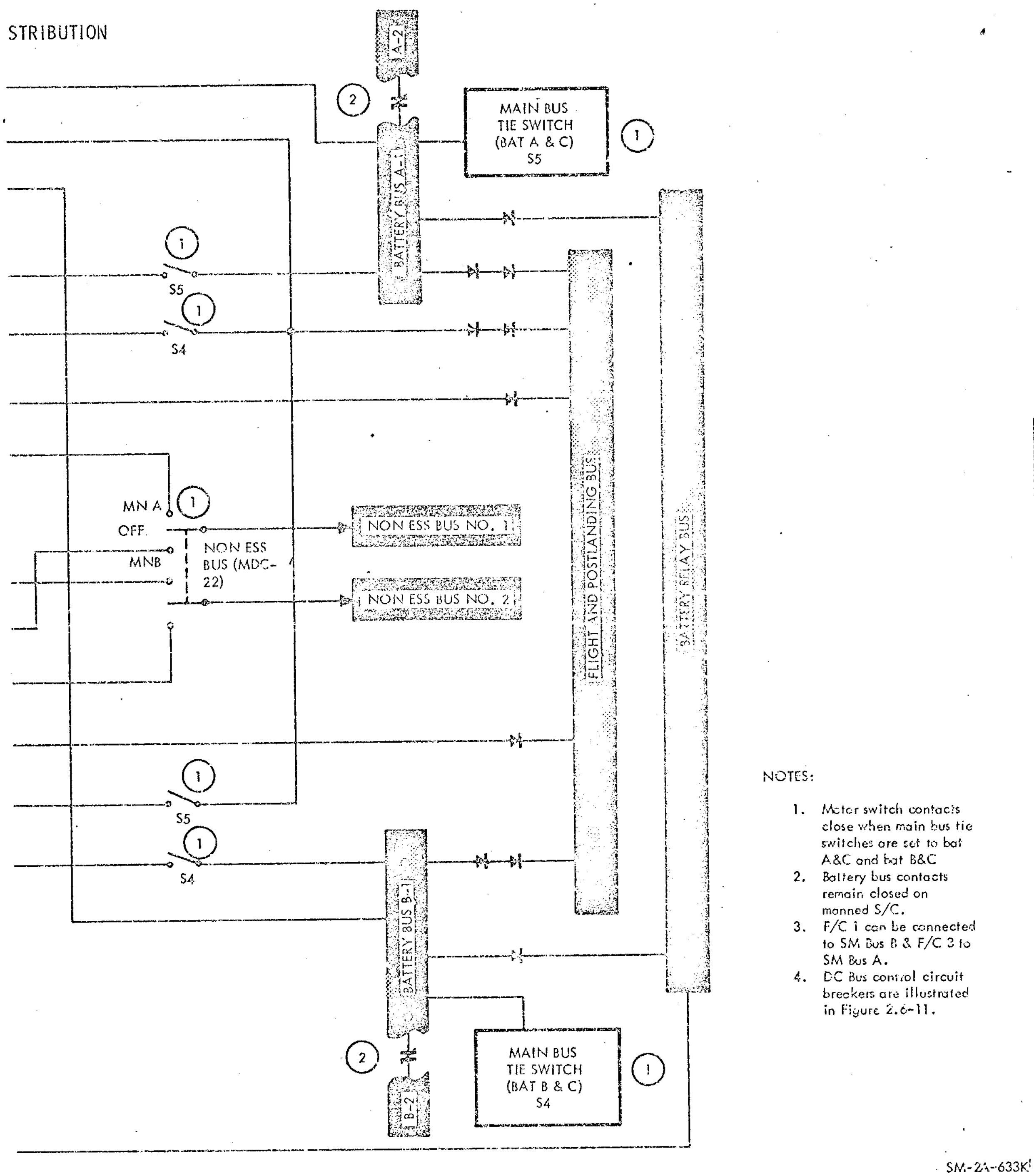
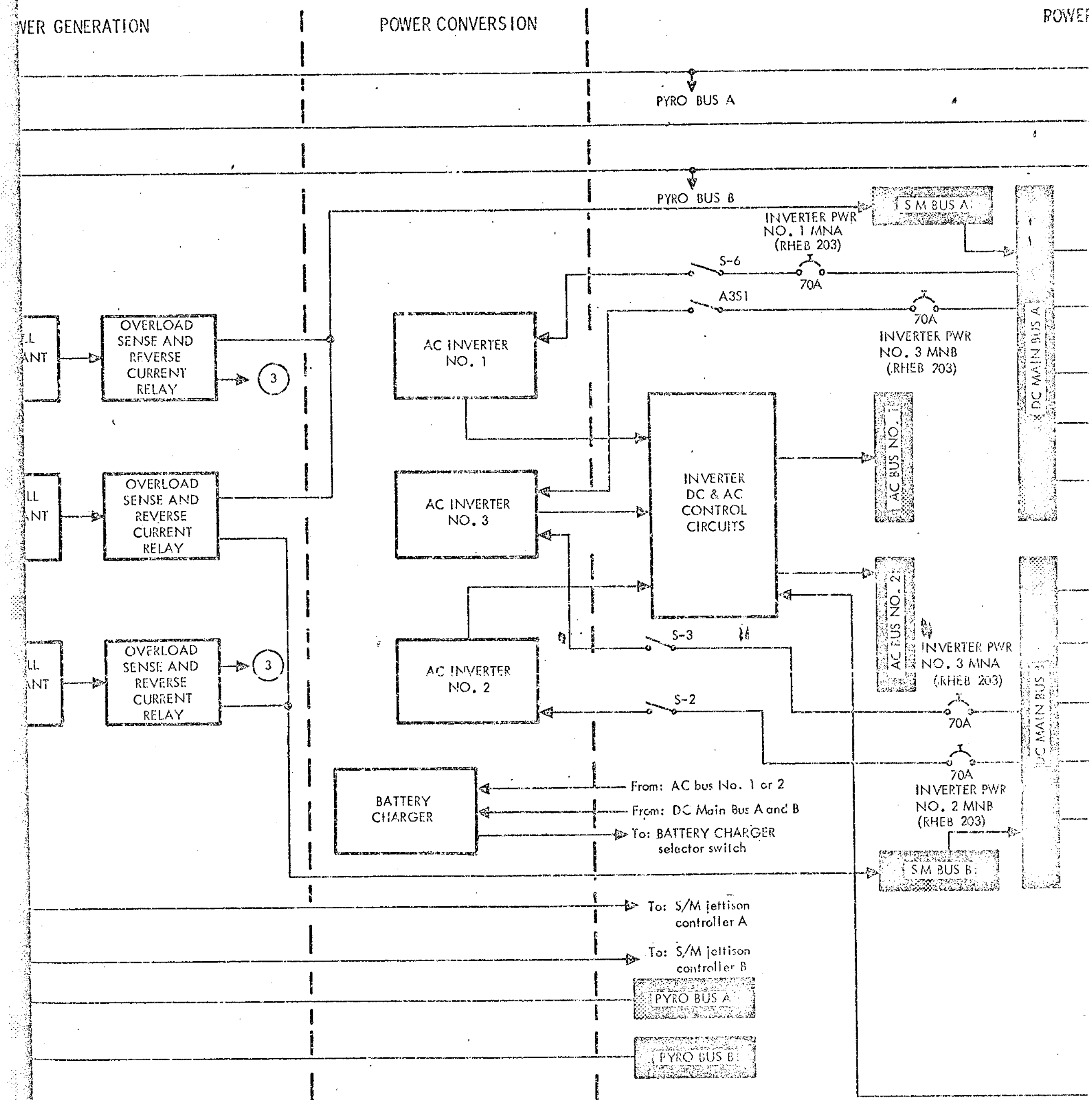


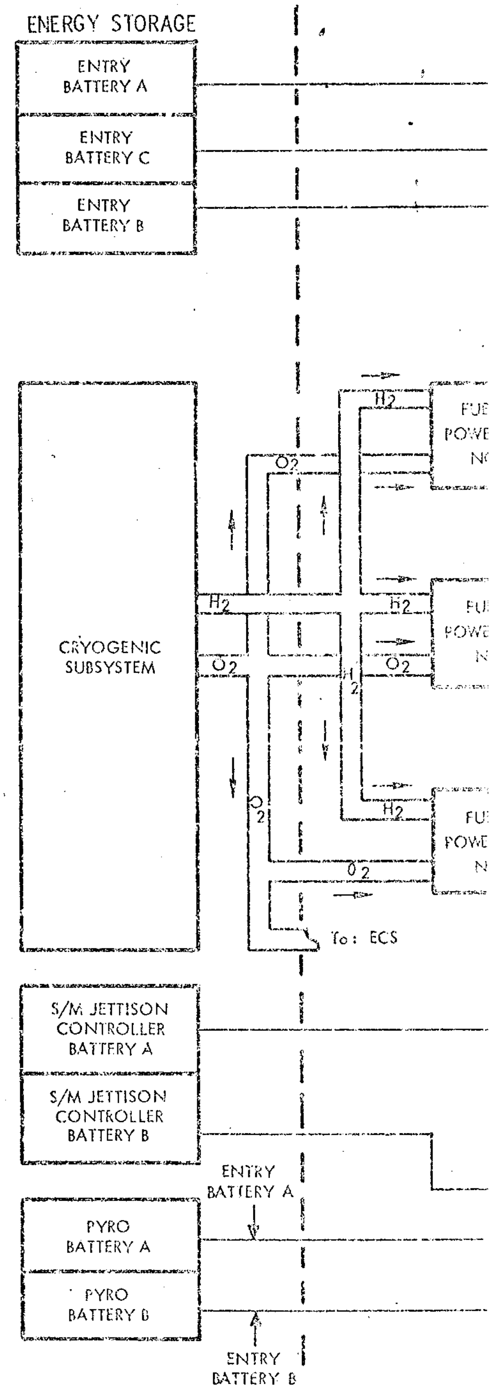
NOTES:

1. Motor switch contacts close when main bus tie switches are set to bat A&C and bat B&C
2. Battery bus contacts remain closed on manned S/C.
3. F/C 1 can be connected to SM Bus B & F/C 3 to SM Bus A.
4. DC Bus control circuit breakers are illustrated in Figure 2.6-11.

Figure 2.6-1. Electrical Power System Block Diagram



WER GENERATION
POWER CONVERSION
POWE
PYRO BUS A
PYRO BUS B
S M BUS A
INVERTER PWR NO. 1 MNA (RHEB 203)
S-6
70A
A3S1
70A
INVERTER PWR NO. 3 MNB (RHEB 203)
DC MAIN BUS A
LL ANT
OVERLOAD SENSE AND REVERSE CURRENT RELAY
3
AC INVERTER NO. 1
AC BUS NO. 1
INVERTER DC & AC CONTROL CIRCUITS
LL ANT
OVERLOAD SENSE AND REVERSE CURRENT RELAY
AC INVERTER NO. 3
AC BUS NO. 2
S-3
INVERTER PWR NO. 3 MNA (RHEB 203)
LL ANT
OVERLOAD SENSE AND REVERSE CURRENT RELAY
3
AC INVERTER NO. 2
S-2
70A
DC MAIN BUS
70A
INVERTER PWR NO. 2 MNB (RHEB 203)
BATTERY CHARGER
From: AC bus No. 1 or 2
From: DC Main Bus A and B
To: BATTERY CHARGER selector switch
SM BUS B
To: S/M jettison controller A
To: S/M jettison controller B
PYRO BUS A
PYRO BUS B


ENERGY STORAGE
ENTRY BATTERY A
ENTRY BATTERY C
ENTRY BATTERY B
CRYOGENIC SUBSYSTEM
H2
O2
To: ECS
S/M JETTISON CONTROLLER BATTERY A
S/M JETTISON CONTROLLER BATTERY B
ENTRY BATTERY A
PYRO BATTERY A
PYRO BATTERY B
ENTRY BATTERY B

reactant temperature. With design pressures in the tanks, single-phase reactant is available independent of downstream system transfer.

The manual mode of operation simply bypasses the pressure switches. It can be used in case of control failure or when operating with quantity unbalanced depletion. To avoid excessive temperatures, a thermal sensitive interlock device is in series with each heater element in the O_2 and H_2 tanks. These open the heater circuits when internal temperatures reach 80°F and close when temperatures decrease to 70°F. Tank pressures and quantities are monitored on meters located on MDC-13. O_2 tank relief valves initially vent at 983 psig and reseat at 970 psig. H_2 relief valves vent at 273 psig and reseat at 268 psig. The C&W system will alarm when oxygen pressure in either tank exceeds 950 psia, or goes below 800 psia. The hydrogen system alarms the C&W system when pressure in either tank exceeds 270 psia, or goes below 220 psia.

Individual tank pressures, quantities, and reactant temperatures are telemetered to MSFN.

2.6.3.2 Batteries.

A total of seven silver oxide-zinc storage batteries are incorporated in the EPS. Five of these batteries are located in the C/M lower equipment bay, the other two in sector IV of the S/M.

Three entry batteries (A, B, and C) provide the primary source of power after CSM separation and during postlanding operations. Prior to CSM separation, the entry batteries provide a secondary source of power while the fuel cells provide the primary source. The entry batteries are used for the following purposes:

- Provide C/M power after CSM separation
- Supplement fuel cell power during peak load periods (SPS gimbal motor operation)
- Provide power during emergency operations (failure of two fuel cells)
- Provide power for EPS control circuitry (relays, indicators, etc.)
- Provide sequential logic power
- Provide power for recovery aids during postlanding phase
- Batteries A and B can power pyro circuits upon selection.

The entry batteries can be recharged in flight.

2.6.3 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION.

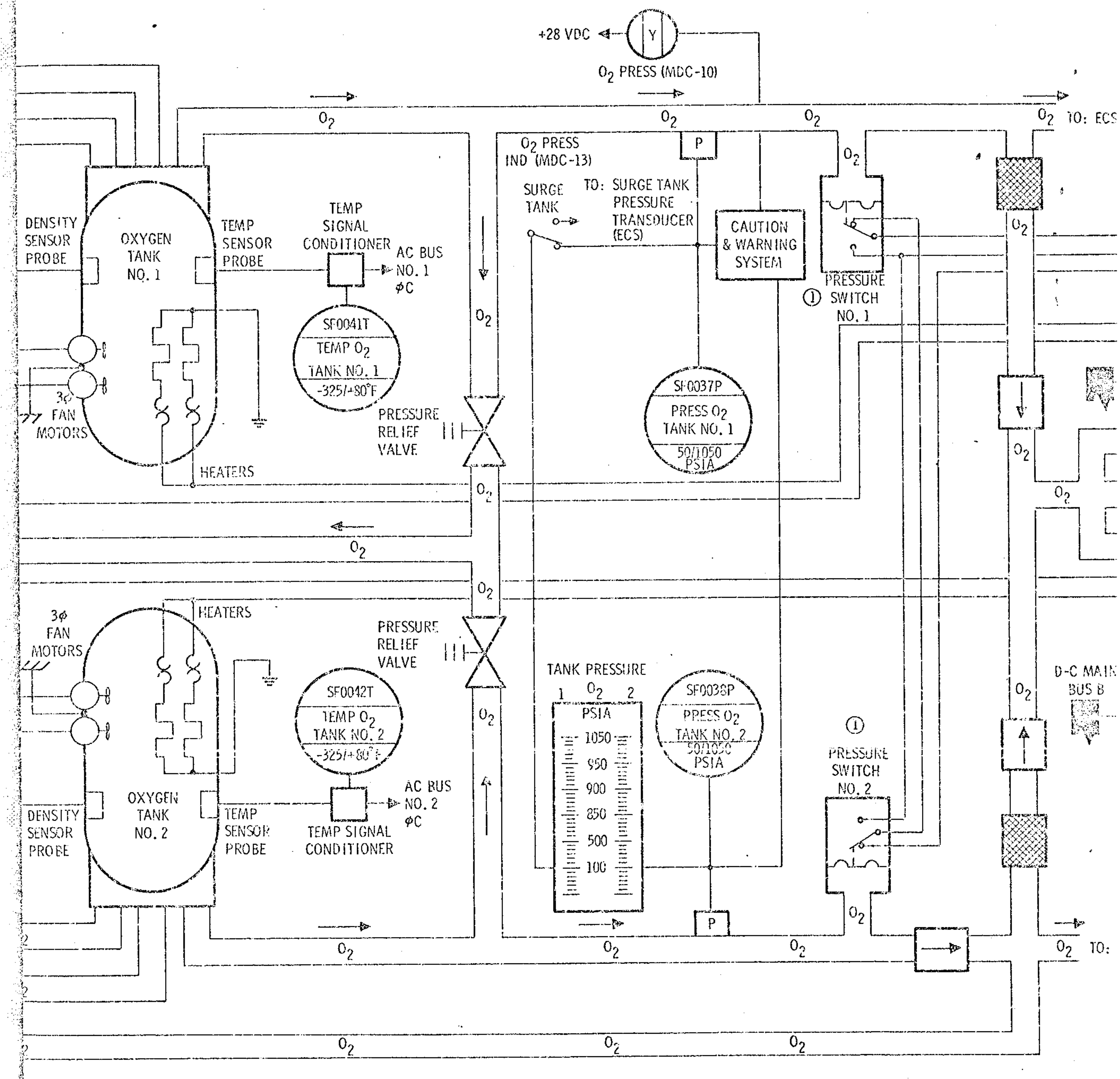
2.6.3.1 Cryogenic Storage.

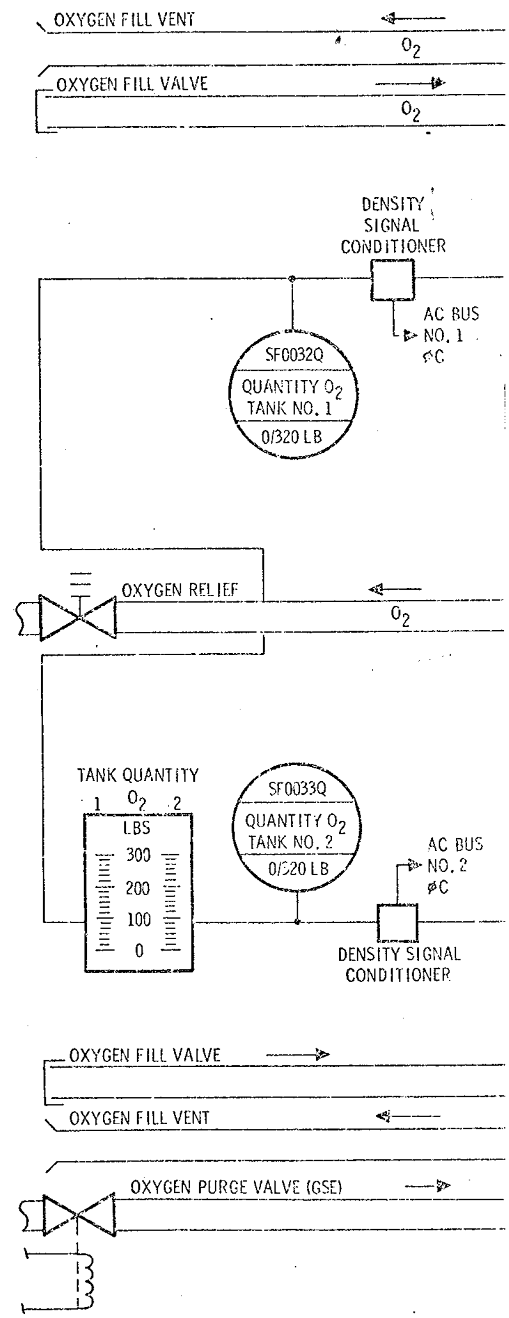
The cryogenic storage system (figure 2.6-2) supplies oxygen and hydrogen reactants to the spacecraft. Hydrogen is supplied to the EPS and oxygen is supplied to both EPS and ECS. The design functions of the two storage systems are identical. The physical data for the cryogenic storage system is given in the following list.

Tank Number	Wt of Usable Cryogenics	Flow Rate at Min dq/dm	Design Storage Press. (Psia)	Min Allowable Operating Pressure	Approx Tank Qtys at Min Heater & Fan Cycling
LO 12	320 lb	0.676 lb/hr	900±35	150 psia	131 to 82 lbs
XTA 0006	320 lb	0.713 lb/hr	900±35	150 psia	131 to 82 lbs
LH 23	28 lb	0.070 lb/hr	245 (+15, -20)	100 psia	14.5 to 7.3 lbs
LH 25	28 lb	0.066 lb/hr	245 (+15, -20)	100 psia	14.5 to 7.3 lbs

The automatic control mode is designed to give a single-phase reactant flow into the F/C and ECS feedlines at design pressures. This control is achieved in effect by controlling the heat transfer within the system. The heat required to maintain constant pressure varies with density. Fill density for oxygen is a little above 70 lbs/ft^3. As depletion proceeds from 70 lbs/ft^3, or 100 percent quantity, to approximately 28 lbs/ft^3, or 40 percent quantity, the cycling of the fans and heaters for repressurization will extend until they cycle least at quantities between 131 and 82 lbs. In the hydrogen system, least amount of heater and fan cycling will occur at quantities between approximately 14.5 and 7.3 lbs. With the system in automatic operation, tank quantities should remain within 15 pounds of each other for oxygen and within one pound difference for hydrogen. The pressure switches activating the heaters and fans are in series. The oxygen switches activate when pressure drops to 865 psia in both tanks. They deactivate when pressure reaches 935 psia in one of the tanks. Keeping the design pressure permits depletion to follow predictable tank densities and respective heat requirements.

When the systems reach the point where the heater and fan cycling is at a minimum, the heat leak of the tank becomes sufficient to maintain design pressures, provided flow is within min dq/dm values as shown in the preceding list. This realm of operation is referred to as being in the minimum dq/dm region. The minimum dq/dm point for oxygen is 23.5 lbs/ft^3 at the nominal operating pressure of 900 psia. The value for hydrogen is 1.87 lbs/ft^3 at 250 psia. The heat required for densities less than the above rises abruptly for both oxygen and hydrogen. The intrinsic flow output of the systems is a maximum at the point where minimum heat is required to maintain pressure. The time-rate of arriving at the minimum dq/dm point is dependent on load demands, tank pressure, and


+28 VDC
Y
O_2 PRESS (MDC-10)
O_2
TO: ECS
O_2 PRESS IND (MDC-13)
P
SURGE TANK
TO: SURGE TANK PRESSURE TRANSDUCER (ECS)
CAUTION & WARNING SYSTEM
PRESSURE SWITCH NO. 1
DENSITY SENSOR PROBE
OXYGEN TANK NO. 1
TEMP SENSOR PROBE
TEMP SIGNAL CONDITIONER
AC BUS NO. 1 φC
SF0041T
TEMP O_2 TANK NO. 1
-325/+80°F
SF0037P
PRESS O_2 TANK NO. 1
50/1050 PSIA
3φ FAN MOTORS
HEATERS
PRESSURE RELIEF VALVE
OXYGEN TANK NO. 2
TEMP SENSOR PROBE
TEMP SIGNAL CONDITIONER
AC BUS NO. 2 φC
SF0042T
TEMP O_2 TANK NO. 2
-325/+80°F
TANK PRESSURE
1 O_2 2
PSIA
1050
950
900
850
500
100
SF0038P
PRESS O_2 TANK NO. 2
50/1050 PSIA
PRESSURE SWITCH NO. 2
D-C MAIN BUS B
TO:
Mi



OXYGEN FILL VENT
O_2
OXYGEN FILL VALVE
O_2
DENSITY
SIGNAL
CONDITIONER
AC BUS
NO. 1
ϕC
SF0032Q
QUANTITY O_2
TANK NO. 1
0/320 LB
OXYGEN RELIEF
O_2
TANK QUANTITY
1 O_2 2
LBS
300
200
100
0
SF0033Q
QUANTITY O_2
TANK NO. 2
0/320 LB
AC BUS
NO. 2
ϕC
DENSITY SIGNAL
CONDITIONER
OXYGEN FILL VALVE
OXYGEN FILL VENT
OXYGEN PURGE VALVE (GSE)

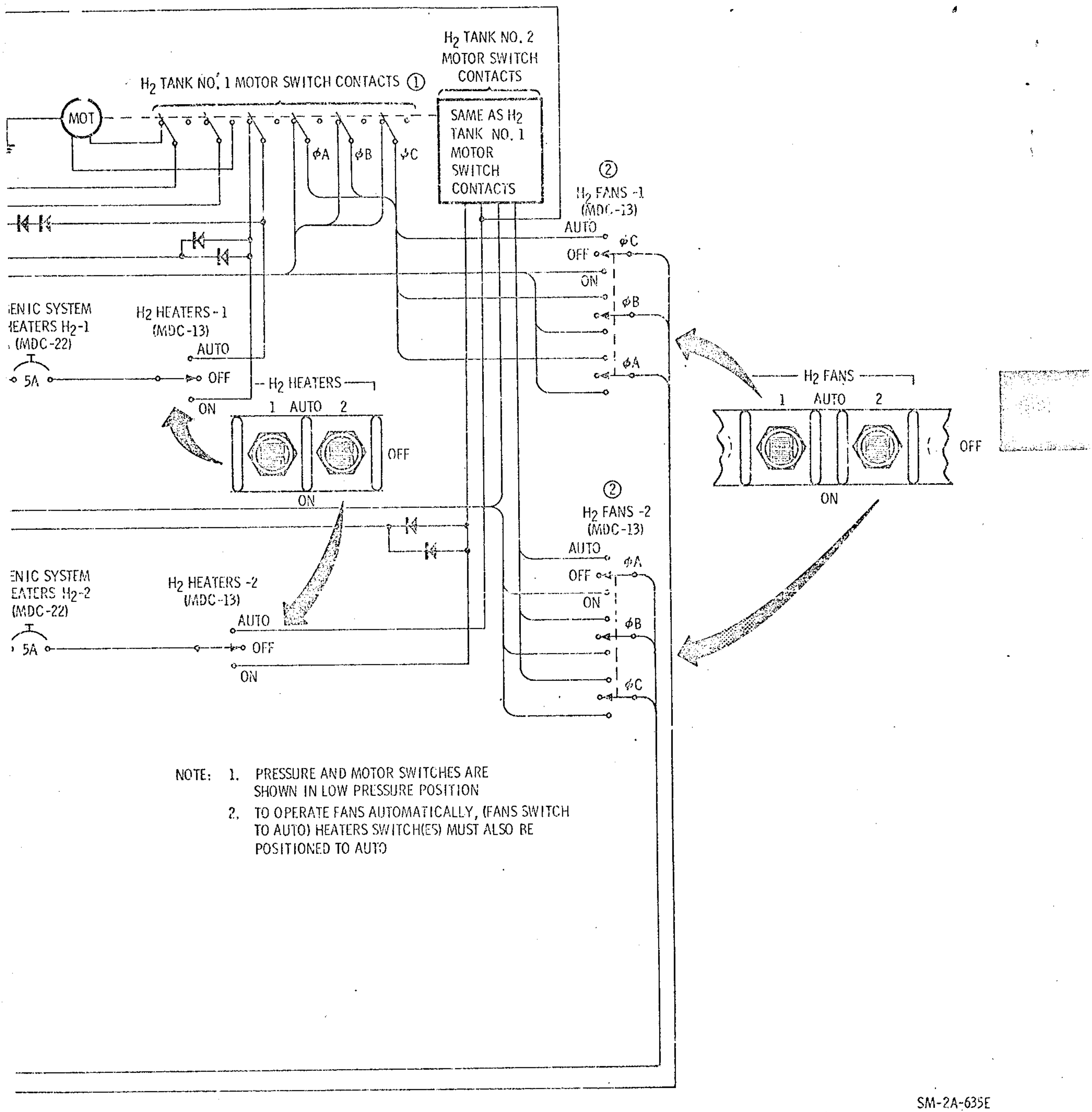
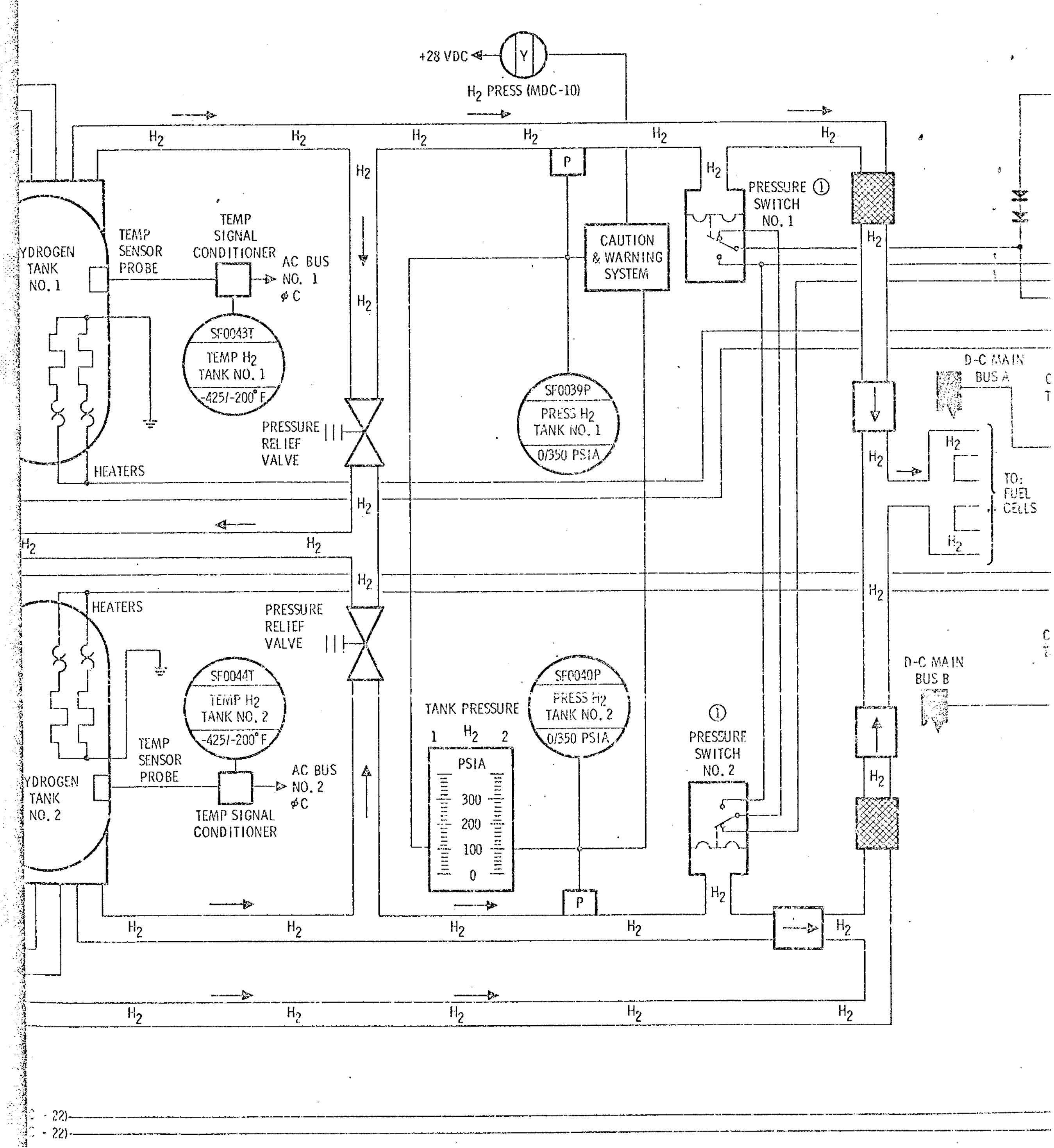
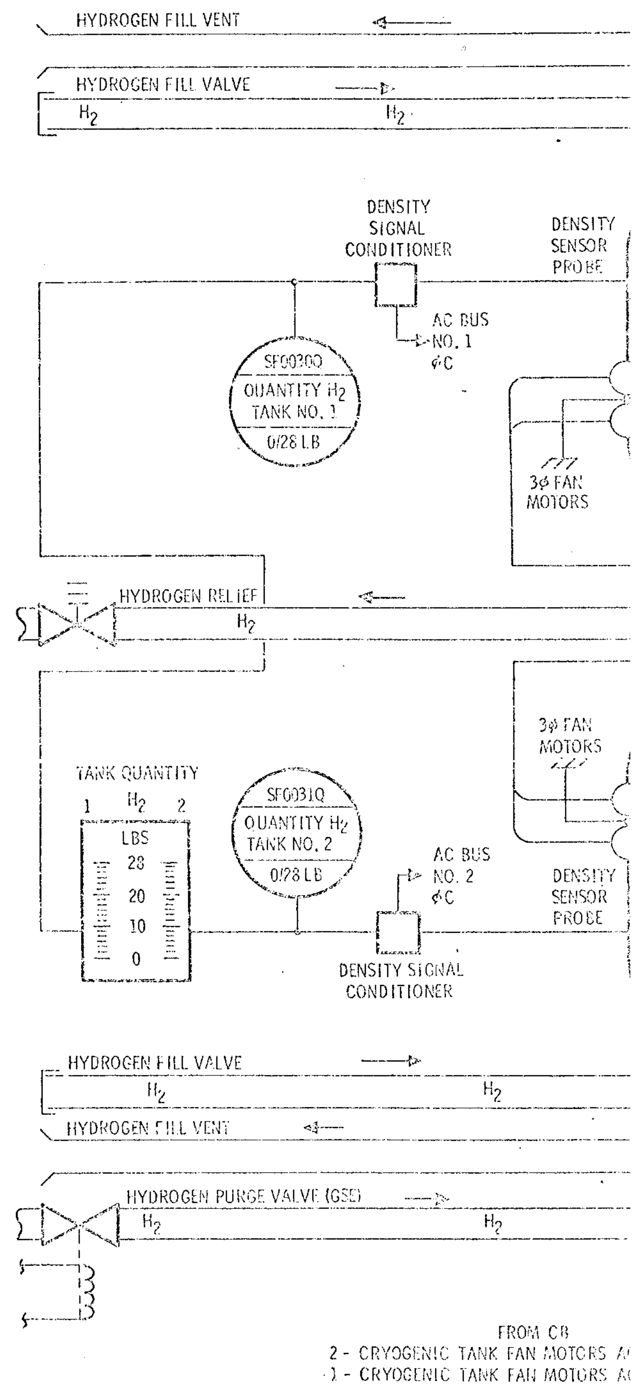


Figure 2.6-2. Cryogenic Storage System (Sheet 2 of 2)


+28 VDC
Y
H_2 PRESS (MDC-10)
YDROGEN TANK NO. 1
TEMP SENSOR PROBE
TEMP SIGNAL CONDITIONER
AC BUS NO. 1 ϕC
SF0043T
TEMP H_2 TANK NO. 1
-425/-200°F
HEATERS
PRESSURE RELIEF VALVE
P
CAUTION & WARNING SYSTEM
SF0039P
PRESS H_2 TANK NO. 1
0/350 PSIA
PRESSURE SWITCH NO. 1
D-C MAIN BUS A
TO: FUEL CELLS
D-C MAIN BUS B
YDROGEN TANK NO. 2
TEMP SENSOR PROBE
TEMP SIGNAL CONDITIONER
AC BUS NO. 2 ϕC
SF0044T
TEMP H_2 TANK NO. 2
-425/-200°F
SF0040P
PRESS H_2 TANK NO. 2
0/350 PSIA
TANK PRESSURE
1 H_2 2
PSIA
300
200
100
0
PRESSURE SWITCH NO. 2
H_2
- 22)
- 22)
M



HYDROGEN FILL VENT
HYDROGEN FILL VALVE
H2
DENSITY SIGNAL CONDITIONER
DENSITY SENSOR PROBE
AC BUS NO. 1 φC
SF0030Q
QUANTITY H2 TANK NO. 1
0/28 LB
3φ FAN MOTORS
HYDROGEN RELIEF
TANK QUANTITY
1 H2 2
LBS
28
20
10
0
SF0031Q
QUANTITY H2 TANK NO. 2
0/28 LB
AC BUS NO. 2 φC
DENSITY SIGNAL CONDITIONER
HYDROGEN PURGE VALVE (GSE)
FROM CB
2 - CRYOGENIC TANK FAN MOTORS
1 - CRYOGENIC TANK FAN MOTORS

Each entry battery is mounted within a vented plastic case. The battery cells are individually encased in plastic containers which contain relief valves that open at 40±10 psig, venting pressure and hydrogen gas into the battery case. Each battery case is vented overboard through a manifold leading to a manually operated valve (BATTERY VENT VALVE), which is connected to the ECS dump line. With the valve at its normal position of VENT, the battery cases are vented overboard through the ECS urine/water dump line. In a failure mode, this would prevent hydrogen gas from entering the crew compartment. With the battery vent valve closed, which would be the position after fracture of a battery case, the possibility exists for pressure buildup in the battery manifold due to outgassing of the batteries. The vent valve will be opened at pressures slightly below CM pressure and allow the built-up pressure to vent overboard. Battery manifold pressure can be monitored using the auxiliary DC VOLTS meter, located on panel 200 in the RHFEB, and is telemetered.

The two pyrotechnic batteries supply power to initiate ordnance devices in the S/C. The pyrotechnic batteries are isolated from the rest of the EPS to prevent the high power surges in the pyrotechnic system from affecting the EPS and to ensure source power when required. These batteries shall not be recharged in flight. Entry battery A or B can be used as a redundant source of power for initiating pyro circuits in the respective A or B pyro system, if either pyro battery fails.

The two S/M jettison controller batteries, located in the S/M, supply power to two jettison sequencers to sustain the S/M RCS retrofire, as well as firing the S/M positive roll RCS engines two seconds after CSM separation. These batteries are isolated from the rest of the EPS and cannot be recharged or monitored in flight.

Performance characteristics of each S/C battery are as follows:

Battery	Capacity per Battery	No. of Cells per Battery	Open Circuit Voltage (Max.)	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
Entry A, B, and C (3)	40-amp-hrs (25 ampere rate)	20	37.8 vdc (37.2 vdc in flight)	29.0 vdc (35 amps load)	27.0 vdc (35 amps load)	50° to 110°F
Pyro A and B (2)	75 amps for 36 seconds	20	37.8 vdc (37.2 vdc in flight)	23.0 vdc (75 amps load)	20.0 vdc (75 amps load) (35.0 vdc open circuit)	60° to 110°F

SYSTEMS DATA

Battery	Capacity per Battery	No. of Cells per Battery	Open Circuit Voltage (Max.)	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
S/M jettison controller A and B (2)	75 amps for 36 seconds	20	37.8 vdc (not measurable in S/C or by telemetry)	23.0 vdc (75 amps load)	20.0 vdc (75 amps load)	60° to 110°F

NOTE Pyro battery load voltage is not measurable due to the extremely short time they power pyro loads.

2.6.3.3 Fuel Cell Power Plants.

Each fuel cell power plant consists of 31 single cells, connected in series, and an accessory section. Each single cell generates approximately 1 volt. The accessory section consists of a nitrogen pressurization system, an oxygen feed, a hydrogen feed, a primary (hydrogen) loop, and a secondary (glycol) loop (figure 2.6-3). The primary and secondary loops control the temperature within the fuel cell power plant. The primary loop also extracts potable water from the power plant for use by the crew. The secondary loop radiates heat from the power plant into space through radiators located on the exterior of the S/M.

The nitrogen system establishes a reference pressure in the fuel cell. There is approximately 0.44 lbs of N_2 contained in the nitrogen tank under a pressure of 1500 psia. The nitrogen regulator reduces this pressure to 52 psia, which is used to pressurize the glycol accumulator, the electrolyte (KOH) in the cells, and as a reference pressure for the oxygen and hydrogen regulators.

Oxygen, stored in a cryogenic state at a pressure of 900±35 psia, is supplied to the fuel cell power plants. Due to the low-flow rate, the oxygen absorbs heat while flowing through the lines, absorbs additional heat in the preheater, flows to the oxygen regulator, and reaches the fuel cell power plants in a gaseous form at temperatures above +100°F. The regulator is designed to maintain a pressure differential of 10.5 psia above the nitrogen pressure, supplying the oxygen to the fuel cell at a nominal 62.5 psia. The oxygen in the system is approximately 99.99 percent pure. Over a period of time, the impurities accumulate in the reactant compartment and decrease fuel cell efficiency. This is noted by a drop in fuel cell performance. To eliminate the impurities, the fuel cell is purged. Normally a fuel cell will be purged every 24 hours; however, the actual purge cycle will be determined by the predicted mission power profile and the purity of the reactant as it is calculated to be after

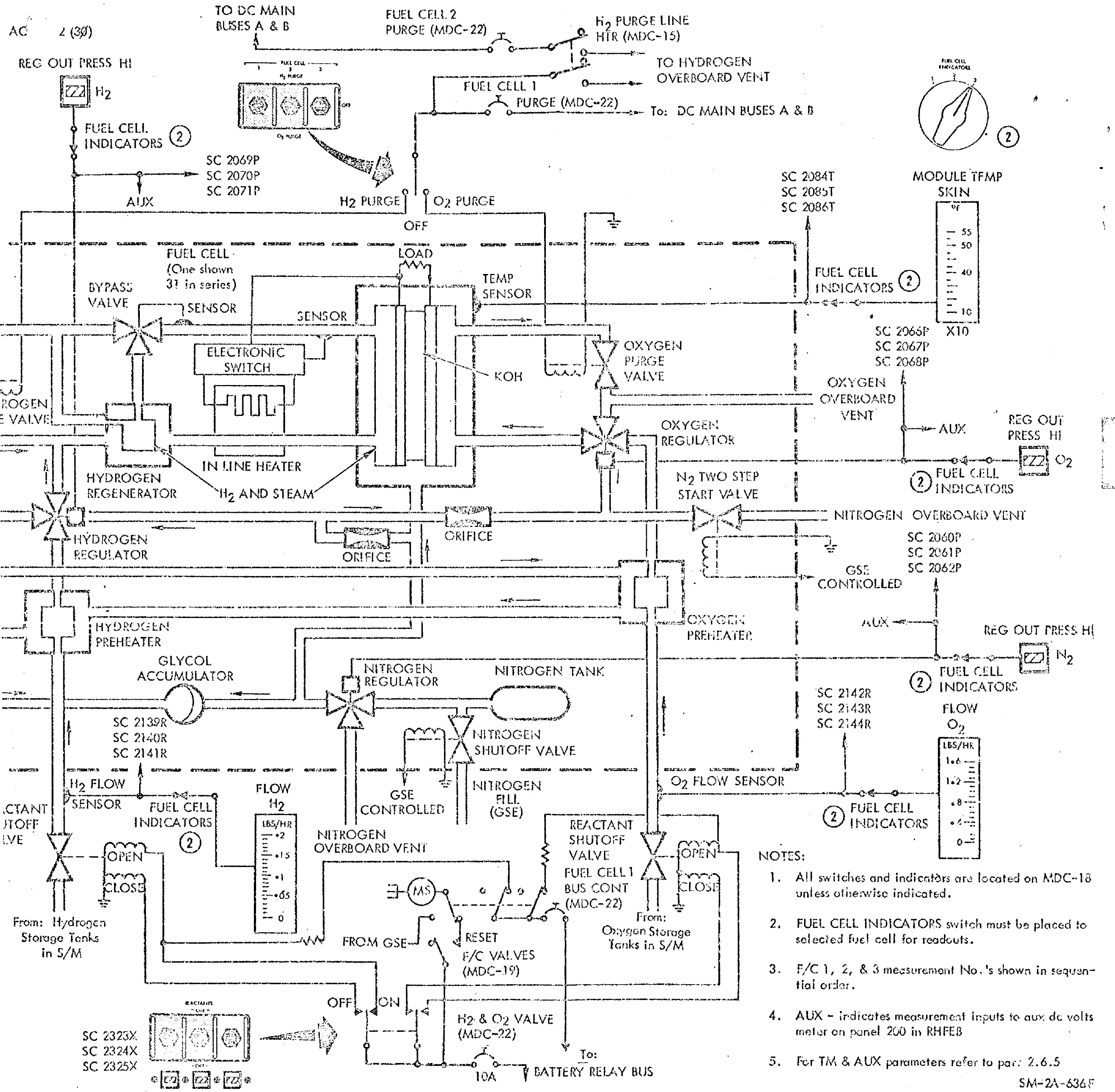
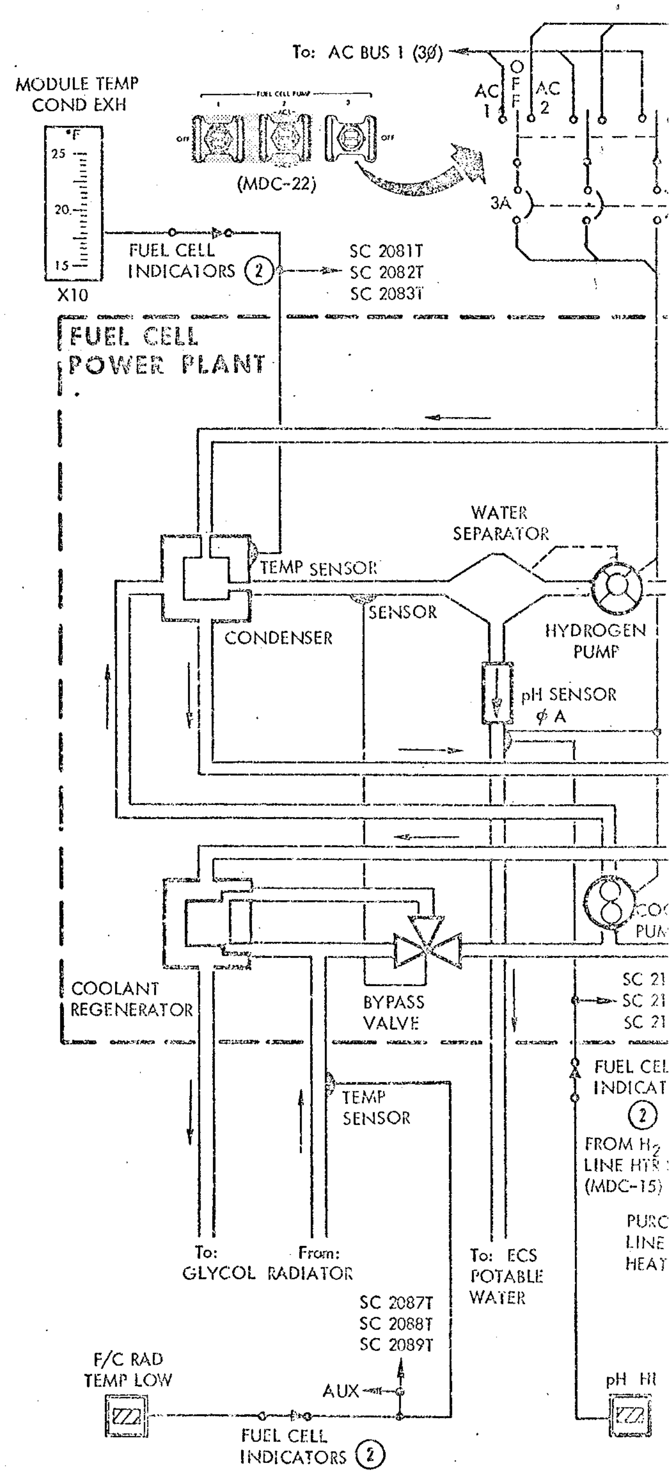


Figure 2.6-3. Fuel Cell Power Plant Flow Diagram



To: AC BUS 1 (3Ø)
MODULE TEMP
COND EXH
°F
25
20
15
X10
(MDC-22)
OFF
AC 1
AC 2
3A
FUEL CELL
INDICATORS (2)
SC 2081T
SC 2082T
SC 2083T
FUEL CELL
POWER PLANT
WATER
SEPARATOR
TEMP SENSOR
SENSOR
CONDENSER
HYDROGEN
PUMP
pH SENSOR
ϕ A
COOLANT
REGENERATOR
BYPASS
VALVE
TEMP
SENSOR
To:
GLYCOL
From:
RADIATOR
To: ECS
POTABLE
WATER
FROM H2
(MDC-15)
SC 2087T
SC 2088T
SC 2089T
F/C RAD
TEMP LOW
AUX
FUEL CELL
INDICATORS (2)
pH HI

completion of S/C cryogenic tank fill. Time required for oxygen purge is 2 minutes for each power plant. Activating the O_2 purge valve allows an additional flow of up to 0.6 lb per hr. An emergency purge can be performed if steady state current output of a power plant decreases by approximately 3 amps. Power plant parameters (primarily voltage, current, and skin temperature) must be considered to determine if an emergency purge is required.

Hydrogen, stored in a cryogenic state at a pressure of 245 (+15, -20), psia and regulated down to a pressure of 60.5 psia, flows into the hydrogen regenerator loop, passing through an in-line heater and into the fuel cell. The in-line heater is an automatic device which aids the fuel cell power plant in sustaining operating temperature at low-power operating levels. The hydrogen, or primary regenerator loop, is used for fuel cell thermal control and permits water removal from the fuel cell. The heat generated by the reaction is transferred to the saturated H_2 fluid. The hot, saturated hydrogen is drawn into the hydrogen exhaust line by the H_2 pump. A sensor in this line provides an input to an electronic switch which controls activation of the H_2 in-line heater. Activation of this heater is accomplished automatically at a hydrogen exhaust temperature of 385±5°F, supplying additional heat to hydrogen gas flowing to the fuel cell power plant. The in-line heater is automatically deactivated at a temperature of 390±5°F. After passing the in-line heater sensor, the saturated hydrogen flows to a sensor-controlled bypass valve. This valve controls the amount of exhaust gas flowing through the H_2 regenerator. The sensor closes the bypass valve at 425°F, allowing all exhaust gas to flow through the regenerator. This heats the returning hydrogen and sustains operating temperature of the fuel cell. With the bypass valve in a full regenerative position (temperatures 425° or lower), if fuel cell power plant temperature continues to decrease, the in-line heater will be activated to supply additional heat. If power plant temperature is above 425°F, the sensor causes the bypass valve to open proportionately (fully open at 495°F) allowing exhaust gas to flow directly to the condenser. A transfer of heat from the hydrogen and steam to the glycol takes place in the condenser. The temperature of the hydrogen and steam is lowered to between 155° and 175°F, thus liquifying some of the water vapor. A sensor in the condenser exhaust, controls a glycol regenerator bypass valve in the glycol radiator return line which regulates the temperature of the glycol. This, in turn, helps control fuel cell temperature and maintains the temperature of the condenser exhaust within the desired range of 155° to 175°F. The liquid water and hydrogen then flows through a centrifugal water separator pump which extracts the water and delivers it to the ECS potable water storage tank in the C/M. The amount of water produced by each fuel cell is in direct relation to the reactants consumed which is related to power output. (See figure 2.6-4.)

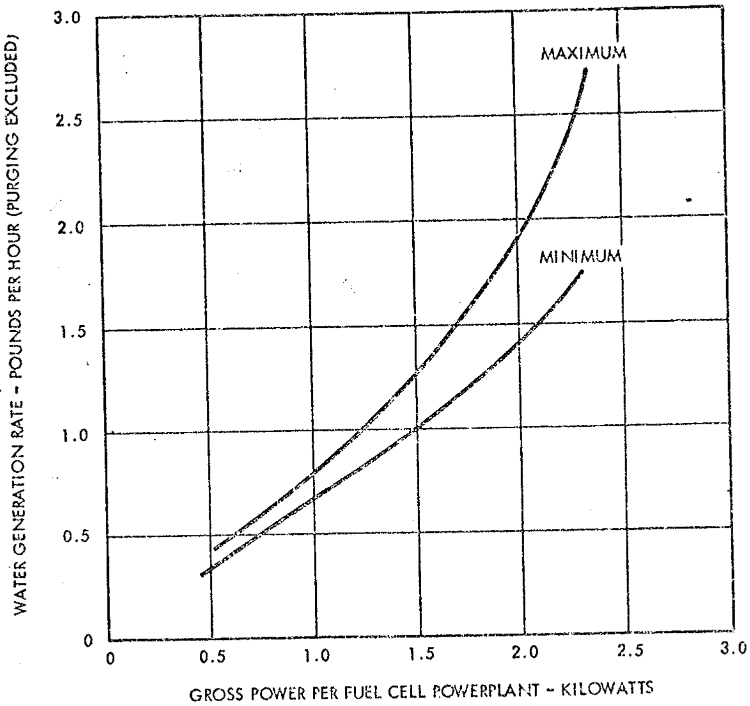


Figure 2.6-4. Water Production Rate vs Power Output

The hydrogen pump circulates the remaining slightly moist fluid through the regenerator and back to the fuel cell. In order to maintain the desired ratio of water to KOH in the fuel cell, the condenser exhaust temperature is regulated at a level so that some moisture is left in the returning hydrogen as it flows back into the cell. The hydrogen in the cryogenic system is approximately 99.94 percent pure. H_2 purge valve activation allows an additional flow of up to 0.75 lbs per hour, and will normally be performed for a period of 80 seconds per power plant every 24 hours. The actual H_2 purge cycle will also depend on the predicted power profile and reactant purity as calculated after cryogenic tank fill. The performance degradation participation by the H_2 electrode is negligible and cannot be seen with on-board instrumentation (with normal degradation). If degradation is suspected to remain after an emergency O_2 purge, an H_2 purge may be warranted. There is some indication that periodic H_2 purging may be eliminated altogether, thereby only performing the degradation purge whenever it may be required. Thirty minutes prior to H_2 purging, the H_2 PURGE LINE HTR switch (MDC-15) is placed in the up position to energize the H_2 fuel cell vent line heater and preclude any freezing of the moist exhaust gas in the vent line.

The secondary loop contains a 62.5 to 37.5 mixture of ethylene glycol and water, respectively. This loop serves to preheat the reactants and to transport waste heat to the space radiators. An accumulator, pressurized by the nitrogen, pressurizes the glycol loop and also acts as a buffer for the expansion and contraction of the coolant as it varies in temperature. Glycol flow through the regenerator is controlled by a bypass valve which operates in conjunction with the condenser exhaust sensor. When the condenser exhaust is at 155°F, the glycol is routed through the regenerator to increase glycol temperature and effect minimum heat transfer in the condenser. The glycol bypass valve is completely open at a condenser exhaust temperature of 175°F, routing the glycol through the pump to the condenser and on to the oxygen and hydrogen preheaters. Since the glycol temperature is lower, a maximum transfer of heat in the condenser lowers the condenser exhaust temperature. The condenser exhaust temperature sensor regulates coolant temperature which affects the amount of water removed from the power plant. The 155° to 175°F operating range will best maintain the desired ratio of water to KOH in the fuel cell.

A 400-cps 3-phase a-c gear pump maintains glycol flow at the rate of 35 to 80 lbs per hour, raising the pressure 6 psi. After the oxygen and hydrogen preheaters, the glycol is routed through the glycol regenerator and to the space radiators, where heat is radiated into the space environment.

Each fuel cell contains electrolyte (KOH) which consists by weight of 83 percent potassium hydroxide and 17 percent water on initial fill, and has a critical temperature of 300°F (figure 2.6-5). The electrolyte remains a solid to an approximate temperature of 220°F; with a temperature increase to 300°F, the electrolyte becomes a liquid and the fuel cell electrochemical reaction becomes effective. Bringing the fuel cell to critical temperature is accomplished using GSE, and cannot be performed from S/C power sources. Placing a load on the power plant will maintain it above this critical temperature.

2.6.3.4 Inverters.

Each inverter (figure 2.6-6) is composed of a clock oscillator, an eight-stage digital countdown section, a d-c line filter, two silicon-controlled rectifiers, a magnetic amplifier, a buck-boost amplifier, a demodulator, two d-c filters, an eight-stage power inversion section, a harmonic neutralization transformer, an a-c output filter, current sensing transformers, a Zener diode reference bridge, a low-voltage control, and an overcurrent trip circuit. The inverter normally uses a 6.4-kc square wave synchronizing signal from the central timing equipment (CTE) which maintains inverter output at 400±2 cps. If this external signal is completely lost, the oscillator within the inverter will provide pulses that will maintain inverter output within ±7 cps. The internal

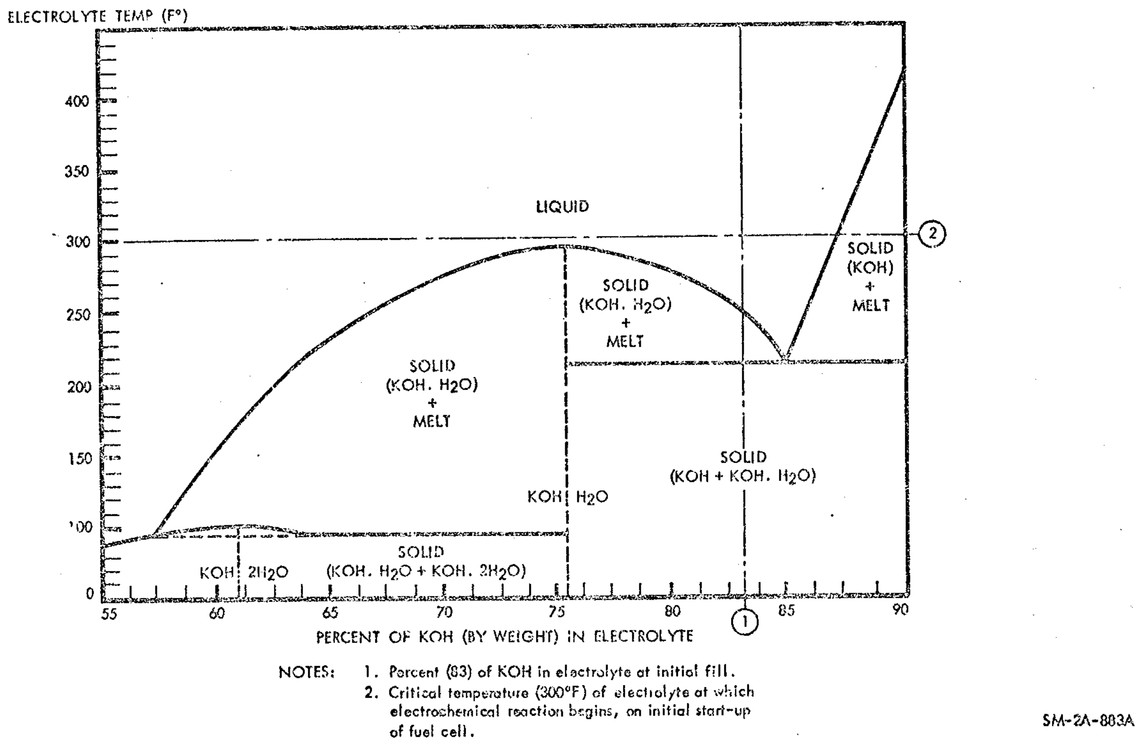


Figure 2.6-5. KOH H_2O Phase Diagram

oscillator is normally synchronized by the external pulse which is provided through the phase synchronizing unit. The phase synchronizer will provide these pulses to the inverter after a maximum of two seconds. The following paragraphs describe the function of the various stages of the inverter.

The 6.4-kc negative square wave provided by the central timing equipment is applied through the phase synchronizer and the oscillator to the eight-stage digital countdown section. The oscillator has two divider circuits which provide a 1600-pps signal to the magnetic amplifier and two silicon-controlled rectifiers.

The eight-stage digital countdown section uses the 6.4-kc square wave signal to produce a series of eight 400-cycle square waves, each mutually displaced one pulse time from the preceding and following wave. Once pulse time is 156 microseconds and represents 22.5 electrical degrees. This series of square waves is applied to the eight-stage power inversion section.

The eight-stage power inversion section, using a controlled voltage from the buck-boost amplifier, amplifies the series of 400-cycle square waves produced by the eight-stage digital countdown section. The amplified square waves, still mutually displaced 22.5 electrical degrees, are applied to the harmonic neutralization transformer, which is described in a subsequent paragraph.

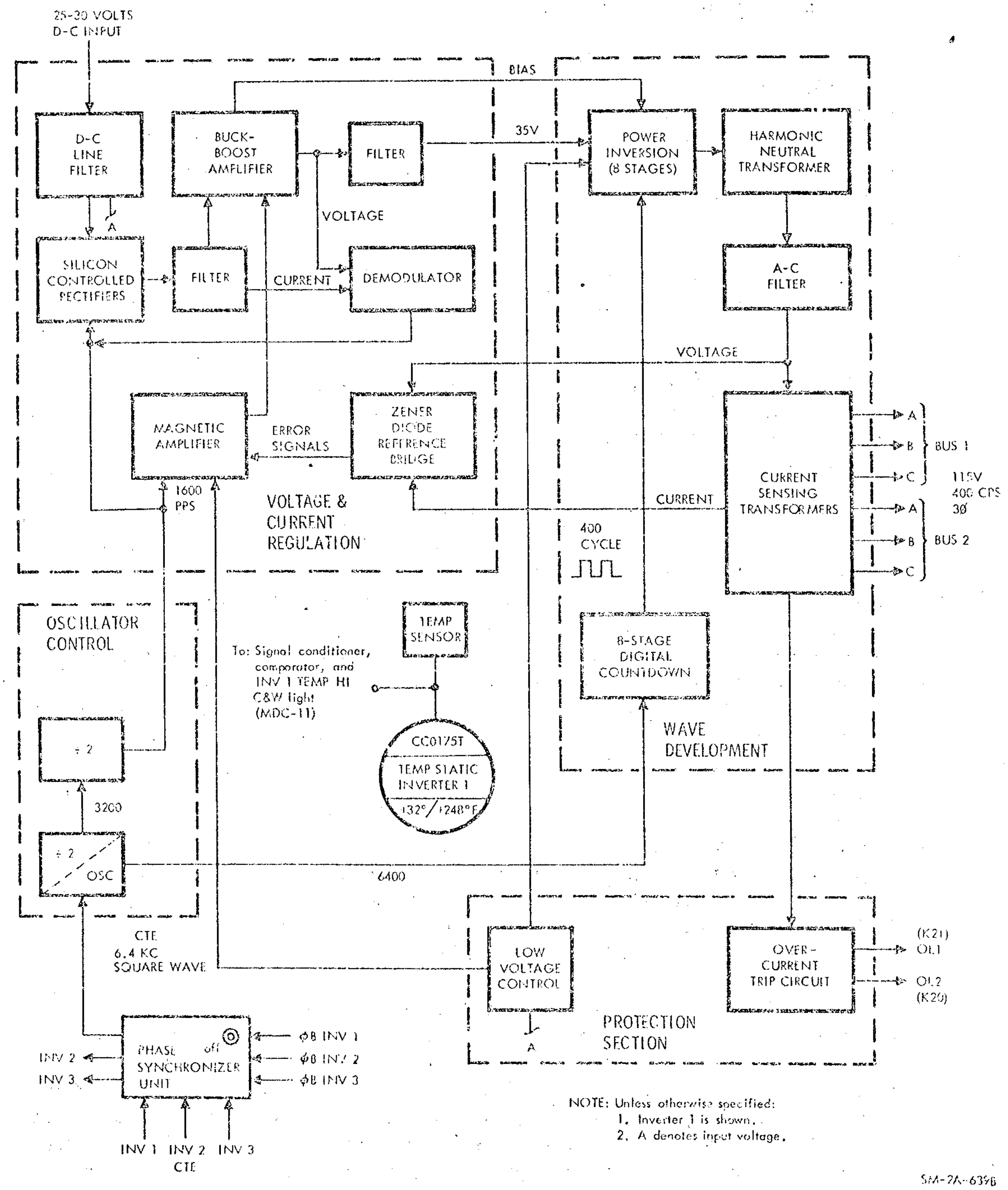


Figure 2.6-6. Inverter Block Diagram

D-C power to the inverter is supplied from the main d-c buses through the d-c line filter. This filter reduces the high frequency ripple in the input, and the 25 to 30 vdc is applied to the silicon-controller rectifiers and buck-boost amplifier.

The silicon-controlled rectifiers, using the filtered d-c power and the 1600-pps signal from the clock oscillator, produce a d-c square wave with an on-time of greater than 90 degrees from each rectifier. This is filtered and supplied to the buck-boost amplifier where it is coupled with the amplified 1600-pps output of the magnetic amplifier to develop a filtered 35 volts dc which is used for amplification in the power inversion stages.

The buck-boost amplifier, using the 1600-pps signal from the magnetic amplifier, the filtered d-c power from the main duc buses, and an error signal feedback from the Zener diode reference bridge, provides a variable bias voltage to the eight-stage power inversion section. The amplitude of this voltage is controlled by the amplitude and phase of the feedback signal from the Zener diode reference bridge. This bias signal is varied by the error signal to regulate inverter voltage and current output.

The demodulator compensates for any low-frequency ripple in the d-c input to the inverter. The high-frequency ripple is attenuated by the filters. The demodulator senses the 35-volt d-c output of the buck-boost amplifier and the current input to the buck-boost amplifier. It compensates for ripple in the 10- to 1000-cps range. An input voltage drop or increase will be reflected in a drop or increase in the 35-volt d-c output of the buck-boost amplifier as well as a drop or increase in current input to the buck-boost amplifier. A sensed decrease in the buck-boost amplifier voltage output would be compensated for a demodulator output, transformer coupled, to the silicon-controlled rectifiers, causing them to conduct foı a longer time, thus increasing their filtered output. A sensed increase in buck-boost amplifier voltage output, caused by an increase in the d-c input to the inverter, would cause the demodulator to produce a signal causing the silicon-controlled rectifiers to conduct for shorter periods, producing a lower filtered output to the buck-boost amplifier. In this fashion, the 35-volt d-c input to the power inversion section is maintained at a relatively constant level.

The low-voltage control samples the input voltage to the inverter and can terminate inverter operation. Since the buck-boost amplifier provides a boost action during a decrease in input voltage to the inverter, in an attempt to maintain a constant 35 volts dc to the power inversion section, the high boost required during a low-voltage input would tend to overheat the buck-boost amplifier. As a precautionary measure, the low-voltage control will terminate inverter operation by disconnecting operating voltage to the magnetic amplifier and a power inversion stage when input voltage decreases to between 16 and 19 volts dc.

The harmonic neutralization section, using the 400-cycle, square-wave output of the eight-stage power inversion section, transforms it into a 3-phase 400-cycle 115-volt sine wave signal. The manner in which these transformers are wound produces flux cancellation which eliminates all harmonics up to and including the fifteenth of the fundamental frequency. The 22.5 electrical degree displacement of the square wave provides a means of electrically rotating the square wave excited primary windings around the 3-phase, wye-connected, secondary windings, thus producing the 3-phase 400-cycle sine wave output. This 115-volt signal is then applied to the a-c output filter.

The a-c output filter eliminates the remaining higher harmonics. Since the lower harmonics were eliminated by the harmonic neutralization section, the size and weight of this output filter was reduced. Circuitry in this filter also produces a rectified signal which is applied to the Zener diode reference bridge. The amplitude of this signal is a function of the amplitude of a-c output voltage. After filtering, the 3-phase 115-volt a-c 400-cycle sine wave is applied to the a-c buses through current-sensing transformers.

The current-sensing transformer section produces a rectified signal, the amplitude of which is in direct function of inverter output current magnitude. This d-c signal is applied to the Zener diode reference bridge to regulate inverter current output. It is also applied to an overcurrent trip circuit.

The Zener diode reference bridge receives a rectified d-c signal, representing voltage output, from the circuitry in the a-c output filter. A variance in voltage output unbalances the bridge providing an error signal of proper polarity and magnitude to the buck-boost amplifier via the magnetic amplifier. When inverter current output reaches 200 to 250 percent of rated current, the rectified signal applied to the bridge from the current sensing transformers is of sufficient magnitude to provide an error signal and cause the buck-boost amplifier to operate in the same manner as during an overvoltage condition. The bias output of the buck-boost amplifier, being controlled by the error signal, will be varied to correct for any variation in inverter voltage or current output. When inverter current output reaches 250 percent of rated current, the overcurrent trip circuit is activated.

The overcurrent trip circuit monitors a rectified d-c signal representing current output. When total inverter current output exceeds 250 percent of rated current, this circuit will effect an inverter disconnect in 15±5 seconds. If current output of any single phase exceeds 300 percent of rated current, this circuit will effect an inverter disconnect in 5±1 second.

A phase synchronizer unit (PSU), located in the RHEB (panel 208), establishes inverter outputs so they are in phase when using a separate inverter on each of the two a-c buses. The two inverter configuration is prevelant during delta V's as a safety precaution in case of a single failure in thrust vector control.

The use of two inverters during delta V's retains redundancy in the stabilization and control subsystem, since power through a-c bus 1 is used for automatic thrust vector control and power through a-c bus 2 is used for manual thrust vector control.

Central timing equipment (CTE) trigger pulses, used for inverter operation, are supplied to the inverters through the PSU. The PSU samples ØB from each inverter output, and when an in-phase relationship is established, supplies the 6400-cps CTE trigger pulse to the inverters being used. The ØB input also supplies power for PSU circuitry.

The in-phase relationship is acquired by initially providing out-of-phase trigger pulses (6080 to 6400 cps) until the two inverters are synchronized, at which time the CTE signal is coupled to the inverters. Phase lock, with a maximum displacement of ±10 degrees, is acquired in a maximum of two seconds.

The synchronizer provides this function for any combination of pairs of the three available inverters. A two-position toggle switch on the PSU, when positioned to OFF, allows for direct input of CTE signals to the inverters in the event of failure of the synchronizer unit. However, in this situation, the in-phase relationship would not be realized.

A temperature sensor with a range of +32° to +248°F is installed in each inverter to provide MSFN the capability of monitoring inverter temperature. It also provides an input to the C&WS which will illumine a light at an inverter overtemperature of 226°F.

2.6.3.5 Battery Charger.

A constant voltage, solid-state battery charger (figure 2.6-7), located in the C/M lower equipment bay, is incorporated into the EPS. The battery charger selector switch (MDC-18) controls power input to the charger, as well as connecting the charger output to the selected battery (figure 2.6-11). When the BATTERY CHARGER selector switch is positioned to entry battery A, B, or C, a relay (K4) is activated, completing circuits from a-c and d-c power sources to the battery charger. Also, the battery charger output is connected to the selected battery to be charged through the MAIN BUS TIE switches (MDC-22). Positioning the MAIN BUS TIE switch (A&C or B&C) to OFF, for the selected batteries, will disconnect main bus loads from the batteries and also complete the circuit from the charger to the battery. Only one battery can be charged at a time.

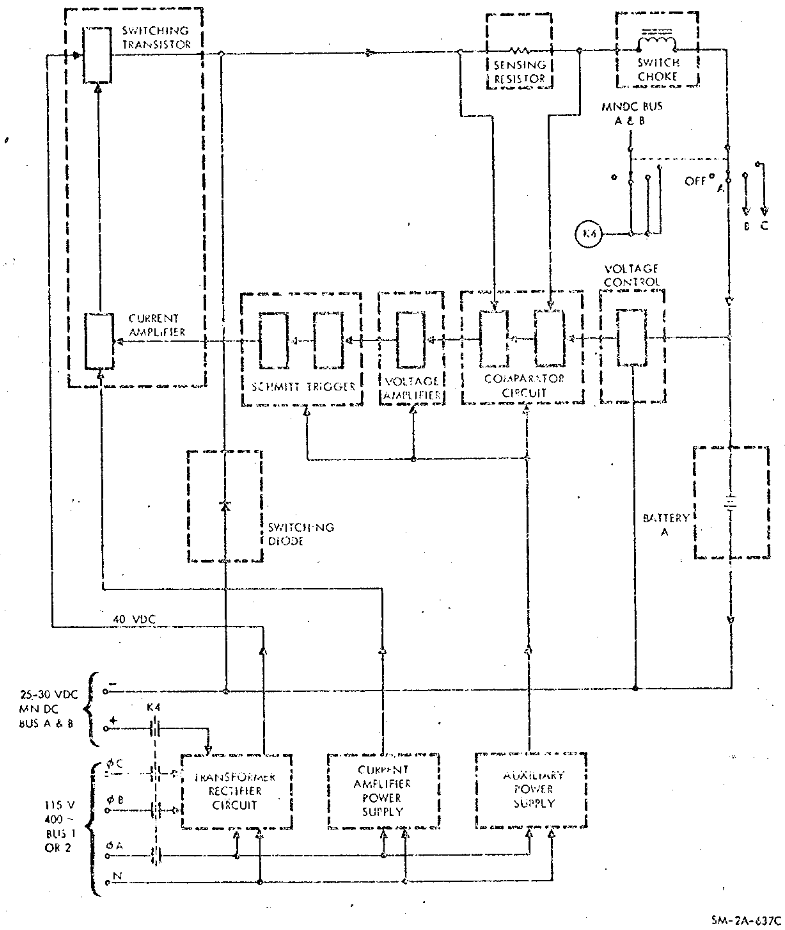


Figure 2.6-7. Battery Charger Block Diagram

The battery charger uses 25 to 30 volts dc from the main d-c buses and 115 volts 400-cps, 3-phase ac from either of the a-c buses. All three phases of ac are used to boost the 25 to 30-volt d-c input to produce 40 volts dc for charging. In addition, phase A of the ac is used to supply power for the rest of the charger circuitry. The logic network in the charger, which consists of a two-stage differential amplifier (comparator), a two-stage Schmitt trigger, a current sensing resistor, and a voltage amplifier will set up the initial condition for operation. The first stage of the comparator is in the on mode, with the second stage in the off mode, placing the Schmitt trigger first stage in the on mode with the second stage off. This condition provides maximum base drive to the current amplifier which turns the switching transistor to the on mode. With the switching transistor on, current flows from the transformer rectifier through the switching transistor, current sensing resistor, and switch choke to the battery being charged. As current flow increases, the voltage drop across the sensing resistor increases. The voltage across the sensing resistor builds to a level which turns the first stage of the comparator to the off mode and the second stage to the on mode. This condition turns off the voltage amplifier which reverses the operation of the Schmitt trigger to first stage off and second stage on. This places the current amplifier off, which turns off the switching transistor. The switching transistor in the off mode will stop current flow from the power source, causing the field in the choke to continue collapsing and discharging into the battery through the switching diode and the current sensing resistor. As the EMF in the choke decreases, the current through the sensing resistor decreases, reducing the voltage drop across the resistor. At some point, the decrease in voltage drop across the sensing resistor, reverses the operation of the comparator circuit, setting up the initial condition and completing one cycle of operation. The output load current, due to the action of the choke, remains relatively constant except for the small variation through the sensing resistor. This variation is required to switch the switching transistor and Schmitt trigger through the action of the comparator.

Battery charger output is regulated by the sensing resistor until the battery voltage reaches approximately 36 volts. At this time, the voltage control network is activated and, in conjunction with the sensing resistor, provides a signal for cycling the battery charger. As the battery voltage increases, the internal impedance of the battery increases, decreasing current flow from the charger. At 39 volts, the battery is fully charged and current flow becomes negligible. (See figure 2.6-8.) Battery charger disconnect will be effected at a current output of approximately 0.6 amps.

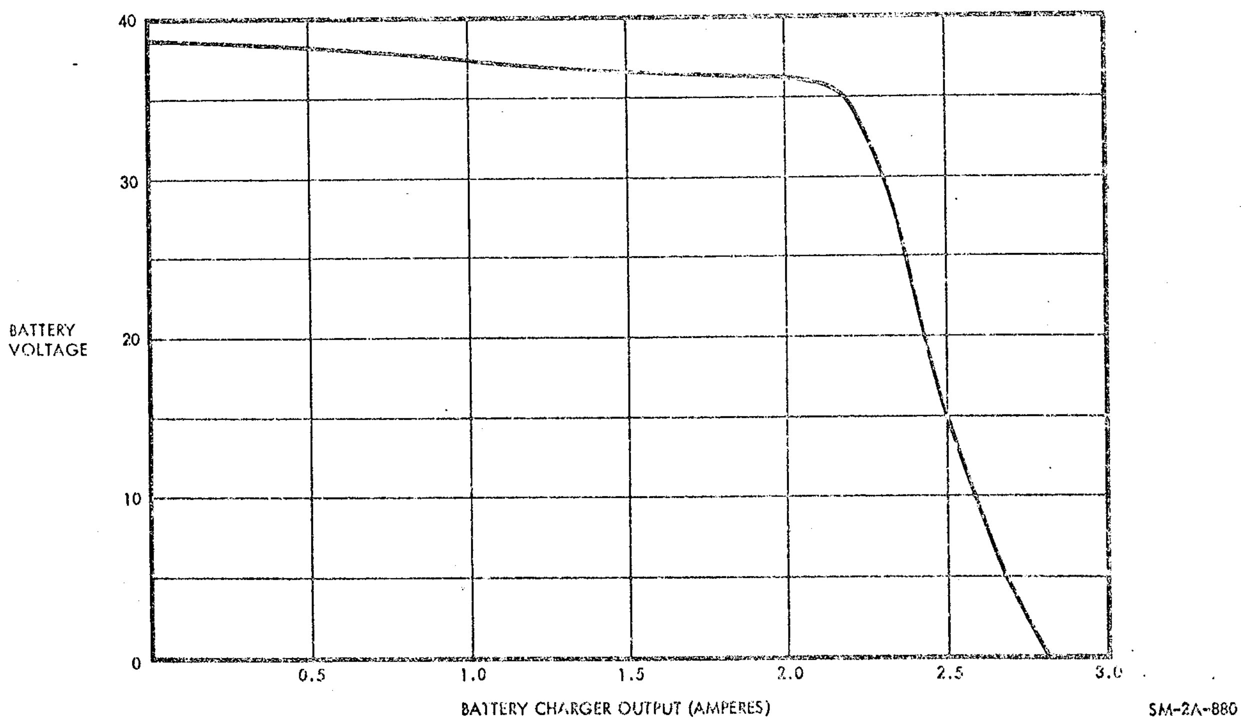


Figure 2.6-8. Battery Charging Rate Chart

Battery input will be monitored by MSFN through the normal battery telemetry measurements.

2.6.3.6 Power Distribution.

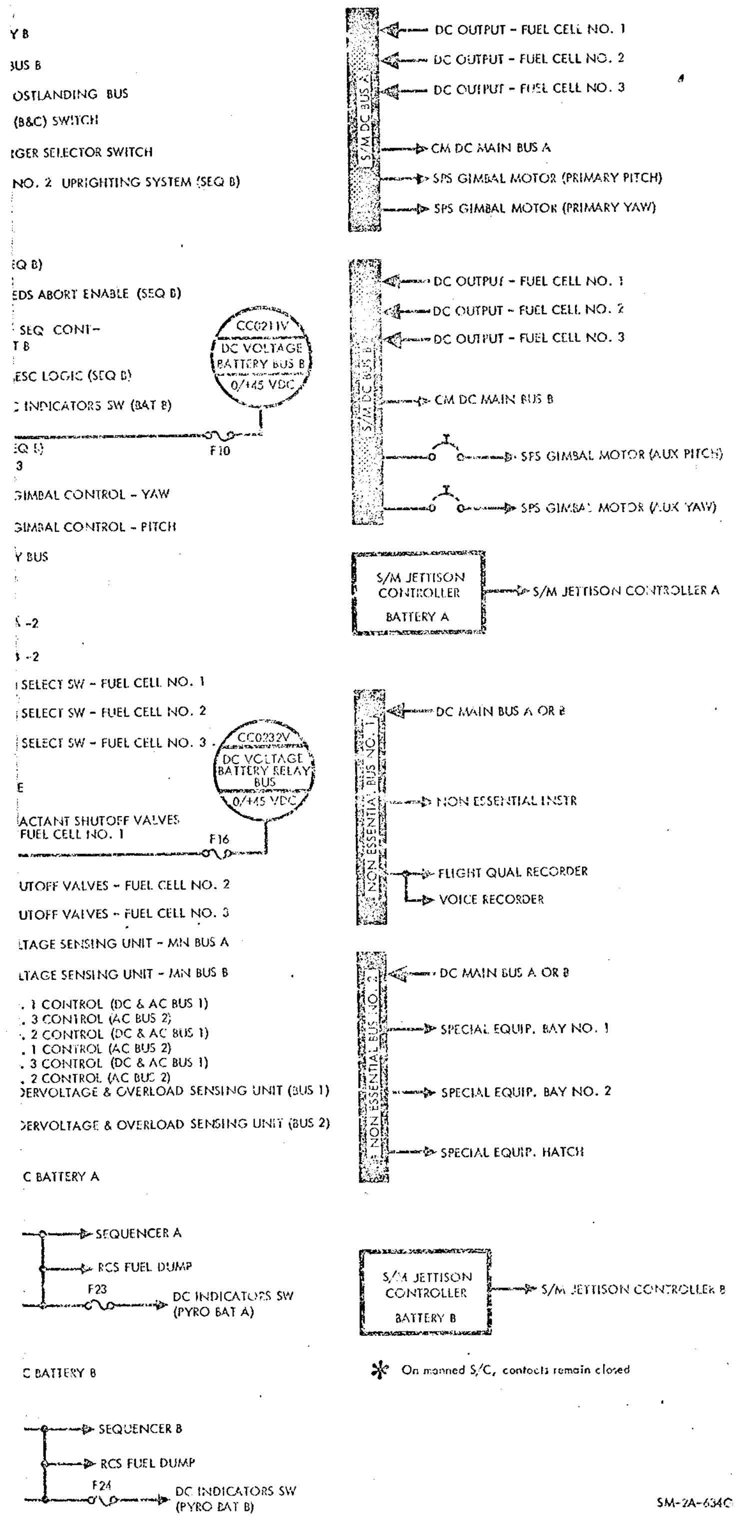
D-C and a-c power distribution to components of the EPS is provided by two redundant buses in each system. A single-point ground on the spacecraft structure is used to eliminate ground loop effects. Sensing and control circuits are provided for monitoring and protection of each bus system.

Distribution of d-c power (figure 2.6-9) is accomplished with a two-wire system and a series of interconnected buses, individual switches, circuit breakers, and isolation diodes. The buses consist of the following:

- Two redundant main d-c buses (A and B) powered by the three fuel cells and/or entry batteries A, B, and C.
- Two battery buses (A and B) each powered by its respective entry battery A and B.
- Flight and postlanding bus, powered through the main d-c buses, and/or the three entry batteries, A, B, and C.
- Two nonessential buses, powered through either d-c main bus A or B.
- Battery relay bus, powered by entry batteries A and B through individual battery buses.
- Pyro buses, which are isolated from the main electrical power system when powered by the pyro batteries. A capability is provided to connect entry battery A or B to the respective A or B pyro system in case of loss of a pyro battery.
- S/M jettison controllers, powered by S/M jettison controller batteries, which are completely isolated from the main electrical power system.

Power from the fuel cell power plants is connected to the main d-c buses through six motor switches (part of overload/reverse current circuits in the S/M which are controlled by switches in the C/M located on MDC-18. Fuel cell power can be connected to either or both of the main d-c buses. Six event indicators show when fuel cell output is connected. When an overload condition occurs, the overload-reverse current sensing circuits automatically disconnect the fuel cell power plants from the overloaded bus and provide visual displays for isolation of the trouble. A reverse current condition will disconnect the malfunctioning power plant from the d-c system. D-C undervoltage sensing circuits (figure 2.6-10) are also provided to indicate bus low voltage conditions. If voltage drops below 26.25 volts dc, an applicable d-c undervoltage light on the caution and warning panel (MDC-11) will illuminate. Since each bus is capable of handling all EPS loads, an undervoltage condition should not occur except in an isolated instance, if too many electrical units are placed on the bus simultaneously or if a malfunction exists in the EPS. A voltmeter, on MDC-18, is provided to monitor bus voltage. An ammeter is provided on MDC-18 to monitor current output of fuel cells 1, 2, 3, batteries A, B, C, and the battery charger. During extreme power loads or emergencies, power to the main d-c buses can be supplied from entry batteries A and B by way of battery buses and directly from battery C (figure 2.6-11). Each battery bus is separated physically into two parts (e.g., battery bus A is A-1 and A-2), but remain connected electrically by motor switch contacts which are not opened on manned S/C. A switch to two nonessential buses permits isolating nonessential equipment during a shortage of power (two fuel cell power plants out). The postlanding bus supplies power to some of the telecommunications equipment, float bag No. 1 and No. 3 controls, and the ECS postlanding vent control. In flight and up to CSM separation, the postlanding bus receives power from the fuel cells and/or entry batteries through the main d-c buses. After CSM separation, the entry batteries supply power to the postlanding bus through the main d-c buses or directly through individual circuit breakers. Motor switch contacts which close when the MAIN BUS TIE switches are positioned ON, complete the circuit between the entry batteries and the main d-c buses and open the connection from the battery charger. The battery relay bus provides d-c power to the d-c and a-c sensing units, and the fuel cell and inverter control circuits. The pyrotechnic batteries supply power to initiate ordnance devices for separation of the LES, forward heat shield, S/M from C/M, and for deployment of the drogue and main parachutes during a pad abort, high-altitude abort, or normal mission progression. The S/M jettison controller batteries, supply power through the S/M jettison controllers for the CSM separation maneuver. To operate recovery communications and other aids after landing, power is provided by the entry batteries through three circuit breakers (figure 2.6-11) which are normally open until just prior to CSM separation.

Distribution of a-c power (figure 2.6-12) is accomplished with a four-wire system via two redundant buses, a-c bus No. 1 and a-c bus No. 2. The a-c neutral bus is connected to the single-point ground. A-C power is provided by the solid-state 115/200-volt 400-cps 3-phase inverters. D-C power is routed to the inverters through the main d-c buses. Inverter No. 1 can be powered through d-c main bus A, inverter No. 2 through d-c main bus B, and inverter No. 3 through either d-c main bus A or B by switch selection. Each of these circuits has a separate circuit breaker and a power control motor switch. Switches for applying power to the motor switches are located on MDC-18. All three inverters are identical and are provided with overtemperature circuitry. A light indicator, in the caution/warning group on MDC-11, illuminates to indicate an over-temperature situation. Inverter operating temperature is telemetered



D-C Power Distribution

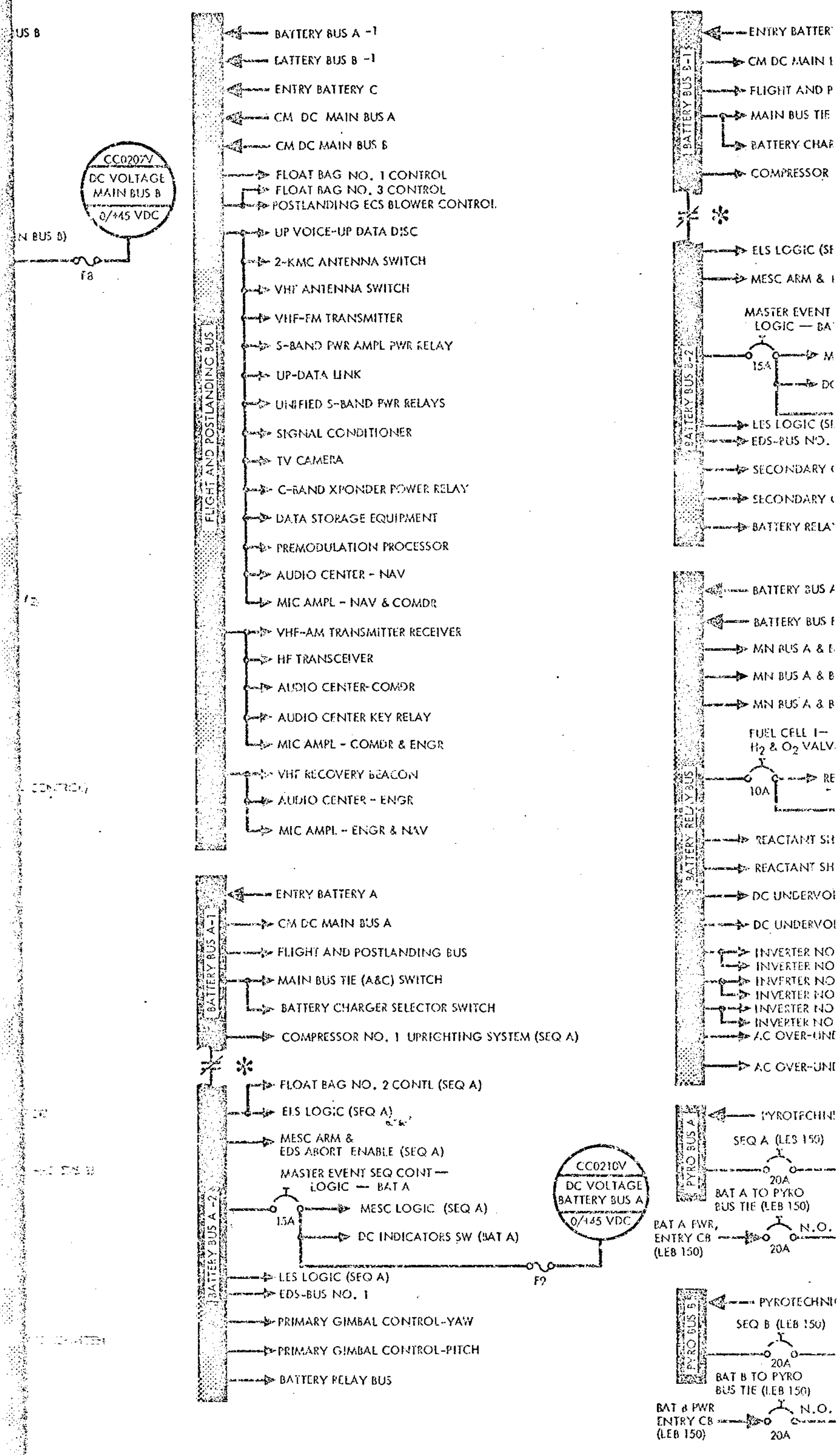
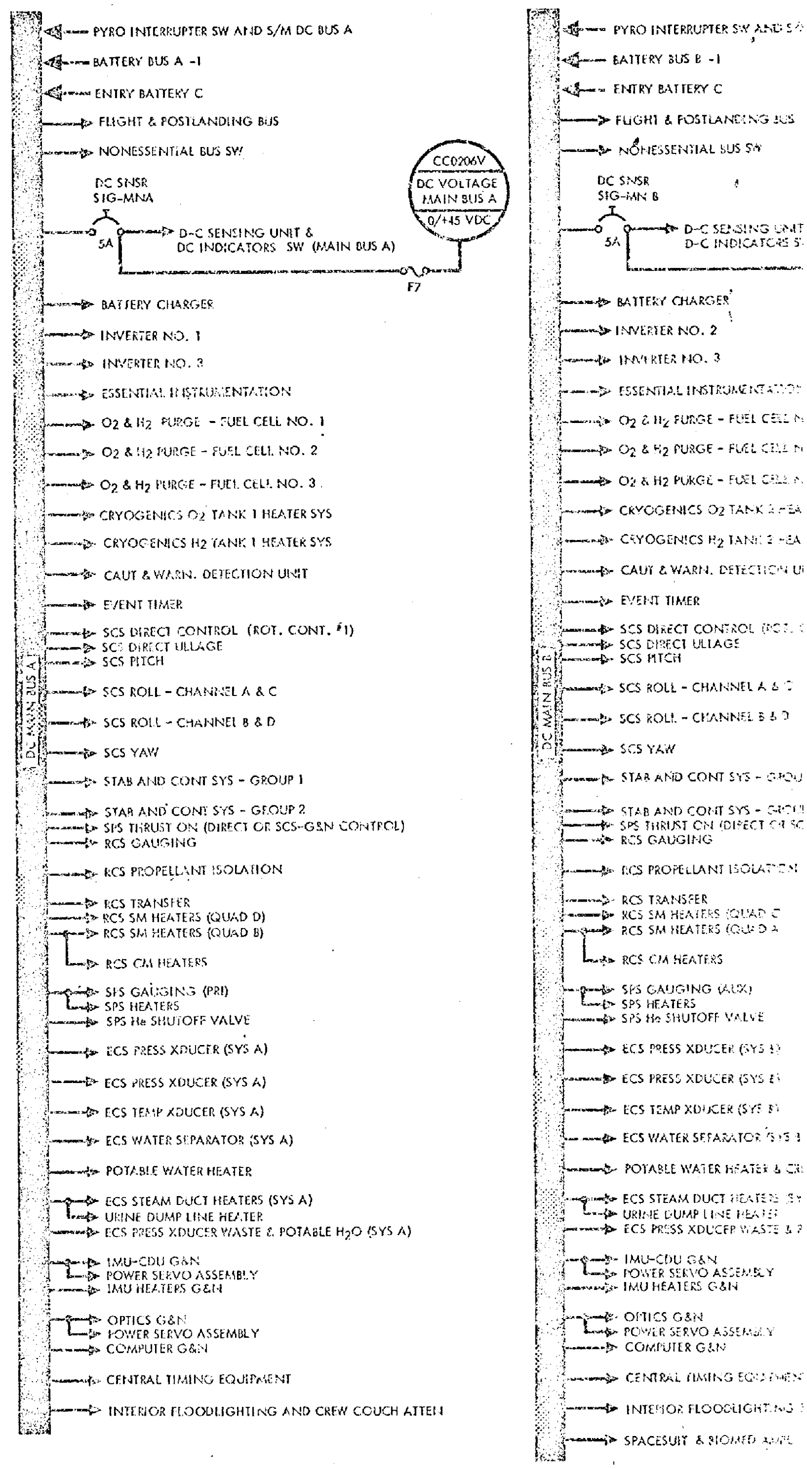

US B
N BUS B)
CC0207V
DC VOLTAGE
MAIN BUS B
0/+45 VDC
F8
BATTERY BUS A -1
BATTERY BUS B -1
ENTRY BATTERY C
CM DC MAIN BUS A
CM DC MAIN BUS B
FLOAT BAG NO. 1 CONTROL
FLOAT BAG NO. 3 CONTROL
POSTLANDING ECS BLOWER CONTROL
UP VOICE-UP DATA DISC
2-KMC ANTENNA SWITCH
VHF ANTENNA SWITCH
VHF-FM TRANSMITTER
S-BAND PWR AMPL PWR RELAY
UP-DATA LINK
UNIFIED S-BAND PWR RELAYS
SIGNAL CONDITIONER
TV CAMERA
C-BAND XPONDER POWER RELAY
DATA STORAGE EQUIPMENT
PREMODULATION PROCESSOR
AUDIO CENTER - NAV
MIC AMPL - NAV & COMDR
VHF-AM TRANSMITTER RECEIVER
HF TRANSCEIVER
AUDIO CENTER-COMDR
AUDIO CENTER KEY RELAY
MIC AMPL - COMDR & ENGR
VHF RECOVERY BEACON
AUDIO CENTER - ENGR
MIC AMPL - ENGR & NAV
FLIGHT AND POSTLANDING BUS
ENTRY BATTERY A
CM DC MAIN BUS A
FLIGHT AND POSTLANDING BUS
MAIN BUS TIE (A&C) SWITCH
BATTERY CHARGER SELECTOR SWITCH
COMPRESSOR NO. 1 UPRIGHTING SYSTEM (SEQ A)
BATTERY BUS A-1
FLOAT BAG NO. 2 CONTL (SEQ A)
ELS LOGIC (SEQ A)
MESC ARM &
EDS ABORT ENABLE (SEQ A)
MASTER EVENT SEQ CONT—
LOGIC — BAT A
15A
MESC LOGIC (SEQ A)
DC INDICATORS SW (BAT A)
CC0210V
DC VOLTAGE
BATTERY BUS A
0/+45 VDC
F9
LES LOGIC (SEQ A)
EDS-BUS NO. 1
PRIMARY GIMBAL CONTROL-YAW
PRIMARY GIMBAL CONTROL-PITCH
BATTERY RELAY BUS
BATTERY BUS A-2
ENTRY BATTER
CM DC MAIN
FLIGHT AND P
MAIN BUS TIE
BATTERY CHAR
COMPRESSOR
BATTERY BUS B-1
ELS LOGIC (S
MESC ARM &
MASTER EVENT
LOGIC — BA
15A
LES LOGIC (S
EDS-BUS NO.
SECONDARY
SECONDARY
BATTERY RELA
BATTERY BUS B-2
BATTERY BUS A
BATTERY BUS B
MN BUS A & B
MN BUS A & B
MN BUS A & B
FUEL CELL 1—
H_2 & O_2 VALV
10A
REACTANT SH
REACTANT SH
DC UNDERVO
DC UNDERVO
INVERTER NO
INVERTER NO
INVERTER NO
INVERTER NO
INVERTER NO
INVERTER NO
AC OVER-UN
AC OVER-UN
BATTERY RELAY BUS
PYROTECHN
SEQ A (LEB 150)
20A
BAT A TO PYRO
BUS TIE (LEB 150)
PYRO BUS A
BAT A PWR,
ENTRY CB
(LEB 150)
N.O.
20A
PYROTECHN
SEQ B (LEB 150)
20A
BAT B TO PYRO
BUS TIE (LEB 150)
PYRO BUS B
BAT B PWR
ENTRY CB
(LEB 150)
N.O.
20A

Figure 2.6-9.



DC MAIN BUS A
PYRO INTERRUPTER SW AND S/M DC BUS A
BATTERY BUS A -1
ENTRY BATTERY C
FLIGHT & POSTLANDING BUS
NONESSENTIAL BUS SW
DC SNSR SIG-MNA
5A
D-C SENSING UNIT & DC INDICATORS SW (MAIN BUS A)
CC0206V
DC VOLTAGE MAIN BUS A
0/+45 VDC
F7
BATTERY CHARGER
INVERTER NO. 1
INVERTER NO. 3
ESSENTIAL INSTRUMENTATION
O2 & H2 PURGE - FUEL CELL NO. 1
O2 & H2 PURGE - FUEL CELL NO. 2
O2 & H2 PURGE - FUEL CELL NO. 3
CRYOGENICS O2 TANK 1 HEATER SYS
CRYOGENICS H2 TANK 1 HEATER SYS
CAUT & WARN. DETECTION UNIT
EVENT TIMER
SCS DIRECT CONTROL (ROT. CONT. #1)
SCS DIRECT ULLAGE
SCS PITCH
SCS ROLL - CHANNEL A & C
SCS ROLL - CHANNEL B & D
SCS YAW
STAB AND CONT SYS - GROUP 1
STAB AND CONT SYS - GROUP 2
SPS THRUST ON (DIRECT OR SCS-G&N CONTROL)
RCS GAUGING
RCS PROPELLANT ISOLATION
RCS TRANSFER
RCS SM HEATERS (QUAD D)
RCS SM HEATERS (QUAD B)
RCS CM HEATERS
SPS GAUGING (PRI)
SPS HEATERS
SPS He SHUTOFF VALVE
ECS PRESS XDUCER (SYS A)
ECS PRESS XDUCER (SYS A)
ECS TEMP XDUCER (SYS A)
ECS WATER SEPARATOR (SYS A)
POTABLE WATER HEATER
ECS STEAM DUCT HEATERS (SYS A)
URINE DUMP LINE HEATER
ECS PRESS XDUCER WASTE & POTABLE H2O (SYS A)
IMU-CDU G&N
POWER SERVO ASSEMBLY
IMU HEATERS G&N
OPTICS G&N
POWER SERVO ASSEMBLY
COMPUTER G&N
CENTRAL TIMING EQUIPMENT
INTERIOR FLOODLIGHTING AND CREW COUCH ATTEN
DC MAIN BUS B
PYRO INTERRUPTER SW
BATTERY BUS B -1
ENTRY BATTERY C
FLIGHT & POSTLANDING BUS
NONESSENTIAL BUS SW
DC SNSR SIG-MN B
5A
BATTERY CHARGER
INVERTER NO. 2
INVERTER NO. 3
SCS DIRECT ULLAGE
SCS PITCH
SCS YAW
RCS GAUGING
RCS TRANSFER
RCS CM HEATERS
SPS GAUGING (AUX)
SPS HEATERS
SPS He SHUTOFF VALVE
IMU-CDU G&N
POWER SERVO ASSEMBLY
IMU HEATERS G&N
OPTICS G&N
COMPUTER G&N

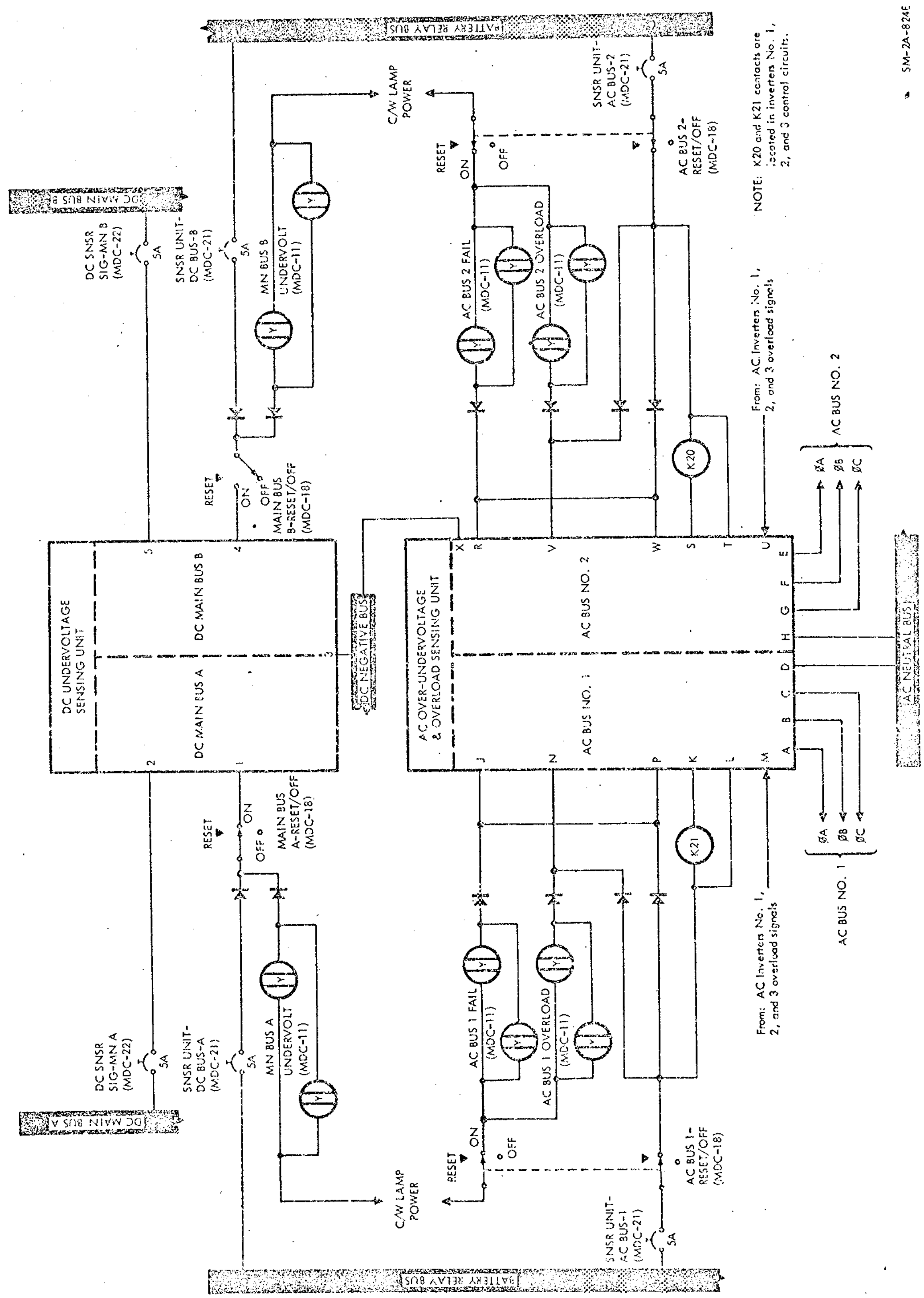


Figure 2.6-10. DC and AC Sensing Circuits

to the MSFN. Inverter output is routed through a series of control motor switches to the a-c buses. Six switches on MDC-18 control motor switches which operate contacts to connect or disconnect the inverters from the a-c buses. The motor switches are designed to prevent connecting two inverters to the same a-c bus at the same time. AC loads are powered through the redundant a-c buses. In some instances, one phase is used for operation of equipment; in others two, and in others all three. Over-undervoltage and overload sensing circuits (figure 2.6-11) are provided for each bus. A-C bus voltage fail and overload lights in the caution/warning group on MDC-11 provide a visual indication of these malfunctions. Monitoring of voltage and frequency of each phase on each bus is accomplished by selection with the AC INDICATORS switch. Readings are displayed on separate AC VOLTS and FREQUENCY meters located on MDC-18. Each phase voltage and ØA frequency is telemetered to MSFN stations.

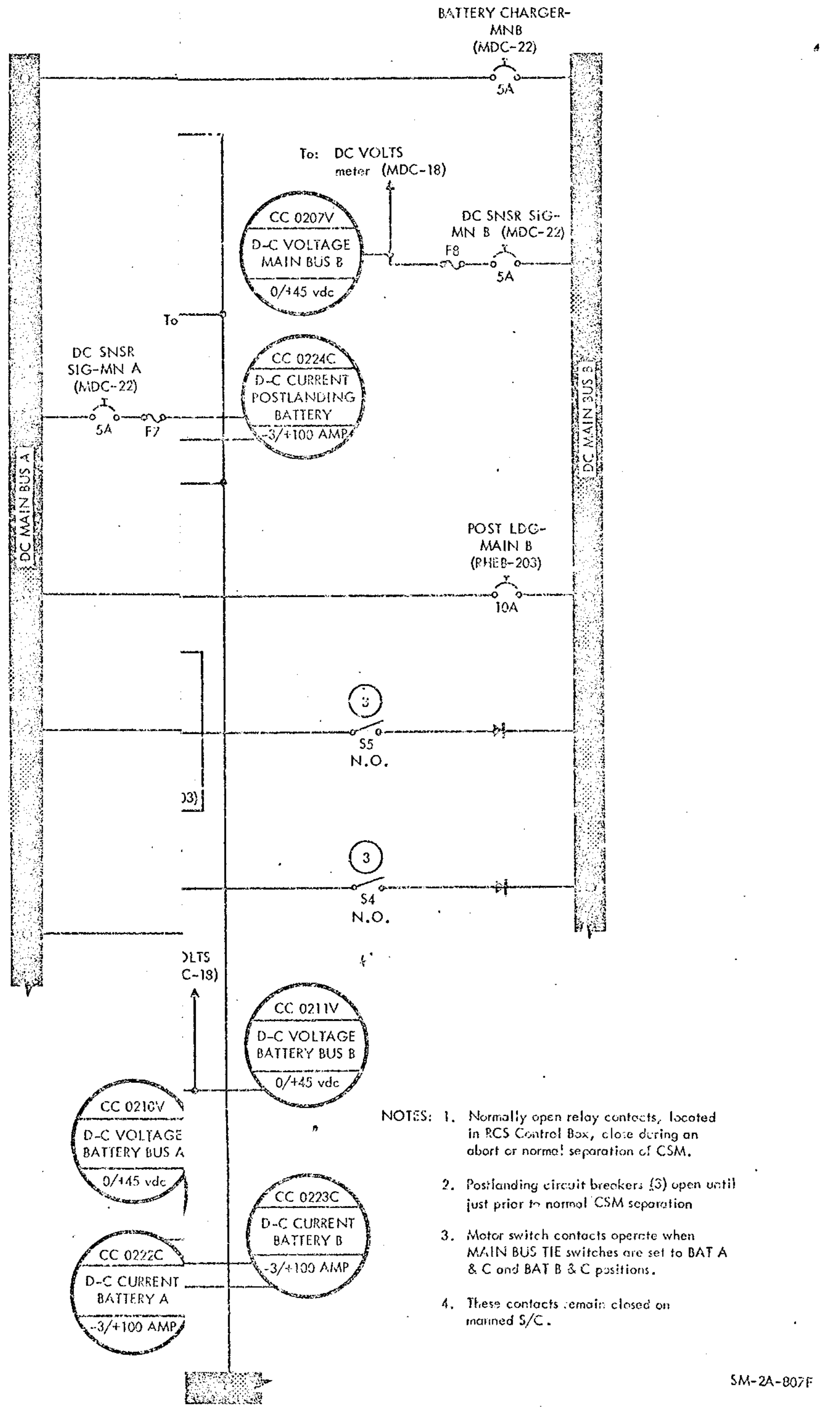
2.6.4 PERFORMANCE AND DESIGN DATA.

2.6.4.1 AC and DC Data.

AC and DC performance and design data for the EPS is as follows:

AC

Phases	3
Displacement	120± 2 degrees
Steady-state voltage	115±2 vac (average of 3 phases)
Transient voltage	115 (+35, -65) vac
Recovery	To 115±10v within 15 ms, steady state within 50 ms
Unbalance	2 vac (worst phase from average)
Frequency limits	
Normal (synchronized to central timing equipment)	400±2 cps
Emergency (loss of central timing equipment)	400±7 cps
Wave characteristics (sine wave)	
Maximum distortion	5 percent
Highest harmonic	4 percent
Crest factor	1.414±10 percent
Rating	1250 va



NOTES:
1. Normally open relay contacts, located in RCS Control Box, close during an abort or normal separation of CSM.
2. Postlanding circuit breakers (3) open until just prior to normal CSM separation
3. Motor switch contacts operate when MAIN BUS TIE switches are set to BAT A & C and BAT B & C positions.
4. These contacts remain closed on manned S/C.

SM-2A-807F

'ger and CM D-C Bus Control Circuits

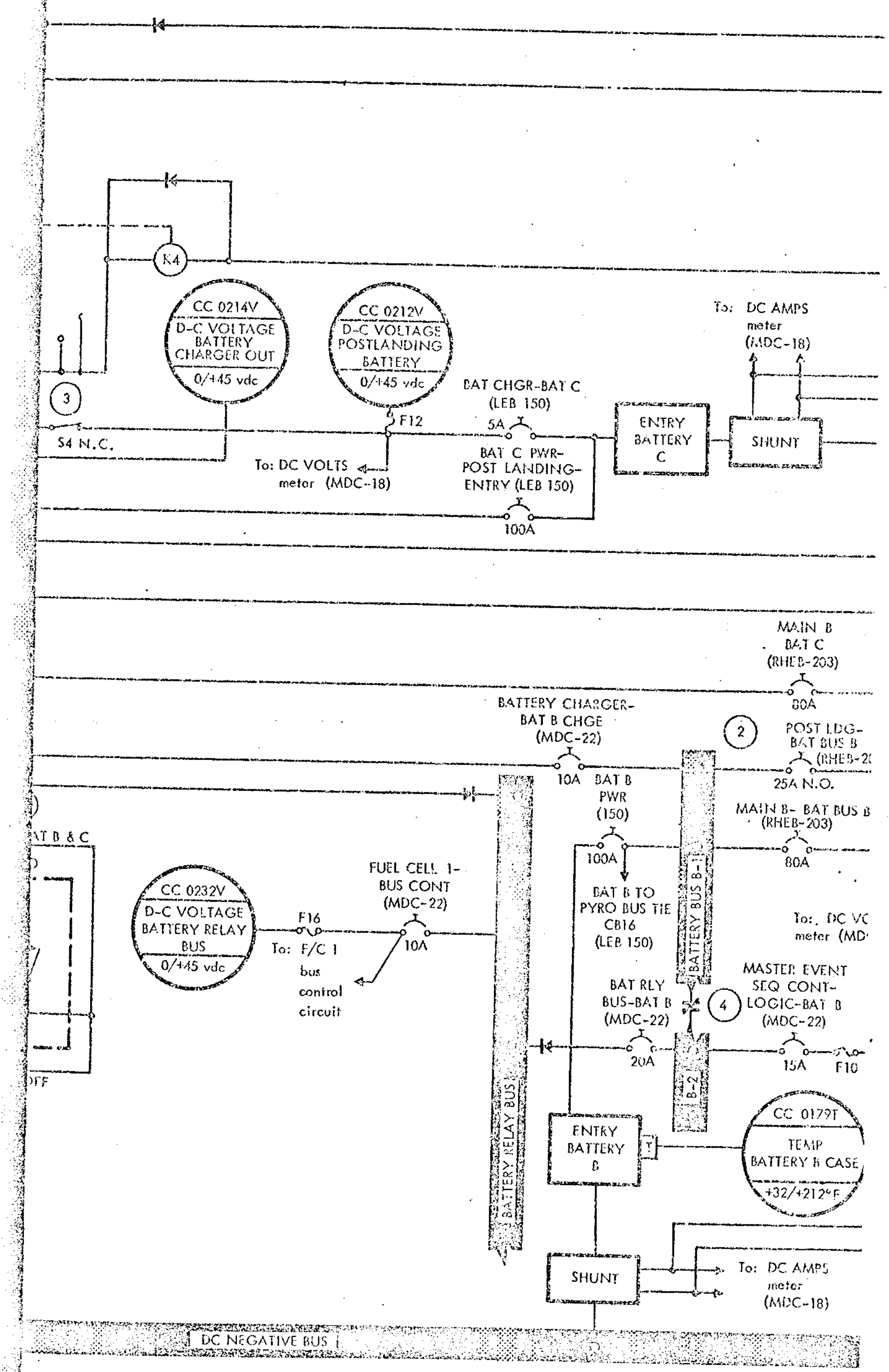
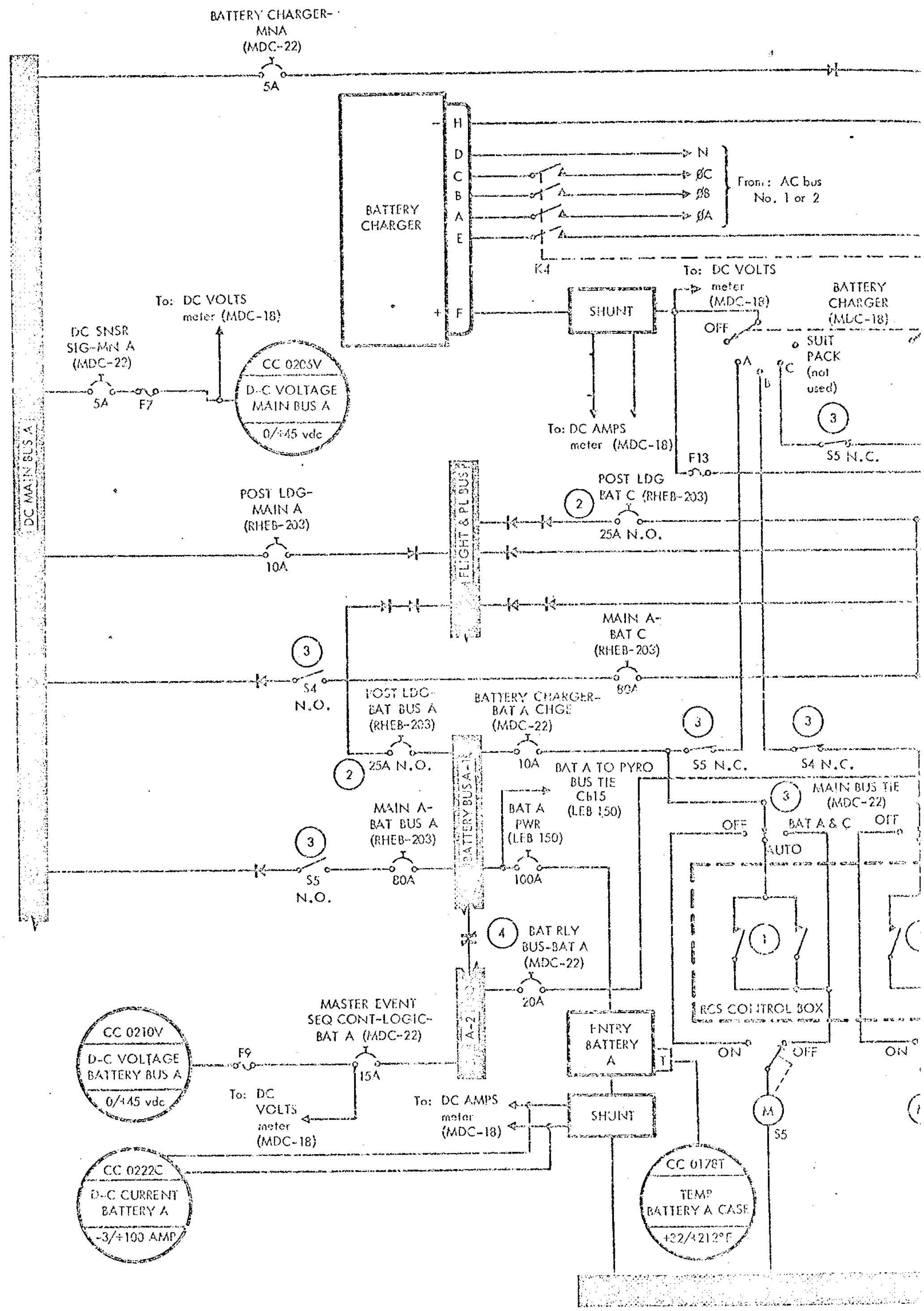


Figure 2.6-11. Battery Char


BATTERY CHARGER-
MNA
(MDC-22)
5A
BATTERY CHARGER
H
D
C
B
A
E
F
N
ØC
ØB
ØA
From: AC bus No. 1 or 2
K4
To: DC VOLTS meter (MDC-18)
SHUNT
BATTERY CHARGER (MDC-18)
OFF
A
B
C
SUIT PACK (not used)
To: DC VOLTS meter (MDC-18)
DC SNSR SIG-MN A (MDC-22)
5A
F7
CC 0206V
D-C VOLTAGE MAIN BUS A
0/+45 vdc
To: DC AMPS meter (MDC-18)
F13
S5 N.C.
DC MAIN BUS A
FLIGHT & PL BUS
POST LDG BAT C (RHEB-203)
25A N.O.
POST LDG-MAIN A (RHEB-203)
10A
MAIN A-BAT C (RHEB-203)
80A
S4
N.O.
POST LDG-BAT BUS A (RHEB-203)
25A N.O.
BATTERY CHARGER-BAT A CHGE (MDC-22)
10A
S5 N.C.
S4 N.C.
BAT A TO PYRO BUS TIE Cb15 (LEB 150)
MAIN BUS TIE (MDC-22)
BAT A & C
OFF
AUTO
MAIN A-BAT BUS A (RHEB-203)
BAT A PWR (LEB 150)
BATTERY BUS A-1
S5
N.O.
80A
100A
RCS CONTROL BOX
BAT RLY BUS-BAT A (MDC-22)
20A
A-2
MASTER EVENT SEQ CONT-LOGIC-BAT A (MDC-22)
F9
15A
CC 0210V
D-C VOLTAGE BATTERY BUS A
0/+45 vdc
To: DC VOLTS meter (MDC-18)
ENTRY BATTERY A
T
ON
OFF
To: DC AMPS meter (MDC-18)
SHUNT
M
S5
CC 0222C
D-C CURRENT BATTERY A
-3/+100 AMP
CC 0178T
TEMP BATTERY A CASE
+32/+212°F

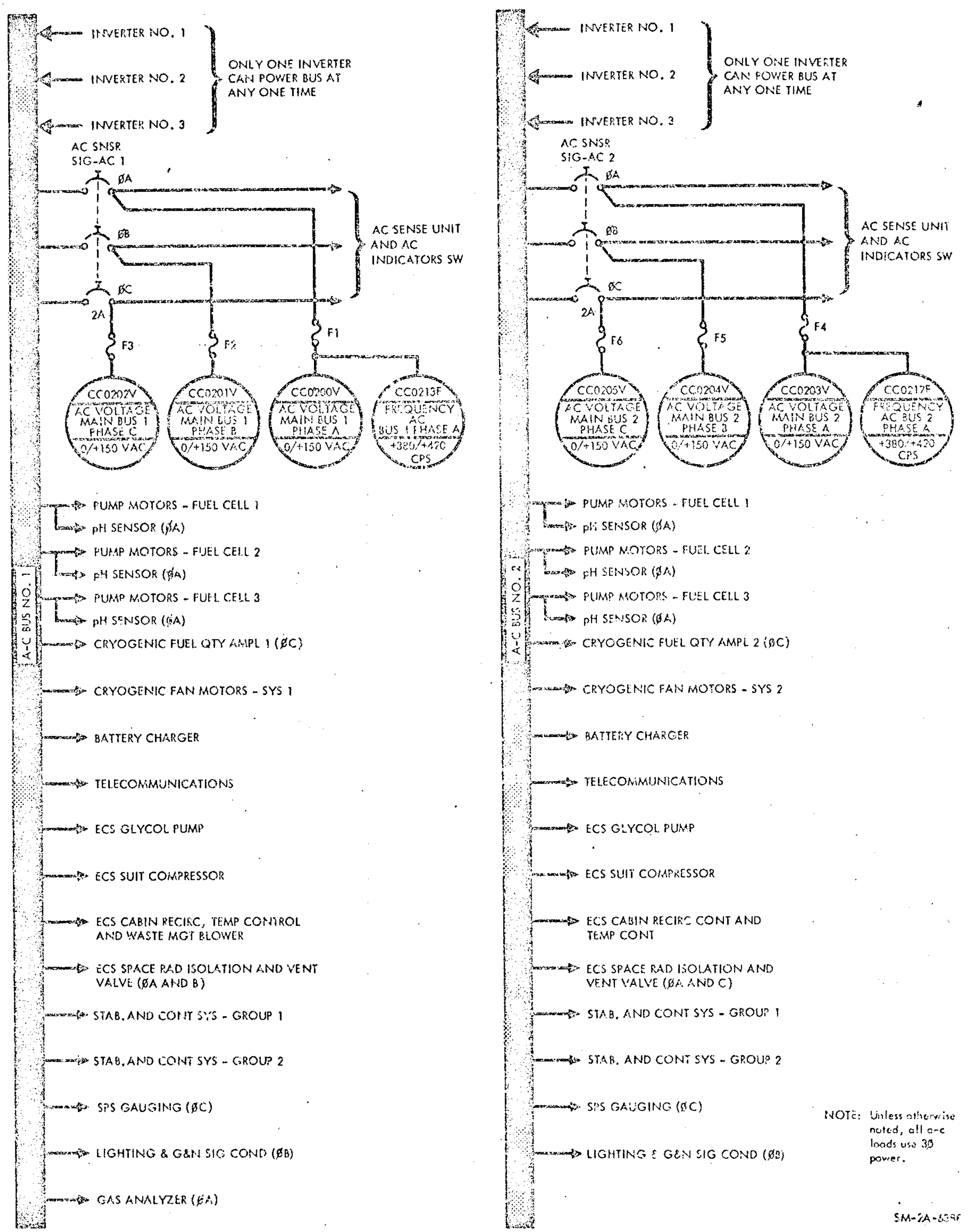


Figure 2.6-12. A-C Power Distribution

DC

Steady-state voltage limits Normal	29±2.0 vdc
During postlanding and preflight checkout periods	27 to 30 vdc
Ripple voltage	1v p-p

2.6.4.2 Power Requirements.

Power requirements for the EPS are as follows:

Unit	Control	Unit Quantity	Unit Input Power (Watts)		Total Input Power (Watts)	
			AC	DC	AC	DC
FUEL CELLS						
Hydrogen pump	FUEL CELL PUMP-1, -2, and -3 sw (MDC-22)	3	100.0		300.0	
Glycol pump	FUEL CELL PUMP-1, -2, and -3 sw (MDC-22)	3	20.0		60.0	
pH indicator	FUEL CELL PUMP-1, -2, and -3 sw (MDC-22) and FUEL CELL INDICATORS sw (MDC-18)	3	2.0		6.0	
Power factor correction for above items		3	2.5		7.5	
Total including pf correction					373.5	
Pressure transducers	FUEL CELL INDICATORS sw (MDC-18)	9		2.0		18.0
H_2 flowmeter circuits	FUEL CELL INDICATORS sw (MDC-18)	3		1.0		3.0

SYSTEMS DATA

Unit	Control	Unit Quantity	Unit Input Power (Watts)		Total Input Power (Watts)	
			AC	DC	AC	DC
O_2 flowmeter circuits	FUEL CELL INDICATORS sw (MDC-18)	3		1.0		3.0
H_2 purge line heater	H_2 PURGE LINE HEATER (MDC-15)	2		2.0		4.0
Purge solenoid	FUEL CELL-1, -2, -3, and H_2 PURGE/O_2 PURGE sw (MDC-18)	6		17.5		105.0
Fuel cell inline heater	None (Automatic on at +385±5°F) (Automatic off at +390±5°F)	3		160.0		480.0
CRYOGENICS						
H_2 tank heater	H_2 HEATERS-1 and -2 sw (MDC-13)	2		20.0		40.0
O_2 tank heater	O_2 HEATERS-1 and -2 sw (MDC-13)	2		155.0		310.0
H_2 tank fan	H_2 FANS-1 and -2 sw (MDC-13)	4	5.0		20.0	
O_2 tank fan	O_2 FANS -1 and -2 sw (MDC-13)	4	14.5		58.0	
Pressure transducer	ESSENTIAL-3 (153) C/B	4		1.5		6.0
Signal conditioner	CRYOGENIC SYSTEM-QTY AMPL-1 and -2-ØC C/B (MDC-22)	4	4.0		16.0	
BATTERY CHARGER	BATTERY CHARGER selector sw (MDC-18)	1			55.0 max	84.0 max

SYSTEMS DATA

Unit	Control	Unit Quantity	Unit Input Power (Watts)		Total Input Power (Watts)	
			AC	DC	AC	DC
SENSING UNITS						
D-C under-voltage sensing unit (2 circuits)	MAIN BUS A and B-RESET/OFF sw (MDC-18)	1				0.5
A-C under and overvoltage and overload sensing unit (2 circuits)	AC BUS 1 and 2-RESET/OFF sw (MDC-18)	1				1.0
PHASE SYNCHRONIZER UNIT	INV PHASE LOCK (panel 208)	1	7.5		7.5	
INVERTERS (See note)	AC INVERTER-1, -2, and -3 sw (MDC-18)					

NOTE With a 28-volt d-c input, each inverter will operate at air efficiency of 76 percent minimum with a 1250 volt-ampere load, 0.9 power factor, and 74 percent minimum with a 625 volt-ampere load, 0.9 power factor.

2.6.5 OPERATIONAL LIMITATIONS AND RESTRICTIONS.

2.6.5.1 Fuel Cell Power Plants.

Fuel cell power plants are designed to function under atmospheric and high vacuum conditions. Each must be able to maintain itself at sustaining temperatures and minimum electrical loads at both environment extremes. To function properly, fuel cells must operate under the following limitations and restrictions:

- External nonoperating temperature: -20° to +140°F
- Operating temperature inside S/M: +30° to +130°F
- External nonoperating pressure: Atmospheric
- Normal voltage: 27 to 31 vdc

• Minimum operating voltage Emergency operation	20.5 vdc at 2295 watts (gross power level)
Normal operation	27 vdc
• Maximum operating voltage	31 vdc
• Fuel cell disconnect (overload and reverse current relay)	75 amperes for over 15 minutes, 112 amperes for 25 to 300 seconds
Maximum reverse current	1 second minimum
• Minimum sustaining power/fuel cell power plant (with in-line heater off)	563 watts
In-line heater	160 watts
• H_2 purge line heater	4 watts
• Maximum gross power under emergency conditions	2295 watts
• Nitrogen pressure	52 to 70 psia
• Reactant pressure	
Oxygen	62 to 75 psia
Hydrogen	60.5 to 75 psia

• Reactant consumption/fuel cell power plant

Power Level	563W	2295W
Hydrogen	0.0476	0.262 lb/hr
Oxygen	0.378	2.08 lb/hr

• Electrolyte water concentration	24.3 to 28.2 percent
• Minimum stack temperature for self-sustaining operation	+385°F
• Approximate external environment temperature range outside S/C (for radiation)	-260° to +400°F
• Fuel cell power plant operating skin temperature	+385° to +500°F
• Condenser exhaust operating temperature	+155° to +175°F

• Purging frequency	Nominally every 24 hrs. (dependent on reactant purity after tank fill)
O_2 switch ON time	2 minutes
H_2 switch ON time	80 seconds
• Additional flow rate while purging	
O_2	Up to 0.6 lb/hr
H_2	Up to 0.75 lb/hr

2.6.5.2 Cryogenic Storage Subsystem.

The cryogenic storage subsystem must be able to meet the following requirements for proper operation of the fuel cell power plants and the ECS:

• Minimum usable quantity	
Oxygen	320 lb each tank
Hydrogen	28 lb each tank
• Temperature at time of fill	
Oxygen	-297°F (approx)
Hydrogen	-423°F (approx)
• Operating pressure range	
Oxygen	865 to 935 psia
Hydrogen	225 to 260 psia
• Temperature probe range	
Oxygen	-325° to +80°F
Hydrogen	-425° to -200°F
• Maximum allowable difference in quantity balance between tanks	
Oxygen tanks No. 1 and 2	15 lb
Hydrogen tanks No. 1 and 2	1 lb
• Pressure relief valve operation	
Crack pressure	
Oxygen	998 psia
Hydrogen	288 psia
Reseat pressure	
Oxygen	980 psia
Hydrogen	283 psia
Full flow, maximum relief	
Oxygen	1025 psia
Hydrogen	300 psia

2.6.6 TELEMETRY MEASUREMENTS.

The following is a complete list of all EPS telemetry data that is monitored by flight controllers and ground support personnel. The last column contains the name and type of S/C crew display. The display utilizes the same pickoff or signal source as telemetry, unless a separate measurement number is included in the display column.

An asterisk (*) by the measurement number denotes information which is not available for recording or telemetry transmission during PCM low bit rate operation.

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
CC 0175 T	Temp static inverter 1	+32/+248°F	+40° to +140°F	INV 1 TEMP HI C&W light
CC 0176 T	Temp static inverter 2	+32/+248°F	+40° to +140°F	INV 2 TEMP HI C&W light
CC 0177 T	Temp static inverter 3	+32/+248°F	+40° to +140°F	INV 3 TEMP HI C&W light
*CC 0178 T	Temp battery A case	+32/+212°F	+50° to 110°F (200°F entry)	None
*CC 0179 T	Temp battery B case	+32/+212°F	+50° to 110°F (200°F entry)	None
*CC 0188 P	Press bat compartment (Manif)	Zero/+18 psia	Zero	Auxiliary DC VOLTS meter
CC 0200 V	AC voltage main bus 1 phase A	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
*CC 0201 V	AC voltage main bus 1 phase B	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
*CC 0202 V	AC voltage main bus 1 phase C	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
CC 0203 V	AC voltage main bus 2 phase A	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
*CC 0204 V	AC voltage main bus 2 phase B	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
*CC 0205 V	AC voltage main bus 2 phase C	Zero/+150 vac	113 to 117 vac	AC VOLTS meter
CC 0206 V	DC voltage main bus A	Zero/+45 vdc	27 to 31 vdc	DC VOLTS meter
CC 0207 V	DC voltage main bus B	Zero/+45 vdc	27 to 31 vdc	DC VOLTS meter
*CC 0210 V	DC voltage battery bus A	Zero/+45 vdc	35 to 37 vdc open circuit	DC VOLTS meter
*CC 0211 V	DC voltage battery bus B	Zero/+45 vdc	27 to 29 vdc on load	DC VOLTS meter

SYSTEMS DATA

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
*CC 0212 V	DC voltage post landing battery	Zero/+45 vdc	35 to 37.2 vdc open circuit 27 to 29 vdc on load	DC VOLTS meter
*CC 0213 F	Frequency ac bus 1 phase A	+380/+420 cps	393 to 407 cps	FREQUENCY meter
*CC 0214 V	DC voltage bat charger out	Zero/+45 vdc	37 to 39 vdc	DC VOLTS meter
*CC 0217 F	Frequency ac bus 2 phase A	+380/+420 cps	393 to 407 cps	FREQUENCY meter
*CC 0222 C	DC current battery A	-3/+100 amp	-3 to 30 amps	DC AMPS meter
*CC 0223 C	DC current battery B	-3/+100 amp	-3 to 30 amps	DC AMPS meter
*CC 0224 C	DC current post landing battery	-3/+100 amp	-3 to 30 amps	DC AMPS meter
CC 0232 V	DC voltage battery relay bus	Zero/+45 vdc	25 to 36.5 vdc	None
*SC 2060 P	N_2 pressure F/C 1 regulated	Zero/+75 psia	50 to 54 psia	F/C 1 C&W light, REG OUT PRESS HI-N_2 event indicator, and auxiliary DC VOLTS meter.
*SC 2061 P	N_2 pressure F/C 2 regulated	Zero/+75 psia	50 to 54 psia	F/C 2 C&W light, REG OUT PRESS HI-N_2 event indicator, and auxiliary DC VOLTS meter
*SC 2062 P	N_2 pressure F/C 3 regulated	Zero/+75 psia	50 to 54 psia	F/C 3 C&W light, REG OUT PRESS HI-N_2 event indicator, and auxiliary DC VOLTS meter
*SC 2066 P	O_2 pressure F/C 1 regulated	Zero/+75 psia	59 to 65 psia	F/C 1 C&W light, REG OUT PRESS HI-O_2 event indicator, and auxiliary DC VOLTS meter
*SC 2067 P	O_2 pressure F/C 2 regulated	Zero/+75 psia	59 to 65 psia	F/C 2 C&W light, REG OUT PRESS HI-O_2 event indicator, and auxiliary DC VOLTS meter

SYSTEMS DATA

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
*SC 2068 P	O_2 pressure F/C 3 regulated	Zero/+75 psia	59 to 65 psia	F/C 3 C&W light, REG OUT PRESS HI-O_2 event indicator, and auxiliary DC VOLTS meter
*SC 2069 P	H_2 pressure F/C 1 regulated	Zero/+75 psia	57.5 to 63.5 psia	F/C 1 C&W light, REG OUT PRESS HI-H_2 event indicator, and auxiliary DC VOLTS meter
*SC 2070 P	H_2 pressure F/C 2 regulated	Zero/+75 psia	57.5 to 63.5 psia	F/C 2 C&W light, REG OUT PRESS HI-H_2 event indicator, and auxiliary DC VOLTS meter
*SC 2071 P	H_2 pressure F/C 3 regulated	Zero/+75 psia	57.5 to 63.5 psia	F/C 3 C&W light, REG OUT PRESS HI-H_2 event indicator, and auxiliary DC VOLTS meter
SC 2081 T	Temp F/C 1 cond exhaust	+150/+250°F	+157° to +172°F	F/C 1 C&W light, and MODULE TEMP COND-EXH indicator
SC 2082 T	Temp F/C 2 cond exhaust	+150/+250°F	+157° to +172°F	F/C 2 C&W light, and MODULE TEMP COND-EXH indicator
SC 2083 T	Temp F/C 3 cond exhaust	+150/+250°F	+157° to +172°F	F/C 3 C&W light, and MODULE TEMP COND-EXH indicator
SC 2084 T	Temp F/C 1 skin	+80/+550°F	+385° to +460°F	F/C 1 C&W light and MODULE TEMP-SKIN indicator
SC 2085 T	Temp F/C 2 skin	+80/+550°F	+385° to +460°F	F/C 2 C&W light and MODULE TEMP-SKIN indicator

SYSTEMS DATA

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
SC 2086 T	Temp F/C 3 skin	+80/+550°F	+385° to +460°F	F/C 3 C&W light and MODULE TEMP-SKIN indicator
SC 2087 T	Temp F/C 1 radiator outlet	-50/+300°F	-30° to +300°F	F/C 1 C&W light, F/C RAD TEMP LOW event indicator and auxiliary DC VOLTS meter
SC 2088 T	Temp F/C 2 radiator outlet	-50/+300°F	-30° to +300°F	F/C 2 C&W light, F/C RAD TEMP LOW event indicator and auxiliary DC VOLTS meter
SC 2089 T	Temp F/C 3 radiator outlet	-50/+300°F	-30° to +300°F	F/C 3 C&W light, F/C RAD TEMP LOW event indicator and auxiliary DC VOLTS meter
SC 2113 C	DC current F/C 1 output	Zero/+100 amps	18 to 22 amps	DC AMPS meter
SC 2114 C	DC current F/C 2 output	Zero/+100 amps	18 to 22 amps	DC AMPS meter
SC 2115 C	DC current F/C 3 output	Zero/+100 amps	18 to 22 amps	DC AMPS meter
SC 2120 X	Fuel cell 1 bus A disconnect	Off/on event	Connected	F/C BUS DISCONNECT C&W light and FUEL CELL-1-MAIN BUS A switch event indicator
SC 2121 X	Fuel cell 2 bus A disconnect	Off/on event	Connected	F/C BUS DISCONNECT C&W light and FUEL CELL-2-MAIN BUS A switch event indicator
SC 2122 X	Fuel cell 3 bus A disconnect	Off/on event	Disconnected	F/C BUS DISCONNECT C&W light and FUEL CELL-3-MAIN BUS A switch event indicator

SYSTEMS DATA

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
SC 2125 X	Fuel cell 1 bus B disconnect	Off/on event	Disconnected	F/C BUS DISCONNECT C&W light and FUEL CELL-1-MAIN BUS B switch event indicator
SC 2126 X	Fuel cell 2 bus B disconnect	Off/on event	Connected	F/C BUS DISCONNECT C&W light and FUEL CELL-2-MAIN BUS B switch event indicator
SC 2127 X	Fuel cell 3 bus B disconnect	Off/on event	Connected	F/C BUS DISCONNECT C&W light and FUEL CELL-3-MAIN BUS B switch event indicator
*SC 2139 R	Flow rate H_2 F/C 1	Zero/+0.2 lb/hr	0.046 to 0.056 lbs/hr	F/C 1 C&W light and FLOW-H_2 indicator
*SC 2140 R	Flow rate H_2 F/C 2	Zero/+0.2 lb/hr	0.046 to 0.056 lbs/hr	F/C 2 C&W light and FLOW-H_2 indicator
*SC 2141 R	Flow rate H_2 F/C 3	Zero/+0.2 lb/hr	0.046 to 0.056 lbs/hr	F/C 3 C&W light and FLOW-H_2 indicator
*SC 2142 R	Flow rate O_2 F/C 1	Zero/+1.6 lb/hr	0.370 to 0.450 lbs/hr	F/C 1 C&W light and FLOW-O_2 indicator
*SC 2143 R	Flow rate O_2 F/C 2	Zero/+1.6 lb/hr	0.370 to 0.450 lbs/hr	F/C 2 C&W light and FLOW-O_2 indicator
*SC 2144 R	Flow rate O_2 F/C 3	Zero/+1.6 lb/hr	0.370 to 0.450 lbs/hr	F/C 3 C&W light and FLOW-O_2 indicator
*SC 2160 X	pH factor water condition F/C 1	Normal/high event	Normal	F/C 1 C&W light and pH HI event indicator
*SC 2161 X	pH factor water condition F/C 2	Normal/high event	Normal	F/C 2 C&W light and pH HI event indicator
*SC 2162 X	pH factor water condition F/C 3	Normal/high event	Normal	F/C 3 C&W light and pH HI event indicator

SYSTEMS DATA

Measurement Number	Description	Sensor Range	Normal Operating Range	Crew Display
SC 2323 X	Fuel cell 1 shut off mon	Close/open event	Open	FUEL CELL REACTANTS event indicator
SC 2324 X	Fuel cell 2 shut off mon	Close/open event	Open	FUEL CELL REACTANTS event indicator
SC 2325 X	Fuel cell 3 shut off mon	Close/open event	Open	FUEL CELL REACTANTS event indicator
SF 0030 Q	Quantity H_2 tank 1	Zero/+28 lb	+28 lbs to zero	TANK QUANTITY-H_2-1 indicator
SF 0031 Q	Quantity H_2 tank 2	Zero/+28 lb	+28 lbs to zero	TANK QUANTITY-H_2-2 indicator
SF 0032 Q	Quantity O_2 tank 1	Zero/+320 lb	+320 lbs to zero	TANK QUANTITY-O_2-1 indicator
SF 0033 Q	Quantity O_2 tank 2	Zero/+320 lb	+320 lbs to zero	TANK QUANTITY-O_2-2 indicator
SF 0037 P	Press O_2 tank 1	+50/+1050 psia	865 to 935 psia	O_2 PRESS C&W light and TANK PRESSURE-O_2-1 indicator
SF 0038 P	Press O_2 tank 2	+50/+1050 psia	865 to 935 psia	O_2 PRESS C&W light and TANK PRESSURE-O_2-2 indicator
SF 0039 P	Press H_2 tank 1	Zero/+350 psia	225 to 260 psia	H_2 PRESS C&W light and TANK PRESSURE-H_2-1 indicator
SF 0040 P	Press H_2 tank 2	Zero/+350 psia	225 to 260 psia	H_2 PRESS C&W light and TANK PRESSURE-H_2-2 indicator
SF 0041 T	Temp O_2 tank 1	-325/+80°F	-284° to -140°F	None
SF 0042 T	Temp O_2 tank 2	-325/+80°F	-284° to -140°F	None
SF 0043 T	Temp H_2 tank 1	-425/-200°F	-417° to -340°F	None
SF 0044 T	Temp H_2 tank 2	-425/-200°F	-417° to -340°F	None

The auxiliary DC VOLTS meter, FUNCTION SELECT and TEST SELECT switches, located on panel 200 in the C/M RHFEB, provide a means of monitoring various telemetered measurements within the S/C and verifying certain parameters displayed only by event indicators. The following list presents the measurements test can be monitored using the auxiliary DC VOLTS meter, their respective switch positions, and the range of each sensor. Normal operating parameters of measurable items are covered in the telemetry listing.

Auxiliary DC VOLTS Meter Indication (Telemetry Identity) and Code No.)	Switch Positions		Sensor Range
	Function Select	Test Select	
N_2 pressure, psia	A		0 to 75 psia
F/C 1 SC 2060 P		1	
F/C 2 SC 2061 P		2	
F/C 3 SC 2062 P		3	
O_2 pressure, psia			0 to 75 psia
F/C 1 SC 2066 P		4	
F/C 2 SC 2067 P		5	
F/C 3 SC 2068 P		6	
H_2 pressure, psia			0 to 75 psia
F/C 1 SC 2069 P		7	
F/C 2 SC 2070 P		8	
F/C 3 SC 2071 P		9	
EPS radiator outlet temp			-50° to +300°F
F/C 1 SC 2087 T		10	
F/C 2 SC 2088 T		11	
F/C 3 SC 2089 T		12	
C/M-RCS oxidizer valve temp	B		-50° to +250°F
-P engine, sys A CR 2205 T		1	
+Y engine, sys B CR 2203 T		2	
-P engine, sys B CR 2204 T		3	
CW engine, sys B CR 2206 T		4	
CCW engine, sys A CR 2201 T		11	
-Y engine, sys A CR 2202 T		12	
PIPA temp CG 2300 T		5	+125° to +135°F
IRIG temp CG 2301 T		6	+128.5° to +138.5°F

SYSTEMS DATA

Auxiliary DC VOLTS Meter Indication (Telemetry Identity) and Code No.)	Switch Positions: Function Select	Switch Positions: Test Select	Sensor Range
IMU current Heater CG 2302 C Blower CG 2303 C		7 8	0 to 5 amps
Battery manifold Pressure, psia CC 0188 P		9	0 to 18 psia
ECS radiator inlet Temp SF 0665 T		10	+60° to +150°F

The conversion of the previously listed telemetry measurements to the auxiliary DC VOLTSmeter indication is presented as follows:

Auxiliary DC VOLTS Meter Display	N_2, O_2, H_2 Pressure (PSIA)	EPS Radiator Outlet Temp (°F)	C/M-RCS Oxidizer Valve Temp (°F)	PIPA Temp (°F)	IRIG Temp (°F)	IMU Heater and Blower Current (Amps)	Battery Manifold Pressure (PSIA)	ECS Radiator Inlet Temp (°F)
0.0	0	-50	-50	+125.0	+128.5	0.0	0.00	+60.0
0.2	3	-36	-38	+125.4	+128.9	0.2	0.72	+63.6
0.4	6	-22	-26	+125.8	+129.3	0.4	1.44	+67.2
0.6	9	-8	-14	+126.2	+129.7	0.6	2.16	+70.8
0.8	12	+6	-2	+126.6	+130.1	0.8	2.88	+74.4
1.0	15	+20	+10	+127.0	+130.5	1.0	3.60	+78.0
1.2	18	+34	+22	+127.4	+130.9	1.2	4.32	+81.6
1.4	21	+48	+34	+127.8	+131.3	1.4	5.04	+85.2
1.6	24	+62	+46	+128.2	+131.7	1.6	5.76	+88.8
1.8	27	+76	+58	+128.6	+132.1	1.8	6.48	+92.4
2.0	30	+90	+70	+129.0	+132.5	2.0	7.20	+96.0
2.2	33	+104	+82	+129.4	+132.9	2.2	7.92	+99.6
2.4	36	+118	+94	+129.8	+133.3	2.4	8.64	+103.2
2.6	39	+132	+106	+130.2	+133.7	2.6	9.36	+106.8
2.8	42	+146	+118	+130.6	+134.1	2.8	10.08	+110.4
3.0	45	+160	+130	+131.0	+134.5	3.0	10.80	+114.0
3.2	48	+174	+142	+131.4	+134.9	3.2	11.52	+117.6
3.4	51	+188	+154	+131.8	+135.3	3.4	12.24	+121.2
3.6	54	+202	+166	+132.2	+135.7	3.6	12.96	+124.8
3.8	57	+216	+178	+132.6	+136.1	3.8	13.68	+128.4
4.0	60	+230	+190	+133.0	+136.5	4.0	14.40	+132.0

SYSTEMS DATA

Auxiliary DC VOLTS Meter Display	N_2, O_2, H_2 Pressure (PSIA)	EPS Radiator Outlet Temp (°F)	C/M-RCS Oxidizer Valve Temp (°F)	PIPA Temp (°F)	IRIG Temp (°F)	IMU Heater and Blower Current (Amps)	Battery Manifold Pressure (PSIA)	ECS Radiator Inlet Temp (°F)
4.2	63	+244	+202	+133.4	+136.9	4.2	15.12	+135.6
4.4	66	+258	+214	+133.8	+137.3	4.4	15.84	+139.2
4.6	69	+272	+226	+134.2	+137.7	4.6	16.56	+142.8
4.8	72	+286	+238	+134.6	+138.1	4.8	17.28	+146.4
5.0	75	+300	+250	+135.0	+138.5	5.0	18.00	+150.0

SECTION 2

SUBSECTION 2.7

ENVIRONMENTAL CONTROL SYSTEM (ECS)

2.7.1 INTRODUCTION.

The environmental control system (ECS) is designed to provide a controlled environment for three crewmen within the Apollo C/M for missions up to 14 days. The system also supplies several of the metabolic requirements, as well as functioning in the removal of by-products resulting from the normal metabolic process. The controlled environment consists of a pressure suit circuit for use during normal or emergency conditions, and a shirtsleeve atmosphere within the C/M cabin, for use when normal conditions prevail. Oxygen and thermally controlled water are supplied for crew consumption; whereas, carbon dioxide and odors, water-production, and heat output are removed. In addition, the ECS disperses equipment heat loads and provides for venting the waste storage compartment. Controls and displays are located in several areas within the C/M cabin; these, in conjunction with automatically functioning components, and sensing and protective devices, aid the crew in the operation of the system. The five subsystems composing the ECS are the oxygen supply, pressure suit circuit, cabin pressure and temperature control, water-glycol coolant, and water supply.

The oxygen supply subsystem controls the inflow of oxygen for the entire Apollo mission. This function is accomplished by pressure regulator, demand regulators, storage tanks, check valves, and manual shutoff valves. The pressure suit subsystem automatically controls the flow, pressure, temperature, and composition of the pressure suit gas. In conjunction with the C/M pressure and temperature control subsystem, it also controls the environment conditions in the cabin when one, or all of the crew are out of their pressure suits. These functions are provided by water separators, temperature controls, a suit heat exchanger, a debris trap, gas compressor, CO_2-odor absorbers, and a water glycol-to-gas heat exchanger.

The cabin pressure and temperature control subsystem automatically maintains the pressure and temperature of the cabin within specified limits. This function is accomplished in conjunction with the pressure suit subsystem by means of regulated oxygen inflow, recirculation blowers, a heat exchanger, a temperature control and sensors, vent valves, and other valves and controls required. The water-glycol subsystem is an intermediate heat transfer loop which permits excess heat to be transferred from the C/M interior to the space radiators where it is rejected to the cosmic sink. This function is accomplished by pumps, heat exchangers, cold plate networks, valves, and controls. The water supply subsystem collects, stores, and provides water for supplemental heat transfer operation, and collects and stores potable water for consumption by the crew. These functions are accomplished by utilizing water tanks, pressure controls, cyclic accumulators, and valves.

Other than the circuitry required for controls and displays or electrical power, three points of interface exist between the ECS and other S/C systems. All oxygen supplied to the ECS flows from the cryogenic storage tanks, which are considered a part of the EPS. The fuel cells, also a part of the EPS, furnish the onboard supply of potable water that is stored by the ECS. The third interface point is with the waste management system, which connects into the ECS overboard dump line.

2.7.2 FUNCTIONAL DESCRIPTION.

The ECS requires a minimum amount of crew time be spent for normal system operation. In addition to periodically monitoring system indicators, the crew is responsible for the accomplishment of several normal tasks on an infrequent basis. For conditions other than normal, the duties of the crew will increase. Electrical and manual override and backup capabilities exist throughout the ECS to maintain the required reliability level of the system.

The oxygen supplied to the ECS from the storage tanks in the S/M is used to carry out a variety of system functions. Upon reaching the ECS, oxygen is automatically regulated and manually routed to various subsystem components by a system of valves and lines. Also incorporated are automatically functioning components to maintain suit and/or cabin pressure in the event of cabin decompression of equipment malfunction.

The atmosphere of the pressurized cabin, as well as that of the pressure garment assemblies (PGA), is routed through the suit circuit for contaminant removal and humidity control. The flow, pressure, and temperature control within the suit circuit, are maintained by other components of the subsystem. This is accomplished automatically by using transducers, sensors, and control units to regulate these functions. Mechanical-type oxygen pressure regulators automatically maintain cabin pressure within prescribed limits. The temperature of the cabin is controlled by an automatic unit that regulates the output of the cabin heat exchanger with the aid of sensors and anticipators.

Carbon dioxide and odors are removed from the suit circuit and cabin gases by routing the gas flow through two filters in the CO_2-odor absorber canisters. Each filter contains sufficient lithium hydroxide (CO_2 removal) and activated charcoal (odor removal) for a 12-hour duty period for a crew of three. The suit circuit and cabin atmospheres are also sampled by a gas chromatograph that will identify up to 28 gas components that may be present.

Heat, generated by the crew and the many items of electrical equipment located in the cabin, is absorbed by recirculating water-glycol. The heat is transferred to the water-glycol as it flows through the suit heat exchanger, the cabin heat exchanger, and the cold plate network for the electrical equipment. The warm water-glycol is then routed through space radiators in the S/M, where the heat is radiated to space. Supplementing the radiators and/or as a backup mode, water evaporators are employed for any additional temperature control of suit gases or insufficiently cooled water-glycol.

Potable and waste water are generated on-board the S/C. The potable water is a by-product of the EPS fuel cells and flows to the ECS where it is stored. Cold potable water is available to the crew for drinking, and hot or cold potable water is available for food reconstitution. Waste water is derived from the moisture that condenses in the water separator of the suit exchanger. It is collected and stored by the ECS and used for evaporative cooling in the suit heat exchanger evaporator and the water-glycol evaporator.

2.7.3 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION.

Pertinent design data in regard to components, their function within each subsystem, and how they interface is contained under major component/subsystem description. The description follows the logical flow, component by component, through each subsystem of the ECS.

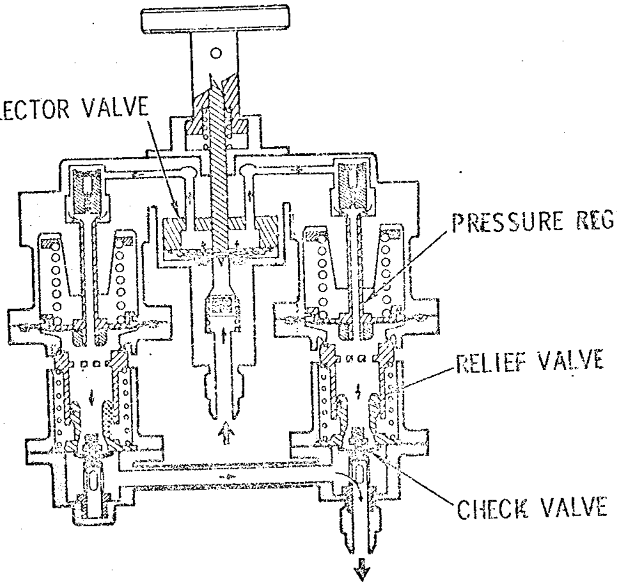
2.7.3.1 Oxygen Supply Subsystem.

Two cryogenic oxygen storage tanks (part of the electrical power system) supply 900±35 psia oxygen flow to the ECS. Each tank contains 320 pounds of oxygen, and of the total supply, approximately one-third is consumed by the ECS. Oxygen flows unrestricted in parallel lines from the S/M supply tanks into the C/M. In the C/M, oxygen flows in each supply line through a filter, a capillary restrictor, and a check valve upstream to their connection to a common distribution line. To assure uniform flow, the capillary restrictors are coiled around a warm water-glycol line to increase the oxygen temperature. Each restrictor allows a maximum flow of 4.5 pounds per hour into the ECS to limit the demands placed on the cryogenic oxygen storage tanks and enable the tank heaters to maintain the prescribed tank pressures. The minimum flow rate will not decrease below 3.4 pounds per hour as the oxygen density decreases due to usage. Illustrated in the ECS integrated schematic (figure 2.7-13) the manual S/M supply shutoff valve, located on the LHEB panel 307, is normally in the ON position and placed to OFF prior to SCM separation for the entry phase of the mission. Downstream of the S/M shutoff valve 900±35 psia oxygen is distributed to a surge tank, an entry O_2 tank, a PLSS fill valve, and the main pressure regulator assembly. Oxygen flows to the surge tank through a manual surge tank isolation valve, located on the LHEB panel 307. The surge tank provides a reservoir of O_2 for the entry mission modes, and during flow requirements above the 0.9 pound per hour maximum allowable by the capillary restrictors. Approximately 3.7 pounds of oxygen is available at nominal inlet pressure of 900±35 psia. A surge tank pressure transducer output is displayed by the TANK PRESS O_2 1 indicator, located on MDC panel 13. The indicator input must be selected by the switch position, SURGE TANK, located below the indicator. To reduce the demand loads on the cryogenic storage system, high flow rates from the surge tank will maintain cabin pressure from 5 to 3.5 psia for 5 minutes, with a 0.5-inch-diameter puncture in the cabin. The flow rate into the cabin is a function of regulator valves downstream of the surge tank. The 5-minute period allows unsuited crewmembers to don PGAs. When isolated by the surge tank manual shutoff valve, the tank is protected by a pressure relief and manual shutoff valve assembly. The relief portion is set between 1020 and 1070 psig. Should the relief valve fail or not reseat properly, the manual shutoff valve will isolate the relief valve function from the system.

Downstream O_2 supply is also stored in a one-pound entry O_2 tank, through a manual three-way selector valve, a check valve, and a check valve bypass. When the manual selector valve is in the FILL position, the entry O_2 supply tank receives high pressure O_2 through the check valve bypass. When the tank is charged, the selector valve may be positioned to OFF to isolate the tank supply, or to ON whereby the O_2 tank supply may augment the surge tank function. The check valve prevents a reverse flow in case of entry O_2 tank damage. An isolation check valve between the two tanks prevents reverse flow and a manual valve permits charging PLSS oxygen tanks from the ECS.

The 900±35-psig oxygen supply, from the cryogenic tanks, is regulated to 100±10 psig by the main pressure regulator assembly illustrated in figure 2.7-1. The main pressure regulator assembly consists of a manual selector valve, two regulators, and two relief and check valves. NORMAL position of the manual selector valve parallels the regulators. Position No. 1 or No. 2 selects its regulator respectively. The OFF position isolates all O_2 supply for the crew and cabin. Should a regulator fail open, the relief valve for that regulator will limit the pressure to 140 psig downstream and vent a maximum flow of 0.75 pounds per minute into the cabin. This fault should be corrected by selecting the alternate regulator only.

An oxygen flow transducer, downstream of the main regulator, provides a signal to the flow indicator, located on the main display console panel 13, and the O_2 FLOW HI light. Although short periods of flow in excess of 0.45 pounds per hour are considered normal, a continuous flow rate between 0.45 and 1.0 pound per hour should not be tolerated. Flow rates above 1.0 pounds per hour and for a period of 15 seconds and above activate the red O_2 FLOW HI warning light located on the caution and warning (C&W) panel 11. The 15-second time delay prevents the O_2 FLOW HI light from lighting during O_2 flow requirements of the cyclic accumulators that remove water from the suit heat exchanger, and during transient conditions. Continued flow rates in this range are indicative of cabin leakage, O_2 supplied subsystem leakage, or subsystem mismanagement.



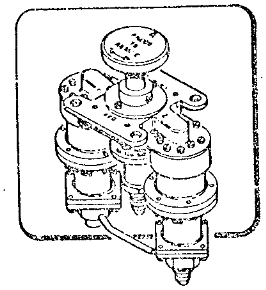


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Figure 2.7-1. Main Oxygen Pressure Regulator

Connected to the 100±10-psig regulated pressure line is a fluid tank pressure regulator and relief valve assembly, located on the OXYGEN CONTROL PANEL No. 314. It consists of redundant pressure regulators and relief valves which provide oxygen at regulated pressure to the expulsion bladders installed in the potable water tank, waste water tank, and the water-glycol (W/G) reservoir. Two four-position selector valves are employed at the inlet and outlet, and enable isolation of malfunctioning elements or complete shutoff as desired. The pressure regulator is a normally opened, diaphragm-operated poppet metering valve which functions to reduce 100±10-psig supply pressure to 20±2-psig O_2 pressure to the fluid tanks, in relation to cabin pressure. The relief valve incorporated in the assembly outlet chamber functions to relieve O_2 pressure in excess of 25±2 psig into the cabin.

Should a regulator diaphragm rupture, and is isolated by the inlet manual selector valve, the manual outlet selector valve must also be positioned to isolate the relief portion of the failed regulator. This prevents a feedback from the alternate regulator flowing oxygen through the ruptured diaphragm of the failed regulator into the cabin.

Should the selector inlet valve of the assembly be placed to position 1, the selector outlet valve must also be placed to position 1 (or NORMAL). If instead, the selector outlet valve were placed to position 2, the valve port to pressurize the tanks would be closed, and the port to the relief valve would remain open. This permits the pressure relief function of the valve to remain operative but prohibits subsequent tank pressurization. Conversely, when the selector outlet valve is set to position 2, the selector inlet valve must also be set to position 2 (or NORMAL). The OFF position of the inlet and outlet selector valves is normally for ground checkout; however, if both pressure regulators malfunction during flight, the selector inlet valve must be set to the OFF position. This eliminates the tank pressurization function, but does not affect the pressure relief function. In response to the possibility of both relief valves malfunctioning, the selector outlet valve must be set to the OFF position. This action will eliminate both the pressurization and pressure relief functions.

The 100±10-psig oxygen supply is controlled by the emergency cabin pressure regulator, located on panel 314, to provide increased oxygen flow to the cabin, and prevent rapid decompression. The emergency cabin pressure regulator consists of dual aneroid-operated, normally closed valves to prevent overpressurization of the aneroids, and a manual four-position selector valve with positions designated No. 1, No. 2, NORMAL, and OFF. A PRESS-TO-TEST button, which closes the cabin pressure sense port allows a fix bleed of 100 cc per min to pressurize an aneroid chamber and drive the valve open. Normally the 100±10-psig oxygen supply to the cabin is controlled by the cabin pressure regulator assembly. It consists of dual, aneroid-absolute type normally closed valves, and each will deliver a minimum of 0.2 pound per hour oxygen flow at a cabin pressure of 5.0±0.2 psia. Failure mode of the valve is normally closed. A manual control valve may be opened and allow a minimum 6 pounds per hour flow of O_2 directly into the cabin for repressurization from 0.0 to 5.0 psia within one hour. The cabin pressure regulator and the emergency cabin pressure regulator are associated with the cabin pressure and temperature control subsystem (paragraph 2.7.3.3). Oxygen distribution at 100±10 psig is routed to a manually operated metering valve, for direct flow into the suit inlet duct. In the full open position, oxygen will flow from 0.6 to 0.7 pound per minute.

Downstream the dual suit demand pressure regulator and relief valve, located on LHEB panel 310, compares suit compressor inlet pressure to cabin ambient pressure. When the compressor inlet pressure is 2.5 to 3.5 inches of water pressure below cabin pressure, the demand regulator controls O_2 flow into the suit circuit at flow rates up to 0.007 pound per minute. When the compressor inlet pressure is above 2 to 9 inches of water pressure above cabin pressure, the relief valve vents the suit circuit gases to the cabin at a maximum flow rate of 0.66 pound per minute. Normally the compressor inlet manifold is regulated to an average of 6.10 inches of water above cabin ambient pressure. When cabin ambient pressure is less than 4 psia, a 100 ccm bleed within the demand regulator is used to maintain the suit circuit pressure at 3.75±0.25 psia. With cabin ambient pressure below 3.5 psia and a 0.66 pound per minute suit leakage, the demand regulator should sustain suit circuit pressure at 3.75±0.25 psia. A four-position manual selector valve with control positions designated as No. 1, No. 2, both, and OFF provides isolation of a fault. The demand pressure regulator and relief valve are described in paragraph 2.7.3.3.

Oxygen regulated at 100±10-psig pressure is used as a motive force in the removal of waste water from the suit circuit and then expelled into the suit heat exchanger.

2.7.3.2 Pressure Suit Circuit Subsystem.

The pressure suit subsystem is a loop or circuit designed to supply a conditioned atmosphere for a crew of three, whether they be in or out of their PGAs. The circuit provides for ventilation and cooling for the crew, the removal of carbon dioxide and odors, and the control of relative humidity. Suit circuit pressure is maintained by controlling the amount of oxygen entering the subsystem.

A supply-return hose assembly is connected between each crewman's PGA and a suit hose connector assembly. This assembly consists of a combined supply-return connection. A three-position suit flow control valve, which diverts oxygen into the cabin when a crewmember is unsuited, and a check valve prevents return flow from the cabin. Normal operation is to disconnect the hose at the suit. There is also a venturi-type flow limiter, located upstream in each supply line, to limit flow to any one suit to a maximum of 0.7 pound per minute. During the time a crewmember is in the shirtsleeve mode, the flow control valve is positioned to permit suit circuit flow into the C/M cabin, through the suit hose, which is removed at the PGA connection. The return section of the suit hose is capped to prevent cabin gas flowing into the suit circuit when crewmen remove their suits.

Cabin gases are returned to the suit circuit for removal of carbon dioxide, odors, heat, and moisture. These gases enter at the suit circuit return air valve assembly, which consists of two check valves in series, and a manual shutoff valve for isolating the suit circuit if the cabin becomes contaminated. The combined cabin and suit circuit atmosphere first flows through the debris trap, where small particles of solid matter are removed. The trap contains a bypass valve in the event the filter screen becomes clogged.

Two suit compressors, connected in parallel, maintain circulation within the suit circuit. Normally only one compressor is operated at a time; however, both may be operated for a small advantage in sensible heat removal with a large increase in power consumption in all cases except prelaunch, or when the three crewmembers are unsuited in a 5-psia pressurized cabin. A differential pressure transducer between the inlet and outlet manifolds of the compressor supplies signals for indication on the main display console (panel 13). Compressor output is dependent on the mode of operation. In normal space operation, the operating compressor delivers approximately 35 cubic feet per minute of suit gas at a pressure rise of 10 inches of water within the condition of 4.93 psia and 88°F. When the cabin is unpressurized, the operating compressor delivers approximately 34.5 cubic feet per minute suit gas at a pressure rise of 6.9 inches of water when inlet conditions are 3.51 psia at 85°F.