

The slow-scan TPG is capable of electronically simulating any of the Apollo formats. The following test signals can be generated:

(1) four slow-scan formats: 10 and $\frac{5}{8}$ frames/s, fps, with either pulse or burst sync;

(2) video test patterns consisting of gray scale, vertical lines, horizontal lines, cross-hatch, multiburst, and half-frame blanking;

(3) a stable flutter-and-wow signal that can be modulated to simulate tape-recorder variations; and

(4) random noise that can be introduced into the video circuits.

The standard rate TPG produces multiburst, stairstep, dot grating, and half-frame blanking.

Equipment

Early in the design of the scan converter, operation and maintenance considerations were given high priority. A human-factors specialist advised on the layout and location of operating controls and displays. Figure 9 is a front view of the scan converter. The equipment is housed in a single welded unit, consisting of three short racks. The operating panel is located directly above a pull-out desk top. Oscilloscopes are included for inspection and measurement of slow-scan signals and standards signals. The output picture is viewed on a "monitor." Figure 10 is a photograph of the Apollo system taken in the laboratory; the secretary is being viewed by the Apollo slow-scan camera and the monitor in the scan converter is displaying the picture at standard rates.

Picture From Space

Three pictures from the Apollo 8 Mission are presented, for which the signals were received at the Apollo Goldstone Tracking Site. Figure 11 shows Astronaut Borman at the controls; Fig. 12 shows Astronaut Anders checking the telephoto lens. The Apollo 8 crew, Borman, Lovell and Anders, were 120,653 nautical miles from the earth traveling at a speed of 3,207 mi/h at the time the TV pictures were transmitted. Figure 13 is a view of the earth as observed by the Apollo 8 Astronauts as they return from their lunar orbit.