



APOLLO TRAINING

ELECTRICAL POWER SYSTEM STUDY GUIDE

COURSE NO. A212

OCTOBER 1, 1965

FOR TRAINING PURPOSES ONLY



PREFACE

THIS STUDY GUIDE HAS BEEN PREPARED TO AUGMENT THE ORAL PRESENTATION OF ELECTRICAL POWER SYSTEM COURSE NUMBER A 212.

THE GUIDE ARRANGEMENT CORRESPONDS TO THE INSTRUCTOR'S PRESENTATION AND AFFORDS REVIEW OF THE MATERIAL ACCOMPANIED BY PRINTED DESCRIPTION. ITS USE WILL REDUCE THE NECESSITY FOR MAKING NOTES AND THE POSSIBILITY OF MISINTERPRETATION OF THE EXPLANATION.

THE DESCRIPTIONS CONTAINED HEREIN ARE INTENDED TO APPLY ONLY TO MANNED APOLLO SPACECRAFT. BOILERPLATE ARTICLES WILL, IN MOST INSTANCES, HAVE CONSIDERABLY LESS SOPHISTICATED SYSTEM CONFIGURATIONS.

THE CONTENTS OF THIS DOCUMENT ARE ACCURATE AS OF THE PUBLICATION DATE. THIS DOCUMENT IS INTENDED FOR TRAINING PURPOSES ONLY AND IS NOT SUBJECT TO SCHEDULED REVISION.

NOTE:

CHANGES OF INFORMATION FROM THE 1 AUGUST EDITION APPEAR IN SECTIONS IV, V, VI & APPENDIX.

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SECTION I

INTRODUCTION

THE ELECTRICAL POWER SYSTEM (EPS) PROVIDES ALL THE ELECTRICAL POWER REQUIRED BY THE SPACECRAFT TO SUCCESSFULLY ACCOMPLISH A LUNAR LANDING MISSION. THIS INCLUDES POWER TO THE LUNAR EXCURSION MODULE (LEM) FOR VARIOUS PURPOSES DURING TRANSLUNAR COAST, HOWEVER THE LEM HAS ITS OWN POWER SYSTEM. POWER FROM SPACECRAFT BATTERY SOURCES IS SUFFICIENT TO SUCCESSFULLY PERFORM ANY ABORT MANEUVER.

I.1 PHYSICAL DESCRIPTION

THE POWER REQUIREMENTS IMPOSED BY A LUNAR LANDING MISSION ARE VARIABLE THROUGHOUT THE MISSION. DURING LAUNCH, THE VARIOUS INJECTION PHASES AND COURSE CORRECTION MANEUVERS, POWER REQUIREMENTS ARE HIGH; HOWEVER, DURING THESE PERIODS WHICH ARE OF SHORT DURATION, BATTERY POWER IS USED TO SUPPLEMENT THE FUEL CELL MODULES. DURING THE COASTING AND ORBITAL PERIODS, WHICH ARE OF LONG DURATION, POWER REQUIREMENTS ARE LOW, AND RELATIVELY STABLE.

PROVIDING POWER TO FULFILL THESE REQUIREMENTS IS ACCOMPLISHED BY THREE FUEL CELL MODULES, SEVEN BATTERIES, AND THREE STATIC INVERTERS. FIGURE I-1 SHOWS THE FUEL CELL MODULES LOCATED IN SECTOR IV, AND THE FOUR REACTANT STORAGE TANKS IN SECTOR I OF THE SERVICE MODULE (S/M). TWO OF THE SEVEN BATTERIES ARE

LOCATED IN SECTOR IV OF THE S/M. TWO SETS OF SPACE RADIATORS, FIGURE I-2, ARE INCORPORATED AS AN INTEGRAL PART OF THE OUTER PANELS OF SECTORS I AND IV OF THE S/M.

FIGURE I-3 SHOWS THE LOCATION OF THE EQUIPMENT BAYS AND THE CONTROL AND DISPLAY PANELS IN THE COMMAND MODULE (C/M). THE CONTROL AND MONITORING DEVICES ARE SITUATED AROUND THE C/M IN POSITIONS NEAR THE ASTRONAUT RESPONSIBLE FOR MONITORING AND CONTROLLING THE PARTICULAR FUNCTION THE DEVICES SERVE. THE MAIN DISPLAY CONSOLE OCCUPIES THE AREA DIRECTLY IN FRONT OF THE ASTRONAUT'S LINE OF VISION. ADDITIONAL CONTROL AND CIRCUIT BREAKER PANELS ARE LOCATED IN THE LOWER, LEFT AND RIGHT HAND EQUIPMENT BAYS. CRITICALITY OF THE COMPONENT CONTROLLED OR MONITORED DETERMINES THE DEGREE OF ACCESSIBILITY.

THE EPS COMPONENTS IN THE C/M ARE LOCATED IN THE LOWER EQUIPMENT BAY. FIGURES I-4 AND I-5 SHOW THE LOCATION OF THE EPS EQUIPMENT IN THE LOWER EQUIPMENT BAY. THE REMAINING BATTERIES, INVERTERS, INVERTER CONTROL CIRCUITS, AND BATTERY CHARGER, ARE LOCATED AT THE BOTTOM OF THE BAY. DUE TO THE ENVIRONMENTAL CONTROL SYSTEM FILTER CONTAINERS LOCATED IN FRONT OF THE BOTTOM SHELF, THE EPS EQUIPMENT IS INACCESSIBLE DURING FLIGHT.

S/M EPS & CRYOGENIC STORAGE

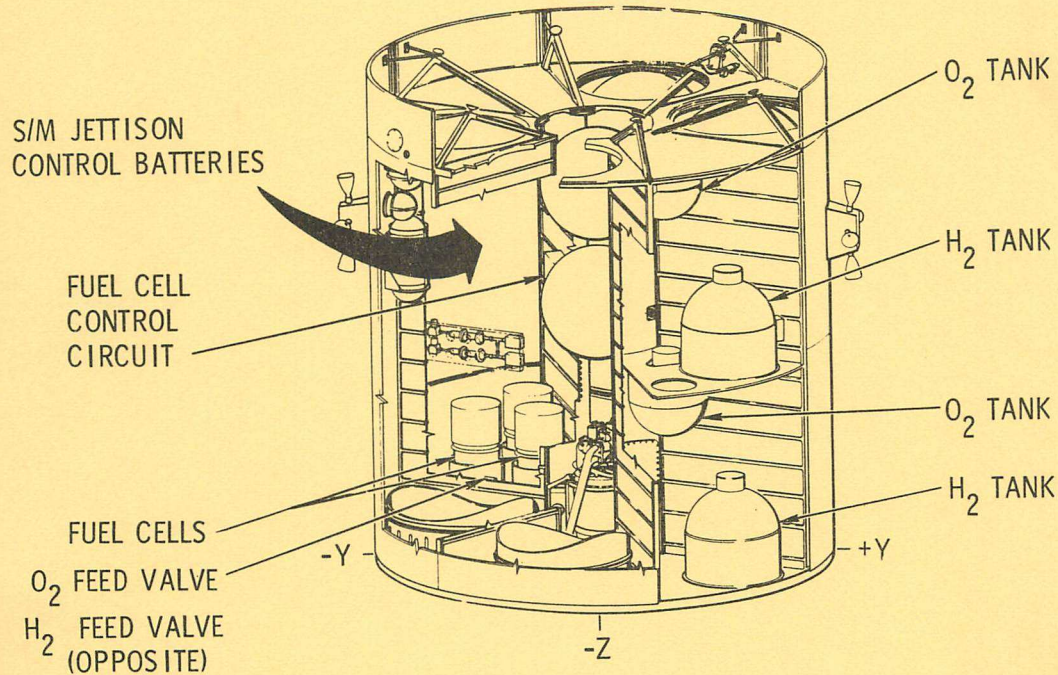


FIGURE 1-1

EP-029A



ELECTRICAL POWER RADIATORS

1

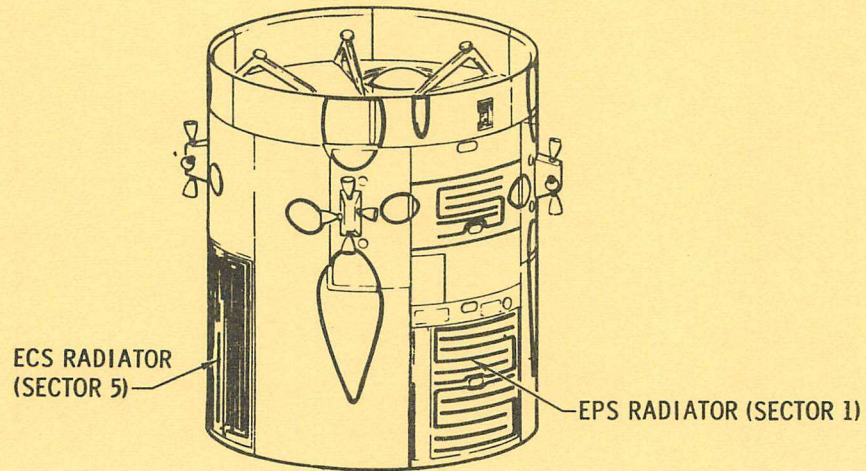


FIGURE 1-2

C/M EQUIPMENT BAYS

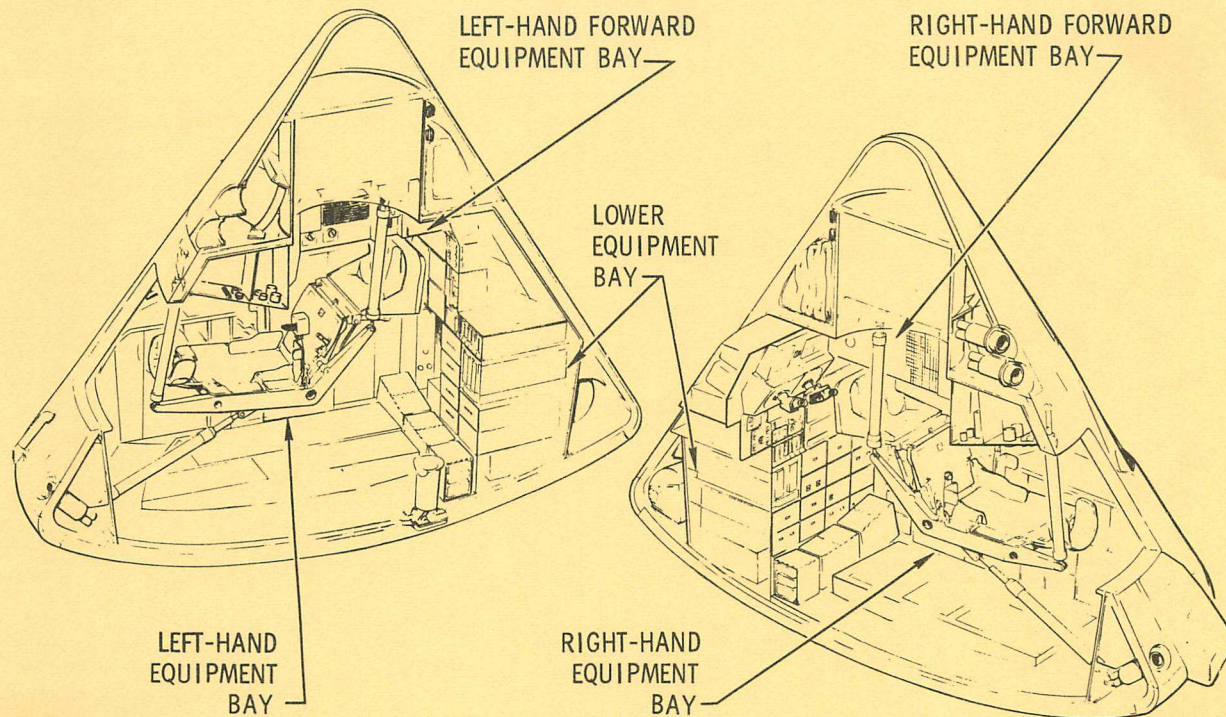


FIGURE 1-3

EP-028 

LOWER EQUIPMENT BAY

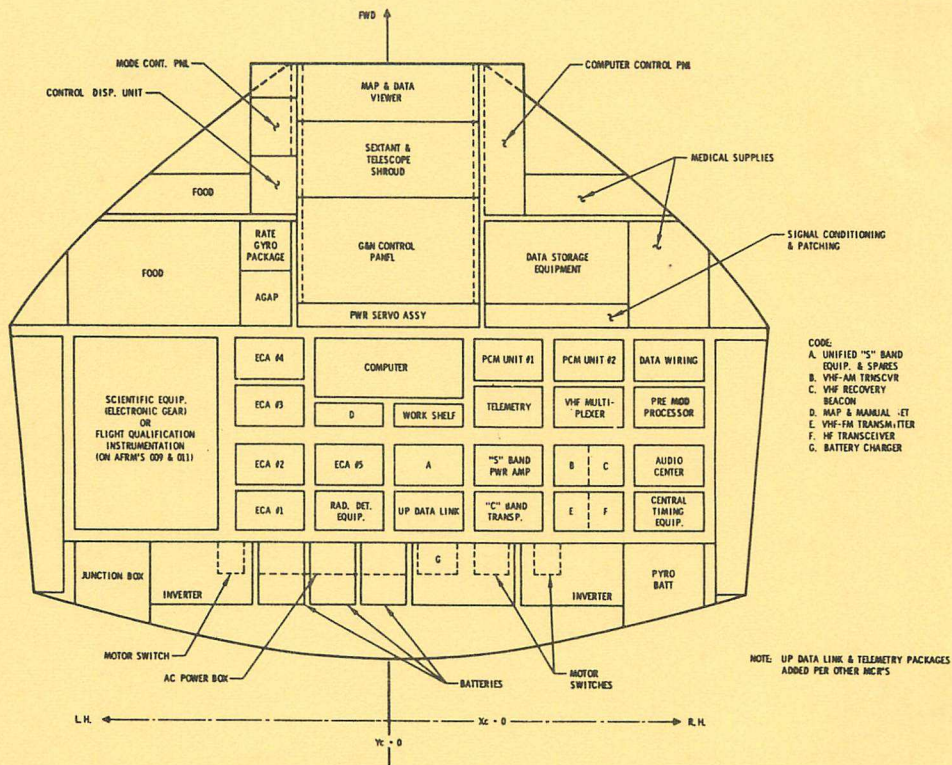


FIGURE 1-4

F-200



EPS COMPONENTS

LOWER EQUIPMENT BAY

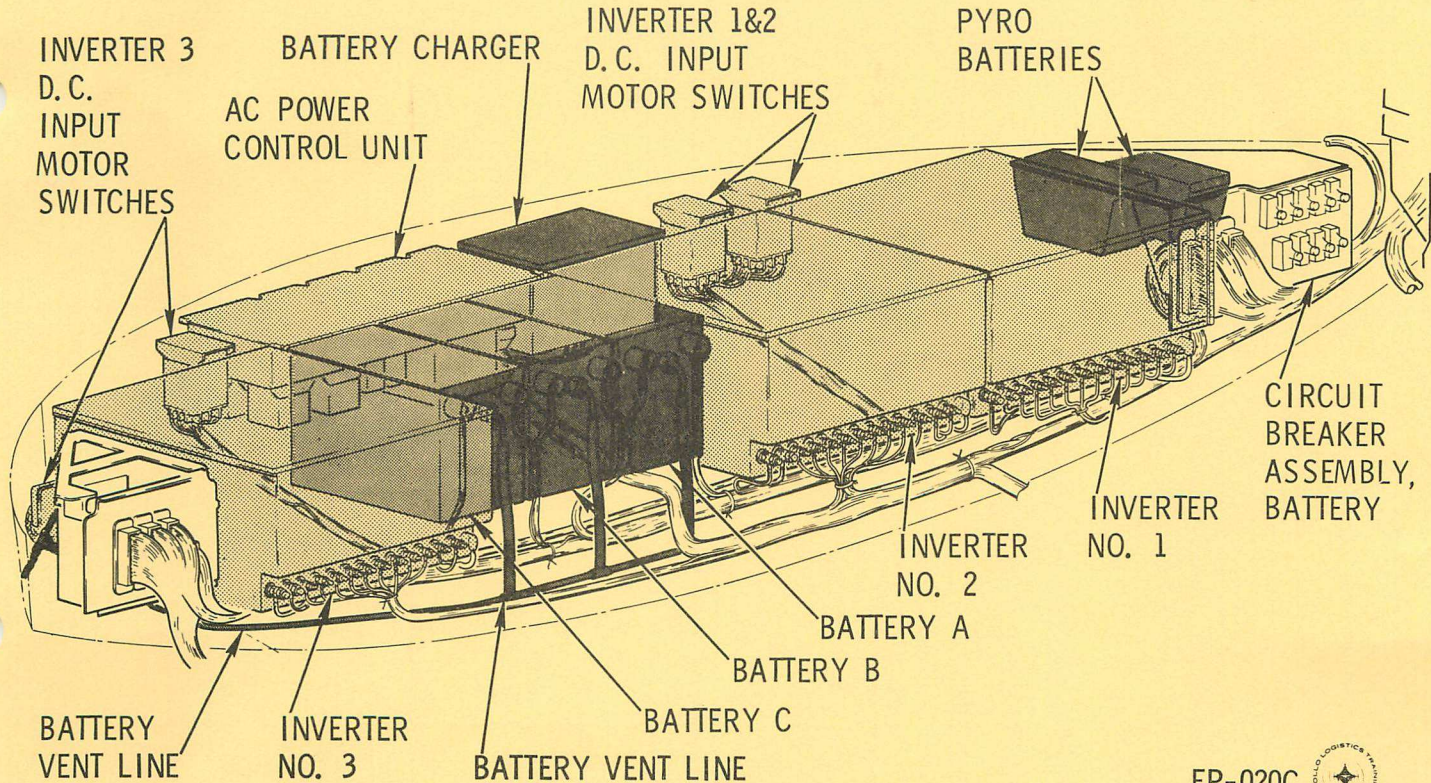


FIGURE 1-5

EP-020C



THE EPS MAY BE DIVIDED INTO THREE BASIC CATEGORIES; POWER GENERATION, POWER DISTRIBUTION AND CONTROLS AND SPECIAL CIRCUITS. THE BASIC CATEGORIES ARE SUB-DIVIDED INTO THE FOLLOWING ELEMENTS.

A. POWER GENERATION

1. DC SYSTEM
 - A. FUEL CELL MODULES (3)
 - B. ENTRY & POST LANDING BATTERIES (A, B, & C)
2. AC SYSTEM
 - A. SOLID STATE INVERTERS (3)

B. POWER DISTRIBUTION & CONTROLS

1. DC DISTRIBUTION
2. AC DISTRIBUTION
3. SENSING & CONTROL CIRCUITS
 - A. F/C CONTROLS
 - (1) OVERLOAD & REVERSE CURRENT SENSING
 - B. DC UNDERVOLTAGE SENSING
 - C. AC CONTROLS
 - (1) AC OVERVOLTAGE & UNDERVOLTAGE SENSING
 - (2) AC OVERLOAD SENSING
 - (3) INVERTER CONTROL CIRCUITS

C. SPECIAL CIRCUITS

1. BATTERY CHARGER (1)
2. PYROTECHNIC BATTERIES (2)
3. S/M JETTISON CONTROL BATTERIES (2)
4. PORTABLE LIFE SUPPORT SYSTEM BATTERIES

1.3 POWER GENERATION

PRIMARY DC POWER, FROM LAUNCH UNTIL C/M-S/M SEPARATION, IS DERIVED FROM THE THREE FUEL CELL MODULES. FOLLOWING C/M-S/M SEPARATION, POWER DURING ENTRY AND POST LANDING IS PROVIDED BY BATTERIES A, B, AND C. AC POWER THROUGHOUT THE MISSION IS PROVIDED BY ONE OR TWO OF THE THREE INVERTERS.

1.3.1 DC SYSTEM

THE THREE FUEL CELL MODULES ARE ACTIVATED PRIOR TO LAUNCH. EACH IS RATED AT 29 ± 2 VDC AND CAN NORMALLY PRODUCE UP TO 1420 WATTS. HYDROGEN AND OXYGEN FROM THE CRYOGENIC STORAGE TANKS ARE THE REACTANTS USED TO PRODUCE POWER. THE PRODUCTS OF THE FUEL CELL MODULES ARE ELECTRICAL POWER, WATER AND HEAT. SOME OF THE HEAT IS USED TO REGULATE MODULE TEMPERATURE AND THE REMAINDER, OR WASTE HEAT, IS RADIATED INTO SPACE THROUGH THE SPACE RADIATORS. SOME OF THE WATER PRODUCED IS SEPARATED AND PUMPED INTO A POTABLE WATER TANK. THE REMAINDER IS RETAINED WITHIN THE FUEL CELL MODULE TO SUSTAIN NORMAL OPERATION.

THE THREE FUEL CELL MODULE OUTPUTS ARE CONNECTED IN PARALLEL TO TWO REDUNDANT DC BUSES. TWO MODULES CAN PROVIDE SUFFICIENT POWER TO FULFILL THE MISSION REQUIREMENTS OF THE SPACECRAFT SYSTEMS. ONE MODULE WILL PRODUCE SUFFICIENT POWER TO ASSURE A SAFE RETURN DURING AN EARLY MISSION TERMINATION FROM ANY POINT.

BATTERIES A, B, AND C SUPPLEMENT THE FUEL CELL MODULES DURING PEAK LOADING PERIODS, AND ARE THE PRIMARY SOURCE OF POWER AFTER C/M-S/M SEPARATION.

THE PYROTECHNIC BATTERIES SUPPLY POWER FOR ACTIVATION OF ALL THE VARIOUS PYROTECHNIC DEVICES.

THE S/M JETTISON CONTROL BATTERIES PROVIDE POWER FOR A FUNCTION PERFORMED DURING C/M-S/M SEPARATION.

1.3.2 AC SYSTEM

SPACECRAFT AC POWER IS PROVIDED THROUGHOUT THE MISSION BY ONE OR TWO OF THE THREE STATIC INVERTERS. THE AC POWERED SYSTEMS COMPRISE APPROXIMATELY 40% OF THE TOTAL SPACECRAFT POWER REQUIREMENT. ONE INVERTER, OPERATING AT 76.5% EFFICIENCY, CAN NORMALLY PROVIDE FOR THE FULL AC LOADS; HOWEVER, DURING CRITICAL PERIODS, SUCH AS LAUNCH, INJECTION OR COURSE CORRECTION MANEUVERS, TWO INVERTERS WILL BE UTILIZED.

EACH INVERTER CAN PRODUCE 115/200 VOLT, 3 ϕ , 400 CYCLE POWER AT A MAXIMUM OUTPUT OF 1250 VOLT AMPS.

VOLTAGE REGULATION, CURRENT LIMITING DURING OVERLOAD, AND AUTOMATIC INVERTER/BUS DISCONNECT IN THE EVENT OF OVER-VOLTAGE OR EXTREME OVERLOAD IS ALSO PROVIDED IN THE INVERTER AND ITS CONTROL CIRCUITS.

1.4 POWER DISTRIBUTION & CONTROLS

DC AND AC DISTRIBUTION TO COMPONENTS IS PROVIDED BY TWO REDUNDANT BUSES IN EACH SYSTEM. SENSING AND CONTROL CIRCUITS ARE PROVIDED FOR PROTECTION AND MONITORING OF THE SYSTEMS.

1.4.1 DC DISTRIBUTION

BASIC DC DISTRIBUTION IS ILLUSTRATED IN FIGURE 1-6, AND IS ACCOMPLISHED WITH A TWO WIRE SYSTEM VIA A SERIES OF INTERCONNECTED BUSES CONSISTING OF;

- A. TWO REDUNDANT MAIN DC BUSES POWERED BY THE THREE FUEL CELL MODULES AND/OR BATTERIES A, B, AND C.
- B. TWO BATTERY BUSES, EACH POWERED BY ITS INDIVIDUAL BATTERY (A & B).
- C. A FLIGHT & POST LANDING BUS POWERED INFLIGHT THROUGH THE MAIN DC BUSES BY THE FUEL CELL MODULES OR BATTERIES, AND AFTER LANDING DIRECTLY BY THE BATTERIES THROUGH VOLTAGE DROPPING DIODES.

DC POWER DISTRIBUTION

SIMPLIFIED SCHEMATIC DIAGRAM

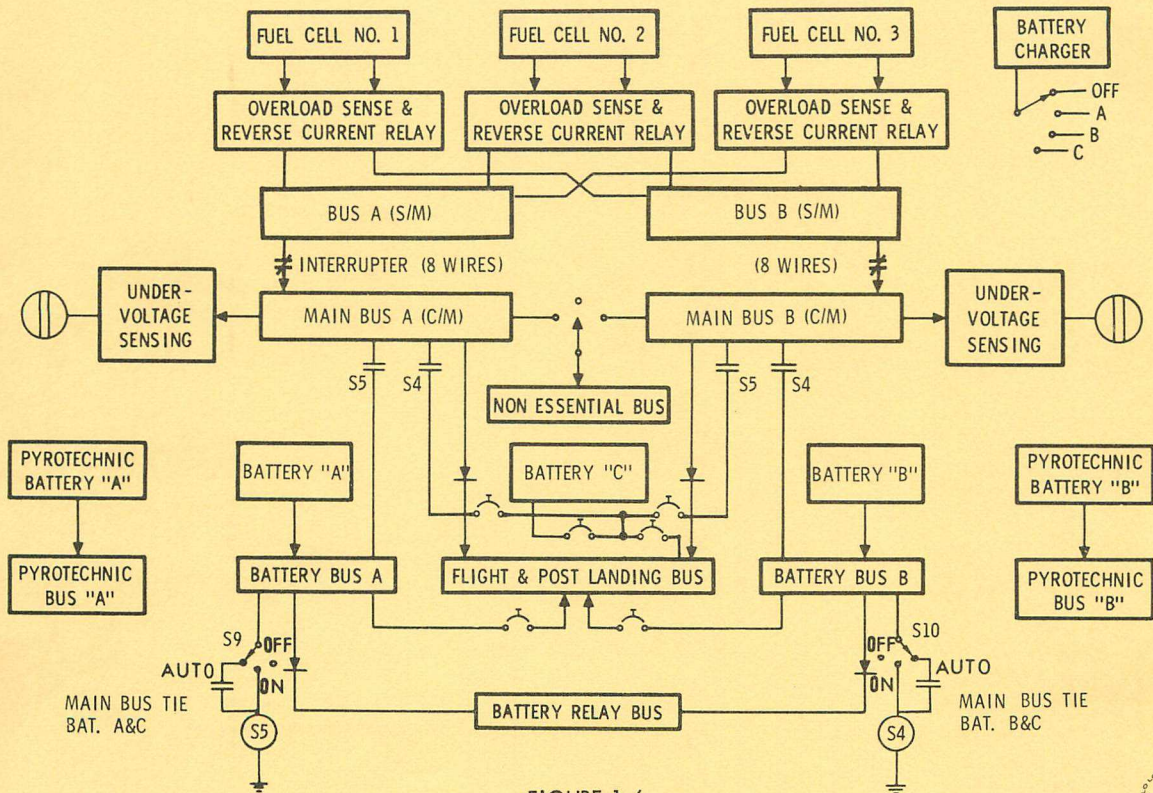


FIGURE 1-6

- D. A NON-ESSENTIAL BUS POWERED THROUGH EITHER MAIN DC BUS A OR B.
- E. A BATTERY RELAY BUS POWERED BY BATTERIES A & B THROUGH THE INDIVIDUAL BATTERY BUSES AND ISOLATION DIODES.
- F. PYRO BUSES POWERED BY THE PYROTECHNIC BATTERIES AND DIVORCED FROM THE MAIN ELECTRICAL POWER SYSTEM.

ALL CRITICAL LOADS ARE CONNECTED DIRECTLY TO BOTH MAIN DC BUSES THROUGH ISOLATION DIODES, OR CAN BE TRANSFERRED FROM ONE BUS TO THE OTHER BY BUS SELECTION SWITCHES.

FAILURES IN THE SYSTEM CAN IN MOST CASES BE COMPENSATED FOR BY REDISTRIBUTION OF THE BUS LOADS. BOTH MAIN DC BUSES UPON DETECTION OF AN UNDERVOLTAGE CONDITION.

1.4.2 AC DISTRIBUTION

BASIC AC DISTRIBUTION IS ILLUSTRATED IN FIGURE 1-7, AND IS ACCOMPLISHED WITH A FOUR WIRE SYSTEM VIA TWO REDUNDANT BUSES (1 & 2). SPACECRAFT AC LOADS MAY BE POWERED BY EITHER BUS AS SELECTED BY THE ASTRO-NAUT.

1.4.3 VEHICLE GROUND POINT

ONLY ONE COMMON GROUNDING POINT IS PROVIDED TO THE SPACECRAFT STRUCTURE. ALL THE NEGATIVE DC

BUSES AND THE AC NEUTRAL BUSES ARE CONNECTED TO THIS POINT. PRIMARY PURPOSE OF THIS BEING TO ELIMINATE GROUND LOOP EFFECTS.

1.4.4 SENSING & CONTROLS

DC SENSING CIRCUITS ARE PROVIDED TO DETECT UNDERVOLTAGE, OVERLOAD AND REVERSE CURRENT CONDITIONS, AND TO ALERT THE ASTRONAUTS. OVERLOAD SENSING CIRCUITS ARE USED TO PROTECT THE FUEL CELL MODULES. REVERSE CURRENT SENSING IS PROVIDED TO REVEAL REVERSE CURRENT FLOW RESULTING FROM A MODULE FAILURE. IN INSTANCES WHEN OVERLOAD OR REVERSE CURRENT OCCURS, DISCONNECT MOTOR SWITCHES ARE AUTOMATICALLY ACTIVATED BY THE SENSING CIRCUITRY. UNDERVOLTAGE AND FUEL CELL/BUS DISCONNECT ARE INDICATED BY ILLUMINATION OF A CAUTION LAMP.

AC SENSING CIRCUITS ARE PROVIDED TO REVEAL INVERTER MALFUNCTIONS AND PROVIDE A WARNING INDICATION. A DISCONNECT MOTOR SWITCH IS AUTOMATICALLY ACTIVATED WHEN AN OVERVOLTAGE OR OVERLOAD OCCURS. CAUTION INDICATORS ARE ILLUMINATED TO REVEAL OVERVOLTAGE AND OVERLOAD, AS WELL AS UNDERVOLTAGE.

SWITCHES, METERS, GAUGES, LIGHTS AND ANNUNCIATORS ARE PROVIDED FOR MONITORING AND CONTROLLING ALL FACETS OF THE EPS.

THE EPS ANNUNCIATORS CONSIST OF FLAG TYPE INDICATORS, AND AVIATION **YELLOW** CAUTION LIGHTS THAT PROVIDE A VISUAL INDICATION OF THE SYSTEM'S STATUS. COMPONENTS OPERATING, CONNECTED OR NOT CONNECTED,

AC POWER DISTRIBUTION

SIMPLIFIED SCHEMATIC DIAGRAM

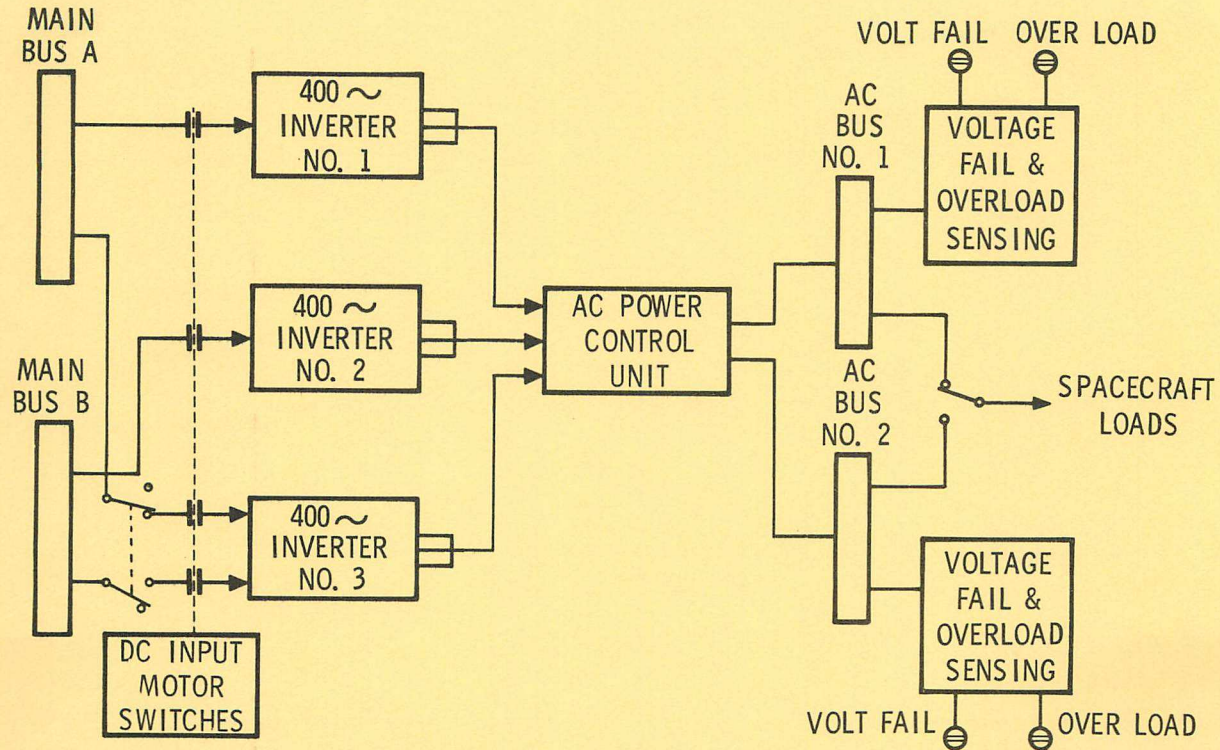


FIGURE 1-7

EP-610



TEMPERATURES, VALVE POSITIONS, EXCESSIVE PRESSURES AND HIGH FLOW RATES, UNDER PRESSURES AND LOW FLOW RATES ARE ALL REPRESENTED BY ELECTRO-MECHANICAL INDICATORS, AND CAUTION LIGHTS IMMEDIATELY IN FRONT OF THE ASTRONAUTS. THE MOST CRITICAL OF THESE ARE MONITORED BY CAUTION LIGHTS ON THE CAUTION & WARNING PANEL. INDICATIONS OF MALFUNCTIONS REQUIRING IMMEDIATE CORRECTIVE ACTION ARE PROVIDED BY RED WARNING LIGHTS ON THE CAUTION & WARNING PANEL.

THE EPS CONTROLS AVAILABLE TO THE ASTRONAUT IN THE NO. 3 SEAT, WHO IS THE SYSTEM MANAGER, INCLUDE THE POWER GENERATION FOR BOTH DC AND AC, FUEL CELL REACTANTS, FUEL CELL PURGING, AND BUS SELECTION. ALL CONTROLS ARE THROUGH ELECTRICAL SWITCHES (ROTARY OR TOGGLE) THAT OPERATE MOTOR SWITCHES, VALVES, OR SIMPLY CLOSE CIRCUITS.

DC & AC BUS VOLTAGES, DC CURRENT, AC FREQUENCIES, COMPONENT TEMPERATURES, REACTANT FLOW, AND PRESSURES ARE DISPLAYED ON METERS OR GAUGES UPON SELECTION.

1.5 SPECIAL CIRCUITS

SEVERAL COMPONENTS HAVE BEEN ADDED TO THE SPACECRAFT TO ENHANCE MISSION COMPLETION.

1.5.1 BATTERY CHARGER

A BATTERY CHARGER PROVIDES THE CAPABILITY OF RECHARGING BATTERIES A, B & C TO MAINTAIN THEM AT PEAK POWER LEVELS AT ALL TIMES.

1.5.2 PYROTECHNIC BATTERIES

THE PYROTECHNIC BATTERIES POWER REDUNDANT PYROTECHNIC BUSES AND SYSTEMS. THIS POWER IS USED TO POWER PYROTECHNIC CIRCUITS, DETONATE ORDNANCE DEVICES AND ACTIVATE SQUIB INITIATORS IN THE LAUNCH ESCAPE, EARTH LANDING AND PROPELLANT STORAGE SYSTEMS.

1.5.3 S/M JETTISON CONTROL BATTERIES

IN BLOCK 1 SPACECRAFT, THESE BATTERIES, LOCATED IN THE S/M, PROVIDE POWER TO A SEQUENCER AND THE S/M REACTION CONTROL SYSTEM AFTER C/M-S/M SEPARATION TO ASSURE POSITIVE DISPLACEMENT OF THE TWO SECTIONS.

1.5.4 PORTABLE LIFE SUPPORT SYSTEM BATTERIES

THE PLSS BATTERIES PROVIDE POWER FOR OPERATION OF THE VARIOUS COMPONENTS IN THE PORTABLE LIFE SUPPORT SYSTEM.

CRYOGENIC STORAGE SYSTEM

2.1 DESCRIPTION

THE CRYOGENIC STORAGE SYSTEM PROVIDES A MEANS OF STORING AND SUPPLYING REACTANTS TO THE SPACECRAFT SYSTEMS. HYDROGEN IS SUPPLIED TO THE EPS, WHILE OXYGEN IS SUPPLIED TO THE ENVIRONMENTAL CONTROL SYSTEM AS WELL AS THE EPS. THE REACTANTS ARE STORED CRYOGENICALLY IN FOUR DEWAR VESSELS LOCATED IN SECTOR IV OF THE S/M. TWO OF THE PRESSURIZED VESSELS CONTAIN OXYGEN, AND THE OTHER TWO CONTAIN HYDROGEN.

2.2 OXYGEN SYSTEM

THE OXYGEN SYSTEM IS SCHEMATICALLY DEPICTED IN FIGURE 2-1. O_2 IS STORED IN TWO INCONEL DEWAR VESSELS. EACH TANK CONTAINS 320 POUNDS OF OXYGEN PRESSURIZED TO 900 ± 35 PSIA. FLOW FROM THE TANKS INTO THE SYSTEM IS GOVERNED BY TANK PRESSURE, AND TANK ISOLATION IS PROVIDED BY CHECK VALVES. PRESSURE IN THE SYSTEM IS MAINTAINED BY TWO PARALLEL HEATERS IN EACH TANK. HEATERS IN EACH TANK DRAW 155 WATTS WHEN ACTIVATED. UNIFORM DENSITY IN EACH TANK IS MAINTAINED BY TWO PARALLEL AC CIRCULATING FANS, WHICH CIRCULATE THE GAS OVER THE HEATING ELEMENTS TO PROVIDE EVEN DISTRIBUTION OF HEAT. POWER TO THE HEATERS AND FANS CAN BE AUTOMATICALLY, OR MANUALLY CONTROLLED. AUTOMATIC PRESSURE CONTROL IS

ACCOMPLISHED BY A PAIR OF PRESSURE SENSITIVE SWITCHES CONNECTED IN SERIES. THE PRESSURE SWITCHES OPERATE MOTOR SWITCHES WHICH CLOSE CONTACTS TO CONNECT OR DISCONNECT POWER TO THE TWO DC HEATING ELEMENTS AND THE TWO AC FANS IN EACH PAIR OF TANKS (O_2 1 & 2 AND H_2 1 & 2). THIS CIRCUIT WILL APPLY POWER TO THE HEATERS AND FANS, OR DISCONNECT POWER, AS A FUNCTION OF TANK PRESSURE AND TEMPERATURE. AS A SAFETY FEATURE, TWO TEMPERATURE SENSITIVE INTERLOCK DEVICES ARE PLACED IN SERIES WITH EACH TANK'S HEATERS. THESE DEVICES TOTALLY DEACTIVATE THE HEATING CIRCUITS WHEN TEMPERATURE OF THE INNER SHELL REACHES 80 DEG. F., AND PLACES THE CIRCUITS BACK INTO OPERATION AT A TEMPERATURE OF 70 DEG. F. PRESSURE TRANSDUCERS PROVIDE A MEANS OF MONITORING TANK PRESSURES. THEY PRODUCE AN ANALOG SIGNAL REPRESENTATIVE OF TANK PRESSURE, WHICH POSITIONS THE PRESSURE GAUGES IN THE C/M, AND WHICH IS ALSO APPLIED AS AN INPUT TO THE CAUTION & WARNING SYSTEM FOR NOTIFICATION OF UNDER OR OVER PRESSURE.

OXYGEN QUANTITY IS SENSED BY A CAPACITIVE PROBE INSERTED INTO EACH STORAGE VESSEL. CAPACITANCE OF THE PROBE IS A FUNCTION OF GAS DENSITY, WHICH ACTS AS THE DIELECTRIC. OUTPUT OF THE PROBE IS AN ELECTRICAL ANALOG SIGNAL REPRESENTING QUANTITY, AND AFTER CONDITIONING, USED TO POSITION THE QUANTITY INDICATORS IN THE C/M. PROPER DISTRIBUTION OF HEAT IS REQUIRED

OXYGEN STORAGE SYSTEM

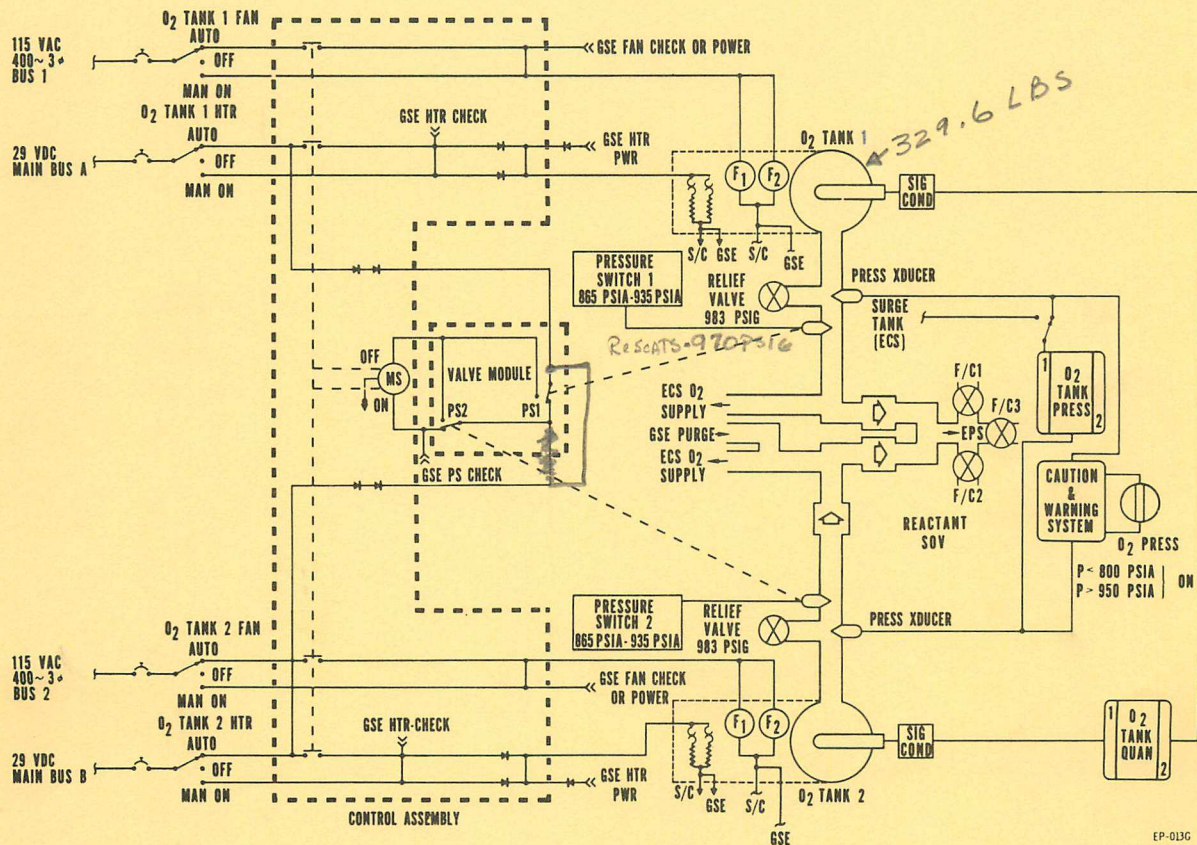


FIGURE 2-1

TO MAINTAIN EQUAL DENSITY, THUS PROVIDING AN ACCURATE READOUT OF QUANTITY.

EACH TANK SYSTEM CONTAINS A PROTECTIVE RELIEF VALVE WHICH WILL START VENTING WHEN THE PRESSURE IN THAT SYSTEM REACHES 983 PSIG. THE VALVE WILL RESEAT WHEN PRESSURE DECREASES TO 970 PSIG. THE OUTER SHELL OF EACH VESSEL HAS A BURST DISC, DESIGNED TO BURST AT A PRESSURE 30% BELOW THE STRUCTURAL LIMIT OF THE TANK.

2.2.1 SYSTEM OPERATION

AFTER GSE ACTIVATION AND FUEL CELL TRANSITION TO SPACECRAFT GASES, SYSTEM OPERATION COMMENCES WITH THE TANKS PRESSURIZED TO THE NOMINAL 900 PSIA, AND THE HEATER AND FAN SWITCHES POSITIONED TO "AUTO". THE ONE WAY CHECK VALVES ALLOW FOR GSE PURGE AND ACTIVATION OF THE FUEL CELLS AND THE ECS PRIOR TO CRYOGENIC SYSTEM OPERATION. AS OXYGEN IS CONSUMED, THE PRESSURE WITHIN THE TANKS DECREASES. WHEN PRESSURE IN BOTH TANKS DECREASES TO 865 PSIA, PRESSURE SWITCHES 1 & 2 CLOSE AND APPLY POWER TO OPERATE THE MOTOR SWITCH, WHICH CLOSSES CONTACTS TO PROVIDE POWER TO THE HEATERS AND FANS IN THE STORAGE VESSELS. SINCE THE PRESSURE SWITCHES ARE ELECTRICALLY IN SERIES, THE PRESSURE IN BOTH TANKS MUST DECREASE TO 865 PSIA BEFORE POWER IS APPLIED TO THE HEATERS AND FANS. HEATER AND FAN POWER WILL REMAIN ON UNTIL ONE OF THE TANKS REACHES 935 PSIA, AT WHICH TIME ONE OF THE PRESSURE SWITCHES WILL OPEN TO REMOVE POWER FROM THE HEATER AND FAN CIRCUITS IN BOTH TANKS.

THE "ON" POSITION OF THE HEATER AND FAN SWITCHES PROVIDES A MEANS FOR MANUAL OPERATION OF THE CIRCUITS. THIS POSITION BY-PASSES THE PRESSURE SWITCHES, AND WOULD BE USED IN CASE OF A MALFUNCTION IN THE PRESSURE SWITCHES, IN ONE OF THE TWO HEATING ELEMENTS IN EACH TANK, OR IN ONE OF THE TWO FANS IN EACH TANK.

THE TWO PRESSURE TRANSDUCERS PROVIDE THE TANK PRESSURE GAUGES AND THE CAUTION & WARNING SYSTEM WITH A DC ANALOG SIGNAL REPRESENTING TANK PRESSURE. THE TANK PRESSURE GAUGE IS A DUAL SCALE VERTICAL INDICATOR. TANK 1 PRESSURE OR SURGE TANK PRESSURE CAN BE APPLIED TO ONE OF THE SCALES BY SELECTION WITH A SWITCH. TANK 2 PRESSURE ONLY IS APPLIED TO THE OTHER SCALE. IF THE PRESSURE IN EITHER TANK DECREASES BELOW 800 PSIA OR EXCEEDS 950 PSIA, A LAMP IN THE CAUTION & WARNING SYSTEM WILL ILLUMINATE, NOTIFYING THE ASTRONAUTS OF AN ABNORMAL CONDITION.

THE TANK QUANTITY SENSING CIRCUIT AND GAUGES PROVIDE A MEANS OF MONITORING THE AMOUNT OF OXYGEN REMAINING. THE QUANTITY INDICATOR IS A DUAL SCALE VERTICAL READING INSTRUMENT WITH A SCALE FOR EACH TANK READING IN POUNDS OF REACTANT REMAINING.

TANK QUANTITIES MUST BE MAINTAINED WITHIN 15 POUNDS OF EACH OTHER TO PROVIDE A SAFE RETURN CAPABILITY NECESSITATED BY AN ABORT DUE TO THE LOSS OF ONE TANK. OPERATING THE SYSTEM IN "AUTO" SHOULD MAINTAIN THIS TOLERANCE WITHOUT ANY MANUAL MANIPULATION OF SWITCHES.

MAINTAINING THIS TOLERANCE WILL PROVIDE SUFFICIENT OXYGEN FOR A SAFE RETURN FROM A LUNAR ORBIT ABORT. OPERATION ON A SINGLE TANK WILL EVENTUALLY RAISE OXYGEN TANK TEMPERATURE CONSIDERABLY AND PRESSURE WILL BE ALLOWED TO DEplete TO A MINIMUM OF 150 PSIA. THIS IS THE MINIMUM PRESSURE REQUIREMENT FOR PROPER ECS AND EPS SYSTEM OPERATION.

2.3 HYDROGEN SYSTEM

THE HYDROGEN SYSTEM IS ILLUSTRATED IN FIGURE 2-2 AND FUNCTIONS IN THE SAME MANNER AS THE OXYGEN SYSTEM WITH THE FOLLOWING EXCEPTIONS.

THE SYSTEM IS PRESSURIZED TO 245 ± 15 PSIA. THE TWO HYDROGEN TANKS CONTAIN 28 POUNDS EACH AND ARE CONSTRUCTED OF TITANIUM. THE CAUTION & WARNING SYSTEM WILL PROVIDE AN INDICATION WHEN PRESSURE DECREASES BELOW 220 PSIA OR EXCEEDS 270 PSIA. THE TANK SYSTEM RELIEF VALVES WILL VENT AT 273 PSIG AND WILL RESEAT AT 268 PSIG.

HYDROGEN TANK QUANTITIES MUST BE MAINTAINED WITHIN ONE POUND OF EACH OTHER TO PROVIDE THE SINGLE TANK SAFE RETURN CAPABILITY. UNDER SINGLE TANK OPERATION, HYDROGEN TEMPERATURE WILL ALSO INCREASE CONSIDERABLY, AND TANK PRESSURE WILL BE ALLOWED TO DEplete TO A MINIMUM OF 100 PSIA.

2.3.1 SYSTEM OPERATION

THE SYSTEM FUNCTIONS IN THE SAME MANNER AS THE OXYGEN SYSTEM, HOWEVER, CYCLING BETWEEN THE NORMAL

HYDROGEN OPERATING PRESSURES OF 230 AND 260 PSIA.

2.4 CRYOGENIC MEASUREMENTS & TELEMETRY

FIGURE 2-3 ILLUSTRATES THE MEASUREMENTS AND MEASUREMENT POINTS IN THE SPACECRAFT CRYOGENIC STORAGE SYSTEM. THE UNDERLINED ITEMS INDICATE THE INFORMATION WHICH IS TELEMETERED TO THE MANNED SPACE FLIGHT NETWORK (MSFN).

TELEMETERED INFORMATION CONSISTS OF GAS TEMPERATURE, TANK QUANTITY AND SYSTEM PRESSURE IN EACH OF THE FOUR TANK SYSTEMS. PULSE CODE MODULATION IS USED FOR TELEMETERING THIS INFORMATION.

2.5 CRYOGENIC SYSTEM & FUEL CELL ACTIVATION

FIGURE 2-4 ILLUSTRATES THE INTERFACE OF THE CRYOGENIC STORAGE SYSTEM WITH THE EPS, ECS AND GSE, AND WILL BE USED TO DESCRIBE INITIAL SYSTEM ACTIVATION.

THE CRYOGENIC SYSTEM TANKS AND LINES, AND THE FUEL CELL MODULES AND LINES ARE INITIALLY PURGED WITH INERT GAS. ALL SYSTEMS EXCEPT THE CRYOGENIC HYDROGEN TANKS AND LINES ARE PURGED WITH NITROGEN GAS. THE CRYOGENIC HYDROGEN SYSTEM IS PURGED WITH HELIUM. AFTER PURGING, WHILE IN AN INACTIVE STATUS, A BLANKET OF THE RESPECTIVE INERT GAS AT A SPECIFIC PRESSURE IS LEFT IN THE SYSTEMS.

CRYOGENIC SYSTEM AND FUEL CELL MODULE ACTIVATION BY GROUND SUPPORT EQUIPMENT (GSE) COMMENCES AT APPROXIMATELY THE SAME TIME. A VACUUM PURGE IS

HYDROGEN STORAGE SYSTEM

Norm op. Pr =
230-260 PSIG

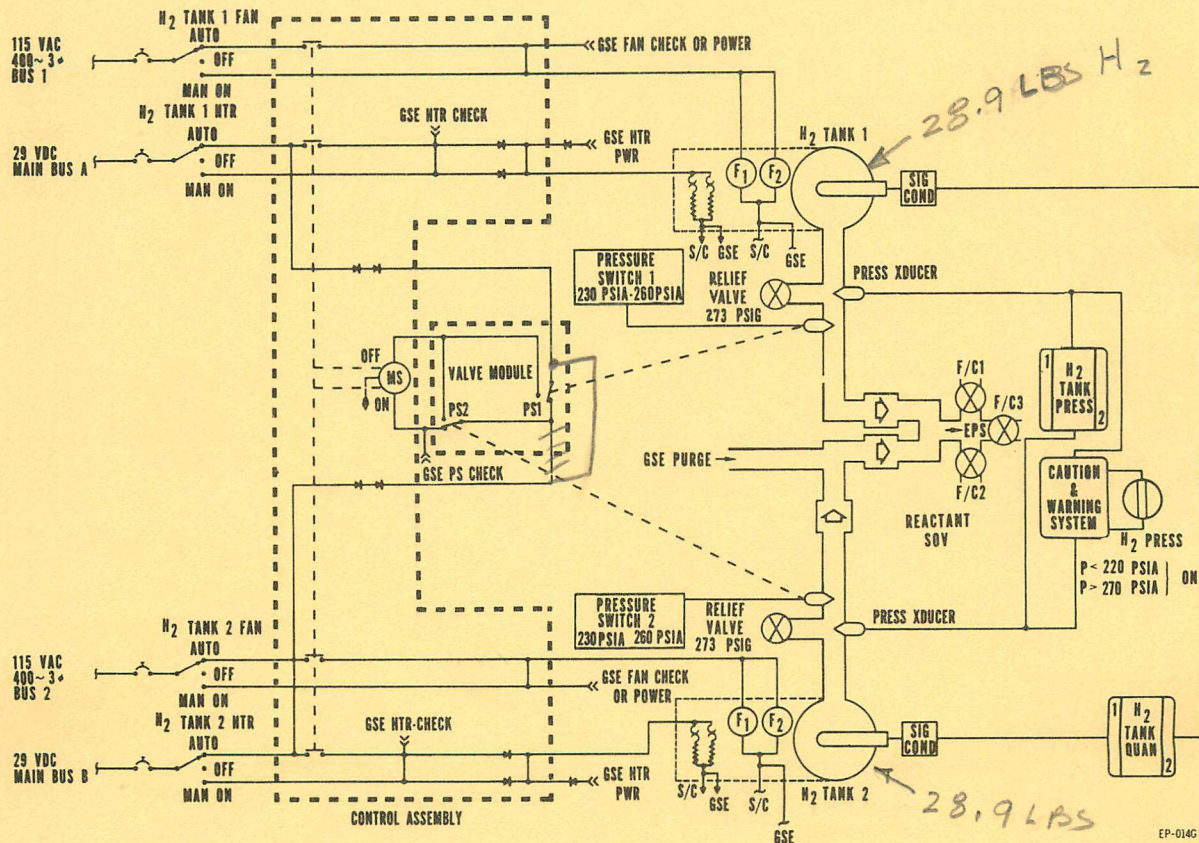


FIGURE 2-2

EP-014G

CRYOGENIC STORAGE SYSTEM TELEMETRY (AFRM-011)

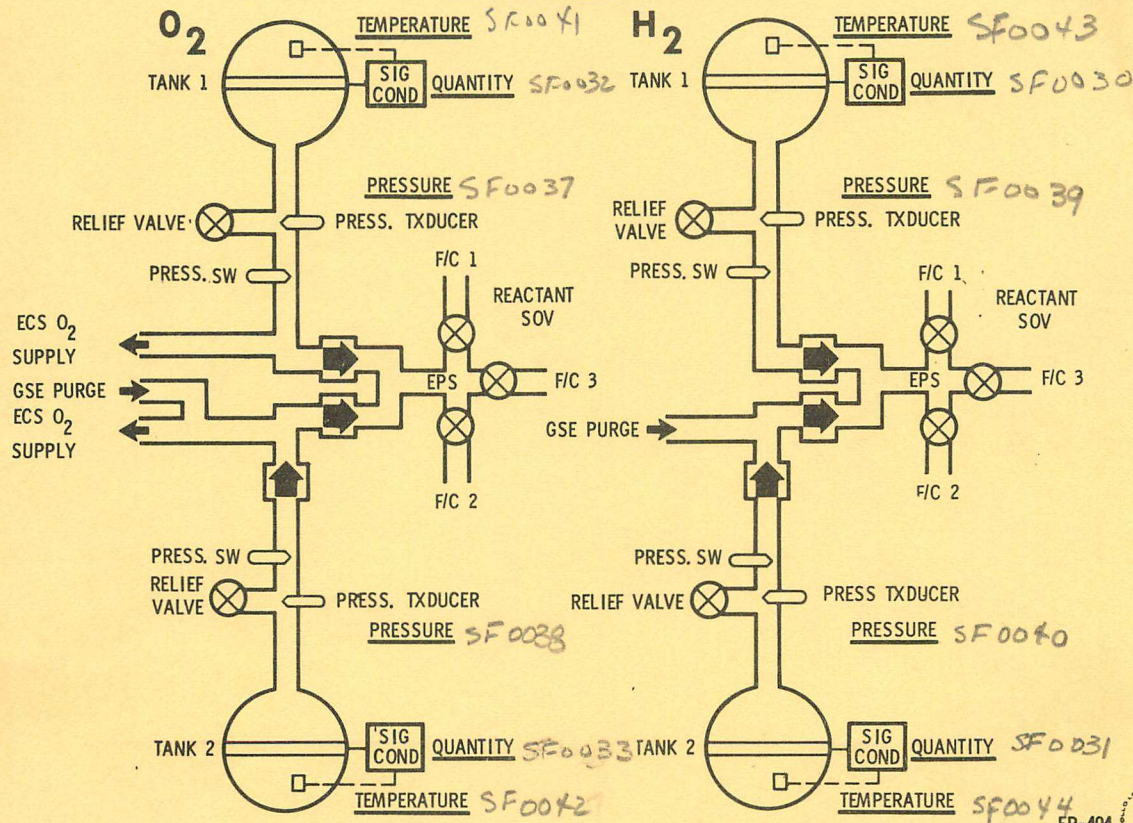


FIGURE 2-3

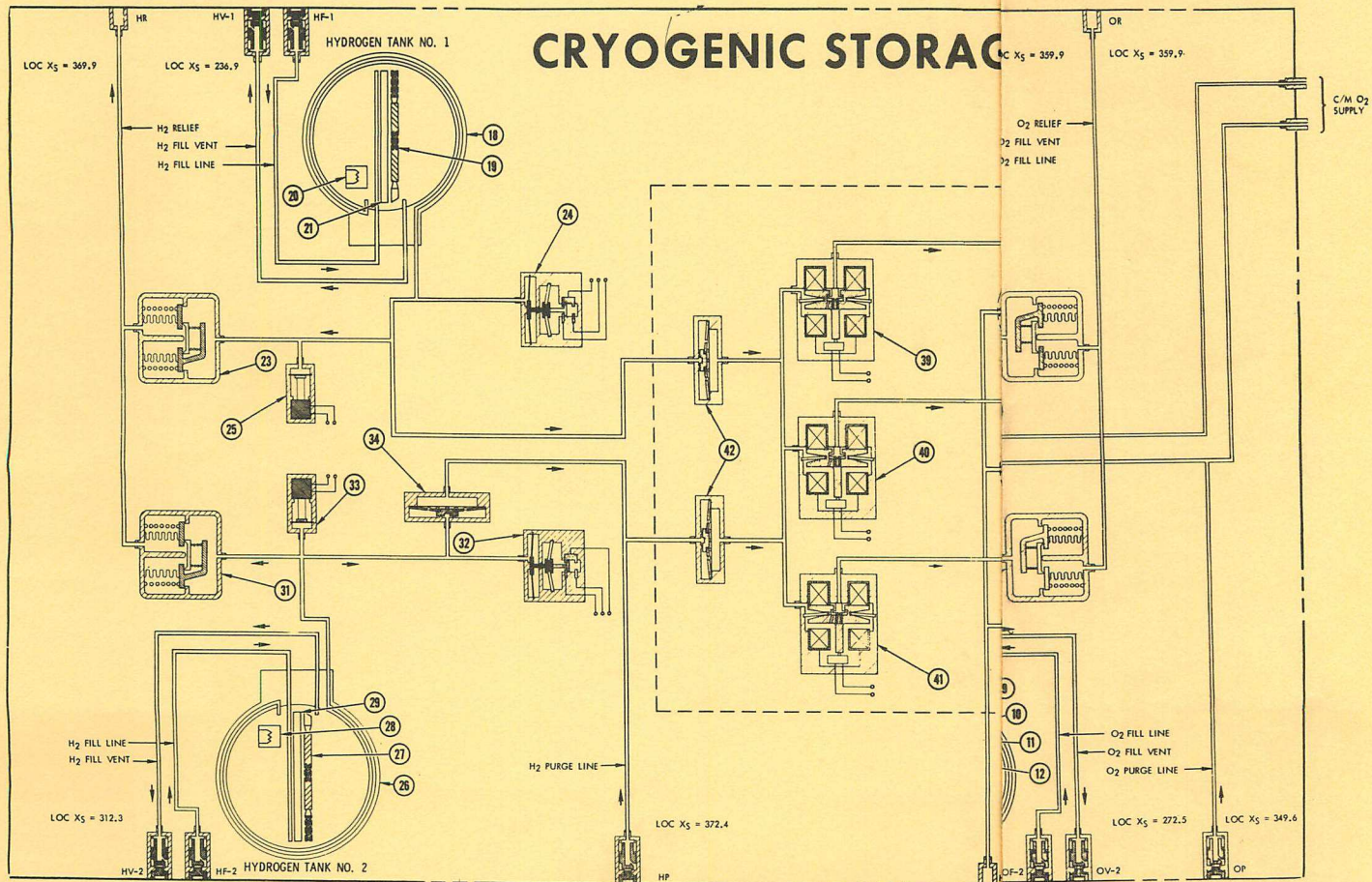


FIGURE 2-4



2

<u>ITEM NO.</u>	<u>DESCRIPTION</u>
1	O ₂ TANK 1
2	HEATER ELEMENT & FAN MOTORS
3	TEMPERATURE SENSOR PROBE
4	DENSITY SENSOR PROBE
5	(DELETED)
6 O	O ₂ TANK 1 PRESSURE RELIEF VALVE
7 X	O ₂ TANK 1 PRESSURE SWITCH
8 Y	O ₂ TANK 1 PRESSURE TRANSDUCER
9 G	O ₂ TANK 2
10 E	HEATER ELEMENT AND FAN MOTORS
11 N	TEMPERATURE SENSOR PROBE
12	DENSITY SENSOR PROBE
13	(DELETED)
14	O ₂ TANK 2 PRESSURE RELIEF VALVE
15	O ₂ TANK 2 PRESSURE SWITCH
16	O ₂ TANK 2 PRESSURE TRANSDUCER
17	O ₂ TANK 2 CHECK VALVE
18	H ₂ TANK 1
19	HEATER ELEMENT & FAN MOTORS
20 H	TEMPERATURE SENSOR PROBE
21 Y	DENSITY SENSOR PROBE
22 D	(DELETED)
23 R	H ₂ TANK 1 PRESSURE RELIEF VALVE
24 O	H ₂ TANK 1 PRESSURE SWITCH
25 G	H ₂ TANK 1 PRESSURE TRANSDUCER
26 E	H ₂ TANK 2
27 N	HEATER ELEMENT & FAN MOTORS
28	TEMPERATURE SENSOR PROBE
29	DENSITY SENSOR PROBE
30	(DELETED)

<u>ITEM NO.</u>	<u>DESCRIPTION</u>
31	H ₂ TANK 2 PRESSURE RELIEF VALVE
32	H ₂ TANK 2 PRESSURE SWITCH
33	H ₂ TANK 2 PRESSURE TRANSDUCER
34	H ₂ TANK 2 CHECK VALVE
35	FUEL CELL 0 ₂ CHECK VALVE (2)
36	FUEL CELL #1 0 ₂ SHUT OFF VALVE
37	FUEL CELL #2 0 ₂ SHUT OFF VALVE
38 F	FUEL CELL #3 0 ₂ SHUT OFF VALVE
39 /	FUEL CELL #1 H ₂ SHUT OFF VALVE
40 C	FUEL CELL #2 H ₂ SHUT OFF VALVE
41	FUEL CELL #3 H ₂ SHUT OFF VALVE
42	FUEL CELL H ₂ CHECK VALVE

DISCONNECT

OR	OXYGEN RELIEF
OV-1	OXYGEN VENT, TANK 1
OF-1	OXYGEN FILL, TANK 1
OP	OXYGEN PURGE
OV-2	OXYGEN VENT, TANK 2
OF-2	OXYGEN FILL, TANK 2
OV-EPS	OXYGEN VENT, FUEL CELLS
HR	HYDROGEN RELIEF
HV-1	HYDROGEN VENT, TANK 1
HF-1	HYDROGEN FILL, TANK 1
HV-2	HYDROGEN VENT, TANK 2
HF-2	HYDROGEN FILL, TANK 2
HP	HYDROGEN PURGE
HV-EPS	HYDROGEN VENT, FUEL CELLS

DISCONNECT KEY
DESCRIPTION

INITIALLY CONDUCTED TO DRAW OUT THE INERT GAS AND ANY OTHER CONTAMINANTS WITHIN THE SYSTEMS. FOLLOWING THIS, THE SYSTEMS ARE PURGED AGAIN WITH THEIR RESPECTIVE GASES AND ALSO PRESSURE TESTED.

OXYGEN AND HYDROGEN FILL IS CONDUCTED INDIVIDUALLY TO ELIMINATE ANY HAZARDOUS CONDITIONS. SINCE THE FILL PROCEDURES DIFFER, EACH WILL BE DISCUSSED SEPARATELY, COVERING OXYGEN FILL FIRST.

GSE PROVIDES SUB-COOLED LO_2 (BELOW -297°F) FROM THE S14-065 STORAGE UNIT, THROUGH THE S14-032 TRANSFER UNIT AND THE FLUID DISTRIBUTION SYSTEM (FDS), DIRECTLY INTO THE SPACECRAFT STORAGE TANKS THROUGH OF-1 AND OF-2 AS SHOWN IN FIGURE 2-4. VENTING OF BOIL OFF IS THROUGH OV-1 AND OV-2. FILL AND COOL-DOWN IS CONDUCTED UNTIL LINE AND TANK TEMPERATURES ALLOW LIQUID FLOW INTO THE TANKS. PROCUREMENT SPECIFICATION MC 901-0005, STORAGE SYSTEM CRYOGENIC, SPECIFIES A MAXIMUM OF 1-1/2 HOURS FOR THIS OPERATION.

THE TANKS ARE PARTIALLY FILLED AND ALLOWED TO VENT FOR APPROXIMATELY 24 HOURS TO ATTAIN TEMPERATURE EQUILIBRIUM IN THE INSULATION. AFTER ATTAINING EQUILIBRIUM, THE TANKS ARE TOPPED OFF TO MAXIMUM CAPACITY AND THE VENTS ARE CLOSED WHILE AWAITING COMPLETION OF FUEL CELL START-UP. THE FLUID IN THE TANKS IS AT APPROXIMATELY 14.7 PSIA AND -297°F .

WHILE THE OXYGEN SYSTEM IS BEING ACTIVATED, GSE SUPPLIES OXYGEN GAS TO THE FUEL CELLS THROUGH THE

OP VALVE AND THE LOWER #35 CHECK VALVE AT A PRESSURE HIGHER THAN THAT IN THE STORAGE TANKS. THIS PROVIDES A BACK PRESSURE ON CHECK VALVES 17 AND UPPER 35, THUS ISOLATING THE STORAGE TANKS FROM THE FUEL CELL SYSTEM.

HYDROGEN FILL IS ACCOMPLISHED BY USE OF THE S14-066 STORAGE UNIT, S14-026 TRANSFER UNIT, AND THE APPROPRIATE FDS. GSE PROVIDES SUB-COOLED LH_2 TO A SUB-COOLER ON THE GANTRY. THIS ADDITIONAL SUB-COOLER IS REQUIRED BECAUSE OF THE LOW LH_2 TEMPERATURES (-423°F AT 14.7 PSIA). ALTHOUGH GSE INITIALLY PROVIDES SUB-COOLED LH_2 , HEAT LEAK IN THE FDS LINES INCREASES FLUID TEMPERATURE ABOVE THAT REQUIRED TO PROVIDE LH_2 INTO THE SPACECRAFT TANKS. THE SUB-COOLER, VENTING TO A 6 PSIA PRESSURE POINT, ALLOWS A MORE RAPID BOIL OFF, THUS DECREASING FLUID TEMPERATURES DUE TO THE RAPID EXPANSION AND VENTING OF THE HYDROGEN. FLOW OF LH_2 INTO THE SPACECRAFT TANKS IS FROM THE SUB-COOLER THROUGH THE HF-1 AND HF-2 VALVES, WITH TANK VENTING THROUGH HV-1 AND HV-2.

SPACECRAFT HYDROGEN FILL AND COOL-DOWN IS CONDUCTED IN THE SAME MANNER AS IN THE OXYGEN SYSTEM. TOP OFF WOULD BE PERFORMED AFTER ATTAINING TEMPERATURE EQUILIBRIUM AND THE SYSTEM WOULD BE CLOSED AT APPROXIMATELY 14.7 PSIA AND -423°F WHILE AWAITING COMPLETION OF FUEL CELL START UP.

AFTER THE OXYGEN AND HYDROGEN SYSTEMS ARE CLOSED OFF, HEAT LEAK INTO THE TANKS WILL TEND TO SLIGHTLY INCREASE FLUID TEMPERATURE AND BUILD UP

PRESSURE IN THE TANKS. HOWEVER, SINCE THERE IS NO SPACE FOR EXPANSION, MOST OF THE HEAT APPLIED DUE TO HEAT LEAK WILL BE CONVERTED TO PRESSURE, THUS THE DENSITY REMAINS RELATIVELY CONSTANT. TANK INSULATION IS SO EFFICIENT THAT IT WILL REQUIRE APPROXIMATELY 30 HOURS FOR HEAT LEAK TO INCREASE PRESSURES TO THE MINIMUM OPERATING LEVEL (865-O₂ AND 230-H₂). IT WILL REQUIRE MORE THAN ONE ADDITIONAL HOUR BEFORE PRESSURES BUILD UP TO THE MINIMUM RELIEF VALVE CRACKING PRESSURE (998-O₂ AND 288-H₂) AND SPACECRAFT GASES BEGIN VENTING OVERBOARD. THIS ALLOWS APPROXIMATELY A 24 HOUR HOLD FROM LAUNCH TIME, SINCE THE SYSTEMS ARE INITIALLY CLOSED OFF APPROXIMATELY 7 HOURS BEFORE LAUNCH. THIS IS ASSUMING THAT A HOLD CONDITION OCCURS PRIOR TO ENERGIZING CRYOGENIC HEATERS FOR PRESSURE BUILD UP AT APPROXIMATELY 5-1/2 HOURS BEFORE LAUNCH.

ACTIVATION OF THE FUEL CELL MODULES AND CRYOGENIC SYSTEMS IS TIMED SO THAT TRANSITION TO SPACECRAFT GASES OCCURS APPROXIMATELY 7 HOURS BEFORE LAUNCH.

AT TIME OF TRANSITION TO SPACECRAFT GASES, THE OXYGEN & HYDROGEN TANKS ARE AT NORMAL OPERATING PRESSURES, WITH OXYGEN TEMPERATURE AT APPROXIMATELY -284°F AND HYDROGEN AT -417°F.

IF AN EXTENDED DELAY IN LAUNCH IS EXPERIENCED, FUEL CELL SHUTDOWN AND CRYOGENIC SYSTEM DETANKING REQUIRES APPROXIMATELY 30 HOURS. NINE HOURS ARE REQUIRED

FOR FUEL CELL MODULE DRY OUT WHICH IS ACCOMPLISHED BY PURGING WITH HYDROGEN GAS. AN ADDITIONAL 19 HOURS ARE REQUIRED TO BRING FUEL CELL MODULE TEMPERATURES TO +125°F TO COMPLETELY SOLIDIFY THE ELECTROLYTE. THE REMAINING TWO HOURS ARE REQUIRED FOR VACUUM PURGE AND PROVIDING AN 18 PSIA N₂ BLANKET PRESSURE WHICH IS RETAINED WHILE THE SYSTEM IS IN AN INACTIVE STATUS.

CRYOGENIC SYSTEM DETANKING, PURGING, AND PROVIDING AN 18 PSIA BLANKET PRESSURE WITH N₂ REQUIRES ABOUT TWO HOURS AND IS CONDUCTED SIMULTANEOUSLY WITH FUEL CELL COOL-DOWN.

2.6 CRYOGENIC TEMPERATURES

AS REACTANTS ARE CONSUMED DURING THE MISSION, PRESSURE WITHIN THE STORAGE VESSELS WILL DECREASE. ADDITIONAL HEAT IS APPLIED TO MAINTAIN PRESSURES WITHIN THE DESIRED RANGE. FIGURE 2-5 ILLUSTRATES THE TEMPERATURE INCREASE OF THE REACTANTS WITH RESPECT TO MISSION TIME. THE UPPER CURVE REPRESENTS THE OXYGEN AND THE LOWER THE HYDROGEN TEMPERATURE INCREASE. SINCE BOTH SYSTEMS FUNCTION ABOVE THEIR CRITICAL PRESSURE LEVEL, LIQUIFICATION CANNOT TAKE PLACE REGARDLESS OF FLUID TEMPERATURE.

CRYOGENIC STORAGE SUBSYSTEM

TEMPERATURE/NORMAL MISSION PROFILE

Based on
1900 WATTS

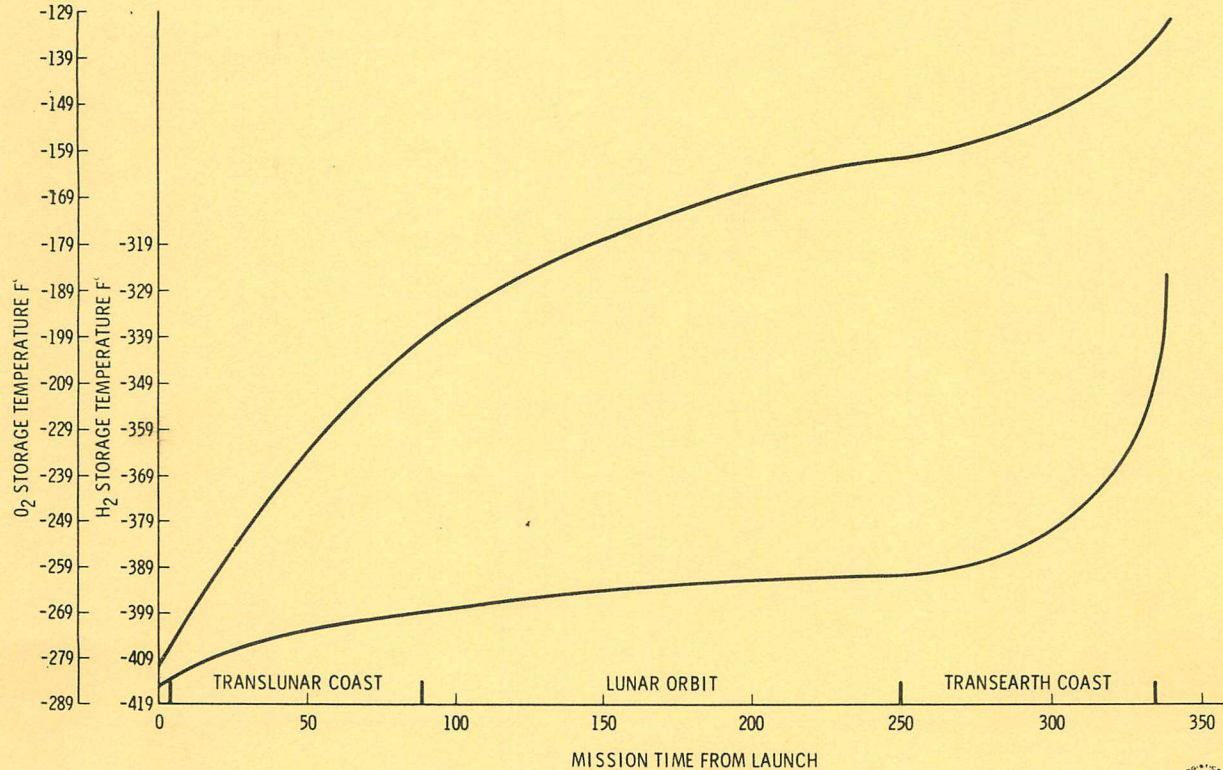


FIGURE 2-5

EP-019

SECTION III

FUEL CELL SYSTEM

3.1 INTRODUCTION

PRIMARY ELECTRICAL POWER IN THE APOLLO SPACECRAFT IS PROVIDED BY THREE BACON TYPE CHEMICAL FUEL CELL MODULES. EACH MODULE IS RATED TO PRODUCE 1.42 KW AT 29 VOLTS DC. THEY ARE LOCATED IN SECTOR IV OF THE S/M. TWO FUEL CELL MODULES CAN SUPPLY ALL THE POWER REQUIRED TO OPERATE ALL THE SPACECRAFT SYSTEMS. A SINGLE MODULE WILL SUPPLY UP TO 2 KW FOR SHORT PERIODS, AND WITH A REDUCED LOAD, WILL PROVIDE SUFFICIENT POWER TO PERMIT SAFE EARLY MISSION TERMINATION FROM ANY POINT.

ONE OF THE REASONS FUEL CELLS WERE SELECTED OVER OTHER POWER GENERATING SOURCES IS BECAUSE OF THEIR HIGH EFFICIENCY UNDER VARIABLE LOAD CONDITIONS. THE CURRENT DENSITY (AMPS/UNIT AREA OF ELECTRODE) VARIES WITH THE LOAD AND REACTANT INPUT. THEY ARE CAPABLE OF PROVIDING HIGH CURRENT DENSITY CAUSED BY HEAVY LOADS, AS REACTANT INPUT IS INCREASED AUTOMATICALLY; AND LOW CURRENT DENSITY UNDER LOW LOADING CONDITIONS, AS REACTANT INPUT IS DECREASED AUTOMATICALLY. FUEL CELL EFFICIENCY IS ILLUSTRATED IN FIGURE 3-1. UNDER AN AVERAGE LOAD, CURRENT DENSITY OF APPROXIMATELY 46 AMPS PER SQUARE FOOT IS DEVELOPED. AT THIS LEVEL THE FUEL CELL MODULE IS APPROXIMATELY 80% EFFICIENT. AS THE LOAD IS INCREASED, CURRENT DENSITY INCREASES AND EFFICIENCY DECREASES. HOWEVER, EFFICIENCY STILL

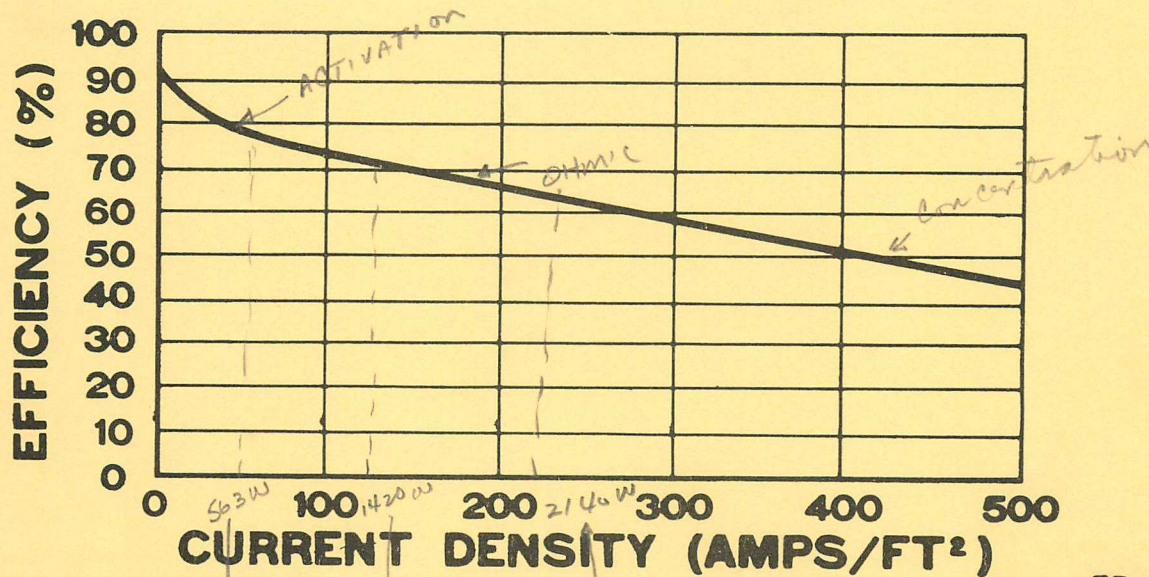
REMAINS HIGHER THAN THAT OF OTHER POWER SOURCES.

A BY-PRODUCT OF THE FUEL CELL SYSTEM IS POTABLE WATER WHICH IS USED FOR CREW CONSUMPTION. UNDER AVERAGE MISSION POWER LOADING, EACH OF THE THREE MODULES WILL PRODUCE APPROXIMATELY .5 POUNDS OF WATER PER HOUR.

3.2 DESCRIPTION

A FUEL CELL MODULE CONSISTS OF A POWER OR ENERGY CONVERSION SECTION, A REACTANT CONTROL SYSTEM, A WASTE HEAT AND WATER REMOVAL SYSTEM, AND INSTRUMENTATION. THE ENERGY CONVERSION SECTION IS HOUSED IN A PRESSURIZED JACKET POSITIONED IN A SUPPORT CONE WHICH IS INSULATED WITH GLASS MATTING AND ALUMINUM FOIL AS ILLUSTRATED IN FIGURE 3-2. A MODULE WEIGHS APPROXIMATELY 245 POUNDS. THE POWER AND ACCESSORY SECTION COMPRISES 222.5 POUNDS OF THE WEIGHT, AND THE REMAINING 22.5 POUNDS CONSISTS OF THE SUPPORT CONE AND FLEX LINES. THE ACCESSORY SECTION RESTS ON TOP OF THE POWER SECTION AND SUPPORT CONE AS ILLUSTRATED IN FIGURE 3-3. IT CONSISTS OF A NITROGEN PRESSURIZATION SYSTEM, THREE REGULATORS, MOTOR DRIVEN PUMPS, A SECONDARY (GLYCOL) LOOP, COMPONENTS OF THE PRIMARY (HYDROGEN) REGENERATIVE LOOP AND THE NECESSARY PLUMBING.

CELL EFFICIENCY



CURRENT DENSITY (AMPS/FT²)

PRATT & WHITNEY AIRCRAFT SERVICE SCHOOL

EP-011B

Cur. Dens. 47A

27.5V
51.7A
CD = 128A

24.5V
86.6A

FIGURE 3-1 CD = 215A

FUEL CELL POWER PLANT

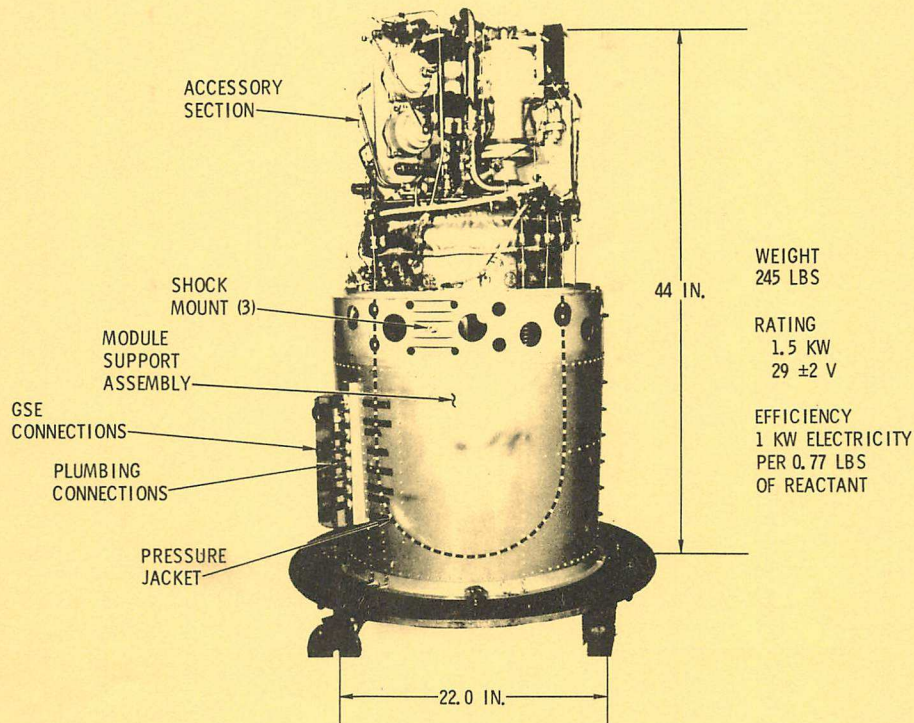


FIGURE 3-2

FUEL CELL MODULE ACCESSORIES

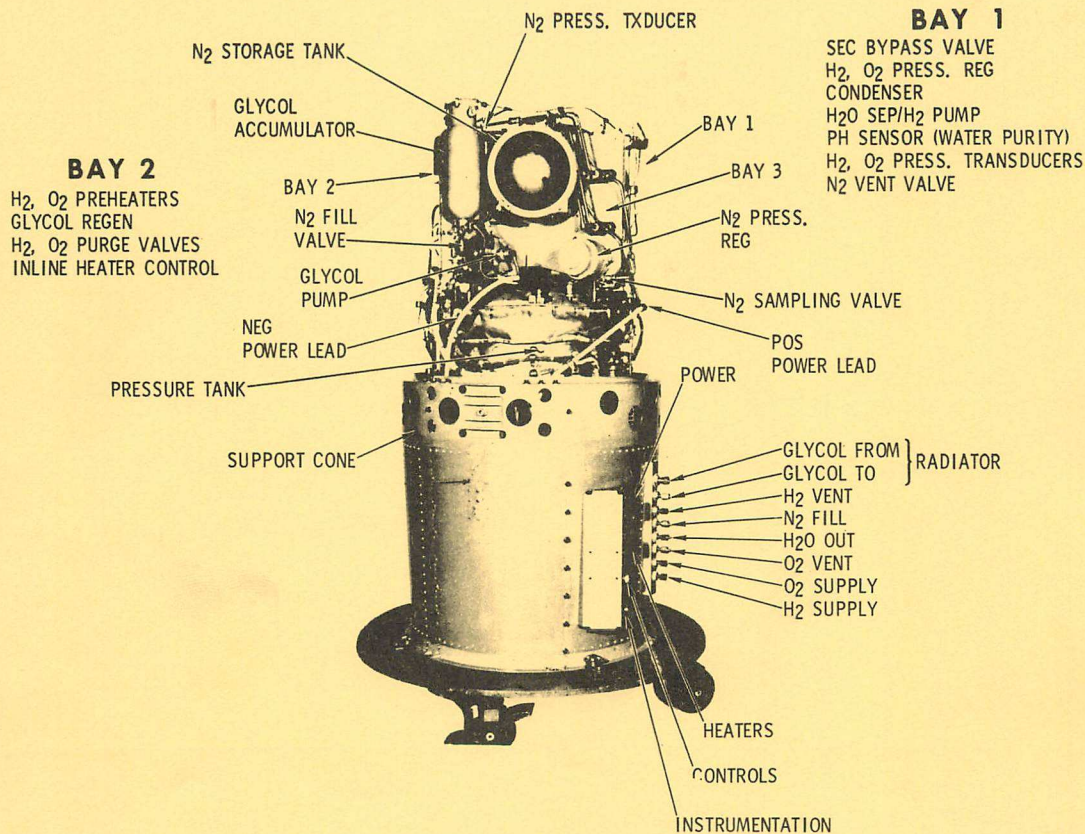


FIGURE 3-3

THE THIRTY-ONE INDIVIDUAL CELLS, PRODUCING APPROXIMATELY ONE VOLT EACH, ARE STACKED IN SERIES AND HELD TOGETHER BY TORSION TIE RODS AS ILLUSTRATED IN FIGURE 3-4. OXYGEN AND HYDROGEN INTAKE MANIFOLDS ARE LOCATED ON THE LEFT SIDE OF THE ILLUSTRATION. THESE MANIFOLDS DISTRIBUTE FLOW THROUGH INDIVIDUAL LINES TO EACH OF THE THIRTY ONE CELLS. EACH INDIVIDUAL LINE HAS A CERAMIC INSULATOR FOR ELECTRICAL ISOLATION. THE PRIMARY BY-PASS VALVE IS IN THE CENTER WITH FLOW FROM THE HYDROGEN EXHAUST MANIFOLD INTO THE INLET SIDE, AND THE TWO OUTLET LINES ALLOWING FLOW TO THE REGENERATOR OR CONDENSOR.

3.3 FUEL CELL OPERATION

THE COMPLETE FUEL CELL MODULE IS SCHEMATICALLY DEPICTED IN FIGURE 3-5. THE REACTANTS, NITROGEN GAS, WATER AND GLYCOL COOLANT ARE CODED TO AID IN IDENTIFICATION OF THEIR PARTICULAR FLOW PATTERN.

3.3.1 NITROGEN SUBSYSTEM

NITROGEN, .45 POUNDS OF WHICH IS STORED IN THE MODULE ACCESSORY SECTION N_2 TANK AT 1500 PSIA, IS SUPPLIED TO THE NITROGEN REGULATOR WHERE THE PRESSURE IS REDUCED TO 53 PSIA. THE REDUCED PRESSURE IS USED AS A REFERENCE PRESSURE IN THE H_2 AND O_2 REGULATORS, AS HEAD PRESSURE IN THE GLYCOL ACCUMULATOR AND TO INTERNALLY PRESSURIZE THE PRESSURE JACKET, THUS PRESURIZING THE ELECTROLYTE IN EACH OF THE 31 INDIVIDUAL CELLS. THE REGULATOR CONTAINS A FILTER, FILTERING EVERYTHING ABOVE 10 MICRONS ABSOLUTE, AND IS DESIGNED TO VENT OVERBOARD AT A TWO TO THREE POUND OVERPRESSURE.

3.3.2

OXYGEN SUBSYSTEM

OXYGEN, CRYOGENICALLY STORED IN THE S/M, IS SUPPLIED TO EACH FUEL CELL MODULE AT A NOMINAL 900 PSIA. LINE FLOW FROM THE STORAGE TANKS TO THE MODULE INCREASES GAS TEMPERATURE TO BETWEEN 0 AND 50 DEGREES F. THE O_2 PREHEATER FURTHER INCREASES GAS TEMPERATURE BY AN EXCHANGE OF HEAT FROM THE GLYCOL TO THE GAS. THE OXYGEN REGULATOR, OPERATING FROM THE N_2 REFERENCE PRESSURE OF 53 PSIA, REDUCES THE INCOMING OXYGEN PRESSURE TO 63.5 PSIA, OR 10.5 PSIA ABOVE THE NITROGEN SYSTEM. THE REGULATOR IS DESIGNED TO MAINTAIN THIS DIFFERENTIAL PRESSURE. THE REGULATED O_2 IS THEN ROUTED TO THE INDIVIDUAL CELLS WHERE IT IS TOTALLY CONSUMED IN THE REACTION PROCESS. A PURGE VALVE, WHEN ELECTRICALLY ENERGIZED, WILL PERMIT A CONTINUOUS FLOW OF ADDITIONAL O_2 THROUGH THE CELL AND BE DUMPED OVERBOARD. PURGING IS A NORMAL SYSTEM MANAGEMENT FUNCTION THAT IS ACCOMPLISHED PERIODICALLY TO REMOVE IMPURITIES CARRIED INTO THE CELLS BY THE STORED OXYGEN.

3.3.3

HYDROGEN SUBSYSTEM

HYDROGEN, STORED CRYOGENICALLY IN THE S/M AT 245 PSIA, IS ALSO WARMED BY THE FLOW IN THE LINES FROM THE TANKS TO THE FUEL CELL MODULE. EACH FUEL CELL MODULE PRE-HEATER FURTHER WARMS THE GAS BY AN EXCHANGE OF HEAT FROM THE GLYCOL. OPERATING FROM THE N_2 REFERENCE PRESSURE, THE H_2 REGULATOR MAINTAINS A DIFFERENTIAL OF 8.5 PSIA ABOVE THE N_2 , THUS REDUCING THE HYDROGEN PRESSURE TO 61.5 PSIA. THE PRESSURE REGULATED HYDROGEN IS THEN SUPPLIED TO THE HYDROGEN REGENERATION LOOP AND INTO THE FUEL CELLS TO REPLACE THE HYDROGEN CONSUMED BY

FUEL CELL MODULE

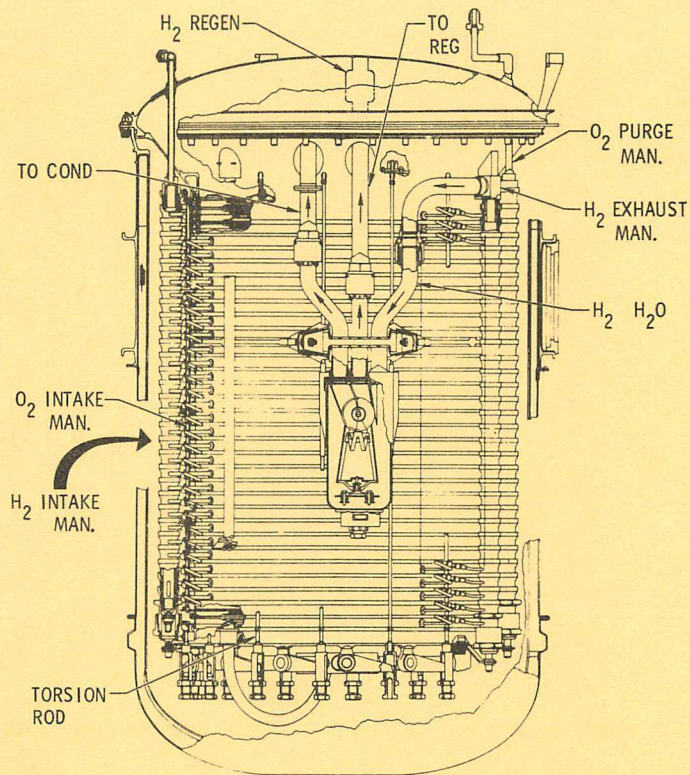


FIGURE 3-4

FUEL CELL MODULE

SCHEMATIC DIAGRAM

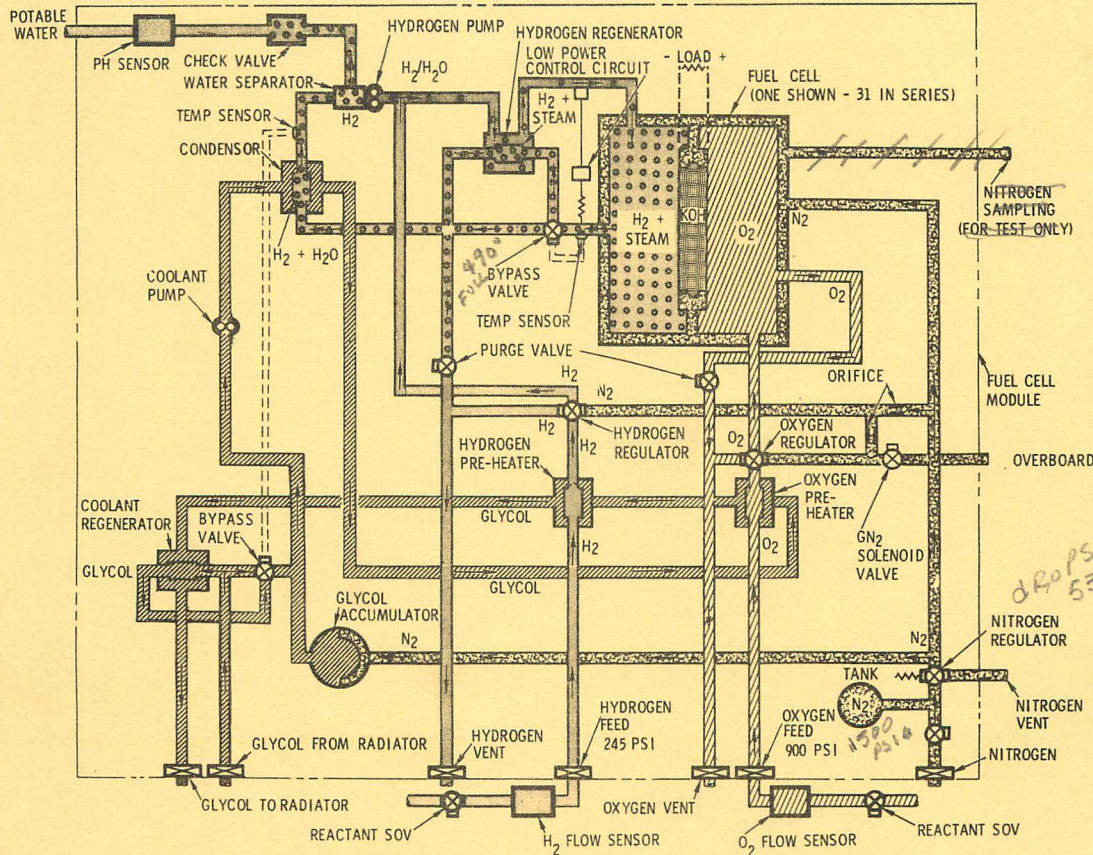


FIGURE 3-5

THE CELL REACTION. A PURGE VALVE IN THIS LOOP PERFORMS THE SAME FUNCTION AS THAT IN THE OXYGEN LOOP.

BOTH REGULATORS HAVE 10 MICRON ABSOLUTE FILTERS, AND ARE DESIGNED TO VENT OVERBOARD AT A .2 TO .4 POUND BACK PRESSURE.

3.3.4 PRIMARY LOOP

TEMPERATURE WITHIN THE FUEL CELL IS CONTROLLED BY THE PRIMARY (HYDROGEN) LOOP AND SECONDARY (COOLANT) LOOP. THE PRIMARY LOOP IS COMPRISED OF THE H_2 EXHAUST SIDE OF EACH OF THE 31 CELLS, A SENSOR CONTROLLED BY-PASS VALVE, A SECONDARY LOOP COOLED CONDENSOR, A WATER SEPARATOR- H_2 PUMP UNIT, THE H_2 REGENERATOR OR HEAT EXCHANGER, AND AN IN-LINE HEATER FOR TEMPERATURE CONTROL AT LOW POWER CONDITIONS.

IN ADDITION TO CONTROLLING CELL TEMPERATURE, THE PRIMARY LOOP EXTRACTS WATER FROM THE CELL FOR USE BY THE CREW. THE WATER SEPARATOR- H_2 PUMP UNIT MAINTAINS CONTINUOUS CIRCULATION IN THE PRIMARY LOOP. THIS WILL CAUSE THE WATER, IN THE FORM OF SUPER-HEATED STEAM, AND THE H_2 IN THE CELL TO EXHAUST ACROSS THE SENSOR AND THROUGH THE BY-PASS VALVE. THE BY-PASS VALVE DIVIDES THE EXHAUST GASES AND PASSES PART THROUGH, AND THE REMAINDER AROUND THE HEAT EXCHANGER. THE AMOUNTS ARE DETERMINED BY THE TEMPERATURE OF THE EXHAUST GAS. THE TWO ARE JOINED AGAIN PRIOR TO FLOWING INTO THE CONDENSOR WHERE THE TEMPERATURE OF THE H_2 AND STEAM IS REDUCED BY A TRANSFER OF HEAT TO THE GLYCOL COOLANT. SOME OF THE STEAM IS CONDENSED AND THE H_2 , LIQUID WATER AND REMAINING STEAM COMBINATION IS PASSED

INTO THE WATER SEPARATOR PUMP.

THE WATER SEPARATOR, A CENTRIFUGAL TYPE PUMP, EXTRACTS THE LIQUID FROM THE GAS. THE WATER IS HYDROSTATICALLY FORCED FROM THE H_2 LOOP INTO A LINE FLOWING TO THE POTABLE WATER TANK IN THE C/M., THE REMAINING HYDROGEN GAS AND WATER VAPOR IS PICKED UP BY THE HYDROGEN PUMP AND ROUTED THROUGH THE H_2 REGENERATOR BACK INTO THE CELLS. THE PUMP ALSO RESTORES PRESSURE LOSSES DUE TO CONDENSATION AND WATER EXTRACTION.

THE AMOUNT OF HEAT TRANSFERRED IN THE REGENERATOR TO THE HYDROGEN AND WATER VAPOR RETURNING TO THE MODULE IS DETERMINED BY THE MODULE TEMPERATURE AND THE POSITION OF THE SENSOR CONTROLLED PRIMARY BY-PASS VALVE.

IF THE TEMPERATURE OF THE EXHAUST GAS, AS SENSED BY THE SENSOR, IS LOW, MORE OF THE EXHAUST H_2 AND STEAM WILL BE ROUTED THROUGH THE REGENERATOR TO PERMIT GREATER TRANSFER OF HEAT TO THE RETURNING GAS. CONVERSELY, IF A HIGHER TEMPERATURE IS SENSED, IT WILL CAUSE LESS EXHAUST H_2 + STEAM TO PASS THROUGH THE REGENERATOR, DECREASING THE AMOUNT OF HEAT TRANSFERRED.

3.3.5 SECONDARY LOOP

A CONSIDERABLE AMOUNT OF HEAT IS GENERATED BY THE REACTION IN THE FUEL CELL MODULE. THE HEAT NOT USED FOR REGENERATIVE PURPOSES, OR WASTE HEAT, IS RADIATED INTO SPACE BY THE SECONDARY, OR COOLANT LOOP. THE COMPONENTS OF THIS LOOP ARE AN ACCUMULATOR TO MAINTAIN PRESSURE AND ABSORB THE VARIATIONS CREATED BY THE EXPANSION OR CONTRACTION OF THE FLUID WITHIN THE LOOP,

THE COOLANT REGENERATOR AND SENSOR CONTROLLED BY-PASS VALVE, THE COOLANT PUMP, THE CONDENSOR (COMMON TO THE H₂ LOOP), THE O₂ AND H₂ PRE-HEATERS, AND THE SPACE RADIATORS.

ALL OF THE SECONDARY LOOP COMPONENTS, EXCEPT THE SPACE RADIATORS, ARE CONTAINED IN THE ACCESSORY SECTION. THE RADIATORS HAVE A MAXIMUM EFFECTIVE RADIATING AREA OF 48 SQUARE FEET, OR 16 SQUARE FEET PER FUEL CELL MODULE, SINCE EACH MODULE HAS ITS OWN FLOW LINE. THE COOLANT, A 62.5/37.5 MIXTURE OF ETHYLENE GLYCOL & WATER, IS PRESSURIZED BY THE N₂ AT THE ACCUMULATOR TO MAINTAIN A CONSTANT 53 PSIA. THE VANE TYPE PUMP CIRCULATES THE FLUID AT BETWEEN 35 AND 80 LBS/HR., DEPENDENT UPON THE VISCOSITY OF THE FLUID WHICH IS DEPENDENT ON TEMPERATURE. THE PUMP ALSO COMPENSATES FOR PRESSURE LOSSES IN THE SYSTEM.

PRIMARY LOOP H₂/H₂O TEMPERATURE IS SENSED AT THE CONDENSOR EXHAUST BY THE SECONDARY LOOP SENSOR. THIS SENSOR CONTROLS THE POSITION OF THE COOLANT BY-PASS VALVE, WHICH IN TURN REGULATES THE AMOUNT OF COOLANT RETURNING FROM THE RADIATORS THAT IS ROUTED THROUGH THE COOLANT REGENERATOR. IF CONDENSOR EXHAUST TEMPERATURE IS LOW, MORE RETURNING COOLANT IS PREHEATED TO INCREASE THE MEAN TEMPERATURE BEFORE IT IS PUMPED THROUGH THE LOOP BY THE PUMP. WHEN THE COOLANT REACHES THE CONDENSOR, THE INCREASE IN MEAN COOLANT TEMPERATURE WILL CAUSE LESS HEAT TRANSFER FROM THE H₂/H₂O AND THE INCREASE IN CONDENSOR EXHAUST TEMPERATURE IS IMPRESSED ON THE SENSOR.

THE COOLANT FLOWING FROM THE CONDENSOR IS ROUTED THROUGH THE O₂ & H₂ PREHEATERS TO WARM THE GAS

FLOWING INTO THE MODULE, THEN TO THE COOLANT REGENERATOR, TO TRANSFER HEAT TO THE BY-PASS VALVE CONTROLLED RETURNING COOLANT, AND OUT TO THE SPACE RADIATORS.

CONVERSELY, IF CONDENSOR EXHAUST TEMPERATURE IS APPROACHING THE UPPER LIMIT, LESS OF THE RETURNING COOLANT IS PREHEATED IN THE REGENERATOR. THE INCREASE OF REACTANT TEMPERATURE IS LESS, AND THE COOLANT CAN ABSORB MORE HEAT FROM THE H₂/H₂O IN THE CONDENSOR.

THIS REGULATION OF CONDENSOR TEMPERATURE IS IMPERATIVE, SINCE IT IS DESIRED TO CONDENSE ONLY A CERTAIN AMOUNT OF MOISTURE, AS THE REMAINDER IS REQUIRED TO SUSTAIN NORMAL CELL OPERATION. CONDENSOR EXHAUST TEMPERATURE IS MAINTAINED BETWEEN 155° AND 165 DEGREES F.

3.3.6 CIRCULATING PUMPS

BOTH OF THE PUMPS ARE VANE TYPE UNITS. POWER IS PROVIDED BY THE 3Ø, 400 CYCLE, 115 VOLT INVERTERS.

3.3.7 GSE ACTIVATION

THE GN₂ SOLENOID VALVE AND ORIFICES PERFORM A FUNCTION ONLY DURING INITIAL START UP OF A FUEL CELL MODULE. THE ELECTROLYTE, AT THE RATIO OF POTASSIUM HYDROXIDE/WATER UTILIZED, REQUIRES A TEMPERATURE OF 300 DEG. F BEFORE LIQUIFYING. THEREFORE, WHILE IT IS INITIALLY BEING HEATED, A DIFFERENTIAL PRESSURE OF 3.5 PSIA HAS TO BE MAINTAINED BETWEEN THE GASES (H₂ AND O₂) AND ELECTROLYTE TO PREVENT ANY GAS DIFFUSION INTO THE ELECTROLYTE BEFORE IT MELTS.

THE SOLENOID VALVE IS OPERATED BY GSE AND ALLOWS A ONE POUND PER HOUR FLOW OF GN_2 THROUGH THE ORIFICES. THE ORIFICES PROVIDE A VENTURI EFFECT, THUS CREATING A DROP IN THE N_2 REFERENCE PRESSURES TO THE HYDROGEN AND OXYGEN REGULATORS. THE ORIFICE IN THE LINE LEADING TO THE HYDROGEN REGULATOR IS DESIGNED TO PROVIDE A DROP OF 5 PSIA. SINCE THE H_2 REGULATOR IS DESIGNED TO PROVIDE A DIFFERENTIAL OF 8.5 PSIA ABOVE THE REFERENCE, IT NOW ONLY SEES AN N_2 REFERENCE OF 48 PSIA, THUS PROVIDING HYDROGEN GAS TO THE FUEL CELL MODULE AT 56.5 PSIA. THE ORIFICE IN THE LINE LEADING TO THE OXYGEN REGULATOR IS DESIGNED TO PROVIDE AN ADDITIONAL 2.0 PSIA DECREASE. THIS IS REQUIRED SINCE THE OXYGEN REGULATOR IS DESIGNED TO PROVIDE A DIFFERENTIAL OF 10.5 PSIA ABOVE THE REFERENCE PRESSURE. THUS THE OXYGEN REGULATOR SEES AN N_2 REFERENCE PRESSURE OF 46 PSIA, AND PROVIDES OXYGEN TO THE FUEL CELL MODULE AT 56.5 PSIA. THE NORMAL 53 PSIA OF NITROGEN PRESSURE IS PROVIDED TO THE PRESSURE JACKET TO PRESSURIZE THE ELECTROLYTE.

AFTER ATTAINING THE DESIRED FUEL CELL MODULE TEMPERATURE, THE SOLENOID VALVE IS CLOSED, AND ALL GASES ARE SUPPLIED AT NORMAL PRESSURES.

3.3.8 LOW POWER CONTROL CIRCUIT (IN LINE HEATER)

THE LOW POWER CONTROL CIRCUIT IS AN AUTOMATIC FEATURE DESIGNED TO AID THE FUEL CELL MODULE IN SUSTAINING OPERATION AT LOW POWER LEVELS, WHICH EVOLVE IN LOW OPERATING TEMPERATURES. IT CONSISTS OF A PLATINUM RESISTIVE SENSOR IN THE HYDROGEN EXHAUST LINE, A TRANSISTORIZED CONTROL CIRCUIT LOCATED IN THE ACCESSORY

SECTION, AND A CARTRIDGE IMMERSION HEATER IN THE HYDROGEN RETURN LINE. THE PRIMARY BY-PASS VALVE IS IN A FULL REGENERATIVE POSITION AT A MODULE TEMPERATURE OF 380 DEG. F. IF MODULE TEMPERATURE DECREASES, THE IN-LINE HEATER SENSOR WILL PROVIDE AN INPUT TO THE CONTROL CIRCUIT WHICH WILL ACTIVATE THE 160 WATT CARTRIDGE HEATER AT 380 ± 5 DEG. F. THIS WILL SUPPLY ADDITIONAL HEAT TO THE HYDROGEN GAS FLOWING INTO THE FUEL CELL MODULE. THE SENSOR AND CIRCUIT WILL DEACTIVATE THE HEATER AT 390 ± 5 DEG. F. POWER FOR HEATER OPERATION IS PROVIDED BY THE RESPECTIVE FUEL CELL MODULE.

DURING INITIAL FUEL CELL START-UP, GSE CONTROLS DEACTIVATE THIS CIRCUIT UNTIL OPERATING TEMPERATURES ARE ATTAINED.

3.4 SINGLE CELL OPERATION

THE FOLLOWING EXPLAINS THE INTERNAL FUNCTION WITHIN ONE OF THE THIRTY ONE CELLS.

3.4.1 PHASE DIAGRAM FOR $\text{KOH-H}_2\text{O}$

TO OBTAIN BEST VOLTAGE REGULATION UNDER VARYING LOAD CONDITIONS, THE FUEL CELLS MUST OPERATE WITHIN A RELATIVELY NARROW DESIRED TEMPERATURE RANGE. THE ELECTROLYTE IN THE CELLS ON INITIAL FILL, CONSISTS OF 83% POTASSIUM HYDROXIDE AND 17% WATER, AND HAS A CRITICAL TEMPERATURE OF 300 DEGREES F., AS ILLUSTRATED IN FIGURE 3-6. THE ELECTROLYTE MIXTURE REMAINS A SOLID TO A TEMPERATURE OF APPROXIMATELY 220 DEG. F. WITH A TEMPERATURE INCREASE TO 300 DEG. F, THE ELECTROLYTE BECOMES A LIQUID AND THE F/C ELECTROCHEMICAL REACTION

PHASE DIAGRAM FOR KOH-H₂O

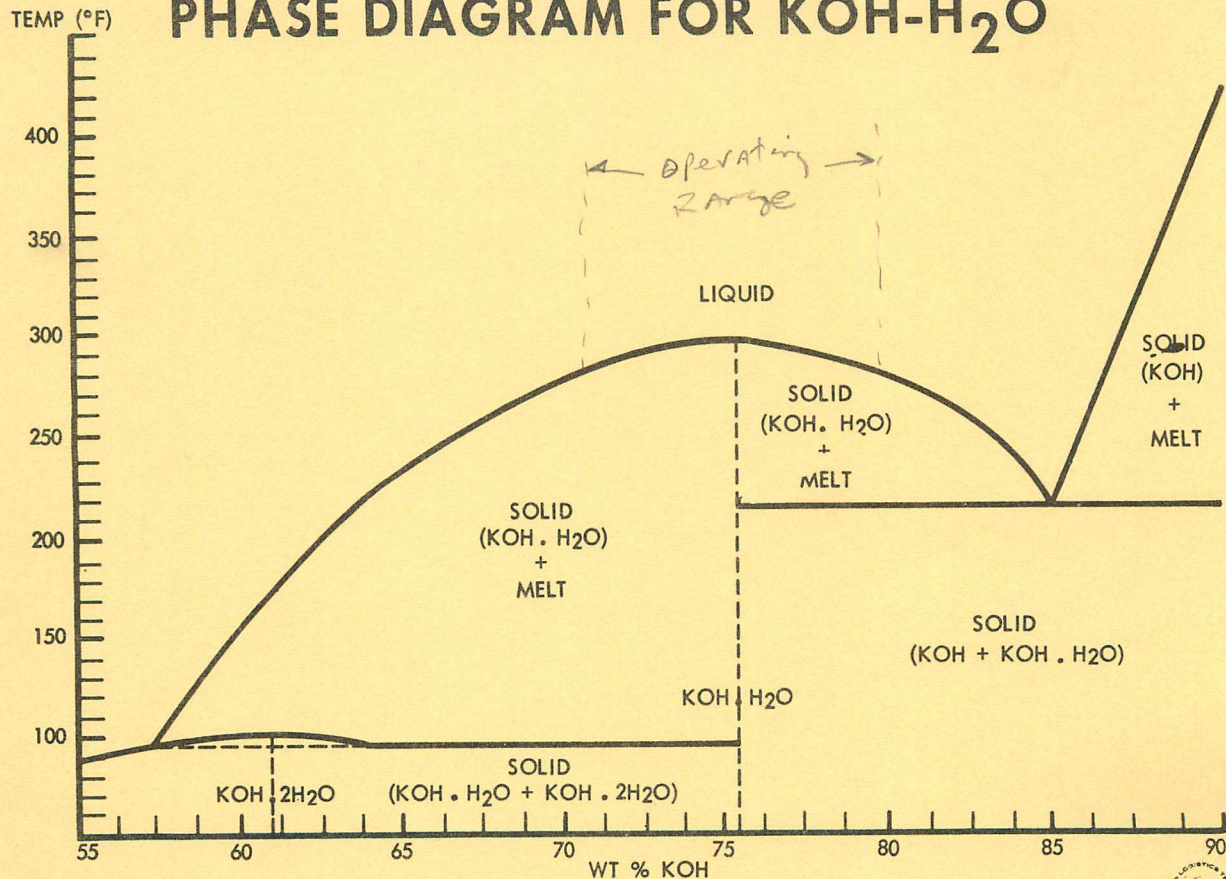


FIGURE 3-6

EP-007



WILL BEGIN, THOUGH QUITE INEFFICIENT AT THIS TEMPERATURE. WITH THE PLACEMENT OF A LOAD ON THE FUEL CELL MODULES, THE REACTION WITHIN THE CELLS WILL GENERATE SUFFICIENT HEAT TO BRING THE MODULE UP TO THE NORMAL OPERATING TEMPERATURE, WHICH WILL BE MAINTAINED BY THE SENSOR REGULATED BY-PASS VALVES AND THE LOW POWER CONTROL CIRCUIT.

REMOVING THE LOAD WILL DROP THE OPERATING TEMPERATURE FROM THE NORMAL TO 300 DEG. F IN A FEW HOURS. IF REACTANT PRESSURES WERE MAINTAINED, THE MODULE COULD BE PUT BACK ON THE LINE AT ANY TIME WITHIN THIS PERIOD, OR BEFORE THE TEMPERATURE DROPPED BELOW 300 DEGREES F. OPERATION OF THE MODULE WOULD RESUME AT A RELATIVELY INEFFICIENT LEVEL UNTIL FULL OPERATING TEMPERATURE WAS ATTAINED. THE REMOVAL OF A MODULE FROM THE LINE WOULD BE PERFORMED ONLY IF THE MODULE HAD BECOME DEGRADED TO THE POINT WHERE CONTINUED USE WAS CONSIDERED DETRIMENTAL TO THE EPS. RESTORING MODULE OPERATION WOULD ONLY BE ATTEMPTED AS A LAST RESORT MEASURE.

3.4.2 FUEL CELL ELEMENT

EACH OF THE 31 CELLS IS IN THE SHAPE OF A DISC APPROXIMATELY 11.25 INCHES IN DIAMETER, CONTAINING TWO ELECTRODES APPROXIMATELY 8.5 INCHES IN DIAMETER, AS ILLUSTRATED IN FIGURE 3-7. REACTANT FLOW IS CHANNLED ACROSS THE ELECTRODES BY A SERIES OF WELDS WITH O_2 DISTRIBUTED ON ONE SIDE AND H_2 ON THE OTHER. THE HYDROGEN ELECTRODE, COMPOSED OF SINTERED NICKEL, AND THE OXYGEN ELECTRODE, COMPOSED OF SINTERED NICKEL AND BLACK LITHIUM IMPREGNATED NICKEL OXIDE, ARE HOUSED INTERNALLY AND SEPARATED BY THE ELECTROLYTE

AND A TEFLON SEAL. THE ELECTRODE MATERIALS ARE RESISTANT TO CORROSION BY THE ELECTROLYTE AND SERVE ONLY AS A CATALYST IN THE ELECTROCHEMICAL REACTIONS. EACH ELECTRODE IS SUPPORTED BY A PURE NICKEL BACK UP PLATE STRUCTURE. THE INSULATING TEFLON SEAL IS PROVIDED AROUND THE PERIPHERY FOR ELECTRODE ISOLATION AND TO CONTAIN THE ELECTROLYTE. THE OUTER PERIPHERY OF THE BACK UP PLATE ACTS AS A DIAPHRAGM FOR ELECTROLYTE EXPANSION AND CONTRACTION. THE CELLS MAKE PHYSICAL CONTACT FOR ELECTRON FLOW BY A CELL SPACER ON THE OUTER PERIPHERY.

3.4.3 ELECTROCHEMICAL REACTION

AN ELECTROCHEMICAL SCHEMATIC OF A SINGLE FUEL CELL IS DEPICTED IN FIGURE 3-8. THE SEPARATOR BETWEEN THE HYDROGEN GAS AND THE ELECTROLYTE IS THE NEGATIVE ELECTRODE MADE OF DUAL POROSITY SINTERED NICKEL WHICH IS FORMED FROM NICKEL POWDER PRESSED INTO SHEETS. THE ELECTRODE IS FORMED SO THAT THE PORES ON THE GAS SIDE ARE LARGER THAN THE PORES OPPOSING THE ELECTROLYTE. THE PORES OPPOSING THE GAS ARE APPROXIMATELY 40 MICRONS IN SIZE, AND THOSE OPPOSING THE ELECTROLYTE ARE APPROXIMATELY 10 MICRONS. THE SELECTION OF PORE SIZES AND PRESSURE BALANCE BETWEEN THE GAS AND THE ELECTROLYTE WILL DETERMINE THE GAS/ELECTROLYTE INTERFACE WITHIN THE ELECTRODE.

THE OTHER ELECTRODE, SEPARATING THE OXYGEN AND ELECTROLYTE, IS MADE IN THE SAME MANNER BUT CONTAINS A LITHIUM COATING ON THE ELECTROLYTE SIDE TO INHIBIT OXIDATION DURING NORMAL OPERATION.

SINGLE CELL CONSTRUCTION

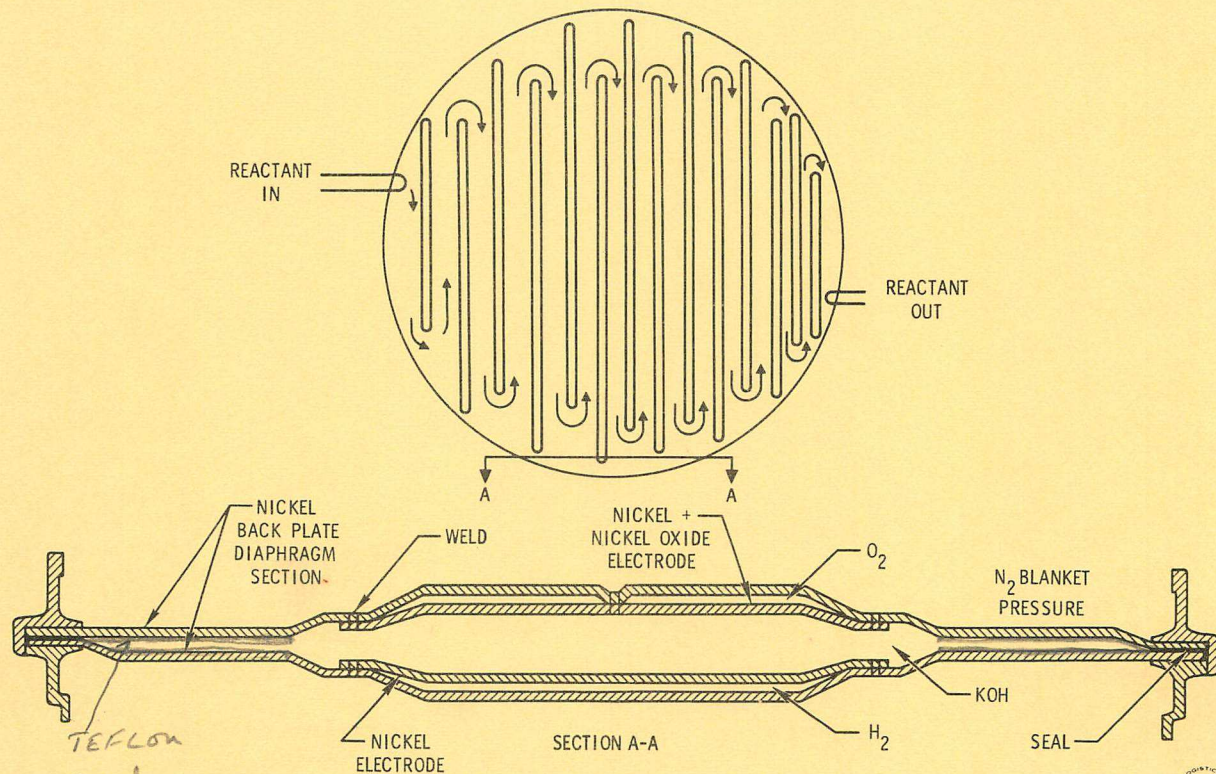


FIGURE 3-7

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FUEL CELL ELECTROCHEMICAL FLOW SCHEMATIC

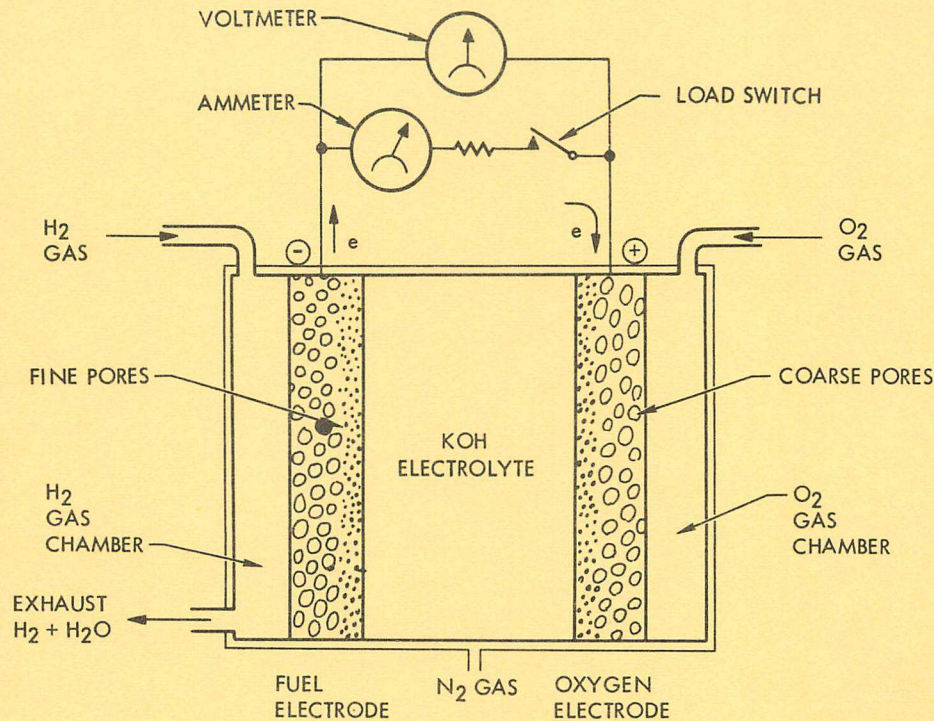


FIGURE 3-8

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3.4.4 HYDROGEN ELECTRODE REACTION

FIGURE 3-9 DEPICTS IN DETAIL THE REACTION THAT TAKES PLACE IN THE HYDROGEN ELECTRODE. THE ELECTROLYTE, DRAWN INTO THE SMALLER PORES BY CAPILLARY ACTION, IS COUNTERACTED BY A HIGHER PRESSURE ON THE HYDROGEN GAS TO PREVENT THE ELECTROLYTE FROM ENTERING THE HYDROGEN SECTION OF THE CELL AND CAUSING WATER CONTAMINATION. FOR MOST EFFICIENT OPERATION, THIS PRESSURE DIFFERENCE SHOULD BE MAINTAINED AT 8.5 PSID, ALTHOUGH IT MAY VARY FROM APPROXIMATELY 6.5 TO 10.5 PSID AND STILL MAINTAIN MODULE OPERATION. AT 8.5 PSID THE ELECTROLYTE AND HYDROGEN GAS INTERFACE WILL BE AT THE JUNCTION OF THE LARGE AND SMALL PORES. BELOW 6.5 PSID; THE ELECTROLYTE WOULD BE DRAWN THROUGH THE ELECTRODE, FLOOD INTO THE HYDROGEN COMPARTMENT, AND BE EXTRACTED INTO THE H_2 EXHAUST MANIFOLD. THIS WOULD THEN BE EXTRACTED WITH THE CONDENSED WATER AND CONTAMINATE THE POTABLE WATER SUPPLY. ABOVE 10.5 PSID, THE HYDROGEN GAS WOULD BE FORCED THROUGH THE ELECTRODE AND BUBBLE INTO THE ELECTROLYTE. IN EITHER EXTREME, THERE WOULD BE NO CONTACT WITH THE ELECTRODE, THUS NO REACTION WOULD TAKE PLACE. A DIFFERENTIAL WITHIN THESE TOLERANCES, BUT OTHER THAN 8.5 PSID, CHANGES THE INTERFACE JUNCTION, THUS DECREASING THE AMOUNT OF CONTACT WITH THE NICKEL. THIS WILL DECREASE THE AMOUNT OF REACTION, THUS SLIGHTLY DECREASING CELL EFFICIENCY. A DIFFERENTIAL PRESSURE BELOW 6.5 OR ABOVE 10.5 WILL MOVE THE INTERFACE AWAY FROM THE NICKEL CATALYST, CAUSING THE CELL TO CEASE OPERATION.

THE REACTION IN THE HYDROGEN ELECTRODE IS CAUSED BY THE GAS MOLECULES IMPINGING ON THE ELECTROLYTE AND IONIZING. THE ELECTRON IS GIVEN OFF TO THE

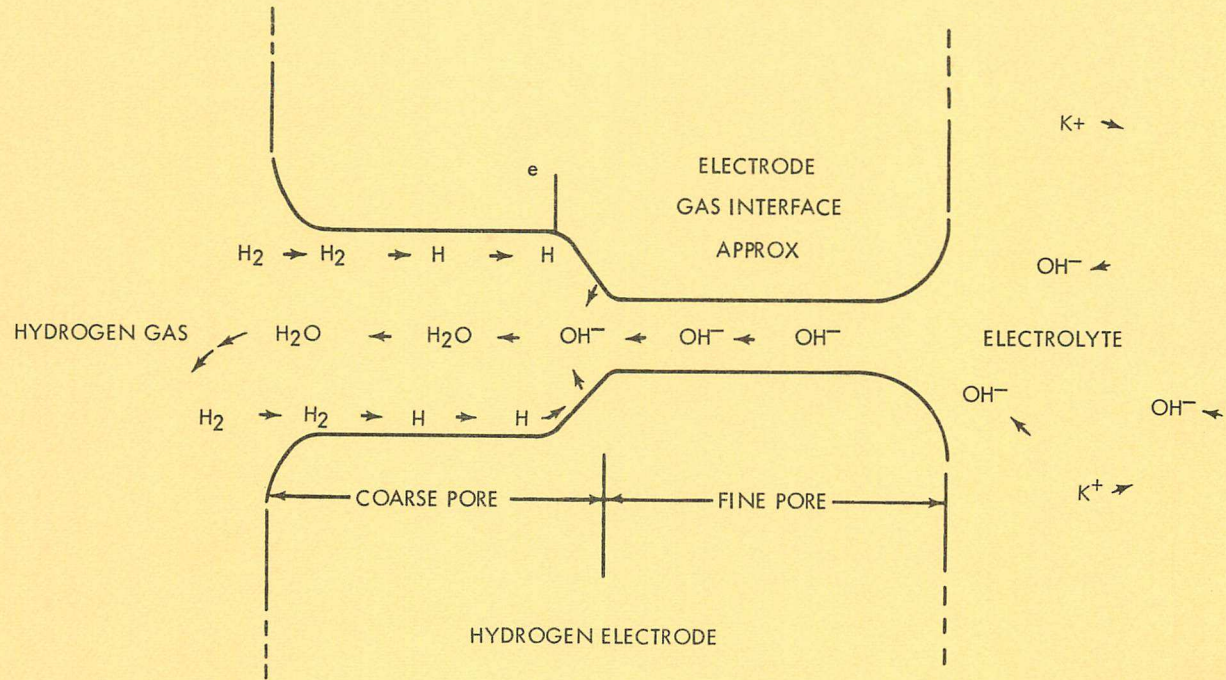
ELECTRODE AND THE POSITIVE ION COMBINES WITH THE HYDROXYL IONS IN THE ELECTROLYTE IN THE PRESENCE OF THE NICKEL CATALYST. THE REACTION THEREFORE PRODUCES ELECTRONS, WATER IN THE NATURE OF STEAM, AND HEAT. SOME OF THE HEAT IS USED TO MAINTAIN THE MODULE AT OPERATING TEMPERATURE, AND THE REMAINDER, OR WASTE HEAT, IS TRANSFERRED TO THE COOLANT SYSTEM AND RADIATED INTO SPACE. SOME OF THE STEAM VAPOR PRODUCED IS FORCED INTO THE ELECTROLYTE TO REPLACE THE WATER USED IN THE OXYGEN ELECTRODE REACTION. THE ELECTRONS ARE PASSED THROUGH THE LOAD AND TO THE OXYGEN ELECTRODE.

3.4.5 OXYGEN ELECTRODE REACTION

THE REACTION IN THE OXYGEN ELECTRODE IS SIMILAR TO THAT IN THE HYDROGEN ELECTRODE, AND IS ILLUSTRATED IN FIGURE 3-10. OXYGEN, AT A PRESSURE 10.5 PSIA GREATER THAN THE ELECTROLYTE, FLOWS INTO THE LARGER PORES AND BALANCES THE CAPILLARY ACTION OF THE ELECTROLYTE ENTERING THE SMALLER PORES. AT THE INTERFACE, THE OXYGEN MOLECULES IMPINGE ON THE ELECTROLYTE. WITH THE NICKEL ACTING AS A CATALYST, THEY REACT WITH THE RETURNING ELECTRONS AND THE WATER IN THE ELECTROLYTE TO REPRODUCE THE HYDROXYL IONS THAT WERE CONSUMED IN THE REACTION AT THE HYDROGEN ELECTRODE.

THE OVERALL REACTION IN A SINGLE CELL IS SIMPLY THE COMBINATION OF OXYGEN AND HYDROGEN TO FORM WATER, HEAT AND ELECTRICITY THROUGH CATALYTIC ACTION. THE REACTANTS ARE CONSUMED BY THE CELL STOICHIOMETRICALLY. TWO MOLECULES OF HYDROGEN AND ONE MOLECULE OF OXYGEN ARE USED TO FORM TWO MOLECULES OF WATER. THE GRAM MOLECULAR WEIGHT (GMW) OF H_2 IS TWO, AND THAT OF O_2 IS 32.

HYDROGEN ELECTRODE REACTION



EP-005A



FIGURE 3-9

OXYGEN ELECTRODE REACTION

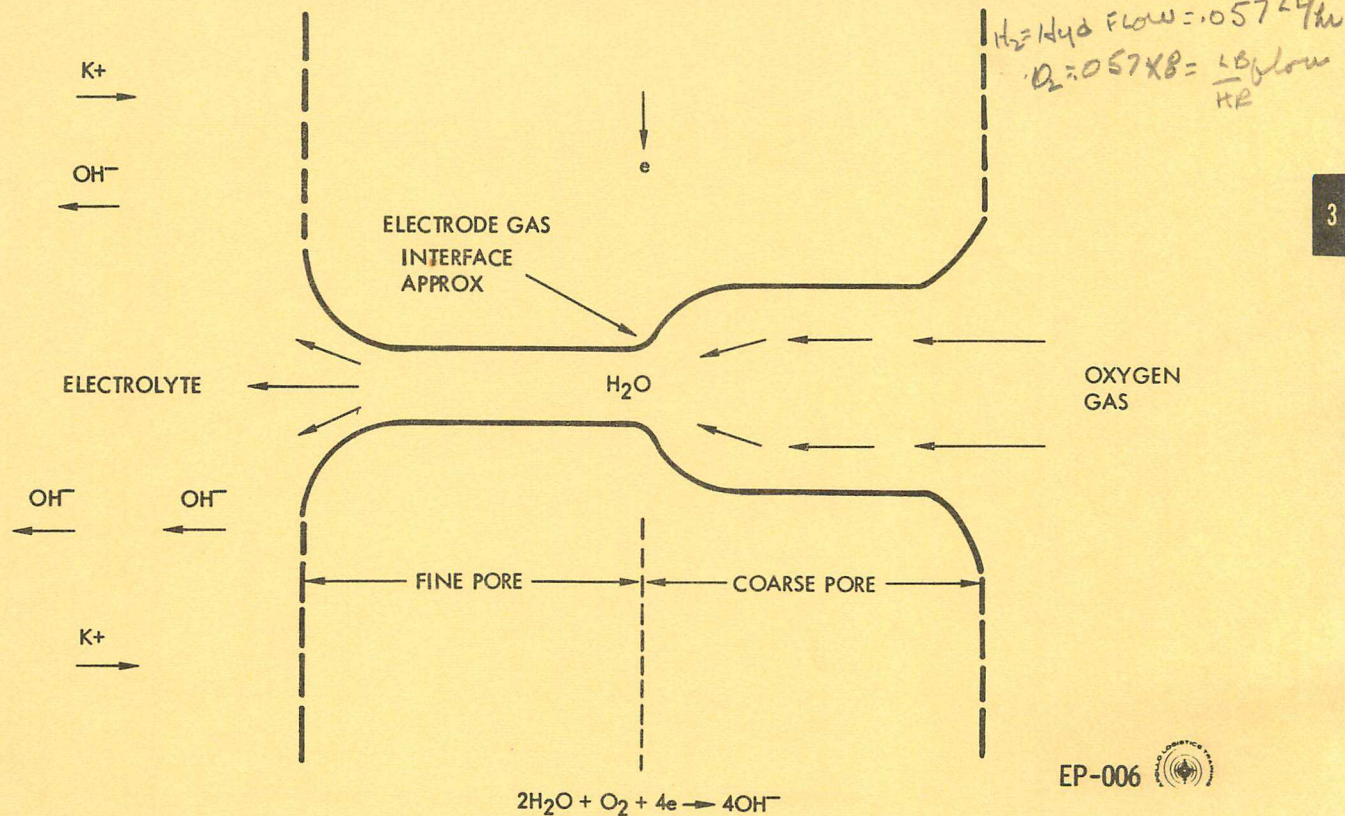


FIGURE 3-10

THEREFORE, THE RATIO OF COMBINATION IS 2 GMW H_2 /1 GMW O_2 , OR $2 \times 2/1 \times 32$, OR 1/8. THIS INDICATES THAT BY WEIGHT, EIGHT TIMES AS MUCH OXYGEN AS HYDROGEN WILL BE CONSUMED. THE TOTAL CONSUMPTION RATE IS DEPENDENT ON SYSTEM DEMAND. IF THERE IS NO DEMAND FOR POWER, THE AMOUNT OF REACTANTS CONSUMED WILL BE EXTREMELY SMALL; ONLY ENOUGH TO COMPENSATE FOR INTERNAL MODULE RESISTANCE. AS POWER DEMAND IS INCREASED, REACTANT CONSUMPTION WILL INCREASE.

3.5 FUEL CELL SYSTEM (FLOW DIAGRAM)

THE FUEL CELL MODULES ARE CONTROLLED FROM THE C/M (FIGURE 3-11). THE SQUARES WITH THE STRIPES INDICATE ELECTROMECHANICAL FLAG TYPE DISPLAYS ON THE MAIN DISPLAY CONSOLE, AND THE SMALL SQUARES INDICATE INFORMATION WHICH IS TELEMETERED TO THE MANNED SPACE FLIGHT NETWORK (MSFN). IN THE UPPER LEFT OF THE ILLUSTRATION ARE THE THREE SWITCHES WHICH CONTROL BOTH THE HYDROGEN AND COOLANT PUMPS FOR EACH OF THE MODULES. EACH MODULE IS CONTROLLED SEPARATELY AND MAY BE SWITCHED TO AC BUS 1, AC BUS 2, OR OFF. BOTH PUMPS ARE OPERATED SIMULTANEOUSLY WITH ONE SWITCH.

IN THE CENTER LEFT OF THE ILLUSTRATION IS THE "FUEL CELL INDICATOR" ROTARY SWITCH THAT PROVIDES TIME SHARING OF THE FOLLOWING MODULE INDICATORS:

THE THREE "REG OUT PRESS HI" MECHANICAL INDICATORS WHICH ARE SHOWN IN THE CENTER-RIGHT SECTION OF THE DIAGRAM. THE H_2 AND O_2 INDICATORS DISPLAY A FLAG IF THE RESPECTIVE PRESSURE IN THE MODULE EXCEEDS 75 PSIA. THE N_2 INDICATOR WILL DISPLAY A FLAG IF THE PRESSURE

INTO THE MODULE (PRESSURE JACKET & ELECTROLYTE) EXCEEDS 70 PSIA.

THE "FLOW" INDICATOR, LOWER-LEFT, DISPLAYS THE RATE OF FLOW OF H_2 AND O_2 INTO THE SELECTED FUEL CELL MODULE.

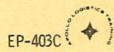
THE "RAD TEMP LO" MECHANICAL INDICATOR, TO THE LEFT OF THE FLOW RATE INDICATOR, WILL DISPLAY A FLAG WHEN THE TEMPERATURE OF THE COOLANT RETURNING FROM THE RADIATORS IS BELOW -30 DEGREES F.

THE "PH HI" INDICATOR, UPPER LEFT OF THE DIAGRAM, WILL INDICATE A FLAG WHEN WATER CONTAMINATION OCCURS IN THE RESPECTIVE FUEL CELL MODULE. A POSITIVE INDICATION OF WATER CONTAMINATION WOULD REQUIRE IMMEDIATE SHUT DOWN OF THE RESPECTIVE FUEL CELL MODULE.

THE "MODULE TEMP" GAUGE, CENTER-TOP OF THE DIAGRAM, WILL INDICATE THE OPERATING TEMPERATURE OF THE MODULE (SKIN), AND THE TEMPERATURE OF THE CONDENSOR EXHAUST (COND).

IN THE EVENT OF A MODULE MALFUNCTION, IT MAY BE SHUT DOWN BY POSITIONING THE APPLICABLE F/C PUMP SWITCH TO "OFF", POSITIONING THE APPLICABLE "REACTANTS" SWITCH TO "OFF" (CENTER-BOTTOM OF DIAGRAM), AND POSITIONING THE APPROPRIATE "BUS A" AND "BUS B" SWITCHES TO "OFF". THE F/C PUMP SWITCH SIMULTANEOUSLY TURNS OFF BOTH PUMPS; THE REACTANTS SWITCH SIMULTANEOUSLY CLOSES SOLENOID VALVES IN THE H_2 AND O_2 FLOW LINES OF THE RESPECTIVE MODULE, AND THE BUS SWITCHES DISCONNECT THE MODULE FROM THE BUS SYSTEM.

3



3-19

SECTION IV

BATTERIES AND BATTERY CHARGER

4.1 INTRODUCTION

RECHARGEABLE BATTERIES (A, B, C) ARE INCORPORATED INTO THE SPACECRAFT ELECTRICAL SYSTEM. THEY ARE USED TO SUPPLEMENT THE FUEL CELL MODULES DURING MISSION PEAK LOAD PERIODS, COMPENSATE FOR SLOW REACTION OF THE MODULES IN RESPONDING TO RAPID LOAD CHANGES, AND PROVIDE C/M POWER AFTER C/M-S/M SEPARATION.

THE ISOLATED PYROTECHNIC, AND S/M JETTISON CONTROL CIRCUITS ARE REDUNDANT, AND POWERED BY BATTERIES WHICH ARE NOT RECHARGEABLE IN FLIGHT.

PORTABLE LIFE SUPPORT SYSTEM BATTERIES, INSTALLED IN THE INDIVIDUAL SUIT PACKS, ARE NOT CONSIDERED PART OF THE SPACECRAFT ELECTRICAL SYSTEM.

A SOLID STATE BATTERY CHARGER SATISFIES THE IN-FLIGHT CHARGING REQUIREMENTS OF BATTERIES A, B AND C.

4.2 BATTERIES

THE TOTAL SPACECRAFT BATTERY POWER SOURCE CONSISTS OF SEVEN SILVER OXIDE/ZINC STORAGE BATTERIES, FIVE LOCATED IN THE C/M LOWER EQUIPMENT BAY AS ILLUSTRATED IN FIGURE 4-1, AND TWO LOCATED IN SECTOR IV OF THE S/M. THE RECHARGEABLE BATTERIES (A, B, C) HAVE A

REGENERATIVE LIFE SPAN OF SIX COMPLETE CHARGING CYCLES. ALL BATTERIES CAN FUNCTION IN ANY ATTITUDE AND ARE CAPABLE OF WITHSTANDING 20G.

4.2.1 BATTERIES A, B AND C

THREE IDENTICAL BATTERIES, LOCATED IN THE LOWER EQUIPMENT BAY, ARE DESIGNATED AS BATTERIES A, B AND C AND ARE ILLUSTRATED IN FIGURES 4-2 AND 4-3.

ALL THREE ARE USED IN PARALLEL TO SUPPLY C/M POWER DURING ENTRY AFTER C/M-S/M SEPARATION, AS WELL AS AFTER LANDING. A PAIR (A&C OR B&C) WILL ALSO BE USED TO SUPPLEMENT OUTPUT OF THE THREE FUEL CELL MODULES DURING THE PEAK LOAD PERIODS SUCH AS SERVICE PROPULSION SYSTEM GIMBAL MOTOR OPERATION DURING THRUSTING MANEUVERS. THEY WILL PROVIDE SUPPLEMENTAL POWER DURING EMERGENCY OPERATION IN THE EVENT TWO FUEL CELL MODULES FAIL.

4.2.1.1 DESCRIPTION

EACH OF THESE BATTERIES IS RATED AT 29 VDC, 40 AMPERE HOURS, AND CAN SUPPLY 35 AMPS DOWN TO 27 VOLTS. AT 27 VOLTS THE BATTERIES ARE CONSIDERED TO BE DISCHARGED FOR THE PURPOSE OF THE MISSION. OPEN CIRCUIT

VOLTAGE IS 37.2 VOLTS DC, AND OPEN CIRCUIT DISCHARGE VOLTAGE IS 32 VOLTS DC. OPEN CIRCUIT VOLTAGES WILL BE USED FOR VOLTAGE MEASUREMENT IN THE SPACECRAFT, SINCE BATTERY LOADS EXIST FOR VERY SHORT TIME PERIODS, EXCEPT WHEN THE BATTERIES ARE CONNECTED TO THE MAIN DC BUSES.

THE BATTERIES ARE DESIGNED TO WITHSTAND SIX COMPLETE RECHARGING CYCLES. IN FLIGHT, THE BATTERIES WILL BE RECHARGED EACH TIME AFTER THEY ARE USED ON THE MAIN BUS SYSTEM, AND JUST PRIOR TO THE LAST COURSE CORRECTION MANEUVER, THUS THEY SHOULD NEVER REACH A LOW CHARGE CONDITION.

THE OUTER CASE AND COVER ARE OF A PLASTIC AND FIBER GLASS MATERIAL, AND THE COMMAND MODULE ENVIRONMENT WILL PROVIDE TEMPERATURE CONTROL. BATTERY OPERATING TEMPERATURE WILL BE MAINTAINED BETWEEN +50 AND +110 DEGREES F. INSTALLED IN EACH OF THE TWENTY PLASTIC ENCASED CELLS IS A RELIEF VALVE DESIGNED TO OPEN AT A PRESSURE OF 50 ± 10 PSIG, DISCHARGING INTO THE VOLUME ENCLOSED BY THE BATTERY CASING. EACH BATTERY CASE IS VENTED OVERBOARD BY A LINE CONNECTION FROM THE OUTER CASE TO A MANIFOLD LEADING TO THE WASTE WATER OVERFLOW LINE. (FIGURE 4-1)

THE BATTERY CELLS ARE COMPOSED OF SILVER PLATED AND ZINC OXIDE COATED ELECTRODES INDIVIDUALLY WRAPPED WITH FOUR LAYERS OF .004 INCH IRRADIATED POLYETHYLENE MEMBRANE FOR SEPARATION. THIS MEMBRANE IS

POROUS AND ALLOWS THE 38% POTASSIUM HYDROXIDE (KOH) AND 62% WATER SOLUTION (ELECTROLYTE) TO COME IN CONTACT WITH THE ELECTRODES. THE ELECTROLYTE IS NOT CONSUMED DURING THE REACTION BUT IS ONLY THE MEDIUM FOR TRANSPORTING THE HYDROXYL IONS FROM ELECTRODE TO ELECTRODE.

BATTERY LIFE IS LIMITED PRIMARILY BY THE ABILITY OF THE MEMBRANE IN WITHSTANDING THE IONIC PENETRATIONS.

4.2.2 PYROTECHNIC & JETTISON CONTROL BATTERIES

THESE BATTERIES ARE OF IDENTICAL CONSTRUCTION AND HAVE NO PROVISION FOR IN-FLIGHT RECHARGING.

4.2.2.1 DESCRIPTION

THE PYROTECHNIC AND THE JETTISON CONTROL BATTERIES, ILLUSTRATED IN FIGURE 4-4, ARE 2.6 INCHES WIDE, 2.8 INCHES HIGH, 6.25 INCHES LONG AND WEIGH 3.5 POUNDS EACH WHEN COMPLETELY FILLED WITH ELECTROLYTE. THE BATTERY CASE IS CONSTRUCTED OF PLASTIC WHICH IS COATED WITH A THIN LAYER OF STAINLESS STEEL. EACH OF THE TWENTY INTERNAL CELLS IS SEPARATED BY A SHEET OF NON-CORROSIVE MATERIAL. PRESSURE RELIEF DEVICES ARE PROVIDED IN EACH OF THE CELLS, AND A RELIEF VALVE IN THE BATTERY CASE RELIEVES EXCESSIVE PRESSURES IN THE EVENT OF A MALFUNCTION. RELIEF PRESSURE OF EACH CELL IS APPROXIMATELY 35 PSIG, VENTING INTO THE BATTERY CASE. THE CASE RELIEF VALVE VENTS DIRECTLY INTO THE

DC COMPONENTS

LOWER EQUIPMENT BAY

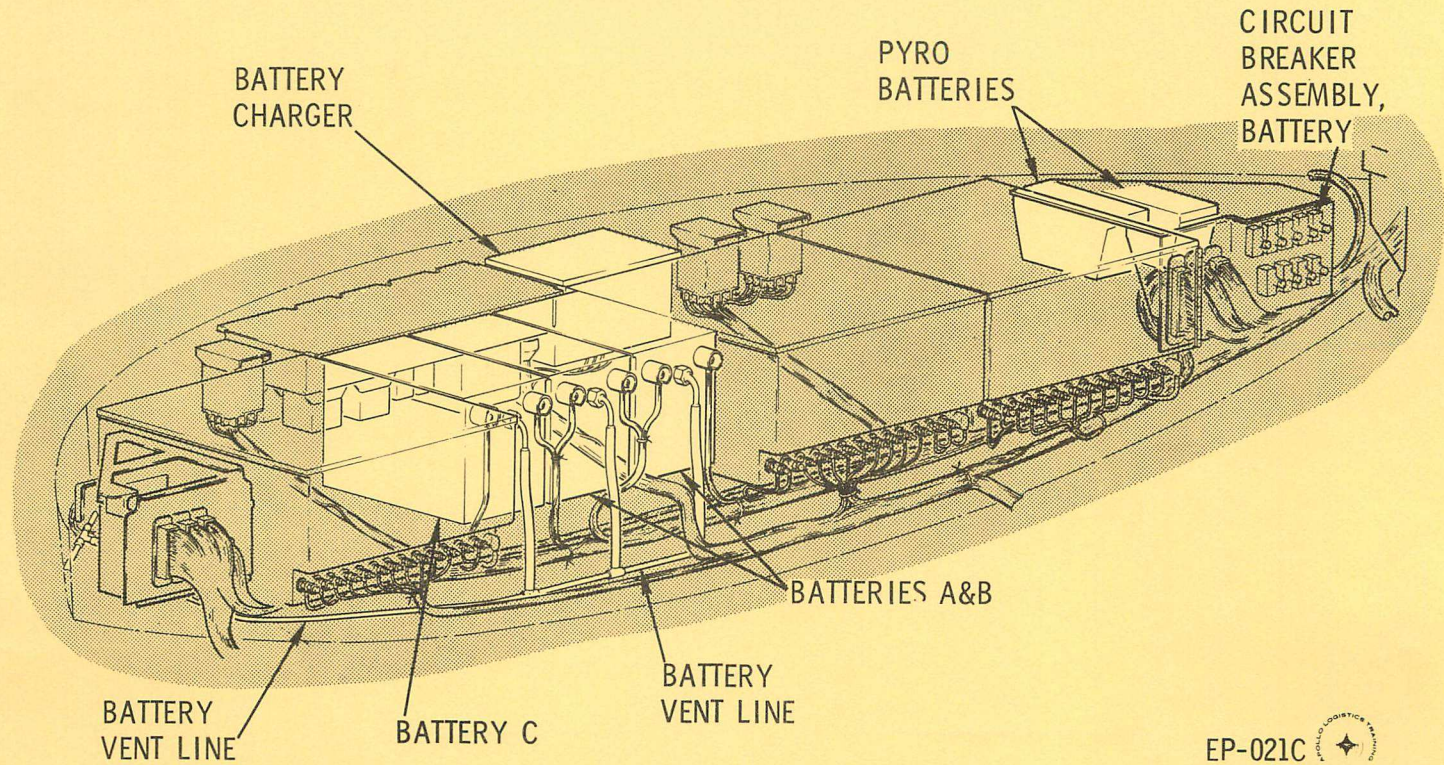


FIGURE 4-1

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ENTRY & POST LANDING BATTERY

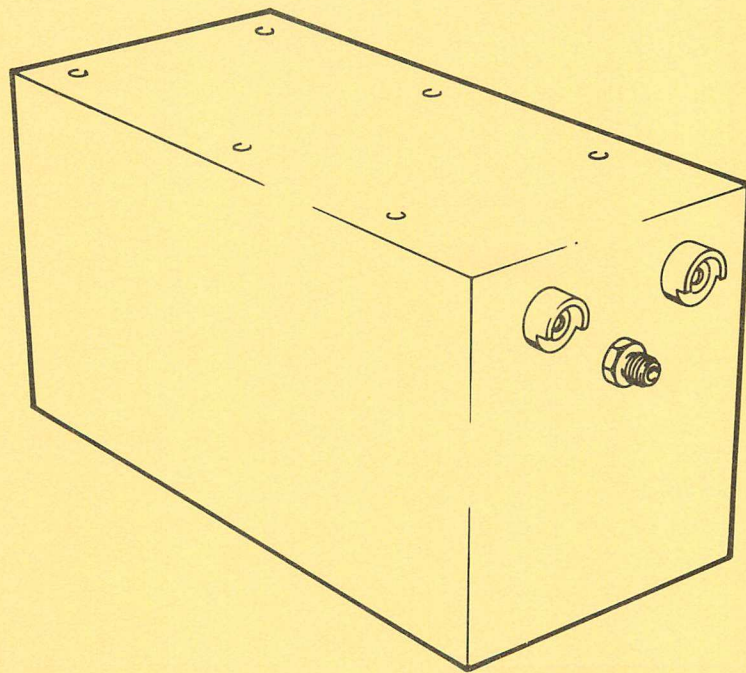


FIGURE 4-2

ENTRY & POST LANDING BATTERY

INTERIOR

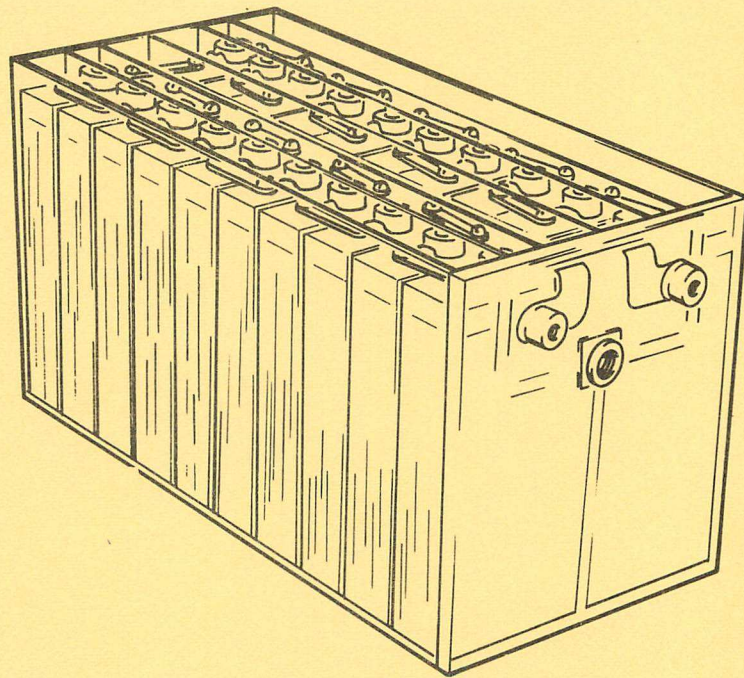


FIGURE 4-3

C/M ENVIRONMENT AT 30 ± 5 PSIG, AND RESEATS AT 20 PSIG.

EACH BATTERY, RATED AT 23 VDC, .75 AMPERE HOURS CAN PRODUCE 75 AMPS FOR 36 SECONDS DOWN TO 20 VDC, AT WHICH POINT THE BATTERY IS CONSIDERED TO BE DISCHARGED FOR THE PURPOSE OF THE MISSION. OPEN CIRCUIT VOLTAGE IS 38.0 VDC. SINCE THE BATTERIES ARE NOT NORMALLY CONNECTED TO ANY SUSTAINED LOAD, OPEN CIRCUIT VOLTAGE WILL BE USED AS A BASIS FOR VOLTAGE MEASUREMENT.

4.2.2.2 PYROTECHNIC BATTERIES

TWO OF THE FOUR BATTERIES, DESIGNATED THE PYROTECHNIC BATTERIES, SUPPLY POWER TO INITIATE ORDNANCE DEVICES FOR SEPARATION OF THE LAUNCH ESCAPE SYSTEM, THE FORWARD HEAT SHIELD, THE S/M FROM THE C/M, AND FOR DEPLOYMENT OF THE DROGUE AND MAIN CHUTES DURING A PAD ABORT, HIGH ALTITUDE ABORT OR NORMAL MISSION PROGRESSION.

THE PYROTECHNIC SYSTEM IS COMPLETELY ISOLATED FROM THE REST OF THE S/C ELECTRICAL SYSTEM, EXCEPT FOR A VOLTMETER CONNECTION, TO PREVENT INADVERTENT INITIATION OF ANY OF THE ORDNANCE DEVICES BY TRANSIENT VOLTAGES, AND ALSO TO PREVENT THE HIGH TRANSIENTS IN THE PYROTECHNIC SYSTEM FROM AFFECTING THE SPACECRAFT ELECTRICAL SYSTEM.

4.2.2.3 JETTISON CONTROL BATTERIES

THE TWO JETTISON CONTROL BATTERIES, LOCATED IN THE S/M, SUPPLY POWER THROUGH THE JETTISON CONTROL

SEQUENCER TO SUSTAIN S/M REACTION CONTROL SYSTEM RETRO FIRE AS WELL AS FIRING THE ROLL RCS ENGINES AFTER C/M-S/M SEPARATION. FIRING OF THE S/M RETRO AND ROLL RCS ASSURES UMBILICAL SEVERANCE, POSITIVE DISPLACEMENT OF THE TWO VEHICLES, AND PROVIDES A TUMBLING ACTION TO THE S/M WHICH WILL PREVENT THE S/M FROM OVERTAKING THE C/M DURING ENTRY.

4.2.3 PORTABLE LIFE SUPPORT SYSTEM BATTERIES

TWO PLSS (SUIT PACK) BATTERIES ARE LOCATED IN EACH INDIVIDUAL SUIT PACK. THESE BATTERIES WILL PROVIDE FOR APPROXIMATELY A FOUR HOUR LUNAR EXCURSION. THEY ARE SILVER OXIDE/ZINC BATTERIES, CONTAIN ELEVEN CELLS AND ARE RATED AT 16.8 VOLTS ON LOAD. OPEN CIRCUIT VOLTAGE IS $22 \pm .5$ VDC. EACH BATTERY WEIGHS 3.38 POUNDS.

SINCE THE LEM POWER SOURCE HAS BEEN CHANGED FROM FUEL CELLS TO BATTERIES, ADDITIONAL SUIT PACK BATTERIES WILL BE PROVIDED. THEY WILL PROVIDE 28 VDC (THROUGH A CONVERTER) TO THE DUPLEX MICROPHONES, 16.8 VDC TO THE DUPLEX COMMUNICATIONS & TELEMETRY CIRCUITS, AND 16.8 VAC TO THE FAN AND PUMP MOTORS IN EACH SUIT PACK.

4.3 BATTERY CHARGER

A SOLID STATE BATTERY CHARGER, LOCATED IN THE C/M LOWER EQUIPMENT BAY, IS INCORPORATED INTO THE SPACECRAFT ELECTRICAL SYSTEM. THE CHARGER COMBINES DC AND

PYRO BATTERY

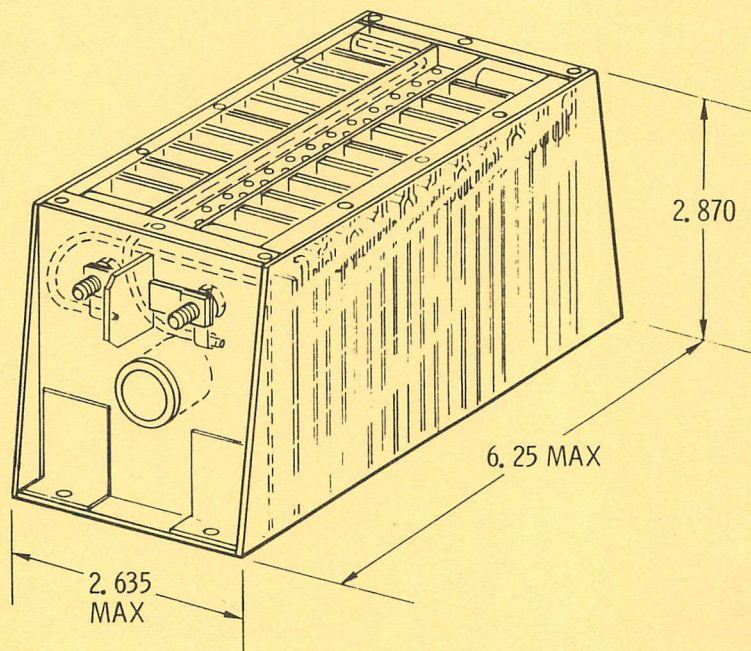


FIGURE 4-4

EP-026



AC INPUTS TO PRODUCE SUFFICIENT POWER TO FULLY CHARGE ANY OF THE SELECTED COMPONENTS.

IN A WORST CASE SITUATION INVOLVING LOSS OF TWO FUEL CELL MODULES DURING LUNAR ORBIT, ADDITIONAL BATTERIES WOULD BE REQUIRED TO SUPPLEMENT THE REMAINING FUEL CELL MODULE DURING TRANS-EARTH INJECTION, MID-COURSE CORRECTIONS AND TO PROVIDE POWER DURING ENTRY. UTILIZING THE 4.3 POUND BATTERY CHARGER RESULTS IN A WEIGHT SAVING OF SEVERAL POUNDS.

4.3.1 THEORY OF OPERATION

FIGURE 4-5 IS AN ILLUSTRATION OF THE COMPACT BATTERY CHARGER WHICH IS 4 INCHES HIGH, 6 INCHES WIDE AND 6 INCHES LONG. FIGURE 4-6 DEPICTS A FUNCTIONAL FLOW DIAGRAM OF BATTERY CHARGER OPERATION. ONE SWITCH ON THE MAIN DISPLAY CONSOLE CONTROLS POWER INPUT TO THE CHARGER, AS WELL AS CONNECTING THE CHARGER OUTPUT TO THE SELECTED BATTERY. THE "MAIN BUS TIE" SWITCH FOR THE SELECTED BATTERY MUST BE POSITIONED TO "OFF" TO PROVIDE A COMPLETE CIRCUIT FROM THE CHARGER TO THE BATTERY.

THE BATTERY CHARGER USES 29 VOLTS DC FROM THE FUEL CELLS THROUGH THE MAIN DC BUSES, AND 115 VOLTS AC, 400 CPS, 3Ø FROM THE INVERTER THROUGH EITHER OF THE AC BUSES. ALL THREE PHASES OF THE AC ARE USED TO BOOST THE 29 VDC INPUT AND PRODUCE 40 VDC FOR CHARGING. IN ADDITION, PHASE A IS RECTIFIED AND USED TO SUPPLY POWER FOR THE REMAINDER OF THE CHARGER CIRCUITRY.

THE LOGIC NETWORK IN THE CHARGER, CONSISTING OF A TWO STAGE DIFFERENTIAL AMPLIFIER (COMPARATOR), A VOLTAGE AMPLIFIER, A SCHMITT TRIGGER, AND A CURRENT SENSING RESISTOR WILL SET UP THE INITIAL CONDITION FOR OPERATION. THE FIRST STAGE OF THE COMPARATOR IS IN THE ON MODE, AND THE SECOND STAGE OFF, THE VOLTAGE AMPLIFIER IS CONDUCTING, THUS PLACING THE SCHMITT TRIGGER FIRST STAGE ON AND SECOND STAGE OFF. THIS CONDITION PROVIDES MAXIMUM BASE DRIVE TO THE CURRENT AMPLIFIER WHICH TURNS ON THE SWITCHING TRANSISTOR, CLOSING THE CIRCUIT.

WITH THE SWITCHING TRANSISTOR ON, CURRENT FLOWS FROM THE TRANSFORMER RECTIFIER THROUGH THE SWITCHING TRANSISTOR, CURRENT SENSING RESISTOR, AND SWITCHING CHOKE TO THE BATTERY BEING CHARGED. AS CURRENT FLOW INCREASES, A FIELD OF ENERGY IS BUILT UP IN THE CHOKE AND THE VOLTAGE DROP ACROSS THE SENSING RESISTOR INCREASES. NORMAL CHOKE ACTION CAUSES THE CURRENT TO LAG BEHIND THE VOLTAGE.

THE VOLTAGE ACROSS THE SENSING RESISTOR INCREASES TO A LEVEL WHICH TURNS OFF THE FIRST STAGE OF THE COMPARATOR CAUSING THE SECOND STAGE TO CONDUCT. THIS CONDITION TURNS OFF THE VOLTAGE AMPLIFIER, WHICH REVERSES THE OPERATION OF THE SCHMITT TRIGGER TO FIRST STAGE OFF, SECOND STAGE ON. THIS SHUTS OFF THE CURRENT AMPLIFIER, 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 COLLAPSE AND DISCHARGE INTO THE

APOLLO BATTERY CHARGER

INTERIOR

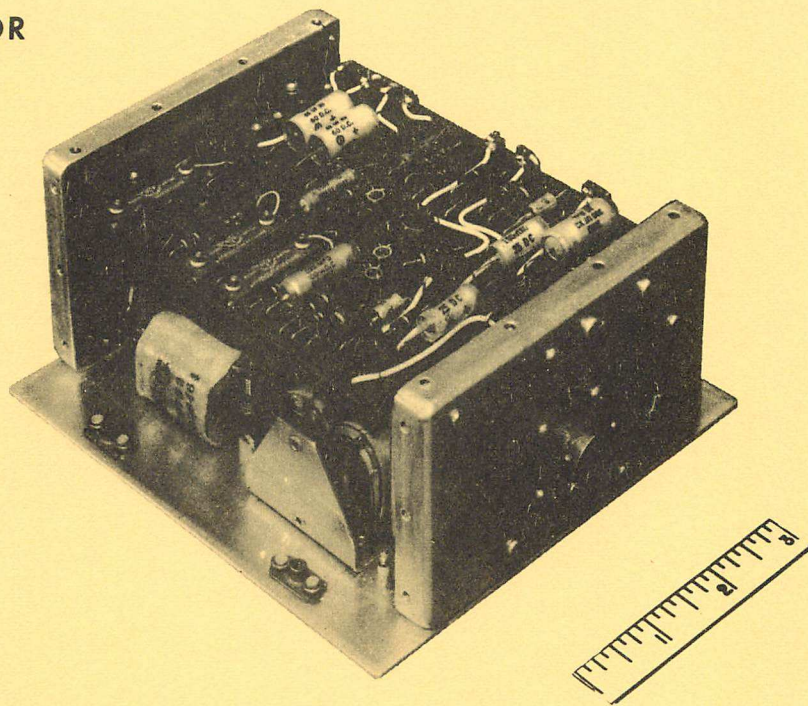


FIGURE 4-5

BATTERY CHARGER FUNCTIONAL DIAGRAM

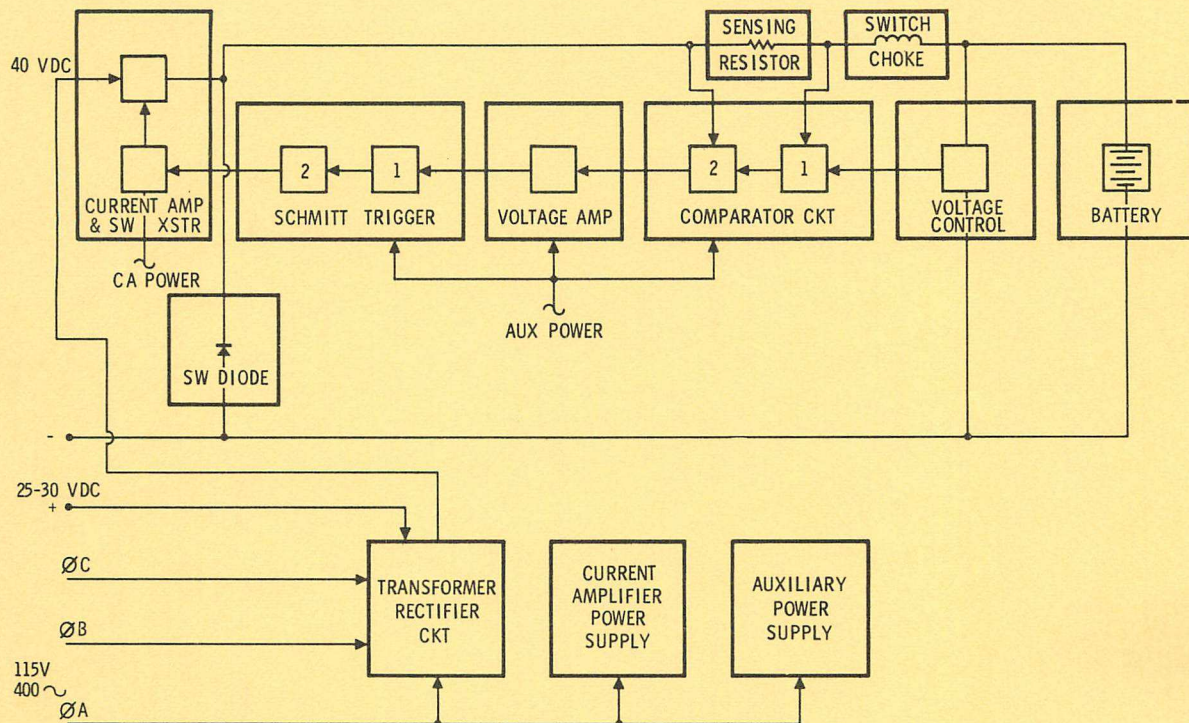


FIGURE 4-6

BATTERY, THEN THROUGH THE SWITCHING DIODE, THE CURRENT SENSING RESISTOR, BACK TO THE OTHER SIDE OF THE CHOKE. AS THE EMF IN THE CHOKE DECREASES, CURRENT THROUGH THE CURRENT SENSING RESISTOR WILL DECREASE, THUS REDUCING THE VOLTAGE DROP ACROSS THIS RESISTOR. AT SOME POINT, THE DECREASE IN VOLTAGE ACROSS THE SENSING RESISTOR REVERSES THE OPERATION OF THE COMPARATOR, SETTING UP THE INITIAL CONDITION AND COMPLETING ONE CYCLE OF OPERATION. THIS CYCLIC ACTION OCCURS AT A VERY RAPID RATE. WITH LOW BATTERY VOLTAGE, IT WILL OCCUR AT APPROXIMATELY 5 KC, INCREASING TO AS HIGH AS 2 MC AS BATTERY VOLTAGE INCREASES AND THE CHARGER MERELY PROVIDES A TRICKLE CHARGE. 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 SCHMITT TRIGGER AND THE SWITCHING TRANSISTOR THROUGH THE ACTION OF THE COMPARATOR.

BATTERY CHARGER OUTPUT IS CURRENT CONTROLLED UNTIL BATTERY VOLTAGE REACHES APPROXIMATELY 36 VOLTS, AT WHICH TIME THE OUTPUT IS VOLTAGE REGULATED. AT THIS TIME THE VOLTAGE CONTROL NETWORK IS UNBIASED, AND IN CONJUNCTION WITH THE SENSING RESISTOR PROVIDES INPUTS TO THE COMPARATOR CONTROLLING THE CYCLING OPERATION OF THE CHARGER.

FIGURE 4-7 ILLUSTRATES THE CHARACTERISTIC CURVE OF BATTERY CHARGER OUTPUT. AS THE DIFFERENCE BETWEEN BATTERY AND CHARGER VOLTAGE DECREASES, CURRENT OUTPUT FROM THE CHARGER WILL DECREASE. AT APPROXIMATELY 40 PLUS 0 MINUS 1 VOLTS CURRENT FLOW BECOMES NEGLIGIBLE.

CURRENT VS VOLTAGE REGULATION CURVE

OUTPUT VOLTAGE
(VOLTS)

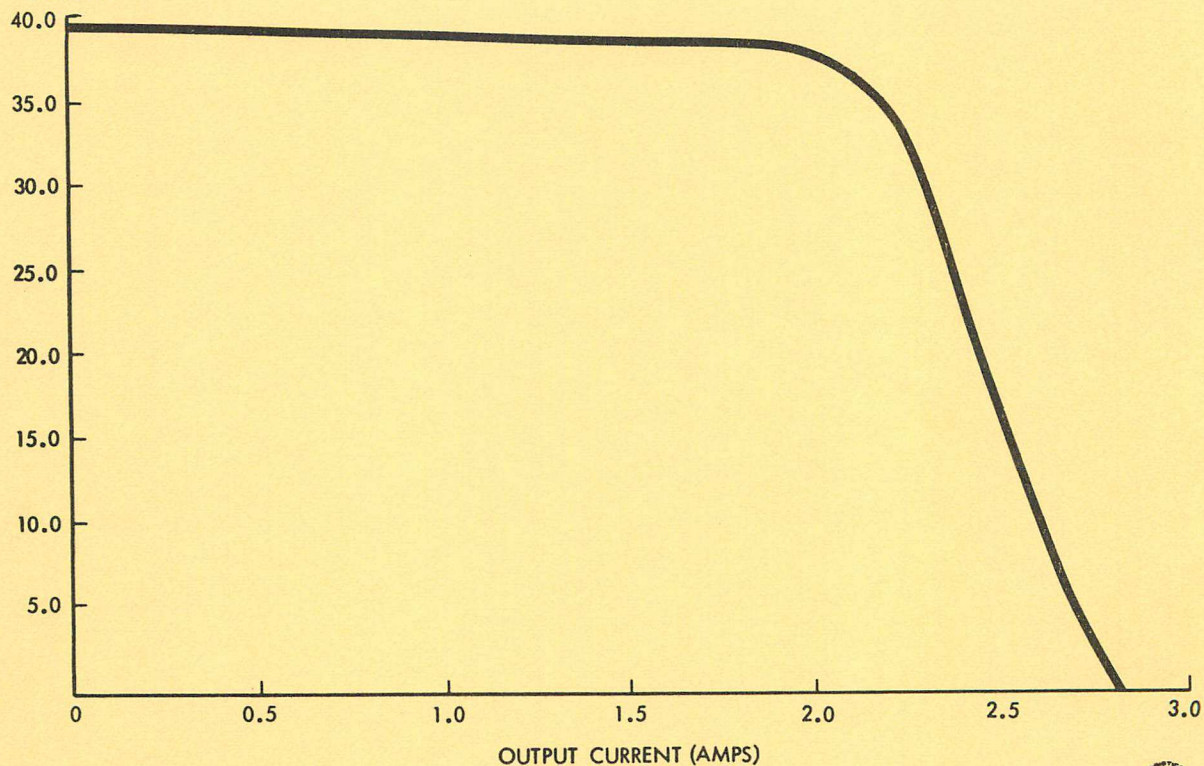


FIGURE 4-7

SECTION V

DC POWER SYSTEM

5.1 DC POWER DISTRIBUTION

THIS SYSTEM, CONSISTING OF POWER SUPPLIES, BUSES, CONTROL AND SENSING CIRCUITS, IS THE MEANS OF POWER DISTRIBUTION IN THE SPACECRAFT. THE MAJOR COMPONENTS CONCERNED ARE THE FUEL CELLS, BATTERIES, MAIN AND BATTERY BUSES, CIRCUIT BREAKERS, ISOLATION DIODES AND PROTECTION CIRCUITS. FIGURE 5-1 DEPICTS THE DC POWER DISTRIBUTION SYSTEM. THROUGHOUT THIS DIAGRAM PARTICULAR POINTS ARE MARKED BY VM, AM AND DOUBLE SQUARES. THESE ARE VOLTAGE AND CURRENT SAMPLING POINTS WHICH FURNISH INFORMATION OF ELECTRICAL POWER SYSTEM OPERATING CONDITIONS TO THE ASTRONAUTS BY VISUAL DISPLAYS, OR TO THE MSFN. THE POINTS MARKED VM INDICATE VOLTAGE MEASUREMENTS WHICH ARE DISPLAYED ON THE "DC VOLTS" METER. THE POINTS MARKED AM INDICATE CURRENT MEASUREMENTS WHICH ARE DISPLAYED ON THE "DC AMPS" METER. THE VM AND AM MEASUREMENTS TO BE DISPLAYED ARE SELECTED BY THE "DC INDICATORS" SWITCH. THE DOUBLE SQUARES INDICATE VOLTAGE OR CURRENT MEASUREMENTS WHICH ARE TELEMETERED TO THE MSFN.

5.1.1 FUEL CELL MODULES

EACH F/C MODULE OUTPUT CONTAINS TWO PARALLEL OVERLOAD/REVERSE CURRENT SENSING CIRCUITS. THE INPUT TO EACH CIRCUIT IS CONTROLLED BY THE "BUS A" AND "BUS B" SWITCHES ON THE FUEL CELLS, ELECTRICAL POWER SYSTEM PANEL OF THE MAIN DISPLAY CONSOLE. THESE SWITCHES ALSO

CONNECT FUEL CELL OUTPUT TO THE MAIN DC BUSES. THE SENSING CIRCUITS PROVIDE AN AUTOMATIC DISCONNECT AT AN OVERLOAD ABOVE 75 AMPS OR A REVERSE CURRENT FLOW ABOVE 4 AMPS. ANY MANUAL OR AUTOMATIC DISCONNECT WILL BE DISPLAYED ON ONE OF THE SIX MECHANICAL FLAG INDICATORS LOCATED JUST BELOW THE "BUS A" AND "BUS B" SWITCHES. THE "F/C BUS DISCONNECT" LAMP ON THE CAUTION AND WARNING PANEL WILL ACCOMPANY ANY AUTOMATIC DISCONNECT.

5.1.2 DC MAIN BUSES

THE TWO MAIN DC BUSES, A & B, ARE NORMALLY POWERED BY THE THREE FUEL CELL MODULES. COMBINATIONS OF BATTERIES, A & C AND/OR B & C, CAN BE CONNECTED TO THE MAIN BUSES TO SUPPLEMENT THE F/C'S DURING THE PEAK LOAD PERIODS, AND TO PROVIDE PRIMARY POWER DURING ENTRY AND POST LANDING. EITHER OF THE MAIN DC BUSES IS INDIVIDUALLY CAPABLE OF DISTRIBUTING SUFFICIENT POWER FOR ALL SPACECRAFT SYSTEMS.

EACH MAIN DC BUS HAS AN UNDERVOLTAGE SENSING CIRCUIT. IF BUS VOLTAGE FALLS BELOW 26.8 VOLTS, BATTERY RELAY BUS POWER WILL ILLUMINATE AN "UNDERVOLTAGE" LAMP ON THE CAUTION & WARNING PANEL. MANUAL OPERATION OF THE RESPECTIVE "RESET" SWITCH WILL EXTINGUISH THE LAMP. IF THE CAUSE WAS TEMPORARY, THE LAMP WILL REMAIN EXTINGUISHED, BUT IF THE CAUSE PERSISTS, THE LAMP WILL REMAIN ILLUMINATED, REQUIRING SOME REMEDIAL ACTION BY THE ASTRONAUTS.

EPS POWER DISTRIBUTION DC POWER SYSTEM

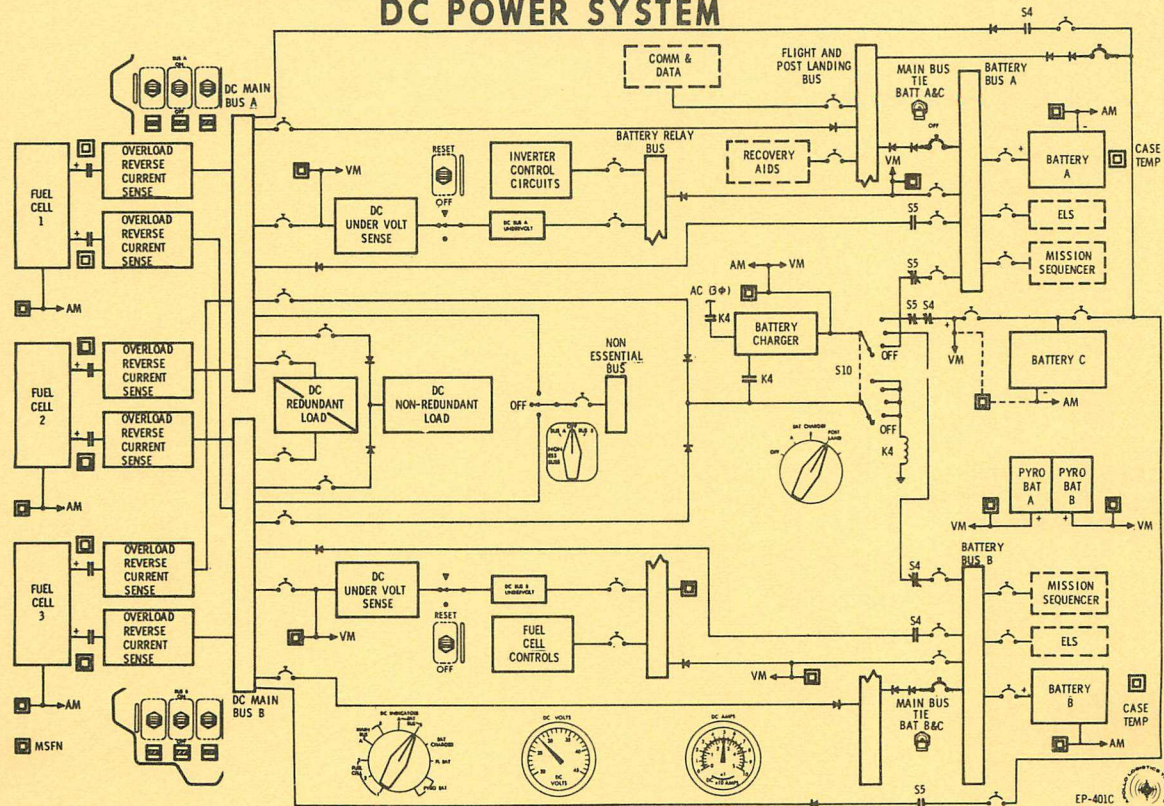


FIGURE 5-1

5.1.2.1 DISTRIBUTION

BOTH MAIN DC BUSSES, A & B, PROVIDE DISTRIBUTION OF POWER THROUGH CIRCUIT BREAKERS TO THE DC REDUNDANT LOADS, AND THROUGH CIRCUIT BREAKERS AND ISOLATION DIODES TO THE FLIGHT & POST LANDING BUS, NON-REDUNDANT LOADS, AND THE BATTERY CHARGER. NON-ESSENTIAL BUS POWER IS CONTROLLED BY A SWITCH WHICH PERMITS SELECTION OF MAIN BUS A OR B OR AN OFF POSITION. POWER WILL BE MANUALLY REMOVED FROM THE NON-ESSENTIAL BUS DURING A POWER EMERGENCY CONDITION, THAT IS, TWO OF THE THREE FUEL CELL MODULES INOPERATIVE. THE NON-ESSENTIAL BUS DISTRIBUTES POWER TO COMPONENTS CONSIDERED NOT ESSENTIAL FOR A SAFE RETURN.

5.1.3 FLIGHT & POST LANDING BUS

THE FLIGHT & POST LANDING BUS DISTRIBUTES POWER TO THE COMMUNICATIONS AND DATA EQUIPMENT. POWER IS SUPPLIED TO THE BUS THROUGH BOTH MAIN DC BUSSES IN PARALLEL THROUGH ISOLATION DIODES. THE FUEL CELL MODULES PROVIDE THIS POWER DURING FLIGHT. AFTER C/M-S/M SEPARATION, POWER IS PROVIDED BY BATTERIES A, B AND C. THE F & PL BUS HAS CIRCUIT BREAKERS FOR CONNECTION DIRECTLY TO EACH OF THE THREE BATTERIES. THESE ARE CIRCLED ON THE DIAGRAM, AND WILL NORMALLY BE OPEN IN FLIGHT FROM ATTAINMENT OF EARTH ORBIT UNTIL AFTER LANDING. POWER DURING ENTRY WILL BE PROVIDED BY THE BATTERIES THROUGH THE MAIN DC BUSSES. THE CIRCUIT BREAKERS PROVIDE ISOLATION OF THE F & PL FROM THE BATTERIES WHILE THEY ARE BEING CHARGED BY THE 40 VOLT OUTPUT OF THE BATTERY CHARGER.

5.1.4 BATTERIES A, B, C & BATTERY BUSSES A & B

BACKUP FOR S/C FUEL CELL POWER IS PROVIDED BY THE BATTERY SYSTEM. BATTERIES A & B, UNLESS OTHERWISE SELECTED, WILL POWER ONLY THE BATTERY RELAY BUS THROUGH THE INDIVIDUAL BATTERY BUSSES AND ISOLATION DIODES, AS WELL AS CIRCUIT BREAKERS.

EACH OF THE EARTH LANDING AND MISSION SEQUENCER SYSTEMS (A & B) IS POWERED THROUGH CIRCUIT BREAKERS FROM THE RESPECTIVE A OR B BATTERY BUS. AFTER COMPLETION OF TRANSPOSITION AND DOCKING AND UNTIL PREPARATION FOR ENTRY, THESE CIRCUIT BREAKERS WILL BE OPENED TO ELECTRICALLY DISCONNECT THE SYSTEMS FOR POWER CONSERVATION, AND TO PREVENT INADVERTENT SEQUENCING OF THE ENTRY AND LANDING SYSTEMS.

TO PROVIDE THE FUEL CELL BACK-UP CAPABILITY, THE BATTERIES MUST BE MANUALLY CONNECTED TO THE MAIN DC BUSSES. BATTERIES A & B ARE CONNECTED THROUGH THEIR INDIVIDUAL BATTERY BUSSES, AND BATTERY C IS CONNECTED DIRECT. THE "MAIN BUS TIE" SWITCH OF THE CORRESPONDING A & C AND/OR B & C BATTERIES MUST BE MANUALLY OPERATED TO THE "ON" POSITION. THIS WILL CLOSE THE NORMALLY OPEN CONTACTS OF S-4 AND/OR S-5 TO ELECTRICALLY CONNECT THROUGH CIRCUIT BREAKERS, MOTOR SWITCH CONTACTS, AND ISOLATION DIODES, THE SELECTED PAIR OF BATTERIES TO MAIN DC BUS A & B. THE THIRD SET OF CONTACTS OF MOTOR SWITCHES S-4 AND S-5, WHICH ARE NORMALLY CLOSED, ARE OPENED AND CHARGING OF THE RESPECTIVE PAIR OF BATTERIES IS PREVENTED UNTIL THEY ARE DISCONNECTED FROM THE MAIN BUSSES.

PAIRS OF DIODES HAVE BEEN PLACED IN THE CONNECTION BETWEEN THE THREE CIRCUIT BREAKERS WHICH CONNECT THE F & PL DIRECTLY TO THE BATTERIES. AFTER LANDING, WHEN THE THREE CIRCUIT BREAKERS ARE CLOSED TO PROVIDE A DIRECT CONNECTION OF BATTERY POWER TO THE F & PL BUS, THE DIODES PROVIDE A VOLTAGE DROP TO BRING OPERATING VOLTAGE DOWN TO THE LEVEL REQUIRED BY THE LOW LOADS OF THE RECOVERY EQUIPMENT.

5.1.5 BATTERY CHARGER

THE CHARGER IS CONTROLLED BY A SINGLE SWITCH, "BATTERY CHARGER", LOCATED ON THE FUEL CELLS, ELECTRICAL POWER SYSTEM PANEL OF THE MAIN DISPLAY CONSOLE. PLACING THE SWITCH IN EITHER THE A, B, OR C POSITION PROVIDES THE POWER INPUT INTO THE CHARGER, AS WELL AS PROVIDING A CONNECTION TO THE BATTERY SELECTED. THE "OFF" POSITION REMOVES POWER FROM THE CHARGER AND DISCONNECTS IT FROM ALL OUTPUT CIRCUITS. THE BATTERY SELECTED FOR CHARGING MUST BE DISCONNECTED FROM THE MAIN DC BUS BEFORE THE CHARGER CONNECTION CAN BE MADE.

5.1.6 VOLTMETER & AMMETER

INPUTS TO THE METERS ARE CONTROLLED BY THE DC INDICATORS SWITCH. VOLTAGE CAN BE MEASURED ON MAIN BUS A OR B, BAT BUS A OR B, BAT CHARGER, PL BAT, AND PYRO BAT. CURRENT CAN BE MEASURED ON F/C 1, 2 OR 3, BAT BUS A OR B, BAT CHARGER, AND PL BAT. THE OUTER SCALE OF THE AMMETER PROVIDES A CURRENT INDICATION OF ALL BUT BATTERY CHARGER OUTPUT. THE INNER SCALE PROVIDES AN INDICATION OF BATTERY CHARGER CURRENT OUTPUT, AND WILL BE USED TO DETERMINE HOW MUCH OF A CHARGE IS REQUIRED BY ANY OF THE SELECTED BATTERIES.

5.2 FUEL CELL CONTROL CIRCUIT

PROTECTIVE CIRCUITS, INCORPORATED INTO THE OUTPUT OF EACH FUEL CELL MODULE, WILL DISCONNECT THE MODULE FROM THE BUS IF AN OVERLOAD OR REVERSE CURRENT CONDITION IS SENSED. THESE ARE ILLUSTRATED AS A BLOCK DIAGRAM IN FIGURE 5-2.

5.2.1 OPERATION

FIGURE 5-2 DEPICTS THE PRESENT CONCEPT OF OPERATION OF THE OVERLOAD/REVERSE CURRENT SENSING AND AUTOMATIC DISCONNECT. THE FUEL CELL CIRCUIT IS DEPICTED IN AN OFF CONDITION. THE BATTERY RELAY BUS PROVIDES POWER THROUGH THE CIRCUIT BREAKER TO THE "ON-OFF" SWITCH. WHEN THIS SWITCH IS MOMENTARILY POSITIONED "ON", POWER IS APPLIED TO THE MOTOR, WHICH ROTATES, CLOSING CONTACT C-1 TO POINT A, CONTACT C-2 TO POINT B, AND CONTACT C-3 TO POINT C, AS INDICATED BY THE DASHED LINES. CONTACT C-1 REMOVES POWER FROM THE MOTOR AND IS POSITIONED TO ACCEPT AN OFF COMMAND. CONTACT C-2 CONNECTS FUEL CELL OUTPUT TO THE MAIN DC BUS THROUGH THE SENSING CIRCUIT. CONTACT C-3 PROVIDES A TELEMETRY OUTPUT THAT THE FUEL CELL IS CONNECTED TO THAT PARTICULAR BUS.

FUEL CELL MODULE OUTPUT MAY BE DISCONNECTED FROM A MAIN DC BUS IN ONE OF THREE WAYS. THE MANUAL CONTROL SWITCH MAY BE POSITIONED TO "OFF", THE OVERLOAD SENSING CIRCUIT MAY DETECT CURRENT GREATER THAN 75 AMPS, OR THE REVERSE CURRENT SENSING CIRCUIT MAY DETECT REVERSE CURRENT OF MORE THAN 4 AMPS. DURING AN AUTOMATIC DISCONNECT BY THE SENSING CIRCUITS, A "F/C BUS DISCONNECT" LAMP IN THE CAUTION & WARNING GROUP,

FUEL CELL CONTROL CIRCUIT

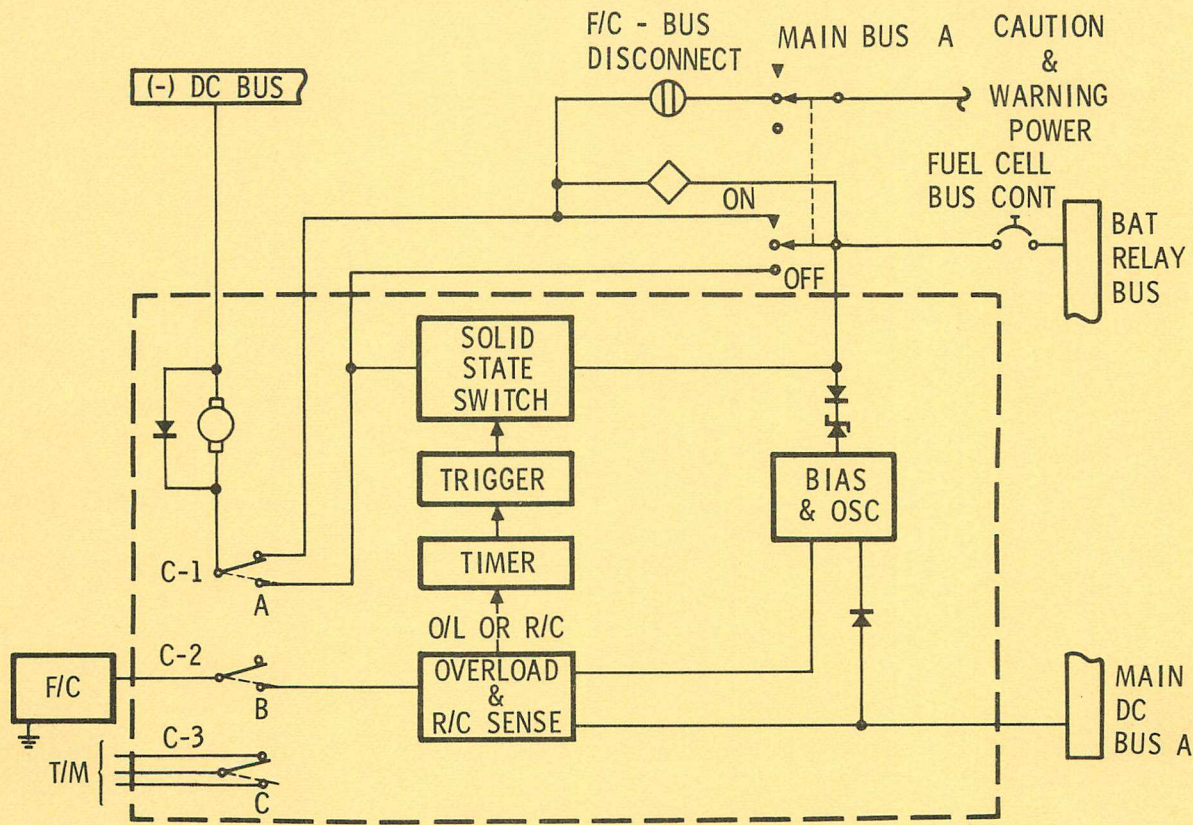


FIGURE 5-2

AND A FLAG ANNUNCIATOR ON THE FUEL CELLS, ELECTRICAL POWER SYSTEM PANEL WILL BE ACTIVATED. ONLY THE FLAG ANNUNCIATOR WILL BE ACTIVATED DURING A MANUAL DISCONNECT.

WHEN AN OVERLOAD OR REVERSE CURRENT CONDITION OCCURS, THE SENSING UNIT PROVIDES A SIGNAL, DELAYED BY THE TIMER, TO THE TRIGGER NETWORK. THE DELAY IS INVERSE TO THE AMOUNT OF CURRENT DETECTED. DURING 100% OVERLOAD, CURRENT FLOW OF 75 AMPS MUST EXIST FOR APPROXIMATELY 15 MINUTES, WHILE AN OVERLOAD OF 150% WOULD BE PERMITTED FOR ONLY 25 TO 30 SECONDS, BEFORE A SIGNAL WOULD BE PROVIDED TO THE TRIGGER TO EFFECT A DISCONNECT.

THE SWITCH WILL NOT FUNCTION BELOW A REVERSE CURRENT FLOW OF 4 AMPS. REVERSE CURRENT BETWEEN 4 AND 11 AMPS WOULD HAVE TO EXIST FOR A PERIOD OF OVER 10 SECONDS BEFORE DISCONNECT. ELEVEN TO 20 AMPS REVERSE CURRENT WOULD HAVE TO EXIST FOR A PERIOD BETWEEN 1 AND 10 SECONDS. THE ONE SECOND TIME DELAY IS THE MINIMUM ALLOWED TO ELIMINATE TRANSIENT EFFECTS.

THE TRIGGER OPERATES THE SOLID STATE SWITCH TO COMPLETE A CIRCUIT FROM THE BATTERY RELAY BUS TO POINT A OF CONTACT C-1, PROVIDING POWER TO THE MOTOR.

THE FLAG ANNUNCIATOR IS IN SERIES WITH THE MOTOR. THE VOLTAGE DROP ACROSS THE ANNUNCIATOR IS OF SUFFICIENT MAGNITUDE THAT THERE IS INSUFFICIENT VOLTAGE TO DRIVE THE MOTOR, THUS THE MOTOR MERELY PROVIDES A GROUND FOR THE ANNUNCIATOR. CONTACT C-3 PROVIDES TELEMETRY INFORMATION WHETHER THE FUEL CELL MODULE IS OR IS NOT CONNECTED.

NOTE THAT THE CONTROLLING MOTOR SWITCH OPERATES FROM THE BATTERY RELAY BUS, THUS MAKING IT INDEPENDENT OF FUEL CELL OUTPUT.

5.3 DC UNDERVOLTAGE SENSING

AN UNDERVOLTAGE SENSING UNIT IS USED TO MONITOR EACH MAIN DC BUS TO PROVIDE A WARNING INDICATION IN THE EVENT OF THIS CONDITION. FIGURE 5-3 DEPICTS THIS CIRCUIT. THE UNDERVOLTAGE SAMPLES THE VOLTAGE OF THE MAIN BUSES, BUT CAN DRAW OPERATING POWER FROM THE BATTERY RELAY BUS TO MAINTAIN ITS INDEPENDENCE FROM THE MAIN BUSES.

5.3.1 OPERATION

THE SAMPLED VOLTAGE FROM THE MAIN DC BUS IS REDUCED ACROSS THE CURRENT LIMITING RESISTOR. THIS LEAVES 10.2 VDC WHICH IS APPLIED TO THE BRIDGE NETWORK WHEN MAIN BUS VOLTAGE IS AT THE PROPER LEVEL. THE 10.2 VDC APPLIED TO THE BRIDGE PROVIDES 5.1 VDC ACROSS EACH OF THE FOUR LEGS, THUS BALANCING THE BRIDGE NETWORK. THE FOUR RESISTORS IN SERIES WITH THE CURRENT LIMITING RESISTOR ARE USED FOR CALIBRATION OF THE BRIDGE CIRCUIT. THE TWO DIODES IN SERIES WITH THE RESISTORS PROVIDE TEMPERATURE COMPENSATION TO MAINTAIN THE PROPER BRIDGE POTENTIAL IRRESPECTIVE OF ENVIRONMENTAL TEMPERATURE.

ANY VARIATION IN BUS VOLTAGE WILL BE REFLECTED IN A PROPORTIONAL CHANGE IN THE BRIDGE NETWORK. THE CIRCUITRY IS DESIGNED TO PROVIDE A CAUTION LAMP

DC UNDERVOLTAGE SENSING UNIT

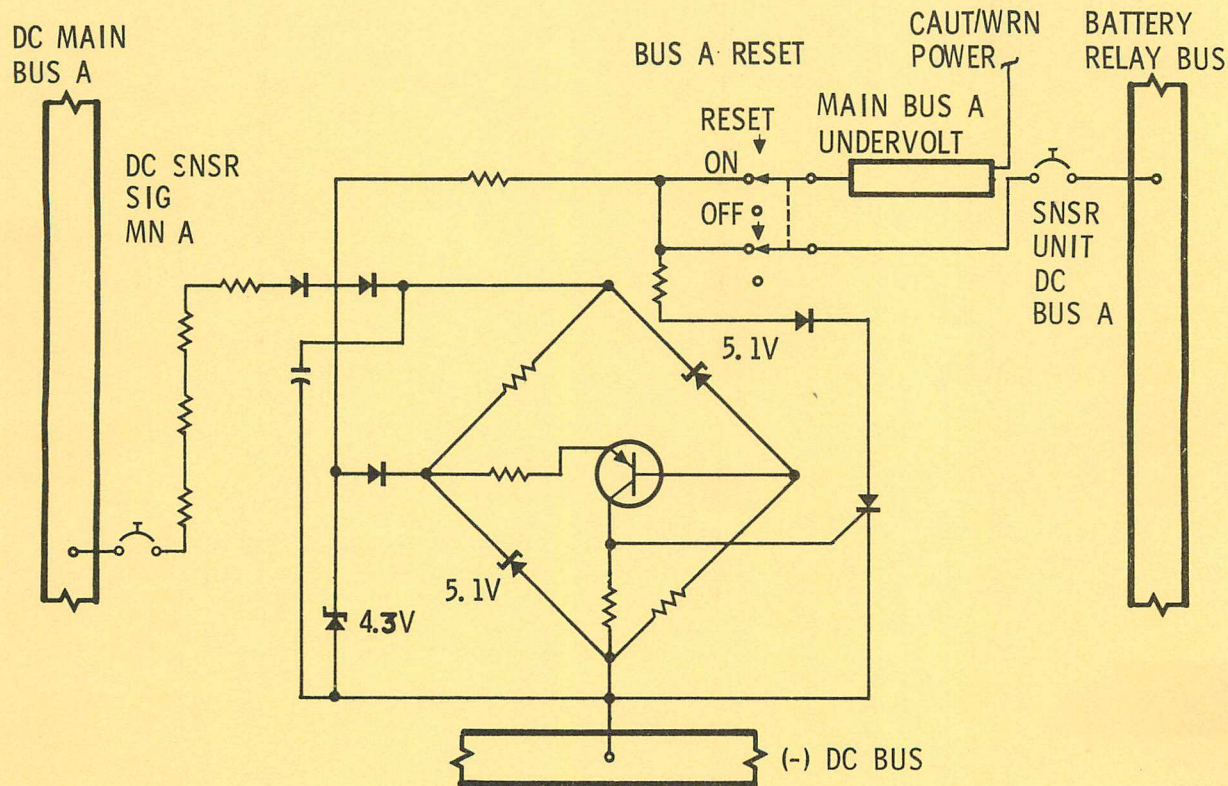


FIGURE 5-3

ILLUMINATION WHEN BUS VOLTAGE DECREASES BELOW $26.8 \pm .8$ VDC. A DECREASE BELOW THIS LEVEL SUFFICIENTLY UNBALANCES THE BRIDGE TO TRIGGER THE SILICON CONTROLLED RECTIFIER (SCR) INTO CONDUCTION, THUS COMPLETING A CIRCUIT FROM THE CAUTION/WARNING POWER SOURCE THROUGH THE "MAIN BUS UNDERVOLTAGE" LAMP AND THE "RESET" SWITCH TO GROUND. A PARALLEL PATH IS COMPLETED FROM THE BATTERY RELAY BUS THROUGH THE CURRENT LIMITING RESISTOR AND THE "RESET" SWITCH. ONCE THE SCR IS TRIGGERED INTO CONDUCTION, IT WILL CONTINUE CONDUCTING UNTIL POWER IS INTERRUPTED, IRRESPECTIVE OF THE CONDITION OF THE BRIDGE OR MAIN BUS VOLTAGE. INTERRUPTION OF POWER IS ACCOMPLISHED BY ACTIVATING THE "RESET" SWITCH TO THE MOMENTARY "RESET" POSITION. THIS EXTINGUISHES THE LAMP BY DISCONTINUING POWER TO THE SCR. IF THE BRIDGE REMAINS UNBALANCED DUE TO LOW BUS VOLTAGE, THE LAMP WILL RE-ILLUMINATE THROUGH THE SENSING CIRCUIT. IF BUS VOLTAGE IS ABOVE THE TRIGGER LEVEL, THE LAMP WILL REMAIN EXTINGUISHED.

IN A BALANCED CONDITION, ALL LEGS OF THE BRIDGE HAVE 5.1 VDC APPLIED. WITH A DECREASE IN BUS VOLTAGE, INPUT TO THE BRIDGE IS DECREASED PROPORTIONATELY. THE ZENER DIODES MAINTAIN THEIR 5.1 VDC, AND THE REMAINING LESSER VOLTAGE IS APPLIED ACROSS EACH OF THE TWO BRIDGE RESISTORS. THE POTENTIAL DIFFERENCE ACROSS THE BRIDGE CENTER PROVIDES A MORE POSITIVE VOLTAGE TO THE TRANSISTOR EMITTER, CAUSING THE PNP TRANSISTOR TO CONDUCT. THE VOLTAGE DEVELOPED ACROSS THE RESISTOR BETWEEN THE TRANSISTOR AND THE NEGATIVE DC BUS PROVIDES A POSITIVE POTENTIAL TO THE GATE OF THE

SCR CAUSING IT TO CONDUCT. THIS COMPLETES A CIRCUIT FROM THE CAUTION/WARNING POWER SUPPLY THROUGH THE UNDERVOLTAGE LAMP AND THE "RESET" SWITCH, ILLUMINATING THE LAMP. A PARALLEL PATH IS COMPLETED FROM THE BATTERY RELAY BUS THROUGH THE CURRENT LIMITING RESISTOR AND THE "RESET" SWITCH. INTERRUPTION OF POWER BY USE OF THE "RESET" RESETS THE CIRCUIT TO A MONITORING STATUS IF BUS VOLTAGE IS ABOVE $26.8 \pm .8$ VDC.

IF MAIN DC BUS VOLTAGE DECREASES TO ZERO, OR BELOW 5.1 VDC, THE BRIDGE WILL NOT BE FUNCTIONAL. THEREFORE, AN INPUT IS PROVIDED TO THE BRIDGE TRANSISTOR FROM THE BATTERY RELAY BUS. THIS INPUT IS 4.3 VDC (DETERMINED BY THE 4.3 VOLT ZENER DIODE) TO THE EMITTER OF THE TRANSISTOR, WITH THE REMAINING VOLTAGE ACROSS THE CURRENT LIMITING RESISTOR WHICH IS IN SERIES WITH THE ZENER DIODE. THIS 4.3 VDC WILL CAUSE THE TRANSISTOR TO CONDUCT, SWITCHING ON THE SCR AND PROVIDING THE SAME REACTION AS AN UNDERVOLTAGE ON THE MAIN DC BUS. SINCE THIS ZENER VOLTAGE (4.3 VDC) IS LESS THAN THE NORMAL VOLTAGE APPLIED TO THE BRIDGE ZENER'S, IT DOES NOT AFFECT CIRCUIT OPERATION WHEN BUS VOLTAGE IS ABOVE 5.1 VDC.

THE UNDERVOLTAGE SENSING CIRCUIT RESPONSE TIME IS 1.25 SECONDS, THUS ALLOWING FOR ANY TRANSIENT INPUTS OF LESSER DURATION.

SECTION VI

AC POWER GENERATION & DISTRIBUTION

6.1 INTRODUCTION

AC POWER GENERATION CONSISTS OF THREE SOLID STATE STATIC INVERTER UNITS, AND THE ASSOCIATED INVERTER CONTROL CIRCUITS. THE THREE INVERTERS AND INPUT AND OUTPUT CONTROL MOTOR SWITCHES ARE LOCATED IN THE LOWER EQUIPMENT BAY AS SHOWN IN FIGURE 6-1. AC POWER DISTRIBUTION CONSISTS OF TWO REDUNDANT BUSES THAT CONNECT POWER TO THE SPACECRAFT COMPONENTS THROUGH CIRCUIT BREAKERS, THE ASSOCIATED PROTECTIVE CIRCUITS, AND BUS SELECTOR SWITCHES WHERE APPLICABLE.

6.2 STATIC INVERTER UNITS

EACH OF THE INVERTERS, FIGURE 6-2, PRODUCES 115/200 VAC, 3 ϕ , 400 CYCLE POWER AND IS RATED AT 1250 VOLT AMPS. INVERTER OUTPUT WILL BE MAINTAINED WITHIN 115 PLUS 1 MINUS 1.5 VAC. AN INVERTER WILL WEIGH APPROXIMATELY 42.5 POUNDS, HAVE A LIFE SPAN OF 1200 HOURS, AND SUPPLY ALL THE AC POWER NORMALLY REQUIRED. DIMENSIONS ARE APPROXIMATELY 14.8 INCHES LONG, 14.5 INCHES WIDE, 6.8 INCHES HIGH AT THE FRONT AND 4.0 INCHES HIGH AT THE BACK.

6.2.1 OPERATION

A BLOCK DIAGRAM OF THE INVERTER IS ILLUSTRATED IN FIGURE 6-3. THE INVERTER CIRCUITRY IS COMPOSED OF A

CLOCK OSCILLATOR, AN EIGHT STAGE DIGITAL COUNTDOWN SECTION, A DC LINE FILTER, A FOUR STAGE POWER BOOSTER SECTION, A BUCK-BOOST REGULATOR, A DC BOOST FILTER, AN EIGHT STAGE POWER INVERSION SECTION, AN AC OUTPUT FILTER, CURRENT SENSING TRANSFORMERS, A ZENER DIODE REFERENCE BRIDGE AND AN OVERCURRENT TRIP CIRCUIT.

THE INVERTER NORMALLY USES A 6400 CPS SYNCHRONIZING SIGNAL FROM THE MASTER TIMING UNIT, WHICH MAINTAINS INVERTER OUTPUT AT $400 \pm .5$ CYCLES PER SECOND. IF THIS EXTERNAL SIGNAL IS LOST, THE CLOCK OSCILLATOR WITHIN THE INVERTER WILL PROVIDE PULSES THAT WILL MAINTAIN INVERTER OUTPUT WITHIN ± 7 CPS. THE INTERNAL CLOCK OSCILLATOR IS NORMALLY SYNCHRONIZED BY THE EXTERNAL PULSE. ON INITIAL TURN ON, OPERATING VOLTAGES TO ALL STAGES EXCEPT THE CLOCK OSCILLATOR AND THE DIGITAL COUNTDOWN ARE SUPPLIED THROUGH A .2 SECOND TIME DELAY CIRCUIT. THIS DELAY ALLOWS THE COUNTDOWN UNIT TO ATTAIN THE DESIRED OPERATING CONFIGURATION PRIOR TO COMPLETE INVERTER TURN-ON.

6.2.1.1 CLOCK OSCILLATOR

THE SYNCHRONIZED CLOCK OSCILLATOR PROVIDES A 6400 PPS SIGNAL WHICH IS APPLIED TO THE EIGHT STAGE DIGITAL COUNTDOWN SECTION, AND A 3200 PPS SIGNAL WHICH IS APPLIED TO THE FOUR STAGE POWER BOOSTER SECTION.

AC COMPONENTS

OWER EQUIPMENT BAY

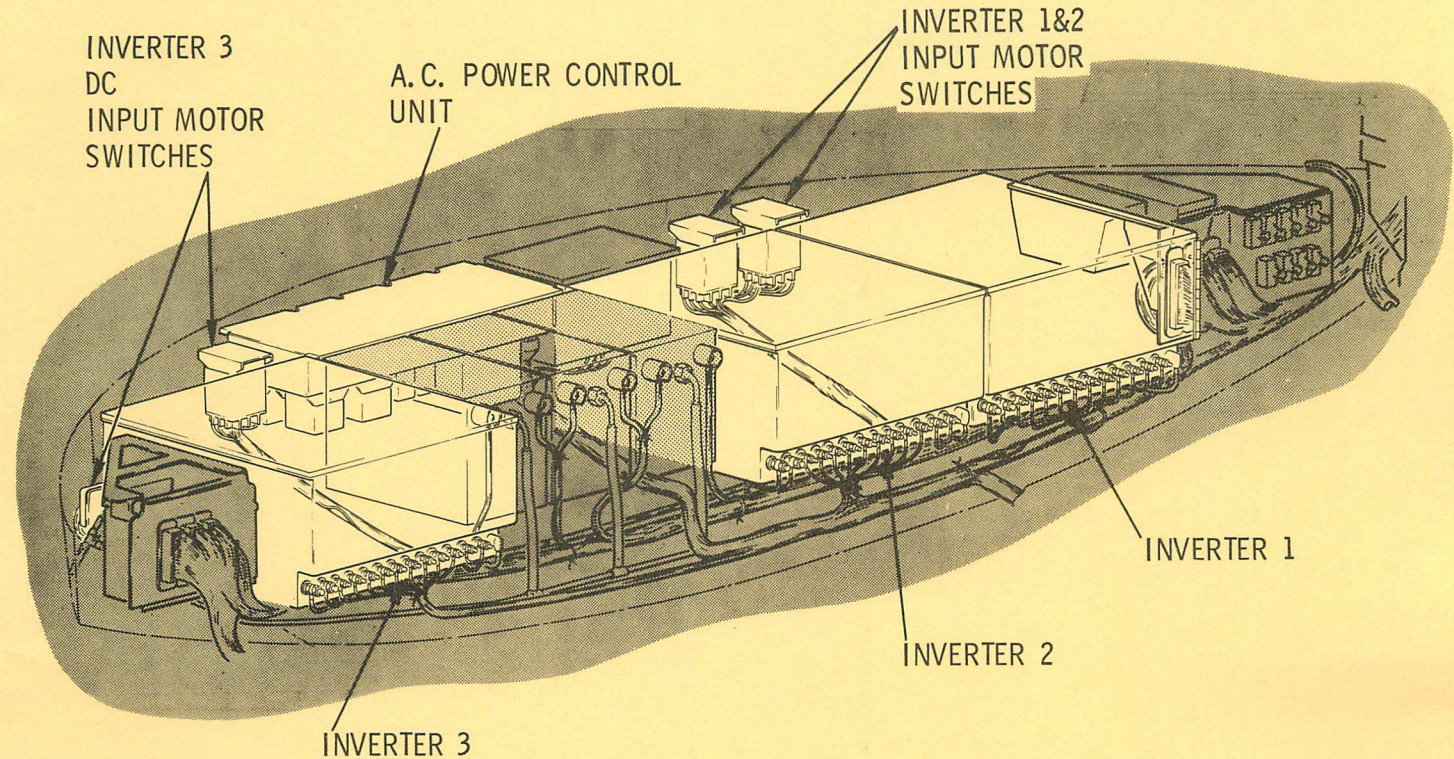


FIGURE 6-1

EP-022B



APOLLO STATIC INVERTER

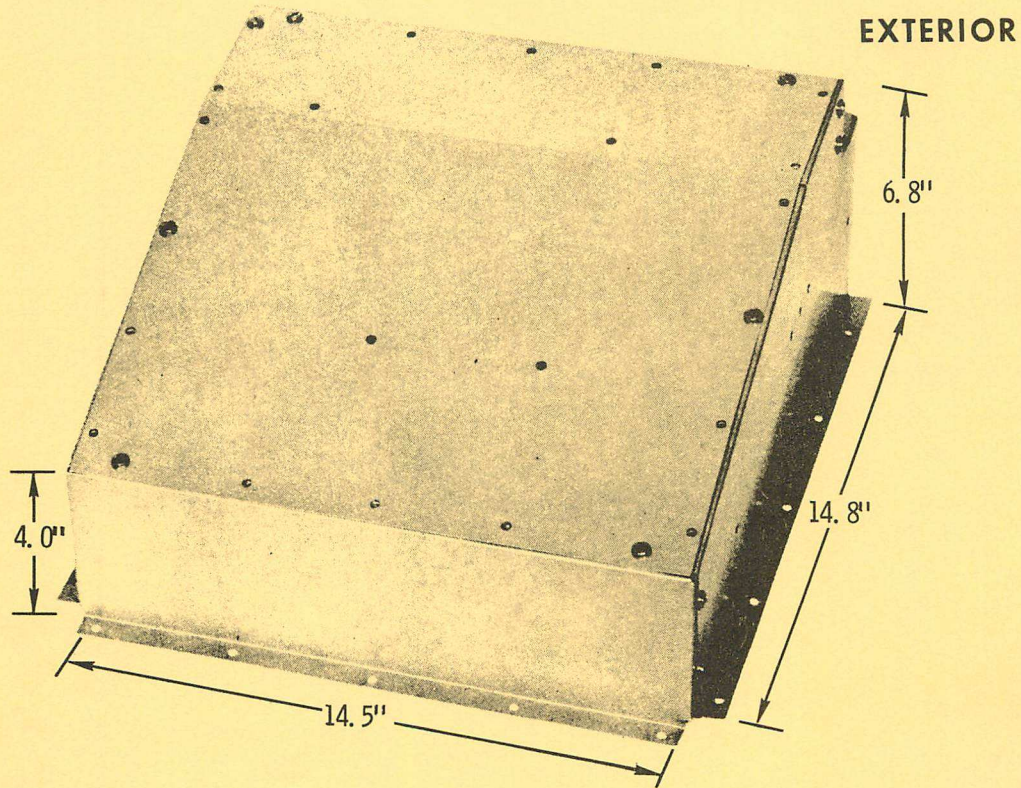


FIGURE 6-2

EP-025-1



APOLLO STATIC INVERTER

BLOCK DIAGRAM

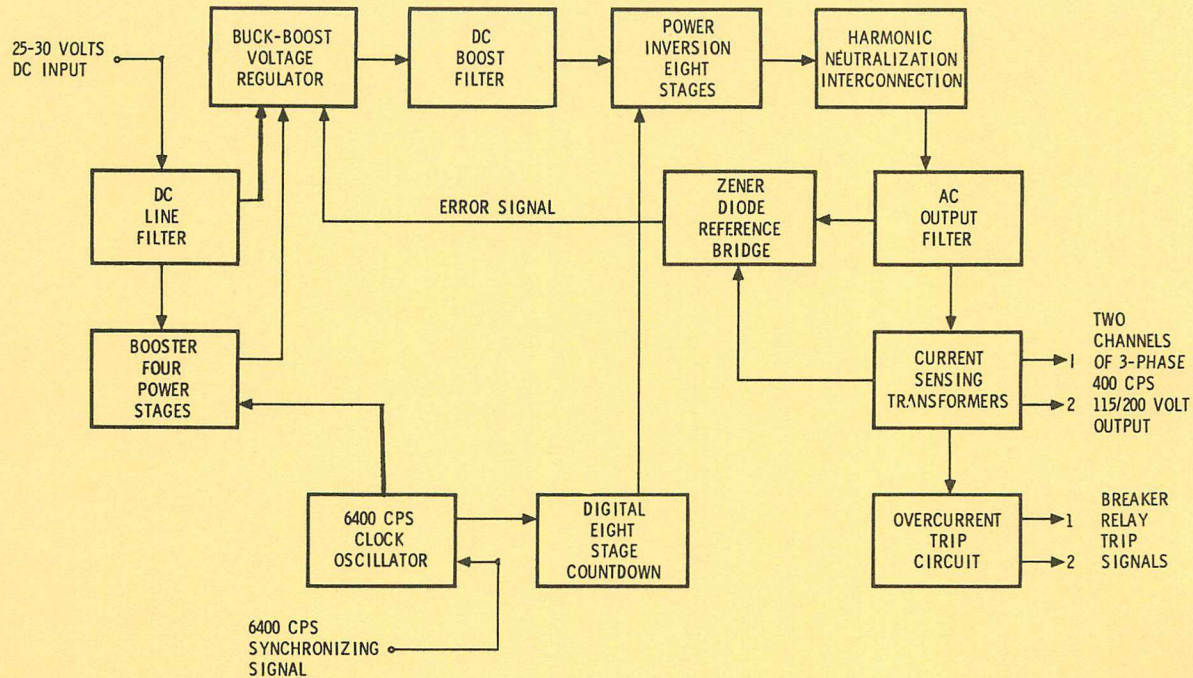


FIGURE 6-3

6.2.1.2 EIGHT STAGE DIGITAL COUNTDOWN

THIS SECTION USES THE 6400 PPS SIGNAL TO PRODUCE A SERIES OF EIGHT 400 CYCLE SQUARE WAVES EACH MUTUALLY DISPLACED ONE CLOCK PULSE TIME FROM THE PRECEDING AND FOLLOWING WAVE. ONE CLOCK PULSE TIME IS 156 MICRO-SECONDS AND REPRESENTS 22.5 ELECTRICAL DEGREES. THIS SERIES OF SQUARE WAVES IS APPLIED TO THE EIGHT STAGE POWER INVERSION SECTION.

6.2.1.3 EIGHT STAGE POWER INVERSION

THIS SECTION, USING A CONTROLLED VOLTAGE FROM THE BUCK-BOOST REGULATOR, AMPLIFIES THE SERIES OF 400 CYCLE SQUARE WAVES PRODUCED BY THE EIGHT STAGE DIGITAL COUNTDOWN. THE CONTROLLED VOLTAGE FROM THE BUCK-BOOST REGULATOR VARIES THE AMOUNT OF AMPLIFICATION OF THE 400 CYCLE SQUARE WAVES, THUS CONTROLLING THE VOLTAGE AND CURRENT OUTPUT OF THE INVERTER. THE AMPLIFIED SQUARE WAVES, STILL MUTUALLY DISPLACED 22.5 ELECTRICAL DEGREES, ARE APPLIED TO THE HARMONIC NEUTRALIZATION TRANSFORMER.

6.2.1.4 DC LINE FILTER

DC POWER TO THE INVERTER IS SUPPLIED FROM THE FUEL CELLS THROUGH THE MAIN DC BUSES. THE LINE FILTER REDUCES ANY RIPPLE IN THE INPUT, AND THE 28 VDC IS APPLIED TO THE FOUR STAGE POWER BOOSTER, THE INVERTER CIRCUITRY, AND THE BUCK-BOOST REGULATOR.

6.2.1.5 FOUR STAGE POWER BOOSTER

USING THE FILTERED DC POWER, AND THE 3200 PPS SIGNAL FROM THE CLOCK OSCILLATOR, THE POWER BOOSTERS OPERATING IN PARALLEL, PRODUCE A POWER AMPLIFIED 1600 PPS SIGNAL WHICH IS APPLIED TO THE BUCK-BOOST REGULATOR.

6.2.1.6 BUCK-BOOST REGULATOR

COMBINING THE 1600 PPS SIGNAL, THE FILTERED DC POWER, AND AN ERROR SIGNAL FEEDBACK FROM THE ZENER DIODE REFERENCE BRIDGE, THE REGULATOR PROVIDES AN OPERATING VOLTAGE TO THE EIGHT STAGE POWER INVERSION SECTION. THE AMPLITUDE OF THIS VOLTAGE IS CONTROLLED BY THE PHASE AND AMPLITUDE OF THE FEEDBACK SIGNAL FROM THE ZENER DIODE REFERENCE BRIDGE. NOMINALLY A 38 VDC SIGNAL IS PROVIDED TO THE EIGHT STAGE POWER INVERSION SECTION. THIS VOLTAGE IS VARIED BY THE ERROR SIGNAL TO REGULATE INVERTER VOLTAGE AND CURRENT OUTPUT.

6.2.1.7 HARMONIC NEUTRALIZATION

THIS TRANSFORMER, USING THE 400 CYCLE SQUARE WAVE OUTPUT FROM THE EIGHT STAGE POWER INVERSION SECTION, AND THE INPUT FROM THE BUCK-BOOST REGULATOR, TRANSFORMS IT INTO A 3 ϕ , 400 CYCLE, 115 VOLT AC SIGNAL. THE MANNER IN WHICH THESE TRANSFORMERS ARE WOUND AROUND THE SINGLE CORE PRODUCES FLUX CANCELLATION WHICH ELIMINATES ALL HARMONICS UP TO AND INCLUDING THE FIFTEENTH. THE 22.5 DEGREE ELECTRICAL DISPLACEMENT OF

THE SQUARE WAVES PROVIDES A MEANS OF ELECTRICALLY ROTATING THE SQUARE WAVE EXCITED PRIMARY WINDINGS AROUND THE 3 ϕ WYE CONNECTED SECONDARY WINDINGS, THUS PRODUCING THE 3 ϕ , 400 CYCLE OUTPUT. PHASE DISPLACEMENT IS PROVIDED BY THE POSITIVE AND NEGATIVE TRANSFORMER COUPLING IN THE EIGHT TRANSFORMERS IN EACH OF THE THREE PHASES. PHASE A STARTS AT ZERO VOLTAGE; PHASE B AFTER THE INITIAL EIGHT PULSES FALLS 120 DEGREES BEHIND PHASE A; AND PHASE C AFTER THE INITIAL EIGHT PULSES FALLS 120 DEGREES BEHIND PHASE B. THIS 115 VOLT OUTPUT IS THEN APPLIED TO THE AC OUTPUT FILTER.

6.2.1.8 AC OUTPUT FILTER

FILTERING OF THE REMAINING HIGHER HARMONICS IS ACCOMPLISHED BY THIS SECTION. SINCE THE LOWER HARMONICS WERE ELIMINATED PREVIOUSLY, 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 AC OUTPUT VOLTAGE. AFTER FILTERING, THE 3 ϕ , 115 VOLT AC, 400 CYCLE SINE WAVE IS APPLIED TO THE AC BUSES THROUGH THE CURRENT SENSING TRANSFORMERS.

6.2.1.9 CURRENT SENSING TRANSFORMERS

THESE TRANSFORMERS AND RECTIFIERS PRODUCE A DC SIGNAL, THE AMPLITUDE OF WHICH IS A DIRECT FUNCTION OF INVERTER OUTPUT CURRENT. THIS SIGNAL IS APPLIED TO THE ZENER DIODE REFERENCE BRIDGE TO REGULATE INVERTER

CURRENT OUTPUT DURING AN OVERLOAD CONDITION. CURRENT OF EACH PHASE FLOWS THROUGH ITS OWN INDIVIDUAL TRANSFORMER. OUTPUT FROM THESE TRANSFORMERS IS ALSO APPLIED TO AN OVERCURRENT TRIP CIRCUIT TO EFFECT A DISCONNECT DURING EXTREME OVERLOAD CONDITIONS.

6.2.1.10 ZENER DIODE REFERENCE BRIDGE

TO CONTROL INVERTER VOLTAGE OUTPUT, A RECTIFIED SIGNAL REPRESENTING VOLTAGE OUTPUT IS APPLIED TO THE BRIDGE. A VARIATION IN VOLTAGE OUTPUT UNBALANCES THE BRIDGE PROVIDING AN ERROR SIGNAL OF PROPER POLARITY AND MAGNITUDE TO THE BUCK-BOOST VOLTAGE REGULATOR, WHICH IN TURN PROVIDES THE OPERATING VOLTAGE FOR THE EIGHT STAGE POWER INVERSION SECTION, THUS VARYING THE VOLTAGE IN THIS SECTION. ALSO, WHEN INVERTER CURRENT OUTPUT REACHES 200 TO 250% OF UNIT CURRENT, THE RECTIFIED SIGNAL APPLIED TO THE BRIDGE FROM THE CURRENT SENSING TRANSFORMERS AND RECTIFIERS IS OF SUFFICIENT MAGNITUDE TO OVERRIDE THE VOLTAGE REGULATING SIGNAL, AND THUS PROVIDE AN ERROR SIGNAL TO THE BUCK-BOOST REGULATOR. THIS SIGNAL IS OF THE SAME POLARITY AS AN OVERVOLTAGE ERROR SIGNAL, THUS DECREASING INVERTER CURRENT AND VOLTAGE OUTPUT.

THE OUTPUT OF THE BUCK-BOOST REGULATOR, 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% OF UNIT CURRENT, THE OVERCURRENT TRIP CIRCUIT IS ACTIVATED.

6.2.1.11 OVERCURRENT TRIP CIRCUIT

THIS CIRCUIT MONITORS THE RECTIFIED DC SIGNAL REPRESENTING CURRENT OUTPUT. WHEN TOTAL INVERTER CURRENT OUTPUT EXCEEDS 250% OF UNIT CURRENT, THIS CIRCUIT WILL EFFECT AN INVERTER DISCONNECT. IF CURRENT OUTPUT OF ANY OF THE THREE PHASES EXCEEDS 300% OF UNIT CURRENT, THIS CIRCUIT WILL ALSO EFFECT A DISCONNECT.

6.2.2 AC GENERATION

THE AC GENERATION DIAGRAM (FIGURE 6-4) SHOWS IN GREATER DETAIL THE DEVELOPMENT OF THE ELECTRICAL ROTATION AND THREE PHASE POWER OUTPUT. OPERATION OF THE EIGHT STAGE DIGITAL COUNTDOWN, EIGHT STAGE POWER INVERSION AND HARMONIC NEUTRALIZATION CIRCUITS IS AS FOLLOWS.

6.2.2.1 EIGHT STAGE DIGITAL COUNTDOWN

EACH OF THE EIGHT STAGES OF THE COUNTDOWN CIRCUIT IS A MODIFIED ECCLES-JORDAN BISTABLE MULTIVIBRATOR (FLIP-FLOP). EACH FLIP-FLOP (F/F) CONSISTS OF TWO NPN TRANSISTORS, A & B, AND THE ASSOCIATED CIRCUITRY. THE OUTPUT OF TRANSISTOR A IS DEFINED AS THE "Q" OUTPUT. THE OUTPUT OF TRANSISTOR B IS DEFINED AS THE "Q" (Q BAR) OUTPUT. THE INPUT TO TRANSISTOR A IS THE "J" INPUT, AND TO TRANSISTOR B IS THE "K" INPUT. WHEN A TRANSISTOR IS NOT CONDUCTING, ITS OUTPUT AS MEASURED ON THE COLLECTOR WILL BE AT B+ OR "HIGH". OUTPUT OF A CONDUCTING TRANSISTOR WILL BE LESS THAN B+ OR "LOW".

THE "Q" OUTPUT OF STAGES ONE THROUGH SEVEN IS APPLIED TO THE "K" INPUT OF THE FOLLOWING STAGE, AND THE "Q" OUTPUT IS APPLIED TO THE "J" INPUT OF THE FOLLOWING STAGE. THE OUTPUTS FROM STAGE EIGHT TO STAGE ONE ARE REVERSED, "Q" TO "J", AND "Q" TO "K". ALSO APPLIED TO THE "J" AND "K" INPUTS IS THE NEGATIVE 6400 PPS CLOCK PULSE. THE INPUT CIRCUITRY IS DESIGNED SO THE CONDUCTING TRANSISTOR WILL BE TURNED OFF BY THE CLOCK PULSE EXCEPT WHEN THE "Q" OR "Q" SIGNAL APPLIED TO IT IS HIGH. SINCE, ON INITIAL INVERTER TURN-ON, THE COUNTDOWN UNIT CAN BE POSITIONED IN A VARIETY OF CONFIGURATIONS, THE .2 SECOND TIME DELAY ALLOWS IT TO ATTAIN THE PROPER CONFIGURATION.

EACH STAGE IN THE COUNTDOWN UNIT PRODUCES A 400 CPS SQUARE WAVE SIGNAL. EACH OF THESE SIGNALS IS MUTUALLY DISPLACED 22.5 ELECTRICAL DEGREES. THE OUTPUT OF THE COUNTDOWN UNIT IS TRANSFORMER COUPLED TO THE EIGHT STAGE POWER INVERSION CIRCUITS.

6.2.2.2 EIGHT STAGE POWER INVERSION

EACH OF THE EIGHT POWER INVERSION STAGES USES TWO PUSH-PULL BASE DRIVE TRANSISTOR AMPLIFIERS TO AMPLIFY THE SQUARE WAVE INPUT FROM THE COUNTDOWN UNIT. EACH AMPLIFIED SQUARE WAVE IS APPLIED TO ONE OF EIGHT INDIVIDUAL PRIMARIES IN THE HARMONIC NEUTRALIZATION TRANSFORMER.

AC GENERATION

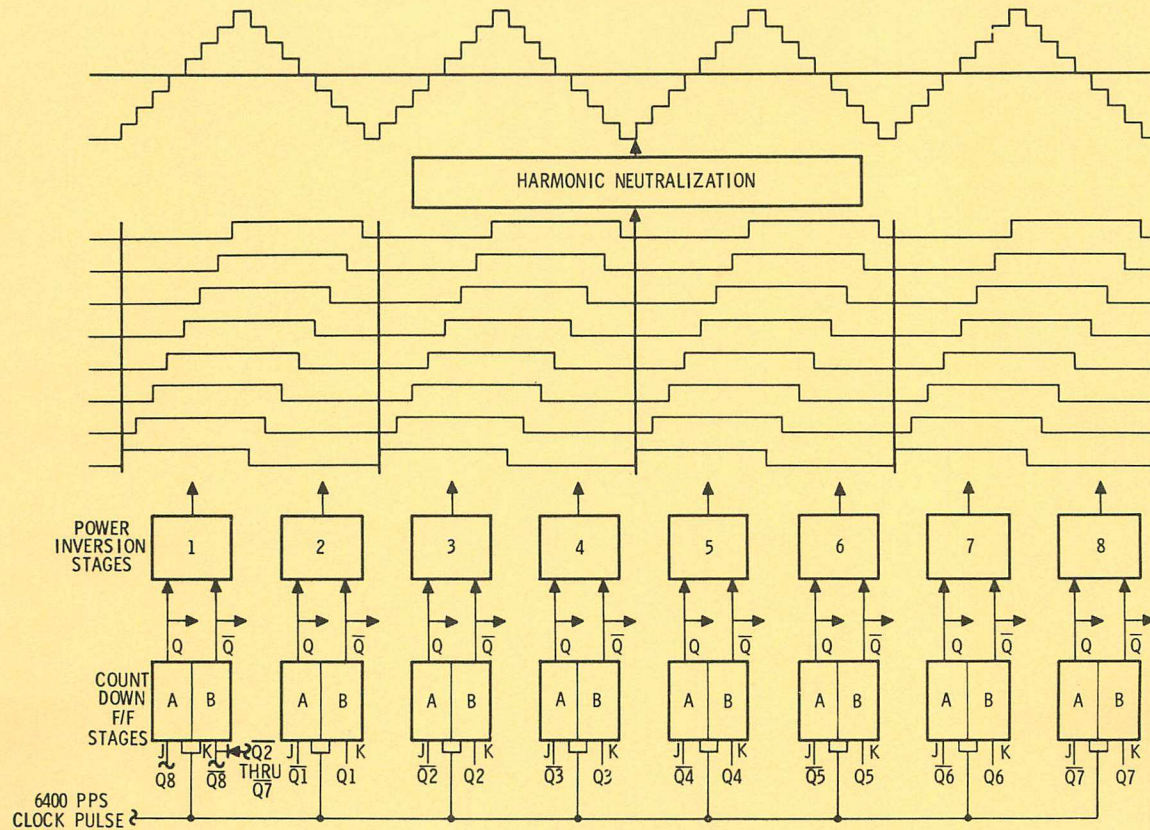


FIGURE 6-4

EP-015B

6.2.2.3 HARMONIC NEUTRALIZATION TRANSFORMER

THIS TRANSFORMER IS A SINGLE CORE MULTIWOOUND DEVICE. EACH OF THE EIGHT POWER INVERSION OUTPUTS, APPLIED TO A SEPARATE WINDING, IS INDUCTIVELY COUPLED WITH THREE SECONDARIES, ONE SECONDARY FOR EACH PHASE. EIGHT OF THESE SECONDARIES, CONNECTED IN SERIES, DEVELOP A SINGLE PHASE, AS ILLUSTRATED IN FIGURE 6-5. THE MANNER IN WHICH THE TRANSFORMERS ARE WOUND AND INTERCONNECTED CAUSES FLUX CANCELLATION TO TAKE PLACE WITHIN THE TRANSFORMER CORE, THUS NEUTRALIZING ALL HARMONICS UP TO THE FIFTEENTH.

ON INITIAL INVERTER TURN-ON, DURING THE FIRST EIGHT PULSES AFTER THE PROPER CONFIGURATION IS ATTAINED, THE EIGHT TRANSFORMERS DEVELOP THE VOLTAGES INDICATED IN FIGURE 6-5. SINCE THE EIGHT TRANSFORMERS IN EACH PHASE (EXCEPT PHASE A WHICH HAS SEVEN BECAUSE ITS WAVE OUTPUT STARTS AT ZERO), ARE CONNECTED IN SERIES, THE OUTPUT IS ADDITIVE AND THE INITIAL WAVE FORMATION WILL BE AS ILLUSTRATED BY THE FIRST EIGHT STEPS IN FIGURE 6-6. ON THE NINTH AND SUBSEQUENT PULSES, TRANSFORMER ACTION WILL PRODUCE A 180 DEGREE REVERSAL IN THE VOLTAGE PRODUCED IN EACH TRANSFORMER, AND THE WAVE WILL BE DEVELOPED AS INDICATED FROM THE NINTH PULSE ONWARD.

THE PRIMARY TO SECONDARY TURNS RATIO, AND BECAUSE EACH OF THE EIGHT PRIMARIES IS EXCITED BY A SEQUENCE OF SIGNALS MUTUALLY DISPLACED 22.5 ELECTRICAL DEGREES, PROVIDES A MEANS OF ELECTRICALLY ROTATING THE PRIMARY WINDINGS ABOUT THE SECONDARIES. THIS ELECTRICAL

ROTATION PRODUCES THE 3 ϕ WYE OUTPUT WHICH IS FREE OF THE LOWER HARMONICS.

6.3 SAFETY CIRCUITS

SAFETY CIRCUITS INCORPORATED INTO THE INVERTER SYSTEM PROVIDE FOR MONITORING OF OVER AND UNDER VOLTAGE, AS WELL AS OVERLOAD. THE OVERLOAD CIRCUITRY WAS PREVIOUSLY DESCRIBED UNDER INVERTER OPERATION IN PARAGRAPHS 6.2.1.9 THROUGH 6.2.1.11.

6.3.1 AC OVER-UNDERVOLTAGE SENSING UNIT

SIX OF THESE CIRCUITS, ONE FOR EACH PHASE ON EACH BUS, PROVIDE VOLTAGE MONITORING. A TYPICAL EXAMPLE OF PHASE TO SENSING CIRCUIT TIE IN IS ILLUSTRATED IN FIGURE 6-7. AN UNDERVOLTAGE BELOW 100 VOLTS OR AN OVERVOLTAGE ABOVE 130 VOLTS WILL ACTIVATE THE CIRCUIT. A "VOLT FAIL" LAMP IN THE CAUTION & WARNING GROUP WILL BE ILLUMINATED BY EITHER CONDITION.

THE AC BUS DISCONNECT RELAYS (K-20 FOR BUS 2, K-21 FOR BUS 1) WILL AUTOMATICALLY DISCONNECT THE BUS FROM THE INVERTER DURING AN OVERVOLTAGE OR OVERLOAD CONDITION. INVERTER DISCONNECT MUST BE PERFORMED MANUALLY WHEN AN UNDERVOLTAGE IS CAUSED BY INVERTER FAILURE.

PHASING & HARMONIC NEUTRALIZATION

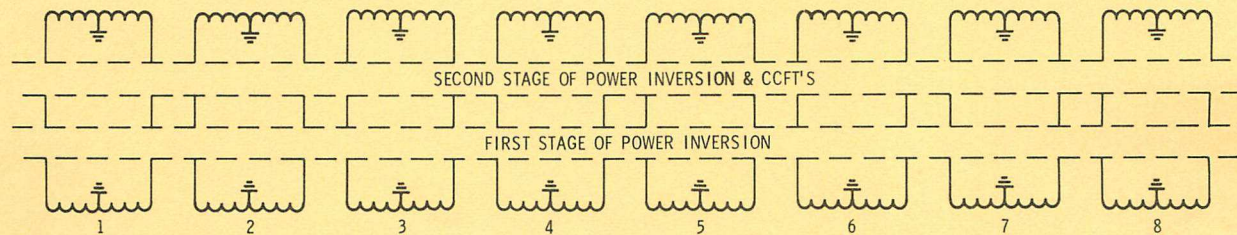
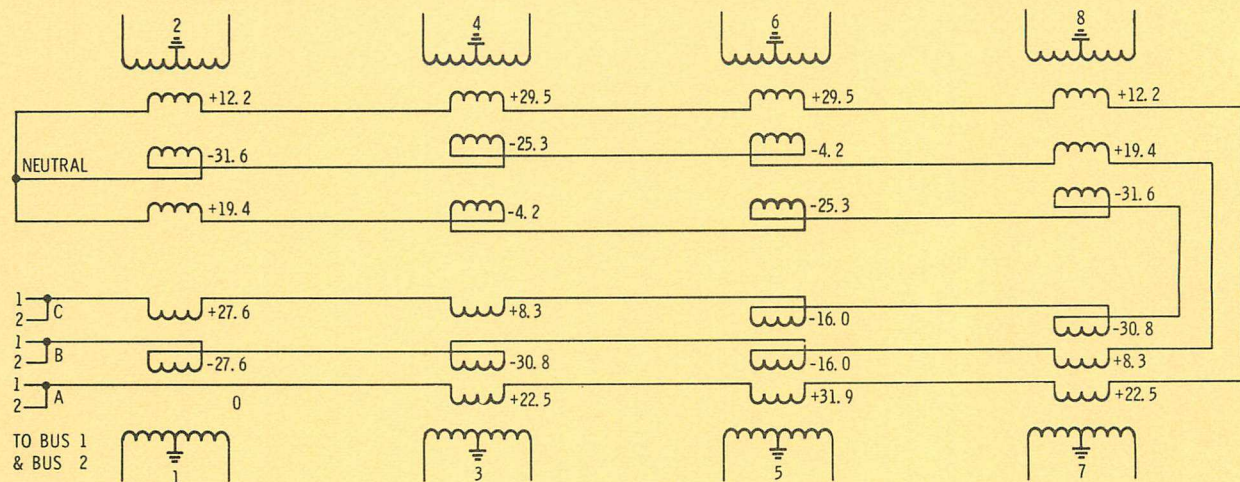


FIGURE 6-5

WAVE DEVELOPMENT

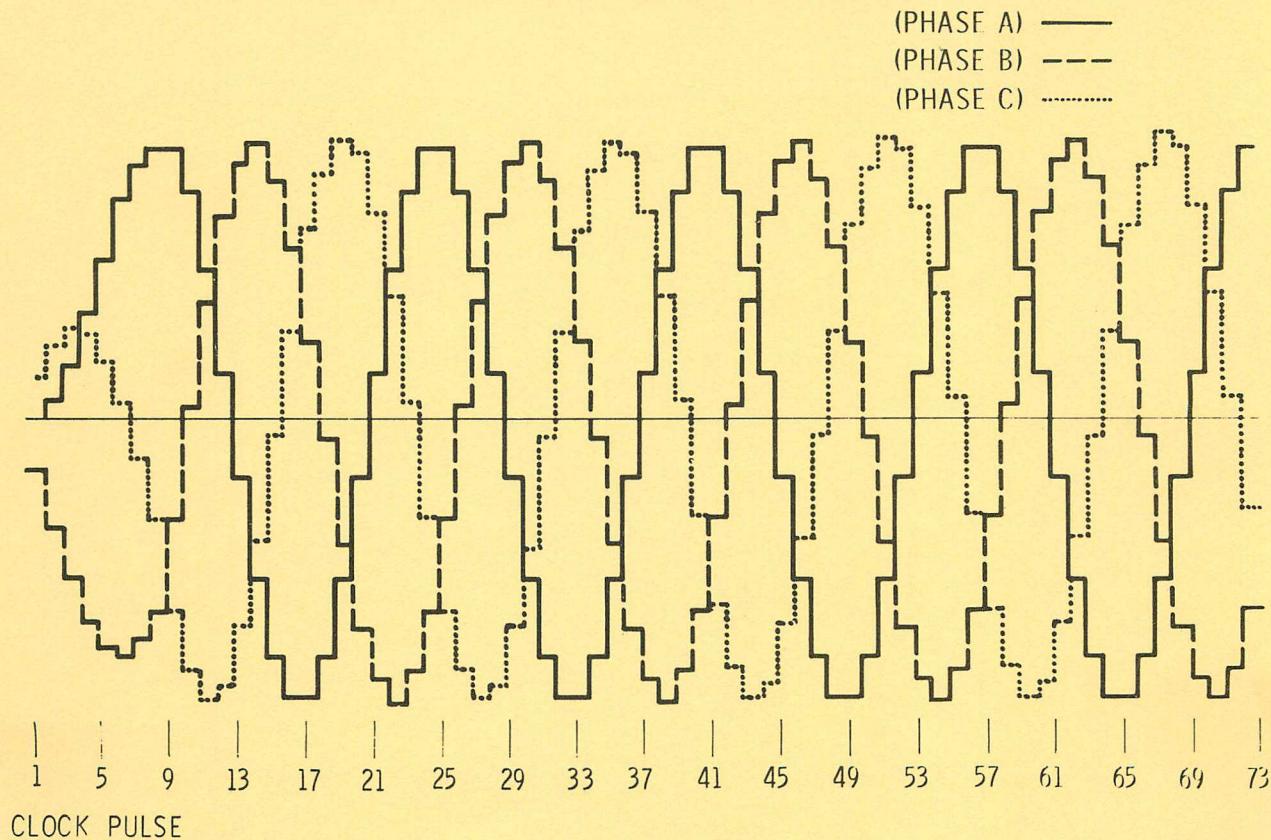


FIGURE 6-6

FP-608

AC OVER-UNDER VOLTAGE SENSING UNIT (PHASE TIE IN)

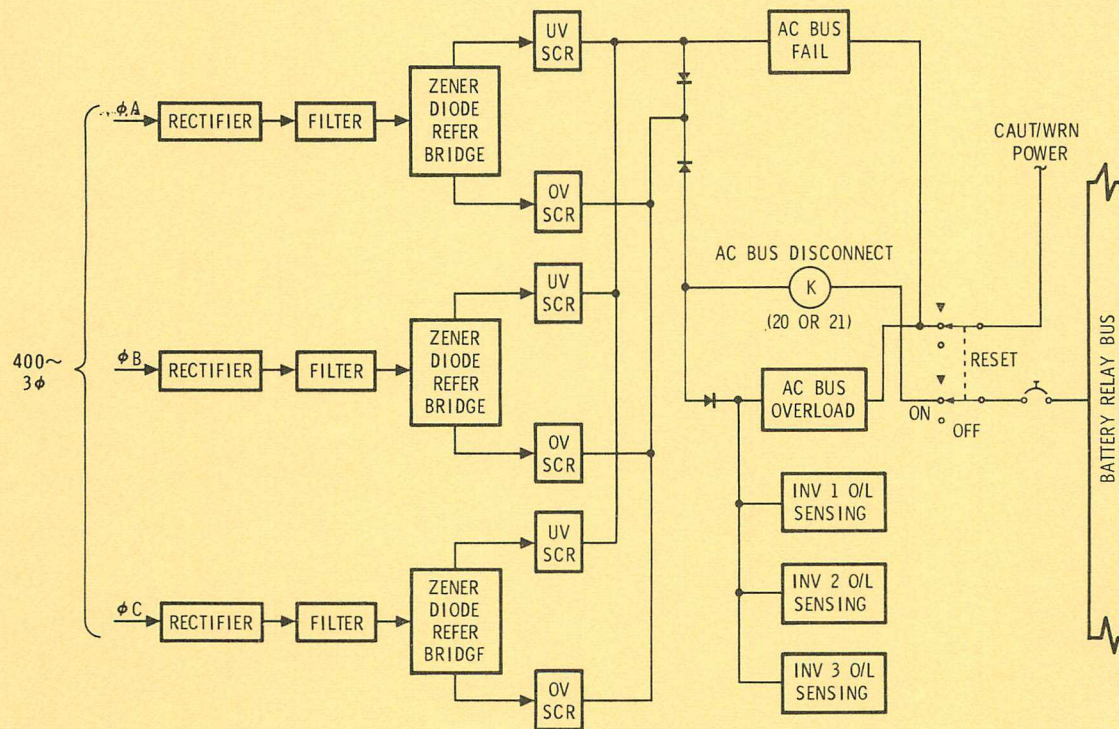


FIGURE 6-7

EP-603B



6.3.1.1 AC OVER-UNDERVOLTAGE SENSING

SINCE ALL SIX SENSING CIRCUITS ARE IDENTICAL, ONLY ONE WILL BE EXPLAINED, AS ILLUSTRATED IN FIGURE 6-8.

6.3.1.1.1 OPERATION

SENSING OF SINGLE PHASE VOLTAGE IS ACCOMPLISHED BY TRANSFORMER COUPLING TO A BRIDGE CIRCUIT. THE BRIDGE CONSISTS OF DIODES, RESISTORS AND SILICON CONTROLLED RECTIFIERS (SCR) THAT COMPLETE CIRCUITS FROM THE CAUTION/WARNING POWER SUPPLY AND THE BATTERY RELAY BUS TO THE NEGATIVE DC BUS WHEN THE BRIDGE IS UNBALANCED.

A PHASE OF INVERTER OUTPUT VOLTAGE IS REDUCED IN A STEPDOWN TRANSFORMER AT A RATIO OF APPROXIMATELY 11 TO 1, RECTIFIED AND FILTERED. THE RECTIFIED DC VOLTAGE IS APPLIED TO THE BRIDGE CIRCUIT TO BIAS TWO SCR'S WHICH DO NOT CONDUCT WHEN THE BRIDGE IS BALANCED. AN INCREASE OR DECREASE IN VOLTAGE FROM THE TRANSFORMER COUPLING WILL UNBALANCE THE BRIDGE SUFFICIENTLY TO TRIGGER ONE OF THE SCR'S, COMPLETING A CIRCUIT TO THE NEGATIVE DC BUS, PROVIDING CURRENT FOR ACTIVATION OF RELAYS AND ILLUMINATION OF INDICATOR LAMPS.

THE BATTERY RELAY BUS FURNISHES POWER FOR THE DISCONNECT RELAY THROUGH THE "AC BUS OVERLOAD SENSOR" CIRCUIT BREAKER AND THE BUS "RESET" SWITCH. THE CAUTION/WARNING POWER SUPPLY FURNISHES POWER FOR ILLUMINATION OF THE CAUTION LAMPS.

THE TRANSFORMER COUPLING AND RECTIFICATION PROVIDES 10.2 VDC TO A BALANCED BRIDGE. OF THIS, 5.1 VDC IS APPLIED ACROSS EACH OF THE TWO ZENER DIODES, Z-1 AND Z-2, AND THE REMAINING 5.1 VDC IS APPLIED ACROSS RESISTORS R-1 AND R-2.

A VOLTAGE DECREASE TO APPROXIMATELY 100 VOLTS AC WILL UNBALANCE THE BRIDGE BY PROVIDING LESS THAN 10.2 VDC ACROSS THE BRIDGE NETWORK. THE VOLTAGE APPLIED ACROSS THE ZENER DIODES WILL REMAIN 5.1 VDC. THE REMAINING LESSER VOLTAGE IS APPLIED ACROSS RESISTORS R-1 AND R-2, PROVIDING A MORE POSITIVE POTENTIAL AT POINT A-4 AS OPPOSED TO POINTS A-3 & A-2, POINT A-3 BEING MORE POSITIVE THAN POINT A-2. THIS MORE POSITIVE POTENTIAL AT POINT A-4 IS APPLIED TO THE GATE OF THE U/V SCR CAUSING IT TO CONDUCT, COMPLETING A DC PATH FROM THE CAUTION/WARNING POWER SUPPLY THROUGH THE "RESET" SWITCH, THE "AC BUS 1 FAIL" LAMP AND THE U/V SCR TO THE NEGATIVE DC BUS, THUS ILLUMINATING THE LAMP.

OVERVOLTAGE SENSING IS ACCOMPLISHED IN A SIMILAR MANNER, HOWEVER, THE BRIDGE IS UNBALANCED IN THE OPPOSITE DIRECTION. THE VOLTAGE ACROSS RESISTORS R-1 AND R-2 IS GREATER THAN THAT ACROSS THE ZENER DIODES Z-1 AND Z-2, MAKING POINT A-2 MORE POSITIVE THAN EITHER A-3 OR A-4, POINT A-3 BEING MORE POSITIVE THAN POINT A-4. THIS CONDITION TRIGGERS THE O/V SCR CAUSING IT TO CONDUCT, COMPLETING A PATH FROM THE BATTERY RELAY BUS THROUGH THE "RESET" SWITCH, THE AC BUS DISCONNECT RELAY (K-21), AND THE SCR TO THE NEGATIVE DC BUS, DISCONNECTING THE INVERTER FROM THE BUS. A PARALLEL PATH IS COMPLETED FROM THE CAUTION/WARNING POWER SUPPLY THROUGH

AC OVER-UNDERVOLTAGE SENSING

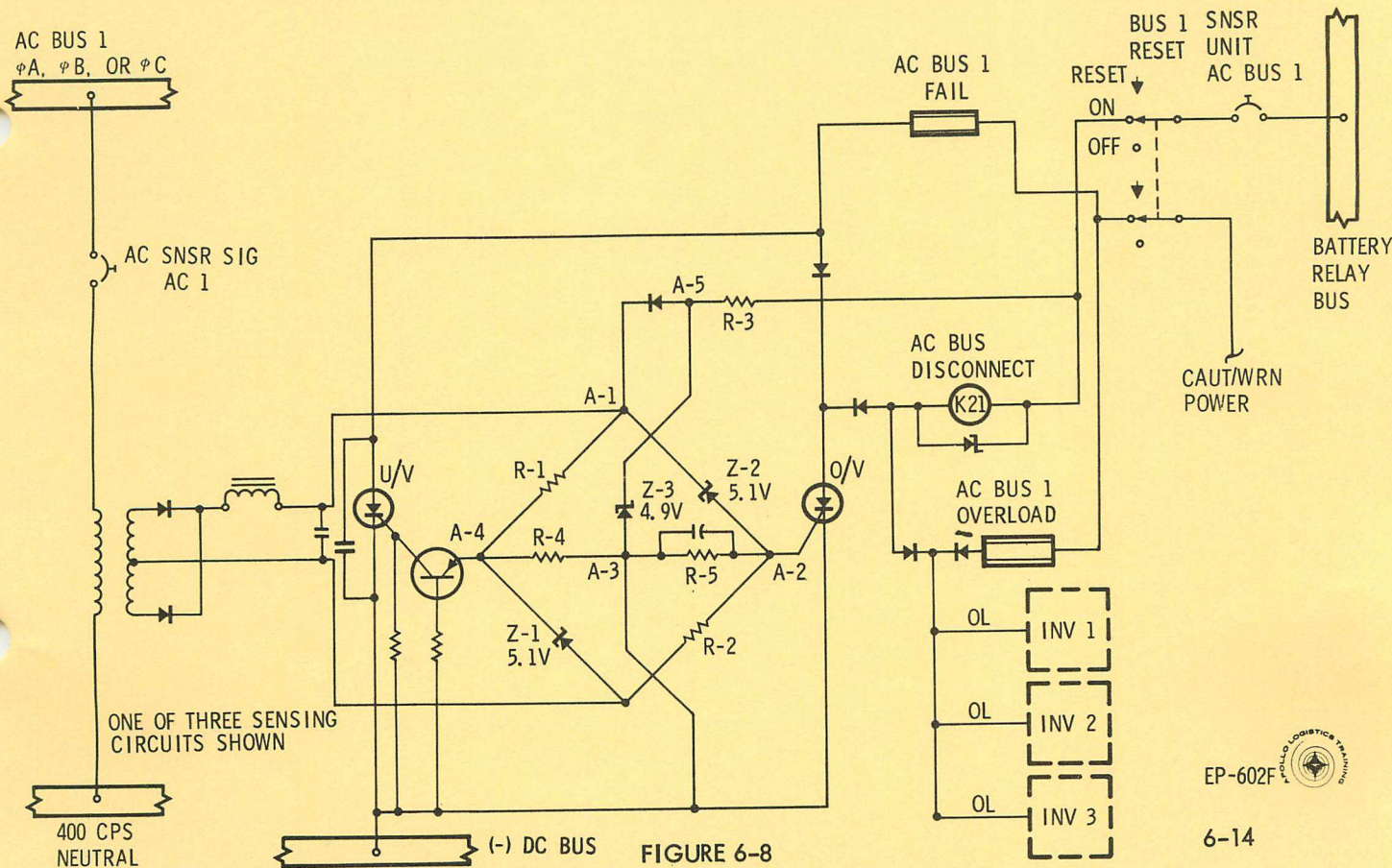


FIGURE 6-8

EP-602F



6-14

THE "RESET" SWITCH, THE "AC BUS FAIL" LAMP AND THE SCR TO THE NEGATIVE DC BUS, ILLUMINATING THE LAMP.

IN CASE OF ZERO VOLTAGE ON THE AC BUS, THE BATTERY RELAY BUS PROVIDES POWER TO ENERGIZE THE CIRCUIT. ZENER DIODE Z-3 PROVIDES 4.9 VDC ACROSS THE PARALLEL CIRCUIT FROM POINT A-5 TO POINT A-3. THIS AGAIN PROVIDES A MORE POSITIVE POTENTIAL AT POINT A-4 TRIGGERING THE U/V SCR AND PROVIDING THE SAME ACTION AS AN UNDERVOLTAGE.

THE OVERLOAD SENSING CIRCUITS LOCATED INTERNALLY IN THE INVERTER WILL PROVIDE A PATH TO THE NEGATIVE DC BUS DURING AN OVERLOAD CONDITION. THIS WILL PROVIDE BATTERY RELAY BUS POWER TO ENERGIZE THE DISCONNECT RELAY (K-21), AND CAUTION/WARNING POWER TO ILLUMINATE THE "AC BUS 1 OVERLOAD" LAMP. A DISCONNECT DUE TO OVERLOAD WOULD ALSO CAUSE THE "AC BUS FAIL" LAMP TO ILLUMINATE DUE TO INVERTER DISCONNECT FROM THE BUS.

ONCE THE CIRCUIT IS TRIGGERED INTO CONDUCTION, RELAY K-21 WILL REMAIN ENERGIZED, AND THE CAUTION LAMPS WILL REMAIN ILLUMINATED UNTIL POWER TO THE SCR IS INTERRUPTED. THE ABNORMAL CONDITION MUST BE CORRECTED, AND THE "RESET" SWITCH MUST BE ACTIVATED TO EXTINGUISH THE CAUTION LAMPS AND DE-ENERGIZE THE DISCONNECT RELAY. SINCE THE DISCONNECT RELAY IS COMMON TO ALL THREE INVERTER CIRCUITS, IT MUST BE DE-ENERGIZED BEFORE ANOTHER INVERTER CAN BE CONNECTED TO THE BUS. THIS IS ACCOMPLISHED BY POSITIONING THE "RESET" SWITCH TO THE MOMENTARY "RESET" POSITION. HOWEVER, IN ORDER NOT TO

TRIGGER THE CIRCUIT AGAIN, THE MALFUNCTIONING INVERTER MUST BE TURNED OFF, AND A REPLACEMENT INVERTER TURNED ON PRIOR TO ACTIVATING THE "RESET" SWITCH. THE SAME ACTION MUST BE TAKEN WITH RELAY K-20 WHICH IS APPLICABLE TO AC BUS 2, IF A DISCONNECT OCCURED ON THAT BUS.

CIRCUIT RESPONSE TIME IS APPROXIMATELY 25 MILLISECONDS. THE OVER/UNDERVOLTAGE SENSING CIRCUIT IS PRESENTLY IN FOR REDESIGN. SENSITIVITY WILL BE INCREASED TO PROVIDE CAUTION LAMP INDICATIONS AT 95 ± 3 VAC AND 130 ± 2 VAC. CIRCUIT RESPONSE TIME WILL BE INCREASED TO 40 MILLISECONDS TO ALLOW FOR 25 MILLISECOND TRANSIENT INPUTS.

6.4 INVERTER CONTROL CIRCUITS

THE INVERTER CONTROL CIRCUITRY IS DESIGNED TO ELIMINATE THE POSSIBILITY OF CONNECTING MORE THAN ONE INVERTER TO ANY ONE BUS AT THE SAME TIME. THIS IS NECESSARY TO PREVENT A PHASE DIFFERENTIAL ON THE BUS. IT IS POSSIBLE TO HAVE ONE INVERTER POWERING BOTH BUSES, OR A SEPARATE INVERTER POWERING EACH BUS.

FIGURE 6-9 WILL BE USED TO EXPLAIN THE OPERATION OF THE INVERTER CONTROL CIRCUITS AND MOTOR SWITCHES WITH INVERTER 3 SUPPLYING POWER TO BUS 2. DC POWER TO INVERTER 3 CAN BE SELECTED THROUGH EITHER MAIN BUS A OR B. SWITCH S-24 CONTROLS POWER TO THE MOTOR SWITCHES THAT PROVIDE THE CONNECTION OF DC TO INVERTER THREE. IT ALSO CONTROLS BATTERY RELAY BUS POWER TO THE SWITCHES (S-28 AND S-32) WHICH CONTROL

INVERTER CONTROL CIRCUIT

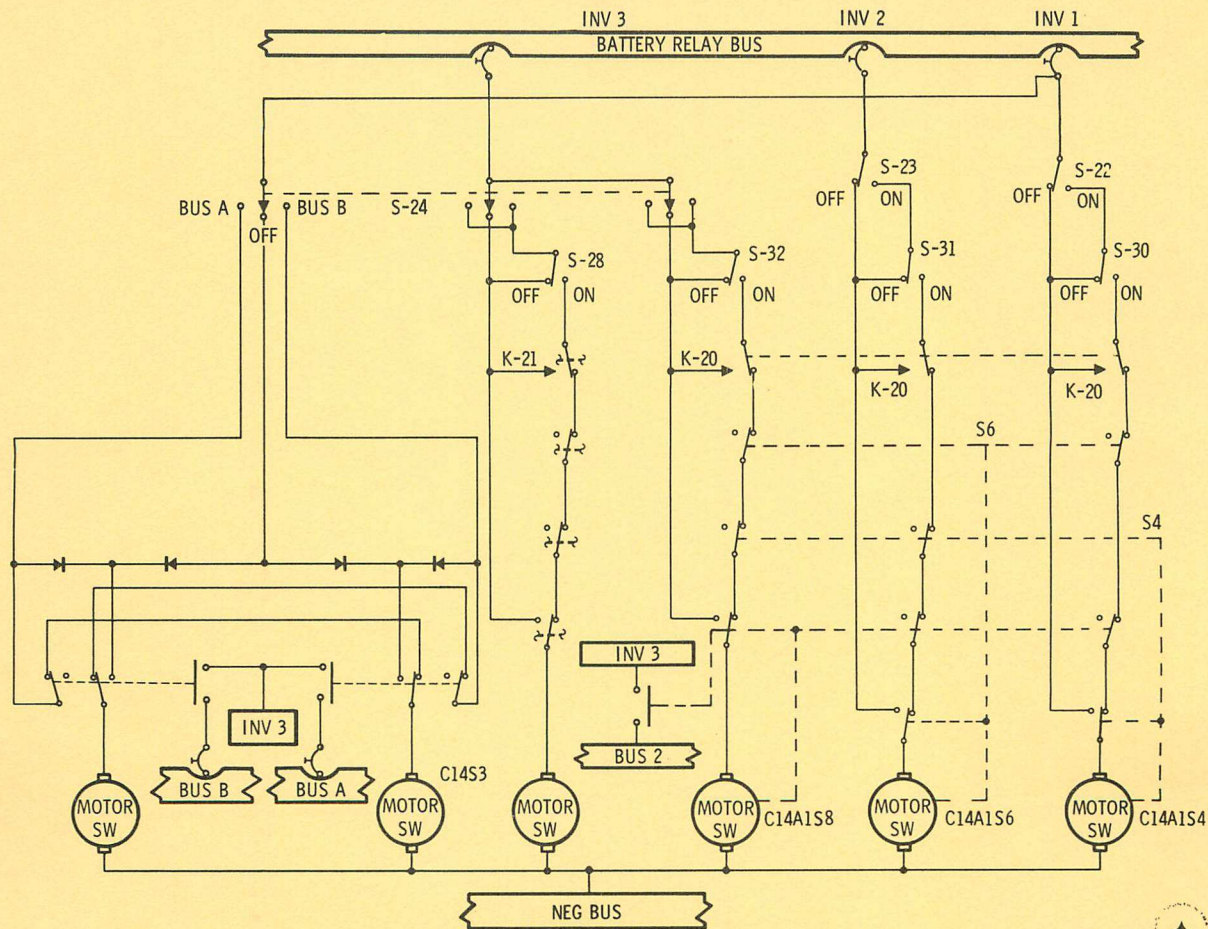


FIGURE 6-9

THE MOTOR SWITCH WILL RESET IT TO THE POSITION SHOWN, DISCONNECTING THE INVERTER 3 TO BUS 2 CONTACT. WITH K-20 ENERGIZED, THE ON CIRCUIT OF EACH OF THE THREE MOTOR SWITCHES CONTROLLING INVERTER POWER TO BUS 2 IS OPENED, PREVENTING THE CONNECTION OF ANY INVERTER TO BUS 2. ACTIVATION OF THE SENSING CIRCUIT "RESET" SWITCH INTERRUPTS POWER TO K-20, AND RESETS IT TO THE CONDITION SHOWN, ALLOWING OUTPUT OF ANY ONE OF THE THREE INVERTERS TO BE CONNECTED TO BUS 2, AFTER POSITIONING THE INVERTER 3 DC INPUT SWITCH S-24, OR AC BUS 2 SWITCH S-32 TO OFF.

THE CIRCUITS IN INVERTERS 1 AND 2 FUNCTION IN A SIMILAR MANNER, WITH THE EXCEPTION THAT THE DC INPUT CONTROL SWITCH IS NOT DC BUS SELECTIVE. POWER TO INVERTER 1 IS SUPPLIED THROUGH MAIN DC BUS A, AND TO INVERTER 2 THROUGH MAIN DC BUS B, AS SHOWN IN FIGURE 6-10.

6.5 AC POWER DISTRIBUTION

AC POWER DISTRIBUTION IS SHOWN SCHEMATICALLY IN FIGURE 6-10. THE THREE INVERTERS ARE DISPLAYED IN THE CENTER OF THE FIGURE, WITH THE CONNECTIONS TO THE MAIN DC BUSES AS INDICATED. TEMPERATURE SENSING CIRCUITS IN EACH INVERTER ACTIVATE A CAUTION LAMP WHEN AN OVERTEMPERATURE (+248 DEG. F) CONDITION IS DETECTED. TEMPERATURE INFORMATION IS ALSO TELEMETERED TO MSFN. ON THE LEFT SIDE OF THE FIGURE ARE DISPLAYED THE SENSING CIRCUITS WITH THE CONNECTIONS TO THE BUSES AND TO THE BATTERY RELAY BUS.

MOST OF THE AC COMPONENTS IN THE SPACECRAFT UTILIZE THREE PHASE AC POWER. HOWEVER, IN SOME INSTANCES, ONLY TWO PHASES ARE USED, AS IN THE CASE OF THE ECS SPACE RADIATOR CONTROL VALVES, AND IN OTHERS, ONLY A SINGLE PHASE IS USED, AS IN THE CASE OF G & N LIGHTING. ALL COMPONENTS SHOWING CONNECTIONS TO BOTH BUSES UTILIZE A BUS SELECTOR SWITCH FOR SELECTION OF POWER SOURCE.

THE LOWER LEFT OF THE FIGURE SHOWS THE "AC INDICATORS" ROTARY SWITCH, AND THE VOLTMETER AND FREQUENCY METER, FOR MEASURING THE VOLTAGE AND FREQUENCY OF EACH PHASE ON EACH BUS. VOLTAGE INFORMATION OF ALL THREE PHASES ON EACH BUS IS TELEMETERED. ONLY THE FREQUENCY OF PHASE A ON BOTH BUSES IS TELEMETERED.

EPS POWER DISTRIBUTION

AC POWER SYSTEM

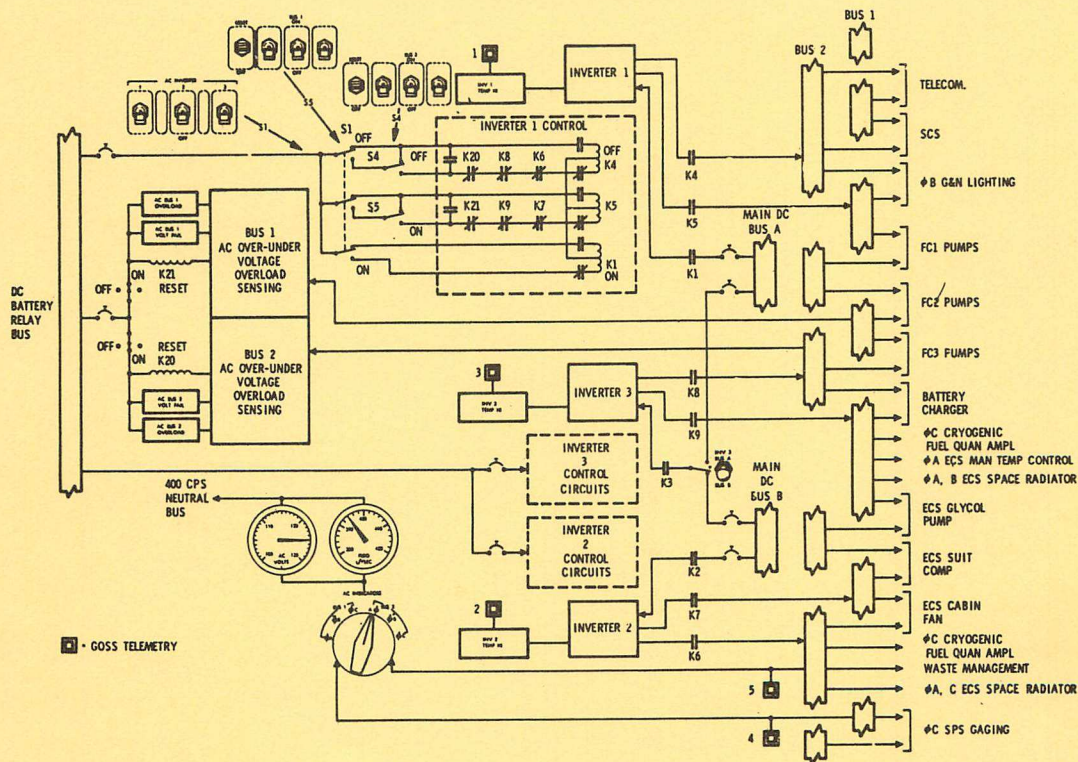


FIGURE 6-10

EP-402A



SECTION VII

CONTROLS AND DISPLAYS

7.1 INTRODUCTION

OPERATION OF THE EPS IS PRIMARILY A MANAGEMENT FUNCTION. SYSTEM OPERATION DOES NOT PRODUCE DYNAMIC REACTIONS IMMEDIATELY EVIDENT TO THE ASTRONAUTS THROUGH PHYSICAL MEDIA. THEREFORE, THE MAJOR CONTROLS AND DISPLAYS ASSOCIATED WITH THIS SYSTEM HAVE BEEN MADE EASILY ACCESSIBLE TO THE ASTRONAUT IN THE No. 3 SEAT, WHOSE PRIME DUTY IS SYSTEM MANAGEMENT. THE SHADED AREAS IN FIGURE 7-1 ILLUSTRATE THE LOCATION OF THE PANELS WHICH CONTAIN THE INDICATORS, CONTROLS, DISPLAYS AND ANNUNCIATORS ASSOCIATED WITH THE EPS. OPERATION AND FUNCTION OF EACH CONTROL AND DISPLAY WILL BE DISCUSSED IN THIS SECTION. IN ADDITION TO THE PANELS HIGH-LIGHTED IN FIGURE 7-1, CIRCUIT BREAKER PANELS ARE LOCATED IN THE LOWER AND RIGHT HAND EQUIPMENT BAYS.

7.2 CAUTION AND WARNING

THE SHADED AREA OF FIGURES 7-2 AND 7-3 SHOWS THE EPS CAUTION & WARNING LAMPS THAT INDICATE PARTICULARLY CRITICAL PARAMETERS.

7.2.1 INDICATORS

THE FOLLOWING EPS CAUTION & WARNING INDICATORS ARE LOCATED ON PANEL 10 AS ILLUSTRATED IN FIGURE 7-2.

7.2.1.1 H₂ PRESS

ILLUMINATION OF THIS LAMP IS CAUSED BY HYDROGEN TANK PRESSURE BELOW 220 PSIA OR ABOVE 270 PSIA.

7.2.1.2 O₂ PRESS

ILLUMINATION OF THIS LAMP IS CAUSED BY OXYGEN TANK PRESSURE BELOW 800 PSIA OR ABOVE 950 PSIA.

7.2.2

THE REMAINING CAUTION & WARNING INDICATORS ARE LOCATED ON PANEL 11 AS ILLUSTRATED IN FIGURE 7-3.

7.2.2.1 F/C BUS DISCONNECT

THIS INDICATOR WILL ILLUMINATE WHEN ANY ONE OR MORE OF THE THREE FUEL CELL MODULES IS AUTOMATICALLY DISCONNECTED FROM A MAIN DC BUS BY THE OVERLOAD/REVERSE CURRENT SENSING CIRCUIT.

7.2.2.2 F/C 1, F/C 2, F/C 3

ANY ONE OF THE FOLLOWING MALFUNCTIONS IN THE RESPECTIVE FUEL CELL SYSTEM WILL CAUSE RESPECTIVE LAMP ILLUMINATION: ABNORMAL H₂ OR O₂ FLOW, WATER

MAIN DISPLAY CONSOLE LOCATOR

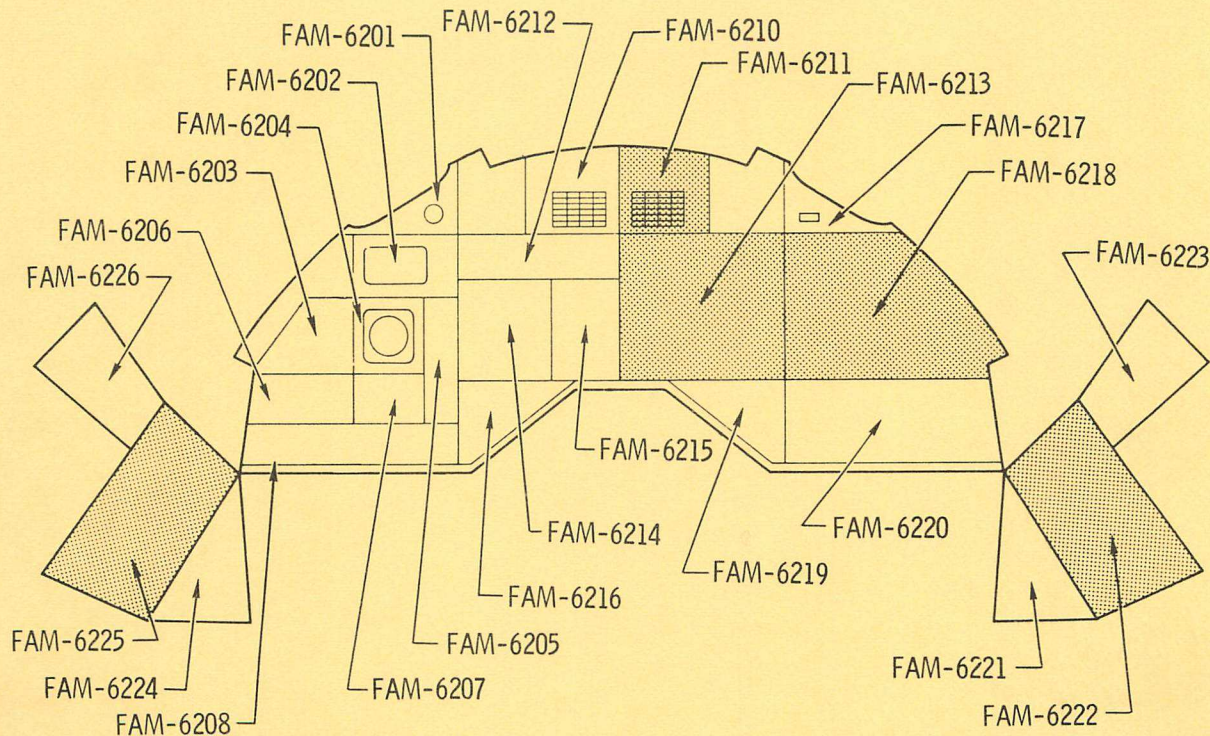
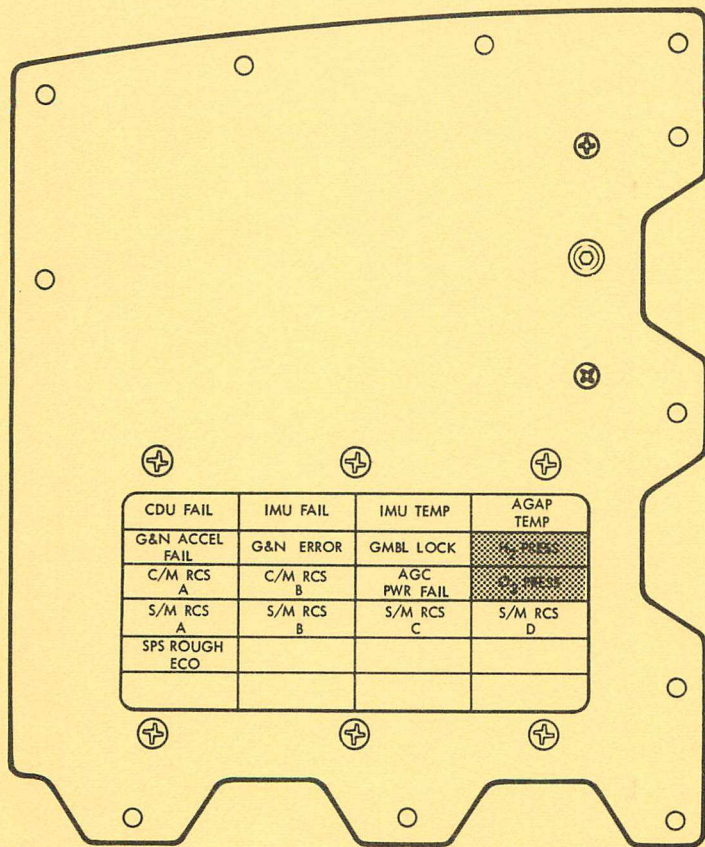


FIGURE 7-1



10

7

FIGURE 7-2

H ₂ O SEP PUMP FAIL	F/C-BUS DISCONNECT	F/C 1	INV 1 TEMP HI
GLYCOL TEMP LOW	SPS PRESS	F/C 2	INV 2 TEMP HI
PITCH GMBL DR FAIL	SPS WALL TEMP HI	F/C 3	INV 3 TEMP HI
YAW GMBL DR FAIL	SPS PU SNSR FAIL	MN BUS A UNDERVOLT	MN BUS B UNDERVOLT
	CO ₂ PP HI	AC BUS 1 FAIL	AC BUS 2 FAIL
CAUT/WARN FAIL	O ₂ FLOW HI	AC BUS 1 OVERLOAD	AC BUS 2 OVERLOAD

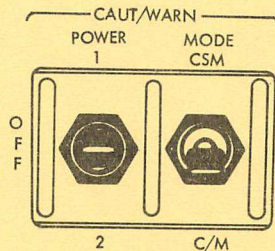


FIGURE 7-3

CONTAMINATION (PH), SKIN OR CONDENSOR EXHAUST TEMPERATURE OUT OF TOLERANCE, INLET RADIATOR TEMPERATURE BELOW -30 DEGREES F, O₂, H₂, N₂ REGULATOR OUT PRESSURE TOO HIGH. THESE LAMPS ARE MASTER INDICATORS FOR THOSE ASSOCIATED WITH FUEL CELL OPERATION WHICH ARE LOCATED ON THE FUEL CELLS, ELECTRICAL POWER SYSTEM PANEL.

7.2.2.3 MN BUS A UNDERVOLT, MN BUS B UNDERVOLT

VOLTAGE BELOW 26.25 VOLTS, AS DETECTED BY THE UNDERVOLTAGE SENSING CIRCUIT, WILL ILLUMINATE THE CORRESPONDING LAMP.

7.2.2.4 AC BUS 1 FAIL, AC BUS 2 FAIL

THIS LAMP WILL ILLUMINATE UPON DETECTION OF AN UNDERVOLTAGE (85-100 VOLTS AC), OR AN OVERVOLTAGE (130-145 VOLTS AC) IN ANY ONE OF THE THREE PHASES OF THE RESPECTIVE BUS. OVERVOLTAGE DISCONNECTS THE INVERTER.

7.2.2.5 AC BUS 1 OVERLOAD, AC BUS 2 OVERLOAD

THIS LAMP WILL ILLUMINATE UPON DETECTION OF AN OVERLOAD (SINGLE PHASE OR THREE PHASE) ON THE RESPECTIVE BUS. AN AUTOMATIC INVERTER DISCONNECT FROM THE RESPECTIVE BUS WILL ACCOMPANY AN OVERLOAD.

7.2.2.6 INV 1 TEMP HI, INV 2 TEMP HI, INV 3 TEMP HI

THE APPLICABLE LAMP WILL ILLUMINATE WHENEVER AN OVERTEMPERATURE CONDITION IS DETECTED IN THE

RESPECTIVE INVERTER. (+248 DEG. F.)

7.2.3 SWITCHES

THE FOLLOWING FUNCTIONS ARE PERFORMED BY THE SWITCHES LOCATED ON PANEL 11.

7.2.3.1 CAUTION/WARNING POWER

THIS SWITCH SELECTS ONE OF TWO POWER SOURCES FOR OPERATION OF THE CAUTION/WARNING SYSTEM. EACH POWER SOURCE HAS A REDUNDANT CONNECTION TO BOTH MAIN DC BUSES, THROUGH ISOLATION DIODES.

NOTE: THE CAUTION LAMP TEST CONTROL IS LOCATED ON PANEL 23.

7.2.3.2 CAUTION/WARNING MODE

THIS SWITCH SELECTS THE INPUT TO THE CAUTION/WARNING LAMPS FROM EITHER THE C/M ONLY, OR THE C/M AND S/M COMBINED. THE SWITCH WILL BE POSITIONED TO C/M JUST PRIOR TO C/M-S/M SEPARATION TO DISABLE THE INPUTS NORMALLY PROVIDED FROM THE S/M COMPONENTS, SO THAT THESE LAMPS WILL NOT BE ILLUMINATED AFTER SEPARATION.

7.3 RADIATION, AUDIO, CRYOGENIC & ECS SYSTEM

THE FOLLOWING INDICATORS AND CONTROLS ON THIS PANEL ARE ASSOCIATED WITH THE EPS SYSTEM (FIGURE 7-4).

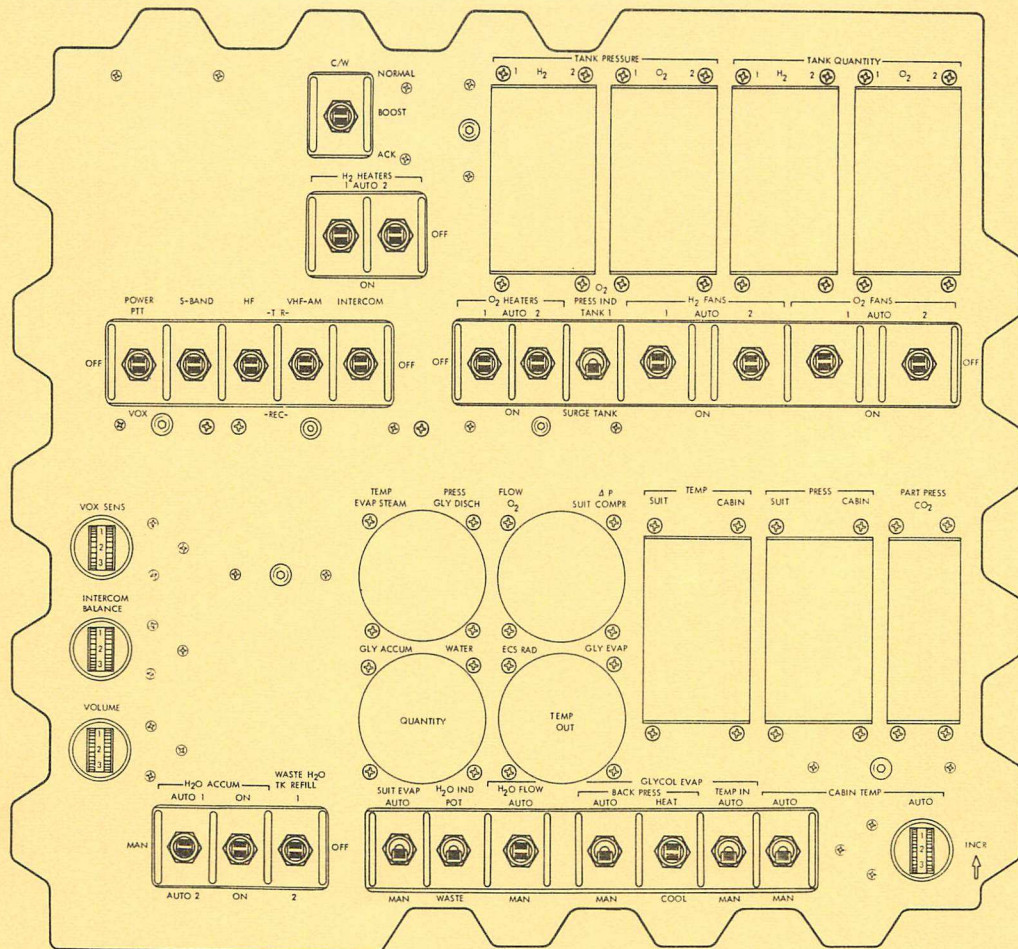


FIGURE 7-4

7.3.1 INDICATORS

THE INDICATORS ON THIS PANEL PERFORM THE FOLLOWING FUNCTIONS.

7.3.1.1 TANK PRESSURE H₂ 1 & 2, O₂ 1 & 2

BOTH INDICATORS ARE VERTICALLY SCALED DUAL DISPLAYS. THE H₂ TANK PRESSURE INDICATOR IS SCALED FROM 0 TO 300 PSIA WITH NORMAL READINGS FROM 230 TO 260 PSIA. THE O₂ INDICATOR IS SCALED FROM 50 TO 1200 PSIA WITH NORMAL READINGS FROM 865 TO 935 PSIA. O₂ TANK 1 IS TIME SHARED WITH THE SURGE TANK.

7.3.1.2 TANK QUANTITY, H₂ 1 & 2, O₂ 1 & 2

BOTH INDICATORS ARE VERTICALLY SCALED DUAL DISPLAYS. THEY INDICATE QUANTITY IN POUNDS OF REACTANT REMAINING IN THE FOUR TANKS AS MEASURED BY THE CAPACITIVE TYPE MEASUREMENT UNITS.

7.3.2 CONTROLS

THE FOLLOWING CONTROLS ON THIS PANEL ARE ASSOCIATED WITH THE EPS.

7.3.2.1 C/W - NORMAL, BOOST, ACK

PROVIDES LIGHT CONTROL OF THE CAUTION/WARNING LAMPS. NORMAL POSITION ALLOWS NORMAL OPERATION OF ALL THE CAUTION & WARNING AND MASTER ALARM INDICATORS.

BOOST POSITION DISABLES THE MASTER ALARM INDICATOR ON PANEL 3, LOCATED IN FRONT OF THE NO. 1 ASTRONAUT. THIS POSITION IS USED DURING LAUNCH TO ELIMINATE ILLUMINATION OF THE MASTER ALARM INDICATOR IN FRONT OF THE NO. 1 ASTRONAUT, SO THAT ONLY THE ABORT LAMP WILL BE ACTIVE DURING THIS PHASE OF THE MISSION. THE ACK POSITION DISABLES THE C/W INDICATORS ON PANELS 10 & 11 AND WILL BE USED DURING PERIODS WHEN DARKNESS IS DESIRED. THE MASTER ALARM INDICATORS ARE ACTIVE WHEN THIS POSITION IS USED AND WILL PROVIDE MALFUNCTION INDICATIONS.

7.3.2.2 H₂ HEATERS 1 & 2, O₂ HEATERS 1 & 2

PROVIDE A MEANS OF APPLYING DC POWER TO THE HEATER CIRCUITS IN THE RESPECTIVE CRYOGENIC STORAGE TANKS. THE "AUTO" POSITION PROVIDES FOR AUTOMATIC OPERATION BY USE OF THE PRESSURE SWITCHES. THE "ON" POSITION PROVIDES MANUAL CONTROL OF POWER INPUT TO THE HEATERS.

7.3.2.3 PRESS IND

SELECTS INPUT TO O₂ 1 TANK PRESSURE GAUGE EITHER FROM TANK 1 OR THE SURGE TANK. THE SURGE TANK CONTAINS OXYGEN TO BE USED DURING ENTRY.

7.3.2.4 H₂ FANS 1 & 2, O₂ FANS 1 & 2

PROVIDES SIMILAR CONTROL FOR THE FANS AS IS APPLICABLE TO THE HEATERS.

7.4 FUEL CELLS, ELECTRICAL POWER SYSTEM

FIGURE 7-5 SHOWS THE LOCATION OF THE FOLLOWING CONTROLS, INDICATORS AND DISPLAYS.

7.4.1 FUEL CELLS CONTROLS, DISPLAYS AND INDICATORS

THE FOLLOWING ARE ASSOCIATED WITH THE FUEL CELLS.

7.4.1.1 FUEL CELL INDICATORS

THIS SWITCH, LOCATED IN THE CENTER-LEFT OF THE PANEL, DETERMINES WHICH OF THE THREE F/C'S PARAMETERS WILL BE DISPLAYED ON THE INDICATORS OF THIS PANEL. THE SWITCH HAS NO OFF POSITION, THEREFORE, CONDITIONS OF A SELECTED FUEL CELL MODULE WILL BE DISPLAYED AT ALL TIMES.

7.4.1.2 FLOW, H₂, O₂

THIS VERTICALLY SCALED, DUAL READING INDICATOR SHOWS THE REACTANT FLOW RATES OF THE SELECTED FUEL CELL MODULE. IT IS GRADED IN POUNDS/HOUR. PURGING OF THE SELECTED REACTANT COMPARTMENT WILL BE INDICATED BY A MAXIMUM FLOW INDICATION.

7.4.1.3 MODULE TEMP - SKIN, COND EXH

THIS IS A VERTICALLY SCALED, DUAL READING INDICATOR. THE LEFT SIDE INDICATES MODULE SKIN, OR OPERATING TEMPERATURE; THE RIGHT SIDE INDICATES THE CONDENSOR EXHAUST TEMPERATURE.

7.4.1.4 REG OUT PRESS HI - H₂, O₂, N₂

FLAGS WILL BE DISPLAYED WHENEVER OXYGEN OR HYDROGEN PRESSURE FROM THE REGULATORS EXCEEDS 75 PSIA, OR NITROGEN PRESSURE EXCEEDS 70 PSIA.

7.4.1.5 F/C RAD TEMP LO

THIS FLAG WILL BE DISPLAYED WHENEVER TEMPERATURE OF THE GLYCOL/WATER COOLANT RETURNING FROM THE EPS RADIATORS DECREASES BELOW -30 DEGREES F.

7.4.1.6 PH HI

A FLAG WILL BE DISPLAYED WHENEVER ANY CONTAMINANT IS SENSED IN THE WATER EXTRACTED FROM THE RESPECTIVE FUEL CELL MODULE.

7.4.1.7 H₂ PURGE, O₂ PURGE

A THREE POSITION SWITCH IS PROVIDED FOR EACH OF THE THREE FUEL CELL MODULES. THE UP POSITION ENERGIZES THE HYDROGEN PURGE VALVE, THE CENTER POSITION IS OFF, AND THE DOWN POSITION ENERGIZES THE OXYGEN PURGE VALVE IN THE RESPECTIVE FUEL CELL SYSTEM. THE SWITCHES ARE MAINTAINING TYPE.

7.4.1.8 REACTANTS

THERE IS A THREE POSITION SWITCH FOR EACH OF THE THREE FUEL CELL MODULES. THE MOMENTARY UP POSITION PROVIDES POWER TO OPEN THE RESPECTIVE F/C REACTANT SHUT OFF VALVES (H₂ AND O₂) SIMULTANEOUSLY.

FUEL CELLS, ELECTRICAL POWER SYSTEM

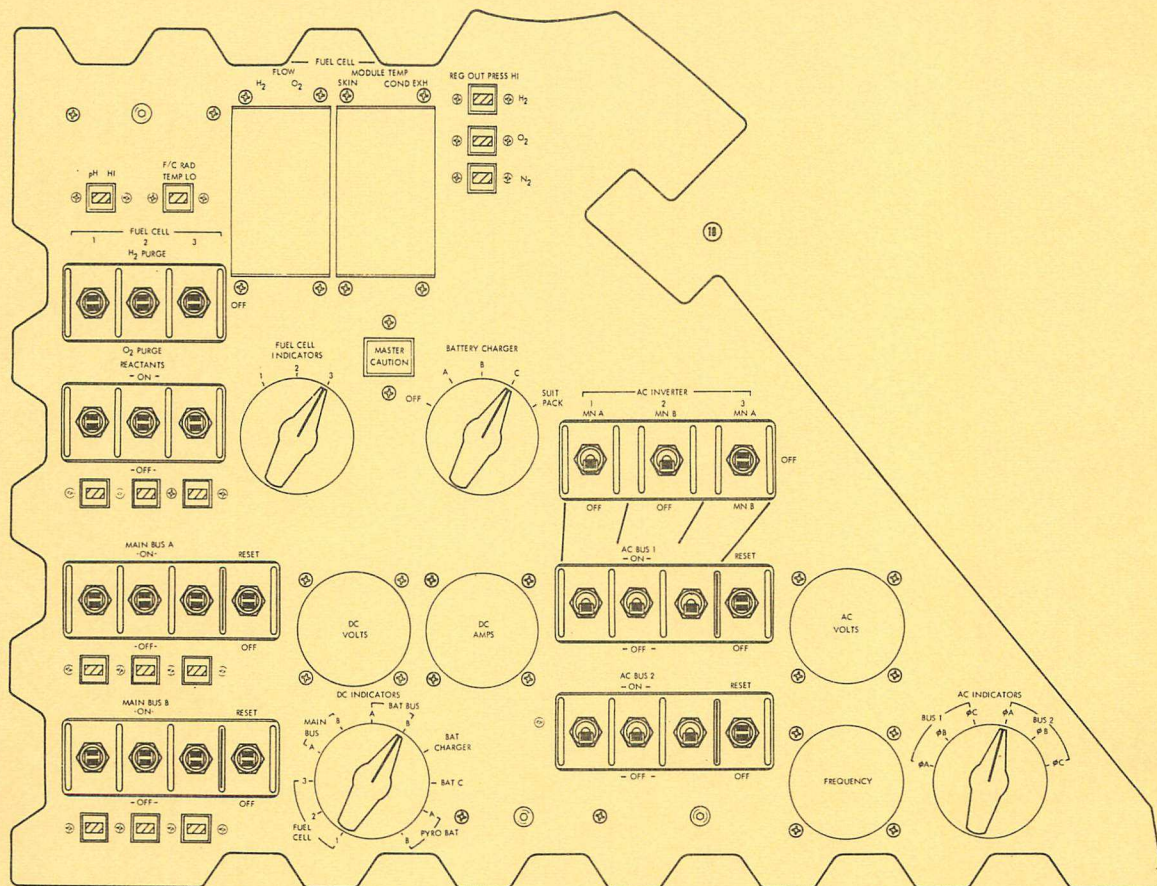


FIGURE 7-5

THE CENTER MAINTAINING POSITION REMOVES POWER FROM THE SOLENOIDS AND THE VALVES REMAIN IN THE LAST COMMANDED POSITION. THE MOMENTARY DOWN POSITION CLOSSES BOTH SOLENOID VALVES SIMULTANEOUSLY.

7.4.2 MASTER CAUTION LAMP

THIS LAMP WILL ILLUMINATE WHENEVER ANY LAMP IN THE CAUTION & WARNING GROUP IS ILLUMINATED. SIMULTANEOUSLY, A WARBLING AUDIO TONE WILL BE PRESENTED IN THE INTERCOMMUNICATIONS SYSTEM. DEPRESSING THIS INDICATOR DEACTIVATES THE LAMP AND **AUDIO** TONE FROM THE PARTICULAR MALFUNCTION OCCURRING, AND RESETS THE CIRCUITS SO THEY ARE ACTIVE WITH THE REMAINDER OF THE CAUTION & WARNING INDICATORS. ANOTHER IDENTICALLY FUNCTIONING LAMP IS LOCATED ON PANEL 3, AND A THIRD IS LOCATED IN THE LOWER EQUIPMENT BAY.

7.4.3 DC CONTROLS & DISPLAYS

THE FOLLOWING CONTROLS & DISPLAYS ARE ASSOCIATED WITH THE DC SYSTEM.

7.4.3.1 MAIN BUS A

THERE IS A THREE POSITION SWITCH CONTROLLING CONNECTION OF EACH OF THE THREE FUEL CELL MODULES TO MAIN BUS A. THE MOMENTARY UP POSITION PROVIDES POWER TO MOTOR SWITCHES TO CONNECT THE RESPECTIVE FUEL CELL TO BUS A. THE MAINTAINING DOWN POSITION POWERS THE MOTOR SWITCH TO REVERSE THE OPERATION. THE FLAG WILL

BE DISPLAYED WHENEVER A FUEL CELL MODULE IS DISCONNECTED FROM THE BUS. THE "RESET" SWITCH IS USED TO RESET THE UNDERVOLTAGE SENSING CIRCUIT WHENEVER IT IS ACTIVATED BY AN UNDERVOLTAGE CONDITION.

7.4.3.2 MAIN BUS B

THESE SWITCHES AND FLAG INDICATORS SERVE THE SAME FUNCTION FOR BUS B AS THOSE FOR BUS A.

7.4.3.3 DC INDICATORS

THIS SWITCH SELECTS THE BUS OR COMPONENT TO BE DISPLAYED ON THE "DC VOLTS" OR "DC AMPS" INDICATORS. ONE CIRCUIT WILL BE DISPLAYED AT ALL TIMES.

7.4.3.4 BATTERY CHARGER

A ROTARY SWITCH FOR SELECTION OF THE BATTERY TO BE CHARGED. THE SWITCH CONTROLS INPUT INTO THE CHARGER AS WELL AS CONNECTION OF BATTERY CHARGER OUTPUT TO THE SELECTED COMPONENT.

7.4.4 AC CONTROLS & DISPLAYS

THE FOLLOWING CONTROLS & DISPLAYS ARE ASSOCIATED WITH THE AC SYSTEM.

7.4.4.1 AC INVERTER 1, 2, 3

THESE MAINTAINING TYPE SWITCHES CONTROL DC POWER INPUT TO THE RESPECTIVE INVERTER.

7.4.4.2 AC BUS 1

THESE MAINTAINING TYPE SWITCHES CONTROL POWER TO MOTOR SWITCHES WHICH CONTROL CONNECTION OF THE RESPECTIVE INVERTER TO BUS 1. THE "RESET" SWITCH, MOMENTARY IN THE UP POSITION, AND MAINTAINING IN THE OFF AND CENTER OR ON POSITION, CONTROLS RESETTING OF THE OVER-UNDERVOLTAGE AND OVERLOAD SENSING CIRCUITS. IF AN INVERTER IS AUTOMATICALLY DISCONNECTED, THIS SWITCH MUST BE ACTIVATED AFTER THE AC BUS 1 SWITCH OF THE REPLACEMENT INVERTER IS ACTIVATED.

7.4.4.3 AC BUS 2

CONTROL CONNECTION OF THE INVERTERS TO BUS 2 IN THE SAME MANNER AS THOSE FOR BUS 1.

7.4.4.4 AC INDICATORS

PROVIDES SELECTION OF AN AC BUS AND A PHASE ON THAT BUS FOR DISPLAY ON THE "AC VOLTS" AND "FREQUENCY" METERS.

7.4.4.5 AC VOLTS

PROVIDES A VISUAL DISPLAY OF THE VOLTAGE ON THE SELECTED BUS AND PHASE OF THAT BUS.

7.4.4.6 FREQUENCY

PROVIDES A VISUAL DISPLAY OF THE FREQUENCY ON THE SELECTED BUS AND PHASE OF THAT BUS.

7.5

RH CIRCUIT BREAKER PANEL

FIGURE 7-6 DEPICTS THE APPLICABLE CIRCUIT BREAKERS AND CONTROLS.

THE CIRCUIT BREAKERS ON THIS PANEL ARE SIMPLE PROTECTIVE DEVICES PERTINENT TO THE VARIOUS SPACECRAFT SYSTEMS. THEY ARE TRIP-FREE, AND CANNOT BE RESET ONCE THEY ARE TRIPPED BY A MALFUNCTION, IF THAT MALFUNCTION STILL EXISTS. ONCE TRIPPED BY A MALFUNCTION, THEY CAN BE DEPRESSED, AND IF THE MALFUNCTION STILL EXISTS, THEY WILL TRIP INTERNALLY.

THE CIRCUIT BREAKERS WITH ALPHABETICAL DESIGNATIONS PERTAIN TO DC SYSTEMS, AND THOSE WITH NUMERICAL DESIGNATIONS PERTAIN TO AC SYSTEMS.

7.5.1

CONTROLS

THE FOLLOWING CONTROLS ON THIS PANEL PERTAIN TO THE EPS.

7.5.1.1

FUEL CELL PUMP 1, 2, 3

THE THREE, THREE POSITION MAINTAINING TYPE TOGGLE SWITCHES PROVIDE CONTROL OVER EACH OF THE THREE INDIVIDUAL FUEL CELL MODULES HYDROGEN AND COOLANT PUMPS. SELECTION IS PROVIDED FOR CONNECTING POWER FROM AC BUS 1 OR 2.

7.5.1.2 MAIN BUS TIE - BAT A & C, BAT B & C

A THREE POSITION MAINTAINING TYPE SWITCH WHICH PROVIDES POWER TO MOTOR SWITCHES FOR CONNECTING THE RESPECTIVE BATTERY PAIR TO THE MAIN DC BUSES. BATTERY A IS CONNECTED TO BUS A AND BATTERY C TO BUS B WITH ONE SWITCH. THE OTHER SWITCH CONNECTS BATTERY B TO BUS B, AND BATTERY C TO BUS A. UP POSITION IS ON, AND THE DOWN POSITION IS OFF. THE AUTO POSITION PROVIDES FOR CONNECTION OF THE BATTERIES AUTOMATICALLY ON C/M-S/M SEPARATION.

7.5.1.3 BAT CHGR

CONTROLS SELECTION OF AC INPUT TO THE BATTERY CHARGER FROM EITHER AC BUS 1 OR 2.

7.5.1.4 NON ESS BUS

THIS MAINTAINING TYPE THREE POSITION SWITCH PERMITS SELECTION OF POWER TO THE NON-ESSENTIAL BUS THROUGH EITHER MAIN DC BUS A OR B. THE CENTER "OFF" POSITION PERMITS TURNING OFF OF ALL POWER TO THIS BUS AND WOULD BE USED DURING PERIODS OF LOW POWER AVAILABILITY.

7.6

FIGURE 7-7 ILLUSTRATES SWITCHING AND CIRCUIT BREAKERS APPLICABLE TO COMPONENTS AS INDICATED BY THE RESPECTIVE NOMENCLATURE.

7.7 LH CIRCUIT BREAKER PANEL

FIGURE 7-8 ILLUSTRATES THE APPLICABLE CIRCUIT BREAKERS AND CONTROLS. THESE ARE PRIMARILY ASSOCIATED WITH SPACECRAFT MANEUVERING.

7.7.1 BATTERY CIRCUIT BREAKER PANEL (LEB)

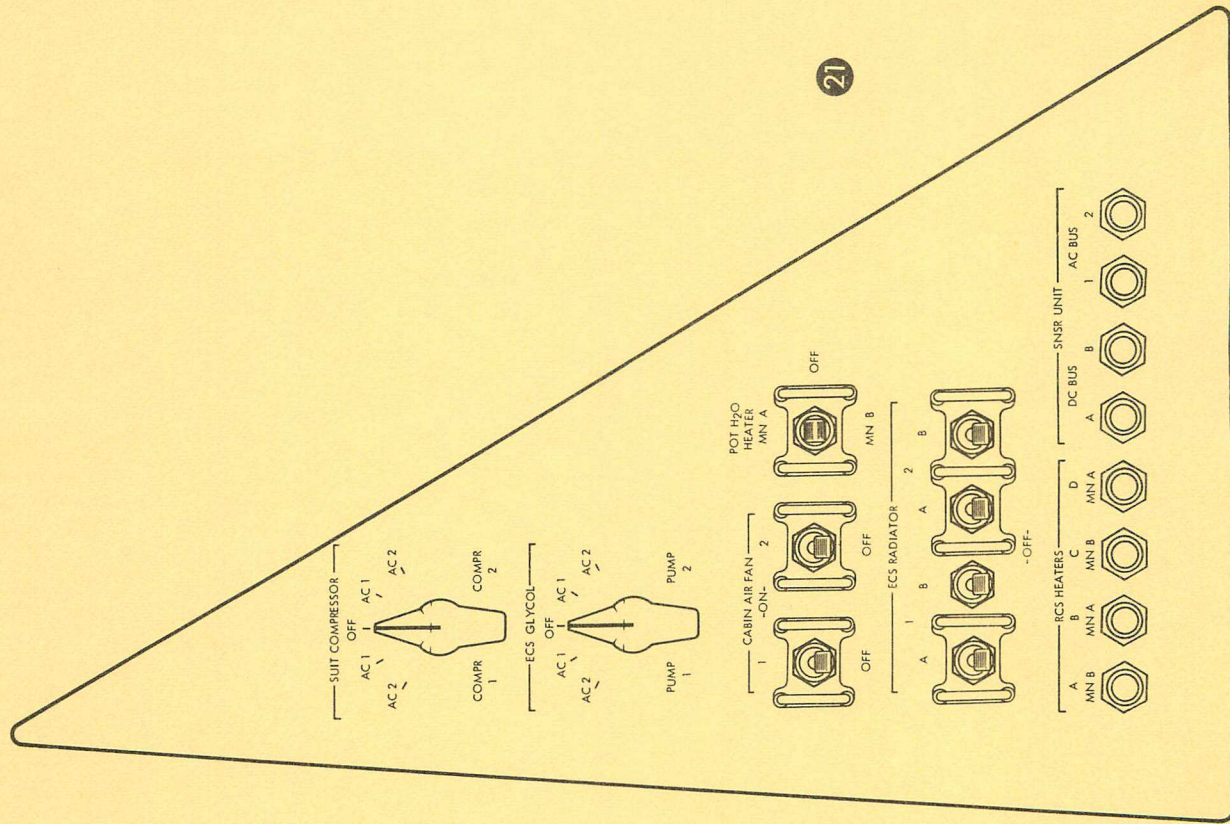
THIS PANEL IS LOCATED IN FRONT OF THE PYRO-TECHNIC BATTERIES IN THE LOWER EQUIPMENT BAY.

7.7.2 ELECTRICAL POWER SYSTEM CB PANEL (RHEB)

THE "BUS TIE", "POST LDG", "BAT BUS A, BAT BUS B, AND BAT C" CIRCUIT BREAKERS ON THIS PANEL ARE THE THREE CIRCUIT BREAKERS WHICH WILL BE NORMALLY OPEN IN FLIGHT. SINCE THEY PROVIDE A DIRECT TIE FROM THE BATTERIES TO THE FLIGHT & POST LANDING BUS, THEY MUST BE OPEN WHENEVER BATTERIES A, B OR C ARE BEING CHARGED TO PREVENT THE HIGHER VOLTAGE FROM THE BATTERY CHARGER FROM BEING APPLIED TO THE FLIGHT & POST LANDING BUS.

7.8 EPS CIRCUIT BREAKERS

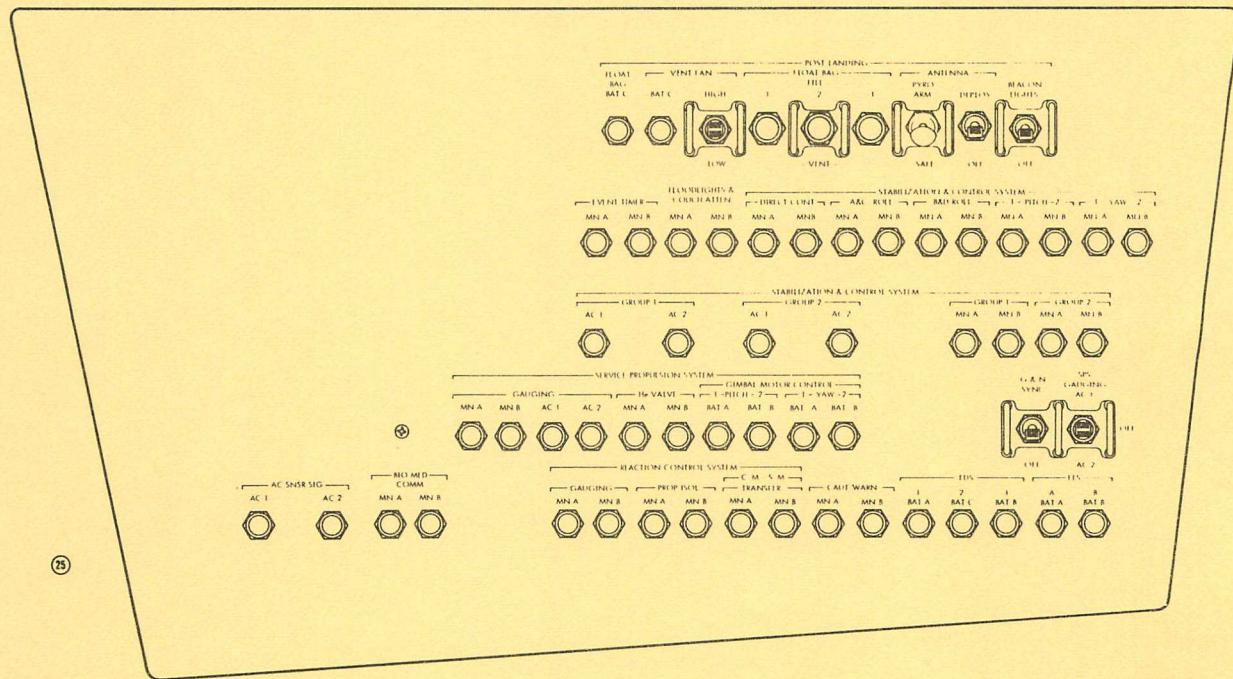
THIS ILLUSTRATION (FIGURE 7-9) DEPICTS THE LOWER EQUIPMENT BAY AND RIGHT HAND EQUIPMENT BAY CIRCUIT BREAKER PANELS.



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FIGURE 7-7

LH CIRCUIT BREAKER PANEL

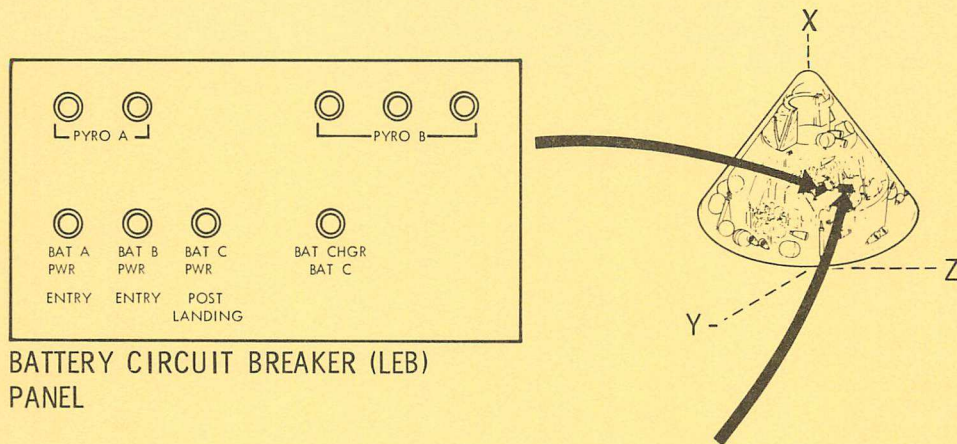


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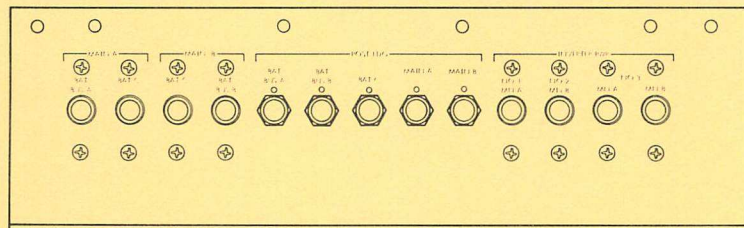
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FIGURE 7-8

EPS CIRCUIT BREAKERS



BATTERY CIRCUIT BREAKER (LEB)
PANEL



ELECTRICAL POWER SYSTEM
CIRCUIT BREAKER PANEL (RHEB)



APPENDIX A
BIBLIOGRAPHY

BIBLIOGRAPHY

GENERAL INFORMATION

DRAWINGS

V14-945512A SCHEMATIC DIAGRAM,
ELECTRICAL POWER SYSTEM,
C/M & S/M (2/5/65)

V16-451501 ELECTRICAL SYSTEM INSTALL-
ATION, CREW COMPARTMENT

V17-450059 FUEL CELL INSTALLATION,
EPS

FUEL CELL

DRAWINGS

V17-945102 SCHEMATIC DIAGRAM, FUEL CELL
SYSTEM, SUPPLY & CONTROL

SPECIFICATIONS

MC 464-0015 PROCUREMENT (CONFIDENTIAL)

MC 432-0100 MONITOR, WATER CONDITION, PH

DOCUMENTS

PRATT & WHITNEY-MONTHLY & QUARTERLY PROGRESS
AIRCRAFT REPORTS

BATTERIES

DRAWINGS

V16-444121 ELECTRICAL SYSTEMS INSTALL-
ATION LOWER EQUIPMENT BAY

SPECIFICATIONS

MC 461-0012 BATTERY, SPACECRAFT, STORAGE,
SILVER OXIDE-ZINC, 29 VOLT

MC 461-0007A BATTERY, SPACECRAFT, PYRO-
TECHNIC, SILVER OXIDE-ZINC

DOCUMENTS

EAGLE PICHER - MONTHLY & QUARTERLY PROGRESS
REPORTS

BATTERY CHARGER

DRAWINGS

ITT 5006152 SCHEMATIC, BATTERY CHARGER

SPECIFICATIONS

MC 461-0002E PROCUREMENT

BIBLIOGRAPHY

INVERTER

DRAWINGS

WESTINGHOUSE 967J318 SCHEMATIC DIAGRAM,
INVERTER

SPECIFICATIONS

MC 495-0001 F PROCUREMENT

POWER DISTRIBUTION

DRAWINGS

V16-945902 B SCHEMATIC, DC UNDERVOLTAGE
SENSING UNIT

V16-945901 C SCHEMATIC, AC OVER-UNDERVOLT-
AGE & OVERLOAD SENSING UNIT

V16-976362 C SCHEMATIC DIAGRAM - CAUTION
& WARNING DETECTION SYSTEM

SPECIFICATIONS

MC 452-0036 PROCUREMENT - POWER TRANSFER
SWITCH

MC 452-0055 C PROCUREMENT - SWITCH, POWER,
OVER-CURRENT

RELAY (GIMBAL
MOTORS)

MC 901-0295 E PROCUREMENT-DETECTION UNIT,
CAUTION & WARN-
ING SUBSYSTEM

CRYOGENICS

DRAWINGS

V14-945804 F SCHEMATIC, ELECTRICAL,
CRYOGENIC SYSTEM

SPECIFICATIONS

MC 901-0005 F STORAGE SUBSYSTEM, CRYOGENIC

DOCUMENTS

BEECH AIRCRAFT-MONTHLY PROGRESS REPORTS

DISPLAYS & CONTROLS

DRAWINGS

V16-976035 A DESIGN LAYOUT - MAIN DISPLAY
CONSOLE,
C/M 012 & 014

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DISPLAYS & CONTROLS - (CONT)

V16-451165 PANEL ASSY - ELECTRICAL
 POWER, CIRCUIT
 BREAKER

V16-451167 PANEL ASSY,- BATTERY, CIRCUIT
 BREAKER

GSE INFORMATION

AMPTF - DESIGN REFERENCE MISSION
VOL II - PREFLIGHT SEQUENCE OF EVENTS
GRUMMAN 5 OCTOBER 1964

ALL SYSTEMS

V14-900112 FUNCTIONAL INTEGRATED SYSTEM
 SCHEMATICS SPACECRAFT 012

VOLUME I
VOLUME 2 REVISION B EPS, SECS, ECS, SPS
VOLUME 3 NC COMM.