THESIS

Ku-Band High Power Amplifier
System Functionality and Operation

by

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The subsystems and their respective functionality of a Ku-band high power amplifier are carefully documented. Figures identifying physical components, wiring, contact points, switches, and valves with their labels on the system blueprints are presented. These figures will be helpful if system performance parameter adjustments are desired. Operation, maintenance, troubleshooting and testing procedures are also included to make this thesis a self-contained operator’s manual for the high power amplifier.

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High Power Amplifier System, RF Amplifier Unit, Control Unit, High Voltage Supply Unit, Cooling Unit, Modulation Unit, System Operation, Maintenance and Troubleshooting Procedures.
Ku-Band High Power Amplifier
System Functionality and Operation

by

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ABSTRACT

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I. INTRODUCTION

The High Power Amplifier (HPA) studied in this thesis was built by Ground System Group of Hughes Aircraft Company for the Naval Research Laboratory (NRL) in 1980. In November 1982, a new Solid State Modulator (SSM) was installed to improve system reliability and performance. A total of four units with SSM were built. One of them was transferred to the Naval Postgraduate School (NPS) in August 1989 for research in radar signal propagation and scattering.

The heart of the HPA is a high power traveling wave tube (TWT). It amplifies and modulates a one watt signal into a 10 kilowatt pulse of up to ten microseconds width. To achieve such power amplification, a direct current (DC) voltage drop as high as 30 kilovolts has to be present between the anode and the cathode of the tube. To supply the free electron flow in the tube, an ion pump is needed. To confine the high energy electrons, a solenoid is required to set up a magnetic field in the TWT. Pulse modulation is accomplished through turning on and off the flow of electrons in the TWT via applying a positive or a negative bias to the grid.

Working with such a high power, high voltage system calls for carefully implemented safety features. Many monitoring and interlocking mechanisms are built into the HPA. As complicated as such a system may be, all the available information on the operation, maintenance and performance of the system is limited to several blueprints and two technical reports, one entitled Technical Manual For Special Purpose Transmitter [Ref. 1]; the other on the performance testing of the SSM.
Hence when the HPA arrived at the Microwave Propagation Lab with severed wires with labels not matching any description in the Technical Manual, it become the first priority to look into the blueprints and to physically identify on the HPA each item described in the Technical Manual.

This goal is achieved in chapter II of this thesis. Not considering the flow charts, the figures in chapter II are grouped according to the functionality of the HPA subsystems. All these figures are in fact overlays of the relevant parts of the blueprints on the physical HPA. Related work performed on the HPA but not included in this thesis is the identification and labeling of the HPA subsystems, components, wires, connectors, junctions, switches and valves in accordance with their labels on the blueprints.

Chapter III describes the facility requirements and the operation, maintenance and troubleshooting procedures of the HPA. Only those requirements and procedures most directly related to setting up and operating the HPA at NPS are included in this chapter. The rest are placed in the Appendices. Appendix A contains flow charts of the maintenance procedures adapted from the Technical Manual. Appendix B contains flow charts which combine step-by-step instructions of the Technical Manual with explanatory notes for troubleshooting.

Appendix C lists the specifications of the TWT which are either scattered throughout the Technical Manual or found only on the label attached to the TWT. For easy reference, the many abbreviations and labels related to the HPA are listed in Appendix D.
This thesis will serve as the HPA manual specifically written for the unit in the Microwave Propagation Lab.
II. HIGH POWER AMPLIFIER SYSTEM CIRCUITRY AND FUNCTIONALITY

This High Power Amplifier (HPA) is a ku-band high power amplifier, with an average power of 3.4 kW and a peak power of 10 kW. It uses a Traveling Wave Tube (TWT) for amplification of the RF signal. The system configuration is shown in Figure 1.

![HPA Physical setup](image)

Figure 1 HPA Physical setup

The HPA system physically separates into the HPA cabinet, the Solenoid Power Supply cabinet and the Water Filter. They are currently located in room Sp-537.
According to their functions, the HPA can be separated into the following six functional units as shown in Figure 2.

Figure 2 HPA Functional Blocks

1. RF Amplifier Unit.
2. High Voltage Power Supply Unit.
3. Modulator Unit.
4. Control Unit.
5. HPA Power Distribution Unit.
6. HPA Cooling Unit.
The following sections describe the functions and the circuitry of each unit. The abbreviations of the components will be introduced in parentheses and used in the schematic drawings and block diagrams.

A. RF AMPLIFIER UNIT

The purpose of this unit is to provide RF amplification and to monitor the RF incoming and outgoing signals to prevent damages to the TWT caused by reflected RF power. The unit consists of a high power TWT, an ion pump power supply, monitoring circuits, and a solenoid power supply. All these circuits are housed in the HPA cabinet, except the solenoid power supply which is housed in a separate cabinet. The block diagram of this unit is shown in Figure 3.

1. RF Amplifier

This component contains the primary parts of the RF amplifier unit. These parts include all the elements the RF signal pass through.

a. The Directional Couplers (DC1, DC2)

The direction couplers DC1 and DC2 couple RF signal out of the waveguide for testing. They are located respectively at the beginning and at the end of the waveguide inside the HPA. DC2 also routes samples of reflected RF signals through the 25 dB attenuator (AT2) and a power detector to the monitor circuit (A9) to detect the presence of high VSWR.

b. The Liquid-cooled Circulators (AT1, AT8)

The circulator (AT8) attenuates reflected RF and isolates the high power TWT from the load during waveguide arcs or high VSWR.
Figure 3 RF Amplifier Unit Block Diagram
situations. The AT8 is located above the TWT. It minimizes the effect of load impedance mismatch to the high power TWT.

The circulator (AT1) prevents any leakage from the TWT to backup into the low power RF driver. It is located under CD1.

c. **The Equalizer (EQ1)**

The equalizer (EQ1) matches the input impedance of the high power TWT to the waveguide and is located under AT1.

d. **TWT (V1)**

The TWT (V1) provides the final amplification of the RF signal. The TWT specifications are given in Appendix C.

2. **Ion Pump Power Supply (A4)**

The ion pump power supply furnishes an approximately +3.8 kV voltage to the TWT ion pump. It is located next to the TWT. The ion pump, located inside the TWT, is part of the TWT. It continuously ionizes the gas inside the TWT to free up electrons for RF amplification.

3. **Solenoid Power Supply**

Two Systron Donner Power Supplies are connected in series to provide the solenoid of the RF amplifier with a power of 320 V at 15 amperes maximum.

4. **Cathode-to-Body Voltage Cable (A2A6j6)**

The wire A2A6j6 is the high voltage cable used by the high voltage power supply unit to provide the -28 to -34 kV voltage to the TWT cathode.
5. Collector-to-Body Voltage Cable (A2j7)

The high voltage power supply unit provides the -8.9 to -10.8 kV voltage to the TWT collector through the high voltage cable A2j7.

B. HIGH VOLTAGE POWER SUPPLY UNIT

The high voltage power supply unit provides the cathode-to-body and the collector-to-body voltages to the TWT. The unit consists of an error amplifier/inverter driver card, an inverter assembly, and high voltage power supplies for the cathode and for the collector. Assemblies containing the high voltage circuits, inverter and the high voltage power supplies are immersed in a Fluorinert compound, FC77, inside the high voltage assembly. The fluid serves the dual purpose of cooling the components and providing high voltage insulation. The error amplifier/inverter driver card is located outside on top of the high voltage assembly. The unit is shown schematically in Figure 4.

1. Rectifier Filter Assembly (A5)

The rectifier filter assembly provides dc power to the inverter assembly. The assembly rectifies and filters the 440 V 400 Hz 3-phase prime power with the use of a choke input filter. A power factor close to one is achieved while supplying a nominal output voltage of 600 Vdc.

2. Error Amplifier and Inverter Driver Card (A2j1)

The error amplifier and inverter driver card senses the high voltage and indirectly regulates the high voltage power supply output by sending the silicon-controlled-rectifier (SCR) drive pulses to the inverter assembly.
Figure 4 High Voltage Power Supply Unit
Schematic Diagram
3. Inverter Assembly (A2)

The inverter assembly provides the drive power for the high voltage power supply. The inverter assembly receives filtered 600 Vdc from the rectifier filter assembly. When the inverter SCR drive pulses are received from the error amplifier and inverter driver, the 600 Vdc is switched by a bridge inverter circuit, composed of four SCR's, to form a variable frequency squarewave of 1200 V peak-to-peak. The squarewave is coupled by an inverter transformer to the high voltage power supply.

4. High Voltage Power Supply (A2)

The step-up voltage from the inverter transformer is rectified in an offset tap configuration and filtered to furnish two high voltage dc outputs to operate the TWT in a depressed collector mode. Both high voltage outputs are adjustable, from -28 kV voltage to -34 kV voltage (cathode supply) and from -8.9 kV voltage to -10.8 kV voltage (collector supply), while maintaining a 32% depression.

C. MODULATION UNIT

The modulation unit provides modulated grid voltage and filament voltage required by the high power TWT. The solid state modulator consists of a low level modulator drive assembly called the ground level and a floating deck. The floating deck is immersed in FC-77 inside the high voltage assembly A2. The modulator low level drive assembly is located on the top cover of the high voltage assembly. The block diagram of this unit is shown in Figure 5.
Figure 5  Modulator Unit Block Diagram
1. **Low Level Modulator Drive (A6j5)**

The low level modulator drive assembly contains the necessary video interface and bias supplies. It provides amplification of the modulator video (mod. video) input signal. The mod. video input signal is differentiated and two outputs are applied to separate drive circuits which generate on and off drive signals corresponding to the video leading and trailing edges. The on and off signals are then coupled through isolation transformers to the floating deck.

2. **Floating Deck (A6j2)**

The floating deck consists of the on and off Field Effect Transistor (FET) switches and the associated rectifiers and filters for the bias and filament voltages. When on and off triggers are received, these two triggers are amplified and shaped by the high level drive circuits. The signals leaving the high level drive circuits drive the FET on and off switches which modulate the grid. The entire floating deck is enclosed in a Faraday shield to minimize voltage gradients within the modulator. The modulator also incorporates a fail safe feature by limiting the maximum grid pulse width to less than 10 microseconds in the event of a missing off trigger.

D. **CONTROL UNIT**

The control unit completely controls and monitors the operation of the HPA. Whenever a fault is detected, an appropriate fault indicator is lit, the modulator is inhibited and the body voltage is shut off. All the circuits are located on the control circuit card assembly, mounted in the top front of the HPA cabinet. This unit contains three kinds of monitor circuits:
1. Fault Monitor Circuits.

2. Control Logic Circuits.

3. Test Circuits.

1. Fault Monitor Circuits

There are 20 fault monitors, 8 status monitor circuits and 9 BNC connections to monitor the HPA. They are located on the control panel and are clearly marked.

The fault monitor circuits are divided into three main categories: the interlock monitors, the DC comparator monitors and the pulse monitors. The functions of the categories are shown in Figure 6.

a. Interlock Monitors

A circuit in this category senses the opening of a switch contact to register a fault. The following fault monitors are in this category:

(1) Circuit Breaker Open (j14-20, 21): senses the opening of the switches CB1, CB2 and CB5 located in the upper-right corner of the HPA cabinet.

(2) Coolant Flow (j14-1): monitors the coolant flow through the coolant flow switches (S4, S5), which are located above the TWT, near the throttle valve (TV1). See Figure 9, p. 26.

(3) Coolant Temperature/WG Pressure (j14-19): senses the signal from coolant overtemperature switch (S1) which is right above the heat exchanger (HE1).

(4) Coolant Level (j14-13): monitors the coolant level in the expansion tank through the liquid level switch (S2). The location of S2
Figure 6 Fault Monitor Circuits Diagram
is under the expansion tank. See Figure 9, p. 26.

**b. DC Comparator Monitors**

1. **Ion Pump Power Supply Undervoltage (j3-18):** senses the ion pump power supply (A4) output voltage. If the ion pump power supply voltage decreases below 1800 V, the output of the comparator is switched to 0 and triggers the indicator driver flip-flop to register a fault.

2. **Ion Pump Power Supply Overcurrent (j3-19):** senses the ion pump power supply through a voltage divider. If the ion pump power supply exceeds 10 microamperes, it is determined that there is too much gas present to operate the high power TWT.

3. **Negative Bias Voltage (j3-13):** this circuit includes the bias relay logic and the crowbar initiate logic. If the negative bias voltage, with respect to the cathode of the TWT, is increased by more than 5% from -400 V, the negative bias voltage monitor turns off the bias relay drive (j14-14) and generates the crowbar initiate signal.

4. **Positive Bias Voltage (j3-20):** monitors that the positive bias voltage remains between +200 V and +400 V, referenced to the cathode of the TWT. Should the voltage moves above or below the values, a fault signal is generated.

5. **Filament Voltage (j3-22):** monitors that the filament voltage remains between -9.5 V and -11.5 V, referenced to the cathode of the TWT. If the voltage is not in this range, a fault is generated.

6. **Body Voltage (j8-21):** senses an increase in body voltage due to the decrease of the TWT collector voltage. No allowed voltage range is specified.
(7) 440 Vac (j4-1,2): monitors the voltage of the input 400 Vac power line. It registers a fault and opens the circuit breaker CB1, when the voltage does not stay within 400 Vac and 465 Vac.

(8) Collector Voltage (j3-2): monitors that the collector output voltage stays between -8.9 kV and -10.8 kV. A fault is registered if voltage fluctuates outside this range.

(9) Solenoid Current (j2-16): monitors the solenoid power supply output current. An over or under current of 1.0 A from 13 A will cause the circuit to register a fault and turn off the solenoid power supply relay driver.

c. Pulse Monitors

(1) HI VSWR (j4-1): detects the high VSWR condition in the waveguide by examining the reflected RF output samples coupled through CD2 to the RF monitor circuit (A9).

(2) TWT Arc: senses the situation when the TWT sustains an internal high voltage arc from grid to ground. If a TWT arc is detected, the body would be shut off to protect the modulator.

(3) Body Overcurrent (j14-21): senses an increase in body current due to decrease in the TWT collector current. The maximum current allowed is 0.4 A.

(4) TWT Overduty Fault and Limit: This function is performed by a pulse integrator which registers a fault in the event that the TWT duty exceeds 10 microseconds or the TWT remains on continuously for longer than 16 microseconds.
(5) HV Assembly Short (j8-24): senses a grid-to-cathode short circuit condition and provides protection to the modulator.

(6) Crowbar Trigger O.K. (j8-25): senses that the triggered spark gap is fired. This short circuits both high voltage outputs to divert supply energy away from the TWT.

2. Control Logic Circuits

The control logic circuit contains the initial power on and fault control logic. The initial power on circuits activate parts of the HPA's circuits and provide the necessary conditions before the whole HPA system is operated. The fault control logic circuits are designed to accomplish automatic control of the system when a fault occurs after the HPA is operating.

a. Initial Power On

The initial power on circuits start to operate when the primary power is turned on. The following conditions are initiated simultaneously:

(1) The ±15 V power supplies start to supply voltage to the control panel and activate the monitor circuits.

(2) The coolant pump starts the coolant flow which is monitored by coolant time delay circuit. If the coolant does not come up to full flow within four seconds, the 440 Vac is removed by removing the 15 V coolant level switch signal.

(3) The TWT filament starts to warm up, drawing a very heavy initial current. The filament timer is started. Three minutes after
initial power on the filament timer times out. The TWT is ready for high voltage operation and the HV switch is enabled to be turned on.

(4) Sets the HV switch to the ON position to turn on the body voltage. The body voltage attains full voltage approximately one second after HV switch is set to the ON position.

b. Fault Control Logic

To describe the fault control logic involved when a fault occurs, the TWT coolant flow fault (j14-1) circuit, the filament fault circuit (j3-22) and the negative bias fault circuit (j3-13) are used as examples.

(1) TWT Coolant Flow Fault

When a TWT coolant flow fault occurs, one of the coolant flow switches (S4 or S5) opens. This causes the TWT coolant flow fault indicator to light and the generation of an HV inhibit signal. The HV inhibit signal turns off the high voltage and inhibits the modulator. The TWT solenoid will shut off the solenoid power supply. The HPA will remain in the HV OFF or the standby states until the coolant flow is restored and the reset pushbutton switch (S3) on the control panel is pressed and released.

(2) Filament Voltage Fault

The filament fault control logic is triggered when the filament senses a voltage variation of more than +5 or -25 percent from -400 V. When such a voltage variation occurs, the filament voltage regulator fault indicator will light. The body voltage is shut off and the modulator is inhibited. The filament relay drive signal de-energizes the relay in the power distribution assembly to be discussed later, and the timer running
indicator is turned on. If the filament power can be restored within less than one minute, the full three minutes will not have to elapse before HV operation can be resumed; otherwise, it will take the full three minutes to resume HV operation, after the reset pushbutton is released.

(3) Negative Bias Fault

The negative bias voltage regulator controls the negative bias voltage for the TWT and the SSM of the HPA. A negative bias voltage regulator fault condition gets the bias relay logic and the crowbar initiate logic involved. Should the negative bias voltage increase by more than 5 percent from the specified value, the negative bias voltage sense signal triggers the fault flip-flop, which in turn lights the negative bias voltage fault indicator, then turns off the bias relay drive, and finally generates the crowbar initiate signal.

c. Test Circuits

The test circuits contain several built-in test circuits to facilitate adjustment and troubleshooting. Each test circuit is set into operation by means of a toggle switch. When the switch is set to the ON position, the HPA is in the test configuration and can not be operated normally. Any switch in the test position will cause a test status indicator to light. The test circuit can be divided into three categories:

(1) Bias Test: this permits adjustment of the positive voltage between +200 V and +400 V. It is enabled by setting the bias test switch (S1) to the ON position.

(2) The Open Loop Test: this permits adjustment of the cathode voltage with the regulator feedback loop disabled. This mode of
operation is useful in troubleshooting HV breakdown and inverter problems. Setting the open loop test switch (S2) to the ON position brings up the high voltage. The magnitude of this voltage is adjusted by the open loop adjust potentiometer which is located on the control panel right near S3.

(3) The Manual Test: this is accomplished by applying a simulated fault signal to the input of each monitor and observing that the respective fault indicator lights. Since all fault monitors are tested simultaneously, all fault indicators are lit simultaneously. A fault indicator that does not light indicates a defective monitor circuit. Likewise, a fault indicator that does not de-energize after the simulated fault signal is removed and the reset pushbutton (S3) is activated, indicates either a defective monitor circuit or the presence of an actual fault. Several dc input comparator type monitors check the incoming signals for overvoltage and undervoltage conditions and register the faults on respective signal indicators. The manual test switch is a spring-loaded, center 4-pole, double-throw, toggle switch. To enable the separation of the overvoltage situations from the undervoltage situations, the manual test switch checks the overvoltage monitors in position 1 and the undervoltage monitors in position 2.

E. HPA POWER DISTRIBUTION UNIT

This unit distributes the incoming power supplied to the HPA. There are three types of input power: 440 Vac at 400 Hz in 3 phases, 115 Vac at 60 Hz in single phase, and 115 Vac at 400 Hz in single phase.
1. 440 Vac 400 Hz 3-Phase Switches (CB, CB2)

The switches control the HPA's rectifier filter assembly (A5) and the cooling pump (B1). It includes filters, switches, relays, and circuit breakers, housed in the power distribution panel (A10). The power lines are shown in Figure 7.

2. 115 Vac 60 Hz Single Phase Switch (CB3)

The switch controls the HPA's Ion Pump (A4) power supply. The power line is shown in Figure 7.

3. 115 Vac 400 Hz Single Phase Switch (CB4)

The 115 Vac 400 Hz power is converted to dc and used mostly in the HPA's control unit. The CB4 switch controls the power flow to the rectifiers PS#1, PS#2 and PS#3.

   a. ±15 Vdc (PS#1) and (PS#2)

   PS#1 and PS#2 supply the ±15 Vdc power to the control panel (A3) and the Modulation Unit (A6) through the switch S3 via the PS1-6 and PS2-4 wires. The tolerance of the ±15 Vdc for the Modulation Unit is ±5%. The maximum allowed current is 200 microamperes. The detailed wiring is shown in Figure 8.

   b. +48 Vdc (PS#3)

   PS#3 supplies the +48 Vdc power to the modulator through the positive bias regulator (A7), the negative bias regulator (A8) and the filament regulator (A9).

F. HPA COOLING UNIT

The HPA cooling unit provides liquid cooling for the high power TWT and for the high voltage assembly. The coolant is a Fluorinert compound.
Figure 7 440 Vac and 115 Vac 60 Hz Power Distribution
Figure 8 115 Vac 400 Hz and DC Power Lines
(FC-77). The FC-77 coolant also serves as a dielectric to prevent high voltage breakdown in the high voltage assembly. The cooling unit and the coolant flow diagram are shown in Figure 9 and Figure 10.

1. Coolant Pump (B1)

During normal operation, a coolant pump circulates FC-77 liquid at approximately 6 gpm (5 gpm for the TWT and 0.2 gpm for the circulator) through the heat exchanger (HE1), filter, drier (HP6), TWT, AT8 and the HV Tank. Heat in the coolant is transferred to water in the heat exchanger and then dissipated into air in the water filter.

2. High Voltage Tank

The HV tank encloses all the complete high voltage assembly. It serves as the reservoir for the coolant pump. A pressure equalizer line connects the expansion tank to the HV tank. HP12 and HP13 are air bleed valves. HP10 is the drain valve of the HPA tank.

TV1 is a throttle valve which controls coolant flow rate into the TWT. QD1 and QD2 are the quick disconnect valves of the TWT. BV1 is a flow bypass loop to ensure cooling of the coolant pump at all times.

3. Expansion Tank

The expansion tank is equipped with an auxiliary valve (HP3), a reservoir shut off valve (HP2), a liquid level switch (S2), a vent valve (HP4) and a moisture separator (HP9). All valves and the switch are housed around the expansion tank.

a. Vent Valve (HP4) and Moisture Separator (HP9)

The vent valve (HP4) is a two-way relief valve used to prevent buildup of reservoir pressure or vacuum. The moisture separator
Figure 9 Cooling Unit Block Diagram
Figure 10 Coolant Flow Diagram
(HP9) is a desiccant device which removes moisture due to any in-breathing through the vent valve. The vent valve and the moisture separator are combined as a unit and used as a fill port on top of the expansion tank.

**b. Sight Glass (SG1)**

The sight glass is a visual liquid level indicator that is mounted on the expansion tank.

**c. Auxiliary Valve (HP3) and Reservoir Shut Off Valve (HP2)**

HP2 is the control valve between the expansion tank and the HPA tank. During operation it is always open. HP3 is an auxiliary valve which controls the coolant flow between the cooling pump and the expansion tank. It is always kept closed during normal operation.

**d. Liquid Level Switch (S2)**

This switch monitor the expansion tank liquid level. If the coolant level becomes too low, a signal is sent to the control card to register a fault.

**4. Filter and Drier (HP6), Automatic Vent Valve (HP8) and Miscellaneous**

The filter and drier are installed in the coolant line ahead of the HPA tank. An automatic vent valve (HP8) is plumbed into the outlet of the filter and drier and returns accumulated vapor to the expansion tank. The operation of the vent valve is controlled by a float and valve assembly. Vapor or bubbles entering the aerator cause the float to drop and
open the valve. Vapor returns to the expansion tank through a flexible hose. As fluid fills the vent valve, the float rises and closes the valve.

5. **Heat Exchanger (HE1)**

Heat from the HPA is carried away by the FC-77 coolant and transferred to water through a liquid-to-liquid heat exchanger. A cooling water modulation valve (HP5) is installed in the cooling water line to prevent condensation on the coolant lines in the HPA cabinet. HP19 and HP20 are the water inlet and outlet connections.

6. **Water Filter**

The water filter is located in a different cabinet which contains a pump, a de-ionizer, a filter, a radiator, a temperature alarm and a water tank. The temperature alarm can be set to a specific temperature to alarm the operator by adjusting the temperature switch which is located in the front panel of the water filter.
III. SYSTEM OPERATION, MAINTENANCE AND TROUBLESHOOTING

This chapter contains the necessary information to operate the HPA. It lists the system operation, maintenance, troubleshooting and testing procedures for the operator. The contents of this chapter are adapted from the Technical Manual with some modification. Only those requirements and procedures most directly related to setting up and operating the HPA at NPS are included in this chapter. For further detail, Appendix A contains flow charts of the maintenance procedures adapted from the Technical Manual. Appendix B contains flow charts which combine step-by-step instructions of the Technical Manual with explanatory notes for troubleshooting.

The HPA is a complicated system to operate. However, its operation and maintenance are relatively safe when proper equipment is used and procedures are followed. Safety precautions toward using the electrical and electronic equipment, the pressurized systems, and toward radiation hazards should be carefully reviewed. See Ref. 1, p. 24 to p. 29 for detailed information.

A. OPERATION

1. Facility Requirements.
   1.1 440 Vac 3-phase 400 Hz 45 A (CB1) Service Delta.
   1.2 115 Vac 1-phase 400 Hz 10 A (CB4) Service.
   1.3 115 Vac 1-phase 60 Hz 80 A Service (CB3, CB5).
1.4 25 GPM flow of water at 45 °F to 110 °F.
1.5 Regulated dry air or nitrogen, 20 to 30 PSI.
1.6 Before applying power to the transmitter, make a visual inspection of the waveguide to assure proper connection. Check the RF output for either an antenna or an adequately rated dummy load connection.

2. **Turn-on Procedures.**

The following procedures are listed step-wise.

2.1 Turn off circuit breaker CB1 (400 Vac) and CB4 (115 Vac).
2.2 Turn on circuit breakers CB2 (Cooling Pump), CB3 (115 Vac 60 Hz), CB5 (115 Vac 60 Hz), S3 (15 Vdc) and S4 (Ion pump).
2.3 Check for leaks in the FC-77 coolant lines. Verify that the auxiliary valve (HP3) is closed and that the reservoir shut off valve (HP2) is open. These valves are located near the bottom of the expansion tank. See Figure 9.

2.4 Bleed air from the high voltage assembly through air bleed valves (HP12, HP13) located above the HV tank which encloses the modulator and high voltage assemblies. Let the HPA run in this mode for at least 5 minutes to assure that no air voids exist in the FC-77 fluid. Then turn off air bleed valves (HP12, HP13).

2.5 Turn off switch S3 (15 Vdc).
2.6 Turn on circuit breakers CB1 (440 Vac) and CB4 (115 Vac).
2.7 Turn on switch S3 (15 Vdc) and wait for the 3-minute filament timer time-out.
2.8 Manually reset the control circuit card if fault lights are present.
2.9  After a reset, if a fault light persists, refer to the fault troubleshooting flow charts.

2.10 Turn on the high voltage switch (HV ON) located on the control panel.

2.11 HPA is now operational.

3. Turn-off Procedures.

The following procedures are listed step-wise.

3.1 Turn off the high voltage switch (HV ON).

3.2 Turn off S3 (15 Vdc). This will shut off CB1 and CB4.

3.3 The ion pump switch (S4) can be turned off or left on as desired.

3.4 If the unit has been operating at a high duty cycle for an extended time, it is recommended that following step 3.2 above, CB1 (440 Vac) and CB4 (115 Vac) be turned off and then S3 (15 Vdc) turned back on. This allows the FC-77 to circulate and avoids thermal shock.

B. GENERAL MAINTENANCE

The following procedures contain the information required to perform alignments, adjustments and repairs on the equipment which are within the capability of the HPA user.

1. High Voltage Tank FC-77 Fill and Drain

   a. Tools, Parts, Material and Test Equipment

      (1) 3/8" Drive Socket Set.

      (2) Open-End Wrench Set.

      (3) Teflon Thread Sealing Tape.

      (4) FC-77 Fluid.

      (5) Warning Tag.
b. Drain Procedures: Reduce the coolant level in the high voltage assembly

b.1 Turn off CB1 (440 Vac), CB4 (115 Vac), CB5 (115 Vac) and tag the warning sign. This step must be performed before the fluid level is reduced; otherwise, arcing might occur in the high voltage assembly.

b.2 Turn on CB2 (cooling pump), CB3 (115 Vac) and S3 (15 Vdc) to circulate the coolant flow.

b.3 Close the reservoir shutoff valve HP2 to let the circulating coolant flow into the expansion tank.

b.4 Open the auxiliary valve HP3 and be ready to close the valve HP3 at the moment the fluid reaches the tank drain level marked on the sight class (SG1).

b.5 Shut off the auxiliary valve HP3 when fluid reaches the tank's drain well.

b.6 Turn off CB2 (cooling pump), CB3 (115 Vac) and S3 (15 Vdc).

b.7 Remove and replace failed sub-assembly in accordance with the appropriate procedures.

c. Fill Procedures: Add coolant to the high voltage assembly after the replacement of sub-assemblies

c.1 Turn off CB1 (440 Vac), CB4 (115 Vac) and CB5 (115 Vac) and the tag warning sign.

c.2 Fill the FC-77 fluid through the fill port after removing the vent valve (HP4).
c.3 Open the reservoir shutoff valve (HP2) to let the coolant flow into the HPA tank.

c.4 Bleed air from the high voltage assembly through air bleed valves (HP12, HP13) located on the modulator and high voltage assembly. This will allow proper draining of the FC-77 expansion tank.

c.5 Turn on CB2 (cooling pump), CB3 (115 Vac) and S3 (15 Vdc) to circulate the coolant.

c.6 After 5 minutes of running, bleed air from the high voltage tank before turning on high voltage.

c.7 Turn off air bleed valves (HP12, HP13).

\textbf{d. Replace coolant filter HP6}

d.1 Turn off CB1 (400 Vac), CB2 (cooling pump), CB3 (115 Vac), CB4 (115 Vac), CB5 (115 Vac), S4 (ion pump) and tag warning sign.

d.2 Remove the automatic vent valve HP8 and the check valve HP11 to facilitate removal of the filter cover and all assemblies located on the right side of the cabinet near the rectifier filter (A5).

d.3 Loosen 2 clamps securing the filter cover and remove the cover.

d.4 Replace filter.

d.5 Reverse step d.3 and then step d.2.

d.6 Turn on CB2 (cooling pump), CB3 (115 Vac), and S3 (15 Vdc) to circulate the coolant.
d.7 After 5 minutes of running the coolant pump, and before turning on high voltage, bleed air from the air bleed valves (HP12, HP13).

2. High Power TWT Removal and Replacement

a. Tools, Parts, Material and Test Equipment

(1) 3/8" Drive Socket Set.
(2) Allen Wrench Set.
(3) Warning Tag.
(4) Modulator Test Plug.
(5) Tektronix 465 Scope (or equivalent).
(6) Tektronix 100-to-1 (1500V) Probe.
(7) Digital Voltmeter Fluke 8080 (or equivalent).
(8) Pulse Generator 101A (or equivalent).

b. Removal and Replacement Procedures

b.1 Turn off circuit breakers CB1, CB2, CB3, CB4, CB5, S3, S4 and tag the warning sign.

b.2 Remove high voltage plugs from the TWT cathode supply and from the modulator. Ground modulator output terminals with "chicken sticks" before continuing.

b.3 Remove top and bottom coolant hoses quick-disconnect fittings located on the TWT.

b.4 Remove high voltage plug from the top of the TWT collector supply.

b.5 Remove solenoid voltage supply plug.

b.6 Disconnect the plug from the ion pump power supply.
b.7 Disconnect the input and output waveguides from the TWT. The TWT is heavy (approximately 80 lbs) and requires 2 persons to remove it. One person must hold the TWT in position while the final bolts are removed.

b.8 Remove the 6 bolts holding the TWT.

b.9 Remove the TWT by lifting it and pulling straight out from rear of the cabinet.

b.10 Install new TWT by performing steps 3 through 9 in reverse order. One person must hold the TWT in position while the initial bolts are attached.

b.11 Check that CB1 is turned off.

b.12 Connect the modulator test adapter to the modulator and TWT.

b.13 Connect a pulse generator to j1, the video buffer circuit located on the inside lower left wall of the cabinet. Set the generator for 3 V peak, 1 microsecond pulse width and 1 kHz PRF.

b.14 Connect the scope with the 100-to-1 probe to the TWT grid test point on the modulator adapter. Scope ground goes to the TWT cathode test point.

b.15 Turn on CB3, CB4, CB5, S3 and S4. *Do not turn on CB1 or CB2.*

b.16 After the 3 minutes delay is over, turn on the bias test switch located on the control panel.

b.17 Adjust variac on the ac regulator located on upper left side of the cabinet for a 600 V to 850 V grid swing.
b.18 Turn off bias test switch.
b.19 Turn off CB3, CB4, CB5, S3 and S4.
b.20 Disconnect the pulse generator, the scope and the modulator test adapter.
b.21 Connect high voltage cable (cathode supply) to the modulator and the TWT.
b.22 Connect the digital voltmeter to j15 located on the control panel to measure cathode voltage.
b.23 Turn on circuit breakers CB1, CB2, CB3, CB4, CB5, S3 and S4.
b.24 After the 3 minutes delay is over, high voltage should be present.
b.25 Adjust pot on the error amplifier card located on the right hand-side on top of the HPA for the -2.7 to -3.4 V. The actual voltage is the digital voltmeter reading multiplied by 10,000.
b.26 Return the equipment to normal condition.

3. Solenoid Power Supply Alignment
   a. Alignment Procedures
      a.1 Turn the 15 Vdc switch S3 off.
      a.2 Use a clip lead to connect pin 12 of U39 to ground on the control panel.

---

1 On initial turn on of a new TWT, high ion current could be encountered. Ion current must be below 10 microampers before the ion current fault can be reset.
a.3 On the HPA power distribution unit, set the coolant pump circuit breaker CB4 and the 15 Vdc switch S3 to on.

a.4 On the bottom solenoid power supply adjust the current control fully counterclockwise, and the voltage control fully clockwise.

a.5 On the top solenoid power supply, adjust the voltage control fully counterclockwise, and the current control fully clockwise.

a.6 Remove the connector from j2 on the right side of HPA cabinet.

a.7 Turn on the two solenoid power supplies.

a.8 Adjust voltage control on the top power supply until the meter reads 120 Vdc.

a.9 Turn off both circuits breakers on the supplies and attach connector to j2.

a.10 Turn on both circuit breakers and adjust the current control on the bottom power supply until the current meter indicates 13 A.

a.11 Readjust voltage control on the top power supply as necessary to equalize voltage readings on both supplies. Small differences in current readings are due to meter errors.

a.12 Turn off the 15 Vdc switch on A10 and remove the jumper attached in step a.2 from the control card assembly.

a.13 Turn the 15 Vdc switch to on. The solenoid power supply will automatically come on during the power on sequence.
C. SYSTEM TROUBLESHOOTING

1. Detection By Fault Monitor Circuits

Three kinds of fault monitor circuits are used in the HPA. They are the interlock monitors, the dc comparator monitors and the pulse monitors. Each monitor circuit has a different detecting approach depending on the subject being monitored.

a. Detection By Interlock Monitors

This type of circuit simply senses the opening of a switch contact to register a fault. A typical circuit is the coolant level switch (S2) monitor. The coolant level switch (S2) is normally closed. When the coolant level is too low, the switch is opened to remove the +15 V input. This causes the coolant level circuit flip-flop to switch to the fault position, register the fault and turn the coolant level indicator on.

b. Detection By DC Comparator

This type of monitor operates on the principle of comparing a dc voltage level with a fixed voltage reference. The DC voltage signal and the reference voltage are each an input to a differential amplifier comparator integrated circuit. When the DC voltage signal exceeds the reference, the differential switches its output from +15 V to 0. The comparator output, which is connected to an indicator driver flip-flop, triggers the flip-flop to register a fault. A typical monitor circuit is the ion power supply undervoltage monitor port (j3-18). The ion pump power supply (A4) voltage is sampled and sent to the control panel j3-18. The comparator compares it to the reference voltage (3.15 V). If the voltage sample is lower than the reference voltage, the undervoltage monitor will reg-
ister a fault and light the indicator. It generates the MOD INHIB signal which shuts off the body voltage. The test points PTP35 and PTP36 are provided to test the voltage source. The circuit is drawn schematically as Figure 11.

![Figure 11 Ion Power Undervoltage Circuit Schematic Diagram](image)

c. Detection By Pulse Comparator

The pulse monitor works like the DC comparator. A typical monitor of this type is the body overcurrent monitor. A positive 8 V cathode pulse is sampled from the cathode current transformer located in A2. This voltage is compared to the negative 7.8 V collector current pulse. Their sum results in a net positive pulse of 0.2 V. If the TWT collector current decreases due to an increase in the body voltage, the net positive
pulse voltage will increase. Should the positive pulse exceed the threshold voltage of 0.6 V, the output of the comparator will be switched to 0 and a fault will be registered.

2. General Troubleshooting

There are two possible means of entry into the troubleshooting procedures:

(1) From a scheduled maintenance test: when a fault is sensed during a scheduled maintenance test, proceed to the relevant troubleshooting flowchart. Use the troubleshooting flow chart to isolate a fault down to a faulty assembly. After the fault is isolated, use the parts location diagram to draw and locate the replacement item. Corrective action may be accomplished. Read the system maintenance procedures for repair instructions.

(2) From an operation malfunction: whenever an equipment malfunction is observed in the course of normal operation, consult the appropriate troubleshooting flowchart. After a fault is detected in the equipment, the primary tool for fault isolation is the troubleshooting flowchart. These charts provide step-by-step instructions in a visual form. Entry into the charts at the appropriate point is accomplished by means of the troubleshooting index which is listed at the beginning of Appendix B.

The procedures contain various YES/NO decision blocks which localize the malfunction to particular functions within the equipment. If an improper exit is made from the decision block, the steps are easily retraced on the flowchart to the decision block where a proper exit can then be made.
3. Solid State Modulator Phase Measurement

There are stringent phase stability requirements on the transmitter. The phase measurement setup is shown in Figure 12 for the verification of phase stability over a single pulse or a pair of RF pulses using a phase bridge.

a. CW Input Phase Measurement

a.1 Before starting the procedure, verify that the input RF signal level is the same as that listed in Appendix C by measuring it from the 10 dB input coupler (DC1).

a.2 Set both attenuators to 5 dB.

a.3 Turn on the HPA following the operation procedures.

a.4 Check if the observed positive detector or inverted negative detector output are similar to Figure 13.

a.5 Adjust the phase shifter until a null occurs. Alternately adjust the attenuators for the sharpest possible null. Keep one of the attenuators to 0 dB. This provides the maximum possible input signal from both arms and gives the best measurement sensitivity. Figure 14 shows a typical output.

a.6 To provide maximum phase change readability and to compensate for scope DC offset limitations, adjust the phase shifter until the scope display looks similar to Figure 15.

a.7 Change the scope display to AC coupling and adjust vertical deflection for maximum sensitivity. Adjust the phase shifter to obtain a display as in Figure 16.
Figure 12 Phase Measurement Setup
Figure 13 Initial Detection

Figure 14 Phase Shift Adjustment

Figure 15 DC Offset Limitation Phase Shift Adjustment

Figure 16 AC Vertical Deflection Phase Shifter Adjustment
b. Pulse RF Phase Measurement

b.1 The triggering scheme used in this measurement is shown in Figure 17. Adjust the pulse width and delay of pulse generator #2 so that it falls within the transmitter video pulse.

b.2 Verify the input RF signal level by measuring the output of the 10 dB input coupler (CD1) using a power meter.

b.3 Phase bridge setup is identical to the Figure 12.

b.4 Turns on the HPA.

b.5 Figure 18 shows a typical scope display prior to the null adjustment.

b.6 Set the pulse generator for internal triggering while initially adjusting the null. After setup, externally trigger the pulse generator from the inverter for a better display.

b.7 Adjust the phase shifter for a null. Alternately adjust the attenuators for a sharp null and note that it is possible to set a false null if both attenuators are adjusted for high attenuation.

b.8 Ideally, one attenuator should read zero. Figure 19 shows the expected waveform.

b.9 Back off on the phase shifter. The detector output will appear like Figure 20.
Figure 17 Pulse RF Setup
Figure 18 Typical Detector Output Prior To Null Adjustment

Figure 19 Detector Output After Null Adjustment

Figure 20 Detector Output After Phase Shifter Is Adjusted To View Phase
IV. CONCLUSIONS AND DISCUSSIONS

This thesis can be used as an operations and maintenance manual for the HPA as it was originally designed. On the other hand, having a deeper understanding of the system, some changes may be made to better utilize it.

The HPA is intended to be used as the final stage amplifier for an instrumentation radar system for studying propagation effects and sea clutter characteristics outside the Monterey Bay. Since the peak output power of the HPA is fixed, one way to increase the detection range or to improve the probability of detection (or equivalently, data accuracy) is to increase the pulse width. What can be done immediately is to adjust the TWT Overduty (A3R261) and the TWT Overduty Fault (A3R195) variable resistors located on the control panel to go beyond the 10 microseconds preset limit.

The extent to which the pulse width can be increased depends on the capability of the cooling system to remove heat from the HPA. Since the long term duty cycle of the HPA is specified at 0.08 while the system runs safely at a short term duty cycle of 0.425 for 1 millisecond before the 0.08 long term duty cycle is restored [Ref. 2], it is clear that the HPA can handle a pulse width of 0.4 millisecond at a 200 Hz pulse repetition rate. Further study on increasing the pulse width is desirable.

Another modification being contemplated is to replace the 400 Hz input power with regular 60 Hz power. With the exception of the coolant pump which can be easily replaced, all the 400 Hz input power is con-
verted to DC before it is used. The system can run on 60 Hz power if appropriate power supplies can be found to feed the required 600 V, 15 V and 48 V dc power directly to the proper contact points. The system can then be moved away from the few 400 Hz generator at NPS.
APPENDIX A SYSTEM OPERATION AND MAINTENANCE FLOWCHARTS

Turn off CB1, CB4

Turn on CB2, CB3, CB5, S3, S4

Check for leaks in the FC-77 coolant line

Leak in coolant line

Y → Change the coolant line

N

Turn off HP3, Turn on HP2

A

Figure A.1 HPA Turn-On Operation Flowchart
Open HP12, HP13 bleed the air voids at least 5 minutes then close HP12, HP13

Turn off S3

Turn on CB1, CB4

Turn on S3 and wait for the 3 min filament timer

Is any fault light on?

Push the Reset button S3

Is fault light still on?

Turn on HV ON

HPA is operational

Go to the appropriate troubleshooting flowchart

Figure A.1 HPA Turn-On Operation Flowchart (continued)
Has HPA been operated at high duty cycle for an extend time?

Y
- After appropriate time, turn off S3

N
- Turn off S3
  - Turn off CB1, CB4
  - Turn on S3. This allows the FC-77 to circulate and avoids thermal shock
  - After appropriate time, turn off S3

Figure A.2 HPA Turn-Off Operation Flowchart
Tools: 1.3/8” Drive Socket Set.  
2. Open-end Wrench Set.  
3. Teflon Thread Sealing Tape.  
4. FC-77 Fluid.  
5. Warning Tag.  

Turn off CB1, CB4, S3 before the fluid level is reduced  

Turn of CB2, CB3, S3  

Close HP2, let the coolant flow into the expansion tank  

Open HP3  

Watch the coolant level in sight class SG1  

Does fluid reach the tank drain well?  

Y  

Turn off CB2, CB3, S3 and remove failed assembly  

N  

Figure A.3 High Voltage Tank FC-77 Fill And Drain Maintenance Flowchart
Turn off CB1, CB4, CB5 and tag warning sign

Add the fluid to fill port HP4

Open HP2, allow coolant flow into the HPA tank

Open HP12, HP13

Turn on CB2,CB3,S3

After 5 minutes of running coolant pump, close HP12, HP13

Tools: 1.3/8" Drive Socket Set.
2. Open-end Wrench Set.
3. Teflon Thread Sealing Tape.
4. FC-77 Fluid.
5. Warning Tag.

Figure A.4 High Voltage Tank Adding Coolant Maintenance Flowchart
Tools: 1.3/8" Drive Socket Set.
2. Open-end Wrench Set.
3. Teflon Thread Sealing Tap.
4. FC-77 Fluid.
5. Warning Tag.

Turn off CB1, CB2, CB3, CB4, CB5, S4 and tag warning signal

Remove the HP8 and check HP11 to facilitate removal of the filter cover

Loosen 2 clamps and remove the cover

Replace the filter

Install the cover and secure the 2 clamps

Install the HP8

Return to operation

Figure A.5 Replacing Cooling Fluid Filter Maintenance Flowchart
Tools: 1.3/8" Drive Socket Set.
2. Open-end Wrench Set.
3. Teflon Thread Sealing Tape.
4. FC-77 Fluid.
5. Warning Tag.

Turn off CB1, CB2, CB3, CB4, Cb5, S3 and S5 and tag warning signal

Remove high voltage (cathode supply) plug (A2-A6-j6) from modulator and TWT

Ground modulator output terminals with chicken stick

Close QD1, QD2

Remove high voltage (collector supply) plug (A2-j7) from TWT

Remove solenoid supply plug and disconnect the plug from power supply

Disconnect input and output waveguide

Figure A.6 High Power TWT Removal and Replacement Maintenance Flowchart
Remove 6 bolts holding the TWT, one person must hold the TWT in position while the final bolts are removed

Remove the TWT by lifting it and pulling straight out from the rear of the cabinet

Install the new TWT

Secure 6 bolts holding the TWT, one person must hold the TWT in position while the first bolts are attached

Connect the input and output waveguide

Figure A.6 High Power TWT Removal and Replacement Maintenance Flowchart (continued)
Test equipments:
1. Modulator Test Plug.
2. Tektronix 465 Scope.
3. Tektronix 100:1 probe.
5. Pulse Generator 101A.

- Connect the plug to the ion pump power supply
- Connect the high voltage plug (A2-j7) to TWT
- Open QD1, QD2
- Connect modulator test adapter to TWT and modulator
- Connect pulse generator to J1 video circuit, set the generator for 3 V peak, 1µ sec pulsewidth and 1kHz PRF
- Connect scope probe (100:1) to TWT grid test point on the modulator adapter, scope ground goes to TWT cathode test point
- Turn off CB1, CB2
- Turn on CB3, CB4, CB5, S3 and S4

Figure A.6 High Power TWT Removal and Replacement Maintenance Flowchart (continued)
Wait till 3 min delay is over, turn on bias test S1 on the control panel

Adjust the variac on A7, A8, A9 to get the grid swing voltage between 600 and 800 V

Turn off bias test S1

Turn off CB3, CB4, CB5 and S4

Disconnect pulse generator, scope, modulator adapter

Connect digital voltmeter to j15 located on the control panel

Turn on CB1, CB2, CB3, CB4, CB5, S3 and S4

Figure A.6 High Power TWT Removal and Replacement Maintenance Flowchart (continued)
Is measured cathode voltage between -2.7 V and -3.4 V?

Adjust R33 on the error amplifier card located on the top right side of the high voltage tank.

Return to operation

Figure A.6 High Power TWT Removal and Replacement Maintenance Flowchart (continued)
Figure A.7 Solenoid Power Supply Alignment Maintenance Flowchart
Adjust the voltage control on the top supply until the meter reads 120 Vdc.

Turn off both power supplies and connect the j2 to HPA.

Turn on both power supplies.

Adjust the current control on the bottom supply until the meter reading is 13 A.

Readjust voltage control on the top supply to equalize voltage reading on both supplies.

Turn off S3 and remove the jumper on control card U39.

Turn S3 on.

Figure A.7 Solenoid Power Supply Alignment Maintenance Flowchart (continued)
# APPENDIX B SYSTEM TROUBLESHOOTING

## FLOWCHARTS

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HPA Fault

Push reset button S3 and observe fault lights

Are any fault lights still on?

N → Return to operation

Y → Repeat Two more times

Turn HV ON off

Check fault monitor CKTs with manual test switch S10

Set manual test switch to position 1 and hold while observing fault lights

Are all fault lights on?

N → Use schematics to repair fault monitor CKTs

Y → A

Figure B.1 HPA Troubleshooting Flowchart
Figure B.1 HPA Troubleshooting Flowchart (continued)
Turn HV ON to on

Is there any fault light on?

Y
Go to troubleshooting procedure of fault indicated

N
Return to operation

Figure B.1 HPA Troubleshooting Flowchart (continued)
Coolant (FC-77) Level Flow Fault

Check coolant level at sight glass SG1

Is coolant above min level marked?

N

Visually check of system for leaks and correct problem

Y

Measure voltage at test point PTP 157 on control card

Is voltage 12.5±1 V?

Y

Replace coolant level switch S2

N

Remove throttling valve (TV1) located in FC-77 coolant lines on inside back wall near top of cabinet and inspect for blockage

Return to operation

Figure B.2 Coolant (FC-77) Level Fault Troubleshooting Flowchart
Check initial PWR on coolant time delay CKT R2 and Q3

Turn off CB2 and Turn on S3

Measure PTP 157 on the control card

Does voltage at PTP 157 stay at 12.5±1 V for a min of 4 seconds?

Replace flow interlock switch S5

Correct problem

Use schematics to find and correct problem

Return to operation

Figure B.2 Coolant (FC-77) Level Fault Troubleshooting Flowchart (continued)
Test equipments:
1. Digital voltmeter 8080.
2. Tektronix 100:1 probe.

Is Ion P.S. Overcur Fault light on?

Disconnect P35 from ion pump P.S. and measure 115 Vac

Is voltage 115 ± 6 Vac?

Connect plug and measure ion P.S. output

Figure B.3 Ion Pump Power Supply Undervoltage Fault Troubleshooting Flowchart
Figure B.3 Ion Pump Power Supply Undervoltage Fault Troubleshooting

Flowchart (continued)
TWT Ion Overcurrent Fault

Observe ion P.S. current meter near the TWT

- Digital voltmeter 8080.
- Tektronix 100:1 probe.

Is meter reading >10 µA?

- Record reading and repeat after 5 minutes
- Check PTP 38 at control card

- Is current falling?
- Go back and check three times
- Replace TWT and EQ1

- Use schematics and troubleshoot control card
- Replace Ion Pump P.S.

- Is voltage at 2.8±0.14 V?
- Return to operation

Wait for current to drop below 10 µA

Figure B.4 TWT Ion Overcurrent Fault Troubleshooting Flowchart
HI VSWR Fault

Test equipment: Tektronix 465 Scope.

Connect scope to A9 PTP3 to detect VSWR RF pulse

Turn HV ON to on

Start pulse and find TWT in mode creating fault

Is pulse higher in amplitude than PTP4 voltage?

Y

Remove system load and connect 500 W load to HPA RF output

N

Use schematics and isolate problem to A9 or control card

Replace faulty component

Return to operation

Return RF pulses to HPA

A

Figure B.5 High VSWR Fault Troubleshooting Flowchart
Continue pulse TWT at low RF duty (<10 µs) in mode creating fault

HI VSWR fault?

Adjust R4 on A9

Readjust pot R4 to obtain reference voltage at PTP4 > PTP3

Return to operation

Vary output PWR by 3 dB and observe A9 VSWR pulse change

Is previous pulse voltage measured at PTP4 greater than 1 dB of just measured pulse voltage?

Isolate fault component in system load

Figure B.5 High VSWR Fault Troubleshooting Flowchart (continued)
Negative Bias Fault

Turn HV On off and push reset button S3

Is Neg Bais Fault still at fault?

Any other fault?

Turn HV ON to on and push reset button S3

Perform modulator fault isolation procedures

Are PS#3, A7 and modulator O.K.?

Replace AC regulator or modulator

Go to appropriate troubleshooting procedures

Return to operation

Figure B.6 Negative Bias Voltage Fault Troubleshooting Flowchart
Figure B.6 Negative Bias Voltage Fault Troubleshooting Flowchart
(continued)
Positive Bias Fault

Turn HV On to off and push reset button S3

Is Pos Bias Fault still at fault?

Any other fault?

Go to appropriate troubleshooting procedures

Perform modulator fault isolation procedures

Any fault?

Return to operation

Are PS#3, A8 and modulator O.K.?

Replace AC regulator or modulator
Check HV cable for shorts

Is HV cable O.K.?  

Replace HV cable

Y

Check TWT grid-cathode for short

Is TWT grid-cathode shorted?

Replace TWT and EQ1

N

Use schematics and check control card interface

Return to operation

Figure B.7 Positive Voltage Fault Troubleshooting Flowchart (continued)
Figure B.8 Filament Voltage Regulator Fault Troubleshooting Flowchart
Measure filament voltage and current at adapter test point

Voltage and current may take 2-3 minutes to stabilize due to filament warmup

Is Fil voltage between -9.5 V and -11.5 V?

Y

High/Low: if deviations >±2 voltage or ±10 A current observed

N

Use schematics and troubleshoot control card

Return to operation

Warning: 440Vac CKT CB1 must remain off whenever the modulator test adapter is connected and/or the modulator output connected is not properly terminated for HV usage.

<table>
<thead>
<tr>
<th>Fil V</th>
<th>Fil I</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Ø</td>
<td>Open TWT Fil. Replace TWT</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>DC regulator failed. Replace TWT</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Output short. Check TWT</td>
</tr>
<tr>
<td>Ø</td>
<td>Ø</td>
<td>Check PS#3, if O.K. replace regulator</td>
</tr>
</tbody>
</table>

Figure B.8 Filament Voltage Regulator Fault Troubleshooting Flowchart
(continued)
Figure B.9 Solenoid Power Supply Troubleshooting Flowchart
Figure B.9 Solenoid Power Supply Troubleshooting Flowchart (continued)
TWT Arc Fault

Is Ion P.S. Ovrcur Fault light on?

Y  Go to Ion P.S. Ovrcur Fault procedure

N  Push reset button S3

Is TWT Arc Fault light on?

N  Return to operation

Y  Turn off CB1, S3

Remove HV cable and connect modulator test plug

A

Figure A.10 TWT Arc Fault Troubleshooting Flowchart
Figure A.10 TWT Arc Fault Troubleshooting Flowchart (continued)
TWT Coolant (FC-77) Tools:
1. 3/8" Drive Socket Set.
2. Open-end Wrench Set.
3. Teflon Thread Sealing Tape.
4. FC-77 Fluid.
5. Warning Tag.
6. Flow meter

Make a visual on the plumbing for leaks

Is any leak?

- Y: Correct the problem → Return to operation
- N: Is 440 Vac Fault light on?

- Y: Go to 440 Vac troubleshooting procedure
- N: Is CKT BKR CB2 open?

- Y: Go to CKT BKR Open Fault procedure
- N: Check coolant pump B1

Note: Normal operation pressure is 90 PSIG. Operating pressure of approx. 60 PSIG indicates a phase reversal on 440 Vac line. Reverse two phases and try again. If still low pressure and no leaks, then replaces pump.

Figure A.11 Coolant (FC-77) Flow Fault Troubleshooting Flowchart
A

Is coolant pump operating properly?

Y

Replace filter HP6

Push reset button S3

N

Replace the pump

Is TWT Coolant Flow Fault light on?

N

Return to operation

Y

Check coolant lines for clogging and removing foreign material

Install flow meter in TWT cooling line and check flow

N

Is flow ≥ 4 GPM?

Y

B

Note: Low flow may be caused by a change in setting on the throttling valve or pressure relief valve. Open throttling valve and readjust pressure relief valve for proper TWT coolant flow. If unable to make adjustment, check for clogged coolant line, possible in the TWT itself.

Figure A.11 Coolant (FC-77) Flow Fault Troubleshooting Flowchart (continued)
Adjust flow switch trip point for 4 GPM

Can trip point be adjusted between 4 GPM to 6 GPM?

Return to operation

Replace flow switch S4

Figure A.11 Coolant (FC-77) Flow Fault Troubleshooting Flowchart (continued)
Coolant (FC-77) Overtemperature Fault

Note: This overtemperature fault senses the FC-77 coolant temperature. Except for a coolant flow problem (which is separately sensed), water flow or source problems are most likely to cause by the FC-77 overtemperature condition.

1. 3/8" Drive Socket Set.
2. Open-end Wrench Set.
3. Teflon Thread Sealing Tape.
4. Thermocoupler.
5. Warning Tag.

Tools:

Verify fresh water flow through HE1

Use flow meter to measure water flow rate

Is flow less than 25 GPM?

Increase flow by adjusting modulation valve HP5, it can be access by removing the lower right side panel. Adjustment screw is on the top of the valve. Turn adjustment screw CCW to increase flow.

Can flow be adjusted for 25 GPM?

Return to operation

Figure B.12 Coolant Overtemperature Fault Troubleshooting Flowchart
Disconnect fresh water line from HE1 and measure flow when inlet and outlet hoses connected through flowmeter.

Can fresh water be delivered at 25 GPM?

- N: Locate and repair water filter problem
- Y: Replace modulation valve HP5

Return to operation

Figure B.12 Coolant Overtemperature Fault Troubleshooting Flowchart (continued)
Figure B.13 440 Vac Fault Troubleshooting Flowchart
Turn HV ON to on

Does 440 Vac CKT BRK CB1 trip?

Replace inverter assembly A2A4

Check firing and filter and replace bad part

Return to operation

Does CKT BRK still close?

Figure B.13 440 Vac Fault Troubleshooting Flowchart (continued)
CKT BRK Open Fault

- Is CB2 open?
  - Yes: Return to operation
  - No: Disconnect plug from P19 and reset CB2

- Is CB1 open?
  - Yes: Disconnect plug
  - No: Is CB5 open?
    - Yes: Use filter assembly schematics to isolate and repair problem
    - No: Does CB5 still close?
      - Yes: Replace inverter assembly A2A4
      - No: Locate and repair AC regulator blower

- Is CB5 open?
  - Yes: Does CB5 still close?
    - Yes: Replace cooling pump B1
    - No: Connect plug P33 from cooling pump B1

- Does CB1 still close?
  - Yes: Replace cooling pump B1
  - No: Reset CB2

Figure B.14 Circuit Breaker Open Fault Troubleshooting Flowchart
Figure B.15 Body Overcurrent Fault Troubleshooting Flowchart
Measure cathode voltage at BNC cack located at lower left control panel with DMV. The typical internal voltage drop of BNC will be 200 to 250 V.

Adjust the cathode voltage on the error amplifier R33

Connect the video pulse

Adjust video pulses to low duty, connect video and reset

Re-Null body current at low duty. The TWT aging may be required renulling of the body current occasionally. Use maintenance for TWT removal and replacement.

Return to operation

Increase duty until full duty is achieved

Figure B.15 Body Overcurrent Fault Troubleshooting Flowchart

(continued)
Using the Modulator/AC regulator fault troubleshooting flow chart, reverify the grid pulse voltage and the negative bias voltage is to the nameplate value on the TWT.

- Is modulator O.K.?  
  - Y: Re-null body current at low duty. The TWT aging may require re-nulling of the body current occasionally. Use maintenance procedures for TWT removal and replacement.  
  - N: Replace AC regulator PS#3 or modulator as required

- Use schematics and troubleshoot control card

- Is problem in control card?  
  - Y: Replace control card  
  - N: Replace TWT and EQ1

Return to operation

Figure B.15 Body Overcurrent Fault Troubleshooting Flowchart
(continued)
Some tables and figures have been omitted from this page. The text provided includes:

- A list of test equipments:
  1. Modulator Test Plug.
  2. Tektronix 465 Scope.
  3. Tektronix 100:1 probe.
  5. Pulse Generator 101A.

- Instructions for troubleshooting a TWT Overduty Fault:
  1. Push reset button S3.
  2. Disconnect the video pulse located at lower left inside the cabinet.
  3. Turn HV ON and CB1 to off.
  4. Use schematics and troubleshoot the duty cycle limiter or TWT Overduty CKT on the control panel.

Figure B.16 TWT Overduty Fault Troubleshooting Flowchart
Turn bias test switch on

Monitor low level drive on and off signals at TP1 and TP2, they locate on top of the modulator case.

Connect video pulses, the video PRF should be set to 10 kHz to enhance viewing of the narrow (20-50 ns) spikes at TP1 and TP2. Vary video pulse width over range of 0.1 to 6 μs. The off signal at TP2 will follow trailing edge of video pulse.

Is low level signal O.K.?  
N  Replace low level drive card
Y  Turn bias test S1 and ±15 V S3 to off

Remove HV cable and check for shorts

Go to Modulator/AC Regulator Fault flowchart
N  Is any shorts?  
Y  Replace TWT and EQ1

Return to operation

Figure B.16 TWT Overduty Fault Troubleshooting Flowchart (continued)
Collector Voltage Fault

Push reset button S3

Does Collector Volt Fault still light on?

Y

Connect DVM to J16 on control panel

Push reset button S3 and observe DVM

Is voltage between -8.9 to -10.8 V?

Y

Use schematics and repair fault monitor CKTs

N

Turn off HV ON, CB1, CB4 and S3

Disconnect collector lead from j7 on HV tank and ground collector pin using chicken stick

N

Return to operation

Warning: Under certain failure conditions, HV may remain at terminals when cables are disconnect. Use chicken stick to ground all HV terminals when connector are removed after power is on.

Test equipment:
1. Digital voltmeter Fluke 8080.
2. Modulator test adapter.
3. Chicken stick.

Figure B.17 Collector Voltage Fault Troubleshooting Flowchart
Use an OHM meter in high ohm scale to measure the TWT collector and body (chassis). Also measure resistance of collector flying lead and replace it, if CKT is open.

Is resistance infinite?

Y

Disconnect j6 between TWT and modulator. Ground modulator output terminals using chicken stick.

Use an OHM meter in high ohm scale to measure between the TWT collector and cathode voltage terminals on the HV tank. Positive voltage from OHM meter at collector jack.

Is resistance between 3 to 5 megaohms?

N

Replace HV assembly

Y

Is resistance between 7 to 9 megaohms?

N

Repair or replace as required

Y

Use schematics and troubleshoot HV CKT

Figure B.17 Collector Voltage Fault Troubleshooting Flowchart

(continued)
Figure B.18 Body Voltage Fault Troubleshooting Flowchart
Rotate open loop adjustment pot fully CCW, then turn open loop switch to on

Vary open loop adjustment pot in CW to get DVM's reading between -2.6 and -3.4 V

Is voltage adjusted between this range?

Check waveform at TP18 and TP23 on error amplifier card. TP18 and TP23 are the inverter SCR trigger signals. Trigger is a short pulse going from approx. +15 V to GND with a pulse width of 30±10 μs. Trigger at TP18 and TP23 are 180° out of phase and alternate.

Are pulses as shown?

Check inverter current waveform

Replace error amplifier card and align

Replace error amplifier card and align by performing maintenance procedures

Return to operation

Figure B.18 Body Voltage Fault Troubleshooting Flowchart (continued)
Disconnect HV cable from TWT and modulator.

Connect modulator adapter to TWT and modulator. Make sure connector mating surfaces are clean and dry. Ensure that the plug is completely engaged or else HV breakdown may occur in the receptacle.

Turn off CB1, turn on ±15 V S3 and push reset switch S3

Use maintenance procedure to drain HV tank to level where modulator can be removed.

Turn off ±15 V S3, remove modulator. Perform maintenance procedure and bolt dummy cover over slot.

Figure B.18 Body Voltage Fault Troubleshooting Flowchart (continued)
C

Turn on ±15 Vdc S3

Refill tank and bleed air. Perform maintenance procedures.

Turn off CB1, CB4 and push reset button S3

Replace HV assembly and perform maintenance procedures

Does Body Volt Fault light on?

Y

N

Replace modulator and perform maintenance procedures

Return to operation

Figure B.18 Body Voltage Fault Troubleshooting Flowchart (continued)
HV Assembly Short Fault

Connect DVM to cathode and collector voltage monitors J15, J16

Turn HV ON to off

Set open loop adjustment R63 fully CCW

Set open loop test switch S2 to on

Slowly increase open loop adjustment R36 and observe DVM so that cathode voltage (J15) does not exceed -3.4 V

Does voltage go to -3.4 V?

Y: Check spark gap and fault monitor CKTs

N: Fix problem

A: Return to operation

Figure B.19 High Voltage Assembly Short Fault Troubleshooting Flowchart
Set open loop test switch S2 off

Turn CB1 and ±15 Vdc S3 off

Disconnect HV cable and plug modulator test adapter into modulator connect j6, greater care must be taken to insure that plug is securely and properly engaged to the socket to prevent HV arcing to ground.

Turn CB1 to off and ±15 Vdc S3 to on

Set open loop test switch S3 fully CCW

Set open loop test switch S3 to on

Slowly increase R36 and observe DVM so that cathode voltage does not exceed -3.4 V.

Figure B.19 High Voltage Assembly Short Troubleshooting Fault Flowchart (continued)
Does cathode voltage go to -3.4 V?

- Y: Set open loop test switch to off
  - Replace TWT and EQ1, perform maintenance procedures

- N: Set open loop test switch to off
  - Remove modulator, perform fill and drain maintenance procedures

- Next, check collector and cathode HV P.S. in the tank for bad component

Figure B.19 High Voltage Assembly Short Troubleshooting Flowchart (continued)
Test equipments:
1. Modulator Test Plug.
2. Tektronix 465 Scope.
3. Tektronix 100:1 probe.
5. Chicken Stick

Modulator Fault

Turn HV ON to off and CB1, ±15 Vdc S3 to off

Disconnect HV cable between modulator and TWT. Ground modulator HV terminals with a chicken sitck. Connect the modulator test adapter between TWT and modulator

Connect a scope or DVM to the grid and cathode (ground) test points and measure grid voltage.

Turn ±15 Vdc S3 to on and observe grid voltage

Is grid volt at -400 V?

Y

Wait for 3 minutes after turning on S3, then measure filament voltage at adapter test points.

E

A

N

B

Figure B.20 Modulator Fault Troubleshooting Flowchart
Is filament volt between -8.5 to -10.5? 

Connect video pulses from a pulse generator which generate pulse with amplitude 3 V peak, pulse width 6 μs, PFR 1 kHz. Set bias test switch to on and start modulator test.

Is grid bias volt between -450±10 to -400±10 V?

Connect scope to TP1 and TP2 located on the top of modulator case. TP1 and TP2 signals are narrow spikes with swing from -15±5 V peak. TP1 is the on trigger coincident with the video leading edge. TP2 is the off trigger coincident with the video trailing edge.

Replace low level drive card

Is trigger O.K.? 

Figure B.20 Modulator Fault Troubleshooting Flowchart (continued)
Can grid pulse volt be adjusted between 200 to 400 V by using recessed varic control on ac regulator?

- **Y**: Adjust to 200 to 400 V
- **N**: Replace modulator

Return to operation

Figure B.20 Modulator Fault Troubleshooting Flowchart (continued)
Remove cover on AC regulator to check or replace fuse. Use a 3 A slow blow fuse.

Is fuse O.K.?  

Replace fuse and turn ±15 Vdc S3 on

Measure grid voltage

Is grid bias voltage at -400 V?  

Repeat check again

Replace fuse  

Is fuse O.K.?  

Turn ±15 Vdc S3 off. Disconnect ac power from modulator

Figure B.20 Modulator Fault Troubleshooting Flowchart (continued)
Connect AC regulator test load to AC power plug.

Turn ±15 Vdc to on

Measure AC voltage which is 400 Hz square wave by using a true RMS reading DVM at test load

Is voltage at 180±1 Vac?

Y

Replace modulator

N

Replace AC regulator

Return to operation

Figure B.20 Modulator Fault Troubleshooting Flowchart (continued)
### APPENDIX C TWT SPECIFICATIONS TABLE

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<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode Voltage (Ek)</td>
<td>29.5</td>
<td>kV</td>
</tr>
<tr>
<td>Cathode Current (ik)</td>
<td>3.6</td>
<td>A</td>
</tr>
<tr>
<td>Collector Voltage (Ec)</td>
<td>-400</td>
<td>V</td>
</tr>
<tr>
<td>Filament Voltage (Ef)</td>
<td>-10.8</td>
<td>V</td>
</tr>
<tr>
<td>Solenoid Voltage (Egy)</td>
<td>260</td>
<td>V</td>
</tr>
<tr>
<td>Solenoid Current (Is1)</td>
<td>150</td>
<td>A</td>
</tr>
<tr>
<td>Solenoid Current (Is2)</td>
<td>150</td>
<td>A</td>
</tr>
<tr>
<td>Input Signal Level</td>
<td>29</td>
<td>dBm</td>
</tr>
<tr>
<td>FC-77 Flow Rate</td>
<td>4.5</td>
<td>GPM</td>
</tr>
<tr>
<td>RF Duty</td>
<td>0.004</td>
<td></td>
</tr>
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## APPENDIX D HPA COMPONENT ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Component or Wiring</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC1</td>
<td>Direction Coupler</td>
</tr>
<tr>
<td>CP1</td>
<td>RF Detector Connector</td>
</tr>
<tr>
<td>AT1</td>
<td>Liquid Cooled Circulator</td>
</tr>
<tr>
<td>EQ1</td>
<td>Equalizer</td>
</tr>
<tr>
<td>V1</td>
<td>TWT</td>
</tr>
<tr>
<td>AT8</td>
<td>Liquid Cooled Circulator</td>
</tr>
<tr>
<td>DC2</td>
<td>Bi-direction Coupler</td>
</tr>
<tr>
<td>CP2</td>
<td>RF Detector Connector</td>
</tr>
<tr>
<td>CP3</td>
<td>RF Detector Connector</td>
</tr>
<tr>
<td>AT1</td>
<td>25 dB Attenuator</td>
</tr>
<tr>
<td>A2-A6-j6</td>
<td>Cathode-To-Body Voltage Cable</td>
</tr>
<tr>
<td>A2-j7</td>
<td>Collector-To-Body Voltage Cable</td>
</tr>
<tr>
<td>A9</td>
<td>RF Monitor Circuit</td>
</tr>
<tr>
<td>A9-j3-2</td>
<td>High VSWR Monitor wiring</td>
</tr>
<tr>
<td>A4</td>
<td>Ion Pump Power Supply</td>
</tr>
<tr>
<td>A4-j3-18</td>
<td>Ion P.S Undervoltage wiring</td>
</tr>
<tr>
<td>A4-j3-19</td>
<td>Ion P.S Overcurrent wiring</td>
</tr>
<tr>
<td>j2</td>
<td>Solenoid P.S. power line</td>
</tr>
</tbody>
</table>

Table D.1 RF Amplifier Abbreviations (Figure 3)

112
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Component or wiring</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>High Voltage Supply Tank</td>
</tr>
<tr>
<td>A2-j1</td>
<td>Error Amplifier And Inverter Driver Card</td>
</tr>
<tr>
<td>A2-j1-&gt;P15,8,25</td>
<td>Inverter INHIB, HV sense and Open Loop Trig signals output line</td>
</tr>
<tr>
<td>A2-j3-25-&gt;P3,8,32</td>
<td>Body Voltage, HV Assembly Short and Crowbar Trig sensing signals output line</td>
</tr>
<tr>
<td>A2-j6</td>
<td>Inverter Current sensing signal output line</td>
</tr>
<tr>
<td>A6</td>
<td>Modulator</td>
</tr>
<tr>
<td>A6-j5</td>
<td>Low Level Modulator Drive Card</td>
</tr>
<tr>
<td>A6-j5-P13</td>
<td>Modulator Video signal input line</td>
</tr>
<tr>
<td>A6-j5-p23-&gt;P5,6,3</td>
<td>Output line of the sensing signals include collector's and cathode's current and voltage signals</td>
</tr>
<tr>
<td>A6-j4-p20-&gt;P16</td>
<td>Crowbar power line (115 Vac)</td>
</tr>
<tr>
<td>PS#3</td>
<td>48 Vdc Regulator</td>
</tr>
<tr>
<td>PS#3-&gt;A7-j1-P52-8,7,A8-j1-P54-8,7,A9-j1-P56-8,7</td>
<td>48 Vdc power lines</td>
</tr>
<tr>
<td>A7-j1-P52-5,9,A8-j1-P54-5,9,A9-j1-P56-5,9-&gt;A6-j2-P16</td>
<td>Sensing voltage output line</td>
</tr>
<tr>
<td>A7-j1-P53-4,5,A8-j1-P55-4,5,A9-j1-P57-4,5-&gt;A6-j2-P26</td>
<td>Output voltage lines of Regulators</td>
</tr>
<tr>
<td>A7-j1-P53-1,2,A8-j1-P55-1,2,A9-j1-P57-1,2-&gt;j7-1,3,5</td>
<td>Voltage monitor lines</td>
</tr>
<tr>
<td>Blj1-&gt;P16</td>
<td>440 Vac 400 Hz 3-Phase power line</td>
</tr>
<tr>
<td>A5-&gt;A2-P19</td>
<td>600 Vdc power line</td>
</tr>
</tbody>
</table>

Table D.2 High Power Supply Unit And Modulator Unit Abbreviations (Figure 4)
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Component or Wiring</th>
</tr>
</thead>
<tbody>
<tr>
<td>A10</td>
<td>Power Distribution Unit</td>
</tr>
<tr>
<td>CB1</td>
<td>400 Vac 400 Hz 3-Phase switch</td>
</tr>
<tr>
<td>CB2</td>
<td>Cooling Pump Control switch</td>
</tr>
<tr>
<td>CB3</td>
<td>115 Vac 60 Hz single phase switch</td>
</tr>
<tr>
<td>A10-A1,B1,C1 -&gt; A5-CR-8,9,10</td>
<td>400 Vac 400 Hz 3-Phase power line</td>
</tr>
<tr>
<td>A10-j3-p16-1,2,3-&gt; B1-j1</td>
<td>400 Vac 400 Hz 3-Phase power line</td>
</tr>
<tr>
<td>A10-j3-p16-30,31-&gt; A4-j1-P35-A,B</td>
<td>115 Vac 60 Hz Single Phase power line</td>
</tr>
<tr>
<td>A10-P16-j3-5,6,27,28,34,35,36-&gt;PS #1,PS#2,A6-j2-P26-14,15,A6-j4-P20-1,2</td>
<td>115 V 400 Hz Single Phase power line</td>
</tr>
<tr>
<td>A6-P26-16,17-&gt;PS#3</td>
<td>115 V 400 Hz Single Phase power line</td>
</tr>
<tr>
<td>PS#3-&gt;A7,A8,A9-7,8</td>
<td>48 Vdc Power Line</td>
</tr>
<tr>
<td>PS-1-4,PS2-6-&gt;A10-j2-5,6,7,8,12,13</td>
<td>±15 Vdc power line</td>
</tr>
<tr>
<td>A10-P15-j4-25,26,27,28,29,30,33,36,37,38,39,40,43,44,47,55,56-&gt;A3-j2-P2,A6-j1,A2-j1,A2-j3-P25,A9-j3,TTL,j7-8</td>
<td>±15 Vdc power line</td>
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Table D.3 Power Distribution Unit (Figure 7,8)
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Component or Wiring</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Cooling Pump</td>
</tr>
<tr>
<td>HP2</td>
<td>Reservoir Valve</td>
</tr>
<tr>
<td>HP3</td>
<td>Auxiliary Valve</td>
</tr>
<tr>
<td>HP4</td>
<td>Vent Valve</td>
</tr>
<tr>
<td>HP5</td>
<td>Cooling Water Modulation Valve</td>
</tr>
<tr>
<td>HP6</td>
<td>Filter And Drier</td>
</tr>
<tr>
<td>HP8</td>
<td>Automatic Vent Valve</td>
</tr>
<tr>
<td>HP9</td>
<td>Moisture separator</td>
</tr>
<tr>
<td>HP10</td>
<td>Drain Valve</td>
</tr>
<tr>
<td>HP11</td>
<td>Check Valve</td>
</tr>
<tr>
<td>HP12</td>
<td>Air Bleed Valve</td>
</tr>
<tr>
<td>HP13</td>
<td>Air Bleed Valve</td>
</tr>
<tr>
<td>HP14</td>
<td>W/G Air Pressure</td>
</tr>
<tr>
<td>HP19</td>
<td>Water Inlet Connection</td>
</tr>
<tr>
<td>HP20</td>
<td>Water Outlet Connection</td>
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Table D.4 Cooling Unit Abbreviations (Figure 9)
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Component or Wiring</th>
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<tbody>
<tr>
<td>QD1</td>
<td>Quick Disconnect</td>
</tr>
<tr>
<td>QD2</td>
<td>Quick Disconnect</td>
</tr>
<tr>
<td>HE1</td>
<td>Heat Exchanger</td>
</tr>
<tr>
<td>TV1</td>
<td>Throttle Valve</td>
</tr>
<tr>
<td>BV1</td>
<td>Bypass Valve</td>
</tr>
<tr>
<td>S1</td>
<td>Coolant Overtemperature Switch</td>
</tr>
<tr>
<td>S2</td>
<td>Liquid Level Switch</td>
</tr>
<tr>
<td>S4</td>
<td>Flow Interlock Switch</td>
</tr>
<tr>
<td>S5</td>
<td>Flow Interlock Switch</td>
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<tr>
<td>SG1</td>
<td>Sight Class</td>
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</table>

Table D.4 Cooling Unit Abbreviation (continued)
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   Naval Postgraduate School
   Monterey, California 93943-5100
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4. Professor Hung-Mou Lee, EC/LH
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   Monterey, California 93943-5100
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5. Professor Gearld D. Ewing, EC/EW
   Naval Postgraduate School
   Monterey, California 93943-5100
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