O P E R A T I N G   M A N U A L

Guardian™
Co-Deposition Controller

PN 074-517-P1F

INFICON

O P E R A T I N G   M A N U A L

Guardian™

Co-Deposition Controller

PN 074-517-P1F

INFICON Instruments for Intelligent Control®

www.inficon.com reachus@inficon.com

Trademarks

The trademarks of the products mentioned in this manual are held by the companies that produce them.

INFICON® is a trademark of INFICON Inc.

Guardian™ is a trademark of INFICON GmbH.

LabVIEW™ is a trademark of National Instruments

Windows®, Access®, Excel® and AxtiveX® are registered trademarks of Microsoft Corporation.

Wonderware® is a registered trademark of Invensys plc

All other brand and product names are trademarks or registered trademarks of their respective companies.

Disclaimer

The information contained in this manual is believed to be accurate and reliable. However, INFICON assumes no responsibility for its use and shall not be liable for any special, incidental, or consequential damages related to the use of this product.

Due to our continuing program of product improvements, specifications are subject to change without notice.

Copyright

INFICON

DECLARATION OF CONFORMITY

This is to certify that this equipment, designed and manufactured by:

INFICON Inc.
Two Technology Place
East Syracuse, NY 13057
USA

Meets the essential safety requirements of the European Union and is placed on the market accordingly. It has been constructed in accordance with good engineering practice in safety matters in force in the Community and does not endanger the safety of persons, domestic animals or property when properly installed and maintained and used in applications for which it was made.

Equipment Description: EIES Guardian (including all options)

Applicable Directives:
2014/35/EU (LVD)
2014/30/EU (General EMC)
2011/65/EU (RoHS)

Applicable Standards:

Safety:	EN 61010-1: 2010 Safety Requirements for Electrical Equipment For Measurement, Control, And Laboratory Use. PART 1: General Requirements
Emissions:	EN 61326-1: 2013 (Radiated & Conducted Emissions) (EMC – Measurement, Control & Laboratory Equipment) CISPR 11/EN 55011 Edition 2009-12 Emission standard for industrial, scientific, and medical (ISM) radio RF equipment FCC Part 15 Class A emissions requirement (USA)
Immunity:	EN 61326-1: 2013 (Industrial EMC Environments) (EMC – Measurement, Control & Laboratory Equipment)
RoHS:	Fully Compliant

CE Implementation Date: May 2008 (Updated July, 2015)

Authorized Representative: Steve Schill

Thin Film Business Line Manager
INFICON Inc.

ANY QUESTIONS RELATIVE TO THIS DECLARATION OR TO THE SAFETY OF INFICON'S PRODUCTS SHOULD BE DIRECTED, IN WRITING, TO THE AUTHORIZED REPRESENTATIVE AT THE ABOVE ADDRESS.

Warranty

WARRANTY AND LIABILITY - LIMITATION: Seller warrants the products manufactured by it, or by an affiliated company and sold by it, and described on the reverse hereof, to be, for the period of warranty coverage specified below, free from defects of materials or workmanship under normal proper use and service. The period of warranty coverage is specified for the respective products in the respective Seller instruction manuals for those products but shall not be less than two (2) years from the date of shipment thereof by Seller. Seller's liability under this warranty is limited to such of the above products or parts thereof as are returned, transportation prepaid, to Seller's plant, not later than thirty (30) days after the expiration of the period of warranty coverage in respect thereof and are found by Seller's examination to have failed to function properly because of defective workmanship or materials and not because of improper installation or misuse and is limited to, at Seller's election, either (a) repairing and returning the product or part thereof, or (b) furnishing a replacement product or part thereof, transportation prepaid by Seller in either case. In the event Buyer discovers or learns that a product does not conform to warranty, Buyer shall immediately notify Seller in writing of such non-conformity, specifying in reasonable detail the nature of such non-conformity. If Seller is not provided with such written notification, Seller shall not be liable for any further damages which could have been avoided if Seller had been provided with immediate written notification.

THIS WARRANTY IS MADE AND ACCEPTED IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, WHETHER OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE OR OTHERWISE, AS BUYER'S EXCLUSIVE REMEDY FOR ANY DEFECTS IN THE PRODUCTS TO BE SOLD HEREUNDER. All other obligations and liabilities of Seller, whether in contract or tort (including negligence) or otherwise, are expressly EXCLUDED. In no event shall Seller be liable for any costs, expenses or damages, whether direct or indirect, special, incidental, consequential, or other, on any claim of any defective product, in excess of the price paid by Buyer for the product plus return transportation charges prepaid.

No warranty is made by Seller of any Seller product which has been installed, used or operated contrary to Seller's written instruction manual or which has been subjected to misuse, negligence or accident or has been repaired or altered by anyone other than Seller or which has been used in a manner or for a purpose for which the Seller product was not designed nor against any defects due to plans or instructions supplied to Seller by or for Buyer.

NOTE: These instructions do not provide for every contingency that may arise in connection with the installation, operation or maintenance of this equipment. Should you require further assistance, please contact INFICON.

INFICON

www.inficon.com   reachus@inficon.com

Table Of Contents

PN 074-517-P1F

PN 074-517-P1F

Chapter 1
Introduction and Specifications

1.1 Introduction

The EIES-IV Guardian uses Electron Impact Emission Spectroscopy (EIES) to control vacuum deposition of thin films.

In EIES, the material being deposited is energized by a thermionic emitter, which creates optical emission spectra. An optical filter passes a characteristic wavelength of the spectra to a Photomultiplier Tube (PMT) Detector, which measures the intensity of the emission. The measured intensity is fed to a PID control loop, which generates a control signal for the material's evaporation power supply. By proper filter selection, multiple PMT Detectors can control deposition of multiple materials simultaneously.

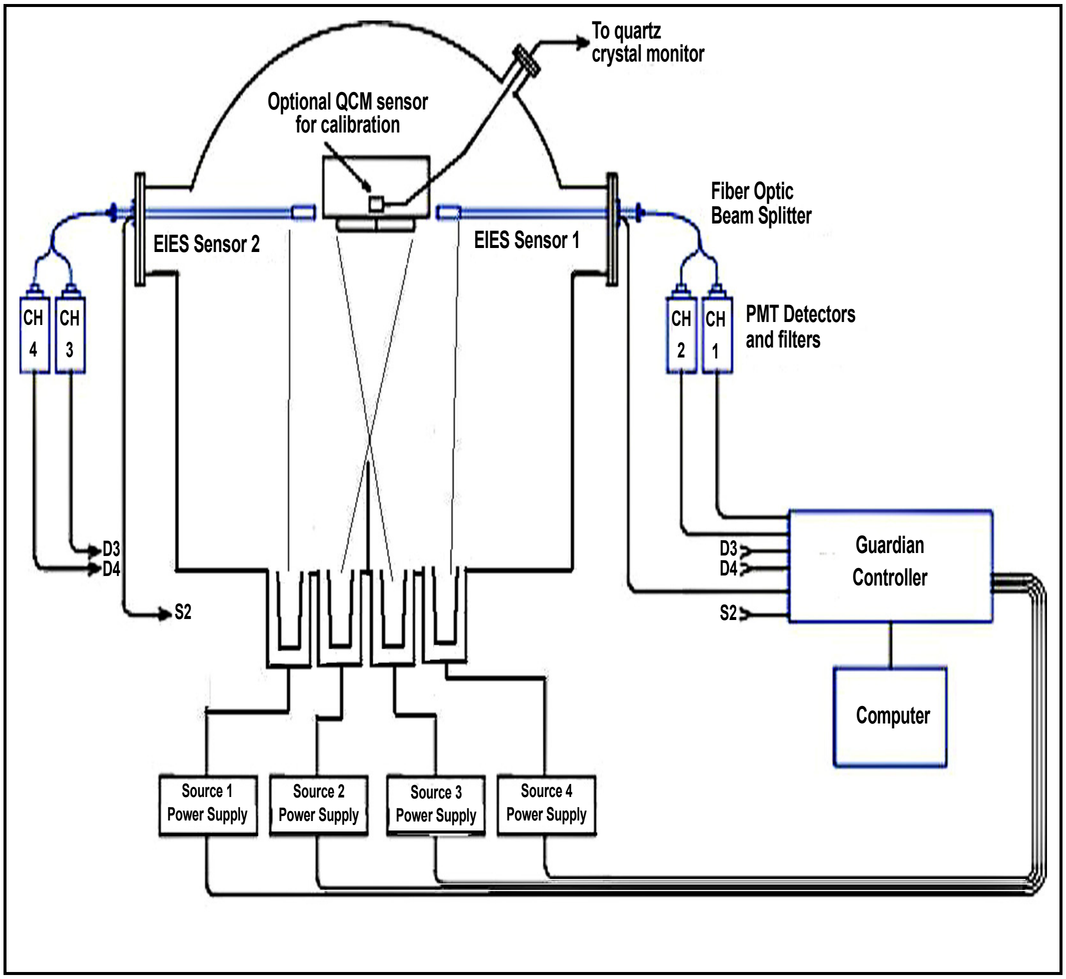
The EIES-IV Guardian consists of five basic elements:

- controller
- sensor(s)
- PMT Detector(s)
- software
- optional quartz crystal monitor

A four channel, two sensor system is shown in Figure 1-1.

Source to sensor alignment must considered before installation. See section 4.2.1, Sensor Position, on page 4-4.

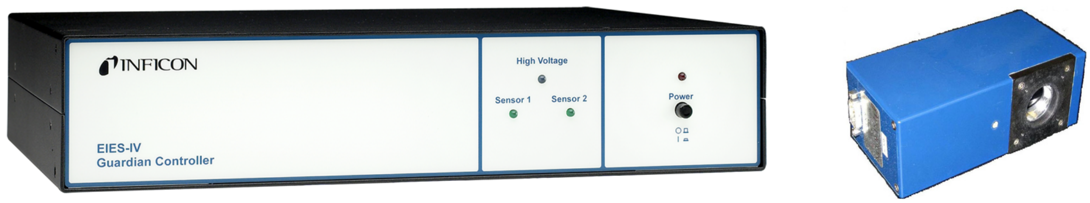
Figure 1-1 Four channel two sensor system



1.2 EIES Controller

The EIES-IV Guardian Controller is the interface between the EIES sensor(s) and PMT Detector(s), the evaporation power supply, and the computer running the EIES software. See Figure 1-2.

Figure 1-2 Guardian controller with PMT detector



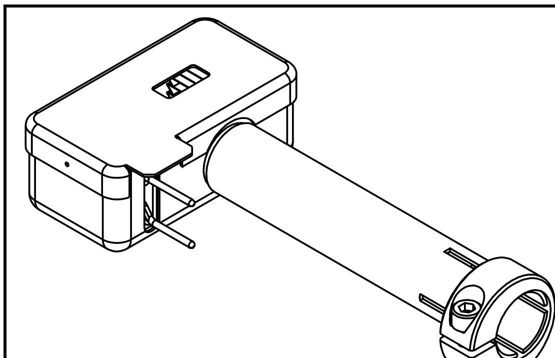
The controller supplies power to both the filament of the sensor assembly and to the PMT Detector. It communicates with each PMT Detector, passing the PMT Detector measurements to the computer running the EIES software. Control voltages for evaporation power supplies are also generated in the controller. Finally, relays and digital inputs to operate shutters, etc., are included in the controller.

The controller is operated from a computer running the EIES software via RS-232 or Ethernet. Other than a power switch and four status LEDs, there are no operator controls on the EIES-IV Guardian Controller.

1.3 EIES Sensor

In the sensor assembly, see Figure 1-4, high-energy electrons from a hot filament excite the valence electrons of the deposited material. These excited electrons emit light at wavelengths that are characteristic of each material. A light tube conducts the light to a feedthrough with a viewport, where it is measured by the Photomultiplier Tube (PMT) of the PMT Detector(s). A single sensor, see Figure 1-3, can be used to create emissions from multiple materials by installing multiple PMT Detectors, see section 4.3.3 on page 4-10.

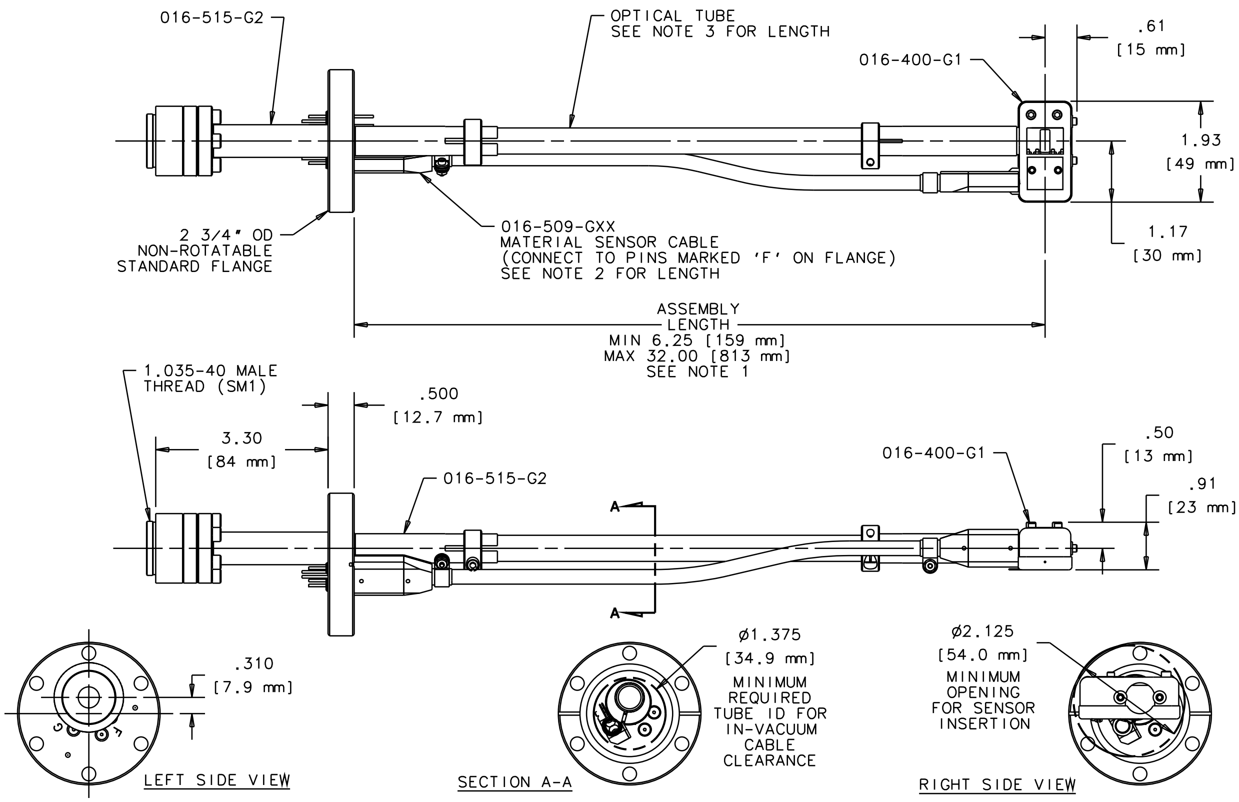
Figure 1-3 EIES Single sensor 016-400-G1



Sensor shown with High Rate cover (small opening).

See Figure 2-2 on page 2-2 for Standard Rate cover (large opening) included with sensor.

Figure 1-4 EIES single sensor and feedthrough 016-600-Gxx



NOTE: (1) Assembly length is specified by customer.

NOTE: (2) Material sensor in-vacuum cable length required is equal to assembly length.

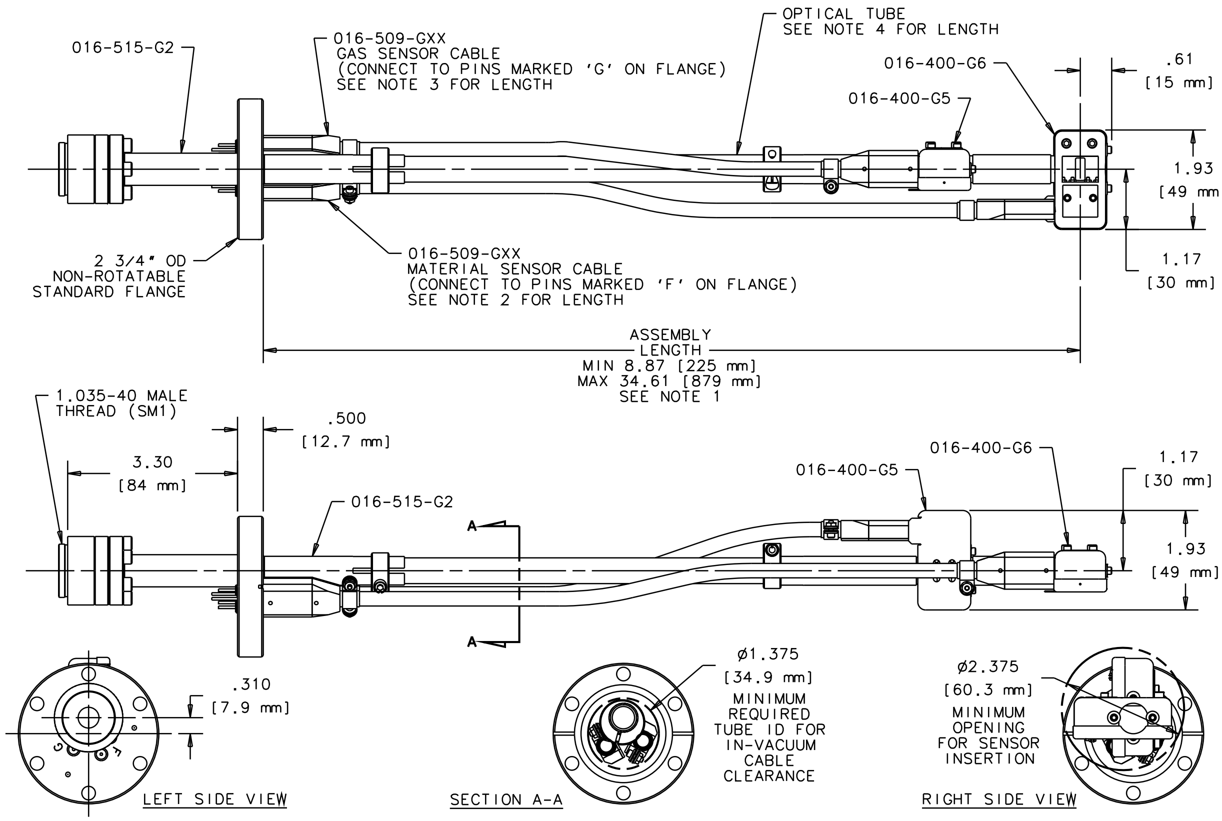
NOTE: (3) Optical tube length required is assembly length minus 51 mm (2 in.).

The sensor assembly consists of a 1.33 in. sapphire viewport attached to a 2.75 in. Conflat® flange. On the vacuum side of the flange, a telescoping light tube and two electrical connections are attached to the thermionic emitter. The telescoping tube can be adjusted to locate the thermionic emitter in the vapor flux.

In the Gas Compensating Sensor, see Figure 1-5, two sensors are stacked on the same optical tube with the gas compensating sensor rotated 90 degrees out of the vapor stream.

NOTE: The sensor will not pass through the 2.75 in. CF (NW35CF) port. If the chamber is too small to allow installation from the inside, a 4.5 in. CF (NW63CF) or larger flange adapted to the 2.75 in. CF flange is required to allow the entire sensor to pass through.

Figure 1-5 Gas compensating sensor and feedthrough 016-601-Gxx



NOTE: (1) Assembly length is specified by customer.

NOTE: (2) Material sensor in-vacuum cable length required is equal to assembly length.

NOTE: (3) Gas sensor in-vacuum cable length required is assembly length minus 64 mm (2.5 in.).

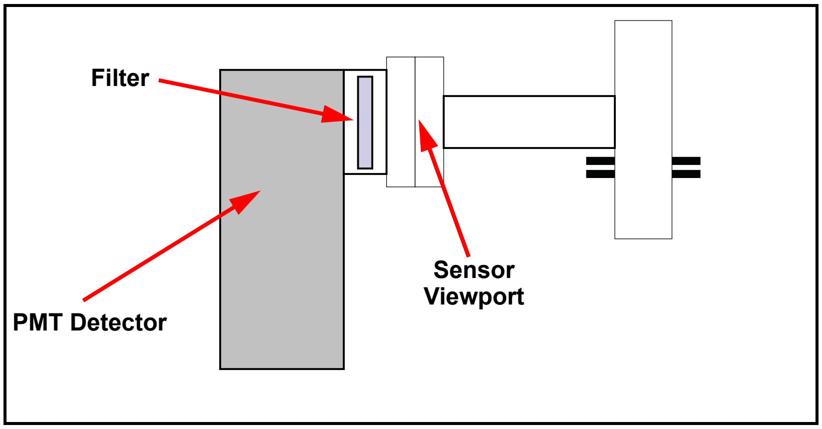
NOTE: (4) Optical tube length required is assembly length minus 114 mm (4.5 in.).

1.4 EIES PMT Detector

The EIES PMT Detector's photo multiplier tube measures the emission intensity of a characteristic wavelength of the deposited material.

For detecting a single material, an optical filter and PMT Detector can be attached directly to the viewport. See Figure 1-6.

Figure 1-6 EIES PMT detector



For multiple materials, an optional fiber optic beam splitter is attached to the viewport. The split signal is then fed to multiple PMT Detectors. Each PMT Detector is fitted with a filter specific to the material it measures. An optional monochromator is available for adjustable wavelength filtering, see section 4.8 on page 4-25.

NOTE: Splitting the signal reduces the intensity available at each PMT Detector.

PN 074-517-P1F

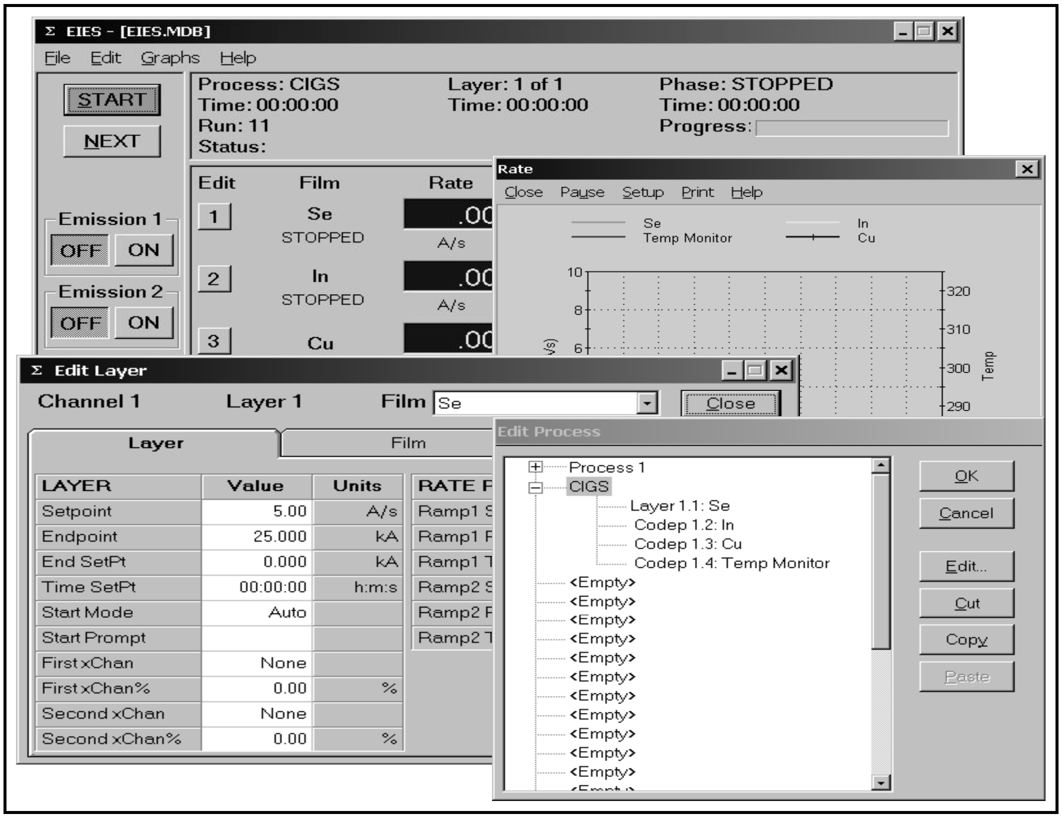
1.5 EIES Software

The EIES software, see Figure 1-7, provides the user interface for operating the EIES-IV Guardian system. The EIES software provides all of the functions required for an eight sensor, eight output, multi-layer co-deposition controller. Process settings, numeric data, and graphs can be displayed during all phases of deposition.

The EIES software stores process recipes in a Microsoft Access® compatible database. Process data is logged to disk in comma-delimited format for easy import into spreadsheet and graphing programs, such as Microsoft Excel®.

Chapter 3 details EIES software functions.

Figure 1-7 EIES software



1.6 Quartz Crystal Monitor

In the EIES system, rate is proportional to light intensity, measured as PMT Detector current. To calibrate the PMT Detector current to actual rate, an optional quartz crystal monitor (QCM) is recommended.

The EIES system uses the INFICON SQM-242™ PCI card or Q-pod™ Transducer for QCM calibration of the EIES PMT Detector(s). QCM calibration can be initiated by the user, or automatically at regular intervals during deposition. Control of a source is also possible with a QCM input.

A separate Operating Manual covers installation of the SQM-242 or Q-pod, and attaching the quartz sensors.

1.7 Analog Measurements

The INFICON SAM-242™ analog input card measures four 0 to +/-10 V (dc) signals. The SAM-242 card can be used to measure and control process parameters such as temperature and pressure. The SAM-242 card is an add-on for the SQM card and is not a stand-alone card.

The SAM-242 card is installed in the computer running the EIES software. Installation is covered in the SQM-242 Operating Manual.

1.8 Specifications

1.8.1 Sensor

Type	Single filament hot cathode or Dual filament Gas Compensating
Sensor Materials	304 SS, Inconel x-750, Ceramic
Filament Life (typical)	~1000 hours @ 1 x 10^{-5} Torr
Filament Material	Thoria coated Iridium, Optional Yttria coated
Filament Current	2 A to 4 A
Emission Current	Yttria: 2 mA max, Thoria 4 mA max
Bias Voltage	180 Volts
Operating Pressure	5 x 10^{-4} Torr maximum
Operating/Bakeout Temperature for in-vacuum components	450ºC maximum
Size L x W x H	49 x 26 x 21 mm (1.94 x 1.03 x 0.81 in.)

PN 074-517-P1F

Mounting. . . . . 2-3/4 in. CF (NW35CF) with sapphire viewport stainless steel rigid tube from 178 to 406 mm (7 to 16 in.)

Optical Path . . . . 12.25 mm (0.5 in.) dia. 304 stainless steel rigid tube, centerless ground

In-vacuum cable . . . . 16 AWG Mica insulated nickel clad Copper Cable 016-509-Gxx (Contact INFICON for available lengths)
Optional ceramic bead insulated 1.3 mm (0.050 in.) dia. Molybdenum wire Refractory Cable 016-513-Gxx (Contact INFICON for available lengths xx)

External Wiring . . . . 16 AWG except 18 AWG ground conductor, 12 m (40 ft.) maximum

1.8.2 PMT Detector

Photomultiplier Tube (PMT) . . . . Hamamatsu R7518 or equivalent

Spectral Response . . . . 185 to 730 nm

Detection Limit . . . . >5 fW of optical input power

PMT Gain . . . . ~10^3 to 10^7 depending on PMT voltage

Resolution . . . . 20 bits

Mounting. . . . . 1.035 in. x 40 threads per inch, compatible with Omega SM1 series

Filter Holder . . . . 25 mm (1 in.) dia x 5 mm (0.2 in.) thick filters

Size . . . . (50 x 140 x 70 mm)
(2 x 5-1/2 x 2-3/4 in.)

Weight . . . . 0.8 kg (1.7 lb.)

Wiring . . . . DB9 Male/Female, 12 m (40 ft.) maximum

Warm Up . . . . Allow the PMT Detector to warm up for one hour for maximum stability.

1.8.3 Controller

Sensors	1, 2 optional
PMT Detectors	8
Source Control Outputs	8 outputs, 0 to ±10 V (dc) programmable
Digital I/O	12 relays 30 V (dc), 3 A, 12 inputs 5-12 V (dc)
Communications	RS-232 or Ethernet static IP address
Power	100-240 V (ac) ~ ±10% nominal, 50/60 Hz, 110 W
Fuse	250 V 1.6 A T
Temporary Overvoltages	Short Term: 1440 V, <5 s Long Term: 490 V, >5 s
Size	483 x 89 x 305 mm (19 x 3-1/2 x 12 in.)
Weight	8.5 lb. (3.9 kg)
Computer	Windows 2000/XP/Vista/7, user supplied
Operating Environment	0°C to 40°C
	Relative Humidity: 0 to 80%, non-condensing
	Elevation: 0 to 2,000
	Indoor Use Only
	Class 1 Equipment (Grounded Type)
	Suitable for Continuous Operation
	Ordinary Protection (not protected against harmful ingress of moisture)
	Pollution Degree 2
	Installation (Overvoltage) Category II for transient overvoltages
Storage Environment	-40 to +40°C

1.9 Definition of Notes, Cautions and Warnings

Before using this manual, please take a moment to understand the Cautions and Warnings used throughout. They provide pertinent information that is useful in achieving maximum instrument efficiency while ensuring personal safety.

NOTE: Notes provide additional information about the current topic.

HINT: Hints provide insight into product usage.

CAUTION

Failure to heed these messages could result in damage to the instrument.

WARNING

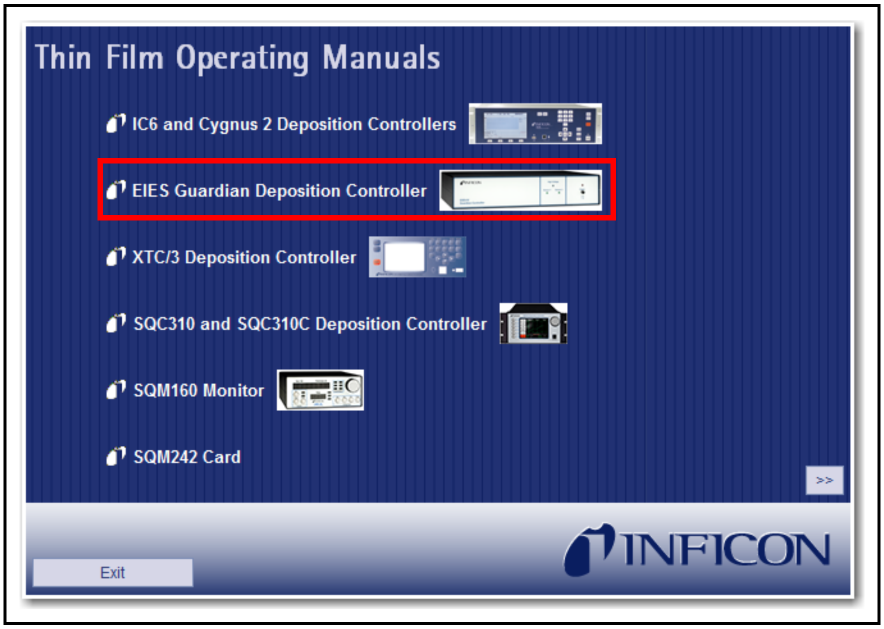
Failure to heed these messages could result in personal injury.

1.10 Operating Manual

To access Guardian Operating Manual, insert the 074-5000 Thin Film Manuals CD into your CD drive. The CD will autorun and display the window shown in Figure 1-8.

If the computer housing the drive containing he 075-5000 Thin Film Manuals CD is not configured to allow CD autorun: (1) Open Windows Explorer. (2) Click on the drive holding the 074-5000 CD to display the drive contents. (3) Click **TechDoc.exe**.

Figure 1-8 074-5000 Manuals CD Menu



PN 074-517-P1F

Chapter 2
Quick Start

2.1 Introduction

This chapter covers the system connections and software set up required to run the EIES-IV Guardian system. Consult later chapters for more detailed installation and operating instructions.

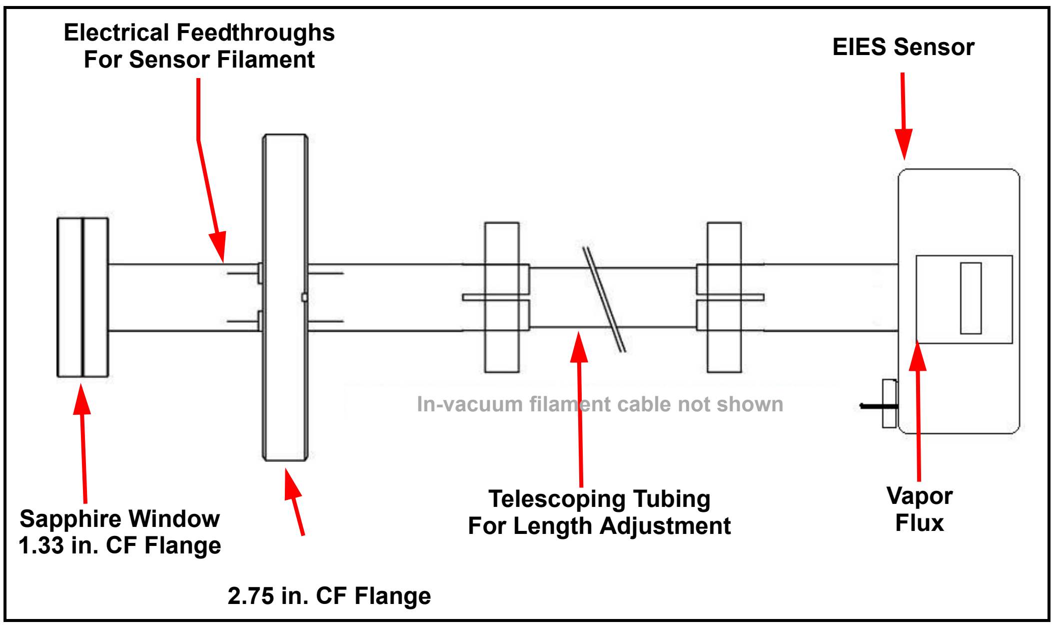
2.2 Installation

2.2.1 Sensor Installation

Placement of the EIES sensor is the most significant factor determining EIES system performance. The sensor must be placed so that the material vapor flux reaches the sensor without obstruction. The sensor opening must be oriented so that material can pass through the sensor without accumulating inside the sensor, with the smaller sensor cutout toward the flux. See Figure 2-1. See Chapter 4 for detailed installation instructions.

NOTE: The sensor will not pass through the 2.75 in. CF (NW35CF) port. If the chamber is too small to allow installation from the inside, a 4.5 in. CF (NW63CF) or larger flange adapted to the 2.75 in. CF flange is required to allow the entire sensor to pass through.

Figure 2-1 Sensor placement



To install the sensor, loosen the collar that secures the telescoping tube and separate the 2.75 in. flange from the sensor assembly. Install the 2.75 in. CF feedthrough to the vacuum chamber port, with the telescoping tube inside the chamber. See Figure 1-4 on page 1-4 and Figure 1-5 on page 1-5 for in-vacuum filament cable connection.

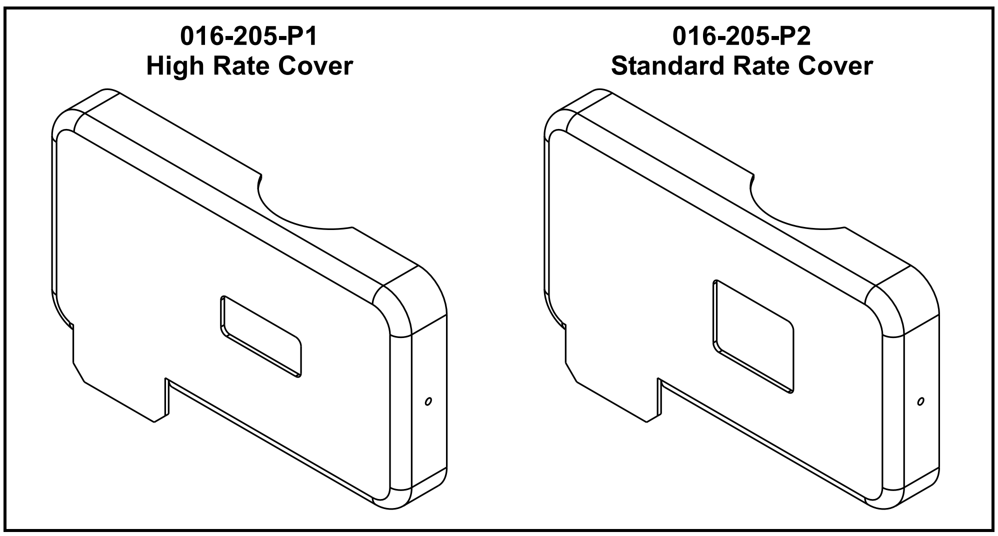
2.2.1.1 Sensor Covers, High Rate and Standard Rate

The High Rate cover 016-205-P1 is shipped installed on the EIES flux sensor.

The Standard Rate cover 016-205-P2 is shipped separately in a poly bag. For MBE and other applications where the sensor receives deposition rates below 10 Å/s or the emission signal is weak, the Standard Rate cover may be preferable as it allows more evaporant to enter the sensor.

When replacing covers, be sure the cover is securely snapped in place and no accumulated material is obstructing the aperture.

Figure 2-2 High Rate and Standard Rate covers



In the vacuum chamber, slide the sensor assembly onto the telescoping light tube and adjust the length so that the vapor flux passes through the sensor. The smaller opening in the sensor cover points toward the evaporant. If necessary, provide mechanical support to stabilize the sensor assembly. However, do not block the flux path. Secure the assembly by tightening the tube collar.

Attach the cables from the feedthrough to the sensor.

- For a standard sensor, attach the in-vacuum cable to the pins marked **F** (Flux).
- For a gas compensating sensor, attach the cable from the outermost sensor (sensor at the far end of the optical tube, measures the material flux) to the pins marked **F** (Flux). Attach the in-vacuum cable from the inner sensor (sensor nearest to feedthrough, measures the gas background), to the pins marked **G** (Gas).

Make sure there are no potential shorting paths to the chamber.

The outermost sensor's cover must be aligned to allow evaporant material to pass through it, entering at the smaller rectangular opening and exiting at the large opening.

The gas sensor must be oriented at a right angle relative to the flux sensor to minimize entry of evaporant material. Its cover has several small holes to permit residual gas to enter. See Figure 5-1 on page 5-2.

2.2.2 PMT Detector—Direct Installation

For single PMT Detector applications, the PMT Detector may be mounted directly to the sensor assembly viewport. See section 4.3.2, Single-PMT Detector Systems, on page 4-9 for detailed installation instructions.

2.2.3 Sensor to Fiber Optic Installation

In multi-material applications, a fiber optic beam splitter attached to the viewport can tailor signal transmission and PMT Detector mounting to specific process needs. Contact INFICON for fiber optic beam splitting requirements and capabilities. See section 4.3.3, Multiple-PMT Detector Systems, on page 4-10 for detailed installation instructions.

CAUTION

Turn the controller main power off or set the channel's PMT voltage to 0 to remove power whenever the PMT is exposed to room light.

2.2.4 Controller Installation

Mount the controller in a location that allows easy wiring access to the EIES sensor and PMT Detector assemblies. 3 m (10 ft.) and 12 m (40 ft.) filament and PMT Detector cables are available.

The controller may be placed up to 8 m (25 ft.) from the EIES computer. See section 4.6, Controller Installation, on page 4-19

CAUTION

Properly ground the system. Connect a solid copper strap from the EIES controller to a vacuum chamber ground.

When connecting the analog control voltage outputs to the evaporation power supplies, be sure that the outer conductor of each BNC cable is at system ground potential.

2.2.4.1 Digital Inputs and Relays Connection

Consult Chapter 4 for information on digital I/O wiring.

CAUTION

A system interlock must be present. Plug the Interlock connector 782-505-077 (jumpers from pin 1 to 10 and from pin 3 to 16) supplied in the 782-703-G1 Ship Kit into the Inputs connector. Emission cannot be turned on unless this connector or an equivalent system interlock is present.

2.2.4.2 Power Connection

With the power switch OFF, connect the AC mains to the controller power input. The controller automatically accepts 100-240 V (ac) @ 50-60 Hz.

WARNING

Verify that the power cable provided is connected to a properly grounded mains receptacle.

WARNING

Maintain adequate insulation and physical separation of sensor, PMT Detector, and I/O wiring from hazardous voltages.

WARNING

Relay contacts are rated for 30 V (dc) maximum duty. Any customer supplied relay contact circuit must be fused at not more than 5 A if the circuit is capable of supplying more than 5 A, including the available short circuit current.

2.2.4.3 Controller Power-up Sequence

WARNING

Do not turn power on until the installation, including PMT Detectors, is complete.

NOTE: Always follow the power-up sequence described below to avoid power glitches appearing at the evaporation power supply outputs during start up.

1. Press the power switch on the Guardian controller.
2. Start the EIES Software.
3. Turn on the evaporation power supplies.

2.2.5 QCM Option Installation

If an SQM-242 or Q-pod will be used for calibration or control, follow its Operating Manual to install the QCM software and sensor(s).

For accurate rate calibration, locate the QCM sensor(s) in the vacuum chamber so that the QCM sensor(s) receives a representative sample of the materials being deposited.

2.3 EIES Software

Leave the Guardian Controller power OFF while becoming familiar with the EIES software. The following sections introduce the concepts necessary to operate the EIES-IV Guardian system. Please, follow this section in the order it is presented.

2.3.1 Software Installation

1. Insert the 074-5000 INFICON Thin Film Manuals CD into your CD-ROM drive.
2. Open Windows Explorer.
3. Click the drive holding the 074-5000 CD.
4. Click the **EIES Guardian** folder.

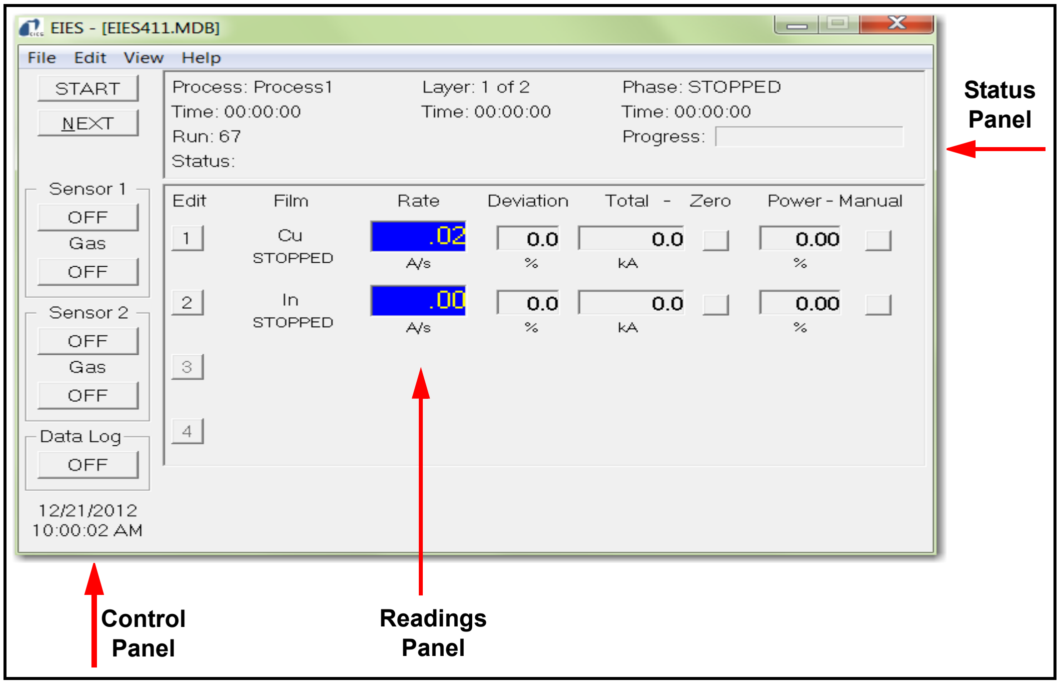
   This folder contains Guardian manuals and the software for both obsolete instruments versions and the current version.
5. Click **EIES_V4xx_SETUP.EXE** to install the current software version compatible with the current firmware version 4.xx

   NOTE: Contact INFICON to upgrade an earlier firmware version or for information about other software versions.
6. When EIES software installation finishes, there may be a prompt to restart your computer.

2.3.2 EIES Main Screen

Click the **EIES** icon on the desktop (or click **Start >> Programs >> INFICON >> EIES**). Initially, the display may look slightly different than Figure 2-3.

Figure 2-3 Process display



The Control Panel provides operating controls for running the process.

The Status Panel displays process status information.

The Readings Panel displays individual channel readings.

2.3.2.1 Readings Panel

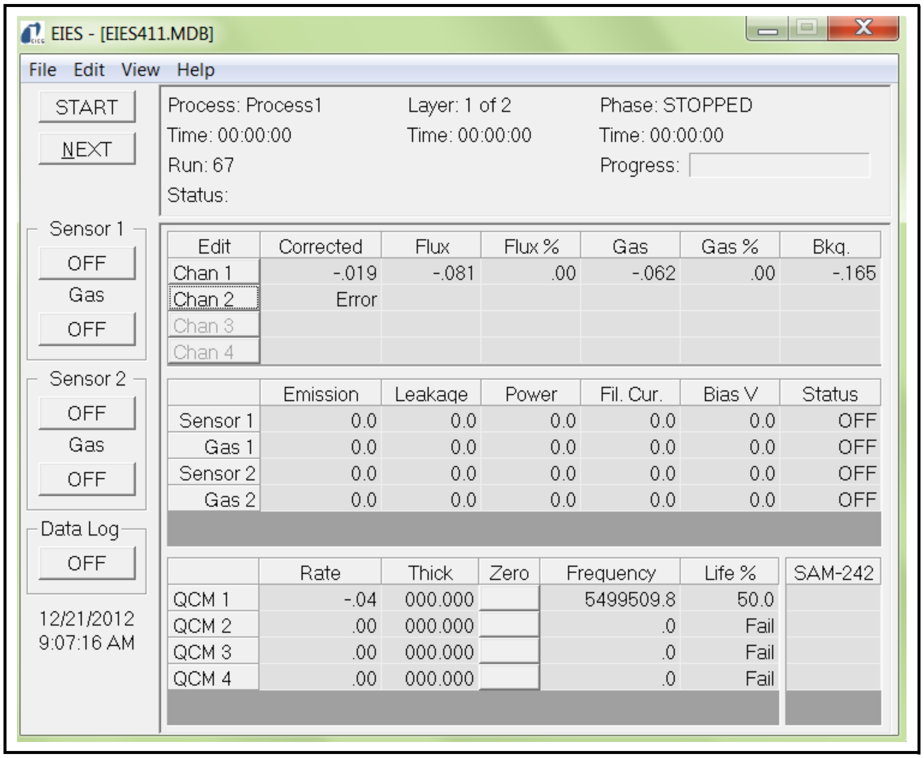
The Readings Panel has three display modes: **Process**, **Ratio** and **Readings**.

Click **View >> Process** to see the **Process** display mode. The **Process** display shows process related information such as films, setpoints, and manual operating controls.

Click **View >> Ratio** to see the **Ratio** display mode. The **Ratio** display is similar to the **Process** display except that the deviation readings are replaced with the ratio of the channel's reading to another channel. The other channel number is shown below the ratio reading. Ratios are set up in the **Edit Layer** window. See Ratio Display Grid on page 3-22, for more information on channel ratios.

Click **View >> Readings** to see the **Readings** display mode, see Figure 2-4. This display shows unfiltered readings from all sensors and PMT Detectors. The **Readings** display is useful for equipment setup and troubleshooting.

Figure 2-4 Readings display



If **Error** appears in a **Chan #** row under the **Corrected** column, and a PMT Detector is connected to the corresponding Module # connector on the Guardian controller rear panel, turn the controller power off and on again. Guardian recognizes PMT Detectors only on power-up. This error also appears if a channel is programmed as a co-dep layer but has no PMT Detector connected.

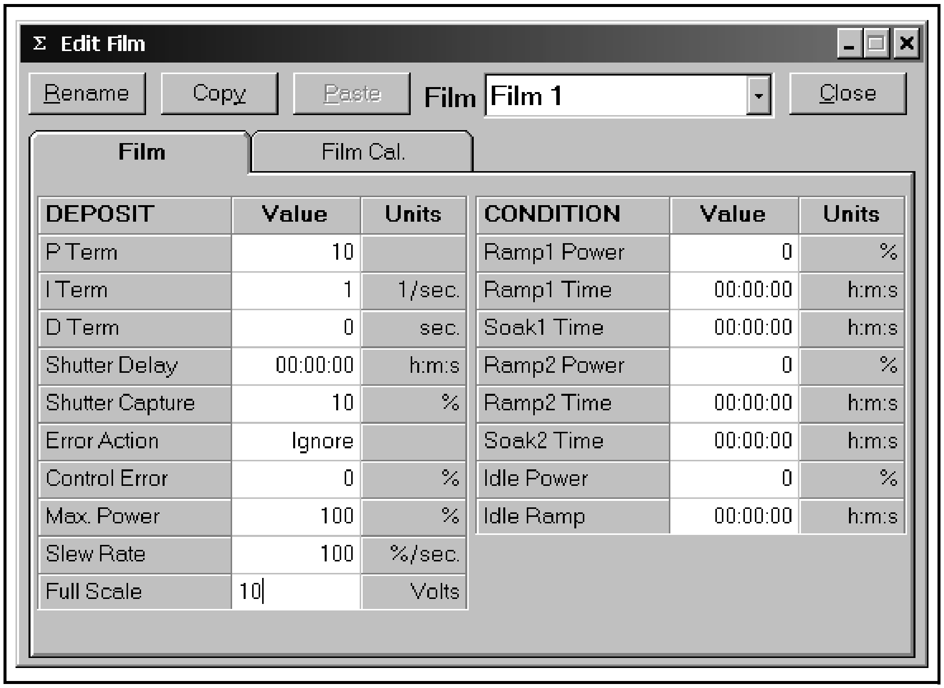
If the error persists after verifying that the Process is programmed correctly and the PMT Detector cable and the PMT Detector module are connected securely, contact INFICON Service (see section 5.1 on page 5-1).

There are several references to a Gas sensor in both the Readings Panel and the Control Panel. The EIES Guardian controller can be configured for standard EIES sensors or Gas Compensating (GC) sensors, see Sensor Setup on page 2-21.

2.3.3 Edit Film

Each material deposited will require unique setup parameters for proper deposition. Twenty-five materials can be programmed. Click **Edit >> Films** to display the **Edit Film** window shown in Figure 2-5.

Figure 2-5 Edit Film window



Click the **Film** drop-down to display a list of all films. Select the first film in the list, then click **Rename**. Change the film name to **Cu**, for Copper. This film will define the basic deposition parameters for Copper. We could adjust the film parameters, but for now we'll just rename a few more films.

Use the film drop-down to **Rename** the next three films **In**, **Ga** and **Se**.

Close the **Edit Film** window and return to the main screen.

2.3.4 Edit Processes

Select **Edit >> Processes** to display a listing of the twenty-five processes. A process is a sequence of layers, each consisting of one or more deposited films. We will use the **Edit Process** window to create a multi-layer co-deposition process.

Click the first process, then click **Edit**. Name the first process **CIGS**. We will construct an arbitrary layer sequence using arbitrary parameters for each.

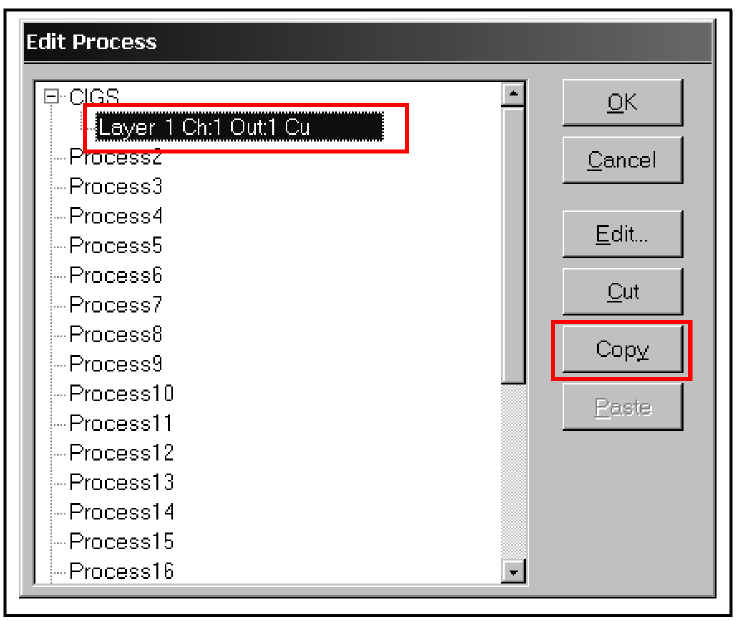
Processes are shown in an outline view, similar to Windows Explorer. Click **+** beside a process to expand the process and show the individual layers. Click **-** to collapse the view of the process.

1. Layers are numbered sequentially starting at layer 1.
2. After the layer number is the EIES software channel that will display readings.
3. Next is the EIES Guardian output that will control the deposition power supply.
4. And finally, the film that will be deposited.

It is important to know which channels and outputs are being used in co-deposition to avoid assigning more than one film to the same measurement channel or control output.

Now, click the first layer of process CIGS (appearance may differ from below). Be sure the first layer is highlighted, then click **Copy.** (See Figure 2-6.)

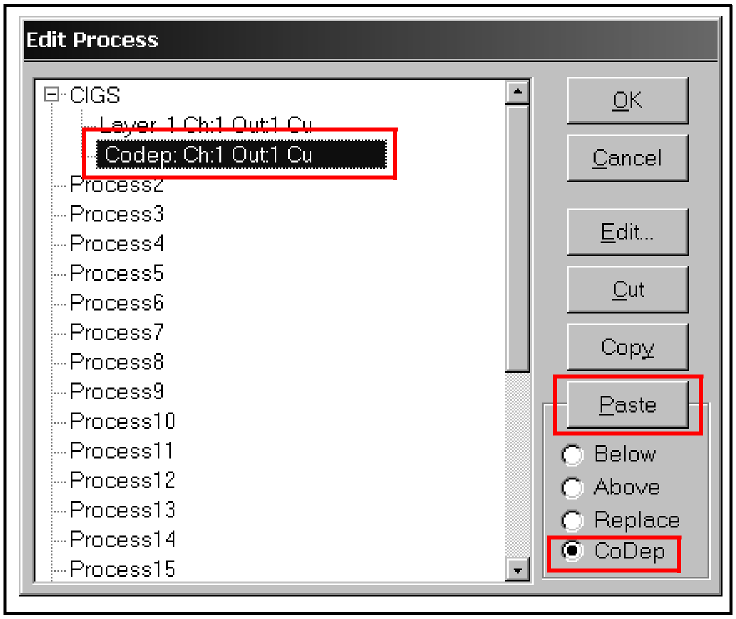
Figure 2-6 Selecting first layer of process CIGS



PN 074-517-P1F

This places a copy of the selected layer on the edit clipboard and enables **Paste**. With the first layer still highlighted, click the **CoDep** option and then click **Paste**. See Figure 2-7.

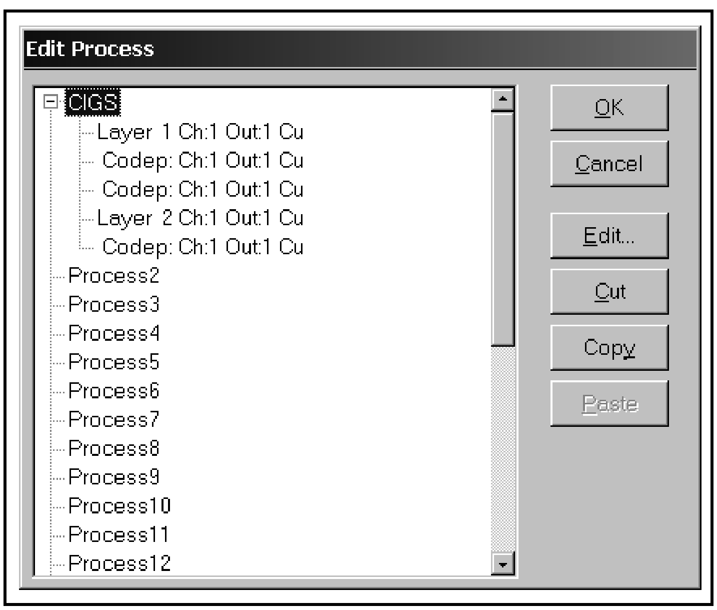
Figure 2-7 CoDep option



A co-deposition film has been added to the first layer. Click **Paste** again to create a three film co-deposition layer.

Select **Below** and click **Paste** to add a second layer below layer 1. Finally, select **CoDep** and click **Paste** to add a CoDep film to layer 2. See Figure 2-8.

Figure 2-8 Pasting CoDep layer



The CIGS process now consists of Layer1 and Layer2.

- Layer1 will co-deposit three films.
- Layer2 will co-deposit two films.

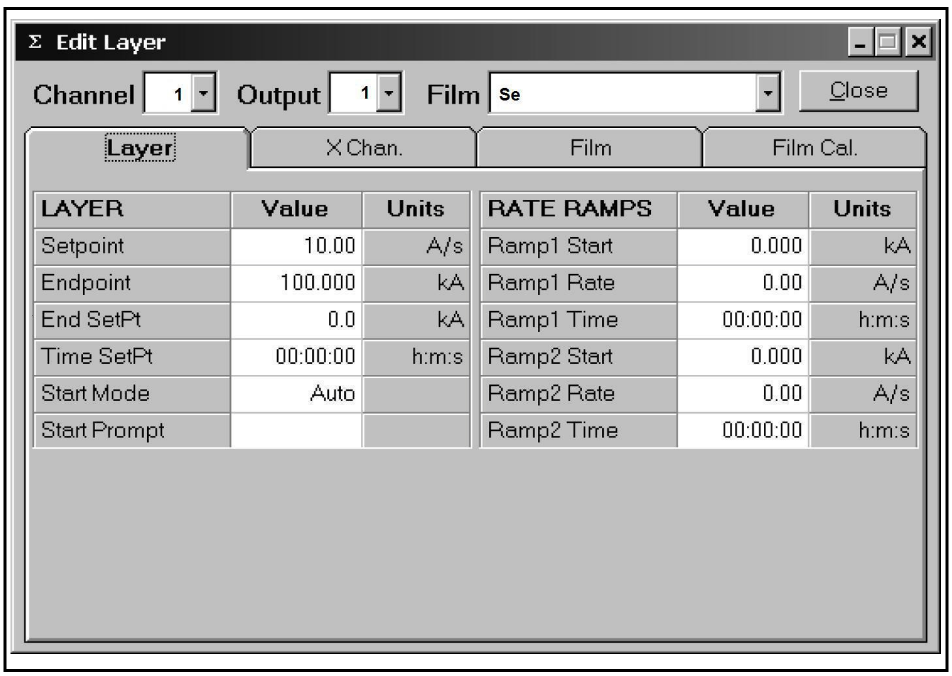
However, the channel, output, and films are all duplicates. We will correct that error in the next section.

2.3.5 Edit Layer

Highlight **Layer 1: Ch:1 Out:1 Cu** and click **Edit** to display the **Edit Layer** window. See Figure 2-9.

The **Edit Layer** window shows all of the parameters needed to deposit the selected layer. At the top of the window, select the measurement **Channel** and **Output** to be used, and the **Film** to be deposited in this layer. Select **Channel 1**, **Output 1**, and **Film Se**. We will set this up to be a QCM channel.

Figure 2-9 Edit Layer window

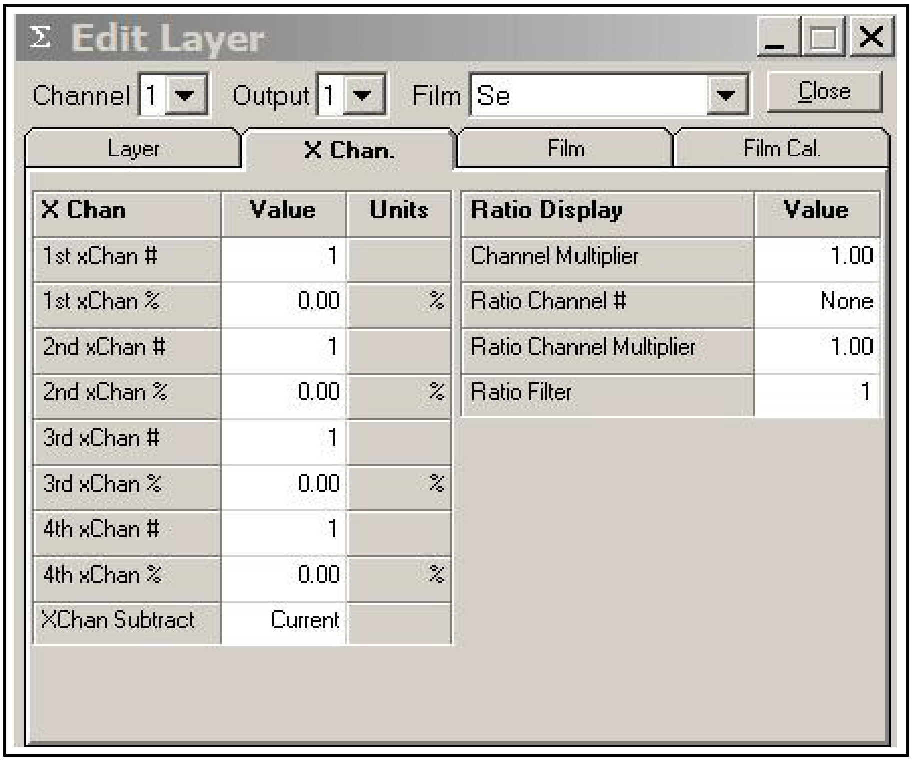


Select the **Layer** tab. Set **Rate Setpoint** to **10 Å/s** and **Thickness Endpoint** to **100 kÅ**.

PN 074-517-P1F

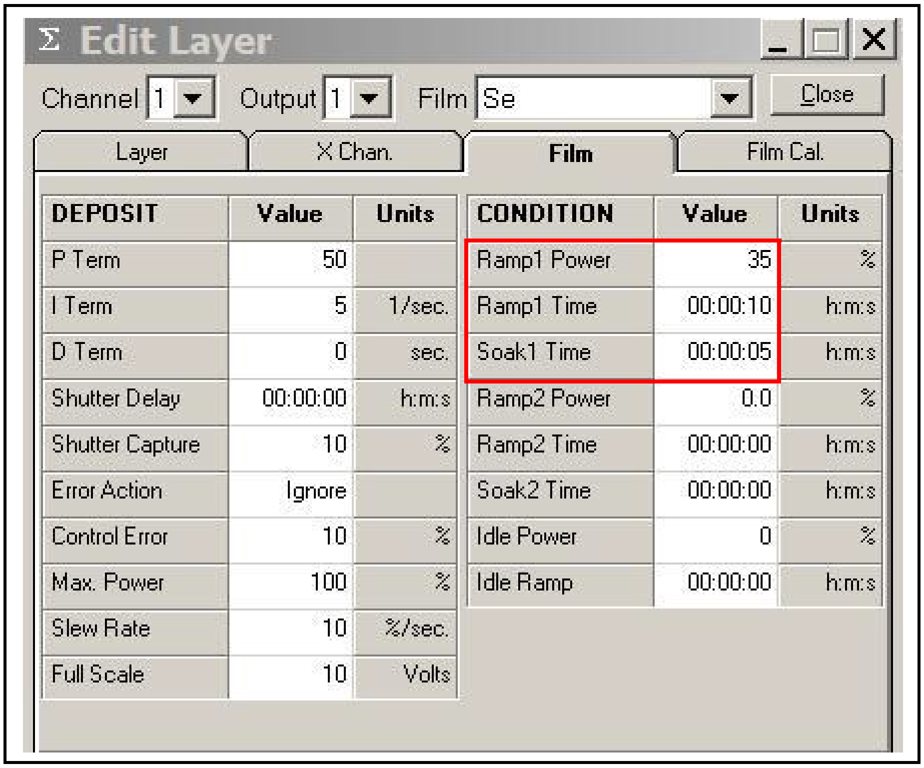
Click the **X Chan** tab to view the settings used to eliminate cross-channel interference and display the ratio of two channel's readings. For now, these features will not be used. See Figure 2-10.

Figure 2-10 Settings used to eliminate cross channel interference



The **Film** and **Film Cal**(ibration) tabs are for the selected film, **Se**. On the **Film** tab set preconditioning **Ramp1 Power**, **Ramp1 Time**, and **Soak1 Time** as shown in Figure 2-11.

Figure 2-11 Film Tab settings



DEPOSIT	Value	Units
P Term	50	
I Term	5	1/sec.
D Term	0	sec.
Shutter Delay	00:00:00	h:m:s
Shutter Capture	10	%
Error Action	Ignore	
Control Error	10	%
Max. Power	100	%
Slew Rate	10	%/sec.
Full Scale	10	Volts

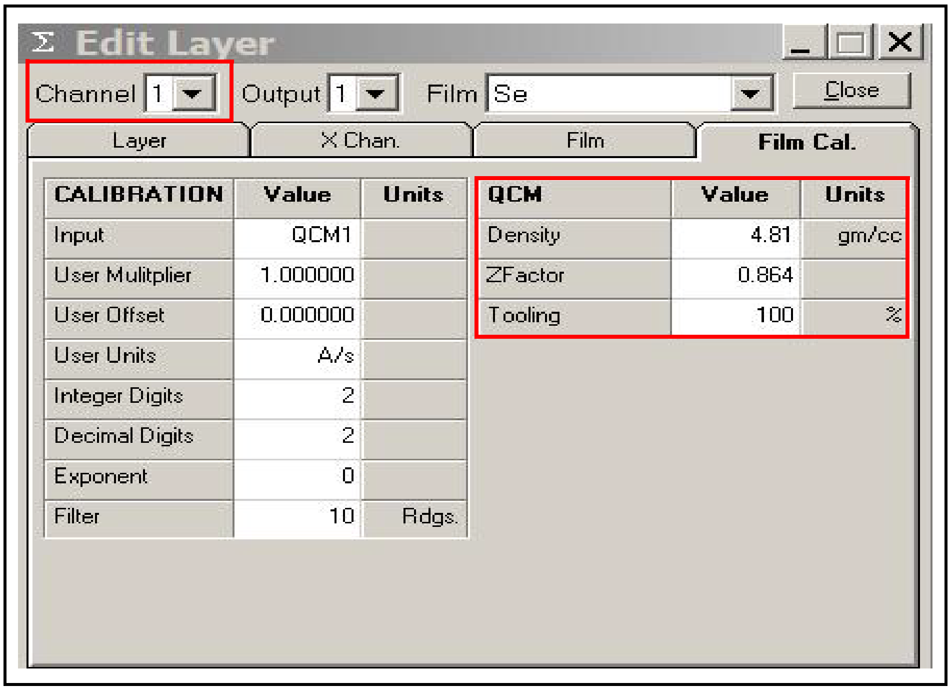
CONDITION	Value	Units
Ramp1 Power	35	%
Ramp1 Time	00:00:10	h:m:s
Soak1 Time	00:00:05	h:m:s
Ramp2 Power	0.0	%
Ramp2 Time	00:00:00	h:m:s
Soak2 Time	00:00:00	h:m:s
Idle Power	0	%
Idle Ramp	00:00:00	h:m:s

PN 074-517-P1F

Select the **Film Cal**(ibration) tab and verify **Channel Input** and **QCM** values are as shown in Figure 2-12. Note that the software for the Q-pod or SQM242 QCM to be used must be installed per the relevant instructions. Tooling must be established as described in the QCM manual or in this manual under Tooling Factor on page 6-8.

Channel numbers correspond to inputs from up to eight EIES PMT Detectors, up to four QCM inputs or up to four SAM inputs. Any combination using up to eight inputs for rate control is possible.

Figure 2-12 QCM Film Calibration tab



Keep in mind that parameters on the **Layer** and **X Chan.** tabs are unique to this layer. Those on the **Film** and **Film Cal.** tabs pertain to any layer using the film.

Take a few minutes to review the parameters on each tab. Point to a parameter to view its brief explanation. Press **F1** to view the Help file for the selected tab.

When ready, return to the **Edit Process** window, shown in Figure 2-13.

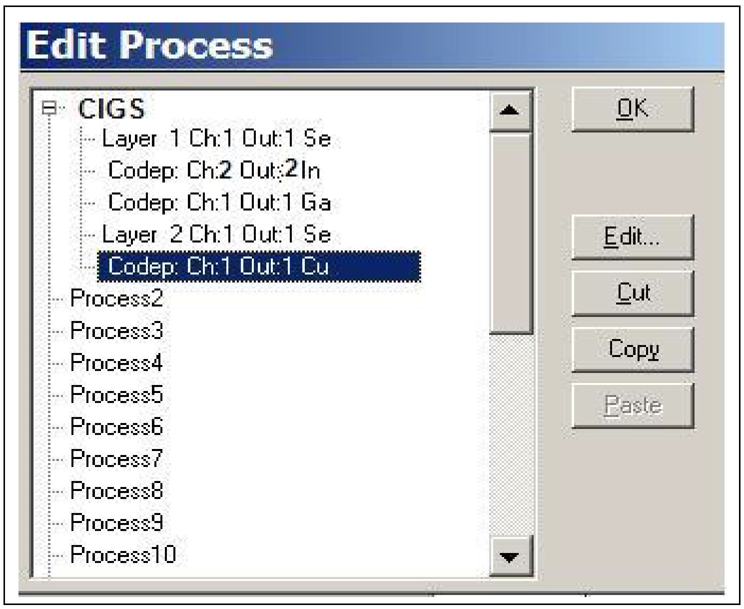
Click the indented **CoDep:** film, immediately below **Layer 1 Ch:1 Out:1 Se**.

The **Edit Layer** window will update to display the parameters for the selected layer.

In the **Edit Layer** window, set this CoDep film to **Channel 2**, **Output 2,** and select **Film In**.

- On the **Layer** tab, enter a **Setpoint** of **5 Å/s** and an **Endpoint** of **5 kÅ**.
- On the **Film** tab, set **Ramp1 Power** to **25%** and set the remaining **Film** parameters to match those for **Se**, as shown on the previous page.
- In the **Film Cal.** tab, select **EIES** as **Input** and set **Cal QCM#** to **2**.

Figure 2-13 Edit process



Return to the **Edit Process** window and click the CoDep film immediately below **Codep Ch:2 Out 2 In**.

In the **Edit Layer** window, set this CoDep film to **Channel 3**, **Output 3**, and **Film Ga**.

- On the **Layer** tab, enter a **Setpoint** of **2 Å/s** and an **Endpoint** of **2 kÅ**.
- On the **Film** tab, set **Ramp1 Power** to **15%**.
- Edit the remaining **Film** and **Calibrate** parameters to match those for **In**, as shown on the previous page.

That completes the definition of the first co-deposition layer, consisting of **Se**, **In**, and **Ga**.

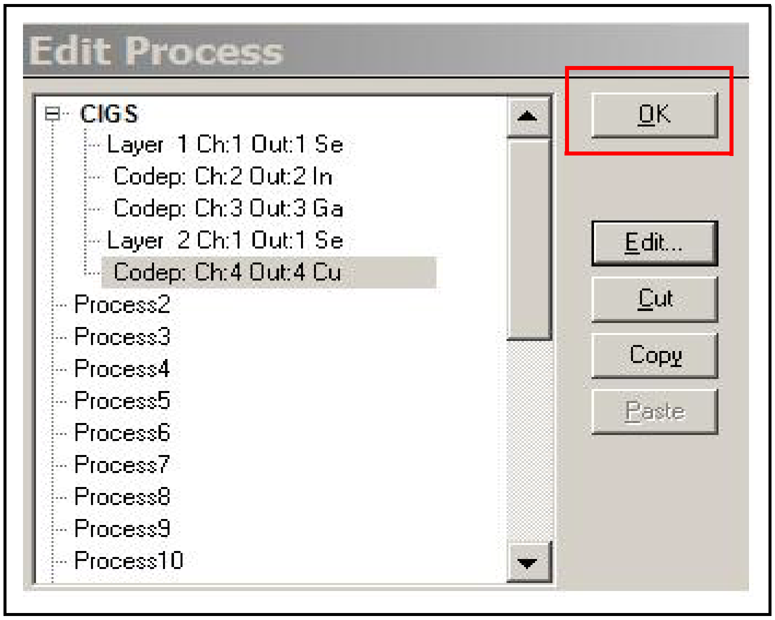
Edit Layer 2 so that the first entry is **Layer 2 Ch:1 Out:1 Se** with a **Rate Setpoint** of **10 Å/s** and **Thickness Endpoint** of **10 kÅ**.

Change the codep layer for Layer 2 to **CoDep Ch:4 Out: 4 Cu** with a **Setpoint** of **3 Å/s** and **Endpoint** of **3 kÅ EIES Input**.

When finished, the 2-layer CIGS process is as shown in Figure 2-14.

Click **OK** to return to the main screen with CIGS as the active process.

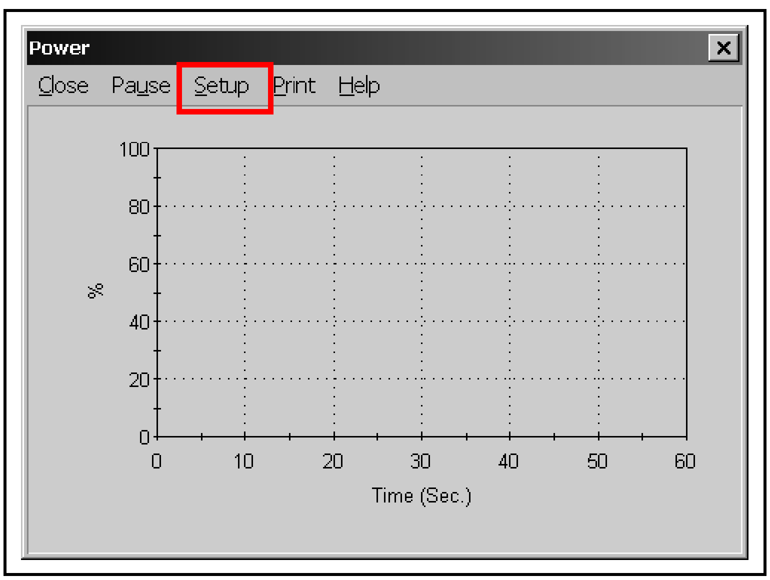
Figure 2-14 2-Layer CIGS process



2.3.6 Views

On the main screen, click **View** and select **3. Power**. You may want to rearrange some program windows at this point. You can also resize the graph by dragging its window border. See Figure 2-15.

Figure 2-15 Power graph

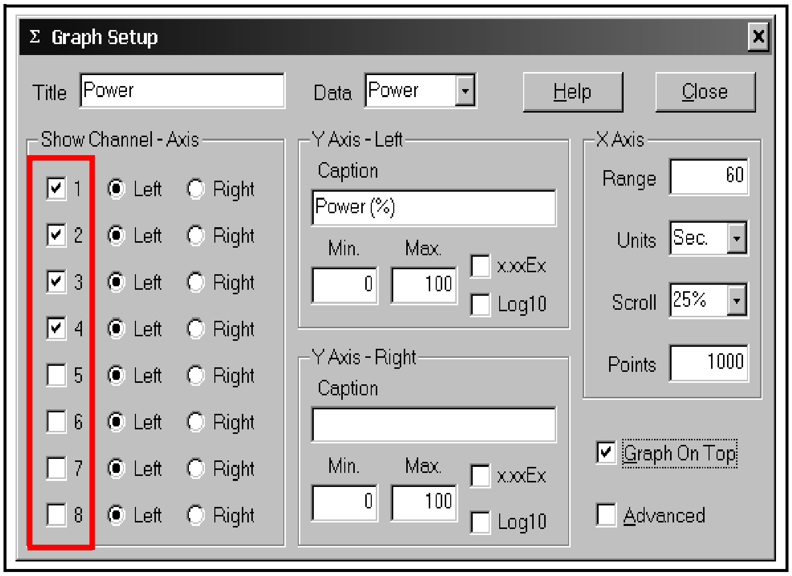


PN 074-517-P1F

The **Power** window is normally a graph of the output power of the active channels during deposition.

Click **Setup** on the graph menu to show the **Graph Setup** window.

Figure 2-16 Graph Setup window



Assign channels 1 to 4 by selecting the **Show Channel** check boxes. Also, select **Graph On Top** to keep the graph above other windows. When your **Graph Setup** window matches the one above, close the **Graph Setup** window.

2.3.7 Software Summary

Spend some time with this process to become familiar with its setup. Especially, the creation of a multi-layer and co-deposition layer process. Also, review the parameters contained in the **Layer Edit** screen. The **Layer Edit** screen will be crucial to fine-tuning your process.

2.4 Initial Setup

Connect the Guardian controller rear panel RS-232 connector to the computer's serial port using a straight through DB-9 Male-Female cable (PN 068-0464 in Guardian ship kit).

Connect your PMT Detector(s) to the rear panel of the Guardian controller with PN 782-505-065 3 m (10 ft.) or PN 782-505-065-40 12 m (40 ft.) cable(s).

2.4.1 Power-up Sequence

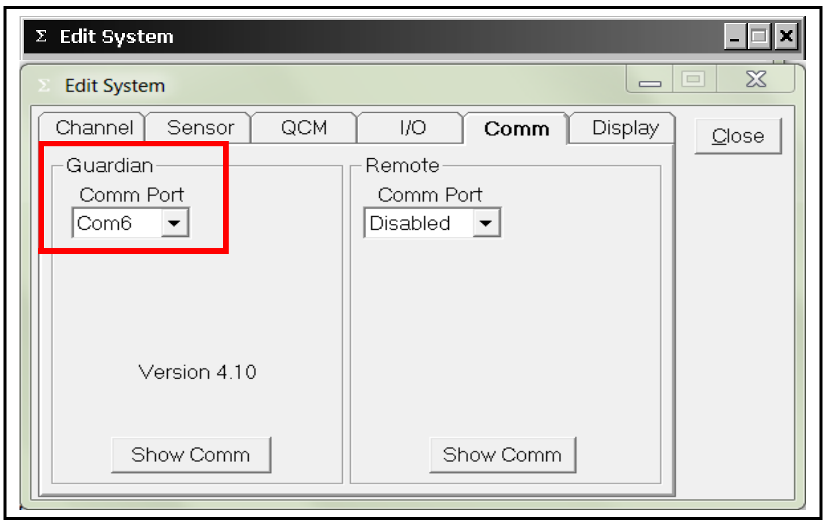
After installation has been completed per chapter 4:

1. Press the power switch on the Guardian controller.
2. Start the EIES Software.
3. Turn on the evaporation power supplies.

2.4.2 Communications

If a Comm Error message appears on the main screen status line, click **Edit >> System**, and click the **Comm** tab. Select the **Comm Port** used for communications with the Guardian controller.

Figure 2-17 Selecting Comm Port



If you are connecting to the Guardian controller by Ethernet, select **Ethernet** in the **Comm Port** drop-down list. Enter the Port (typically **2101**) and address (the default factory setting is **192.168.1.200**).

When the proper communications parameters are entered and communication is successfully established, the main screen **Comm Error** message will disappear and the screen will show **Version x.xx** where **x.xx** is the firmware version in the controller.

2.4.3 PMT Detector Calibration

Each EIES PMT Detector is pre-calibrated at the factory. To compensate for background noise once installed to a system, the following calibration must be performed.

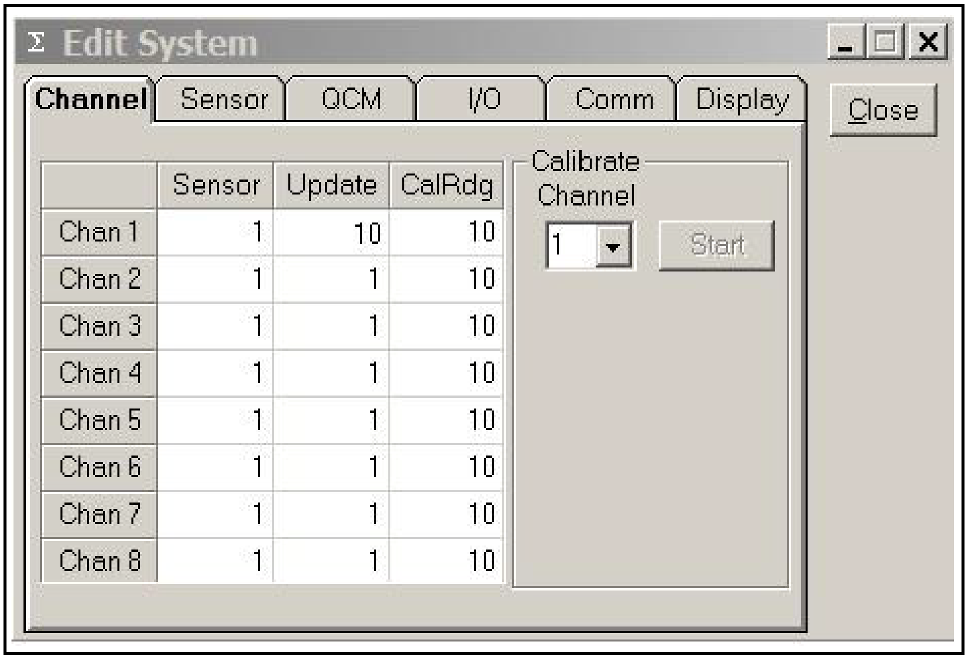
NOTE: A calibration is required when a PMT Detector is replaced or exchanged.

To calibrate a PMT Detector, click the **Channel** tab on the **Edit System** window.

Select the **Channel** you want to calibrate.

- Turn off Sensor emission.
- PMT voltage is automatically turned off during this calibration.

Figure 2-18 System Edit Channel tab



If the **Start** button is not available or there is a **No Response!** error message, shown below the **Start** button in the calibration frame, check the PMT Detector to controller cable. Power the controller off, then on again. The Guardian controller recognizes PMT Detectors only during power-up. Establishing ethernet connection may take a minute or more.

Set the PMT Detector **Update Rate** to **10 Hz** and **Cal Readings** to **10**. Lowering the **Update Rate** increases the amount of filtering and the calibration time.

When there are no errors, click the **Start** button. The screen will indicate the calibration process and end with a **Calibration Complete** message.

Select and calibrate any additional PMT Detector channels in use.

PN 074-517-P1F

2.4.4 Sensor Setup

The Guardian controller can operate up to two standard or two gas compensating sensors. During operation, the controller must maintain a constant sensor emission current. As a sensor is used and material is deposited on the sensor, an unwanted leakage current can develop. When the leakage current becomes too large, the Guardian controller can no longer control emission current.

Depending on the EIES software version, **Emission** current may be limited to:

- **2 mA** (version 5.11)
- as high as **10 mA** (version 4.xx and earlier)

In all cases **Emission** current *must* be set at no more than:

- **4 mA** when using 016-xxx series sensors with **Thoria** filaments
- **2 mA** when using 016-xxx series sensors with **Yttria** filaments

On the the sensor or replacement emitter package is a label showing the allowable emission current. **Leakage** setting of one-half the emission current setting is recommended for most applications. See Chapter 3 for more information on sensor setup.

CAUTION

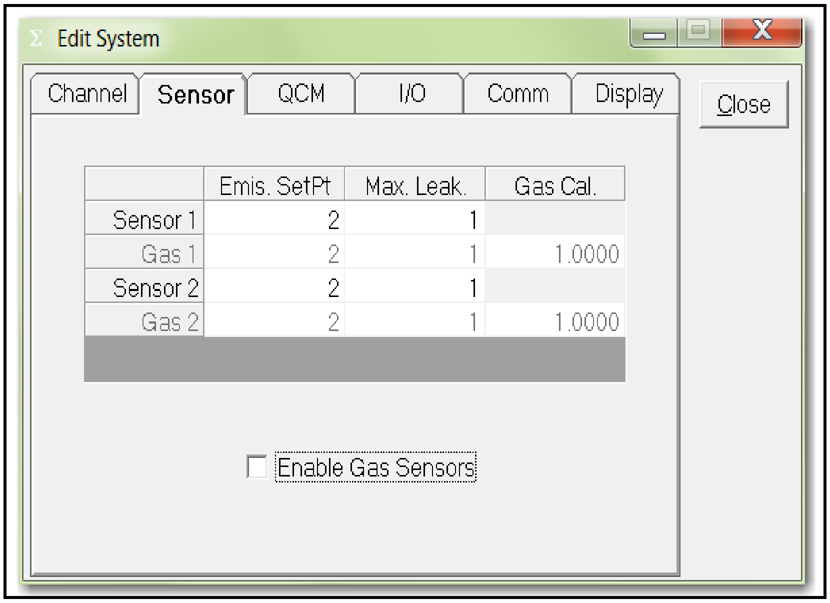
Refer to the label attached to the sensor or emitter assembly package for correct emission current settings.

CAUTION

Do not operate 016-xxx series sensors with Yttria filaments at Emission current greater than 2 mA. Instant filament failure may occur!

016-xxx series sensors with Thoria filaments with ####T serial numbers may be operated at up to 4 mA emission.

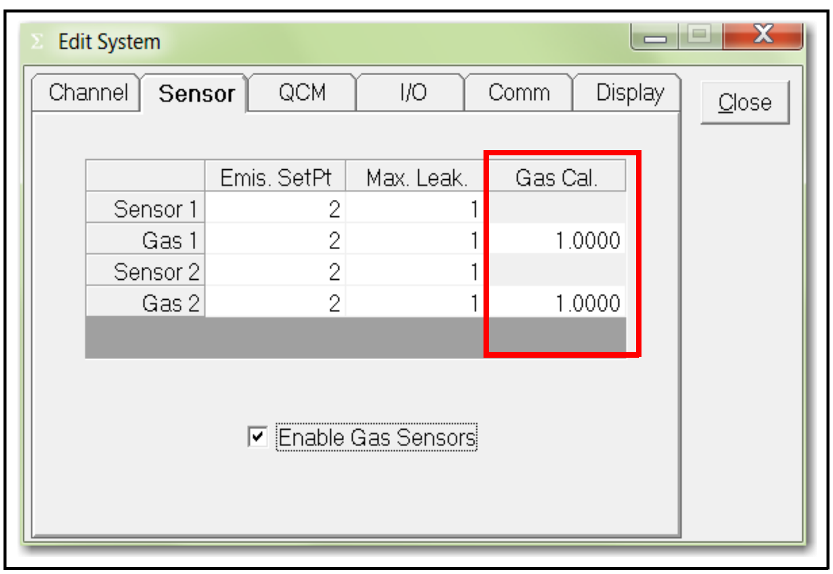
Figure 2-19 Edit System Sensor tab



This is set up for standard sensor(s). **Gas** # rows and **Gas Cal** column are dimmed.

A **Gas Cal**(ibration) factor is used to null the gas effect from the main sensor readings when a gas compensating sensor is in use. See Figure 2-20.

Figure 2-20 Gas Calibration factor



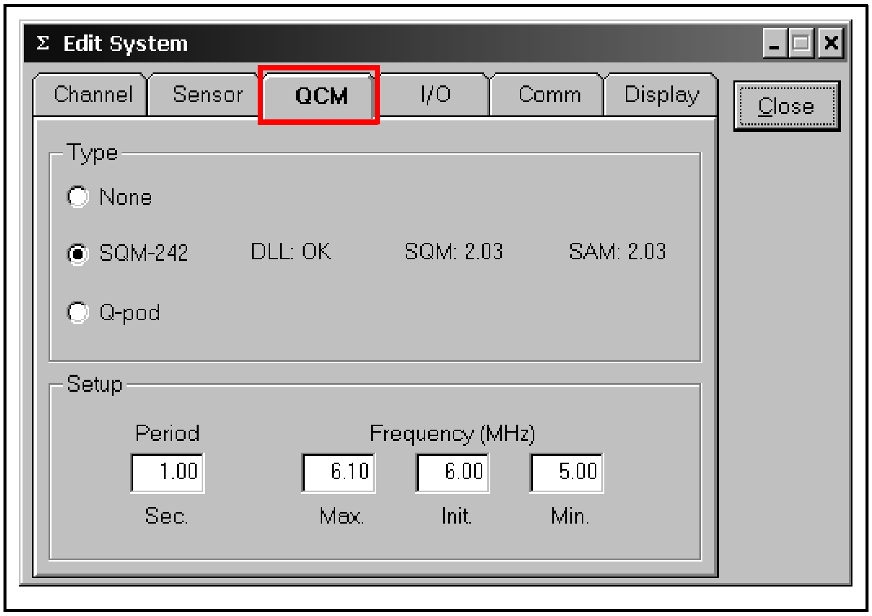
See Sensor Tab on page 3-33 for a description of the **Gas Cal** parameter.

PN 074-517-P1F

2.4.5 QCM Option

If the optional SQM-242 card or Q-pod is installed, click the **QCM** tab on the **Edit System** window.

Figure 2-21 QCM tab



If the SQM-242 card is installed properly, **Card: 2.XX, DLL: OK** is displayed.

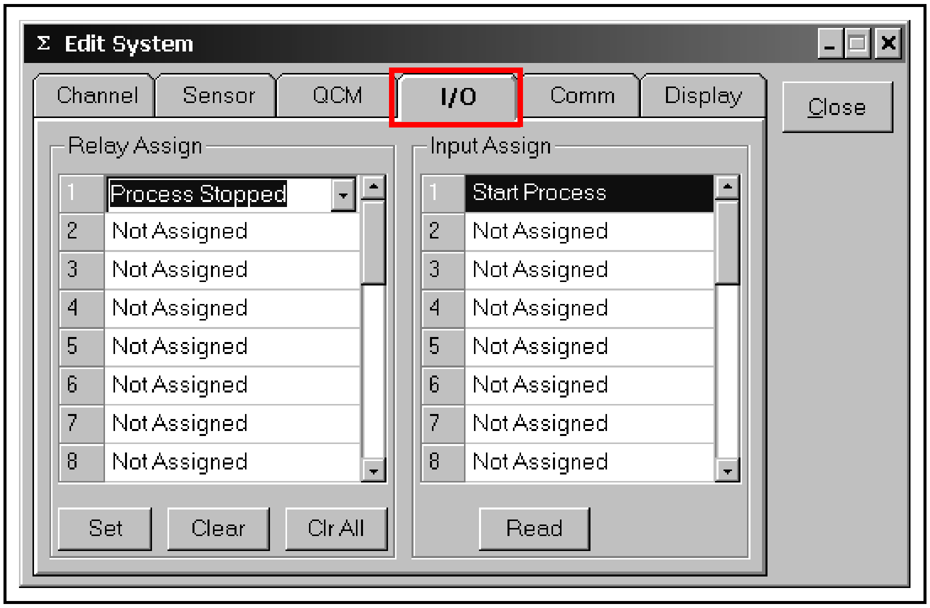
If you are using a Q-pod, its serial number appears.

Verify that each sensor attached to the QCM displays a frequency reading on the main screen.

2.4.6 Digital I/O

The **I/O** tab of the **Edit System** window assigns the Guardian controller's relays and digital inputs to program functions. See Figure 2-22. Most digital I/O are not necessary for initial operation. See Chapter 3 for I/O programming, and Chapter 4 for I/O wiring.

Figure 2-22 I/O tab



2.5 Operation

Before continuing, work through the example process of section 2.2, Installation, on page 2-1 and the initial PMT Detector calibration of section 2.3, EIES Software, on page 2-6.

2.5.1 Build a Single Layer Process

Build a simple single-layer, single-film process in the EIES program and make it the active process (refer to section 2.2 on page 2-1).

Verify that the EIES channel used has no errors, and shows a reading near zero (refer to section 2.3 on page 2-6).

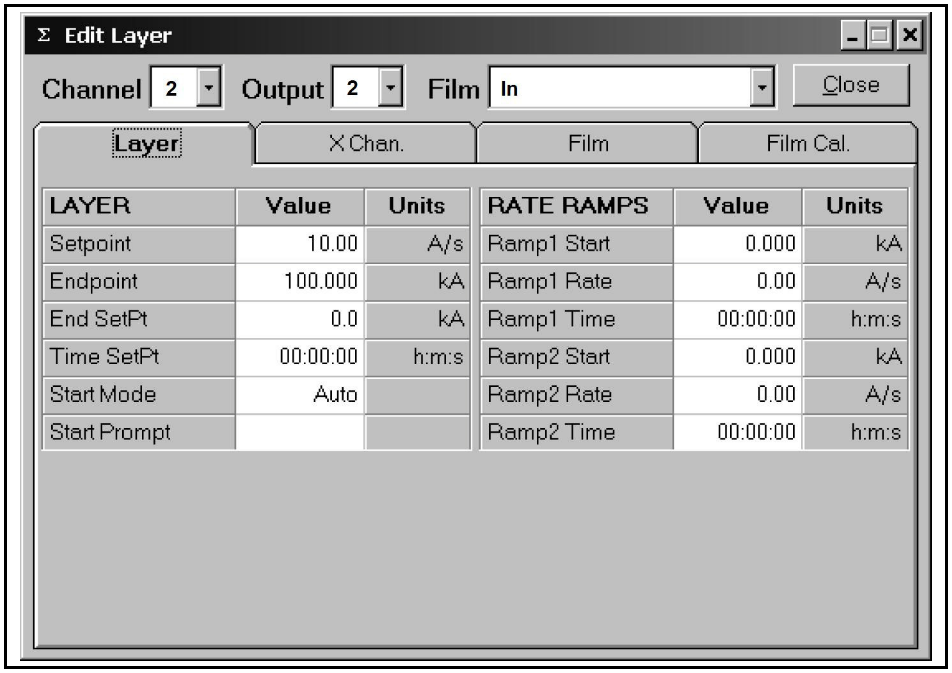
PN 074-517-P1F

2.5.2 Setup Layer Parameters

Click **Edit** to display the **Edit Layer** window for the channel in use. (**Edit** is located to the left of that channel on the main screen.)

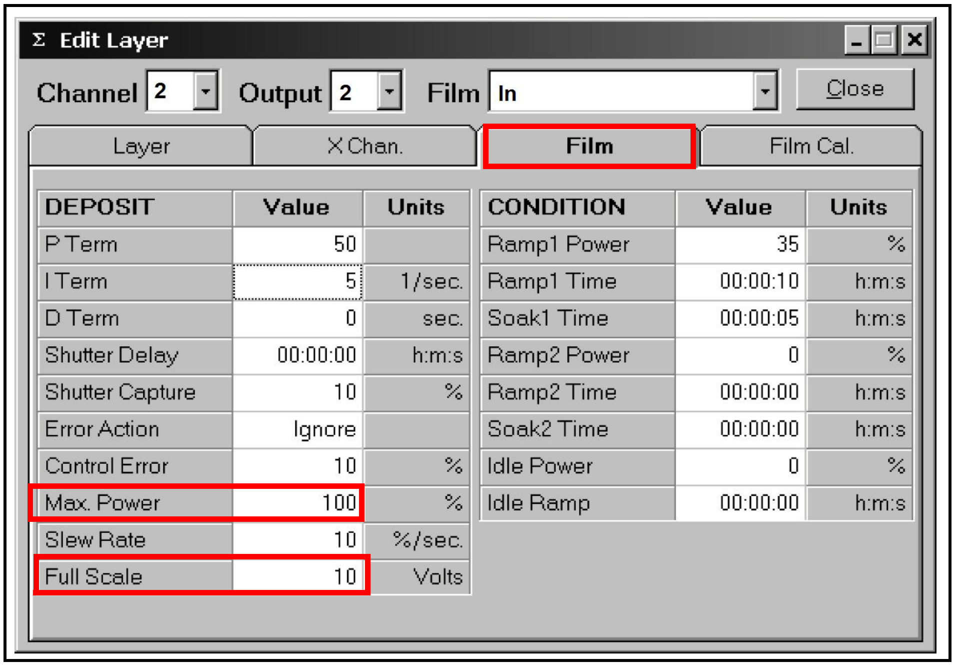
Select the **Layer** tab on the **Edit Layer** window and verify that the **Endpoint** is a value high enough to avoid prematurely halting the process during calibration. See Figure 2-23.

Figure 2-23 Endpoint value



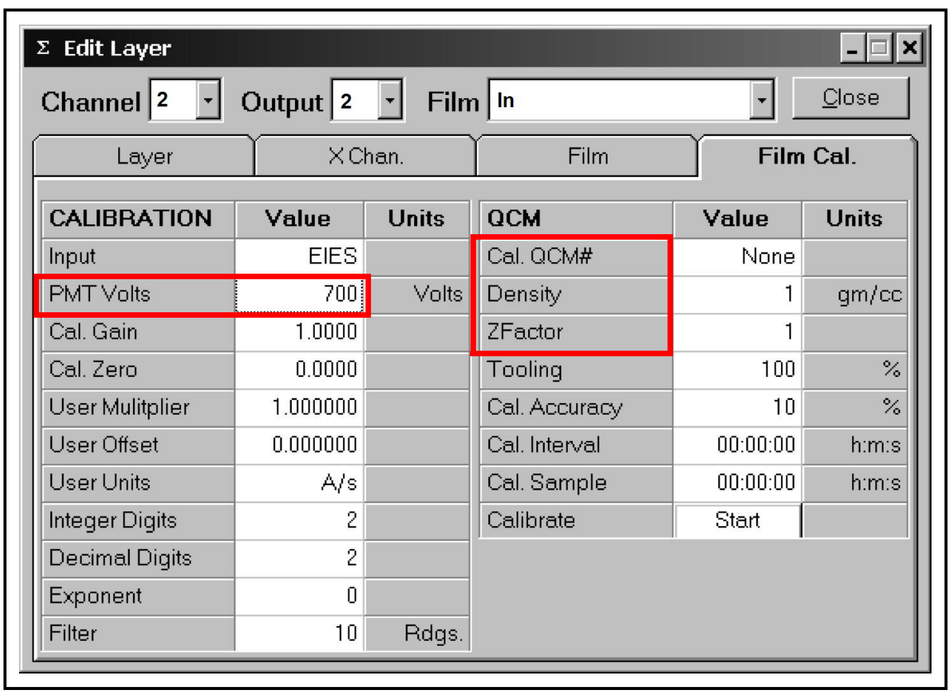
On the **Film** tab, see Figure 2-24, verify that the **Full Scale** voltage matches the input of the power supply. Also verify that **Max. Power** is consistent with the material being evaporated.

Figure 2-24 Film tab full scale voltage



Select the **Film Cal**(ibration) tab, and verify that the **PMT Volts** setting is about **700**.

Figure 2-25 PMT voltage setting



If using QCM calibration of the EIES measurements, select the proper **QCM** Sensor# and enter the material **Density** and **ZFactor** (Z-Ratio). See Appendix B for ZFactors.

PN 074-517-P1F

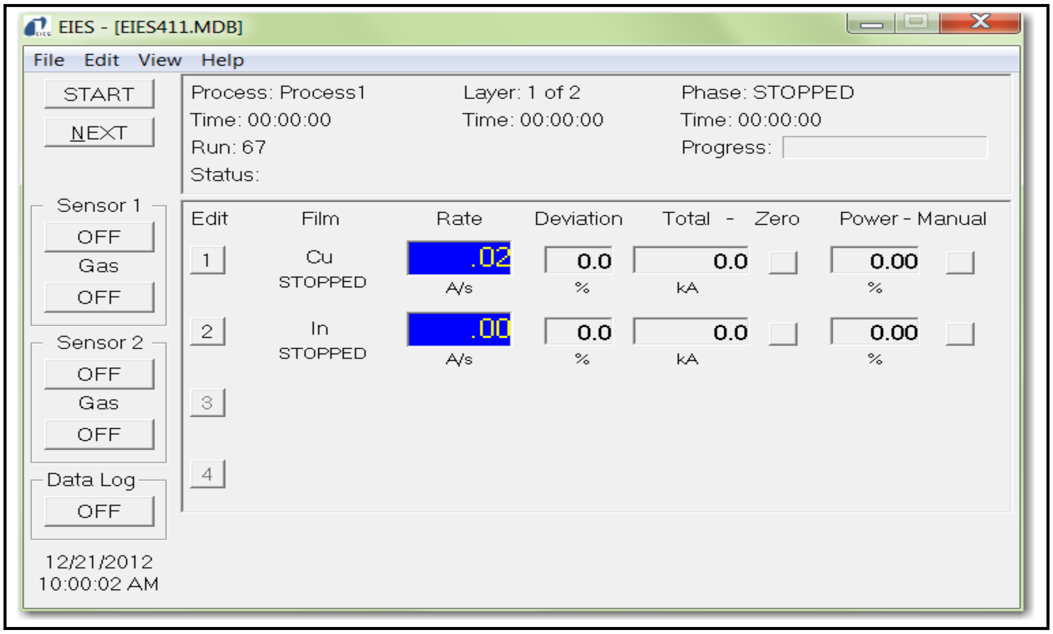
2.5.3 Start Deposition

CAUTION

Pump down the vacuum chamber to below 1E-5 Torr before operating the EIES-IV system.

On the EIES main screen verify that there is no error message in the **Film** column on the channel(s) being used, and verify that **Rate** reading is near zero.

Figure 2-26 Verifying rate reading is near zero



On the main screen, turn Emission **ON** for the EIES sensor(s) by clicking **OFF** under the sensor number on the left side of the screen.

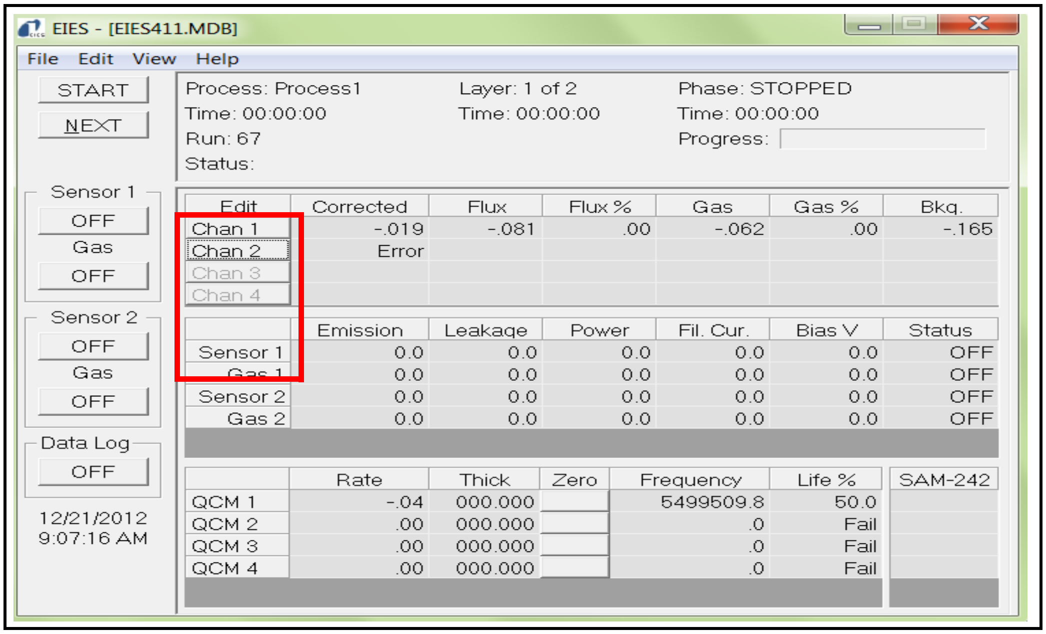
Gas compensating sensors have two filaments, one in the flux sensor, the other in the gas sensor, see Figure 5-1 on page 5-2. The **OFF** button under the Gas designator is used to turn the filament for the gas sensor on and off. The rate reading on each channel should still be near zero, but changing slightly.

Turn on your evaporation power supply. Click **Channel 1 Manual Power** (on the right side of the screen). Enter a small power value and press **Enter** to send the value to the power supply. Slowly increase power until the material vaporizes and the rate reading starts to increase above zero.

If everything looks OK, increase the power to near the desired deposition rate. The deposition rate can be determined before EIES calibration from previous experience with the power supply output level, another measurement reference, or from the optional QCM readings.

To optimize the detector PMT voltage, select **View >> Readings** to show the PMT Detector readings, see Figure 2-27.

Figure 2-27 Channel Edit button

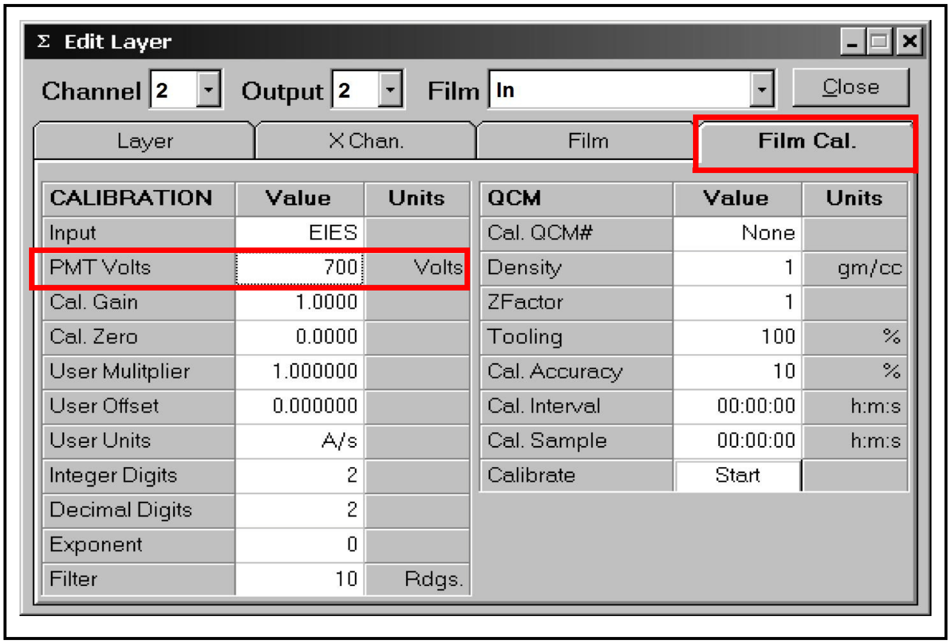


If an installed SQM-242 or Q-pod does not show a frequency reading, display the **Edit System** screen, see Figure 2-21 on page 2-23. Set **Type** to **None** and then **SQM-242** or **Q-pod**. Click the channel **Edit**.

The **Edit Layer** window is displayed, see Figure 2-28. On the **Film Cal.** tab of the **Edit Layer** window, adjust the **PMT Volts** until the readings for the appropriate channel are stable and low.

HINT: Low PMT Volts values cause low flux readings.
High PMT Volts values increase noise and may saturate the PMT.

Figure 2-28 Film Calibration tab PMT Voltage



2.5.4 Manual Calibration

Calibrate the main screen rate reading to match the actual rate by entering a **Cal. Gain** on the **Edit Layer**, **Film Cal.** tab. The **Cal. Gain** parameter is calculated by equation [1].

$$\text{Cal. Gain} = \frac{\text{EIES Measured Rate}}{\text{Actual Rate}} \qquad [1]$$

2.5.5 QCM Calibration

If you are not using the QCM calibration option, skip to section 2.5.6.

If you are using the QCM calibration option, select **View >> Readings** to display the QCM readings grid. Verify that the QCM measured rate is as expected. The QCM measured rate will be used to calibrate the EIES PMT Detector channel.

CAUTION

Allow the controller to warm up for one hour with the emission turned on for fifteen minutes prior to calibration.

On the **Edit Layer** window, **Film Cal.** tab, click calibrate **Start**. After a few seconds the calculated **Cal. Gain** will display. Verify that the main screen's rate reading matches the QCM rate.

2.5.6 Stop Deposition

This completes the initial operational checkout. Set **Manual Power** to zero on the main screen to stop deposition. If you previously pressed **Start**, click **Stop** to halt the process.

Chapter 3
EIES Software

3.1 Introduction

EIES-IV Guardian software is a turnkey deposition control program for the EIES Guardian controller. The program uses ASCII commands to communicate with the Guardian controller. EIES-IV Guardian software is a powerful computer-based thin film deposition controller that can:

- Measure up to eight materials simultaneously.
- Operate two standard or two gas compensating (GC) sensors.
- Control up to eight deposition sources simultaneously.
- Calibrate EIES sensors against quartz crystal sensors (when used with either the SQM-242 or Q-pod option).
- Monitor and control analog variables such as temperature and pressure (when used with the SAM-242 option).
- Store up to 25 processes and 250 layers on disk.
- Graph and log deposition data to disk for process documentation and analysis.

Version 4.xx and higher EIES-IV Guardian software is compatible only with version 4.x firmware and vice versa.

Version 5.11 software only allows 2 mA operation and is otherwise identical to version 4.11.

Firmware versions prior to 4.x are compatible with version 2.x EIES-IV Guardian software.

The controller firmware is shown on the instrument label affixed to the controller side panel. Earlier versions of the controller may not have this label.

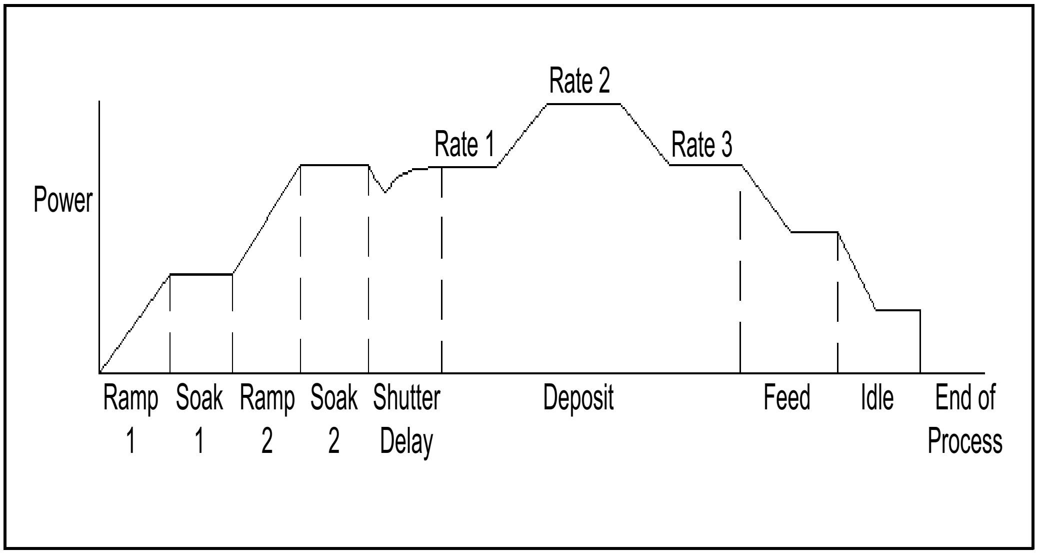
NOTE: If parameters are sent to the Guardian via external communications using commands as described in section 7.3, Guardian Controller Direct Communications, on page 7-9, the new parameters will not be updated on the EIES-IV Guardian software screens.

New parameters sent to the Guardian via the ActiveX interface described at section 7.2, ActiveX (COM) Interface, on page 7-1, will be shown after the relevant screen is closed and reopened.

A typical deposition cycle for a thin film can be broken into three distinct phases:

1. Pre-conditioning (ramp/soak)
2. Deposition
3. Post-conditioning (idle)

Figure 3-1 Phases of the deposition cycle



During pre-conditioning, the source material is prepared for deposition. The first ramp/soak pre-conditioning phase is used to bring the material to a uniform molten state. The second ramp/soak phase is typically set to a power that produces evaporation below, but near the desired deposition rate.

When pre-conditioning ends, PID rate control of deposition begins. Initially, the substrate material may remain shuttered until the desired deposition rate is achieved (shutter delay). Once the control loop achieves the desired rate, the shutter opens and deposition begins. During deposition, multiple rates (rate ramps) can be programmed.

When the desired thickness is reached, the evaporation source can be set to zero or non-zero idle power. At this point the process may be complete, or deposition of another layer may begin. Up to eight separate films can be co-deposited within a single layer.

In addition to using EIES PMT Detectors for rate control, QCM inputs (from INFICON SQM-242 card or Q-pod) can also be used to control deposition, or to calibrate the EIES PMT Detector. DC voltage inputs (measured by INFICON SAM-242 card) can also be used to control other process variables.

3.2 Installation

NOTE: The EIES program may be installed and used without an EIES-IV Guardian controller. This is useful for learning the software, and for off-line process development.

To install the software:

1 Insert the 074-5000 INFICON Thin Film Manuals CD into your CD-ROM drive.

2 Open Windows Explorer.

3 Click the drive holding the 074-5000 CD.

4 Click the **EIES Guardian** folder.

This folder contains Guardian manuals and the software for both obsolete instruments versions and the current version.

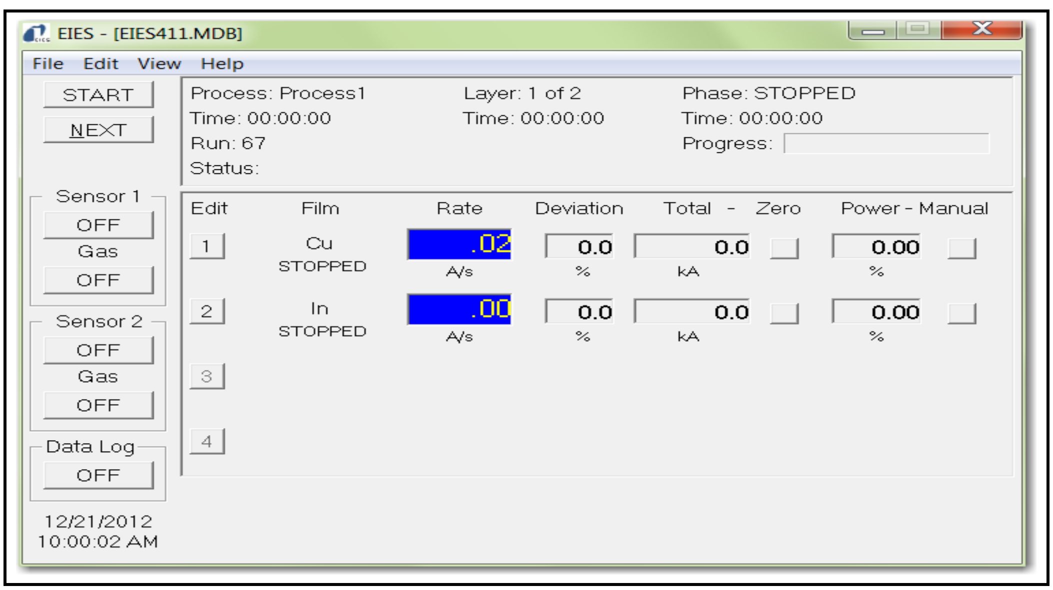
5 Click **EIES_V411_SETUP.EXE** to install the current software version compatible with the current firmware version 4.x.

NOTE: Contact INFICON to upgrade an earlier firmware version or for information about other software versions.

6 When EIES software installation finishes, a prompt to restart your computer may be displayed.

To start the EIES software click the **EIES** desktop icon, or click **Start** >> **Programs** >> **INFICON** >> **EIES**. The EIES program main screen will be displayed.

Figure 3-2 EIES program main screen



NOTE: The following description covers operation without a Guardian connected. If a Guardian is to be connected at this time, select the communications interface as described at section 3.8.5, Comm Tab, on page 3-38 before proceeding.

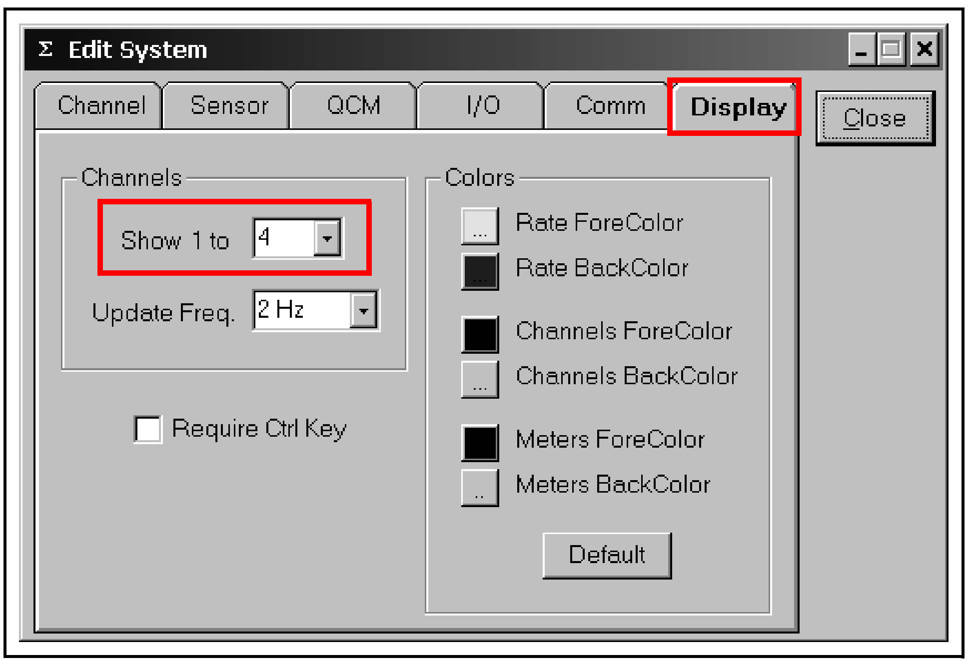
To make RS232 connections, connect a serial cable from the Guardian serial port to the computer's serial port. The cable required is a DB9 female-to-male. Guardian baud rate is fixed at 115,200 and the communications format is No Parity, 8 bits, 1 stop bit.

To make ethernet connections, connect an ethernet cable and set the IP Address as described at section 3.8.5, Comm Tab, on page 3-38.

The EIES main screen displays the last used Process, and the film(s) defined for the first layer of the process.

The main screen can show from four to eight channels of data. For most applications, four channels will be adequate. To select the number of channels displayed, click **Edit >> System**. On the **Edit System** window click the **Display** tab. In the **Show 1 to** box, select the number of channels to be displayed.

Figure 3-3 Edit system display tab



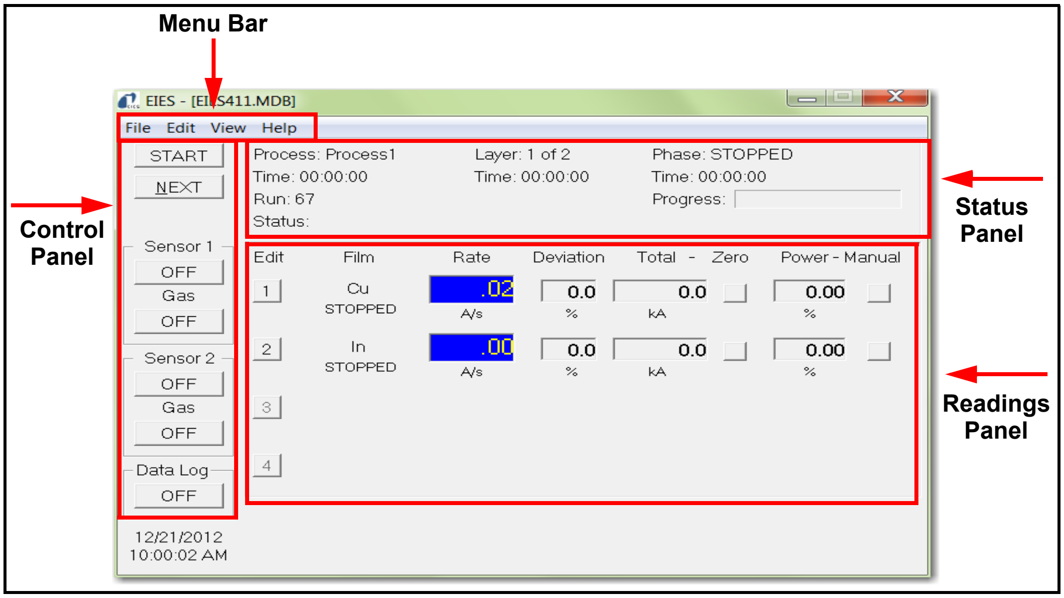
PN 074-517-P1F

3.3 Main Screen

The EIES main screen, see Figure 3-4, consists of three panels and a menu bar.

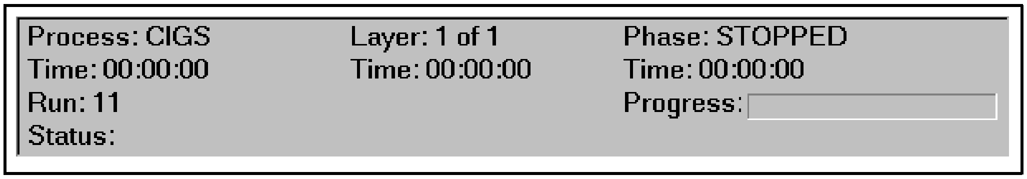
- The **Status** panel displays information on the active process.
- The **Control** panel controls operation of the EIES-IV Guardian system.
- The **Readings** panel displays readings from each of the channels used by the active process layer.
- The **Menu Bar** provides access to process recipe and instrument setup functions.

Figure 3-4 EIES main screen



3.3.1 Status Panel

Figure 3-5 Status panel



Process: Name of the current process. Select the active process using **File >> Open Process**.

(Process)Time: The accumulated time for this run of the selected process. Resets to zero, then starts counting when the **Start** button is clicked.

Run: The number of times this process has been run. The run count can be zeroed on the **File >> DataLog** screen.

Status: Displays error conditions and other status information.

Layer: Displays the current layer and the total number of layers in the active process. Use the **Next** button on the Control Panel to select layers.

(Layer) Time: The accumulated time for this layer. Resets to 0 if the layer is stopped.

Phase: The current layer phase. Phases consist of pre-conditioning (Ramp1, Soak1, Ramp2, Soak2), Shutter Delay, Deposition, and post-conditioning (Idle Ramp). Additional phases, such as Stopped, Layer Stopped and Filter change are also displayed.

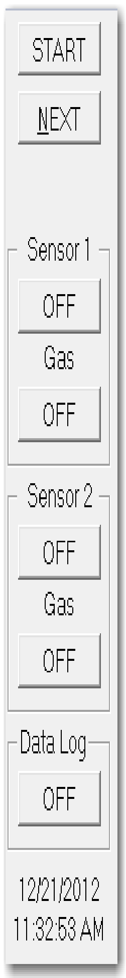
(Phase) Time: Phase time is shown as ElapsedTime/TimeRemaining.

Progress: A graphical display of the percent complete for the current phase.

3.3.2 Control Panel

NOTE: To avoid accidental activation of the **Start/Stop**, **Auto/Man**, and **Emission** controls, press and hold the **Ctrl** key while clicking the control. This feature can be disabled on the **Display** tab of the **Edit System** screen.

Figure 3-6 Control panel



Start/Stop: Click **Start** to run the process. The **Start** control is disabled if there are no communications with the EIES controller. When the process is running, the top control displays **Stop**. Click **Stop** to stop the process and set all outputs to **0**. Press **Start** again to restart the layer.

Next: When the process is stopped, click **Next** to move to the next process layer. The selected layer is displayed in the **Status** panel. When **Start** is clicked, the process will start at the selected layer.

Reset: When a process is stopped, click **Reset** to abort the process and reset the selected layer to **1**.

Emission Controls: When first started, both the EIES instrument and this program turn both sensors Off. Be sure Emission is turned on by clicking on the **OFF** button before running the process or no valid EIES readings will occur. Turn sensor Emission Off when not in use, or anytime the pressure exceeds 5×10^{-4} Torr. When Gas Compensating sensors are used, both the main sensor and the Gas sensor should be on, otherwise gas compensation will not be in effect.

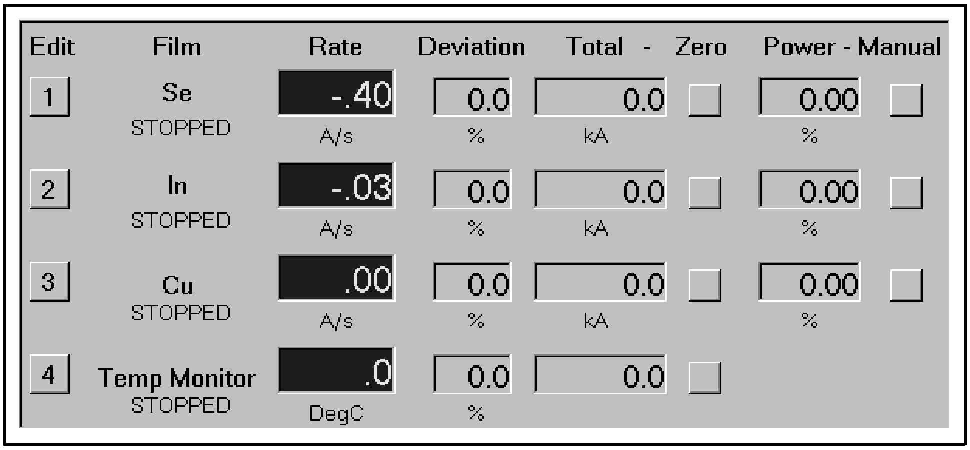
When emission is On, the sensor's emission current is displayed with a green background. If the leakage current reaches 70% of the maximum allowed value, the background turns yellow. Maximum Leakage is set in the **Edit System** window, **Sensor** tab.

DataLog Control: Turns disk data logging on/off. Data is logged only while the process is running. Edit data logging options in the **File >> DataLog** menu.

3.3.3 Readings Panel—Process Mode

The **Readings** Panel, see Figure 3-7, has two display modes: **Process** and **Readings**. Click **View >> Process** to see the **Process** display. The **Process** display mode shows process related information such as films, setpoints, and manual operating controls. Only channels that are defined for the selected layer are displayed. Use **Edit >> System >> Display** to select a 4 to 8 channel display.

Figure 3-7 Readings Panel Process display



Edit Button: Click **Edit** to display the **Edit Layer** display for the channel. See section 3.6, Edit Layer, on page 3-18 for detailed layer edit information.

Channel Film Display: Displays the film assigned to the channel and the current phase of the channel. During deposition, the current rate setpoint for the channel is also displayed.

Channel Rate: Displays the deposition rate reading for the channel. The EIES PMT Detector measures rate as a current. The current reading is converted to Å/s (or the desired user units) using film parameters described in section 3.7, Edit: Film, on page 3-29.

Deviation: The deviation in percent of the measured rate from the desired rate setpoint.

Total: The accumulated Total thickness for the channel. Typically, rate is displayed in Angstrom per second (Å/s) and Total is displayed in kÅ.

- For EIES PMT Detector measurements, Total is calculated by summing each reading times the reading period (then dividing by 1000 to convert to kUnits).
- For QCM inputs, Total is the thickness returned by the quartz crystal. If a channel uses a SAM analog input, Total is meaningless and is not displayed.

Zero (Total): Zeroes the accumulated total for the channel. To zero all channel totals, hold the **Shift** key and click any channel **Zero** button.

Power: Displays the output power in percent of full-scale voltage.

Manual (Power): Switches the output power between PID loop control and manual user setting. When pressed, the background of the **Manual** power button and the **Power** display turns green. The initial manual power value is the same as it was when the **Manual** power button was pressed. In Manual power mode, you may type a new power setting and press **Enter** to change the output power setting.

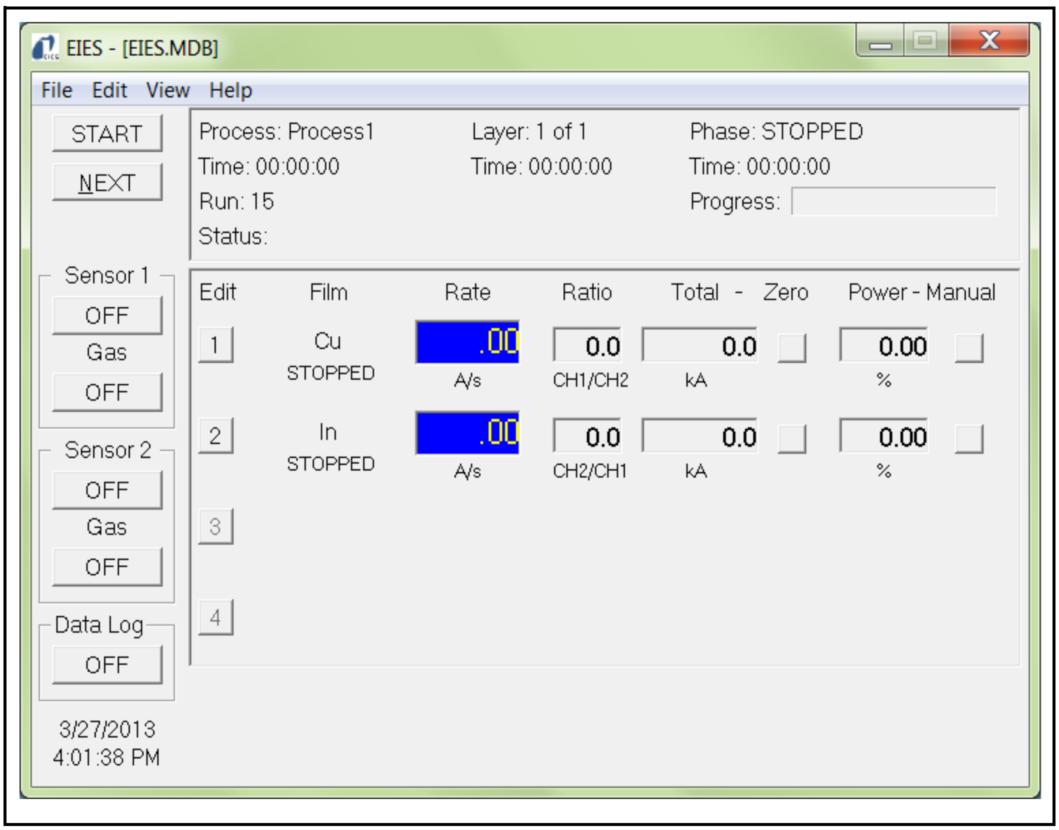
Click **Manual** again to return to auto (PID control) mode.

- If the process is stopped, the power will be set to zero.
- If the process is running, the channel goes immediately to the deposit phase, with power set by the PID control loop.

NOTE: Because the **Edit Process** display allows editing of a layer's input and output assignments, Manual Power can only be changed when the **Edit Process** window is closed.

3.3.4 Readings Panel—Ratio Mode

Figure 3-8 Ratio mode

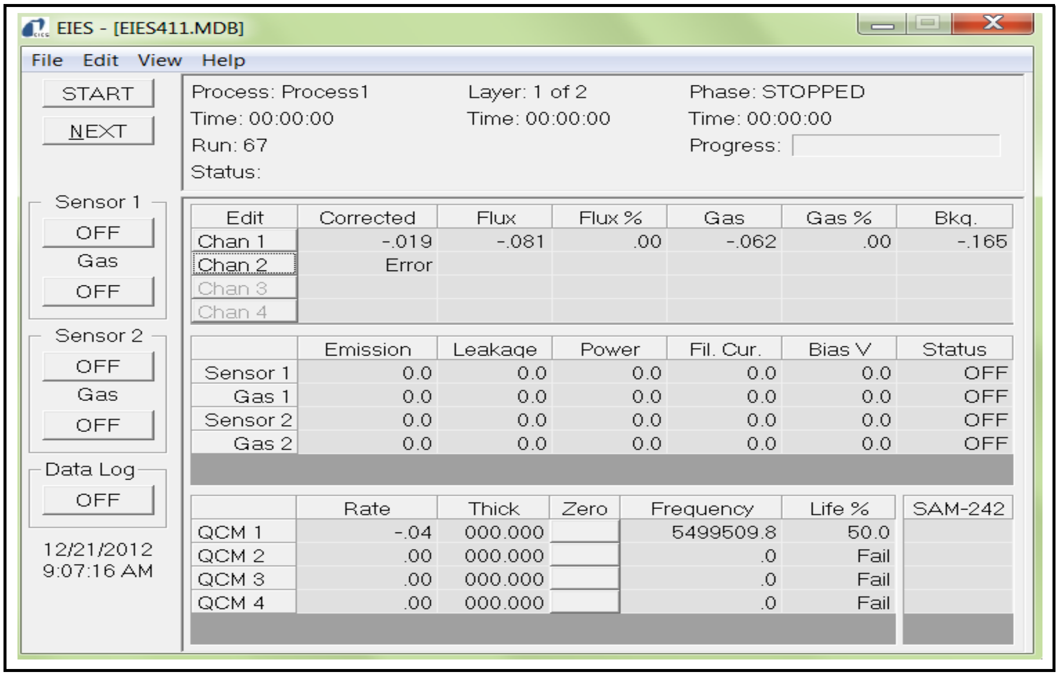


Click **View >> Ratio** to see the **Ratio** display. Refer to Figure 3-8. The **Ratio** display is similar to the **Process** display except that the deviation readings are replaced with the ratio of the channel's reading to another channel. The two channel numbers are shown below the ratio reading. Ratios are set up in the **Edit Layer** window. See Ratio Display Grid on page 3-22 for more information on channel ratios.

3.3.5 Readings Panel—Readings Mode

Click **View >> Readings** to see the **Readings** display. See Figure 3-9. The **Readings** display shows unfiltered channel (PMT Detector), sensor, and QCM readings.

Figure 3-9 Readings Panel Readings display



3.3.5.1 Channel Readings

Each channel uses the following three measurements to calculate the channel current signal.

1. **PMTCurOn:** The first measurement cycle measures the PMT current with sensor bias voltage on. This is a measure of the deposition flux, plus any background signal from ambient light or the sensor filament. This measurement also includes any broadband emission from other process gases.
2. **PMTCurOff:** The second measurement cycle measures the PMT current with sensor bias voltage off. With bias voltage off, no electron emission occurs. Hence, this is a measure of only background light.
3. **PMTCurGas:** The third measurement cycle measures the PMT current generated if the gas compensating (GC) sensor is present. The GC sensor includes an element that is not exposed to materials being deposited. It measures only the emission caused by gases, especially water vapor and nitrogen plus any background light. If the standard sensor is in use, this current will be near zero.

When the three measurements are completed, the channel readings are displayed as:

Corrected: equals PMTCurOn minus PMTCurGas.

Flux (nA): The flux plus gas signal, minus the background light.

Flux %: The % of full scale for the PMT and A/D converter circuits. Large values risk overloading the measurement circuit. Small values cause poor signal to noise ratios. Adjust the detector PMT voltage to achieve 30 to 80%.

Gas (nA): equals PMTCurGas minus PMTCurOff.

Gas %: The % of full scale for the PMT and A/D converter circuits of the GC sensor.

Bkg (nA): The ambient light signal.

3.3.5.2 Sensor Readings

Emission (Current): The sensor filament emits electrons to excite the valence electrons of the measured material. Emission current is a measure of the electron current emitted by the filament.

CAUTION

Refer to the label attached to your sensor or emitter assembly package for correct emission current settings.

CAUTION

Do not operate 016-xxx series sensors with Yttria filaments at Emission current greater than 2 mA. Instant filament failure may occur!

016-xxx series sensors with Thoria filaments with ####T serial numbers may be operated at up to 4 mA emission.

Leakage (Current): As a sensor is used, material deposited on the sensor can create leakage paths for the emission current. Leakage current is measured when the bias on the filament is at +180 V, and no emission occurs. Values above 50% of the Emission current indicate the sensor may need to be cleaned or replaced.

(Filament) Power: The power, in watts, supplied to the sensor filament. 8.5 W or less is normal. As the chamber pressure rises or the filament wears, filament power and light intensity created by the filament will increase.

Fil(ament) Cur(rent): The current flowing through the filament. Around two to three amps is normal.

Bias V(oltage): The voltage used to accelerate the emitted electrons. The factory setting is 180 V.

Status: Fail indicates an open filament.

3.3.5.3 QCM Readings

The QCM grid is shown only when an SQM-242 or Q-pod QCM is installed.

Rate: The deposition rate (in Å/s) measured by each QCM sensor.

Thick(ness): The deposited thickness measured by each QCM sensor.

Zero: Click to zero the measured thickness, or shift-click to zero all thickness. Normally handled automatically by the EIES software when a new layer begins.

Frequency: The measured frequency of each QCM sensor. A negative value indicates a sensor failure. A QCM requires a density, Z-Ratio, and tooling factor to properly display rate and thickness. However, frequency is always displayed. During deposition, the frequency will decrease. With no deposition, the frequency reading should be relatively stable.

Life%: The estimated percent life remaining on the crystal based on the spread between the Max. (typically 6.0 MHz) and Min (typically 5.0 MHz) frequency range values set for the Frequency.

SAM-242: The measured DC voltage on the SAM-242 analog measurement card.

3.3.6 Menu

The menu along the top of the main screen provides access to functions for building deposition processes, configuring the hardware for your vacuum system, and data display.

The following sections detail the functions of each menu selection. For an overview of program operation, click each menu selection, then read the corresponding section in this chapter to understand the concepts involved.

Once you have worked through all menu items, go back to Chapter 2, Quick Start, and build the sample process for a better operational understanding.

3.4 File Menu

NOTE: The current process must be stopped for the **File** menu to be available.

3.4.1 File >> Open Process

Used to select a process from a list of all processes in the current database. If the process selected is different than the current process, you are prompted to confirm the change.

3.4.2 File >> Open and Save Database

Open Database: Selects a database of processes to be used for deposition.

- A single process database holds 25 processes.
- The number of process database files is unlimited.

Save Database As: Saves the current process database to disk under a different name in the default folder. The path cannot be changed. This is useful for saving the process database for backup, or for making trial changes without affecting your working database. Process databases are saved in Microsoft Access format.

3.4.3 File >> Data Log On/Off

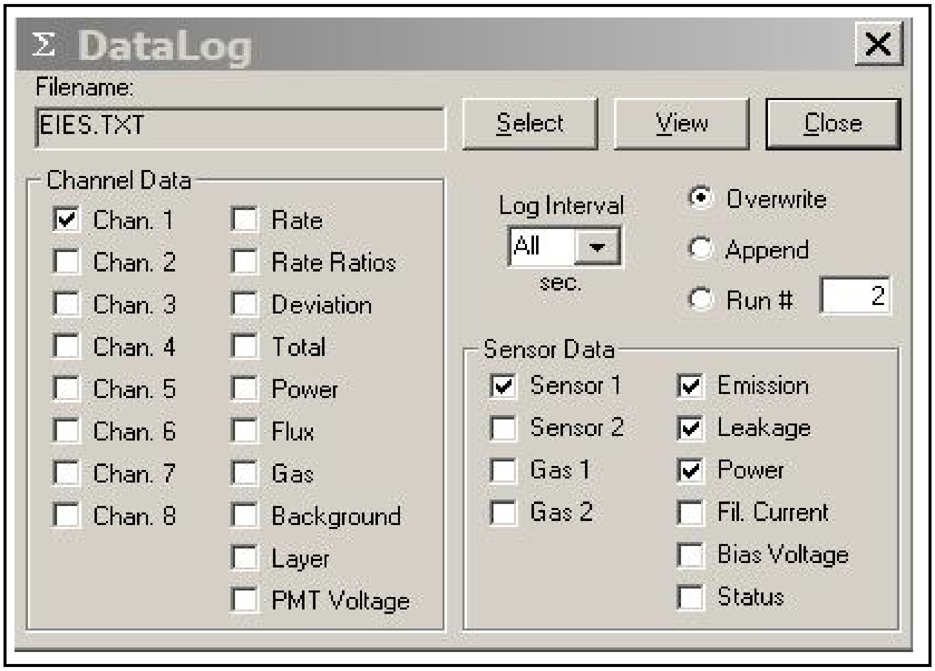
Turns disk data logging on/off. Data is logged only while the process is running. This menu item duplicates the functionality of the main screen DataLog On/Off control.

3.4.4 File >> Data Log Setup

Configures the disk data logging functions. See Figure 3-10. Data is saved on disk in a comma delimited format for easy import into a spreadsheet for graphing and analysis.

Filename: Displays the name of the current DataLog file as explained below.

Figure 3-10 Datalog set up



Select: To modify the DataLog file's name, click **Select**. A **Save LogFile As** window will be displayed. Enter a new filename and click **Save**. The file will be saved in the default folder. To change the file path, the EIES software must be opened in the **Run as Administrator** mode.

NOTE: To avoid delays in data acquisition, save to the hard disk, and transfer the files to a USB stick later.

View: Opens the selected DataLog using Window's Notepad program.

Log Interval: The elapsed time between data log entries. The data log is updated only when the process is running.

Overwrite: The log file will be overwritten each time data logging is started by pressing **DataLog On** on the main screen. Only the last run of the process is saved, and it appears as **FileName.LOG**.

Append: Data is added to the end of the existing **FileName.LOG** file.

Run#: A data file, **FileName_Run#.LOG**, is written for each process run. **Run#** is incremented each time the process is started. Enter a new **Run#** to reset the counter.

Channel Data: Selects the channel(s) to log, and the data that is logged for each channel.

Sensor Data: Selects the sensor(s) to log, and the data that is logged for each sensor.

3.4.4.1 Format of the DataLog file

Start Log	Process Name	Run:364	Date	Time

Layer: 1 Setup:

Chan:1	Film:Se	Rate:000.000	Units:Å/s	Total:005.500	TimeSP:00:05:00
Chan:2	Film:Press Mon.	Rate:000.000	Units:Torr	Total:000.000	TimeSP:00:00:00
Chan:3	Film:Temp	Rate:000.000	Units:DegC	Total:000.000	TimeSP:00:00:00
Chan:4	Film:Se	Rate:000.000	Units:Å/s	Total:005.500	TimeSP:00:05:00

Time,	Phase,	Chan#,	Rate,	Dev	Total	Power
00:00:05,	RAMP 1,	CH1:,	0.00,	0.0,	000.0,	00.0,
00:00:10,	RAMP 1,	CH1:,	0.00,	0.0,	000.0,	00.0,

How to Graph data in Microsoft Excel®:

Start the Excel program and select **File >> Open**. In the **File Open** window, select **Files of Type: All Files**. Navigate to the proper folder and click on the data log you want to open, then click **Open**.

In the Excel Text Import Wizard select **Delimited**, then **Next**. Select **Comma** as the delimiter. Check **Treat Consecutive Delimiters as One**. Select **Text Qualifier (None)**. Click **Finish** to open the DataLog in Excel.

To graph the data, select the column with time, then each of the channel data columns you wish to graph. For example, to graph channel rates select column A (time), column D (Chan1 Rate), and column I (Chan2 Rate).
Click **Insert >> Chart**.

In the Chart Wizard select **Line chart**, then **Next**. The chart should appear with the rates graphed against time. There will be some extra entries along the time axis; you are welcome to clean this up, but the graph will be quite usable with just these few steps.

3.4.5 File >> Print Screen

Sends a copy of the main screen to the printer selected in the Page Setup menu.

3.4.6 File >> Page Setup

Provides printer selection and page orientation for the Print Screen function.

3.4.7 File >> Exit

Stops the current process, turns off Emissions, and exits the EIES program.

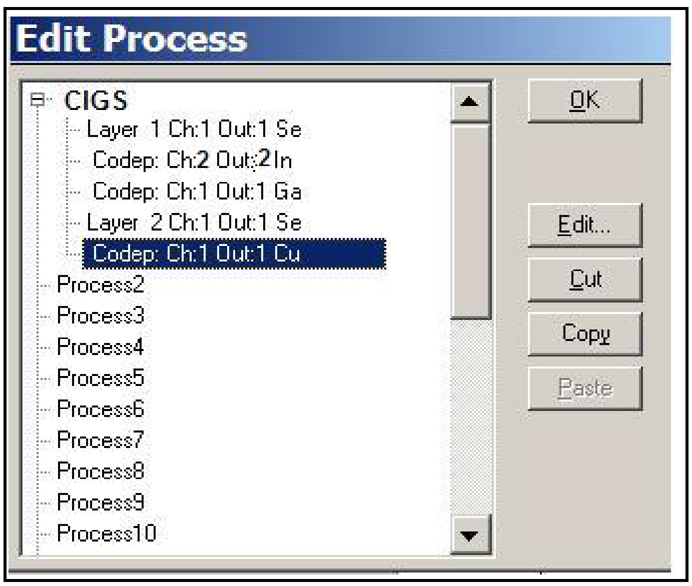
3.5 Edit Process

The **Edit Process** window is accessible in the Stopped mode. It provides the functions needed to create and edit thin film deposition processes. A few definitions will be helpful as you use this manual.

- A Process is a sequence of Layers of different Films.
- Each Layer establishes the desired rate and thickness of the deposited Film.
- A Film defines the physical material being deposited, plus all of the instrument setup parameters associated with that material.
- Multiple films deposited simultaneously are known as a Co-Deposition (or CoDep) Layer.

The **Edit Process** window, see Figure 3-11, displays the 25 processes of the current database in a "treeview" display (similar to the file folders of Windows Explorer). Click the [+] beside a process to show the layers in that process.

Figure 3-11 Edit Process window



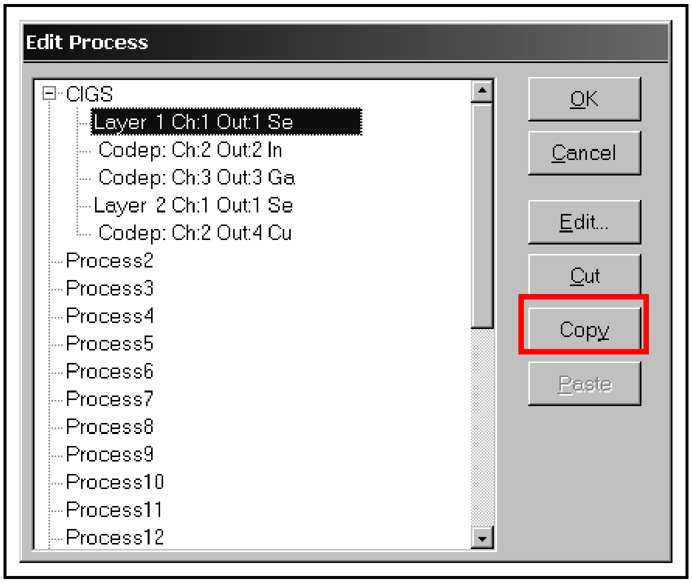
Layers are shown as Layer# Channel# Output# FilmName. Channel number is the EIES channel used for monitoring deposition. Co-deposited layers are marked as CoDep and listed similarly.

NOTE: The **Edit Process** window can only be accessed when the process is stopped.

To add layers to a process, click any existing layer (in any process) then click **Copy**. See Figure 3-12. This places a copy of the highlighted layer on the clipboard, and enables the **Paste** button.

PN 074-517-P1F

Figure 3-12 Edit process highlighted layer



There are four Paste options:

- **Below:** Insert the clipboard layer below the highlighted layer.
- **Above:** Insert the clipboard layer above the highlighted layer.
- **Replace:** Replace the existing layer with the clipboard layer.
- **CoDep:** Insert the clipboard layer as a co-deposition layer of the highlighted layer.

Click a layer in the process where you want to paste the clipboard layer, and click **Paste**.

To copy an entire process to the clipboard, click on the process, then click **Copy**. Click another process and click **Paste** to replace it with the clipboard process.

CAUTION

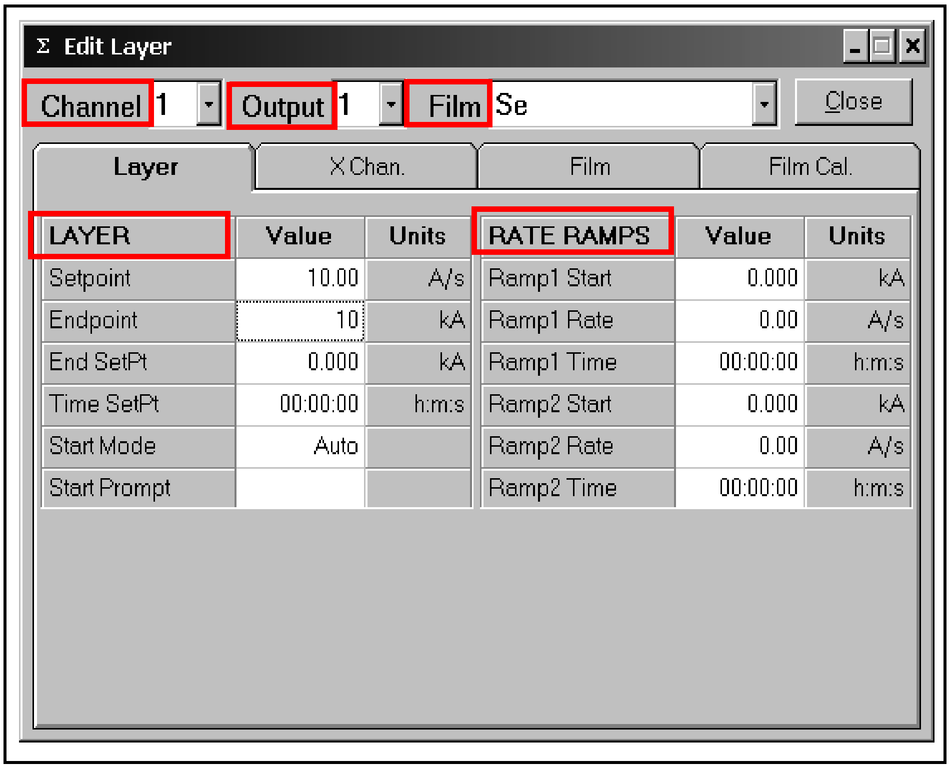
Be careful when pasting processes, there is no undo!

To edit a layer's parameters, click the layer, then the **Edit** button. The **Edit Layer** window for the selected layer is displayed. See the next section for detailed information on using the **Edit Layer** window.

3.6 Edit Layer

A Layer establishes the desired rate and thickness (plus a few other parameters) for a deposited film. The **Edit Layer** window, see Figure 3-13, can be accessed by clicking a channel **Edit** button on the main screen, or by highlighting a layer and clicking **Edit** on the **Edit Process** window.

Figure 3-13 Edit Layer window



NOTE: The Channel and Output settings can only be changed by accessing **Edit Layer** from the **Edit Process** window when the process is stopped.

Channel (1 to 8): The channel that displays this layer's readings on the main screen. Typically this is the same as the PMT Detector input channel (labeled MODULE 1 to MODULE 8) on the Guardian controller back panel. If a QCM or analog input is used as the input for this layer, it is selected on Channel Input of the **Film Cal.** tab (see section 3.7.3 on page 3-31).

Output (1 to 8): The Guardian control output that is used when depositing this layer.

Film: This is the most important layer parameter. It establishes the material to be deposited, and many of the instrument setup parameters associated with that material. Select the desired film from the **Film** drop-down list. This selection determines the values that are displayed on the **Film** and **Film Cal.** tabs of the **Edit Layer** window.

3.6.1 Layer Grid

Parameters on the **Layer** tab are unique to this layer. Those on the **Film** and **FilmCal** tabs pertain to any layer using the film. Point to any parameter to see a brief description. Edit a parameter by clicking in the parameter's value cell, then typing a value, or by selecting a value from a drop-down list. Time values may be entered in hh:mm:ss format, or as whole seconds (which are automatically converted to hh:mm:ss format).

When you click in another cell, or press **Enter**, the parameter value is checked for validity and stored in the process database. If the process is running, the parameters are also sent to the EIES Controller.

Setpoint Å/s: The desired deposition rate for the layer. 0.00 causes the layer to be skipped.The PID loop will control the channel output voltage during deposition to achieve the setpoint. Rate is typically displayed in Angstroms per second (Å/s). This value can be modified by user-supplied Units conversion factors consisting of a Multiplier and Offset, found on the Channel tab. The displayed deposition rate is calculated as:

Rate (Å/s) = (ChannelRate - QCMCalZero - xChan1 - xChan2) x QCMCalFactor [1]

- or -

Rate (User Units) = (Rate(Å/s) x UserMultiplier) + UserOffset [2]

Endpoint kÅ: The desired material thickness for the layer. **0.00** causes the layer to be skipped.When Endpoint is reached, deposition ends for the layer. The value is typically in kÅ, but may be scaled by the user units as described in Setpoint above. The displayed thickness is calculated as:

Endpoint (kÅ) = Sum of (Rate(Å/s) x Measurement Period / 1000) [3]

- or -

Endpoint (UserUnits) = Sum of (Rate(UserUnits) x Measurement Period / 1000) [4]

EndSetPt kÅ: When EndSetPt is reached, the EndSetPt relay is activated. **0.00** disables the function. However, deposition continues until EndPoint thickness is reached.

Time SetPt hh:mm:ss: Closes the Time Setpoint relay after a certain time up to the maximum value of 23:59:59. If Time SetPt occurs before EndPoint thickness is reached, the layer stops. A time SetPt value of **00:00:00** disables this function.

Start Mode: A layer may start in three ways.

- In Auto, the layer starts immediately upon completion of the previous layer.
- In Manual, the layer waits for the user to click the **Start** button. If there are CoDep channels, they will also wait for a user start if any channel Start Mode is set to Manual.
- Constant start is a special case used for controlling constant process variables such as temperature and pressure. Constant start holds the channel at the rate setpoint throughout the process. Only clicking **Reset** or completing the process will set the channel output to zero.

Start Prompt: Allows a user prompt to appear at the beginning of a Manual Start layer. If any text is entered in this parameter, it shows as an on-screen prompt with two user choices: **OK** to start the layer, or **Cancel** to stop the layer. This is useful for prompting for operator actions such as opening valves or checking settings.

3.6.2 Rate Ramps Grid

Rate ramps change the initial rate setpoint.

Each rate ramp has:

- a starting thickness
- an elapsed time to ramp to the new rate setpoint
- a new Ramp#Rate setpoint

Each layer can have two rate ramps.

NOTE: These rate ramps alter the rate during deposition. Do not confuse these ramps with the preconditioning ramp/soak power ramps on the **Film** tab.

Ramp1 Start kÅ: The thickness that triggers a timed ramp to a new rate. Setting Ramp1 Start to zero disables the rate ramp. Ramp1 Start should be less than the layer Endpoint, otherwise the rate ramp is ignored.

Ramp1 Rate: The new deposition rate for the layer.

Ramp1Time: The time to ramp to the new Ramp1 Rate setpoint. If the rate ramp is too fast, a PID control error may be generated.

Ramp2 Start kÅ: The thickness that triggers a timed ramp to a new rate. Setting Ramp2 Start to zero disables the rate ramp. Ramp2 Start should be greater than Rate1 Ramp and less than the layer Endpoint, otherwise the rate ramp is ignored.

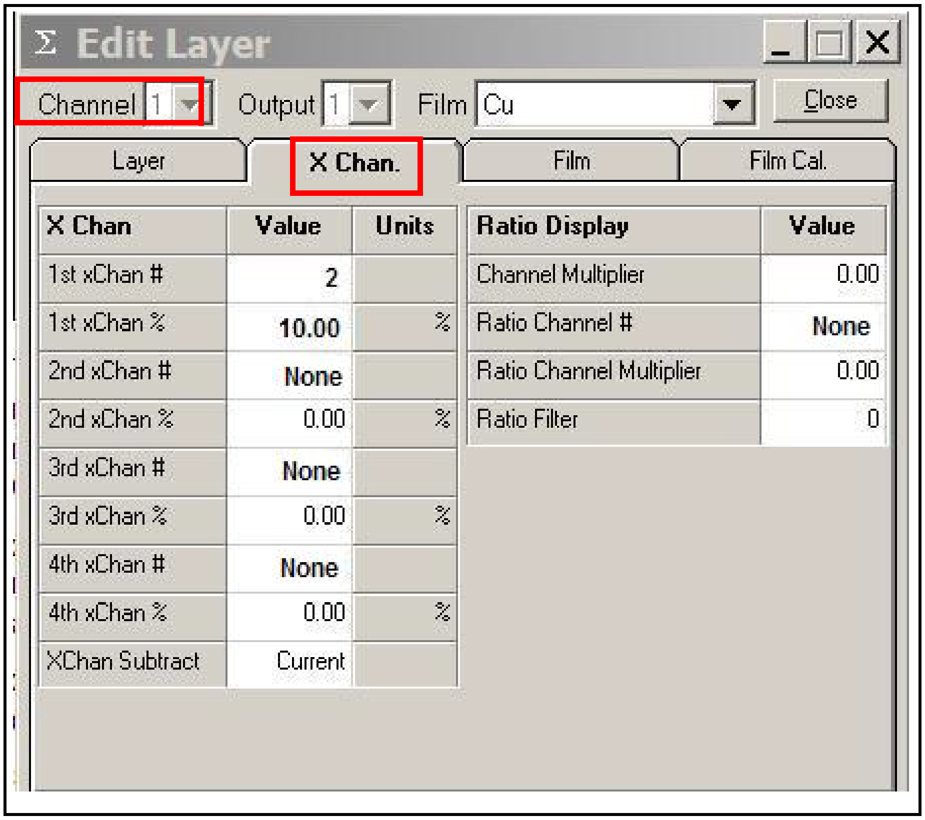
Ramp2 Rate: The new deposition rate for the layer.

Ramp2Time: The time to ramp to the new Ramp2 Rate setpoint. If the rate ramp is too fast, a PID control error may be generated.

3.6.3 X Chan (Cross Channel) Tab

Parameters on the **X Chan.** tab are unique to this layer. Those on the **Film** and **FilmCal** tabs pertain to any layer using the film. Each EIES PMT Detector channel measures an emission line that is unique to the material. However, other materials being evaporated at the same time may have emission lines that overlap the bandwidth of the desired material's filter. In that case, a portion of the unwanted channel's signal must be subtracted from the reading. Cross Channel Calibration (**X Chan.**) establishes the amount of the unwanted signal(s) to subtract.

Figure 3-14 Cross Channel Grid



The channel listed at the top left of the form, Channel 1 in the example, is the channel being measured. A percent of the channels in the grid will be subtracted from that measurement channel. Up to four cross channel readings may be subtracted. Cross channels must be different from the measurement channel.

xChan #: The readings of the channel selected at the top of the form will be modified by subtracting a portion of each xChan# readings. Select value None for any unused xChan Cross channels.

xChan%: The percent of the xChan signal to be subtracted from the measurement channel reading. 0.00 disables the function.

XChan Subtract: Select Current or Rate to be subtracted

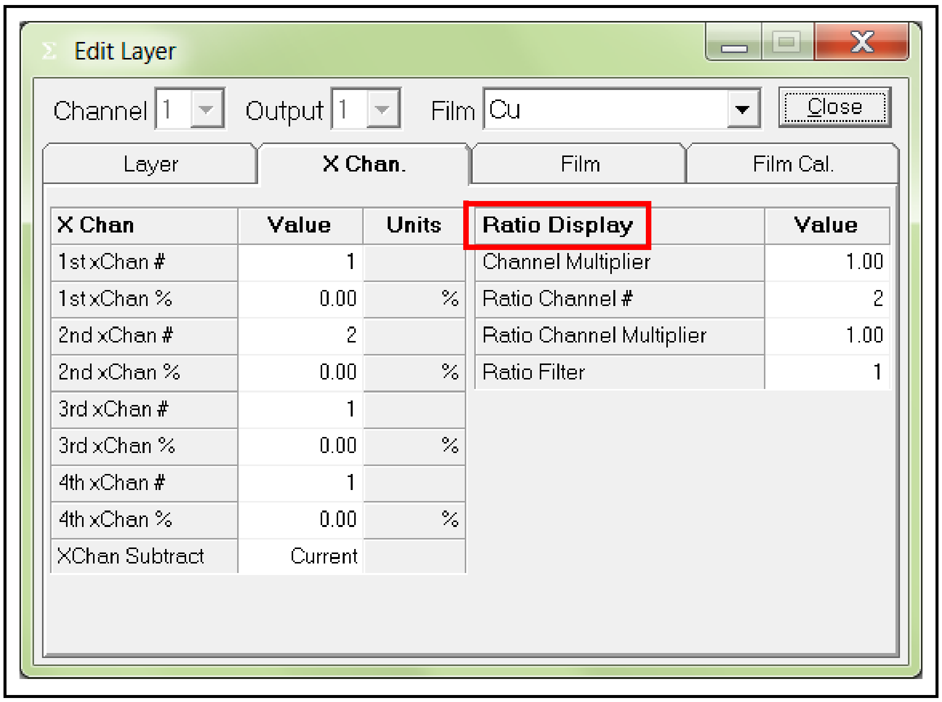
Current: A percent of each xChan PMT Detector current is subtracted, before any material calibration, tooling factors, etc., have been calculated. The advantage of this method is that a change in the xChan calibration factors does not impact the amount of xChan compensation.

Rate: A percent of each xChan PMT Detector rate is subtracted, after material calibration, tooling factors, etc. have been calculated. This method allows recalibration of an xChan to alter the amount of xChan compensation.

3.6.4 Ratio Display Grid

In addition to cross channel calibration, the **X Chan.** tab of the **Edit Layer** window allows setup of the main screen **Ratio** display.

Figure 3-15 Ratio Display



Channel Multiplier: The channel reading is multiplied by this value before the ratio is calculated. Useful for scaling or calibrating to a desired value. 0.00 disables the function.

Ratio Channel #: Channel used for (denominator of) ratio calculation.

Ratio Channel Multiplier: Multiplies ratio channel reading by this amount. 0.00 disables the function.

PN 074-517-P1F

Ratio Filter: The number of readings averaged for the ratio display. **0** disables the function. Because we are dividing two channels, and possibly multiplying their readings, a larger filter may be desirable.

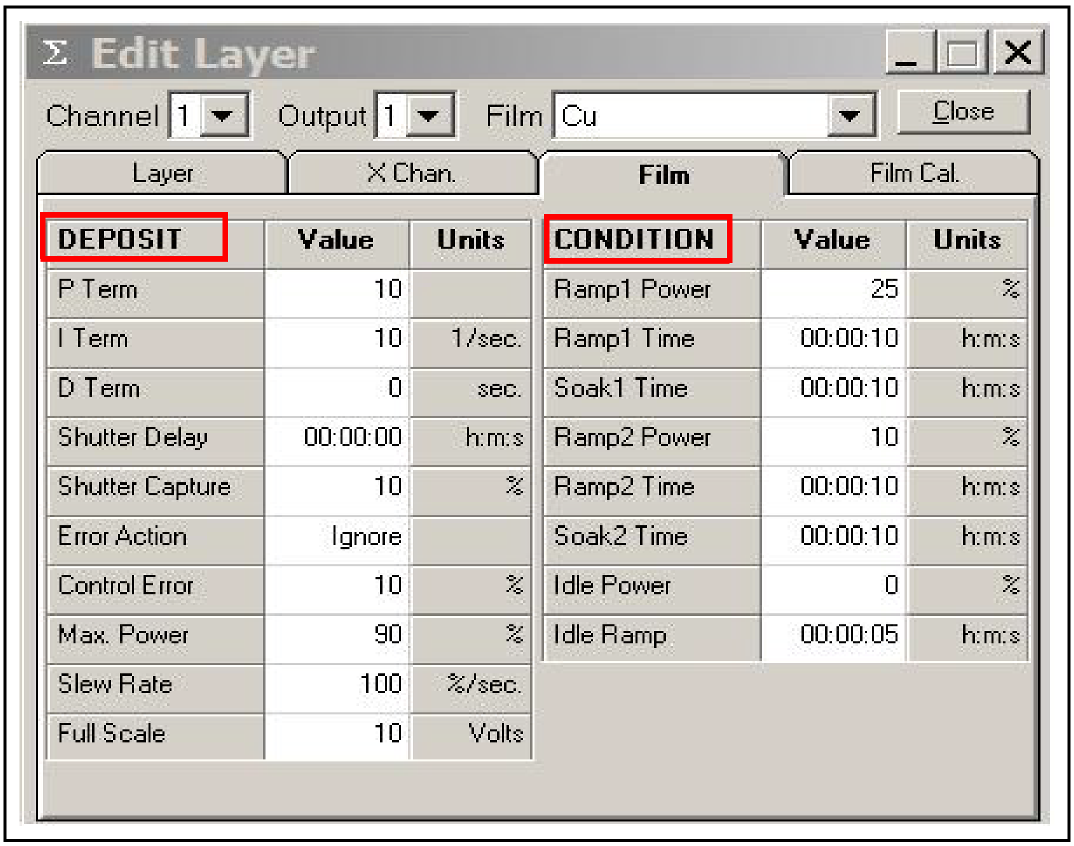
The value displayed is:

$$\text{Ratio Display} = \frac{(\text{Channel Reading} \times \text{Channel Multiplier})}{(\text{Ratio Channel Reading} \times \text{Ratio Channel Multiplier})} \quad [5]$$

3.6.5 Edit Layer Film Tab

NOTE: The parameters on the **Film** tab are Film parameters. They are determined by the Film selected for a layer. If you change the parameters on either of these tabs, they will be changed for any layer (in any process) that uses the selected film.

Figure 3-16 Edit Layer Film display



PN 074-517-P1F

3.6.5.1 Deposit Grid

P Term: Sets the gain of the control loop. High gains yield more responsive (but potentially unstable) loops. Try a low value then gradually increase/decrease to respond as desired to step changes in setpoint.

I Term: The integral term controls the time constant of the loop response. A small I term, 0.5 to 1 seconds, will smooth the response of most loops. A value of 0 effectively disables PID control.

D Term: The differential term causes the loop to respond quickly to changes. Use 0 or a very small value to avoid oscillations.

Shutter Delay: Shutter delay sets the time allowed for a channel to achieve deposition control. Shutter delay assures that the channel reaches a certain accuracy before deposition begins. If the accuracy is not reached, the process halts. If accuracy is reached and maintained for five seconds before Shutter Delay time, the substrate shutter opens and deposition begins. Set Shutter Delay to 0 to disable this function.

Shutter Capture: Sets the shutter delay rate accuracy that must be reached for deposition to begin.

Error Action: If the control loop cannot maintain the desired Setpoint (due to the loss of source material, or excessively high rate ramps, or equipment malfunction) a control error occurs. When an error condition occurs, three actions are possible:

- **Ignore** the error and let the PID loop attempt to maintain rate control based on "control percentage."
- **Stop** the layer and allow the user to fix or manually control deposition.
- **Hold** deposition at the last good Power setting to "estimate" rate and thickness. For best results, use shutter delay to assure adequate process control before entering the deposition phase.

Control Error: The rate error in percent that must not be exceeded during deposition to prevent a control error. Set Control Percent to zero to disable this function.

Max Power: The maximum output power allowed for the film. Max Power controls the maximum % of the full scale voltage that can be used by this film in any process phase.

Slew Rate: The maximum power change allowed on an output, per second. If rate ramps or PID power requirements exceed this value, an error occurs.

Full Scale: The maximum output voltage for your deposition supply's input range. Values from 0 to +/-10 V are possible.

3.6.5.2 Condition Grid

Ramp1 Power: The power level desired at the end of the Ramp 1 phase, in % of full scale.

Ramp1 Time: The time to ramp linearly from the initial power to the Ramp 1 Power. If multiple channels have preconditioning programmed, the start of Ramp1 may be delayed so that the Soak2 phase for all channels ends at the same time.

Soak1 Time: The time the output remains at Ramp 1 Power. At the end of Soak 1 Time, the Ramp 2 phase starts.

Ramp2 Power: The power level desired at the end of the Ramp 2 phase, in % of full scale.

Ramp2 Time: The time to ramp linearly from Ramp1 Power to Ramp2 Power.

Soak2 Time: The time the output remains at the Ramp 2 power level. At the end of Soak 2, all channels will enter the Shutter Delay phase.

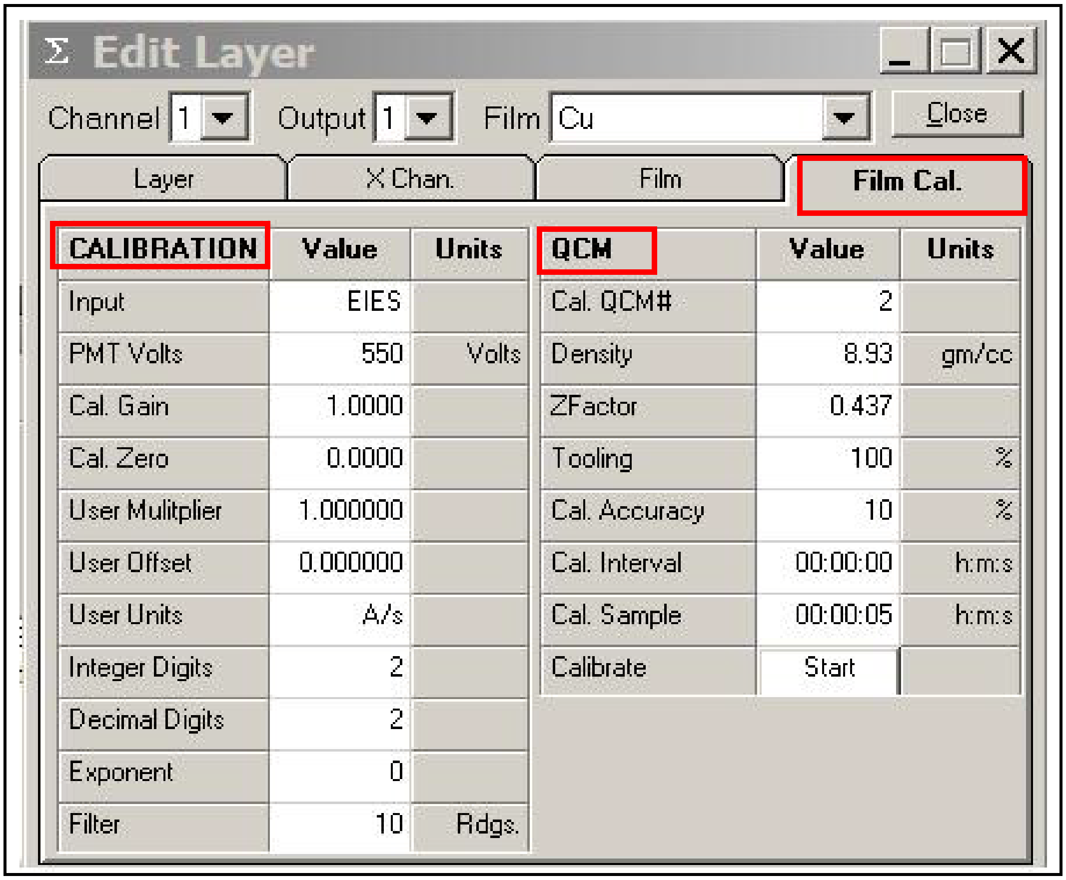
Idle Power: Idle power usually holds the material at a state that is ready for deposition, typically the same as Ramp 2 power if the material is to be used in a subsequent layer.

Idle Ramp: The time to ramp linearly from deposition power to Idle Power.

3.6.6 Edit Layer Film Cal

NOTE: The parameters on the **Film Cal.** tab are Film parameters. They are determined by the Film selected for a layer. If you change the parameters on either of these tabs, they will be changed for any layer (in any process) that uses the selected film.The **Film Cal.** tab displays parameters that control the calibration and display of channel readings. Depending on the Input type selected, all of the parameters listed may not be available.

Figure 3-17 Edit Layer Film Cal display



PN 074-517-P1F

3.6.6.1 Calibration Grid

Input: Selects which sensor is used for measurement of the channel. Select EIES to use the selected EIES PMT Detector channel input. Select a QCM input to use an SQM-242 card or Q-pod sensor for deposition measurement. SAM uses the SAM-242 analog card inputs for measurement.

PMT Volts: 0 to 1250. Sets the bias voltage (gain) of the channel's photomultiplier tube. The emission from different materials may require different PMT voltages to optimize performance. Typical values range from 600 to 700. Use the lowest setting that provides adequate signal. As PMT voltage is increased, PMT noise is also increased, reducing the signal to noise ratio.

Cal Gain: The multiplier used to convert EIES current measurements to calibrated rate/thickness. You may enter a value manually, or the value is updated each time **QCM Calibrate** is clicked.

Cal Zero: Due to gas background emission, there may be an EIES rate reading when there is no deposition. Enter the background rate to correct EIES rate to zero.

User Multiplier: This value is multiplied by the calibrated rate (in Å/s) to convert to User Units on the main screen rate display. Set the multiplier to 1 to display readings in Å/s. Also used with the SAM-242 analog card to convert volts to different units.

User Offset: Value subtracted from the calculated rate (in Å/s) to convert to User Units shown in the channel's reading display. Set the offset to 0 to display readings in Å/s.

User Units: The units displayed below the channel reading on the main screen. Typically Angstroms per second (Å/s).

Integer Digits: The number of integer digits (left of the decimal point) displayed in the channel's rate display. The channel rate display can show four total digits, plus the decimal point and sign. If IntDigits plus DecDigits is greater than four, the left-most digits will not be seen.

Decimal Digits: The number of decimal digits (right of the decimal point) displayed in the channel's rate display. The channel rate display can show four total digits, plus the decimal point and sign. If IntDigits plus DecDigits is greater than four, the left-most digits will not be seen.

Exponent: Scales the channel rate display by powers of 10. For example, select 3 to display kilo-units or -3 to display milli-units.

Filter: The number of readings that are averaged for display on the main screen.

3.6.6.2 QCM Grid

Cal QCM#: Establishes which QCM sensor is used to calibrate this channel's EIES PMT Detector.

Density: Sets the QCM density for this material. Material density has a significant impact on deposition calculations when a QCM is used for calibration or control. See Appendix B for common material densities.

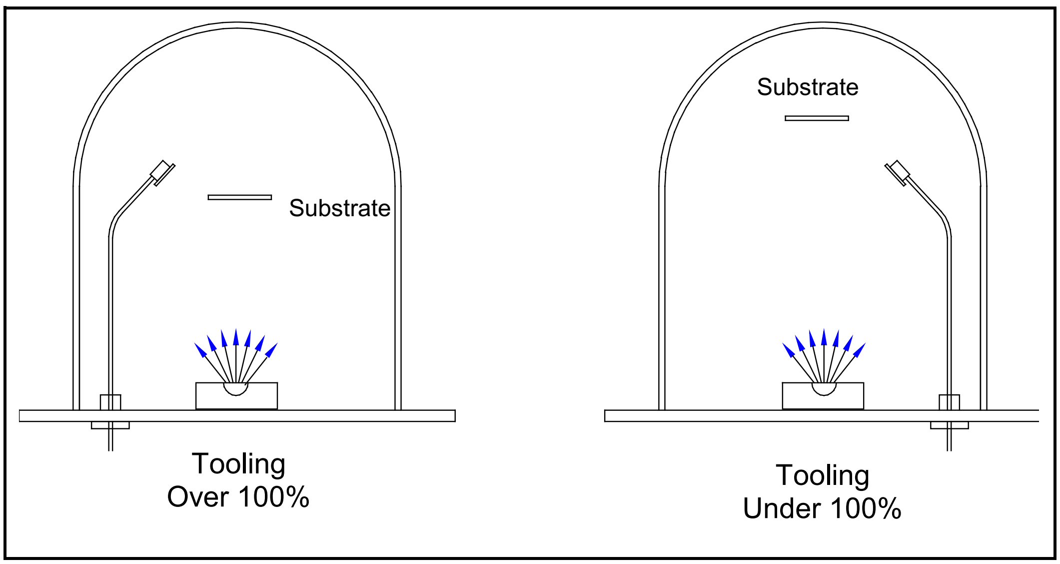
Z-Factor: Sets the QCM Z-Factor or Z-Ratio, the measure of a material's effect with increased thickness on QCM accuracy. See Appendix B for common material Z-Ratios.

Tooling %: Adjusts for deposition rates measured by the QCM that differ from the substrate deposition rate. A higher tooling value yields higher rates. See Figure 3-18. For example, if the sensor sees only 50% of the substrate rate, set Tooling to 200%. Setting Tooling to 0% causes a sensor to be ignored for this film.

The defining equation is:

$$\frac{\text{Substrate Thick}}{\text{Sensor Thick}} = \frac{\text{Correct Tooling}}{\text{Current Tooling}} \qquad [6]$$

Figure 3-18 Tooling value



Cal Accuracy%: The EIES channel calibration accuracy to be achieved during QCM calibration. A lower value means higher accuracy is required.

Cal Interval: The time interval between automatic QCM calibration of the EIES channel. Set to 00:00:00 to disable periodic automatic calibration.

Cal Sample: The time the QCM shutter remains open for QCM calibration of the EIES channel.

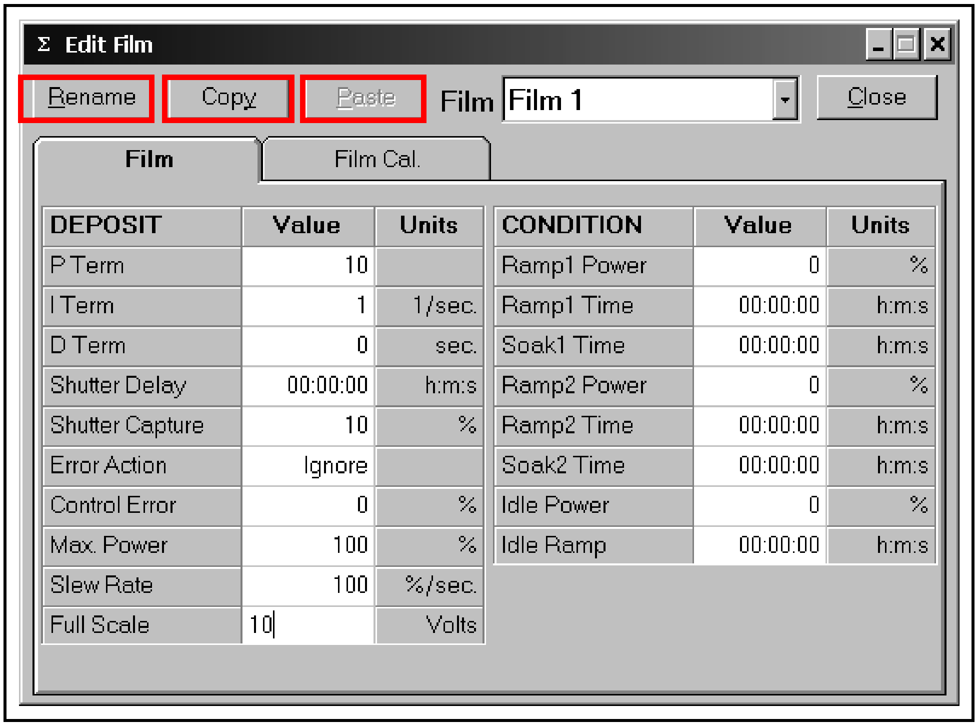
Calibrate: Starts a QCM calibration cycle as defined by Cal Accuracy, Cal Interval and Cal Sample. Shown only when the Layer version of this window is selected.

PN 074-517-P1F

3.7 Edit: Film

The **Edit Film** window is accessible in the Stopped mode. A Film sets the parameters for the material to be deposited in a layer, the control loop tuning, pre/post conditioning, and many of the instrument hardware parameters associated with that material.

Figure 3-19 Edit Film window



The **Film** tab displays the deposition and pre/post conditioning parameters for the selected film. The Film Calibration (**Film Cal.**) tab contains instrument, display, and QCM parameters.

NOTE: Changing any parameters under the **Film** and **Film Cal.** tabs also changes those parameters in the layer using the film.

Pause the mouse over any parameter to see a brief description. Edit a parameter by clicking in the parameter's value cell, then typing a value, or by selecting a value from a drop-down menu. Time values may be entered in hh:mm:ss format, or as whole seconds (which are automatically converted to hh:mm:ss format).

When you click in another cell, or press **Enter**, the parameter value is checked for validity and stored in the process database. If the process is running, the parameters are also sent to the EIES-IV Guardian controller.

Rename: Gives a meaningful name (often the material) to the film.

Copy: Copy the film parameters to the clipboard.

Paste: Select another film and click **Paste** to replace it with the clipboard film parameters.

CAUTION

Be careful when pasting films, there is no undo function!

3.7.1 Deposit Grid

Refer to section 3.6.5.1.

3.7.2 Condition Grid

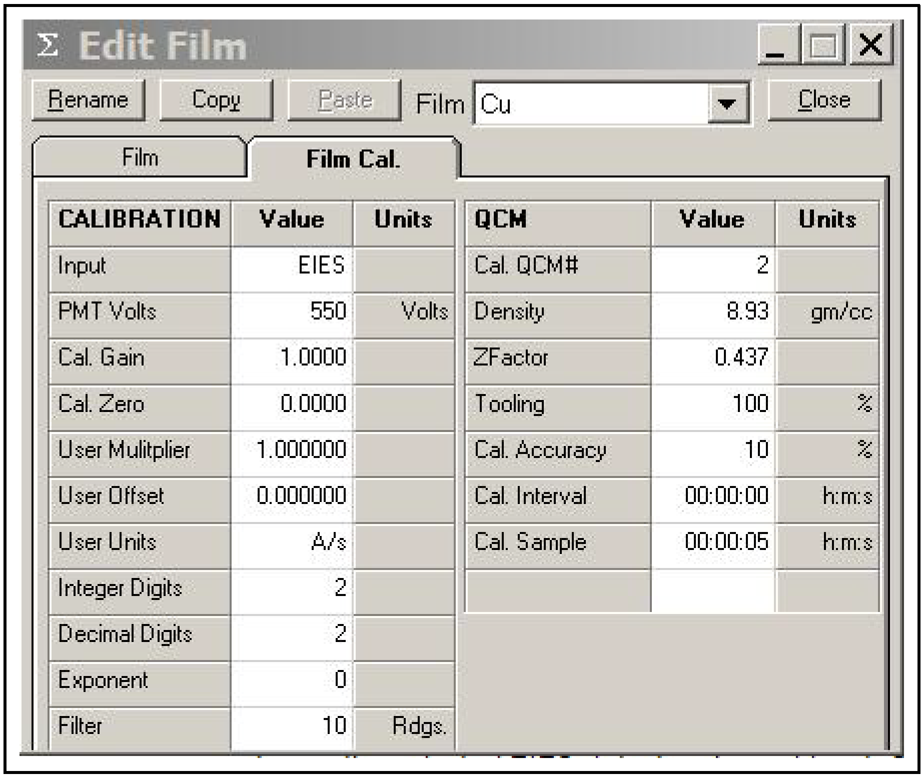
Refer to section 3.6.5.2.

PN 074-517-P1F

3.7.3 Film Cal(ibration) Tab

Changing any parameter here also changes the parameter in the layer using the film. Refer to section 3.6.6.

Figure 3-20 Edit Film Calibration tab



3.7.3.1 Calibration Grid

Refer to section 3.6.6.1.

3.7.3.2 QCM Grid

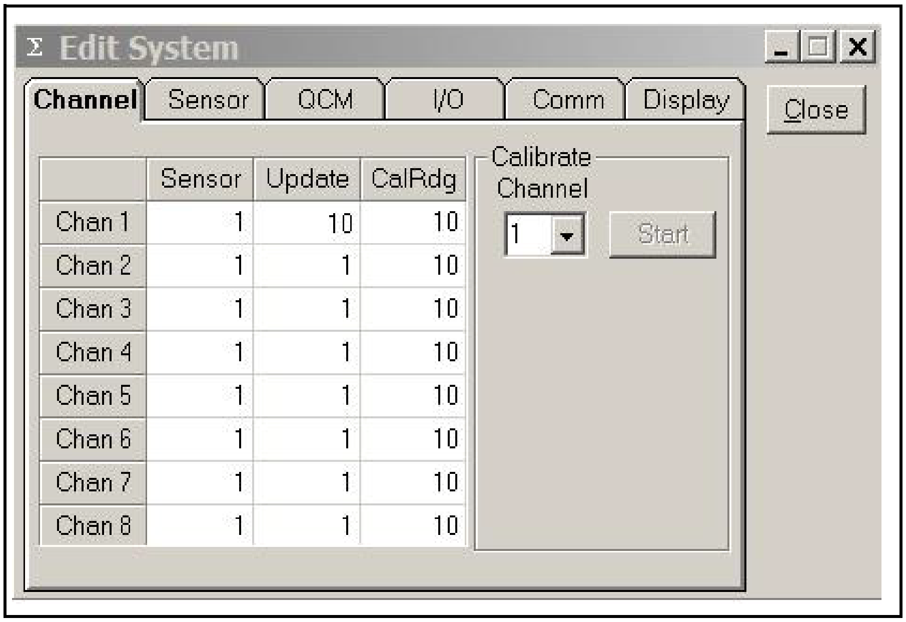
Refer to section 3.6.6.2.

3.8 Edit >> System

The **Edit System** window contains parameters that apply to all of the processes in a process database. The settings are arranged on a tabbed window.

3.8.1 Channel Tab

Figure 3-21 Edit System Channel tab



Sensor: Must be set to the EIES sensor (standard or gas compensating) that the channel PMT Detector is attached to.

Update: The rate at which readings are returned from the EIES PMT Detector. The PMT Detector takes 1000 readings per second and averages readings between updates. A lower Update rate increases the amount of filtering and reduces noise fluctuation in the rate value displayed. Select a Cal(ibration) Rdg (readings) value that is equal to the Update (Hz) value shown. This will assure four seconds for a total calibration time.

Cal Rdg (Readings): The number of PMT Detector readings averaged to calculate the calibration constants. The total calibration time for a channel is four times the Cal. Readings divided by Update.

Start: Starts calibration of the selected EIES PMT Detector channel. PMT voltage is automatically turned off during calibration. Depending on the number of readings and the channel update interval, calibration may take several seconds.

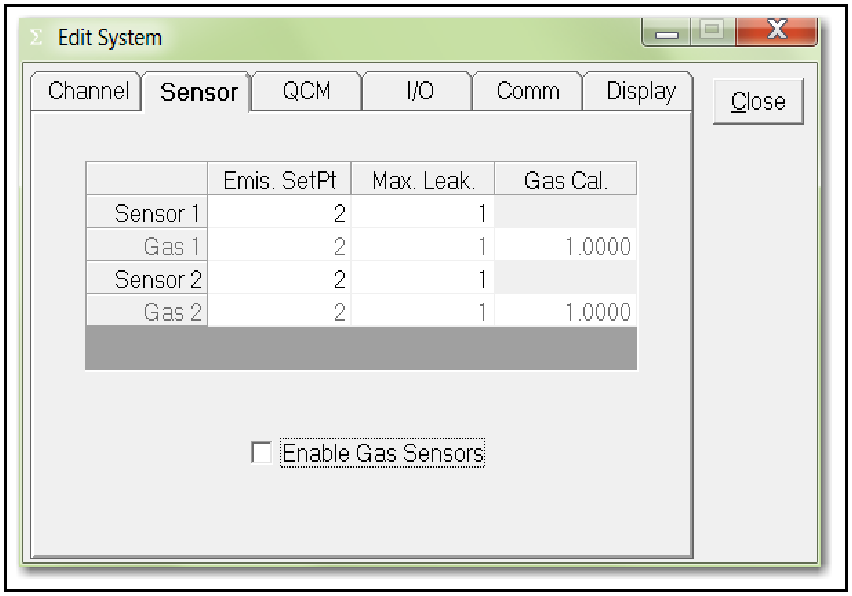
NOTE: This calibrates the PMT Detector electronics assuming no current from deposition. It is different from QCM calibration, which calibrates PMT Detector readings relative to a QCM while deposition is occurring.

Calibrate Channel: The PMT Detector channel selected for calibration.

3.8.2 Sensor Tab

When a gas compensating (GC) sensor is used, see Gas compensating sensor and feedthrough 016-601-Gxx on page 1-5, click **Enable Gas Sensors** (see Figure 3-22.) Gas # and Gas Cal. parameter boxes will then become accessible.

Figure 3-22 Sensor tab



CAUTION

Refer to the label attached to your sensor or emitter assembly package for correct emission current settings.

CAUTION

Do not operate 016-xxx series EIES sensors with Yttria filaments, see New 016-Series sensor exploded on page 5-5, at settings greater than 2 mA. Instant filament failure may occur!

016-xxx sensors with Thoria filaments with ####T serial numbers may be operated at 4 mA emission.

When co-depositing materials, there must be a balance between signal strength and noise for multiple channels. Changing the detector PMT voltage (**Film Cal.** tab, **Edit Layer**) can help match the materials to the selected sensor emission current.

Max. Leak(age): As material is deposited on a sensor, the leakage current increases until the Guardian can no longer adequately control emission current. This field establishes the leakage current that will stop deposition.

PN 074-517-P1F

When leakage current reaches 70% of Max. Leakage, the background of the emission current reading on the main screen turns yellow, see section 5.3, Sensor Maintenance, on page 5-2.

Gas Cal: INFICON gas compensating sensors provide a measurement of the emission caused by background gases. The gas calibration factor is used to null this portion of the signal from the main flux sensor measurements. If the EIES rate reading with no evaporation is negative, decrease the Gas Cal. parameter until the rate averages near zero. If the rate reading is positive with no evaporation, increase the Gas Cal. parameter until the reading averages near zero.

Enable Gas Sensors: Click to select the gas compensating feature. Requires gas compensating (GC) sensors.

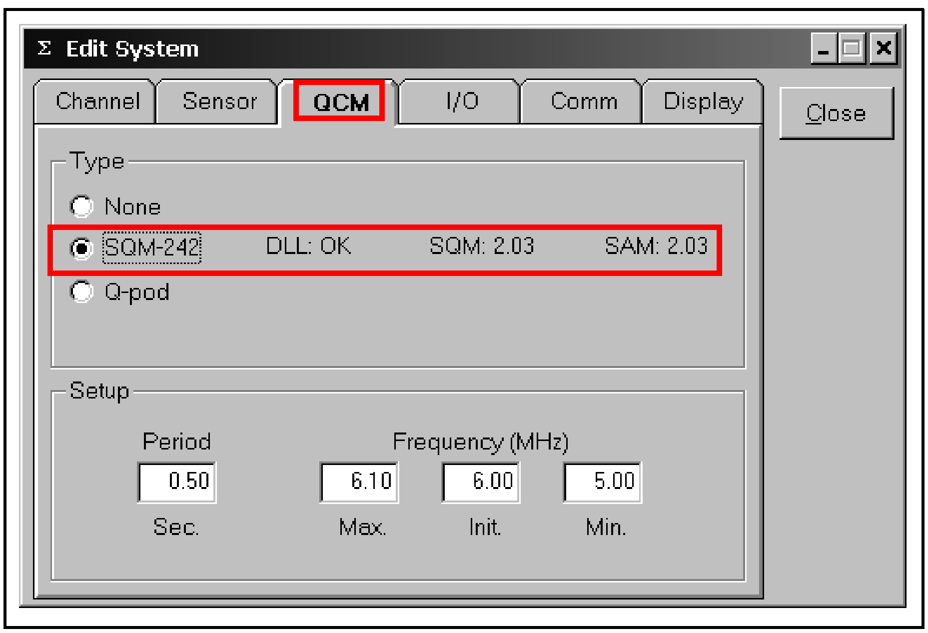
3.8.3 QCM Tab

NOTE: See the SQM-242 Card or Q-pod Manual for detailed QCM installation and troubleshooting instructions.

None: No QCM inputs are used.

SQM_242: INFICON SQM-242 card is used for QCM measurements. DLL shows the status of the SQM-242 card's Windows drivers. A DLL display of 9XX indicates a card installation error. The firmware revision of the installed SQM-242 and SAM-242 cards are also listed. A value of 0 indicates the card is not installed.

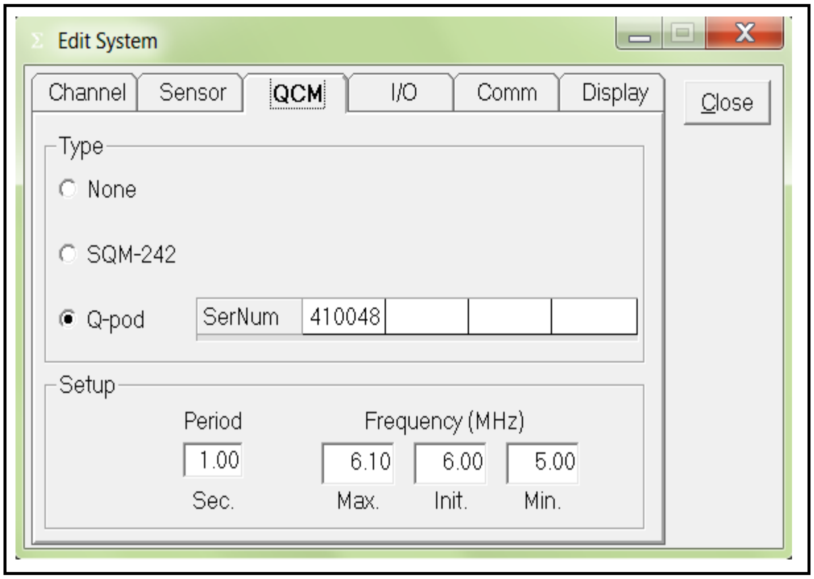
Figure 3-23 Edit System QCM tab



PN 074-517-P1F

Q-pod: INFICON Q-pod transducers are used for QCM measurements. The serial number of each installed Q-pod is shown.

Figure 3-24 QCM tab Q-pod selection

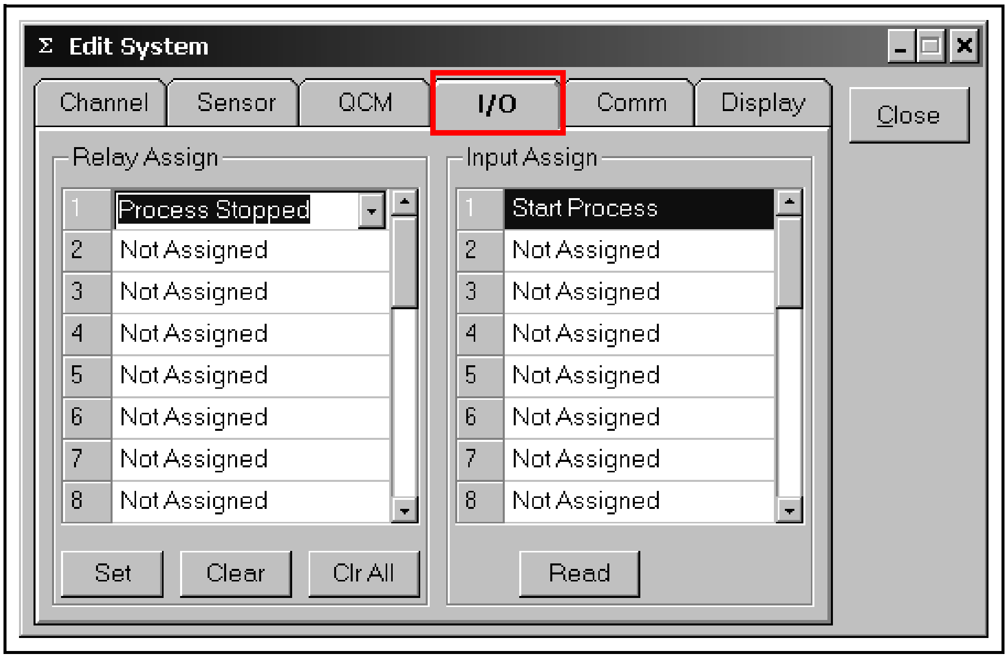


Period: Sets the QCM measurement period between 0.2 seconds (five readings per second) and 2 seconds. A longer period gives higher reading accuracy, especially at low rates.

Max/Init/Min Frequency: The frequency values for the quartz crystal sensors used as inputs to the QCM. Typical values are Max. 6.10, Init. 6.0, Min. 5.0. Sensor readings outside the min/max values cause a Sensor Fail error.

3.8.4 Digital I/O Tab

Figure 3-25 Edit System I/O tab



3.8.4.1 Relay Assignment

To assign a deposition event to a relay, click the Relay #, then select the desired event from the drop-down list. The **Set**, **Clear**, and **Clear All** buttons manually operate the selected relay. A description of each relay event follows:

Process Running and Stopped Relays: These relays indicate the overall status of the process. The Process Running relay closes as soon as **Start** is selected (by front panel or digital input), and opens when Reset is activated after a Stop. The Process Stopped relay contacts behave in the inverse manner.

Layer Running and Stopped Relays: These relays indicate the overall status of the layers. The Layer Running relay closes as soon as **Start** is selected (by front panel or digital input), and opens when **Stop** is selected. The Layer Stopped relay contacts behave in the inverse manner

Deposit Phase Relay: This relay indicates that Guardian is in the deposit phase of a film. If shutter delay is enabled, this relay will close at the end of the shutter delay.

Pre-Cond Phase Relay: This relay closes for the preconditioning phases (Ramp1, Soak1, Ramp2, Soak2) of a film.

Soak Hold Phase Relay: Relay closes for the duration of the Soak Hold phase.

Process Active Relay: This relay action is similar to the Process Running relay, except it will open if the process is temporarily halted for any reason, e.g., Manual Power.

PN 074-517-P1F

Manual Mode Relay: Closes when the program is placed in Manual mode.

Max Power Relay: Closes when any control voltage output is at the programmed maximum power level.

Time Setpoint Relay: This relay will close when Run Time equals the Time Setpoint.

Channel Error: This function is not implemented.

Channel Relays 1 to 8: These relays control sensor shutters. They close during shutter delay and deposition.

Source Relays 1 to 8: These relays control the Shutter that covers the deposition source. They close during deposition.

QCM Relays 1 to 4: These relays control QCM sensor shutters. These relays close during shutter delay and deposition.

3.8.4.2 Input Assignment

To assign a deposition event to an input, click the Input #, then select the desired event from the drop-down list. Click **Read** to read the current state of the highlighted input. A brief description of each input event follows:

Start Process: Triggering this input is equal to clicking **Start Process**.

Stop Process: Triggering this input will abort the process.

Start Film: Triggering this input starts the current film.

Stop Film: Triggering this input will stop the current film.

Zero Time Setpt: Triggering this input resets the Time Setpt to zero.

Emission 1/2 Interlock: Set this input to inhibit turning on emission from the front panel.

Emission 1/2 On: Turns sensor 1 or 2 emission On

Emission 1/2 Off: Turns sensor 1 or 2 emission Off

End Channel 1 to 8: Stops deposition phase and goes to Idle phase.

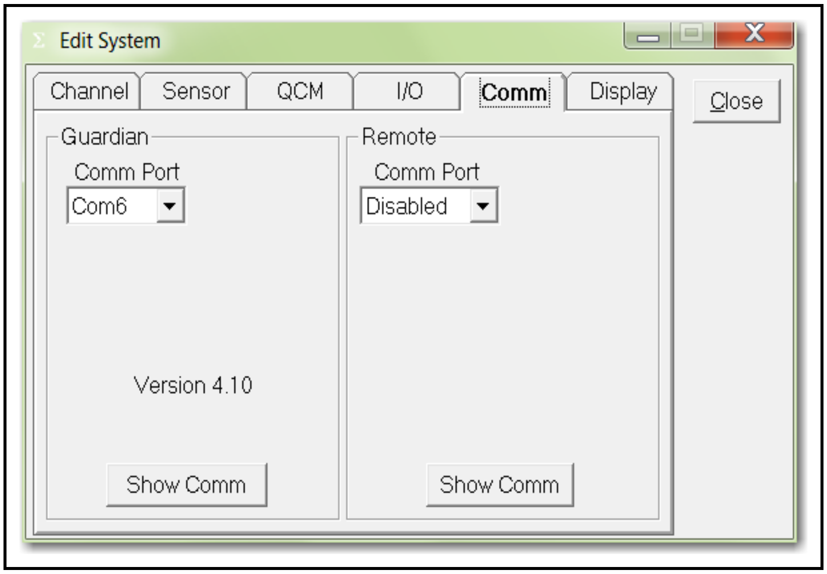
Calibrate Channel 1 to 8: Starts calibration of the selected channel.

NOTE: Input 5 is hardware assigned to the General Emission interlock function.

3.8.5 Comm Tab

The **Comm Tab** sets up communications between the EIES program and the Guardian controller. Settings are made in two panels, **Guardian** and **External**.

Figure 3-26 Edit System Comm tab



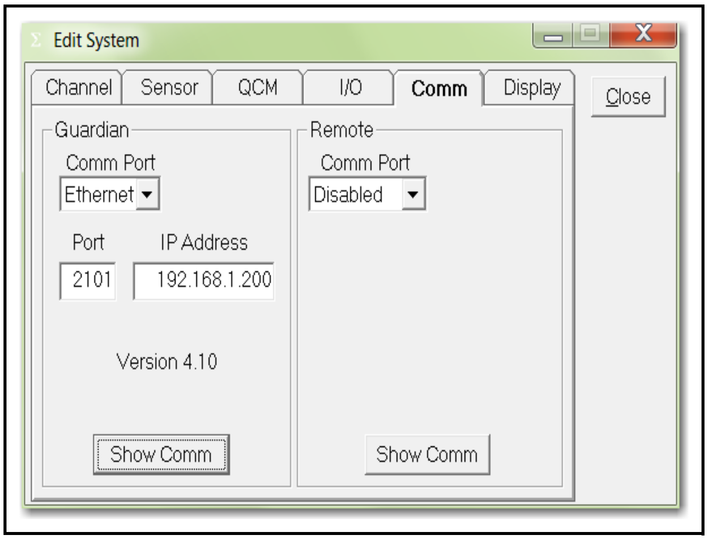
3.8.5.1 Guardian

Comm Port: . . . . Disabled, Com 1 to 9, Ethernet

Selects a computer RS-232 serial port or Ethernet port for communicating with the Guardian controller. If a comm port is not installed, or is being used by another program, an error message will be displayed, otherwise, the Version # for the controller firmware is shown.

If Ethernet is selected as the Comm Port, Port and IP Address selection fields will appear as shown in Figure 3-27.

Figure 3-27 Ethernet Comm Port



Port: Shows the current IP port and allows changing it. The default port is 2101.

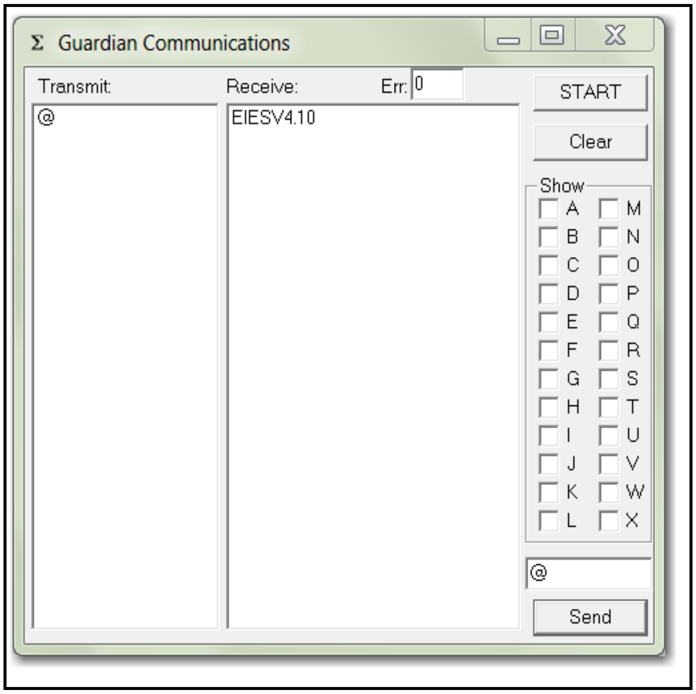
NOTE: Only port numbers below 32767 are supported.

IP Address: Displays the current IP address and allows changing it. The default Guardian IP address is 192.168.1.200. For a direct connection, set the computer's IP address to be the same as the Guardian's except the last group must be different. For example, to communicate with a Guardian at the default address, set the computer to 192.168.1.100.

Show Comm: Displays a diagnostic screen that shows communications between the EIES program and the Guardian controller. See Figure 3-28.

For troubleshooting purposes, you can manually Transmit: (send) ASCII commands to the EIES instrument and Receive: (see) the response. For example, send @ to see the EIES instrument version.

Figure 3-28 Guardian Communications window

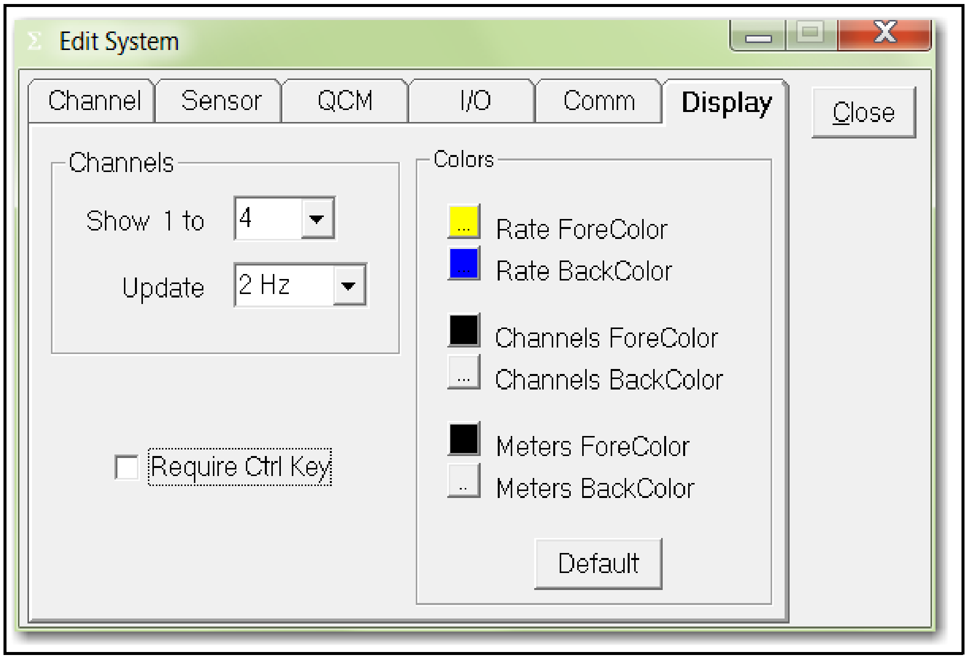


3.8.5.2 Remote

This option is not supported, set Remote Communication Comm Port to Disabled, (see Figure 3-26).

3.8.6 Display Tab

Figure 3-29 Edit System Display tab



Show 1 to: Sets the main screen to display 4 or more (maximum of 8) channels of EIES data. The minimum number of channels is four to allow adequate space on the left control panel.

Update: The frequency, 1, 2, 5 or 10, at which the main screen readings are updated per second.

Require Ctrl Key: When checked, you must press and hold the <**Ctrl**> key to activate main screen controls. This helps prevent accidental operation.

Colors: Sets the colors of several of the main screen display elements. Click **Default** to return the colors to their default settings.

3.9 View Menu

3.9.1 Process, Ratio, Readings

Refer to:

- section 3.3.3, Readings Panel—Process Mode, on page 3-8
- section 3.3.4, Readings Panel—Ratio Mode, on page 3-9
- section 3.3.5, Readings Panel—Readings Mode, on page 3-10

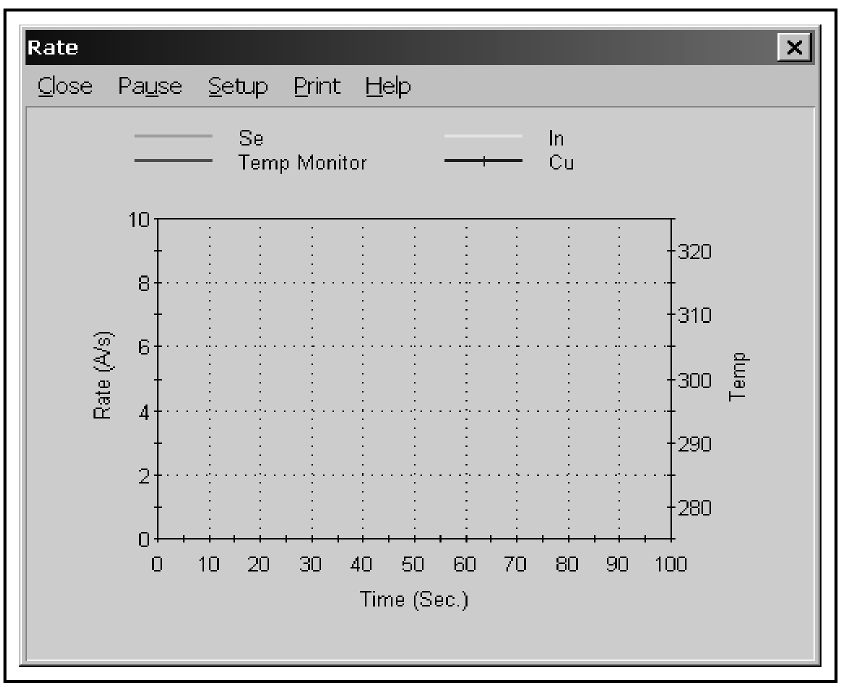
The check mark indicates which one is active. Click on the title to select that display. In addition, four graphs may be viewed as described below.

3.9.2 Graph Selection

The EIES program supports four independent graphs. Initially they are shown on the **View** menu as **Rate** (see Figure 3-30), **Deviation**, **Power**, and **Total**. The titles may be changed.

To size a graph, click and drag the form's border. The size and location are automatically stored on exit from the program.

Figure 3-30 Rate graph



Close: Closes the selected graph display.

Pause/Run: Click **Pause** to temporarily stop the graph from displaying data. Click **Run** to resume graphing.

PN 074-517-P1F

Setup: The graph's name and data, as well as many other setup parameters, can be changed on the Graph Setup screen. Graph setup is detailed in section 3.9.2.1, Graph Setup, on page 3-43.

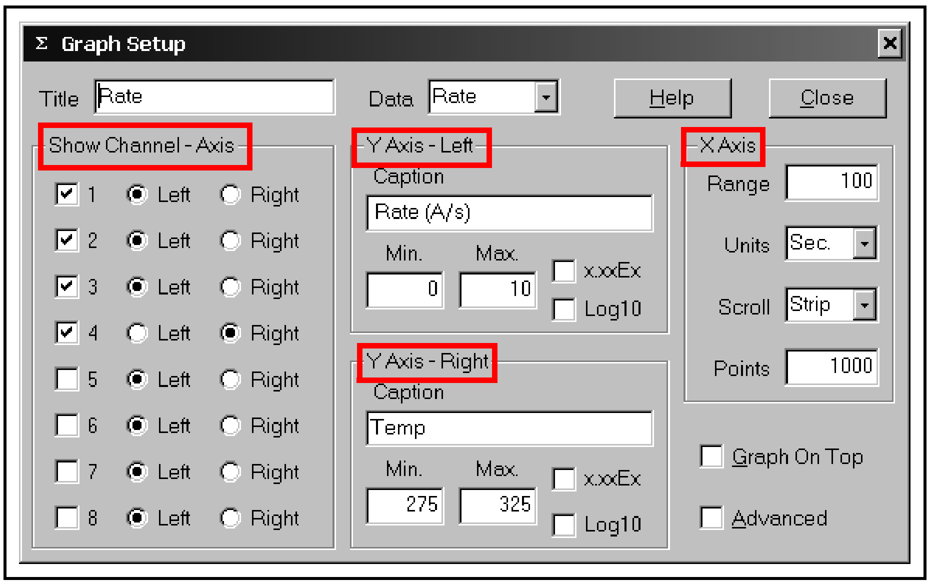
Print: Prints the graph to the system printer.

Help: Displays the graph help screen.

3.9.2.1 Graph Setup

The **Graph Setup** window provides access to the most commonly used graph setup parameters. It also provides total control of graph setup, using the Advanced Property Editor.

Figure 3-31 View Setup



Title: The caption that appears at the top of the graph window and on the main window's Graph menu. However, the graph's setup properties are always stored on disk as Graph 1 to Graph 4.

Data: Drop-down list of the seven possible data sources are used for this graph — **Rate**, **Filtered Rate**, **Rate Ratio**, **Dev**(iation), **Power**, **Total**, or **Sensor Data**. **Sensor Data** displays the main flux and gas compensating signals for each PMT Detector.

Help: Shows the graph setup help window if the **Advanced** checkbox is not selected. If the **Advanced** checkbox is selected, advanced Property Editor help is displayed.

Close: Closes the **Graph Edit** window.

3.9.2.1.1 Show Channel — Axis

Channel 1 to 8: Selects the EIES channels to be graphed. If the channel is used in a layer, and the channel is selected here, its data is displayed. If the channel is not assigned to a layer, the show channel selection for that channel is ignored.

Left: The data for this channel is referenced to the left axis of the graph. When Sensor Data is selected (see above) the left axis shows the main flux sensor.

Right: The data for this channel is referenced to the right axis of the graph. When Sensor Data is selected (see above) the right axis shows the gas compensating sensor.

3.9.2.1.2 Y Axis Left/Right

Caption: The caption shown along the graph's left or right axis.

Min: The minimum value for the Y axis.

Max: The maximum value for the Y axis.

x.xxEx: Shows the selected Y axis values in scientific format (i.e., 2.00E-4).

Log10: Shows the selected Y axis in Log base 10 values.

3.9.2.1.3 X Axis

Range: Sets the width of the X axis in seconds, minutes, or hours. The X axis scrolls as needed to display the current readings, maintaining this range.
If the range is set to zero, the program will select the X axis range.

Units: Show the X axis in seconds, minutes, or hours.

Scroll: Selects the % of the graph to scroll when data overruns the X axis maximum value. Select scroll to smoothly scroll the graph.

Points: Enter the number of points to be plotted on the graph.

Graph on Top: When selected, the graph will be shown above other windows. When not selected, other windows may hide the graph. Use **View** on the main screen to show all opened graphs.

Advanced: The program's graph setup window is adequate for most users. However, the graphing control used by the EIES program is much more powerful (and potentially confusing). Select **Advanced** to override this setup screen and use the graph control's advanced Property Editor to customize the graph.

Before making changes in the advanced Property Editor, make a backup of the original **Graph#.OC2** — where **#** is the number before the graph name in the **View** menu.

The advanced Property Editor is accessed by right-clicking on the graph window to edit (but not the **Graph Setup** window), then left-click on **Properties**. To save advanced Property Editor changes, select the **Control** tab, then click **Save** to overwrite the **Graph#.OC2** file.

To view Property Editor Help, click the **Help** button on the **Graph Setup** window.

This page is intentionally blank.

Chapter 4
Installation

4.1 Introduction

Chapter 2 provided a "quick start" guide to the installation and operation of the Guardian system. Chapter 4 provides more detail on mechanical and optical installation requirements, and recommendations to help achieve the best results from the Guardian system.

Optical components (filters, lenses, light tubes, beam-splitters, fiber optics, etc.) are a critical part of the EIES system. INFICON evaluates optical components for use with EIES systems. Some components that meet specific performance criteria are sold with our Guardian systems. In many cases, however, you will want to evaluate and purchase components to meet your own specific requirements.

The companies listed below are excellent sources for lenses, filters, and other optical components needed to complete your EIES system installation.

CeramOptec Industries
515A Shaker Road
East Longmeadow, MA 01028
413-525-0600
www.ceramoptec.com

Edmund Optics
101 E. Gloucester Pike
Barrington, NJ 08007-1380
800-363-1992
www.edmundoptics.com

Omega Optical
21 Omega Dr., Delta Campus
Brattleboro, VT 05301
802-254-2690
www.omegafilters.com

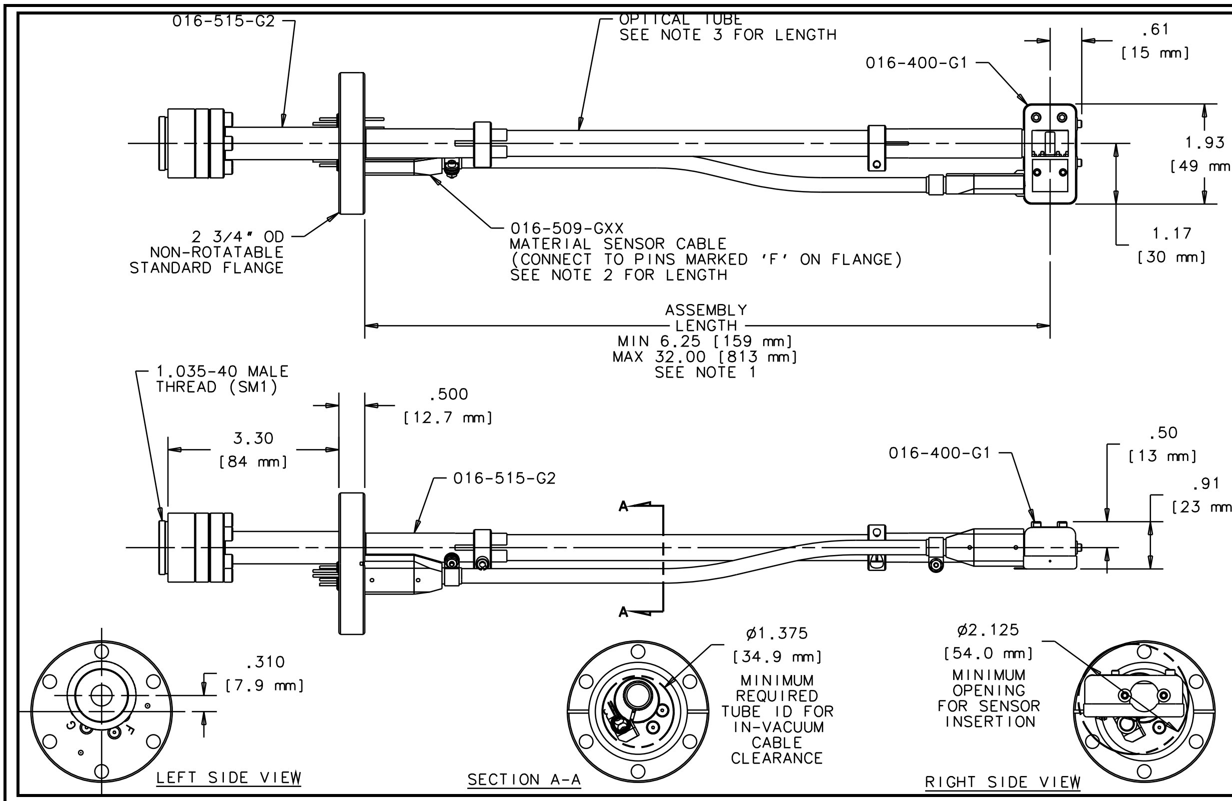
Thorlabs
435 Route 206   Box 366
Newton, NJ 07860-0366
973-579-7227
www.thorlabs.com

For additional help, see section 5.1, How To Contact Customer Support, on page 5-1.

4.2 Sensor / Feedthrough Assembly

The sensor will not pass through a 2.75 in. CF (NW35CF) port. If the chamber is too small or inaccessible to allow installation from the inside by securing the sensor to the optical tube and connecting the in-vacuum filament cable at the feedthrough and sensor, a 4.5 in. CF (NW63CF) or larger flange must be provided on the chamber and adapted to the 2.75 in. CF flange to allow the entire sensor to pass through.

Figure 4-1 EIES standard single sensor & feedthrough assy 016-600-Gxx

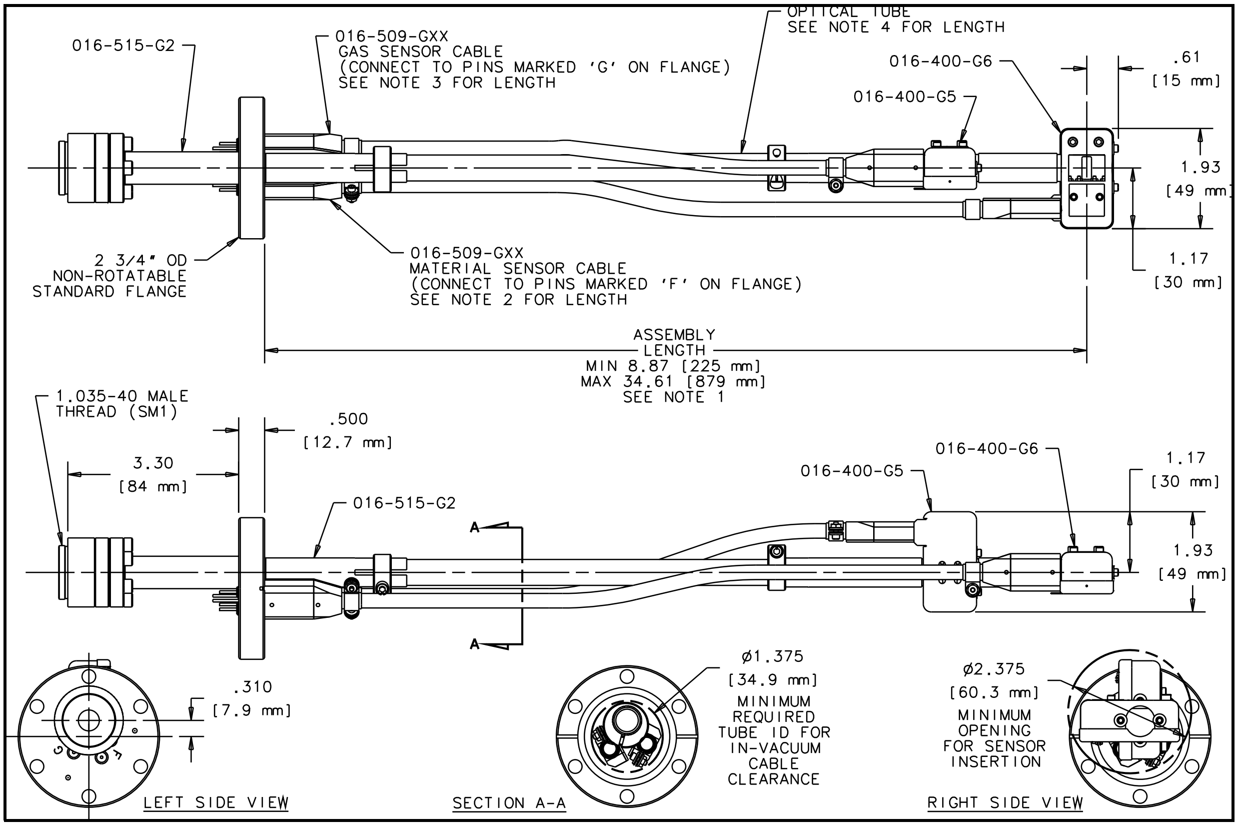


NOTE: Assembly length is specified by customer.
Material sensor in-vacuum cable length required is equal to assembly length.
Optical tube length required is assembly length minus 2 inches (51 mm).

NOTE: JT type CAD drawings are available from INFICON to facilitate your chamber design. See section 5.1, How To Contact Customer Support, on page 5-1.

PN 074-517-P1F

Figure 4-2 EIES gas compensating sensor & feedthrough assy 016-601-Gxx



NOTE: Assembly length is specified by customer.
Material sensor in-vacuum cable length required is equal to assembly length.
Gas sensor in-vacuum cable length required is assembly length minus 2.5 inches (64 mm).
Optical tube length required is assembly length minus 4.5 inches (114 mm).

4.2.1 Sensor Position

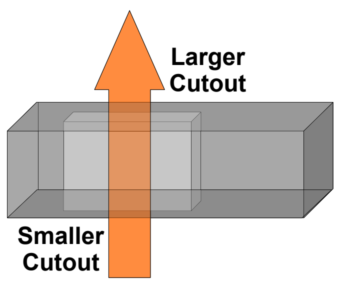
Location of the sensor within the vacuum system is the most significant factor in determining EIES system performance. The optical signal generated by the sensor is often small, especially when the deposition rate for a material is low. The objective in EIES system installation is to maximize the light output from the sensor, and deliver as much of that optical signal as possible to the PMT Detector(s).

Position the sensor to maximize the material vapor flux passing through it.

The best location is directly above the evaporant source, with the sensor opening perpendicular to the vapor flux, so the material passes straight through the opening. When multiple sources are involved, determine a best estimate of the average flux from all sources.

NOTE: If the sensor is not aligned properly to allow material vapor flux to pass through it, sensitivity will be reduced. Also, material will accumulate inside the sensor and sensor life will be shortened.

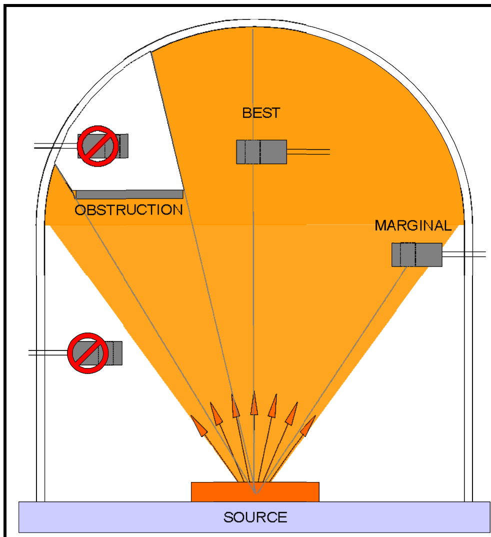
Figure 4-3 EIES sensor cutouts



The EIES sensor has two cutouts that allow the flux to pass through the sensor. Place the smaller cutout toward the flux, so that the flux exits via the larger cutout.

.

Figure 4-4 Sensor placement



Avoid locations where obstructions such as fixturing would interfere with the flux of material through the sensor.

PN 074-517-P1F

4.2.2 Sensor Covers

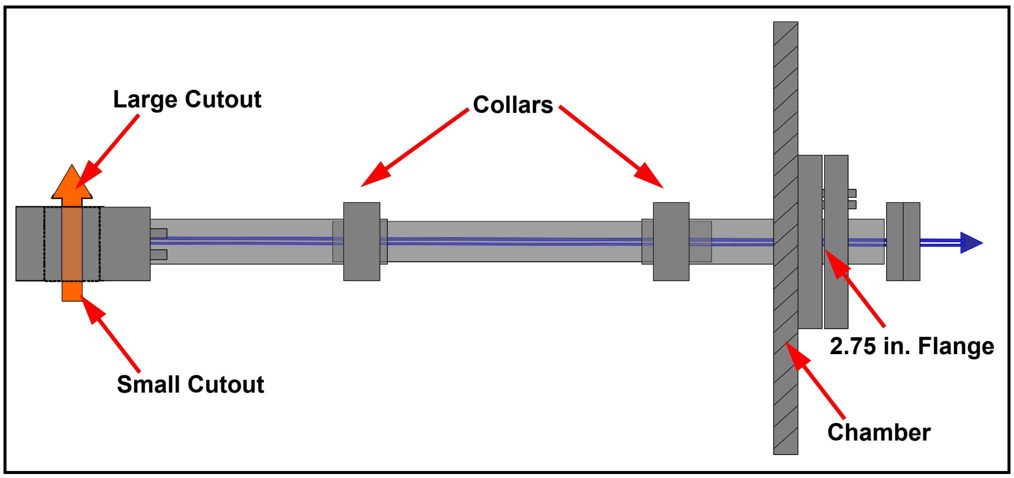
Two sensor covers are provided for the flux sensor, refer to Figure 2-2 on page 2-2.

- The High Rate cover 016-205-P1 is shipped installed on the flux sensor.
- The Standard Rate cover 016-205-P2 is shipped separately in a poly bag. For MBE and other applications where the sensor receives deposition rates below 10 Å/s or the emission signal is weak, the Standard Rate cover may be preferable as it allows more evaporant to enter the sensor.

When replacing covers, be sure the cover is securely snapped in place.

4.2.3 Rigid Sensor Installation

Figure 4-5 Rigid sensor installation



1. Loosen the telescoping tube collars and separate the sensor from the feedthrough.
2. Attach the feedthrough 2.75 in. CF flange to the mating port on the vacuum chamber wall with the telescoping tube inside the chamber.
3. Slide the telescoping tube into the feedthrough and adjust it (slide it in or out of the tube attached to the feedthrough) to the approximate position desired. The telescoping tube may be cut to a suitable length.
4. Tighten the collar around the tube and attach the sensor to the other end of the telescoping tube.
5. Adjust the sensor position and tighten the collar around the tube to hold it in place. For light pipes longer than 25 cm (10 in.), additional external support is required to prevent vibrations from affecting its position.

6 Attach the in-vacuum cable(s) from the feedthrough to the sensor(s). Polarity is not important, but make sure there are no potential shorts to the chamber or fixturing, (the signals on these wires are biased ±180 V to ground).

- For a standard single sensor, attach the cable to the pins marked **F**.
- For a Gas compensating sensor, attach the cable from the outer sensor, the Flux sensor, to the pins marked **F** and the cable from the inner sensor, the Gas sensor, to the pins marked **G**.

NOTE: These cables can be shortened if required to avoid kinking them.

WARNING - Risk Of Electric Shock

The sensor outputs are a potential shock hazard.
If a sensor cable is damaged, contact INFICON for a replacement.

7 Wrap aluminum foil (may not be suitable for use with Se) or other shielding around the light tube, cables, and sensor assembly. Do not obstruct the flow of material vapor through the sensor opening.

8 Include special provisions for cooling if your process requires, to allow Sensor temperature to remain below 450°C.

9 Be sure the sensor is in an area with less than two gauss of stray magnetic field during deposition. Higher fields may deflect the electron beam and cause the sensor to have little or no sensitivity to evaporant.

4.2.3.1 Maximizing the Optical Signal

Use the shortest possible length of light tube between the sensor and feedthrough to minimize light loss and consider inserting a quartz tube inside the stainless steel centerless ground light tube. If more than about 25 cm (15 in.) is needed, consider using a hollow quartz light tube with transmission >95%/cm from 195 to 1,000 nm. Suitable optical grade quartz and fused silica tube sizes are available from Technical Glass Products with diameters around 10 to 11 mm (0.4 in.)

The length should be tailored for the specific installation and be equal to the distance between the vacuum window in the feedthrough and the material flux sensor minus 12.7 mm (0.5 in.). The 12.7 mm insures that the coating of the sensor end of the rod is kept to a very low level. The use of hollow tubing instead of solid is suggested because even the best grade of quartz will strongly attenuate the optical signal when the path through it is exceptionally long. With the hollow tube the losses due to absorption are restricted to the path length the photons take through the quartz, which is small compared to the path in vacuum. Nevertheless, the more rugged nature of the solid rod makes its use desirable for shorter light paths (<381 mm (15 in.) where the attenuation loss is acceptable. It is considerably easier to damage the thin wall tubing during system maintenance than the solid rod.

NOTE: INFICON does not supply these quartz tubes or rods.

4.2.4 Sensor Filament Cables

4.2.4.1 016-600-Gxx Standard Single Sensor

Attach the 600-1406-P10 (3 m) or 600-1406-P40 (12 m) filament cable to the feedthrough pins labeled **F** using the thumbscrew to secure the connector. Plug the circular end into the controller's **Sensor 1** or **Sensor 2** connector.

4.2.4.2 016-601-Gxx Gas Compensating Sensor

Attach the 600-1407-P10 (3 m) or 600-1407-P40 (12 m) Dual Filament Cable branch labeled **FLUX** to the feedthrough pins marked **F** and the cable branch labeled **GAS** to the feedthrough pins marked **G**, using the thumbscrews to secure the connectors.

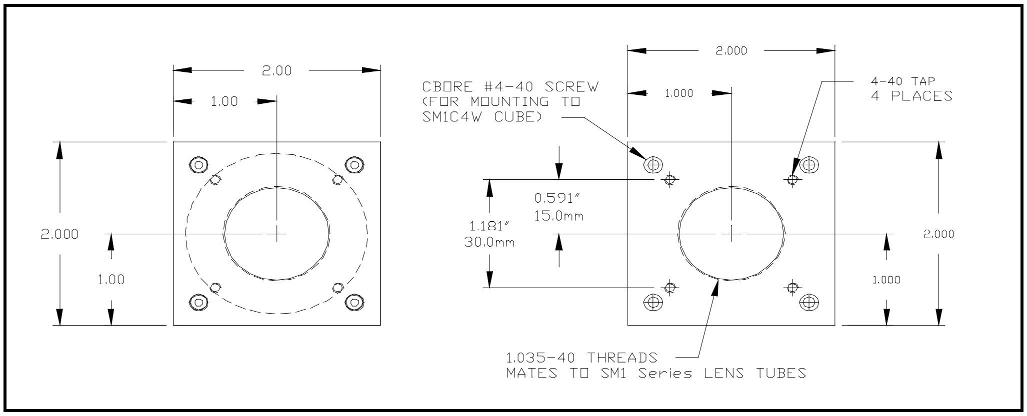
Plug the circular end into the controller's **Sensor 1** or **Sensor 2** connector.

4.3 PMT Detector

Specific system configuration and space constraints will determine the parts required to connect the light output from the sensor feedthrough to one or more PMT Detectors. Couplings, extension tubes, filters, and many other optical components are available from INFICON and a variety of other suppliers.

The PMT Detector uses a Thorlabs BC1 mounting plate to interface to other optical components. Several tapped mounting holes are provided on the mounting plate to attach the unit to external brackets or lens tubes.

Figure 4-6 Mounting plate



The PMT Detector may be mounted in any orientation, but should be protected from sources of mechanical shock or vibrations, such as might be generated by valve actuators or mechanical pumps.

The EIES PMT Detector has a 1 in. (25 mm) internal threaded coupling (PN 070-1622) on the optical inlet. A standard 1 in. (25 mm) round optical filter fits into the coupling and is held in place by a retaining ring, see Figure 4-7.

4.3.1 PMT Detector Cable(s)

Connect each PMT Detector to one of the eight EIES PMT Detector inputs 1 through 8 on the Guardian rear panel with 9-pin PMT Detector cable(s), PN 782-505-065, 3 m (10 ft.) or 782-505-065-40, 12 m (40 ft.)

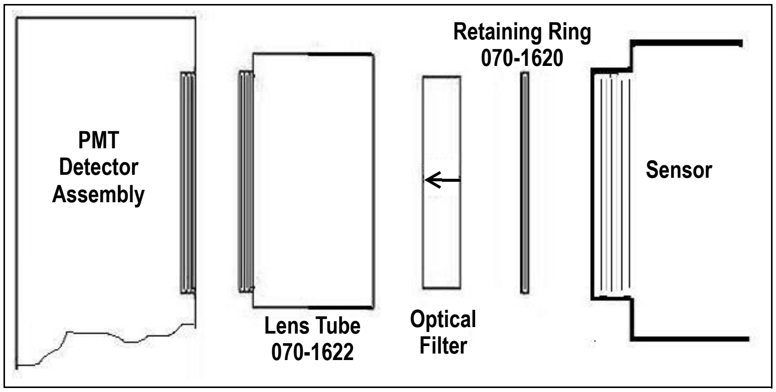
CAUTION

Turn controller power off whenever the PMT is exposed to room light to avoid damage to the PMT. PMT High Voltage is on whenever the controller power is on, regardless of the High Voltage LED status.

4.3.2 Single-PMT Detector Systems

For single-material thin film systems, only one PMT Detector is needed and it can be mounted directly to the feedthrough as shown below.

Figure 4-7 Single sensor direct mounting



1 Thread the 070-1622 Lens Tube into the 782-900-030 PMT Detector assembly.

2 Insert the 782-900-035-xxx optical filter into the lens tube with the arrow on the filter case pointing to the PMT Detector and secure the filter with the 070-1620 Retaining Ring supplied with the lens tube. Tighten the retaining ring using the 070-1628 tool supplied with the Guardian Ship Kit 782-703-G1.

3 Thread the completed assembly onto the sensor feedthrough.

The feedthrough/viewport assembly can support the weight of one PMT Detector mounted directly on the flange. If an extension is required to clear obstructions, additional support of the PMT Detector is required.

4.3.3 Multiple-PMT Detector Systems

When multiple materials are being deposited, one PMT Detector is typically required for each material. Each PMT Detector is fitted with a different optical filter, chosen to pass the specific emission wavelength characteristic of that material.

One solution for two-material systems is to use a second sensor/feedthrough, and to mount the second PMT Detector directly on that feedthrough (as in a one-PMT Detector system). This configuration achieves the best possible signal/noise ratio. However, the second sensor adds cost and complexity to the in-vacuum mounting and fixturing.

The alternative is to split the optical signal into several beams, see section 4.3.3.1 and section 4.3.3.3, which are directed into separate PMT Detectors. The beam can be split using traditional optical or fiber-optic beam splitters.

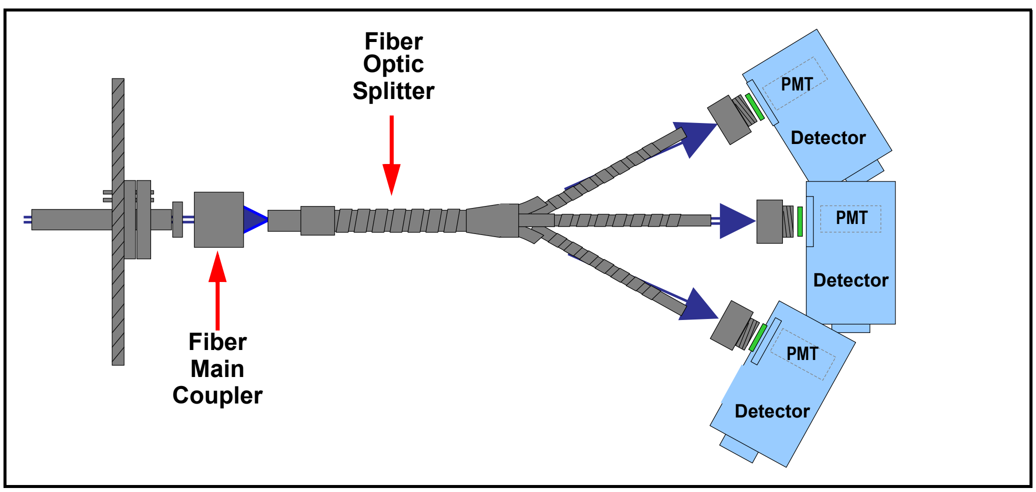
- PN 782-900-034-2-400 1:2 Fiber Optic Beam Splitter, 400 mm long
- PN 782-900-034 1:3 Fiber Optic Beam Splitter, 400 mm long

In both cases, optical signal losses can be significant, which may result in a signal that has a low signal/noise ratio. As a general rule, split the beam into three PMT Detectors at most.

4.3.3.1 Fiber Optic Beam Splitting

Fiber optic components cost more, but introduce lower light losses than equivalent optical components. They are especially beneficial when the signal is low or must be split into several components.

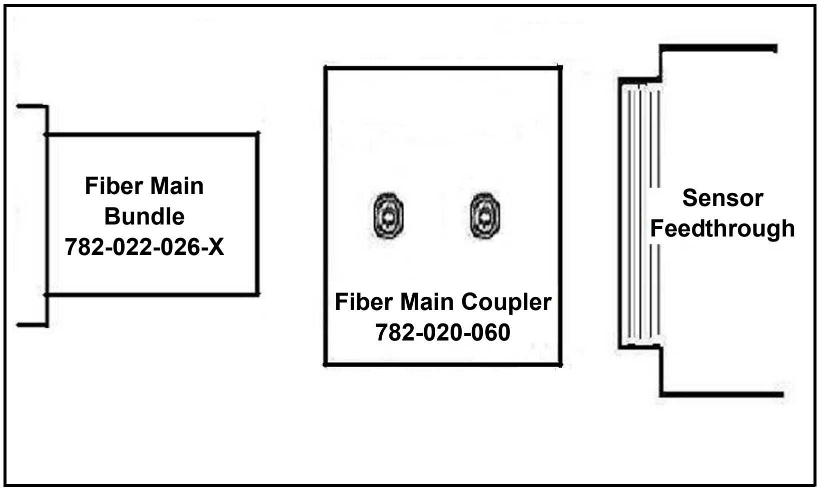
Figure 4-8 Fiber optic beam splitting 782-900-034



PN 074-517-P1F

4.3.3.2 Fiber Optic Beam Splitter Installation

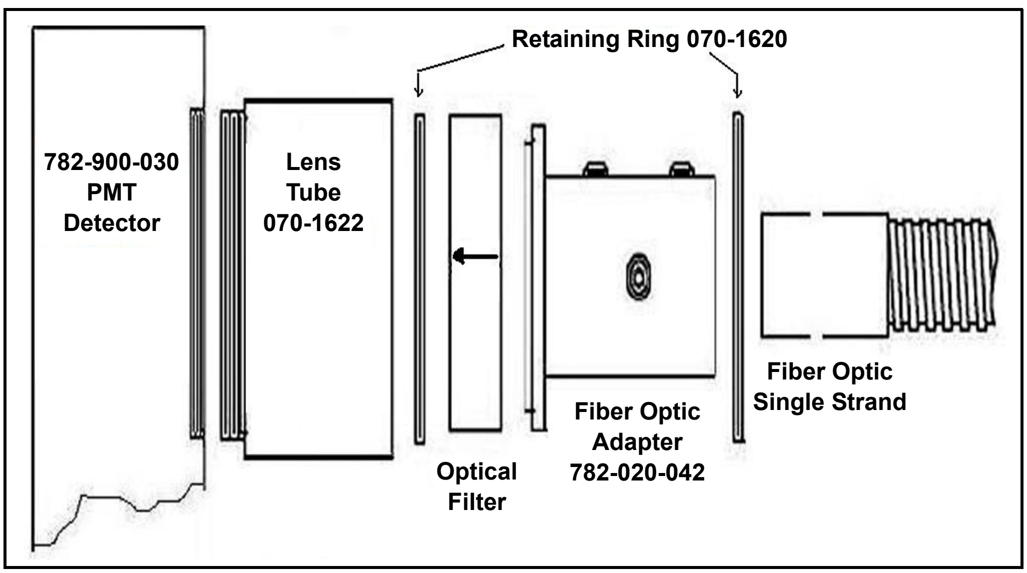
Figure 4-9 Fiber to sensor installation



To attach the main fiber optic bundle to the sensor viewport:

1. Thread the 782-020-060 Fiber Main Coupler onto the sensor feedthrough.
2. Insert the main fiber optic bundle into the Fiber Main Coupler and secure the fiber optic bundle with two set screws, *do not overtighten*.
3. Now attach each leg of the fiber optic bundle to an EIES PMT Detector. See Figure 4-10.

Figure 4-10 Attaching fiber ends to PMT Detectors



1. Thread an 070-1620 Retaining Ring part way into the 070-1622 Lens Tube so that it is approximately 1 cm (0.45 in.) deep into the lens tube.
2. Insert the 782-900-035-xxx optical filter into the lens tube with the arrow on the filter pointing to the PMT Detector.

PN 074-517-P1F

3 Insert the 782-020-042 Fiber Optic Adapter and secure the filter and adapter with a second 070-1620 Retaining Ring. Tighten the retaining ring using the 070-1628 tool supplied with the Guardian Ship Kit 782-703-G1.

All three setscrews in the fiber optic adapter should be accessible. Adjust the location of the first retaining ring as necessary to provide access to all set screws in the Fiber Optic Adapter.

4 Finally, insert the fiber end into the Fiber Optic Adapter and secure with three set screws, *do not overtighten*.

CAUTION

Be careful when bending fiber optic lines. Individual internal fibers are easily broken, which reduces the light signal at the output. PMT Detectors must be supported by external means. Do not hang a PMT Detector from the Fiber Optic Beam Splitter fibers.

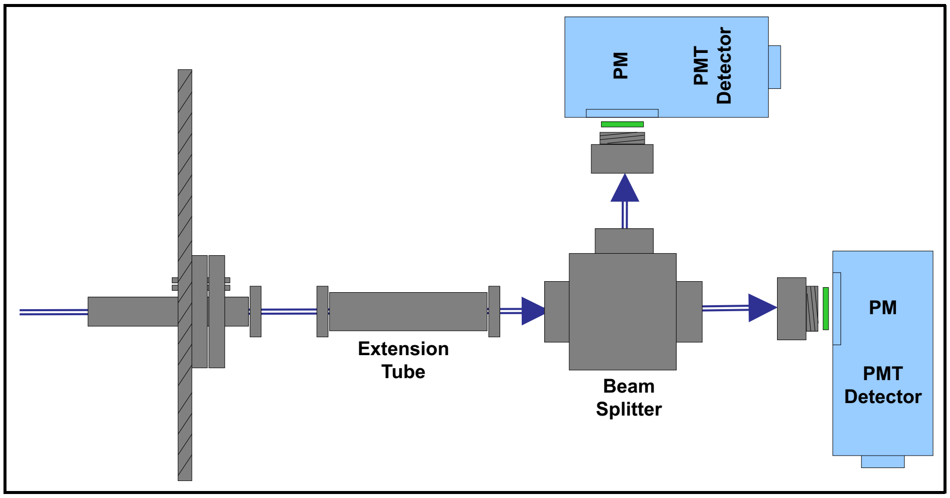
CAUTION

Be sure power to the PMT Detector is turned off by turning the controller power off whenever the PMT is exposed to room light to avoid damage to the PMT.

4.3.3.3 Optical Beam Splitter

For two-material systems, two PMT Detectors can be mounted at the two outlets of one beam-splitter. If there were no losses, half the original light signal would go to each PMT Detector. In reality, light losses are significant and much less than half actually goes to each PMT Detector. Figure 4-11 shows a simplified schematic of an optical beam splitting system for two PMT Detectors.

Figure 4-11 Beam Splitter



Beam splitters from Thorlabs are available with 25 mm (1 in.) threaded fittings to mate with the Guardian PMT Detectors and flange couplings.

Multiple PMT Detectors and the associated optical components add size and weight to the detection system. Sufficient clearance and support must be provided for all these components. They cannot be supported by the vacuum feedthrough as in the one-PMT Detector case. When installing the PMT Detector system be sure to allow clearance for maintenance of the sensor/feedthrough assembly.

For three-material systems, the signals reaching all three PMT Detectors are not the same magnitude; one receives more than the other two. The Guardian controller and software provide for gain adjustments to compensate for these differences; however, that does not adequately compensate for the lower signals inherent in the setup. In a three PMT Detector configuration, install the first PMT Detector on the material with the lowest deposition rate (lowest signal).

4.4 Optical Filters

A 25 mm (1 in.) round optical filter is mounted in the inlet of each PMT Detector. See section 4.3.2 and section 4.3.3 on page 4-10 for installation instructions.

This filter selectively passes a specific wavelength of light that is the characteristic emission from a specific material. The filter is a critical EIES component. The characteristics and quality of the filter have a strong influence on the results. Filter characteristics to consider include:

Transmission: The filter should transmit (pass) as much of the light as possible for the specified wavelength. A filter is a lens with a special coating that blocks all light except for a specified wavelength. Unfortunately, that coating also partially blocks the desired wavelength. The result is a reduced light beam even for the wavelength of interest.

Bandwidth: A filter passes wavelengths a little above and below the specified wavelength (the transmission curve is a bell-shape). A 100 nm filter with a bandwidth of 10 nm passes wavelengths from roughly 95 nm up to about 105 nm. A very narrow-bandwidth filter is more selective in passing only the wavelength of interest, but it may also result in lower signal level as well.

Some materials have primary emission wavelengths very close to other materials, which means the filter and PMT Detector cannot distinguish one material from the other. In these cases, a secondary emission wavelength may produce sufficient signal to be usable. For assistance in selecting an appropriate filter line, see section 5.1, How To Contact Customer Support, on page 5-1.

Appendix A lists common materials and their characteristic emission wavelengths.

4.5 Computer Connections

Guardian requires a connection to an external computer via RS232 cable or ethernet cable. For information about installing the EIES Guardian software, refer to section 3.2, Installation, on page 3-3.

4.5.1 RS232 Serial Interface

Connect a serial cable from the Guardian serial port to the computer serial port. The cable required is a DB9 female-to-male, (PN 068-0464 in Guardian ship kit). A USB to RS232 converter like the XetatroniX XS880 is required if the computer only provides the USB connection.

Guardian baud rate is fixed at 115,200. Communications format is No Parity, 8 bits, 1 stop bit. Hardware handshaking is not supported.

4.5.2 TCP/IP Ethernet Interface

The TCP/IP interface supports only the Standard Ethernet TCP/IP protocol. Guardian will communicate via TCP/IP on TCP port number 2101. The interface supports static addressing, DHCP is not supported. Ethernet parameters allowed to be set are the IP address.

4.5.2.1 Network Connection

If the Guardian is connected through a network or hub connection, a standard "straight" ethernet cable is required.

4.5.2.2 How to Set Up the Network Protocol on the computer

Most computers are configured to obtain the IP address, an address which defines the computer on the Internet, automatically from a server.

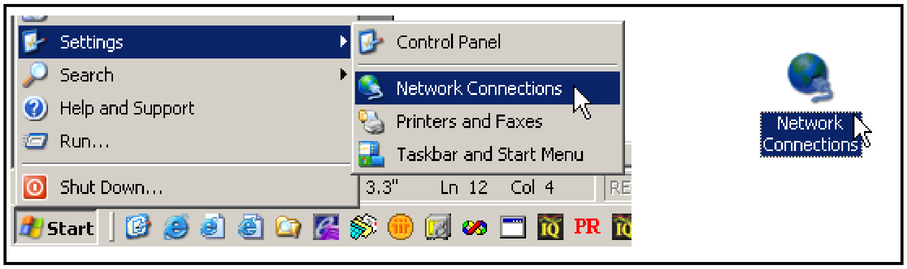
To communicate directly with the Guardian, the Internet protocol (IP) on the computer must be configured manually and an ethernet crossover cable (for example, PN 600-1211-P5) must be connected between the computer and the Guardian. Some computer’s will auto-configure and work with either straight or crossover cables. Instructions are provided here for manually configuring the Internet protocol.

NOTE: If the computer only has one ethernet port (that is, one network connection) then setting the computer for direct communications will prohibit it from accessing the Internet until that setting is reversed.

These instructions will set two values—the IP address and the Subnet mask—which will most likely prohibit access to the Internet. If these values already contain information then this information should be recorded somewhere for use in restoring the Internet connection.

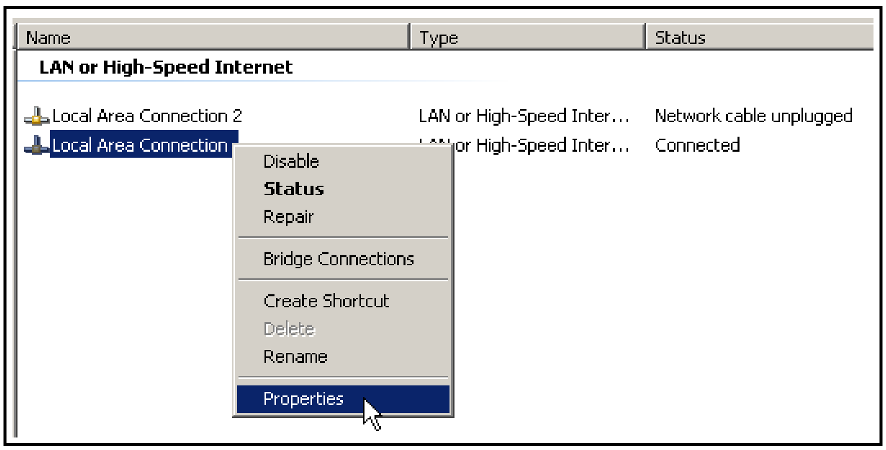
To access the Network Connection on the computer, click **Network Connections** on the Windows® **Start** menu or on the **Control Panel**. See Figure 4-12.

Figure 4-12 Accessing Network Connections



Click the **Local Area Connection** to be changed, right-click and select **Properties**. See Figure 4-13.

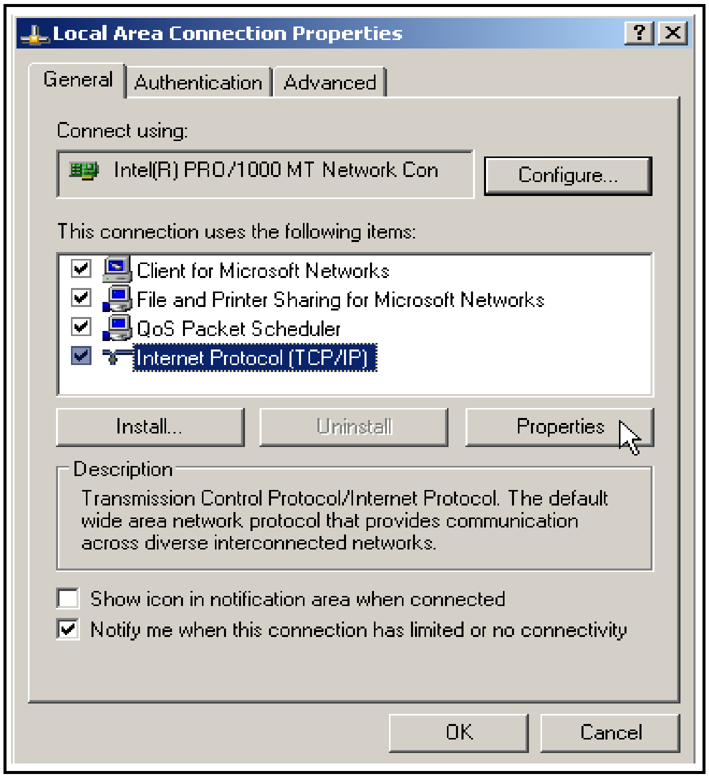
Figure 4-13 Local Area Connection Properties



PN 074-517-P1F

On the **General** tab, click **Internet Protocol (TCP/IP)** and click **Properties**. See Figure 4-14.

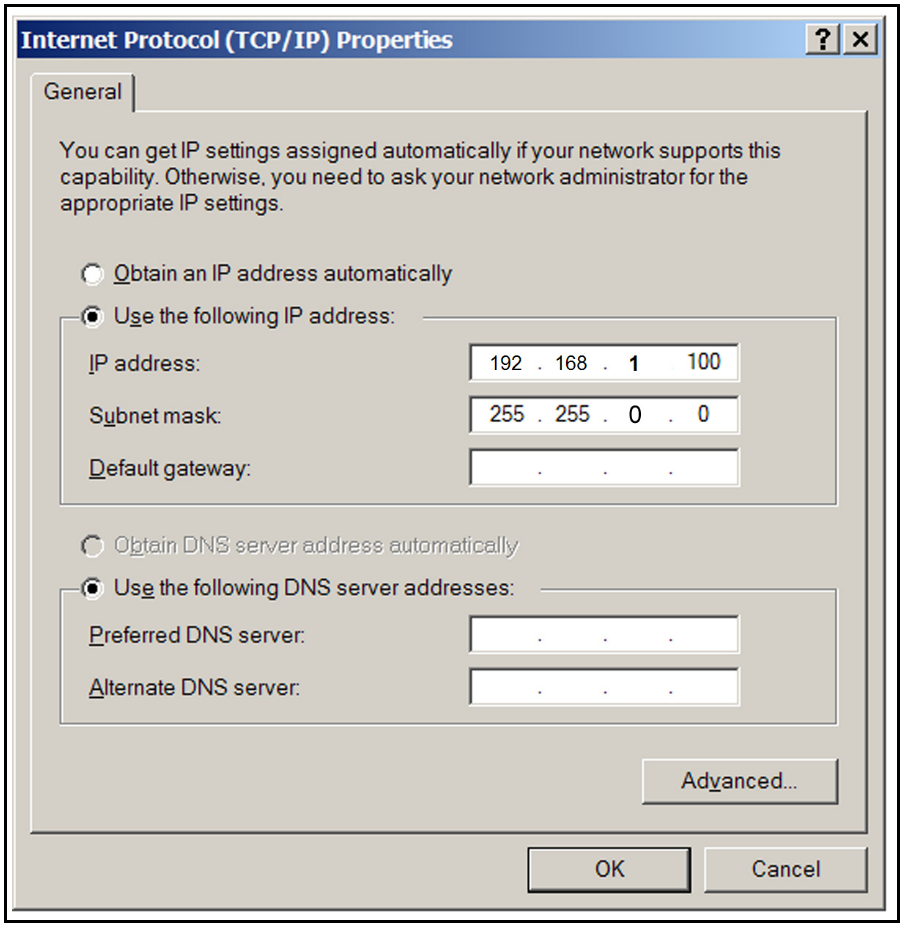
Figure 4-14 Internet Protocol (TCP/IP) Properties



Select **Use the following IP address**, enter the **IP address** and **Subnet mask** shown in Figure 4-15, and press **OK**. With this selection, the computer is assigned an IP address to use when communicating with the Guardian.

The Guardian is shipped from INFICON with address 192.168.1.200.
To communicate directly with Guardian from a computer, the computer must also be assigned an address that starts with 192.168.1 *but cannot be set to 192.168.1.200*.
The example in Figure 4-15 uses the address 192.168.1.100 for the computer.

Figure 4-15 Entering the IP address and Subnet mask



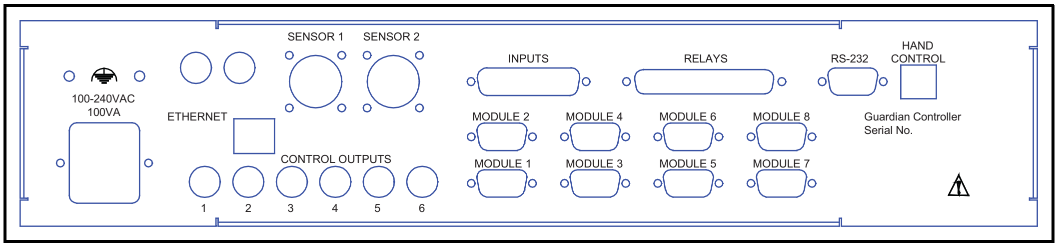
Click **OK** to all open dialogs to close out the Internet Protocol setup for the Local Area Connection.

PN 074-517-P1F

4.6 Controller Installation

Mount the controller in a location that allows easy wiring access to the EIES sensor and PMT Detector assemblies. The controller may be placed up to 7.62 m (25 ft.) from the EIES computer.

Figure 4-16 Rear panel

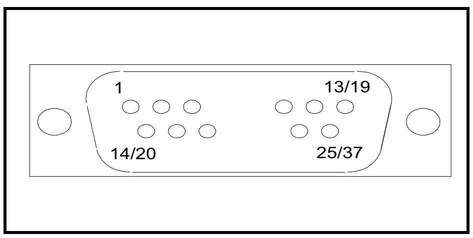


4.6.1 Digital I/O

Two connectors, labeled INPUTS and RELAYS on the rear panel provide digital inputs and relay output connections. Connect the Emission Interlock connector or equivalent to the INPUTS connector as described at section 4.6.1.3 Emission Interlock.The digital inputs are supplied on a 25-pin male D-sub connector.

Relay outputs are on a 37-pin male D-sub connector. Figure 4-17 shows the connector pin numbering, as seen from the rear of the Guardian controller.

Figure 4-17 Inputs and Relays connector rear view



On both connectors, pin one is in the upper left corner.
The last pin (25 or 37) is in the lower right corner.

4.6.1.1 Relay Connector Pinout

Table 4-1 Relay connector pinout

Relay	Pins		Relay	Pins
1	9, 27		7	6, 24
2	10, 28		8	13, 31
3	8, 26		9	4, 22
4	11, 29		10	5, 23
5	7, 25		11	14, 32
6	12, 30		12	15, 33

The relays are Form1A (SPST, normally open) mechanical relays rated for 30 V (dc) at 3 A maximum duty.

WARNING

The relay, relay circuit, and associated pins in the I/O connector(s) have a maximum voltage rating of 30 V (dc) or 30 V (ac) RMS or 42 V (peak). The maximum current rating per connector pin or relay contact is 3.0 Amps.

4.6.1.2 Input Connector Pinout

Table 4-2 Input connector pinout

Input	Pin		Input	Pin
1	13		7	19
2	14		8	20
3	17		9	21
4	15		10	22
5 (Interlock)	16		11	23
6	18		12	24
Common	10			
Ground	3, 4, 5, 6		+12V	1

Tie Common (pin 10) to a supply voltage, (+12 V is available on pin1). Inputs are activated by pulling the input pin to ground (pin 3, 4, 5 or 6).

WARNING

Digital inputs are not isolated! Voltage must be limited to between 0 and +12 volts with respect to ground.

4.6.1.3 Emission Interlock Connector

To enable emission to be turned on, the Interlock connector PN 782-505-077 from the ship kit must be plugged into the INPUTS connector or an equivalent system connection must be present. The Interlock connector supplied with the Guardian Ship Kit performs this function and jumpers pins 1 to 10 and pins 3 to 16.

The emission interlock is recommended to be tied to a gauge setpoint relay set to <5 x 10^{-4} Torr so that emission is automatically turned off when the pressure exceeds the setpoint.

CAUTION

A system interlock must be present. Plug the Interlock connector 782-505-077 (jumper pin 1 to 10 and pin 3 to 16) supplied in the 782-703-G1 Ship Kit into the Inputs connector. Emission cannot be turned on unless this connector or an equivalent system interlock is present. High Voltage and Sensor LEDs on the front panel will be blinking if emission is turned on and the interlock connection is not present.

4.6.2 Sensor(s)

Connect the sensor filament cable (PN 600-1407-P10 [3 m (10 ft.)] or P40 [12 m (40 ft.)] Dual or 600-1406-P10 or P40 Single) from the controller to the appropriate electrical connections on the sensor feedthrough. The single sensor controller only has the Sensor 1 connector.

WARNING - Risk Of Electric Shock

The relay, relay circuit, and associated pins in the I/O connector(s) have a maximum voltage rating of 30 V (dc) or 30 V (ac) RMS or 42 V (peak). The maximum current rating per connector pin or relay contact is 3.0 Amps.

4.6.3 Control Outputs

Connect a BNC cable (not supplied) from the EIES Control Output, (see Figure 4-16 on page 4-19) for each channel to the control input of your evaporation power supply.

Outputs 1 to 6 are located along the bottom of the rear panel; outputs 7 and 8 are located at the top of the panel. The channel control signal is a DC voltage from 0 to +/-10 V (dc). Consult your power supply vendor's manual for proper connection.

CAUTION

Properly ground the system. Connect a heavy braided cable from the EIES controller to vacuum chamber ground. If you are using multiple power supplies, be sure that the outer conductor of each BNC cable is at system ground potential.

4.6.4 Computer

Connect the EIES controllers RS-232 connector to the computer RS-232 port with a straight-through 9-pin cable (PN 068-0464 supplied in Guardian Ship Kit). If needed, you can use a USB to RS-232 adapter like the XetatroniX XS880 that supports 115 K baud rates and all Windows platforms.

Alternatively, connect an Ethernet cable from the controller Ethernet connector to the computer or an Ethernet hub. See section 4.5, Computer Connections, on page 4-15.

4.6.5 PMT Detectors

Connect the PMT Detectors to the connectors labeled MODULE 1 through 8 on the rear panel using the 782-505-065 3 m (10 ft.) or 782-505-065-40, 12 m (40 ft.) cables. PMT Detectors are only recognized by the controller when it is powered up with the detector cable connected.

4.6.6 Mains Power

With the power switch OFF, connect the AC mains to the controller power input. The controller automatically accepts 100-240 V (ac), 50-60 Hz.

NOTE: Observe the power-up sequence described below to avoid power glitches appearing at the evaporation power supply outputs during startup.

CAUTION

High voltage is present at the PMT Detectors whenever controller power is on and the PMT Detector cable is connected, even if the High Voltage LED is off.

WARNING

Power up sequence: (1) Press the power switch on the Guardian controller. (2) Start the EIES Software.
(3) Turn on the evaporation power supplies.

WARNING

Verify that the power cable provided is connected to a properly grounded mains receptacle.

WARNING

Maintain adequate insulation and physical separation of sensor, PMT Detector, and I/O wiring from hazardous voltages.

4.7 Quartz Crystal Monitor Option (QCM)

A Quartz Crystal Monitor (QCM) is commonly used with EIES systems for calibration of the EIES sensor, and control of materials for which EIES measurement is not suitable. The INFICON SQM-242 PCI Card or Q-pod is the recommended QCM for use with the Guardian system because they can be integrated to provide convenient and automatic calibration.

Consult the SQM-242 or Q-pod Operating Manual for detailed instructions on installing the SQM-242 QCM (and optional SAM-242 Analog Input card) or Q-pod in your computer. Chapter 3 of this manual describes setup and operation of the QCM in conjunction with the Guardian system.

NOTE: QCM calibration to substrates should be first importance. Second is QCM relation to EIES sensor. Both QCM and EIES sensor placement should have good material flux arrival with respect to that arriving at substrates.

For accurate rate calibration, locate the QCM sensor in the vacuum chamber so that it receives a representative sample of the materials being deposited. The length from the crystal to the oscillator must be under 1 m (40 in.) for proper SQM-242 and Q-Pod QCM operation. A shuttered quartz crystal sensor is recommended for rate calibration. The crystal should be located as close to the EIES sensor as possible so as to minimize the spatial variations of the evaporation sources. See the recommendations of the sensor's Operating Manual when installing the optional shuttered crystal sensor. It is possible to mount the crystal sensor so as to capture the evaporant passing through the EIES sensor. The use of the Sputtering Sensor (PN 750-618-G1) is convenient for this application as the crystal removes from the rear.

A quartz crystal sensor may also be used for direct rate control, independent of an EIES sensor. In that case, the quartz sensor should be installed in a region where it will receive uniform deposition material representative of the amount of material arriving at the substrate.

4.8 Monochromator Option

The 782-900-070 Monochromator Kit, see Figure 4-18, contains just one optical element, an aberration-corrected holographic grating. It has no internal mirrors.

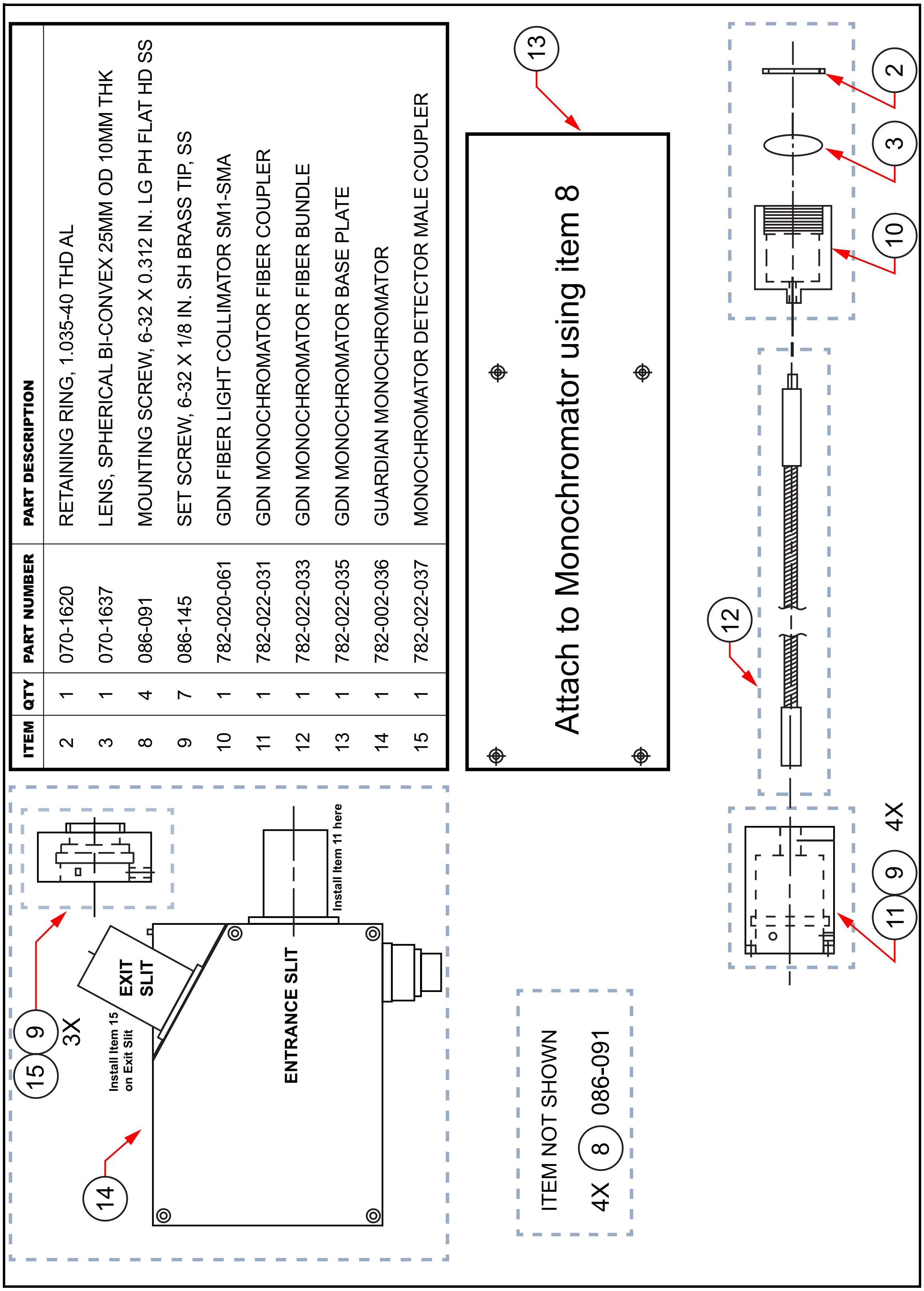
4.8.1 Monochromator Specifications

- Focal length 100 mm, Aperture F/3.5, Bandwidth 5 nm
- Grating: Groove density 1200 gr/mm, Blazed for 250 nm
- Wavelength counter: Digital, direct reading in nm, graduated in 0.2 nm intervals
- Wavelength 200-800 nm

Entrance/Exit couplers to connect to PMT Detector and fiber optic bundle to connect to Guardian sensor feedthrough are included in the kit.

4.8.2 Monochromator Installation

1. Place the PN 782-022-031 coupler on the monochromator entrance slit. Rotate until it drops into the locating pins, then secure with three PN 086-145 set screws.
2. Install the fiber light collimator and lens assembly (PN 782-020-061, PN 070-1637 and PN 070-1620) onto the Guardian feedthrough.
3. Attach the PN 782-022-033 fiber bundle to the collimator. Handle fiber with care to avoid breaking fibers in the bundle.
4. Secure the monochromator within range of the fiber bundle, using the PN 782-022-035 base plate or the four 6-32 threads in the monochromator itself. Provide sufficient clearance space to accommodate the PMT Detector in step 7.
5. Insert the rectangular end of the PN 782-022-033 fiber bundle, smooth side facing the set screw in the PN 782-022-031 coupler, until it bottoms on the monochromator entrance slit and secure with set screw. *Do not overtighten*.
6. Thread the PN 782-022-037 male coupler into the PMT Detector.
7. Secure the PMT Detector with coupler to the monochromator exit slit using three set screws *Do not overtighten*.
8. Verify that all connections are optically tight. Stray light entering will increase noise levels and may cause PMT saturation.



ITEM	QTY	PART NUMBER	PART DESCRIPTION
2	1	070-1620	RETAINING RING, 1.035-40 THD AL
3	1	070-1637	LENS, SPHERICAL BI-CONVEX 25MM OD 10MM THK
8	4	086-091	MOUNTING SCREW, 6-32 X 0.312 IN. LG PH FLAT HD SS
9	7	086-145	SET SCREW, 6-32 X 1/8 IN. SH BRASS TIP, SS
10	1	782-020-061	GDN FIBER LIGHT COLLIMATOR SM1-SMA
11	1	782-022-031	GDN MONOCHROMATOR FIBER COUPLER
12	1	782-022-033	GDN MONOCHROMATOR FIBER BUNDLE
13	1	782-022-035	GDN MONOCHROMATOR BASE PLATE
14	1	782-002-036	GUARDIAN MONOCHROMATOR
15	1	782-022-037	MONOCHROMATOR DETECTOR MALE COUPLER

Figure 4-18 Monochromator kit

PN 074-517-P1F

4.8.3 Monochromator Operation

Once the monochromator is installed, set the wavelength readout to the chosen point, using the readout and adjustment knob and making sure the wavelength lock is loose (left position).

Once deposition has begun, the wavelength may be selected more accurately by varying it slightly around the initial setpoint. The maximum rate reading (at constant power) indicates that the wavelength has been tuned. Slight wavelength tuning may improve signal throughput at this point. Record the final wavelength and whether it was approached in clockwise or counterclockwise rotation; this will speed the return to this emission line in the future. Tighten the wavelength lock (right position).

This page is intentionally blank.

Chapter 5
Maintenance & Troubleshooting

WARNING

There are no adjustments or user-serviceable parts inside the EIES Guardian Controller or PMT Detectors.

5.1 How To Contact Customer Support

Worldwide support information regarding:

- Technical Support, to contact a Support Engineer with questions regarding INFICON products and applications, or
- Sales and Customer Service, to contact the INFICON Sales office nearest you, or
- Repair Service, to contact the INFICON Service Center nearest you,

is available at www.inficon.com.

If you are experiencing a problem with your instrument, please have the following information readily available:

- the Model designation and serial number for your instrument,
- a description of your problem,
- an explanation of any corrective action that you may have already attempted,
- and the exact wording of any error messages that you may have received.

To contact Customer Support, see Support at www.inficon.com.

5.2 Returning Your Instrument to INFICON

Do not return any component of your instrument to INFICON without first speaking with a Customer Support Representative. You must obtain a Return Material Authorization (RMA) number from the Customer Support Representative.

If you deliver a package to INFICON without an RMA number, your package will be held and you will be contacted. This will result in delays in servicing your instrument.

Prior to being given an RMA number, you may be required to complete a Declaration Of Contamination (DOC) form if your instrument component has been exposed to process materials. DOC forms must be approved by INFICON before an RMA number is issued. INFICON may require that the instrument component be sent to a designated decontamination facility, not to the factory.

5.3 Sensor Maintenance

Maintenance is for the sensor (see Figure 5-1 and Figure 5-2) and consists of

- periodic cleaning
- occasional Filament replacement
  PN 782-530-015 replaces discontinued PN 782-900-029 and PN 782-900-052 Sensor and Feedthrough Assemblies (not shown)

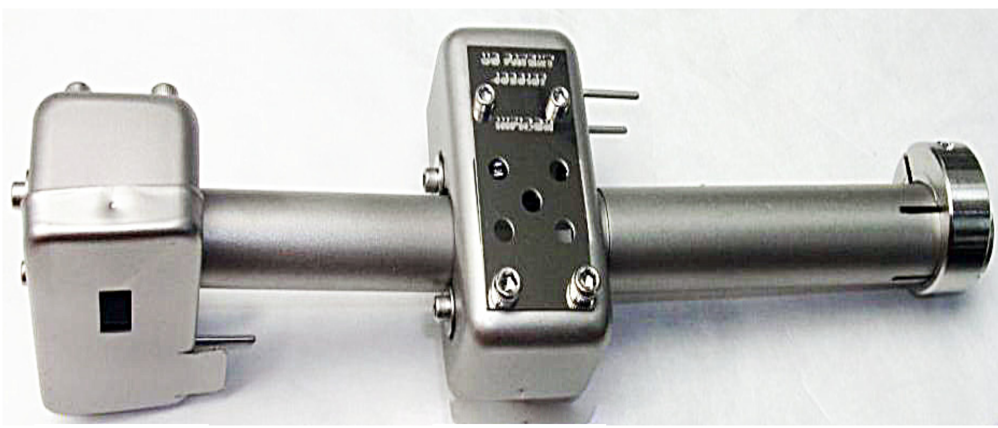
  or

- occasional Emitter Assembly replacement (PN 016-201-G1 for all PN 016-600-Gxx and PN 016-601-Gxx Sensor and Feedthrough Assemblies).

  NOTE: The standard and gas compensating sensors use the same Emitter Assembly.

Maintenance is performed by removing the sensor assembly from the vacuum system and working with it on a clean bench.

Figure 5-1 016-601-Gxx Gas Compensating Sensor (feedthrough and cables not shown)



Flux Sensor **Gas Sensor**

NOTE: The PN 016-600-Gxx Standard Sensor only has the Flux Sensor, otherwise it is identical to the PN 016-601-Gxx Gas Compensating Sensor.

PN 074-517-P1F

5.3.1 Sensor Cleaning

Aluminum foil, which may not be suitable for use with Se, or other shielding will minimize build-up of material on sensor surfaces. However, some accumulation is inevitable. Follow the same safe cleaning techniques used to clean any other sensitive devices in the vacuum system. The sensor is constructed of vacuum-compatible materials that may be cleaned using alcohol or other vacuum-friendly solvents.

Most Guardian sensor parts can be replaced in the field. For assistance, refer to How To Contact Customer Support on page 5-1. In extreme cases, the entire sensor might need to be replaced. *Do not return your sensor or feedthrough to INFICON for cleaning.*

5.3.2 EIES Filament or Emitter Assembly Replacement

NOTE: The emitter assembly PN 016-201-Gx (G1=Thoria, G2=Yttria, obsolete) itself is not a repairable item.

While average filament and emitter life is approximately 1,000 hours at 2 mA for Yttria filaments and 4 mA for Thoria filaments, process parameters will affect life expectancy.

Refer to the label attached to your emitter and sensor packaging for the correct emission current setting.

Operating at lower filament currents extends filament life.

A routine service schedule should be established for each installation.

Before replacing the filament or emitter assembly, read the cautions listed below:

CAUTION

Be sure the sensor is replaced in the exact location and orientation as before its removal. This will minimize the calibration error experienced on the first run after the replacement.

CAUTION

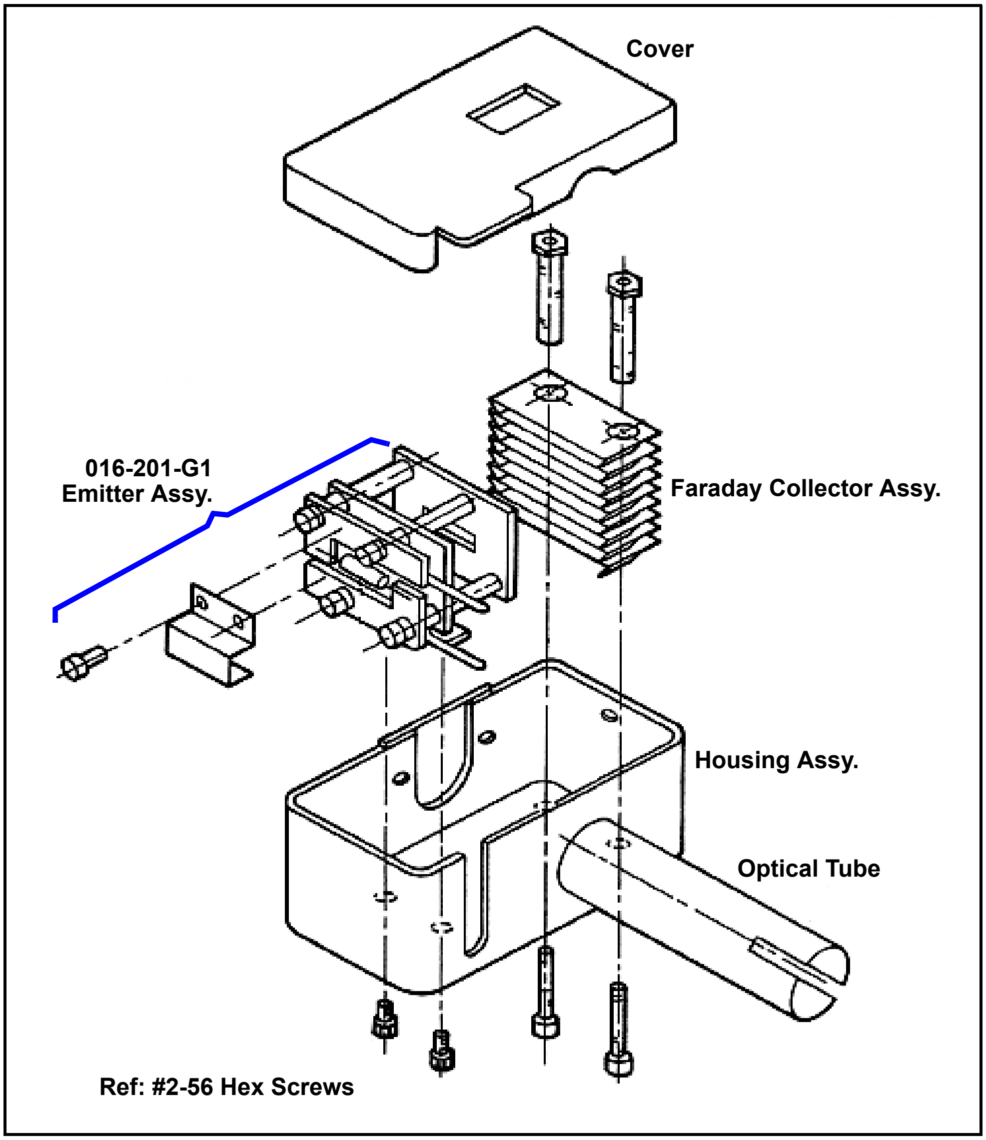
Apply a light, fresh coating of graphite (PN 009-175) or equivalent on all screws removed from the sensor before replacing them.

CAUTION

Follow standard vacuum procedures to prevent emitter contamination by improper handling.

See Figure 5-2 and follow the steps below to replace the PN 016-201-G1 emitter assembly:

Figure 5-2 New 016-Series sensor exploded



1 Unplug the in-vacuum cable from the sensor connector pins by grasping the connector body and pulling outward with a slight rocking motion.

2 If necessary, loosen the clamping ring at the end of the optical tube to remove the sensor from the vacuum system.

3 Carefully pry the cover off the sensor housing.

4 Remove the two #2-56 hex screws which hold the emitter assembly and name plate in place.

5 Check the general mechanical condition of the assembly before installing the new emitter assembly. Remove excess evaporant and flaking, if necessary.

6 Install the new emitter such that the connector pins are centered in the housing slot and the aperture plate is parallel with the Faraday collector.

7 Replace the sensor cover.

8 Check the resistance between the emitter's connector pins (it should be approximately 1 ohm) and between one pin and the sensor housing assembly (it should exceed 1 megohm). Use the highest resistance range when checking between a connector pin and the housing. Use the lowest when checking between connector pins.

If there is continuity between the housing and the connector pins, check the position of the emitter assembly and insure that it is properly installed.

If there is no continuity between the connector pins, the filament is open and the emitter assy must be replaced.

5.4 Chassis Cleaning

Use a damp cloth, wetted with water or a mild detergent, to clean the outer surfaces.

5.5 Troubleshooting

High Voltage and Sensor 1 or 2 LEDs are blinking when sensor is turned on

Verify that the Interlock connector or equivalent connection is present, see section 4.6.1.3 on page 4-21. If present, contact INFICON—refer to How To Contact Customer Support on page 5-1.

Chapter 6
Theory & Calibration

6.1 Introduction

This chapter contains information for determining calibration values that will achieve the best possible performance and accuracy from the EIES-IV Guardian system.

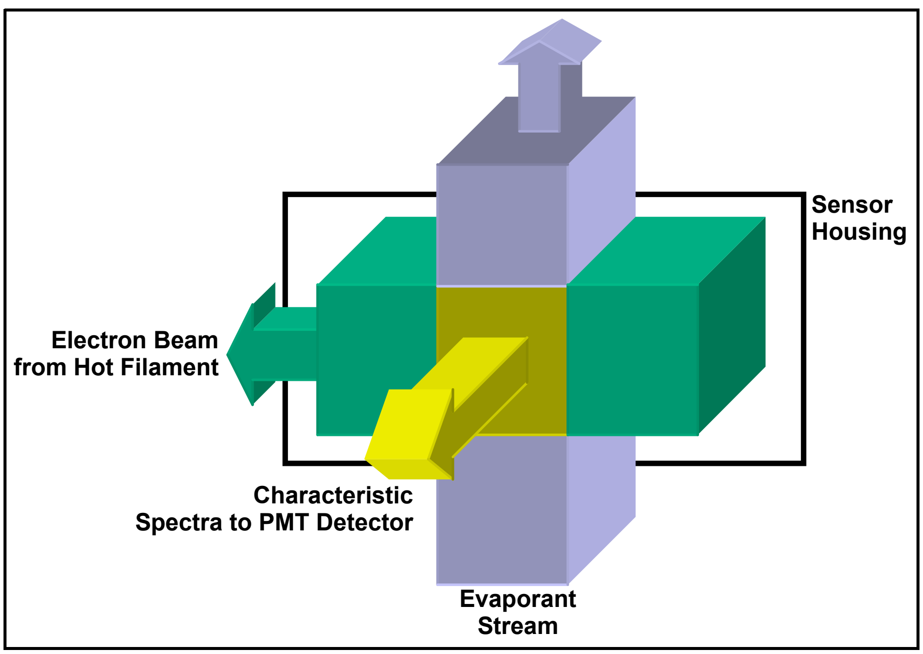
6.2 Theory of EIES Measurements

Electron Impact Emission Spectroscopy (EIES) uses a thermionic emitter to excite outer shell electrons to a higher valence band. When these excited electrons return to their normal state, they emit photons of a characteristic wavelength(s). An optical filter passes the characteristic wavelength to a photomultiplier tube (PMT) detector. The intensity of the characteristic wavelength is proportional to the rate of deposition of the selected material.

6.2.1 Sensor

The EIES emitter assembly (referred to as the "sensor" for historical reasons) consists of a hot cathode filament used to emit high-energy electrons. The sensor is installed so that a portion of the evaporant stream passes through the active sensor region. See Figure 6-1.

Figure 6-1 Sensor



PN 074-517-P1F

Within the sensor housing, electrons from the filament strike the evaporant atoms, raising the energy level of the outer electrons. These excited electrons immediately return to their normal energy level, emitting photons. The wavelength of the photons is characteristic of the material, and the intensity is proportional to the number density of the atoms.

For any material:

$$J \propto iN \quad [1]$$

where:

J = Emission Intensity

i = Electron Beam Current

N = Number Density of Atoms

and:

$$D = mvN \quad [2]$$

where:

D = Mass Deposition Rate

m = Mass of Atom

v = Average Velocity of Atoms

Finally, for a constant velocity:

$$J = kD \quad [3]$$

where:

k is a calibration constant.

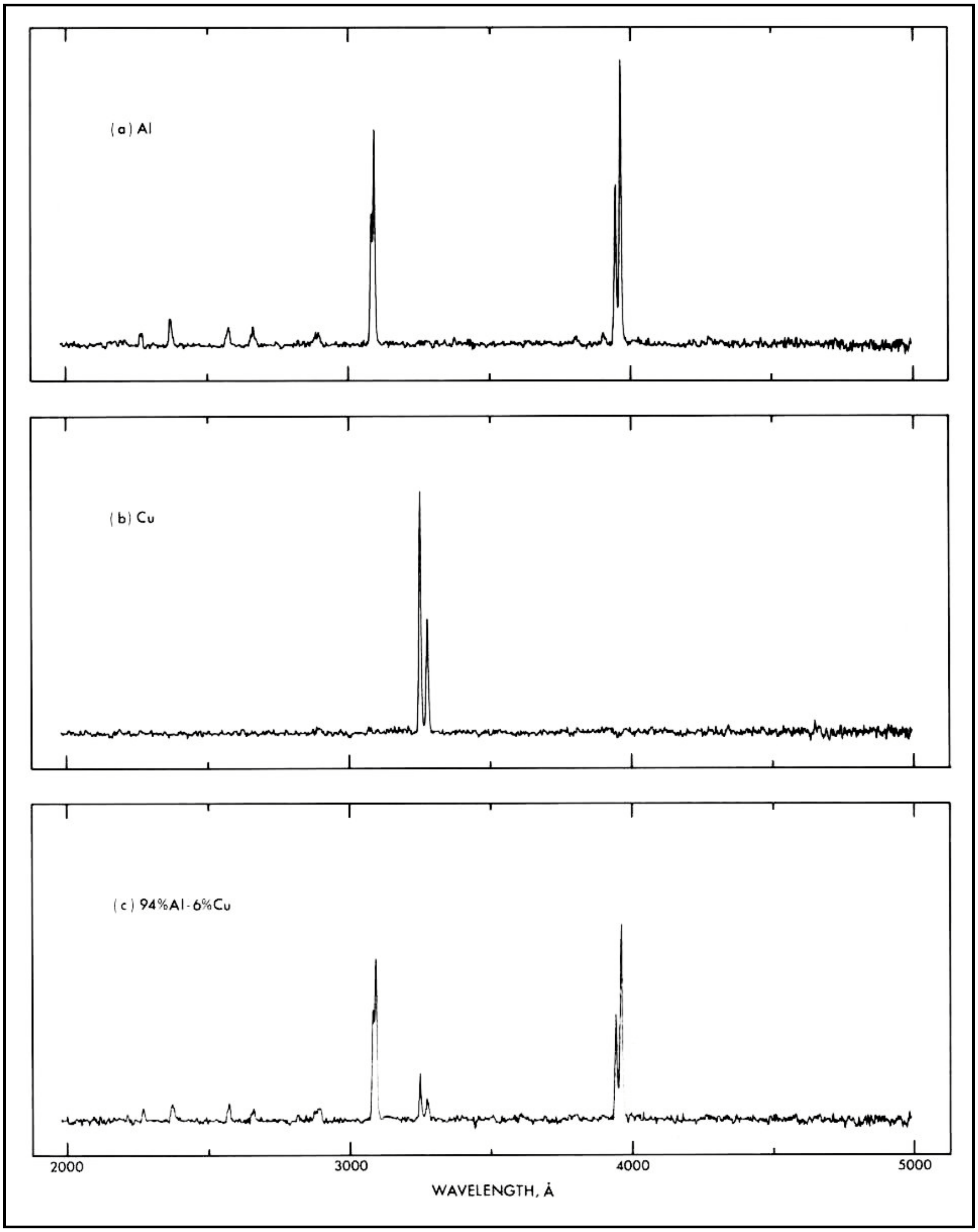
The calibration constant incorporates several assumptions inherent in the above derivation—constant velocity, constant source temperature, and optical losses.

The emitted light must be efficiently transmitted to the detection device(s). For short, straight transmission paths from the sensor to the PMT Detector(s), the sensor's hollow tube may be adequate. However, the number of photons reaching the PMT Detector is proportional to the inverse of the light path squared ($1/D^2$).

For straight paths, a quartz light pipe placed inside the sensor 's hollow light tube is inexpensive and simple to fabricate. For transmission of the UV wavelengths used in EIES, a high-purity fused quartz guide is required. A quartz light guide can provide nearly a factor of ten improvement in light transmission. For non-linear paths, and efficient signal splitting, a fiber optic splitter allows flexibility in sensor/PMT Detector placement, and significantly less optical loss.

6.2.2 Optical Discrimination

Figure 6-2 Spectra for aluminum, copper, and a co-deposition of 94% Al - 6% Cu



Issues common to material co-deposition are clearly illustrated in Figure 6-2. The Al line near 4000 Å is useful. The intensity is not diminished when co-deposited with Cu, and no interfering emission lines are nearby.

However, for Cu the line near 3250 Å is not only attenuated, but is also near the secondary Al line around 3100 Å. To accurately measure the Cu emission, we need a discriminating device with the conflicting goals of a narrow bandwidth and low attenuation of the desired signal.

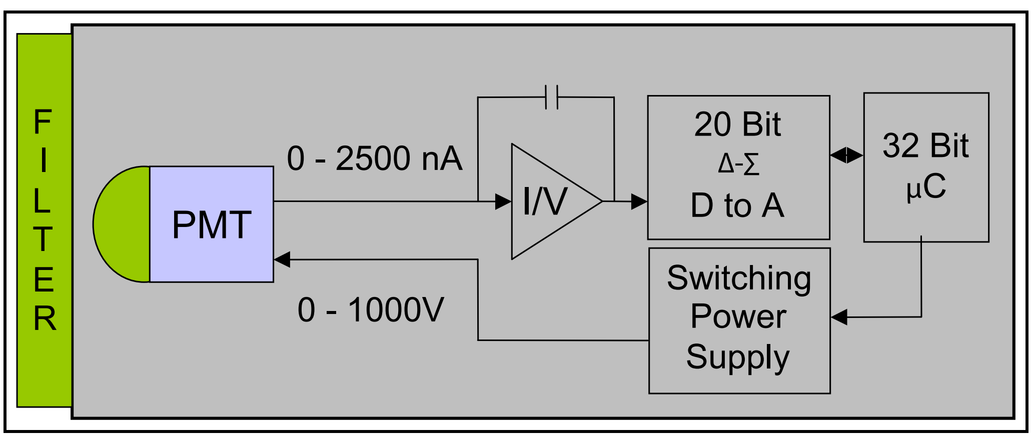
Thin film optical filters are both efficient and selective. In addition they are readily available, small, and relatively inexpensive. The main disadvantages are that a specific filter is required for each material, and the filters degrade over time. Periodic spectrometer verification of filter central wavelength and pass band is required.

An alternative to optical filters are monochromators. Both wavelength and bandwidth are tunable, but the efficiency does vary with the square of the bandwidth. For applications requiring deposition of many different materials, monochromator size and expense may be an acceptable trade-off to stocking and changing filters.

6.2.3 PMT Detector

Once the characteristic wavelength is discriminated by a filter or monochromator, it must be accurately measured by a PMT Detector. The EIES-IV Guardian uses a photomultiplier tube (PMT) to convert the optical signal to electric current. See Figure 6-3.

Figure 6-3 PMT



In addition to the PMT, a programmable high voltage power supply and microprocessor are housed within the PMT Detector. This allows each PMT Detector to be calibrated to a PMT voltage specific to the material and deposition rate being measured. A single DB-9 cable carries the RS-232 communications and low voltage power between the PMT Detector and Guardian controller.

PN 074-517-P1F

6.3 Theory of QCM Measurements

As material is deposited on a quartz crystal, its frequency decreases. The frequency change correlates to a thickness, using the QCM equation:

$$T_f = \frac{N_q \cdot D_q}{\pi \cdot D_m \cdot F_c \cdot Z} \cdot \operatorname{atan}\left[Z \cdot \tan\left[\frac{\pi \cdot (F_q - F_c)}{F_q}\right]\right] \quad [4]$$

AT crystal constant: $$N_q = 1.668 \times 10^5 \cdot \text{Hz-Cm} \quad [5]$$

Density of quartz: $$D_q = 2.648 \cdot \frac{\text{gm}}{\text{cm}^3} \quad [6]$$

6.3.1 Density

Material density tables (in gm/cc) are commonly available in an Appendix to this Operating Manual, chemical handbooks, and on the Internet. If you cannot find the density of your material, it can be calculated empirically using this method:

1. Place your substrate adjacent to a new quartz sensor.
2. Set QCM Density to an approximate value; Z-Ratio =1; Tooling =100.
3. Deposit approximately 1000 to 5000 Å of material.
4. Use a profilometer or interferometer to measure the substrate's film thickness.
5. The actual density value is calculated by:

$$\text{Density}_{\text{Actual}} = \text{Density}_{\text{Approx}} \times \frac{\text{Thickness}_{\text{QCM}}}{\text{Thickness}_{\text{Actual}}} \quad [7]$$

6.3.2 Z-Ratio or Z-Factor

Z-Ratio is used to match the acoustic impedance of the deposited material (Z_m) to that of the base quartz material (Z_q=8.83) of the sensor crystal:

$$\text{Z-Ratio} = \frac{Z_q}{Z_m} \quad [8]$$

For example, the acoustic impedance of gold is Z=23.18, so:

$$\text{Gold Z-Ratio} = \frac{8.83}{23.18} = 0.381 \quad [9]$$

Z-Ratio can be calculated using the Shear Modulus of quartz (U_q) and the deposited material (U_m):

$$Z = ((D_q * U_q)/(D_m * U_m))^{1/2} \quad [10]$$

where:

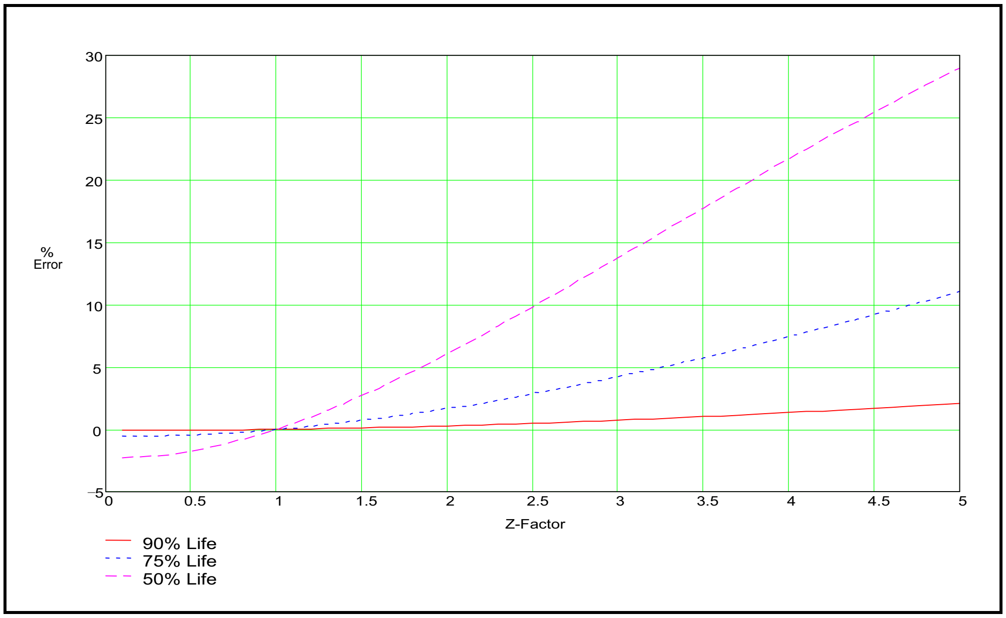
Uq = 32 GPa

Unfortunately, Z-Ratio and Shear Modulus are not readily available for many materials. Z-Ratio can also be calculated empirically using this method:

1. Deposit the material until Crystal Life is near 50%, or near the end of life, whichever is sooner.
2. Place a new substrate adjacent to the used quartz sensor.
3. Set QCM Density to the calibrated value; Tooling to 100%. Zero thickness.
4. Deposit approximately 1000 to 5000 Å of material on the substrate.
5. Use a profilometer or interferometer to measure the actual substrate film thickness.
6. Adjust the Z-Ratio (Z-Factor) of the Guardian until the correct thickness reading is shown.

Another alternative is to change crystals frequently. The graph in Figure 6-4 shows the % Error in Rate/Thickness from using the wrong Z-Ratio. For a crystal with up to 90% Life (10% used), the error is negligible for even large errors in the programmed versus actual Z-Ratio. The error increases as % Life decreases.

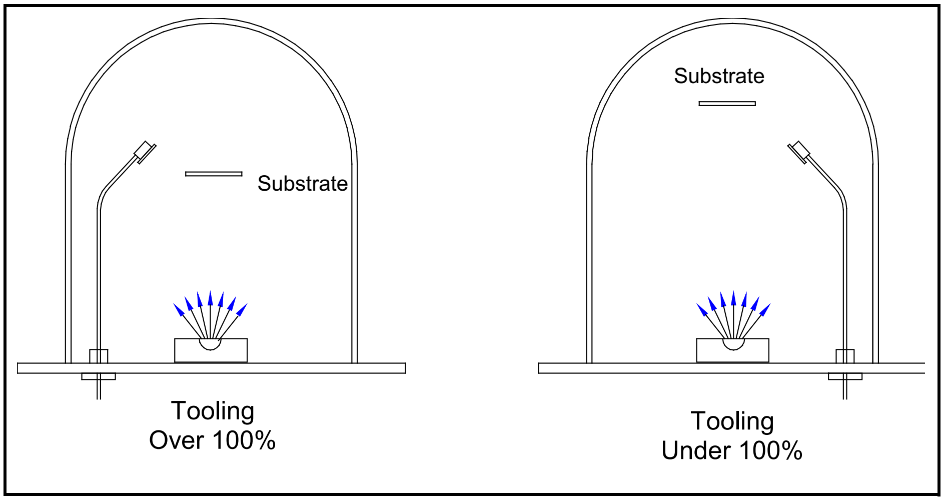
Figure 6-4 % Error vs Z-Ratio



6.3.3 Tooling Factor

Tooling Factor adjusts for the difference in material deposited on the quartz sensor versus the substrate. Tooling may be less than or greater than 100% as shown in Figure 6-5.

Figure 6-5 Tooling value



1. Place your substrate and a new quartz sensor in their normal position.
2. Set Tooling to an approximate value; Density as determined above; Z-Ratio =1.
3. Deposit approximately 1000 to 5000 Å of material.
4. Use a profilometer or interferometer to measure the substrate's film thickness.
5. The correct Tooling Factor is calculated by:

$$\mathrm{Tooling}_{\mathrm{Actual}} = \mathrm{Tooling}_{\mathrm{Approx}} \times \frac{\mathrm{Thickness}_{\mathrm{Actual}}}{\mathrm{Thickness}_{\mathrm{QCM}}} \qquad [11]$$

PN 074-517-P1F

6.4 EIES Calibration

EIES is an accurate means of measuring deposition rate and deposition thickness over a wide dynamic range. However, it must be set up properly and calibrated periodically for accurate results.

Read Chapter 3 before continuing.

6.4.1 PMT Detector Calibration

Before use, the electronics of each PMT Detector must be calibrated and stored in the EIES software. Calibration must occur each time the PMT Detector is replaced or moved to another channel on the Guardian controller. Because sensor emission and PMT voltage are off, calibration can be done at atmosphere or vacuum, with or without deposition.

1. Connect the PMT Detector to the Guardian Controller.
2. Start the EIES software.
3. Click **Edit >> System**.
4. Click the **Channel** tab.
5. Select the channel for the PMT Detector to be calibrated.
6. Select a calibration readings value that is equal to the Update (Hz) value shown. This will assure four seconds for a total calibration time.
7. When calibration is finished, the calibration constants for the selected PMT Detector will be refreshed.

6.4.2 PMT Voltage Selection

The PMT voltage of the EIES PMT Detector can be adjusted to optimize the operating point for the material and deposition rate to be measured.

NOTE: To achieve optimum stability prior to calibration, allow a one hour warm-up for the PMT Detector and a fifteen minute warm-up for sensor emission.

The PMT voltage setting affects the gain (and to a lesser extent, offset) of the PMT Detector. A low PMT voltage causes noisy readings, while high voltage risks saturating the PMT output.

In the EIES software, create a layer for the material (film) that will be used in process conditions.

Click **Edit >> System**, then click the **Channel** tab.

Display the channel's **Edit Layer** window, **Film Cal.** tab.

Start deposition of the single material by manually controlling the deposition source, or using the Manual Power function of the EIES software. Set the power to achieve a rate near the maximum deposition rate that will measured during process conditions. This can be determined from previous experience with the power supply setting, or by measuring the true rate with a QCM. It is not important that the value be exact, near the upper range of the desired deposition rate is sufficient.

On the **Edit Layer** window, adjust the PMT voltage until the **Flux%** reading on the **View >> Readings** display shows 30% to 80%. Typical PMT voltage values are 500 V to 700 V. The 30% to 80% value may seem low, but some headroom may be necessary when other materials are being co-deposited.

6.4.3 Zero Calibration

The EIES PMT Detector may read a residual gas signal, even when no deposition is occurring.

NOTE: Allow a one hour warm-up for the PMT Detector.

To remove this error term,

1. Create a layer for the material (film) that will be used in process conditions.
2. Show the channel's **Edit Layer** window, **Film Cal.** tab.
3. Verify that the film's User Multiplier setting is 1 and User Offset is 0.
4. Verify that the Cal Gain setting is 1 and the Cal Zero setting is 0. This assures that the PMT Detector reading displayed is PMT Detector current in nA.
5. With the EIES sensor enabled, but *with no deposition*, observe the channel readings. Enter the reading into the **Cal. Zero** field of the **Edit Layer** window. Click **Enter**. The channel reading will now show zero.

6.4.4 Gain Calibration - Test Run

Gain calibration matches the EIES PMT Detector's relative rate/thickness measurement to a known rate/thickness measurement by completing a trial deposition on a substrate whose thickness can be measured by some other means, such as a QCM, interferometer, profilometer, or weight.

NOTE: Allow a one hour PMT warm-up for optimum stability.

Record the EIES thickness reading at the end of the deposition and correct the value by entering a Cal Gain:

$$\text{Cal. Gain} = \frac{\text{Measured Thickness}}{\text{EIES Total}} \quad [12]$$

CAUTION

This method of EIES gain calibration is both time-consuming and prone to error.

PN 074-517-P1F

6.4.5 Gain Calibration - QCM

A Quartz Crystal Monitor (QCM) provides an accurate means of calibrating EIES PMT Detector gain. While it can be used in the manner described above, SQM-242 or Q-pod provide an automated approach.

1. On the **Edit Layer** window, click the **FilmCal.** tab.
2. Select the QCM input to use from the **Cal. QCM #** drop-down list.
3. Enter the Density and ZFactor (Z-Ratio) for the material being calibrated.

   NOTE: If you don't know the Z-Ratio, use a new crystal and set ZFactor = 1. Set Cal. Accuracy to 100% and Cal. Interval = 0. Set Cal. Sample to a value that will give adequate measurement time, at least ten seconds.

4. Make sure the PMT Detector was calibrated as described in section 6.4.1.
5. Allow the PMT Detector one hour to warm up.
6. Start deposition of only the material to calibrate, under PID control.
7. When deposition reaches a stable value, click **Calibrate Start**. The QCM shutter will open, then after five seconds the calibration sample will begin.
8. When calibration is done, the **Cal. Gain** value will be updated so that the EIES channel reading matches the QCM reading.

The algorithm used for QCM calibration is:

1. Open the crystal shutter.
2. Wait five seconds for thermal stabilization.
3. Measure rate and thickness of EIES and QCM.
4. Verify that stability of rate signals are within Cal. Accuracy value.
5. Measure rate and thickness until the end of Cal. Sample time.
6. Verify that EIES and QCM thickness are ≥100 Å.
7. Calculate:

$$\text{Cal. Gain} = \frac{\text{QCM Thickness}}{\text{EIES Thickness}} \quad [13]$$

PN 074-517-P1F

6.4.6 Cross Channel Calibration

The EIES PMT Detector may detect optical emission from background gases or other materials. This is particularly true if the emission wavelengths of other materials are near the wavelength of the material being measured. To compensate for this effect, measure and subtract the interfering (cross channel) rate(s).

1. In the EIES software, create a co-deposition layer for the materials to be calibrated.
2. On the **Edit Layer** window, click the **FilmCal.** tab.
3. With *no deposition on the selected channel*, start deposition on the interfering channel.
4. When the interfering channel rate stabilizes, calculate the percent of the interfering channel's rate reading that shows in the channel being calibrated.
5. Select the interfering channel in the **First xChan** drop-down list and enter the percent value in the **First xChan%**.
6. Repeat this procedure with a second, third, or fourth interfering channel.

For example, assume co-depositing copper (Cu) on Channel 1 and cadmium (Cd) on channel 2. The wavelength for Cu is 3261, for Cd the wavelength is 3247. It is unlikely that either of these filters will adequately reject the other material's signal.

While not depositing copper on channel 1, start depositing cadmium on channel 2, near the desired rate. For this example, assume channel 2 rate (Cd) is 1 Å/s, and with no copper being deposited channel 1 measures 0.1 Å/s. Then for channel 1, enter First xChan = 2 and First xChan% = 10. This will calibrate the channel 1 reading to show 0 Å/s, the true Cu reading.

Repeat this procedure while depositing Cu on channel 1, and no Cd deposition on channel 2. Assume that the channel 1 rate (Cu) is 20 Å/s and channel 2 measures 1 Å/s. For channel 2 enter First xChan = 1 and First xChan% = 5%.

This procedure can compensate for three other materials. In each case, deposit no material on the channel being calibrated, and calibrate for the other channels.

PN 074-517-P1F

6.5 Loop Tuning

This section will explain how to adjust control loop PID parameters to achieve a stable deposition process. Keep in mind that there is no "best" way to determine PID parameters, and no single set of settings are "best."

Setup System Parameters: Be sure that the output Full Scale voltage and crystal Min/Max Frequency parameters are accurate. If the correct Tooling parameters have not already been previously determined, set them to 100% for now. An Update rate of 4 Hz is a good starting point.

Create a One-Layer Test Process: Create a new process that has a single film as its only layer, and select it as the current process. Set the film's Initial Rate to the desired rate of the intended process and Final Thickness to ten times the desired Final Thickness. Select the proper Sensor(s), Output, and Material. Set Max Power to 100% and Slew rate to 100%. Set Error Action to Ignore.

Test the Setup: Press Auto/Manual to start the layer in Manual mode. Slowly increase to a power of 10%, and verify that the power supply output is about 10% of full scale. Continue to increase the power until a Rate (Å/s) above 0 is shown. Again, verify that the power supply output agrees with the Power(%) reading. If the readings don't agree, check the wiring and process setup. In particular, verify that the System, Outputs, Full Scale voltage agrees with power supply input specifications.

Determine Open Loop Gain: Slowly adjust the power until the Rate (Å/s) reading approximately matches the desired Initial Rate setting. Record the Power(%) reading as PWR_{DR} (power @ desired rate). Slowly lower the power until the Rate (Å/s) reading is just at (or near) zero. Record the zero rate Power(%) reading as PWR_{0R}.

Determine Open Loop Response Time: Calculate one-third of the desired rate ($RATE_{1/3}$), and two-thirds of the desired rate ($RATE_{2/3}$) for this layer. Slowly increase the power until Rate (Å/s) matches $RATE_{1/3}$. Record the loop's response to an input change. Quickly adjust Power(%) to PWR_{DR}. Measure the time for the Rate (Å/s) reading to reach $RATE_{2/3}$. You may want to do this several times to get an average response time reading. Displaying the Rate graph will help. Twice the measured time is the step response time, $TIME_{SR}$ which is the I Term in the control loop. $TIME_{SR}$ is typically 0.7 to 1.5 seconds for E-Beam evaporation, 5 to 20 seconds for thermal evaporation.

Click Abort Process, then Manual/Auto to return to Auto mode.

Set Preconditioning: The power level you recorded as PWR_{0R} is the power where deposition just begins. That is a good value for Ramp 1 power. PWR_{DR}, or slightly less, is a good value for Ramp 2 Power. This will eliminate a large step change when entering the deposition phase. Enter Ramp 1, Soak 1, Ramp 2 and Soak 2 Times to ensure the material can heat up slowly and outgas properly.

Set PID Values: In the Edit Layer, DEPOSIT tab set P Term =25, I Term = $TIME_{SR}$, D Term =0. Assure that all CONDITION values are set to zero. Save the values and close the Edit Layer window.

Press START and observe the Power graph. The power should rise from 0%, and stabilize near PWR_{DR} with little ringing or overshoot. If there is more than about 10% overshoot, lower the P Term. If the time to reach PWR_{DR} is very slow, increase the P Term. A lower I Term will increase response time, a higher value will eliminate ringing and setpoint deviations. It is unlikely you will need any D Term.

Continue the process and adjust PID until steady-state response is smooth and the step response is reasonably controlled. It’s not necessary to totally eliminate ringing during the step if the steady-state response is smooth. Preconditioning will minimize step changes.

Once PID terms are established for a material, they will typically be similar for other materials evaporated from the same source. Only the P Term and preconditioning power levels may need adjustment.

Chapter 7
Communications

7.1 Introduction

The computer interface capabilities of the EIES-IV software allow operation from an external computer via Ethernet or RS-232 serial communications using a simple ASCII command set.

Programs like the EIES_Vxxx_COMM.EXE running on the same computer as the EIES software can control the EIES-IV software using ActiveX®.

The EIES Guardian can be controlled using ASCII commands as described under Guardian Controller Direct Communications, see section 7.3 on page 7-9.

HINT: When using EIES software 5.11 and 4.11 or lower, do not specify an ethernet port number greater than 32767.

7.2 ActiveX (COM) Interface

EIES-IV software must be running to use the AxtiveX interface. Any program that supports Microsoft's COM (ActiveX) interface (i.e., LabVIEW™, Wonderware®, etc.) can communicate with the EIES-IV software.

A small ActiveX interface program, EIES_Vxxx_COMM.EXE, (found in the Comm sub-directory of the EIES-IV software), provides receive data and transmit data entry points to the global cComm242 class.

7.2.1 Setup for ActiveX Control

Load the EIES_Vxxx_COMM.EXE program on the same computer that is running the EIES-IV software. Start the EIES_Vxxx_COMM program and select ActiveX on the Utility tab. Start the EIES-IV software.

7.2.2 EIES ActiveX Comm Program

EIES_Vxxx_COMM.EXE is a simple Windows program to demonstrate EIES communications concepts. It can send commands and read the responses returned by the EIES-IV software. EIES_Vxxx_COMM is written in Visual Basic. Only the ActiveX interface is supported.

The response from the EIES-IV software will display in the Comm program Response window. A typical response is @QU;ACK;4.1.1;02, indicating software version 4.11. The next section describes the Query/Update and Response strings in detail.

NOTE: EIES software does not refresh. The screen must be reopened to refresh values.

New parameters sent to the Guardian via external communications using commands as described under section 7.3, Guardian Controller Direct Communications, on page 7-9, will not be updated on the EISE-IV Guardian software screens, even after a screen refresh.

7.2.3 EIES ActiveX Comm Program Protocol

EIES program commands are:

- **Query** commands that request data from the EIES program
- **Update** commands that update a setting or instruct the program to take an action

7.2.3.1 Query Command Format

@<command>;<param1>;…;<paramn>;<Chksum><CR>

Example: Software Version Query

@QU;11;44<CR>

where:

@	Message start character
QU	Query Utility command
;	Separator
11	Parameter 11 (EIES Software Version)
;	Separator
0	Optional parameter (not used for this query)
;	Separator
44	Checksum (see section that follows on checksums)
<CR>	Carriage Return (ASCII 13)

PN 074-517-P1F

Example: Response to Software Version Query
@QU;<ACK>;4.1.1;02<CR>(Response to Software Version query)
where:

@;QU;<ACK>;	Query Acknowledged (ASCII 06)
4.1.1	Message (Software Version)
;	Separator
02	Checksum (actual checksum varies with different versions)
<CR>	Carriage Return (ASCII 13)

7.2.3.2 Update Command Format

@<command>;<param1>;...;<paramn>;<data>;<Chksum><CR>
Example: Set Process Update
@UP;01;MyProcess;44<CR>
where:

@;UP;	Update Process command
;	Separator
01	Parameter 01 (Set Process)
;	Separator
MyProcessData	
;	Separator
??	Checksum
<CR>	Carriage Return (ASCII 13)

Example Response: Set Process Update Succeeded
@UP;<ACK>;??<CR>

Example Response: Set Process Update Failed
@UP;<NAK>;<ERR>;??<CR>
Where:

01 Illegal Command
02 Illegal Parameter
03 Illegal Format
04 Checksum Error
05 Request Denied
06 Unknown Error

7.2.3.3 EIES ActiveX Program Command Summary

Query Process

@QP;<param1>

where <param1> is:

01	Process Name			
02	Process Time (mm:ss)			
03	Active Layer #			
04	Layer Time (mm:ss)			
05	Phase # (where phase numbers returned are)			
	00 Application Startup		09	ShutterDelay Phase
	01 Program Initializing		10	Deposit Phase
	02 Not Used		11	Layer Stopped
	03 Not Used		12	Layer Starting
	04 Process Stopped		13	Not Used
	05 Ramp1 Phase		14	Not Used
	06 Soak1 Phase		15	Not Used
	07 Ramp2 Phase		16	Idle Ramp Phase
	08 Soak2 Phase		17	Idle Phase
06	Phase Time (mm:ss)			
07	Run #			
08	All Process Names (comma delimited list)			
09	Number of Process layers			
1n	Source Shutter Status, n=1 to 8 (0=Open, 1=Close)			
2n	Sensor Shutter Status , n=1 to 8 (0=Open, 1=Close)			
34	DataLog Status (0=Off, 1=On)			
36	DataLog FileName			
37	DataLog Interval			
38	DataLog Type (0=Overwrite, 1=Append, 2=Run#)			
4n	Power Mode Channel n (1 to 8), 1 = PID, 0= Manual Power			

Update Process

@UP;<param1>;<data> where <param1> is:

NOTE: Update commands 01, 07, and 09 are only valid in Stop Mode.

01	Set Active Process (data = process name)
02	Start Process
03	Stop Process
04	Start Layer
05	Stop Layer
06	Reset
07	Set Run #
08	Next Layer
09	Set Active Layer #
34	DataLog Off
35	DataLog On
36	DataLog FileName
37	DataLog Interval
38	DataLog Type (0=Overwrite, 1=Append, 2=Run#)
4n	Channel n (1 to 8) to Auto Power

49 Set all active channels to Auto Power
5n Channel n (1 to 8) to Manual Power (<Data> = % Power)
59 Set all active channels to Manual Power (<Data> = % Power)
69 Zero all totals

Query/Update Layer

@QL;<param1>;<layer>;<channel>@UL<param1>;<layer>;<channel>

NOTE: A <layer> value of zero sets/returns data on the current layer.

where <param1> is:

01 Film Name
02 Rate Setpoint (Å/s)
03 Final Thickness (kÅ)
04 Time SetPt (mm:ss)
05 Thickness SetPt (kÅ)
06 Start Mode (0/1)
10 Phase of the requested channel (query only)
11 Ramp 1 Start Thickness
12 Ramp 2 Start Thickness
21 Ramp 1 Ramp Time
22 Ramp 2 Ramp Time
31 Ramp 1 New Rate
32 Ramp 2 New Rate
61 xChan1 #
62 xChan2 #
63 xChan3 #
64 xChan4 #
71 xChan1 %
72 xChan2 %
73 xChan3 %
74 xChan4 %

Query/Update Film

@QF;<param1>;<layer>;<channel>@UF;<param1>;<layer>;<channel>;<value>

NOTE: A <layer> value of zero sets/returns data on the current layer.

where <param1> is:

01 P Term
02 I Term
03 D Term
05 Shutter Timeout
06 Shutter Accuracy
10 Calibration Accuracy
11 Calibration Sample Time
12 Calibration Interval Time
13 Ramp 1 Power
14 Ramp 1 Time
15 Soak 1 Time
16 Ramp 2 Power
17 Ramp 2 Time

18	Soak 2 Time
19	Not Used
20	Not Used
21	Not Used
22	Idle Power
23	Idle Ramp Time
27	Slew Rate
28	QCM Density
29	QCM Tooling
30	QCM Z-Factor (Z-Ratio)
31	Input Type
32	PMT Voltage
33	Cal Gain
34	Cal Offset
35	User Units
36	User Multiplier
37	User Offset
38	Exponent
39	Integer Digits
40	Decimal Digits
41	Filter
42	QCM Cal Number

Query Sensor

@QS;<param1>

where <param1> is:

01	Sensor 1 Status (0=Off, 1=On)	
03	Sensor 2 Status (0=Off, 1=On)	
05	Gas 1 Status (0=Off, 1=On)	
07	Gas 2 Status (0=Off, 1=On)	
1n	Sensor n Emission SetPt (mA)	1=Sens1, 2=Sens2, 3=Gas1, 4=Gas2
2n	Sensor n Maximum Leakage (mA)	1=Sens1, 2=Sens2, 3=Gas1, 4=Gas2
3n	Sensor n Gas Calibration	1=Sens1, 2=Sens2

Update Sensor

@US;<param1>;<value>

where <param1> is:

01	Sensor 1 Off	
02	Sensor 1 On	
03	Sensor 2 Off	
04	Sensor 2 On	
05	Gas1 Off	
06	Gas1 On	
07	Gas 2 Off	
08	Gas 2 On	
1n	Sensor n Emission SetPt (mA) 1=Sens1, 2=Sens2, 3=Gas1, 4=Gas2	
2n	Sensor n Maximum Leakage (mA) 1=Sens1, 2=Sens2, 3=Gas1, 4=Gas2	
3n	Sensor n Gas Calibration	1=Sens1, 2=Sens2

CAUTION

Refer to the label attached to your sensor or emitter assembly package for correct emission current settings.

Do not operate 016-xxx series sensors with Yttria filaments at Emission current greater than 2 mA. Instant filament failure may occur! 016-xxx series sensors with Thoria filaments with ####T serial numbers may be operated at 4 mA emission.

Query/Update Utility

@QU;<param1>

@UU;<param1>;<Param1>

02 Simulate Mode (0/1)

06 Front Panel Disable

Param 1 is sum of these disable values:

1	Start Buttons	32	Zero
2	Emission 1	64	Manual Power
4	Emission 2	128	File Menu
8	DataLog	256	Edit Menu
16	Chan Edit	512	Graph Setup

For example: <Param1> = 9 would disable Start Buttons and DataLog

07 Application Visible (0/1)

11 EIES Software Version (Query only)

12 EIES Computer Operating System (Query only)

13 EIES Computer Name (Query only)

14 EIES On Top (0/1, Update only)

Query Measurement
@QM;<param1>

1n	Channel n Power (n=1 to 8)
2n	Channel n Rate
3n	Channel n Thickness
4n	Channel n Deviation
5n	Sensor n Emission Current (mA), n = 1 to 4 1=Sens1, 2=Sens2, 3 = Gas1, 4=Gas2
5n	Sensor n Leakage Current (mA), n = 5 to 8 5=Sens1, 6=Sens2, 7 = Gas1, 8=Gas2
6n	Sensor n Power (watts), n = 1 to 4 1=Sens1, 2=Sens2, 3 = Gas1, 4=Gas2
6n	Sensor n Fail (0 OK, 1 Fail), n = 5 to 8 5=Sens1, 6=Sens2, 7 = Gas1, 8=Gas2
7n	Sensor n Filament Current (A), n = 1 to 4 1=Sens1, 2=Sens2, 3 = Gas1, 4=Gas2
7n	Sensor n Bias Voltage (V), n =5 to 8 5=Sens1, 6=Sens2, 7 = Gas1, 8=Gas2

7.3 Guardian Controller Direct Communications

To control Guardian without EIES-IV software, create a deposition control program using the following commands.

NOTE: Guardian (software versions greater than 4) only responds to commands received. It never initiates communications.

7.3.1 Serial Interface

Connect a serial cable from the Guardian serial port to the computer's serial port. The cable required is a DB9 female-to-male, (PN 068-0464; in Guardian ship kit).

Guardian baud rate is fixed at 115,200.

Communications format is No Parity, 8 bits, 1 stop bit. Handshaking is not supported.

7.3.2 Ethernet Interface

Connect a cable from the Ethernet connector to the Ethernet network or computer.

Guardian default IP Address is 192.168.1.200.

The Ethernet connector on the Guardian controller has two status LEDs:

- Top Left (yellow): Link Status
  - Extinguished: Link not detected
  - Illuminated: Link detected
- Top Right (green): Data Status
  - Extinguished: No data
  - Blinking: Data being transmitted or received

7.3.3 Guardian Controller Firmware Versions

Version 4.XX of the Guardian controller is the current firmware version. It is compatible only with version 4.xx and higher command set and CRC error checking formatting.

Versions 1.XX and 2.XX are obsolete and must be upgraded before you can use the commands shown in this manual.

Version 3.XX and 4.XX use the same command set, but version 3.XX does not include CRC error checking and is therefore not compatible with version 4.XX and higher Guardian controller firmware.

Firmware versions 3.XX and 4.XX are covered by this document. See the @ command for determining the controller version.

7.3.3.1 V3.XX Controller Command/Response Format

The V3.XX controller command format is:

`(Command)(Data)(LF)`

Where:

`(Command)` = ASCII command letter

`(Data)` = command parameters

`(LF)` = Hex 0A (end of message)

The V3.XX controller response format is:

`(Command)(Data)(LF)`

Where:

`(Command)` = the command the message is responding to

`(LF)` = Hex 0A (end of message)

7.3.3.2 V4.XX Controller Command/Response Format

Version 4.XX and higher differs from V3.XX by adding error checking characters before and after the message.

NOTE: V4.XX and higher also adds an additional communication timeout requirement. If the controller does not receive any communications for three seconds, it goes into a safe mode where all PMT, Sensor and Control Output voltages are set to zero. This prevents potentially dangerous operation during power outages or computer failures.

The V4.XX and higher controller command format is:

```
<sync character><length character><1 to n data
characters><space><CRC1><CRC2><LF>
```

The sync character is always an exclamation point "!." Following the sync character is the length character. This is the number of characters in the packet (not counting the sync and CRC characters). The length character has a decimal 34 added to it so there cannot accidentally be a sync character (!) embedded in the packet.

NOTE: Packet length can not exceed 220 characters (255-35).

Following the length character are the command and data characters followed by two CRC characters.

The Guardian will return a CRC in its response computed with the same algorithm.

PN 074-517-P1F

The CRC is computed using the following algorithm:

1 The CRC is initialized to 3FFF hex.

2 Each character in the message is examined, bit by bit, and added to the CRC in the following manner:

2a The character is exclusive OR'd with the CRC.

2b The CRC is shifted right one bit position.

2c If a character's least significant bit is a 0 then the CRC is exclusive OR'd with 2001h.

2d Steps b and c are repeated for each of the 8 bits in the character.

The CRC contains 14 significant bits. This is split into two characters of 7 bits each, and then a decimal 34 is added to offset the character outside the range of the Sync Character.

All messages are terminated with a LF character (0x0a).

The following is notional software (in java form) which describes the generation and decoding of Guardian messages:

```
public class SigmaAPI_Guardian
 {
   public static boolean useCheckSum = true;

   private static short calcCRC (byte[] str) {
      short crc = 0;
      short tmpCRC;
      int length = str[1] - 34;
      if (length > 0) {

         crc = (short) 0x3fff;

         for (int jx = 1; jx <= length; jx++) {
            crc = (short) (crc ^ (short) str[jx]);

            for (int ix = 0; ix < 8; ix++) {
               tmpCRC = crc;
               crc = (short) (crc >> 1);
               if ((tmpCRC & 0x1) == 1) {
                  crc = (short) (crc ^ 0x2001);
               }
            }
            crc = (short) (crc & 0x3fff);
         }
      }
      // 14 bit CRC of contents of str

      return crc;
   }

   private static byte crcHigh(short crc) {
      byte val = (byte) (((crc >> 7) & 0x7f) + 34);
      return val;
   }

   private static byte crcLow(short crc) {
      byte val = (byte) ((crc & 0x7f) + 34);
      return val;
   }
   public static byte[] pack(String str) {
      int cursor = 0;
      byte[] cmd = null;
       str += " ";
       cmd = new byte[str.length() + 5];
       cmd[cursor++] = (byte) '!';
       cmd[cursor++] = (byte) (34 + str.length() + 1);
```

```
        char[] chrs = str.toCharArray();
        for (int ix = 0; ix < str.length(); ix++) {
           cmd[cursor++] = (byte) chrs[ix];
        }
        if (useCheckSum) {
           short crc = calcCRC(cmd);
           cmd[cursor++] = (byte) crcLow(crc);
           cmd[cursor++] = (byte) crcHigh(crc);
        } else {
           cmd[cursor++] = (byte) 0;
           cmd[cursor++] = (byte) 0;
        }
        cmd[cursor++] = (byte) 0x0a /* LF */;

       return cmd;
    }

    public static String unpack(String msg) {
       String str = null;
       if (msg != null && msg.length() > 4) {
          str = msg.substring(3, msg.length() - 2);
       }
       return str;
    }
}
```

A small utility program, MessageGen, is available to illustrate proper message generation. A typical complete command/response string is illustrated in section 7.3.4.1, @, on page 7-14.

7.3.4 Command Summary for V3.XX and V4.XX Guardian Controller

In the following sections, # indicates channel, V indicates value

7.3.4.1 @

Description: Returns controller firmware version

Parameters: None

Example: @

The complete command string is: !%@Md(LF)

That is, Hex (21)(25)(40)(20)(4D)(64)(0A)

Returns: EIESVX.XX

A typical response from a V4.XX Guardian controller is:

!.AEIESV4.03 (59)(55)(OA)

That is, Hex (21)(2E)(45)(49)(45)(53)(56)(34)(2E)(30)(33)(20)(59)(55)(0A)

7.3.4.2 A

Description: Get active PMT modules. The response is a comma delimited listing of the status of each PMT module. A one indicates a PMT module is connected and communicating. A zero indicates no PMT module. The controller tests for PMT modules only at power up.

Parameters: None

Example: A

Returns: A1,0,0,0,0,0,0,0 indicating the first PMT module is the only one installed.

7.3.4.3 B

Description: Set PMT module update rate in milliseconds. Also establishes whether a gas compensating or standard sensor is attached to the PMT module. There is no Get command for the PMT module update rate.

Parameters: PMT#, Rate, Gas Sensor On/Off

Example: B2,100,1

This sets the second PMT module to convert a reading every 100 milliseconds, and also enables gas compensation. Because three sensor readings are taken by the PMT module (Off, On, and Gas), the actual reading update rate is three times as long as the value sent. In the example above, the PMT module will actually return the three readings each 300 milliseconds (see F & G commands below).

NOTE: The current firmware no longer uses the Gas Sensor On/Off function but the character must be sent, otherwise the command is not recognized.

Returns: B

7.3.4.4 C

Description: Sets the bias current into the PMT module A to D converter. This command is used to calibrate the PMT module. To calibrate, set a 100nA bias current and take readings from the PMT module (G command). Next set a 2000nA bias current and take readings. For normal operation, be sure to leave the current at 2000nA. Calculate the slope and intercept of the y=mx + b transfer function, where y is counts and x is current, as shown below. These values will be used to convert counts to current in the G command (below).

Slope(PMT1) = (2000nA - 100nA) / ((Reading(2000nA) - Reading(100nA))

Intercept(PMT1) = 2000nA - (Slope(PMT1) * Reading(2000nA))

Parameters: PMT#, Current in nA

Example: C2,100 sets the second PMT module bias current to 100nA

Returns: C

7.3.4.5 D

Description: Get sensor readings. Readings are returned as a comma delimited string of all measurements for all sensors, in A/D counts. The final value is a sensor status, which is no longer used (always zero). The format of the returned string is:

EimissionCurrent1,LeakageCurrent1,Power1,FilamentCurrent1,BiasVoltage1, EimissionCurrent2,LeakageCurrent2,Power2,FilamentCurrent2,BiasVoltage2, EimissionGas1,LeakageGas1,PowerGas1,FilCurrentGas1,BiasVoltageGas1, EimissionGas2,LeakageGas2,PowerGas2,FilCurrentGas2,BiasVoltageGas2,

SensorStatus

Parameters: None

Example: D

Returns:D;78568,4932,85744,640773,4575,96472,2075,699535,638957,4637,0, 0,92533,641379,4588,0,0,699515,639978,4645,0

7.3.4.6 F

Description: Queries the controller if any PMT module has a new reading available. A response of 1 indicates a new reading is available; 0 indicates no new reading is available. When a new reading is ready, send a G command (see below) to get the reading(s).

Parameters: None

Example: F

Returns: F1 or F0

7.3.4.7 G

Description: Get PMT readings.

Readings are returned as a comma delimited string of average A to D counts (Cts) and number of A to D conversions (Cnv) use to calculate the average Cts. The readings for each PMT module are separated by a semi colon. Readings are only returned for modules with a new reading available. The format of the returned string when a new reading is available for PMT modules 1, 2, and 8 is:

OnCtsPMT1,OnCnvPMT1,OffCtsPMT1,OffCnvPMT1,GasCtsPMT1,GasCnvPMT1;

OnCtsPMT2,OnCnvPMT2,OffCtsPMT2,OffCnvPMT2,GasCtsPMT2,GasCnvPMT2;

;;;;;OnCtsPMT8,OnCnvPMT8,OffCtsPMT8,OffCnvPMT8,GasCtsPMT8,GasCnvPMT8

Use the Slope and Intercept values calculated using the C command to calculate the current for a PMT module:

OnCurrentPMT# = 2000nA - (Slope(PMT#) * OnCtsPMT#) + Intercept(PMT#)

OffCurrentPMT# = 2000nA - (SlopePMT# * OffCtsPMT#) + InterceptPMT#

GasCurrentPMT# = 2000nA - (SlopePMT# * GasCtsPMT#) + InterceptPMT#

Finally, the measured PMT current is calculated by:

CurrentPMT# = (OnCurrentPMT# - OffCurrentPMT#) -

(GasCurrentPMT# - OffCurrentPMT#)

Parameters: None

Example: G

Returns: G;992445,99,992492,99,992462,100;
992445,99,992492,99,992462,100;;;;; 992445,9

7.3.4.8 H

Description: Sets PMT bias voltage. Values from 0 V to 1250 V are possible.

See Note in section 7.3.3.2 on page 7-10 re "safe mode" timeout.

Parameters: PMT#,Voltage

Example: H1, 750 (set PMT1 bias voltage to 750 V)

Returns: H

7.3.4.9 K

Description: Sets the output voltage of control outputs 1 to 6 to a value between -10 V to +10 V. The command is in DAC counts with 0 = -10V, 32767= 0 V, and 65535=+10 V

See Note in section 7.3.3.2 on page 7-10 re "safe mode" timeout.

See the W command below for outputs 7 & 8.

Parameters: Out#, Counts

Example: K132767,232767,332767,432767,532767,632767 (sets outputs 1-6 to 0 V)

Returns: K

7.3.4.10 M

Description: Reads the state of the digital inputs. The response is a comma delimited string of 13 ones or zeros. The first 12 values correspond to each of the 12 inputs. The 13th value is unused. A value of one is input true (+V) , 0 is input false (0V).

Parameters: None

Example: M

Returns: M1,0,1,1,1,1,1,1,1,1,1,1,1 (Input 2 is false, all others are true)

7.3.4.11 N

Description: Sets the state of the twelve relay outputs. The command is a comma delimited string of 12 ones or zeros. One is relay closed, 0 is replay open.

Parameters: Relay1,Relay2,Relay3,Relay4,Relay5,..........,Relay12

Example: N1,0,1,1,1,1,1,1,1,1,1,1 (Relay2 is open, all others are closed)

Returns: N

7.3.4.12 S

Description: Turns sensor emission on/off.

See Note in section 7.3.3.2 on page 7-10 re "safe mode" timeout.

1: Sensor 1 standard sensor
2: Sensor 1 gas sensor
3. Sensor 2 standard sensor
4. Sensor 2 gas sensor

Parameters: Sensor#, On/Off

Example: S2,1 (turns on Sensor 1 gas sensor)

Returns: S

7.3.4.13 T

Description: Reads voltage on one of the eight controller outputs. Value is returned in DAC counts, with 0 = -10 V, 32767 = 0V, and 65535 = +10 V.

Parameters: Output#

Example: T1 (reads Output 1 voltage)

Returns: T

7.3.4.14 V

Description: Sets sensor emission current using a comma delimited string of four current values: Sensor1 Current, Sensor1 Gas Current, Sensor2 Current, Sensor2 Gas Current. The emission current value is sent as mA x 100.

CAUTION

Refer to the label attached to your sensor or emitter assembly package for correct emission current settings. Do not operate 016-xxx series sensors with Yttria filaments at Emission current greater than 2 mA. Instant filament failure may occur! 016-xxx series sensors with Thoria filaments with ####T serial numbers may be operated at up to 4 mA emission.

Parameters: S1Current, S1GasCurrent, S2Current, S2GasCurrent

Example: V100,200,300,400 (sets Sensor1 to 1ma, Sensor1Gas to 2ma, etc.)

Returns: V

7.3.4.15 W

Description: Sets the output voltage of Guardian controller outputs 7 or 8. The command is in DAC counts with 0 = -10V, 32767 = 0 V, and 65535 = +10 V.

See Note in section 7.3.3.2 on page 7-10 re "safe mode" timeout.

Parameters: Out# - 7,Counts

Example: W0,32767 (sets Output 7 to 0 V)

Returns: W

This page is intentionally blank.

Appendix A
Material Optical Parameters

NOTE: Items in parenthesis indicate additional lines for a material (2), or lines that overlap other materials Au (Co).

Material	Symbol	Wave-length Å	Material	Symbol	Wave-length Å
aluminum	Al	3961	molybdenum	Mo	3133
argon	Ar	4596	nickel	Ni	3415
barium	Ba	3072	niobium	Nb/(U238)	3582
barium	Ba(2)	3500	nitrogen	N_2	3914
boron	B	2496	oxygen	O_2	2594
cadmium	Cd	3261	palladium	Pd	2455
calcium	Ca	4226	platinum	Pt	2659
carbon dioxide	CO_2	2890	rhenium	Re	2275
chromium	Cr	3605	samarium	Sm/(La)	4422
cobalt	Co/(Au)	2428	scandium	Sc	4020
copper	Cu	3247	silicon	Si	2520
erbium	Er	4008	silver	Ag	3281
gallium	Ga	*2940, 4170	strontium	Sr/(Ar)	4596
germanium	Ge/(Ta)	2650	tantalum	Ta/(Ge)	2650
gold	Au	2676	tin	Sn	3175
gold	Au(2)/(Co)	2428	titanium	Ti/(Pb)	3637
hafnium	Hf/(Zr)	2983	titanium	Ti(2)	3982
helium	He	5016	tungsten	W	2551
indium	In	*3040, 4511	uranium	U238/(Nb)	3582
iridium	Ir	2640	vanadium	V	3184
iron	Fe	3720	water	H_2O	3100
lanthanum	La/(Sm)	4422	yttrium	Y	4077
lead	Pb/(Ti)	3637	zinc	Zn	2025
manganese	Mn	2796	zirconium	Zr/(Hf)	2985
*** Indicates line recommended for use with Gas Compensating Sensor**					

This page is intentionally blank.

Appendix B
Material QCM Parameters

Material	Density	Z-Ratio
aluminum	2.73	1.08
aluminum oxide	3.97	1
antimony	6.62	0.768
arsenic	5.73	0.966
barium	3.5	2.1
beryllium	1.85	0.543
bismuth	9.8	0.79
bismuth oxide	8.9	1
boron	2.54	0.389
cadmium	8.64	0.682
cadmium selenium	5.81	1
cadmium sulfide	4.83	1.02
cadmium teluridium	5.85	0.98
calcium	1.55	2.62
calcium fluoride	3.18	0.775
carbon diamond	3.52	0.22
carbon graphite	2.25	3.26
cerium fluoride	6.16	1
cerium oxide	7.13	1
chromium	7.2	0.305
chromium oxide	5.21	1
cobalt	8.71	0.343
copper	8.93	0.437
copper sulfide	4.6	0.82
copper sulfide b	5.8	0.67
copper sulfide a	5.6	0.69
dysprosium	8.54	0.6
erbium	9.05	0.74
gadolinium	7.89	0.67
gallium	5.93	0.593
gallium arsenide	5.31	1.59
germanium	5.35	0.516
gold	19.3	.381
hafnium	13.1	0.36
hafnium oxide	9.63	1
holmium	8.8	0.58
indium	7.3	0.841
indium intimnide	5.76	0.769
indium oxide	7.18	1
iridium	22.4	0.129
iron	7.86	0.349
lanthanum	6.17	0.92
lanthanum fluoride	5.94	1
lanthanum oxide	6.51	1
lead	11.3	1.13
lead sulfide	7.5	0.566
lithium	0.53	5.9
lithium fluoride	2.64	0.774
magnesium	1.74	1.61

Material	Density	Z-Ratio
magnesium fluoride	3	1
manganese	7.2	0.377
manganese sulfide	3.99	0.94
mercury	13.46	0.74
molybdenum	10.2	0.257
neodymium fluoride	6.506	1
neodymium oxide	7.24	1
nickel	8.91	0.331
niobium	8.57	0.493
niobium oxide	4.47	1
palladium	12	0.357
platinum	21.4	0.245
potassium chloride	1.98	2.05
rhenium	21.04	0.15
rhodium	12.41	0.21
samarium	7.54	0.89
scandium	3	0.91
selenium	4.82	0.864
silicon	2.32	0.712
silicon dioxide	2.2	1.07
silicon oxide	2.13	0.87
silver	10.5	0.529
silver bromide	6.47	1.18
silver chloride	5.56	1.32
sodium	0.97	4.8
sodium chloride	2.17	1.57
sulfur	2.07	2.29
tantalum	16.6	0.262
tantalum oxide	8.2	0.3
tellurium	6.25	0.9
terbium	8.27	0.66
thallium	11.85	1.55
thorium fluoride	6.32	1
tin	7.3	0.724
titanium	4.5	0.628
titanium oxide	4.9	1
titanium oxide iv	4.26	0.4
tungsten	19.3	0.163
tungsten carbide	15.6	0.151
uranium	18.7	0.238
vanadium	5.96	0.53
ytterbium	6.98	1.13
yttrium	4.34	0.835
yttrium oxide	5.01	1
zinc	7.04	0.514
zinc oxide	5.61	0.556
zinc selenide	5.26	0.722
zinc sulfide	4.09	0.775
zirconium oxide	5.6	1.001

This page is intentionally blank.

Index

S

T

U

Z