ADVANCED ENERGY®

Rapid F 6kW

Remote Plasma Source

June 2003 *5707038-C*

User Manual

User Manual

Rapid™ F 6 kW Remote Plasma Source

ADVANCED ENERGY®

5707038-C

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PRODUCT USAGE STATEMENT

⚠ WARNING:

Read this entire manual and all other publications pertaining to the work to be performed before you install, operate, or maintain this equipment. Practice all plant and product safety instructions and precautions. Failure to follow instructions can cause personal injury and/or property damage. If the equipment is used in a manner not specified by the manufacturer the protection provided by the equipment may be impaired. All personnel who work with or who are exposed to this equipment must take precautions to protect themselves against serious or possibly fatal bodily injury.

Advanced Energy Industries, Inc., (AE) provides information on its products and associated hazards, but it assumes no responsibility for the after-sale operation of the equipment or the safety practices of the owner or user. This equipment produces or uses potentially lethal high-voltage, high-current, radio frequency (RF) energy. NEVER DEFEAT INTERLOCKS OR GROUNDS.

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Table of Contents

Chapter 1. Introduction

Chapter 2. Theory

Chapter 3. Specifications

Chapter 4. Controls, Indicators, and Interfaces

Chapter 5. Installation, Setup, and Operation

Chapter 6. Troubleshooting and Global Support

Chapter A. Appendix A

List of Figures

List of Tables

Introduction

This manual documents how to install, operate, maintain, and troubleshoot the Advanced Energy® Rapid F 6 kW plasma source. Retain this manual for future reference.

READ THIS SECTION!

To ensure safe operation, read and understand this manual before attempting to install or operate this unit. At a minimum, read the safety instructions and follow the safety practices under the heading “Safety” on page 1-3.

INTERPRETING THE MANUAL

The following sections explain the type conventions, icons, and symbols that appear in this manual.

Type Conventions

Please note the following type conventions:

- Pin and signal names appear in capitalized italics (*POWER_ON*).
- New terms appear in italicized text.
- Unit labels (switches, indicators, and so on) appear in boldface text (**MODIFY**).
- Commands (**162**) and command names (**set point**) appear in boldface, lowercase text.

Icons (Symbols)

This symbol represents important notes concerning potential harm to people, this unit, or associated equipment. Advanced Energy® includes this symbol in Danger, Warning, and Caution boxes to identify specific levels of hazard seriousness.

DANGER:
This box identifies hazards that could result in severe personal injury or death.

WARNING:
This box identifies hazards or unsafe practices that could result in personal injury.

CAUTION:
This box identifies hazards or unsafe practices that could result in product or property damage.

The following symbols may appear on the unit:

High voltage

Protective earth ground

CE label

1020

Non-ionizing radiation

1030

Hot surface

1309

Warning (refer to manual)

1027

NRTL

1154

Heavy object

1751

SAFETY

Do not attempt to install or operate this equipment without proper training.

- Ensure that this unit is properly grounded.
- Ensure that all cables are properly connected.

- Verify that input line voltage and current capacity are within specifications before turning on the power supplies.
- Use proper ESD precautions.
- Operate this device only within the specified range of vacuum pressures, powers, duty-cycles and gas chemistries.
- Do not attempt to disassemble the source assembly or its integrated power supply to clean or service the vacuum housing from potential process-related deposition.
- BE CAREFUL AROUND THIS EQUIPMENT

PRODUCT COMPLIANCE AND CONDITIONS OF USE

The following sections include information about unit compliance and certification, including the conditions of use and installation required to be in compliance with the standards and directives.

Safety and Compliance Directives and Standards

Certain options of this unit have been tested for and comply with the following safety and electromagnetic compatibility (EMC) directives and standards and semiconductor industry guidelines:

Table 1-1. *Electromagnetic Compatibility (EMC) Directives*

Directive	Description
89/336/EEC	EC Council directive on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive)

Table 1-2. *Electromagnetic Compatibility (EMC) Standards*

Standard	Description
47 CFR Part 18	Code of Federal Regulations—Limits and methods of measurement of radio interference characteristics of industrial, scientific, and medical equipment

Table 1-2. *Electromagnetic Compatibility (EMC) Standards (Continued)*

Standard	Description (Continued)
EN 55011	Limits and methods of measurement of radio disturbance characteristics of industrial, scientific, medical (ISM) radio frequency equipment (Group 2, Class A) (CISPR 11)
EN 61000-6-2	Electromagnetic Compatibility - Generic Standards- Immunity for Industrial Environments

Table 1-3. *Safety Directives*

Directive	Description
73/23/EEC	EC Council directive on the harmonization of the laws of the Member States relating to electrical equipment designed for use within certain voltage limits (LVD - Low Voltage Directive)

Table 1-4. *Safety Standards*

Standard	Description
ANSI/ISA 82.02.01	Safety standard for electrical and electronic test, measuring, controlling and related equipment—general requirements (harmonized standard to IEC publication 61010-1)
CSA C22.2 No. 1010.1	Safety requirements for electrical equipment for measurement, control, and laboratory use
EN 61010-1	Safety requirements for electrical equipment for measurement, control, and laboratory use

Table 1-5. *Semiconductor Industry Guidelines*

Guideline	Description
SEMI F47	Environmental, health, and safety guidelines for semiconductor manufacturing equipment

This device must be installed and used only in compliance with the directives and standards listed in addition to VDE 0113, EN 60204 (IEC 60204), and applicable requirements.

Certification

Certain options of this product are certified by:

- Canadian Standards Association (CSA) (NRTL/C)
- CE marking is self-addressed by AE Compliance Engineering
- EMC measurements verified by TÜV Product Services

For more information, refer to the letter of conformance (US) or declaration of conformity (EU) accompanying the product.

Installation Requirements

Install this unit according to the following requirements.

The following section describes required steps to be taken before attempting installation.

⚠ WARNING:
Operating and maintenance personnel must receive proper training before installing, troubleshooting, or maintaining high-energy electrical equipment. Potentially lethal voltages could cause death, serious personal injury, or damage to the equipment. Ensure that all appropriate safety precautions are taken.

⚠ WARNING:
RISK OF DEATH OR BODILY INJURY. Disconnect and lockout/tagout all sources of input power before working on this unit or anything connected to it.

Conditions of Use

To comply with the stated directives and standards, you must meet the following conditions of use:

- Before making any other connection, connect the auxiliary protective earth ground stud on the front panel.
- Install and operate this device only in a pollution degree 2 or better environment, which means an indoor location such as a computer room, office, or factory floor where only non-conductive pollution occurs during operation.

- Use only clean, well-conditioned water with low conductivity (refer to Table 3-4 on page 3-4). High conductivity cooling water with high rust and salt content can inhibit the reliable performance of this device.
- Operate this device under flows, vacuum pressures, and power levels declared in the specifications to avoid inadvertent or unintended vacuum arc issues due to high voltages when igniting a plasma in the source.
- Use only ASM #326 O-rings for mounting the Rapid F 6 kW plasma source to existing vacuum hardware.
- Use only shielded cables on the AE Bus (**RS-232**) port and the user (**Analog Control**) port connectors.
- Install and operate this device in an over-voltage category III or better environment.
- To provide the required over-current protection, you must install and operate this device with a 35 A (max) circuit breaker switch on the AC input. The circuit breaker must be easily accessible and near the device.
- This device must be installed so that the input power connection is inaccessible to the user.

Theory

The following chapter provides general information about the Rapid F 6 kW plasma source as well as an explanation of its operating principles.

GENERAL DESCRIPTION

This combination plasma source and integrated mid-frequency (~400 kHz) 6 kW generator is compact and easy to mount, and it provides flexibility and control of a wide range of reactive plasma chemistries at a number of critical points within the process stream. The Rapid F 6 kW plasma source is inductively-coupled, with a closed-path, water-cooled metal manifold in which induced plasma currents act as a single-turn secondary to a ferrite-core transformer. This manifold not only has unique electrical features that ignite the source, but also possesses frequency agile, self-resonant tuning features that facilitate power control into the plasma load via integrated impedance matching components. Thus, this versatile unit is capable of providing power to plasmas over a wide range or flows and pressures. The source itself is controlled through its 25-pin user (**Analog Control**) port or 9-pin AE Bus (**RS-232**) port. It also includes an internal AC line filter and user-interlocked contactor.

The primary application for this product is to provide a reactive etch gas (NF_3) for remote chamber cleaning in semiconductor and flat panel display applications.

THEORY OF OPERATION

In the Rapid F 6 kW plasma source, 60 Hz, three phase AC is DC conditioned and then switched at RF mid-frequencies (~400 kHz). The switch-mode power supply adjusts its switching frequency to match the power in a resonant CLL transformer circuit, as shown in Figure 2-1 on page 2-2. As soon as energy is stored in this resonant tank circuit, a secondary strike circuit provides a controlled high electrostatic potential RF burst to a portion of the vacuum vessel wall in order to ignite the discharge. Once ignited, a ferrite transformer core couples mid-frequency power to the plasma within the vacuum housing such that the conductive plasma body forms a single turn secondary. The frequency of the CLL circuit and power are mutually adjusted to sustain the discharge and provide the desired power set point depending upon the resistive characteristics of the plasma body. The high density plasma formed in the vacuum housing can then ionize, excite, or dissociate feed gases that flow through its interior. Typically, the source is ignited in argon (Ar) gas, which is easy to

ionize, for an ignition period of about one second. After the formation of a high density inductively-coupled plasma, the reactive gases are then introduced until the plasma reaches the desired operating point.

Figure 2-1 shows the circuit topology of the unit, where R_p is the plasma resistance and is a function of pressure, power, and gas chemistry. R_{eff} and X_{eff} are the effective resistance and reactance, respectively, of the plasma-loaded transformer as seen by the power supply.

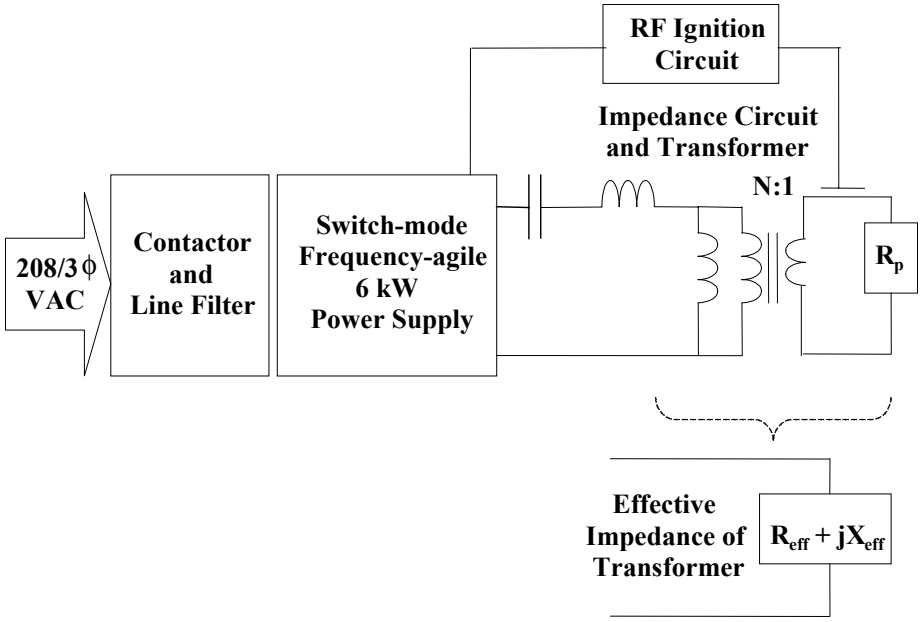


Figure 2-1. *Rapid F 6 kW plasma source block diagram*

Note: Since RF power is directly coupled to the inductively-coupled plasma by the ferrite transformer without the use of transmission lines or a fixed output impedance of a separate generator, measures of forward and reflected power that are conventionally used in plasma source generation have no meaning in this integrated generator/source topology.

The Rapid F 6 kW plasma source is designed to work with pure molecular gas mixtures; however, for ignition, the source requires an easily ionized noble gas such as Ar. Thus, the operator or process engineer must integrate the source's operation with dynamic or sequential adjustment of gas flow, vacuum pressure, and power set point steps.

Note: If sufficient power is applied and the pressure of the source is not too high, it is possible to remove the Ar starting gas from the process, if desired.

Because operation is a function of the dynamic control of the user's vacuum installation and process, it is important to review the theory of operation in the context of typical vacuum process equipment and control. Figure 2-2 on page 2-3 shows a high-level diagram of a typical vacuum system, the Rapid F 6 kW plasma source, and controls, as might be configured for a chamber clean or a remote plasma surface strip process. See "First Time Operation" on page 5-12 for details on the operation of this installation.

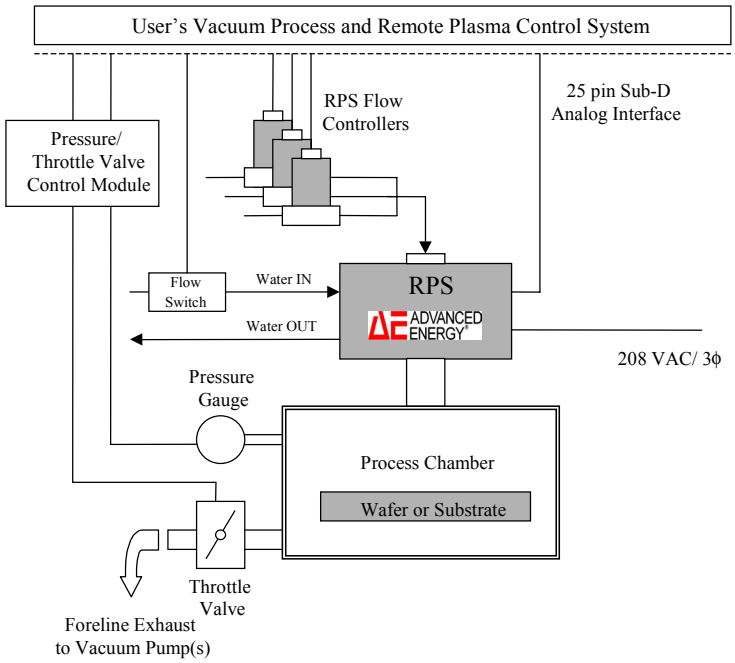


Figure 2-2. *Typical installation*

Figure 2-3 illustrates the source topology. The source body is a torodial aluminum vacuum vessel with hard anodization and copper water-cooling channels. The inner walls of the source manifold are hard-anodized to support fluorine-bearing chemistries.

Note: Figure 2-3 recommends a certain direction for gas flow. This gas flow may be reversed if necessary.

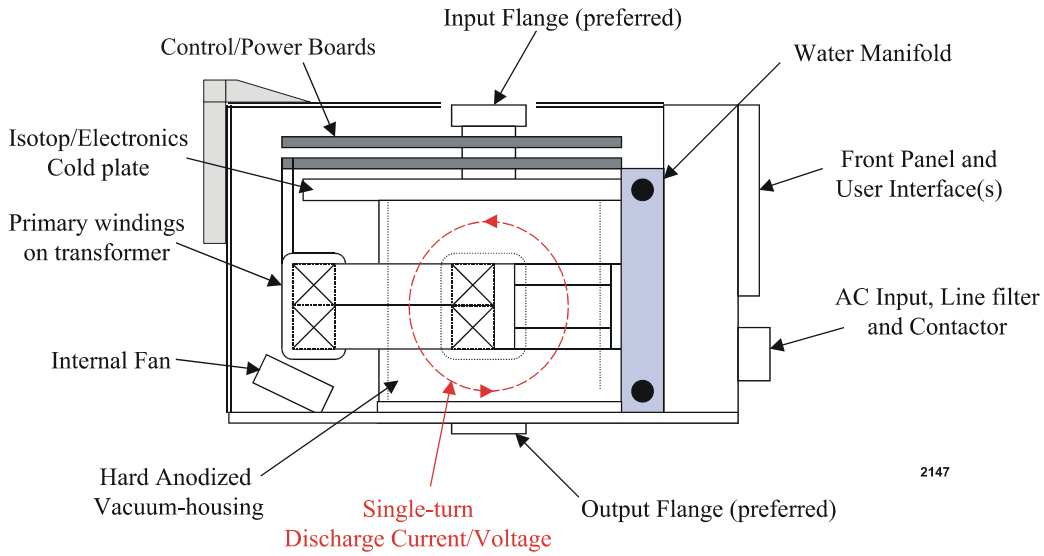


Figure 2-3. *Rapid F 6 kW plasma source topology*

Specifications

PHYSICAL SPECIFICATIONS

Table 3-1 describes the physical specifications of the Rapid F 6 kW plasma source.

Table 3-1. *Physical specifications*

Description	Specification
Size	25.6 cm (H) x 25.3 cm (W) x 45.7 cm (D) 10.1" (H) x 9.9" (W) x 18.0" (D)
Weight	Approximately 25 kg (55 lb)
Clearance	10.16 cm (4″) required at front for cable connections
Mounting	
Vacuum	Symmetric ISO NW 40 Split Clamp mating flanges with six #10-32 screw holes—top and bottom of unit (ISO NW 40 split clamps and #10-32 x 5/8" screws supplied by user)
Mechanical	Six 1/4-20 threaded PEM fastener holes on each side panel 1/4-20 x 5/8" L hardware suggested for mounting to1/4" thick mechanical support or bracing) 10.16 cm (4″) required at front for cable connections
Lifting Handles	Two collapsible handles rated at 4 times the weight of the unit
Connector Specifications	
AC input power	Male, 6-pin, Harting type, Han® 6HSB
User (**Analog Control**) port	Female, 25-pin, shielded, subminiature-D
AE Bus host (**RS-232**) port	Female, 9-pin, shielded, subminiature-D
Water connectors	Two female SAE 5/16" straight thread

ELECTRICAL SPECIFICATIONS

Table 3-2 describes the electrical specifications of the Rapid F 6 kW plasma source.

Table 3-2. *Electrical specifications*

Description	Specification
Input Power Specifications	
Line voltage	208 VAC nominal (190 VAC to 229 VAC), 3 ϕ, with ground, phase insensitive
Line frequency	50/60 Hz nominal (47 Hz to 63 Hz)
Line current	26 A nominal, 35 A maximum per phase
Ground leakage current	3.5 mA or less
Ground connection	Chassis ground near AC connector suitable for ring lug connection
Overcurrent protection	30 A internal bus fuse
Overvoltage	Use in an overvoltage category III environment
Warm-up delay	Approximately 60 s average for AC on (bus is charged) Approximately 4 s for RF on (after bus is charged)
Load power specifications	
Frequency	290 kHz to 650 kHz, limited to 290 kHz to 490 kHz for specified operation
Peak power under load	6000 W with variable duty cycle of no more than 50%, maximum allowed on-time of 300 s
Minimum power under load	1500 W
Accuracy	±5% or 200 W of peak power rating, whichever is greater
Linearity	±200 W or less from 1500 W to full-scale output
Power leveling	Internal load power leveling
Operational load	Load determined by plasma impedance within operational range of about 3:1
Efficiency (line to load)	Approximately 80% typical at full-rated power, nominal line
Zero set point	Less than 1 W actual and readback when zero or negative set point or when interlock is not satisfied

Table 3-2. *Electrical specifications (Continued)*

Description	Specification
Calibration means	Auxiliary secondary winding for non-plasma calibration via resistive/inductive load external to the unit
Ignition	Ignition requires a low ionization voltage gas (Argon preferred) at .5 to 2 Torr. After ignition, the process gases should be introduced within 90 seconds to prevent a current limit fault.
Power factor	> 0.73

VACUUM SPECIFICATIONS

Table 3-3 describes the vacuum specifications for the Rapid F 6 kW plasma source.

Table 3-3. *Vacuum specifications*

Description	Specification
Leak rate	He: < 10^{-6} mbar-liter per second (converts to <0.0006
Plasma source wall surfaces	Anodized aluminum, Class III Hard-anodization with deionized water seal post-treatment
Vacuum seals	Chemraz® O-rings
O-Ring grooves	Masked aluminum surfaces against O-ring surfaces
Input/output vacuum fittings	ISO NW 40 flanges

Note: If the source is stored for an extended period of time at atmospheric pressure, outgassing will occur when pumping down the source for the first time. To check for leaks upon installation, it is recommended that the source be pumped down to its base pressure and operated in Ar:O_2 mixtures to remove air contaminants and moisture.

COOLING SPECIFICATIONS

Table 3-5 provides cooling specifications. The source is air and water cooled by a single-series loop water flow path.

Table 3-4. *Cooling specifications*

Description	Specification
Air—internal exchange	Internal fans for localized cooling of critical components
Air—external exchange	External air exchange through perforations at critical locations and an exhaust fan (in the rear of the unit); maximum ambient air temperature = 40ºC (104ºF)
Water temperature	+5ºC to +25° C (+41ºF to +77° F) *Note:* Maximum water temperature at minimum flow rate and maximum ambient air temperature (+40° C)
Water flow rate	1.3 gpm to 2.0 gpm for derated power, on-time, and duty cycle
Minimum pressure differential (supply to drain required to achieve specified minimum flow rates)	1.4 bar (20 psi) for 1.5 gpm, 1400 kPa, requires 7.6 lpm (2 gpm) at peak power (6 kW).
Maximum pressure rating	4.5 bar (65 psi), 450 kPa
Contaminates	The following specifications are recommended for the water used to cool the Rapid F 6 kW plasma source: • pH between 7 and 9 • Total dissolved solids < 250 ppm • Specific resistivity of 2500 Ω/cm or higher at 25° C • Total dissolved solids (TDS) as estimated by the following: $TDS \leq \frac{640{,}000}{\text{specific resistivity } (\Omega/\text{cm})}$

Note: Internal fans assist the thermal management of the unit.

WARNING:
Under normal operation, the chassis case and cooling water reach temperatures hot enough to scald. Before touching the source or disconnecting the water cooling lines, allow the cooling water to flow for several minutes to remove stored thermal energy from the unit.

CAUTION:
Do not use de-ionized water for cooling purposes. De-ionized water causes both corrosion and erosion of cooling manifolds.

ENVIRONMENTAL SPECIFICATIONS

Table 3-5 provides climatic specifications.

CAUTION:
Install and operate this device only in a pollution degree 2 or better environment, which means an indoor location such as a computer room, office, or factory floor where only non-conductive pollution occurs during operation.

Table 3-5. *Climatic specifications*

	Temperature	Relative Humidity	Air Pressure
Operating	5°C to +40°C +41°F to +104°F	15% to 85% [1] +2 g/m^3 to +25 g/m^3	<74.5 kPa <745 mbar approximately 2500 m (8203´) above sea level
Storage	-25°C to +55°C -13°F to +131°F	15% to 85% [1] +2 g/m^3 to +25 g/m^3	<58.5 kPa <585 mbar approximately 4000 m (13,124´) above sea level
Transportation	-25°C to +55°C -13°F to +131°F	15% to 85% [1] +2 g/m^3 to +25 g/m^3	<48.0 kPa <480 mbar approximately 5000 m (16.405´) above sea level

[1] noncondensing

[2] Maximum relative humidity when the unit temperature slowly increases, or when the unit temperature directly increases from -25°C to +30°C

[3] Maximum absolute humidity when the unit temperature directly decreases from +70°C to +15°C

PROCESS OPERATING SPECIFICATIONS

This section describes the operational specifications for the Rapid F 6 kW plasma source. Table 3-6 shows the general operational parameters for the Rapid F 6 kW plasma source.

Table 3-6. *General operational parameters*

Description	Specification
Vacuum pressure range	0.5 Torr to 6 Torr for NF_3 processes up to 2.5 slpm with the appropriate gas feed apparatus for high gas flows.
Power requirements	1500 W to 6000 W as limited by thermal management, current, and voltage limits within the range
Process application s	Remote delivery of gases for downstream chamber cleaning by the utilization of NF_3 as the feed gas

Table 3-6. *General operational parameters (Continued)*

Description	Specification
Chemical compatibilities	Fluorine-bearing gases, perfluorocarbon-bearing gases (nondepositing) hydrogen, nitrogen, oxygen-bearing gases, and combinations thereof
Long-term stability	No internal parts are consumable (consumables are defined as parts with a lifetime of less than 6000 hours of operation), with the exception of the source anodization. Drift in NF_3 dissociation efficiency within 6000 hours of operation = <2%

GAS PRESSURE AND OPERATING RANGE

The Rapid F 6 kW plasma source ignites in Ar gas and then transitions to pure NF_3 or O_2 gas (AE also permits blends of NF_3 with Ar or O_2 with Ar dilution). The viable operating range of the Rapid F 6 kW plasma source in any given gas depends on power, pressure, and gas flow. These factors define the effective plasma resistance into which the supply can deliver power. Figure 3-1 on page 3-8 illustrates the viable operating range for the Rapid F 6 kW plasma source as restricted by the internal current and voltage limits of the power supply. You must provide a satisfactory power set point in order to maintain a stable power balance for the given gas-phase chemistry and operating pressure between these two limits. The power balance depends on gas chemistry and pressure but is independent of the viable impedance range of the Rapid F 6 kW plasma source.

Note: The unit reaches a stable power balance when it disposes enough power into the plasma that the net rate of ion and electron production in the plasma body is equivalent to ion and electron volume and wall recombination. It may be difficult to maintain a stable power balance when the unit is operating in pure or diluted electronegative gases such as SF_6, NF_3, O_2, or in various perfluorocarbon gases at low powers and high pressures.

Imposed on the operating range, Figure 3-1 shows examples of NF_3 discharge for operation at the pressures and flow rates listed in Table 3-7 on page 3-9. At high power levels and low pressures where the gas discharge is very conductive, the power

supply's current limit may restrict delivered power. At low power levels and high pressures where the discharge is more resistive, the power supply's voltage limit may restrict delivered power.

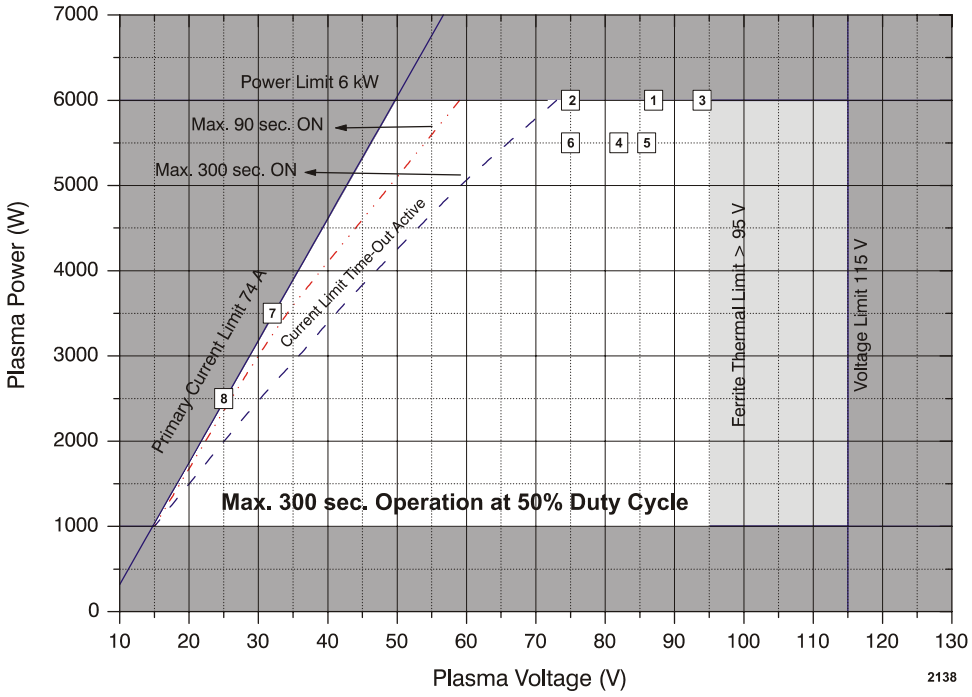


Figure 3-1. *Viable operating range of Rapid F 6 kW plasma source*

On the graph, you can see lines that indicate a range of operation near the current limit in which the power supply enables the current limit time-out counter. In this range of operation, currents on the primary windings are exceptionally high and can lead to high heating losses. To protect the long term integrity of the windings, the unit derates the allowable on-time in this range of operation. This derating is a function of primary current and scales from 300 seconds (maximum) to 90 seconds (minimum). This range of high current operation is usually restricted to Ar ignition or the process transition steps immediately after Ar ignition. When the unit is operating is this range, the E21 error code flashes on the display panel, but output continues. If the unit continues to operate in this range for longer than the limit, the E21 error code stays on

the display and the unit shuts output off. To avoid this fault and to avoid long-term operation in this part of the range, increase the increase the operation pressures of gas flows.

Table 3-7. *Power, pressure, and gas flow examples for Figure 3-1*

Number in Figure 3-1	Pressure (Torr)	NF_3/Ar (sccm)	Plasma Voltage (V)	Plasma Power (kW)
1	12.0	2800 / 5600	87	6.0
2	10.0	2000 / 4000	75	6.0
3	6.5	1500 / 0	94	6.0
4	3.0	2000 / 0	82	5.5
5	3.5	2500 / 0	86	5.5
6	3.0	1500 / 0	75	5.5
7	1.0	0 / 500	32	3.5 (current limited)
8	0.42	0 / 500	25	2.5 (current limited

Under typical operating conditions, the interaction between the plasma's resistive properties and the power supply's control dynamics near the voltage limit will lead to disruption and loss of the discharge. Avoid operating the unit at or very close to the voltage limit. Also avoid pressure bursts, which may induce transient spikes or overshoots in plasma resistance.

CAUTION:
This unit is intended for use in select molecular gases. Do not operate continuously in argon and nitrogen for prolonged periods of time (>10 s).

Gas Operation Parameters

Table 3-8 provides gas operation specifications in fluorine (NF_3).

Table 3-8. *Gas operational specifications*

Description	Specification
Flows and dilutions	At least 2.5 slpm of NF_3 at up to 6 Torr at 6 kW At least 2.5 slpm of NF_3:Ar at 1:1 ratio up to 10 Torr at 6 kW
Dissociation efficiency	>98% dissociation of 2.5 slpm at 6 kW, as measured by mass spectroscopy
Gas quality	Operation in low-grade NF_3 (~95% pure) with no additional particulate formation

Controls, Indicators, and Interfaces

The Rapid F 6 kW plasma source provides two communication interfaces, the user (**Analog Control**) port and the serial AE Bus (**RS-232**) port. You can also use AE's Virtual Front Panel (VFP) software interface to communicate with the unit. For more information about VFP, see "Virtual Front Panel (VFP) Software Interface" on page 4-20.

The Rapid F 6 kW plasma source also has a passive front panel display with several LEDs and a display panel. For more information, see "Indicators" on page 4-22.

USER (ANALOG CONTROL) PORT

On the unit, this connector is labeled **Analog Control**.

The following section provides the connector type, cabling requirements, signal characteristics, pin descriptions, and wiring diagrams for the Rapid F 6 kW plasma source's user (**Analog Control**) port.

The unit's 25-pin user (**Analog Control**) port provides analog and digital signals to remotely control and monitor the Rapid F 6 kW plasma source. It uses a 25-pin, shielded, male, subminiature-D connector.

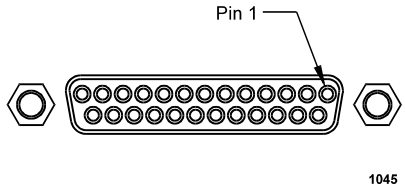


Figure 4-1. *User (Analog Control) port connector*

Interface Cabling Requirements

The cable used to connect the unit's 25-pin user (**Analog Control**) port to the system controller must be a shielded, 25-wire I/O cable. Twisted-pair wiring may be used but is not mandatory. Signal losses should be minimized by keeping the cable length as short as possible. The maximum recommended cable length between the Rapid F 6

kW plasma source and the controller is 10 meters (33´). To minimize interference from adjacent electrical equipment, the EMI shield in the cable should be terminated to ground at the plasma source end of the cable. Additionally, the chassis of the Rapid F 6 kW plasma source must be tied to a local earth ground through a copper grounding strap that is sized in accordance with applicable requirements (local electrical code).

Signal Characteristics

Table 4-1 provides remote interface connector signal types.

Table 4-1. *Remote interface connector signal types*

Signal Type	Description
Analog	Unless otherwise specified, all analog signals are 0 to 10 V.
Digital	Unless otherwise specified, all digital signals are 5 to 24 V, opto-coupled (open-collector signals with return lines nonreferenced to ground).
Grounds	All ground lines are to chassis ground.

Pin Descriptions

Table 4-2 provides the connector pin descriptions for the user (**Analog Control**) port interface.

Table 4-2. *User (Analog Control) port pin descriptions*

Signal Pin	Related Pin	Name	Signal Type	Description
1		*GROUND*	Analog output common	This pin is the return for all analog output lines. It is connected internally to pins *5* and *14* and the internal (chassis) ground of the unit.
2	4	*PLASMA ON ENABLE RETURN*	Digital return	This pin is the return for the +24 VDC *PLASMA ON ENABLE* signal *(*pin *4)*. See Figure 4-2 on page 4-5.
3	18	*RF POWER SET POINT RETURN*	Analog output return	This pin is the return for the *RF POWER SET POINT* signal.

Table 4-2. *User (Analog Control) port pin descriptions (Continued)*

Signal Pin	Related Pin	Name	Signal Type	Description
4	2	*PLASMA ON ENABLE*	Digital input	When a positive voltage of +24 VDC is applied to this pin with respect to pin *2*, the RF power to the plasma source module is enabled. *Note:* The user must provide the +24 Vdc. The current flow between pins *4* and *2* must be <30 mA. See Figure 4-2 on page 4-5.
5		*GROUND*	Analog output return	This pin is a return for analog outputs. This pin is connected to pins *1* and *14* and the internal (chassis) ground of the unit. See Figure 4-8 on page 4-8.
6		Not used		
7		Not used		
8		Not used		
9		Not used		
10		Not used		
11		Not used		
12		Not used		
13	25	*INTERLOCK*	Interlock loop	This pin, when connected externally to pin *25*, closes the interlock. Closure of the interlock enables the unit's AC input power contactor. See Figure 4-3 on page 4-6. *Note:* RF power will not come on until the **plasma on enable** command is given (pin *4*).
14		*ANALOG GROUND*	Analog output common	This pin is the return for all analog output lines. It is connected internally to pins *1* and *5* and internal (chassis) ground of the unit.

Table 4-2. *User (Analog Control) port pin descriptions (Continued)*

Signal Pin	Related Pin	Name	Signal Type	Description
15	20	*READY*	Digital output	When the Rapid F 6 kW plasma source is successfully interlocked and AC power is ready, a low impedance is established between this pin and pin *20* (+24 V return). • low = true • high = false SeeFigure 4-4 on page 4-6.
16	20	*PLASMA ON*	Digital output	When a plasma exists within the source, a low impedance is established between this pin and pin *20* (+24 V return). • low = true • high = false Figure 4-5 on page 4-7.
17	20	*FAULT*	Digital output	When an error code is displayed, a low impedance is established between this pin and pin *20* (+ 24 V return). • low = true • high = false See Figure 4-6 on page 4-7.
18	3	*RF POWER SET POINT*	Analog input	A 0 to 10 V signal applied to this pin linearly controls the RF power level requested by the user. 10 V = max rated output. See Figure 4-7 on page 4-8.
19	1, 5, or 14	*RF DELIVERED POWER*	Analog output	This 0 to 10 V signal provides a linearly-scaled readback of the power delivered into the internal plasma load. 10 V = max rated output.
20	17	*+24 V RETURN*	Digital common	This pin is the return for pins *15, 16,* and *17*.
21		Not used		

Table 4-2. *User (Analog Control) port pin descriptions (Continued)*

Signal Pin	Related Pin	Name	Signal Type	Description
22		Not used		
23		Not used		
24		Not used		
25	13	*INTERLOCK RETURN*	Interlock loop	See pin *13*.

User (Analog Control) Port Wiring Diagrams

Use these wiring diagrams in conjunction with the pin description in Table 4-2 to interface the unit to your system controller. Each wiring diagram is divided with a dashed line into two sections:

- The left side of the dashed line (User) shows the necessary external connections.
- The right side of the dashed line (Unit) represents the Rapid F 6 kW plasma source's internal circuitry.

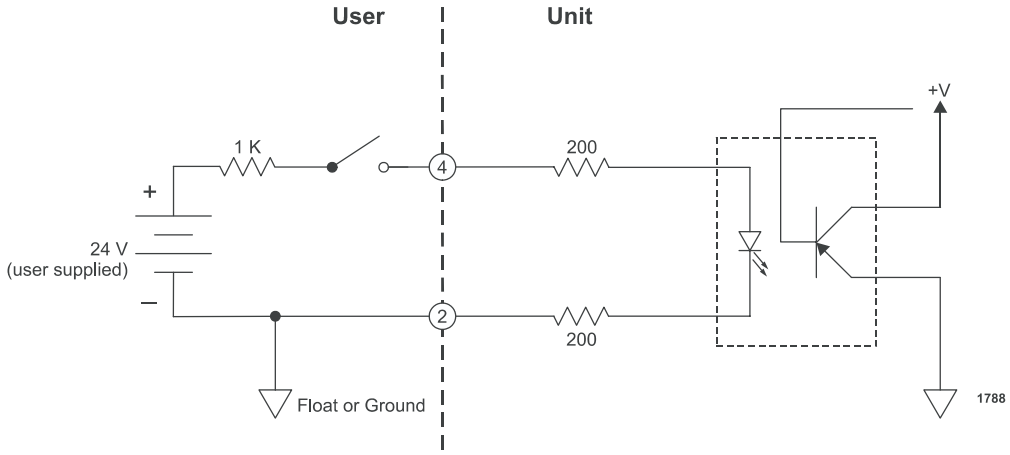


Figure 4-2. *Plasma on enable (pins 4 and 2)*

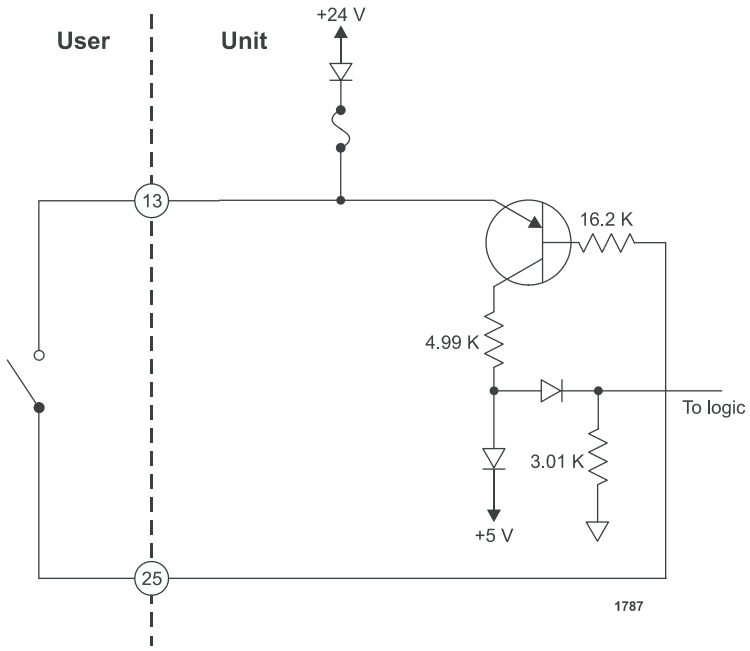


Figure 4-3. *Interlock (pins 13 and 25)*

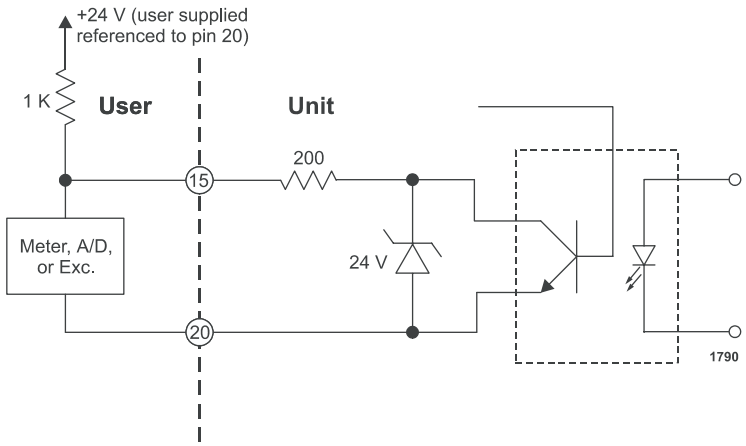


Figure 4-4. *Ready (pins 15 and 20)*

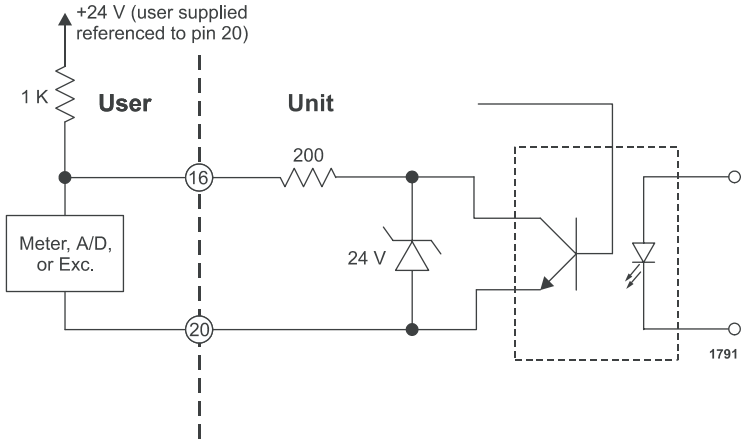


Figure 4-5. *Plasma on (pins 16 and 20)*

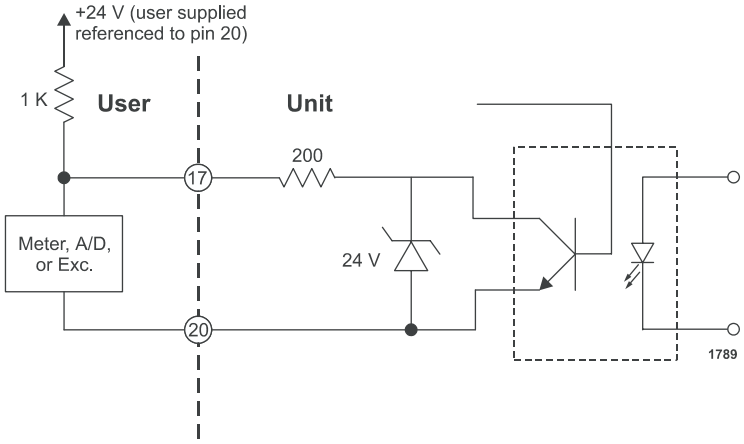


Figure 4-6. *Fault (pins 17 and 20)*

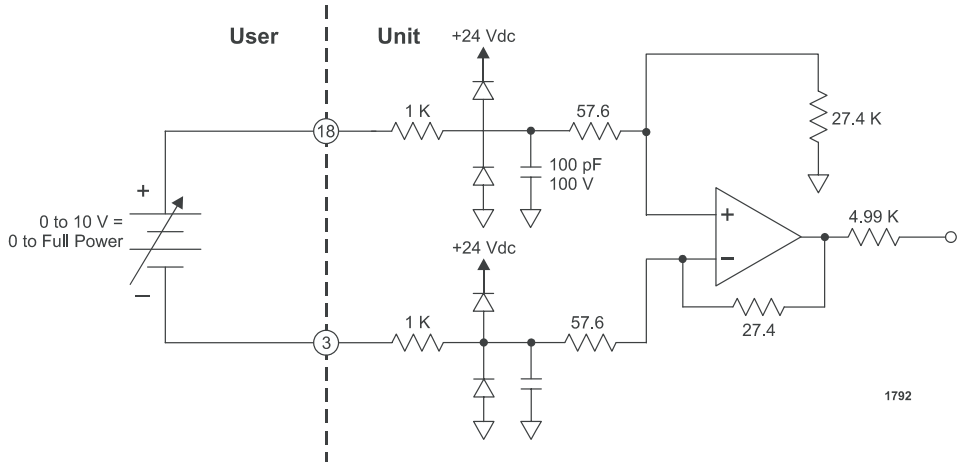


Figure 4-7. *RF power/set point (pins 18 and 3)*

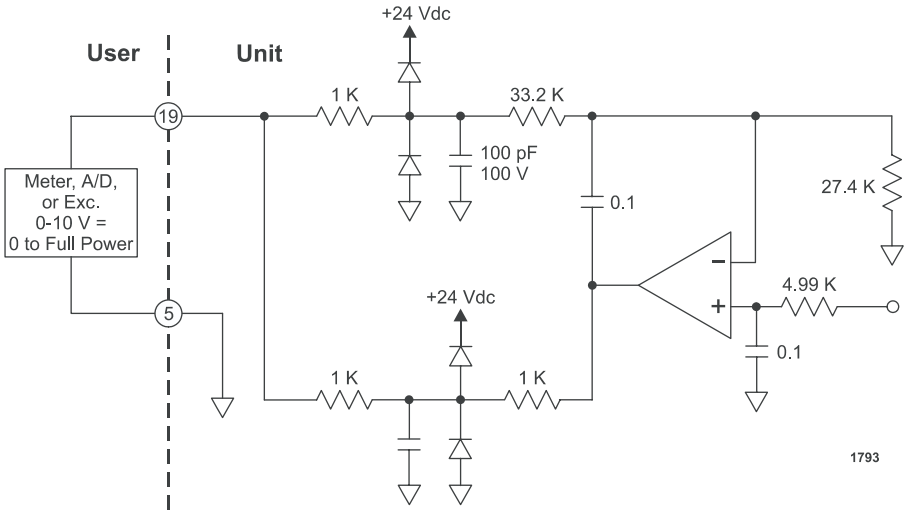


Figure 4-8. *RF delivered power (pins 19 and 5)*

AE BUS HOST (RS-232) PORT

On the Rapid F 6 kW plasma source, this port is labeled **RS232**. The AE Bus (**RS-232**) port uses a 9-pin, female, shielded, subminiature-D connector.

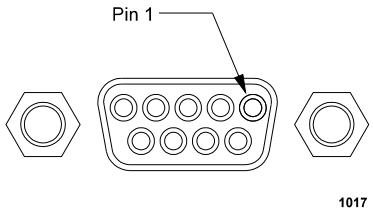


Figure 4-9. *AE Bus (RS-232) port connector*

The AE Bus (**RS-232**) port uses an RS-232 signal format and AE Bus communication protocol. See “Communicating Through the AE Bus (RS-232) Port” on page 4-10 for further details on the communications protocol. AE can also provide simple command host software.

The signals available at the AE Bus (**RS-232**) port conform to the RS-232 interface standards. The Rapid F 6 kW plasma source has an nonadjustable, factory-set baud rate of 19.2 kB.

Table 4-3. *AE Bus (RS-232) port pin descriptions*

Signal Pin	Name	Description
1	*RESERVED*	Reserved for future use
2	*TXD*	RS-232 transmit data
3	*RXD*	RS-232 receive data
4	*RESERVED*	Reserved for future use
5	*COM*	Data Common
6	*RESERVED*	Reserved for future use
7	*RESERVED*	Reserved for future use
8	*RESERVED*	Reserved for future use
9*	*RESERVED-(FACTORY)*	Reserved for future use
Note: *Do not ground this factory reserved pin. Grounding this pin will disrupt the operation of the unit.		

Communicating Through the AE Bus (RS-232) Port

You can control the Rapid F 6 kW plasma source through the AE Bus (**RS-232**) port. The AE Bus (**RS-232**) port on your Rapid F 6 kW plasma source uses the AE Bus communications protocol. The AE Bus communications protocol uses pure binary data. The transmission parameters are as follows:

- Odd parity
- One start bit, eight data bits, one stop bit

Low-order bytes (of the Data field) are transmitted before high-order bytes.

Two types of information are sent over the RS-232 link:

- Message packet
- Single byte packet (NAK or ACK)

WHAT IS THE MESSAGE PACKET?

The AE Bus message packet combines chunks of information in such a way that much information can be sent over communication lines at one time. Each packet contains four, or possibly five, types of information or “fields”:

- Header (contains the unit’s address and the length of Data field)
- Command
- Optional (supplements the Header field)
- Data (contains parameter setting or status, Command Status Response (CSR), or nothing)
- Checksum (aids in error checking)

Figure 4-10 shows the organization of these data fields in the AE Bus message packet. The subsequent paragraphs describe each data field.

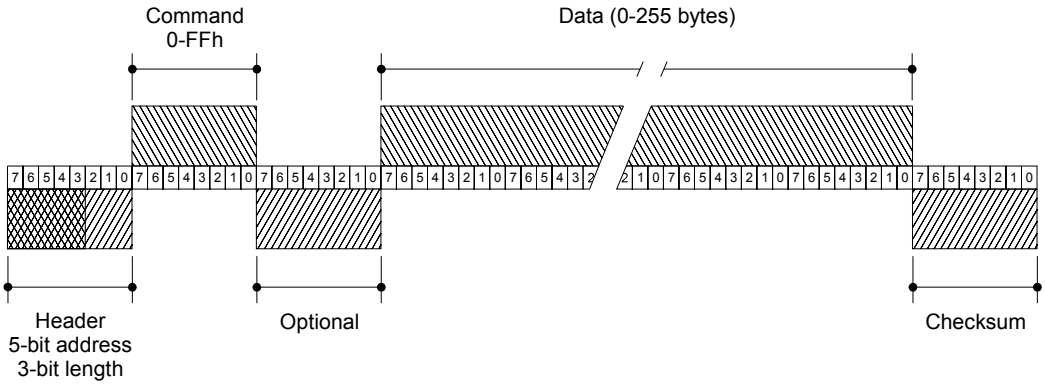


Figure 4-10. *Graphic representation of a message packet*

Header

This field contains two pieces of information: the first five bits contain the address, factory preset to 1, and the last three bits contain the length of the Data field. If the message packet originates with the host computer (master), the address specifies the packet's destination (to a Rapid F 6 kW plasma source, for example). If the packet is going to the host, the address specifies the packet's origin (from the Rapid F 6 kW plasma source). The address section of the Header field is five bits long (bits 3-7), which allows a total of 32 distinct addresses. Address 0 (zero) is reserved for the network broadcast address; when this address is used in a host-originated packet, all units receive the packet (but will not respond).

The remaining three bits (bits 0,1, and 2) tell the receiving unit how long the Data field is so that the unit can determine when the entire message has been received.

Note: The value in these bits should refer only to the number of actual data bytes. Do not include the checksum byte when calculating the value for these bits.

The header field (address and length) must be at the beginning of the message packet so that the receiving unit can compute the length of the packet after receiving the first byte.

Optional

This field exists to supplement the header field. The optional field contains a value only when the length bits in the header field contain a value of 7. (A value of 7 indicates that the data field contains more than 6 bytes of data.) Under those circumstances, the optional field contains a one-byte value (between 7 and 255) indicating the actual length of the data field.

Command

This field contains a one-byte value: 00h to FFh (0 to 255). If the message packet originates with the host computer, this value specifies the purpose of the message packet. If the message originates with the Rapid F 6 kW plasma source, the value specifies the command to which it is responding. See Table 4-5 for a complete list of host commands.

Data (Data Bytes)

The Data field can contain from 0 to 255 bytes of binary data, which are interpreted in various ways, depending on the value that appears in the command field. The data field typically contains data or a CSR, depending on what was requested. Since some commands do not require data, sometimes the data field contains no value.

If the value specified in the length bits of the header field is 0 to 6, the Rapid F 6 kW plasma source expects 0 to 6 bytes of data. However, if the value in the header field is 7, the Rapid F 6 kW plasma source looks for an additional eight-bit byte after the command field (the optional field) and expects 7 to 255 bytes of data (as specified by the optional field).

Checksum

This one-byte field is the last one in the packet. The content depends on the value of each of the preceding fields. The transmitting unit determines this value by accumulating the XOR (exclusive-or) of all bytes of the packet up to, but not including, the checksum value. The receiving unit accumulates the XOR of all bytes of the packet, including the checksum. If the result is zero, the packet has likely been received intact.

Only after the checksum of a message packet is validated will the Rapid F 6 kW plasma source act on the message (which consists of the contents of the command, and if appropriate, the data fields).

IDEAL COMMUNICATIONS TRANSACTION

Figure 4-11 is a simplified graphic showing the steps in an ideal communications transaction between a host computer and an Rapid F 6 kW plasma source.

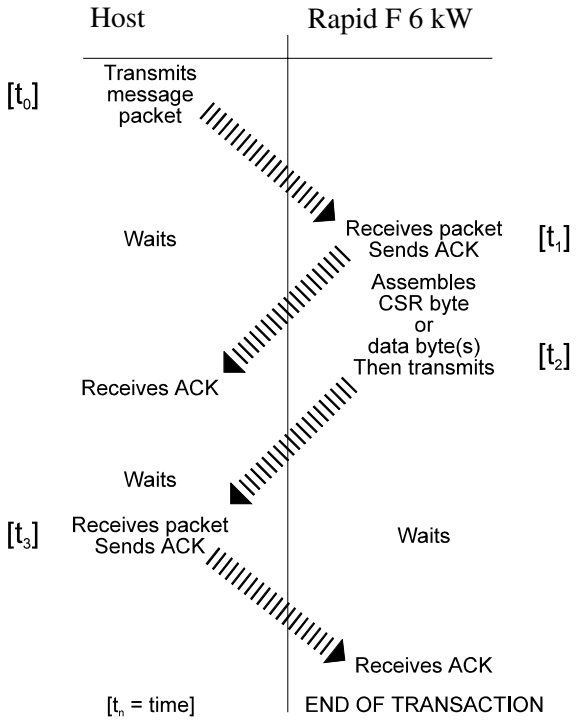


Figure 4-11. *Communications transaction*

First, the host computer sends a message packet to the Rapid F 6 kW plasma source. The packet contains one of the following:

- A command that requests data or status information

- A command and data that change a parameter setting
- An executable command

The Rapid F 6 kW plasma source analyzes the checksum to verify that the message was received correctly.

If the address is incorrect (that is, if the message was not intended for the Rapid F 6 kW plasma source that received it), the unit does not respond to the host; the unit resets and resumes waiting for a message addressed to it. If the sum of the bytes in the packet (including the checksum) is not zero, the Rapid F 6 kW plasma source sends a negative acknowledgment (NAK) with a hex code of 15h to the host. If the message is intact, the unit sends an acknowledgment ACK with a hex code of 06h to the host.

If the Rapid F 6 kW plasma source receives a request for data or status information, it gathers and sends the requested information. Otherwise, it evaluates the incoming command and sends a message-packet that contains a 1-byte data value (CSR code) to the host (see “Command Status Response (CSR) Codes” that follow). CSR code 0 is sent when the command has been accepted.

If the host receives a NAK from the unit, the host either re-transmits the packet or does whatever else it has been programmed to do in this situation. If the host receives an ACK, it waits for the requested data or status information or for the CSR code telling it whether or not the new parameter was accepted. If the host receives no response within a reasonable period (usually 1 s), it takes whatever action it has been programmed to take.

Meanwhile, the unit has prepared a message packet with the requested information or appropriate CSR code, which it then transmits to the host. The host determines by means of the checksum if the message is complete. If the host detects an error in the transmission (by using the Checksum), it can request the packet be sent again by transmitting a NAK.

If the unit receives an ACK, it returns to the normal waiting state. If the unit receives a NAK, it re-transmits the message packet. The unit continues to re-transmit in response to NAK transmissions until the host stops the cycle. If the unit receives no response, it assumes an ACK and returns to the waiting state.

COMMAND STATUS RESPONSE (CSR) CODES

When the Rapid F 6 kW plasma source sends a Command Status Response (CSR) code in response to a command, interpret the CSR (a one-byte response) code as shown in Table 4-4.

Table 4-4. *CSR Codes*

Value	Meaning
0	Command accepted.

Table 4-4. *CSR Codes*

1	Command not accepted because the control mode is incorrect.
2	Command not accepted because the output is on.
3	Command not accepted because the output is off.
4	Command not accepted because it specifies a value that exceeds the limit for that parameter.
7	Command not accepted because one or more faults are active.
9	Command not accepted because the command's data byte count is incorrect.
99	Command not implemented

AE BUS COMMAND SET

The following section describes the AE Bus commands used with the Rapid F 6 kW plasma source's AE Bus (**RS-232**) port.

Table 4-5. *AE Bus Commands*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
1 **RF off**	Requests RF output off; request is always honored regardless of which interface has control.	0	1
2 **RF on**	Requests RF output on; host control must have been selected.	0	1
8 **set point**	Specifies the output set point level. Accepts a value of 0 to 6000 W.	2 data bytes 16-bit value	1
14 **control transfer**	Sets the active control mode of the Rapid F 6 kW plasma source (2 = AE Bus (**RS-232**) port, 4 = user (**Analog Control**) port). (Read back with command **155**)	1 data byte 8-bit value	1

Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
39 set host heartbeat timeout	Sets the time allowed between packets in milliseconds for the AE Bus (**RS-232**) port. If the unit receives no communication packets from the host computer for longer than this period, it disables output. Send a value of 0 to 65535 (0 disables the feature), representing milliseconds. The timer resolution is 100 ms; any portion of 100 ms will be truncated. This value defaults to zero on power-up. • Set byte 1 = 1 • Bytes 2 and 3 set the heartbeat timeout value (LSB first). Read back with command **139**.	3 data bytes One 8-bit value One 16-bit value (LSB first)	1 (CSR only)
40 AE Bus (RS-232) port timeout value	Sets the AE Bus (**RS-232**) port timeout value. Accepts a value of 2 to 500, representing 0.02 to 5.0 s. Default = 0.5 s upon power up.	2 data bytes 16-bit value	1
128 supply type	Requests the Rapid F 6 kW plasma source type; returning packet contains 4 ASCII characters (e.g. “IICP”).	0	4 data bytes 4 ASCII characters
129 supply size	Requests the output capacity of the Rapid F 6 kW plasma source; returning packet contains 6 ASCII characters.	0	6 data bytes 6 ASCII characters
130 read mainframe software version number	Requests the version number of the mainframe software. The returning packet contains 7 ASCII characters—a 7-digit number. This command is used in conjunction with command **198** to obtain the version/ revision number of the mainframe software.	0	7 data bytes 7 ASCII characters

Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
139 report Host heartbeat timeout	Reports the time allowed between packets in milliseconds for the AE Bus (**RS-232**) port. Reports values of 0 to 65535, representing milliseconds (0 indicates that the feature is disabled). The timer resolution is 100 ms, so any portion of 100 ms will be truncated. This value defaults to zero on power-up. Send one data byte set with a value of 1. Returns 2 data bytes indicating the timer setting, in milliseconds. Set with command **39**.	1 data byte 8-bit value	2 data bytes 16-bit value (LSB first)
140 report Host timeout value	Requests the serial Host port timeout value, from 002 to 500, representing 0.02 to 5.00 seconds.	0	2 data bytes 16-bit value
147 report output frequency	Requests the output frequency of the unit in hertz. Returns 4 data bytes.	0	4 data bytes 64 bit value LSB first
155 report control mode	Requests control mode setting. Returns 1 data byte: • 2 = AE Bus (**RS-232**) port • 4 = user (**Analog Control**) port Set with command **14**.	0	1 data byte 8-bit value

Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
162 report process status	Requests report on process status; returning packet contains 4 data bytes. • First status byte: ▸ 0 = Output power is on ▸ 1 = Output power is requested ▸ 2 = Output is at set point ▸ 3 = Supply is ready for use (no fault conditions) ▸ 4 = Interlock satisfied ▸ 5 = Overtemperature fault active ▸ 6 = Output on is disabled (held active by faults and output on requested) ▸ 7 = Bus over-voltage fault active • Second status byte: ▸ 0 = Bus under-voltage fault active ▸ 1 = No plasma timeout fault active ▸ 2 = Plasma is on ▸ 3 = Overtemperature fault defeated ▸ 4 = No plasma time-out fault defeated ▸ 5 = Ignition voltage enabled ▸ 6 = Self-test enabled ▸ 7 = Self-test error • Third status byte: ▸ 0 = Ignition signal defeated ▸ 1 = Bus undervoltage defeated ▸ 2 = Fan fault ▸ 3 = Fan fault defeated ▸ 4 = Unassigned ▸ 5 = Load out of range fault ▸ 6 = Load out of range fault defeated ▸ 7 = Com heartbeat time-out fault • Fourth status byte: ▸ 0 = Duty cycle fault ▸ 1 = Current limit time-out fault ▸ 2 = Plasma wink-out fault ▸ 3 through 7 = unassigned	0	4 data bytes 8-bit values

Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
164 read set point/ regulation mode	Requests output set point level (set with command **8**) and method of output regulation. • First and second bytes = set point value • Third byte = output regulation mode *Note:* This byte always returns the same value (6). Conventional terms for power regulation have no meaning in this integrated power supply/plasma source.	0	3 data bytes 16-bit value 8-bit value
167 read delivered power	Requests a snapshot of load power level.	0	2 data bytes 16-bit value
198 read mainframe software revision level	Requests the revision level of the mainframe software. The returning packet contains three ASCII characters—one letter, followed by a two-digit number. This command is used in conjunction with command **130** to obtain the version/revision of the mainframe software.	0	3 data bytes 3 ASCII characters

Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
212 report last nonzero error code	Requests the last non-zero error code that occurred. (See Table 6-1 on page 6-4 for error codes.) *Note:* The unit does not save this information when it powers off. Returning values: • 1 = Unassigned • 2 = Unassigned • 3 = Thermal limit exceeded • 4 = Fan fault • 5 = Bus undervoltage fault • 6 = Bus over-voltage fault • 7 = Plasma ignition timeout error • 11 = Heartbeat time-out error • 16 = Ambient thermistor error • 19 = Ambient temperature too high • 20 = Duty cycle fault • 21 = Current limit time-out fault • 24 = Plasma wink-out fault	1 data byte 8-bit value	4 data byte 32-bit value

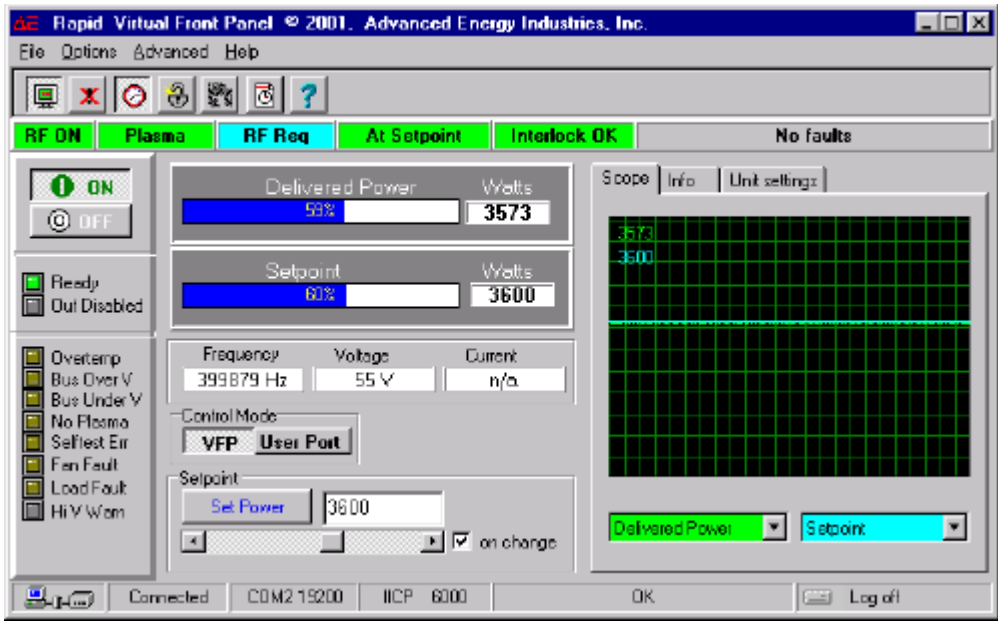
Table 4-5. *AE Bus Commands (Continued)*

Command	Description	Number of Host Data Bytes	Number of Response Data Bytes
220 report statistical data	Requests operational and cycle statistics recorded by unit. *Note:* The unit saves this information in nonvolatile memory. Send one data byte indicating the desired statistic • 0 = Number of ignition cycles • 1 = Minutes of AC on time • 2 = Minutes of output on time • 3 = Number of overtemperature faults • 4 = Number of duty cycle faults • 5 = Number of bus high faults • 6 = Number of bus low faults • 7 = Number of no ignition faults • 8 = Number of heartbeat time-out faults • 9 = Number of fan faults • 10 = Number of current limit time-out faults • 11 = Number of ambient thermistor faults • 12 = Number of high ambient temperature faults • 13 = Number of plasma lost faults Returns 4 bytes, representing the value of the statistic.	0	4 data bytes 32-bit value (LSB first)

VIRTUAL FRONT PANEL (VFP) SOFTWARE INTERFACE

AE manufactures Virtual Front Panel (VFP), a software application that provides an easy way to communicate with a Rapid F 6 kW plasma source from a personal computer. VFP communicates with the unit through the AE Bus interface. It allows you to set unit operating parameters, turn RF output on and off, troubleshoot the unit

through fault status indicators, fingerprint new chamber set up, as well as build and optimize process settings. The following illustration shows an example of a VFP interface.



VFP software includes the following functions:

- Establish communication with a Rapid F 6 kW plasma source (through the AE Bus interface on the plasma source)
- Change the control mode between VFP and the plasma source **Analog Control** port
- Set or change the unit set point within the operating range of the unit
- Turn RF output on and off
- Monitor multiple plasma source operating parameters at rates up to 100 ms; parameters that can be monitored include: connection status, set point, delivered power, frequency, voltage, current, plasma status, and fault status

  Note: VFP allows you to monitor some of these parameters in both numerical format and on a line graph that charts the parameter over time.

- Log operational data for the plasma source including: time, delivered power, set point, frequency, voltage, current, and unit status

To order Rapid VFP or to receive a free, time-limited evaluation copy of the software, contact AE. See “AE Global Customer Support” on page 6-10 for contact information.)

Note: The documentation included with the software provides complete instructions for using the software to control and monitor a Rapid F 6 kW plasma source.

INDICATORS

The front panel of the Rapid F 6 kW plasma source has a digital display and LEDs that indicate the unit's status. The digital display provides an alphanumeric indication of delivered plasma power in kilowatts and registers error codes when faults occur. (See Table 6-1 on page 6-4 for error codes and their descriptions). Five status LEDs allow you to check the source's status, verify its operation, and troubleshoot problems.

Table 4-6 provides detailed descriptions of the status LEDs and display.

Table 4-6. *Indicators and displays*

Indicator	Description
AC POWER	When lit, this green LED indicates that the AC mains contactor and the interlock loop are closed and thus AC power is available within the generator. When off, this LED indicates that no AC power is being supplied to the power supply. However, power is still available and stored in the system.
RF POWER	When lit, this green LED indicates that the RF power enable state is satisfied and that RF power is being applied to the primary windings of the inductively-coupled plasma source. When off, this LED indicates that no power is being supplied to the primary windings of the plasma source.

Table 4-6. *Indicators and displays (Continued)*

Indicator	Description
PLASMA	This green LED has three modes of operation: • *Off:* Indicates that no plasma is present because RF power is not being supplied. • *Continuous (solid):* Indicates that RF power is being coupled to the plasma and that the supply is meeting the desired set point. • *Flashing:* Indicates that the supply is unable to reach the desired set point. ◗ The power supply is responding to a recent change in gas composition or pressure and is attempting to level power. ◗ The plasma has failed to ignite (soon to be followed by a fault and "E07" error; see Table 6-1 on page 6-4) ◗ The plasma ignited, but then went out (unit will display a E24 fault); see E24 in Table 6-1 on page 6-4 for more information ◗ The plasma body is too conductive and the supply is at its current limit as typically seen in high power Ar discharges or low pressure discharges. See "Appendix A" for more information. ◗ The plasma body is too resistive and the supply is at its voltage limit.
INTERLOCK	When lit, this green LED indicates that the user interlock condition is satisfied through the user (**Analog Control**) port. This interlock should be tied to the vacuum status and the cooling water flow status to the unit. When off, this LED indicates that the user interlock state has not been satisfied on the user (**Analog Control**) port.

Table 4-6. *Indicators and displays (Continued)*

Indicator	Description
FAULT	When lit, this yellow LED indicates that a fault has occurred. When a fault occurs, the RF power enable state is overridden and the **RF POWER** and **PLASMA** status indicators turn off, signifying that no RF power is being applied to the plasma source. The fault is accompanied by an error code displayed on the digital readout. (See Table 6-1 on page 6-4 for error code information.) *Note:* AC power is still active in the device even after a fault has registered.
DISPLAY	This three digit (seven segment) alphanumeric display is used to display error codes (EXX) and the immediate power being delivered to the plasma load in kilowatts (X.XX). For more information on the error codes, see Table 6-1 on page 6-4.

UNIT ILLUSTRATIONS

Front View

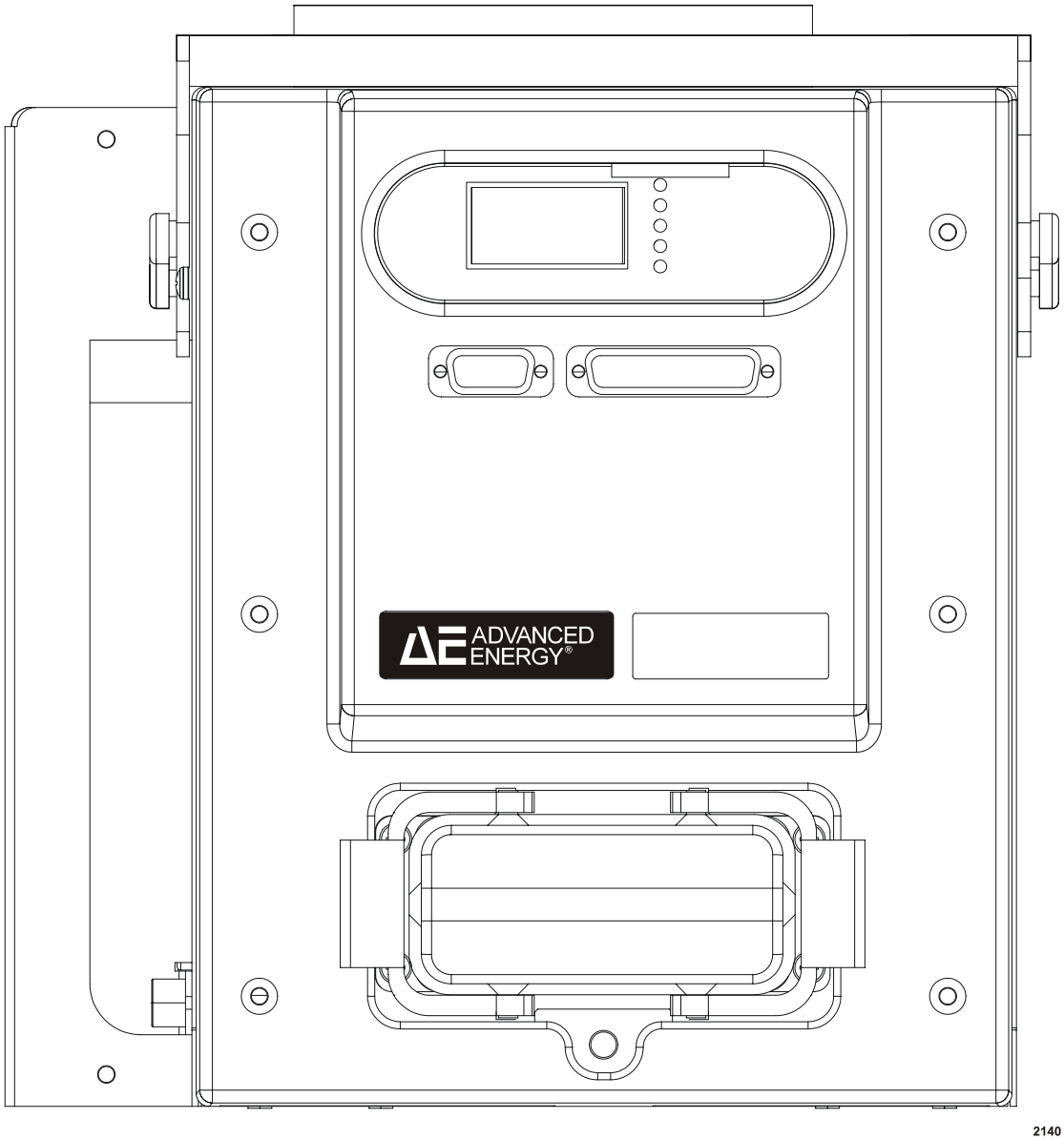


Figure 4-12. *Front view*

Left Side View

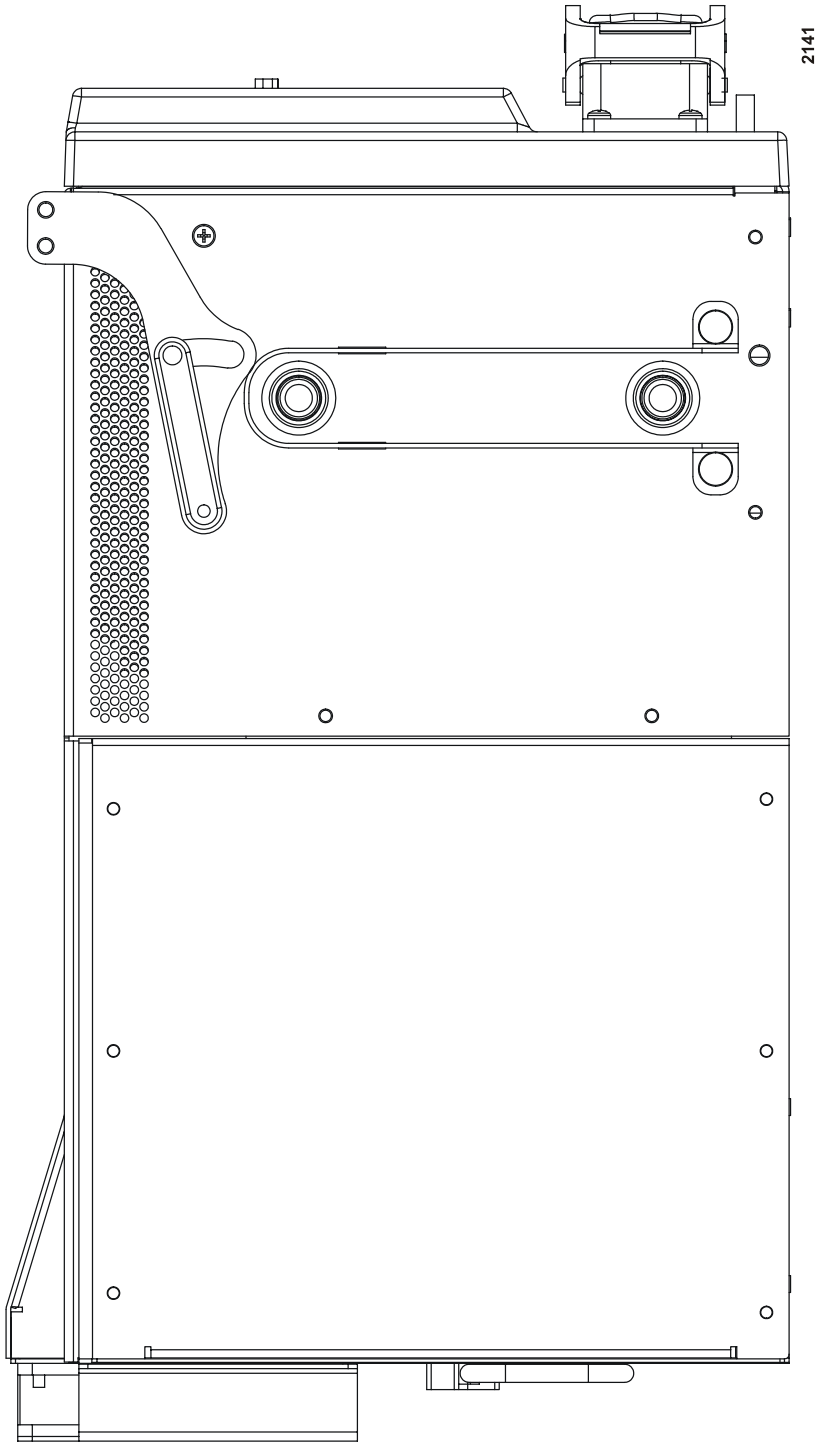


Figure 4-13. *Left side view*

Right Side View

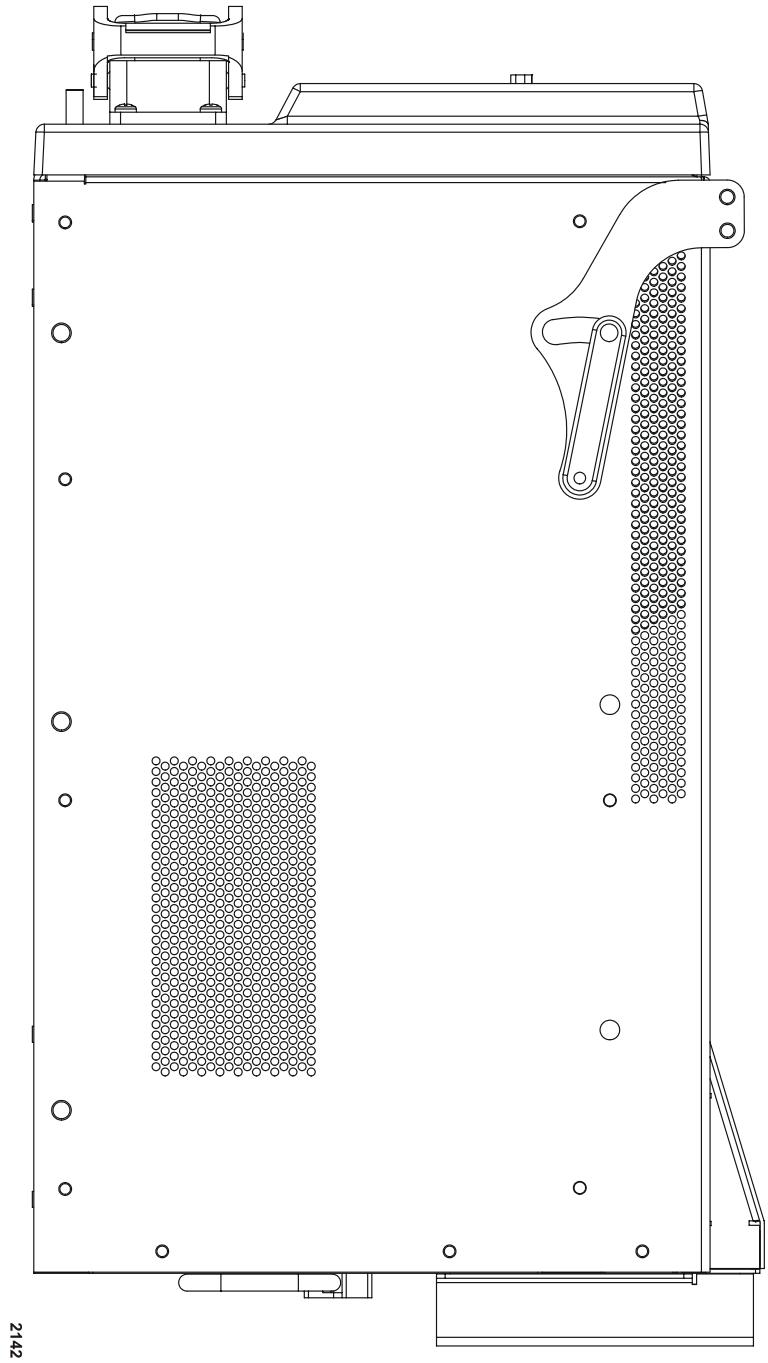


Figure 4-14. *Right side view*

Top View

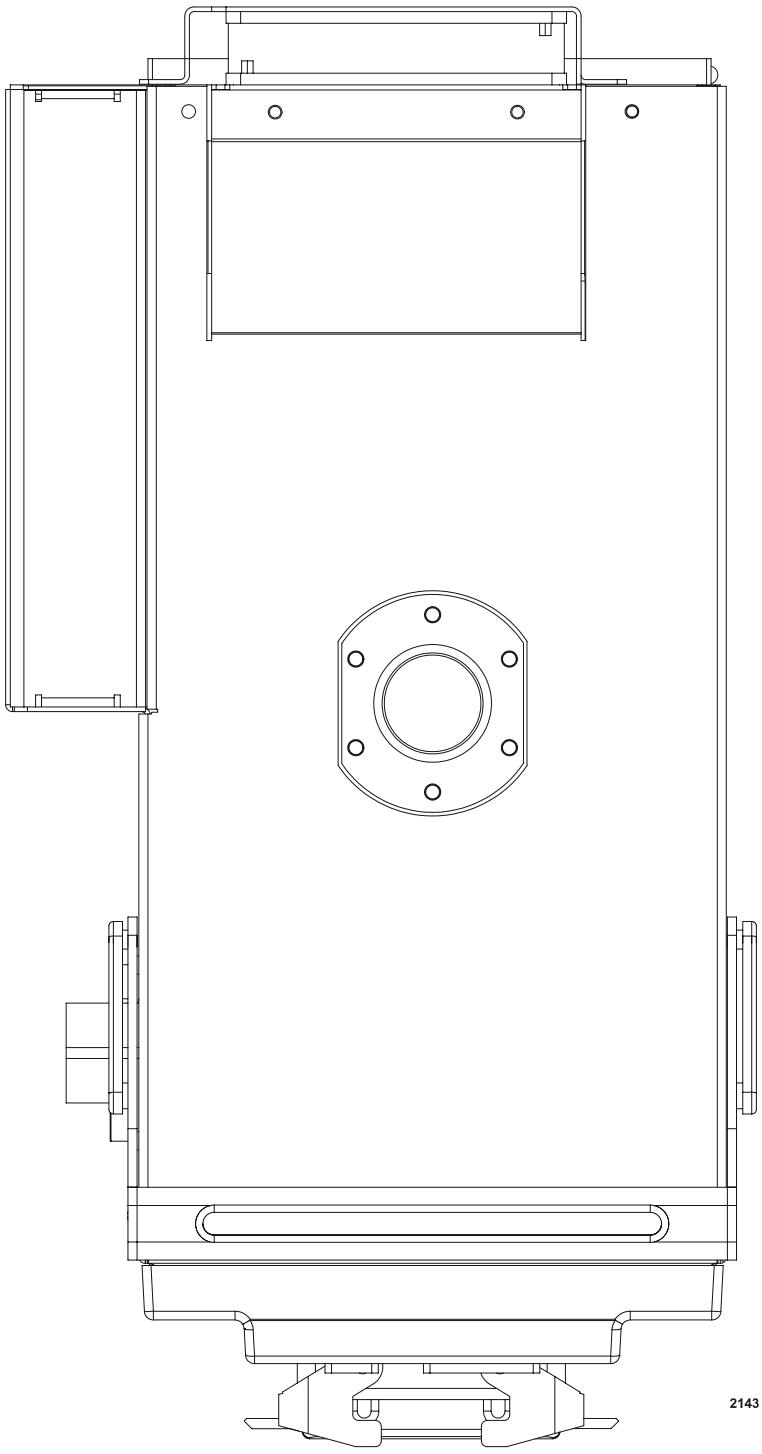


Figure 4-15. *Top view*

Bottom View

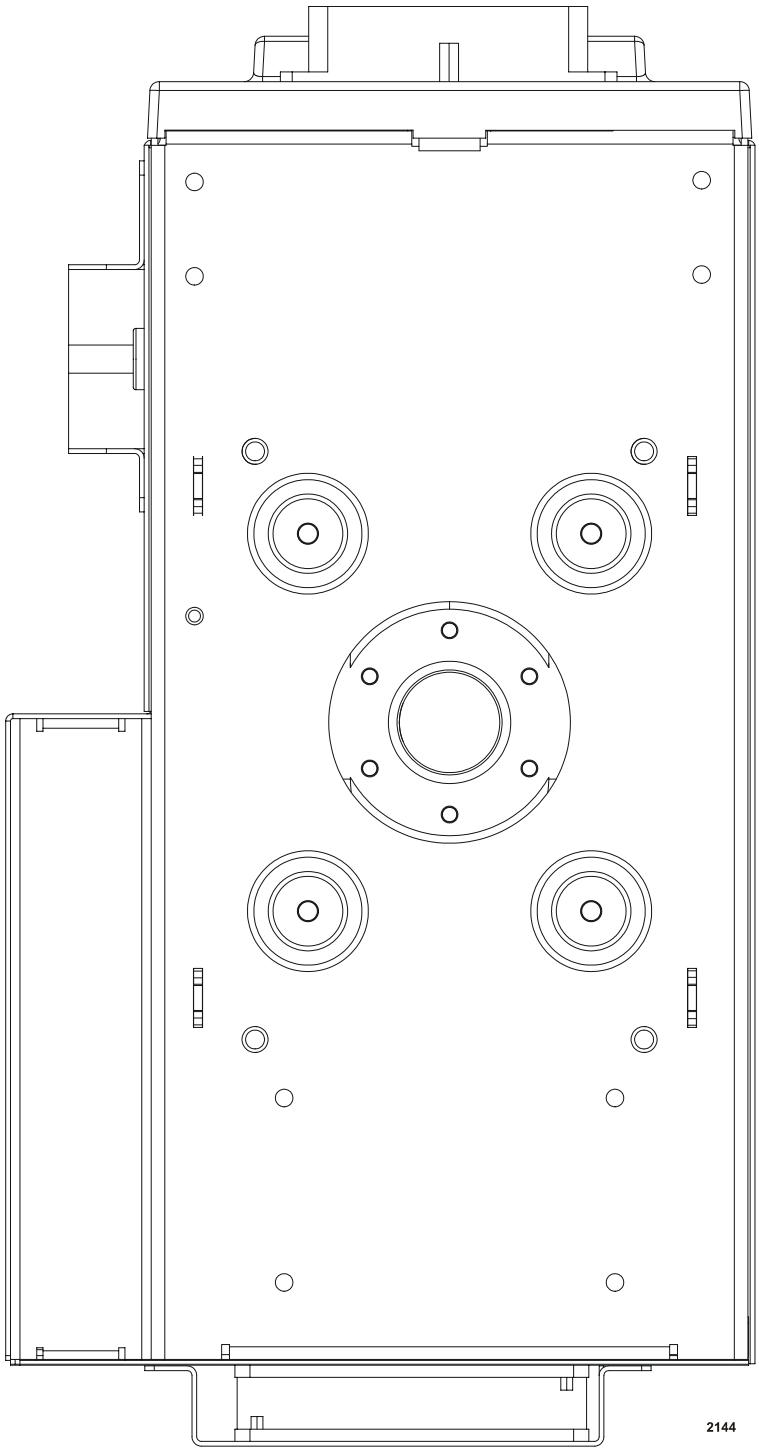


Figure 4-16. *Bottom view*

Installation, Setup, and Operation

This chapter includes information about making connections to the unit, and provides steps for first time as well as normal operation.

INSTALLING

The following sections will aid you in installing your Rapid F 6 kW plasma source.

DANGER:

RISK OF DEATH OR BODILY INJURY
Disconnect and lockout/tagout all sources of input power before working on this unit or anything connected to it.

DANGER:

Operating and maintenance personnel must receive proper training before installing, troubleshooting, or maintaining high-energy electrical equipment. Potentially lethal voltages could cause death, serious personal injury, or damage to the equipment. Ensure that all appropriate safety precautions are taken.

CAUTION:

Occasionally, a temporary conductivity caused by condensation occurs when the device is not operating. Operate only in noncondensing environments.

Unpacking

Unpack and inspect the unit carefully. Check for obvious physical damage. If none is apparent, proceed with the unit connections. If you do see signs of shipping damage, contact Advanced Energy Industries, Inc., and the carrier immediately. Save the shipping container for submitting necessary claims to the carrier.

Grounding

WARNING:
Do not attempt to turn on power until the chassis of the Rapid F 6 kW plasma source is tied to a local earth ground through a copper grounding strap that is sized in accordance with applicable requirements.

A suitable chassis ground connection made to the RFI ground stud (1/4 - 20 brass) on the front panel below the AC power input connection prevents or minimizes radio frequency interference. See Figure 5-1 on page 5-3 for the location of the ground stud.

Spacing Requirements

Refer to Figure 5-1 on page 5-3 for unit dimensions. The fan exhaust grill at the rear of the unit and all air vents require at least 1.9 cm (0.75") clearance for proper ventilation.

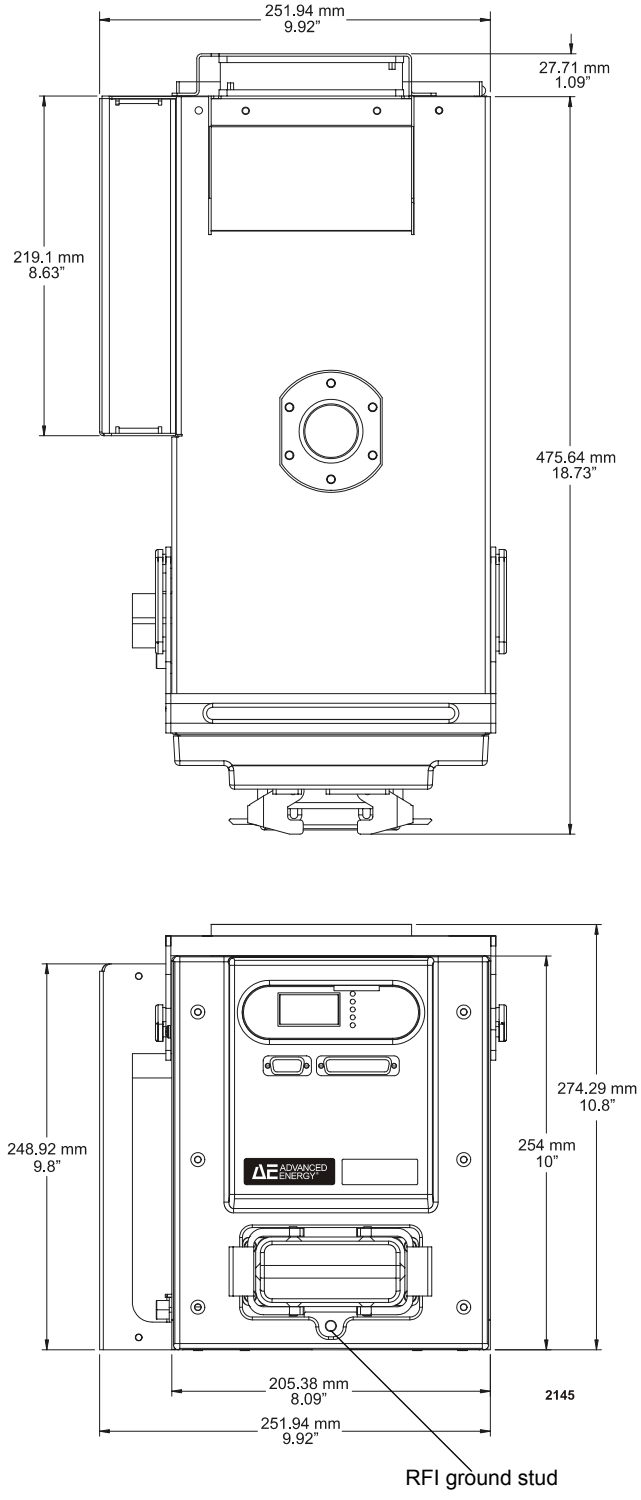


Figure 5-1. *Dimensions*

Before Installing

Read the following recommendations and requirements before attempting to install the unit:

- Process gas flows must be shut off, disconnected, and disabled (lockout/tagout procedures are strongly recommended), and the source must be purged of all process gasses before working on this device or anything connected to it.
- Gas plumbing must be installed in accordance with applicable safety and environmental requirements.
- The Rapid F 6 kW plasma source requires the following standard vacuum connection for input and output gasses:
  - ISO KF 40 Flange (x2)
  - ISO KF 40 Centering Ring Assembly (x2)
  - ISO KF 40 split-ring bulkhead clamps (x2)
  - 10-32 x 5/8" long stainless-steel screws and washers (x12)
- The following vacuum equipment is recommended for operation between 500 mT and 10 Torr:
  - A capacitance manometer vacuum pressure gauge rated for at least 10 Torr
  - An Ar flow controller rated for about 1.4 slpm
  - An NF_3 flow controller rated for about 2.5 slpm
  - An O_2 flow controller rated for about 1.0 slpm
  - A pumping system rated for 10 to 100 liter/second (effective pumping speed at the output of the process chamber or near a the throttle valve before the foreline of the pumping system)
  - A throttle valve with either integrated or manual control

Mounting the Unit

After unpacking the Rapid F 6 kW plasma source, prepare it for mounting by removing the protective end caps from the input and output flanges in a dust-free environment. Keep the end flanges free of dust and grease and use powder-free clean-room gloves when handling the vacuum fittings.

The unit is designed to operate in any physical orientation (see Figure 2-2 on page 2-3 for typical installation). It is mounted to the top of the source assembly and shares its thermal management with the vacuum housing. Use the 1/4"-20 mounting fittings on

each face of the unit when installing. Use only 1/4-20 x 1/2 long stainless-steel or brass hardware to prevent deep intrusion of the mounting hardware into the source's chassis.

Note: Use only ASM #326 O-rings for mounting the unit to existing vacuum hardware.

See Figure 5-2 for the location of the unit's mounting holes.

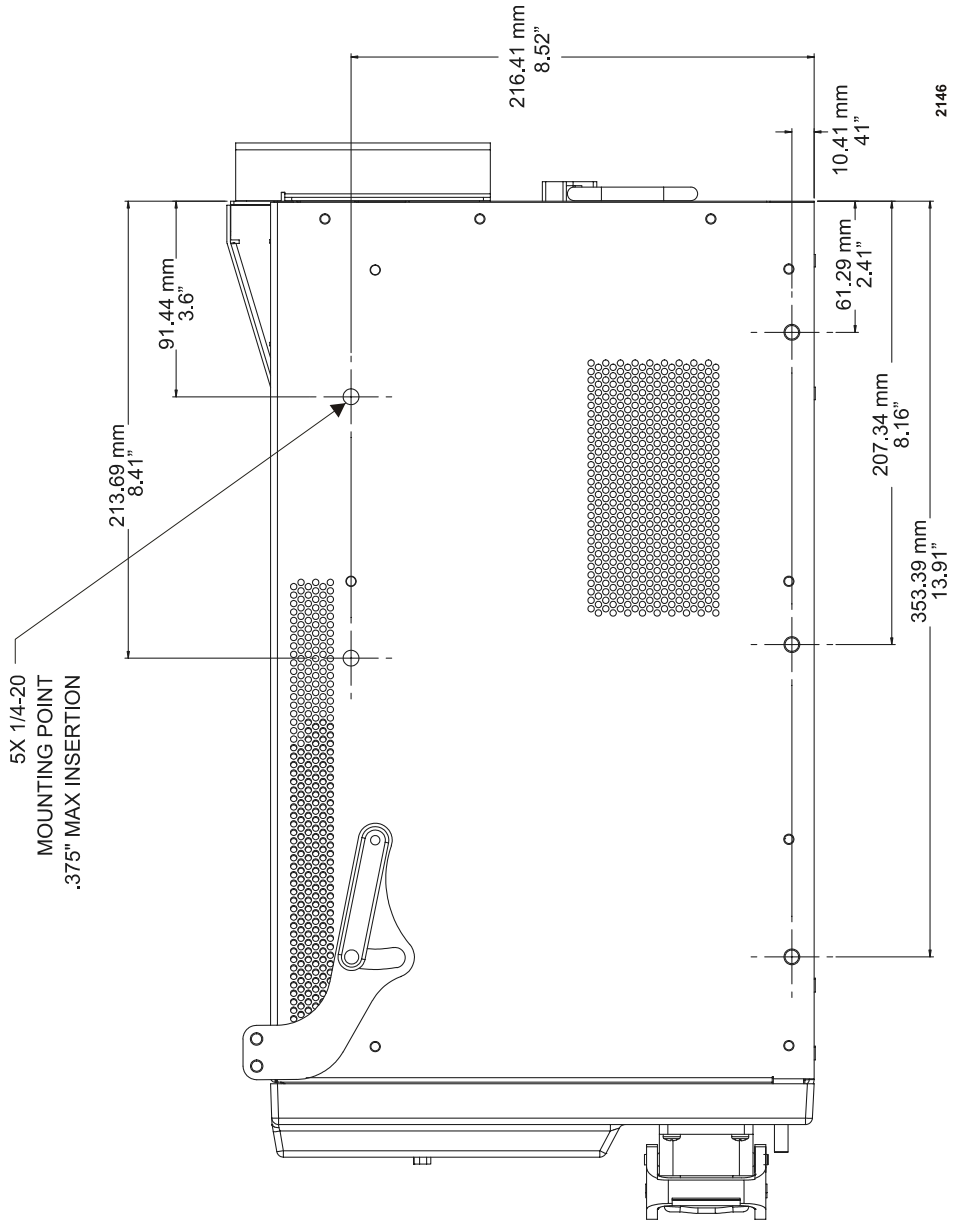


Figure 5-2. *Right side mounting holes*

Note: These holes are intended for mounting the Rapid F 6 kW plasma source to your system. Do not use these assembly holes to mount additional hardware not associated with the product.

Note: Though the unit is operational in a variety of orientations, do not cantilever the source such that the full weight and torque of the unit is solely supported from

the ISO KF 40 fitting on either its input or output connection. The #10-32 screws used for the split flange fittings are insufficient to hold the weight and torque of the assembly. If the source must sit in a cantilevered orientation, it is possible to mount the source in an upright and vertical position on its bottom-side ISO KF 40 fitting with a user provided fixture. If the unit is oriented vertically, it is possible to support the full weight of the unit on the exit flange of the source.

Vacuum Connections

CAUTION:
Interlock the Rapid F 6 kW plasma source operation against minimal water flow requirements and recommended peak vacuum pressure levels. Failure to do so could damage polymeric cooling lines or cause internal damage to the unit if operated at near atmospheric pressures.

Note: The Rapid F 6 kW plasma source has no water flow switch or pressure switch for internal interlocks or protection. It is the responsibility of the user to provide protection for water flow, operating pressure, and gas chemistry.

To avoid getting water in the source chamber, prepare and complete all vacuum connections prior to making water cooling connections.

The source has two ISO KF 40 vacuum connections for input and output gases.

1. Inspect the input and output ISO KF 40 flanges for scratches, dust, or debris before mounting. Do not allow any dust or foreign objects to enter the source's vacuum interior during installation. If necessary, the sealing surfaces of the end-flange fittings may be cleaned with isopropyl alcohol and lint-free clean wipes.
2. Once the Rapid F 6 kW plasma source is mounted and the vacuum connections are sealed, vacuum pressure may be applied. (See "Troubleshooting and Global Support" on page 6-1 if you suspect any significant vacuum leaks as a result of the installation of the unit).

Note: When used for the first time, the source requires longer pumping time due to outgassing.

Connecting Cooling Water

The following section contains information on connecting cooling water to the Rapid F 6 kW plasma source.

CAUTION:
Interlock unit operation against minimal water flow requirements and recommended peak vacuum pressure levels. Failure to do so could damage polymeric cooling lines or cause internal damage to the unit if operated at near atmospheric pressures.

CAUTION:
Because of the high volume of cooling water recommended, use the source only in a noncondensing environment. Condensing water vapor within the device can damage the unit. (see "Environmental Specifications" on page 3-5 for permissible range of water conductivity.)

CAUTION:
Do not use de-ionized water for cooling purposes. De-ionized water causes both corrosion and erosion of cooling manifolds.

CAUTION:
Avoid electrically conductive cooling water (such as salty or rusty water), which can compromise the isolation of electrically active components.

The Rapid F 6 kW plasma source is primarily water cooled, though internal fans assist the thermal management of the unit. To avoid getting water into the vacuum housing of the source, ensure that vacuum connections are made *before* making water connections. Do not operate the unit until water connections are made and cooling flow requirements are met. The Rapid F 6 kW plasma source requires two male SAE 9/16"-18 straight thread with O-ring fittings for input and output flow. Figure 4-13 on page 4-26 shows the locations and flow orientation for input and output water.

The unit has no water flow interlock. While the source can protect itself and will register an over-temperature fault in the event of loosing adequate cooling water, it is strongly recommended that you provide a flow-switch interlock. Be certain to flow water in the correct direction to ensure the maximum available thermal protection and

range of operation in your installation and application. Do not allow water flow to drop below recommended levels or to exceed the maximum allowable water temperature.

The following steps explain how to connect cooling water lines to the unit.

1. Connect the input and output water fittings and tighten securely.
2. Turn on the water and verify that there are no leaks at the connections.
3. Check that the flow rate and input water temperature are within the specified range (see “Cooling Specifications” on page 3-4) before operating the unit.

Note: Keep the cooling water flowing through the unit even when RF power is disabled, especially during cycled operation.

Connecting AC Input Power

The following section provides information on connecting AC power to the Remote Power Source.

WARNING:
This device must be installed so that the input power connection is inaccessible to the user.

CAUTION:
To provide the required over-current protection, you must install and operate this device with a 35 A (max) circuit breaker switch on the AC input. The circuit breaker must be easily accessible and near the device.

CAUTION:
Do not connect any power to this unit without first connecting cooling water and ensuring there are no leaks.

CAUTION:
Supply wire must be approved to carry 35 A or greater and rated at least 300 Vac.

The unit has a 6", 6-pin, Harting Type, Han 6HSB, male, connector for AC input power (See Figure 5-3.). The Rapid F 6 kW plasma source is phase insensitive.

Table 5-1 provides pin descriptions for the AC power connector.

Table 5-1. *Pin descriptions*

Pin	Description
1	Phase
2	Phase
3	Phase
4	Not connected
5	Ground
6	Not connected

To connect to AC power, perform the following operations:

1. Remove the protective cover from the Harting connector by releasing the pressure-loaded side tabs. Save the cover in case the unit needs to be moved, stored, or shipped.
2. Ensure that the AC power circuit breaker to the connector is switched off (lockout and tagout procedures are strongly advised.). Connect a properly wired Harting female connector and lock it in place with the two pressure-loaded side tabs.

Note: Connect the unit to a balanced three phase AC line. Connection to an unbalanced line could negatively impact the dynamic performance of this device and its viable range of operation.

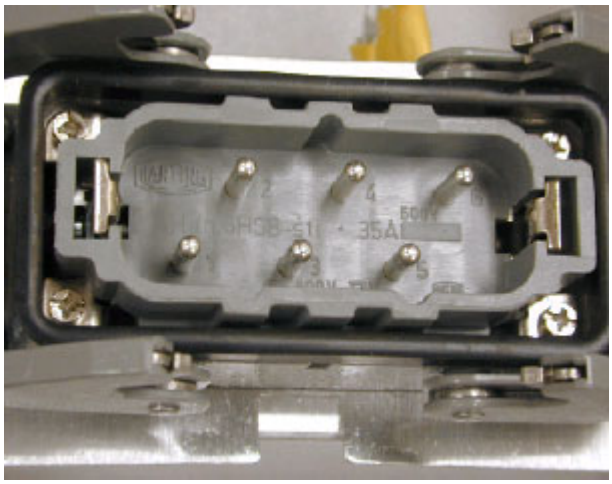


Figure 5-3. *Input connector*

Connecting I/O and Auxiliary Connectors

On the Rapid F 6 kW plasma source, locate the user (**Analog Control**) port and secure a 25-pin, shielded, male, subminiature-D connector per the pin-out connections described in Table 4-2 on page 4-2.

The AE Bus port is labeled **RS-232.** If required for your application, connect a 9-pin, female, shielded, sub-miniature-D connector to this port per the pin-out connections described in Table 4-3 on page 4-9.

OPERATION

The following section provides information on protection and interlock, an overview of the Rapid F 6 kW plasma source's operation, as well as instructions for first-time and normal use.

⚠ WARNING:
The Rapid F 6 kW plasma source has no chassis cover interlock. Do not attempt to operate the unit without the chassis cover properly affixed to the unit.

Interlock

The Rapid F 6 kW plasma source provides a system interlock through its 25-pin user (**Analog Control**) port. When you close the interlock (pin *13* to pin *25*), the AC power contactor is closed, making power available to the DC bus of the device's switch mode power supply.

Plasma Source Operational Overview

The following section gives an overview of the Rapid F 6 kW plasma source's operation.

⚠ CAUTION:
Read all of the following instructions before proceeding with the initial operation of the Rapid F 6 kW plasma source.

CAUTION:
This source was designed for ignition in pure Ar gas. Direct ignition in other gases could lead to unsuccessful start-up of the source or to damage or shortened lifetime of the anodized walls within the device. Contact AE for range of operation for direct ignition in molecular gas mixtures.

CAUTION:
This unit is intended for use in select molecular gases. Do not operate continuously in argon and nitrogen for prolonged periods of time (>10 s).

The Rapid F 6 kW plasma source is designed to work with pure molecular gas mixtures; however, for ignition, the source requires an easily ionized noble gas such as argon (Ar). Thus, it is necessary to integrate the source's operation with dynamic or sequential adjustment of gas flow, vacuum pressure, and power set point steps.

The test recipe described in "First Time Operation" illustrates the operation of the source using Ar and O_2. Use it during first-time operation to verify that the Rapid F 6 kW plasma source is installed and working properly.

Note: Very similar recipe steps can be adopted for operation in Ar with NF_3 or in Ar with O_2:C_xF_y gas mixtures.

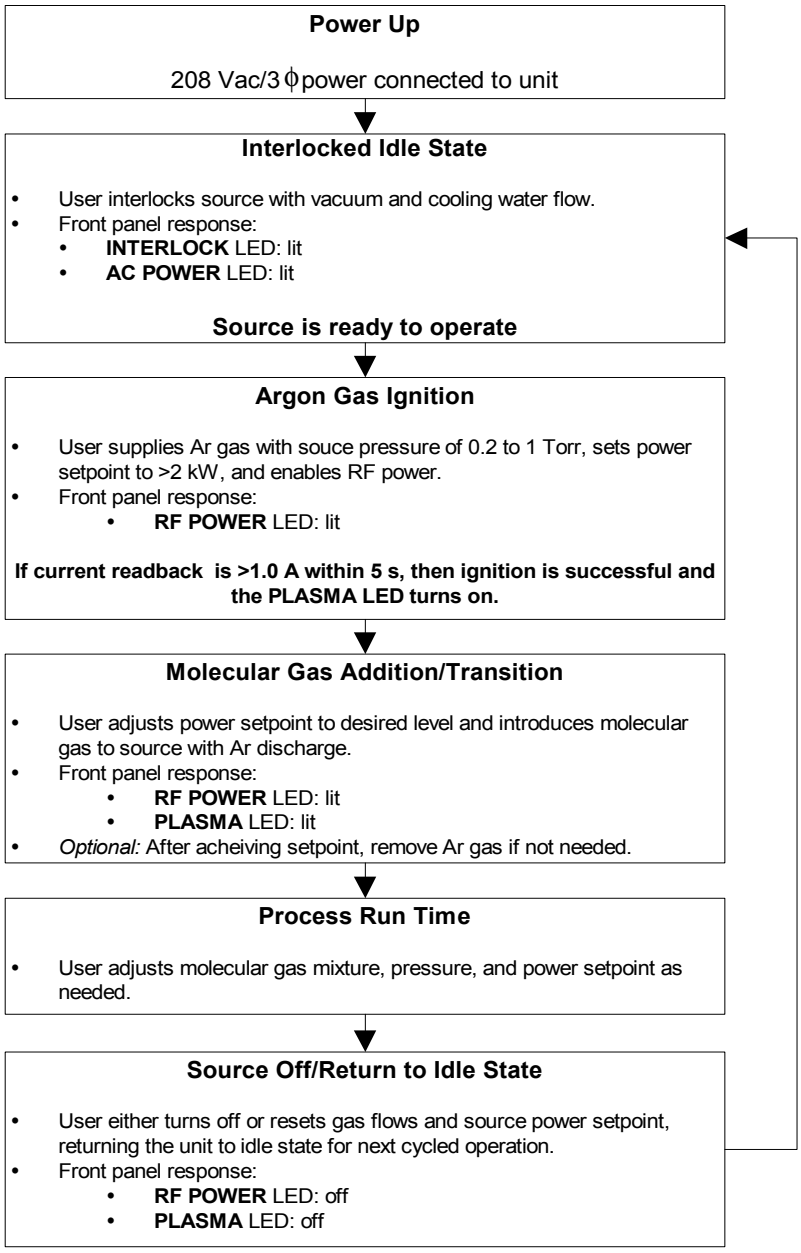
First Time Operation

The following procedures take you through the initial operation of the Rapid F 6 kW plasma source. See Figure 2-2 on page 2-3 for a diagram of the installation used in the test recipe.

PROCEDURAL OVERVIEW

Figure 5-4 gives an overview of the test recipe.

Figure 5-4. *Typical process sequence for normal operation*



PROCEDURE

Use the following steps to initially turn on and test the installation of the Rapid F 6 kW plasma source.

1. Ensure that you have installed the unit properly by following the preceding procedures.
2. Verify the vacuum integrity installation of the unit on the vacuum process chamber by examining base-pressure and leak-back pressure rates. Base vacuum pressures will depend upon your vacuum system capabilities.
3. Confirm that all power and control connections are secure.
4. Provide AC power to the unit. For approximately 60 s, the unit cycles through a front panel test sequence on the LEDs and alphanumeric display while the internal bus capacitors charge.
5. Close the connection between pins *13* and *25* on the user (**Analog Control**) port so that the unit is interlocked to cooling water flow and the working pressure.

   Note: You must provide the sensing switches and logic for water flow and vacuum pressure.

6. Verify that the green **INTERLOCK** LED on the front panel is illuminated. After a brief delay, you will hear a click as the internal AC contactor closes. Shortly thereafter, the green **AC POWER** LED illuminates. The unit is now in its Idle-Ready state.
7. Provide an Ar gas flow, establishing 0.2 to 1 Torr of pressure in the source.

   Note: The use of long gas delivery lines, gas diffusers, diverters, or baffles could induce a pressure in the unit that is substantially higher than that measured in the vacuum process chamber.

   Note: On first time installation, atmospheric air present in the gas lines may require several seconds of gas flow to purge.

8. Provide a set point of >2 to 4 kW (0 to 10 V full signal for 6 kW, user (**Analog Control**) port pins 18 and 3).

   Note: In order for ignition to occur, set point must be above 1 kW

9. Close the connection between pins *4* and *2* on the user (**Analog Control**) port to satisfy the RF enable condition. The green **RF POWER** LED on the front panel illuminates, and source responds in one of three ways:

   Note: Code E21 may flash intermittently on the display screen during ignition. This flashing does not indicate an error. Rather, it indicates that the unit has reached the current limit, which is normal during ignition. If the unit remains at the current limit for longer than 90 seconds, it will disable output and provide a steady display of E21 (not flashing) (for information on resolving this condition, see Table 6-1 on page 6-4).

- *Ignition successful; power limited by user set point*: the green **PLASMA** LED is illuminated continuously and the display reads the desired set point. (This limitation is bounded by the current limit of the power supply when attempting to power a highly conductive plasma load, as is often the case with high electron density Ar gas discharges.)
- *Ignition successful; power limited by current control limit of power supply*: the green **PLASMA** LED flashes and the display reads between 2 and 3.5 kW. (This limitation is bounded by the current limit of the power supply when attempting to power a highly conductive plasma load, as is often the case with high electron density Ar gas discharges.) This response occurs when the power to the plasma is limited to approximately 2.6 kW while your set point is >2.6 kW.
- *Ignition failure; Ar discharge did not ignite*: the **PLASMA** LED is off and the front panel displays the "E07" (Ignition Fault) error code if this condition persists for more than 5 s. Reset the *PLASMA ON ENABLE* signal on the user (**Analog Control**) port to clear the error. Return to step 7 and repeat with a higher or a lower Ar pressure. See Table 6-1 on page 6-4 for more information on error codes.

10. Increase the power set point to 4.5 to 6 kW while the Rapid F 6 kW plasma source is operating in pure Ar.
11. With the Ar still flowing, introduce O_2 into the process mix at an Ar:O_2 ratio of approximately 1.5:1 at a pressure of 1 to 2 Torr. (Alternatively you may use NF_3 at and Ar:NF_3 ratio of about 1:1.) One of two conditions will occur:
    - *Transition to molecular gas mixture successful; power limited by user set point*: the green **PLASMA** LED is illuminated continuously. The power levels to within 200 W of your set point.
    - *Transition to molecular gas mixture failure; loss of high power density inductive mode:* the power level displayed on the front panel drops below 1 kW, the green **PLASMA** LED turns off, and the front panel displays error code E24. Return to step 7 and repeat with a higher power set point or a lower vacuum pressure set point. (For more information on the E24 error code, see Table 6-1 on page 6-4.)

      Note: A sizable pressure burst could cause this failure. Check for any flow or high pressure overshoots due to under-damping of system flow controllers or throttle valves.

12. *Optional Step:* if your process does not require Ar dilution, you may choose to perform this step with first time operation. With a power set point of 5 to 6 kW, remove the Ar gas from the mixture. One of two conditions will occur.
    - *Transition to a pure molecular gas mixture successful; power limited by user set point:* The green **PLASMA** LED is illuminated continuously. The delivered power should be within 200 W of your set point.

- *Transition to a pure molecular gas mixture failure; loss of high power density inductive mode:* the power level drops below 1 kW, the green **PLASMA** LED turns off, and the front panel displays error code E24. Return to step 7 and repeat with a higher power set point or a lower vacuum pressure set point. (For more information on the E24 error code, see Table 6-1 on page 6-4.)

Normal Operation

The following section gives directions for the normal operation of the unit.

CAUTION:
This unit is not intended for operation in chlorine bearing gases or any gases that may deposit insulating or conductive films. Examples of depositing gases include siloxanes, silanes, hydrocarbons, and any metal bearing precursor gas or vapor. Use of these gases could lead to damage of the internal vacuum housing of the unit.

CAUTION:
This source was designed for ignition in pure Ar gas. Direct ignition in other gases could lead to unsuccessful start-up of the source or to damage or shortened lifetime of the anodized walls within the device. Contact AE for range of operation for information on direct ignition in molecular gas mixtures.

CAUTION:
This unit is intended for use in select molecular gases. Do not operate continuously in argon and nitrogen for prolonged periods of time (>10 s).

Provided that the installation and first time operational tests are successful, normal operation should proceed per steps 7 through 14 in “First Time Operation.” However, consult the following section, “Process Integration” before operation.

PROCESS INTEGRATION

The Ar:O_2 test recipe instructions and reference vacuum conditions should be treated as guidelines for typical dynamic operation. Because each vacuum system is configured for different pumping speeds and gas flow, you will need to develop your own process gas chemistry, pressure, flow, and transition steps. Provided that your flow controllers and vacuum hardware have satisfactory response times and relatively low dynamic pressure overshoot, the Rapid F 6 kW plasma source can be ignited and power-leveled for steady-state operation within a few seconds.

Current, voltage, and frequency limits are needed to protect the power supply. These electrical restrictions dictate the viable range of power and pressure for any given gas mixture. Though not all plasma and power conditions can be satisfied, the Rapid F 6 kW plasma source's topology provides a compact means of delivering high power levels (6 kW) into a wide range of plasma conditions that would be more expensive and complicated with conventional segregated plasma source, matching network, and power supply approaches.

Note: See Appendix, "Selecting Gas Mixtures, Gas Pressures, and Power Levels" for more information.

Note: Unless otherwise specified, AE does not warranty any process method or material composition results associated with the sale or application of this product.

Working Gas and Vapor Compatibility

The Rapid F 6 kW plasma source was designed for remote excitation and dissociation of reactive gas species in vacuum applications. The following guidelines apply to its application to plasma-based processes.

- This source was designed to ignite on Ar gas at pressure below ~1 Torr. Unless operated below 50 mT, Ar gas is generally recommended for reliable ignition of the source. (Other easily-ionizable noble gases may be used to ignite the source.)
- After ignition, the source may operate in either pure O_2 or NF_3 gases over a broad range of pressures. For example, the source may provide near-complete dissociation of NF3 gases at flows up to 2 Torr to 2.5 Torr at full power. The exact level of dissociation is a function of operating pressure and residence time of gases in the source. Higher pressure operation at a constant flow can provide more dissociation as the net residence time of the gas in the source is longer. However, the source and power supply have a finite viable plasma impedance range that will limit the pressure/flow range for stable operation with a given gas. Some attempts to increase the pressure range or apparent transport of reactive F species from the remote source to the chamber have been made by using Ar dilution of NF3. While Ar dilutions can decrease the impedance of the plasma, such dilution does not change the viable plasma impedance range of the remote plasma source. For a viable operating range of NF3 and NF3/Ar mixtures, see "Process Operating Specifications" on page 3-6.
- When the plasma is present in the unit, do not operate the device with depositing gases and vapors without a secondary oxidant or other gas additive that inhibits deposition within the source. For example, hydrocarbon and perfluorocarbon gases should be accompanied with appropriate level of O_2 or H_2O.
- Depositing gases such as silane, siloxanes, silazanes, or any metal-bearing deposition precursors should never be disposed directly through the source.

- Gases that may be highly corrosive to the anodized aluminum walls of the vacuum chamber should never be disposed through the source. In particular, chlorine-bearing gases should never be used.

Note: See "Process Operating Specifications" on page 3-6 for operational specifications and working gases.

PREVENTIVE MAINTENANCE

CAUTION:
Do not attempt to disassemble, re-work or perform repairs on the vacuum housing of the source, as it is integrated with the power supply. Doing so could invalidate any warranty associated with this product or cause damage to the power supply or vacuum source components.

Note: There are no user-serviceable parts or components associated with this product.

Your Rapid F 6 kW plasma source has been designed to have minimal preventative maintenance that would require removing the source from its vacuum installation. For most applications that involve fluorine and oxygen bearing chemistries, deposits and wall contamination introduced by the process can be cleaned from the anodized aluminum walls by in-situ processes using other fluorine, hydrogen, or oxygen based gases or mixtures. Because the power supply and vacuum source are completely integrated into a single mechanical structure, you cannot disassemble and inspect the vacuum walls of the source assembly. As such, preventative maintenance is limited to inspection of the integrity of the source's ISO KF 40 fittings and seals.

Note: An annual water pressure test at 19.5 bar (1950 kPa) for a duration of 1 minute is recommended.

Troubleshooting and Global Support

This chapter provides information on diagnosing and resolving problems with the unit. It also gives contact information for Global Support.

Note: You can also troubleshoot the Rapid F 6 kW plasma source using AE's Virtual Front Panel (VFP) software interface. For more information about VFP, see "Virtual Front Panel (VFP) Software Interface" on page 4-20.

CAUTION:
Do not attempt to disassemble, re-work, or perform repairs on the vacuum housing of the source as it is integrated with the power supply. Doing so could invalidate any warranty associated with this product or cause damage to the power supply or vacuum source components.

BEFORE CALLING AE CUSTOMER SUPPORT

Before calling AE Customer Support, perform the following steps or procedures.

DANGER:
RISK OF DEATH OR BODILY INJURY. Disconnect and lockout/tagout all sources of input power before working on this unit or anything connected to it.

WARNING:
Process gas flows must be shut off, disconnected, and disabled (that is, locked out/tagged out), and the source must be purged of all process gases before working on this device or anything connected to it.

WARNING:
There are no user serviceable parts or components associated with this product. Contact AE for any service issues related to the unit.

Checks With Input Power Off

The following section provides steps for checking the unit's operation with the power off and the unit installed on a working vacuum system.

1. Ensure that the power to the unit is off.
2. Check that the unit is securely mounted to the vacuum chamber and is under vacuum.
3. Check the operation of flow controller, pressure controllers, throttle valves, and all associated auxiliary vacuum equipment that is required for the unit to run.
4. Perform leak checks or leak-back rate checks on the Rapid F 6 kW plasma source installation to see if the unit has been installed properly on the vacuum chamber.
5. Check for external damage to the unit, power cable, and control connectors.
6. Check to determine whether any system-related circuit breakers have been tripped.
7. Ensure the input power meets specifications and, in particular, that all three phases are present.
8. Check that the input line connectors are properly attached to the unit.
9. Verify that ground connections are adequate and secure.
10. Ensure that the cooling water to the unit meets specifications (in terms of flow, temperature, contaminant levels, and conductivity.)

Checks With Input Power On

The following section provides steps for checking the unit's operation with the power on.

Note: You can also troubleshoot the Rapid F 6 kW plasma source using AE's Virtual Front Panel (VFP) software interface. For more information about VFP, see "Virtual Front Panel (VFP) Software Interface" on page 4-20.

1. Turn on input power.
2. After AC power is turned on, the unit cycles through a front panel test sequence on the status LEDs and alphanumeric display for approximately 60 seconds while

the internal bus capacitors charge. Verify that the unit performs this test while charging up.

3. Satisfy the interlock condition on the user (**Analog Control**) port by connecting pins *13* and *25*. See “User (Analog Control) Port” on page 4-1 for more information about making this connection.
4. Verify that the **INTERLOCK** LED is illuminated. If the interlock condition is satisfied, the internal AC contactor closes in about 10 seconds. The **AC POWER** LED turns on, indicating that the unit is ready to operate.

TROUBLESHOOTING

Troubleshooting the source’s operation may require that you investigate or make adjustments to elements of the process such as gas mixtures as well as flow and pressure dynamics. The dynamic impedance range of Rapid F 6 kW plasma source has limitations; therefore, not every operating pressure, gas chemistry, and power level can be satisfied. For instance, higher power will likely be required in order to sustain plasma at higher pressures when using pure or weakly diluted molecular gases. Also, you may find problems sustaining a plasma in the source when the response of flow/pressure controllers leads to high pressure bursts when turning on or making transitions from low flow/pressure to high flow/pressure conditions. Such process integration work should be anticipated when applying the unit to any new or untested process. See “Selecting Gas Mixtures, Gas Pressures, and Power Levels” in the appendix for further information.

CAUTION:
This source was designed for ignition in pure Ar gas. Direct ignition in other gases could lead to unsuccessful start-up of the source or to damage or shortened lifetime of the anodized walls within the device. Contact AE for range of operation for direct ignition in molecular gas mixtures.

Error Code Troubleshooting Table

The Rapid F 6 kW plasma source displays an error code on the front display when an error or fault occurs. Table 6-1 defines these codes and provides procedures to resolve the faults.

Note: The unit clears all faults and errors when it powers off. It reports a lifetime count of errors and faults through AE Bus command **220** (saved in nonvolatile memory). AE Bus command **212** reports the most recent error code (the unit erases this information when it powers off).

Table 6-1. *Error code troubleshooting table*

Error Code Number and Message	Problem Indicated	Suggested Action
E03 Thermal limit exceeded	The source is inadequately cooled, causing thermal switches associated with the vacuum housing and electronics cold plate to open and shut off the delivery of power to the plasma source.	To resolve this fault: 1. Send an RF off command or reset the user port *PLASMA ON ENABLE* signal to clear the fault. 2. Check cooling water flow and local environmental temperature and adjust to regulate the unit to working temperatures. If this error code persists after completing the previous steps, contact AE Global Support (see "AE Global Customer Support" on page 6-10).
E04 Internal fan fault	The convective cooling fan inside source chassis has failed.	Contact AE Global Support. (See "AE Global Customer Support" on page 6-10.)

Table 6-1. *Error code troubleshooting table (Continued)*

Error Code Number and Message	Problem Indicated	Suggested Action
E05 Bus AC undervoltage fault	Facility AC power to the bus is too far below its nominal working limits.	Check the line voltages on each phase coming in to the unit. Correct any abnormal condition. If you find no abnormalities and the error persists, contact AE Global Support. (See "AE Global Customer Support" on page 6-10.)
E06 Bus AC overvoltage fault	Facility AC power to the Bus is above the unit's nominal working limits.	Check the line voltages on each phase coming in to the unit. Correct any abnormal condition. If you find no abnormalities and the error persists, contact AE Global Support. (See "AE Global Customer Support" on page 6-10.)
E07 Plasma ignition failure	The source has failed to ignite a discharge. Upon any attempt to ignite the source, if the power readback is less than 1500 W for the first 5 s, the E07 fault will be displayed. *Note:* This fault is only associated with the inability to ignite a plasma. If the gas discharge extinguishes during typical run-time operation after the first 5 s of operation, the "E24" fault will appear on the display.	To resolve this fault: 1. Send an RF off command or reset the user port *PLASMA ON ENABLE* signal to clear the fault. 2. Check for proper Ar flow and pressure conditions entering the source. 3. Verify that no molecular gases are leaking through the flow controllers or valves. 4. Restart your process. If this fault recurs, contact AE Global Support. (See "AE Global Customer Support" on page 6-10.)

Table 6-1. *Error code troubleshooting table (Continued)*

Error Code Number and Message	Problem Indicated	Suggested Action
E11 AE Bus (**RS-232**) port heart beat time-out fault	The **RS-232** port time-out has been exceeded, and the unit has shut output off. That is, the Rapid F 6 kW plasma source has not received a communication packet from the host computer in the time set with AE Bus command **40** (see page 4-15 for a description of this command).	To resolve this problem: 1. Send an RF off command or reset the user port *PLASMA ON ENABLE* signal to clear the fault. 2. Make sure that communication links between the host computer and the plasma source are properly connected. For installation information, see "Connecting I/O and Auxiliary Connectors" on page 5-11. 3. Make sure that the host computer is sending communication packets at a rate that complies with the time-out set with AE Bus command **40**. If it is not, change either the time-out value or the rate at which the host computer is sending communication packets.
E16 Bad ambient temperature thermistor	This error code indicates a malfunction of the ambient temperature thermistor within the unit.	Contact AE Global Support (see "AE Global Customer Support" on page 6-10 for contact information).
E19 Ambient overtemperature fault	Ambient temperature of unit has exceeded 60ºC (140ºF).	Allow the unit to cool (with the output off) to below 50ºC (122ºF). Unit will reset when temperature returns to a level below 50ºC (122ºF). Make sure that all cooling requirements are met (see Table 3-4 on page 3-4).

Table 6-1. *Error code troubleshooting table (Continued)*

Error Code Number and Message	Problem Indicated	Suggested Action
E20 Duty cycle fault	The Rapid F 6 kW plasma source has a maximum duty cycle of 50%. As the unit runs, the duty cycle timer counts on and off time, adding a second to the timer for each second of on-time and subtracting a second for each second of off-time. If the timer reaches 300 seconds (meaning that there have been 300 more seconds of o-time than off-time, the unit shuts output off and activates the duty cycle error.	To resolve this fault: 1. Wait 300 seconds for the condition to clear. 2. Send an RF off command or reset the user port *PLASMA ON ENABLE* signal to clear the fault. 3. Adjust the process times to avoid the error. 4. Restart the process.

Table 6-1. *Error code troubleshooting table (Continued)*

<table>
<tr><th>Error Code Number and Message</th><th>Problem Indicated</th><th>Suggested Action</th></tr>
<tr><td>E21
Current limit fault</td><td>This error code has two states:

When flashing, this error code indicates that the unit is operating at the current limit, which is normal during ignition. A flashing E21 does not indicate a fault; the flashing should stop after ignition and transition to regular process gases.

When on steady, this error code indicates that the unit has exceeded the software current limit by 20 A for more than 90 seconds or that it has exceeded a maximum current limit duty cycle of 23% and turned output off. The unit calculates current by dividing delivered power by single-turn voltage. Both values are available through the AE Bus (RS-232) port or VFP software (see Chapter 4).

The software current limit is 80 A. The hardware current limit is 100 A. Use the following equation to calculate the maximum time that the unit can operate at the current limit before generating a steady E21 fault:
Time (s) = 1800 / (current [A] - 80)

Use the following equation to calculate the maximum current limit duty cycle:
Duty cycle (%) = 600 / (current [A] - 74)

The following table displays examples of maximum current, time, and duty cycles.

<table><tr><th>Maximum Current (A)</th><th>Maximum Time (s)</th><th>Max Current Limit Duty Cycle (%)</th></tr><tr><td>100</td><td>90</td><td>23.1</td></tr><tr><td>95</td><td>120</td><td>28.6</td></tr><tr><td>90</td><td>180</td><td>37.5</td></tr><tr><td>85</td><td>360</td><td>54.5[1]</td></tr><tr><td colspan="3">1. RF-on duty cycle is limited to 50%</td></tr></table></td><td>To resolve this fault:

1. Wait 300 seconds for the condition to clear.
2. Send an RF off command or reset the user port PLASMA ON ENABLE signal to clear the fault.
3. Make process adjustments as suggested in the following paragraph.

The following conditions may contribute to this fault. To resolve the problem, make the necessary process adjustments.

• Plasma pressure may be too low
• There may be too much argon in the mixture
• The argon mass flow controller may be leaking</td></tr>
</table>

Table 6-1. *Error code troubleshooting table (Continued)*

Error Code Number and Message	Problem Indicated	Suggested Action
E24 Plasma wink-out fault	After the first 5 seconds of operation, the unit monitors the delivered power level. A power level below 1500 W activates this fault and the unit turns output off.	To resolve this fault: 1. Send an RF off command or reset the user port *PLASMA ON ENABLE* signal to clear the fault. 2. Make process adjustments as suggested in the following paragraph. The following conditions may contribute to this fault. To resolve the problem, make the necessary process adjustments. • Gas pressure may be too high (causing excessively high voltage) • Gas pressure or flow may be fluctuating • Power set point may be too low for the plasma pressure

AE GLOBAL CUSTOMER SUPPORT

Please contact one of the following offices if you have questions:

Table 6-2. *Global Customer Support locations*

Office	Contact
AE, World Headquarters 1625 Sharp Point Drive Fort Collins, CO 80525 USA *Note:* For returns and repairs, please call Global Customer Support to get the correct shipping address.	Phone (24 hrs/day, 7 days/week): 800.446.9167 or 970.221.0108 Fax (M–F, 7:00 am – 5:30 pm MST): 970.407.5981 Email: technical.support@aei.com (We will respond to email by the next business day.) *Note:* For customers outside the US, please contact your local AE office.
AE, GmbH Raiffeisenstrasse 32 70794 Filderstadt (Bonlanden) Germany	Phone: 49.711.779270 Fax: 49.711.7778700
AE, Japan KK TOWA Edogawabashi Bldg. 347 Yamabuki-cho Shinjuku-ku Tokyo 162-0801 Japan	Phone: 81.3.32351511 Fax: 81.3.32353580
AE, Korea Ltd. Gongduk Building, 4th floor 272-6 Seohyun-Dong, Bundang-Gu, Seongnam-Si Kyunggi, 463-050 Korea	Phone: 82.31.705.2100 Fax: 82.31.705.2766
AE, United Kingdom Unit 5, Minton Place, Market Court, Victoria Road Bicester, Oxon OX26 6QB UK	Phone: 44.1869.320022 Fax: 44.1869.325004

Table 6-2. *Global Customer Support locations (Continued)*

Office	Contact
AE, Taiwan, Ltd. 10F-6, No. 110, Chung Shan Rd. Sec. 3, Chungho City, Taipei Hsien Taiwan 235	Phone: 886.2.82215599 Fax: 886.2.82215050
AE China 469 Huaxia Dong Road Zhangjiang Town Shanghai, China 201203	Phone: 86.21.58579011 Fax: 86.21.58579003

RETURNING UNITS FOR REPAIR

Before returning any product for repair and/or adjustment, ***first follow all troubleshooting procedures***. If, after following these procedures, you still have a problem or if the procedure instructs you to, call AE Customer Support and discuss the problem with a representative. Be prepared to give the model number and serial number of the unit as well as the reason for the proposed return. This consultation call allows Customer Support to determine whether the problem can be corrected in the field or if the unit needs to be returned. Such technical consultation is always available at no charge.

If you return a unit without first getting authorization from Customer Support and that unit is found to be functional, you will be charged a re-test and calibration fee plus shipping charges.

To ensure years of dependable service, Advanced Energy® products are thoroughly tested and designed to be among the most reliable and highest quality systems available worldwide.

WARRANTY

Advanced Energy® (AE) products are warranted to be free from failures due to defects in material and workmanship for 12 months after they are shipped from the factory (please see warranty statement below, for details).

In order to claim shipping or handling damage, you must inspect the delivered goods and report such damage to AE within 30 days of your receipt of the goods. Please note that failing to report any damage within this period is the same as acknowledging that the goods were received undamaged.

For a warranty claim to be valid, it must:

- Be made within the applicable warranty period
- Include the product serial number and a full description of the circumstances giving rise to the claim
- Have been assigned a return material authorization number (see below) by AE Customer Support

All warranty work will be performed at an authorized AE service center (see list of contacts at the beginning of this chapter). You are responsible for obtaining authorization (see details below) to return any defective units, prepaying the freight costs, and ensuring that the units are returned to an authorized AE service center. AE will return the repaired unit (freight prepaid) to you by second-day air shipment (or ground carrier for local returns); repair parts and labor will be provided free of charge. Whoever ships the unit (either you or AE) is responsible for properly packaging and adequately insuring the unit.

Authorized Returns

Before returning any product for repair and/or adjustment, call AE Customer Support and discuss the problem with them. Be prepared to give them the model number and serial number of the unit as well as the reason for the proposed return. This consultation call will allow Customer Support to determine if the unit must actually be returned for the problem to be corrected. Such technical consultation is always available at no charge.

Units that are returned without authorization from AE Customer Support and that are found to be functional will not be covered under the warranty (see warranty statement, below). That is, you will have to pay a retest and calibration fee, and all shipping charges.

Warranty Statement

The seller makes no express or implied warranty that the goods are merchantable or fit for any particular purpose except as specifically stated in printed AE specifications. The sole responsibility of the Seller shall be that it will manufacture the goods in accordance with its published specifications and that the goods will be free from defects in material and workmanship. The seller's liability for breach of an expressed warranty shall exist only if the goods are installed, started in operation, and tested in conformity with the seller's published instructions. The seller expressly excludes any warranty whatsoever concerning goods that have been subject to misuse, negligence, or accident, or that have been altered or repaired by anyone other than the seller or the seller's duly authorized agent. This warranty is expressly made in lieu of any and all other warranties, express or implied, unless otherwise agreed to in writing. The

warranty period is 12 months after the date the goods are shipped from AE. In all cases, the seller has sole responsibility for determining the cause and nature of the failure, and the seller's determination with regard thereto shall be final.

Appendix A

SELECTING GAS MIXTURES, GAS PRESSURES, AND POWER LEVELS

The following paper discusses the operational impedance range of the Rapid F 6 kW plasma source in order to assist process design.

Power Supply Limitations

All power supplies must operate within the limits of their maximum output voltage and maximum output current capabilities. These limits define the load impedance into which full power (maximum current at maximum voltage) can be delivered. The advanced topology of the power supply integrated within the Rapid F 6 kW plasma source automatically varies the output impedance and frequency, allowing the delivery of full power into a *range* of load impedances. However, even though its capabilities are much broader than other power supplies, this unit still operates within a given range of load impedances.

Plasma Impedance

The impedance of a plasma load within the source is a function of numerous parameters, including gas or vapor chemistry, pressure, and plasma discharge power level. These and other factors also affect plasma ignition. To ignite the plasma, the power supply must deliver enough voltage to drive sufficient current into the high impedance of the unignited gas. Further, in order to sustain the plasma discharge and provide high power levels, it must deliver high levels of voltage and current into the much lower impedance of the ignited gas.

Because noble gases ionize easily, they present a much lower ignition *and* operating impedance to the power supply than do reactive gases. The *undiluted* flow of a noble gas such as argon greatly improves the probability of ignition. However, once ignited, the low operating impedance of argon may result in excessive current demands on the power supply, thus creating a condition that limits current at the maximum specified level. This produces an output power level below the power set point. The plasma is sustained, but the set point is lost, indicated by a flashing **PLASMA** LED.

After the plasma ignites, it is possible to transition to reactive process gas flow. Because the operating impedance of the molecular gas is substantially higher than that of argon, this plasma may require a higher voltage than the power supply is capable of producing, usually resulting in the loss of the plasma. The power supply responds by turning off the **PLASMA** LED.

To prevent plasma impedance from going outside the range of the power supply's capabilities, end users have three options:

- When in current limit, increase the flow rate of the molecular gas. This increases plasma impedance. If the plasma extinguishes, use argon to re-ignite it.
- Dilute the molecular gas with a noble gas to reduce the plasma impedance.
- Increase the power set point. This increases the plasma charged-particle density, lowering the plasma impedance.

Summary

The Rapid F 6 kW plasma source is specified to operate within a certain range of plasma impedances. The end user controls impedance by varying gas chemistry, gas pressure, and power set point. In proper combination, the resulting impedance permits successful ignition and operation. An improper combination prohibits ignition, causes operation below the power set point, or extinguishes the plasma. If you suspect that the unit is not functioning in accordance with its specifications, please consult the Troubleshooting chapter.

Index