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APOLLO EXPERIENCE REPORT -
LUNAR MODULE INSTRUMENTATION SUBSYSTEM

by David E. O'Brien III and Jared R. Woodfill IV

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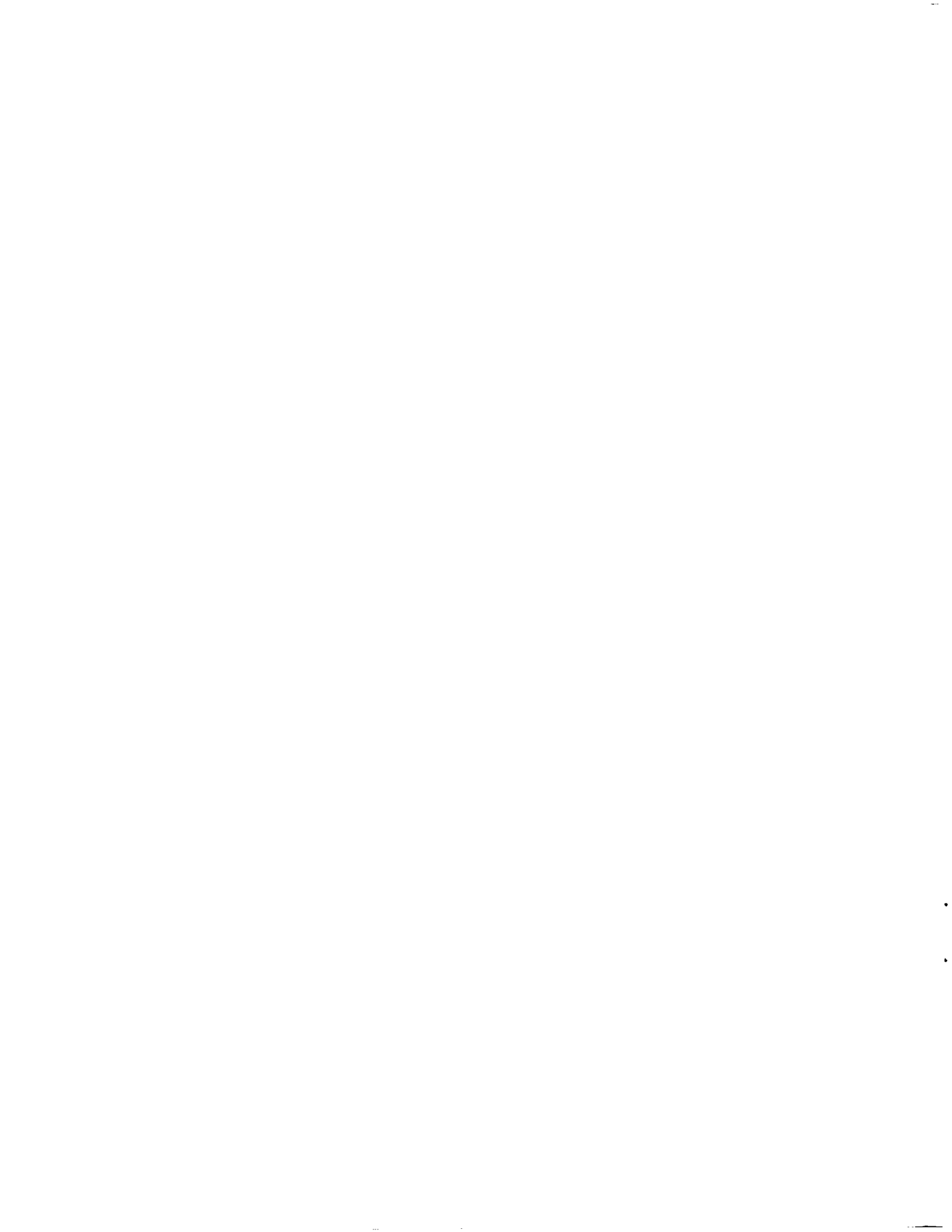


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16. Abstract The design concepts and philosophies of the lunar module instrumentation subsystem are discussed along with manufacturing and systems integration. The experience gained from the program is discussed, and recommendations are made for making the subsystem more compatible and flexible in system usage. Characteristics of lunar module caution and warning circuits are presented.					
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CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
DISCUSSION	1
Signal Conditioning Electronics Assembly	2
Caution and Warning Electronics Assembly	11
Data Storage Electronics Assembly	13
Transducers	15
CONCLUSIONS AND RECOMMENDATIONS	18
APPENDIX — LUNAR MODULE CAUTION AND WARNING SYSTEM CHARACTERISTICS AND NUISANCE ALARMS	20

TABLE

Table		Page
I	CHARACTERISTICS OF SUIT FAN CAUTION (GL4056) AND WARNING (GL4037) CIRCUITS	34

FIGURES

Figure		Page
1	Lunar module instrumentation subsystem	2
2	Power supply in each SCEA subassembly	3
3	Direct-current amplifier 501-1	3
4	Attenuator 502-2	4
5	Alternating current to direct current converter 503-2	4
6	Analog signal isolating buffer 504-1	5
7	Discrete signal isolating buffer	5
8	Signal isolating buffer 504-3, 4, 5	6
9	Frequency-to-dc converter 505-1	6
10	Resistance-to-dc converter 506-2, 3	7
11	Phase-sensitive demodulator 507-1	7
12	Electronic replaceable assembly	8
13	Discrete buffer, showing the lead to power ground rerouted to signal ground	9
14	Discrete buffer, showing how the 200-foot ground lead produced a +6-V dc potential between SCEA and signal ground	10
15	Discrete buffer, showing how a 50 000-ohm resistor between SCEA power and ATCA transistor produced approximately 18 V dc when transistor was off	11
16	Caution and warning electronics assembly	12

Figure		Page
17	Functional block diagram of DSEA	14
18	Ascent pressure failure-detection circuit	22
19	Helium pressure regulator manifold failure-detection circuit	23
20	Control electronics section dc power-supply failure-detection circuit	25
21	Control electronics section ac power-supply failure-detection circuit	26
22	Abort guidance section power-supply failure-detection circuit	27
23	Lunar module guidance computer failure-detection circuit	29
24	Reaction control subsystem TCA failure-detection circuit	31
25	Reaction control subsystem helium pressure regulator failure-detection circuit	32
26	Environmental control subsystem suit outlet pressure failure-detection circuit	33
27	Electrical power subsystem inverter voltage and frequency failure-detection circuit	36
28	Radar data-no-good indicators for LM-3 and LM-4	
	(a) Early landing radar logic	38
	(b) Early rendezvous radar logic	38
29	Radar data-no-good indicators for LM-5 and subsequent vehicles	
	(a) Revised landing radar logic	38
	(b) Revised rendezvous radar logic	39
30	Explosive devices subsystem stage sequence failure-detection circuit	40
31	Heater caution circuit	43
32	Typical plot of carbon dioxide pressure variation during ground checkout	45
33	S-band receiver AGC failure-detection circuit	45

Figure		Page
34	Descent propellant low-level quantity circuit	
(a)	For LM-3 and LM-4	46
(b)	For LM-5 and subsequent vehicles	46

ABBREVIATIONS AND ACRONYMS

A	amperes
ac	alternating current
AE	abort electronics
AEA	abort electronics assembly
AGC	automatic gain control
AGS	abort guidance section
AMB	ambient
ang	angular
AOH	Apollo Operations Handbook
approx	approximately
ASA	abort sensor assembly
ASC	ascent
assy	assembly
ATCA	attitude and translation control assembly
ATP	acceptance test procedure
C	caution
CB	circuit breaker
CDR	commander
CES	control electronics section
ckt	circuit
CO ₂	carbon dioxide
COMD	command
COMM	communications
compar	comparator

cond	conditioner
conn	connector
CWEA	caution and warning electronics assembly
dc	direct current
DECA	descent engine control assembly
DEDA	data entry and display assembly
DES	descent
diff	differential
DISP	display
DSEA	data storage electronics assembly
DSKY	display and keyboard
DT	delay timer
DVT	design verification test
ECS	environmental control subsystem
ED	explosive devices
ERA	electronic replaceable assembly
EVA	extravehicular activity
F	farad
freq	frequency
ft	feet
GND	ground
GSE	ground-support equipment
H	high
H ₂ O	water
He	helium

hr	hours
Hz	hertz
ICS	intercommunication system
INCR	increase
in.	inch
ind	indicator
inv	inverter
k	kilo
kpps	kilopulses per second
L	low
LD	level detector
LGC	lunar module guidance computer
LM	lunar module
LR	landing radar
LTA-8	LM test article 8
MA	master alarm
min	minutes
MSC	Manned Spacecraft Center
msec	milliseconds
MSFN	Manned Space Flight Network
O ₂	oxygen
OPER	operate
oxid	oxidizer
PCM	pulse code modulation
PCMTEA	pulse code modulation and timing electronics assembly
P/J	connector designator



PQGS propellant quantity gaging system
PQMD propellant quantity measuring device
PRESS pressure
PROP propellant
P/S power supply
psia pounds per square inch absolute
PTT push to talk
PWD pulse-width detector
QTY quantity
R reset
RCDR recorder
RCS reaction control subsystem
RCV receive
RCVR receiver
RD relay driver
rect rectifier
reg regulator
ret return
rms root mean square
rpm revolutions per minute
RR rendezvous radar
S set
SC signal conditioner
S&C stabilization and control
SCEA signal conditioning electronics assembly
sec seconds

sel	selector
SENS	sensitivity
sep	separator
sig	signal
STDBY	standby
SUPCRIT	supercritical
sys	system
TCA	thrust chamber assembly
TCD	time-correlation data
TEMP	temperature
TMF	test mode fail
T/R	transmit/receive
TV	television
V	volts
VD	voltage detector
vel	velocity
vhf	very high frequency
VOX	voice-operated relay
W	warning
WQMD	water quantity measuring device
WSTF	White Sands Test Facility
Δ	difference
μ	micro
ϕ	phase
Ω	ohms

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LUNAR MODULE INSTRUMENTATION SUBSYSTEM
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Manned Spacecraft Center

SUMMARY

The lunar module instrumentation subsystem processes approximately 250 measurements during each mission for display, caution and warning, and telemetry. These measurements include analog measurements (pressure, temperature, and quantity) and discrete measurements (switch closures and step voltages). Some problems were encountered with the various components of the subsystem from manufacturing through preflight checkout, but the subsystem performed well in flight. The only inflight problems were broken spacecraft wires going to the lunar module 5 data storage electronics assembly and to a pressure transducer on lunar module 4, noticeable data shifts on two lunar module 4 pressure transducers and a lunar module 3 water quantity measuring device, and nuisance caution and warning alarms. The primary preflight problems were pressure transducers shifting off calibration (usually less than 5 percent), water quantity measuring devices shifting off calibration (3 to 10 percent), and interface problems involving the signal conditioning electronics assembly. The pressure transducers were redesigned to alleviate the shifting problem. Modifications to the interface circuits were required to overcome the signal conditioning and nuisance caution and warning alarm problems.

INTRODUCTION

The lunar module (LM) instrumentation subsystem monitors the LM subsystems during preflight and inflight activities and prepares the data for entry into the pulse code modulation and timing electronics assembly (PCMTEA) and subsequent transmission to the Manned Space Flight Network (MSFN). In addition, critical parameters are monitored for out-of-tolerance conditions, and voice and time-correlation data (TCD) are stored for recovery after the return to earth.

DISCUSSION

The LM instrumentation subsystem consists of a signal conditioning electronics assembly (SCEA), a caution and warning electronics assembly (CWEA), a data storage electronics assembly (DSEA), and transducers (fig. 1). Each of these components is discussed separately in the following sections.

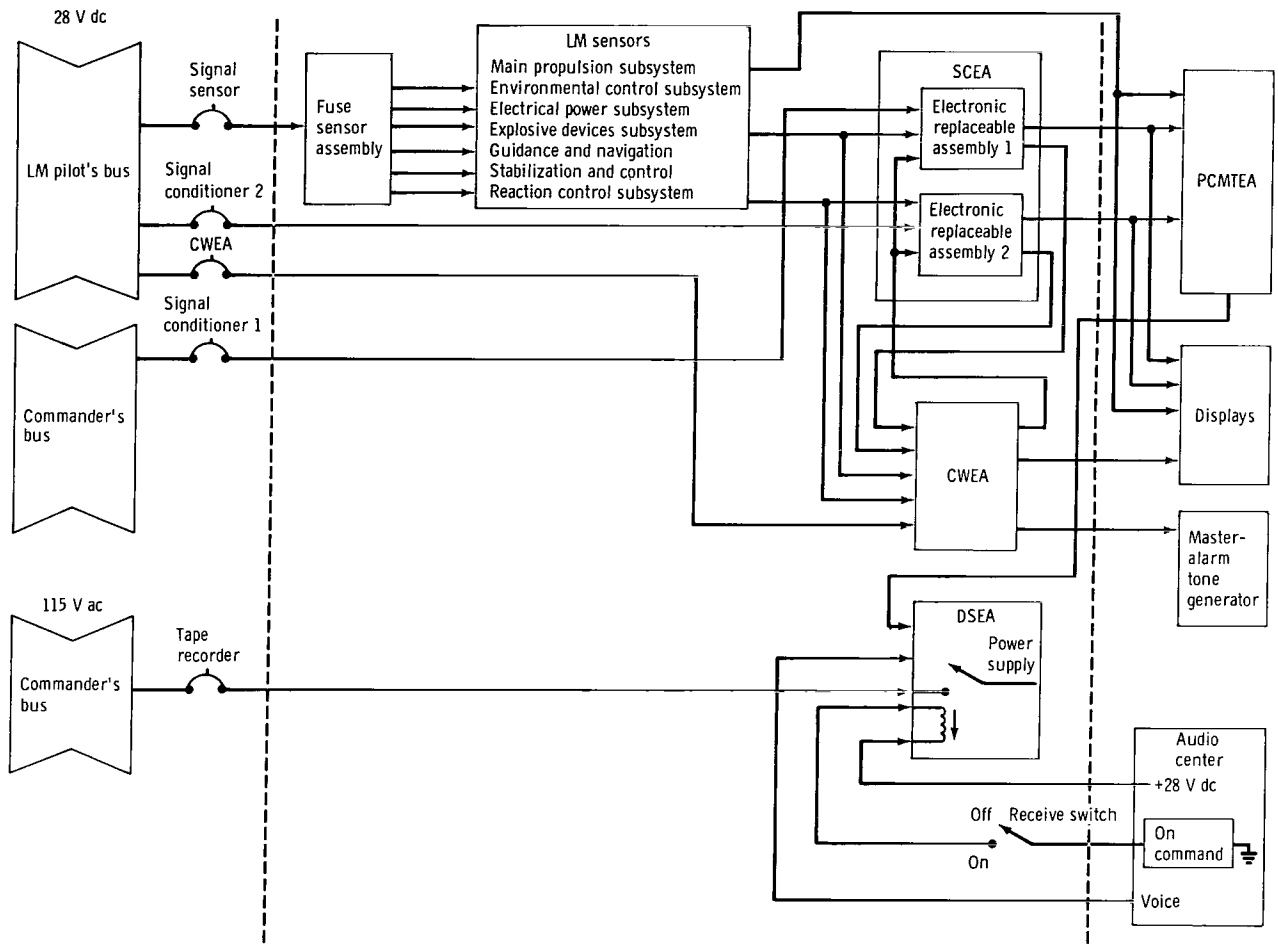


Figure 1. - Lunar module instrumentation subsystem.

Signal Conditioning Electronics Assembly

The SCEA converts all unconditioned transducer (sensor) signals and events with one or more of its seven basic subassemblies to the proper voltage levels required by the PCMTEA, CWEA, and displays. Isolation also is provided between the CWEA and the other users of a shared signal. The seven basic subassemblies are dc amplifiers, dc attenuators, ac-to-dc converters, analog and discrete isolating buffers, frequency-to-dc converters, resistance-to-dc converters, and phase-sensitive demodulators (figs. 2 to 11). The SCEA consists of two chassis called electronic replaceable assemblies (fig. 12), each of which has a capacity of 22 subassemblies. The electronic replaceable assembly (ERA) provides the interface connections between the subassemblies and the unconditioned signals. Each subassembly can be replaced easily with another subassembly of the same type, even after the ERA has been installed in the flight vehicle.

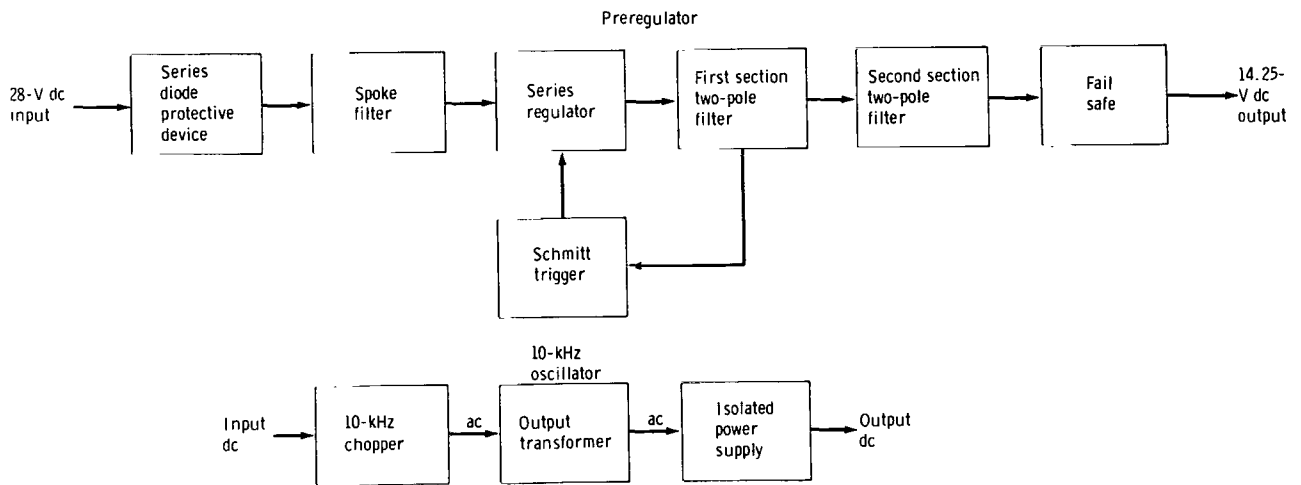


Figure 2. - Power supply in each SCEA subassembly.

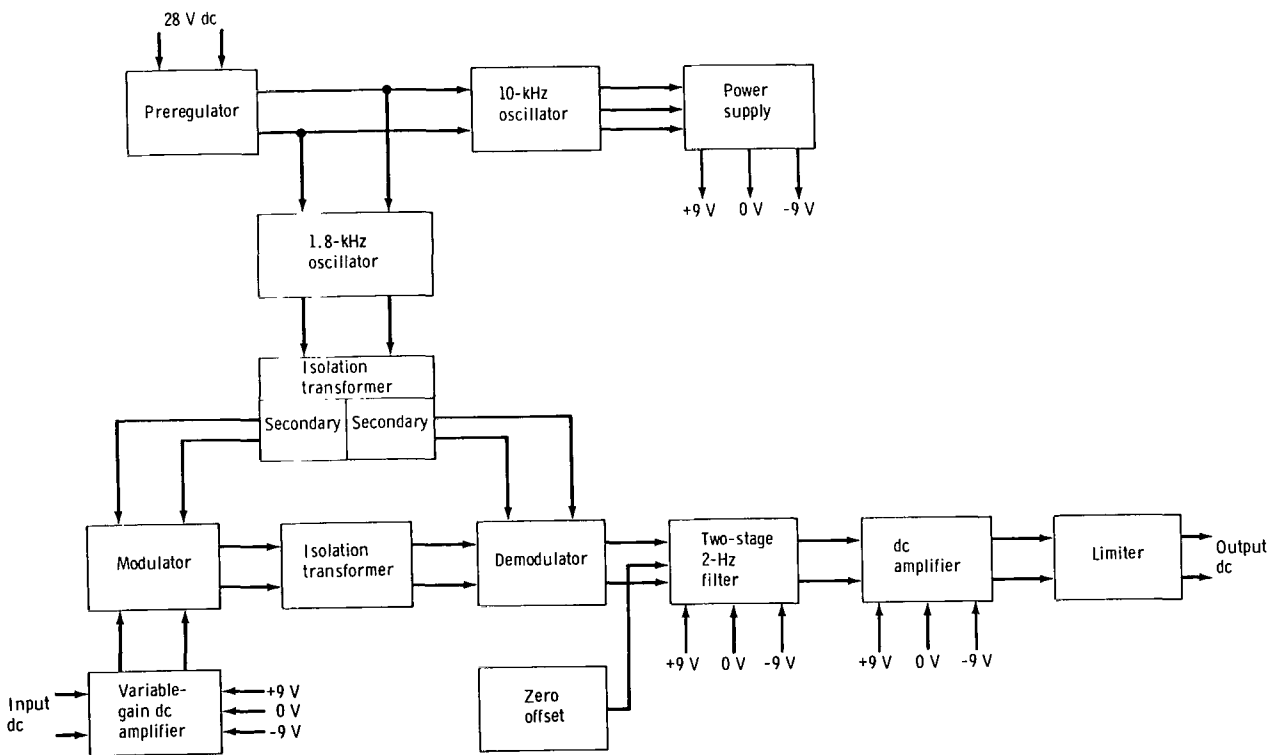


Figure 3. - Direct-current amplifier 501-1.

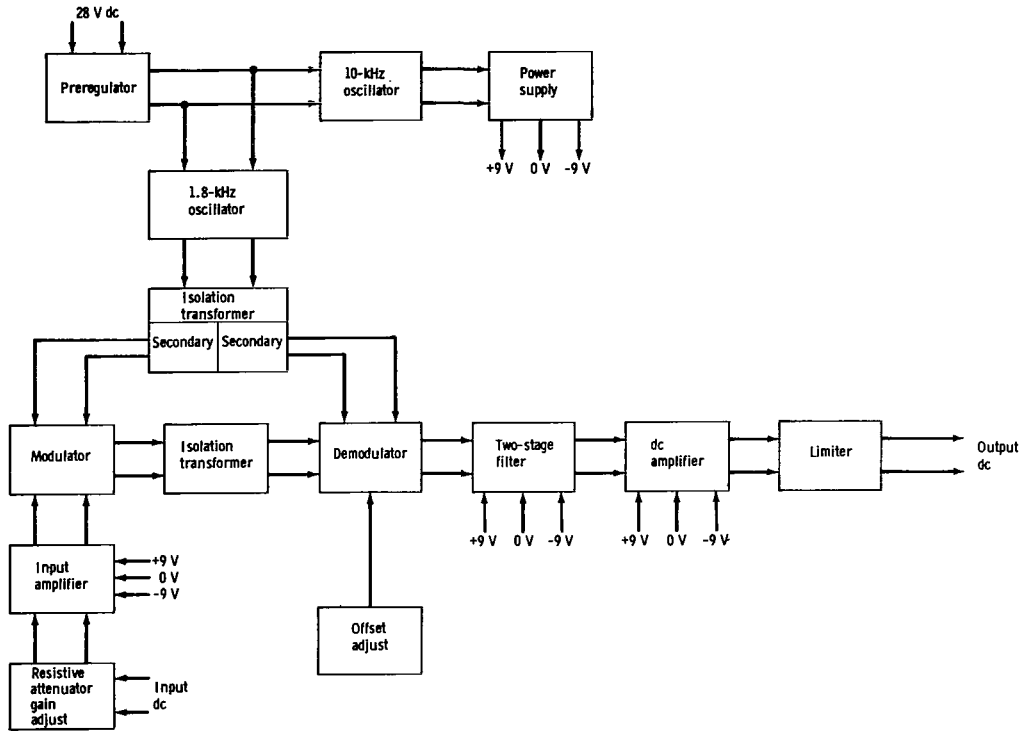


Figure 4. - Attenuator 502-2.

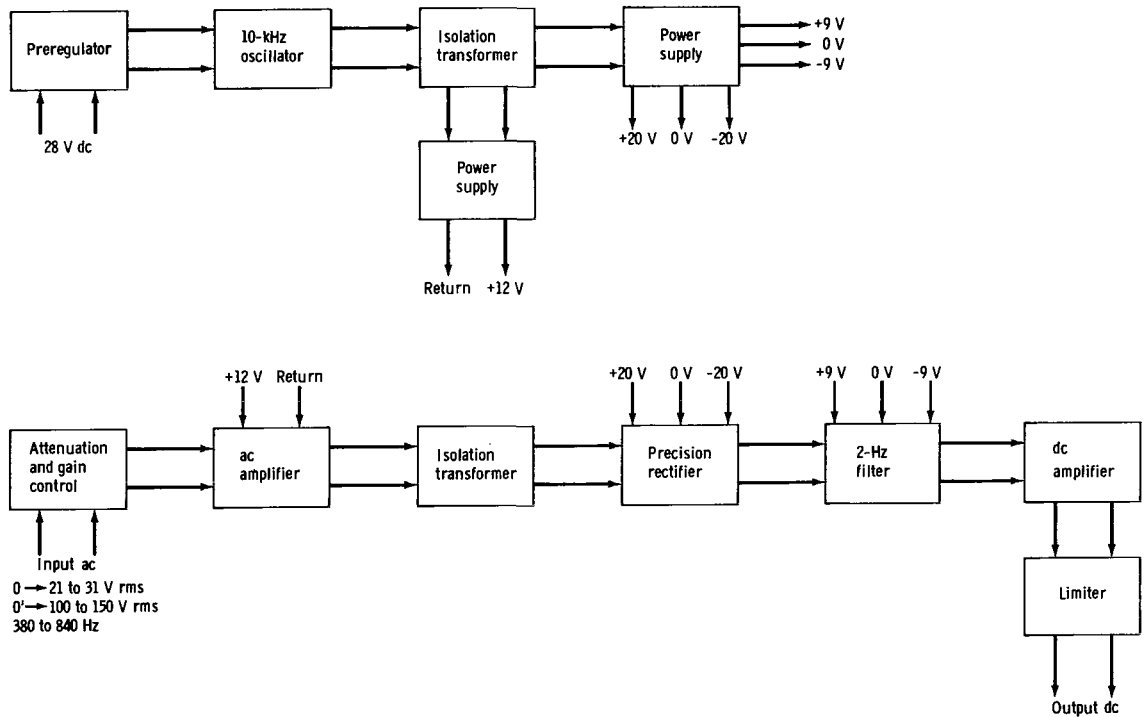


Figure 5. - Alternating current to direct current converter 503-2.

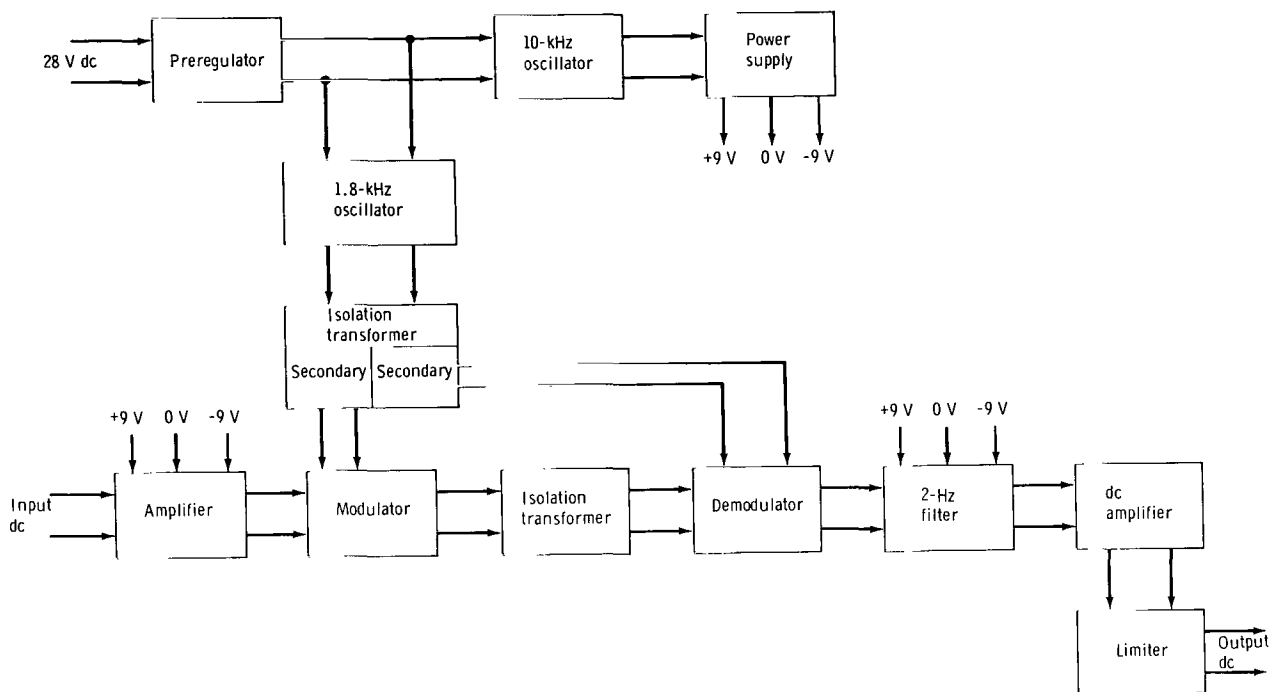


Figure 6. - Analog signal isolating buffer 504-1.

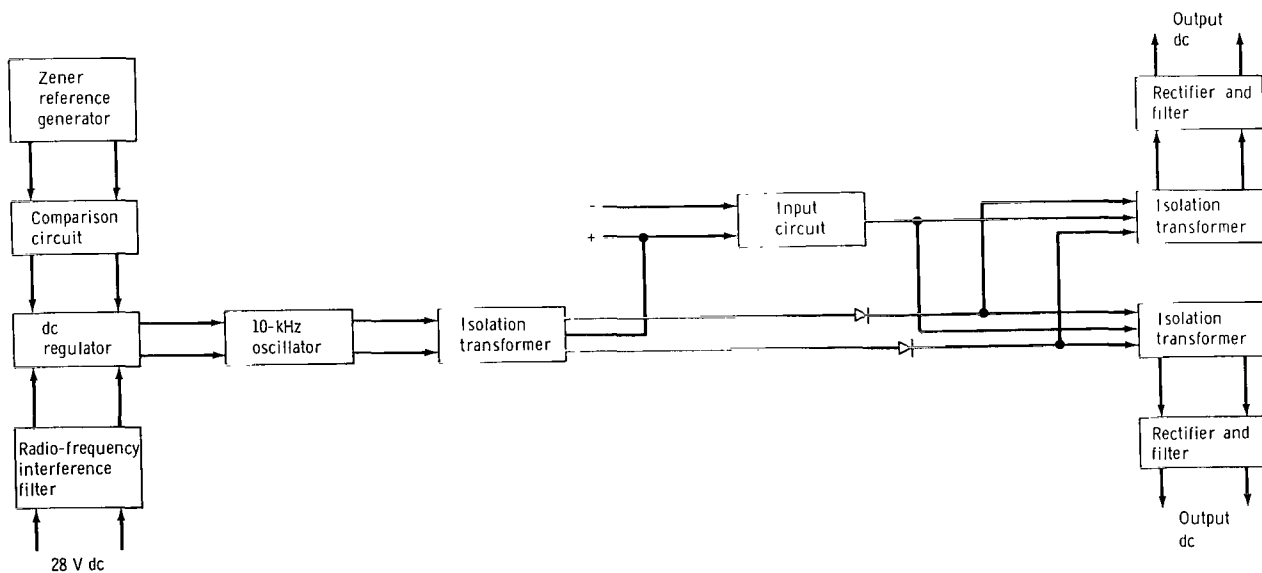


Figure 7. - Discrete signal isolating buffer, 504-2.

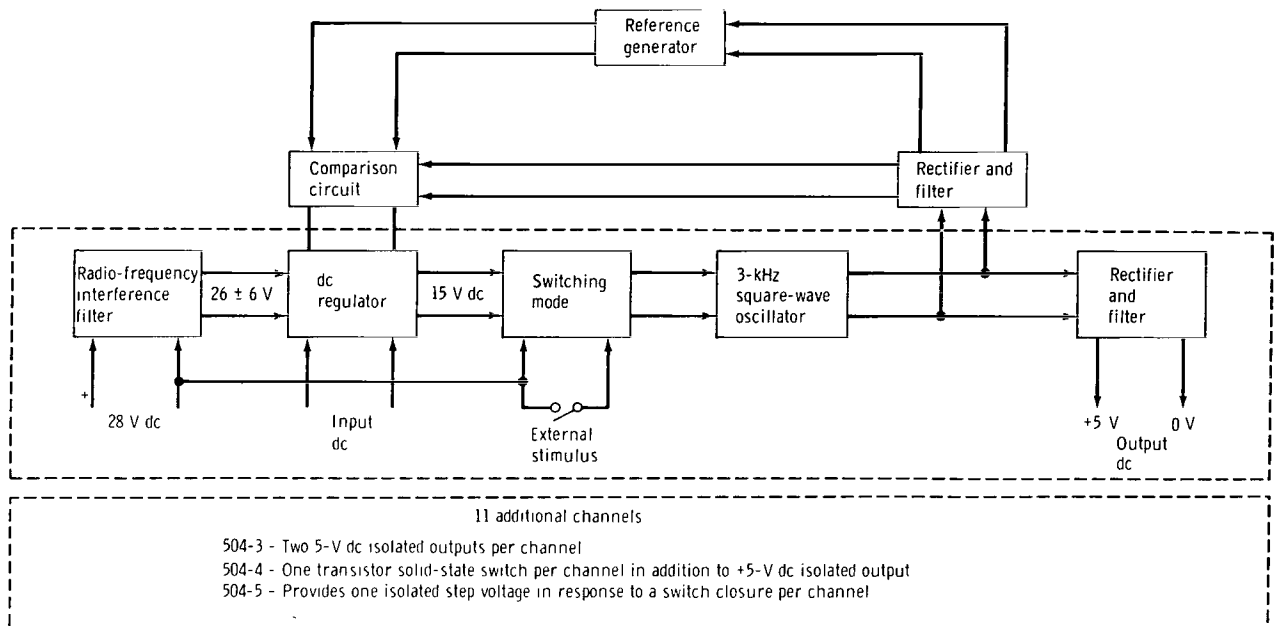


Figure 8. - Signal isolating buffer 504-3, 4, 5.

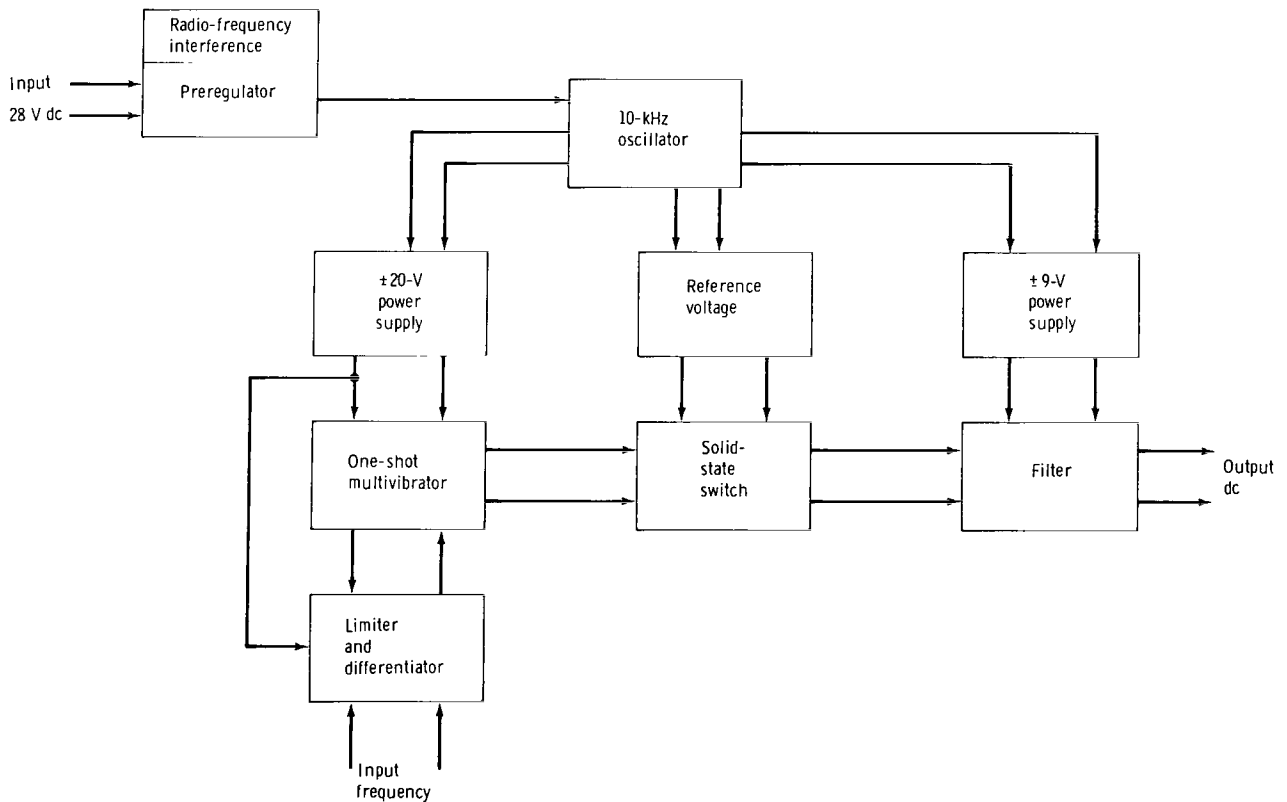


Figure 9. - Frequency-to-dc converter 505-1.

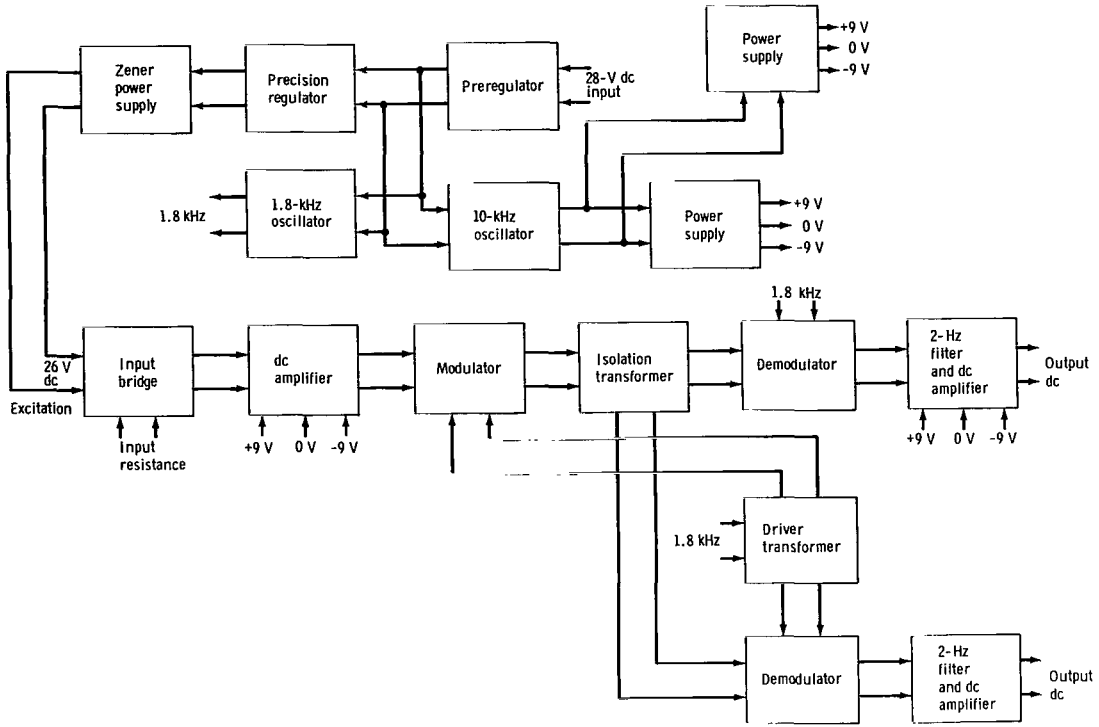


Figure 10. - Resistance-to-dc converter 506-2, 3.

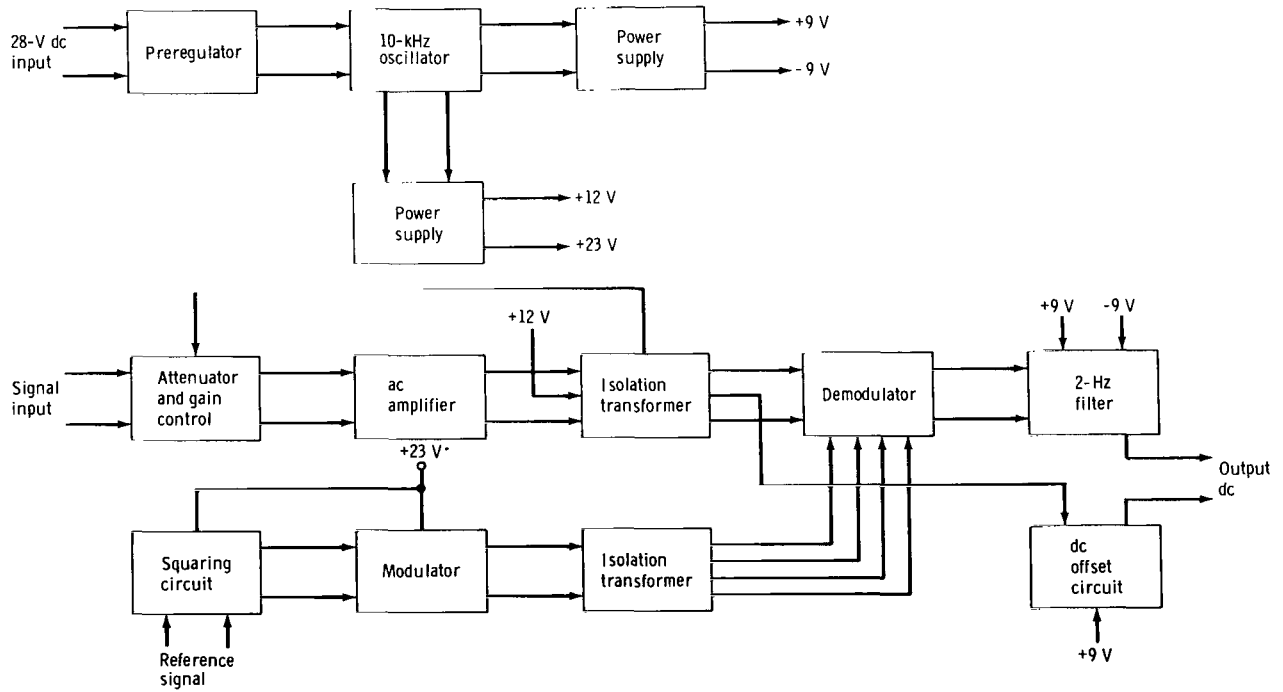


Figure 11. - Phase-sensitive demodulator 507-1.

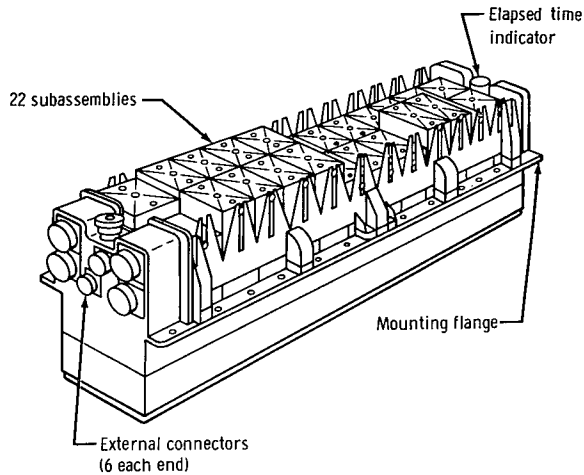


Figure 12. - Electronic replaceable assembly.

This concept of plug-in subassemblies with point-to-point wiring (subassembly plug-in connector to the unconditioned signal-input connector) in the ERA was developed through consultation among NASA personnel, LM contractor personnel, and command module contractor personnel who designed the command and service module signal-conditioning equipment. This design was required (1) to vary the mix of each circuit according to the requirement of each vehicle, (2) to replace a minimum of hardware in case of a failure, (3) to provide accessible gain and zero adjustments, (4) to achieve minimum weight and power and maximum reliability, and (5) to adapt to the shape dictated by the space in the aft equipment bay. Much of this flexibility was lost, however, during a weight-saving program that resulted in removal of all spare

wiring. The removal of the spare wiring requires that wires be added or rerouted (or both) whenever an ERA subassembly is replaced with another type of subassembly or whenever a subassembly is added to an ERA spare location. The signal-conditioning requirements for the remaining vehicles were supposedly firm when this decision was made, but subsequent requirement changes have been costly to implement because of the charges for retention of personnel to perform the work and the acceptance test procedure (ATP).

The circuits were designed according to the following ground rules.

1. No ground or common loops in the instrumentation subsystem
2. Minimal fault propagation
3. Multirange capability for each subassembly

These ground rules required that the SCEA provide isolation between the CWEA and PCMTEA (both grounded systems), isolation between the monitoring systems (CWEA, PCMTEA, and displays) and grounded sources (batteries and transducers), and isolation between the battery ground and the signal ground. A further requirement was that the SCEA be designed to protect the CWEA from the effect of failures in the pulse code modulator (by a short across an output or a failure in a circuit) and that each subassembly be capable of accepting signals with a variety of ranges.

To accomplish the requirements established by these ground rules, isolation transformers, independent power supplies in each subassembly, and trim potentiometers were needed in the complex circuits. Approximately 16 500 parts are required for each SCEA to provide 266 channels of signal conditioning.

In manufacturing these subassemblies, welded cordwood construction (with full encapsulation in potting) was chosen because this method provides the highest packing density and reliability. The only problems involved with the manufacturing were those resulting from the extremely high packing density of the modules.

With so many welds, it was easy to overlook one or more, and it was difficult for the inspectors to find any manufacturing errors. This situation resulted in many reworked units and a delay in the deliveries. Only nominal piece-part failures occurred during the qualification tests and in flight. The most significant of these failures were shorted transformers and cracked Mepco resistors. An additional thermal cycle was incorporated into the ATP to identify these weak components.

Some difficulties arose during the vehicle/instrumentation-subsystem integration. One of the most difficult problems involved the discrete buffer that monitors the reaction control subsystem (RCS) thruster commands in the attitude and translation control assembly (ATCA) (fig. 13). The discrete buffer is designed to monitor either mechanical or solid-state switch closures. The buffer gives a 5-volt ON signal when the resistance across mechanical contacts drops below 120 000 ohms or when the voltage across a solid-state switch drops below 4 volts with a corresponding drop in resistance. The firing command is given in the ATCA by grounding the low side of a solenoid through a transistor switch. The inputs of the discrete buffers are connected across the transistor so that, when the system is activated, the buffer input senses 28 volts until a firing command is given; then, voltage drops to zero and the buffers produce a 5-volt ON output signal. The problem arose when the solenoid circuit breaker was open and no voltage was present across the transistor and buffer inputs. The high emitter-to-collector resistance normally prevents the buffer from giving the ON signal. However, during these periods of no voltage on the transistor, the buffer would occasionally output the 5-volt ON signal. This problem was attributed to noise on the power ground to which one side of the buffer was connected. This connection was moved to signal ground, and the other input remained on the high side (emitter) of the transistor.

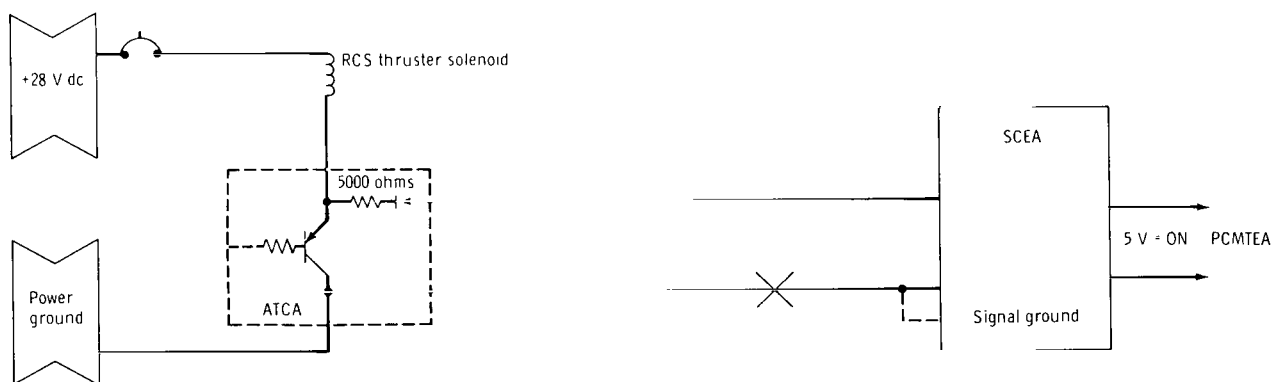


Figure 13. - Discrete buffer, showing the lead to power ground rerouted to signal ground.

After this change, RCS tests were performed at the White Sands Test Facility (WSTF), and a new problem appeared in the form of short-firing indications. The buffer would give the ON command and then go OFF after a few seconds while the ATCA was still firing the thrusters. The cause of this problem was traced to the setup at the WSTF. The ATCA and the SCEA were located in the blockhouse, and command wires were routed to the pad where the thruster and the electrical power were located. Therefore, the ground wire leading from the collector of the transistors was approximately 200 feet in length (fig. 14). When the firing command was given, the voltage at the transistor dropped to zero, but rose to 6 volts as the current through the solenoid increased. This 6-volt rise was caused by the IR (current \times resistance) drop across the 200-foot ground lead. If the buffer had been connected in the original configuration, with its low side on the collector instead of on signal ground, this short-firing indication would not have occurred. Only a small (0.5 volt) drop across the transistor rather than the 6-volt drop between the transistor and the battery ground would have reached the buffer. No modification was made to the WSTF test setup after the problem had been identified.

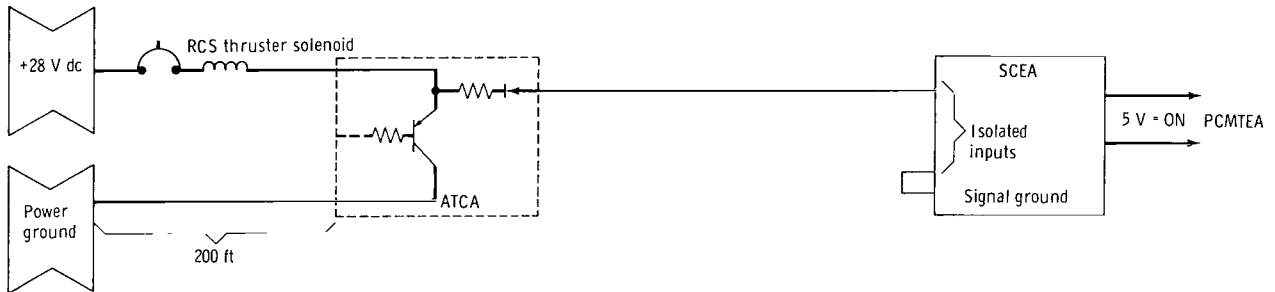


Figure 14. - Discrete buffer, showing how the 200-foot ground lead produced a +6-V dc potential between SCEA and signal ground.

Meanwhile, the first problem (spurious jet firing) still was occurring occasionally. Further investigation revealed that some of the ATCA transistors had a low emitter-to-collector resistance of approximately 120 000 to 130 000 ohms. This low resistance, with noise on the power ground, was sufficient to trigger the buffer into the ON state sporadically. With the new information, the low side of the buffer input was returned to the collector side of the transistor, and a 50 000-ohm resistor was placed between the SCEA circuit breaker and the emitter side of the ATCA transistor (fig. 15). This resistor formed a voltage divider whenever the SCEA was energized and maintained approximately 18 volts across the buffer input until the transistor switched on and the voltage dropped to approximately 0.5 volt. The current through the resistor and transistor was negligible with the transistor on or off. This arrangement proved to be a satisfactory fix for the interface incompatibility.

The first problem occurred again when the open-contact resistance of a relay decreased with usage until it reached the 120 000-ohm level and triggered the buffer on. This condition was eliminated in a similar manner.

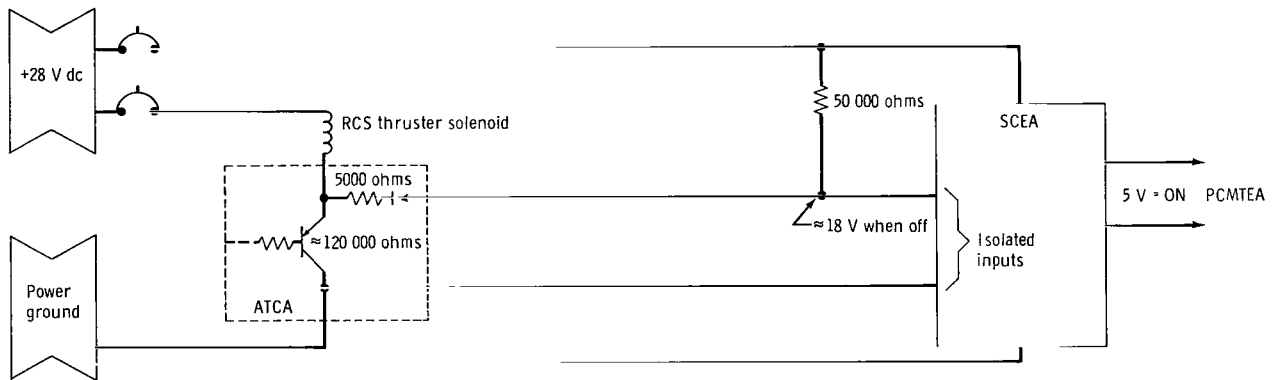


Figure 15. - Discrete buffer, showing how a 50 000-ohm resistor between SCEA power and ATCA transistor produced approximately 18 V dc when transistor was off.

The worst prelaunch vehicle problem with the SCEA involved intermittent failures. Some instances occurred when measurements that were inexplicably bad for a short time cleared up before the defective item in the measurement link could be identified. Extensive testing of the suspected components was required to repeat the failure. Some of the SCEA subassemblies underwent several thermal vacuum tests and many thousands of operational cycles before they would repeat a failure mode. Overall, there were few prelaunch vehicle problems at the NASA John F. Kennedy Space Center and no inflight failures of the SCEA.

The basic design concepts and the resulting SCEA have proved adequate to satisfy the signal-conditioning requirements of the LM instrumentation. The only major drawback to the present SCEA is the lack of flexibility in subassembly arrangement in the electronic replaceable assemblies. When the weight-saving campaign resulted in removal of all wiring not being used for existing circuits, the type of subassembly for a given location was fixed, and the spare locations were useless. Although the majority of the signal-conditioning requirements have remained unchanged, some of the spare locations and all of the unused subassembly channels should have been kept fully wired to meet new requirements. In addition, there should be a means of changing the ranges of the resistance-to-dc converters without reworking either the subassembly or the ERA. The changes caused by new requirements and the range of the resistance-to-dc converters have been very costly because of this inflexibility.

Caution and Warning Electronics Assembly

The concept of a real-time monitoring system to provide the LM crew caution and warning signals by an alarm tone and master-alarm indicator light evolved in 1965. An approach was taken in which the most critical parameters would be processed by a single unit called the CWEA (fig. 16). Software requirements for the logic of the unit (which included inhibits, enables, and level detectors) were determined through coordination with the LM subsystem engineers for the critical subsystems. A vendor was selected on the basis of technical and production capability and proximity to the LM contractor. Welded cordwood construction was selected as the fabrication and packaging

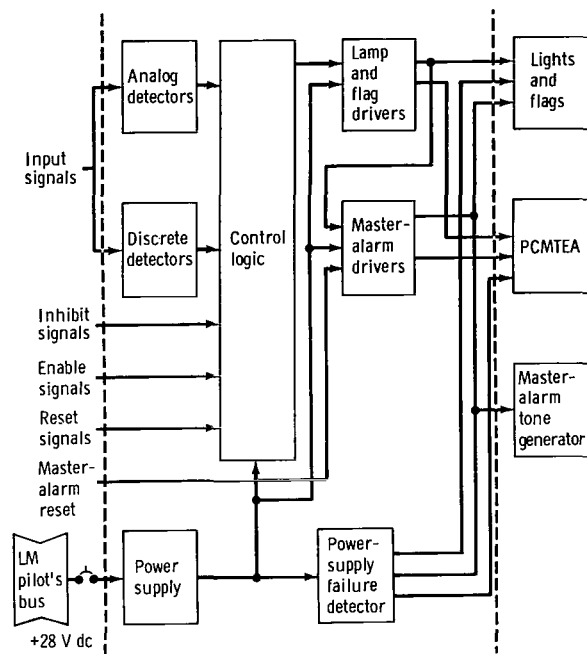


Figure 16. - Caution and warning electronics assembly.

technique for the CWEA, and a subcontractor was selected by the vendor to package the 29 logic components. A second subcontractor was chosen to manufacture the relay component and the four power-supply components. The final construction, including the completed assembly and testing, was accomplished by the vendor.

The design of the CWEA box included such salient features as accessible trim-level resistors to facilitate trip-level modifications after final CWEA unit assembly; the use of switch-closure relay outputs in place of solid-state closures (to eliminate system electrical-interface problems); a redundant power supply; and a triple redundancy with majority-voting logic, micro-circuit counter logic in a selected number of channels, and flip-flop resettable logic for one-third of approximately 100 inputs. The redundant power supply and the redundancy voting logic were eliminated as an LM weight-saving measure.

Parts vendors were selected by the CWEA vendor to provide the 3000 parts for each CWEA. All parts requests were processed and approved by the LM contractor, with NASA concurrence. A major testing program was conducted to evaluate relays, and a miniature Wabco type was selected.

A program of monthly meetings was established at the vendor facility to permit periodic discussion of technical problems, delivery-status monthly progress, costs, manpower, and testing by LM contractor representatives, NASA engineering representatives, and others related to the current program problems. During these meetings, many problems were solved through the coordination of experienced LM contractor, vendor, and NASA engineers who traded ideas and suggested solutions to problems.

In 1966 and 1967, delivery of the CWEA became the pacing item for total LM completion as defined by the Program Evaluation and Reporting Technique network instituted by the LM contractor. Production was expedited at the vendor facility, and the design verification test (DVT) models and their associated tests were deleted. A DVT unit then was used satisfactorily in the LM test article 8 (LTA-8) thermal vacuum test-vehicle program, thus reducing schedule difficulties and costs for the overall CWEA program. Changes to the CWEA, resulting from LM-system-design modifications, were made with no impact upon final LM-delivery dates.

A thorough qualification test program was an integral part of the total CWEA program; design, fabrication, and test preparation were accomplished concurrently with CWEA assembly. One manual test station and two automatic test stations were manufactured by the vendor and successfully used for the qualification tests, which were successful also.

The manufacture of the CWEA was completed with the occurrence of only one serious problem. Improper setup of a thermal curing chamber caused an entire assembly to be overstressed and scrapped. A reallocation of assembled units prevented the loss of the unit from affecting LM delivery.

Throughout the test program and whenever problems occurred, NASA engineers traveled to the LM contractor and vendor facilities to monitor tests and to implement solutions to these problems. The greatest NASA input to the CWEA program occurred when CWEA integration into the LM indicated numerous unforeseen system difficulties. Most of the difficulty arose from lack of system planning earlier in the total LM program and a lack of communication between the subsystem managers and the caution and warning system managers. A series of weekly (and, later, monthly) meetings was instituted at the LM contractor facility at the request of NASA to work out immediate solutions to the system difficulties. A representative from the NASA Manned Spacecraft Center (MSC) participated in these meetings, and the system problems were solved.

The CWEA performed in an outstanding manner on the lunar missions, and a program was set up by NASA to analyze all recorded master alarms for system problems before, during, and after the lunar mission. As a result of this program, information was compiled in semitechnical language and drawings on all known caution and warning alarms caused by interface idiosyncrasies. Additions and deletions were incorporated in later revisions as engineering changes were implemented and as analyses of test and mission data revealed additional system incompatibilities. This information is contained in the appendix of this paper. Because of the lack of latching CWEA circuitry, some difficulty was encountered in identifying the channel that initiated a master alarm. A more suitable CWEA design would have included latching/resettable CWEA inputs on every channel rather than on one-third of the channels. Also, the level detectors would preferably have been field adjustable. Several CWEA functions had to be deleted because of measurement-range changes that caused the CWEA to trip at unwanted levels.

The success of the CWEA program resulted from a continued dialogue that included representatives of NASA; representatives of the LM contractor; and vendor design, test, and systems engineers. Such communication ensured quick identification and satisfactory resolution of problems through a coordinated Government-industry operation that typified the entire Apollo Program.

Data Storage Electronics Assembly

The DSEA is a single-speed magnetic tape recorder that stores voice and mission elapsed time (fig. 17). A maximum recording time of 10 hours is provided by driving the tape in one direction, reversing direction, and switching to the next track when the end of the tape has been reached. Four tracks can be recorded, with a total of 2-1/2 hours of data recorded on each track. The DSEA has only the recording function, and the tape must be played at a specially built ground station.

A specially designed 400-hertz, single-phase, hysteresis, synchronous motor was used to provide constant, steady (± 0.1 percent of input power frequency) tape motion at the low speed of 0.6 in/sec. The voice-frequency recording capability is limited to 300 to 3000 hertz, and the timing signals are recorded as a 4625-hertz signal for a

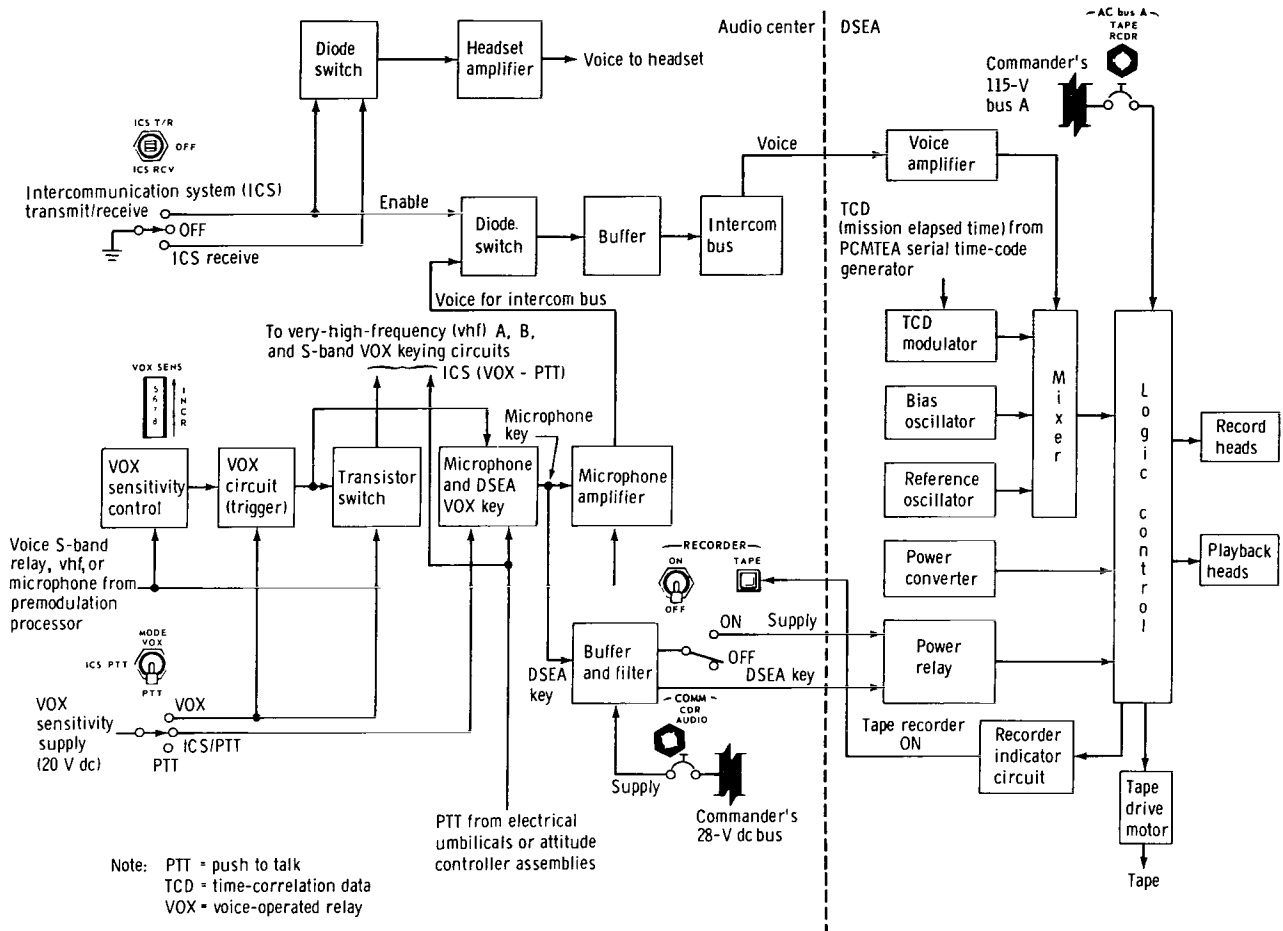


Figure 17. - Functional block diagram of DSEA.

"zero" and as a 4175-hertz signal for a "one." In addition, a 5200-hertz signal is recorded as a reference to reduce flutter during tape playback. Steady tape movement (provided by the motor) and sharp filtering are required for effective recording and playback.

A tape cartridge is used because it is the most efficient way to handle the tape each time it is removed for playback and replacement. Negator springs are used in the cartridge to assist the drive motors and to maintain the proper tension on the tape. A pair of negator springs is installed on each of the coaxial reels of the cartridge; these springs apply a force that tends to wind the tape onto the reel. The motor-drive capstans pull the tape from one reel and wind up the pair of negator springs for that reel while the negator springs for the other reel wind the tape onto that reel.

During developmental testing, it was very difficult to keep the flutter (tape-speed variations) within the specification of 3 percent during vibration. Extensive tests and studies revealed that the problem existed because the cartridge contact in the head and capstan area of the transport was too firm, causing the vibration of the reels to be fed to the recording area and increasing the flutter. The cartridge and the tiedown system were modified slightly to alleviate this problem.

After the qualification tests had been completed, the vibration levels were raised because of a program at MSC to identify weak components. During the requalification testing at the higher vibration levels, the flutter again exceeded specification to approximately 5 percent. This high flutter could not be corrected without an extensive redesign. Most of the units had already been built, and the cost of modifying them would have been prohibitive. It was decided to waive the flutter requirement because the units performed properly with no signs of damage after the vibration, because the vibration levels were higher than flight vibration levels, and because voice reproduction was satisfactory at the higher flutter level. Only the timing data are lost at the higher flutter, and the highest vibration during a mission occurs during descent or ascent. The recorder runs continuously shortly before and during descent or ascent; therefore, the time from the last good timing signal received is easily determined if the timing drops out. In fact, no significant timing losses have occurred during the LM flights.

Another design problem was presented by lubricant leaking from the bearings in the tape cartridge. A small amount of lubricant was used in the small bearings; however, during long idle periods (2 to 3 months), the lubricant drained out, creating the possibility of slippage between the tape and capstan and fouling of the recording heads. Extensive testing showed that very little or no lubricant was required in the cartridge. This problem was solved by initiating a new lubrication specification that required only a very small amount of lubricant and by operating the units for 30 minutes every 120 days.

During flights, the only problem experienced was the breaking of vehicle wires leading to the DSEA. The small 26-gage signal wires broke on three vehicles and caused the loss of all data from the Apollo 11 DSEA. Also, during normal insertion of the cartridge, the tape was damaged. The cartridge had to be inserted at an angle so that the upper edge of the tape contacted the capstans first. It took the full force required to unwind enough tape from the reels to make good contact with the capstans. This force caused the upper edges at the beginning of the tape to become wrinkled and cupped after several loadings. The use of a loading tool, which was developed to allow straight insertion of the cartridge, prevented the damage.

Any future voice recorders should use an easily insertable cartridge and a voice-operated-relay (VOX) circuit in the recorder. During the lunar missions, the crew does not use the VOX mode because of voice clipping, but keeps the intercom and DSEA on continuously. This procedure results in the DSEA running out of tape before the end of the mission. A VOX circuit in the DSEA, independent of the audio center, would have allowed a much more efficient use of tape. In addition, the time required for the recorder to be operating is becoming longer with each mission. Because the cartridge cannot be easily replaced during flight, the only way in which these new requirements can be met is by adding another DSEA or a VOX circuit between the DSEA and the audio center.

Transducers

The LM instrumentation transducers sense physical data such as temperature, valve and switch positions, pressure, and water and propellant quantities. The transducers then convert this physical data to electrical signals that are compatible with the SCEA, PCMTEA, and CWEA and with the panel meters. All but one of the transducers

employ integral signal conditioning that produces the standard 0- to 5-volt dc output. The temperature-transducer outputs are routed to the SCEA where they are converted to the standard 0- to 5-volt dc signal. All the transducers that use integral signal conditioning (except temperature transducers, which require no power) receive power through the signal-sensor circuit breaker and through individual fuses in the fuse sensor assembly.

The transducer designs were selected on the basis of accuracy, power consumption, size, weight, reliability, developmental time and cost, multirange capability, mounting requirements, background of the device, and possible effects on the system to be monitored. Most of the transducers were developed by modifying commercial equipment; however, these modified transducers caused most of the instrumentation problems. Units that could pass qualification tests could be produced, but the units were not reliable if they were produced in quantity. The only transducer that has been trouble-free is the resistance-thermometer type used to measure temperatures.

The switches used to detect LM landing-gear deployment and to turn on the tracking lights and floodlights are modified versions of commercial hardware. Normally, these pushbutton devices are made of stainless steel. However, the LM versions are the only aluminum switches qualified for the space environment. To save weight, aluminum was used for everything in the switches except the springs and contacts. This use of aluminum created special design considerations, such as finding an epoxy that has the same thermal expansion characteristics as aluminum within a temperature range of -260° to $+260^{\circ}$ F. Another problem that developed during vacuum-chamber tests was that the contacting aluminum parts would cold-weld together. All the parts that had to move freely were plated with a dry film lubricant to prevent any sticking. The only vehicle problem concerned a manufacturing deficiency in one lot. The collar on the plunger was badly crimped; however, this defect was easily detected by X-ray and was isolated to one lot.

Two types of pressure transducers were developed to provide two sources for hardware. The designs of these transducers are entirely different, and different problems have occurred. The transducers are mechanically and electrically interchangeable and have identical pressure ranges. Both transducers are designed so that the outer case serves as a leak-proof chamber that can withstand the monitored pressure if the sensing element leaks or ruptures.

One type of transducer consisted of a sensor with a semiconductor strain-gage network mounted on a diaphragm and of an electronics package built with discrete parts. The electronics components have performed very well, but the sensor has been prone to erratic, unpredictable shifts caused by the strain gages. Screening techniques during and after delivery isolated the defective shifters, but no method has been found to produce a highly reliable pressure transducer of this type. A similar problem occurred with the water quantity measuring device (WQMD); this problem is discussed in a later section of this report.

Another problem occurred with the high-temperature version of the first type of transducer. This problem involved a very low manufacturing yield of acceptable transducers. By offsetting the center of the diaphragm and increasing the size of the fillet (the portion of the diaphragm that connects to the transducer barrel), the yield of good

transducers rose to an acceptable level; however, a new problem occurred. The new feed-through header required for the diaphragm change was subject to damage during manufacturing. This damage resulted in slow leaks. A stringent, 24-hour, overpressure leak test was incorporated to identify the leaky transducers.

The other type of pressure transducer had a twisted Bourdon tube with a variable-reluctance position sensor and a hybrid thin-film electronics package. The sensing element has been extremely stable, but the electronics package caused much trouble. Eventually, the electronics package was redesigned using discrete components, a method that produced good results in the first transducer electronics package. With the new electronics package, this transducer has worked quite well. Few pressure transducers of either design have failed during flight.

The WQMD caused more problems than any other item in the instrumentation subsystem. The WQMD is a temperature-compensated pressure transducer that produces an extremely nonlinear output. This transducer consists of a strain-gage network and a resistance thermometer (for temperature compensation) mounted on a diaphragm. The electronics portion takes the strain-gage resistances and produces a linear quantity output; this output is nonlinear in regard to the pressure. The pressure drop for a unit of water usage is much greater for a nearly full water tank than for a nearly empty water tank. This pressure drop forces the electronics unit to produce a nonlinear output with regard to the pressure remaining. Also, the WQMD can be adjusted to produce a 100-percent-full reading for a water-tank loading of from 45 percent to 75 percent full. In this case, the electronics unit compensates for the differently shaped curves of amount of water remaining compared with pressure for any of these loadings. The more fully loaded tanks produced the most bowed curves. Originally, the WQMD was designed for only a 75-percent-full loading. Later, it was modified to accept a smaller loading. The WQMD always has been plagued with shift problems related to the strain gages. The strain gages would shift or become nonohmic (shorted) for no apparent reason. Extensive studies revealed that contaminants in the silicon dioxide coating caused the strain gages to become nonohmic. The time required for the occurrence of this condition varied with (1) the amount of voltage and the amount of time it was applied, (2) the amount of contaminants, and (3) the temperature. Nothing was found to eliminate the problem. No screen test was reliable, and the problem could not be solved easily. Thus, the WQMD was replaced with the Bourdon tube-type pressure transducer on LM-9 and later vehicles. The conversion from pressure to amount of water remaining is accomplished by ground personnel.

Before the launch of LM-4, one of the installed water quantity measuring devices failed. Investigation showed that iodine in the water tanks had corroded through the WQMD diaphragm. It was the only WQMD to show signs of this type of corrosion. Tests were indicative that the iodine would attack the inclusions (impurities) in the diaphragm. The diaphragm and body of the WQMD are milled from a single piece of Ni Span-C alloy (nickel base). The grain of the metal is perpendicular to the surface of the diaphragm. With the grain alined in this manner, needle-shaped impurities also are alined perpendicular to the diaphragm. If these impurities are long enough, the diaphragm is penetrated. Usually, these impurities are not long enough to cause penetration. Several methods to correct the problem were considered: (1) building the diaphragm out of a different material, (2) building new diaphragms out of Ni Span-C

with the grain aligned parallel to the surface so that inclusions would not penetrate the diaphragm, or (3) finding a protective coating for the diaphragm. This last method was chosen because it had the least cost and time impact. Gold, silver, and platinum platings were ineffective; and, eventually, an epoxy was chosen that worked well.

This epoxy coating, however, caused another problem. The epoxy absorbed a small amount of water and swelled slightly. This swelling depressed the diaphragm, causing a positive shift of 3 to 5 percent in the output. This shift was minimized by making the epoxy coating as thin and as uniform as possible. Tests were run to determine the amount of shift, then repeated to determine the repeatability. Acceptance of a unit was based on a repeatability of not more than 1 percent of the original reading. The amount of shift caused by the epoxy absorbing water was used to bias the error out of the flight data.

Although numerous failures occurred during testing and the WQMD was replaced eventually with absolute pressure transducers, only one of the 15 water quantity measuring devices drifted out of specification during a mission.

The propellant quantity measuring device (PQMD) used to monitor the RCS fuel level was essentially the same device as the WQMD. The PQMD was designed to measure higher pressures than the WQMD, and the PQMD has a much smaller diaphragm. This smaller diaphragm is an installation requirement. In contrast to the WQMD, very few problems and failures were experienced with the PQMD; the failures were only 1 to 2 percent out of tolerance. The only explanation so far presented is that the PQMD is not as sensitive to shift because it operates at higher pressures. The history of these two devices, both manufactured by the same vendor, makes it apparent that a great deal is yet to be discovered about semiconductor strain-gage technology.

CONCLUSIONS AND RECOMMENDATIONS

Although many failures and problems occurred during development and vehicle integration tests, the lunar module instrumentation subsystem performed well during missions. This performance has been accomplished by testing to determine the cause of the problems, then developing a cure for the problems or a screening test to eliminate the problem items. From the experience gained from vehicle integration tests, it is obvious that all components of the instrumentation subsystem must be as versatile as possible to accept changing interfaces and the eccentricities of those interfaces.

The following recommendations are made for signal conditioning.

1. Use plug-in modules to the lowest subassembly practical in order to have the smallest impact in case of failure.
2. Make all range changes easily accessible.
3. Make all module locations (including spares) on the chassis capable of accepting any type of subassembly.

4. Make the discrete signal conditioners trip at as low a resistance as possible to prevent high resistance (120 000 ohms or less) from causing false indication.

5. Have ground-support-equipment connectors for testing and monitoring all inputs and outputs.

The following recommendations are made for the caution and warning system.

1. Make all functions latching and resettable.

2. Make all analog level detectors easily adjustable and capable of being inhibited or enabled.

3. Have a number of spare discrete and analog detectors available for any new requirements. These spare detectors should be capable of being easily connected (either by jumper wires at the connectors or by easily manufactured plug-in jumper modules) to create the desired circuit.

4. Have inhibit and enable signals for major events (such as ascent/descent staging) that can be routed to any of the circuits.

The following recommendations are made for voice recording.

1. Use cartridges that do not require any special skill for installation and replacement and that protect the tape as much as possible during storage and handling.

2. Have a built-in voice-operated circuit provided with an external override.

The following recommendations are made for transducers.

1. Have adjustments available to compensate for small (less than 10 percent) long-term drifts.

2. Thoroughly investigate materials used for compatibility to their environment and potential environment. This investigation would include cold-welding in a vacuum, thermal expansion, and corrosive and oxygen exposure.

3. Ensure that all transducers used in fluid lines and tanks contain secondary pressure seals. In the case of pressure transducers, these can be provided by the reference chamber seals.

Manned Spacecraft Center
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Houston, Texas, October 29, 1971
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APPENDIX
LUNAR MODULE
CAUTION AND WARNING SYSTEM
CHARACTERISTICS AND NUISANCE ALARMS

INTRODUCTION

For reference purposes and for aid in locating specific caution and warning circuits, pertinent information is listed in the following table.

Measurement code number	Indicator number	Nomenclature	Page
GL4022	6DS2	Ascent low-pressure warning	21
GL4023	6DS3	Helium pressure regulator outlet manifold warning	22
GL4026	6DS6	Control electronics section ac power-supply failure warning	24
GL4027	6DS7	Control electronics section dc power-supply failure warning	24
GL4028	6DS8	Abort guidance section power-supply failure warning	26
GL4029	6DS9	Primary guidance and navigation section LM guidance computer warning	29
GL4031	6DS11	Reaction control subsystem thrust chamber assembly jet-failure warning	30
GL4032	6DS12	Reaction control subsystem helium regulator outlet pressure warning (system A)	32
GL4033	6DS13	Reaction control subsystem helium regulator outlet pressure warning (system B)	32
GL4037	6DS17	Suit/fan warning	33
GL4046	6DS26	Electrical power subsystem inverter caution	36

Measurement code number	Indicator number	Nomenclature	Page
GL4048	6DS28	Rendezvous radar data-no-good caution	37
GL4049	6DS29	Landing radar data-no-good caution	39
GL4051	6DS31	Explosive devices malfunction caution	40
GL4053	6DS33	Heater caution (RCS quad-cluster temperatures)	42
GL4053	6DS33	Heater caution (landing radar antenna temperatures)	42
GL4056	6DS36	Environmental control subsystem caution	45
GL4060	6DS40	S-band receiver (automatic gain control alarm) caution	45
GL4024	6DS4	Low descent propellant quantity warning	46

ASCENT LOW-PRESSURE WARNING

Characteristic

Ascent low-pressure warning is ON when the CWEA is first activated and remains ON until ascent pressurization.

Discussion

The ascent propellant tanks are loaded to capacity for a "G" (lunar landing) mission with a resulting small ullage volume. Prior to launch, a blanket pressure of helium (approximately 180 psia) is applied to the propellant tanks. However, because of the relatively small volume of helium, absorption of helium by the propellants causes this blanket pressure to decay below the CWEA trip level of 120 psia. As a result of this absorption, low inlet pressures (<120 psia) at the engine isolation valves are expected during the LM-5 mission, at initial CWEA turn-on (ground elapsed time 94:37). This condition will cause initiation (at CWEA activation) of an ascent pressure warning that cannot be removed prior to ascent pressurization.

Impact on LM-5

The ascent pressure failure-detection circuit (fig. 18) consists of four separate parameters in OR-gate configuration. An out-of-tolerance condition existing at any one

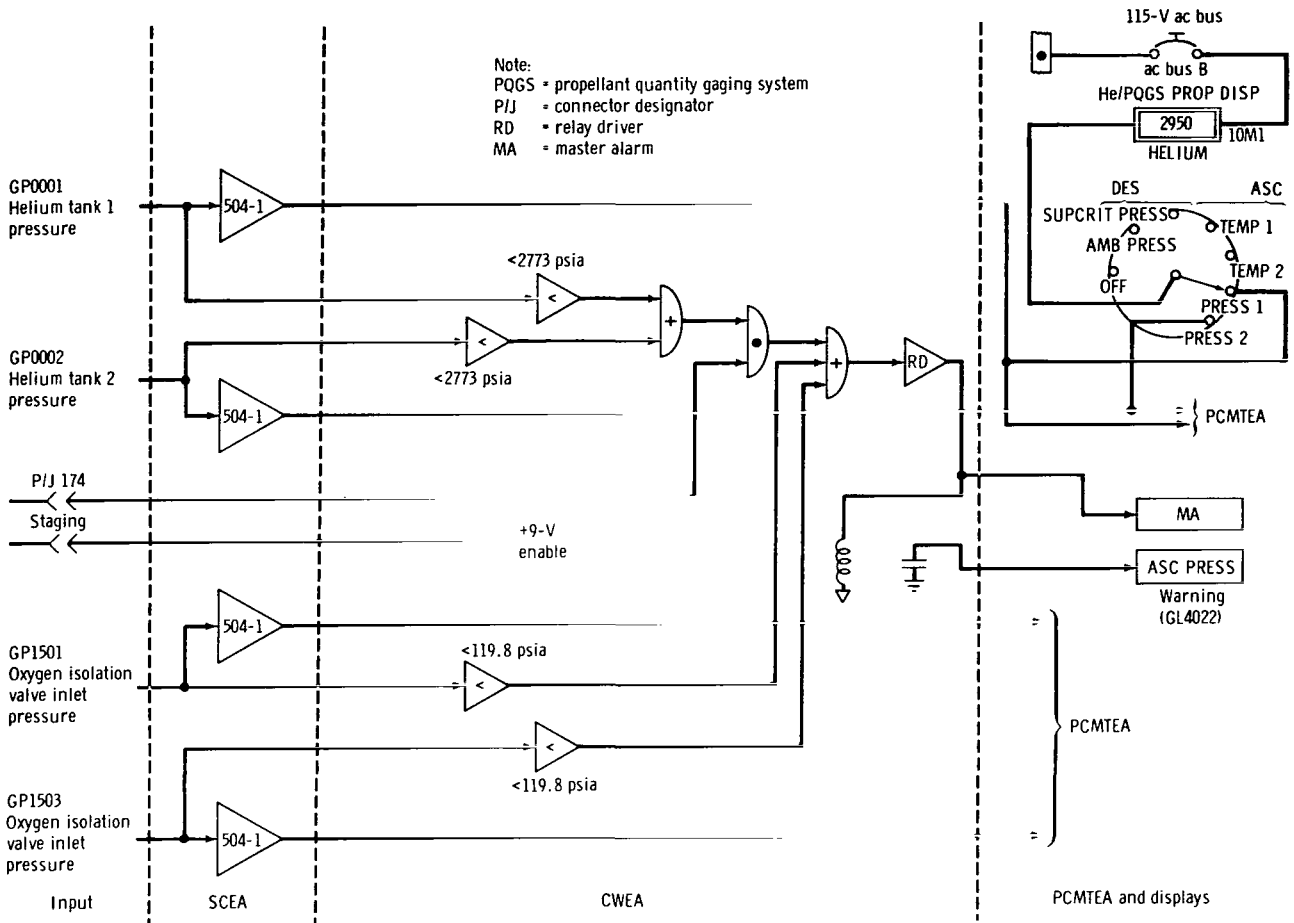


Figure 18. - Ascent pressure failure-detection circuit.

of the four input parameters activates the warning light. Once the light is activated, subsequent failures at the other inputs cannot be detected. Because an out-of-tolerance condition is expected as a result of low isolation-valve inlet pressure (GP1501 and GP1503), an ascent helium leak (GP0001 or GP0002) cannot be detected by the CWEA. Helium tank pressures are available to the crew by means of onboard digital display and to the MSFN by means of telemetry.

HELIUM PRESSURE REGULATOR OUTLET MANIFOLD WARNING

Characteristic 1

Venting of descent helium will cause a descent helium regulator warning indication and a master alarm.

Discussion. - The fuel vent (GQ3500X) and the oxidizer vent (GQ4000X) are used to vent the descent helium shortly after lunar landing. The helium regulator outlet pressure (GQ3018P) will fall below the CWEA trip level of 219.2 psia and activate warning light GL4023 (fig. 19) and the master alarm.

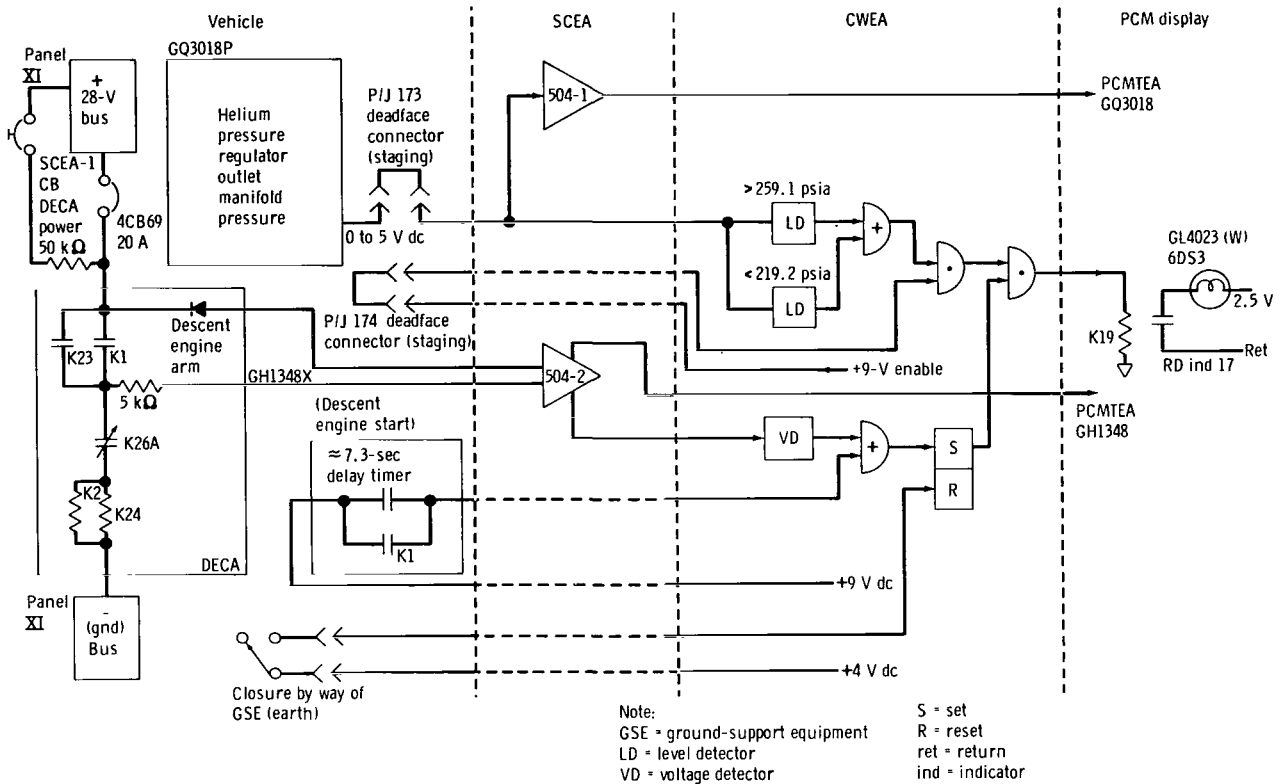


Figure 19. - Helium pressure regulator manifold failure-detection circuit.

Corrective action. - The master alarm should be reset. The warning light will be extinguished automatically at staging. However, it can be extinguished before staging by cycling the CWEA circuit breaker following removal of descent engine arm.

Characteristic 2

A false descent helium regulator warning occurs with the descent engine control assembly (DECA) circuit breaker open.

Discussion. - Characteristic 2 is caused by a gradual decrease of insulation resistance in the DECA Jennings relay after repeated operations. When the DECA circuit breaker is closed, +28 volts is fed to the SCEA input, biasing the SCEA to an off position. This bias voltage effectively reduces the sensitivity of the SCEA input, making the SCEA insensitive to the open-contact resistance of the Jennings relay. However, when this bias voltage is not present (DECA circuit breaker open), the sensitivity of the SCEA increases to a point at which the open-contact resistance of the Jennings relay appears to the SCEA as a closed contact. This condition is recognized by the CWEA as a descent engine arm signal from the DECA with no helium pressure in the manifold, and the master alarm is activated.

Corrective action for LM-3 and LM-4. - No hardware change will be implemented. During vehicle ground checkout, a false descent regulator alarm may occur any time the DECA circuit breaker is open. This occurrence should be expected on these vehicles.

For flight operation, a procedural change to close the DECA power circuit breaker before the CWEA circuit breaker is closed has been incorporated in the Apollo Operations Handbook (AOH).

Corrective action for LM-5 and subsequent vehicles. - A biasing resistor is installed between the SCEA-1 circuit breaker and the power lead to the DECA. This resistor applies a bias voltage to the SCEA input whenever the CWEA breaker is closed and is independent of the position of the DECA circuit breaker.

CONTROL ELECTRONICS SECTION ac AND dc POWER-SUPPLY FAILURE WARNINGS

Characteristic

This condition is characterized by a loss of failure-detection capability during the power-up sequence.

Discussion

Each control electronics section (CES) power-supply output is monitored by an individual level detector in the CWEA (figs. 20 and 21). Each level detector is designed to produce a logic zero at its output if the power supply being monitored is delivering a voltage within predetermined levels. If the power supply exceeds these levels (either above or below), a logic one is produced at the output of the level detector. The outputs of each group (ac or dc) of level detectors are OR-gated and fed to their respective flip-flops. When all power supplies are in limits, a logic zero from the output of each level detector is applied to the flip-flop. The flip-flop is in the reset state with a logic zero at its output. If any power supply goes out of limits, a logic one is transferred to the input of the flip-flop. This transition from a logic zero to a logic one at the input to the flip-flop is required to set the flip-flop, activate the master alarm, and illuminate the annunciator light.

During LM missions, the CWEA is turned on prior to activation of the CES power supplies. As a result, the level detectors in the CWEA sense zero voltages at their respective inputs and produce logic ones at their outputs. The flip-flop is set, the annunciator lights are turned on, and the master alarm is activated. The annunciator lights can be extinguished by resetting the flip-flop by means of the rate gyro assembly gyro test switch. This action, however, does not remove the logic one at the input to the flip-flop.

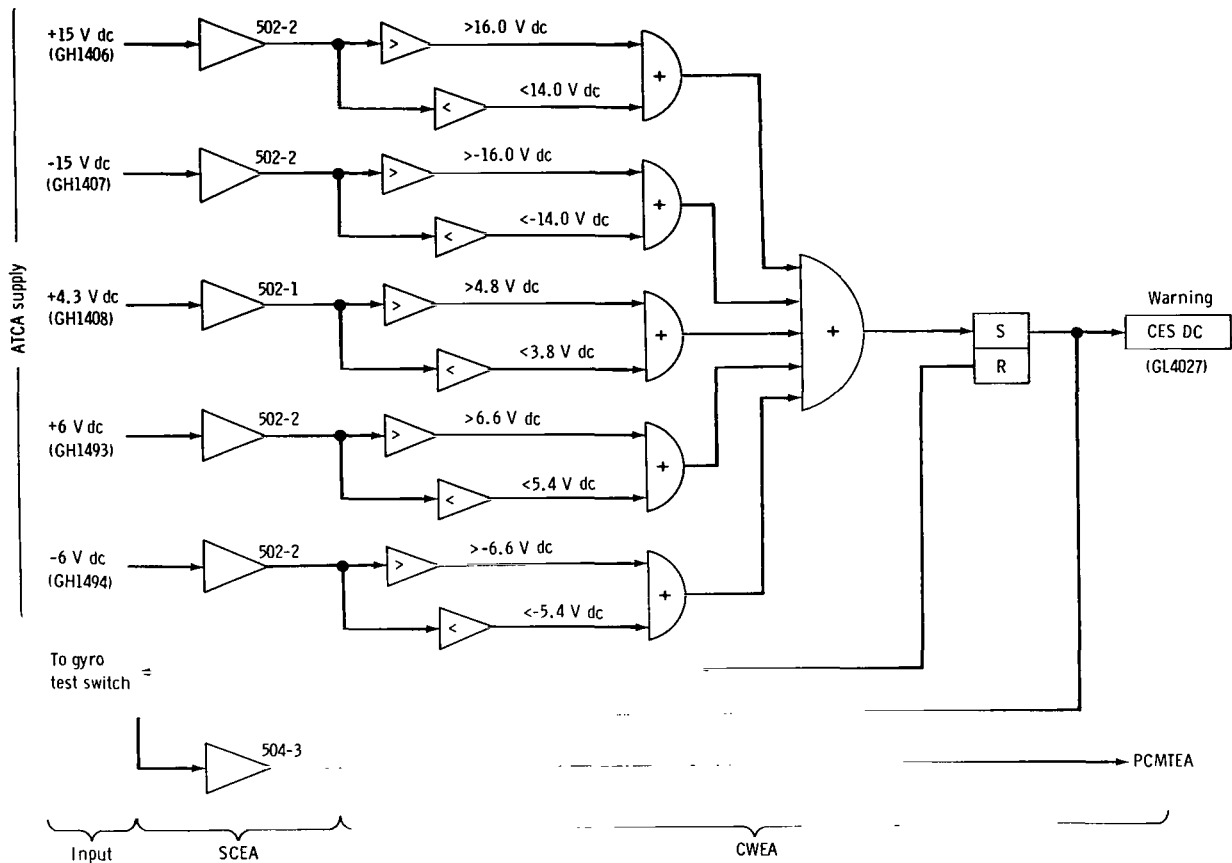


Figure 20. - Control electronics section dc power-supply failure-detection circuit.

When the CES power supplies are subsequently turned on by means of the ATCA circuit breaker, two possibilities exist.

1. All power supplies operate normally and are in limits. In this case, the logic one at the input to the flip-flop is removed, and the failure-detection circuits are able to recognize a subsequent power-supply failure.

2. One or more of the power supplies fails to come within limits. In this case, the logic one remains at the input to the flip-flop, and the failure-detection circuits are unable to detect the failure.

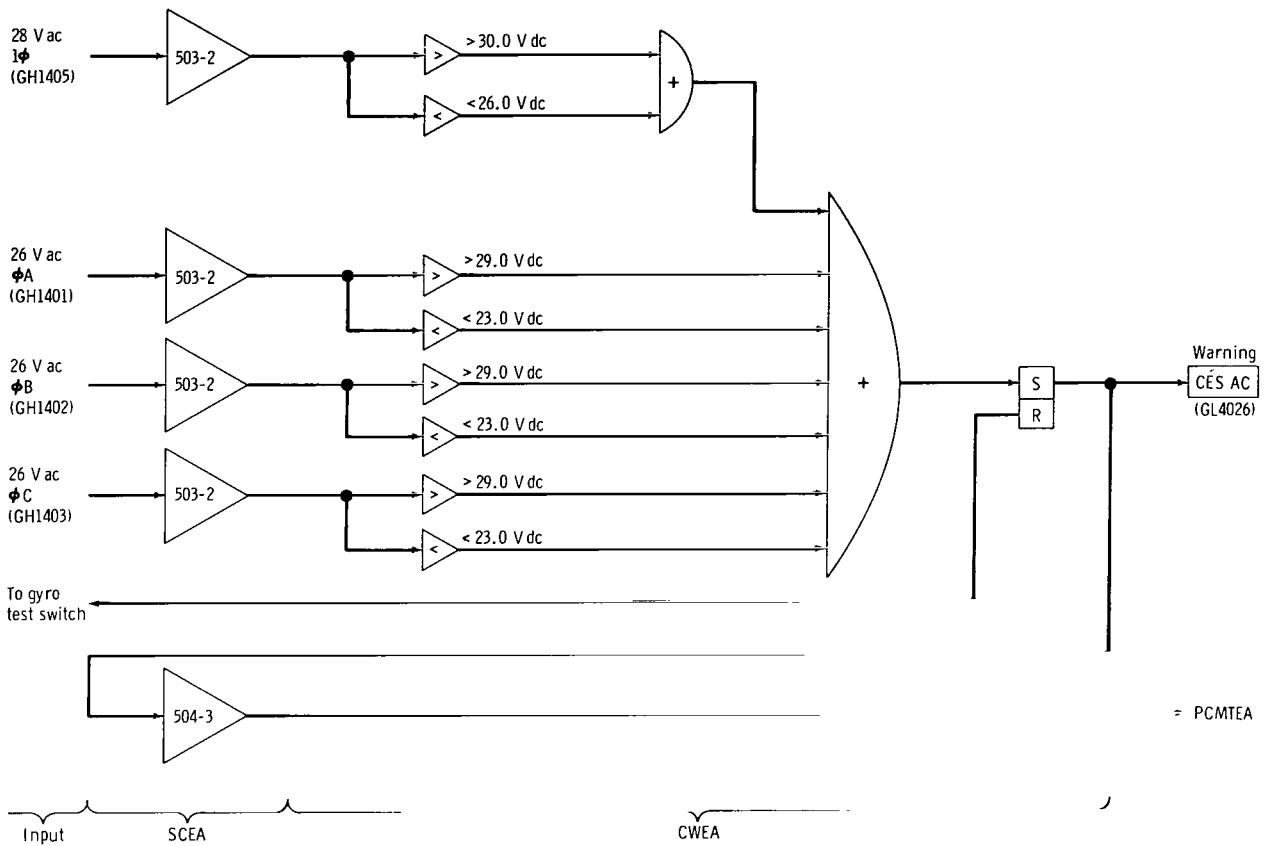


Figure 21. - Control electronics section ac power-supply failure-detection circuit.

Corrective Action for LM-3 and Subsequent Vehicles

A procedural change to the AOH power-up sequence provides for recycling the CWEA circuit breaker after closing the ATCA circuit breaker. This procedure will ensure that the previous CES power-supply failure indications (caused by an open ATCA circuit breaker) registered in the CWEA circuits are erased, that the flip-flops are reset, and that the annunciator lights are extinguished. The CWEA will be fully enabled to detect any existing or subsequent failures. This same procedure also should be used during ground checkout to ensure that a failed CES power supply will not go undetected.

ABORT GUIDANCE SECTION POWER-SUPPLY FAILURE WARNING

Characteristic 1

A master alarm occurs when the abort guidance section (AGS) status switch is placed in the standby or operate position.

Discussion. - The CWEA abort guidance circuit (fig. 22) monitors four separate AGS parameters. Three of these are power-supply parameters located in the abort sensor assembly (ASA). The fourth parameter being monitored is the abort electronics assembly (AEA) test mode fail (TMF). All four parameters are OR-gated and fed to a dual-input AND-gate, which is inhibited when the AGS status switch is in the off position.

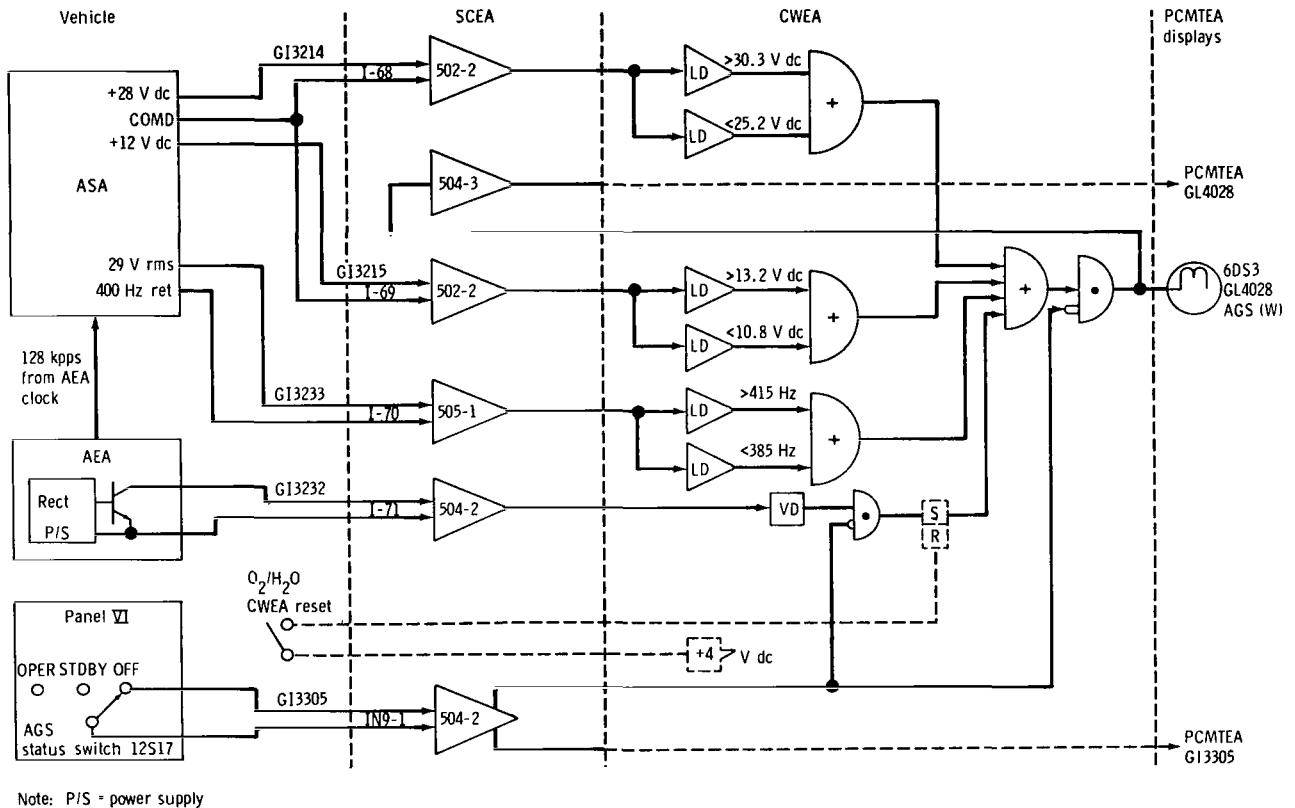


Figure 22. - Abort guidance section power-supply failure-detection circuit.

Abort guidance section power up: A master alarm occurs when the AGS status switch is moved from the off position to the standby position. In this case, the CWEA inhibit is removed and the ASA power supplies are turned on. The AGS warning light will stay on until the AEA circuit breaker is closed and all ASA power supplies reach a stabilized, in-limits condition, removing the failed indication from the CWEA input. The 400-hertz ASA power supply is derived from a 128-kpps clock pulse provided by the AEA; therefore, the AEA circuit breaker must be closed to extinguish the AGS warning light in the standby position.

A master alarm occurs when the AGS status switch is moved from the standby position to the operate position. In this case, the AEA operational power supplies are

turned on and the hardwired memory cores are primed in the AEA memory. This action sets the TMF flip-flop, indicating a failure for approximately 200 milliseconds until the core priming is complete.

Abort guidance section power down: A master alarm occurs when the AGS status switch is moved from the operate position to the standby position to the off position.

The AOH power-down procedures place the stabilization and control (S&C): AEA circuit breaker in the open position, prior to moving the AGS status switch out of the operate position. An AGS warning will result from loss of the AEA 128-kpps clock pulse to the 400-hertz ASA power supply. The AGS warning light will remain on until the AGS status switch is placed in the off position.

Corrective action for LM-3 and LM-4. - Characteristic 1 is noted in the AOH as an expected alarm during operation of the AGS status switch. The crew will acknowledge and reset the master alarm as part of the procedure.

Corrective action for LM-5 and subsequent vehicles. - Because of a design change in the CWEA (addition of a flip-flop to AEA TMF logic), an additional AOH procedure is required for LM-5 and subsequent vehicles. When the AGS status switch is placed in the operate position, an AEA TMF is generated and the flip-flop is set. The crew must (1) reset the flip-flop by manually placing the environmental control subsystem (ECS) O₂/H₂O quantity monitor switch in the CWEA reset position (to extinguish the AGS warning light) and (2) use the data entry and display assembly (DEDA) to verify the status of the AEA.

Characteristic 2

A master alarm occurs during operation of the AGS with no accompanying AGS annunciator light.

Discussion. - Characteristic 2 is caused by a short-duration loss of memory in the AEA, resulting in an AEA restart. The failure is detected by the CWEA, and a master alarm is generated. The AGS annunciator light will be illuminated while the failure exists and will be extinguished automatically when the failure is removed. If the failure is of short duration (on the order of milliseconds), the annunciator light will only blink on and off and can go undetected.

Corrective action for LM-3 and LM-4. - The AOH will be revised to note the possible occurrence of an AEA restart, initiating a master alarm with no CWEA annunciator light. The AOH procedure will direct the crew to use the DEDA to verify AEA status.

Corrective action for LM-5 and subsequent vehicles. - A flip-flop was added to the AEA TMF logic to preclude the possibility of an undetected AEA restart. With the incorporation of this change to the CWEA, all AEA failures will set the flip-flop, initiate a master alarm, and illuminate the AGS warning annunciator light. The annunciator light will remain on until manually reset by placing the ECS O₂/H₂O quantity monitor

switch in the CWEA reset position. Resetting the flip-flop will extinguish the AGS warning light and enable the CWEA to monitor subsequent failures. The ability to extinguish the AGS warning light with the reset verifies that the failure occurred in the AEA. The current status of the AEA then must be verified by using the DEDA. If the AGS warning light is activated by an ASA power-supply failure, it cannot be extinguished by using the reset capability.

PRIMARY GUIDANCE AND NAVIGATION SECTION LM GUIDANCE COMPUTER WARNING

Characteristic

A false master alarm may be generated with activation of the LM guidance computer (LGC)/display and keyboard (DSKY) circuit breaker subsequent to turn-on of the CWEA circuit breaker (fig. 23).

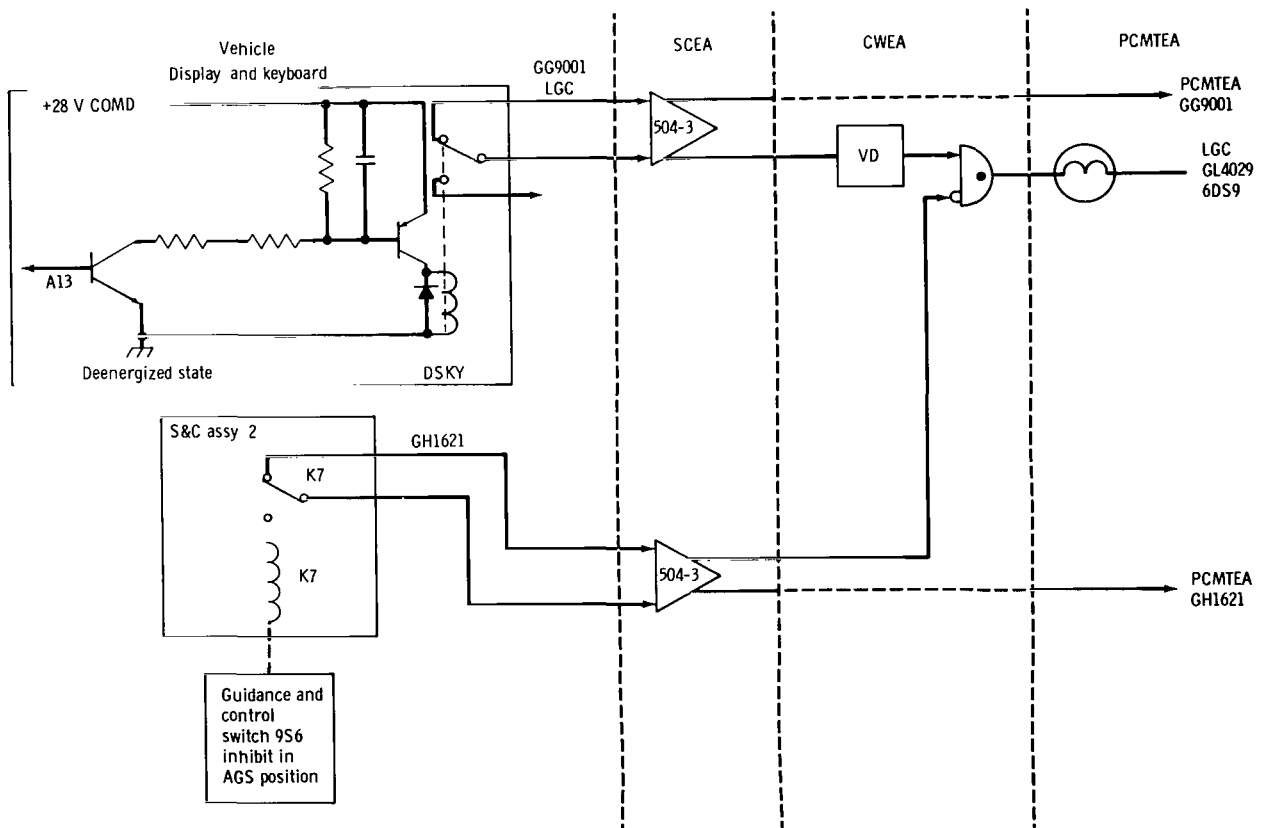


Figure 23. - Lunar module guidance computer failure-detection circuit.

Discussion

If the CWEA circuit breaker is closed and the LGC/DSKY circuit breaker is open, the LGC fail relay will be in the deenergized state and the CWEA will initiate a master alarm. Subsequent closure of the LGC/DSKY circuit breaker will produce one of the following conditions.

1. In the majority of cases, the warning light will be extinguished immediately because the LGC fail relay will be energized immediately, and a master alarm will not be generated.
2. In some cases, as a result of LGC variables, it is possible that the LGC fail relay will be interrupted momentarily, causing a false master alarm to be displayed for as long as 20 seconds.

Corrective Action for LM-3 and Subsequent Vehicles

A procedural note is included in the AOH to indicate that an alarm, with accompanying LGC warning light illuminated for as long as 20 seconds, should be expected when the LGC/DSKY circuit breaker is closed.

REACTION CONTROL SUBSYSTEM THRUST CHAMBER ASSEMBLY JET-FAILURE WARNING

Characteristic

False jet-failure indications occur with thrust chamber assembly (TCA) quad circuit breakers open.

Discussion

Extremely long wire-runs from the TCA quad circuit breakers, to the jet-driver solenoids on the quad clusters, back to the ATCA, and, finally, to the SCEA are the cause of this condition. When the quad circuit breakers are closed, +28 volts is fed to the SCEA inputs, effectively biasing the SCEA to an off condition (fig. 24). When the quad circuit breakers are open, these long-lead lengths at the input to the SCEA act as antennas and are susceptible to noise pickups. Because no biasing voltage is present at the SCEA input, the noise appears to the SCEA as jet-driver commands. These false jet-driver commands can indicate a failed-TCA-jet condition and activate the master alarm by either of two paths:

1. By means of the counters in the CWEA logic when seven consecutive commands are received without an accompanying thruster response
2. By means of the opposing jet logic in the CWEA when commands are sent simultaneously to opposing jets

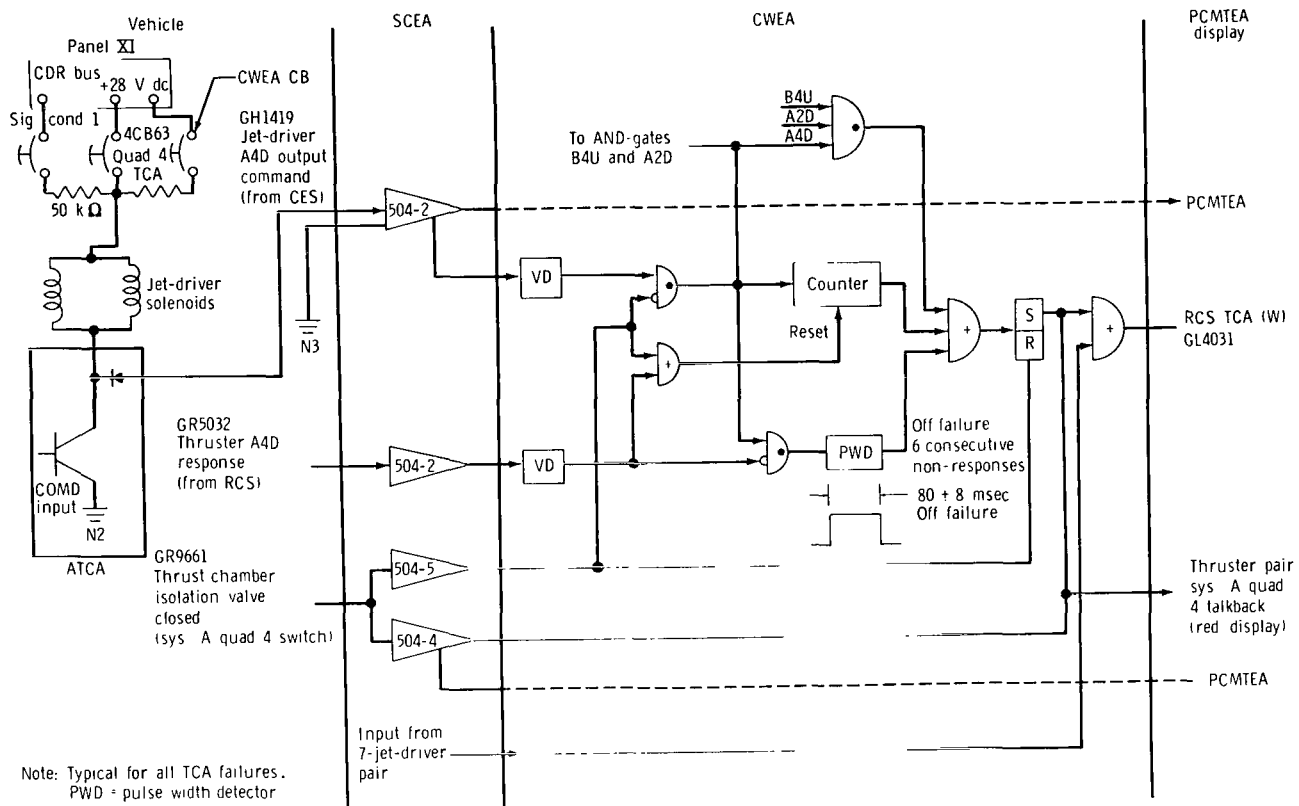


Figure 24. - Reaction control subsystem TCA failure-detection circuit.

Corrective Action for LM-3 and LM-4

No hardware change will be implemented. During vehicle ground checkout, any indication of jet failures with the TCA quad breakers open should not be considered a problem worthy of any further investigation. For flight operation, a procedural workaround has been included in the AOH to preclude an erroneous jet-failure indication during the periods of the mission when the ECS is powered down for an extravehicular activity (EVA) period. The procedural workaround is as follows. Prior to EVA, all quad circuit breakers are open and all (eight) counters in the CWEA logic are loaded by operation of the thrust/translation controller assembly to induce a failure in all quads. The master alarm is reset, and no possibility of an erroneous jet-failure alarm exists during the EVA period. At the conclusion of EVA, the CWEA circuit breaker is cycled (off/on) to enable the CWEA to detect subsequent failures.

Corrective Action for LM-5 and Subsequent Vehicles

Biassing resistors are installed between the SCEA-1 and CWEA circuit breakers and the jet-driver solenoid lines. These resistors effectively apply a bias voltage to the SCEA input whenever the SCEA and CWEA circuit breakers are closed and are independent of the position of the quad-cluster circuit breakers.

REACTION CONTROL SUBSYSTEM HELIUM REGULATOR OUTLET PRESSURE WARNING

Characteristic

The RCS helium regulator warning lights come on prior to pressurization (fig. 25).

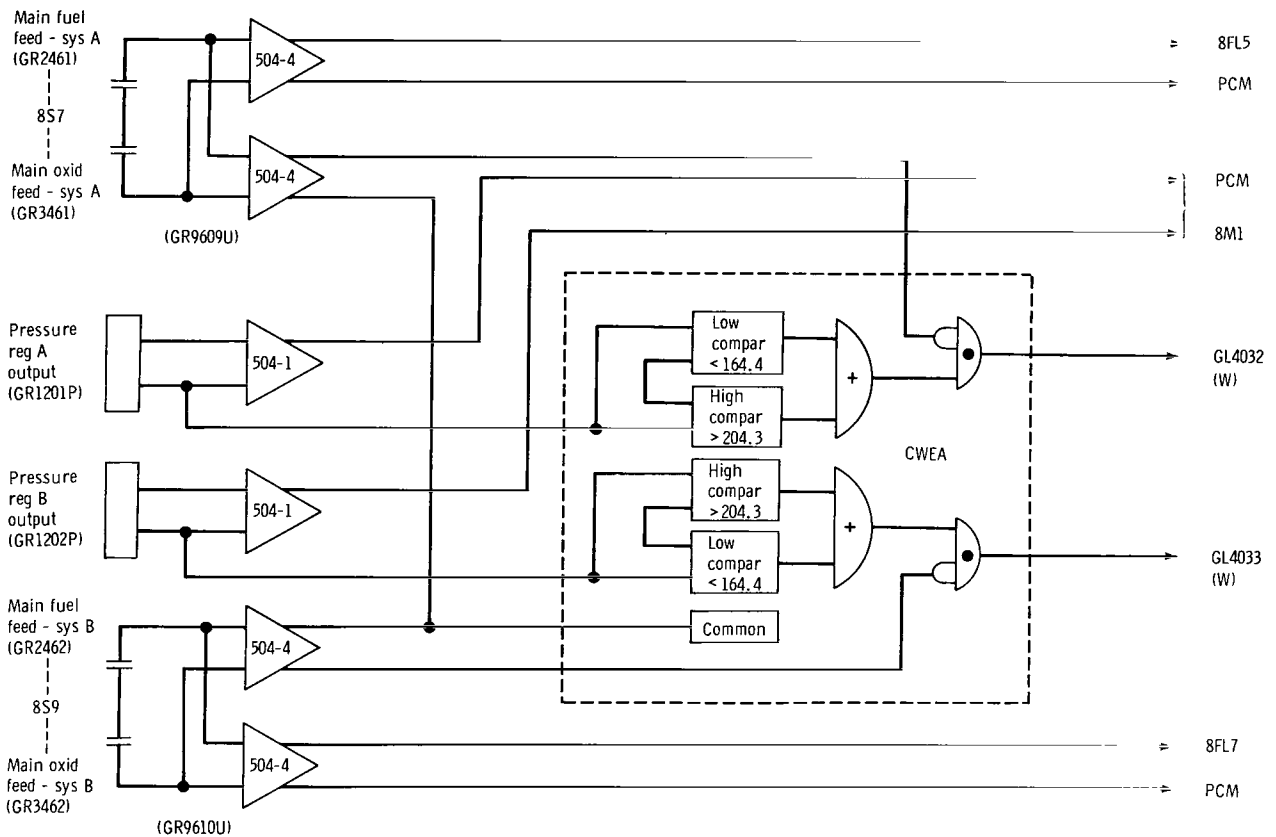


Figure 25. - Reaction control subsystem helium pressure regulator failure-detection circuit.

Discussion

Current RCS procedure calls for the main propellant valves of RCS systems A and B to be opened before launch. By placing these valves in the open position, the RCS helium regulator warning circuits in the CWEA are enabled. This procedure will cause both RCS helium regulator warning lights to come on when the CWEA circuit breaker is first closed. Both lights will remain on until the RCS system is pressurized.

Corrective Action for LM-3 and Subsequent Vehicles

No hardware change will be implemented. A note alerting the crew to this characteristic will be added to the AOH procedure.

SUIT/FAN WARNING

Characteristic

Switching from suit fan 1 to suit fan 2 (under a condition of low differential pressure with fan condition signal-control relay K12 energized) may cause two successive suit/fan warnings (fig. 26).

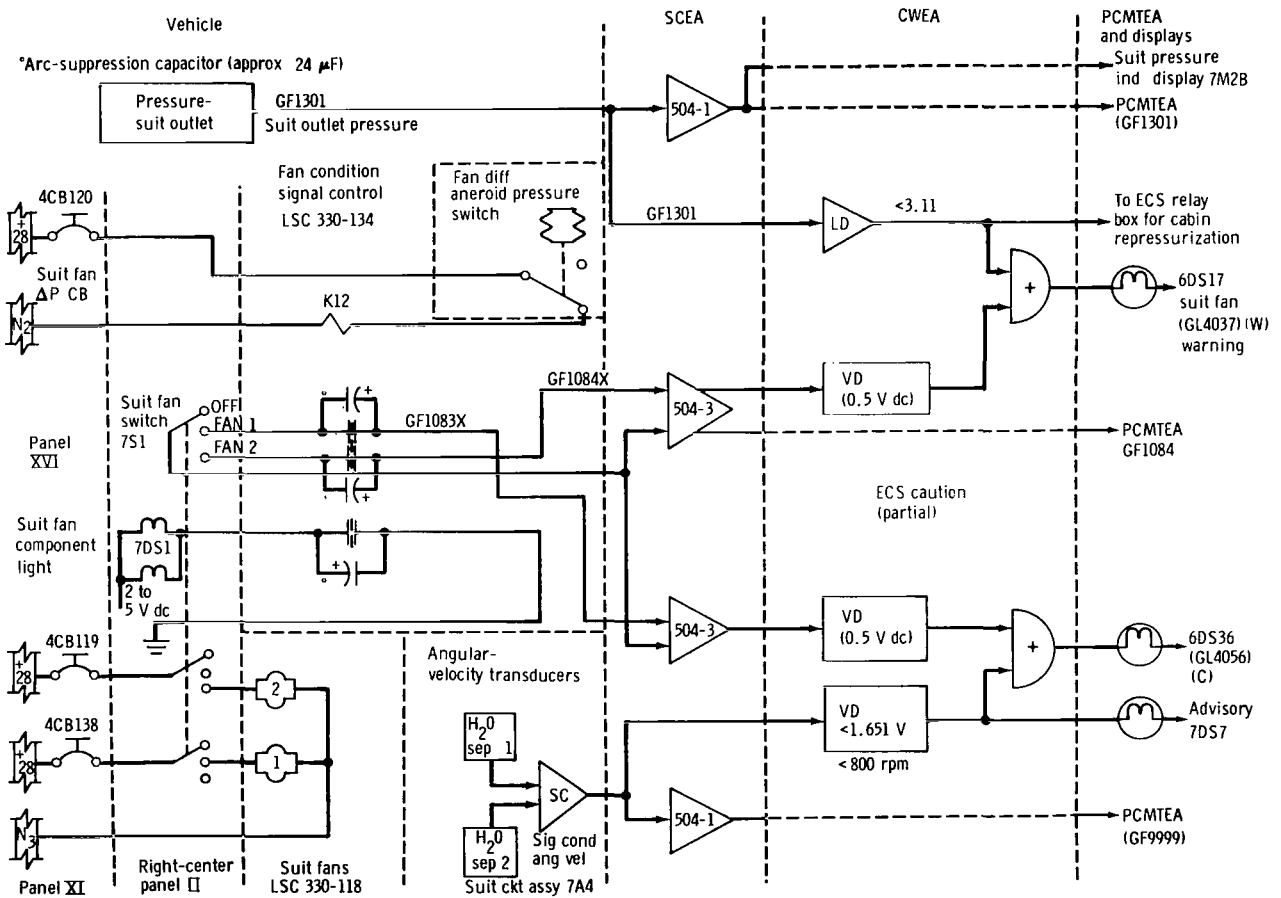


Figure 26. - Environmental control subsystem suit outlet pressure failure-detection circuit.

Discussion

The first warning occurs because of the time required for suit fan 2 to build up enough pressure to open the differential pressure switch; that is, relay K12 is still energized at the instant of switching. The crew then resets the master alarm. The second warning would occur approximately 5 to 10 seconds after relay K12 opens and is dependent on the specific characteristics of the individual SCEA module and the CWEA detector. Because of a 25-microfarad capacitance across the contacts of relay K12, the SCEA input voltage rises exponentially rather than discretely. This characteristic, combined with the internal feedback characteristics of the 504-3 SCEA buffer, produces a short period of output voltage oscillation. If this oscillation occurs after the CWEA has reset, the second master alarm may occur. Note that the component warning light will be extinguished. Additional characteristics of this circuit are included in table I.

TABLE I. - CHARACTERISTICS OF SUIT FAN CAUTION (GL4056) AND WARNING (GL4037) CIRCUITS

Position and cycling of suit fan select switch 7S1	Display characteristics and conditions				
	ECS component light		6DS36 ECS caution light	6DS17 suit fan warning light	Master alarm
	7DS1 suit fan	7DS7 H ₂ O separator			
Off	On If suit fan differential pressure (ΔP) circuit breaker is closed	On No driving power, both suit fans off	On Caused by H ₂ O separator impeller speed <800 rpm	Off	Yes Caused by H ₂ O separator impeller speed <800 rpm
Off to suit fan 1	On Goes out when suit fan ΔP is established and relay K12 is deenergized	On Goes out when H ₂ O separator impeller speed exceeds 800 rpm	On Goes out when H ₂ O separator impeller speed exceeds 800 rpm	Off Stays off Does not monitor fan 1 operation	No Has been reset prior to selection of suit fan 1, caused by H ₂ O separator impeller speed <800 rpm
Suit fan 1 to off	Off Goes on when loss of ΔP energizes relay K12	Off Goes on when impeller speed drops below 800 rpm	Off Goes on when impeller speed drops below 800 rpm	Off Stays off	Yes When impeller speed drops below 800 rpm
Off to suit fan 2 (passing quickly through suit fan 1 position)	On Goes out when suit fan ΔP is established and relay K12 is deenergized	On Goes out when H ₂ O separator impeller speed exceeds 800 rpm	On Goes out when H ₂ O separator impeller speed exceeds 800 rpm	Off Goes out when suit fan 2 is selected Goes out when ΔP is established and relay K12 is deenergized May blink on again approximately 5 to 10 sec later from action of capacitor across relay K12 contacts	Yes When fan 2 is selected because relay K12 is already energized by absence of ΔP If master alarm is reset immediately, the alarm may be generated again from action of the capacitor across the contacts of relay K12
Suit fan 2 to off (passing quickly through suit fan 1 position) when suit fan 2 did not fail	Off Goes on when loss of ΔP energizes relay K12	Off Goes on when impeller speed drops below 800 rpm	Off Goes on when impeller speed drops below 800 rpm	Off Stays off	Yes When impeller speed drops below 800 rpm
Suit fan 1 to suit fan 2 without fan 1 failure	Off Blinks on and off when momentary loss of ΔP energizes relay K12	Off Stays off Inertia of impeller maintains speed >800 rpm during switchover	Off Stays off Does not monitor fan 2 operation	Off Blinks on, then off - when suit fan ΔP drops below normal - faster than fan 2 can restore ΔP May blink on and off a second time, 5 to 10 sec after ΔP is established, from action of capacitor across relay K12 contacts	Yes Relay K12 is energized by drop in ΔP during switchover If master alarm is reset immediately, the alarm may be generated again by the capacitor action across the contacts of relay K12

TABLE I. - CHARACTERISTICS OF SUIT FAN CAUTION (GL4056) AND WARNING (GL4037) CIRCUITS - Concluded

Position and cycling of suit fan select switch 7S1	Display characteristics and conditions				
	ECS component light		6DS36 ECS caution light	6DS17 suit fan warning light	Master alarm
	7DS1 suit fan	7DS7 H ₂ O separator			
Suit fan 1 to suit fan 2, resulting from fan 1 failure	On When drop in ΔP energizes relay K12 Goes off when ΔP is restored and relay K12 is deenergized	Off Comes on if impeller speed drops below 800 rpm before selection of suit fan 2	On When drop in ΔP energizes relay K12 If H ₂ O separator impeller speed does not drop below 800 rpm, light goes out when fan 2 is selected If impeller speed does drop below 800 rpm, light will go out when impeller speed >800 rpm	Off Comes on when suit fan 2 is selected Goes out when ΔP is restored and relay K12 is deenergized May blink on and off 5 to 10 sec later from action of capacitor across relay K12 contacts	Yes When drop in ΔP energizes relay K12 If master alarm is reset prior to selecting suit fan 2, a second alarm will be generated when fan 2 is selected If alarm is reset immediately, a third alarm may be generated 5 to 10 sec after the second alarm by action of capacitor across the contacts of relay K12
Suit fan 2 to suit fan 1, without suit fan 2 failure	Off Blinks on and off when momentary loss of ΔP energizes relay K12	Off Stays off Inertia of impeller maintains speed >800 rpm during switchover	Off Blinks on and off when momentary loss of ΔP energizes relay K12 May blink on and off a second time, 5 to 10 sec after ΔP is restored, from action of capacitor across relay K12 contacts	Off Stays off Does not monitor fan 1 operation	Yes When drop in ΔP energizes relay K12 If reset immediately, a second alarm may be generated 5 to 10 sec after ΔP is restored by action of capacitor across relay K12 contacts
Suit fan 2 to suit fan 1 (suit fan 2 failure, fan 1 is good)	On When drop in ΔP energizes relay K12 Goes off when ΔP is restored and relay K12 is deenergized	Off Comes on if impeller speed drops below 800 rpm before selection of suit fan 1	Off Comes on when fan 1 is selected as a result of low ΔP If H ₂ O separator impeller speed does not drop below 800 rpm, light goes out when ΔP is restored Light may blink on and off a second time 5 to 10 sec after ΔP is restored from action of capacitor across contacts of relay K12 If H ₂ O separator impeller speed does drop below 800 rpm, light will go out when impeller speed >800 rpm The light may blink on and off a second time only if impeller speed reaches 800 rpm in <5 sec after ΔP is established	On Results from drop in ΔP energizing relay K12 Goes out and stays out when suit fan select switch is moved from fan 2 position	Yes Results when drop in ΔP energizes relay K12 as a result of fan 2 failure If master alarm is reset prior to selection of suit fan 1, a second alarm will be generated when fan 1 is selected as a result of ECS caution If alarm is reset immediately, a third alarm may be generated 5 to 10 sec after ΔP is restored by action of capacitor across relay K12 contacts This third alarm will not occur if the impeller speed drops and remains below 800 rpm for more than 10 sec after ΔP is restored

Corrective Action

No hardware changes were implemented. The crew will be made aware of this situation by means of the AOH.

ELECTRICAL POWER SUBSYSTEM INVERTER CAUTION

Characteristic

An inverter caution occurs when selecting either inverter from the off position (fig. 27).

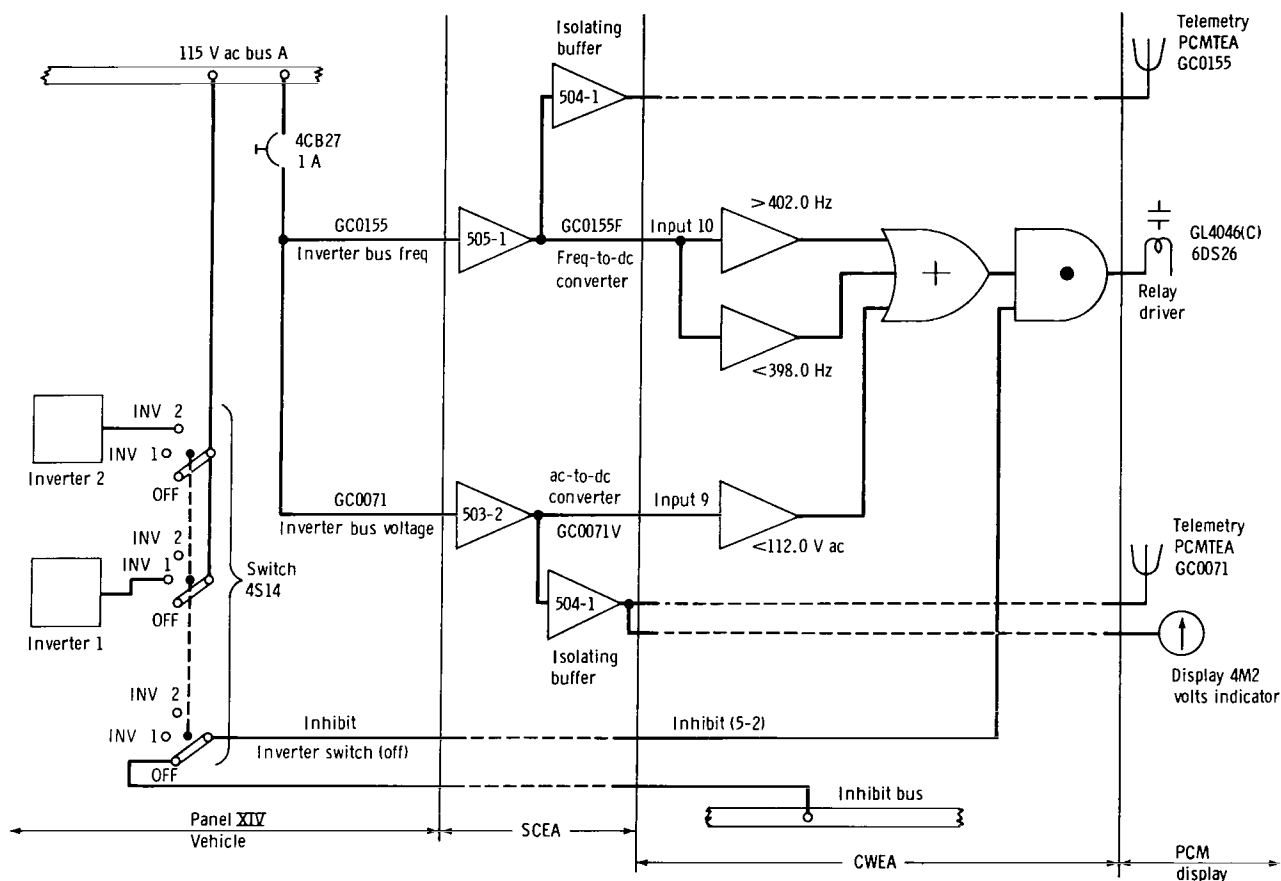


Figure 27. - Electrical power subsystem inverter voltage and frequency failure-detection circuit.

Cause

This instrumentation characteristic is strictly one of timing. With the inverter-select switch in the off position, no inverter voltage is applied to the SCEA and the CWEA. This condition is analogous to a failed inverter to the CWEA detection circuits, and a failed signal is applied to the output AND-gate. Actuation of the inverter caution is prevented by the inhibit voltage applied through the off position of the inverter-select switch to the other input of this AND-gate. When the inverter-select switch is moved

from the off position, the inhibit voltage is removed immediately and the inverter caution light is illuminated with an accompanying master alarm. The inverter light is not extinguished until after the inverter voltage has been processed by the SCEA and the CWEA and an in-limits voltage and an in-limits frequency have been established.

Corrective Action for LM-3 and LM-4

No hardware change will be implemented. During vehicle ground checkout, an inverter caution should be expected when an inverter is selected from the off position.

For flight operation, a procedural change — to select an inverter before closing the CWEA circuit breaker — has been incorporated in the AOH.

Corrective Action for LM-5 and Subsequent Vehicles

Removal of inhibit voltage is delayed until inverter voltage has been processed by the SCEA and the CWEA. The delay is incorporated into CWEA part number LSC-360-8-11-9.

RENDEZVOUS RADAR DATA-NO-GOOD CAUTION

Characteristic

A master alarm occurs when the rendezvous radar (RR) mode-select switch is placed in the "auto track" position.

Discussion

When the RR mode-select switch is placed in the auto track position, the range-tracker circuit and the CWEA are enabled. A no-track signal is sent to the CWEA, and a master alarm is initiated. The RR caution light remains on until the range tracker locks on to the radar return signals and the no-track signal is removed from the CWEA.

Corrective Action for LM-3 and LM-4

No hardware change is incorporated (fig. 28). A procedural change has been incorporated in the AOH to alert the crew to expect occurrence of and to reset the master alarm when placing the RR mode-select switch in the auto track position. A similar procedure should be used for vehicle ground checks.

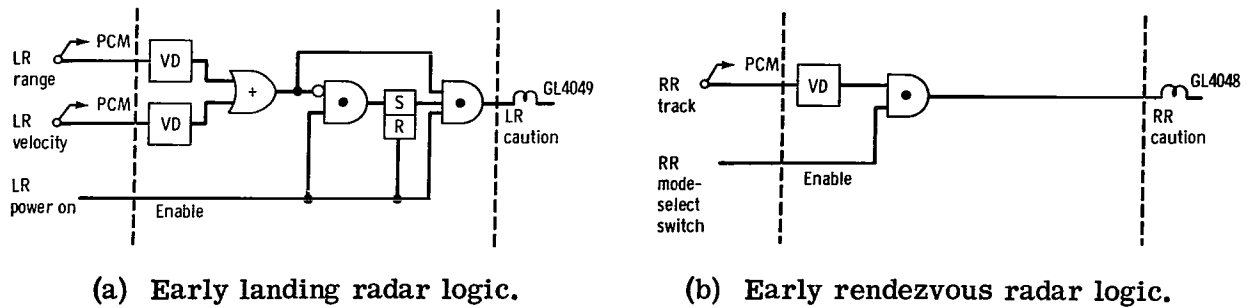


Figure 28. - Radar data-no-good indicators for LM-3 and LM-4.

Corrective Action for LM-5 and Subsequent Vehicles

A wiring change in the vehicle harness to interchange the RR and landing radar (LR) CWEA logic circuits has been incorporated (fig. 29). The logic now used by the RR requires that a data-good signal be established to enable the CWEA. Therefore, a master alarm cannot be initiated when the RR mode-select switch is placed in the auto track position during track acquisition. Once track is established and a data-good signal is issued, the CWEA logic is enabled and will activate the master alarm if a subsequent loss of track occurs.

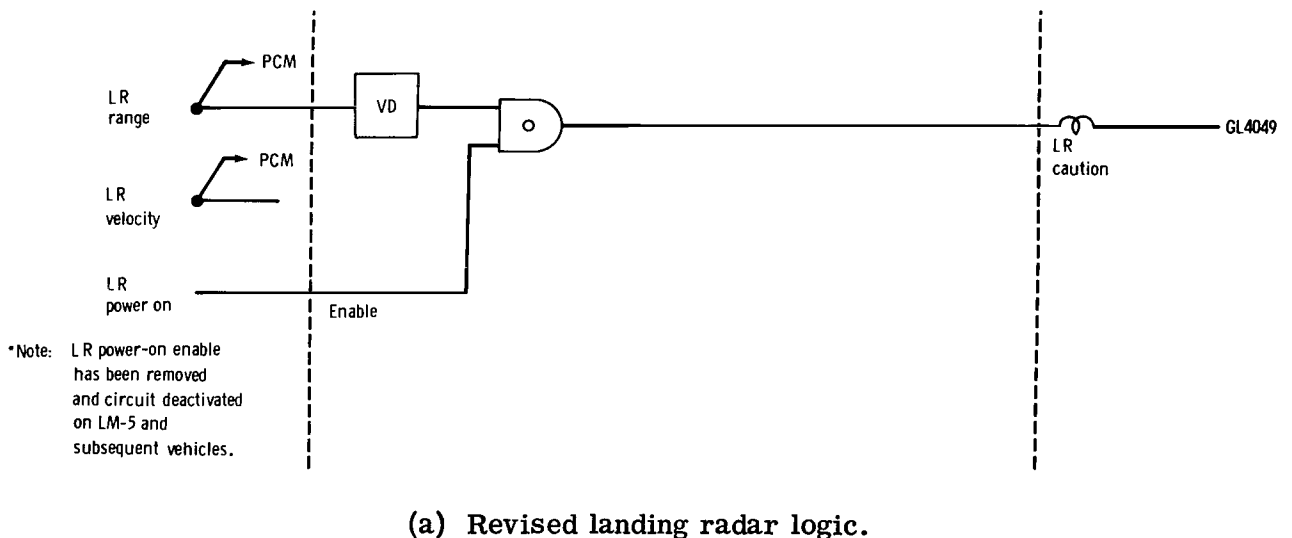
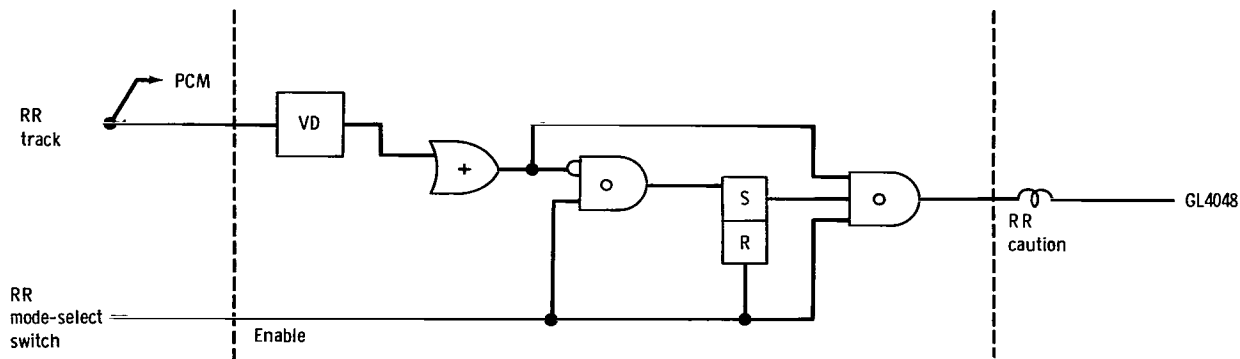


Figure 29. - Radar data-no-good indicators for LM-5 and subsequent vehicles.



(b) Revised rendezvous radar logic.

Figure 29. - Concluded.

LANDING RADAR DATA-NO-GOOD CAUTION

Characteristic

When the primary guidance and navigation section/LR circuit breaker is opened, a master alarm occurs.

Discussion

When power is removed from the LR, the data-good relay contacts open a few milliseconds before the power-on relay contacts.

Corrective Action for LM-3 and LM-4

The LR equipment installed on LM-3 and LM-4 has been modified to provide both velocity and range data-good signals to the CWEA (fig. 28) during all modes of radar operation. As a result, the only master alarm that should be generated by the LR equipment for these vehicles is the one described previously.

A procedural change has been incorporated in the AOH to inform the crew to expect occurrence of and to reset the master alarm when the LR is powered down. A similar procedure should be used during vehicle ground checkout.

Corrective Action for LM-5 and Subsequent Vehicles

The LR measurement has been removed from the CWEA (fig. 29) because of a high probability that an undesirable alarm would occur during the hover maneuver of the landing approach.

EXPLOSIVE DEVICES MALFUNCTION CAUTION

Characteristic 1

An explosive devices (ED) malfunction alarm occurs when the abort stage switch is reset after staging.

Discussion. - When the abort stage switch (fig. 30) is depressed, ED relay K1 is set and the ED bus is armed. This action completes the contact closure path in the relay "daisy chain" (relays K1 to K6) and provides an input to the CWEA. The master alarm does not operate, however, because S&C relay K19 also is energized by the abort stage switch and inhibits the CWEA. A third set of contacts on the abort stage switch signals the CES to issue a stage command. This stage command from the CES sets relay K2, which initiates staging by sequentially energizing relays K3 to K6.

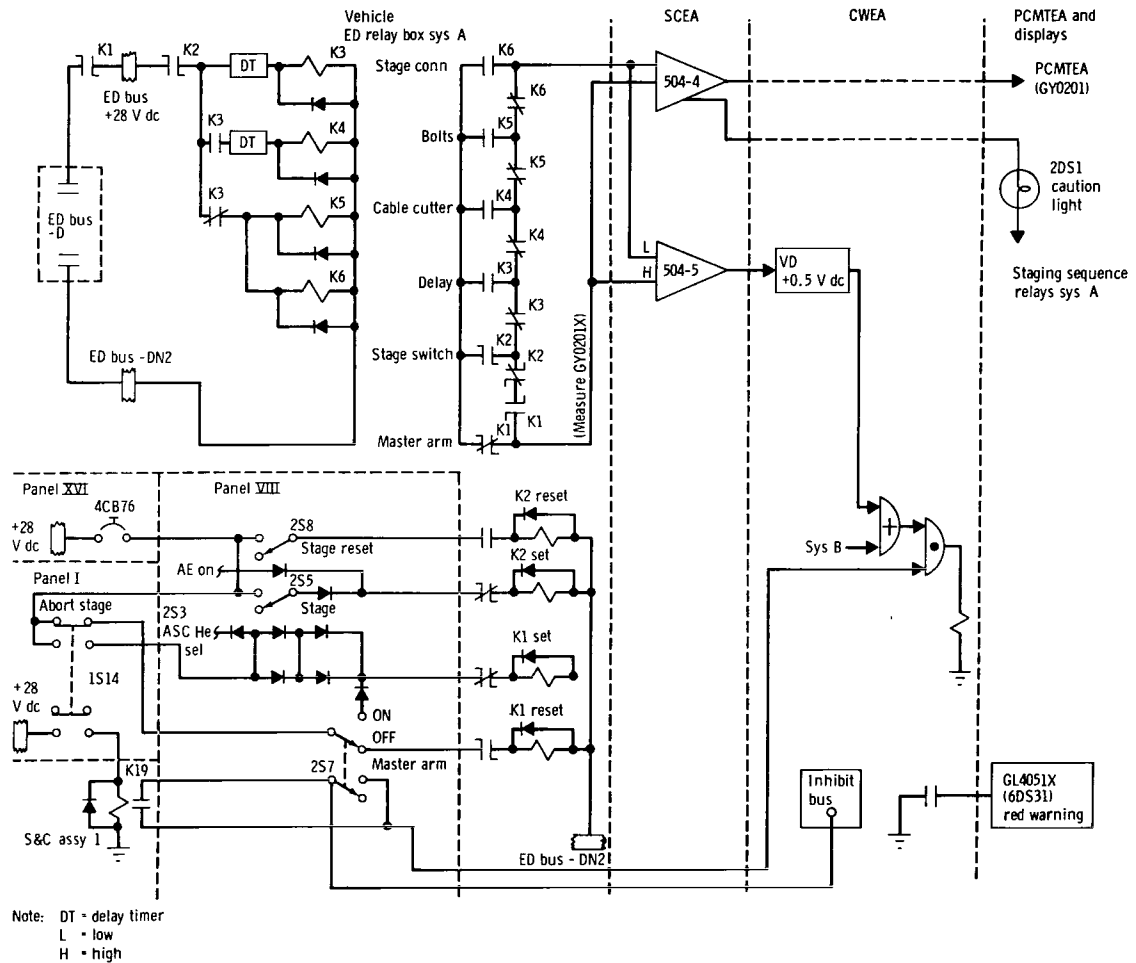


Figure 30. - Explosive devices subsystem stage sequence failure-detection circuit.

Resetting the abort stage switch after staging removes the inhibit voltage from the CWEA by deenergizing relay K19. Relay K1 is reset, removing the +28 volts from the ED bus and deenergizing relays K3 to K6. Relay K2 has no automatic-reset capability and, therefore, completes the closed-contact path to the SCEA input, activating the master alarm.

Corrective action for LM-3 and subsequent vehicles. - No hardware change will be implemented. A procedural change has been incorporated in the AOH to place the master arm switch in the on position before resetting the abort stage switch. This action will inhibit the CWEA. The ED logic A and B circuit breakers are to be opened after staging to remove any unnecessary power drain. The same procedure should be used during vehicle ground testing.

Characteristic 2

An ED malfunction alarm occurs when the master arm switch is moved from ON to OFF at the completion of normal staging sequence.

Discussion. - During normal staging, placing the master arm switch in the on position inhibits the CWEA and arms the ED bus by setting relay K1. Staging can be accomplished automatically by firing the ascent engine or manually by closing the stage switch without firing the ascent engine. In either case, relay K2 is set and initiates the staging sequence. At the completion of staging, if the master arm switch is placed in the off position, the inhibit voltage is removed from the CWEA and relay K1 is reset, causing reconfiguration of relays K3 to K6. Relay K2 has no automatic reset; thus, it completes the closed-contact path to the SCEA and activates the master alarm.

Corrective action for LM-3 and subsequent vehicles. - A procedural change has been incorporated in the AOH to leave the master arm switch in the on position after staging to inhibit the CWEA. The ED logic A and B circuit breakers are to be opened after staging to remove any unnecessary power drain.

Characteristic 3

An ED malfunction alarm occurs when the master arm switch is moved from ON to OFF at the completion of any ED function other than staging.

Discussion. - Relay K2 is not set during ED functions that do not involve staging. This alarm condition is of short duration and exists during the time required to reset relay K1, after the inhibit voltage has been removed from the CWEA.

Corrective action for LM-3 and LM-4. - A procedural change to the AOH has been incorporated to inform the crew to expect the occurrence of and to reset the master alarm. A similar procedure should be used during ground check.

Corrective action for LM-5 and subsequent vehicles. - Removal of inhibit voltage is delayed while relay K1 is reset. This change is incorporated into CWEA part number LSC-360-8-11-9.

With the hardware change incorporated in the CWEA to delay the removal of the inhibit voltage when relay K19 is deenergized or the master arm switch is placed in the off position, it is recognized that manually resetting relay K2 after staging also would prevent the occurrence of a master alarm. However, any subsequent engine firing would set relay K2 and initiate a master alarm.

HEATER CAUTION (RCS QUAD-CLUSTER TEMPERATURES)

As a result of data obtained during the LM-3 flight and subsequent RCS red-line-temperature ground tests, the following design changes have been implemented.

Design Change for LM-4

The CWEA trip levels for the RCS quad-cluster temperature measurements have been changed to 113° and 241° F. During certain phases of the mission (such as docking), a master alarm is still possible and should be expected during normal procedures. This possible master alarm will be noted in the LM-4 AOH procedures.

Design Change for LM-5 and Subsequent Vehicles

The RCS quad-cluster temperatures have been deleted from the CWEA by cutting the interface wiring between the SCEA and the CWEA. This change will cause a heater caution indication and a master alarm when the CWEA circuit breaker is initially closed and will be included as an expected master alarm in the AOH procedures. The heater caution light must be reset by rotating the temperature monitor switch through the four RCS quad temperature positions.

HEATER CAUTION (LR ANTENNA TEMPERATURES)

Characteristic 1

Characteristic 1 is caused by the lack of a staging enable to the CWEA logic (fig. 31). When vehicle staging is performed, the wiring to the LR temperature sensor is severed by the cable cutter. This operation places an open circuit at the input to the SCEA, which is analogous to an out-of-temperature condition at the high end; and the CWEA initiates a master alarm.

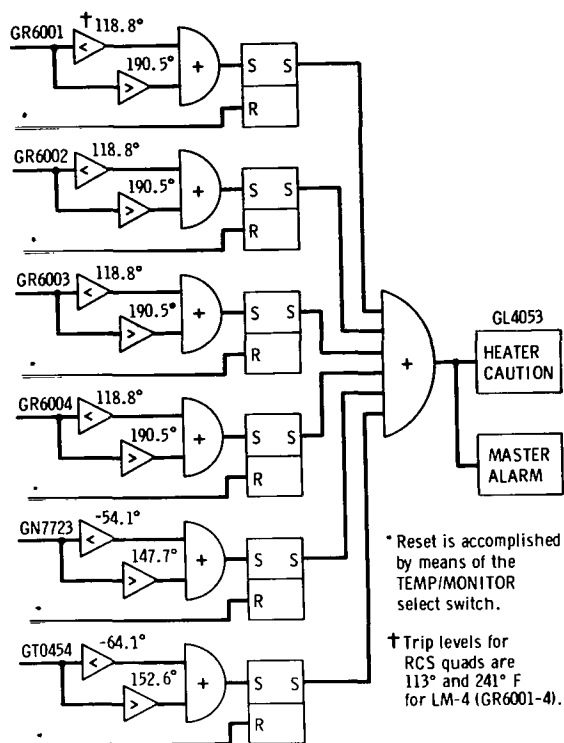


Figure 31. - Heater caution circuit.

other undesirable characteristics of this circuit were identified. During touchdown on a lunar landing mission, heat from the descent engine plume will be reflected back to the LR antenna from the lunar surface. This heat will cause the LR antenna temperature to go beyond the upper limits and initiate a master alarm during a period of high activity. After landing, the LR electronics and antenna heater circuit breakers are opened to conserve battery power. Following an undetermined period of cold soak on the lunar surface, the antenna temperature would gradually decrease to an in-limits condition, remove the failure indication to the CWEA, and enable it for future failures. The antenna temperature would continue to decrease until it eventually reached the out-of-limits condition on the low end and would initiate a second master alarm.

A high probability exists that this second alarm condition could occur during an EVA period. The master alarm would alert the ground crew to a failure that could be identified; however, with both crewmembers on EVA, the master alarm could not be reset and, thus, could not be used as a cue to ground personnel in the event of a subsequent failure.

Because both of these alarm conditions would occur when the LR equipment was no longer required, they could serve only to hinder the completion of the mission. As a result, measurement of LR antenna temperature has been removed from the CWEA. This modification was accomplished by removing the stage enable at the input to the CWEA.

Corrective action for LM-3 and LM-4. - To preclude the issuance of a master alarm during staging, the LR temperature interface was removed between the SCEA and the CWEA. This modification will cause a master alarm when the CWEA circuit breaker is closed; however, because a master alarm is assured when the CWEA is activated during the mission as a result of the incapability of the RCS quad heaters to establish an in-limits condition before activation, the master alarm is of no significance. The LR heater caution can be reset by rotating the temperature monitor switch to the LR antenna position. After resetting, the circuit is disabled for the remainder of the mission, unless the CWEA is turned off and then back on. This cycling of the CWEA circuit breaker would require resetting the LR heater caution.

Corrective action for LM-5 and subsequent vehicles. - A staging-enable circuit was added to the LR temperature logic (internal to CWEA part number LSC-360-8-11-9) to inhibit this circuit at staging. Subsequent to this change, two

The following measurements are OR-gated inputs to GL4053.

1. GR6001T (LM-4 only) — quad cluster number 4 temperature ($<113^{\circ}$ and $>241^{\circ}$ F)
2. GR6002T (LM-4 only) — quad cluster number 3 temperature ($<113^{\circ}$ and $>241^{\circ}$ F)
3. GR6003T (LM-4 only) — quad cluster number 2 temperature ($<113^{\circ}$ and $>241^{\circ}$ F)
4. GR6004T (LM-4 only) — quad cluster number 1 temperature ($<113^{\circ}$ and $>241^{\circ}$ F)
5. GN7723T — RR antenna temperature ($<-54.1^{\circ}$ and $>147.7^{\circ}$ F)
6. GT0454T — S-band antenna assembly temperature ($<-64.1^{\circ}$ and $>152.6^{\circ}$ F)

Characteristic 2

An in-limits temperature condition first must be established to enable the CWEA to detect a failed-off heater (fig. 31). The antenna heaters are activated before lift-off and are, therefore, not affected by this characteristic during flight.

Discussion. - An in-limits temperature condition for the parameters identified previously will produce a logic zero at the output of the detectors (fig. 31). An out-of-limits temperature condition on any of these parameters will produce a logic one at the output of its associated detector. A transition from a logic zero (in-limits condition) to a logic one (out-of-limits condition) at the detector output is required to set a flip-flop. When any flip-flop is set, the heater caution light is turned on and a master alarm is initiated. The caution light can be extinguished manually by resetting the flip-flop with temperature monitor select switch 18S10. However, the failed indication (a logic one) still remains at the output of the detector and can be removed only by establishing an in-limits temperature condition (logic zero).

During LM missions, the RCS quad heaters are turned on after the crew transfers to the LM. The CWEA is turned on after activation of the heaters but before the quad temperatures have reached a normal operating level. Therefore, a failed indication (logic one) exists at the output of the low-level detectors and all four quad-cluster flip-flops are set when the CWEA is turned on. The flip-flops are reset manually by rotating switch 18S10, but the logic ones at the output of the detectors effectively inhibit the CWEA until the heaters raise the quad temperatures to within normal limits. If a heater should fail off before an in-limits condition is established, the failure will not be detected by the CWEA.

Corrective action for LM-3 and LM-4. - The crew is instructed by the AOH to periodically monitor the quad-cluster temperatures after turn-on, to verify that the temperatures have reached an in-limits condition. Once this condition has been established, the CWEA is enabled and will detect any subsequent heater failures.

POSSIBLE MASTER ALARM RESULTING FROM CARBON DIOXIDE SENSOR (ECS CAUTION)

Discussion

A master alarm may occur during vehicle ground checkout when the carbon dioxide (CO₂) sensor circuit breaker is closed (fig. 32). This possibility results from a transient voltage produced by the CO₂ sensor when power is applied. The magnitude of this transient voltage varies with CO₂ sensors and may not be sufficient to trip the ECS caution light and produce a master alarm. A master alarm resulting from this characteristic has been experienced only during checkout of one vehicle (LM-4).

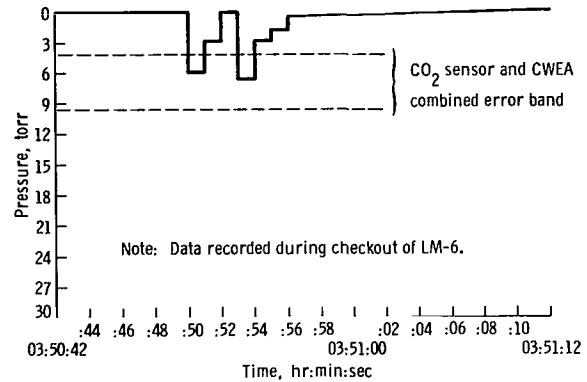


Figure 32. - Typical plot of carbon dioxide pressure variation during ground checkout.

Corrective Action for LM-3 and Subsequent Vehicles

The CO₂ sensor characteristic will not cause a master alarm during inflight checkout of the vehicle if existing AOH procedures are followed. Existing procedures call for closing the CO₂ sensor circuit breaker before the master alarm circuit breaker is closed. During ground checkout, a master alarm may occur if the CO₂ sensor breaker is closed after the CWEA and master alarm breakers are closed.

S-BAND RECEIVER (AUTOMATIC GAIN CONTROL ALARM) CAUTION

Discussion

At the completion of the S-band ranging function, the S-band range-function switch (13S1) is placed in the off/reset position (fig. 33). This action will reset the S-band caution circuit. However, any subsequent decrease of the S-band automatic gain control (AGC) voltage (as a result of signal fading) below the CWEA reference level, while the switch remains in the off/reset position, will register a failure in the CWEA memory. Subsequent enabling of the S-band caution indicator would cause a master alarm.

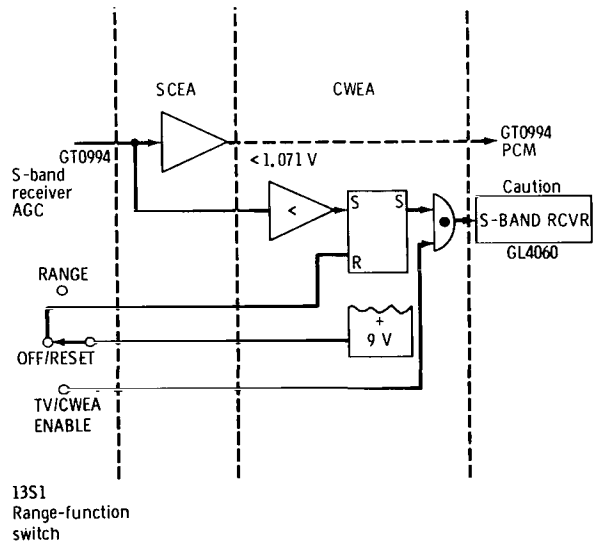


Figure 33. - S-band receiver AGC failure-detection circuit.

Corrective Action for LM-3 and Subsequent Vehicles

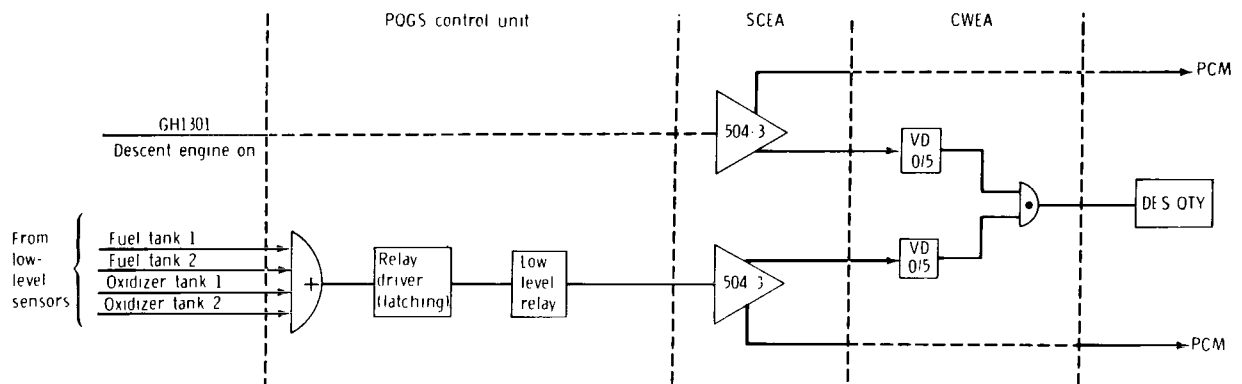
This condition can be avoided by placing the S-band range-function switch momentarily in the range position immediately prior to enabling the CWEA. This action will reset the S-band caution circuit and remove any prior failures.

LOW DESCENT PROPELLANT QUANTITY WARNING

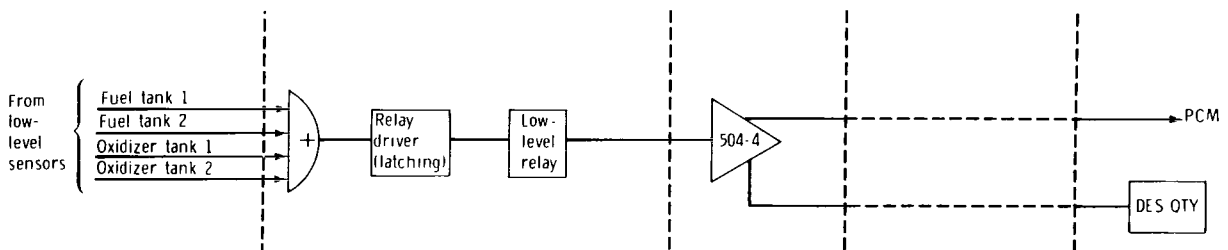
Characteristic 1

A high probability exists for the occurrence of a master alarm during a normal lunar landing.

Discussion. - The GL4024 warning indication (fig. 34) was designed to alert the crew to a propellant quantity remaining equal to 2 minutes at 25 percent thrust. There is a high probability that the propellant level will reach this point prior to touchdown on a normal lunar landing.



(a) For LM-3 and LM-4.



(b) For LM-5 and subsequent vehicles.

Figure 34. - Descent propellant low-level quantity circuit.

Corrective action for LM-4. - No corrective action is required for the "F" (lunar orbit) mission. The master alarm will be initiated when the descent propellant level is equal to a 2-minute engine burn at 25 percent thrust.

Corrective action for LM-5 and subsequent vehicles. - The low descent propellant quantity measurement has been removed from the CWEA and the master alarm circuits. The low-level quantity annunciator light has been retained for this measurement on the caution and warning array, and this light will illuminate when the propellant remaining is equal to 2 minutes at 25 percent thrust. This visual indication will not be accompanied by a master alarm.

Characteristic 2

A possible low-level indication is anticipated prior to the ullage maneuver.

Discussion. - If the descent propellant quantity gaging system (PQGS) is activated before performance of the ullage maneuver, the four low-level sensors in the PQGS may be exposed to the ullage (fig. 34). Should any one of these four sensors be exposed to ullage, a low-level indication is latched in the PQGS control unit. On LM-5 and subsequent vehicles, this condition will illuminate the annunciator light on the CWEA array. A master alarm will not occur. On LM-4, because of logic circuitry in the CWEA, this condition will go unnoticed until a descent engine-on command is initiated; thus, a master alarm and a low-level quantity warning will occur when the engine is commanded to fire.

Corrective action for LM-4. - Two possible courses of action are available.

1. Recycle the PQGS after the ullage maneuver is performed and before the first descent engine-on command is initiated.

2. Expect a possible master alarm when the descent engine is initially fired, verify that the descent quantity light is on, and reset the master alarm.

The LM-4 AOH procedures identify this condition and specify the second course of action.

Corrective action for LM-5 and subsequent vehicles. - The AOH procedure calls for recycling the PQGS subsequent to the ullage maneuver, if the descent quantity light is on.



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