Ground-Commanded Television Assembly (GCTA)

Operation and Checkout Manual

Prepared for:
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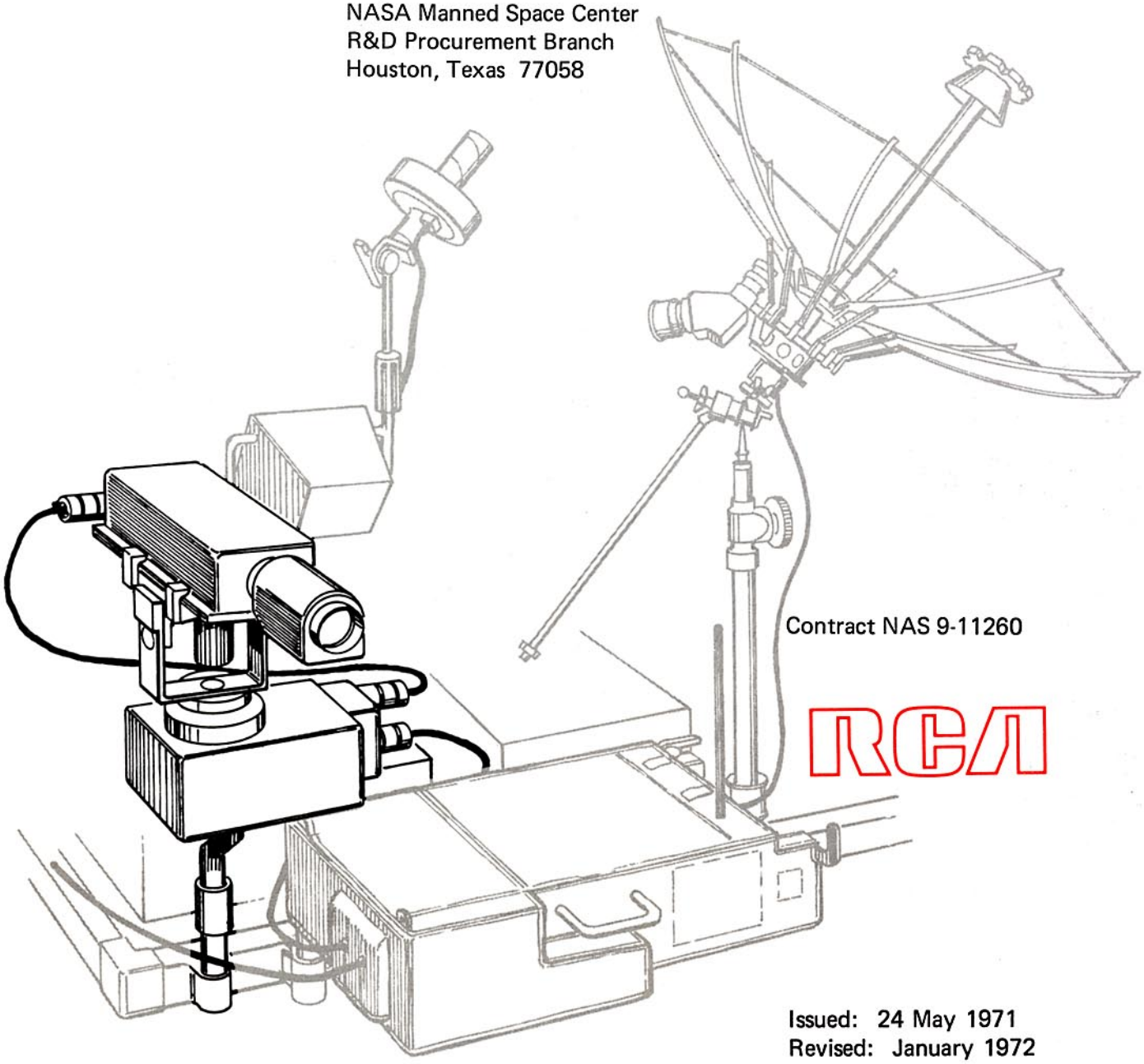

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PREFACE

The RCA Ground-Commanded Color Television Assembly (GCTA) is designed for use on lunar explorations associated with the Apollo 15 through Apollo 17 missions. The equipment consists of a color television camera (the CTV), a television control unit (the TCU) and associated cabling, bracketry, and hardware. Design of the GCTA is based on the RCA Lunar Surface Color Camera produced for NASA under Contract NAS 9-10781. Both systems use a silicon intensifier target (SIT) sensor and field-sequential color wheel to generate color television images. The assemblies are being produced by RCA for the NASA Manned Spacecraft Center (MSC) in Houston, Texas under Contract NAS 9-11260.

Material in the GCTA Operation and Checkout Manual is presented in four sections. Section 1 describes the functional design and operation of the GCTA, and identifies the modes in which the assembly may be operated. Both manual control by the astronauts and ground-commanded control by MSC are discussed. Section 2 covers the prelaunch test and handling operations required to assure specified GCTA performance during the Apollo missions. Lunar surface operation of the assembly is detailed in Section 3. Section 4 provides the data required by ground personnel to achieve maximum performance during ground-controlled operation of the GCTA.

Manual revisions in January 1972 reflect changes made to the GCTA design subsequent to the Apollo 15 mission.

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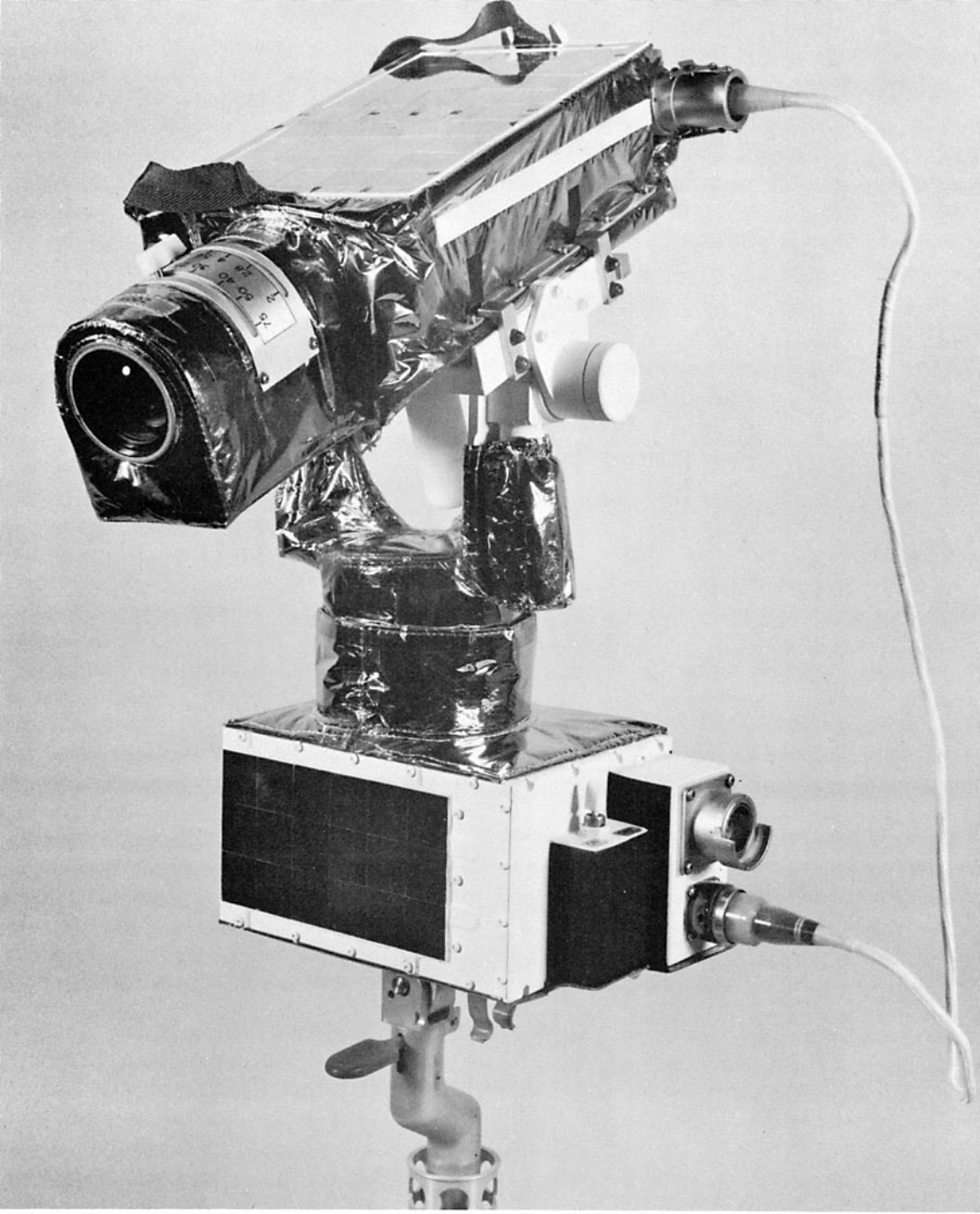
GCTA BOARD DESIGNATIONS

Color Television Camera (CTV)		RCA Drawing Number
1A1	Motor Drivers	2265829-501
1A2	Power Supply Regulators	2265830-501
1A3	Current Regulators	2265828-501
1A4	Video Circuits	2265817-501
1A5	Sync Generator	2265815-501
1A6	Deflection Generators (H&V)	2265832-501
1A7	HV Power Supply	2260510-1
1A8	DC/DC Converter	2265831-501
1A9	Color Flag Detector	2264293-501
1A10	Vidicon Yoke Assembly	2264795-501
1A10A2	Electrode Divider	2265833-501
1A11	ALC Circuits	2271051-501
1A13	Motor Dampers	2262459-501
1A14	Video Preamplifier	2270011-501
1A15	Connector Block	2263224-501

Television Control Unit (TCU)		RCA Drawing Number
2A1	DC/DC Converter	2265606-501
2A2	Discriminator Board	2265608-501
2A3	Discriminator Board	2265296-501
2A4	Digital Decoder Board	2265811-501
2A5	Digital Decoder Board	2265813-501
2A6	Voltage Regulator	2265615-501
2A7	Test Signal Generator	2265899-501
2A8	Command Control Board	2265607-501
2A9	Motor Drivers	2271061-501
2A10	Motor Drivers	2271061-503
2A11	Motor Dampers	2262457-501
2A12	Motor Dampers	2262457-501
2A13	Noise Filter	2270362-501

ACRONYMS USED IN MANUAL

AGC	Automatic Gain Control
ALC	Automatic Light Control
CTV	Color Television Camera
FET	Field-Effect Transistor
GCTA	Ground-Commanded Television Assembly
KSC	Kennedy Space Center (Florida)
LCRU	Lunar Communications Relay Unit
LM	Lunar Module
LRV	Lunar Roving Vehicle
MCCH	Mission Control Center-Houston
MESA	Modularized Equipment Stowage Assembly
MSC	Manned Spacecraft Center (Texas)
NTSC	National Television Standards Committee
SIT	Silicon Intensifier Target
SMA	Stowage Mount Assembly
TCU	Television Control Unit



Frontispiece. RCA Ground-Commanded Television Assembly

SECTION 1

GCTA SYSTEM FAMILIARIZATION

1.1 GCTA DESCRIPTION

The Ground-Commanded Television Assembly (GCTA) is a color television camera system designed to operate on the lunar surface. The camera system is operated manually on the moon by an astronaut or by remote commands from Earth. The assembly consists of a color television camera and a television control unit. The television control unit permits ground-commanded positioning and operation of the camera. The GCTA is illustrated in the Frontispiece.

The Color Television Camera (CTV) is a small, lightweight unit producing high-quality, field-sequential color television at standard line and frame rates. The camera uses a single silicon intensifier target (SIT) tube and a rotating filter wheel to generate color video data. A zoom lens is incorporated in the CTV with provisions for manual or remote control of zoom and iris settings. Automatic light control (ALC) operating on average or peak scene luminance also is incorporated. ALC may be selected manually or by remote control.

The Television Control Unit (TCU) provides an azimuth/elevation mount for the color television camera, and permits manual or ground-controlled television coverage from the Apollo Lunar Roving Vehicle (LRV). The TCU receives a command subcarrier from the Lunar Communications Relay Unit (LCRU) mounted on the LRV and executes commands for: azimuth and elevation movement of the TCU camera cradle; CTV zoom, iris, automatic light control, and power functions; as well as transmitter/voice subcarrier control within the LCRU. The TCU accepts the CTV video signal, adds a test signal, and routes the combined video to the LCRU for transmission to earth.

Figure 1-1 shows front (a) and side (b) views of the GCTA in its operational configuration mounted to the Lunar Roving Vehicle. The CTV mounts in the TCU cradle to allow remote positioning, and the TCU provides the electronics required for decoding and execution of remote commands. A short staff at the base of the TCU electronics box mounts the GCTA to a fitting on the LRV chassis frame. The mounting staff has a swing-away capability to allow removal of the LCRU from the LRV chassis frame without removing the GCTA.

1.1.1 Color Television Camera (CTV)

The CTV is approximately 18-inches long, 6.5-inches wide, 4-inches high, and weighs 12.8 pounds. The lens assembly houses an f/2.2 Angenieux

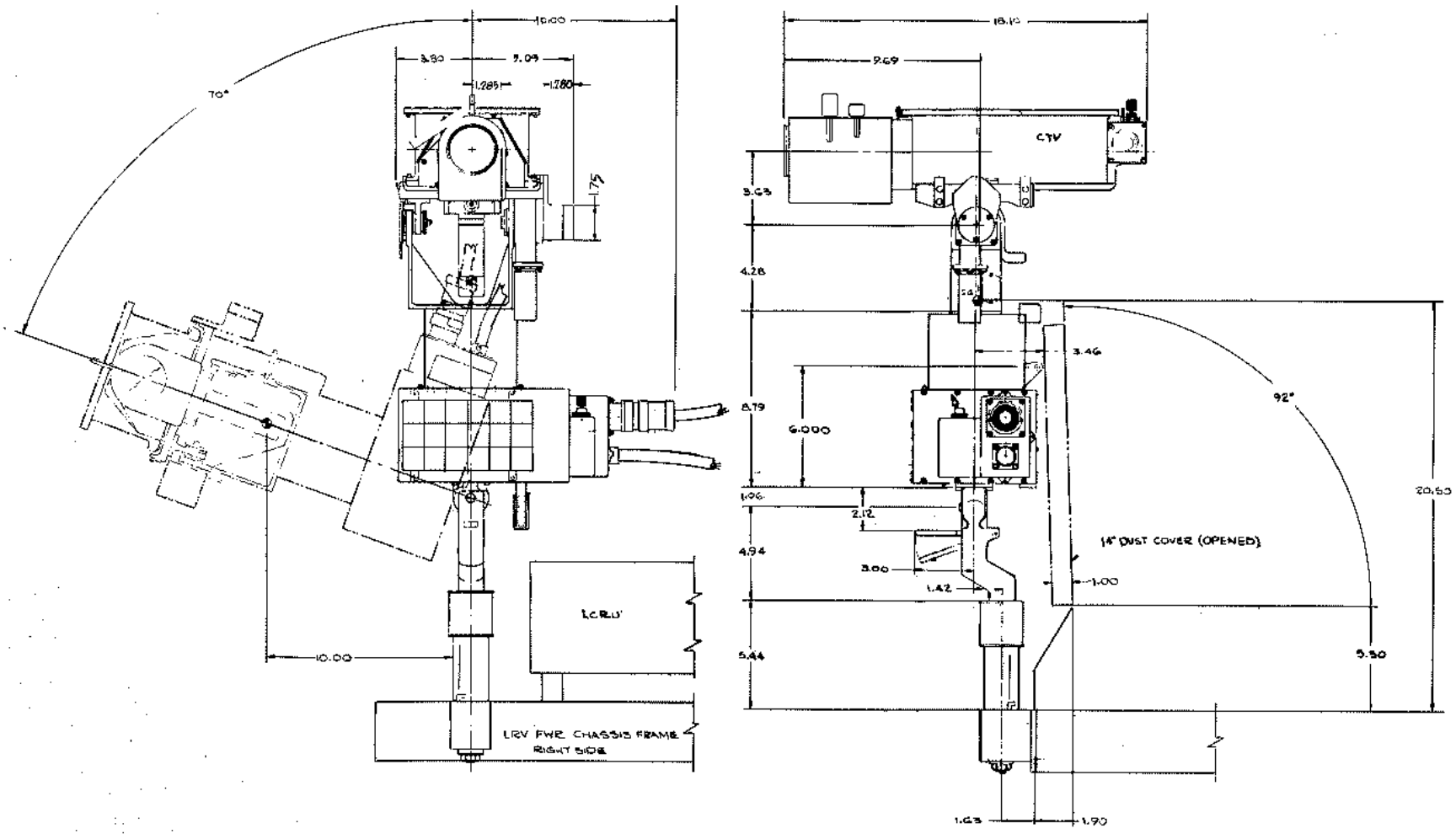


Figure 1-1. GCTA Configuration Mounted on the LRV

lens with a zoom ratio of 6:1. Both zoom and iris may be manually or remotely controlled by electric drives in the lens assembly.

The camera body contains the SIT tube, color-wheel assembly, and all synchronization, deflection, and video components required to provide a standard 525-line composite video format at the CTV output.

A cable block at the rear end of the camera provides a connector for the CTV/TCU electrical interface cable and houses two control switches - one for CTV power and one for switching automatic light control (ALC) modes. A folding handle on the bottom surface of the camera allows hand-held operation. A tripod may be attached to the handle.

With the exception of the lens opening and a thermal radiator covering the top of the camera, the entire CTV is covered with thermal insulation blanketing. The thermal radiator is constructed of second-surface mirrors.

The performance summary of the CTV is given in Table 1-1.

TABLE 1-1. CTV PERFORMANCE SUMMARY

Parameter	Characteristic
Sensor	SIT camera tube
Sensitivity	Greater than 32 dB signal-to-noise at 3 foot-lamberts
Resolution	80 percent response at 200 TV lines
ALC Dynamic Range	1000 to 1 (minimum)
Non-linearity	3 percent (maximum)
Gray Scale	10 $-\sqrt{2}$ steps
Video Output Level	1.0 volts p-p into 75 ohms Full EIA sync
ALC	Peak or average detection modes
Optics	
Zoom Ratio	6:1
Iris Control	f/2.2 to f/22
Pan Angle	+214 / -134 degrees from front
Tilt Angle	+85 / -45 degrees from horizontal
Power	14.8 watts @ 28 volts input
Weight	12.8 pounds

1.1.2 Television Control Unit (TCU)

The TCU azimuth/elevation pedestal allows the CTV to pan 214 degrees to the right and 134 degrees to the left of forward and to tilt -45 to +85 degrees from horizontal. Geared stepping-motor drives are used, and a single quick-release mechanism is provided on the cradle for capture and release of the camera. The TCU weighs 13.0 pounds.

The TCU electronics box receives a 70-kHz command subcarrier from the LCRU and decodes 18 real-time commands for execution. Motor drivers for control of CTV azimuth, elevation, zoom, and iris; and relay drivers for CTV power, automatic light control (ALC), and LCRU subcarrier commands also are contained in the TCU. Camera video is routed to the TCU where a vertical-interval test signal is generated and added prior to transmission to earth through the LCRU.

The TCU is partially covered with thermal insulation blanketing. The unblanketed surfaces are covered by second-surface mirrors or white and black paint.

1.1.3 Interfaces

The GCTA interfaces with the LCRU, the LRV, and the Lunar Module (LM).

1.1.3.1 LCRU Interface

The GCTA interfaces with the LCRU through a "Y"-shaped cable attached to the forward frame member of the LRV. The LCRU supplies +29 Vdc power and a 70-kHz command subcarrier signal to the GCTA. The GCTA supplies the LCRU with a composite video signal and with signals for power control of the LCRU FM transmitter and for ON/OFF control of the LCRU 1.25-MHz downlink voice subcarrier.

The electrical interface with the LCRU is established by a zero-g receptacle connector on the TCU. The LCRU "Y" cable may be connected directly to the CTV, however, in a contingency mode of operation. No remote command capability is possible in the contingency mode.

1.1.3.2 LRV Interface

The TCU is mounted on the Lunar Roving Vehicle by a tubular staff. The staff folds against the TCU base for stowage in the lunar module. When mounting the TCU on the LRV, the staff is extended and the tapered end is inserted into a mating fitting on the LRV frame. The fitting is keyed for proper orientation.

No electrical interface exists between the GCTA and the LRV.

1.1.3.3 LM Interface

Provisions to stow the CTV and TCU on the LM Mechanized Electronics Stowage Assembly (MESA) during translunar flight, and electrical connection of a 100-foot cable from the CTV to the LM are required for the mission. The camera is stowed on the LM MESA on a Stowage Mount Assembly (SMA) that in turn attaches to four vibration isolators on the MESA support bracket. The SMA may be removed with the MESA support bracket to provide access to other equipment stowed in the MESA. The camera is removed from the SMA by "pip" pins that release two clamps and allow the camera to be lifted from the cradle. The CTV cradle is oriented to aim the camera at the astronauts as they descend from the LM. Camera stowage on the LM MESA is illustrated in Figure 1-2.

The TCU is stowed on a pallet in the LM MESA. Three support points are provided on the pallet, and the TCU is attached by a tongue and clevis (on the TCU side) and two pins on the TCU base plate. To remove the TCU, a "pip" pin is pulled that releases the tongue from the clevis. The TCU may be removed without removing the pallet. Figure 1-3 illustrates the TCU/LM MESA stowage arrangement.

The GCTA/LM electrical interface consists of a 100-foot cable connection to the LM. This cable provides +28 Vdc power to the camera, and permits video transmission from the camera directly to the LM communications system.

1.1.4 System Cabling

Two interconnection cables are required in the GCTA system:

- A 100-foot cable to connect the CTV directly to the Lunar Module (LM) and
- A 3 1/2-foot cable to connect the CTV to the TCU. This cable is permanently connected to the TCU.

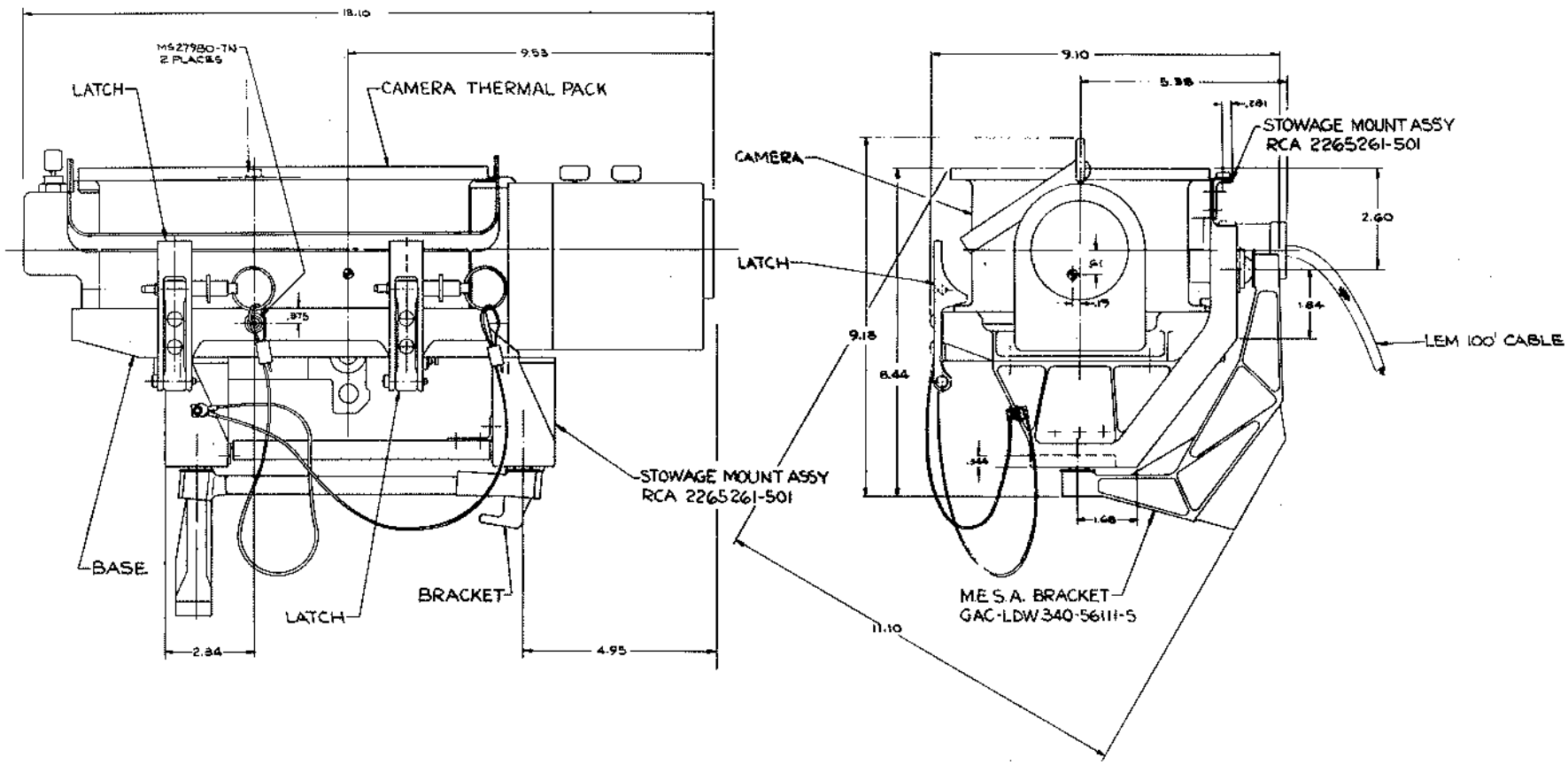


Figure 1-2. CTV Stowage on the LM MESA

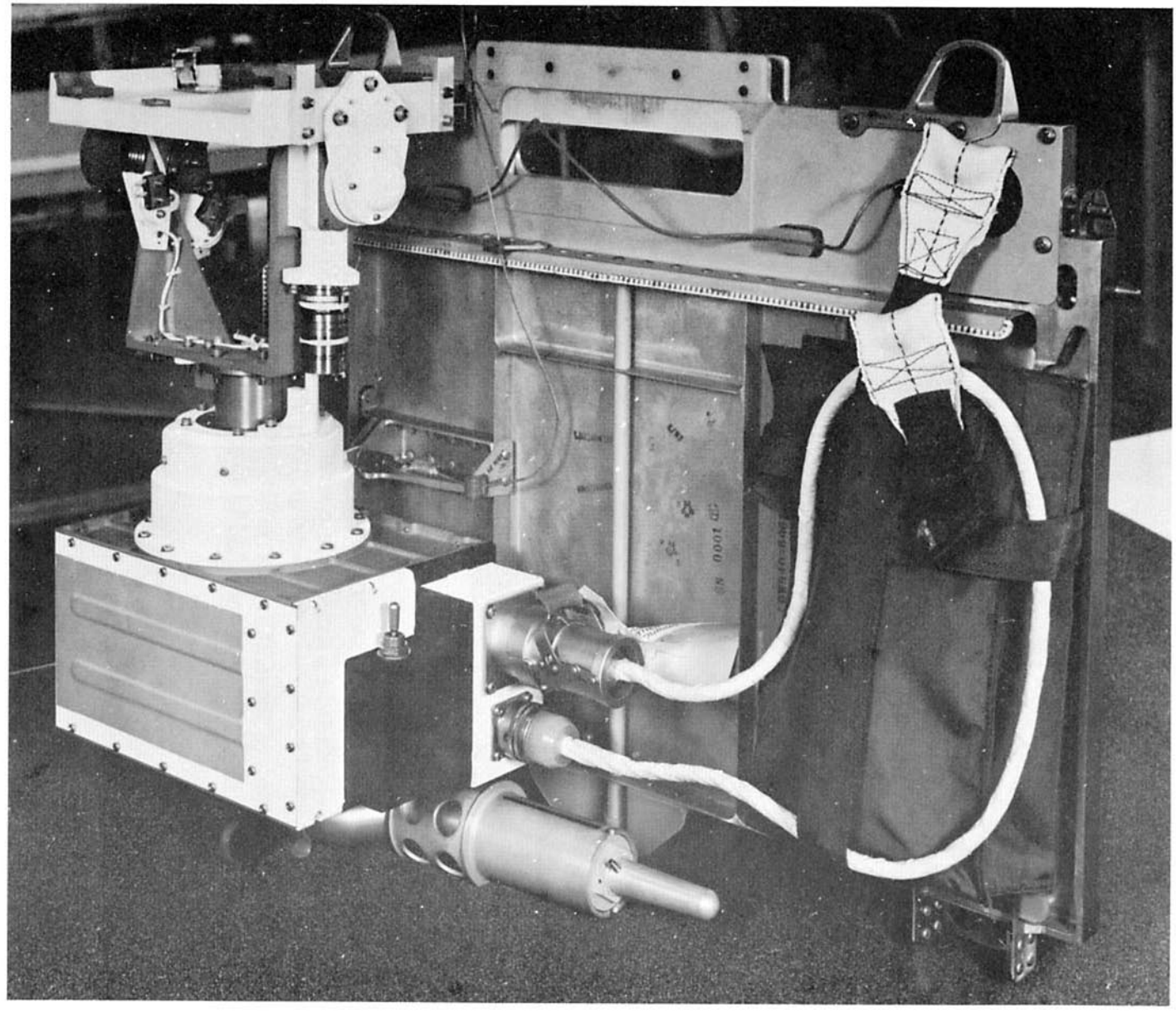


Figure 1-3. TCU Stowage on the LM MESA

1.2 GCTA OPERATIONAL MODES

The GCTA system has four operational modes: two associated with operation through the Lunar Module (LM) and two associated with the Lunar Roving Vehicle (LRV). Diagrams of each mode are shown in Figure 1-4.

1.2.1 LM MESA Mode

In the LM MESA mode, the CTV remains in the Stowage Mount Assembly (SMA) and is connected to the LM through the 100-foot cable. Deployment of the LM MESA brings the CTV into position to view the astronaut descending the steps on the +Z leg of the LM.

By operation of the TV circuit breaker in the LM, the camera is turned ON prior to astronaut egress. The TCU is inactive and no ground-commanded control of the CTV is possible.

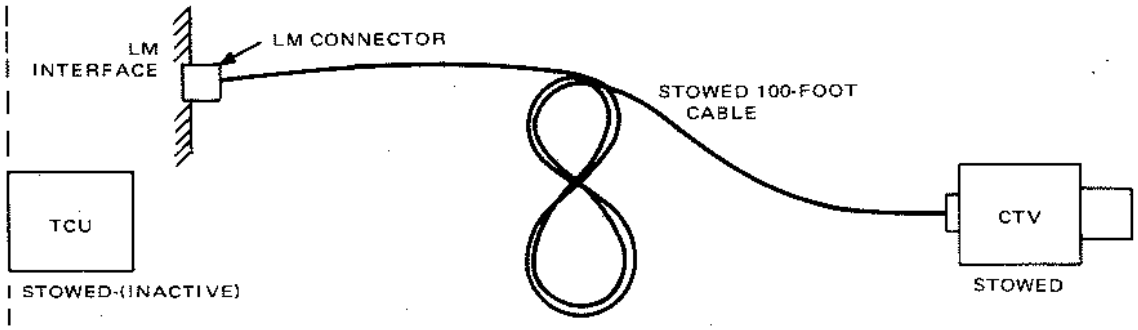
1.2.2 LM Tripod Mode

In the LM Tripod Mode, the CTV is released from the Stowage Mount Assembly and mounted on the LM tripod. The 100-foot cable is deployed, and the camera is placed at any location in the vicinity of the LM. The TCU remains stowed on the LM MESA pallet. Control of the camera is manual, and no ground-commanded control is possible.

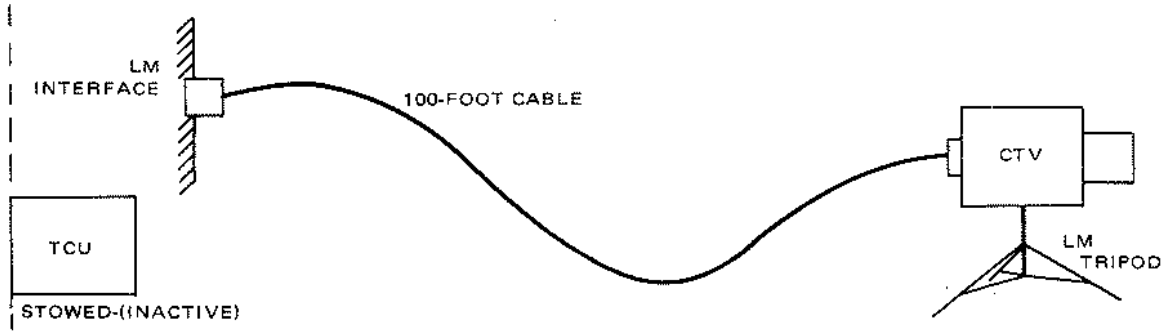
1.2.3 LCRU/CRV Mode

The complete GCTA system is operable during the LCRU/LRV Mode. The TCU is unstowed from the LM MESA pallet and, using the staff, is mounted to the forward frame of the LRV. The LCRU "Y" cable then is connected to the TCU receptacle, the CTV is mounted in the TCU cradle, and the TCU 3 1/2-foot cable is connected to the CTV.

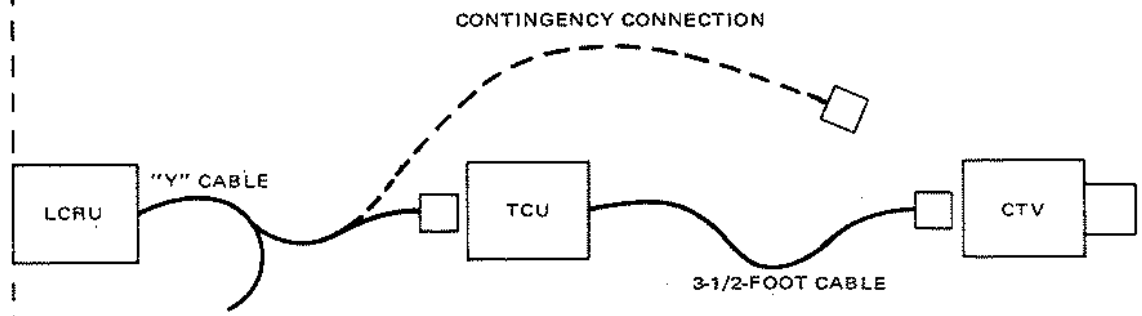
In the LCRU/LRV mode, the GCTA may be operated manually or by ground commands. The camera may (1) remain in the TCU cradle for remotely-controlled panning and tilting or (2) may be hand-held by the astronaut.



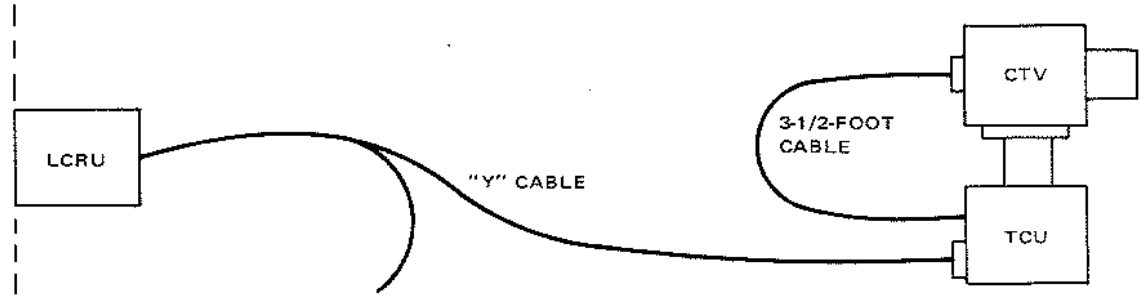
a. LM MESA Mode



b. LM Tripod Mode



c. LCRU/LRV Mode



d. LM Lift-Off Mode

Figure 1-4. GCTA Mode of Operation Diagrams

For contingency operation (under manual control only), the TCU may be bypassed by connecting the LCRU "Y" cable directly to the CTV. See Figure 1-4 (c).

1.2.4 LM Lift-Off Mode

During LM Lift-Off operation, the GCTA remains in the LCRU/LRV Mode configuration but is operated by remote control only. The LRV is parked approximately 300 feet from the LM at a location uprange of the ascent trajectory plane. At LM Lift-Off, ground commands are sent to the GCTA to provide TV coverage of the LM ascent from the lunar surface.

1.3 MANUAL CONTROLS

The following manual controls are used for crew operation of the CTV.

- Zoom

Lens focal length can be controlled over a 12.5 mm to 75 mm range, giving a diagonal field-of-view from 54 degrees to 9 degrees, respectively. The zoom is controlled manually by rotation of the forward control knob on the lens barrel (See Figure 1-5).

- Iris

Lens opening is controlled over a f/2.2 to f/22 range and is controlled manually by the knob to the rear of the zoom control.

- Automatic Light Control (ALC)

A 3-position switch (PEAK, REMOTE, and AVERAGE) at the rear end of the camera controls ALC operation for peak or average scene luminance. The REMOTE position permits ground control of the ALC function, and selection of operation on peak or average luminance. The switch is spring-loaded and returns to the center (REMOTE) position when not being actuated.

- LM Power

An LM power switch is located at the rear end of the camera. Power is controlled to the CTV by this switch only when the CTV is operating through the 100-ft cable to the LM. When operating with the TCU, CTV power is controlled by the TCU power switch.

The following manual controls may be used for crew operation of the TCU.

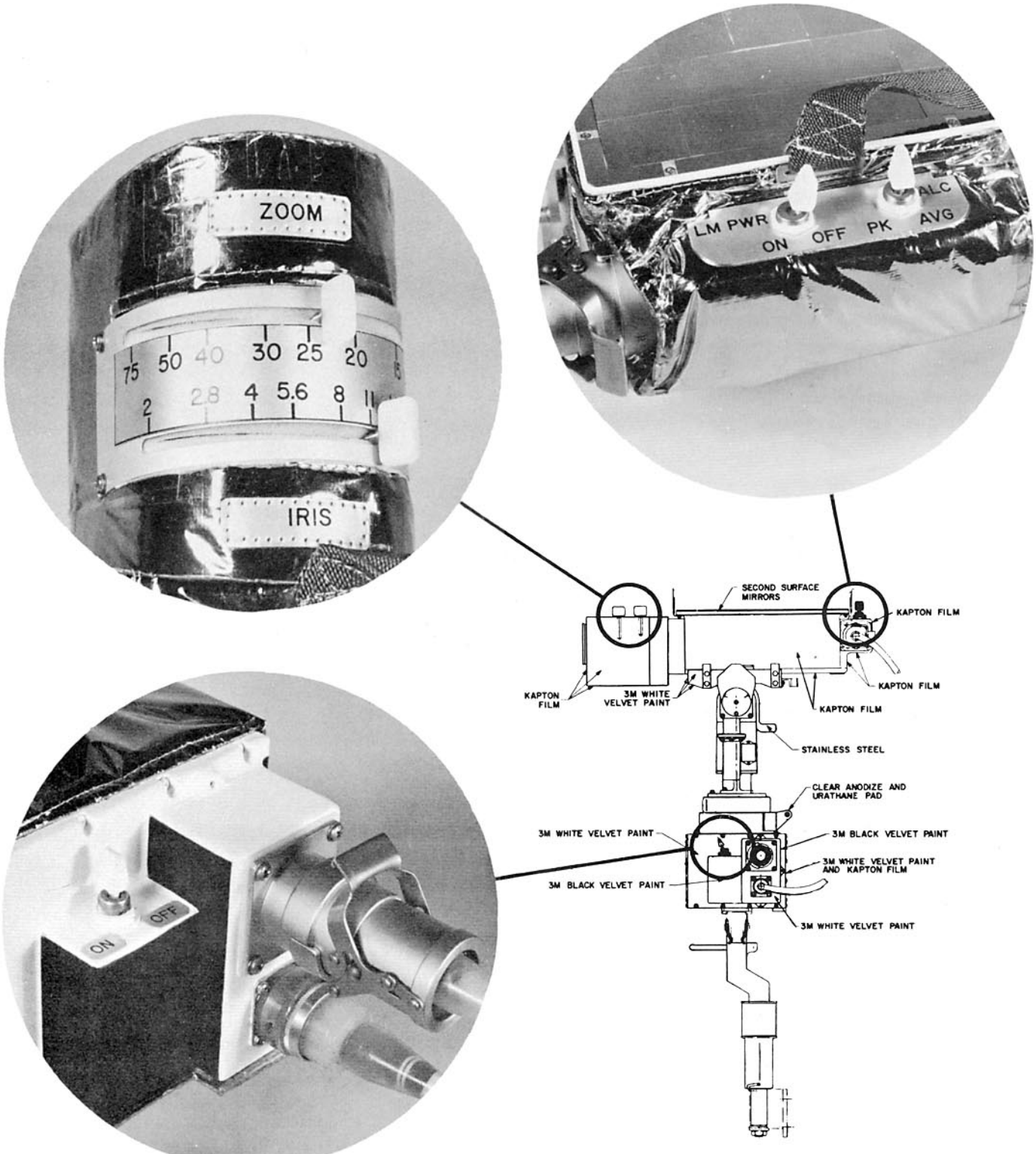


Figure 1-5. Location of GCTA Manual Controls

- Azimuth and Elevation

When cradled in the TCU, the CTV may be positioned manually by overriding the slip clutches in the azimuth and elevation drives.

- Power

A 3-position TCU power switch (ON, REMOTE, and OFF) is located on the TCU connector block to provide power control for the CTV and the TCU when operating with LCRU. This switch is spring-loaded and returns to the center (REMOTE) position when not being actuated. The power switch on the CTV does not interact with the TCU power control switch.

1.4 GROUND-COMMANDED OPERATION

Eighteen distinct real-time commands may be transmitted to the GCTA for ground control of the system. The commands are listed in Table 1-2. An astronaut manually controlling the camera may override the ground commands. The astronaut cannot, however, disable the system's ground-command capability by leaving a switch or other control in the wrong position.

1.5 CTV DESCRIPTION

1.5.1 Electrical Description

The CTV camera uses conventional monochrome television techniques to provide color information. The video signal is generated by a synchronously-driven, segmented color wheel. The system operates at commercial (NTSC) scan rates. A functional block diagram of the system is shown in Figure 1-6.

The CTV employs a Silicon Intensifier Target (SIT) tube for image sensing. This tube has high sensitivity and relative immunity to image burn. The color wheel between the camera lens and the SIT tube is rotated by a motor driven in step with signals from a sync generator. The color wheel consists of six filter segments, two each of red, green, and blue. An optical pick-up provides color wheel position for properly phasing the segments of the color wheel with respect to the camera vertical scan.

The three primary-color video signals are transmitted sequentially at a 60-Hz field rate. Red information is transmitted during the first field, blue information during the second field, and green during the third field. The sequence is repeated continuously. A color flag pulse is inserted during the vertical interval of each green field to permit automatic color-field phasing at the receiving site.

TABLE 1-2. GCTA REMOTE CONTROL (GROUND) COMMANDS

Command	Function
PAN RIGHT	Pan right at 3.03 degrees per second.
PAN LEFT	Pan left at 3.03 degrees per second.
PAN STOP	Stop pan.
TILT UP	Tilt up at 3.12 degrees per second.
TILT DOWN	Tilt down at 3.12 degrees per second.
TILT STOP	Stop tilt.
ZOOM IN	Increase focal length. Full range covered in 14.6 seconds maximum.
ZOOM OUT	Decrease focal length.
ZOOM STOP	Hold existing focal length.
IRIS OPEN	Decrease f/number. Full range covered in 13.1 seconds maximum.
IRIS CLOSE	Increase f/number.
IRIS STOP	Hold existing f/number.
ALC PEAK	Change CTV circuit connections to provide peak level light control.
ALC AVERAGE	Change CTV circuit connections to provide average level light control.
POWER ON	Power camera, enable LCRU FM Transmitter, commands S/C ON.
POWER OFF	Turn camera OFF, disable LCRU FM Transmitter when in TV mode.
S/C ON	Enable LCRU voice subcarrier (S/C).
S/C OFF	Disable LCRU voice subcarrier (S/C).

The CTV camera is a complete system and provides a composite video output signal with only a single power input (+28 Vdc). A dc/dc converter is used to convert the 28 volt input to all voltages required for circuit operation. Critical voltages are stabilized by internal voltage regulators. A sync generator furnishes timing pulses for video and deflection circuits, for synchronizing the operation of the dc/dc converter, and also provides timing signals to the TCU.

The video circuits amplify and process the sensor output to provide the required camera output format. The processing includes ALC and AGC, aperture and gamma correction, sync and blanking addition, and black and white clipping.

Stepping motors mounted on the lens assembly permit remote operation of the zoom and iris controls. These motors are actuated by drive signals sent from the TCU. Limit switches stop remote operation of the zoom and iris functions at the end of normal ranges.

All electrical interfaces are routed through a single, 26-pin, zero-g connector located at the rear of the CTV. Pin connections are arranged to permit CTV operation (1) through the LM link, (2) through the TCU into the LCRU, or (3) into the LCRU directly as a contingency mode.

1.5.2 Mechanical Description

The CTV mechanical configuration is shown in Figure 1-7. The main structural member is a rigid baseplate, with the lens and SIT tube assembly mounted to the baseplate to maintain accurate alignment and minimize the vibration of sensitive components during launch. The camera cover housing is a 2-piece metal can that interfaces with a mounting flange on the baseplate. Circuit boards are mounted on each side of the SIT tube assembly. Urethane pads mounted on the baseplate position the circuit boards. Similar pads on the cover housing engage the boards and hold them by compression when the cover is secured to the baseplate. The lens and color-wheel assemblies are at the front of the camera. The lens is a commercial unit modified to provide a ruggedized assembly. Motor drive units also are incorporated that provide for remote control of zoom and iris functions. The color-wheel and drive assembly is located between the lens assembly and the front flange of the baseplate. The drive assembly consists of an 6300-rpm hysteresis synchronous motor and 3.5:1 gearhead that drives the color-wheel.

Six printed-circuit boards are mounted vertically in the camera housing on the sides of the SIT tube assembly. A low-voltage power supply, packaged in cordwood module form, is located at the rear of the SIT tube assembly. A high-voltage power supply is located below the SIT tube close to the image intensifier

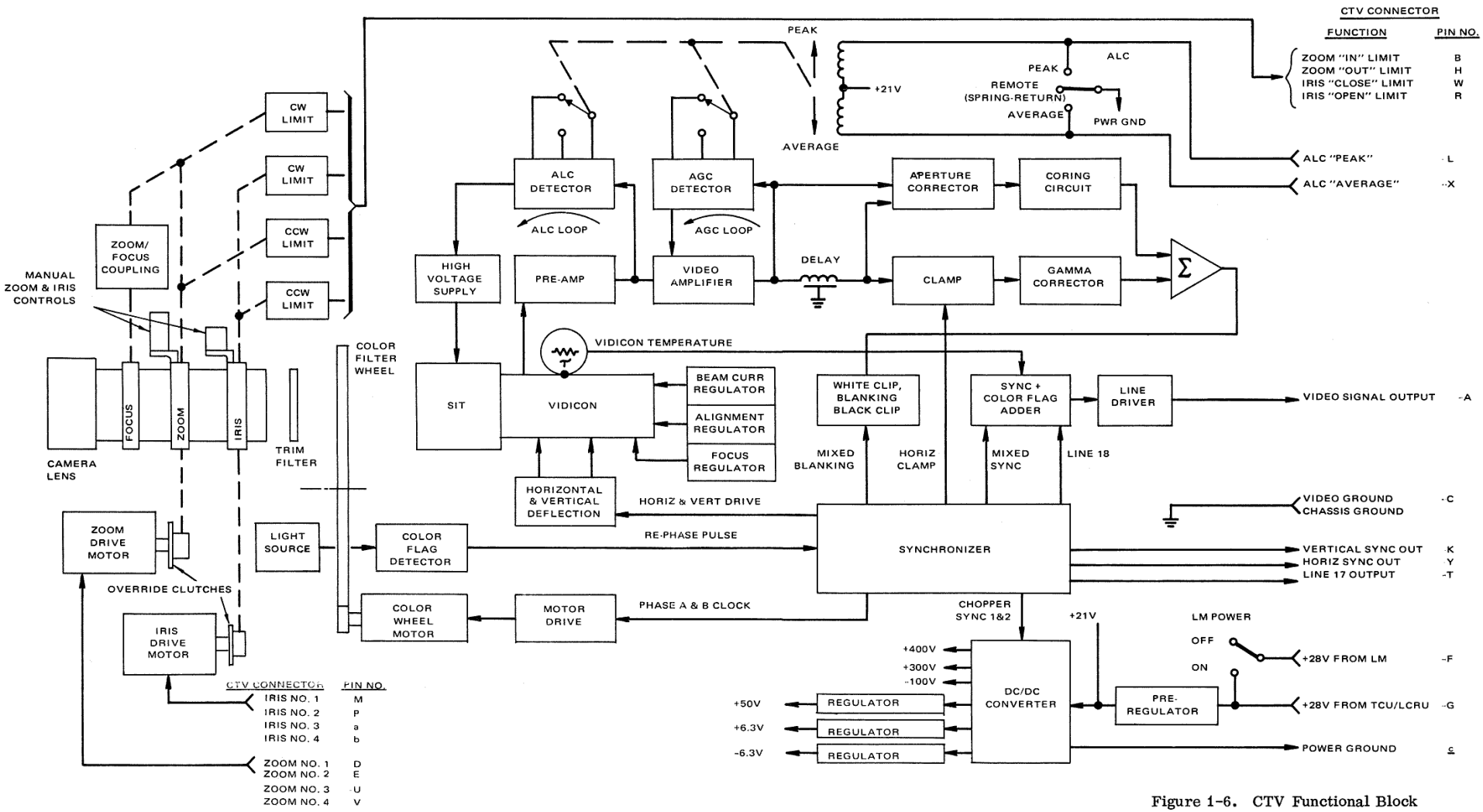


Figure 1-6. CTV Functional Block Diagram

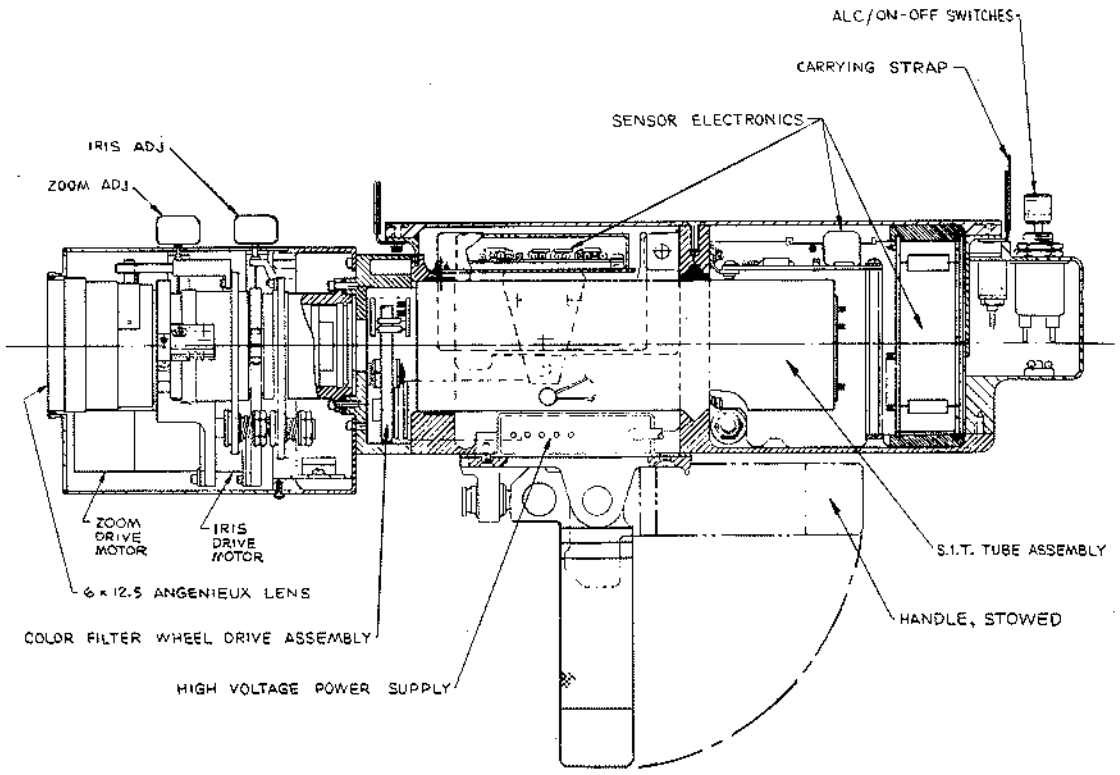


Figure 1-7. CTV Mechanical Configuration

section of the tube. Two grooved urethane pads are used to position the boards in the camera base, and preload the boards in compression when the cover is fitted. No inter-board connectors are used and a prewired harness provides soldered board-to-board interconnections.

The connector block assembly mounted at the rear of the camera contains the CTV electrical interface connector, the LM power ON/OFF switch, and the ALC mode control switch. A handle located on the bottom surface of the base-plate folds for stowage on the LM MESA during translunar flight. When deployed, the handle locks in the extended position for hand;held operation, triped mounting, or use on the TCU cradle during EVA's.

1.5.3 Lens Assembly

The CTV lens is an Angenieux 6 × 12.5 mm zoom lens. The unit has an f-stop range from f/2.2 to f/22 and a 6:1 zoom range. The lens is modified to provide motor-driven iris and zoom operation. The zoom drive is coupled to the focus control and an object at any distance from 1.7 meters to infinity may be brought into focus by operating the zoom control. Two knobs extending from the top of the lens housing also are provided for manual operation of iris and zoom functions. The lens assembly is ruggedized to withstand vibration exposure and extended operation in a vacuum. To exclude lunar dust a shield completely encloses the lens and drive mechanisms. Lens characteristics are listed in Table 1-3.

TABLE 1-3. CTV ZOOM LENS CHARACTERISTICS

Manufacturer	Pierre Angenieux, Paris, France
Type	6 × 12.5, variable focal length
Focal Length Range	12.5 mm to 75 mm
Diagonal Field-of-View	54 degrees maximum (zoom-out limit) 9 degrees minimum (zoom-in limit)
f-Stop Range	f/2.2 to f/22

Permanent magnet stepping motors are employed to drive the iris and zoom controls. The motors are coupled to the lens through a gearhead and a spur gear driving the lens iris and zoom rings. The spur gears are mounted to a friction clutch that provides a manual override capability for the zoom and iris functions. The drive motors are mounted to the body of the lens on metal yokes and form an integral lens drive assembly. Electrical limit switches are provided on both zoom and iris drives to sense end-of-travel. The switches signal the TCU drive circuits to stop motion at the limit positions. Mechanical stops also are provided within the lens assembly to limit motion during manual operation. The electrical limit switches are set to trip and stop motion 3 degrees prior to hitting the mechanical stops. Manual overrides are provided by a friction clutch integral with the motor/gearhead. The clutches are set to slip when a force in excess of 1.5 pounds is applied to the iris or zoom knobs.

Zoom and focus coupling is incorporated in the lens assembly. As shown in Figure 1-8, a direct coupling is made between the zoom and focus rings at focal lengths from 12.5-mm to 40-mm. At 40-mm, focus is set at infinity. A spring coupling permits the zoom ring to continue rotating up to 75-mm while the focus setting remains at infinity.

1.5.4 Color Wheel Drive Assembly

The filter wheel drive assembly is shown in Figure 1-9. The filter wheel itself is a precision stainless steel gear with 150 teeth and six machined cutouts containing spectral and neutral density filter segments. The wheel rotates on two bearings press fit in the wheel hub. Two holes are provided in the rim of the wheel for synchronization of the color wheel using a light sensor.

Three pair of filters (red, blue, and green) are mounted in the six machined cutouts of the filter wheel. Neutral density filters are mounted with the color filters to balance the total light energy transmitted through the six apertures.

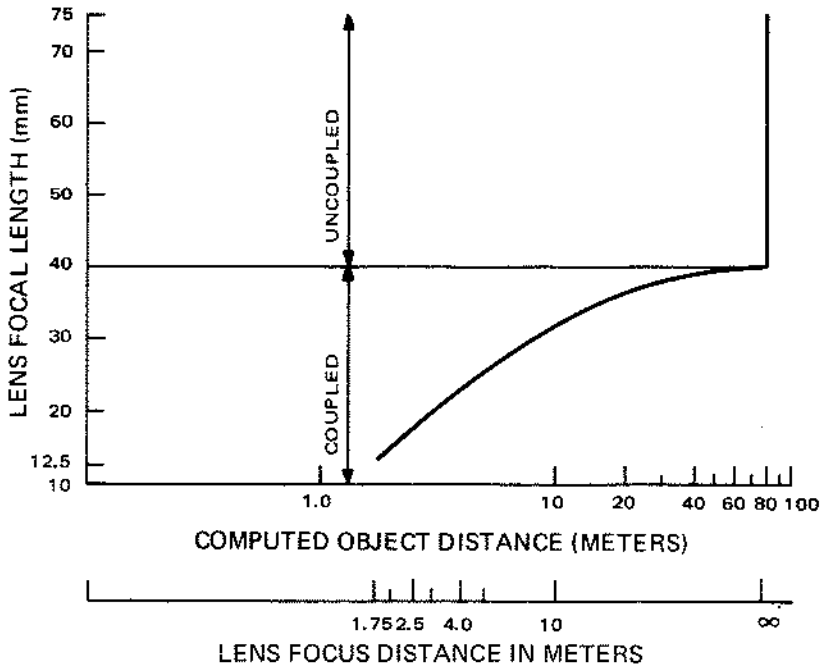


Figure 1-8. CTV Lens Zoom/Focus Coupling

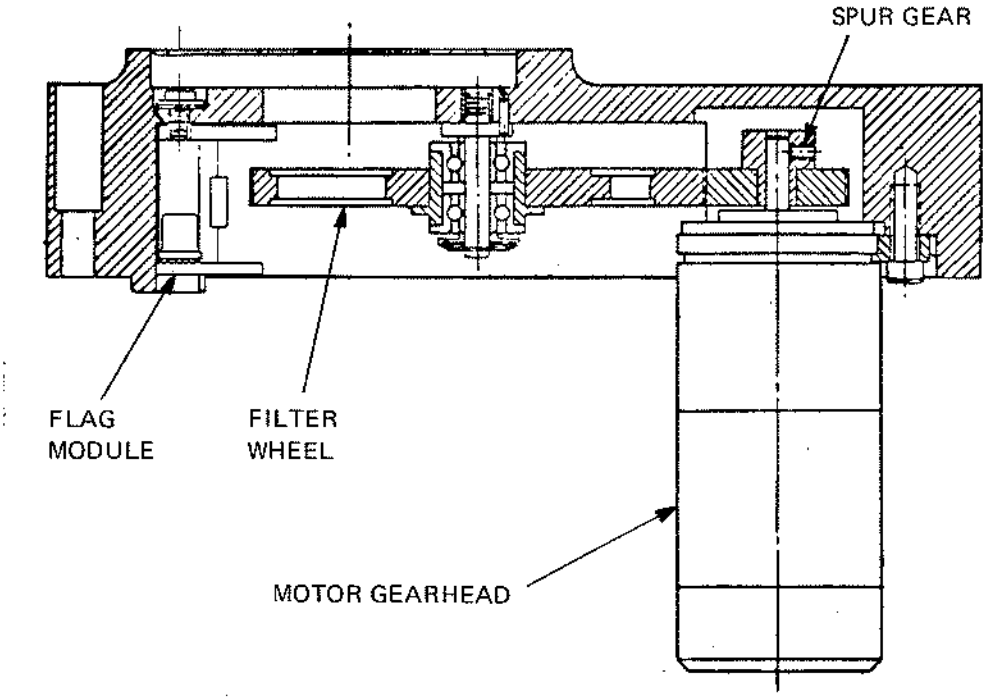


Figure 1-9. Configuration of Filter Wheel Drive Assembly

The design uses Schott absorption filters with interference coatings on one surface to form a narrow bandpass. Filter characteristics are illustrated in Figure 1-10. A luminance "trim" filter is included at the lens output to shape response in the red channel and to block spurious near-infrared energy from entering the blue and green channels. The neutral density filter segments are mounted in the wheel and balance the measured output through the red, blue and green channels to within 5 percent.

The filter wheel is driven by a synchronous motor and a gearhead assembly providing a 3.5:1 speed reduction. The output gear of the gearhead drives the filter wheel directly to provide a 3:1 reduction. The motor is an 8-pole, 2-phase hysteresis-synchronous type. Synchronous motor speed is 6300 rpm. The motor/gearhead is lubricated by a Ball Brothers Research Corporation process. The lubricant is a low vapor pressure synthetic oil designed specifically for extended operation in a vacuum. The lubricant is applied as a molecular film to the bearing balls and raceways. Lubricant migration is minimal, and a reservois is maintained in the phenolic retainer to replenish lubricant lost through outgassing.

The light sensor assembly (for wheel synchronization) is located in the gear housing and straddles the filter wheel. The sensor consists of a light-emitting diode and a photo-transistor sensor circuit. When one of the two holes in the rim of the color wheel transmits the light from the emitting diode to the silicon sensor, a rephasing pulse is generated. Rephasing pulses are generated at the beginning of a green field (when the color wheel is properly phased).

1.5.5 Sensor Assembly

The Sensor Assembly consists of the SIT sensor, a yoke/focus coil assembly, and an electrode divider assembly that filters the SIT control voltages. The assembly is secured in a magnesium sleeve to provide electrical shielding, a positive index for mounting, and thermal conduction to the camera baseplate. A sectional view of the Sensor Assembly is shown in Figure 1-11.

The 16-mm Silicon Intensifier Target (SIT) sensor is a ruggedized tube providing high sensitivity, broad spectral response, and a limiting resolution of 600 TV lines. The tube is capable of operation at light levels as low as 4×10^{-6} foot candle (illumination incident at faceplate). Good pictures can be secured, therefore, with scene highlights as low as 1 foot candle when using wheel filters and color-correction filters. Widerange automatic light control, (ALC) implemented by variation of image intensifier gain, permits the sensor to image the sun for short periods with no burn or damage. An internal optical filter is incorporated to prevent scene highlights from veiling desired images, thereby permitting high contrast scenes to be photographed.

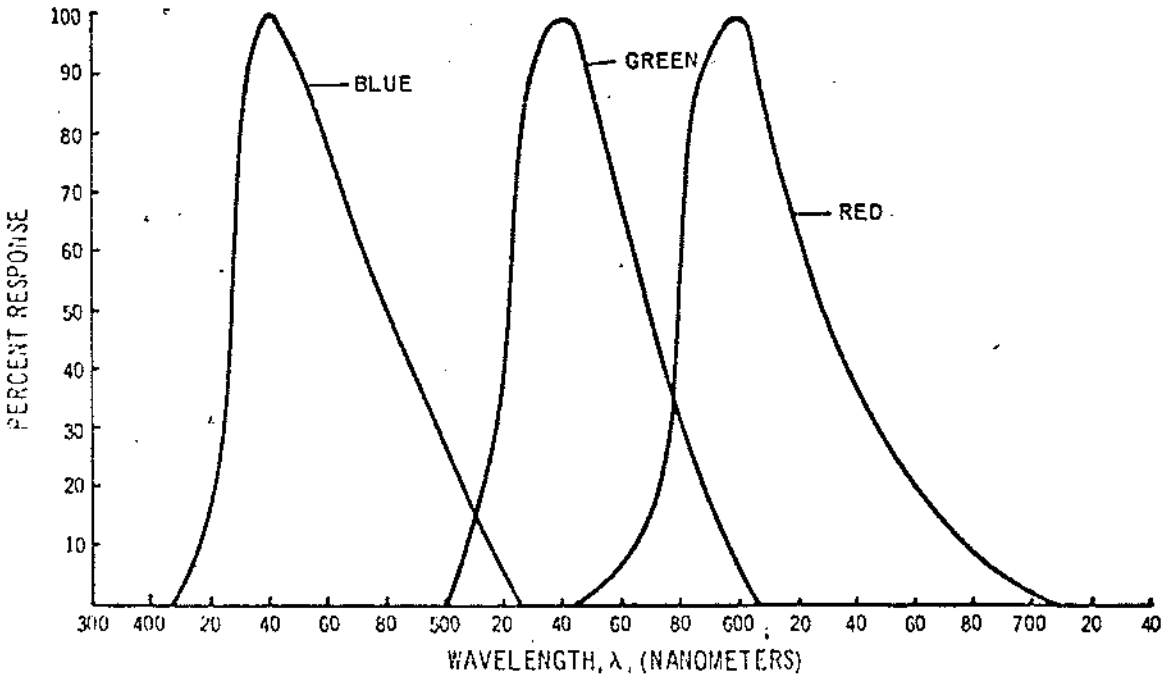


Figure 1-10. Normalized Spectral Response of Color Wheel Filters

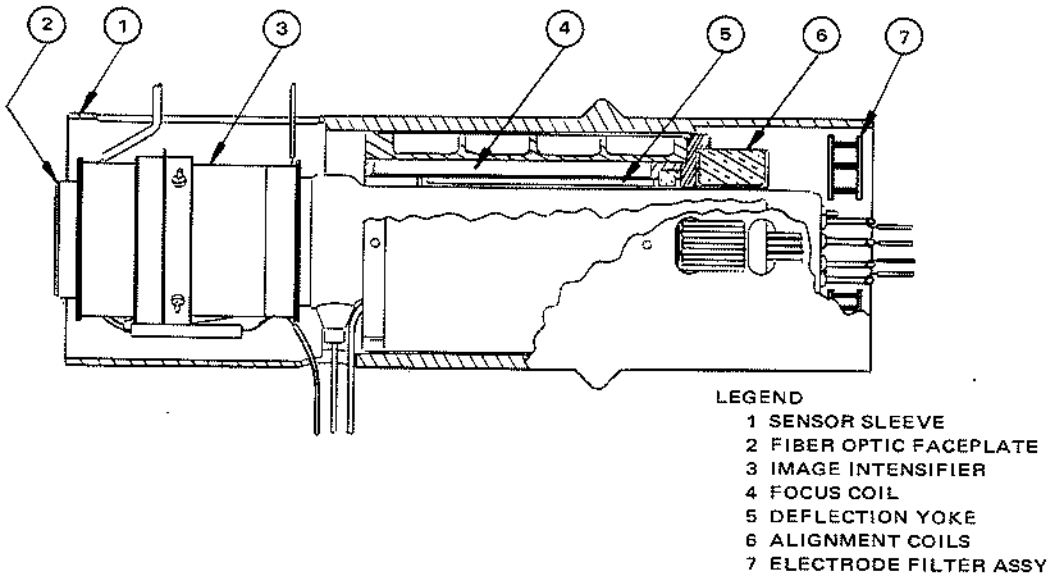


Figure 1-11. CTV Camera Sensor Assembly

The SIT Sensor diagrammed in Figure 1-12 uses a photocathode as the prime sensor and a silicon-diode-array target to produce gain by impact of photoelectrons. A scanning beam produces an output signal at the target. The silicon target can produce electron gains of 3000 or more. The target consists of a two-dimensional array of p-n junction diodes in an n-type single-crystal silicon wafer and is formed using planar silicon techniques. The p-region of each diode faces the electron scanning beam. An insulator covers the regions between the diodes to prevent the beam from reaching the n-type substrate. Due to the insulating properties of the reverse-biased p-n junction, the diodes act as elemental storage capacitors, and are biased by the low-velocity scanning beam.

Operation of the target is illustrated by Figure 1-13. Hole-electron pairs are produced when an energetic electron strikes the silicon target. The holes created in the valence band diffuse through the n-region, and pass through the depletion layer, which contributes to the discharge of the storage capacitance. The output signal is generated by the capacitive displacement current that flows during the recharge of each elemental capacitor by the scanning beam.

The yoke/focus coil assembly uses printed-circuit deflection windings to provide tight coupling to the tube's electron scanning beam and to allow high efficiency in the deflection circuits. The vertical and horizontal (saddle-type) windings are separated by a Faraday shield and are contained within a solenoid-wound focus coil. Orthogonal alignment coils mounted above the electron gun permit adjustments to the electron beam trajectory and optimization of sensor performance.

The electrode divider assembly mounted in the rear of the sensor sleeve contains filters for the electrode voltages of the SIT sensor. The divider assembly also contains components that adjust the G3 electrode (gun focusing grid) for optimum signal uniformity on each camera. Performance characteristics of the CTV SIT assembly are given in Table 1-4.

1.5.6 Video and ALC/AGC Circuits

The video circuits accept the input from the SIT tube and perform the functions required to process the input into a composite video in the format required at the camera output. To accomplish these functions, a number of circuit refinements have been developed and incorporated in the present design. Included are (1) an aperture corrector that contains a "coring" circuit to slice out excess noise in the low-amplitude areas of the video signal, and (2) a gamma corrector to modify the overall gamma of the sensor/video amplifier chain to approximately 0.7. Both these circuits improve the apparent quality of the output video signal.

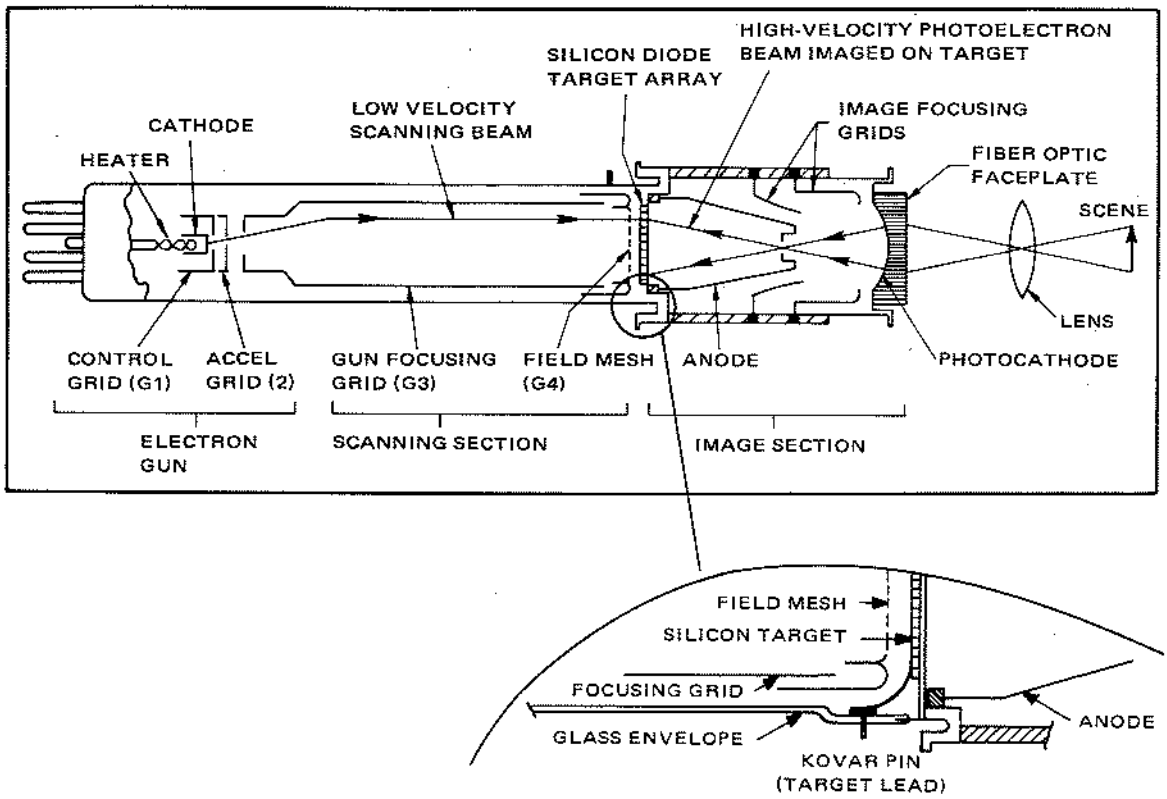


Figure 1-12. Sectional View of the SIT Sensor

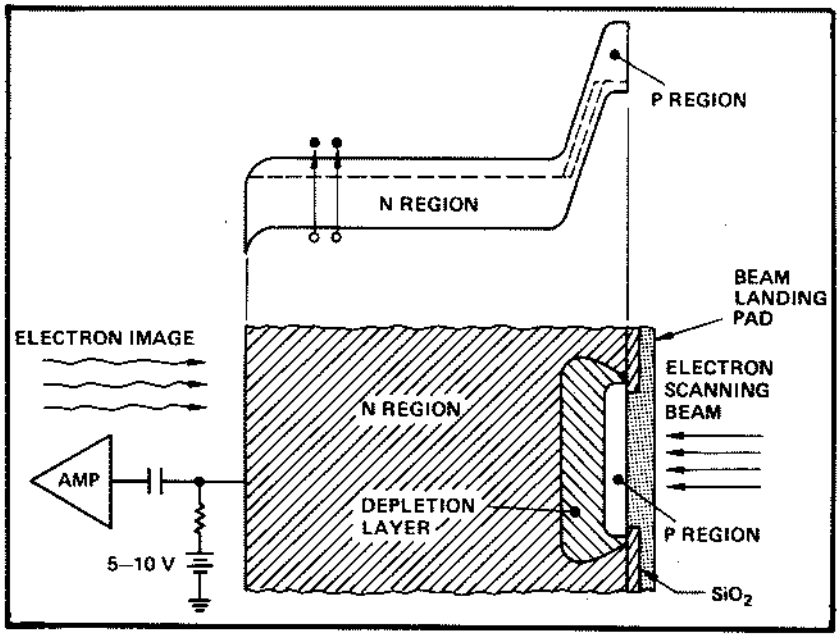


Figure 1-13. Operation of the SIT Sensor Target

TABLE 1-4. SIT PERFORMANCE CHARACTERISTICS

Parameter	Value
• Spectral Response	S-20
• Resolution	Minimum 40% @200 TVL
• Signal Current	Typical 400 nA
• Dark Current	Maximum 15 nA @30°C
• Sensitivity & Dynamic Range Typical	1 to 10,000 foot-lambert Scene
• Gamma	1.0
• Scene Dynamic Range	32/1 Minimum
• Shading	Maximum 20%
• Operating Temperature	(-10°C to +50°C)
• Life	Minimum 500 Hours

A block diagram of the video circuits is shown in Figure 1-14. As shown, the signal from the SIT target is amplified in a low-noise preamplifier, using a field-effect transistor (FET) as the input stage. The preamplifier receives the high-impedance output from the tube target and provides a low-impedance to the video amplifier. The signal level at the preamplifier output is 60 millivolts (nominal) for peak scene highlights. To minimize coherent noise pickup, the preamplifier is housed in a shielded box located adjacent to the SIT target.

The preamplifier delivers two outputs: a signal to the ALC control loop and an output to a video amplifier.

The ALC function in the camera is accomplished by a closed-loop feedback from the preamplifier output to the image intensifier section of the SIT sensor. The loop, consisting of the SIT sensor, pre-amplifier, ALC video amplifier, ALC detector, and the high-voltage power supply, maintains a constant video output over an extremely wide range of scene illumination.

The signal output of the preamplifier is fed to a fixed-gain ALC video amplifier. The ALC amplifier output is clamped to provide the dc reference voltage, then detected to generate a dc control signal. The mode of detection can be switched between peak and average levels of illumination. The dc ALC control signal is amplified and used to program the high-voltage power supply. The high-voltage output then is applied to the photocathode of the SIT sensor.

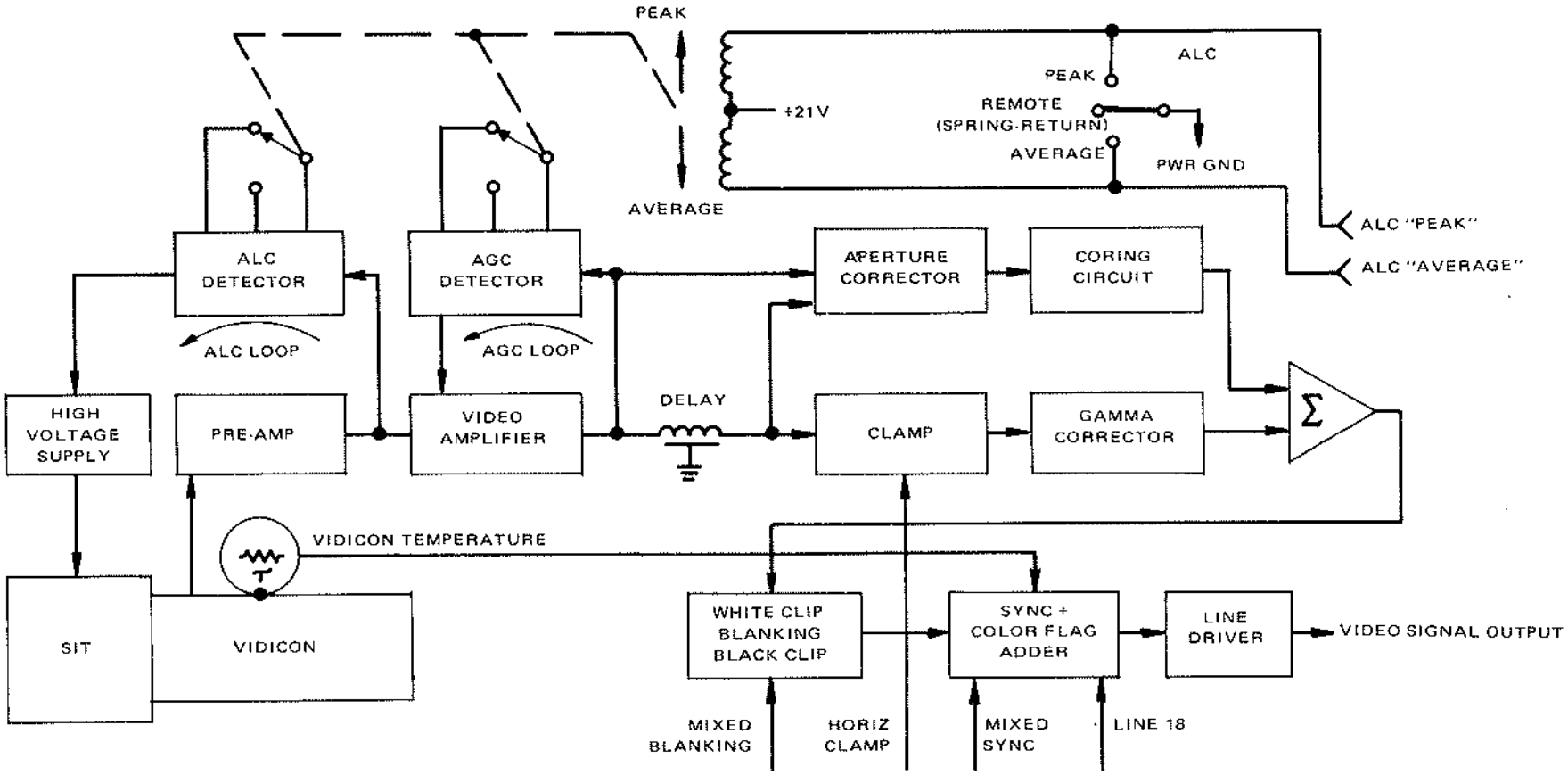


Figure 1-14. Video Circuits, Block Diagram

As the high-voltage to the photocathode varies, the photoelectron energy is changed and the gain of the image section of the SIT varies. With the ALC feedback loop closed, the system maintains a fixed output at the preamplifier output. The loop response time is designed to prevent color contamination by field-to-field gain changes.

The video amplifier also contains the feedback AGC loop; AGC action is accomplished by detecting the output of the video amplifier and applying the detected video as a control signal to a FET stage at the input of the video amplifier. The detection mode of the AGC circuit is switched from peak to average by a relay actuated by an external toggle switch, or by command control signals from the TCU.

The output of the video amplifier is clamped to restore the dc component of the signal, and is routed to the gamma corrector. The gamma corrector uses an integrated circuit transistor array that provides a line-segment approximation to the 0.7 gamma transfer function.

Gamma correction modifies the dynamic range of the camera from a linear transfer function (where the voltage output is proportional to the light input) to a transfer function where:

$$V_{out} \propto (B_{in})^{\gamma}$$

Numerically, gamma is the exponent of the power function produced by the correction circuit.

Gamma correction is used in the CTV to provide the following improvements in overall GCTA system performance:

- Definition of shadowed areas in a scene is increased. This is an advantage when operating the camera in the ALC/AGC "Peak" mode to view high-contrast lunar scenes.
- Picture "appearance" is improved in the presence of noise expected in the overall system communications network.
- Color hue tracking over the system dynamic range is more accurate.

Figure 1-15 is a log-log plot of the gamma correction circuit transfer function and shows both the idealized and actual transfer characteristics. The inset shows an oscilloscope trace of the 0.7 gamma function (curved) and a linear circuit (straight line). The gamma corrector circuitry generates three line segments to produce the proper curve. In the black region, gamma gain is 2.0 (minimum). At white level, gain is 0.7 (nominal).

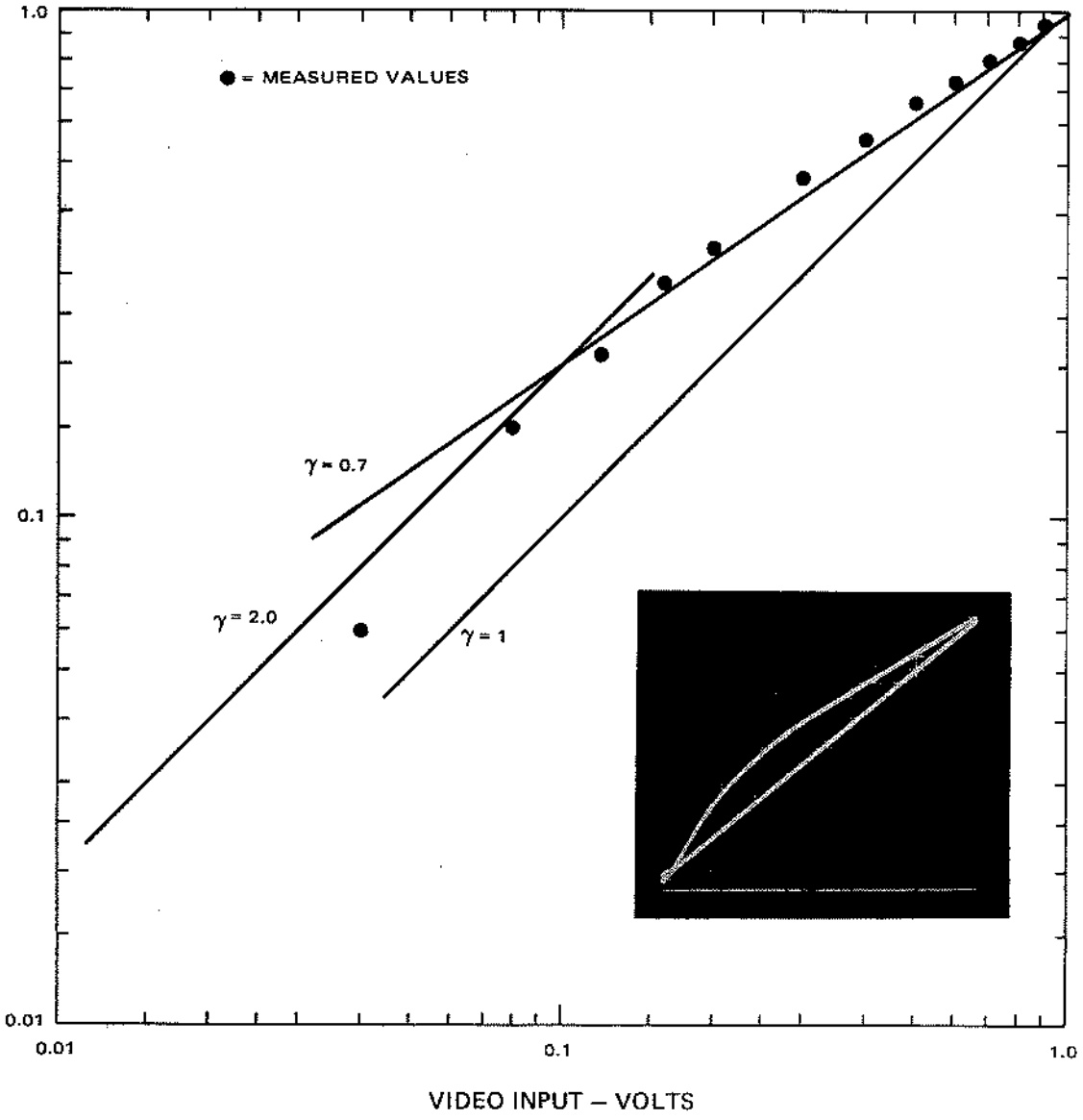


Figure 1-15. Gamma Correction Circuit Transfer Function

The aperture corrector (see Figure 1-14) is a differential amplifier that uses the difference signal appearing across a delay line to separate the high-frequency component of the video signal. The high-frequency components then are amplified and sent through a "coring" threshold circuit that clips low amplitude elements (noise) from the signal. Figure 1-16 diagrams the coring function that permits the high-resolution response of the SIT to be increased without increasing noise in most scene areas. After coring is accomplished, the aperture-correction signal is summed with the gamma-corrected signal at the input of the white clipper.

The white clipper removes signals and transients exceeding the specified peak-white video level. Insertion of blanking and black clipping on the video signal front porch are accomplished in the following stage.

Sync insertion is performed with an FET switch. A parallel FET switch inserts the color-flag pulse into the composite video format during line 18. The width of the pulse is modulated to provide temperature telemetry of the SIT sensor assembly. The composite video signal then is routed to a line driver with a current source output to deliver a 0 to 1 volt video signal of proper format into a 75-ohm load.

1.5.7 Sync Generator

The sync generator consists of a master oscillator and related counting and decoding circuits. The master oscillator supplies an output clock frequency of 1,006,992 + Hz. The highly stable output provides the required stability and tolerance for all sync, blanking, and internal camera timing pulses. The logic functions within the generator are implemented with high-speed, low-power, TTL integrated-circuit logic. The counting and decoding functions are accomplished synchronously.

A block diagram of the sync generator is shown in Figure 1-17. The generator supplies rate signals for vertical and horizontal deflection generation, for SIT blanking, for dc restoration in the video amplifier, and for insertion of mixed sync and blanking pulses in the composite output video signal. The generator also provides timing pulses to synchronize the dc/dc converter at one-half the line rate, and provides a split-phase drive signal to operate the synchronously-driven color-wheel motor.

The proper phase relationship between the color-wheel and the scanning beam after power application is established and maintained by the sync generator. The coherence of the horizontal and vertical synchronizing pulses remain undisturbed and independent of the color-wheel scanning beam synchronizing operation. During each one-half revolution of the color-wheel, a flag pulse is

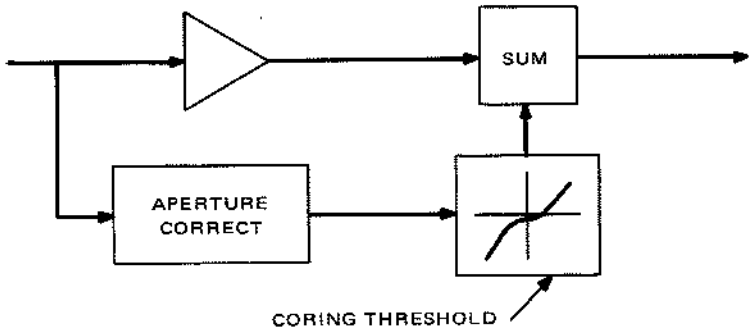


Figure 1-16. Diagram of "Coring" Function

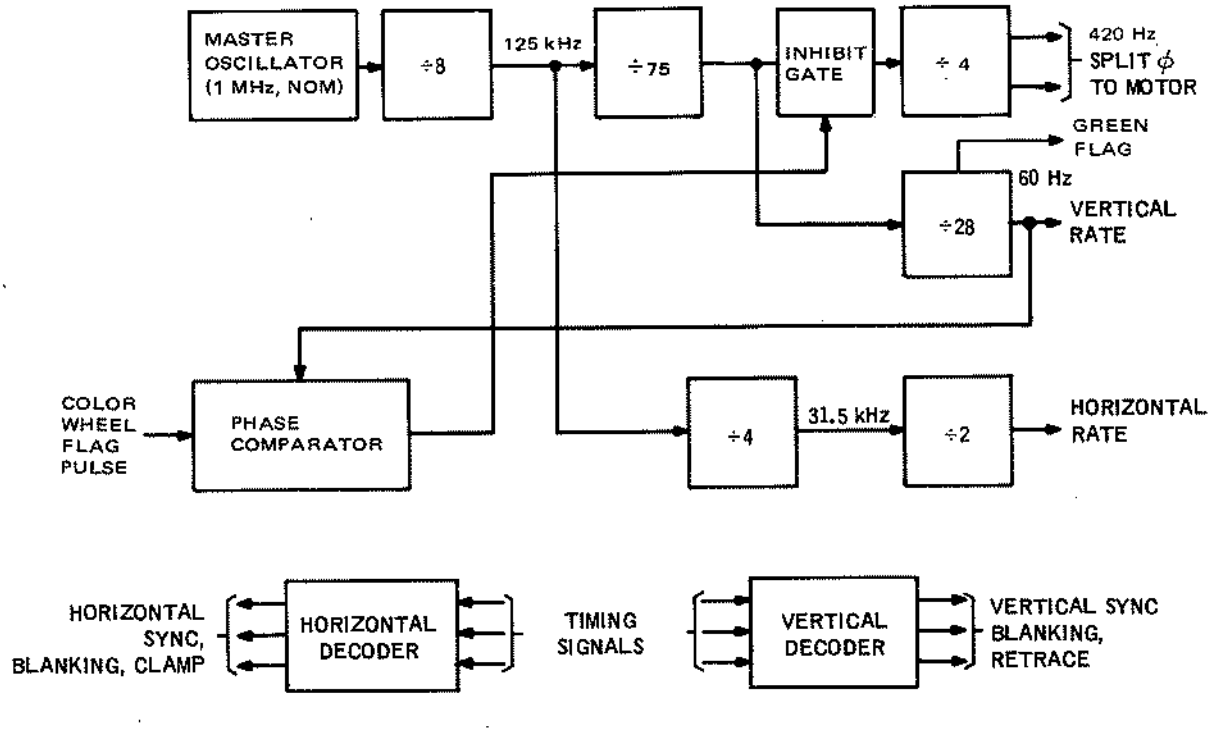


Figure 1-17. Sync Generator Simplified Block Diagram

generated by an optical pickup. This color-wheel flag pulse is routed to a phase comparator that compares the timing of the flag pulse with the vertical sync pulse. If the flag pulse and the vertical sync pulse are not properly phased, an inhibit gate causes the 420-Hz split-phase counter to drop one count. One 420-Hz cycle then terminates 90 degrees later than normal, causing the motor to change phase by 90 electrical degrees.

One count is dropped for each flag pulse that is not in proper phase with the vertical sync. Since this occurs twice during each revolution of the color-wheel, the motor speed is decreased (although still running synchronously) until the flag pulses and vertical sync pulses are properly phased with each other. At this time, the inhibit gate allows the split-phase counter to count normally, the motor rotates the color-wheel at the proper speed, and the "dead zones" between segments of the color-wheel track the scanning beam. During the period when the above phase relationship is being established between the color-wheel and vertical sync, the horizontal and vertical synchronizing pulses are transmitted uninterrupted and without timing errors.

The sync generator also initiates the color-flag pulse applied during line 18 of each green field. This pulse, processed in the video amplifier for addition to composite video output, can be used at the receiving site to provide automatic phasing of scan conversion equipment.

Signals required by the TCU also are generated by the CTV sync generator. A line 17 tag is generated to initiate insertion of a test signal into the composite video output. A 60-Hz vertical rate signal is provided for the stepping motor drivers. The CTV horizontal rate also is provided as sync information for the TCU dc/dc converter.

1.5.8 Deflection Generators

The horizontal and vertical deflection generators are driven by signals from the sync generator. Each deflection circuit consists of a precision ramp generator and a high-efficiency output stage. The output stages drive the deflection yoke windings. The circuits use dual-transistor differential amplifiers to provide stable raster size and centering. The horizontal output stage employs an energy-recovery system to boost horizontal and vertical deflection circuit voltages and thereby minimize total power requirements. Except for this feature, the horizontal and vertical deflection circuits are basically the same.

1.5.9 Color-Wheel Drive Circuits

The color-wheel drive motor is powered by the motor drive electronics. The motor is 6300-rpm, Size 11, two-phase, synchronous-hysteresis unit. The motor has a "start-to-run" power-switching capability and operates through a speed-reducing gear train. Each of the phase windings in the motor is center-tapped to permit the change of motor power inputs from "start" to "run" levels. A relay is used to switch the motor windings from start mode to run mode after synchronous speed is reached. Total motor and motor electronics power requirements are 1.8 watts (nominal) in the run mode.

The motor inverter drive electronics illustrated in Figure 1-18 consists of a two-phase, switching transistor bridge. Each bridge is driven by a squarewave voltage input derived from the sync generator, which also supplies the required 90-degree phase shift between the two drive signals. Saturated switching operation permits high-efficiency operation and minimum dc power drain.

The rotational sync required between the color-wheel and the sync generator is achieved by controlling the timing signal inputs from the sync generator to the motor drive circuits. The technique used is described in Paragraph 1.5.8.

1.5.10 Power Supplies

The CTV camera contains a high-voltage power supply for potentials required by the image-intensifier section of the SIT sensor, and a low-voltage supply for all other internal operating voltages required in the camera. Figure 1-19 illustrates the low-voltage supply.

The low-voltage supply converts the unregulated input bus voltage (+24 to +33 Vdc) into seven regulated output voltages:

- +21.5 Vdc
- +400 Vdc
- +300 Vdc
- -100 Vdc
- +6.3 Vdc
- +5.0 Vdc
- -6.3 Vdc

The supply contains an input filter, a pre-regulator, a dc/dc converter, rectifiers and filters and output series-pass regulators for the ± 6.3 Vdc and +5.0 Vdc outputs.

The L-C input filter at the pre-regulator input is used to minimize ripple current reflected back to the input bus. Power ON/OFF control is provided at the pre-regulator input by the CTV power switch when in the LM modes of operation, and by power switching in the TCU when operating from the LCRU. The pre-regulator supplies power to the color-wheel motor drive circuitry as well as the dc/dc converter.

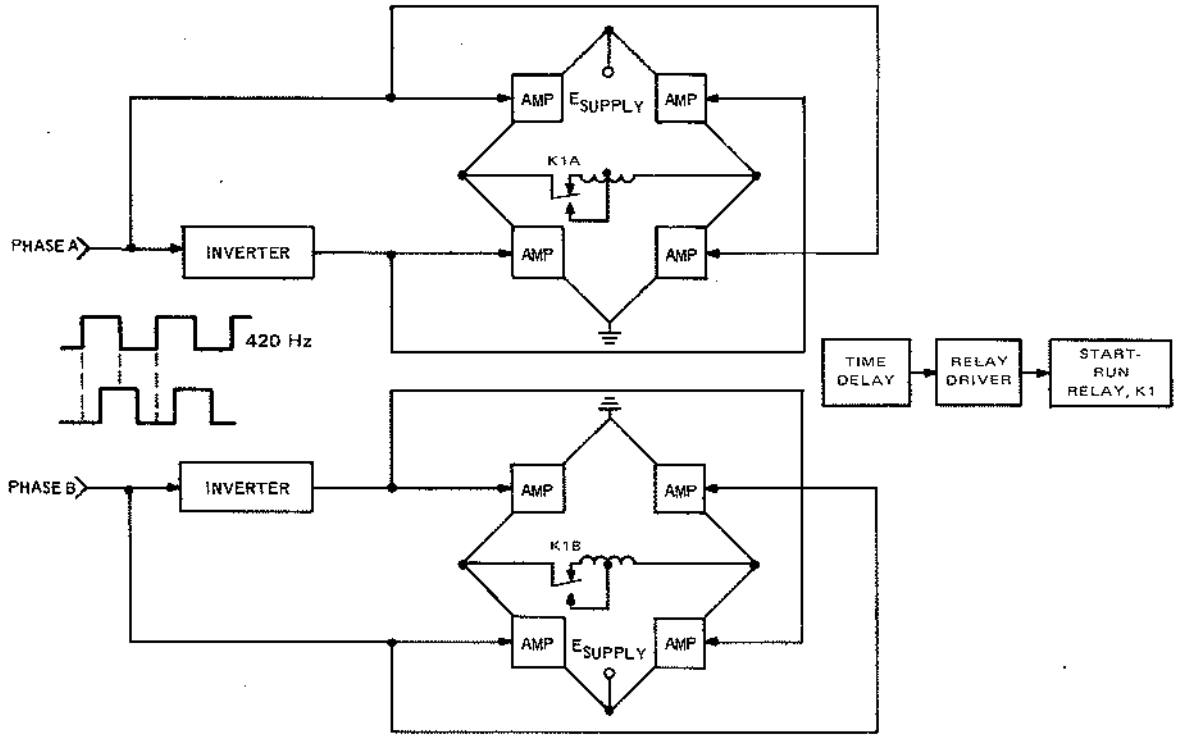


Figure 1-18. Motor Drive Circuit Block Diagram

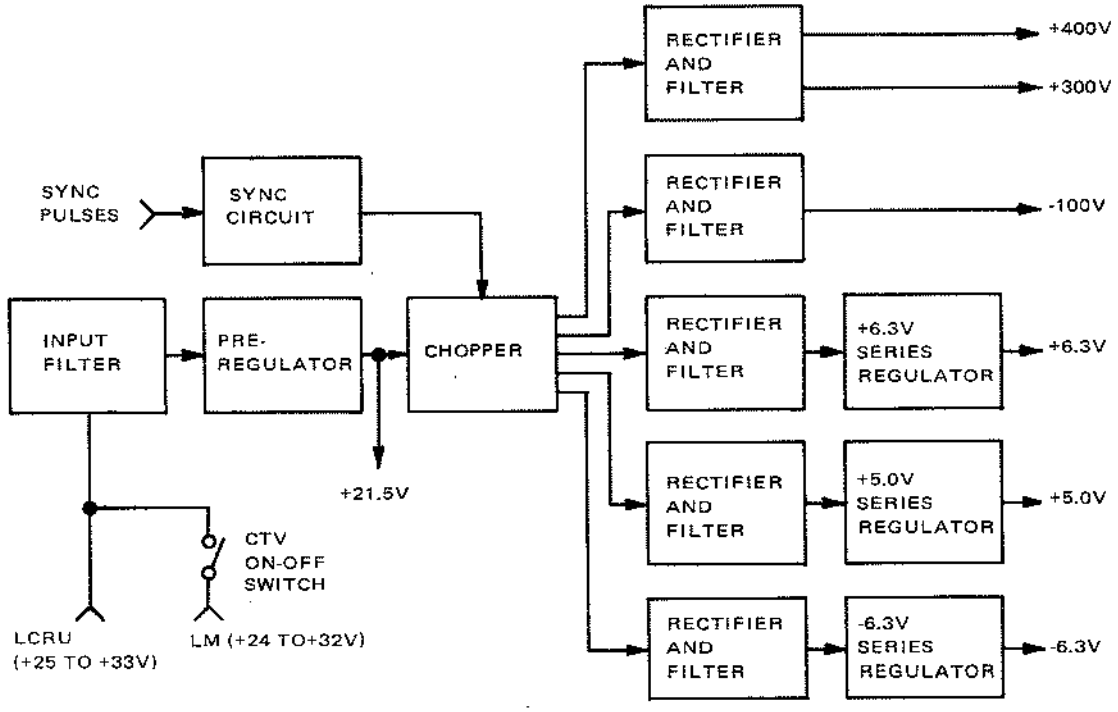


Figure 1-19. Low-Voltage Power Supply Block Diagram

The master oscillator and counter chain of the sync generator circuitry is used to synchronize the operating frequency of the dc/dc converter to the horizontal scan rate. Switching transients generated in the dc/dc converter, therefore, are not present in the video output signal. The converter synchronizes at one-half the horizontal rate (7875 Hz) and the switching transients are blanked out by insertion of horizontal blanking in the video. All other regulator circuits operate from the output side of the converter and are referenced to the video return.

The high-voltage (HV) supply module (1A7) is housed in a fully-shielded container and is mounted directly below the SIT tube adjacent to the image intensifier HV connection. This supply is programmed by the ALC control signal to deliver an output of 3 to 9 kilovolts to change the gain (and sensitivity) of the SIT. The container houses a high-frequency oscillator (50 kHz) and the voltage multiplier assembly. Access to the supply is possible by removing the handle assembly from the base of the CTV.

Current regulators are included in the camera to stabliize critical parameters of the SIT sensor. To maintain uniform picture quality, SIT beam-current is controlled by sampling the cathode current and automatically adjusting the G1 electrode voltage to maintain a constant current. This assures SIT performance unaffected by cathode-aging and provides for rapid performance stabilization when camera power is turned ON. The focus and alignment coils each are provided with constant current supplies to maintain correct electron optics in the SIT sensor over the specified range of thermal environments.

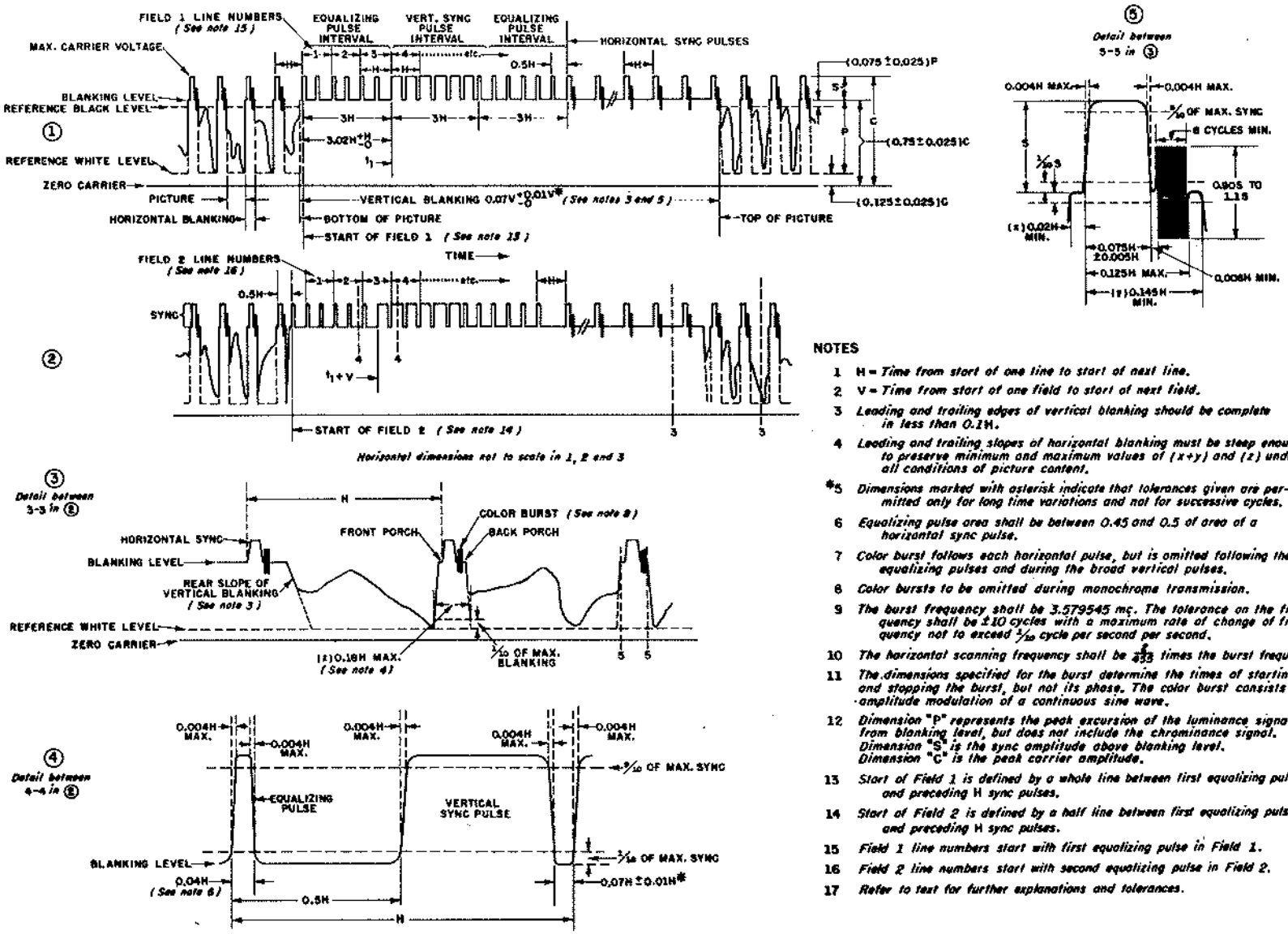
1.5.11 Video Output Format

1.5.11.1 Scan Format

The CTV camera scan format is in accordance with Figure 1-20, taken from section 73 of the Federal Communications Commission Specification for Color Television Operation, with the following differences:

- Color reference burst and subcarrier are omitted,
- Video information is provided by sequential fields in a red-blue-green sequence,
- Equal amplitude field outputs are provided for a color temperature of 6000°K, and
- Scan rate tolerances are ±100 parts per million.

These rates are summarized in Table 1-5.



NOTES

1. H = *Time from start of one line to start of next line.*
2. V = *Time from start of one field to start of next field.*
3. *Leading and trailing edges of vertical blanking should be complete in less than 0.1H.*
4. *Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x+y) and (z) under all conditions of picture content.*
5. *Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.*
6. *Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse.*
7. *Color burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.*
8. *Color bursts to be omitted during monochrome transmission.*
9. *The burst frequency shall be 3.579545 mc. The tolerance on the frequency shall be ±10 cycles with a maximum rate of change of frequency not to exceed 1/10 cycle per second per second.*
10. *The horizontal scanning frequency shall be $\frac{4}{455}$ times the burst frequency.*
11. *The dimensions specified for the burst determine the times of starting and stopping the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.*
12. *Dimension "P" represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension "S" is the sync amplitude above blanking level. Dimension "C" is the peak carrier amplitude.*
13. *Start of Field 1 is defined by a whole line between first equalizing pulse and preceding H sync pulses.*
14. *Start of Field 2 is defined by a half line between first equalizing pulse and preceding H sync pulses.*
15. *Field 1 line numbers start with first equalizing pulse in Field 1.*
16. *Field 2 line numbers start with second equalizing pulse in Field 2.*
17. *Refer to text for further explanations and tolerances.*

Figure 1-20. FCC Television Synchronizing Waveform (Color)

TABLE 1-5. CTV SCAN RATES AND TOLERANCES

Parameter	Standard
Number of lines per frame	525
Number of fields per second	59.94+
Number of lines per second	15,734.26+
Number of frames per second	29.97+
Tolerance on number of lines/sec	±100 parts per million
Interlace Ratio	2:1
Vertical Blanking	18.4 lines (min), 21.0 lines (max) (0.07 V to 0.08 V)
Horizontal Blanking	0.165 H (min), 0.180 H (max)

1.5.11.2 Video Format

The composite output from the CTV is a 0 to 1 volt signal when terminated in a 75-ohm load. Signal characteristics, when properly terminated, are shown in Table 1-6.

In addition to the standard video information, two special signals are included in the composite video signal. The first is the color flag generated within the CTV. The second is a test signal added to the composite video by the TCU and present only during operation of the complete GCTA configuration with the LCRU.

1.5.11.3 Color Flag

The color flag signal is inserted in the vertical blanking interval of line 18 during every third field in sync with the start of the green video field. The flag pulse is modulated to provide telemetry of the CTV temperature near the faceplate of the SIT tube. The pulse amplitude is nominally 0.8 V above the sync tip, and may be used to provide automatic color phasing of the ground station color scan converter. Figure 1-21 shows the format of the color flag pulse and Figure 1-22 illustrates the typical temperature versus pulse width transfer characteristic.

TABLE 1-6. CTV VIDEO SIGNAL PARAMETERS

Parameter	Specification
Sync Tip	0±0.1 V
Blanking	0.280 V±50 MV
Green Field Output	1.0 V±50 MV
Video Clip Level	1.05 V max
Intra-Scene Dynamic Range	32:1 (Ten $\sqrt{2}$ gray steps) min
Signal-to-Noise (Random)	35 dB (p-p/rms) for a 500:1 light range, measured in a 2.0-MHz bandwidth.
Signal-to-Noise (Coherent)	40 dB (p-p/rms) within 2.0-MHz bandwidth.
Resolution (Amplitude Response)	Relative to response @25 TV lines; 90% min @100 TV lines (1.25 MHz) 80% min @200 TV lines (2.5 MHz)

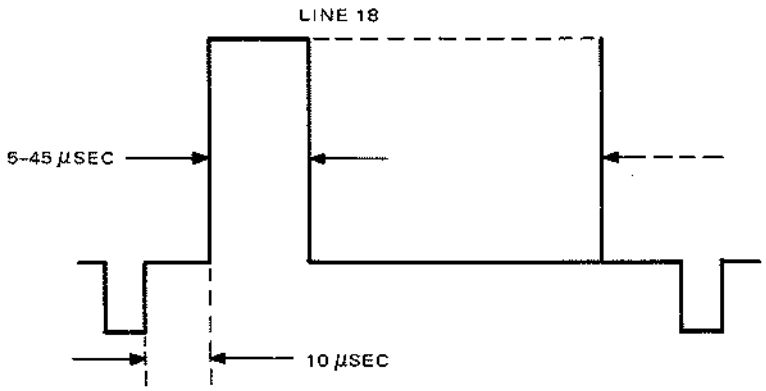


Figure 1-21. Color Flag Temperature Telemetry

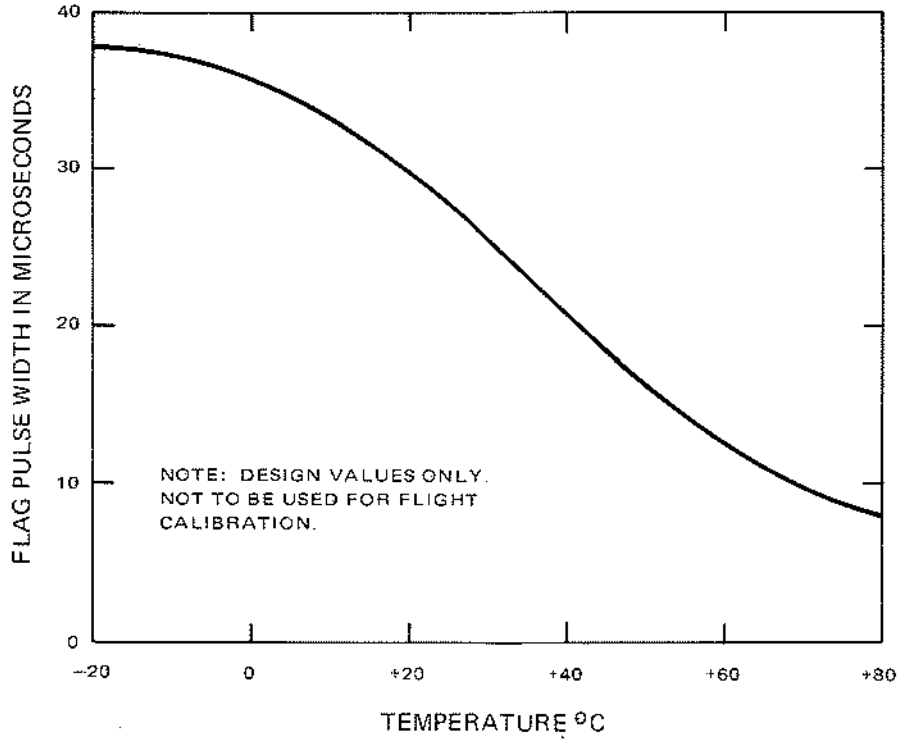


Figure 1-22. Flag Pulse Width Transfer Characteristic

1.5.11.4 Test Signal

The test signal is generated within the TCU, and inserted in line 17 of each field during operation of the complete GCTA configuration. Test signal format is illustrated in Figure 1-23. As shown, the signal contains (1) a fast-rise leading edge to determine system bandwidth and transient performance, (2) a peak-white reference level for gain adjustment and measurement, and a controlled ramp for checking system linearity. A small step also is provided at the end of the peak-white signal level and prior to the ramp to verify that the white signal has not been compressed. The step also permits oscilloscope triggering at the start of the negative-going ramp.

The rise time of the signal (T_r) has been chosen to be consistent with the bandwidth requirements of the CTV video signal at 200 line transmission. The corresponding cutoff frequency (F_c) with a linear phase-type filter is:

$$F_c = \frac{0.35}{T_r} = \frac{0.35}{0.14\ (10^{-6})} = 2.5\ \text{MHz}$$

The block diagram in Figure 1-24 shows the method by which the test signal is generated. A timing signal from the CTV sync generator (line 17 tag) identifies

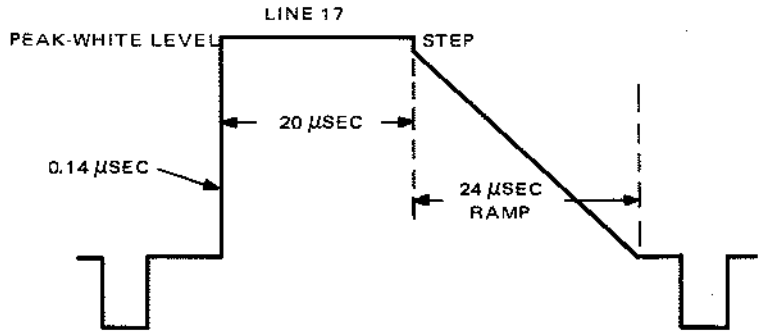


Figure 1-23. Test Signal Format

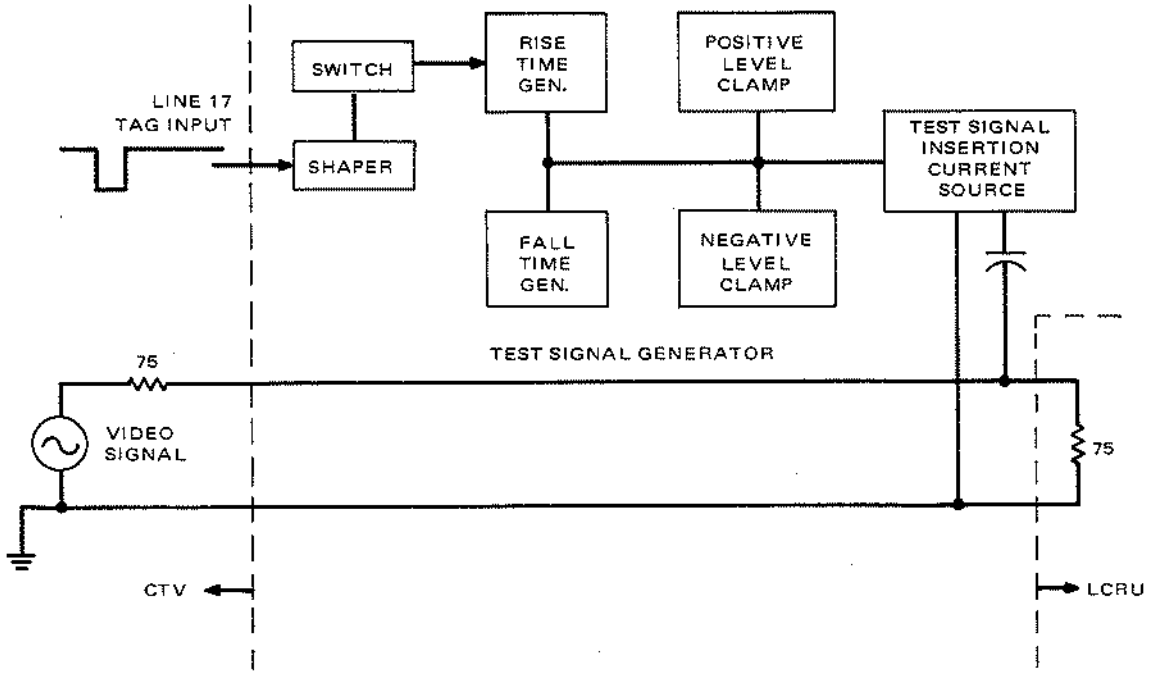


Figure 1-24. Test Signal Generator Block Diagram

the start of each test signal. The test signal generator acts as a controlled-current source and is ac-coupled to the paralleled CTV source and LCRU terminating impedance. The generator floats on the video line, except during insertion of a test pulse. The TCU power supply provides the test signal generator with an isolated power supply. This allows connection of the test signal generator across the terminated video signal cable without producing coupling between power and video signal grounds.

1.6 TCU DESCRIPTION

The Television Control Unit (TCU) permits ground-commanded operation of the CTV. A 70-kHz modulated subcarrier signal is sent to the TCU from the LCUR, and the TCU decodes this signal and executes valid real-time commands. The TCU cradle, mechanically driven in azimuth and elevation, holds the CTV for remote pointing in response to ground commands. The TCU electronics provide control signals to operate the zoom, iris, and ALC functions of the camera, and provides CTV power ON/OFF control in response to ground command or manual switch operation. Commands to the LCRU for ON/OFF control of the FM transmitter and ON/OFF control of the 1.25-MHz voice subcarrier also are generated in the TCU. After adding a vertical interval test signal on line 17 of each field, the TCU routes the CTV composite video output signal to the LCRU. A functional block diagram of the TCU is shown in Figure 1-25.

1.6.1 Mechanical Configuration

The mechanical configuration of the TCU is illustrated by Figure 1-26. The camera is mounted to a plate in the TCU yoke support that may be tilted up 85° or down 45° from horizontal. The shaft supporting the yoke can be rotated 134° left and 214° right from the forward-pointing position. The lower housing of the TCU contains the azimuth drive motor and bearings as well as the electronic circuit boards. The printed circuit boards are mounted vertically in the lower housing. The lower housing, yoke support, shaft and camera mounting plate are fabricated from ZK60A high-strength magnesium to minimize weight. Slip clutches at the output drive gears are used to provide manual override in the TCU azimuth and elevation drives. Positive mechanical stops are provided at the end-of-travel for each drive to limit motion. Electrical limit switches also are provided to signal the end-of-travel in each direction.

The elevation tilt motion of the camera is accomplished by a spiroid gear segment attached to the CTV mounting plate that engages a pinion driven directly by the motor/gear head. The tilt-motion rate is 3.12° per second. The azimuth (pan) drive is accomplished with a motor/gear head that drives the elevation support shaft through a spur gear set. Panning rate is 3.03° per second.

1.6.2 Real-Time Command Format

The uplink command signal from the LCRU to the TCU is a 70-kHz subcarrier frequency modulated by a composite command signal. The composite command signal consists of the linear sum of a 2-kHz message subcarrier and a 1-kHz coherent synchronization tone. The message subcarrier and the synchronization tone have equal carrier frequency deviation. Total peak deviation is ±5-kHz.

Digital command information is carried by the 2-kHz message subcarrier and is phase-shift keyed (PSK) at a rate exactly one-half the rate of the subcarrier frequency. The message subcarrier is modulated by a train of binary "ones" and "zeros" (referred to as sub-bits) at a rate of 1000 per second. The train is in two-level, non-return-to-zero (NRZ) binary code.

A sub-bit "1" is present when the 1-kHz synchronization tone and the 2-kHz PSK tone are in phase at the start of a sub-bit interval. When the 2 kHz tone is 180 degrees out of phase with the 1-kHz tone at the start of the sub-bit interval, a sub-bit "0" is present. Figure 1-27 illustrates these phase relationships.

For decoding purposes, certain patterns of message sub-bits are identified as "info-bits." An information bit (info-bit) consists of five sub-bits. The code for an info-bit "zero" is the "ones" complement of the info-bit "one". Two different info-bit codes are used: one for the vehicle address, and a second for the remaining portion of the message (system address and data word).

The real-time command message structure consists of three vehicle address info-bits (using vehicle address sub-bit codes) followed by three system address info-bits and six data info-bits (using system/data sub-bit codes). The sequence is as follows:

Vehicle Address			System Address			Function Code					
1	2	3	4	5	6	7	8	9	10	11	12

The vehicle address (information bits 1, 2 and 3) is fixed as binary 0, 1, 1 (Octal 3). The system address (information bits 4, 5, and 6) is fixed as binary 0, 1, 0 (Octal 2).

The codes for all GCTA command functions are given in Table 1-7.

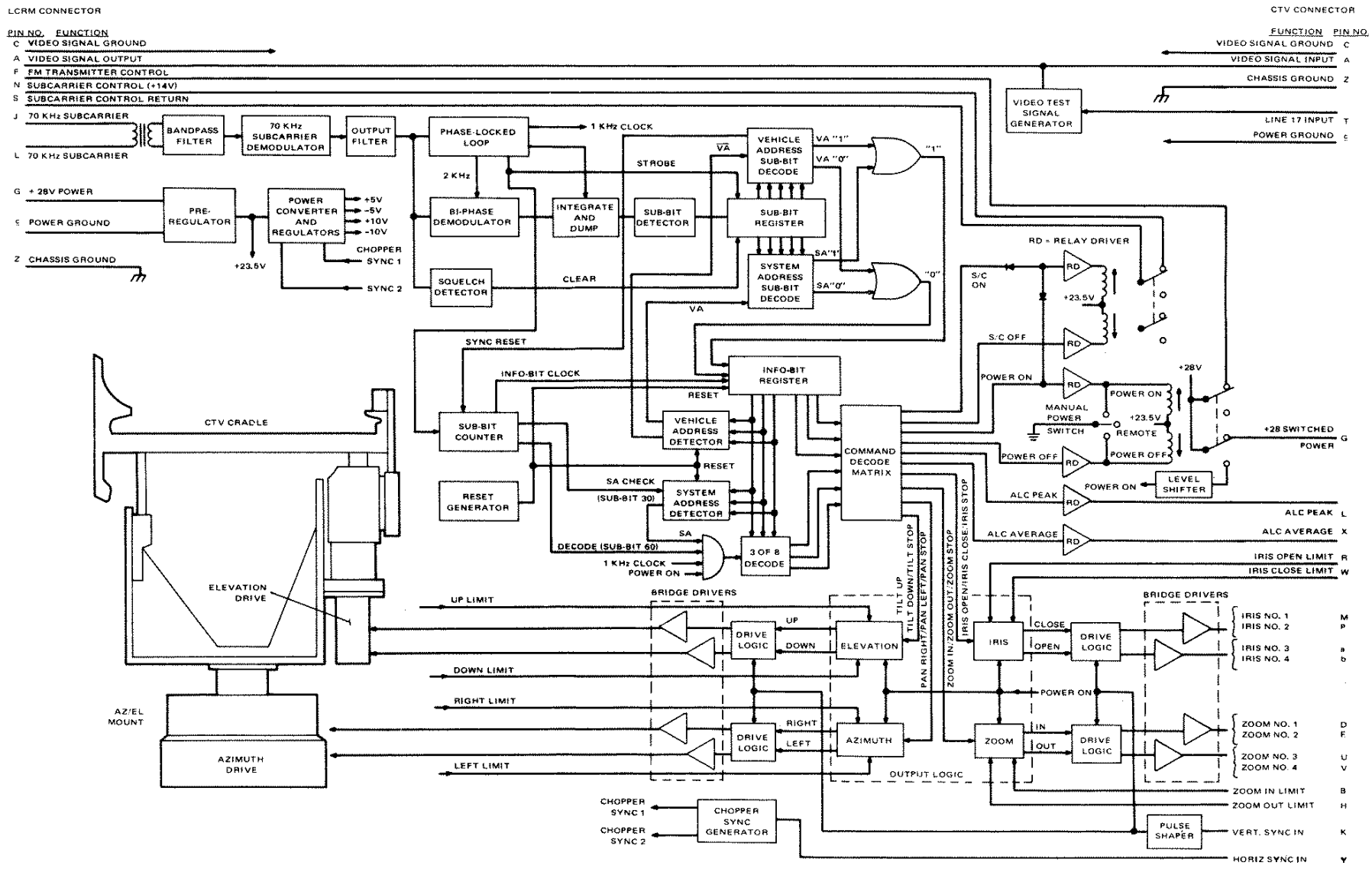


Figure 1-25. TCU Functional Block Diagram

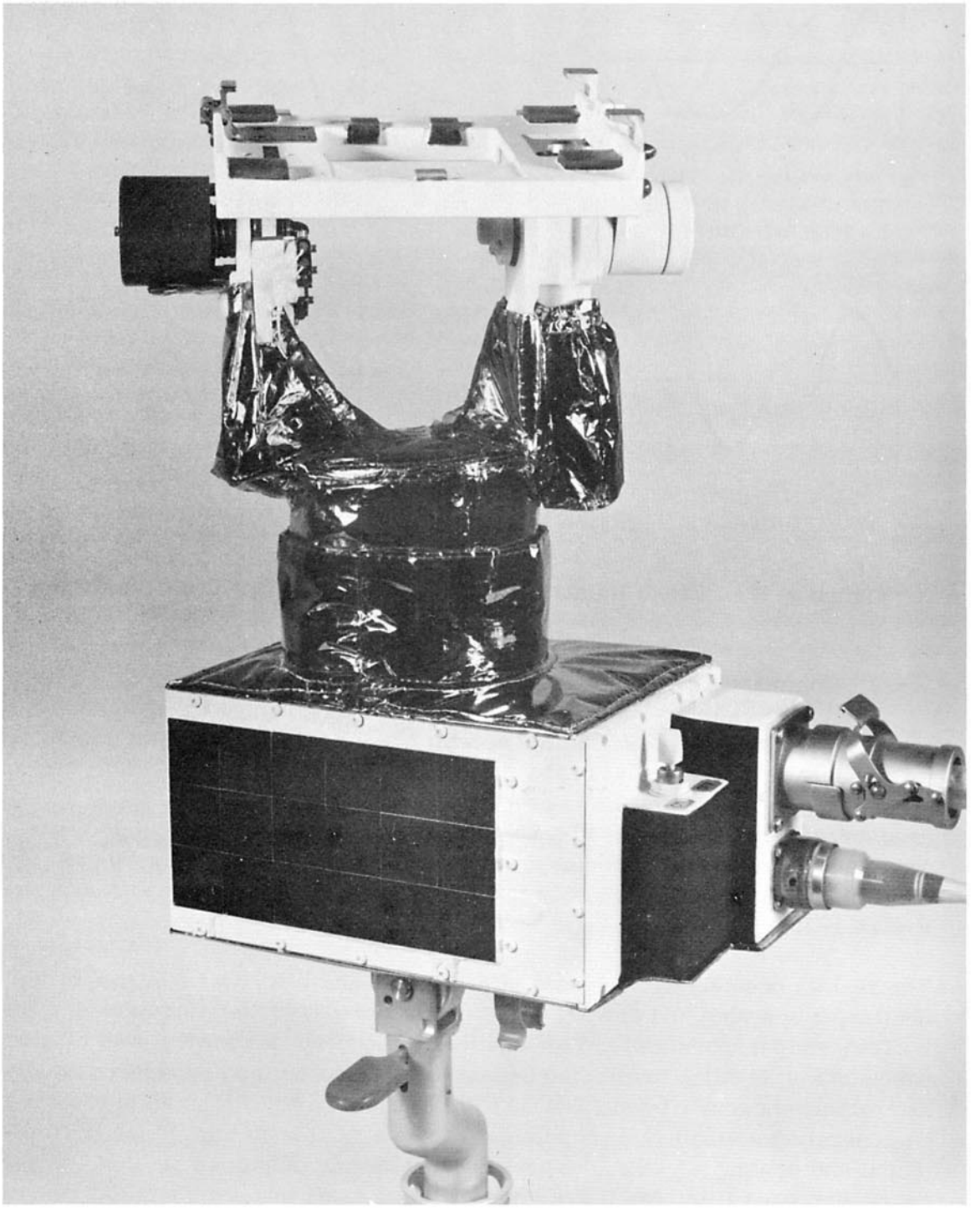


Figure 1-26. Mechanical Configuration of the TCU

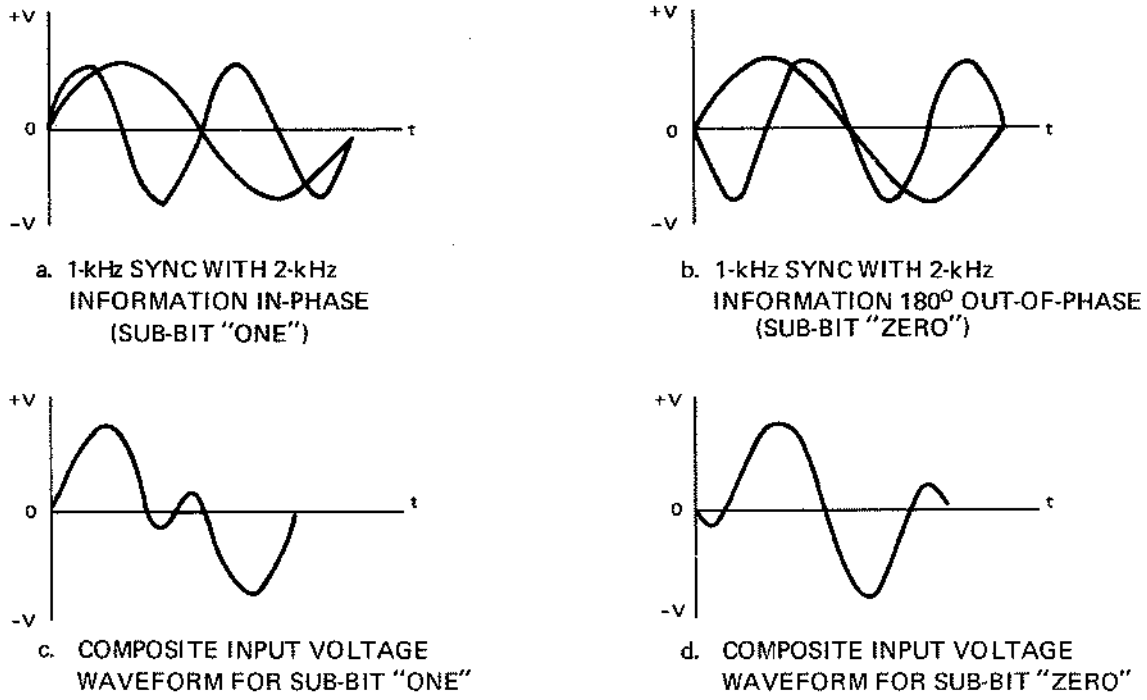


Figure 1-27. Phase Relationships for Sub-bit "1" and "0" Generation

1.6.3 Command Demodulator

The command demodulator accepts the 70-kHz subcarrier from the LCRU for processing. The output of the demodulator consists of a digital bit stream, two 1-kHz clock signals, and a squelch level. All output signals go to the digital decoder. The unit consists of a 70-kHz demodulator to extract the baseband waveform from the FM modulated subcarrier, and a biphase demodulator to extract the clock, squelch, and command data from the baseband waveform. See Figure 1-25.

The 70-kHz demodulator consists of a 70-kHz bandpass filter followed by a limiter, a one-shot and driver, and a 5-kHz low-pass filter that acts as a digital frequency demodulator. The input bandpass filter is passive, has a noise bandwidth of 20-kHz, passes the entire 70-kHz spectrum, and rejects the 30-kHz voice subcarrier by at least 50 dB. Frequency demodulation is achieved by generating a stable 3.5-μs pulse at each positive transition of the limiter output and driving a 5-kHz low-pass filter with this output. The linear-phase 5-kHz low-pass filter has a 3-dB bandwidth of 5 kHz and a differential delay of 2.1-μs from zero to 7-kHz.

TABLE 1-7. GCTA COMMAND FUNCTION CODES

Command Function	Octal Code			Binary Code (Bits 7-12)
	Vehicle Address	System Address	Function	
PAN RIGHT	3	2	04	000100
PAN LEFT	3	2	01	000001
PAN STOP	3	2	02	000010
TILT UP	3	2	14	001100
TILT DOWN	3	2	11	001001
TILT STOP	3	2	12	001010
ZOOM OUT	3	2	24	010100
ZOOM IN	3	2	21	010001
ZOOM STOP	3	2	22	010010
IRIS OPEN	3	2	34	011100
IRIS CLOSE	3	2	31	011001
IRIS STOP	3	2	32	011010
ALC PEAK	3	2	44	100100
ALC AVERAGE	3	2	41	100001
POWER ON	3	2	54	101100
POWER OFF	3	2	52	101010
S/C ON	3	2	64	110100
S/C OFF	3	2	62	110010

Referring again to Figure 1-25, note that the biphase demodulator has three functional subsections: a phase-lock loop to extract the 1-kHz data clock, a squelch circuit to inhibit the decoder when the baseband input is not present, and an "integrate and dump" circuit to extract the digital data from the baseband signal. Each of these subsections receives inputs through a separate phase detector. These phase detectors are identical except for the reference frequencies used at the input, and the gain of the stage. Operation of this circuitry is described below in the discussion of the "integrate and dump" circuit in the biphase demodulator.

The voltage-controlled oscillator (VCO) used in the phase-lock loop uses a unijunction transistor oscillator triggered by a sawtooth voltage. The sawtooth is generated by charging a precision capacitor from a temperature-compensated current source. The frequency of the VCO is set at 4 kHz (nominal). With a signal present at the phase detector input, the output of the phase-lock loop filter causes the frequency of the oscillator to change and lock the oscillator phase and frequency to the incoming signal. The 4-kHz oscillator frequency is divided by four in the clock logic section and then compared to the input frequency in the phase detector. The 1-kHz clock signal from the clock logic is used throughout the demodulator and digital decoder to extract command information from the incoming data stream.

The squelch detector subsection of the demodulator is a phase detector driven by the in-phase 1-kHz clock. The detector senses the signal from the out-of-phase detector and when this latter signal rises above the squelch threshold, the squelch amplifier output allows the digital decoder to process commands from the "integrate and dump" output. The actual biphase demodulation is accomplished by a phase detector driven by the 2-kHz clocks and an "integrate and dump" circuit.

A simplified schematic of the demodulator is shown in Figure 1-28. In the Figure, the transistor switches are replaced with ideal switches (S1, S2) driven by a "recovered" 2-kHz, coherent switching signal. The switches alternately ground nodes M and N to generate waveforms B and C. The signals at nodes M and N result in waveforms F and G at the output of operational amplifier (OA). The M-input (waveform C) is non-inverting and the N-input (waveform B) is inverting. The composite output of the operational amplifier is waveform H shown in Figure 1-28. The average value of the output over a bit period determines the bit level of "1" or "0".

The "integrate and dump" circuit is equivalent to a matched filter and recovers the raw non-return-to-zero (NRZ) data from the biphase demodulator. The circuit uses a high-gain operational amplifier with stabilized gain and capacitor feedback. A field-effect transistor (FET) is used to dump the capacitor at the end-of-bit time.

When the input signal-to-noise ratio (S/N) is 10 dB (measured in the 20-kHz noise bandwidth of the 70-kHz subcarrier input from the LCRU), the output S/N for the subcarrier demodulator is 12.5 dB. The ratio is calculated as follows:

$$S/N = \frac{3}{2} (C/N) \frac{Bf_D^2}{fm^3}$$

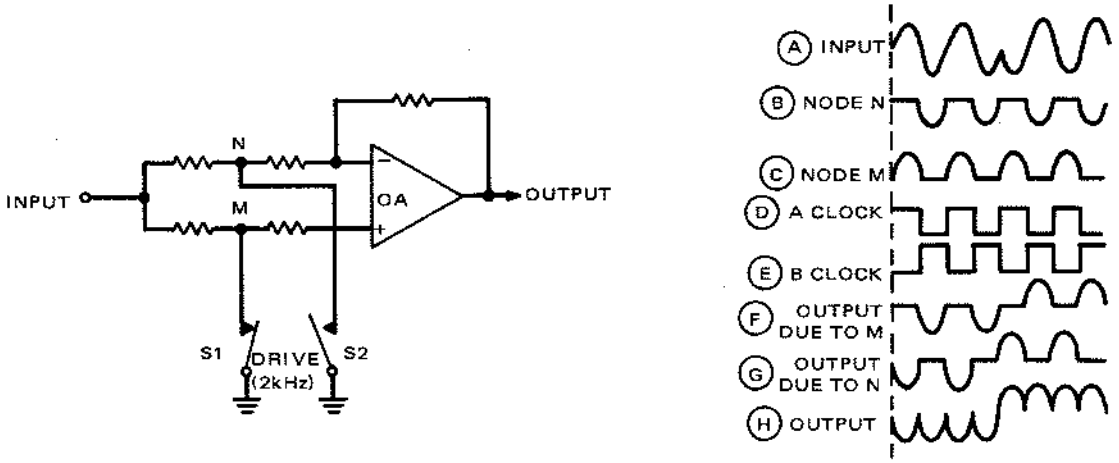


Figure 1-28. Demodulator Schematic and Waveforms

where

C/N = subcarrier SNR = 10 dB

B = 20 kHz noise bandwidth

f_D = frequency deviation of 2-kHz tone = 2.8 kHz

fm = output noise bandwidth = 5.2 kHz

For the demodulator output S/N of 12.5 dB, E/N_o is calculated to be 19.6 dB, as follows:

$$\frac{E}{N_o} = (S/N)\,\frac{fm}{b}$$

where

E/N_o = energy per bit/noise power spectral density

b = sub-bit rate = 1 kHz

Assuming the demodulator and the "integrate and dump" bit detector depart from theoretical performance by a maximum of 2 dB, the error probability corresponding to an E/N_o of 17.6 dB (19.6 - 2.0) is 10^{-26}.

1.6.4 Command Decoder

The decoder receives a serial bit stream of command data from the command demodulator, and decodes eighteen real-time commands for remote control of GCTA azimuth, elevation, zoom, iris, CTV power, ALC, and voice-subcarrier functions. The output section of the decoder provides logic-level outputs for the motor driver circuits and relay driver circuits.

The decoder checks the incoming bit stream for twelve-bit commands, with each bit coded in a pattern of five sub-bits. The decoder responds to all commands having the correct three-bit vehicle address, followed by a correct three-bit system address, followed by six bits of command data. If one of the sixty required sub-bits is incorrect, or either address is incorrect, or the sixty sub-bits containing the command are not received in a continuous bit stream, the command will be rejected. If the CTV is ON, and the squelch circuit has enabled the decoder, a maximum of six valid commands can be decoded per second. The decoder will not decode any command except "Power ON" unless the CTV is ON. Turning the CTV OFF will terminate any decoder activity and prevent the decoding of any further commands.

The decoder receives four signals from the demodulator: the squelch, the "integrate and dump", the strobe, and the 1-kHz clock signals. The squelch signal holds the sub-bit register in a reset condition. Whenever the amplitude is above the threshold, the squelch line goes high and allows the accumulation of sub-bits in the register. The output of the "integrate and dump" circuit in the demodulator is the data input to the decoder. This analog signal is fed into a pair of comparators in the sub-bit detector. Each time the strobe pulse is received, the output state of the comparators is clocked at 1-kHz into the sub-bit register. If the data input is above threshold when the strobe pulse occurs, a sub-bit "1" is detected. If the data input is below threshold, a sub-bit "0" is detected.

Once detected, the sub-bits are shifted through the sub-bit register by each succeeding strobe pulse. When a pattern of five sub-bits is accumulated in the register that matches one of the hardwired patterns in the unit, an info-bit is decoded. The output of the vehicle address (VA) pattern decoding and the system address (SA) pattern decoding blocks are the decoded "1" and "0" bits that make up a command.

The sub-bit counter shown in the block diagram (Figure 1-25) also is clocked by the strobe pulses. This counter is reset when the first vehicle address (VA) pattern bit is detected. The counter then starts a sub-bit count. Once this first VA bit is detected, the bit clock (every fifth strobe pulse) is synchronized to the incoming bits and is used to clock bits into the bit register. When the sub-bit counter has counted 30 sub-bits, the system address (SA) detector is strobed for the presence of the system address. A sub-bit count of 60 strobes the "3 of 8" section of the decode matrix and generates the actual command decoder output.

The decoder reset logic accepts signals from the sub-bit counter, the pattern decoding section, and the bit decoding section to generate reset signals for the bit register, the VA detector, and the SA detector. Reset will occur for a power turn on, a bad sub-bit decoding pattern while processing a command, or after decoding a valid command. The bit register shown in the block diagram accumulates bits detected by the pattern decoding and is reset prior to receiving

VA bits of a command. When the three correct bits of a valid vehicle address are in this register, the VA detector will recognize it and store the information. Bits coded in the system address (SA) pattern then are shifted into the bit register. After thirty sub-bits of a command have been received, the SA detector will strobe the bit register, and (if the correct system address is present) the SA detector will recognize it and store the information. System address bits (coded) continue to be shifted through the register until sixty sub-bits have been received. The count from the sub-bit counter then enables the decode matrix to strobe the bit register and provide an output on one of the eighteen output lines. The sub-bit register then signals the reset logic to clear the decoder in preparation for a new command.

The decode matrix decodes the six bits of command data in two pieces. All eight possible combinations of the first three bits are decoded, but only three of the eight combinations of the last three bits are decoded. The gate feeding the "3 of 8" decode indicates the conditions required to output a command decode.

The output logic section of the decoder consists of four identical blocks. The azimuth block is used as an example. The block receives three decoded commands (azimuth right, left, and off). Two limit switch inputs and a power on/off level also are received. When the CTV power is OFF, the output to the azimuth motor drivers also are off and the output sequencer will ignore all commands. When power is ON, the output sequencer responds to the azimuth motion commands by sending a ground-level signal to the stepper motor driver on one of two lines (azimuth right, azimuth left). This signal will remain on until (1) the "Azimuth OFF" command is received, (2) the opposite azimuth motion is commanded, or (3) the end-of-travel limit switch for that motion is activated.

If a motion is commanded while the opposite motion is in progress, the output signal to the stepper motor driver switches to drive the motor in the opposite direction. The output line pairs are mutually exclusive to prevent simultaneous motion commands to a single driver.

The power, ALC, and subcarrier (S/C) outputs from the digital decoder are pulse outputs of the decode matrix. Pulse stretcher/driver circuits located on the command and control board (2A8) provide outputs that drive the coils of the latching relays used for these functions.

1.6.5 Motor Drivers

Four stepper motor drivers in the TCU provide the necessary drive waveforms and switching functions for azimuth, elevation, zoom, and iris motors. Each motor driver operates a single motor. The driver receives a logic-level input on one of two lines (from the command decoder) to control clockwise or counterclockwise motor rotation. If both input lines to a driver are inactive, the associated motor does not run.

All four drivers receive a 60-Hz clock signal derived from the 60-Hz vertical sync signal in the CTV, and this clock is used to generate the motor driver switching waveforms. As a result, all transients due to stepper motor switching occur during the vertical blanking interval of the video signal and do not add noise to the picture.

Each drive circuit (bridge-type) switches +23.5 Vdc and ground across a parallel pair of motor windings. Permanent magnet stepper motors are used in the GCTA and operate on the principle of reaction between an electromagnetic field stator and a permanent magnet rotor. Figure 1-29 shows the excitation technique for the 90-degree motor. Shaft motion is achieved by using a specific sequence of current reversals in the two motor windings.

For clockwise rotation, the excitation sequence is as follows:

Step 1. Excite windings 1-2 and 3-4

Step 2. Excite windings 1-2 and 4-3

Step 3. Excite windings 2-1 and 4-3

Step 4. Excite windings 2-1 and 3-4

For counterclockwise rotation, the excitation sequence involves reversing the sequence of steps 2 and 4:

Step 1. Excite windings 1-2 and 3-4

Step 2. Excite windings 2-1 and 3-4

Step 3. Excite windings 2-1 and 4-3

Step 4. Excite windings 1-2 and 4-3

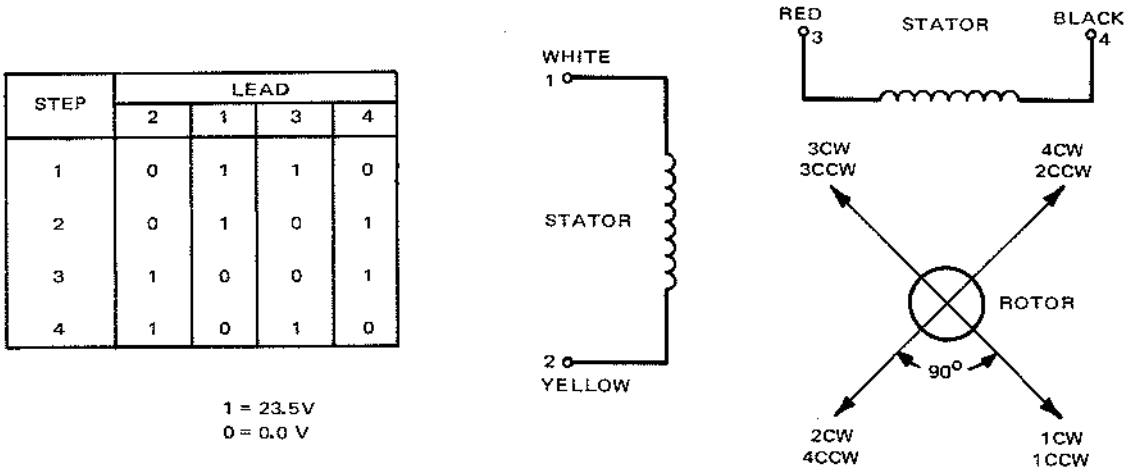


Figure 1-29. Stepper Motor Wiring Configuration

The motor winding excitation sequences are summarized by the logic tables shown in Figure 1-29. With respect to a given half-winding (e.g., -4), the logic table shows the excitation voltage is a square wave with a frequency equal to one-quarter of the stepping rate. With respect to two given corresponding half-windings (e.g., -4 and 2), the excitation voltages will be two square waves with fixed 90-degree phase relationship.

1.6.6 Azimuth Drive

Figure 1-30 illustrates the azimuth drive assembly. The azimuth axis drive uses a thrust tube mounted in the electronics box assembly. The tube contains the azimuth shaft, with bearings at the top and bottom of the tube. The motor-gearhead assembly is mounted to one side of the azimuth axis and is coupled to the shaft through a spur-gear set. A wrap spring type of override clutch is included above the motor gearhead assembly between the gearhead output shaft and the spur-gear set pinion. Gearhead reduction is 487:1 with the spur-gear set providing an additional 3.64:1 ratio. The overall assembly provides a 3.03 degree per second azimuth rate.

1.6.7 Elevation Drive

The elevation drive assembly is shown in Figure 1-31. The assembly mounts on one side of the TCU yoke. The motor gearhead assembly is mounted below the drive-gear housing and is connected to the spiroid-gear set through a flexible-shaft coupling. The spiroid-gear set is a skew-axis gear (intermediate between a bevel gear and a worm gear). The spiroid gears have more teeth in contact at any moment than an equivalent worm gear and, unlike worm or bevel gears, are (1) insensitive to normal position variations, (2) have positive backlash control, (3) allow high gear ratios in one stage, and (4) cannot be backdriven. These features minimize jitter.

The spiroid-gear set couples through a slip clutch to the CTV cradle to provide elevation motion. The slip clutch is a wire-wrap spring type, which has several advantages over the conventional axial type of clutch. The chief advantage is that the breakaway torque is fixed and varies by less than 10 percent over a wide temperature range. The gearhead and spiroid-gear set reductions are 48:1 and 36:1 respectively, giving a CTV elevation drive rate of 3.11 degrees per second.

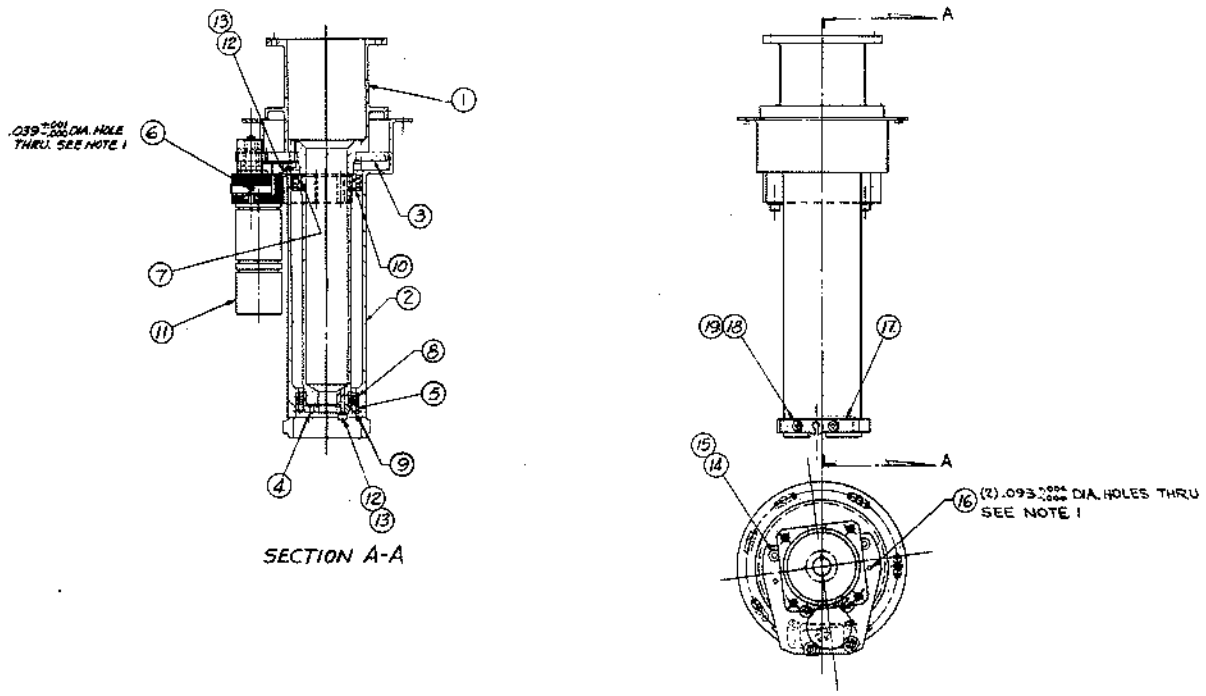


Figure 1-30. Azimuth Drive Assembly Drawing

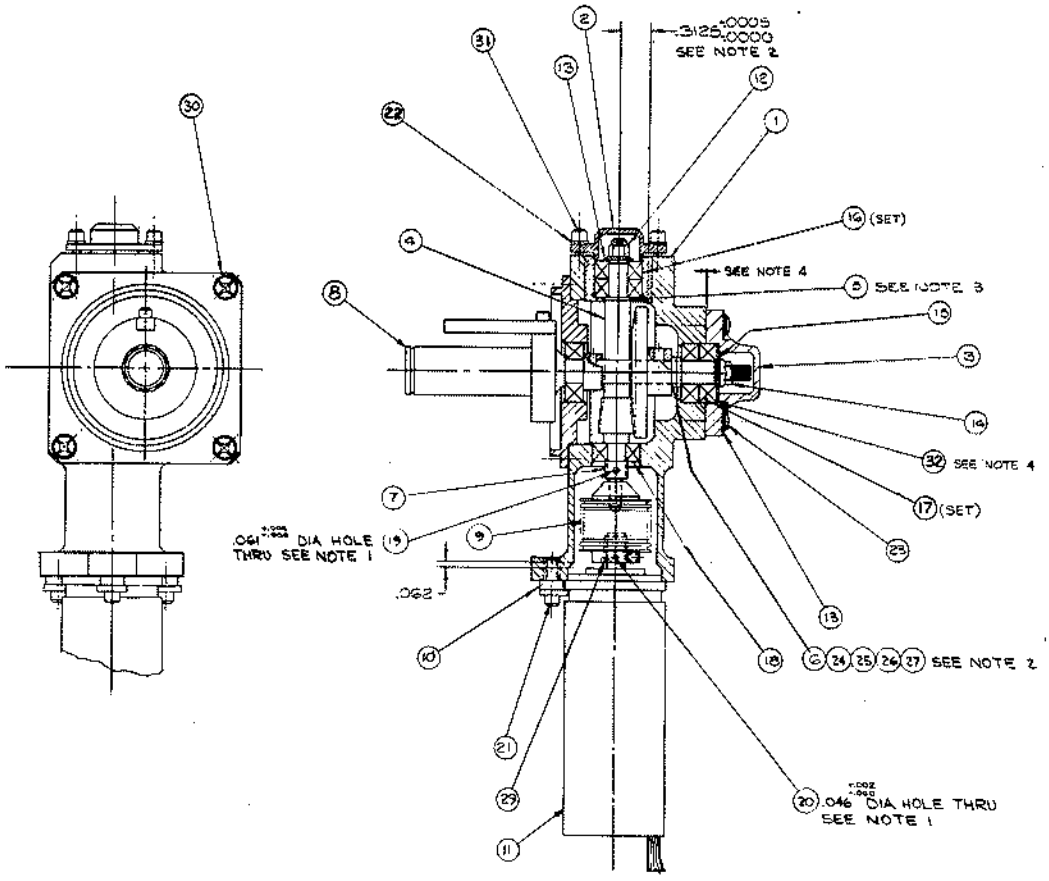


Figure 1-31. Elevation Drive Assembly Drawing

1.6.8 Power Converter

The TCU power supply is similar to the CTV supply. The unregulated bus voltage (+25 to +33 Vdc) is divided into five regulated output voltages:

- +23.5 Vdc
- -5 Vdc
- +5 Vdc
- -10 Vdc
- +10 Vdc

Two unregulated output voltages, +12 Vdc and -12 Vdc also are available.

The TCU power supply operates in two modes: "synchronized", when the CTV is operating; and "free-running", when the CTV is OFF. In the "free-running" mode, the dc/dc inverter is allowed to self-oscillate at a natural frequency of approximately 5.5 kHz. In the synchronous mode, the dc/dc inverter is driven by the sync circuit at 7.867 kHz. In the synchronous mode, inverter switching noise is generated only during the video blanking period.

An input filter is used with the supply to minimize ripple current reflected back to the input bus. A pre-regulator converts the unregulated input voltage to a regulated +23.5 Vdc, and this voltage is converted, rectified, filtered, and series-regulated to secure the required ±5 Vdc and ±10 Vdc outputs for the TCU electronics.

1.7 Thermal Control

Thermal control of the CTV is achieved by the interaction of a second-surface mirror radiator on the top of the camera with the lunar surface and with deep space. The CTV rejects heat through radiation and receives heat by internal heat dissipation, solar radiation incident on the mirror radiator, and lunar surface radiation when the radiator is tilted toward the lunar surface. A thermal insulating blanket covers the remaining surfaces of the camera to insulate against radiation from the lunar surface. The camera is cooled by orienting the second-surface mirror radiator level (horizontal) with the lunar surface. The camera can be heated by activating the CTV electronics and by tilting the radiator toward the lunar surface.

Thermal control of the TCU is achieved through the use of side radiators on the lower housing (electronics compartment). At low sun angles, the radiators absorb sufficient solar and lunar heat in any azimuth position to prevent the unit from exceeding the minimum temperature limits for the assembly. The radiators also are large enough to prevent the TCU from exceeding the maximum temperature limits when the unit is operating under worst-case hot conditions. The worst-case hot condition occurs when maximum heat inputs are present due to lunar dust degradation of the TCU radiators and the TCU presents maximum projected area for solar irradiation. All other surfaces of the TCU (other surfaces of the electronics box and the entire azimuth/elevation drive unit) are thermally blanketed. See Figure 1-32.

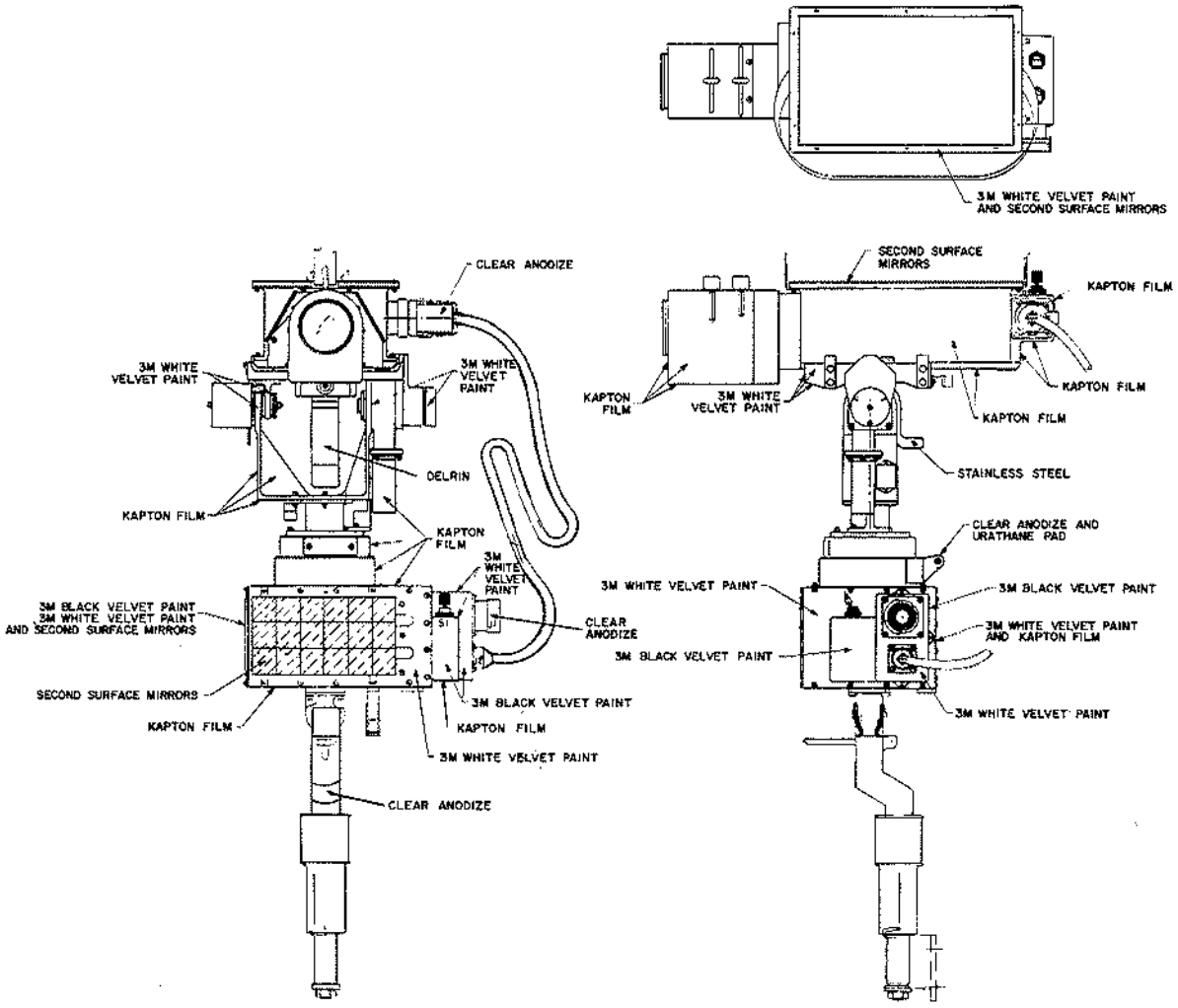


Figure 1-32. GCTA Thermal Control

SECTION 2

PRELAUNCH TEST AND HANDLING

Section 2 describes the functional test requirements and prelaunch handling procedures and constraints for the GCTA.

2.1 CHECKOUT EQUIPMENT REQUIREMENTS

The GCTA is not delivered with any special Ground Checkout Equipment other than the Command Simulator Unit (CSU). For checkout at MSC or KSC, therefore, additional equipment must be provided for this purpose. The test setup must be capable of obtaining valid test data without damaging the camera. Equipment is required to checkout input power, input command signals, test scene lighting, and video output of the assembly.

2.1.1 Power Input

The +28 Vdc input power requirements are given in Table 2-1 for the complete GCTA and for the CTV alone.

TABLE 2-1. INPUT POWER SUPPLY REQUIREMENTS

COMPLETE GCTA	
Steady-State Power Level:	29 ±4 Vdc
Maximum Overvoltage:	37 Vdc (1 minute)
Random Line Noise: (Closed Circuit)	0.2 V rms (5 Hz to 20 kHz) 0.1 V rms (20 kHz to 100 kHz)
CTV ONLY	
Steady-State Power:	+24 to +33 Vdc
Critical Overvoltage:	78 Vdc (10 microseconds recovery, 2 pulses per second repetitive)
Maximum Undervoltage:	21 Vdc (1 second recovery, non-repetitive)
Ripple:	1 volt peak-to-peak, (50 Hz to 20 kHz)
Maximum Overvoltage:	37 volts (1 minute)

2.1.2 Command Signal Input

The uplink command subcarrier signal input shall meet the following requirements:

- Frequency Response - For modulating frequencies from 60 kHz to 80 kHz, the 70-kHz subcarrier input to the TCU shall not vary more than 1 dB (when measured at 70 kHz).
- Signal Level - Across a 5-kilohm resistive load, the 70-kHz input shall be within 0.7 to 3.5 Vp-p with a nominal value of 2 Vp-p.
- Source Impedance - Source impedance shall be 100 ohms (maximum), balanced and isolated from ground.
- Noise Level - In the 60 kHz to 80 kHz frequency band, the ratio of rms signal-plus-noise to rms noise at the subcarrier input shall be no less than 10 dB.
- Intermodulation Distortion - The products of intermodulation distortion shall be a minimum of 30 dB below a reference 70-kHz sinusoid.

2.1.3 Test Chart Lighting

The colorimetric characteristics of the CTV are adjusted to provide equal-amplitude video output from a reference-white test chart. The chart is illuminated by a light source with a color temperature of 6000° Kelvin(K). This color temperature closely represents the Johnson air-mass zero solar spectrum.

A quartz-iodide lamp or other light source having a color temperature of 3400° K is recommended to illuminate the test chart. A Kodak Wratten 80A compensating filter also is required on the CTV to provide the correct color balance with the above light source. The use of a 3200° K lamp with the Wratten 80A filter will cause a 10 to 15 percent imbalance between channels. Fluorescent, mercury vapor, and other types of discharge lamps produce unsatisfactory color renditions and should not be used during any tests.

2.1.4 Video Output Level

The GCTA video output ranges from zero volts, representing the sync tip, to one volt, representing the peak-white level. Source and load impedance is 75 ohms. All tests of video output levels, therefore, should employ 75-ohm coax cable.

2.2 PRELAUNCH OPERATING CONSTRAINTS

2.2.1 Thermal Constraints

The GCTA may be operated continuously indoors and/or in sunlight for ambient temperatures up to 75° F. At ambient temperatures of 75° F to 85° F, continuous operation of the GCTA must be limited to two hours. For ambient temperatures of 85° F to 95° F, operation must be limited to one hour. After ground operations, the assembly must be removed from sunlight and allowed to cool for a minimum of two hours.

CAUTION

THE CTV IS NEVER TO BE OPERATED ON THE GROUND WITH THE REMOVABLE THERMAL BLANKET COVERING THE THERMAL RADIATOR.

2.2.2 Elevation Drive Compensator

The GCTA elevation drive is designed for a 1/6-g lunar environment. A compensator spring is provided on the elevation axis, therefore, to reduce the torque required to tilt the camera in a ground environment (one-g). The compensator includes two separate torsion springs that compensate for ground loads during elevation travel down (45°) and up (85°) from horizontal. The +85° spring is identified by RCA Drawing No. 2262462. The -45° spring is shown in RCA Drawing No. 2262463.

CAUTION

THE ELEVATION DRIVE COMPENSATOR MUST BE REMOVED PRIOR TO FLIGHT.

The following procedure is recommended for removal and reinstallation of the spring assembly. The procedure references the callout numbers shown in Figure 2-1. Procede as follows:

1. Remove cover (16) by removing bolt (41) and washer (49).
2. Tilt camera mount until one of the two compensator springs is in a relaxed position.
3. Using tool provided, engage the end of the relaxed spring and deflect spring and camera mount in the opposite direction to relax the second spring. Remove upper spring drive rod (17).

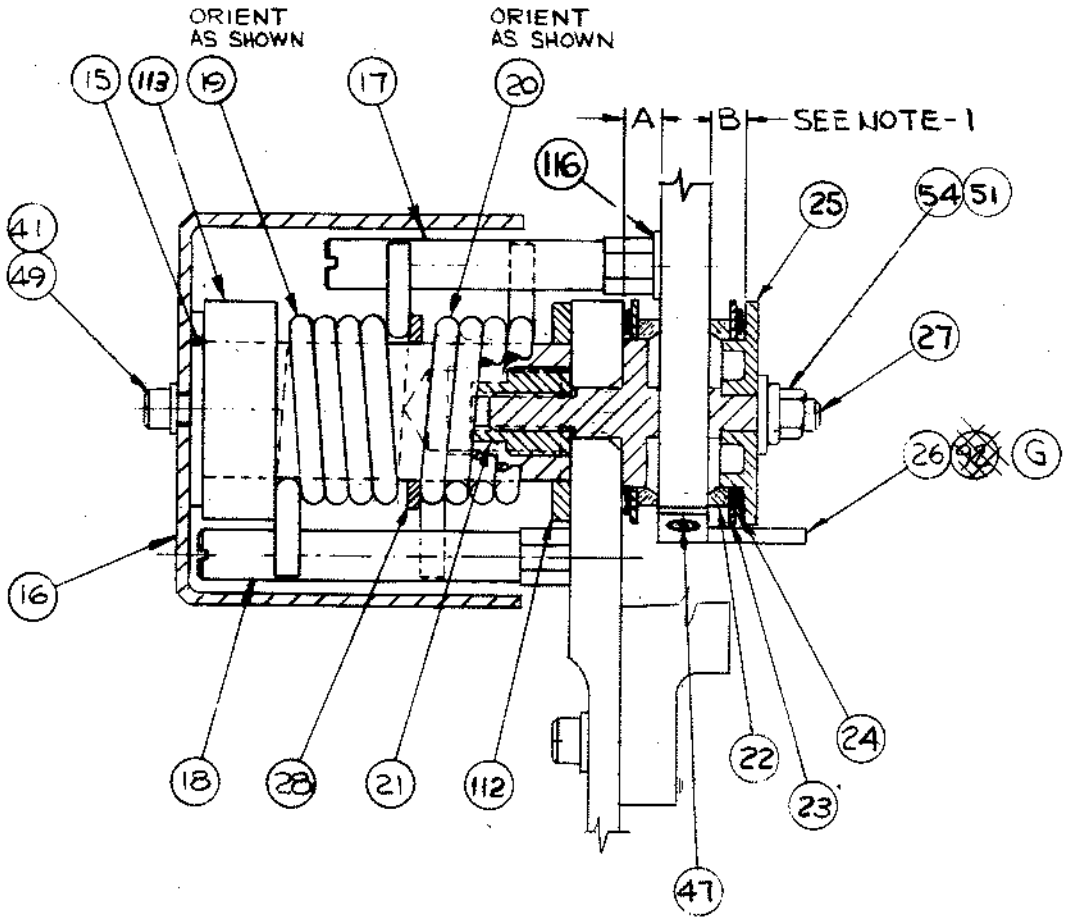


Figure 2-1. Elevation Drive Compensator Assembly

4. Remove the lower drive rod (18).
5. Remove hub (15), separator (28), and springs (19) and (20).

NOTE

BUSHING (21) REMAINS SECURE ON SHAFT (27).

To reinstall the compensator:

1. Position springs (19) and (20), and separator (28) on hub (15).
2. Install lower drive rod (18) on TCU yoke.
3. Install hub and spring assembly on bushing (21), engaging springs with lower drive rod (18).

4. Using tool provided, engage the end of one spring and deflect both the spring and camera mount to a position where the upper drive rod (17) may be inserted freely in the hole of the flange on the camera mount.

5. Refit cover (16) using bolt (41) and washer (49).

The TCU should not be operated with the compensator springs installed unless the CTV is in position on the yoke. To verify TCU operation under lunar conditions, a mass simulating the lunar weight and correct center of gravity must be installed in the CTV mount.

2.2.3 Lens Filter Attachment

All attachments at the CTV lens shield (filters or dust cap) should be made to the pilot diameter of the lens shield. Use of the internal thread on the front lens element may cause damage to the manual zoom adjust mechanism.

CAUTION

NO AUXILIARY FILTERS OR OTHER DEVICES SHOULD BE ATTACHED TO THE INTERNAL THREAD FORWARD OF THE FRONT LENS ELEMENT.

2.3 STORAGE AND HANDLING PROCEDURE

All white-painted surfaces and second-surface mirrors on the GCTA are subject to degradation by dirt, oil, grease, and other contaminants. The CTV and TCU should be handled with white gloves during all physical operations to avoid changes in the thermal control characteristics of surface materials. Whenever possible, test operations should be carried out in a relatively dust-free contaminant-free area. The lens cover should be installed and kept free from dust or other contaminants when the camera is not in use.

Extra care should be taken to avoid any damage to the 6-mil second-surface mirrors on the CTV and TCU. The top thermal blanket covering of the CTV should be kept in place during all handling of the camera. When stowing the TCU, avoid damage to the mirrors on the front and one side of the TCU. A TCU protective cover is provided for ground handling. During installation in the MESA, a plastic film may be inserted between the TCU and the MESA structure. Remove the film after installation of the TCU.

The TCU should be lifted only by the electronics box beneath the CTV cradle. Handling of the azimuth axis of the cradle should be avoided to prevent distortion of the thermal blanket sleeve that allows free motion of the azimuth drive.

The CTV and TCU should be placed in their respective shipping containers for transportation, ground handling operations, and storage. During storage of the camera, the following environment is specified:

- Temperature — 23° ±10° C (73° ±18° F)
- Relative Humidity — 50% ±30%
- Atmospheric Pressure — $725 \, ^{+50}_{-115}$ mm of mercury (Hg)
  ($28.5 \, ^{+2.5}_{-4.5}$ in. Hg)

The CTV contains a time-sensitive SIT tube. The camera should be operated once every month for a 1-hour period.

2.4 CLEANING PROCEDURES

2.4.1 Lens

Use a gentle blast of air from a syringe or a vacuum cleaner to remove dust from the lens. Stroke lightly with a camel-hair brush to remove remaining dirt or other particles. To remove fingerprints or liquid spots, repeat the above procedure. Then partially moisten a cotton swab with Kodak Lens Cleaner. Isopropyl alcohol may be used as an alternate.

CAUTION

IS USED IN EXCESS, ALCOHOL MAY ENTER THE INTERIOR OF THE LENS AND ATTACK THE BONDING CEMENT. USE CLEANER SPARINGLY.

Clean only the affected area using a circular motion. Replace swabs frequently. Dry with a clean, dry swab. Replace lens cover immediately after cleaning or use.

2.4.2 Gold and Mirrored Surfaces

Clean contaminated areas with a clean camel-hair brush. If brushing fails to remove the foreign material, use several clean cotton swabs and uncontaminated Freon TF. Fluff up a cotton swab and saturate it with Freon TF. Wipe once, very gently, across the contaminated area. Discard swab. Inspect the surface. If contamination is still present, repeat the application of Freon TF with cotton swabs.

NOTE

DO NOT DIP A USED SWAB IN THE FREON TF. HARD OR PROLONGED RUBBING WILL SCRATCH THE SURFACES.

5. Position the TCU base on the pallet locating pins.

6. Swing the azimuth drive assembly to the position where the torque on the assembly fits into the clevis on the pallet.

7. Insert the pip-pin through the torque and clevis to secure the TCU to the pallet.

Exercise care during TCU stowage to avoid damage to the mirrors on the front and one side of the unit. A protective cover is provided for ground handling. For protection during installation in the MESA, a plastic film should be inserted between the TCU and the MESA structure. Remove the film after installation of the TCU.

SECTION 3

LUNAR SURFACE OPERATIONS

Section 3 describes GCTA deployment and manual operation on the lunar surface. The procedures outlined are based soleiy on GCTA requirements.

3.1 CTV DEPLOYMENT — LM TRIPOD OPERATION

For launch, the CTV is stowed in the Stowage Mount Assembly (SMA) on the LM MESA. The camera is constrained vertically by two fixed and two hinged clamps secured by pip-pins. Horizontal constraint is provided by the clamps and by flanges on the SMA. To remove the camera, the pip-pins are pulled from the latches (see Figure 1-2), and the camera is lifted vertically using a carrying strap.

The carrying strap is attached to both ends of the camera housing. It is fitted with Velcro tape that mates with tape placed on the camera flanges. Prior to camera operation, the strap is stowed alongside the camera clear of the mirror radiating surfaces. Care should be taken not to hit the mirror surfaces when lifting the camera or handling the carrying strap.

Once the CTV has been lifted off the SMA, the carrying handle on the underside of the camera should be unfolded. A detent locks the handle in the extended position. The handle remains extended for hand-held operation, and interfaces with the LM Tripod for operation without the TCU through the 100-foot cable.

3.2 GCTA DEPLOYMENT — LRV OPERATION

The following procedure assumes: (1) the CTV has been deployed previously and is operating on the LM tripod, (2) the LRV has been deployed, and (3) the LCRU has been installed on the LRV.

3.2.1 TCU Unstow

The TCU is removed by pulling the lanyard attached to the pip-pin. The TCU should be held by the camera cradle and lifted vertically away from the pallet. Care should be taken to avoid damaging the front, back, and side mirrors on the unit.

3.2.2 TCU Mounting on LRV

After TCU removal, the support staff attached to the base of the TCU should be unfolded until it locks into an extended position.

The tapered end of the mast then is inserted into the right-hand adapter on the LRV. The cross pin must engage a slot in the LRV adapter. The locking sleeve then is pushed down to engage pins on the adapter and rotated clockwise to a locking position. To facilitate CTV installation, the TCU camera cradle is rotated in azimuth to position the clamp lever points away from the LRV.

3.2.3 CTV Mounting on TCU Cradle

The 100-foot cable must be disconnected at the zero-g connector on the CTV connector block prior to mounting the unit on the TCU. The CTV then is removed from the tripod for placement on the TCU. The CTV is mounted with the lens pointing in the direction indicated by the arrow on the TCU cradle. Stripes placed on each side of the CTV then are aligned with the TCU fixed and release clamps, and the CTV is tilted upward at the side nearest the release clamp. The CTV flange then is placed under the fixed clamps. When resting on the TCU cradle, the CTV is locked into position by pushing the release clamp downwards. To remove the CTV, the release clamp is pulled upward, and the camera is lifted out with the carrying strap. A spring positions the release clamp in an open position.

3.2.4 GCTA Electrical Interconnections

After mounting the TCU and CTV, the GCTA should be interconnected as follows. The 3-1/2-foot cable on the TCU should be connected to the CTV first. One end of the 3-1/2-foot cable is permanently attached to the TCU. For flight stowage, the CTV end of the cable is looped back into the TCU. The CTV end must be disconnected from the TCU and reinserted at the connector block of the CTV.

Next, the LCRU "Y" cable is connected to the TCU. The cable is connected where the CTV end of the 3-1/2-foot cable was initially stowed. This completes the electrical interconnection for the GCTA.

3.2.5 GCTA Swingaway — LCRU Hand Carry

In the event that the LCRU must be removed from the LRV, the GCTA does not have to be disassembled or removed. The lever at the top of the TCU support staff is depressed to unlock the mast joint, and the TCU is tilted away from the LCRU. This position allows clearance to remove the LCRU.

Care should be exercised to prevent the GCTA from falling on the LCRU. Once unlocked, the TCU mast joint is free to swing in either direction.

3.3 GCTA OPERATING CONFIGURATIONS

The GCTA is operated manually by using the controls described in Section 1.3. Operating configurations are as follows:

3.3.1 LM Configuration

Only the CTV is used in this configuration. The camera is connected to the LM through the 100-foot cable. Zoom and iris controls, and ALC and LM power switches are operable. There is no ground-command capability in the LM configuration.

3.3.2 TCU Configuration

Both the CTV and TCU are operated with the LCRU in the TCU configuration. Zoom, Iris, and ALC controls on the CTV are operable. The TCU power switch controls power to the CTV, and the LM Power switch on the CTV is inoperative and may be left in either position. Ground-commanded operation is possible. The camera may be manually positioned in azimuth or elevation, however, by overriding the slip clutches in azimuth and elevation drives.

3.3.3 Contingency Configuration

In the event of TCU malfunction, the CTV may be operated directly with the LCRU. This mode allows only manual control, and is limited due to the short cable length between the LCRU and CTV. the LM Power switch is inoperative in this mode, and CTV power must be controlled by LCRU switching.

3.4 MANUAL CONTROL FUNCTIONS

3.4.1 Automatic Light Control (ALC)

The ALC exposure control provides a nearly constant CTV video output over a 1000:1 range of light inputs. This range of control provides completely automatic camera operation for most input light levels. Iris adjustment also may be required for scenes at very low light levels.

The ALC operates in "peak" or "average" modes. In the peak mode, exposure is set to produce 100-percent modulation at the video output for the brightest portions of the scene. Peak mode is used where bright objects in the scene are the primary interest. The mode should be used when viewing the astronauts, the LM, Earth, lunar-surface experiments, or views of the lunar horizon where there is an appreciable percentage of black in the picture.

In the average mode, exposure is set to provide an average video modulation of about 60 percent. This mode provides visibility in shadowed areas by allowing scene highlights to saturate and bloom. Most effective when the astronauts are working in scene shadows, average mode ALC also may be used to view lunar terrain where little or no sky is in view. It never should be used to view astronauts in direct sunlight.

3.4.2 Iris Control

The CTV iris control provides a lens aperture range of f/2.2 to f/22. Although it does control the amount of light incident on the SIT tube faceplate, the iris control has little control over exposure because of the ALC. If the iris setting is changed, the ALC will readjust SIT tube image-section gain to provide a constant video output, unless the ALC operating range is exceeded.

The type of control that iris adjustment does permit is illustrated in Figure 3-1. Figure 3-1 shows the typical video output level and signal-to-noise performance as a function of light level. If the camera views a scene with a 1000-foot-lambert highlight, essentially no variations in video output occur when the iris is varied from f/2.2 to f/22. The signal-to-noise ratio, however, does vary over this range of iris settings, going from 37.7 dB to a maximum of 42.1 dB and then back to 40.8 dB. The iris control, therefore, can provide adjustments in picture quality and extend the total light-range capability of the camera by a factor of 100.

The iris setting also controls the depth of field over which the camera is in focus. This is discussed more fully in Paragraph 3.4.3.

3.4.3 Zoom Control

The zoom control varies the lens focal length from 12.5 to 75 millimeters. This range of focal length provides a diagonal field of view from 54° (wide-angle at 12.5 mm) to 9° (telephoto at 75 mm). Marks on the top of the camera lens housing at the periphery of the thermal radiator indicate the horizontal angle-of-view at the above extremes of lens setting.

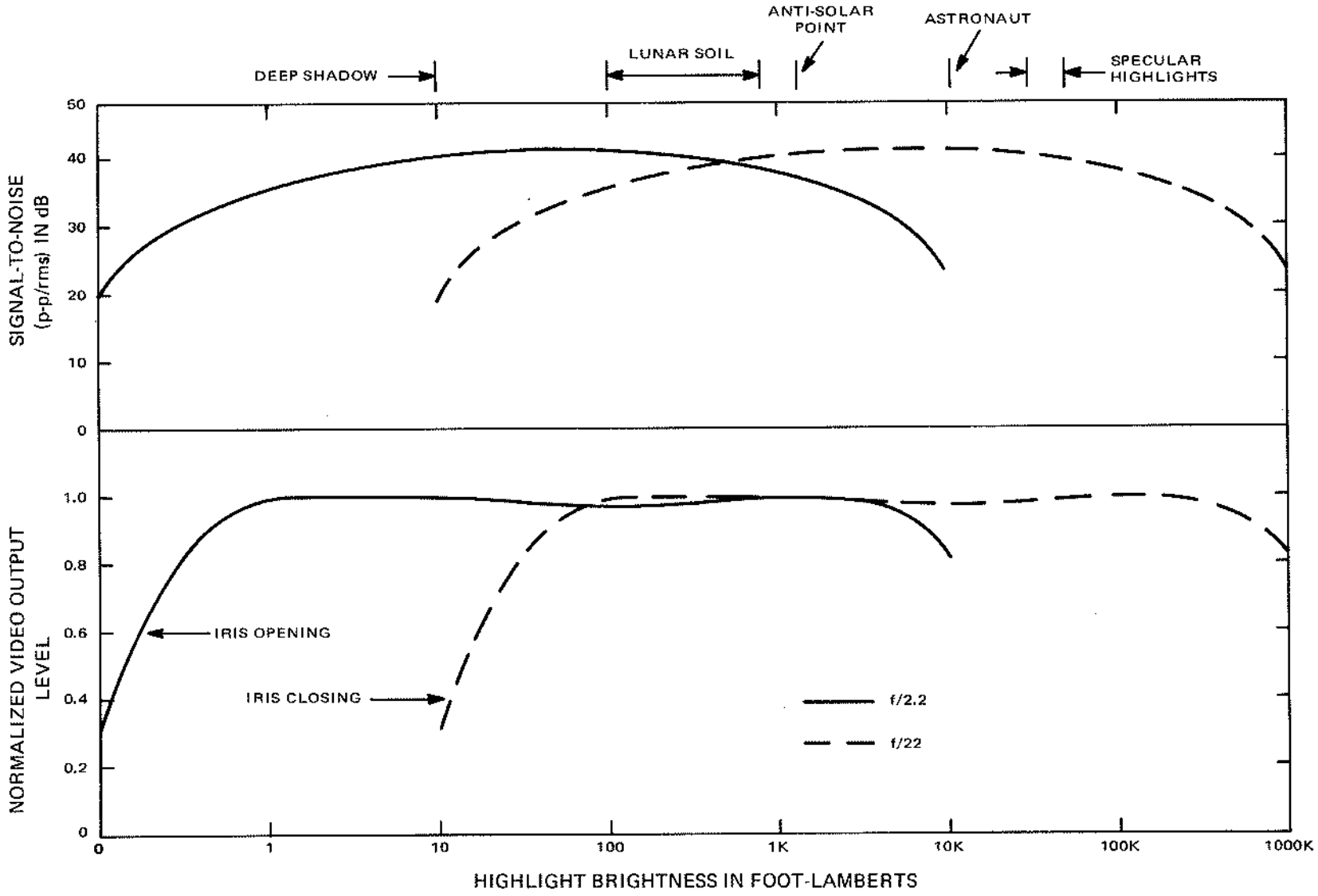


Figure 3-1. Typical CTV Video Output Level and S/N Performance

The lens focus ring is internally connected to the zoom control, and for focal lengths of from 40 mm to 75 mm, the lens is always focused at infinity. As the focal length is reduced below 40 mm, the focus ring is rotated to focus the lens at increasingly shorter distances. At 12.5 mm, the lens is focussed at approximately 1.75 meters.

Figure 3-2 shows the focus distance for various zoom settings. The figure also shows the depth of field at each zoom setting for three different aperture settings. For scenes requiring an aperture of f/2.2, the zoom control is used primarily as a focus control. For apertures of f/8 to f/22, sufficient depth of field exists to keep distant objects in focus at all zoom settings. The iris control setting affects only the near-focus limit (the hyperfocal distance).

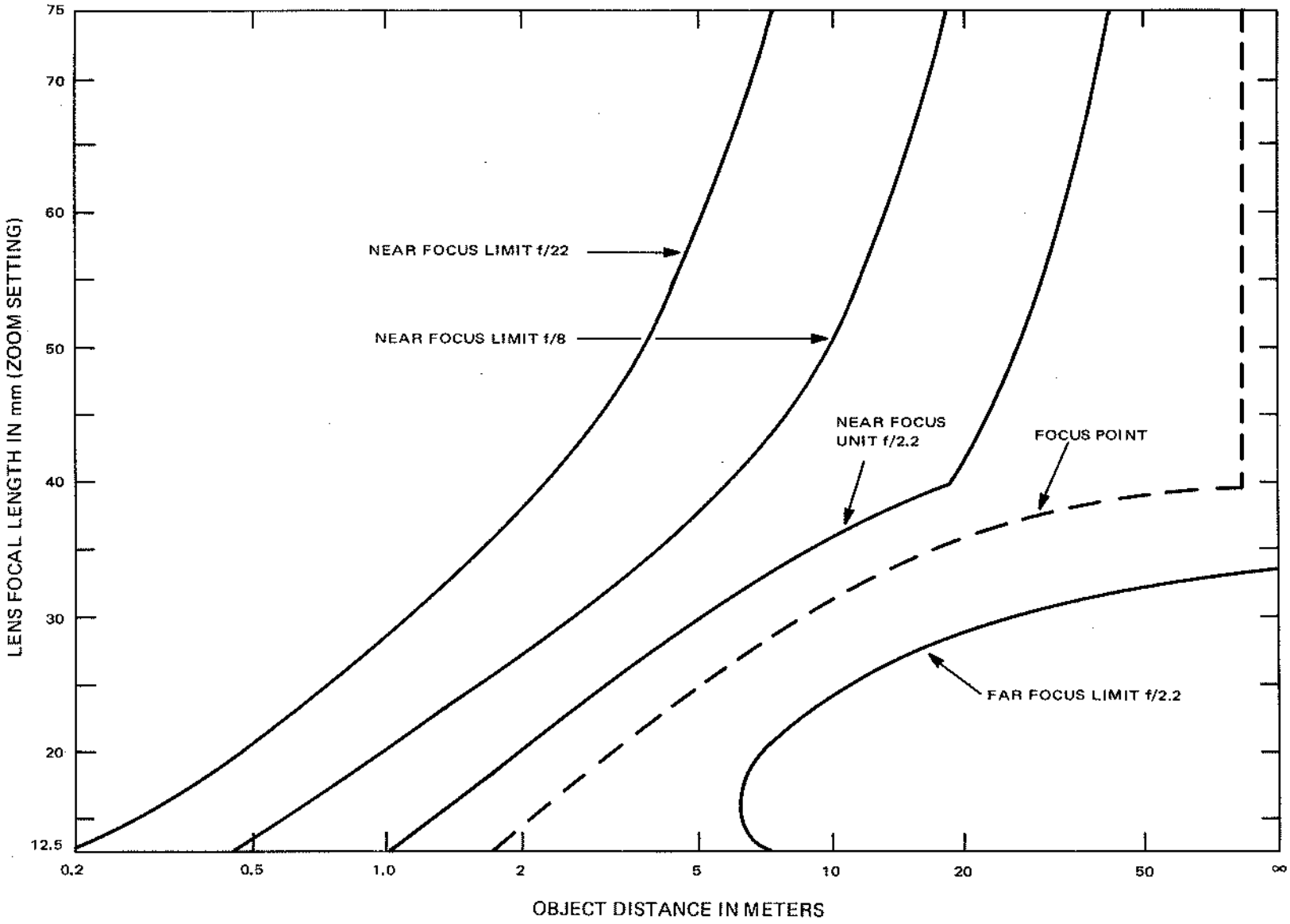


Figure 3-2. Focus Limits for Various Zoom Settings and Apertures

SECTION 4

COMMAND CONTROL OPERATION

4.1 INTRODUCTION

Section 4 describes operation and control of the GCTA by remote commands, and details the operating characteristics and constraints of the command control mode.

4.2 REAL-TIME COMMANDS

4.1.1 Command Code Format

The real-time command messages consist of three vehicle address bits (using vehicle address sub-bit codes) followed by three system address bits and six command data bits (using system/data sub-bit codes). The vehicle address (bit numbers 1, 2, and 3) are always fixed as binary 0, 1, 1, respectively (octal 3). The system address (bit numbers 4, 5, 6) are always fixed as binary 0, 1, 0 (octal 2). Command data codes (bit numbers 7 through 12) for all GCTA command function are given in Table 4-1.

TABLE 4-1. COMMAND DATA CODES

Command	Binary Code (Bits 7-12)	Octal
PAN RIGHT	000100	04
PAN LEFT	000001	01
PAN STOP	000010	02
TILT UP	001100	14
TILT DOWN	001001	11
TILT STOP	001010	12
ZOOM OUT	010100	24
ZOOM IN	010001	21
ZOOM STOP	010010	22
IRIS OPEN	011100	34
IRIS CLOSE	011001	31
IRIS STOP	011010	32
ALC PEAK	100100	44
ALC AVERAGE	100001	41
POWER ON	101100	54
POWER OFF	101010	52
S/C ON	110100	64
S/C OFF	110010	62

4.2.2 Command Decoder Operation

The GCTA receives real-time commands from the Lunar Communications Relay Unit (LCRU). The commands are modulated on a 70-kHz subcarrier (see Section 1). The GCTA demodulates each command and verifies that the command code is valid prior to execution of the command. The command decoder accepts only commands that have the correct vehicle address, system address, valid command function code, and correct word length. If any of the above criteria are not met, or if a single sub-bit is in error, the command is rejected and the decoder resets for reception of another command word.

For all expected operating conditions on the MSFN to LCRU command uplink, acceptance probability for any GCTA command word is greater than 0.999. The probability of uplink noise errors causing execution of an incorrect command is negligible.

If an uplink signal is not received by the LCRU (i.e., the command input to the GCTA is noise), the decoder squelch system inhibits the decoding operation until the synchronization tone in the uplink command signal is detected again at a level greater than 25 percent of nominal amplitude.

4.2.3 Command Execution Functions

Table 4-2 shows the functions executed by the GCTA upon receipt of valid real-time commands.

4.3 MOTOR-DRIVEN COMMAND FUNCTIONS

4.3.1 Drive Characteristics

Four GCTA motor-driven command functions provide for camera positioning in azimuth and elevation and for operation of camera zoom and iris functions. All the motor drive functions are similar in the following respects:

- All drives use identical stepping motors. When operating, the motors step at the vertical field rate of 59.94 Hz. Each step provides a 90-degree rotation of the motor armature. All motor armatures, therefore, rotate precisely at 14.99 rps.
- All drives are reversible. Three commands provide the necessary forward, reverse, and stop functions for each function.

TABLE 4-2. GCTA COMMAND FUNCTIONS

Command	Execution Function
PAN RIGHT	Drives CTV cradle right in azimuth at 3.03 degrees per second rate
PAN LEFT	Drives CTV cradle left in azimuth at 3.03 degrees per second rate
PAN STOP	Stops azimuth motion of CTV cradle
TILT UP	Drives CTV cradle upward in elevation at 3.12 degrees per second rate
TILT DOWN	Drives CTV cradle downward in elevation at 3.12 degrees per second rate
TILT STOP	Stops elevation motion of CTV cradle
ZOOM OUT	Activates CTV zoom motor drive to decrease lens focal length
ZOOM IN	Activates CTV zoom motor drive to increase lens focal length
ZOOM STOP	Removes power to CTV zoom motors
IRIS OPEN	Activates CTV iris motor drive to decrease lens f/number
IRIS CLOSE	Activates CTV iris motor drive to increase lens f/number
IRIS STOP	Removes power to CTV iris motor
ALC PEAK	Provides latching relay drive pulse to CTV to provide automatic light control on peak scene luminence
ALC AVERAGE	Provides latching relay drive pulse to CTV to provide automatic light control on average scene luminence
POWER ON	1. Provides +28 Vdc power to CTV 2. Provides +28 Vdc power on LCRU FM transmitter control line 3. Commands 70-kHz subcarrier (S/C) ON
POWER OFF	1. Turns off power to CTV 2. Turns off power on LCRU FM transmitter control line
S/C ON	Provides latching relay contact closure between two S/C control lines from LCRU
S/C OFF	Opens latching relay circuit between two S/C control lines from LCRU

- All drives have override slip clutches that allow manual positioning of azimuth, elevation, iris, and zoom without rotation of the motor /gear train assemblies.
- All functions have electrical limit switches and mechanical stops at each end of the command function range.

4.3.1.1 Azimuth Drive

The azimuth drive consists of a stepper motor, a gearhead with reduction of 487:1, and a spur gear set with a 3.64:1 reduction. The drive provides for azimuth motion of 3.03-degrees per second. Real-time commands to PAN RIGHT, PAN LEFT, and PAN STOP control the azimuth motion. Relative to a looking-forward reference position the azimuth axis may be panned 134 degrees to the left and 214 degrees to the right.

4.3.1.2 Elevation Drive

The elevation drive uses a gearhead reduction of 48:1 and a spiroid gear set ratio of 36:1, to provide an elevation drive rate of 3.11-degrees per second. Real-time commands to TILT UP, TILT DOWN, and TILT STOP control the elevation motion. The camera may be tilted up by 85 degrees and down by 45 degrees relative to the horizontal (LRV lateral) plane.

4.3.1.3 Zoom Drive

Lens zoom is controlled by a stepping motor/gearhead assembly with a speed reduction of 192:1. The gearhead drives the zoom ring through spur gears at a reduction of 2.91:1 to provide a zoom ring drive rate of 9.7-degrees per second.

Real-time commands to ZOOM OUT, ZOOM IN, and ZOOM STOP control motion of the zoom drive. A command to ZOOM OUT decreases the focal length and increases the field of view. A command to ZOOM IN increases the focal length and magnifies the scene by decreasing field of view. The ZOOM OUT limits at a focal length of 12.5 millimeters to provide a 54-degree field of view (measured diagonally across the image format). The ZOOM IN limits at a focal length of 75 millimeters to provide a 9-degree diagonal field of view.

The zoom ring requires 142-degree rotation from limit to limit. Focal length as a function of zoom ring rotation is given in Table 4-3. The zoom drive traverses the 142-degree range in 14.6 seconds, maximum.

TABLE 4-3. MOTOR-DRIVEN REMOTE COMMAND FUNCTIONS

COMMANDS	DRIVE RATE	RANGE LIMITS*	TIME/RANGE**	REFERENCE
PAN RIGHT PAN LEFT PAN STOP	3.03°/second	134° left 214° right	112 seconds	0.0° = LRV X AXIS LOOKING FORWARD
TILT UP TILT DOWN TILT STOP	3.12°/second	45° down 85° up	42 seconds	0.0° IS IN LRV XY PLANE
ZOOM OUT ZOOM IN ZOOM STOP	9.7°/second	142°	14.6 sec	0° = 12.5 mm (ZOOM OUT LIMIT) 48° = 20 mm 84° = 30 mm 122° = 50 mm 142° = 75 mm (ZOOM-IN LIMIT)
IRIS OPEN IRIS CLOSE IRIS STOP	9.37°/second	123°	13.1 sec	0° = f/2 (IRIS OPEN LIMIT) 44° = f/4 83° = f/8 110° = f/16 123° = f/22 (IRIS CLOSE LIMIT)

* Range limits listed are to the mechanical stops. Electrical limit switches actuate before the mechanical stop is reached which reduces the range somewhat. Therefore, limits listed are the maximum limits. Actual limits should be obtained from calibration tapes on individual cameras.

** Time to cover range is reduced in proportion to the reduction in range imposed by the electrical limit switches.

4.3.1.4 Iris Drive

The iris drive uses the same stepping motor/gearhead assembly used in the zoom drive. A 3:1 gear reduction to the lens iris ring gives a drive rate of 9.37-degrees per second.

Real-time commands to IRIS OPEN, IRIS CLOSE, AND IRIS STOP control the iris drive. IRIS OPEN drives the iris ring toward the lower f/numbers (f/2.2 limit). IRIS CLOSE drives toward the minimum opening of f/22.

The iris ring rotates 123 degrees from limit to limit and traverses this range in 13.1 seconds maximum. Iris settings as a function of rotation in degrees are given in Table 4-3.

4.3.2 Position Prediction

The use of stepping motors in the GCTA design allows control of camera position and function on a predicted rather than a closed-loop basis. The GCTA stepping motors have no cumulative startup or stop delays and are controlled by a precise frequency source. This permits the relative azimuth and elevation positions of the CTV to be accurately determined in real-time at MCCH. The net right-left motion intervals that have been commanded for azimuth, and the net up-down motion intervals commanded for elevation are accmulated and multiplied by the respective motion rates for the azimuth and elevation axes. The position determination will be valid if no position overrides have been made by an astronaut.

Post-mission angular measurements also may be made, from pan sequences on a frame-by-frame basis. During pan motion, the camera field is moved by approximately 0.050 degree for each CTV field. Each camera is calibrated prior to flight for exact aximuth and elevation motion rates.

4.3.3 Motor Drive Command Interlock

Any of the motor-driven command functions can be operated by commands given in any sequence, including direct reversing commands (i.e. following PAN LEFT with PAN RIGHT). The design also allows operation of more than one command function at any one time. The following interlocks, however, are built into the decoder for the motor drive functions.

1. Electrical Limit. When a motor drive is driven to the point where the electrical limit switch is actuated, an automatic STOP command

is sent to the decoder. Further execution of a command which would drive the motor drive function further into the limit is inhibited until a reverse command is given to move the motor drive from the electrical limit condition.

2. Power Interlock. No motor drive functions will operate when the CTV is in the POWER OFF condition.

3. Power Dropout. If power is turned OFF while any motor drive is running, the motor drive will not continue to operate after restoration of power. The same holds true for momentary power interruptions.

4.4 SWITCHED COMMAND FUNCTIONS

Three switched command functions in the GCTA provide control of ALC mode, the 1.25 MHz down link voice subcarrier in the LCRU, and CTV power. These functions are controlled by latching relays in the TCU and CTV. Two commands are associated with each function to provide relay latching for either state. Table 4-4 summarizes the commands for the switched functions.

4.4.1 ALC Mode

ALC PEAK and ALC AVERAGE commands operate a latching relay in the CTV to control operation of the ALC and AGC circuits. In ALC PEAK, detectors in the ALC/AGC circuits are set to provide 100 percent video level for the brightest object in the scene. This mode is used for viewing astronauts, the LM, LRV, Earth, and to pan the horizon. ALC AVERAGE switches the ALC/AGC detectors to provide a 60 percent video level for the averaged scene. The AVERAGE mode is used for viewing the lunar terrain and to provide visibility into shadow areas.

4.4.2 LCRU Subcarrier (S/C) Control

S/C ON and S/C OFF operate a latching relay in the TCU that provides ON/OFF control of the 1.25 MHz downlink voice subcarrier in the LCRU (when the LCRU is in the TV remote mode of operation). The subcarrier remains ON during EVA operations (when the LCRU is used as the voice/data relay) but is switched OFF when voice and data are relayed through the LM. Switching the subcarrier OFF results in improved transmission of the television pictures.

TABLE 4-4. SWITCHED REMOTE COMMAND FUNCTIONS

COMMAND	FUNCTION
ALC PEAK	PROVIDES LIGHT CONTROL ON PEAK SCENE LUMINANCE
ALC AVERAGE	PROVIDES LIGHT CONTROL ON AVERAGE SCENE LUMINANCE
S/C ON	TURNS ON LCRU VOICE SUBCARRIER
S/C OFF	TURNS OFF LCRU VOICE SUBCARRIER
POWER ON	1. PROVIDES +28 Vdc POWER TO CTV 2. PROVIDES +28 Vdc ON LCRU FM TRANSMITTER CONTROL LINE 3. COMMANDS S/C ON
POWER OFF	1. TURNS POWER TO CTV OFF 2. TURNS OFF +28 Vdc ON LCRU FM TRANSMITTER CONTROL LINE

4.4.3 CTV Power Control

The POWER ON/POWER OFF switch controls a latching relay in the TCU for switching +28 Vdc power to the CTV. When the LCRU is in the TV remote mode, the power switch also provides ON/OFF control for the FM transmitter in LCRU. This mode enables TV operation between EVA' s and at LM liftoff by ground command, without requiring continuous operation of the FM transmitter. The POWER ON/OFF switch also provides a control pulse to the S/C ON/OFF latching relay to turn the S/C ON.

4.4.4 Control Overrides and Interlocks

The CTV power and ALC mode functions may be manually controlled by switches located on the TCU and CTV connector blocks. These switches have three positions, with a spring return to the center position. In the center or REMOTE position, the associated ground commands are operative. However, the switches override the ground command when manually operated to either extreme position (i.e. POWER ON/POWER OFF or ALC PEAK/ALC AVERAGE). The switches control the states of the power control and ALC mode latching relays. The override exists, however, only as long as the switch is held in an extreme position. When released, the switch returns automatically to the center REMOTE position in which ground commands are effective in controlling the associated latching relay.

The following interlocks are provided for the switched command functions:

1. ALC PEAK/AVERAGE and S/C ON/OFF are operable only when the CTV is in a POWER ON condition. When the CTV power is OFF, the TCU decoder is in a standby condition and will respond only to a POWER ON command.

2. The subcarrier control relay is interlocked to the CTV power control relay and POWER ON always provides an S/C ON condition. However, this interlock is not effective if CTV-power is turned ON by the manual control switch.

3. Latching relay state is not affected by power interruptions. When the CTV is turned OFF and then ON again, the ALC mode remains the same as before the power turnoff. Similarly, if power to the GCTA is turned OFF by the LCRU mode control switch and then turned ON again, the CTV power, ALC mode, and S/C control relays will remain in the states they were in prior to the power interruption.

4.5 OPERATIONAL CONSTRAINTS

The following operational constraints should be observed when operating the GCTA by ground command control.

4.5.1 GCTA Warmup

When operating within normal temperature limits (0° C to 40° C), a warmup time of 15 seconds should be allowed for the GCTA to operate within its performance specification.

4.5.2 Decoder Lockup

If transmission of the 70 KHz command subcarrier to the GCTA is interrupted for any reason, a period of 10 seconds should be allowed after restoration of the command subcarrier before commands are sent to assure that the decoder synchronization circuits have locked to the command signal.

4.5.3 Multiple Motor Drive Operation

Although all motor-driven functions may be commanded to operate simultaneously, simultaneous multiple operation is restricted to two motor-driven functions to prevent excessive power drain from the LCRU.

4.6 THERMAL CONSTRAINTS

The CTV and TCU are subject to thermal operating constraints on the lunar surface which are defined in accordance with specific mission time lines. These constraints define orientation and LRU parking for various mission phases. No generalized constraints will be presented here.

4.6.1 Temperature Monitoring and Control

Temperature response characteristics and successful thermal control of the CTV during lunar surface operation depends on camera ON time, operating duty-cycle, and CTV orientation to the lunar surface. Vidicon temperature is sensed and telemetered from the CTV by pulse-duration modulation of the color flag pulse (present on line 18 of every third (green) field). The format and approximate calibration of this color flag telemetry are given in Figure 1-22.

A removable thermal insulation blanket is supplied to cover the CTV radiator. The blanket may be placed on the camera at the start of the mission to be removed at a time determined by the type of mission being executed. Continuous operation with the blanket in place (covering the radiation) should not exceed one hour.

Thermal data are generated for each specific Apollo mission to determine the modes of CTV thermal control. Any deviation from the mission flight plan can change the method of thermal control for the camera. If the flight plan does change, curves reflecting the steady-state and transient thermal response of the camera have been prepared. The curves determine the steady-state temperature that the vidicon target will try to reach for selected sun angles and camera radiator tilt angles. To determine how long it will take the camera vidicon target to change from one temperature level to another, transient curves for a particular orientation are entered at the initial temperature and the time required to reach the desired temperature is determined.