Vacuum Technology

Vacuum Process Engineering

Measuring and Analytical Technology

INFICON

PART NUMBER 074-176

IC/4
IC/4 PLUS
Thin Film Deposition Controller

MANUAL

MAY 1995

Two Technology Place • East Syracuse, NY 13057-9714 • Telephone 315-434-1100 • Telefax 315-437-3803

Vacuum Technology

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INFICON

PART NUMBER 074-176/031595

ADDENDUM TO
IC/4 and IC/4 Plus
Deposition Controller Manual
IPN 074-176

Section 1, p.1-6

Power	90-132 VAC or 180-250VAC, 50/60 HZ, 175 VA
Fuse*	5A/ 250V/ FB

General Specifications

Usage	Indoor use only
Relative Humidity	Up to 80% relative humidity maximum; non-condensing
Altitude range	Up to 2000 m
Pollution Degree I	No pollution occurs
Overvoltage Category II	Local level, appliances, etc.
Cleaning:	The unit enclosure can be safely cleaned with a mild detergent or spray cleaner designed for that purpose. Care should be taken to prevent any cleaner from entering the unit.
Date:	March 15, 1995

* Not replaceable by operator

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DECLARATION OF CONFORMITY

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

Leybold Inficon Inc.
2 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: IC/4™ and IC/4 PLUS™ Thin Film Deposition Controllers, including Oscillators and Crystal Sensors.

Applicable Directives: 73/23/EEC as amended by 93/68/EEC

Applicable Standards: EN 61010-1 : 1993

CE Implementation Date: January 3, 1995

Authorized Representative: Gary W. Lewis
Vice President - Quality Assurance
Leybold Inficon Inc.

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

Registration Card

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Your help is very important in our continuing efforts to improve our manuals.
Using the table below, please circle the appropriate rank for each aspect.
In the Importance column, please indicate the importance of each aspect.

Manual Title ____

Part # (see Title Page) 074-______________________________

Aspect	Very Dissatisfied	Dissatisfied	No Opinion	Satisfied	Very Satisfied	Importance (ranked from 1 to 5, where 1 is low and 5 is high)
Found everything I needed	VD	D	NO	S	VS	
Easy to read	VD	D	NO	S	VS	
Easy to use	VD	D	NO	S	VS	
Relevant to my work	VD	D	NO	S	VS	
Accurate information	VD	D	NO	S	VS	
Well-written	VD	D	NO	S	VS	
Well-organized	VD	D	NO	S	VS	
Technical Enough	VD	D	NO	S	VS	
Helped me solve problems	VD	D	NO	S	VS	

If you have additional comments, please contact INFICON®.

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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 Leybold Inficon Inc.

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The IC/4 and IC/4 PLUS

The IC/4 and the IC/4 PLUS are closed loop process controllers designed for use in physical vapor deposition. These instruments are used for production and research in the semiconductor and optical coating industries. The units monitor and/or control the rate and thickness of the deposition of thin films in thermal evaporation or sputtering processes. Deposition rate and thickness are inferred from the frequency change induced by mass added to a quartz crystal. This technique positions sensors in the path between or to the side of the source of the vaporized material and the target substrate. The sensor incorporates an exposed oscillating quartz crystal. The frequency of oscillation decreases as material accumulates. The change in frequency provides information to determine rate and thickness and to continually control the evaporation power source. With user supplied time, thickness and power limits and with desired rates and material characteristics, the unit is capable of automatically controlling the process in a precise and repeatable manner. User interaction is accomplished via the unit's front panel and consists of selection or entry of parameters to define the process.

The complete system consists of a main electronics unit (IC/4 and IC/4 PLUS), a family of sensor heads and an electronics interface unit for each attached sensor. These items are generally bundled at the factory and are also sold separately.

The IC/4 PLUS contains features not available on the IC/4. These features include co-deposition and Auto Z capabilities. In addition, the IC/4 PLUS has 16 inputs and outputs standard; while in the IC/4 8 is the standard.

The IC/4 and IC/4 PLUS Manual provides user information for installing, programming, calibrating and operating base electronics unit. To facilitate its reference, the manual has been divided into sections which represent the distinct operational aspects of instrument:

From this point, all references to the "IC/4" refers to both the IC/4 and the IC/4 PLUS, unless specifically noted. Features that apply to only the IC/4 PLUS will be designated as "IC/4 PLUS only."

When reading the IC/4 Manual, please pay particular attention to the NOTES, CAUTIONS, and WARNINGS found throughout the text. For our purposes they are defined as follows:

NOTE: Pertinent information useful in achieving maximum instrument efficiency when followed.

CAUTION: *Failure to heed these messages could result in damage to your instrument.*

WARNING!!

THE MOST IMPORTANT MESSAGE. FAILURE TO HEED COULD RESULT IN PERSONAL INJURY AND/OR SERIOUS DAMAGE TO YOUR INSTRUMENT.

You are invited to comment on the usefulness and accuracy of this manual by filling out the reply card and returning it.

Related Manuals

Sensors and sensor interface units are covered in separate manuals.

074-154 - Bakeable
074-155 - CrystalSix
074-156 - Single/Dual
074-157 - Sputtering

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Section 4 - Material Set Up

Section 5 - Process Set Up

Section 6 - Internal/External I/O Set Up

Section 7 - Remote Communications

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Section 12 - Troubleshooting Guide, Status and Error Messages

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Section 1
Introduction

Contents

1.0 Introduction and Specifications

1.1 Instrument Safety

1.1.1 Notes, Cautions, Warnings

When using this manual, please pay attention to the NOTES, CAUTIONS and WARNINGS found throughout. For the purposes of this manual they are defined as follows:

NOTE: Pertinent information that is useful in achieving maximum instrument efficiency when followed.

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

WARNING!!

THE MOST IMPORTANT MESSAGES. FAILURE TO HEED COULD RESULT IN PERSONAL INJURY AND/OR SERIOUS DAMAGE TO THE INSTRUMENT.

WARNING!!

THIS SYMBOL IS INTENDED TO ALERT THE USER TO THE PRESENCE OF IMPORTANT OPERATION AND MAINTENANCE (SERVICE) INSTRUCTIONS IN THE LITERATURE ACCOMPANYING THE INSTRUMENT.

1.1.2 General Safety Information

WARNING!!

THERE ARE NO USER SERVICEABLE COMPONENTS WITHIN THE INSTRUMENT CASE.

POTENTIALLY LETHAL VOLTAGES ARE PRESENT WHEN THE LINE CORD, SYSTEM I/O OR AUX I/O ARE CONNECTED.

REFER ALL MAINTENANCE TO QUALIFIED PERSONNEL.

CAUTION: *This instrument contains delicate circuitry which is susceptible to transient power line voltages. Disconnect the line cord whenever making any interface connections. Refer all maintenance to qualified personnel.*

1.1.3 Earth Ground

This instrument is connected to earth via a sealed three-core (three-conductor) power cable, which must be plugged into a socket outlet with a protective earth terminal. Extension cables must always have three conductors including a protective earth conductor.

WARNING!!

NEVER INTERRUPT THE PROTECTIVE EARTH CIRCUIT.

ANY INTERRUPTION OF THE PROTECTIVE EARTH CONNECTION INSIDE OR OUTSIDE THE INSTRUMENT, OR DISCONNECTION OF THE PROTECTIVE EARTH TERMINAL IS LIKELY TO MAKE THE INSTRUMENT DANGEROUS.

THIS SYMBOL INDICATES WHERE THE PROTECTIVE EARTH GROUND IS CONNECTED INSIDE THE INSTRUMENT. NEVER UNSCREW OR LOOSEN THIS CONNECTION.

1.1.4 Main Power Connection

WARNING!!

THIS INSTRUMENT HAS ALINE VOLTAGE PRESENT ON THE PRIMARY CIRCUITS WHENEVER IT IS PLUGGED INTO A MAIN POWER SOURCE.

NEVER REMOVE THE COVERS FROM THE INSTRUMENT DURING NORMAL OPERATION.

THERE IS NO OPERATOR SERVICEABLE ITEM WITHIN THIS INSTRUMENT.

REMOVAL OF THE TOP OR BOTTOM COVERS MUST BE DONE ONLY BY A TECHNICALLY QUALIFIED PERSON.

IN ORDER TO COMPLY WITH ACCEPTED SAFETY STANDARDS, THIS INSTRUMENT MUST BE INSTALLED INTO A RACK SYSTEM WHICH CONTAINS A MAINS SWITCH. THIS SWITCH MUST BREAK BOTH SIDES OF THE LINE WHEN IT IS OPEN AND IT MUST NOT DISCONNECT THE SAFETY GROUND.

1.1.5 Battery Life

The IC/4 Family of instruments contain a battery on the motherboard. It is recommended this battery be replaced every 3 years. If this battery should fail, an error message will appear during boot-up. The error message will reference a CMOS failure.

Inficon's service department should be called when the battery needs to be replaced. Batteries which are not replaced may leak and cause damage to the motherboard.

1.2 IC/4 Specifications

Measurement	IC/4 PLUS	IC/4
Crystal Frequency	6.0 MHz(new crystal) to 4.5 MHz	6.0 MHz (new crystal) to 4.75 MHz
Internal Precision	± 0.004657 Hz over 100ms sample for fundamental and anharmonic.	±0.0282 Hz over 200ms sample for fundamental
Thickness & Rate Resolution	0.00577 Å (new crystal); 0.01016 Å (crystal @ 4.5 MHz) over 100ms sample for material density = 1.0, Z-ratio = 1.0.	0.0348 (new crystal) 0.0612Å (crystal @ 4.75 MHz) over 200ms sample
Thickness Accuracy	0.5% typical, (dependent on process conditions and materials; especially sensor location, material stress and density)	
Measurement Frequency	10 Hz.	5 Hz
Set Up Parameters		
Processes	4	
Layers	250	100
Materials	24	12
Density	.500 to 99.99 gm/cc	
Z-ratio	0.100 to 15.000 or Automatic	0.100 to 15.000
Sources	2 standard, 2 (optional hardware)	
PID Control Mode	Fast or Slow Source	
Process Gain	.01 to 100 Å/sec/%Power	
Primary Time Constant	1.0 to 200.0 seconds (Slow Source)	
System Dead Time	1.0 to 50.0 seconds (Slow Source)	
Tooling Factor	10.0 to 399.9%	
Secondary Tooling Factor	10.0 to 399.9%	
Sensors	2 standard, 2 (optional hardware)	
Maximum Power	0 to 99%	
Power Ramps	2 per material	
Soak Power	0 to 99%	
Rise Time	00:00 to 99:59 min:sec	
Soak Time	00:00 to 99:59 min:sec	
Shutter Delay	Until rate control established within ± 5% or 60 seconds.	
Feed Ramps	1 per material	
Feed Power	0 to 99%	
Feed Ramp Time	00:00 to 99:59 min:sec	
Feed Time	00:00 to 99:59 min:sec	

Set Up Parameters	IC/4 PLUS	IC/4
Idle Ramps	1 per material	
Idle Power	0 to 99%	
Idle Ramp Time	00:00 to 99:59 min:sec	
Rate	0.0 to 999.9 Å/sec	
Final Thickness	0.0 to 999.9 kÅ	
Thickness Limit	0.0 to 999.9 kÅ	
Time Limit	00:00 to 99:59 min:sec	
Co-deposition	Optional Hardware Required (available on IC/4 PLUS only)	
Ratio Control	0 to 999.9%	
Cross-Sensitivity	0 to 99.9%	
RateWatcher(TM)	Sample and Hold Feature	
RateWatch Time	00:00 to 99:59 min:sec	
RateWatch Accuracy	1 to 99%	
Rate Ramps	2 per layer	
New Rate	0 to 999 Å/sec	
Start Ramp	0 to 999.9 kÅ	
Ramp Time	00:00 to 99:59 min:sec	
Crucible Selection	1 to 64, each source	
Display		
Type	CRT, Amber, 5" H x 9" W	
Thickness Display Range	0.000 to 999.9 kÅ	
Thickness Display Resolution	1 Å	
Rate Display Range	0.0 to 99.9 Å/sec; 100 to 999 Å/sec	
Rate Display Resolution	.1 Å for 0 to 99.9 Å/sec 1 Å for 100 to 999 Å/sec	
Power Display Range	0.0 to 99.9%	
Graphic Display	Rate Deviation at ± 10 or ± 20 Å/sec or Power at 0 to 100%	
Display Data Update Rate	1 Hz	
Source Controls / Recorder Output		
Configuration	2 source channels, 1 recorder; 2 additional channels, 1 additional recorder (optional)	
Analog Ranges		
Sources	0 to 10V, 0 to -10V, 0 to 5V, 0 to -5V, 0 to 2.5V, 0 to -2.5V	
Recorders	0 to 10V	
Resolution	15 bits over full range (10V)	
Update Rate	10 Hz, maximum, (dependent on source characteristics).	5 Hz
Recorder Outputs	Rate or Thickness or Rate Deviation	
Rate Ranges	0 to 100 Å/sec, 0 to 1000 Å/sec	
Thickness Ranges	0 to 100 kÅ, 0 to 1000 kÅ	
Rate Deviation Range	Desired rate ± 50 Å/sec	

Relays / Inputs	**IC/4 PLUS**	**IC/4**
Relays	Sixteen 240V relays; 120 VA inductive; 2A maximum.	8 standard, 8 optional
Inputs	Sixteen lines; 10 to 24VAC(30VDC)	8 standard, 8 optional
Update Rate	10 Hz.	5 Hz
Remote Communications		
RS232 Serial Port	Standard; Inficon protocol with or without checksum	
RS422 Serial Port	Optional; replaces RS232	
IEEE488 Parallel Port	Optional; replaces RS232	
Accessories		
Manual Power Control	Front panel connect wired handheld remote	
IC Memory Card	Optional external storage	
Connector Kit	Connectors for Inputs, Relays and Source Control.	
Power	100-120 VAC or 200-240 VAC, 50/60 Hz	
Operating Temperature	0 to 50°C (32-122°F)	
Warm Up Period	None required; 5 minutes for maximum stability.	
Size		
(not including mounts or user connectors)	5.25" H x 17.625" W x 18.5" D / 13.3cm H x 44.77cm W x 47cm D.	
(including mounts, but no user connectors)	5.25" H x 18.85" W x 18.5" D / 13.3cm H x 47.88cm W x 47cm D.	
Weight (with all options)	10.5 kg / 23 lb	

1.3 Unpacking and Inspection

1. If the IC/4 control unit has not been removed from its shipping container, do so now.
2. Carefully examine the unit for damage that may have occurred during shipping. This is especially important if you notice obvious rough handling on the outside of cartons. IMMEDIATELY REPORT ANY DAMAGE TO THE CARRIER AND TO INFICON.
3. Do not discard the packing materials until you have taken inventory and have at least performed a power on verification.
4. To perform an inventory refer to your order invoice and the information contained in Section 1.4 - Parts and Options Overview.
5. To perform a power on verification, refer to Section 1.5.
6. For additional information or technical assistance, contact your nearest Leybold Inc. sales office.

1.4 Parts and Options Overview

Base Configurations	IC/4 PLUS	IC/4
IC/4 Control Unit	755-500-G1 (120V) or 755-500-G2 (230V)	756-500-G1 (120V) or 756-500-G2 (230V)
Technical Manual	074-176	074-176
Hand Controller	755-262	755-262
Input/Relay Interface Connectors	755-122 or 756-122-G2	756-122-G1
Source Control Interface Connectors	755-144	755-144
Power Cord	068-002 or 068-151 (Eur)	068-002 or 068-151 (Eur)

Pre-Installed Options or Spares		
Additional Sensor Module	755-112-G1	
2 Channel Sensor Module (IC/4 only)		756-112-G1
4 Channel Sensor Module (IC/4 only)		756-112-G2
Additional Source Control Module	755-142-G1	755-142-G1
RS422 Serial Communications	755-232-G1	755-232-G1
IEEE488 Parallel Communications	755-230-G1	755-230-G1
16 Input/Relay Interface Board (IC/4 only)	Standard	756-122-G2

Optional Accessories		
IC Memory Card	755-270-G1	755-270-G1
IC/4 Oscillator	755-252-G1	756-252-G1
Controller to Oscillator Cable, 15'	755-258-G15	755-258-G15
Oscillator to vacuum feedthrough cable, 6"	755-257-G6	755-257-G6
Extension cable, 25'	755-256-G25	755-256-G25
Pneumatic Shutter Actuator Control Valve	007-199	007-199

Oscillator Packages and Sensors	IC/4 PLUS	IC/4
Oscillator, 15' and 6" cable	755-275-G1	756-275-G1
Standard Sensor	750-211-G1	750-211-G1
Standard Sensor with Shutter	750-211-G2	750-211-G2
Compact Sensor	750-213-G1	750-213-G1
Compact Sensor with Shutter	750-213-G2	750-213-G2
Sputtering Sensor	007-031	007-031
UHV Bakeable Sensor, 12"	007-219	007-219
UHV Bakeable Sensor, 20"	007-220	007-220
UHV Bakeable Sensor, 30"	007-221	007-221
UHV Bakeable Sensor with Shutter, 12"	750-012-G1	750-012-G1
UHV Bakeable Sensor with Shutter, 20"	750-012-G2	750-012-G2
UHV Bakeable Sensor with Shutter, 30"	750-012-G3	750-012-G3
Dual Sensor	750-212-G2	750-212-G2
CrystalSix Multiple Sensor	750-260-G1	750-260-G1

1.5 Initial Power On Verification

A preliminary functional check of the instrument can be made before formal installation. It is not necessary to have sensors, source controls, inputs or relays connected to do this. For more complete installation information, refer to Section 10 - Installation and Interfaces and to Section 11 - Calibration Procedures.

WARNING!!

THERE ARE NO USER SERVICEABLE COMPONENTS WITHIN THE INSTRUMENT CASE.

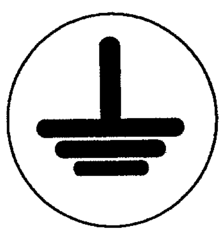
POTENTIALLY LETHAL VOLTAGES ARE PRESENT WHEN THE LINE CORD, SYSTEM I/O OR AUX I/O ARE CONNECTED.

REFER ALL MAINTENANCE TO QUALIFIED PERSONNEL.

WARNING!!

NEVER INTERRUPT THE PROTECTIVE EARTH CIRCUIT.

ANY INTERRUPTION OF THE PROTECTIVE EARTH CONNECTION INSIDE OR OUTSIDE THE INSTRUMENT, OR DISCONNECTION OF THE PROTECTIVE EARTH TERMINAL IS LIKELY TO MAKE THE INSTRUMENT DANGEROUS.



THIS SYMBOL INDICATES WHERE THE PROTECTIVE EARTH GROUND IS CONNECTED INSIDE THE INSTRUMENT. NEVER UNSCREW OR LOOSEN THIS CONNECTION.

---

1. Confirm that AC line voltage is supplied and proper for the instrument. Line voltage should be indicated on an instrument back label.

2. Depress power button on front panel. A green pilot light should be seen above the power switch.

3. The fan at the back of the instrument should be exhausting air.

4. Video monitor will display an image similar to the one below. Some roll may appear prior to the signon screen.

5. Review configuration information on screen against unit configuration ordered.

6. Status of parameter information will be displayed. If information was valid prior to this power up, it should stay valid.

7. After a delay, the instrument will enter the OPERATE display.

8. Confirm that display is centered vertically; lines between function keys (F1...F6) should align with lines between panels on right side of display.

9. Using non-conducting alignment tool, verify that brightness pot is operative; adjust for low brightness. Access to brightness pot is at bottom-center of face panel.

IC/4 PLUS

SOFTWARE VERSION 0.9

PARAMETERS VALID

SENSOR INFORMATION INVALID

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SENSOR BOARD 1	SENSOR BOARD 2
SENSOR 1 SINGLE HEAD CABLE DISCONNECTED	SENSOR 3 SINGLE HEAD FAILED CRYSTAL
SENSOR 2 SINGLE HEAD CABLE DISCONNECTED	SENSOR 4 SINGLE HEAD FAILED CRYSTAL

NO DAC BOARDS PRESENT

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Figure 1.1 IC/4 PLUS Signon Screen

Section 2
Measurement & Control Theory

Contents

2.1 Basics

The Quartz Crystal deposition Monitor, or QCM, utilizes the piezoelectric sensitivity of a quartz monitor crystal to added mass. The QCM uses this mass sensitivity to control the deposition rate and final thickness of a vacuum deposition. When a voltage is applied across the faces of a properly shaped piezo electric crystal, the crystal is distorted and changes shape in proportion to the applied voltage. At certain discrete frequencies of applied voltage a condition of very sharp electro-mechanical resonance is encountered. When mass is added to the face of a resonating quartz crystal, the frequency of these resonances is reduced. This change in frequency is very repeatable and is presently precisely understood for specific oscillating modes of quartz. This heuristically easy to understand phenomena is the basis of an indispensable measurement and process control tool that can easily detect the addition of less than an atomic layer of an adhered foreign material.

In the late 1950's it was noted by Sauerbrey[1,2] and Lostis[3] that the change in frequency, $\Delta F = F_q - F_c$, of a quartz crystal with coated (or composite) and uncoated frequencies, F_c and F_q respectively, is related to the change in mass from the added material, M_f, as follows:

$$\frac{M_f}{M_q} = \frac{(\Delta F)}{F_q} \qquad \text{EQN. 1}$$

where M_q is the mass of the uncoated quartz crystal. Simple substitutions lead to the equation that was used with the first "frequency measurement" instruments:

$$T_f = \frac{K(\Delta F)}{d_f} \qquad \text{EQN. 2}$$

where the film thickness, T_f, is proportional (through K) to the frequency change, ΔF, and inversely proportional to the density of the film, d_f. The constant, $K = N_{at} d_q / F_q^2$; where d_q (= 2.649 gm/cm³) is the density of single crystal quartz and N_{at} (=166100 Hz cm) is the frequency constant of AT cut quartz. A crystal with a starting frequency of 6.0 MHz will display a reduction of its frequency by 2.27 Hz when 1 angstrom of aluminum (density of 2.77 Gm/cc³) is added to its surface. In this manner the thickness of a rigid adlayer is inferred from the precise measurement of the crystal's frequency shift. The quantitative knowledge of this effect provides a means of determining how much material was being deposited on a substrate in a vacuum system, a measurement that was not convenient or practical prior to this understanding.

2.2 Monitor Crystals

No matter how sophisticated the electronics surrounding it is, the essential device of the deposition monitor is the quartz crystal. The quartz resonator shown in Figure 2.1 has a frequency response spectrum that is schematically shown in Figure 2.2. The ordinate represents the magnitude of response, or current flows of the crystal, at the specific frequency.

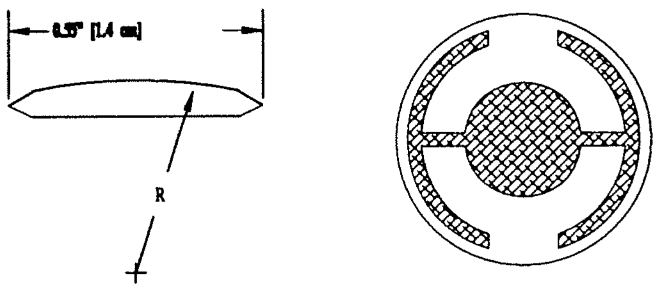


Figure 2.1 Quartz Resonator

The lowest frequency response is primarily a "thickness shear" mode that is called the fundamental. The characteristic movement of the thickness shear mode is for displacement to take place parallel to the major monitor crystal faces. In other words, the faces are displacement antinodes as shown in Figure 2.3. The responses located slightly higher in frequency are called anharmonics, they are a combination of thickness shear and thickness twist modes. The response at about three times the frequency of the fundamental is called the third quasiharmonic. There are also a series of anharmonics slightly higher in frequency associated with the quasiharmonic.

The monitor crystal design depicted in Figure 2.1 is the result of several significant improvements from the square crystals with fully electroded plane parallel faces that were first used. The first improvement was to use circular crystals. The increased symmetry greatly reduced the number of allowed vibrational modes. The second set of improvements was to contour one face of the crystal and to reduce the size of the exciting electrode. These improvements have the effect of trapping the acoustic energy. Reducing the electrode diameter limits the excitation to the central area. Contouring dissipates the energy of the traveling acoustic wave before it reaches the edge of the crystal. Energy is not reflected back to the center where it can interfere with other newly launched waves, essentially making a small crystal appear to behave as though it is infinite in extent. With the crystal's vibrations restricted to the center it is practical to clamp the outer edges of the crystal to a holder and not produce any undesirable effects. Contouring also reduces the intensity of response of the generally unwanted anharmonic modes and hence the potential for an oscillator to sustain an unwanted oscillation is substantially reduced. The use of an adhesion

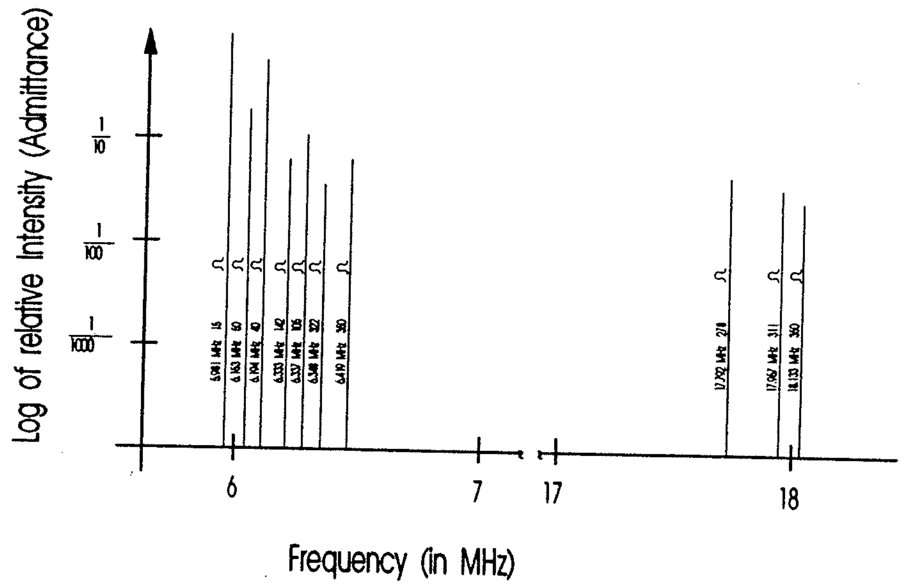


Figure 2.2 Frequency Response Spectrum

layer has improved the electrode to quartz bonding, reducing "rate spikes" caused by micro-tears between the electrode and the quartz as film stress rises. These tears leave portions of the deposited film unattached, and therefore unable to participate in the oscillation. These free portions are no longer detected and the wrong thickness is consequently inferred.

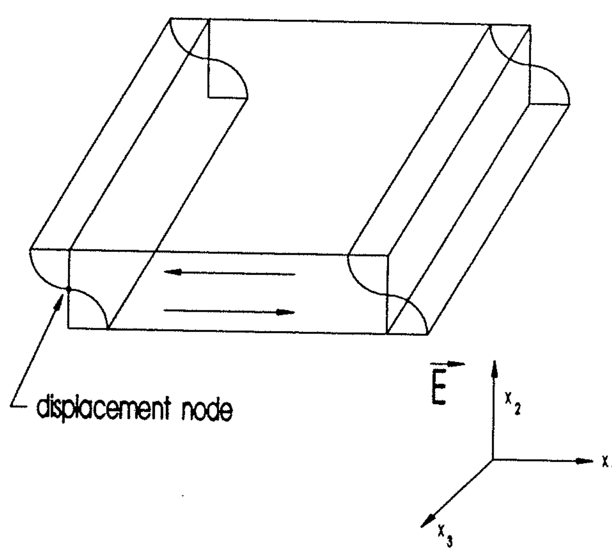


Figure 2.3 Thickness Shear Displacement

The "AT" resonator is usually chosen for deposition monitoring because at room temperature it can be made to exhibit a very small frequency change due to temperature changes. Since there is presently no way to separate the frequency change caused by added mass (which is negative) or even the frequency changes caused by temperature gradients across the crystal or film induced stresses, it is essential to minimize these temperature induced changes. It is only in this way that small changes in mass can be measured accurately.

2.3 Period Measurement Technique

Although instruments using equation 2 were very useful, it was soon noted that they had only a very limited range of accuracy, typically holding accuracy for ΔF's less than 0.02 F_q. In 1961 it was recognized by Behrndt[4] that:

$$\frac{M_f}{M_q} = \frac{(T_c - T_q)}{T_q} = \frac{(\Delta F)}{F_c} \qquad \text{EQN. 3}$$

where T_c and T_q are the periods of oscillation of the crystal with film and the bare crystal respectively. The period measurement technique was the outgrowth of the digital implementation of time measurement and ultimately the recognition of the mathematically rigorous formulation of the proportionality between the crystal's thickness, l_q, and the period of oscillation, $T_q = 1/F_q$. Electronically the period measurement technique utilizes a second crystal oscillator, or reference oscillator, not effected by the deposition and usually much higher in frequency than the monitor crystal. This reference oscillator is used to generate small precision time intervals which are used to determine the oscillation period of the monitor crystal. This is done by using two pulse accumulators. The first is used to accumulate a fixed number of cycles, m, of the monitor crystal. The second is gated (turned) on at the same time and accumulates cycles from the reference oscillator until m counts is accumulated in the first. Since the frequency of the reference is stable and known, the time to accumulate the m counts is known to an accuracy equal to $\pm 2/F_r$ where F_r is the reference oscillator's frequency. The monitor crystal's period is $(n/F_r)/m$ where n is the number of counts in the second accumulator. The precision of the measurement is determined by the speed of the reference clock and the length of the gate time (which is set by the size of m). Increasing one or both of these leads to improved measurement precision.

Having a high frequency reference oscillator is important for rapid measurements (which require short gating times), low deposition rates and low density materials. All of these require high time precision to resolve the small, mass induced frequency shifts between measurements. When the change of a monitor crystal's frequency between measurements is small, that is, on the same order of size as the measurement precision, it is not possible to establish quality rate control. The uncertainty of the measurement injects more noise into the control loop which can only be counteracted by longer time constants. Long time constants cause the correction of rate errors to be very slow, resulting in relatively long term deviations from the desired rate. These deviations may not be important for some simple films, but can cause unacceptable errors in the production of critical films such as optical filters or very thin layered superlattices grown at low rates. In many cases the desired properties of these films can be lost if the layer to layer reproducibility exceeds more than one or two percent. Ultimately, the practical stability and frequency of the reference oscillator limits the precision of measurement for conventional instrumentation.

2.4 Z-match[1] Technique

After learning of fundamental work by Miller and Bolef[5], which rigorously treated the resonating quartz and deposited film system as a one-dimensional continuous acoustic resonator, Lu and Lewis[6] developed the simplifying Z-match™ equation in 1972. Advances in electronics concurrently taking place at that time, namely the micro-processor, made it practical to solve the Z-match equation in "real-time". Most deposition process controllers sold today use this sophisticated equation that takes into account the acoustic properties of the resonating quartz and film system as shown below.

$$T_f = \left(\frac{N_{at}\, d_q}{\Pi \cdot d_f\, F_c\, Z} \right) \arctan \left(Z \tan\left[\frac{\Pi (F_q - F_c)}{F_q} \right] \right) \qquad \text{EQN. 4}$$

where $Z=(d_q u_q/d_f u_f)^{1/2}$ is the acoustic impedance ratio and u_q and u_f are the shear moduli of the quartz and film respectively. Finally, there was a fundamental understanding of the frequency to thickness conversion that could yield theoretically correct results in a time frame that was practical for process control. To achieve this new level of accuracy requires only that the user enter an additional material parameter, Z, for the film being deposited. This equation has been tested and found to hold for a number of materials; exhibiting validity to frequency shifts equivalent to $F_f=0.4F_q$. Keep in mind that equation 2 only was valid to $0.02F_q$ and equation 3 was valid only to $\sim 0.05\ F_q$.

2.5 Active Oscillator

All of the instrumentation developed to date has relied on the use of an active oscillator circuit, generally the type schematically shown in Figure 2.4. This circuit actively keeps the crystal in resonance, so that any type of period or frequency measurement may be made. In this type of circuit oscillation is sustained as long as there is sufficient gain provided by the amplifiers to offset losses in the crystal and circuit and the crystal can provide the required phase shift. The basic crystal oscillator's stability is derived from the rapid change of phase for a small change in the crystal's frequency near the series resonance point, as shown in Figure 2.5.

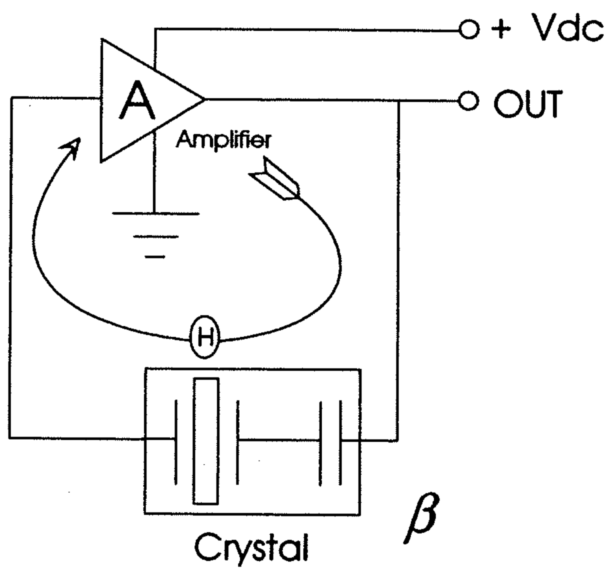


Figure 2.4 Active Oscillator Circuit

The oscillator circuit is normally designed so that the crystal is required to produce a phase shift of 0 degrees that allows it to operate at the series resonance point. Long and short term frequency stabilities are a property of crystal oscillators because very small frequency changes are needed to sustain the phase shift required for oscillation. Frequency stability is provided by the quartz crystal even though there are long term changes in electrical component values caused by temperature or aging or short term noise induced phase jitter. As mass is added to a crystal, its electrical characteristics change.

Figure 2.6 is the same plot as Figure 2.5 with the response of a heavily loaded crystal overlaid. The crystal has lost the steep slope displayed in Figure 2.5. Because the phase slope is less steep, any noise in the oscillator circuit translates into a greater frequency shift than that which would be produced with a new crystal. In the extreme, the basic phase/frequency shape is not preserved, the crystal is not able to provide a full 90 degrees of phase shift.

The impedance, /Z/, is also noted to rise to an extremely high value. When this happens it is often more favorable for the oscillator to resonate at one of the anharmonic frequencies. This condition is sometimes short lived, with the oscillator switching between the fundamental and anharmonic modes, or it may continue to oscillate at the anharmonic. This condition is known as mode hopping and in addition to annoying rate noise can also lead to false termination of the film because of the apparent frequency change. It is important to note that the controller will frequently continue to operate under these conditions; in fact there is no way to tell that this has happened except that the film's thickness is suddenly apparently thinner by an amount equivalent to the frequency difference between the fundamental and the anharmonic that is sustaining the oscillation.

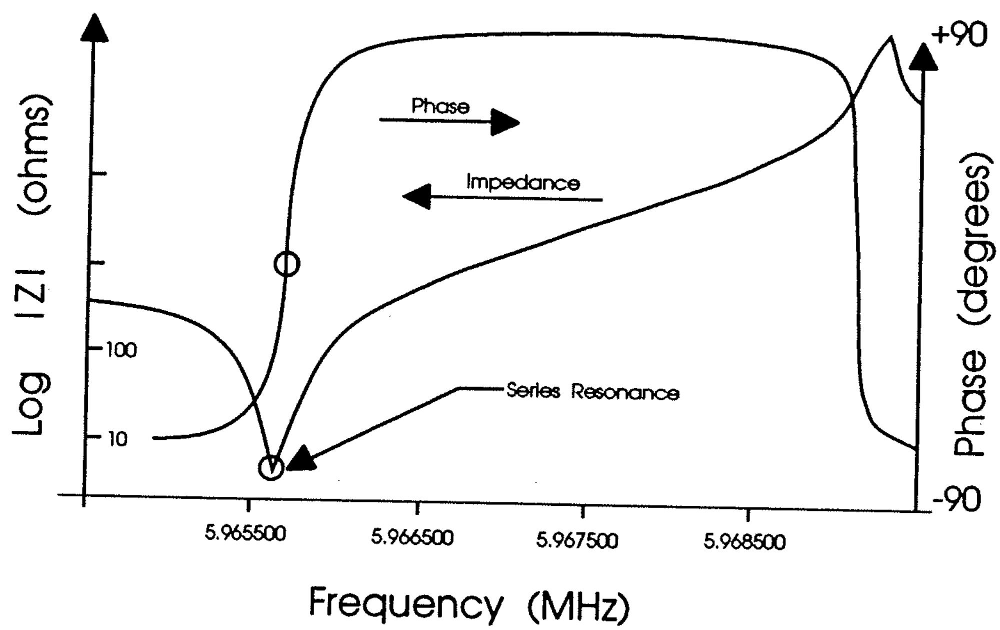


Figure 2.5 Crystal Frequency Near Series Resonance Point

2.6 ModeLock Oscillator

Leybold Inficon has created a new technology that eliminates the active oscillator and its limitations. This new system constantly tests the crystal's response to an applied frequency in order to not only determine the resonant frequency but to also verify that the crystal is oscillating

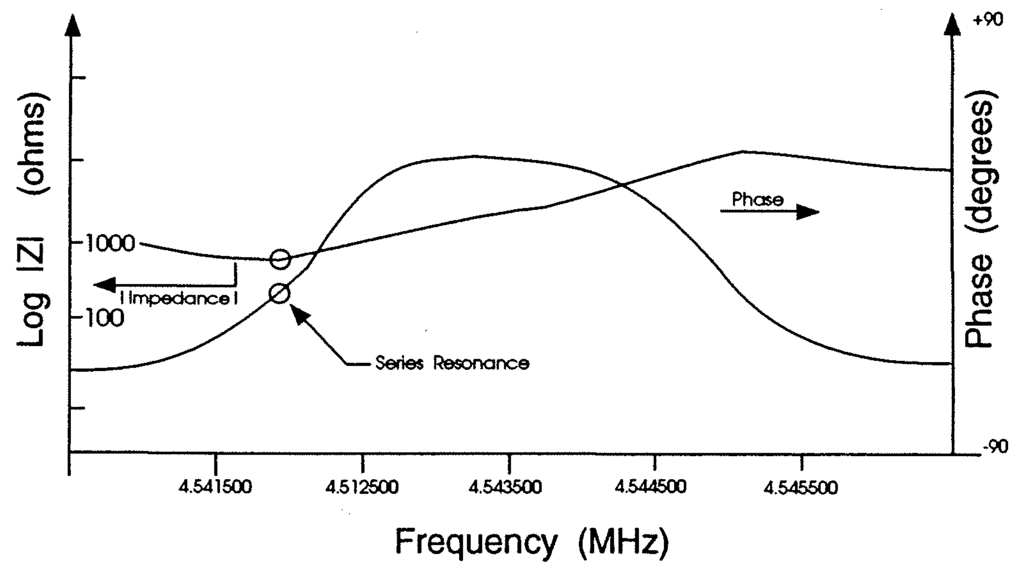


Figure 2.6 Heavily Loaded Crystal

in the desired mode. This new system is essentially immune to mode hopping and the resulting inaccuracies. It is fast and accurate, determining the crystal's frequency to less than .005 Hz at a rate of 10 times per second. Because of the system's ability to identify and then measure particular crystal modes it is now possible to offer new features that take advantage of the additional informational content of these modes. This new "intelligent" measurement system uses the phase/frequency properties of the quartz crystal to determine the resonant frequency. It operates by applying a synthesized sine wave of specific frequency to the crystal and measuring the phase difference between the applied signal's voltage and the current passing through the crystal. At series resonance, this phase difference is exactly 0 degrees; that is, the crystal behaves like a pure resistance. By separating the applied voltage and the current returned from the crystal and monitoring the output of a phase comparator it is possible to establish if the applied frequency is higher or lower than the crystal's resonance point. At frequencies well below the fundamental, the crystal's impedance is capacitive and at frequencies slightly higher than resonance it is inductive in nature. This information is useful if the resonance frequency of a crystal is unknown. A quick sweep of frequencies can be undertaken until the output of the phase comparator changes, marking the resonance event. For AT crystals we know that the lowest frequency event encountered is the fundamental. The events slightly higher in frequency are anharmonics. This information is useful not only for initialization, but also for the rare case that the instrument loses track of the fundamental. Once the frequency spectrum of the crystal is determined the instrument's task is to follow the changing resonance frequency and to periodically provide a measurement of the frequency for subsequent conversion to thickness.

The use of the "intelligent" measurement system has a series of very apparent advantages when compared to the previous generation of active oscillators; namely, immunity from mode hopping, speed of measurement and precision of measurement. The technique also allows the implementation of a sophisticated feature that cannot even be contemplated using the active oscillator approach. The same capability that allows the new technology to sweep and identify the fundamental can be used to identify other oscillation modes, such as the anharmonics and the quasiharmonic. The instrument has the capability to not only track the fundamental mode continuously, but can be implemented to alternate between one or more other modes. This interrogation of multiple modes can be performed as fast as 10 Hz for two modes of the same crystal.

2.7 Auto Z-match Theory (IC/4 PLUS Only)

The one drawback in using equation 4 is that the acoustic impedance must be known. There are several cases where accuracy has to be compromised because of incomplete or limited knowledge of the material constants of the deposited materials.

1. Often the Z-ratio for the bulk material is different from that of the deposited thin film. Thin films are especially sensitive to process parameters especially in a sputtering environment. Consequently the values available for bulk materials may not be pertinent.

2. For many exotic materials including alloys, Z-ratio is not known nor easily available.

3. There has always been a need to accurately measure layer thickness of multiple material films using the same crystal sensor. This is particularly true for multi-layer optical coatings and high-Tc superconductor fabrication. The effective Z-ratio of the composite of multi-material layers is not known.

Therefore, in such cases, the only recourse is to assume the Z-ratio to be unity (that is ignoring the reality of wave propagation in composite media). This false premise introduces error in the thickness and rate predictions. The magnitude of this error depends upon the film thickness and the amount of departure of the true Z-ratio from unity.

In 1989, A. Wajid became aware of the ModeLock oscillator[7]. He speculated that there might be a relationship between the fundamental and one of the anharmonics similar to that noted by Benes[8] between the fundamental and the third quasiharmonic. The frequencies of the fundamental and the anharmonics are very similar, solving the problem of capacitance of long cables. He found the ideas needed for establishing the required connections in papers published by Wilson[9] in 1974 and Tiersten and Smythe[10] in 1979.

Contouring a crystal; that is, giving one face a spherical shape, has the effect of separating the various modes further apart and preventing the transfer of energy from one mode to another. For the sake of identification it is common to assign mode [100] to the fundamental, [102] to the lowest frequency anharmonic and [120] to the next lowest frequency anharmonic. The three indices of the mode assignment refer to the number of phase reversals in the wave motion along the three axis of the crystal. The above referenced papers by Wilson and Tiersten & Smythe are examinations of modal properties, relating the various properties of the radius of curvature to the placement of the anharmonics relative to the fundamental.

As material is deposited upon one face of a crystal, the entire spectrum of resonances shifts to lower frequencies. The three above mentioned modes are observed to have slightly different mass sensitivity and hence undergo slightly different frequency shifts. It is this difference that is used to estimate the Z-ratio of the material. Using the modal equations and the observed frequencies of the modes [100] and [102], one can calculate the ratio of two elastic constants C_{66} and C_{55}. Both of these elastic constants relate to shear motion. The essential element of Wajid's theory is the following equation.

$$\frac{C_{55}/C_{66})_{coated}}{C_{55}/C_{66})_{uncoated}} \sim \frac{1}{(1+MZ)} \qquad \text{EQN. 5}$$

Where, M is the aerial mass density (film mass to quartz mass ratio per unit area) and Z is the Z-ratio. It is a fortunate coincidence that the combination MZ also appears in the Lu-Lewis equation (Eqn. 4), which can be used to extract an estimate of the effective Z-ratio from the equations below:

$$\tan(MZ \bullet \Pi \bullet \frac{F_c}{F_q}) + Z \bullet \tan(\Pi \bullet \frac{F_c}{F_q}) = 0 \qquad \text{EQN. 6}$$

or

$$Z = -\frac{\tan(MZ\ \Pi\ F_c/F_q)}{\tan(\ \Pi\ F_c/F_q)} \qquad \text{EQN. 7}$$

Here, F_q and F_c denote uncoated and coated crystal frequencies in the fundamental mode (mode [100]). Due to the multi-valued nature of the mathematical functions involved, the value of Z-ratio extracted in this manner is not always a positive definite quantity. This is hardly of any consequence however, because m is uniquely determined with the estimated Z and the measured frequency shift. Thus, thickness and rate of deposition are subsequently calculated from the knowledge of M.[11]

One must be aware of the limitations of this technique. Since the estimate for Z-ratio is dependent on the frequency shifts of the two modes, any spurious shift due to excessive mechanical or thermal stress on the crystal will lead to errors. Needless to say similar errors occur with the Z-match™ technique under similar circumstances. However, the automatic Z-ratio estimate is somewhat more prone to error, because the amplitude distribution of the mode [102] is asymmetric, whereas that of the mode [100] is symmetric over the active area of the crystal.

In our experience, film induced stress on the crystal has the most deleterious effect. This effect is most pronounced whenever there is a presence of gas in the environment, for example, in sputtering and reactive evaporation or sputtering processes. In such cases, if the bulk Z-ratio is already well known, it is better to use the bulk value instead of the automatically determined Auto Z-ratio. In cases of co-deposition and sequential layers, automatic Z-ratio estimation is significantly superior.

2.8 Control Loop Theory

The instrumental advances in measurement speed, precision and reliability would not be complete without a means of translating this improved information into improved process control. For a deposition process, this means keeping the deposition rate as close as possible to the desired rate. The purpose of a control loop is to take the information flow from the measurement system and to make power corrections that are appropriate to the characteristics of the particular evaporation source. When properly operating, the control system translates small errors in the controlled parameter, or rate, into the appropriate corrections in the manipulated parameter, power. The controller's ability to quickly and accurately measure and then react appropriately to the small changes keeps the process from deviating very far from the set point.

The most commonly chosen controller model, for converting error into action, is called PID. In the PID, P stands for proportional, I stands for integral and D stands for derivative action. Certain aspects of this model will be examined in detail a little further on. Knowledge of the responses of the evaporation source can be found by repetitively observing the system response to a disturbance under a particular set of controller settings. After observing the response, improved controller parameters are estimated and then tried again until satisfactory control is obtained. Control, when it is finally optimized, essentially matches the parameters of the controller model to the characteristics of the evaporation source.

It is quite laborious and frustrating to tune a controller for a evaporation source that takes several minutes to stabilize. It may take several hours to obtain satisfactory results. Often the parameters chosen for a specific rate will not be satisfactory for another. Ideally, it would be nice if a machine could optimize itself. Inficon's new controller can do this. In a operator initiated mode that is used during initial setup the instrument will observe the source characteristics. It then calculates the parameters that allow near optimum source control using either a PID model for slow sources or an alternate model for fast sources, which have no significant dead time.

In the literature the techniques for tuning controllers can be classified by the type of data used for tuning. They fall into basically three categories:

Closed Loop Methods
Open Loop Methods
Frequency Response Methods

Of these, the open loop methods are considered superior. They are considered superior because of the ease with which the necessary experimental data can be obtained and because of the elimination (to a large extent) of trial and error when the technique is applied.

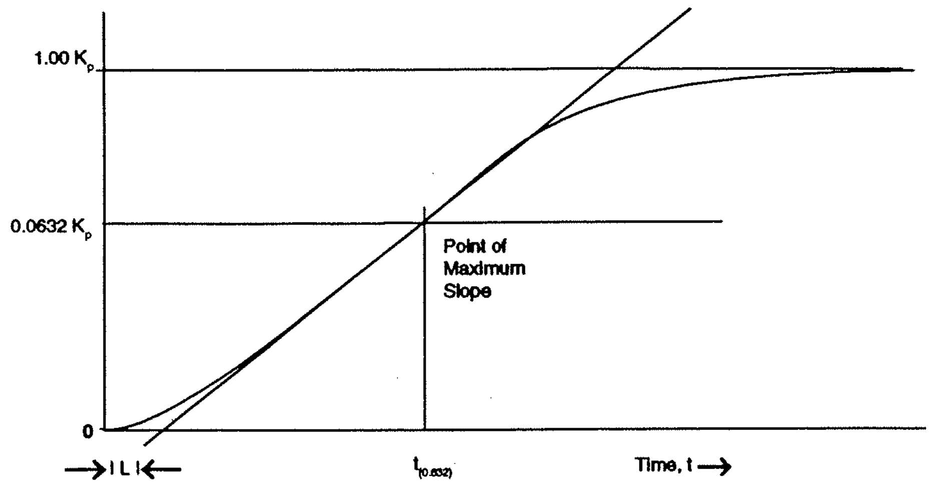
Inficon's Auto-Control-Tune characterizes a process from its step response attributes. After executing a step change of power the resulting rate changes as a function of time are smoothed and stored. The important response characteristics are determined as shown in Figure 2.7.

In general, it is not possible to characterize all processes exactly; some approximation must be applied. The most common is to assume that the dynamic characteristics of the process can be represented by a first-order lag plus a dead time. The Laplace transform for this model (conversion to the s domain) is approximated as:

$$\frac{\text{Output}}{\text{Input}} = \frac{K_p \exp(-L\ / s)}{T1s + 1} \qquad \text{EQN. 8}$$

Three parameters are determined from the process reaction curve. They are the steady state gain, Kp, the dead time, L, and the time constant, T1. Several methods, have been proposed to extract the required parameters from the system response as graphed in Figure 2.7. These are: a one point fit at 63.2% of the transition (one time constant); a two point exponential fit; and a weighted least square exponential fit. From the above information a process is sufficiently characterized so that a controller algorithm may be customized.

A controller model that has been used extensively is the PID type which is shown in Laplace form in equation 9 below.



$T1 = t_{(0.632)} - L$
K_p = (CHANGE IN OUTPUT)/(CHANGE IN CONTROL SIGNAL)

Figure 2.7 Response of Process To An Open Loop Step Change At t=0 (Control Signal is Increased)

$$M(s) = K_c \bullet \left(1 + \frac{s}{T_i} + T_d \bullet s\right) \bullet E(s) \qquad \text{EQN. 9}$$

Where
- $M(s)$ = manipulated variable or power
- K_c = controller gain (the proportional term)
- T_i = integral time
- T_d = derivative time
- $E(s)$ = process error

Figure 2.8 below represents the controller algorithm and a process with first order lag and dead time. The process block implicitly includes the dynamics of the measuring devices and the final control elements, in our case the evaporator power supply. R(s) represents the rate setpoint. The feedback mechanism is the error generated by the difference between the measured deposition rate, C(s), and the rate set point, R(s).

The key to using any control system is to choose the proper values of Kc, Td and Ti. Optimum control is a somewhat subjective quantity as noted by the presence of several mathematical definitions as shown below.

The integral of the squared error (ISE) is a commonly proposed criterion of performance for control systems.

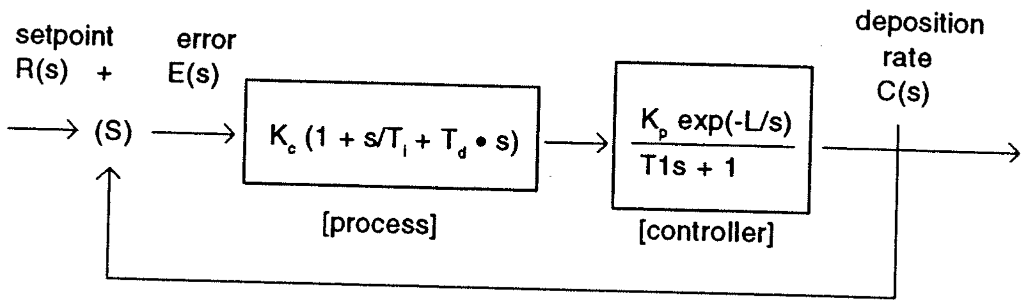


Figure 2.8 PID Controller Block Diagram

It can be described as:

$$ISE = \int e^2 (t)dt \qquad \text{EQN. 10}$$

Where error = e = setpoint - measured rate. The ISE measure is relatively insensitive to small errors, but large errors contribute heavily to the value of the integral. Consequently, using ISE as a criterion of performance will result in responses with small overshoots but long settling times, since small errors occurring late in time contribute little to the integral.

The integral of the absolute value of the error (IAE) has been frequently proposed as a criterion of performance:

$$IAE = \int | e^2 (t) | dt \qquad \text{EQN. 11}$$

This criterion is more sensitive to small errors, but less sensitive to large errors, than ISE.

Graham and Lathrop[12] introduced the integral of time multiplied by the absolute error (ITAE) as a criterion of performance:

$$ITAE = \int t \mid e(t) \mid dt \qquad \text{EQN. 12}$$

ITAE is insensitive to the initial and somewhat unavoidable errors, but it will weight heavily errors occurring late in time. Optimum responses defined by ITAE will consequently show short total response times and larger overshoots than with either of the other criteria. It has been found that this criteria is generally most useful for deposition process control.

Inficon's Auto Control Tune is based on an open loop measurement of the system's response. From a step change in the control signal, the response characteristics of the system are calculated. The experimental determination of response characteristics is accomplished through two types of 2 point curve fits. They are determined either quickly at an arbitrary deposition rate, or more perfectly near the desired rate setpoint. Since the process response characteristics depend on the position of the system (i.e. deposition rate for this discussion), the process response is best measured at the desired operating point of the system. This measured process information (i.e. process gain, K_p, time constant, T1, and dead time, L) is used to generate the best fitting PID control loop parameters for the specific system.

The most satisfactory performance criterion for deposition controllers is the ITAE. There will be overshoot, but the response time is quick, and the settling time is short. For all of the above integral performance criteria, controller tuning relations have been developed to minimize the associated errors. Using manually entered or experimentally determined process response coefficients, ideal PID controller coefficients can be readily calculated for the ITAE criteria as shown below.

$$K_c = (1.36/K_p)(L/T1)^{-0.947} \qquad \text{EQN. 13}$$

$$T_i = (1.19\ T1)(L/T1)^{0.738} \qquad \text{EQN. 14}$$

$$T_d = (0.381 T1)(L/T1)^{-0.995} \qquad \text{EQN. 15}$$

For slow systems, in order to help avoid controller windup (windup: the rapid increase in control signal before the system has the chance to respond to the changed signal), the time period between manipulated variable (control voltage) changes is lengthened. This allows the system to respond to the previous controller setting change, and aggressive controller settings can be used. A secondary advantage is that immunity to process noise is increased since the data used for control is now comprised of multiple readings instead of a single rate measurement, taking advantage of the mass integrating nature of the quartz crystal.

With process systems that respond quickly (short time constant) and with little to no measurable dead time, the PID controller often has difficulty with the deposition process noise (beam sweep, fast thermal shorts of melt to crucible, etc.). In these situations a control algorithm used successfully is an integral/reset type of controller. This type of controller will always integrate the error, driving the system towards zero error. This technique works well when there is little or no dead time. If this technique is used on a process with measurable lag or dead time, then the control loop will tend to be oscillatory due to the control loop over compensating the control signal before the system has a chance to respond. Auto Control Tune detects the characteristics of these fast response systems during measurement of the step response. This information is used to calculate the controller gain coefficient for the non-PID control algorithm.

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Vacuum Technology | Vacuum Process Engineering | Measuring and Analytical Technology

INFICON

Section 3
Operating the IC/4

Contents

Both the IC/4 and the IC/4 PLUS will be referred to as the IC/4. Features unique to the respective instruments will be referred to as such.

3.1 Front Panel Controls

Operational controls for the IC/4 are located on the front panel of the instrument as depicted in Figure 3.1.

1 Display

Provides graphical displays, set up menus, status and error messages.

2 Panel Keys

An array of keys located adjacent to the display. The keys are labeled F1 through F6. They are used to select displays or menu items. Their actual function is indicated on the display.

3 Data Entry Keys

Keypad array with numerics 0 through 9 and keys for Yes, No, Enter and Clear, used for selection and parameter entry. All numeric and Yes/No entries need to be followed by an Enter. Clear is used to erase data entry errors. If an illegal value has been entered, clear will erase the error message and re-display the last valid data.

4 System Switches

An array of three keys that provide START, STOP and RESET functions, for process control see, Executing a Process, Section 3.4.2, for a detailed description of these functions.

5 Memory Card Access Port

Receptacle for the IC Memory Card. The memory card and connector are keyed to prohibit improper insertion. The memory card is only inserted a short distance into the instrument.

6 Remote Control Jack

Receptacle for the wired handheld remote controller. It is similar in design and use to a communications jack.

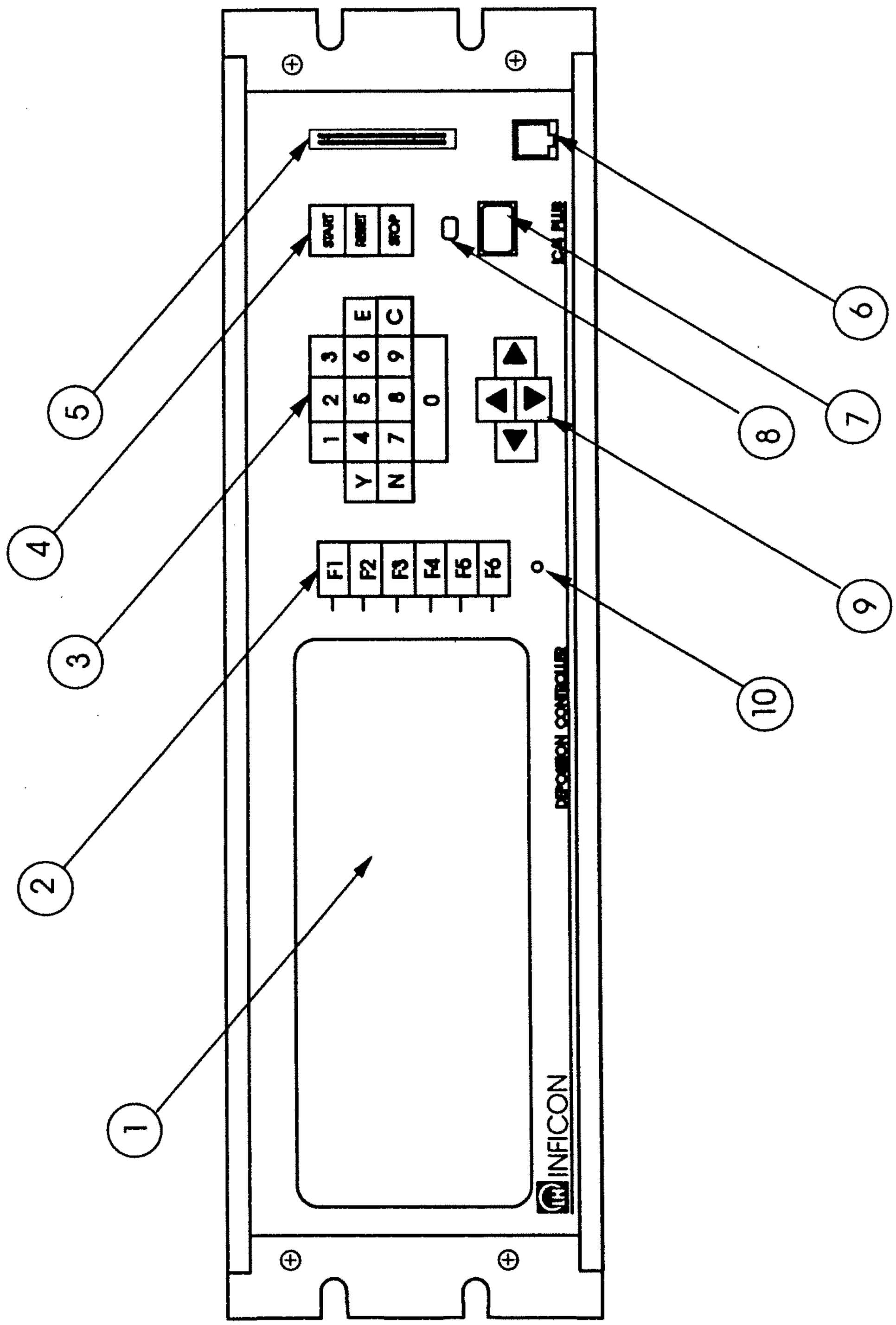
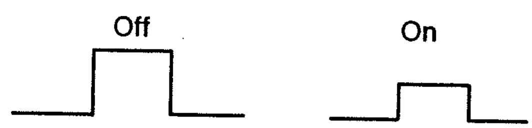


Figure 3.1 IC/4 Front Panel

7 Power

This switch controls line current to the instrument. Power is provided when the button is in its depressed position. The instrument is initialized for approximately 5 seconds before providing an operational screen.



8 Pilot Light

A green pilot light, above the power switch, is lit when power is on.

9 Cursor Keys

An array of four keys that are used to move the display cursor either up, down, left or right. The keys auto-repeat; the cursor will continue to move as long as the key is held down or until a display field bound is met.

10 Brightness Adjustment

An access hole for the display's brightness adjustment. A non-conductive TV adjustment tool can be used to increase the brightness by turning the pot clockwise.

3.2 Rear Panel Interfaces

Interfaces for the IC/4 are located on the rear panel of the instrument as depicted in Figure 3-2. Detailed information is contained in Section 10 Installation & Interfaces.

1 Top Relay Connector & 24 V Outlets

Provides pin connections for eight internal relays rated for up to 240 volts and four power supplies of 24 VDC (0.4 amp maximum all supplies). This is referred to as connector P-4.

2 Sensor Connectors - Channels 1 & 2

Provides connection for the unit's two standard sensor channels.

3 Source Control Port B

Expansion port for the optional second source control module for the instrument. This option provides two additional source voltage controls and an additional recorder output.

4 Remote Communications Connector

RS232 serial interface (standard). Optionally, it can be replaced with an RS422 serial or IEEE488 parallel interface.

5 AC Power Inlet

Provides a common connector for various international plug sets. The unit is factory set for either 120V or 240V service.

6 External Ground Connection

Provides an earth ground attachment to the instrument. Earth ground is required to avoid electrical interference and for optimum instrument performance.

7 Fan Outlet

Exhaust opening for the unit's miniature fan. A grill is attached for safety.

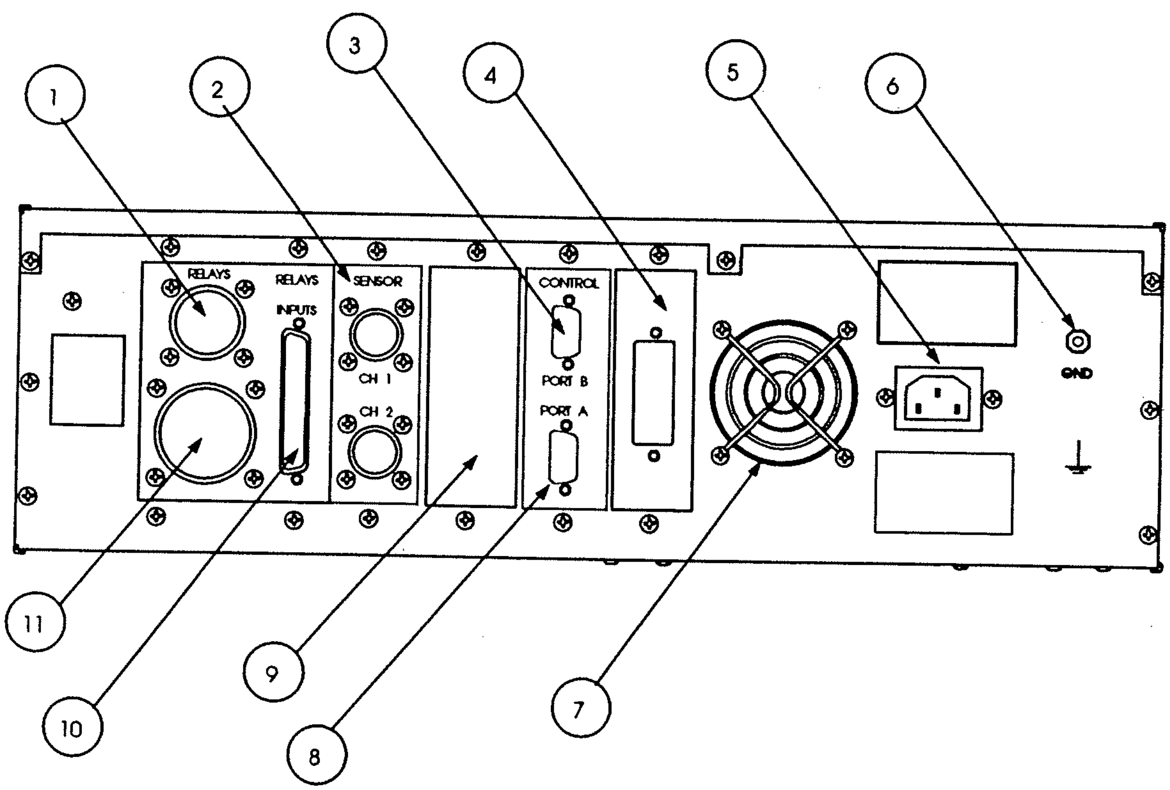


Figure 3.2 IC/4 Rear Panel

8 **Source Control Port A**

This is the unit's standard connection for its two source voltage controls and an analog recorder output.

9 **Sensor Connectors (Expansion) - Channels 3 & 4**

Expansion panel to accommodate the optional addition of two more sensors.

10 **Input Lines**

Provides pin connections for eight standard or sixteen optional (sixteen standard on IC/4 PLUS) isolated input lines with response actuated at 10-24 VAC or 10-30 VDC. This is referred to as connector P-5.

11 **Bottom Relay Connector (optional on IC/4, standard on IC/4 PLUS)**

Provides pin connections for eight internal relays capable of handling up to 240 volts. This is referred to as connector P-3.

3.3 Displays

The IC/4 has several display screens for monitoring and programming processes. Screens are changed using the panel keys to the right of the display. Figure 3.3 gives an overview of how different display screens are entered. The "**F#**" on the diagram indicates which panel should be pressed to get to a screen. To move up the diagram, **F6** is always pressed.

The two main types of screens are the OPERATE screens and the PROGRAM screens.

3.3.1 Operate Screen

The primary OPERATE screen provides information about the current layer(s). This includes the layer, material, source, and sensor currently in process. The rate, thickness, power level, state, state time, layer time, and process time are all updated once a second.

In the middle of the screen is a graph that is updated 5 times a second (10 times a second in the IC/4 PLUS). This graph gives an analog display of the rate deviation from the desired rate while depositing. Alternatively, it can graph the percent power being output during a process. The meaning, scaling, and speed of the graph are controlled using parameters set in the UTILITY screen. (See Section 9.3).

Refer to Section 3.6.10 for information on a screen mark/toggle (speed key) feature.

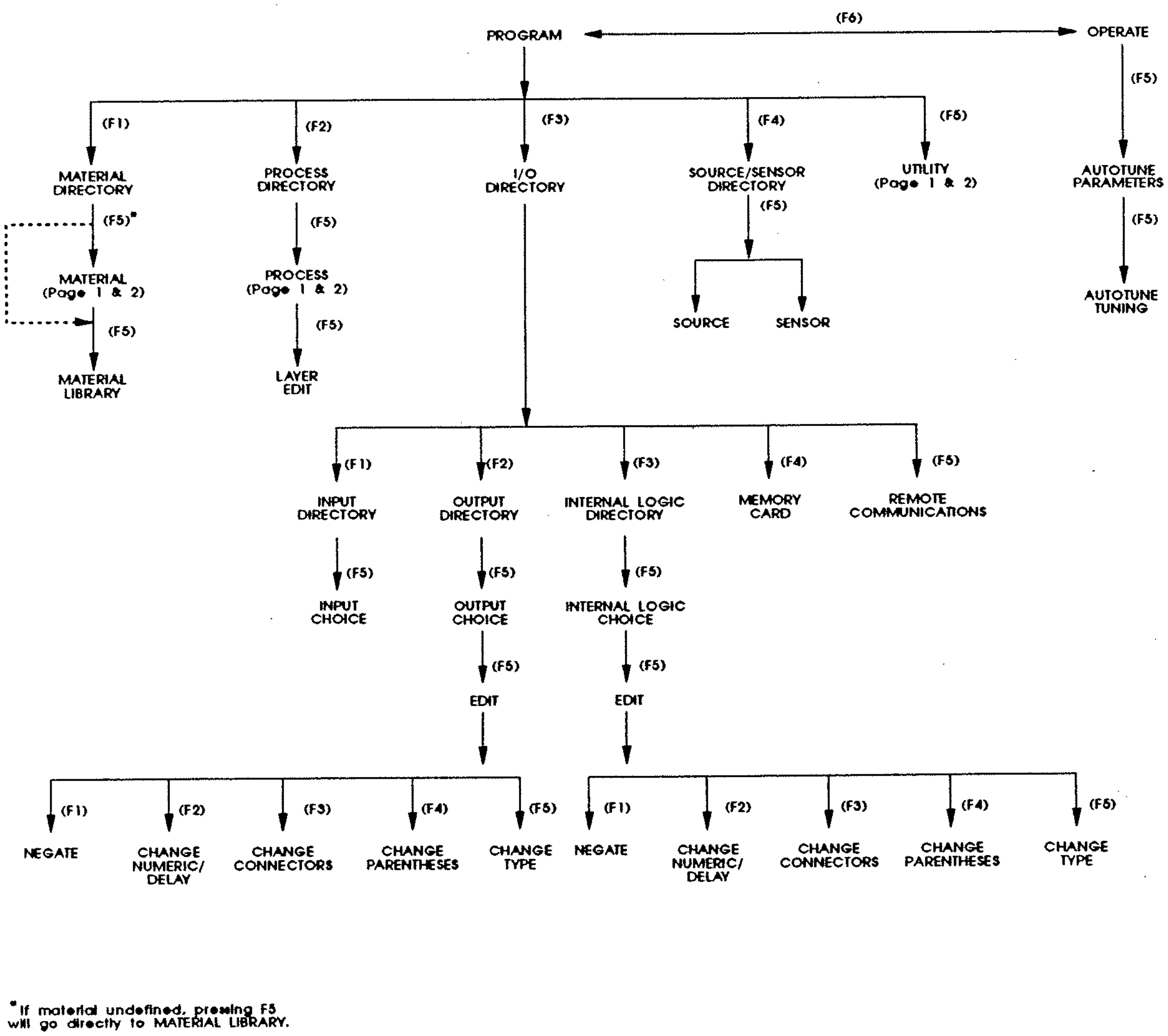


Figure 3.3 Display Hierarchy

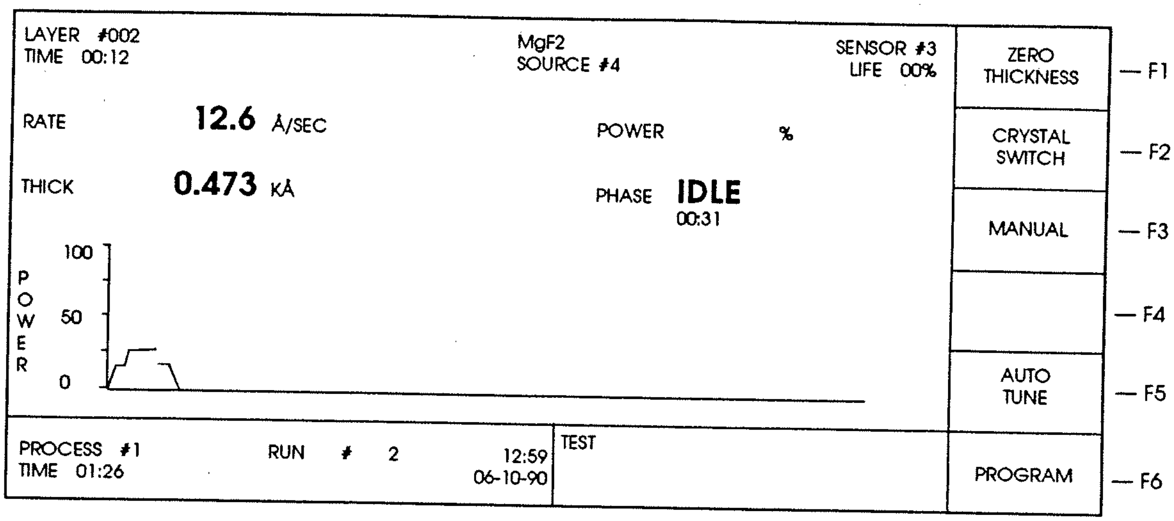


Figure 3.4 Operate Display

On the bottom right of the screen is a status area. This area displays error messages and system status information, such as indicating the instrument is in TEST. For a complete list of error and status messages, see Section 12.

Along the right hand side of the operational screen is a set of function panels. The functions include:

F1	**ZERO THICKNESS**	Pressing this panel will reset the displayed thickness of the current layer to zero.
F2	**CRYSTAL SWITCH**	If the system is configured for a dual sensor, this panel will switch to the alternate crystal or back. If the system is configured for a CrystalSix, this panel will advance to the next crystal. If the system is configured for a single head, this panel has no function.
F3	**MANUAL**	Pressing this panel will put the layer in manual control, that is, the power level is controlled by the handheld controller. When in manual, the F3 panel reads "AUTO," and pressing it will remove the layer from manual and place it in DEPOSIT. See State Descriptions (Section 3.5) for a more complete description of manual operation.

F4 **KEY SWITCH 2** When co-depositing two layers (see Figure 3.5), pressing this panel will change the numeric designators to the secondary layer for F1, F2 and F3.

F5 **AUTOTUNE** Pressing this panel while in READY will change the screen to the AutoTune setup screen. AutoTune is used to automatically calculate the control loop parameters for a specific source. For a detailed description of AutoTune see Section 11.6.

F6 **PROGRAM** Pressing this panel changes the screen to the PROGRAM menu. (See Section 3.3.2)

In addition to the standard operational screen, if the system is configured for co-deposition (IC/4 PLUS only), the operational screen will be divided to show information for both layers. Two options of the co-deposition OPERATE screen are available. One includes the graph information, and the other shows enlarged digital information. The format is determined by a parameter in the UTILITY screen. (See Section 9.3)

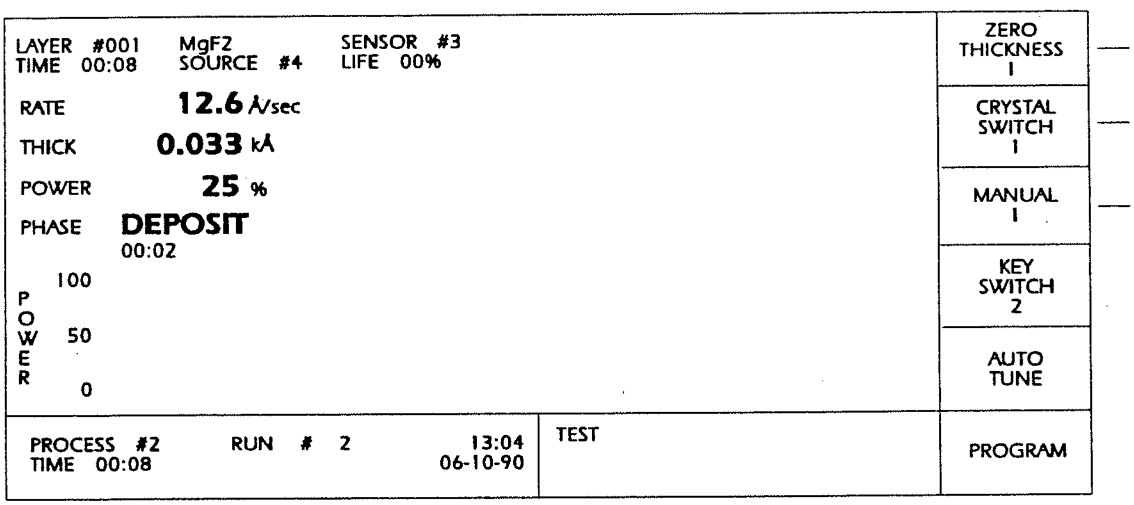


Figure 3.5 Co-deposition Operate Display (IC/4 PLUS Only)

3.3.1.1 Crystal Life and Starting Frequency

In the upper right hand corner of the Operate screen, crystal life is displayed as a percentage of the monitor crystal's frequency shift, relative to the 1.25 MHz (1.50 MHz in the IC/4 PLUS) frequency shift allowed by the instrument. This quantity is useful as an indicator of when to change the monitor crystal to safeguard against crystal failures during deposition. It is normal to change a crystal after a specific amount of crystal life (% change) is consumed.

It is not always possible to use a monitor crystal to 100% of crystal life. Useful crystal life is highly dependent on the type of material being deposited and the resulting influence of this material on the quartz monitor crystal. For well behaved materials, such as copper, at about 100% crystal life the inherent quality, Q, of the monitor crystal degrades to a point where it is difficult to maintain a sharp resonance and therefore the ability to measure the monitor crystal's frequency deteriorates.

When deposition dielectric or optical materials, the life of a gold, aluminum or silver quartz monitor crystal is much shorter; as much as 10 to 20%. This is due to thermal and intrinsic stresses at the quartz-dielectric film interface, which are usually exacerbated by the poor mechanical strength of the film. For these materials, the inherent quality of the quartz has very little to do with the monitor crystal's failure.

It is normal for a brand new quartz monitor crystal to display a crystal life anywhere from 0 to 5% due to process variations in producing the crystal. Naturally, this invites the questions: "Is a brand new crystal indicating 5% life spent inferior to a crystal indicating 1% life spent?"

If a new crystal indicates 5% life spent, it means that either the quartz blank is slightly thicker than normal (more mechanical robustness), or the gold electrode is slightly thicker than normal (better thermal and electrical properties), or both. In either case, its useful life with regard to material deposition should not be adversely affected. To verify this assertion, laboratory testing was performed on crystals which covered the crystal life range in question. Results indicate that a brand new crystal which indicates 3 to 5% life spent is just as good, if not better than a crystal indicating 0 to 2% life spent.

As a consequence, it is important to consider the change in crystal life (%), not just the absolute crystal life (%) indicated.

3.3.2 Program Screens

Program screens allow the user to program processes and system configuration. All the program screens have a section at the bottom that gives the rate, thickness, power level, and status of the process running. PROGRAM is divided into five major categories, with some of these being further subdivided. Each category has one or more complete section in this manual detailing the parameters in that category, and any special information needed to navigate those screens. Following is a brief description of those categories, with reference to the appropriate section of the manual.

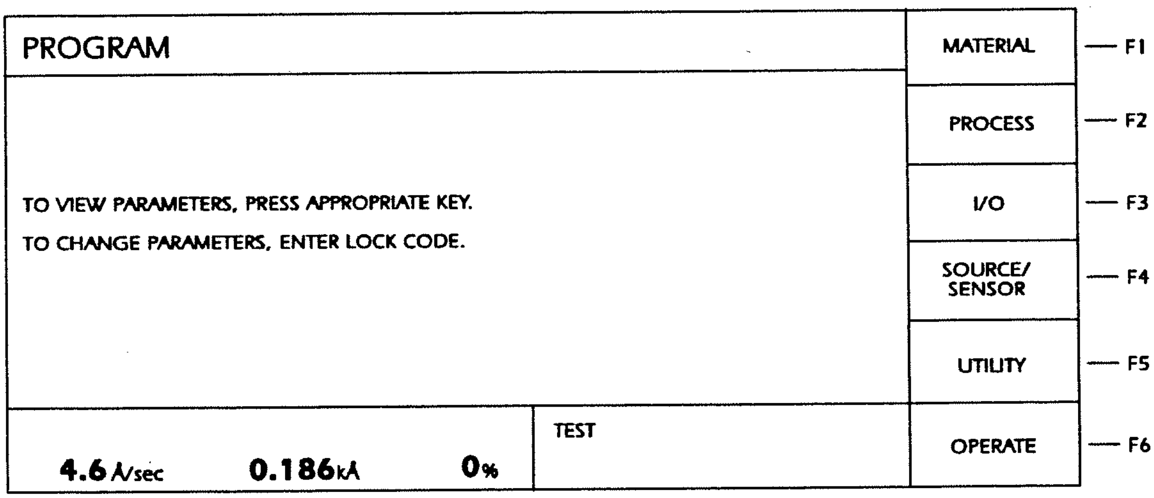


Figure 3.6 Program Display

F1 **MATERIAL** — Material parameters include information specific to a given material to be deposited in a process. The information includes Z-ratio, density, soak times, etc. Up to 12 materials (24 in the IC/4 PLUS) can be defined. See Section 4.

F2 **PROCESS** — The process screens allow the user to program a series of materials into a multi-layer process. Desired rate, final thickness, and other information specific to each layer is also programmed here. Four different processes can be defined, containing up to a total of 100 layers (250 in the IC/4 PLUS). See Section 5.

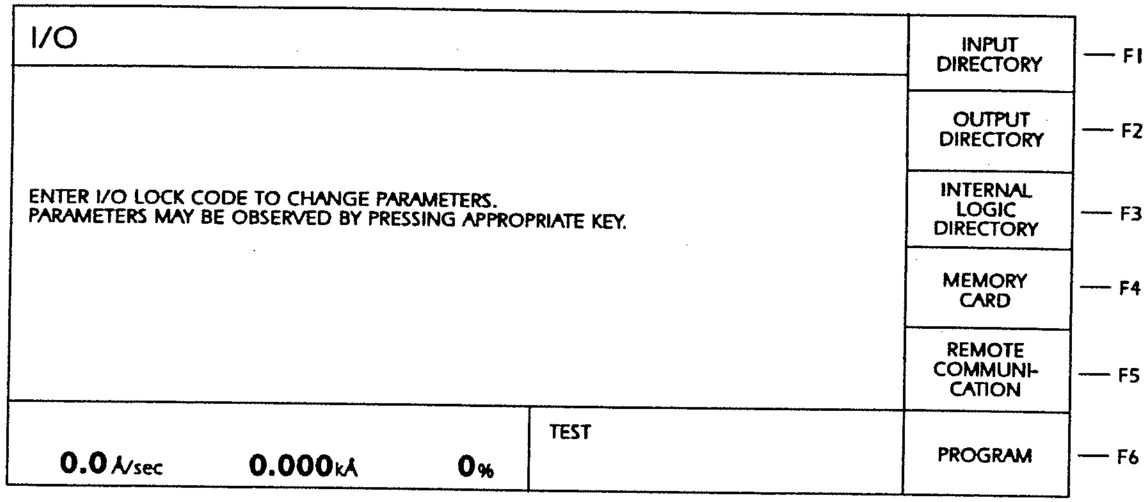


Figure 3.7 I/O Display

F3 **I/O**

I/O screens deal with several different external link from the IC/4 to the vacuum system, along with internal logic. This category is subdivided into the following groups:

INPUT Defines the controller's reaction to the presence of a signal on a particular external input (Section 6)

OUTPUT Defines the controller's action to change an external output (Section 6)

INTERNAL LOGIC Defines cause/effect relationships between IC/4 events and actions (Section 6)

MEMORY CARD Saves or retrieves parameters to or from the external memory card (Section 3.6.8)

REMOTE COMMUNICATIONS Defines configuration for external computer communications (Section 7)

F4 **SOURCE/SENSOR** Source/sensor screens allow the user to set up the configuration for sources and sensors connected to the IC/4. The information includes which output lines are connected, how many crucibles a source has, whether a sensor is a single, dual or CrystalSix. See Section 8.

F5 **UTILITY** Parameters on the UTILITY screens deal with overall system setup, including how displays are formatted and general process choices (such as whether to STOP on max power). See Section 9.

3.4 Process Description

The IC/4 allows the user to control deposition of single or multiple layers of material. This is done by defining and executing a process.

3.4.1 Defining A Process

The following procedure is used to define a process. (All steps do not necessarily have to be followed in the given order.)

1. Make sure the instrument is in READY.

   Some configuration and process parameters can only be changed while the instrument is in READY. Therefore, before setting parameters, make sure READY appears as the state on the OPERATE screen. If it does not, press STOP then RESET.

2. Configure the sensors.

   Configuring the sensors involves selecting if the sensor being used is a single, dual or CrystalSix sensor, and what outputs are connected to the sensor shutter and switcher, if any. Also, on the IC/4 PLUS, the Auto Z feature is activated or deactivated during sensor configuration. These parameters are on the SENSOR screen of the SOURCE/SENSOR display. See Section 8 for a detailed description for programming these parameters. Also see Section 3.6.1 for details on crystal switching.

3. Configure the sources.

   Configuring the sources involves selecting the output voltage range and polarity and indicating the output for the source shutter. Also, if the sources have more than one crucible, they are set up during source configuration. The source parameters are programmed on the SOURCE screen of the SOURCE/SENSOR display. See Section 8 for a detailed description for programming these parameters. Also see Section 3.6.2 for details on crucible selection.

4. Define materials.

   To define materials, the MATERIAL screens are used. Each distinct material used in the process must be defined. If the same material is going to be used more than once in the process, it only needs to be defined once, even if the final thickness or rate is different. These parameters are determined by the layer definition. The material definition includes density, Z-ratio, tooling, and soak power characteristics. Control loop characteristics also relate to the material. Also, a specific sensor and source are associated with each material. See Section 4 for a detailed description for programming these parameters.

NOTE: To set up certain material parameters, specifically those dealing with feed power, the user level parameter on the UTILITY screen needs to be set to 2.

5. Define layer/process.

   To define layers and processes, the PROCESS screens are used. A process is an ordered set of layers. Layers are entered in order on the PROCESS screen. Each layer consists of a material, chosen by number from the material directory, final thickness, and rate. Additional information can be provided here for special process features. These include thickness setpoint and time limit triggers, RateWatcher, rate ramps, crucible selection and co-deposition (IC/4 PLUS only). Note that many of these special features can only be programmed if user level has been set to 2 on the UTILITY screen. For a detailed description of layer parameters see Section 5.

6. Configure utility information.

   The final step in defining a process is to program any process related parameters on the UTILITY screen. This includes which defined process to execute, what layer to begin the process on (typically 1), whether to STOP on max power, and what action to take on a crystal fail. It may also be desirable to modify the definition of the graphical display and analog output. See Section 9 for a detailed description of utility parameters.

3.4.2 Executing A Process

Once a process has been defined, it is ready to execute.

NOTE: It may be desirable to execute a new process in TEST before doing an actual deposition to check correct shutter operation, sequencing and limits.

The execution of a process is depicted in the following state diagram:

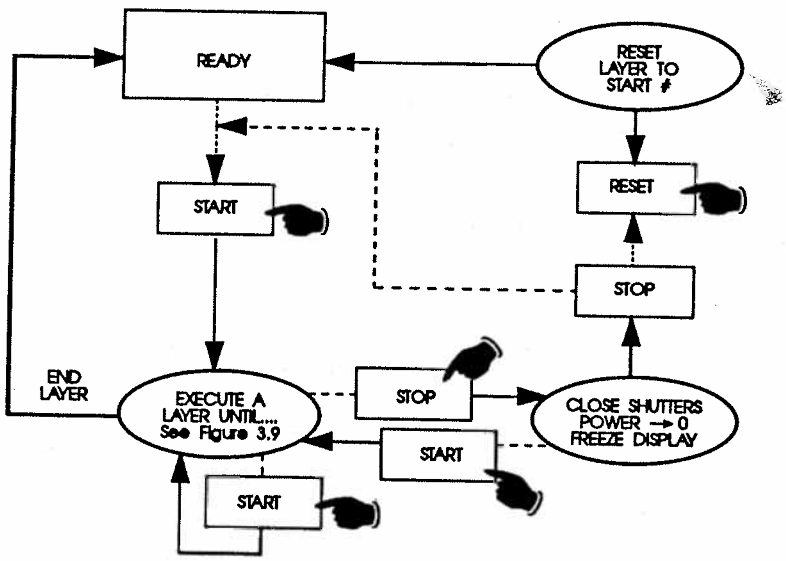


Figure 3.8 Process State Diagram

1. Make sure the instrument is in READY. If not, press STOP then RESET.

2. Press START. Assuming there are no configuration problems, the first layer will enter pre-deposition, and continue on through deposition and post-deposition. (See Section 3.5 for detailed information about the states of a layer.) If there are configuration problems, a message describing the problem will be displayed.

3. When the first layer is complete, it will go to IDLE. Press START again to begin the next layer. Repeat until the process is complete.

4. If at some point, there is a need to interrupt or discontinue the process, press STOP. This will close the sensor and source shutters, set the power to zero, and freeze the display. The process can be restarted where it left off by pressing START. (The pre-deposition phases will be repeated.) To completely abandon the run, press RESET.

5. Critical error may occur while a process is running.

   For example a sensor fail on a single head crystal may occur in pre-deposit. The IC/4 will automatically STOP if a critical error occurs. See Section 12 under STOP for a list of critical errors. Assuming the error has been remedied, the process can be continued where it left off by pressing START. RESET will abandon the run.

3.4.3 Pre-Conditioning A Layer

It may be desirable to prepare a layer for deposition while the previous layer is in progress. Pressing START while a layer is running will begin the pre-deposit states of the next layer. However, there are certain restrictions and some precautions should be taken.

1. The next layer cannot use the same source as the current layer. Pressing START will cause a source conflict and the process will STOP. If pre-conditioning is desired, be sure that the sources defined in the two consecutive layers are different.

2. The next layer cannot enter deposit while the current layer is still in deposit, unless the system is configured for co-deposition (IC/4 PLUS only). (See Section 3.4.4) This can be avoided by using SOAK HOLD 1 or SOAK HOLD 2 inputs or internal logic statements. These will hold the pre-deposition either at the SOAK 1 or SOAK 2 power level until ready to proceed. To set these up, see Section 6.

3.4.4 Co-deposition (IC/4 PLUS Only)

On the IC/4 PLUS it is possible to execute two layers simultaneously, if the system has the optional second sensor board installed. A co-deposition is executed using one sensor from each board (i.e., 1 and 3 or 4; 2 and 3 or 4). A co-deposition is defined on the layer screen. A "YES" is entered for the co-deposition parameter of the first layer of the co-deposition. This layer is referred to as the primary layer. In co-deposit, when the primary layer reaches final thickness, the secondary layer will also leave deposition. There are two other parameters associated with co-deposition. The first is ratio control. This controls the secondary layer's rate at a percentage of the primary layer's desired rate. The second is cross-sensitivity, which compensates for interference between the two depositions. See Section 5.4 for details on programming these parameters.

If two layers are programmed for co-deposition, pressing START once will begin both layers.

> **NOTE:** It is also possible to run two layers at the same time by pressing START twice, but ratio control, cross-sensitivity and automatic completion of the secondary channel would not be active.

3.4.5 Automating A Process

A process can be automated so that a complete process can be executed without having to press START between all the layers. A process can be automated by any of the following methods.

1. Internal logic. Setting the internal logic statement:

   IF LAYER END ALL AND $\overline{\text{PROCESS END ALL}}$
   THEN START

   will cause a complete process to run by pressing START once. For a step by step procedure to set up this statement, see Section 6.7.1.

2. Remote communication control. An external computer could be set up to monitor the status of a process and issue START commands at desired times. (See Section 7.)

3. Remote input line. A remote input line can be configured to issue a START command based on some external event. (See Section 6)

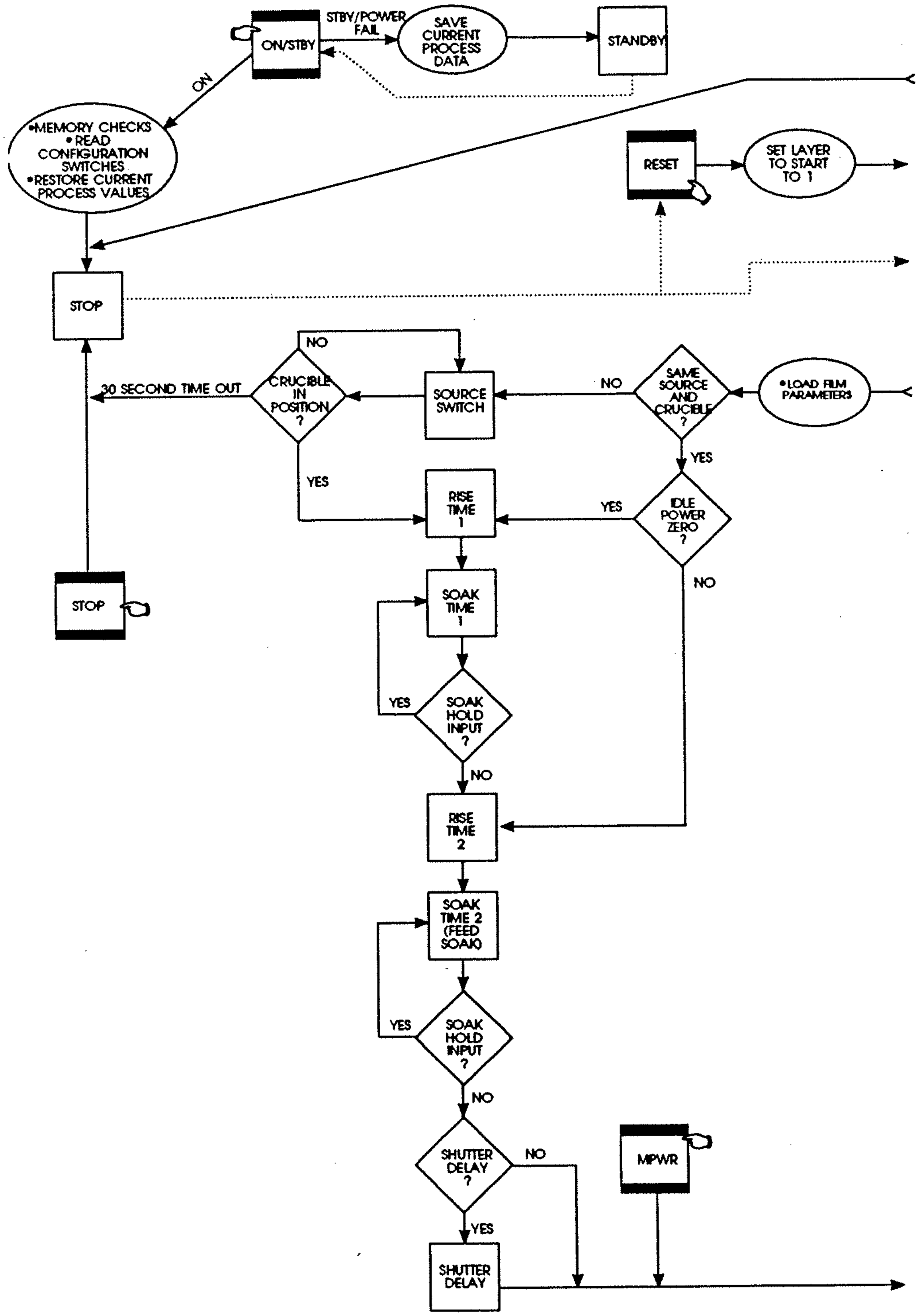


Figure 3.9a State Sequence Diagram

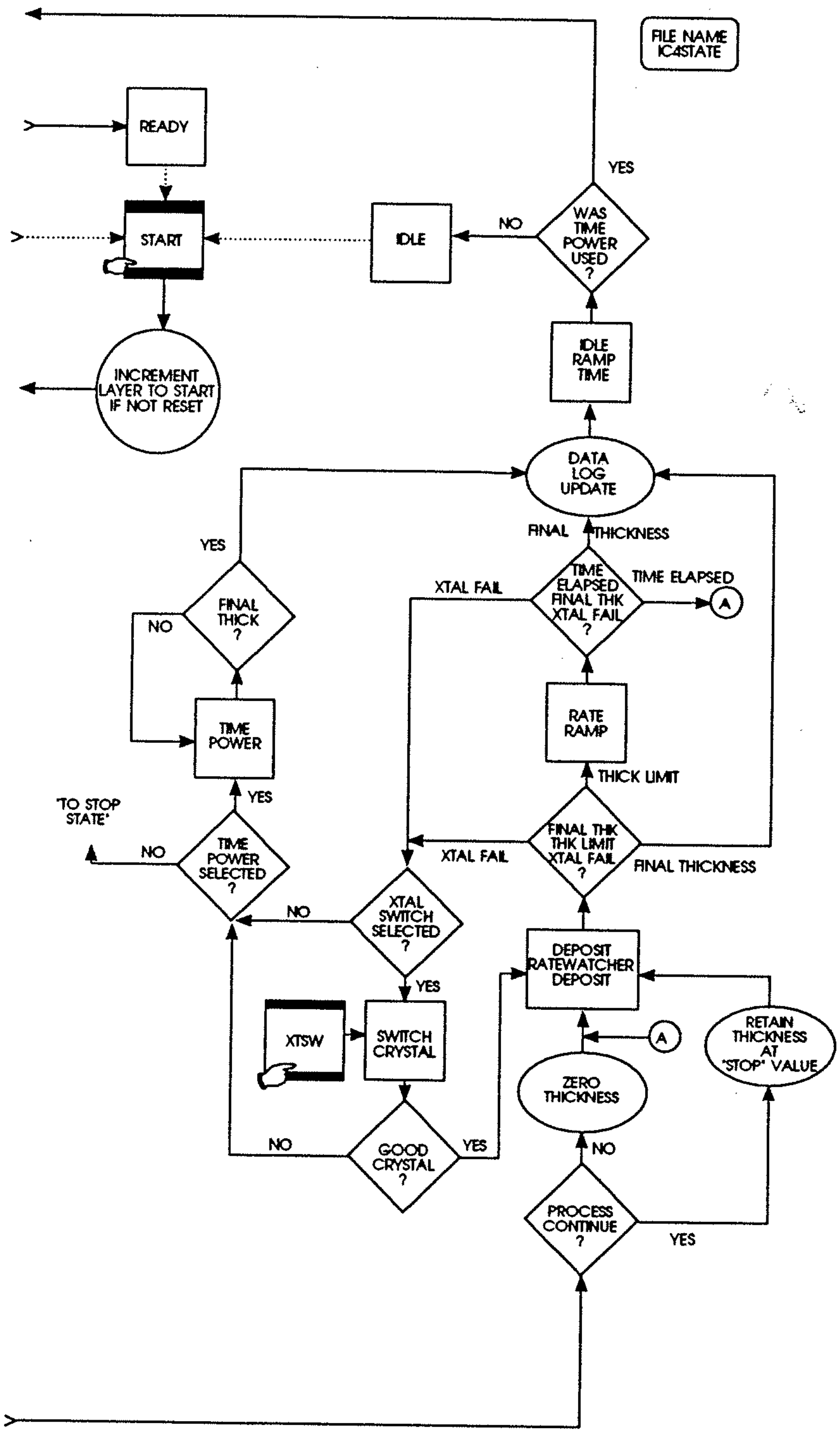


Figure 3.9b State Sequence Diagram

3.5 State Descriptions

A layer sequence consists of many possible states, with a state being defined as one process event. These states are described below; also, see Figure 3.9. The parameters that affect each state are listed in brackets [ ] at the end of the state description.

Table 3.1

STATE	CONDITION	RELAY CONTACT STATUS		
	NOTE: *1 through 7 are Pre-Deposit States.*	Source Shutter	Sensor Shutter	Feed
1. READY	Will accept a START command.	Inactive	Inactive	Inactive
2. SELECT CRUCIBLE	Instrument advances to next state when "turret" input is low, or "turret" delay has elapsed. If IDLE PWR of the previous layer on this source is not equal to zero, power is set to zero before the crucible position changes. [Crucible #, Source #]	Inactive	Inactive	Inactive
3. RISE TIME 1	Source rising to Soak Power 1 level. [Rise Time 1]	Inactive	Inactive	Inactive
4. SOAK TIME 1	Source maintained at Soak Power 1 level. [Soak Time 1, Soak Power 1]	Inactive	Inactive	Inactive
5. RISE TIME 2	Source rising to Soak Power 2 level. [Rise Time 2]	Inactive	Inactive	Inactive
6. SOAK TIME 2	Source maintained at Soak Power 2 level. [Soak Time 2, Soak Power 2]	Inactive	Inactive	Inactive
7. SOAK HOLD	Source maintained at Soak Power 2 level. [Soak Hold Input]	Inactive	Inactive	Inactive

Table 3.1 (continued)

STATE	CONDITION	RELAY CONTACT STATUS		
	NOTE: 8 through 15 are Deposit states.	**Source Shutter**	**Sensor Shutter**	**Feed**
8. **SHUTTER DELAY**	Rate control. Advances to Deposit State once the Source is in Rate Control within 5% [Shutter Delay ON]	Inactive	Active	Inactive
9. **DEPOSIT**	Rate control. [Rate, Final Thickness, PID Control, Process Gain, Primary Time Constant, System Dead Time]	Active	Active	Inactive
10. **RATE RAMP TIME 1**	Rate control, desired rate changing. [New Rate 1, Start Ramp 1, Ramp Time 1]	Active	Active	Inactive
11. **RATE RAMP TIME 2**	Rate control, desired rate changing. [New Rate 2, Start Ramp 2, Ramp Time 2]	Active	Active	Inactive
12. **RATEWATCHER** (SAMPLE)	Rate control. [RateWatch Accuracy]	Active	Active	Inactive
13. **RATEWATCHER** (HOLD)	Constant power, based on last sample's average power. [RateWatch Time]	Active	Inactive	Inactive
14. **MANUAL**	Source power controlled by hand held controller.	Active	Active	Inactive
15. **TIME-POWER**	Crystal failed; source maintained at average control power prior to crystal failure. [Time Pwr Y]	Active	Active	Inactive

Table 3.1 (continued)

STATE	CONDITION	RELAY CONTACT STATUS		
	NOTE: 16 through 19 are Post-Deposit states.	**Source Shutter**	**Sensor Shutter**	**Feed**
16. FEED RAMP	Source changing to Feed Power [Feed Power, Feed Ramp Time]	Inactive	Inactive	Inactive
17. FEED	Source maintained at Feed Power level. [Feed Time]	Inactive	Inactive	Active
18. IDLE RAMP	Source changing to Idle Power. [Idle Ramp Time, Idle Power]	Inactive	Inactive	Inactive
19a. IDLE POWER (=0%)	Source maintained at zero power; will accept a START command. [Idle Power]	Inactive	Inactive	Inactive
19b. IDLE POWER (>0%)	Source resting at Idle Power; will accept a START command.	Inactive	Inactive	Inactive

NOTE: The STOP state - instrument will accept a START provided a Crystal Fail has not occurred for the sensor used in the layer being started.

3.6 Special Features

The IC/4 has several special features to enhance the performance of the instrument.

3.6.1 Crystal Switching

The IC/4 has a choice of single, dual or CrystalSix sensors. The dual or CrystalSix sensor provides a backup in case a crystal fails during deposition. To configure sensors, see Section 8.

A crystal switch will automatically occur when:

1. The instrument is configured for a dual head, a layer is running on the primary sensor, and the primary crystal fails.

2. The instrument is configured for a CrystalSix, a layer is running, and there is at least one good crystal left in the carousel when the active crystal fails.

3. The instrument is configured for a dual head or single heads, a START is executed and the designated primary sensor is different than the last sensor run.

A crystal switch will NOT automatically occur:

1. In STOP, READY or IDLE.

2. When the designated primary sensor is already failed at the START of a layer. (A STOP will occur.)

3. While in Deposit when the secondary crystal of a dual head fails, or when using a CrystalSix sensor the last good crystal fails. (A TIME-POWER or STOP will occur.)

A crystal switch can be manually executed via the front panel, handheld controller, remote communications, input lines, or internal logic, any time the system is configured for dual or CrystalSix.

NOTE: The primary sensor # of a dual head is the sensor programmed in the material parameters. The secondary sensor is the other sensor.

CrystalSix crystal frequencies are all read on power up to determine how many good crystals are present. The operate screen displays the number of good crystals remaining.

3.6.2 Source/Crucible Selection

The IC/4 can control a source with up to 64 crucibles, through up to 6 BCD encoded relays. This is configured by setting the "number of crucibles", "crucible outputs", "turret feedback", "turret input", and "turret delay" parameters on the SOURCE screen of the SOURCE/SENSOR display. (See Section 8.3)

To define which crucible to use for a layer, set the "crucible" parameter on the PROCESS screen. When the layer is started, if the current crucible position is different from the one requested, the system's turret controller will move into position. This will be signified on the OPERATE screen by the state indicator SOURCE SWITCH. The layer sequencing will continue on to RISE 1 after a set delay, or an input indicates that the turret is in position. The specific method used is determined by the parameter "turret feedback" on the SOURCE screen.

NOTE: If the source had been idling at a non-zero power when the START is initiated, the power will be dropped to zero before the crucible is changed.

3.6.2.1 Example: Programming Turret Source Crucible Selection

Interfacing a turret source controller to the IC/4 family instruments requires both hardware interfacing to the turret controller and properly defining certain instrument parameters.

1. Proceed to the SOURCE/SENSOR directory and choose the source that is going to be defined as the turret source. This is accomplished by "Editing" the chosen source as follows:

    a. Designate the "number of crucibles"; for example: 4.

    b. Select the "Crucible Output." This defines the number of the first sequential relay that encodes the crucible number selected by the active layer. The greater the number of crucibles selected , the greater the number of relays required. The number required is based on binary encoding. Any unused sequence of relays may be used if it is long enough to provide sufficient selections.

    c. Select the "Crucible Output Type" as normally open (NO), or normally closed (NC).

Example:		
	Number of crucibles	= 4
	Crucible output	= 6
	Crucible output type	= NO

For this example, wiring to the controller is based on the following table: Only relays 6 and 7 are needed to encode the 4 possible positions.

Crucible Position	Contact Status	
	Relay #6	Relay #7
1	Open	Open
2	Closed	Open
3	Open	Closed
4	Closed	Closed

If the crucible output type were normally closed (NC), the above table would need to be modified by exchanging open and closed.

d. Determine if "Turret Feedback" is desired. This allows the turret position controller to stop further instrument processing until the requested turret position is satisfied. If chosen, a turret input must be chosen and connected to the turret position controller's feedback signal.

e. If step (d) above is not used, program a "Turret Delay Time" which allows an adequate time for positioning to take place. Once the delay time has expired , instrument state processing continues.

2. The selection of a particular crucible for a particular layer is defined in the process directory.

   a. Select the process number to be defined.

   b. Program the particular "Crucible Number" for each layer.

For example:			
	Layer 1:	Crucible Number	= 1
	Layer 2:	Crucible Number	= 2
	Layer 4:	Crucible Number	= 4

To define which crucible to use for a layer, set the "crucible" to use for a layer, set the "crucible" parameter on the PROCESS screen. When the layer is started, if the current crucible position is different from the one requested, the system's turret controller will move it into position. This will be signified on the OPERATE screen by the state indicator SOURCE SWITCH. The layer sequencing will continue on to RISE 1 after a set delay, or an input indicates that the turret is in position. The specific method used is determined by the parameter "turret feedback" on the SOURCE screen.

NOTE: If the source had been idling at a non-zero power when the START is initiated, the power will be dropped to zero before the crucible is changed.

3.6.3 Auto Z (IC/4 PLUS only)

The Auto Z feature of the IC/4 PLUS automatically determines the Z-ratio of a crystal. This feature is enabled on the SENSOR screen of the SOURCE/SENSOR display. (See Section 8.4) For the theory behind Auto Z, see Section 2.7

3.6.4 AutoTune

The control loop parameters can often be calculated automatically by the IC/4. This is done by using the AutoTune feature. For a detailed description of AutoTune, see Section 11.6.

3.6.5 RateWatcher

The IC/4 includes a sample and hold function, which enables periodic sampling of the deposition rate by opening and closing the sensor shutter. If the user is controlling inherently stable deposition sources this function is useful in maximizing crystal life. When RateWatcher is enabled, during deposit, rate control will be established. Then the sensor shutter will close for a designated amount of time. The shutter will once again be opened to validate and adjust the power level. This procedure is repeated through the deposition. Two process parameters - RateWatch time and RateWatch accuracy - control this function. See Section 5.4 for details on programming these parameters.

3.6.6 Hand Held Controller

A handheld controller is provided as an accessory with the IC/4. The controller serves as a wired remote to manually control power, switch crystals and produce a STOP.

The controller is attached to the instrument with a modular plug to the front panel. Power is affected (only when in Manual mode) by moving the POWER/STOP switch laterally. A STOP is produced by plunging the POWER/STOP switch down. When in READY, a crystal switch is activated by depressing the red button on the body of the controller.

The ship kit includes a convenience hook for the controller that can be attached to the instrument or other accessible location.

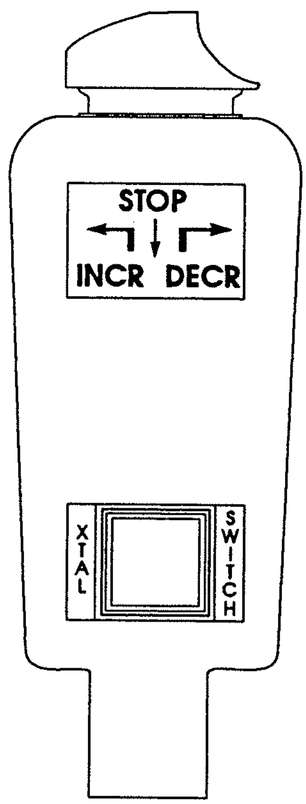


Figure 3.10 Hand Held Controller

3.6.7 Test Mode

This instrument contains a software controlled test mode which simulates actual operation. Optionally, time can be compressed so that a long process can be simulated in one tenth of the time. The purpose of the test mode is to verify basic operation and to demonstrate typical operation. The rate display during test mode operation is:

$$\frac{40}{\text{Density (gm/cc)}} \times \frac{\text{Tooling \%}}{100\%} \quad \text{Å/sec}$$

Crystal fails are ignored in test mode. Crystal switching is disabled. All other relays and inputs operate normally.

3.6.8 IC Memory Card

The Inficon IC Memory Card is an optional accessory for the IC/4. This credit card sized storage media is capable of storing all the parameter information of the IC/4. The memory is battery backed and is capable of providing multiple store and retrieve operations for approximately three years. The data on IC Memory Cards can be transported to and used in other like configured IC/4 instruments. The IC Memory Card has a built-in memory protect switch that can be used to prohibit inadvertent over-writing of information.

NOTE: Memory card access may be limited through the use of an access code. This code allows an operator to only read a preprogrammed card, but not alter it. See Section 3.6.9.

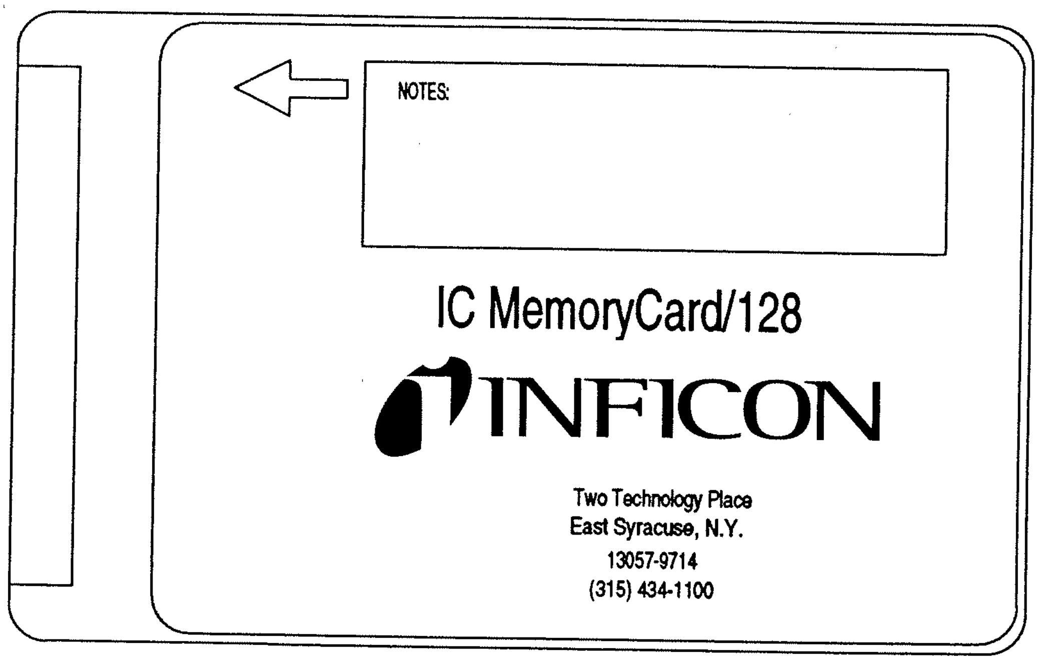


Figure 3.11 IC Memory Card

The connector portion of the IC Memory Card is keyed to assure proper insertion. Refer to the arrow indicator on the label for proper card orientation. Be sure that the card is inserted straight.

The IC Memory Card is reliable and rugged, but certain precautions must be taken.

Do not bend or drop the card.

Keep the card dry and do not expose the card to temperature extremes.

Keep the connector area clean and dust-free.

Avoid static by keeping the card in its anti-static case when not in use.

Do not remove the card from the instrument while a save or retrieve operation is taking place- this will cause data to be corrupted.

Do not touch or bend the terminal pins in the instrument's memory card port.

Data will be lost if the battery is removed; the instrument does not provide voltage at all times.

CAUTION: *Do not remove the battery from the IC Memory Card. If the battery is removed, all your stored data will be lost. The card will become operable if a battery is installed and the card formatted, see F3 below.*

Parameters can be saved to and retrieved from the memory card by going to the MEMORY CARD screen. This screen is reached by going from the PROGRAM screen to the I/O screen (F3) to the MEMORY CARD screen (F4).

The following functions can be performed.

F1	**SAVE PARAMETERS**	Save all parameters to memory card.
F2	**RETRIEVE PARAMETERS**	Retrieve all parameters from memory card.
F3	**FORMAT CARD**	Format memory card. Note that doing this will destroy any parameters saved on the card. This function is intended only to be used in the rare occasion of replacing the battery in the memory card.

CAUTION: *Do not remove the memory card during save or retrieve operations.*
It is recommended to remove the memory card during instrument power cycles.

NOTE: When changing certain sensor, I/O, or remote communications parameters, the instrument must be turned off then turned on for these parameters to be initialized properly. After a retrieve parameters operation, if any of these parameters have been changed the IC/4 will display a message indicating the need to power cycle the instrument.

NOTE: It is recommended that when doing a RETRIEVE PARAMETERS operation, the instrument have the same hardware configuration, including optional Sensor Measurement and Source control boards, as when the parameters were saved to the memory card. If the memory card contains parameters which can only be entered with optional equipment installed, default values will automatically be entered into these parameters when downloading to an instrument without the optional equipment installed. If Input Lines, Output Event Strings, or Internal Logic Strings contain reference to parameters which can only be entered with optional equipment, these statements will not be altered.

3.6.9 Lock and Access Codes

The IC/4 has several forms of protection to prevent unauthorized changing of parameters. Refer to the utility setup section for a description of parameter and I/O lock codes and the memory card access code. In addition, a method of locking the entire display is available through the remote communications.

NOTE: To clear any of the locks, except the memory access code, hold down the clear key on power up. This will clear all lock codes. HOWEVER, if no lock codes are present, all parameters will be cleared by doing this.

3.6.10 Screen Mark / Toggle (Speed Key)

This function allows movement between two displays with a single keystroke. When the instrument is not in a STOP state, the RESET key is pressed to "mark" the display. When a new display is entered and the RESET key is pressed a second time, the instrument returns to the previously "marked" display. Subsequent pressing of the RESET key will toggle between these two displays.

Section 4
Material Set Up

Contents

4.1 Material Set Up Overview

The IC/4 is capable of storing the definition parameters for up to 12 (twenty-four for IC/4 PLUS) materials. Each layer in a Process references one of these materials by its directory number, ranging from 1 to 12 (24 for IC/4 PLUS). Any material that is to be deposited must have been previously defined.

Materials are defined by referencing the internal Material Library and by completing a series of parameter entries at the front panel.

Display Tree for Material Set Up

```
MATERIAL (PROGRAM)
 └─ MATERIAL DIRECTORY
     └─ MATERIAL DEFINITION
         └─ MATERIAL LIBRARY
```

Material Set Up is initiated by selecting the MATERIAL (F1) panel in the Program display. This will invoke the Material Directory (Figure 4.1). Upon entry to the Material Directory, the cursor will be placed at the last referenced material.

4.2 Material Definition

Material definition is initiated by selecting the MATERIAL (F5) panel in the Material Directory. If the cursor is placed at a previously defined material, the definition displays for that material will be entered. If the cursor is placed at an unassigned material, the Material Library will be entered to select from one of the more than two hundred cataloged materials.

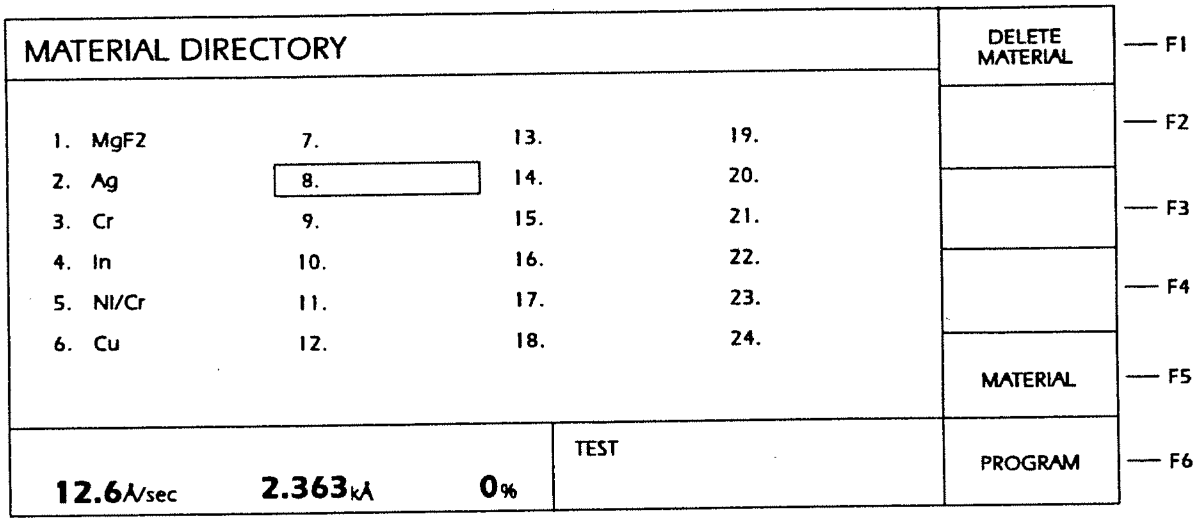


Figure 4.1 Material Directory

A previously defined material can be deleted if it is not referenced in any process. Place the cursor at the material to be deleted and select the DELETE MATERIAL (F1) panel in the Material Directory. The Material Directory will be compressed to eliminate any gaps and Process definitions will be updated to reflect any directory number changes.

NOTE: External and Internal Inputs and Outputs will **not** be updated to reflect directory number changes after deleting a material.

The Material Library provides an alphabetic list of materials by chemical name along with their density and Z-ratio. A custom user material may also be selected. Once the material is selected, Material Definition is completed by selecting the DEFINE MATERIAL (F5) panel.

Move among and through the materials by using the cursor and panel keys.

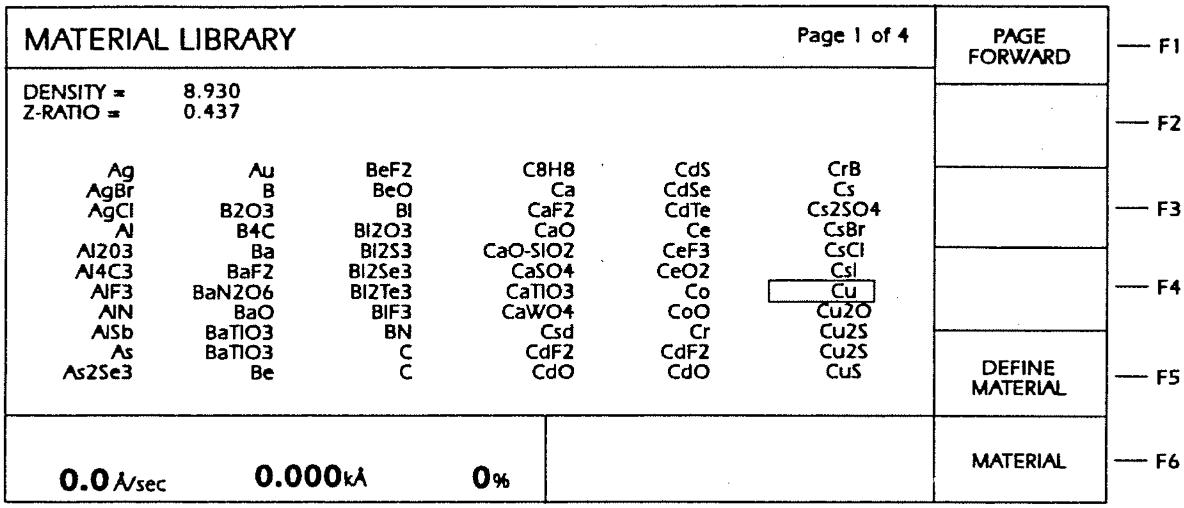


Figure 4.2 Material Library

PANEL SELECTION CHOICES FOR MATERIAL LIBRARY

F1	**PAGE FORWARD**	Select this panel to access additional pages of material listings.
F2	**PAGE BACK**	Select this panel to return to previous pages of material listings.
F5	**DEFINE MATERIAL**	Select this panel to complete the definition of the selected material.
F6	**MATERIAL DIRECTORY**	Select this panel to return to the Material Directory.

CAUTION: *PRIVILEGED OPERATION. You may be denied the ability to edit material definitions if access has been locked.*

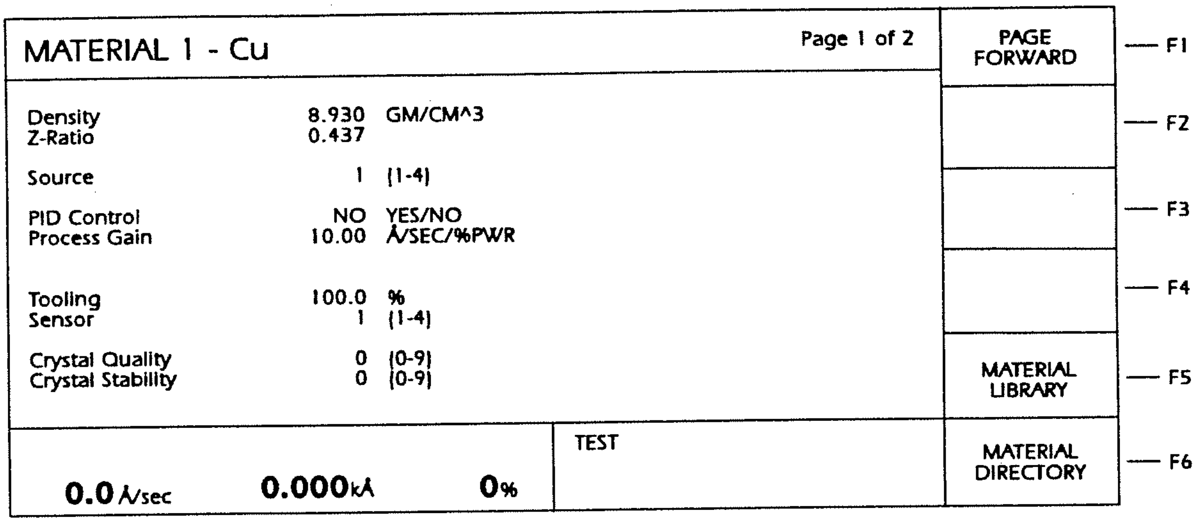


Figure 4.3 Material Definition (Page 1)

PANEL SELECTION CHOICES FOR MATERIAL DEFINITION

F1	**PAGE FORWARD**	Select this panel to access the second page of material definition parameters.
F2	**PAGE BACK**	Select this panel to return to the first page of material definition parameters.
F5	**MATERIAL LIBRARY**	Select this panel to access the Material Library.
F6	**MATERIAL DIRECTORY**	Select this panel to return to the Material Directory.

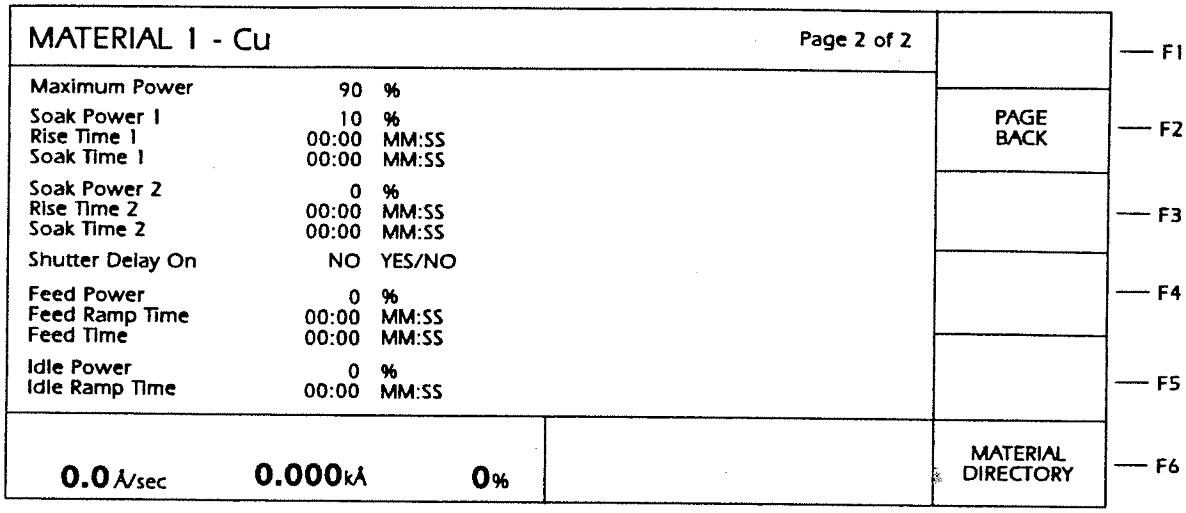


Figure 4.4 Material Definition (Page 2)

4.3 Material Definition Parameters

Some parameters are only available at the advanced user level, Level 2, and are marked ◆. Other parameters are affected by option equipment; they are marked ❖.

DENSITY 0.500 to 99.99 gm/cc

This parameter is specific to the material being deposited onto the Crystal. It is one of two parameters which relates the mass loading on the crystal to a thickness. Values range from 0.500 to 99.999. If a material is chosen from the Material Library the density is automatically entered. The default value is 1.00.

Z-RATIO 0.100 to 15.000

This parameter is specific to the material being deposited. One of two parameters which relates the mass loading on the crystal to a thickness. Values range from 0.100 to 15.000. If a material is chosen from the Material Library the Z-ratio is automatically entered. The default value is 1.00. In the IC/4 PLUS, this parameter is superseded if Sensor Z-ratio or Auto Z-ratio is selected in Source/Sensor Set Up.

SOURCE 1,2,3,4 ❖

This parameter determines which source control voltage output is to be used for the material being defined. Values can range from 1 to 4. The standard configuration for an IC/4 includes two source control outputs - these are sources 1 and 2. Optionally (❖), the unit will support two additional source control outputs - these are sources 3 and 4. The default is 1. This parameter cannot be changed while running a process.

PID CONTROL YES/NO

This parameter establishes the control loop algorithms pertaining to either a slow responding source or a fast responding source. Permissible entries can be either YES or NO. A YES indicates a slow responding source. The default is YES.

PROCESS GAIN 0.01 to 100.0

This parameter determines the change in % Power for a given rate deviation (dRate/dPower). A larger value will give a smaller change in power for a given rate deviation. Values range from 0.01 to 100.00. The default value is 10.00.

PRIMARY TIME CONSTANT 1 to 200 sec

This is the evaporation source's time constant. This value is defined as the time difference between the actual start of a change in rate and the time at which 63% of the new rate is achieved. This value may be measured according to the above criterion or it may be determined empirically. Values range from 1 to 200 seconds. The default value is 1. This parameter is disabled if the PID CONTROL parameters is set to NO.

SYSTEM DEAD TIME 1.0 to 50.0 sec

This value is defined as the time difference between a change in % power and the start of an actual change in rate. Values range from 1.0 to 50.0 seconds. The default value is 1.0. This parameter is disabled if the PID CONTROL parameter is set to NO.

TOOLING 10.0 to 399%

This is a correction factor used for correlating the thickness accumulation on the crystal to the thickness accumulation on the substrate. This thickness difference is due to the geometric distribution of material flux from the source.

The tooling factor is calculated using the equation:

$$\text{TOOLING} = TF_i \times (T_m/T_x).$$

where TF_i = Initial Tooling Factor, T_m = Actual Thickness at the Substrate, and T_x = Thickness on the Crystal.

Values range from 10.0 to 399%. The default value is 100%.

SECONDARY TOOLING 10.0 to 399%

This parameter is enabled when a Dual Sensor is chosen for Sensor 1 or Sensor 3 in Sensor Set Up. This provides a Tooling Factor for the second position of the dual sensor head. The function is identical to the normal Tooling parameter.

CRYSTAL QUALITY 0 to 9

The parameter is used to ensure tight rate control by monitoring the information obtained from the crystal. It can be used to affect a Crystal Fail when operating in the single frequency mode.

Threshold of Crystal Quality	Rate Deviation
9	2.5%
8	5.0%
7	7.5%
6	10.0%
5	12.5%
4	15.0%
3	20.0%
2	25.0%
1	30.0%
0	Disabled

For each rate reading, the percent relative deviation from the programmed rate is calculated. Each time this deviation is greater than the allowed percent relative deviation, as determined by the Crystal Quality value, a counter is incremented by one count. If the deviation is within tolerance, the counter will count down. (The counter will not count below zero.) If the count reaches 50 (100 in the IC/4 PLUS), a crystal fail will be initiated. In this manner only sustained erratic rate readings will trigger a Crystal Fail and instantaneous noise will be ignored.

In the IC/4 PLUS, if Auto Z is in use, the crystal quality will trigger an "Auto Z" failure instead of a crystal fail. This will change the instrument from dual frequency measurement mode to single frequency measurement mode. For some materials it is possible to regain rate stability by this change. Once the switch to single frequency has occurred and a waiting period has elapsed (4 times the Primary Time Constant plus the System Dead Time plus10 seconds), the counter will again trace the rate deviation. If the counter reaches 100 a second time, a Crystal Fail will be triggered.

CRYSTAL STABILITY 0 to 9

The Crystal Stability parameter can also be used to affect a crystal fail. In normal operation when mass is added to a crystal its frequency of oscillation will decrease. There are, however, a number of reasons; such as thermal shock, high stresses in the film, electrical arcing from an electron beam gun, or frequency instabilities, which may cause a positive frequency shift between successive measurements. The Crystal Stability function is used to monitor these positive frequency excursions. Values range from 0 to 9. The default value is 0 which disables the function. Values 1 through 9 correspond to the maximum positive frequency accumulation permitted.

Crystal Stability	Positive Frequency Accumulation (Hz)
9	25
8	100 (max single shift of 50)
7	100
6	200 (max single shift of 100)
5	200
4	400
3	500
2	1000
1	5000 (max single shift of 1250)
0	Disabled

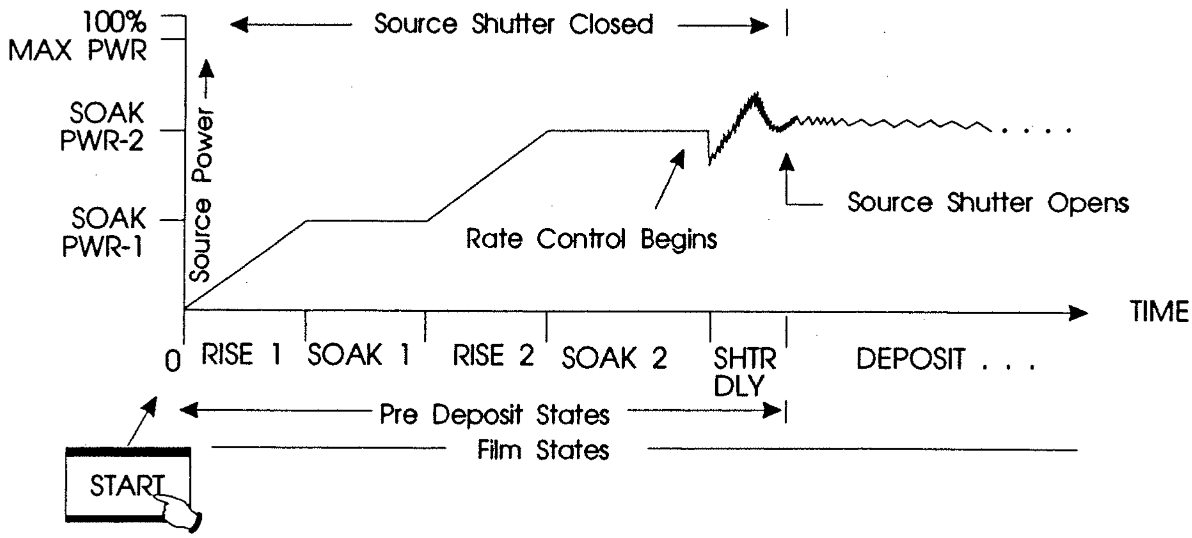
Each time there is a positive shift in frequency, the magnitude of the positive frequency excursion is accumulated. If the cumulative total, or the maximum single shift, exceeds the limit set by the Crystal Stability value a Crystal Fail function is triggered.

SENSOR 1,2,3,4 ❖

This parameter determines which sensor input is to be used for the material being defined. Values can range from 1 to 4. The standard configuration for an IC/4 includes two measurement channels - these are sensors 1 and 2. Optionally (❖), the unit will support two additional sensor channels - these are sensors 3 and 4. The default value is 1. This parameter cannot be changed while running a process.

MAXIMUM POWER 0 to 99%

This parameter is used to set the maximum permissible % power level. The control voltage output will not exceed this limit. Values range from 0 to 99%. The default value is 90%.



Power Ramps (Pre deposit states)

Two power ramps are provided to pre-condition materials. The first power ramp is skipped if the previous layer had the same source, same crucible and its idle power is non-zero.

SOAK POWER 1 0 to 99%

This parameter is used to set the power level (typically) at which the source material just begins to melt. The instrument ramps the power level from zero to Soak Power 1 linearly over the time period Rise Time 1. Values range from 0 to 99%. The default value is 0.

RISE TIME 1 00:00 to 99:59 min:sec

This parameter provides the time period over which the source power is ramped from 0 to Soak Power 1. Values range from 00:00 to 99:59 minutes:seconds. The default values is 00:00.

SOAK TIME 1 00:00 to 99:59 min:sec

This parameter provides the time period for which the instrument holds at Soak Power 1. Values range from 00:00 to 99:59 minutes. The default values is 00:00.

SOAK POWER 2 0 to 99%

This parameter sets the power level at which the rate from the source very nearly matches the desired deposition Rate. Values range from 0 to 99%. The default value is 0%.

RISE TIME 2 00:00 to 99:59 min:sec

This parameter sets the time period in which the instrument linearly ramps the power level from Soak Power 1 to Soak Power 2. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

SOAK TIME 2 00:00 to 99:59 min:sec

This parameter set the time period for which the instrument holds the power level at Soak Power 2. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

SHUTTER DELAY ON YES/NO

This parameter enables a shutter delay state immediately following Soak Power 2, and preceding Deposit. The source shutter relay remains in its normal state and the crystal shutter relay is active. The sensor, which must be positioned to sample the source flux with the source shutter closed, provides closed loop rate control. The rate control must be maintained at ± 5% of the desired deposition rate for 5 seconds before the instrument will enter Deposit, opening the source shutter and thus exposing the substrate to a well controlled rate of evaporant flux. If the required rate control accuracy cannot be achieved within 60 seconds the process will STOP. The default value is NO.

Feed Ramp State

A feed ramp is provided to maintain power levels during a wire feed. After reaching Final Thickness the instrument will enter the Feed Ramp phase for the specified time. Control voltage is ramped from the power level at the end of the deposit phase to the Feed Power level. Feed Power is held constant until the end of Feed Time. At the end of Feed Time, the instrument will proceed to the Idle ramp phase.

FEED POWER 0 to 99% ◆

This is one of three parameters used to affect a Feed Ramp. This value establishes the control voltage power level at which the source is maintained during wire feed. Values range from 0 to 99%. The default value is 0.

FEED RAMP TIME 00:00 to 99:59 min:sec ◆

This is the time interval for the source power to ramp linearly from the power level at the end of Deposit to Feed Power. The Feed Ramp relay is active during Feed Ramp Time. Values range from 00:00 to 99:59 minute:seconds. The default value is 00:00.

FEED TIME 00:00 to 99:59 min:sec ◆

This is the time interval for which the source power is maintained at Feed Power. The wire Feed relay is active during Feed Time. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

Idle Ramp State

An idle ramp is provided to maintain the control voltage power level after the Deposit or Feed phase. Control voltage is ramped from the power level at the end of the Deposit phase (or Feed Power, if one is set) to the Idle Power level. The control voltage is maintained at the Idle Power level until the instrument enters the STOP phase or until the next layer, using the specified source, is started.

IDLE POWER 0 to 99%

This is one of two parameters used to affect an Idle Power Ramp. This value is the power level at which the source is maintained after the Deposit phase (or after Feed phase if one is set up). Idle Power is usually the same as Soak Power 1. Values range from 0 to 99%. The default value is 0%.

IDLE RAMP TIME 00:00 to 99:59 min:sec

This is the time interval over which the source power is ramped linearly from the power level at the end of Deposit (or Feed Powerif one is set) to Idle Power. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

4.4 Error Messages in Material Set Up

Value Too Large
Value Too Small

The value that you are attempting to enter is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press Clear to delete the value and enter again.

Section 5
Process Set Up

Contents

5.1 Process Set Up Overview

The IC/4 is capable of storing the descriptions and parameters for up to four user defined processes. Processes are made of sequential layers of materials. The layers may be allocated to any process, but the total number that can be defined is limited to the maximum number of layers supported. The IC/4 supports up to 100 layers, while the IC/4 PLUS supports up to 250 layers.

Process layer definition includes the specification of a previously defined material (See Material Set Up), deposition rate, thickness and time limits and rate ramps. The optional co-deposition capability of the IC/4 PLUS allows establishing material ratio relationships.

Processes are defined by sequencing defined layers. Layers must be defined sequentially starting with Layer 1. Defined layers may be inserted or deleted by utilizing the LAYER EDITING feature.

Display Tree for Process Set Up

```
PROCESS (PROGRAM)
 └── PROCESS DIRECTORY
      └── LAYER DEFINITION
           └── LAYER EDITING
```

Process Set Up is initiated by selecting the PROCESS panel in the Program display. This will invoke the Process Directory (Figure 5.1). Upon entry to the Process Directory, the cursor will be placed at the last referenced process.

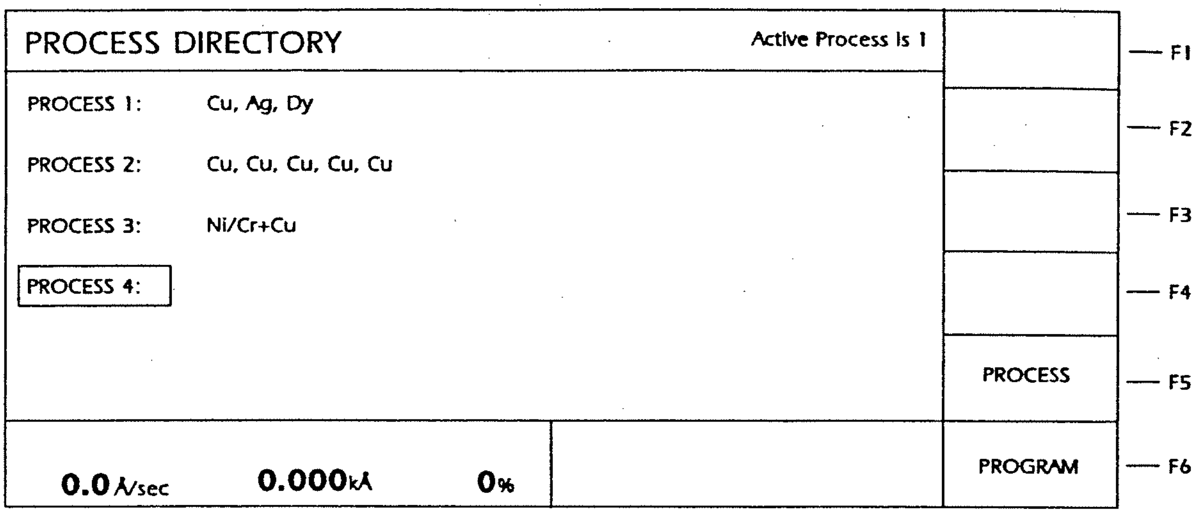


Figure 5.1 Process Directory

5.2 Layer Definition

Selecting the PROCESS panel in the Process Directory will take you to a display (Figure 5.2) that enables layer by layer specification. Four adjacent layers from left to right are visible at any time on a display page. The parameters for each layer can extend ahead to a second page if the unit is at the advanced user level (◆). Optional features (❖) may also affect the contents of a display.

> ***CAUTION:*** *PRIVILEGED OPERATION. You may be denied the ability to edit process or layer definitions if access has been locked.*

You move among and through the layers by using the cursor and panel keys. Parameters are entered with the numeric keypad.

PANEL SELECTION CHOICES FOR PROCESS LAYER DEFINITION

F1	**PAGE FORWARD**	Select this panel to access the second page of Layer Parameters.
F2	**PAGE BACK**	Select this panel to return to the first page of Layer Parameters.
F3	**PAGE RIGHT**	Select this panel to advance beyond the currently defined four layers.
F4	**PAGE LEFT**	Select this panel to view previously defined layers.
F5	**LAYER EDITING**	Select this panel to add or delete layers.
F6	**PROCESS DIRECTORY**	Select this panel to return to the Process Directory.

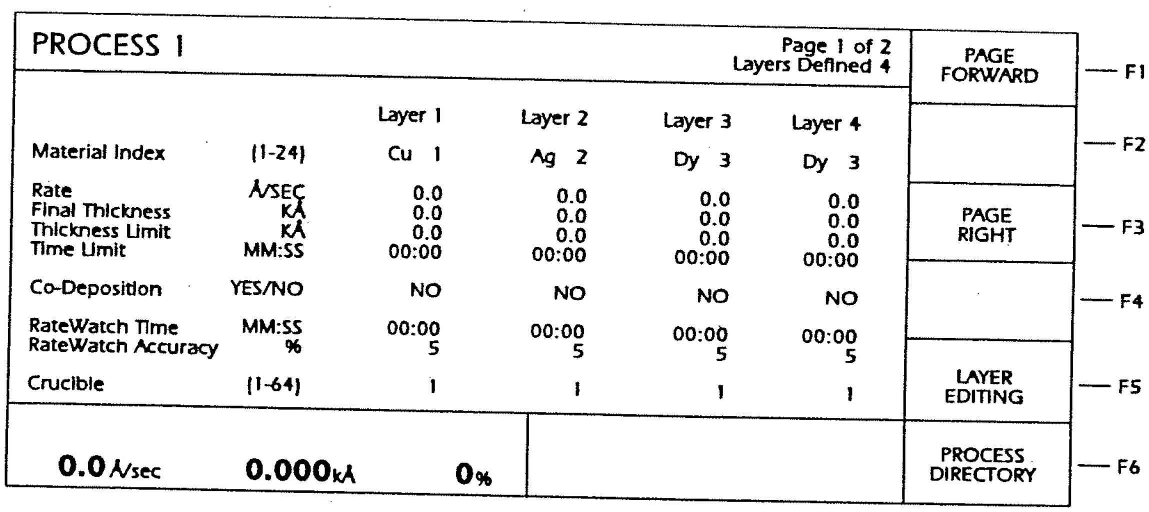


Figure 5.2 Layer Definitions

5.3 Layer Editing

Layers may be deleted from or inserted into the defined layer sequence by selecting the LAYER EDITING panel in the Process display.

F1 **INSERT**

To insert a default layer, position the box cursor to the desired position among the defined layers and select the INSERT panel. A default layer will be inserted at that position. If layers are defined to the right of that position, they will be incremented to the next layer. A default layer has default values for parameters and is assigned Material Number 1.

F2 **DELETE**

To delete a layer, move the box cursor to the desired position and select the DELETE panel. If layers are defined to the right of that position, they will be decremented in layer number.

5.4 Layer Definition Parameters

MATERIAL INDEX 1 to 12 (24 for the IC/4 PLUS)

This indicates which of the predefined materials is to be run with the Layer being defined. Values range from 1 to 12 (24 for the IC/4 PLUS). The default value is 1. This value cannot be changed while running a process. It is not permitted to enter a value corresponding to an undefined material.

RATE 0.00 to 999.9 Å/sec

This specifies the rate at which the deposition is to be controlled during the Deposit and Shutter Delay states. Values range from 0.0 to 999 Å/sec. The default value is 0.0 Å/sec.

FINAL THICKNESS 0.0 to 999.9 kÅ

This is the thickness setting which triggers the end of the Deposit state. The source shutter and crystal shutter relays return to their normal state and the Layer enters the Idle Ramp Time or the Feed Ramp Time states. Values range from 0.0 to 999.9 kÅ. The default value is 0.0 kÅ. Final thickness is not allowed to be less than the thickness limit.

THICKNESS LIMIT 0.0 to 999.9 kÅ

This sets the thickness at which the Thickness Limit relay is triggered. This thickness is accumulated after entering the Deposit state. The relay remains active after reaching Thickness Limit until the beginning of the IDLE state. Values range from 0.0 to 999.9 kÅ. The default value is 0.0 kÅ. See Thickness Limit in Output Relay Set Up. Thickness limit is not allowed to be greater than final thickness.

TIME LIMIT 00:00 to 99:59 min:sec

This is the deposition time at which the Time Limit Relay is triggered. This time begins to accumulate at the start of the Deposit state. The Time Limit Relay, once triggered, remains active until the start of the IDLE state. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00. See Time Limit in Output Relay Set Up.

CO-DEPOSITION (IC/4 PLUS only) Yes/No ◆ ❖

This feature allows two Layers to be run concurrently with the pertinent sources controlled independently. The Layers to be co- deposited must be sequential in the Process. The default value is NO. This parameter cannot be changed while running a Process.

When the first Layer reaches Final Thickness prior to the second Layer, the second Layer will terminate at the first Layer's Final Thickness. When the second Layer reaches Final Thickness prior to the first Layer, the first Layer will continue in DEPOSIT until reaching its own Final Thickness.

NOTE: two measurement boards are required for co-deposition. Co-deposition using sensors 1 and 2 or sensors 3 and 4 is not permitted.

RATIO CONTROL (IC/4 PLUS Only) 0.0 to 999.9% ◆❖

This parameter is used with the co-deposition feature. It establishes a Master/Slave relationship between the two sources being co-deposited. The first Layer is always the Master, with the second Layer's rate being controlled to a percentage of the first Layer's rate. Allowable values range from 0.0 to 999.9%. The default is 0.0 which disables the function.

CROSS SENSITIVITY (IC/4 PLUS Only) 0.0 to 99.9% ◆❖

This parameter provides a value used in an algorithm which compensates for cross interference during co-deposition. Mass accumulation onto the sensor for source A, due to evaporant from source B, can be subtracted from the mass accumulation onto sensor A due to sources A and B. The correction is expressed as a percentage of the rate at sensor A over the rate at sensor B due only to source B. A similar correction can be made for interference from source A onto sensor B. When calculating cross sensitivity, the density and Z-ratio should be the same for each material. Refer to Section 11.5 for a procedure on how to determine cross sensitivity correction values.

The correction is calculated according to the equation (while depositing from source B only):

$$\frac{\text{THICKNESS AT SENSOR A}}{\text{THICKNESS AT SENSOR B}} \times 100\% = \text{VALUE}$$

This would be the value to enter into the Cross Sensitivity parameter for the Layer controlling Source A.

Values range from 0.0 to 99.9%. The default value is 0.0%.

RateWatcher™ Sample and Hold Feature ◆

Two parameters, Ratewatch Time and Ratewatch Accuracy, enable the sample and hold feature. When enabled, the deposition rate is periodically sampled by automatically opening the sensor shutter and exposing the sensor to the deposition source. The power is adjusted so the actual rate is set to the desired rate. The sensor shutter is then automatically closed and power is held at the adjusted level. A five second time delay for stabilization occurs between opening the shutter and taking measurements.

RATEWATCH TIME 00:00 to 99:59 min:sec ◆

The value entered for Ratewatch Time determines the time interval between sample periods. The crystal shutter relay is in its normal state during this time. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00, which disables the function.

During a Rate Ramp, the sample and hold feature is inactive, the crystal shutter is open and the rate is controlled by the crystal.

RATEWATCH ACCURACY 1 to 99.9% ◆

During the rate sampling period, the true deposition rate is measured by the crystal and source power control is active. When the rate is within the desired accuracy continuously for five seconds, the shutter is closed and the deposition returns to HOLD. Values range from 1 to 99.9%. The default value is 5%.

CRUCIBLE 1 to 64 (max) ◆

This value is used in conjunction with the Number of Crucibles selected in Source Set Up. The integer value entered here sets the state of the Crucible relays. Values range from 1 to the number of Crucibles chosen, up to a maximum of 64. The default value is 1. This parameter is set to 1 if the Crucible function is not chosen in configuring the Source/Sensors. Se Number of Crucibles in Source/Sensor Set Up.

Rate Ramp 1 ◆

Rate Ramp 1 is provided to affect a rate change while depositing a Layer. The rate is ramped linearly from the original rate setpoint to the New Rate 1 value over the time interval Ramp Time 1. It is allowed to ramp to a higher or a lower rate.

NEW RATE 1 0.0 to 999 Å/sec ◆

This value sets the newly desired rate. Values range from 0.0 to 999 Å/sec. The default value is 0.0.

START RAMP 1 0 to 999.9 kÅ ◆

This value sets the thickness at which to start the Rate Ramp. Values range from 0 to 999.9 kÅ. This thickness value must be less than or equal to the Start Ramp 2 thickness value if the value of Start Ramp 2 is non-zero. A value of zero disables the feature.

RAMP TIME 1 00:00 to 99:59 min:sec ◆

This value determines the time period over which to ramp the rate from the original rate to New Rate 1. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

Rate Ramp 2 ◆

Rate Ramp 2 is provided to affect a second change in rate during the deposition of a Layer. The rate is ramped linearly from New Rate 1 to New Rate 2 over the time interval Ramp Time 2. It is allowed to ramp to a higher or lower rate.

NEW RATE 2 0.0 to 999 Å/sec ◆

This value sets the newly desired rate. Values range from 0.0 to 999 Å/second. The default is 0.0.

START RAMP 2 0 to 999.9 kÅ ◆

This value determines the thickness at which to begin Rate Ramp 2. Values range from 0 to 999.9 kÅ. The default value is 0. A value of zero disables this feature. Start Ramp 2 thickness must be greater than Start Ramp 1 thickness. Also, Rate Ramp 2 can not be started until the completion of Rate Ramp 1. If the thickness of Start Ramp 2 is exceeded while in Rate Ramp 1, Rate Ramp 2 will begin immediately after Rate Ramp 1.

RAMP TIME 2 00:00 to 99:59 min:sec ◆

This value is the time interval over which the rate is ramped linearly from New Rate 1 to New Rate 2. Values range from 00:00 to 99:59 minutes:seconds. The default value is 00:00.

5.5 Error Messages in Process Set Up

Material Undefined

You have tried to specify a Material Index in Process definition that has not been previously defined. Refer to procedures in Material Set Up. Press the Clear key to resume.

Value Too Large
Value Too Small

The value you are attempting to enter is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press the Clear key to delete the value and enter again.

5.6 Special Layer Parameter Features

Skip Deposit

If the rate parameter is set to 0.0Å/s the instrument will skip the Deposit State. State processing will go directly to the first programmed post-Deposit state from the last pre-Deposit state. Also, if the rate parameter is set to zero during deposit the final thickness will be triggered.

Rate Ramp Trigger of Final Thickness

If either of the rate ramps are programmed for zero New Rate and a non-zero Start Ramp, the Final Thickness will be triggered upon completion of the Rate Ramp.

Section 6
Internal/External I/O Set Up

Contents

6.1 Internal / External I/O Overview

The IC/4 has programmable logic capabilities that allow it to specifically respond to various external stimuli (Inputs), to send control signals to external devices based on very specific instrument conditions (Outputs) and also to internally branch and control the execution of a process or series of processes without operator intervention (Internal logic). These capabilities are tailored by the user programming the Inputs, Output relays and Internal logic, respectively. These three features are interrelated and have a high level of commonality.

1. All are accessed for programming through the I/O branch of the menu tree.
2. Single or multiple actions may be triggered by events which may be an Input or the fulfillment of a user specified logical condition.
3. Single or multiple complex defined conditions are used to define an event.
4. The Logical operators; **AND**, **OR**, and **NOT** as well as grouping operators (parenthesis) are available to define very precise conditionality.
5. It is possible to execute an action immediately or delay it for a definable period of time through use of a delay timer.
6. Each input and every logical statement is evaluated every measurement cycle (100 ms for the IC/4 PLUS or 200 ms for the IC/4).
7. There are means of making each output or logical statement layer, process, or material exclusive or inclusive.
8. The components of the logical statements may be the transition between or entry of a specific state, specific programmable time limits, programmable thickness limits or various error conditions.

These features, combined with the layer based process sequencing, allow moderately complex vacuum processing plants to be controlled without the addition of any other intelligent machines. It is possible that a user may program certain layers within the process definition whose only purpose is to trigger certain other internal sequencing and/or external control events. There "dummy" layers execute very rapidly if the pre and post deposit state times and the final thickness are all set to zero.

Eight inputs and eight outputs are standard, with an additional eight of each optional. (16 inputs and 16 outputs are standard on the IC/4 PLUS). Refer to Section 10.3.3.2 for pin-out and connection information.

The IC/4 has the capacity for 8 internal logic statements, while the IC/4 PLUS's capacity is 16.

> ***CAUTION:*** *Privileged Operation. You may be denied passage to Input Line, Output Relay, or Internal Logic editing if access has been locked.*

6.2 Editing the Inputs

Input actions will take place, in the order defined, in response to a low voltage signal received over the input interface. Actions are assigned to input lines by selecting or "tagging" the desired items in EDIT INPUT.

Display Tree for Input Line Set Up

```
I/O (PROGRAM)
└── INPUT DIRECTORY ←┐
      └── EDIT INPUT │
            └── SAVE ┘
```

Input Line Set Up is initiated by selecting the I/O panel (F3) in the Program display and then selecting the Input Directory panel (F1). This invokes the Input Directory (Figure 6.1). Upon entry the cursor is placed at the last referenced input line. Eight input lines are shown on each display page.

INPUT DIRECTORY		Page 1 of 2		
1. SELECT PROC 1	and START		PAGE FORWARD	F1
2. SELECT PROC 1				F2
3. SELECT PROC 2				F3
4. SELECT PROC 3				F4
5. SELECT PROC 4				
6. ZERO THICKNESS				
7. STOP	and TRIG FNL THICK			
[8.] SWITCH XTAL			EDIT INPUT	F5
0.0 Å/sec	0.000 kÅ	0%	I/O	F6

Figure 6.1 Input Directory

6.2.1 Input Line Directory

An input line is selected for editing by positioning the box cursor at the desired line number. Then, by selecting the EDIT INPUT panel (F5), an edit mode will be entered where actions can be chosen or cleared.

PANEL SELECTION CHOICES FOR THE INPUT DIRECTORY

F1	**PAGE FORWARD**	Select this panel to access the second page - lines 9 through 16.
F2	**PAGE BACK**	Select this panel to return to the first page - lines 1 through 8.
F5	**EDIT INPUT**	Select this panel to select or change action assignments.
F6	**I/O**	Select this panel to return to the I/O display.

6.2.2 Input Line Editing

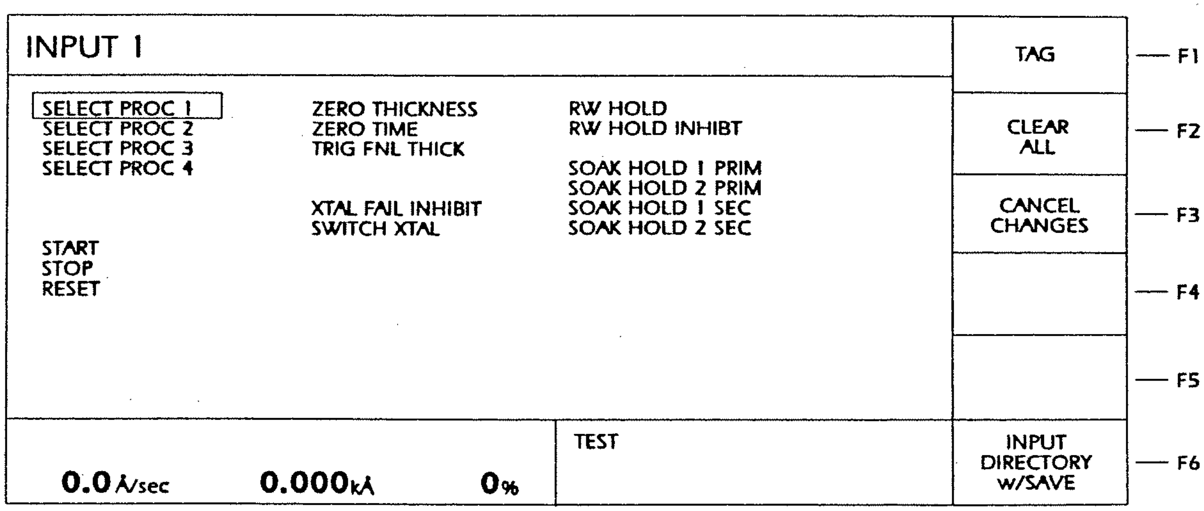


Figure 6.2 Line Action Editing

PANEL SELECTION CHOICES FOR INPUT LINE EDITING

F1	**TAG**	Press this panel to select or "tag" actions for assignment to a specific input line. The box cursor should be at the desired action. Up to five actions may be selected for each input line. If you select more than one action they will be joined by a logical "and". The action string is shown in the upper part of the display along with the input line number being edited.
F2	**CLEAR ALL**	Select this panel to clear all assigned actions for a particular input line.
F3	**CANCEL CHANGES**	Select this panel to clear any actions assigned since entry into EDIT INPUT.
F6	**INPUT DIRECTORY W/SAVE**	Select this panel to return to the Input Directory and save the actions assigned for particular input line.

6.3 Editing the Outputs

These events can cause a designated relay to be activated when all the pre-defined conditions are met. When the string is determined to be true, the associated relay is activated. When a relay is activated it transitions to its "abnormal" state. For example, when a normally closed relay is activated its contact is open.

Additionally, a time delay from 0.0 to 99.9 seconds can be established before the relay is activated. The hardware Output Relays are capable of high voltage (240V) switching.

Events are assigned to output relays by selecting or "tagging" the desired items in EDIT OUTPUT. The defined events may then be saved or refined further.

Display Tree for Output Relay Set Up

```
I/O (PROGRAM)
 └── OUTPUT DIRECTORY <──┐
      └── EDIT OUTPUT    │
           ├── SAVE ─────┘
           └── STRING EDIT
                ├── NEGATIONS
                ├── NUMERICS
                ├── CONNECTORS
                ├── PARENTHESES
                └── RELAY TYPES
```

Output Relay Set Up is initiated by selecting the I/O panel. (F3) in the Program display and then selecting the Output Directory panel (F2). This invokes the Output Directory (Figure 6.3). Upon entry the cursor is placed at the last referenced output relay. Eight Output Relay lines are shown on each display page.

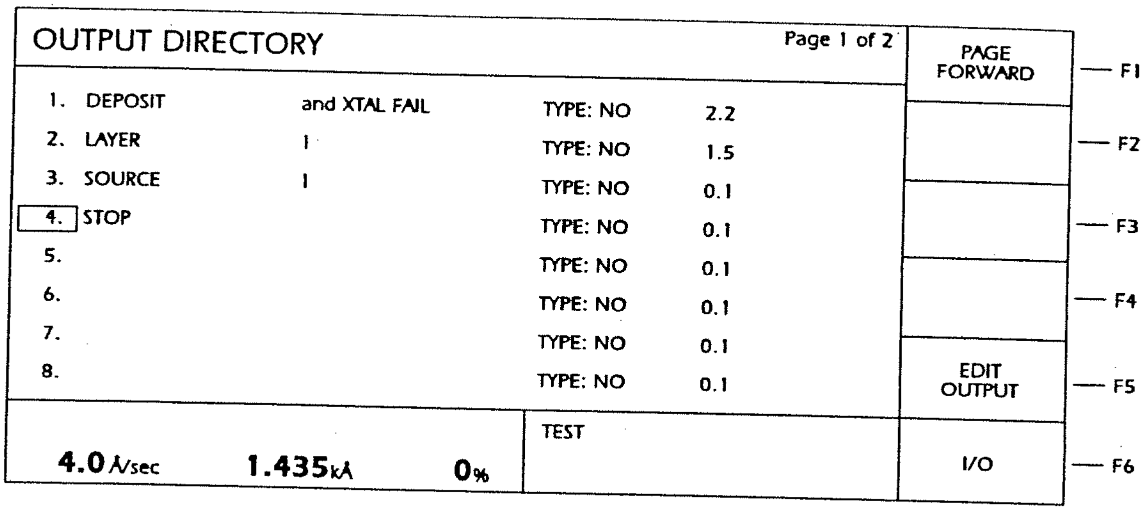


Figure 6.3 Output Directory

6.3.1 Output Relay Directory

NOTE: Certain output functions (e.g., Source Shutter, Sensor Shutter, etc.) are directly related to source or sensor hardware configuration. These outputs are set up in the Source/Sensor configuration displays (see Section 8). If these outputs have been set up, they will be displayed in the Output Directory, however, they may not be modified from this directory.

An output relay is selected for editing by positioning the box cursor at the desired relay number. Then, by selecting the EDIT OUTPUT panel (F5), an edit mode will be entered where events can be chosen or cleared.

PANEL SELECTION CHOICES FOR THE OUTPUT DIRECTORY

F1	**PAGE FORWARD**	Select this panel to access the second page-relays 9 through 16.
F2	**PAGE BACK**	Select this panel to return to the first page-relays 1 through 8.
F5	**EDIT OUTPUT**	Select this panel to select, change or refine event definitions.
F6	**I/O**	Select this panel to return to the I/O display.

6.3.2 Output Relay Editing

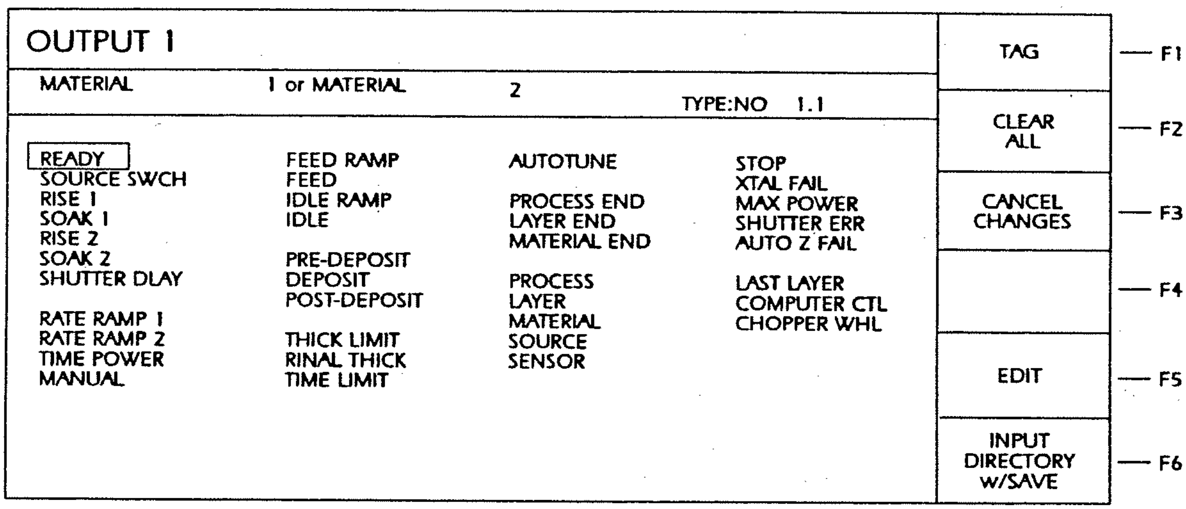


Figure 6.4 Relay Event Selection

PANEL SELECTION CHOICES FOR RELAY EVENT ASSIGNMENT

F1 **TAG**	Press this panel to select or "tag" events for assignment to a specific relay. The box cursor should be at the desired event. Up to five events may be selected for each relay. If you select more than one event, you will later have to determine how the events will be logically joined. The event for a relay line is shown in the upper part of the display. The string "ccc" is used to indicate an undefined logical connector (AND or OR). The string "###" is used to indicate an undefined numeric value, such as Layer or Process number, which must be provided.
F2 **CLEAR ALL**	Select this panel to clear all assigned events for a particular relay.
F3 **CANCEL CHANGES**	Select this panel to clear any actions assigned since entry into EDIT OUTPUT.
F5 **EDIT**	Select this panel to perform event string refinement. Depending on your event selections, another level of editing may be necessary. The next series of displays provide editing capability for negation, numeric assignment, logical connectors, parentheses, and relay type.
F6 **OUTPUT DIRECTORY W/SAVE**	Select this panel to return to the Output Directory and save the assigned events for a particular relay.

6.3.3 Refining the Relay Event String

Another level of string editing may be necessary due to the events chosen. The chosen events may require refinement to achieve the desired evaluation.

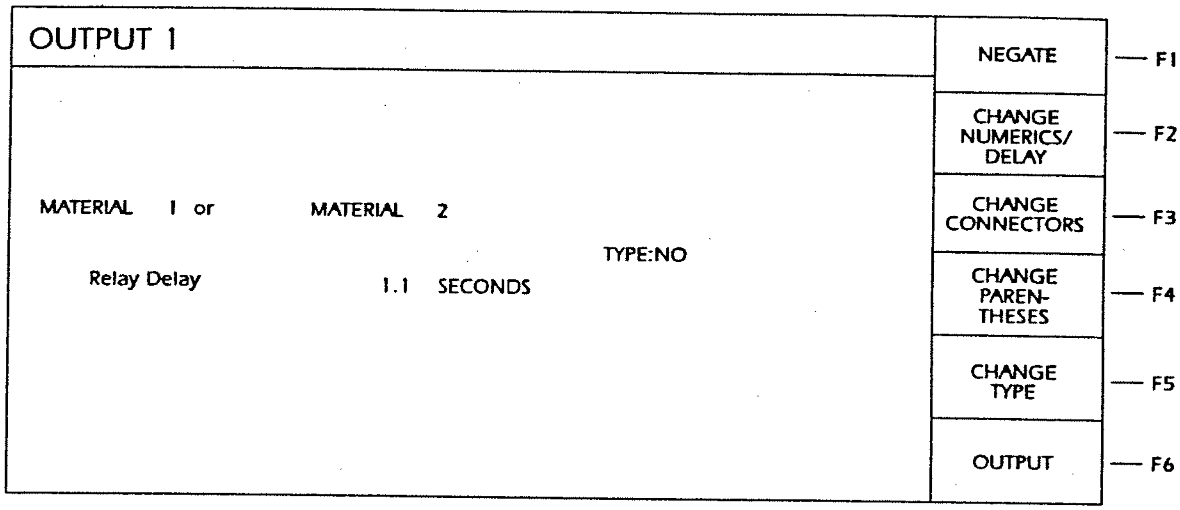


Figure 6.5 Relay Event Editing

NOTE: Relay Delay Timers continue to count down, and relays will be triggered, even when the instrument is in the STOP state. This will happen only if the logic statement becomes true, and hence the timer started, prior to the instrument being placed into the STOP state.

PANEL SELECTION CHOICES FOR RELAY STRING EDITING

F1 NEGATE

Select this panel to enter the NEGATE display. To negate an event, place the box cursor over the event string and select the NEGATE (F1) panel. The logical evaluation of the event is considered "true" when this event is not active. A negated event is signified by a solid line above the event name. To undo a negate, negate the event a second time. You can exit the NEGATE display and continue string refinement by selecting the OUTPUT (F6) panel.

F2 CHANGE NUMERICS

Select this panel to enter the CHANGE NUMERICS display. The delay time can be modified and certain events that require further numeric information such as a layer or process number can be completed. Delays can be set between 0.0 and 99.9 seconds. Place the box cursor over the "###" string or current value and enter the new value. You can exit the CHANGE NUMERICS display and continue string refinement by selecting the OUTPUT (F6) panel.

F3 CHANGE CONNECTORS

Select this panel to enter the CHANGE CONNECTORS display. When two or more events are selected they have to be logically connected by an "AND" or an "OR". Initially this is undefined and indicated by "ccc". Place the box cursor over the current connector and then select panel INSERT AND (F1) or INSERT OR (F2). You can exit the CHANGE CONNECTORS display and continue string refinement by selecting the OUTPUT (F6) panel.

F4 CHANGE PARENTHESES

Select this panel to enter the CHANGE PARENTHESES display. When three or more events are selected they may be placed in logical groups delimited by parentheses. The contents of the groups are evaluated and their "truth" value issued as part of the string evaluation. Parentheses must be balanced; there must be an equal amount of left and right parentheses. Groups may not be nested. Parentheses are entered by moving the box cursor in a left to right direction and selecting the INSERT PARENTHESES (F1) panel.

All parentheses may be removed by selecting the DELETE ALL PARENTHESES (F2) panel. You can exit the CHANGE PARENTHESES display by selecting the OUTPUT (F6) panel.

F5 CHANGE TYPE

Select this panel to enter the CHANGE TYPE display. Relay types are set by default to Normally Open. Select panel NC (F2) to change the type to Normally Closed. Select panel PO (F3) to change the type to Pulsed Open. Select panel PC (F4) to change the type to Pulsed Closed. You can exit the CHANGE TYPE display and continue string refinement by selecting the OUTPUT (F6) panel.

F6 EDIT OUTPUT

Select this panel to return to the EDIT OUTPUT display for event selection or editing.

6.4 Editing the Internal Logic Statements

A series of conditional events and a related series of actions may be defined through the Internal Logic Statements. When the event string is determined to be true the associated actions are executed in left to right order. Additionally a time delay from 0.0 to 99.9 seconds may be established between the time the event string becomes true and when the action string is initiated. The expressions are evaluated in numerical sequence starting with logic statement 1.

Display Tree for Internal Logic Set Up

```
I/O (PROGRAM)
  └── INTERNAL LOGIC DIRECTORY <──┐
        └── EDIT INTERNAL LOGIC   │
              └── SAVE ───────────┘
              └── STRING EDIT
                    ├── NEGATIONS
                    ├── NUMERICS
                    ├── CONNECTORS
                    └── PARENTHESIS
```

Internal Logic Set Up is initiated by selecting the I/O panel (F3) in the Program display and then selecting the Internal Logic Directory panel (F3). This will invoke the Internal Logic Directory (Figure 6.6). Upon entry, the cursor will be placed at the last referenced logical statement. Entries for four statements are shown on each display page.

6.4.1 Internal Logic Directory

An internal logic statement is selected for editing by positioning the box cursor at the desired statement number. Then, by selecting the EDIT INTERNAL LOGIC panel (F5), an edit mode will be entered where events and actions can be chosen or cleared.

PANEL SELECTION CHOICES FOR THE INTERNAL LOGIC DIRECTORY

F1	**PAGE FORWARD**	Select this panel to access the next page of statements.
F2	**PAGE BACK**	Select this panel to return to the previous page of statements.
F5	**EDIT INTERNAL LOGIC**	Select this panel to select or change event or action definitions.
F6	**I/O**	Select this panel to return to the I/O display.

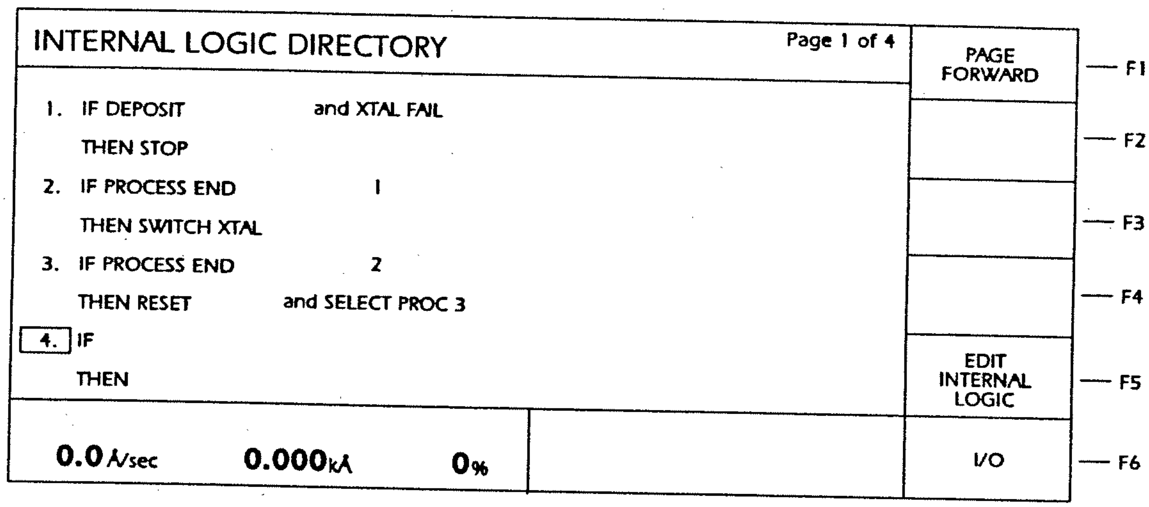


Figure 6.6 Internal Logic Directory

6.4.2 Internal Logic Editing

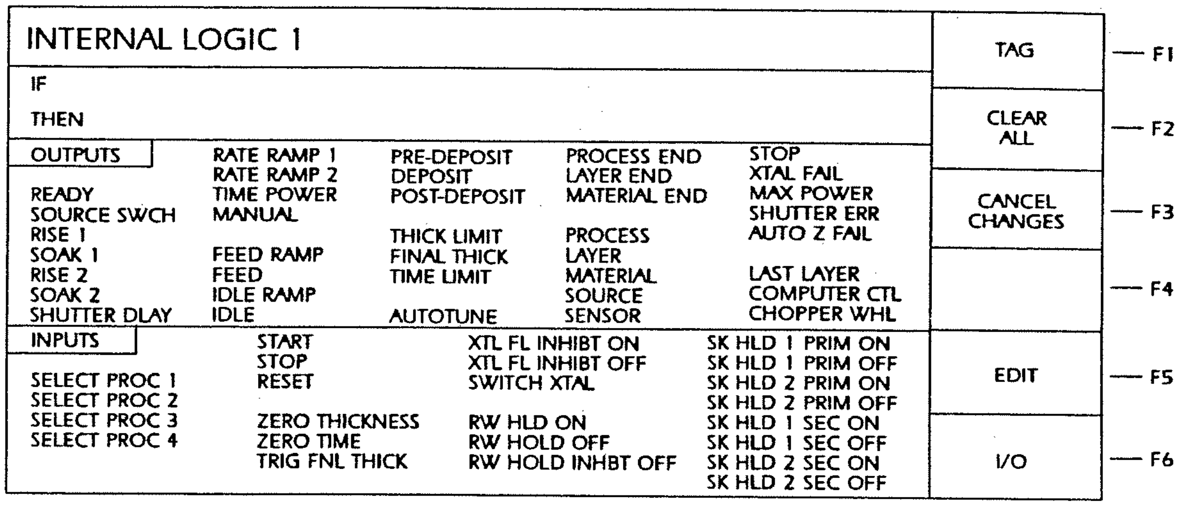


Figure 6.7 Logical Event and Action Selection

PANEL SELECTION CHOICES FOR INTERNAL LOGIC EDITING

F1 TAG

Press this panel to select events or actions for assignment to a specific logical statement. Events (outputs) and actions (inputs) are divided on the display with events on the top and actions on the bottom. The box cursor should be at the desired event or action. Up to five events or actions may be selected for each statement. If you select more than one event, you will later have to determine how the events will be logically joined. Multiple actions are always joined with an "and". The events selected are shown in the upper part of the display after the IF; the actions are shown after the THEN. The string "ccc" is used to indicate an undefined logical connector. The string "###" is used to indicate an undefined numeric value.

F2 CLEAR ALL

Select this panel to clear all assigned events and actions for a particular statement.

F3 **CANCEL CHANGES**

Select this panel to clear any events and actions assigned since entry into EDIT INTERNAL LOGIC.

F5 **EDIT**

Select this panel to refine the conditional string. Depending on your selections, another level of editing may be necessary. The next series of displays provide editing capability for negation, numeric assignment, logical connectors and parentheses.

F6 **INTERNAL LOGIC DIRECTORY w/save**

Select this panel to return to the Internal Logic Directory and save the events and actions for a particular logic statement.

6.4.3 Refining the Logical String

Another level of event string editing may be necessary due to the events chosen. The string may require tailoring or refinement to achieve the desired evaluation needed for activation.

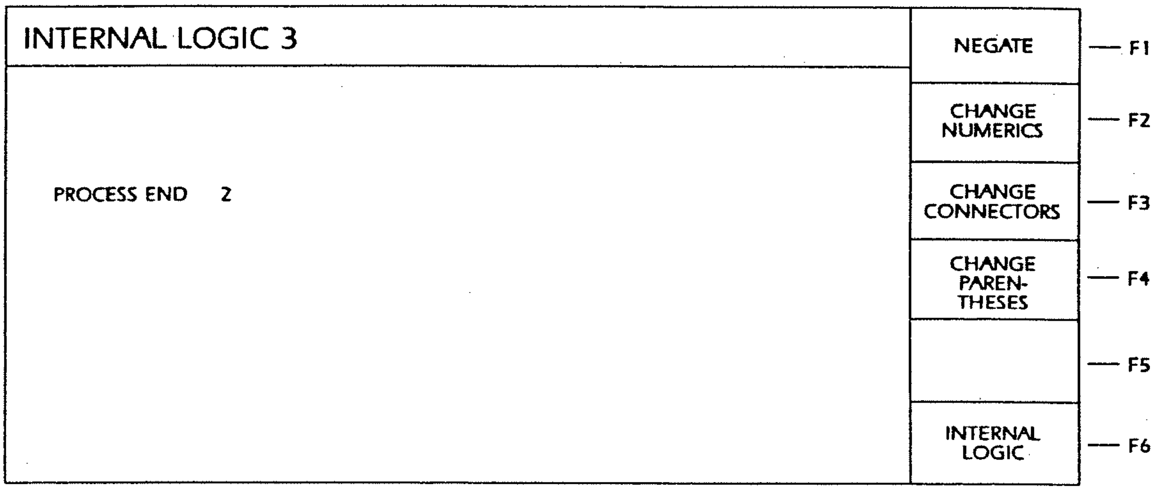


Figure 6.8 Internal Logic Editing

NOTE: Delay timers continue to count down and actions will be triggered even when the instrument is in the STOP state. This will happen only if the logic statement becomes true, and hence the timer started, prior to the instrument being put into the STOP state.

PANEL SELECTION CHOICES FOR LOGICAL STRING EDITING

F1 **NEGATE**

Select this panel to enter the NEGATE display. To negate an event, place the box cursor over the event string and select the NEGATE (F1) panel. The logical evaluation of the event is considered "true" when this event is not active. A negated event is signified by a solid line above the event name. To undo a negate, negate the event a second time. You can exit the NEGATE display and continue string refinement by selecting the INTERNAL LOGIC (F6) panel.

F2 CHANGE NUMERICS

Select this panel to enter the CHANGE NUMERICS display. The delay time can be modified and certain events that require further numeric information such as a layer or process number can be completed. Delays can be set between 0.0 and 99.9 seconds. Place the box cursor over the "###" string or current value and enter the new value. You can exit the CHANGE NUMERICS display and continue string refinement by selecting the INTERNAL LOGIC (F6) panel.

F3 CHANGE CONNECTORS

Select this panel to enter the CHANGE CONNECTORS display. When two or more events are selected they have to be logically connected by an "AND" or an "OR". Initially this is undefined and indicated by "ccc". Place the box cursor over the current connector and then select the panel INSERT AND (F1) or INSERT OR (F2). You can exit the CHANGE CONNECTORS display and continue string refinement by selecting the INTERNAL LOGIC (F6) panel.

F4 CHANGE PARENTHESES

Select this panel to enter the CHANGE PARENTHESES display. When three or more events are selected they may be placed in logical groups delimited by parentheses. The contents of the groups are evaluated and their "truth" value issued as part of the string evaluation. Parentheses must be balanced; there must be an equal amount of left and right parentheses. Groups may not be nested. Parentheses are entered by moving the box cursor in a left to right direction and selecting the INSERT PARENTHESES (F1) panel. All parentheses may be removed by selecting the DELETE ALL PARENTHESES (F2) panel. You can exit the CHANGE PARENTHESES display by selecting the INTERNAL LOGIC (F6) panel.

F6 INTERNAL LOGIC

Select this panel to return to the EDIT INTERNAL LOGIC display for event and action selection or editing.

6.5 Action (Input) Definitions

All hardware line inputs are activated be setting the input high. Hardware input functions which are not leading edge detected, (i.e., CRYSTAL FAIL INHIBIT, RW HOLD, RW HOLD INHIBIT, SOAK HOLD 1 PRIM, SOAK HOLD 2 PRIM, SOAK HOLD 1 SEC, SOAK HOLD 2 SEC, and NON-DEPOSIT CLOCK HOLD) are deactivated by setting the input low.

NOTE: CRYSTAL FAIL INHIBIT (ON/OFF)
RW HOLD (ON/OFF)
RW HOLD INHIBIT (ON/OFF)
SOAK HOLD 1 PRIM (ON/OFF)
SOAK HOLD 2 PRIM (ON/OFF)
SOAK HOLD 1 SEC (ON/OFF)
SOAK HOLD 2 SEC (ON/OFF)
NON-DEPOSIT CLOCK HOLD (ON/OFF)

The above are all level inputs and once turned on will remain active until turned off. This is true even if the Input line or Internal Logic string is cleared.

SELECT PROCESS 1

This action selects Process 1 to be the Active Process. If the instrument is already executing a Process when this input is activated, the input is ignored.

SELECT PROCESS 2

This action selects Process 2 to be the Active Process. If the instrument is already executing a Process when this input is activated, the input is ignored.

SELECT PROCESS 3

This action selects Process 3 to be the Active Process. If the instrument is already executing a Process when this input is activated, the input is ignored.

SELECT PROCESS 4

This action selects Process 4 to be the Active Process. If the instrument is already executing a Process when this input is activated, the input is ignored.

START

This action is identical to pressing the START button on the front panel. (See Section 3.4.2).

STOP

This action is identical to pressing the STOP button on the front panel. (See Section 3.4.2).

RESET

This action is identical to pressing the RESET button on the front panel. (See Section 3.4.2).

ZERO THICKNESS

This action is identical to selecting the ZERO THICKNESS panel in the OPERATE display. The action will zero the thickness accumulated on the display for the Layer being deposited. On the IC/4 PLUS, if two layers are depositing simultaneously, the thickness will be zeroed on both layers.

ZERO TIME

This action will zero the Layer run time for the Layer being deposited. On the IC/4 PLUS, if two layers are depositing simultaneously, the time will zero for both layers. If an output is triggered on a Time Limit, the output will remain triggered even after resetting the Layer Time.

TRIGGER FINAL THICKNESS

This action triggers Final Thickness and the Layer proceeds to the Feed Ramp or Idle Ramp state. This input is ignored if not in the Deposit state.

CRYSTAL FAIL INHIBIT (ON/OFF)

This action prohibits the Crystal Fail output relay. This is useful when changing crystals.

SWITCH CRYSTAL

This action activates the Crystal Switch output. It sets the alternate crystal active when using a Dual sensor head. It indexes to the next crystal position when using the Crystal Six sensor. This function is available only if a Dual or Crystal Six sensor type is chosen in Source/Sensor Set Up. On the IC/4 PLUS, if two layers are active, the crystal switch input will correspond to the layer currently selected for key activity on the OPERATE screen.

RW HOLD (ON/OFF)

When active (ON), this input action will place the Deposit state into the Hold portion of the Ratewatcher feature. The Sample portion of Ratewatcher will not be entered until the input action is deactivated.

RW HOLD INHIBIT (ON/OFF)

When active (ON) this will immediately cause the Deposit state to leave HOLD and not return until deactivated. If both RW HOLD and RW HOLD INHIBIT are active, RW HOLD INHIBIT takes priority.

SOAK HOLD 1 PRIM (ON/OFF)

If active (ON), the Primary Layer (the first layer started) will pause execution and maintain Soak Power 1 until the input action is deactivated.

SOAK HOLD 2 PRIM (ON/OFF)

If active (ON), the Primary Layer (the first layer started) will pause execution and maintain Soak Power 2 until the input action is deactivated.

SOAK HOLD 1 SEC (ON/OFF)

If active (ON), the Secondary Layer (the second layer started) will pause execution and maintain Soak Power 1 until the input action is deactivated. This input is ignored if you are not executing two layers concurrently.

SOAK HOLD 2 SEC (ON/OFF)

If active (ON), the Secondary Layer (the second layer started) will pause execution and maintain Soak Power 2 until the input action is deactivated. This input is ignored if you are not executing two layers concurrently.

NON-DEPOSIT CLOCK HOLD (Hardware line input function only)

This feature "holds" the state timer during any non-deposit state. Non-deposit states include the pre-deposit states; Ready, Source Switch, Rise 1, Soak 1, Rise 2, Soak 2, and the post-deposit states; Feed Ramp, Feed Time, Idle Ramp and Idle Time. For the feature to be activated the state's time must be non zero. The message NON-DEPOSIT HOLD is displayed in the right hand corner of the CRT and is shown in inverse video.

If the instrument is in the IDLE state and a START command is executed while NON-DEPOSIT HOLD is active, the instrument will progress to the first pre-deposit state with a non zero state time. If the instrument is in the Source Switch state, waiting for the Turret Feedback Input, and NON-DEPOSIT HOLD is activated, when the Turret Positioned input is activated, the instrument will progress to the next pre-deposit state having a non zero state time.

This action is invoked by activating a hardware input line programmed for NON-DEPOSIT HOLD. The instrument is prevented from continuing state processing until the input is deactivated.

6.6 Event (Output) Definitions

NOTE: If two layers are active simultaneously, an event condition is considered TRUE if it is true for one or both of the two layers (e.g. if the first layer is in DEPOSIT and the second layer is in PRE-DEPOSIT, both the DEPOSIT and the PRE-DEPOSIT events would be TRUE).

READY

Sets the logic condition to be true as long as the instrument is in the READY state. The condition remains true until a START command is received.

SOURCE SWITCH

Sets the logic condition to be true at the beginning of the Source Switch state. The condition remains true until the end of the Source Switch state. The condition is also cleared when a STOP/RESET or a STOP/START sequence is executed.

RISE TIME 1

Sets the logic condition to be true at the start of Rise Time 1. The condition remains true until the end of the Rise Time 1. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

SOAK TIME 1

Sets the logic condition to be true at the start of Soak Time 1. The condition remains true until the end of Soak Time 1. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

RISE TIME 2

Sets the logic condition to be true at the start of Rise Time 2. The condition remains true until the end of Rise Time 2. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

SOAK TIME 2

Sets the logic condition to be true at the start of Soak Time 2. The condition remains true until the end of Soak Time 2. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

SHUTTER DELAY

Sets the logic condition to be true at the start of Shutter Delay. The condition remains true until the end of Shutter Delay. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

RATE RAMP 1

Sets the logic condition to be true at the beginning of Rate Ramp 1. The condition remains true until the end of Rate Ramp 1. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

RATE RAMP 2

Sets the logic condition to be true at the beginning of Rate Ramp 2. The condition remains true until the end of Rate Ramp 2. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

TIME POWER

Sets the logic condition to be true upon entering a Time Power state. The condition remains true until a START or RESET command is given after STOP.

MANUAL

Sets the logic condition to be true when the Manual state is entered. The condition remains true until leaving the Manual state, when a STOP/RESET or a STOP/START sequence is executed.

FEED RAMP TIME

Sets the logic condition to be true at the start of Feed Ramp. The condition remains true until the end of Feed Ramp. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

FEED TIME

Sets the logic condition to be true at the start of Feed Time. The condition remains true until the end of Feed Time. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

IDLE RAMP

Sets the logic condition to be true at the start of Idle Ramp. The condition remains true until the end of Idle Ramp. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

IDLE

Sets the logic condition to be true at the beginning of the Idle state. The condition remains true until the end of Idle. The condition is also cleared when entering the Manual mode, when a STOP/RESET or a STOP/START sequence is executed.

PRE-DEPOSIT

Sets the logic condition to be true at the beginning of the Ready, Source Switch, Shutter Delay, Rise 1, Rise 2, Soak 1, or Soak 2 states. The condition remains true until the Deposit or Manual states are entered.

DEPOSIT

Sets the logic condition to be true at the beginning of the Deposit state or in the Manual state. The condition remains true until the end of the DEPOSIT state. The condition remains true until the end of the DEPOSIT state, when a STOP/RESET or STOP/START sequence is executed.

POST-DEPOSIT

Sets the logic condition to be true at the beginning of Feed or beginning of Idle Ramp. The condition remains true until a START command is received or until a STOP/RESET sequence is executed.

THICK LIMIT

Sets the logic condition to be true once the Thickness Limit is achieved. The condition remains true until entering the IDLE state for that Layer or until a STOP/RESET sequence is executed.

FINAL THICK

Sets the logic condition to be true once the Final Thickness is achieved or when the Final Thickness Trigger action is activated. The condition remains true until the Layer which has achieved Final Thickness enters the IDLE state or until a STOP/RESET sequence is executed.

TIME LIMIT

Sets the logic condition to be true once the Time Limit is achieved. The condition remains true until the Layer which has achieved Time Limit enters the IDLE state or until a STOP/RESET sequence is executed.

PROCESS END #

Sets the logic condition to be true at the end of the specified process. The condition remains true until a START or a STOP/RESET command is received. Numeric inputs range from 0 to 4, with 1 through 4 indicating the respective Process and 0 indicating any Process.

LAYER END ###

Sets the logic condition to be true when the specified Layer enters the IDLE state. The condition remains true until a START or a STOP/RESET command is received. Numeric inputs range from 0 to the maximum defined layer number, with 0 indicating any Layer.

MATERIAL END

Sets the logic condition to be true when the Layer for the specified Material enters the IDLE state. The condition remains true until a START or a STOP/RESET command is received. Numeric inputs range from 0 to the maximum defined material number, with 0 indicating any material.

PROCESS

Sets the logic condition to be true when Process # is designated as the Active Process. The condition remains true until the Process number is changed. Numeric inputs range from 1 to 4, indicating the respective Process.

LAYER

Sets the logic condition to be true at the beginning of Layer ### (when Layer ### is in the READY state at the beginning of a Process or when STARTed during a Process). The condition remains true until the layer is no longer active. Numeric inputs range from 1 to the maximum defined layer number.

MATERIAL

Sets the logic condition to be true whenever a Layer containing Material ## is in the READY state at the beginning of a Process or when it is STARTed during a Process. The condition remains true until the material is no longer active and can stay true across layers. Numeric inputs range from 1 to the maximum defined material number.

SOURCE

Sets the logic condition to be true whenever a Layer containing Source # is in the READY state, or when it is STARTed. The condition remains true until a Layer containing a Material with a difference Source # is STARTed or placed in the READY state.

SENSOR

Sets the logic condition to be true whenever a Layer containing the Sensor # is in the READY state, or when it is STARTed. The condition remains true until a Layer containing a Material with a different Sensor # is STARTed or placed in the READY state, or until a Crystal Switch on a dual sensor head is done. Numeric inputs range from 1 through 4.

STOP

Sets the logic condition to be true as long as the instrument is in STOP. The condition remains true until a RESET or a START command is received.

XTAL FAIL

Sets the logic condition to be true as long as there is a Crystal Fail without having a Crystal Switch. The logic condition remains false if the XTAL FAIL INHIBIT input is active. The condition remains true until a working crystal is input to the appropriate sensor input.

MAX POWER

Sets the logic condition to be true as long as any source is outputting Maximum Power. The condition remains true until every source is outputting less than Maximum Power.

SHUTTER ERROR

Sets the logic condition to be true when a Shutter Delay Error condition occurs. The condition remains true until a START or a RESET command is received.

AUTO Z FAIL (IC/4 PLUS Only)

Sets the logic condition to be true whenever an Auto Z fail condition occurs. The condition remains true until the Auto Z Fail condition is cleared.

AUTOTUNE

Sets the logic condition to be true when Autotune is started. The condition remains true until Autotune is completed, exited, or until an Autotune Fail condition occurs.

LAST LAYER

Sets the logic condition to be true at the beginning of the Last Layer defined for the active process. The condition remains true until the last Layer enters the IDLE state.

COMPUTER CONTROL

Sets the logic condition to be true when a Remote Global Set Relay vvv command is received from the remote communications port. The logic condition remains true until a Remote Global Clear Relay vvv command is received from the remote communications port.

CHOPPER WHEEL

Sets the logic condition to be true at the start of the SOAK 2 state or MANUAL. The condition remains true until the end of DEPOSIT or until a STOP command is received.

6.7 Examples

6.7.1 Input Line and Output Relay Connection Example

The following example illustrates how to use the input lines and output relays to automate layer sequencing within a process. The purpose of this example is to demonstrate the external I/O capabilities of the IC/4. By contrast, Section 6.7.2 provides an example of how to accomplish this same automated layer sequencing using an internal logic statement.

Overview

Input #1 will be programmed for START. Output Relay #1 will be programmed for LAYER END ALL AND LAST LAYER. Output Relay #1 will be wired in series to one of the 24 volt supplies contained within the IC/4. The 2nd terminal of the output relay will be wired in series to the signal line for Input #1. The 2nd terminal for Input #1 will be wired to the return line for the 24 volt supply, which completes the circuit.

In programming and wiring the IC/4 in this manner it is possible to run a multi-layer process by pressing START only once. As each layer ends, the IC/4 will automatically issue another START, until the last layer has completed.

Programming Input #1

1. On the operational screen, make sure the instrument is in the READY state. If it is not, press STOP, then press RESET.
2. Press PROGRAM (F6), to go to the PROGRAM display.
3. From the PROGRAM display, press the I/O panel (F3), to get to the I/O display.
4. From the I/O display, press the Input Directory (F1) panel to get to the Input directory display.
5. Place the cursor on the number 1 and press the Edit Input (F5) panel, to get to the INPUT 1 display.
6. Cursor to START and press TAG (F1).
7. Press the INPUT DIRECTORY w/SAVE panel (F6) to return to the INPUT DIRECTORY.

8. The INPUT DIRECTORY should now show the word "Start" next to the number 1.

9. Press the I/O panel to return to the I/O display.

Programming Output #1

1. From the I/O directory, press the OUTPUT DIRECTORY (F2) panel to enter the OUTPUT DIRECTORY display.

2. Place the cursor on the number 1 and press the EDIT OUTPUT (F5) panel to enter the OUTPUT 1 display.

3. Cursor to LAYER END and press TAG (F1). The term "LAYER END ###" should appear in the box below OUTPUT 1.

4. Cursor to LAST LAYER and press TAG (F1). "LAYER END ### ccc LAST LAYER" will now appear in the box below OUTPUT 1.

5. Press the EDIT panel (F5), to enter the EDIT display.

6. Press the CHANGE NUMERICS/DELAY panel (F2) to allow numeric editing. The box cursor should now be located at the ### position of the Output statement. Press O and Enter to designate "all" layers. The Output statement should now read "LAYER END ALL ccc LAST LAYER".

7. Press the OUTPUT (F6) panel to return to the EDIT display.

8. Press the CHANGE CONNECTORS (F3) panel to allow editing of logic connectors.

9. The box cursor should now be located at the "ccc" position of the Output statement. Press the INSERT AND panel (F1). The Output statement will now read "LAYER END ALL AND LAST LAYER".

10. Press the OUTPUT panel (F6) to return to the EDIT display.

11. Press the NEGATE panel (F1) to allow logic negation.

12. Place the box cursor around "LAST LAYER" and press the NEGATE (F1) panel. The Output statement should now read "LAYER END ALL AND $\overline{\text{LAST LAYER}}$".

13. Press the Output panel (F6) to return to the EDIT display. Press the Output panel (F6) to return to the OUTPUT 1 display.

14. Press the OUTPUT DIRECTORY w/SAVE panel (F6) to return to the OUTPUT DIRECTORY display.

15. The OUTPUT DIRECTORY should now show the statement "LAYER END ALL AND LAST LAYER" next to the number 1.

16. At this point, power cycle the instrument to ensure the I/O is initialized properly.

This completes programming of the Input line and Output relay. The next step is to wire the electrical circuit.

1. Refer to Section 10.3.3.2 Input/Relay module connections for the Input line and Output Relay pin outs.

2. On connector P-4, 24 volts is supplied on pins 4,9,15,and 21 with pins 8,14,20, and 25 used as returns. Pins 24 and 28 on connector P-4 are Output Relay #1. Pins 1 and 20 on connector P-5 are Input #1.

3. Connect pin 4 on connector P-4 to pin 24 on connector P-4. This connects the 24 volt supply to one side of Output Relay #1.

4. Connect pin 28 on connector P-4 to pin 1 on connector P-5. This connects the other side of Output Relay #1 to one side on Input #1.

5. Connect pin 20 on connector P-5 to pin 8 on connector P-4. This connects the second terminal of Input #1 to the return line for the 24 volt supply and completes the circuit.

6.7.2 Internal Logic Example

The internal logic capability of the IC/4 allows for additional automation of a thin film process. For example, it is possible to run a multi-layer process without manually pressing START after each layer. The statement to accomplish this might be:

IF: LAYER END ALL AND PROCESS END ALL
THEN: START

The PROCESS END ALL assures that when the process ends, it will not automatically repeat itself.

To enter this statement follow this procedure:

1. On the operational screen, make sure the phase(s) is READY. If it is not, press STOP, then press RESET.

2. Press PROGRAM (F6), to go to the PROGRAM display.

3. From the PROGRAM display, press the I/O panel (F3), to get to the I/O display.

4. From the I/O display, press the INTERNAL LOGIC DIRECTORY panel (F3).

5. Place the cursor on any blank logic statement, using the up and down cursors.

6. Press the EDIT INTERNAL LOGIC panel (F5).

7. Cursor to LAYER END and press TAG (F1). The term "LAYER END ###" should appear after the "IF" in the upper left of the screen.

8. Cursor to PROCESS END, and press TAG (F1). "LAYER END ###ccc PROCESS END###" will now appear after the "IF".

9. Cursor down (in the "INPUT" section) to START, and press TAG (F1). "START" will appear after the "THEN".

10. Press EDIT (F5). The screen will be cleared,except for the statement, and the panels.

11. Press NEGATE (F1). The cursor will appear around LAYER END.

12. Cursor to "PROCESS END###", and press NEGATE (F1). A bar will appear above "PROCESS END###".

13. Press INTERNAL LOGIC (F6). The cursor will disappear, and the panels will return to the previous set.

14. Press CHANGE CONNECTORS (F3). The panels will change and the cursor will be around the "ccc".

15. Press INSERT AND (F1). This will replace the "ccc" with "AND".

16. Press F6 to return to the EDIT page.

17. Press CHANGE NUMERICS/DELAY (F2). Cursor will be around "###".

18. Press 0, followed by E(nter) key. The ### will be replaced with "ALL".

19. The cursor will omve to the ### field after PROCESS END. Press 0, followed by E(nter). The ### will be replaced with "ALL".

20. Press F6 to return to the Edit page.

21. Press F6 again to return to the INTERNAL LOGIC choice page.

22. Press F6 again to return to the INTERNAL LOGIC DIRECTORY. At this point the logic statement is entered into memory, and will go into effect.

23. To return to the operate screen press F6 three more times.

6.8 Error Messages

Already 5 Terms

You have tried to tag more than five events. Selections made after the first five are ignored.

Cannot Parenthesize

At least three events are required in order to use parentheses.

Invalid Equation

The string that you are editing is not complete. You may have not defined all "ccc" connectors or "###" numerics.

No Connector to Edit

At least two events are required to have a connector to edit. CHANGE CONNECTORS may be selected only with multiple actions.

Value Too Large
Value Too Small

The value that you are attempting to enter is out of range. Allowable values will vary according to your unit's configuration or the parameter being defined. Press the Clear key to delete the illegal value and enter again.

Section 7
Remote Communications

Contents

7.1 Remote Communication Configuration Overview

There are three types of remote communication interfaces which can be used by a host computer to control or monitor the instrument. An RS232-C communications port is standard equipment. This may be replaced by optional RS422 or IEEE-GPIB interfaces. Device dependent information and protocol selection must be provided before an interface can be used

NOTE: New communications configuration information will take effect on the next power up of the instrument.

Remote Communications operation is covered in detail in Sections 7.5 through 7.9.

Display Tree for Remote Communications Set Up

```
I/O (PROGRAM)
  |
  └── REMOTE COMMUNICATIONS
```

Configuration of the Remote Communications is initiated by selecting the I/0 panel (F3) in the Program display and then selecting the REMOTE COMMUNICATIONS panel (F5) in the I/0 display. This will invoke the Remote Communications Display (Figure 7.1). Upon entry, the cursor will be placed at the last referenced communications parameter. The parameters are contained on a single page.

NOTE: Any time one of the remote communications parameters is changed, the instrument has to be turned off and then back on in order for the instrument to recognize the change. The IC/4 will display a message indicating a power on/off cycle is required.

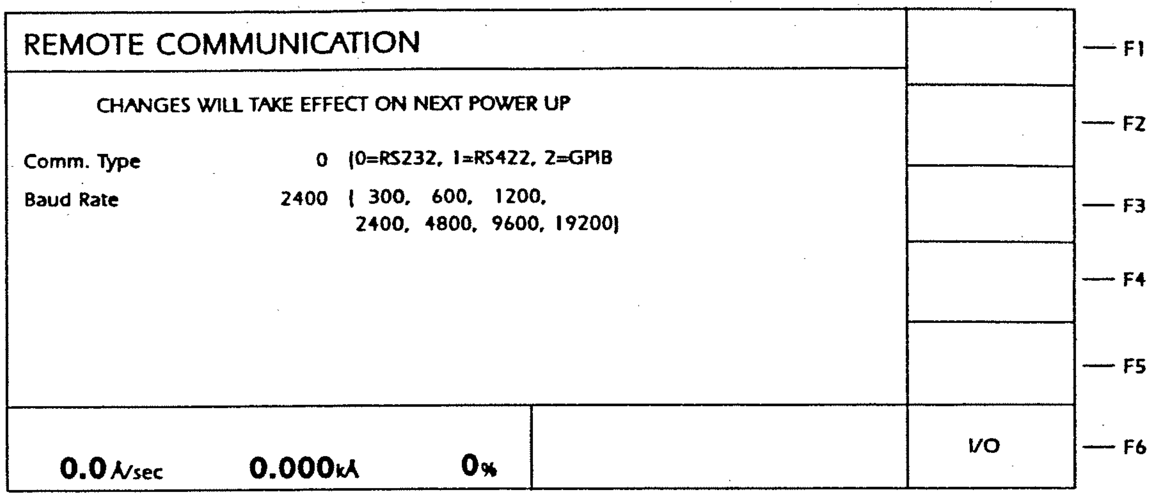


Figure 7.1 Remote Communications Display

7.2 Remote Communications Navigation

A parameter is selected for entry by positioning the box cursor at the desired value following the parameter description. New values are input from the front panel and completed by pressing the Enter key. Values are cleared by pressing the **Clear** key.

PANEL SELECTION CHOICES FOR REMOTE COMMUNICATIONS

F6 **I/0** Select this panel to return to the I/0 display.

7.3 Remote Communications Parameters

Some parameters are only applicable for optional equipment; some are common to more than one communications type. Parameters dealing with optional RS422 or IEEE-GPIB interfaces have a ✠ flag.

COMMUNICATIONS TYPE 0/1/2 ✠

This parameter selects among the three types of communications configurations available. Parameter values range from 0 to 2. RS232 is selected by entering the value 0. A value of 1 selects RS422 (✠) and a value of 2 selects GPIB (✠). The default is 0.

If RS232 or RS422 is selected, parameters for Baud Rate and protocol will be displayed. If GPIB is selected a parameter for GPIB address will be displayed.

GPIB ADDRESS ✠

For IEEE-GPIB interfaces, the GPIB address is a number which identifies an IC/4 to the Host Computer. Values range from 0 to 30. The default value is 3.

BAUD RATE 1200/2400/4800/9600/19200 ✠

For RS232 and RS422 serial interfaces, this parameter sets the rate for data transfer. Permissible values are; 1200, 2400, 4800, 9600, and 19200. The default value is 2400.

Protocol Information

Several variations of protocols are used for the remote communications interfaces. The Inficon Standard protocol is supported for the RS232, RS422 and GPIB interfaces. RS232 and RS422 may be used with or without a checksum format.

CHECKSUM YES/NO

This parameter provides the choice of having a Checksum when using the RS422 or RS232. For the Inficon format, the Checksum is an 8-bit unsigned sum of the command bytes. Permissible values for this parameter are YES and NO. The default value is NO.

7.4 Error Messages In Remote Communications Configuration

Illegal Baud Rate

The value you are attempting to enter is not one of the valid baud rates for serial communications. Valid rates are 1200, 2400, 4800, 9600 or 19200.

Value Too Large
Value Too Small

The value that you are attempting to enter is out of range. Allowable values will vary according to your unit's configuration or the parameter being defined. Press the Clear key to delete the value and enter again.

7.5 Remote Communications Overview

This instrument may be remotely controlled, programmed or interrogated. This is accomplished through remote communications and the use of a remote command set. The instrument will respond to messages that contain these commands. It will accept and operate on messages one at time. It will respond to each command by carrying out valid operations and/or returning a message to the sender.

A host/server relationship is established in remote communications. The instrument, as server, responds to the remote host's commands. The responsiveness of this interaction may be affected by the instrument's operational state. It will be similar to that experienced by a user at the front panel.

NOTE: There are special commands which may be executed to establish a faster response time than is possible when operating normally. Specifically: 1) Screen lock; 2) battery backed RAM lock; and 3) service requests for IEEE488.

7.6 Physical Connections

One of three types of data communications hardware ports may be used. Standard equipment includes a bit serial RS232 port. Optionally, the RS232 electronics can be replaced by a bit serial RS422 port or an IEEE488 parallel port.

Selection and set-up of some general port and communication characteristics are handled in Sections 7.1 through 7.4. Generally speaking, both the host and server must have the same form of communications equipment and complementary setup. For serial communications, baud rates must match and so must the data word format.

The word format for bit serial lines is comprised of ten signal bits- eight data bits, one start bit, one stop bit and no parity. The eight data bits comprise a byte of information or character whose ASCII value ranges from 0 to 255.

7.6.1 RS232 Serial Port

RS232 serial communications interfacing is accomplished through an industry standard 25-pin male connector (DB25P) found on the rear panel of the instrument's enclosure. A mating female connector (DB25S) is required for attachment of a host interface. The host and instrument can be separated by up to fifty feet using multi-conductor shielded data cable.

The instrument is configured as DTE or Data Terminal Equipment and assumes a host acting as DCE or Data Communications Equipment.

The following pin assignments should be used when constructing a cable.

IC/4 (DB25P)		Host (DB25S)
Pin 2 TXD	⟶	RXD
Pin 3 RXD	⟵	TXD
Pin 4 RTS	⟶	CTS
Pin 5 CTS	⟵	RTS
Pin 6 DSR	⟵	DTR
Pin 7 GND	——	GND
Pin 8 DCD	——	DCD
Pin 20 DTR	⟶	DSR

The port incorporates hardware flow control via Request to Send / Clear to Send (RTS/CTS) and Data Terminal Ready / Data Set Ready (DTR/DSR) signaling.

Request To Send (RTS) - The instrument informs the host it is ready to receive a character by asserting the RTS signal. It lowers the signal when the receive buffer is full.

Clear to Send (CTS) - The host informs the instrument it is ready to receive a character by asserting the CTS signal.

Data Terminal Ready (DTR) - The instrument informs the host that it is powered up and able to communicate by asserting this signal.

Data Set Ready (DSR) - The host informs the instrument that it is able to communicate.

7.6.2 RS422 Serial Port

An RS422 circuit card may optionally replace the standard RS232 circuit card. The RS422 electrical connection differs from the RS232 in that a balanced signal is used for transmit and receive data information using dedicated pairs of conductors. Distances of up to 4000 feet, depending on baud rate are possible between the host and server instrument. The physical port is a 25 pin male connector (DB25P). A mating female connector (DB25S) is required to provide the host interface.

The following diagram illustrates typical cabling for a server to host interface with no hardware handshaking.

```
IC/4 (DB25P)                       Host (DB25S)

Pin 2   TXD(+) ---------------->  RXD(+)
Pin 20  TXD(-) ---------------->  RXD(-)
Pin 3   RXD(+) <----------------  TXD(+)
Pin 8   RXD(-) <----------------  TXD(-)
Pin 7   GND    -----------------  GND
Pin 4   RTS(+) --+            +-- RTS(+)
Pin 5   CTS(+) --+            +-- CTS(+)
Pin 6   RTS(-) --+            +-- RTS(-)
Pin 22  CTS(-) --+            +-- CTS(-)
```

7.6.3 IEEE488 Port

An IEEE488 circuit card may be purchased to replace the standard RS232 circuit card. The instrument appears on the IEEE488 bus as a device. A unique device address must be assigned. Refer to Section 7.3 - Remote Communications Parameters. A standard IEEE488 24-pin connector is provided on the instrument.

The instrument makes use of the IEEE488 status byte.

Whenever there is message available (MAV) in the instrument, bit-4 of the status byte will be set. By enabling the automatic serial polling and checking the status byte, very reliable data transfer between the instrument and the host computer can be achieved. The timeouts for the device and the host should be set sufficiently long (at least 0.5 s).

Additionally, service requests are supported. A service request is a request by the instrument to transmit information to the host. The instrument does this by triggering the RQS bit of the status byte. A host initiated serial poll then identifies the requesting device by the presence of a 1 in the RQS (2^6) bit of the status byte. The following conditions of the instrument can be detected by examining the low 4 bits of the status byte in combination with the bit-4.

bit position:	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
MAV/Data ready:	-	-	-	1	-	-	-	-
Final thickness:	-	1	-	1	0	0	0	1
Stop:	-	1	-	1	0	0	1	0
End layer:	-	1	-	1	0	0	1	1
Power up:	-	1	-	1	0	1	0	0
End Process:	-	1	-	1	0	1	0	1

7.7 Message Protocols

There are multiple forms of message protocols to meet the needs of various users and network environments. The message protocol serves as a structure for the contained command or response information. It also can provide a level of acknowledgement between the host and server and a mechanism for verifying the information content.

A standard Inficon command structure has been established for use in its instruments. While some commands need to be instrument dependent, the basic structure and protocol is designed to be common among the products. It provides a comprehensive and reliable method for remote instrument communications.

7.7.1 Inficon Message Formats

There are two message forms for the serial ports and one for the IEEE488 port. All messages are comprised of serial byte information. The byte values represent command or response characters, control characters or numeric values. Mnemonics will be used to describe the portions of each message format.

NOTE: These mnemonics are not part of the message stream; they are used to represent specific ASCII codes, characters or numeric values that comprise the message stream.

Mnemonic	Meaning
<STX>	ASCII code 2 for Start of Transmission
<ACK>	ASCII code 6 for Positive Acknowledgement
<NAK>	ASCII code 21 for Negative Acknowledgement
<LF>	ASCII code 10 for Line Feed (EOT byte for IEEE488)
(command)	ASCII character codes representing the host's command as described in Section 7.8
(response)	ASCII character codes representing the instrument's response as described in Section 7.8
(nrc)	ASCII code (usually for a character) designating a negative response code; used for error responses to a host command.

(checksum) Numeric value from 0 to 255 (one byte) representing the modulo 256 remainder of the sum of the values of the ASCII codes that comprise the message or response.

(count) Numeric value from 0 to 16,383 (two bytes) representing the number of characters in the command or response. Two byte values, high and low order, are required to represent this number. In order of transmission, the high byte will precede the low byte. For most commands, the number of characters will be less than 256. In this situation the low byte will contain the character count while the high byte will have zero value.

Serial With No Checksum Format

Host to Instrument Message

(command)<ACK>

Instrument to Host Message

(response)<ACK> *or*
(nrc)<NAK>

(See Section 7.8.7 for a list of error codes.)

Serial With Checksum Format

Host to Instrument Message

<STX>(count)(command)(checksum)

Instrument to Host Message

<STX>(count)<ACK>(response)(checksum) *or*
<STX>(count)<NAK>(nrc)(checksum)

IEEE488 Message Format

Host to Instrument Message

(command)<LF>

Instrument to Host Message

(response)<LF> *or*
(nrc)<LF>

7.8 Inficon Standard Communication Commands

The standard command set is structured into six categories- **ECHO**, **HELLO**, **QUERY**, **UPDATE**, **STATUS** and **REMOTE**. Most commands require arguments. A space is used between commands and arguments and between multiple arguments.

The instrument utilizes a set of negative response codes (nrc) for commands resulting in an error.

7.8.1 ECHO Command

The format is:

E string

The Echo command returns the ASCII string argument back to the sender. This command is useful for set up or troubleshooting.

7.8.2 HELLO Command

The format is:

H

The Hello command returns the model and version number in the ASCII format "IC/4 VERSION x.xx", or "IC/4 PLUS VERSION x.xx".

7.8.3 QUERY Commands

Query commands are used to request existing parameter values. There is a specific query command for each parameter group. Depending on the User Level and actual hardware configuration, the response to some Query commands will be an 'E' nrc (negative response code) indicating there is no data to retrieve. Each command has one to three arguments which are separated by a space.

The command variations include:

QM	Query Material Parameters
QP	Query Process Parameters
QU	Query Utility Parameters
QS	Query Sensor Parameters

QC	Query Source Control Parameters
QI	Query Input Line Actions
QO	Query Output Relay Events
QT	Query Output Relay Type
QL	Query Internal Logic Conditions

The format is:

QM param# material#

This command returns a material parameter or all material parameters for a specified material.

param#	Material Parameter
0	Compound Name
1	Density
2	Z-Ratio
3	Source
4	PID Control
5	Process Gain
6	Primary Time Const.
7	System Dead Time
8	Tooling
9	Sensor
10	Secondary Tooling
11	Quality
12	Stability
13	Maximum Power
14	Soak Power 1
15	Rise Time 1
16	Soak Time 1
17	Soak Power 2
18	Rise Time 2
19	Soak Time 2
20	Shutter Delay On
21	Feed Power
22	Feed Ramp Time
23	Feed Time
24	Idle Power
25	Idle Ramp Time
99	All parameters

NOTE: The QM 99 ## command returns a string of values, each separated by a space, in the order specified above for parameters 0-25, inclusive.

QP param# process# layer#

This command returns a process parameter or all process parameters for a specific process and layer.

NOTE: Rate, New Rate 1 and New Rate 2 will be output to the hundredth decimal place.

param#	Process Parameter
0	Material Index
1	Rate
2	Final Thickness
3	Thickness Limit
4	Time Limit
5	Co-Deposition (IC/4 PLUS Only)
6	Ratio Control (IC/4 PLUS Only)
7	Cross Sensitivity (IC/4 PLUS Only)
8	RateWatch Time
9	RateWatch Accuracy
10	Crucible
11	New Rate 1
12	Start Ramp 1
13	Ramp Time 1
14	New Rate 2
15	Start Ramp 2
16	Ramp Time 2
99	All parameters; each separated by a space in the above order.

QU param#

This command returns a utility parameter or all utility parameters. The parameters marked * will return only a string of four x's (i.e., xxxx).

param#	Utility Parameter
0	Active Process
1	Run Number
2	Layer to Start
3	Stop on Max Power
4	Crystal Fail
5	Analog Display
6	Analog Scan Rate
7	Analog Output
8	Test On
9	Time Compressed
10	User Level
11	Program Lock Code*
12	Sensor-I/O Lock Code*
13	Mem Card Access Code*
14	System Time
15	System Date
16	Audio Feedback
17	Codep Display (IC/4 PLUS Only)
18	Rate Smoothing
99	All parameters; each separated by a space in the order specified above.

QS param# sensor#

This command returns a sensor parameter or all sensor parameters.

param#	Sensor Parameter
0	Type
1	Xtal Switch Output
2	Xtal Shutter Output
3	Xtal Shutter Type
4	Z-Ratio Type (IC/4 PLUS Only)
99	All parameters; each separated by a space in the order specified above.

QC param# source#

This command returns a source control parameter or all source control parameters.

param#	Source Parameter
0	Voltage Range
1	Shutter Output
2	Shutter Output Type
3	Number of Crucibles
4	Crucible Output
5	Crucible Output Type
6	Turret Feedback
7	Turret Input
8	Turret Delay
99	All parameters; each separated by a space in the order specified above.

QI input#

This command returns the actions assigned to a specific input line. Action codes are provided separated by spaces. Up to five actions codes can be returned in the form -

[action code 1] .... [action code 5]

A zero code indicates the input has not been assigned an action. Codes and action names can be found with the descriptions for Update commands, **UI** and **UL,** that follow. Descriptions of actions can be found in Section 6 - Internal/External I/O Set Up. Additionally, the following input actions established in Source Set Up (Section 8) may be returned.

action code	Input Action
33	Turret Position Source 1
34	Turret Position Source 2
35	Turret Position Source 3
36	Turret Position Source 4

QO output#

This command returns an encoded event string that is assigned to a specific relay. The events are encoded in the form -

[negate] [event code] [numeric qualifier].

Multiple events are connected with AND or OR. Parenthesis indicate groupings. The symbol ~ is used to represent a negate. Certain events have a numeric qualifier. Applicable codes and event names can be found with the descriptions for Update commands, **UO**, that follow. Descriptions of events can be found in Section 6 - Internal/External I/O Set Up. Additionally, the following output actions established in Source/Sensor Set Up (Section 8) may be returned.

event code	Output Event
39	Source Shutter
40	XTAL Shutter
41	XTAL Switch
42	Crucible 4 (First output)
43	Crucible 8 (First output)
44	Crucible 16 (First output)
45	Crucible 32 (First output)
46	Crucible 64 (First output)
47	Crucible 4 (Second output)
48	Crucible 8 (Second output)
49	Crucible 16 (Second output)
50	Crucible 32 (Second output)
51	Crucible 64 (Second output)
52	Crucible 8 (Third output)
53	Crucible 16 (Third output)
54	Crucible 32 (Third output)
55	Crucible 64 (Third output)
56	Crucible 16 (Fourth output)
57	Crucible 32 (Fourth output)
58	Crucible 64 (Fourth output)
59	Crucible 32 (Fifth output)
60	Crucible 64 (Fifth output)
61	Crucible 64 (Sixth output)

QT output#

This command returns the type code for a specific relay. Type code values returned are 0, 1, 2 or 3 where 0 is Normally Open, 1 is Normally Closed, 2 is Pulse Open and 3 is Pulse Closed.

QL logic#

This command returns the encoded conditional string assigned to a specific internal logic 'statement'. The string is represented in the form IF (output event string) THEN (input action string) where these strings are the same as returned in **QO** and **QI** above. Applicable codes and event names can be found with the descriptions for Update commands, **UL**, that follow.

7.8.4 UPDATE Commands

Update commands are used to change a specified parameter to a new value or condition. Some parameters are order dependent in that they cannot be updated prior to certain other parameters. For example in the IC/4 PLUS, two layers must be defined before specifying the co-deposition of those layers.

There is a specific update command for each parameter group. Each command has one to four arguments starting with and separated by a space. The Update command variations include-

UM Update Material Parameters
UP Update Process Parameters
UU Update Utility Parameters
US Update Sensor Parameters
UC Update Source Control Parameters
UI Update Input Line Actions
UO Update Output Relay Events
UT Update Output Relay Type
UL Update Internal Logic Conditions

UM param# material# value

This command changes the value of a material parameter for a specified material. Refer to Section 4 - Material Set Up, for parameter value ranges.

NOTE: To update the compound name in the Material Directory, use the RG 20 command.

param#	Material Parameter
1	Density
2	Z-Ratio
3	Source
4	PID Control
5	Process Gain
6	Primary Time Const.
7	System Dead Time
8	Tooling
9	Sensor
10	Secondary Tooling
11	Quality
12	Stability
13	Maximum Power
14	Soak Power 1
15	Rise Time 1
16	Soak Time 1
17	Soak Power 2
18	Rise Time 2
19	Soak Time 2
20	Shutter Delay On
21	Feed Power
22	Feed Ramp Time
23	Feed Time
24	Idle Power
25	Idle Ramp Time

UP param# process# layer# value

This command changes the value of a process parameter for a specific process and layer. Refer to Section 5 Process Set Up for parameter value ranges.

NOTE: Rate, New Rate 1, and New Rate 2 values can be input to the hundredth position via communications. Deposition will be controlled to the hundredth place, even though the front panel display and input only read to the tenth's place.

param#	Process Parameter
0	Material Index
1	Rate
2	Final Thickness
3	Thickness Limit
4	Time Limit
5	Co-Deposition (IC/4 PLUS Only)
6	Ratio Control (IC/4 PLUS Only)
7	Cross Sensitivity (IC/4 PLUS Only)
8	RateWatch Time
9	RateWatch Accuracy
10	Crucible
11	New Rate 1
12	Start Ramp 1
13	Ramp Time 1
14	New Rate 2
15	Start Ramp 2
16	Ramp Time 2

UU param# value

This command changes the value of a utility parameter. The parameters marked with * cannot be updated. Refer to Section 9 - Utility Set Up, for parameter value ranges.

param#	Utility Parameter
0	Active Process
1	Run Number
2	Layer to Start
3	Stop on Max Power
4	Crystal Fail
5	Analog Display
6	Analog Scan Rate
7	Analog Output
8	Test On
9	Time Compressed
10	User Level
11	Program Lock Code*
12	Sensor-I/O Lock Code*
13	Mem Card Access Code*
14	System Time
15	System Date
16	Audio Feedback
17	Codep Display (IC/4 PLUS Only)
18	Rate Smoothing

US param# sensor# value

This command changes the value of a sensor parameter. Refer to Section 8 - Source/Sensor Set Up, for parameter value ranges.

param#	Sensor Parameter
0	Type
1	Xtal Switch Output
2	Xtal Shutter Output
3	Xtal Shutter Type
4	Z-Ratio Type (IC/4 PLUS Only)

UC param# source# value

This command changes the value of a source control parameter. Refer to Section 8 - Source/ Sensor Set Up, for parameter value ranges.

param#	Source Parameter
0	Voltage Range
1	Shutter Output
2	Shutter Output Type
3	Number of Crucibles
4	Crucible Output
5	Crucible Output Type
6	Turret Feedback
7	Turret Input
8	Turret Delay

UI input# [action 1] .... [action 5]

This command changes the action assignments for a specific input line. Action codes are separated by spaces. Up to five actions codes can be assigned in the form -

[action code 1] .... [action code 5]

Refer to Section 6 - Internal/External I/O Set Up for action descriptions.

action code	Input Action
0	Clear the Input Assignments
1	Start
2	Stop
3	Reset
4	Select Process 1
5	Select Process 2
6	Select Process 3
7	Select Process 4
8	Zero Thickness
9	Zero Time
10	Trig Final Thickness

11	Switch XTAL
12	XTAL Fail Inhibit
13	Hold Soak 1 Primary
14	Hold Soak 1 Secondary
15	Hold Soak 2 Primary
16	Hold Soak 2 Secondary
17	RateWatcher Hold
18	RateWatcher Hold Inhibit
37	Non-Deposit Clock Hold

UO output# [negate] [event code] [numeric qualifier]....

This command changes the event string that is assigned to a specific relay. The events are encoded in the form -

[negate] [event code] [numeric qualifier].

Multiple events are connected with AND or OR. Parenthesis provide groupings. The symbol ~ is used to represent a negate. Spaces are required between numbers, codes and logical connectors. Refer to Section 6 - Internal/External I/O Set Up for event and qualifier descriptions. Events that are marked with an * require a numeric qualifier.

event code	Output Event
0	Clear the event string
1	Source Switch State
2	Rise 1 State
3	Soak 1 State
4	Rise 2 State
5	Soak 2 State
6	Shutter Delay State
7	Rate Ramp 1 State
8	Rate Ramp 2 State
9	Feed Ramp State
10	Feed State
11	Idle Ramp State
12	Idle State
13	Time Power
14	Pre-Deposit
15	Deposit
16	Post-Deposit

event code	Output Event
17	Manual
18	AutoTune
19	Thickness Limit
20	Final Thickness
21	Time Limit
22	Last Layer
23	Process End*
24	Layer End*
25	Material End*
26	Process*
27	Layer*
28	Material*
29	Source*
30	Sensor*
31	Stop
32	XTAL Fail
33	Unable To Auto Z (IC/4 PLUS Only)
34	Max Power
35	Shutter Error
36	Ready
37	Chopper Wheel
38	Computer Control

UT output# [type code]

This command changes the type code for a specific relay. Type code values are 0, 1, 2 or 3 where 0 is Normally Open, 1 is Normally Closed, 2 is Pulse Open and 3 is Pulse Closed.

UL logic# IF(output event string) THEN(input action string)

This command changes the encoded conditional string assigned to a specific internal logic 'device'. The string is represented in the form IF (output event string) THEN (input action string) where these strings are the same as in UO and UI above. Both IF and THEN portions are always required. Events marked with an * require a numeric qualifier.

event code	Output Event
0	Clear the event string
1	Source Switch State
2	Rise 1 State
3	Soak 1 State
4	Rise 2 State
5	Soak 2 State
6	Shutter Delay State
7	Rate Ramp 1 State
8	Rate Ramp 2 State
9	Feed Ramp State
10	Feed State
11	Idle Ramp State
12	Idle State
13	Time Power
14	Pre-Deposit
15	Deposit
16	Post-Deposit
17	Manual
18	AutoTune
19	Thickness Limit
20	Final Thickness
21	Time Limit
22	Last Layer
23	Process End*
24	Layer End*
25	Material End*
26	Process*
27	Layer*
28	Material*
29	Source*
30	Sensor*
31	Stop

event code	Output Event
32	XTAL Fail
33	Unable To Auto Z (IC/4 PLUS Only)
34	Max Power
35	Shutter Error
36	Ready
37	Chopper Wheel
38	Computer Control

action code	Input Action
0	Clear the Input Assignments
1	Start
2	Stop
3	Reset
4	Select Process 1
5	Select Process 2
6	Select Process 3
7	Select Process 4
8	Zero Thickness
9	Zero Time
10	Trig Final Thickness
11	Switch XTAL
19	XTAL Fail Inhibit On
20	XTAL Fail Inhibit Off
21	Hold Soak 1 Primary On
22	Hold Soak 1 Primary Off
23	Hold Soak 1 Secondary On
24	Hold Soak 1 Secondary Off
25	Hold Soak 2 Primary On
26	Hold Soak 2 Primary Off
27	Hold Soak 2 Secondary On
28	Hold Soak 2 Secondary Off
29	RateWatcher Hold On
30	RateWatcher Hold Off
31	RateWatcher Hold Inhibit On
32	RateWatcher Hold Inhibit Off

7.8.5 STATUS Commands

Status commands return pertinent information based on a specific request made. Commands are provided to determine global information which is system level or channel information which is layer oriented. A status code is required for each command. The command and the code are separated by a space. The command variations include-

SG Status of system or instrument level conditions
SP Status of primary channel (first layer started)
SS Status of secondary channel (second layer started)
SA Status of both channels

The format is:

SG global_status_code

This command can be used to determine system or instrument conditions. For the Response Formats: x represents a number (if the value being returned does not occupy the entire width blanks are added to the left); s represents the sign (only a negative sign is displayed, a blank is returned in this position if the value is positive); b represents a blank.

status code	Global Condition	Response Format
0	Active Process- Returns an ASCII value 1, 2, 3 or 4.	x
1	Number of Layers In Progress- Returns an ASCII value 0, 1, or 2.	x
	For commands 2 through 4:	xbxbxbxbxbxbxbxbxbxbxbxbxbxbxbxb
2	Output Settings- Returns 8 std., 8 optional (16 std. on IC/4 PLUS) ASCII bytes, one per output, with a value of 0 or 1, depending on output setting.	
3	Input Settings- Returns 8 std., 8 optional (16 std. on IC/4 PLUS) ASCII bytes, one per input, with a value of 0 or 1, depending on input setting.	
4	Internal Logic- Returns 8 (16 on IC/4 PLUS) ASCII bytes, one per internal logic output, depending on the condition of the internal logic 'if' string.	

status code	Global Condition	Response Format
5	System Messages- Returns a variable length string listing message numbers corresponding to the status messages displayed on the instrument. (This sequence may be repeated if there is more than one message code returned.)	bxxb

Response Codes to SG 05 Command

Message #	System Message
0	NO SYSTEM MESSAGES
33	XTAL FAIL
34	MAX POWER REACHED
36	NO SWITCH: NO XTALS
37	XTAL SWITCHING
38	SWITCHER FAIL
39	AUTOTUNE FAILURE
40	MAX RATE EXCEEDED
41	AUTOTUNE TIMEOUT
42	AUTOTUNE SUCCESSFUL
43	CANNOT DO HALF RATE
44	UNABLE TO AUTO Z (IC/4 PLUS Only)
45	TEST MODE CHANGE
46	LOCK MODE CHANGE
47	SAMPLE
48	HOLD
49	DELAY
50	AUTOTUNE MAX POWER
51	RATE ABOVE MAX
52	SPEED TEST
53	FAST SYSTEM
54	SLOW SYSTEM
55	QUICK BUMP
56	QUICK TUNE GOOD
57	HALF RATE
58	COMPLETE BUMP
59	MEAS SYS COMM FAIL
60	END OF PROCESS

status code	Global Condition	Response Format
6	Stop Status- Returns an ASCII 0 if the system's is not in STOP or returns an ASCII code indicating what caused the stop. Causes marked with an * have numeric designators on the front panel which do not return when the **SG 06** request is sent.	bxxb

Response Codes to SG 06 Command

Code #	Stop Cause
1	SHUTTER DELAY
2	FRONT PANEL
3	TIME POWER
4	MAX POWER
5	XTAL FAIL*
6	SOURCE CONFLICT
7	SENSOR CONFLICT
8	POWER LOSS
9	SOURCE SWITCH
10	SWITCHER FAIL
11	MAX POWER <5%
12	RATE TOO LOW
13	QUICK TUNE FAIL
14	HALF RATE FAIL
15	COMPLETE TUNE FAIL
16	MAX POWER ERROR
17	COMMUNICATIONS
18	INPUT*
19	INTERNAL LOGIC*
20	HAND HELD
21	AUTOTUNE FAILURE
22	MEASUREMENT SYSTEM COMM FAIL

SP channel_status_code
SS channel_status_code
SA channel_status_code

These commands are used to determine the condition of started layers. SP refers to primary channel or the first layer started. SS refers to secondary channel or the second layer started. SA refers to both channels. For the Response Formats: x represents a number (if the value being returned does not occupy the entire width blanks are added to the left); s represents the sign (only a negative sign is displayed, a blank is returned in this position if the value is positive); b represents a blank. The SA Command concantenates the response for each channel. If there is only one channel in use, the SA and SP commands will return the same information.

status code	Channel Condition	Response Format
00	Process information. All the information for codes 01 to 10.	
01	Rate (Å/s) currently read. (Raw reading)	sx.xxxb to sxxxx.b
02	Power (%) currently output.	bxx.xxxb
03	Thickness (KÅ) currently accumulated.	sxxx.xxxb
04	Current instrument state.	bxxb

Response Codes to SP 04, SS 04, or SA 04 Command.

Code #	State In Process
0	READY
1	SOURCE SWITCH
2	RISE 1
3	SOAK 1
4	RISE 2
5	SOAK 2
6	SHUTTER DELAY
7	DEPOSIT (before any rate ramps)
8	RATE RAMP 1

Code #	State In Process
9	DEPOSIT (between rate ramp 1 and rate ramp 2)
10	RATE RAMP 2
11	DEPOSIT (after rate ramp 2)
12	TIME POWER
13	FEED RAMP
14	FEED
15	IDLE RAMP
16	IDLE
17	MANUAL
18	STOP
19	AUTOTUNE MANUAL
20	AUTOTUNE TUNING
21	AUTOTUNE ERROR
22	AUTOTUNE RAMP

status code	Channel Condition	Response Format
05	State time (mm:ss).	xx:xxb
06	Active layer.	xxxb
07	Layer time (mm:ss).	xx:xxb
08	Active crystal.	bbxb
09	Crystal life (%).	bxxb
10	Power source number.	bbxb
11	Rate deviation/power output trend. Average values from the operational screen graph. Format of each data point, response length varies depending on number of data points.	xxx.xxxb
12	Frequency of crystal fundamental. A negative value of the last valid frequency reading is returned if a crystal fail occurs	sxxxxxxx.xxb
13	Frequency of crystal anharmonic. A negative value of the last valid frequency reading is returned if a crystal fail occurs. (IC/4 PLUS Only)	sxxxxxxx.xxb
14	Frequency of crystal fundamental and frequency of crystal anharmonic (12 and 13). A negative value of the last valid frequency reading is returned if a crystal fail occurs. (IC/4 PLUS Only)	sxxxxxxx.xxb
15	Sensor Z-value. (IC/4 PLUS Only)	

7.8.6 REMOTE Commands

Remote commands initiate an action based on the specific command given. Commands are provided to affect global features which are system level or channel information which is layer oriented. Every command requires a remote code and may require a value. Commands, codes and values are separated by a space.

Command variations include-

RG Affects a system or instrument level condition
RP Affects a primary channel (first layer) condition
RS Affects a secondary channel (second layer) condition
RA Affects conditions of both channels

RG global_remote_code value

This command can be used to affect system or instrument level features. A value may be required.

remote code	Global Action
	(Codes 0, 1 and 2 need to be separated by one tenth of a second)
0	Start - equivalent to pressing start key.
1	Stop - equivalent to pressing stop key.
2	Reset - equivalent to pressing reset key.
3	Remote Lock On - prohibits any parameter from being entered via the front panel.
4	Remote Lock Off - clears remote lock condition.
5	Set Relay vvv - sets relay number indicated. NOTE - this will only happen if in the I/O program the given output is set as computer controlled. Otherwise, this command will be ignored.
6	Clear Relay vvv - clears relay number indicated. NOTE - this will only happen if in the I/O program the given output is set as computer controlled. Otherwise, this command will be ignored.
7	Crystal Fail Inhibit On - simulates relay input.
8	Crystal Fail Inhibit Off - simulates relay input.
9	Display lock - locks front panel display and keyboard. Used to speed response time via communications. (Cleared by issuing RG 4 command.)
10	Battery Backed RAM Lock - prevents saving of parameters to the non-volatile RAM. Useful to speed communications when consecutively updating a large number of parameters. It has no effect on the speed of communications when querying parameters. NOTE - If the instrument loses power while the battery backed RAM is locked, any parameters updated during the time the battery backed RAM was locked will not be retained.

remote code	Global Action
11	Unlocks the battery backed RAM lock and resumes normal operation.
12	Non-Deposit clock hold on. "Holds" the state timer during any non-Deposit state. See Section 6.5
13	Non-Deposit clock hold off. Removes the state timer "Hold" and resumes normal operation. See Section 6.5
19	Delete material vv. Removes material vv from the material directory. This command is valid only if the material being deleted is not used in any process.
20	Name Material vv uuu. Give material number vv the name corresponding to material library entry uuu. Library entries range from 0 (Ag) to 255 (USER), with numbers corresponding to the alphabetical listing in the library. The density and Z-ratio will be changed accordingly. This command is valid on any defined material, and the first non-defined material. See Appendix A for Material Table.
21	Add layer v. Will define the next undefined layer in process v, giving it all default parameters.
22	Insert layer u vvv. Will insert a layer immediately before layer vvv of process u.
23	Delete layer u vvv. Will delete layer vvv of process u.

RP channel_remote_code value

RS channel_remote_code value

RA channel_remote_code value

These commands are used to affect actions associated with started layers. RP refers to primary channel or the first layer started. RS refers to secondary channel or the second layer started. RA refers to both channels. Single or multiple values may be required for some commands.

remote code	Channel Action
00	Soak Hold 1 On - simulates relay input.
01	Soak Hold 1 Off - simulates relay input.
02	Soak Hold 2 On - simulates relay input.
03	Soak Hold 2 Off - simulates relay input.
04	Manual On - simulates front panel key.
05	Manual Off - simulates front panel key.
06	Set Power Level uu.u - sets the power to uu.u%.
20	Zero Thickness - simulates relay input.
21	Final Thickness Trigger - simulates relay input.
22	Crystal Switch - simulates relay input.

7.8.7 Negative Response Error Codes

An error code in the form of a single ASCII character is returned when a command results in an error.

error code	Command Error
A	Illegal Command
B	Illegal Value
C	Illegal ID
D	Illegal Command Format
E	No Data To Retrieve
F	Cannot Change Value Now
G	Bad Checksum
O	Data Overrun Error

7.9 Sample Inficon Messages and Host Programs

The following illustrate examples of typical message streams and host programs. The message streams are shown with byte values representing ASCII codes or numeric sums. The programs are in BASIC and were implemented on an XT class PC.

7.9.1 Sample Inficon Messages

Serial Communications Forms (RS232/RS422)

Command Message - No Checksum

Description- Query state of Stop On Max Power
Command- QU 3
Message Form- (command)<ACK>
Message Stream- 81 85 32 51 06

Command Message - With Checksum

Description- Update Maximum power of Material 20 to 60 %
Command- UM 13 20 60
Message Form- <STX>(count)(command)(checksum)
Message Stream- 02 00 11 85 77 32 49 51 32 50 48 32 54 48 46

Response Message - No Checksum

Description- Process 1 is active
Response- 1
Message Form- (response)<ACK>
Message Stream- 49 06

Description- Command was illegal; nrc is A.
Response- A
Message Form- (nrc)<NAK>
Message Stream- 65 21

Response Message - With Checksum

Description- Primary channel power is 42%
Response- 42
Message Form- <STX>(count)<ACK>(response)(checksum)
Message Stream- 02 00 02 06 52 50 102

Description- There is no data to retrieve; nrc is E.
Response- E
Message Form- <STX>(count)<NAK>(nrc)(checksum)
Message Stream- 02 00 01 21 69 69

Parallel Communications Forms(IEEE488)

Command Message

Description- Hello
Command- H
Message Form- (command)<LF>
Message Stream- 72 10

Response Message

Description- Instrument Identification
Response- IC/4 PLUS VERSION 2.20
Message Form- (response)<LF>
Message Stream- 73 67 47 52 32 80 76 85 83 32 86 69 82 83 73 79 78 32 50 46 50 48 10

Description- Illegal command format; nrc is D.
Response- D
Message Form- (nrc)<LF>
Message Stream- 68 10

7.9.2 Sample Host Programs

The following BASIC program listings illustrate examples of host processing that could be used to remotely communicate with the IC/4. They accept commands from the keyboard, and display the response received from the IC/4.

7.9.2.1 Serial Communications - No Checksum

```
5 '——IC/4 RS232/422 COMMUNICATIONS / NO CHECKSUM——
10 OPEN "COM1:2400,N,8,1,CS,DS" AS #1
20 NAK$ = CHR$(21) : ACK$ = CHR$(6)
22 CMD$ = "RG 01"
23 GOSUB 80
24 CMD$ ="RG 02"
25 GOSUB 80
30 INPUT "ENTER COMMAND"; CMD$
40 GOSUB 80
50 PRINT RESPONSE$
60 GOTO 30
70 '
80 '——TRANSMIT COMMAND AND RECEIVE RESPONSE SUBROUTINE——
90 '
100 '——SEND COMMAND——
101 FOR V = 1 TO 200
102 NEXT V
110 PRINT #1, CMD$ + ACK$;
120 '
130 '——RECEIVE RESPONSE——
140 RESPONSE$ = ""
150 TOUT = 8: GOSUB 190
155 IF I$ = ACK$ THEN RETURN
160 IF I$ = NAK$ THEN RETURN
165 RESPONSE$ = RESPONSE$ + I$
170 GOTO 150
180 '
190 '——READ CHARACTER FROM INSTRUMENT TO I$——
200 ON TIMER (TOUT) GOSUB 230: TIMER ON
210 IF LOC(1) < 1 THEN 210 ELSE TIMER OFF: I$ = INPUT$(1,#1)
220 RETURN
230 TIMER OFF: RESPONSE$ = "RECEIVE TIMEOUT": I$ = NAK$: RETURN 220
```

7.9.2.2 Serial Communications With Checksum

```
5 '——IC/4 RS232/422 COMMUNICATIONS PROGRAM WITH CHECKSUM——
10 OPEN "COM1:2400,N,8,1" AS #1
20 STX$ = CHR$(2) : NAK$ = CHR$(21) : ACK$ = CHR$(6)
22 CMD$ = "RG 01"
23 GOSUB 80
24 CMD$ = "RG 02"
25 GOSUB 80
30 INPUT "ENTER COMMAND"; CMD$
40 GOSUB 80
41 IF RESPONSE$ = "RECEIVE TIMEOUT" THEN 50
42 L = LEN(RESPONSE$): L = L - 1
44 RESPONSE$ = RIGHT$(RESPONSE$,L)
50 PRINT RESPONSE$
60 GOTO 30
70 '
80 '——TRANSMIT COMMAND AND RECEIVE RESPONSE SUBROUTINE——
90 '
100 '——SEND COMMAND——
110 SIZEM$ = CHR$(LEN(CMD$) / 256)
120 SIZEL$ = CHR$(LEN(CMD$) MOD 256)
130 CHECKSUM = 0
140 FOR X = 1 TO LEN(CMD$)
150 CHECKSUM = CHECKSUM + ASC(MID$(CMD$,X,1))
160 NEXT X
170 CHECKSUM$ = CHR$(CHECKSUM AND 255)
180 PRINT #1, STX$ + SIZEM$ + SIZEL$ + CMD$ + CHECKSUM$
190 '
200 '——RECEIVE RESPONSE——
210 TOUT = 4: GOSUB 390
220 IF I$ <> STX$ THEN 180
230 TOUT = 3: GOSUB 390
240 SIZE = 256 * ASC(I$)
250 TOUT = 3: GOSUB 390
260 SIZE = SIZE + ASC(I$)
270 CHECKSUM = 0
280 RESPONSE$ = ""
290 FOR I = 1 TO SIZE
300 TOUT = 3: GOSUB 390
310 RESPONSE$ = RESPONSE$ + I$
320 CHECKSUM = CHECKSUM + ASC(I$)
330 NEXT I
340 TOUT = 3: GOSUB 390
350 N = ASC(I$)
360 IF N <> (CHECKSUM AND 255) THEN PRINT "RESPONSE CHECKSUM ERROR"
370 RETURN
380 '
390 '——READ CHARACTER FROM INSTRUMENT TO I$——
400 ON TIMER (TOUT) GOSUB 430: TIMER ON
410 IF LOC(1) < 1 THEN 410 ELSE TIMER OFF: I$ = INPUT$(1,#1)
420 RETURN
430 TIMER OFF: RESPONSE$ = "RECEIVE TIMEOUT": RETURN 440
440 RETURN 370
```

7.9.2.3 IEEE Sample Host Program

This program demonstrates IEEE488 communications with an IC/4. This example program was written using QuickBasic version 4.0 and used a national instruments PCIIA IEEE488 card and drivers.

Below is a listing of the program's variables:

```
bd0%    =  unit descriptor identifying the GPIB
bd1%    =  unit descriptor identifying the ICplus
CNT%    =  size of command or maximum size of response
IBCNT% =   number of bytes read
CMD$    =  command string entered by user to be sent to IC/4 PLUS
status% =  staus returned by national Instrument drivers
```

```
'<<<<<<<<<< INITIALIZATION >>>>>>>>>>
REM $INCLUDE: 'qbdecl4.bas'                 'National Instruments include library

'<<<<<<<<< OPEN DEVICES >>>>>>>>>>
begin:
 bd0%  = ILFIND("gpbi0")                    'Open the GPIB.
 bd1%  = ILFIND("icplus")                   'Open the IC/4 PLUS.

'<<<<<<<<<< CLEAR DEVICES >>>>>>>>>>>
 CALL IBCLR(bd0%)                           'Clear the GPIB.
 CALL IBCLR(bd1%)                           'Clear the IC/4 PLUS.
 CLS                                        'Clear screen.

lup:
 '<<<<<<<<<< SEND COMMAND >>>>>>>>>>
 PRINT
 INPUT "ENTER COMMAND STRING "; CMD$
 CMD$ = CMD$ + CHR$(&HA)                    'Add EOS character to command.
 CNT% = LEN(CMD$)                           'Find length of command.
 status% = ILWRT(bd1%, CMD$, CNT%)          'Write command.

'<<<<<<<<<< READ RESPONSE >>>>>>>>>>
msg$ = SPACE$(2000)                         'Make room for largest response.
CNT% = LEN(msg$)
status% = ILRD(bd1%, msg$, CNT%)            'Read response.
```

```
 '<<<<<<<<<< PRINT RESPONSE >>>>>>>>>>
 msg$ = LEFT$(msg$, IBCNT%)
 PRINT msg$;

GOTO lup                                   'Get next command

END
```

To implement serial polling of the message available (MAV) bit the following lines may be added to the IEEE488 program listed above.

```
'<<<<<<<<<< WAIT FOR MESSAGE AVAILABLE BIT >>>>>>>>>>
WAITMAV:

CALL IBRSP (bd1%, SPR%)
B = SPR%/16
B = INT(B)
IF B = 1 THEN GOTO RESPONSE ELSE GOTO WAITMAV

RESPONSE:
```

After sending a command to the IC/4, the status byte is polled. The response to the command is retrieved only after the MAV bit is set (2^4 = 16).

Section 8
Source/Sensor Set Up

Contents

8.1 Source / Sensor Set Up Overview

The IC/4 provides the capability to configure the instrument's source control and measurement sensor channels. The basic unit has two channels each of source control and measurement sensors. Optionally, it will support four channels of each. Each source control channel is treated as an individual device. The sensors, however, are treated in pairs. The second set of optional sensors is referred to as Sensor Pair 2 in the IC/4 or Sensor Board 2 in the IC/4 PLUS. The second pair of source controls are referred to as Source 3 and Source 4.

Display Tree For Source / Sensor Set Up

```
PROGRAM
  └── SOURCE/SENSOR DIRECTORY
        ├── SOURCE CHANNEL CONFIGURATION
        └── SENSOR BOARD CONFIGURATION
```

Source / Sensor Set Up is initiated by selecting the **Source / Sensor** panel (F4) in the Program display. This will invoke the Source/Sensor Directory (Figure 8.1). Upon entry, the cursor will be placed at the last referenced source channel or sensor pair. You may return to the Program display by selecting the **Program** panel (F6).

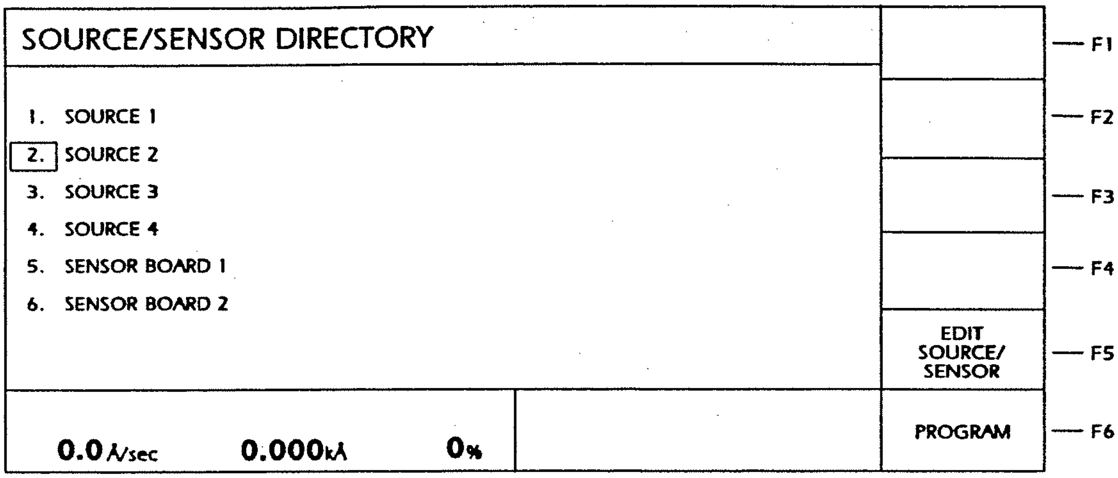


Figure 8.1 Source/Sensor Directory

8.2 Source / Sensor Navigation

Once in the Source/Sensor Directory a source channel or sensor pair is selected for configuration by positioning the box cursor at the desired device and then selecting the **EDIT SOURCE/ SENSOR** panel (F5). The displays that follow are sensitive to the type of device selected and the presence of optional hardware. Certain parameters may be displayed or inhibited depending on the actual hardware configuration or the values entered. The parameters for each channel or board are contained on a single display page. New values are input from the front panel followed by pressing the **Enter** key. Values are cleared by pressing the **Clear** key.

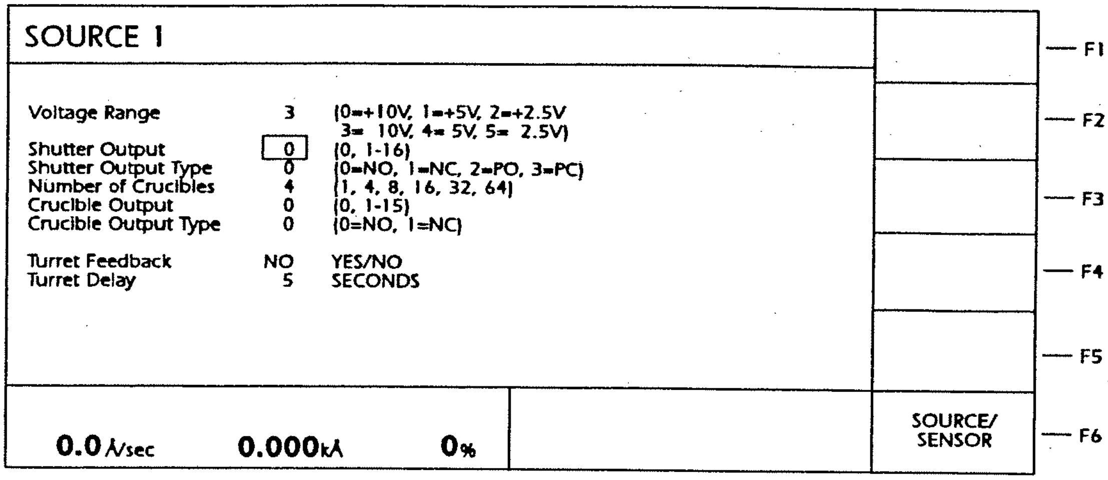


Figure 8.2 Source Parameter Editing

PANEL SELECTION CHOICES FOR SOURCE/SENSOR EDITING

F6 **SOURCE/SENSOR** Select this panel to return to the SOURCE/SENSOR Directory and save the current parameters.

8.3 Source Parameters

The following parameters can be displayed for each of the four supported source control channels. Channels 1 and 2 are part of the basic unit configuration; channels 3 and 4 are optional.

VOLTAGE RANGE 0/1/2/3/4/5

This parameter selects the control voltage output for the source being edited. Permissible values are 0, 1, 2, 3, 4 or 5 for maximum output voltages of 10, 5, 2.5, -10, -5, and -2.5 Volts respectively. The default value is 3, for a control voltage output of 0 to -10 Volts.

SHUTTER OUTPUT 0 to 16

This parameter designates which of the 16 output relays is to be used as the Source Shutter relay. Values range from 0 through 16. 0 indicates that a Shutter is not used and the values 1 through 16 correspond to the appropriate output relay. The default value is 0. If a value other than 0 is entered the relay chosen as the Source Shutter relay is designated as such in the Output Directory of the I/O Display. When running a Layer containing the Source for which the Shutter Output parameter is programmed, the logic condition is set to be true when the Layer is in DEPOSIT or MANUAL. The condition remains true until the end of DEPOSIT or until a STOP command is received.

SHUTTER OUTPUT TYPE 0/1/2/3

This parameter designates the normal state of the relay contact closure for the Shutter Output relay. Permissible values are 0, 1, 2 or 3. 0 indicates an Normally Open relay, 1 indicates a Normally Closed relay, 2 indicates a Pulsed Open relay and 3 indicates a Pulsed Closed relay. The default value is 0.

NUMBER OF CRUCIBLES 1,4,8,16,32,64

Refer to Section 3.6.2.1 for an example of programming Turrets source crucible selection. This parameter can be used to automatically index the turret position when using a multiple pocket turret source. Permissible values are 1, 4, 8, 16, 32 and 64. The value selected denotes the number of pockets in the turret source. The default value is 1 and indicates a single pocket source. If a 1 is chosen, the parameters- Crucible Output, Crucible Output Type, Turret Feedback and Turret Delay or Turret Input are removed from the Display. The number of crucibles determines the number of relays needed for the crucible output. As the relays are BCD encoded, 2 relays are needed for 4 crucibles, 3 for 8, 4 for 16, 5 for 32 and 6 for 64.

CRUCIBLE OUTPUT 0 to 15

This parameter designates which of the output relays are to be used as Crucible Output relays. Values range from 0 to 15. The default is 0 and indicates the Crucible Output is inactive. The value entered into this parameter indicates which of the output relays begins the sequence of relays used as crucible control outputs. For example, a 4 entered into the Number of Crucibles parameter and a 1 entered into the Crucible Output parameter will designate output relays 1 and 2 as crucible control outputs with the least significant bit of the BCD in relay output 1. An 8 entered into the Number of Crucibles parameter and a 1 entered into the Crucible Output parameter will designate output relays 1, 2, and 3 as crucible control outputs with the least significant bit of the BCD in relay 1.

CRUCIBLE OUTPUT TYPE 0/1

This parameter designates the normal state of the relay contact closures for the Crucible Output relays. Permissible values are 0 and 1. 0 indicates an Normally Open relay, 1 indicates a Normally Closed relay.

TURRET FEEDBACK YES/NO

Some turret source indexers may provide feedback to signify when the turret is in the proper position. This parameter allows the IC/4 to accept this input and respond accordingly. Parameter entry may be either YES or NO. A YES indicates that Turret Feedback is expected and the Turret Input parameter is displayed on the screen. A NO indicates there is no Turret Feedback forthcoming and the Turret Delay parameter is displayed. The default value is NO. See the Turret Input and Turret Delay descriptions below.

TURRET INPUT 0 to 16

This parameter designates which of the 16 inputs is to be the Turret Feedback input. Values range from 0 to 16. Values 1 through 16 correspond to the appropriate input. Value 0 indicates that an input for turret feedback is not used. The default value is 0. However, an input must be assigned, or the process will never proceed past the source switching phase of the process. If a value other than 0 is entered, then the input chosen as the Turret Input is designated as such in the Input Directory of the I/O display. Input lines are activated with 10-24 VAC or 10-30 VDC.

TURRET DELAY 1 to 60 sec

If Turret Feedback is not used a timer will be set to allow the source crucible time to rotate into position. This parameter sets the amount of time the Process will remain in the Source Switch phase waiting for the crucible to rotate. Permissible values are 1 to 60 seconds. The default value is 5 seconds.

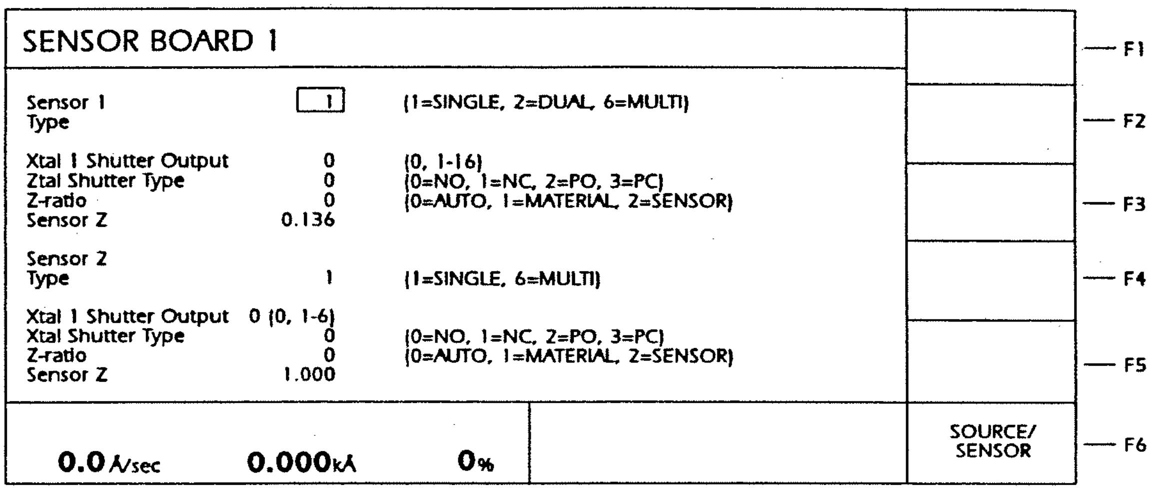


Figure 8.3 Sensor Parameter Editing

8.4 Sensor Parameters

The following entries represent the parameters possible with the standard two sensors. Each sensor is configured separately. If the unit has two additional, optional sensors, the additional pair of sensors will have an identical parameter set.

SENSOR 1

TYPE 1/2/6

This parameter provides selection among the single, dual, and CrystalSix sensor heads. It enables the Crystal Switch feature for the dual and CrystalSix heads; enables the crystal indexing feature on the hand held power controller and enables the Secondary Tooling parameter for the dual sensor head. Allowable values are 1, 2, and 6. The default value is 1. If a value of 1 is entered the Xtal Switch Output parameter is removed from the display. If a value of 2 is entered, then Sensor 2 Type is automatically set to a value of 2. This parameter cannot be changed while executing a process.

CAUTION: *Any time the TYPE value is changed, the instrument has to be turned off and then back on in order for the instrument to recognize the change.*

XTAL SWITCH OUTPUT 0 to 16

This parameter designates which of the 16 output relays is to be used as the Crystal Switch relay for Sensor 1. Values range from 0 to 16. Values 1 through 16 correspond to the appropriate output. Value 0 indicates that the Crystal Switch Output is not used. The default value is 0. ***A non-zero value must be entered if a Sensor Type value of 2 or 6 is chosen.*** If a value other than 0 is entered, the relay chosen as the Crystal Switch relay is designated as such in the Output Directory of the I/O Display. The contact closure on this relay is always Normally Open.

If a dual head is chosen for Sensor 1 Type, the output relay will close upon initiating a Crystal Switch and then open upon initiating a second Crystal Switch. If CrystalSix is chosen in Sensor 1 Type, then upon initiating a Crystal Switch, the output relay will first close for 1 second, then open for 1 second, then close for one second and then open.

NOTE: When using a CrystalSix sensor, the instrument will automatically index each of the 6 crystals when the instrument is turned on. This is done to take the initial frequency readings on each of the crystals, and to verify any changes in their status during the time the power was off.

XTAL SHUTTER OUTPUT 0 to 16

This parameter designates which of the 16 outputs is to be used to activate the Crystal Shutter for Sensor 1. Values range from 0 to 16. Values 1 through 16 correspond to the appropriate output. Value 0 indicates that a shutter is not used. The default value is 0. If a value other than 0 is entered then the relay chosen as the Crystal Shutter relay is designated as such in the Output Directory of the I/O Display. The logic condition is set to be true as long as the Layer containing Sensor 1 is in SHUTTER DELAY, DEPOSIT, MANUAL, or in the Sample period of the Ratewatcher function. The condition remains true until the end of DEPOSIT, until a STOP command is received, or during the Hold period of the RateWatcher function.

XTAL SHUTTER TYPE 0/1/2/3

This parameter designates the normal state of the relay contact closure for the Crystal Shutter relay for Sensor 1. Permissible values are 0, 1, 2 or 3. 0 indicates an Normally Open relay, 1 indicates a Normally Closed relay, 2 indicates a Pulsed Open relay and 3 indicates a Pulsed Closed relay. The default value is 0 for Normally Open.

Z-RATIO (IC/4 PLUS Only) 0/1/2

This parameter designates the method in which the Z-ratio value will be obtained for use in computing thickness with this sensor. Permissible values are 0, 1 or 2. 0 indicates that the Auto Z calculation feature of the system is used. 1 indicates that the Z-ratio established in Material Definition is used. 2 indicates that the Z-ratio used is to be taken from the value shown in SENSOR Z. The default value is 1 for the Material Z-ratio.

SENSOR Z (IC/4 PLUS only) (display only)

The value found here is the most recently calculated Auto Z-ratio associated with this sensor. It is entered by the instrument automatically. When the Z-ratio parameter (above) is set to 0, this value is updated once every second. In the event of an Auto Z failure, the most recently calculated Z value is entered and held constant until the crystal is replaced. When the Z-ratio parameter (above) is set to 2, Sensor Z is used as the constant Z-ratio for this sensor. When the Z-ratio parameter is set to 1, the value found in Sensor Z is disregarded.

SENSOR 2

Sensor 2 parameters are identical to Sensor 1 parameters except that only Type 1 or 6 are allowed. If the sensor is a dual head, that is indicated by selecting 2 for the type in Sensor 1.

8.5 Error Messages In Source / Sensor Set Up

Illegal Input

You are attempting to input a value that is not one of the permissible values for that parameter.

Input In Use

You are attempting to use an input number designation that has already been configured on another screen for another use. See INPUT DIRECTORY in the I/O Display to determine a free input.

Output In Use

You are attempting to use an output relay number designation that has already been configured on another screen for another use. See OUTPUT DIRECTORY in the I/O Display to determine a free output.

Value Too Large
Value Too Small

The value that you are attempting to enter is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press the **Clear** key to delete the illegal value and enter again.

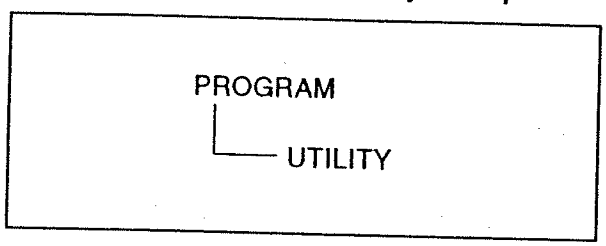
Section 9
Utility Set Up

Contents

9.1 Utility Set Up Overview

The IC/4 provides the capability to modify a series of top level parameters that define the controller's method of handling system level activities or data. Some of the parameters are automatically incremented by the instrument.

Display Tree For Utility Set Up



Utility Set Up is initiated by selecting the UTILITY panel (F5) in the Program display. This will invoke the Utility Display (Figure 9.1). Upon entry, the cursor will be placed at the last referenced utility parameter. The parameters are contained on two display pages.

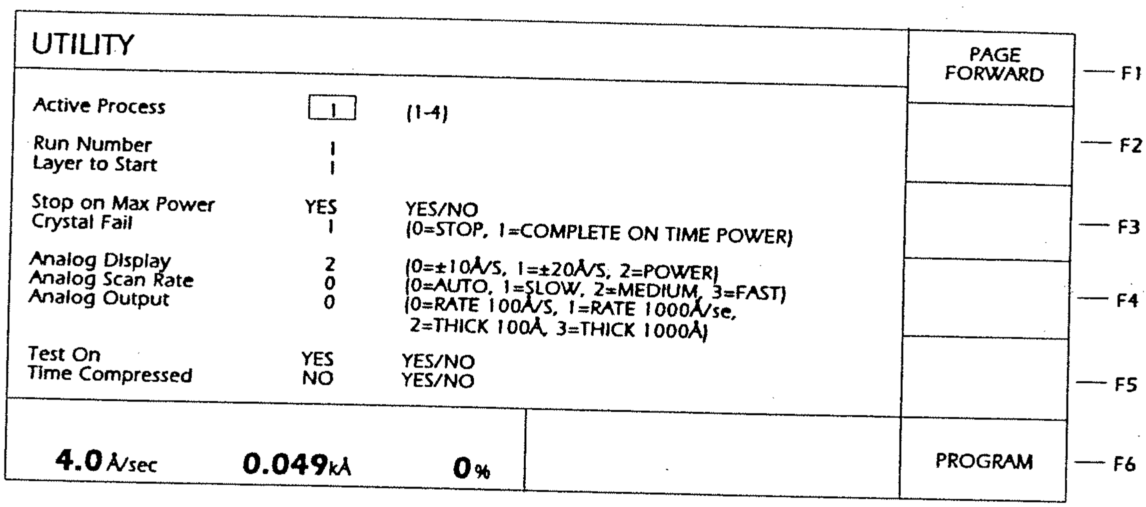


Figure 9.1 Utility Display (Page 1)

9.2 Utility Navigation

A parameter is selected for entry by positioning the box cursor at the desired value following the parameter description. New values are input from the front panel followed by pressing the **Enter** key. Values are cleared by pressing the **Clear** key.

PANEL SELECTION CHOICES FOR UTILITY PARAMETERS

F1	**PAGE FORWARD**	Select this panel to access the second page of parameters.
F2	**PAGE BACK**	Select this panel to return to the first page of parameters.
F6	**PROGRAM**	Select this panel to return to the PROGRAM display.

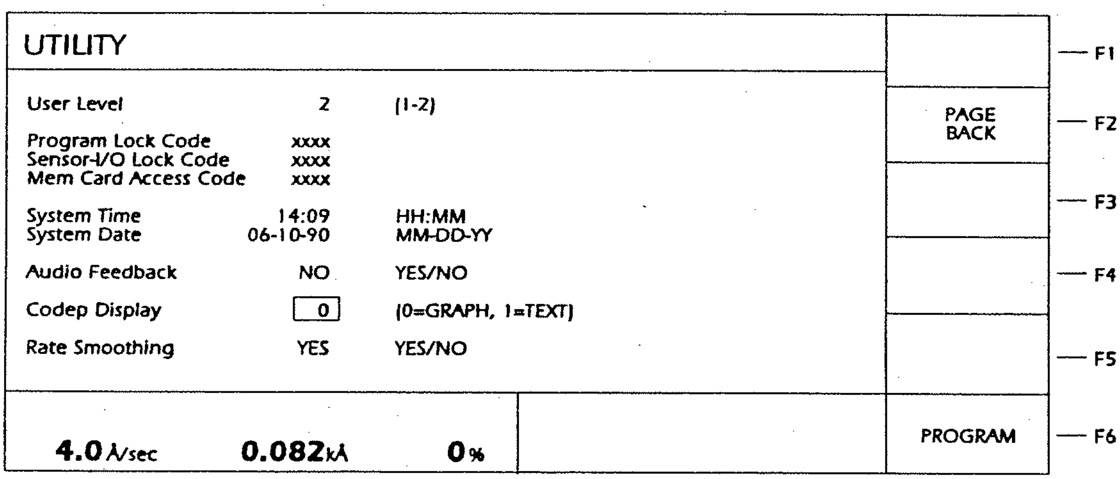


Figure 9.2 Utility Display (Page 2)

9.3 Utility Parameters

ACTIVE PROCESS 1/2/3/4

This parameter selects which sequence of Layers, as defined in Process Set Up, is to be executed. Values are 1, 2, 3, or 4. The default value is 1. This parameter cannot be changed while executing a process.

RUN NUMBER 1 to 999

This is a counter which increments by one at each start of a Process. Any arbitrary value may be entered as a starting point. Values range from 1 to 999. The default value is 1.

LAYER TO START 1 to 100 [250 for the IC/4 PLUS]

This selects the starting Layer from the sequence of Layers defined in the Active Process. The upper limit to the range of values is determined by the number of Layers defined for a given Process. Values range from 1 to a maximum of 100 (or 250 for the IC/4 PLUS). This value cannot be changed while executing a process.

STOP ON MAX POWER YES/NO

This parameter provides a safety feature. If the parameter is set to YES, the control voltage to the source power supply will be set to zero and the instrument will STOP if the power level is held at maximum power for 5 seconds. The default value is YES.

CRYSTAL FAIL 0/1

This parameter determines the instrument response in the event of a crystal failure while in a deposition phase. A "0" will cause the instrument to Stop. A "1" activates the Complete on Time Power feature. The default value is 1.

NOTE: This parameter has no effect if a crystal fail occurs in pre- or post-deposit. The instrument will always STOP if a crystal fail occurs in any of those states.

ANALOG DISPLAY 0/1/2

This determines the vertical scale for the graphics display in the OPERATE mode. Values are 0, 1, or 2. A zero sets the vertical scale to ± 10 Å/s, a 1 sets the vertical scale to ± 20 Å/s, and a 2 sets the scale to % Power. The default value is 0.

ANALOG SCAN RATE 0/1/2/3

This determines the horizontal axis for the graphics display in the OPERATE mode. Values are 0, 1, 2 or 3. A zero places the scan rate into Auto mode. A 3 sets the scale to 3 measurements per pixel, a 2 sets the scale to 10 measurements per pixel, and a 1 sets the scale to 40 measurements per pixel. The default value is 0. When in the auto mode, the scan rate starts in "fast", after reaching the end of the display the graph collapses to half size and continues in "medium", again at the end of the display the graph will collapse to half size and continue in "slow".

ANALOG OUTPUT 0/1/2/3/4

This determines the recorder output function and sets the vertical scale for the Analog output. Values are 0, 1, 2, 3 or 4. The analog output is +10 volts full scale. Values of 0 and 1 set the function to output rate. A 0 sets the vertical scale from 0 to 100 Å/s, a 1 sets the vertical scale from 0 to 1000 Å/s. Values of 2 and 3 set the function to output thickness. A 2 sets the vertical scale for a thickness range of 100 Å, and a 3 sets the scale to a range of 1000 Å. After the maximum thickness has been reached, for the thickness function, the analog control voltage is reset to zero and again begins to increase with increasing thickness. A value of 4 set the function to output rate deviation. When the rate deviation function is chosen, the output voltage for the desired rate will be +5 volts and the range of output is ±50Å/sec. The default value is 0.

TEST ON YES/NO

This feature provides a constant rate signal which can be varied by altering the density and tooling parameters (see Section 3.6.7). It is designed to allow testing of a Process without actually running a deposition. Yes turns the test signal on. The default value is NO. This parameter cannot be changed while executing a process.

TIME COMPRESSED YES/NO

When in TEST MODE, this feature allows a faster than real time execution of the Process. This is useful when testing a long Process. A value of YES increases the speed of execution of 10 to 1. The default value is NO.

USER LEVEL 1/2

This allows the selection of one of the two user levels provided in the instrument. Values are 1 or 2. For User Level 1, certain features, which are not commonly used, are omitted. For User Level 2, all instrument parameters are made available for programming / set up. The default value is 1.

PROGRAM LOCK CODE 1 to 9999, 0

The program lock code restricts access to programming and modifying the instrument. All parameters, including the SENSOR parameters and I/O parameters, can be reviewed but none can be changed unless the correct lock code is entered. Values range from 1 to 9999.

Before entering a new lock code, the current code must be entered.

Entering a value of zero erases the lock code and provides open access. The default condition is unlocked or open access. If a non-zero lock code is programmed, the lock code can be reset to the unlocked condition by holding in the **Clear** key while powering up the instrument. This must be done immediately after the diagnostic beep signals.

> ***CAUTION:*** *If a lock code is not set, that is if it is set to zero, then powering up while holding the Clear key will default all the instrument's parameters.*

When a Program Lock Code is entered, that code must be entered in the Program Display in order to change any of the set up parameters in the instrument.

SENSOR-I/O LOCK CODE 1 to 9999, 0

The Sensor-I/O lock code provides privileged access to programming the SENSORS and I/O devices. Parameters for these devices can be reviewed but cannot be changed unless the correct lock code is entered. Values range from 1 to 9999.

Before changing the sensor I/O lock code, the current code must be entered. Entering a new value of zero erases the lock code and provides open access. The default condition is unlocked for open access. A non-zero lock code can be reset to the unlocked condition by holding in the Clear key while powering up the instrument.

> ***CAUTION:*** *If one or both lock codes are non-zero, powering up the instrument while holding the Clear key will erase the lock code(s). If the lock codes are set to zero, then holding in the Clear key while powering up the instrument will set all the instrument's parameters to their default values.*

When a Sensor-I/O Lock Code is entered in UTILITY Set Up, that code must be entered prior to Sensor or I/O Set Up in order to change any of the device parameters.

MEM CARD ACCESS CODE 1 to 9999, 0

The memory card access code allows the ability to input information from a memory card, even when the program lock code is locked. If there is a memory card lock code set, (a non-zero access code), then by entering the access code on the memory card display, a retrieve parameters operation is allowed. Otherwise memory card retrieval is not allowed when a lock code is present. This parameter has no effect if there are no lock codes, or the access code is set to zero.

> **NOTE:** When holding the Clear key on power up, the memory card access code is cleared when the parameters are cleared; not when the lock codes are cleared. The memory card access code is not stored on nor retrieved from a memory card. Program and I/O lock codes are stored on and retrieved from a memory card.

SYSTEM TIME 00:00 to 23:59 mins:secs

Twenty four hour clock for current time of day. Values range from 00:00 to 23:59.

SYSTEM DATE mm-dd-yy

Current day of year. Increments automatically. Values range from 01-01-00 to 12-31-99.

AUDIO FEEDBACK YES/NO

Activates Audio Feedback; signifying data entry. The default value is Yes which activates the audio signal.

CODEP DISPLAY (IC/4 PLUS only) 0/1

This value determines whether the Operate Display for a co-deposition provides text-only or a text/graphic display. The default is 0 for a text/graphic display.

RATE SMOOTHING YES/NO

This parameter provides an averaging of the instantaneous rate measurement. The default value is YES. When set to YES, the Rate displayed on the CRT and the rate output to the analog output is a 5 point rolling average. When set to NO, the rate displayed on the CRT and the rate output to the analog output is the instantaneous rate measurement. The measurement rate is 5 Hz (10 Hz for the IC/4 PLUS).

9.4 Error Messages In Utility Set Up

Illegal Day

The numeric value you entered is not in the 1 to 31 range or not valid for the month specified. Press the Clear key and enter a valid value.

Illegal Hour

The numeric value you entered is not in the 00 to 23 range. Press the Clear key and enter a valid value.

Illegal Month

The numeric value you entered is not in the 01 to 12 range. Press the Clear key and enter a valid value.

Process Undefined

The process number of 1, 2, 3 or 4 has not been defined. Only process numbers with defined material layers can be entered.

Value Too Large
Value Too Small

The value that you are attempting to enter is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press the Clear key to delete the out of range value and enter again.

Section 10
Installation and Interfaces

Contents

10.1 Location Guidelines

Before permanently installing this controller it is recommended that this entire section on Installation and Interfaces be read and its recommendations be followed as closely as possible. Leybold Inficon has taken numerous steps to insure that its equipment will operate in a variety of harsh situations. Failure to adhere to these simple practices may adversely affect the performance and longevity of this controller, or controllers made by any manufacturer.

10.1.1 Sensor Types

The choice of sensor type must be dictated by the process, the deposition material and the physical characteristics of the process chamber. General guidelines for each sensor type produced by Inficon are outlined in the Sensor Selection table (page 10-3). For specific recommendations, consult your Inficon representative.

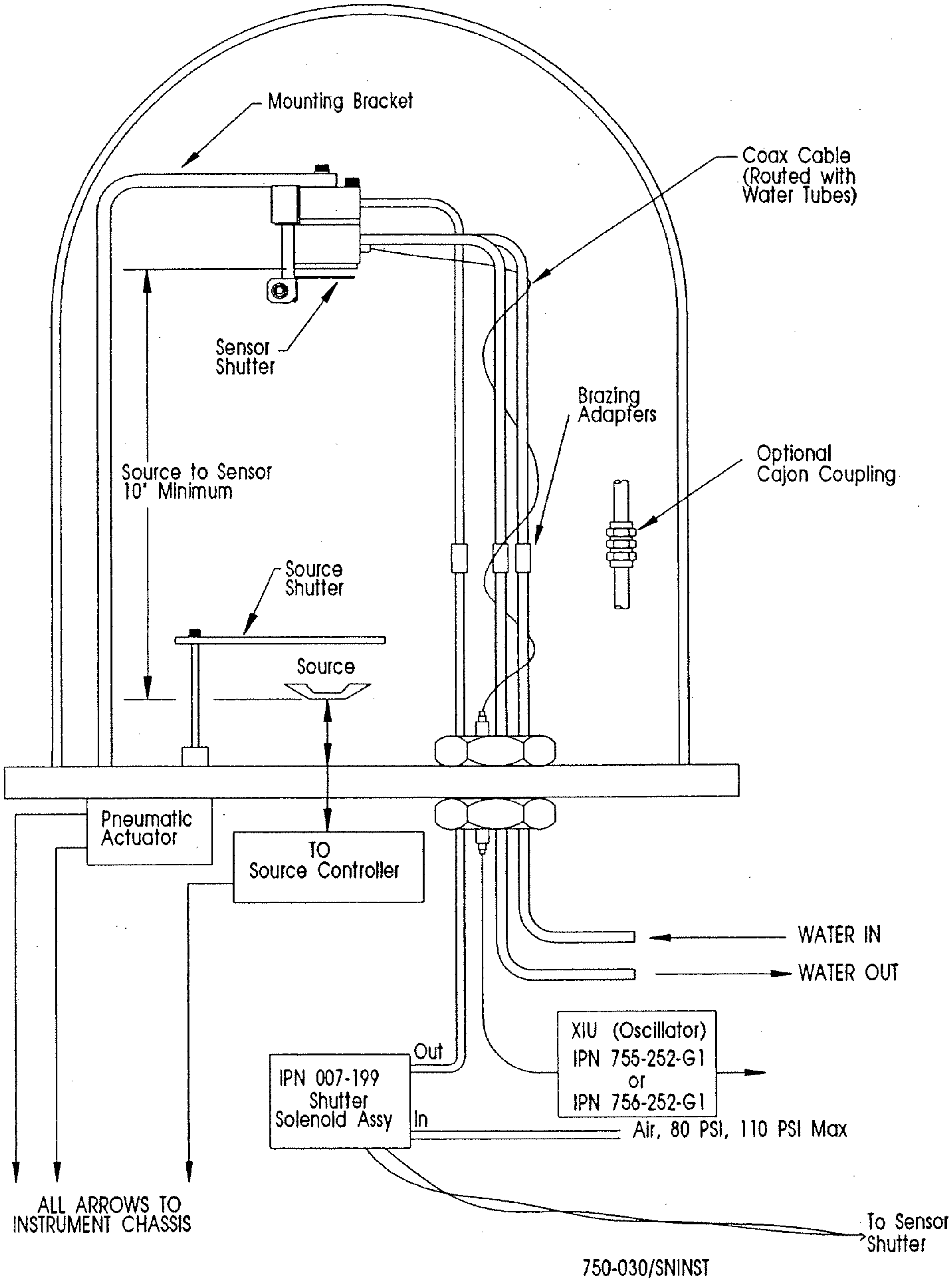


Figure 10.1 Typical Installation

Table 10.1 Sensor Selection Table

FEATURES					
	Max. Bakeout Temperature*	Size (Max. Envelope)	Water Tube & Coax Length	Body & Holder	IPN
CrystalSix Sensor	130°C	3.5" dia. x 2.0" high (8.9cm dia. x 5.1cm high)	30" (76cm)	304 SS (plate, holders, & material shield)**	750-250-G1
Standard Sensor	130°C	1.063" x 2.24" x .69" high (2.7cm dia. x 5.7cm x 1.75cm high)	30" (76cm)	304 SS	750-211-G1
Sputtering Sensor	105°C	1.36" dia. x .47" high (3.45cm dia. x 1.18cm high)	30" (76cm)	Au-plated BeCu	007-031
Compact Sensor	130°C	1.11" x 1.06" x 1.06" high (2.8cm x 2.7cm x 2.7cm high)	30" (76cm)	304 SS	750-213-G1
UHV Bakeable Sensor	450°C	1.35" x 1.38" x .94" high (3.4cm x 3.5cm x 2.4cm high)	12" (30.5cm) 20" (50.8cm) 30" (76.2cm)	304 SS	007-219 007-220 007-221
Dual Sensor	130°C	1.45" x 3.45" x 1.70" high (3.7cm x 8.8cm x 4.3cm high)	30" (76cm)	304 SS	750-212-G2
Shutter Assembly	400°C	two models available	N/A	300-series SS	750-210-G1 750-005-G1 (Sputtering)

*For Bake only; waterflow is required for actual deposition monitoring. These temperatures are conservative maximum device temperatures, limited by the properties of Teflon (PTFE) at higher temperatures. In usage, the water cooling allows operation in environments that are significantly elevated, without deleterious affects.

**Aluminum body for heat transfer.

NOTE: Do not allow water tubes to freeze. This may happen if the tubes pass through a cryogenic shroud and the water flow is interrupted.

NOTE: For best operation, limit the maximum input water temperature to less than 30°C.

NOTE: In high temperature environments more heat may transfer to the water through the water tubes than through the actual transducer. In extreme cases it may be advantageous to use a radiation shield over the water tubes.

CAUTION: *The performance of this instrument depends on the careful installation of the chosen transducer. Improper installation will cause problems with deposition repeatability, crystal life and rate stability.*

10.1.2 Sensor Installation

Figure 10.1 shows a typical installation of an Inficon water cooled crystal sensor in the vacuum process chamber. Use the illustration and the following guidelines to install your sensors for optimum performance and convenience.

Generally, install the sensor as far as possible from the evaporation source (a minimum of 10" or 25.4 cm) while still being in a position to accumulate thickness at a rate proportional to accumulation on the substrate. Figure 10.2 shows proper and improper methods of installing sensors.

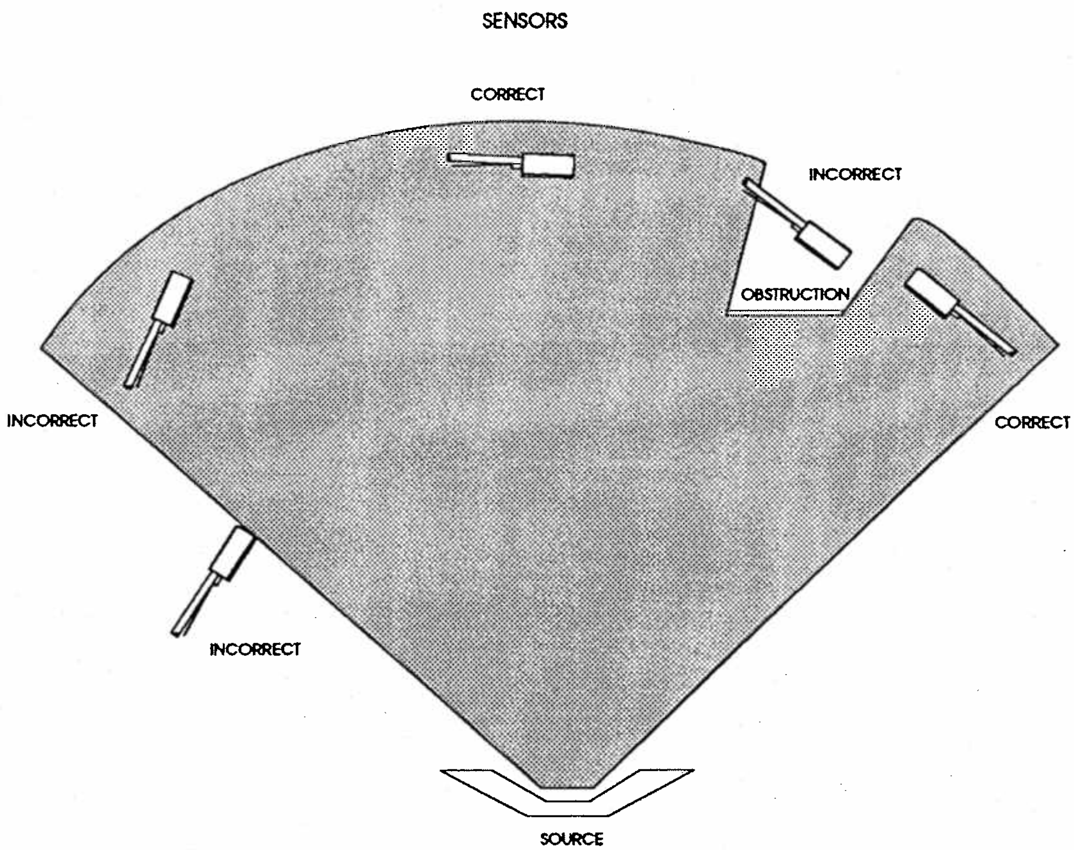


Figure 10.2 Sensor Installation Guidelines

To guard against spattering, use a source shutter or crystal shutter to shield the sensor during the initial soak periods. If the crystal is hit with even a minute particle of molten material, it may be damaged and stop oscillating. Even in cases when it does not completely stop oscillating, it may become unstable.

- Mount the sensor to something rigid and fixed in the chamber. Do not rely on the water tubes to provide support.
- Plan the installation to insure that there are no obstructions blocking the path between the Sensor and the Source. Be certain to consider rotating or moving fixtures.
- Install sensors so their central axis (an imaginary line drawn normal to the center of the crystal's face) is aimed directly at the virtual source being monitored.
- Be sure there is easy access for the exchange of crystals.
- (IC/4 PLUS Only) For systems employing simultaneous source evaporation (co-dep), try to locate the sensors so the evaporant from each source is only flowing to one sensor. This is not generally possible to do without special shielding or optional "material directors".

10.1.3 Control Unit Installation

The control unit is designed to be rack mounted. It may be also used on a table. The controller is forced air cooled, with the air flow exiting from rear of the unit for clean room convenience.

It is generally advisable to centrally locate the controller, minimizing the length of external cabling. The cable supplied from the Sensor card to the XIU is fifteen feet. Up to three twenty-five foot extension cables, 755-256-G25, may be added.

10.2 Avoiding Electrical Interference

Careful consideration of simple electrical guidelines during installation will avoid many problems caused by electrical noise.

To maintain the required shielding and internal grounding and ensure safe and proper operation, the instrument must be operated with all enclosure covers, sub-panels and braces in place and fully secured with the screws and fasteners provided.

> **NOTE:** When using the IC/4 with an RF sputtering system, the cable between the IC/4 and oscillator should be kept as far away from the RF transmission cable as possible. Interference from the RF transmission cable may cause an erroneous crystal fail.

10.2.1 Verifying / Establishing Earth Ground

If a ground must be established, the following procedure is recommended:

Where soil conditions allow, drive two ten foot copper clad steel rods into the ground six feet apart. Pour a copper sulfate or salt solution around to improve the ground's conduction. A near zero resistance measurement indicates earth ground is achieved.

Keep connections to this grounding network as short as possible.

10.2.2 Connections to Earth Ground

There are two earth connectors:

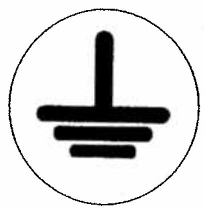
a. The ground connection on the controller is a threaded stud with a hex nut. One suggestion is to connect a ring terminal to the ground strap, thus allowing a good connection, and easy removal and installation. See Figure 10.3 for the suggested method of grounding.

b. This instrument is also connected to earth via a sealed three-core power cable, which must be plugged into a socket outlet with a protective earth terminal. Extension cables must always have three conductors including a protective earth conductor.

(SEE WARNING ON NEXT PAGE)

WARNING!!

NEVER INTERRUPT THE PROTECTIVE EARTHING INTENTIONALLY. ANY INTERRUPTION OF THE PROTECTIVE EARTH CONNECTION INSIDE OR OUTSIDE THE INSTRUMENT, OR DISCONNECTION OF THE PROTECTIVE EARTH TERMINAL IS LIKELY TO MAKE THE INSTRUMENT DANGEROUS.



THIS SYMBOL INDICATES WHERE THE PROTECTIVE EARTH GROUND IS CONNECTED INSIDE THE INSTRUMENT. NEVER UNSCREW OR LOOSEN THIS CONNECTION.

WARNING!!

AN EXTERNAL GROUND CONNECTION IS NORMALLY REQUIRED TO ENSURE PROPER OPERATION, ESPECIALLY IN ELECTRICALLY NOISY ENVIRONMENTS.

When used with RF powered sputtering systems, the grounding method may have to be modified to the specific situation. An informative article on the subject of Grounding and RFI Prevention was published by H.D. Alcaide, in "Solid State Technology", p.117, April, 1982.

In many cases, a braided ground strap is sufficient. However, there are cases when a solid copper strap (0.030" thick x 1" wide) is required because of its lower RF impedance.

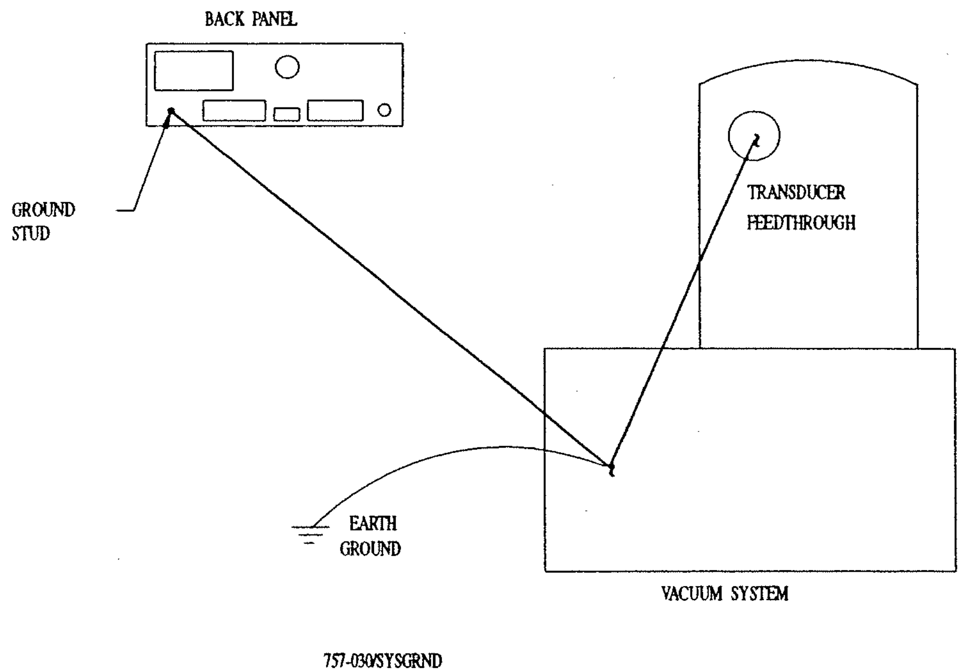


Figure 10.3 System Grounding Diagram

10.2.3 Minimizing Noise Pickup From External Cabling

When a controller is fully integrated into a deposition system, there are many wire connections, each a potential path for noise to reach the inside of the control unit. The likelihood of these wires causing a problem can be greatly diminished by the using the following guidelines.

- Use shielded coax cable or twisted pairs for all connections.
- Minimize cable lengths.
- Avoid routing cables near areas that have the potential to generate high levels of interference. For example, large power supplies such as those used for electron beam guns or sputtering sources can be a source of large, rapidly changing electro-magnetic fields. Placing cables as little as one foot away from these problem areas can be significant.
- Be sure that a good ground system and straps are in place per the above recommendations.
- Ensure that all instrument covers and option panels are in place and tightly secured with the provided fasteners.

10.3 Connecting the Controller

The operation of the controller depends on the proper connection of power and signal interfaces to owner equipment and sources.

10.3.1 Verifying the Correct Input Voltage

The controller is initially powered by AC line current. Two voltage ranges are supported- 90 to 132 and 180 to 264. One of these two operating voltage ranges is factory set and has been marked on a label on the rear panel. The line voltage provided in your facility must be within the voltage range indicated on the unit.

WARNING!!

DAMAGE TO THE UNIT AND/OR ITS INTERFACES AS WELL AS SAFETY HAZARDS WILL RESULT BY OPERATING THE UNIT IN THE INCORRECT VOLTAGE RANGE.

If the unit needs to be operated at the alternate voltage range, it is recommended that the controller be factory changed and provided with the proper safety and identification labeling.

If necessary, the power supply's voltage range can be checked or changed at a site by a knowledgeable technician with extreme caution.

WARNING!!

THIS INSTRUMENT HAS LINE VOLTAGE PRESENT ON THE PRIMARY CIRCUITS WHENEVER IT IS PLUGGED INTO A MAIN POWER SOURCE.

NEVER REMOVE THE COVERS FROM THE INSTRUMENT DURING NORMAL OPERATION.

THERE IS NO OPERATOR SERVICEABLE ITEM WITHIN THIS INSTRUMENT.

REMOVAL OF THE TOP OR BOTTOM COVERS MUST BE DONE ONLY BY A TECHNICALLY QUALIFIED PERSON.

(continued on next page)

IN ORDER TO COMPLY WITH ACCEPTED SAFETY STANDARDS, THIS INSTRUMENT MUST BE INSTALLED INTO A RACK OR SYSTEM WHICH CONTAINS A MAINS SWITCH. THIS SWITCH MUST BREAK BOTH SIDES OF THE LINE WHEN IT IS OPEN AND IT MUST NOT INTERFERE WITH THE SAFETY GROUND.

After removing ***all*** electrical and data interfaces from the rear panel, access is gained to the internal power supply by first removing the top panel cover and then the internal shield.

The set voltage range can be determined by examining the jumper position shown in Figure 10.4. With a jumper in place the voltage range is 90 to 132; with the jumper removed the voltage range is 180 to 264. For your safety, the set voltage must agree with that indicated on the identification labels.

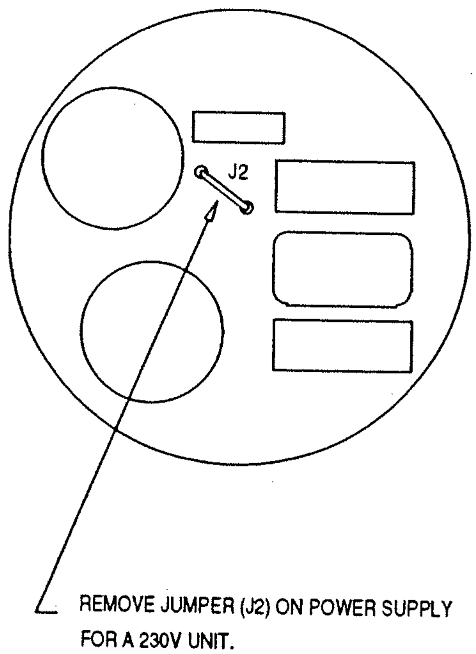


Figure 10.4 Voltage Range Jumper Location

10.3.2 Routing XIU Cables

The controller is shipped with a complete fifteen foot XIU cable, IPN 755-258. This cable can be conveniently extended in twenty-five foot increments up to a total of ninety feet with optional extender cables, IPN 755-256. The signals traveling on this cable are both analog and digital. It is suggested that it not be routed near areas with high levels of electromagnetic interference, even if its length must be somewhat increased.

10.3.3 Interface Cable Fabrication and 'Pin-out'

It is necessary to fabricate several cables in order to interface the controller to the deposition system. Refer to Section 10.2.3 Minimizing Noise Pickup From External Cabling.

10.3.3.1 Source Control Connection

A source control module, IPN 755-142, is included as standard equipment with the controller. It provides three conversion channels, two for source control and another for a chart recorder. A second source control module is available as an option. Except for unique bus addresses, the boards are interchangeable. The necessary connectors and pins for the controller side connections are contained in ship kit 755-144.

Table 10.2 Source Control Pin Connectors

Source Module	Type / Channel		Pins
1 (Address 300H, Port A)	Source	1	1,6 (common)
	Source	2	2,7 (common)
	Recorder	1	3,8 (common)
1 (Address 340H, Port B, optional)	Source	3	1,6 (common)
	Source	4	2,7 (common)
	Recorder	2	3,8 (common)

10.3.3.2 Input / Relay Module Connections

The Input / Relay module, IPN 755-122 or 756-122, is included as standard equipment with the controller and is used to interface with other machinery of the vacuum system. It can control components such as heaters, rotators or shutters through its sixteen relays. It can respond to external instructions through its sixteen isolated input lines. Standard equipment provides eight relays and eight input lines. Optionally, this can be expanded to 16 relays and 16 inputs. (16 relays and 16 inputs are standard on IC/4 PLUS.)

The module provides separate connectors for relay outputs and input lines. Circular connectors support eight high voltage relays; two different sizes are used to prevent mixing. A D-shell connector is used for the input lines. Additionally, an isolated 24V DC source is available with a maximum of 0.4 amps total on connector P-4 at pins 4, 9, 15 and 21 with pins 8, 14, 20 and 25 used as returns. Mating connectors are provided in ship kit 755-124. Refer to Figure 3.2 for connector locations.

Relay connections are rated at 240 volts maximum, 120 VA; 2A maximum.

Inputs are activated by applying 10 to 24 VAC (30 VDC).

CAUTION: *Do not switch voltages beyond the specified limit.*

Table 10.3 Input/Relay Pin Connections

(P-4) Top Relay Connector Relay	Pins	(P-5) Input Lines Input	Pins
1	24,28	1	1,20
2	23,27	2	2,21
3	22,26	3	3,22
4	13,19	4	4,23
5	12,18	5	5,24
6	11,17	6	6,25
7	10,16	7	7,26
8	3,7	8	8,27

	Pins	Returns
24V DC Source	4,9,15,21	8,14,20,25

Optional on IC/4 Standard on IC/4 PLUS

(P-3) Bottom Relay Connector Relay	Pins	(P-5) Input Lines Input	Pins
9	47,50	9	13,32
10	14,17	10	14,33
11	59,63	11	15,34
12	53,60	12	16,35
13	34,36	13	12,31
14	28,30	14	11,30
15	4,11	15	10,29
16	1,5	16	9,28

10.3.3.3 RS232 Communications

The RS232 serial communications module, IPN 755-302, is included in the controller as standard equipment. It is used to remotely control or monitor the IC/4. An industry standard DB25S connector is required for the host computer side connection. Depending on the computer source, all connections may not be necessary. The length of the cable is limited to fifty feet according to published standards. The controller interface operates as DTE (Data Terminal Equipment). Pin assignments are for the IC/4's connector.

Table 10.4 RS232 Pin Connections

Signal	Name	Pin	EIA Name
GND	Chassis Ground	1	AA
TX	Transmit Data	2	BA
RX	Receive Data	3	BB
RTS	Request To Send	4	CA
CTS	Clear To Send	5	CB
DSR	Data Set Ready	6	CC
SG	Signal Ground	7	AB
DCD	Data Carrier Detect	8	CF
DTR	Data Terminal Ready	20	CD
RI	Ring Indicator	22	CE

10.4 Installing Options

An additional source control module, an additional sensor module, an alternate I/O Relay card (IC/4 only), or alternate communications module may be purchased as options. Upgrades can be ordered at time of purchase or installed later by the factory or a qualified technician.

WARNING!!

BEFORE INSTALLING ANY MODULES OR ACCESSING ANY INTERNAL COMPONENTS, REMOVE *ALL* ELECTRICAL AND DATA INTERFACES INCLUDING THE POWER ENTRY CABLE FROM THE REAR PANEL.

DANGEROUS VOLTAGES MAY BE PRESENT WHENEVER THE POWER CORD OR EXTERNAL INPUT / RELAY CONNECTORS ARE PRESENT.

10.4.1 Installing Source Control Modules

An additional and optional source control module can be added to the IC/4 to provide two more source voltage control outputs and another recorder output. The additional source control card is identical to the standard card with the exception of a unique bus address which has been factory preset for you. To verify this address, locate the switch array SW1 on the middle of the circuit board as illustrated in Figure 10.5. The second upgrade board will have switches 3, 5, 6, 7 and 8 ON with switches 1, 2 and 4 OFF. The first card settings are switches 3, 4, 5, 6, 7 and 8 ON. Switches 1 and 2 OFF.

WHEN INSTALLING SECOND SOURCE CARD IN SLOT 5, SW1
(ON SECOND SOURCE CARD) MUST BE SET AS SHOWN BELOW.

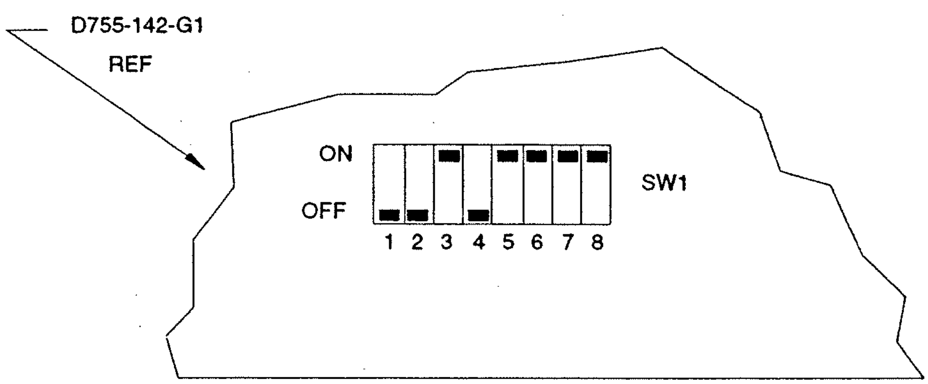


Figure 10.5 Source Control Module Switch Array SW1

1. Remove all electrical and data interfaces from the rear panel.
2. If mounted, remove instrument from equipment rack.
3. Place instrument on table or bench.
4. Unfasten top cover by removing screws at top of rear panel.
5. Remove top cover by sliding back.

6. On the back side of the instrument, remove the small blank panel that covers the Port B connector hole; save the screws; the blank should be retained if board removal is contemplated.

7. Position the module over bus extension location #5 and insert firmly.

8. Insert the DB9 connector in the Port B panel connector opening and secure with the screws saved in step 6.

9. Secure the connector side of the module to the top module brace with the screw included in the upgrade ship kit.

10. Secure the bottom of the module to the bottom of the instrument by inserting a screw through the bottom of the case into the bracket on the module. This is more easily accomplished by overhanging the front of the instrument slightly off the table or bench.

11. Reverse steps 1 through 5 to return the unit to service.

10.4.2 Installing Sensor Modules (IC/4 PLUS only)

An additional and optional sensor module can be added to the IC/4 PLUS to provide sensor channels 3 and 4. The additional sensor card is identical to the standard card with the exception of a unique bus address which has been factory preset for you. To verify this address, locate the jumper J8 on the middle of the circuit board as illustrated in Figure 10.6. A board configured for channels 3 and 4 will have jumper J8 removed as shown. A board configured for channels 1 and 2 will have jumpers J8 installed.

WARNING!!

REMOVAL OF TOP OR BOTTOM COVERS MUST BE DONE ONLY BY A TECHNICALLY QUALIFIED PERSON.

WHEN INSTALLING SECOND SENSOR CARD (CH3 & CH4) IN SLOT 4, REMOVE JUMPER JP8 (FROM SECOND SENSOR CARD) AS SHOWN BELOW.

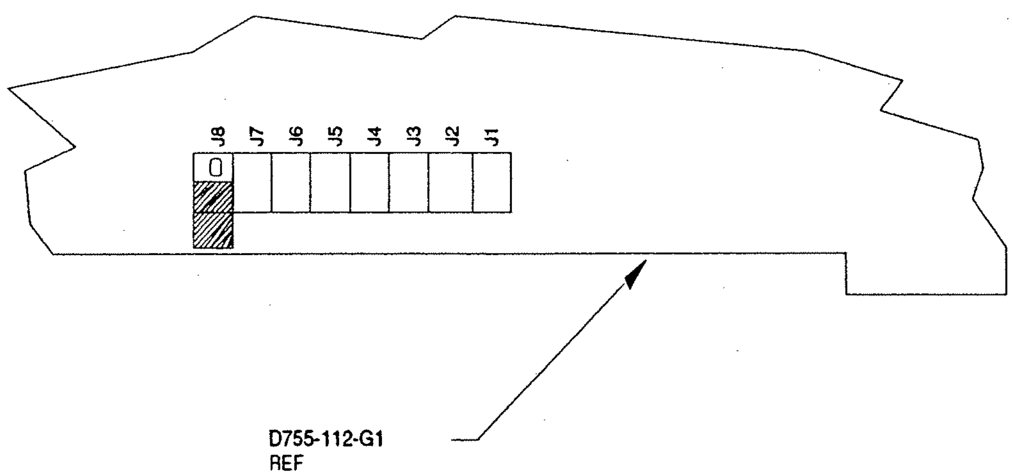


Figure 10.6 Sensor Module Jumper Array J1-J8

1. Remove all electrical and data interfaces from the rear panel.
2. If mounted, remove instrument from equipment rack.
3. Place instrument on table or bench.
4. Unfasten top cover by removing screws at top of rear panel.
5. Remove top cover by sliding back.
6. On the back side of the instrument, remove the middle sub-panel to the right of the current Sensor connector panel; save the screws; the blank should be retained if board removal is contemplated.
7. Position the module over bus extension location #4 and position the attached connector panel in sub-panel opening; insert the module into the bus connectors firmly.
8. Attach the connector sub-panel with the screws saved in step 6.
9. Secure the connector side of the module to the top module brace with the screw included in the upgrade ship kit.
10. Secure the bottom of the module to the bottom of the instrument by inserting a screw through the bottom of the case into the bracket on the module. This is more easily accomplished by overhanging the front of the instrument slightly off the table or bench.
11. Reverse steps 1 through 5 to return the unit to service.

10.4.3 Installing RS422 Serial Communications Module

The optional RS422 serial communications module replaces the standard RS232 module. The RS422 circuit card and connector plate will replace the RS232 circuit card and connector plate. The module is illustrated in Figure 10.7.

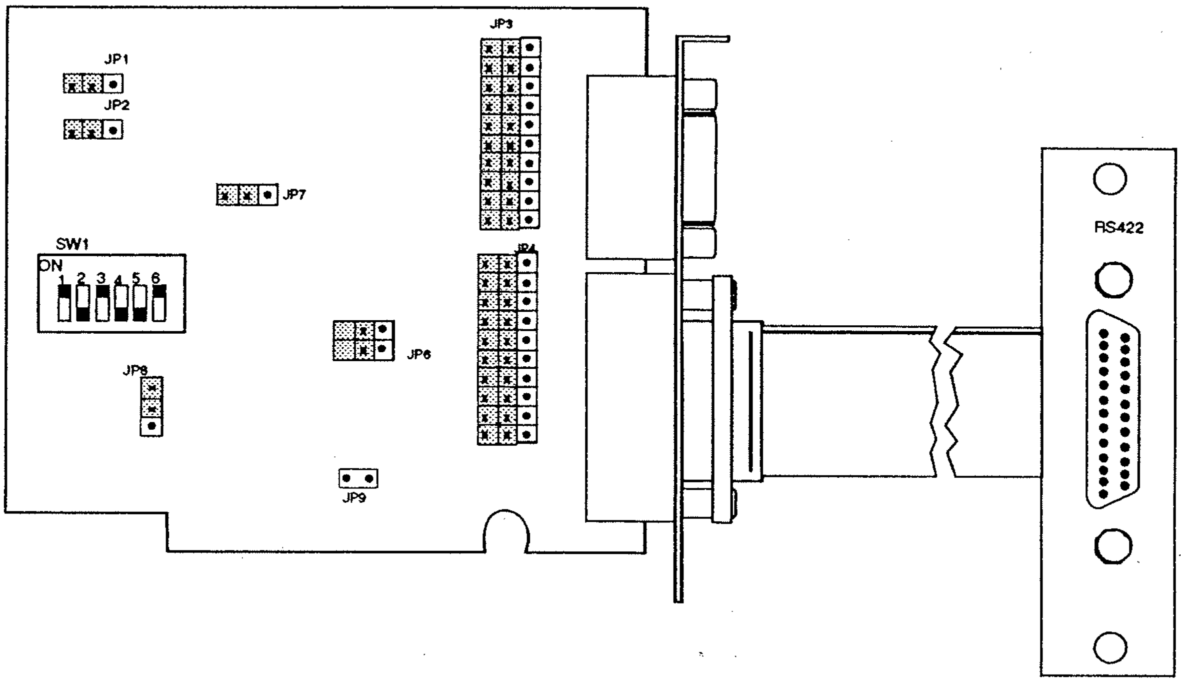


Figure 10.7 RS422 Serial Communications Module

WARNING!!

REMOVAL OF TOP OR BOTTOM COVERS MUST BE DONE ONLY BY A TECHNICALLY QUALIFIED PERSON.

1. Remove all electrical and data interfaces from the rear panel.
2. If mounted, remove instrument from equipment rack.
3. Place instrument on table or bench.
4. Unfasten top cover by removing screws at top of rear panel.
5. Remove top cover by sliding back.
6. On the back side of the instrument, unscrew the far right connector marked COMM saving the screws.
7. Remove the RS232 circuit card from bus position #2 along with its connector plate.

NOTE: In the IC/4 there is a second RS232 card in bus position 3. **DO NOT** remove this card.

8. Position the RS422 circuit card over bus location #2 and insert firmly.
9. Attach the connector plate to the far right opening using the screws saved in step 6.
10. Secure the connector side of the RS422 circuit card to the brace with the brace screw included in the upgrade ship kit.
11. Reverse steps 1 through 5 to return the unit to service.

10.4.4 Installing IEEE Communications Modules

The optional IEEE parallel communications module replaces the standard RS232 module. The IEEE circuit card and connector plate will replace the RS232 circuit card and connector plate. The module is illustrated in Figure 10.8.

WARNING!!

REMOVAL OF TOP OR BOTTOM COVERS MUST BE DONE ONLY BY A TECHNICALLY QUALIFIED PERSON.

1. Remove all electrical and data interfaces from the rear panel.
2. If mounted, remove instrument from equipment rack.
3. Place instrument on table or bench.
4. Unfasten top cover by removing screws at top of rear panel.
5. Remove top cover by sliding back.
6. On the back side of the instrument, unscrew the far right connector marked COMM, saving the screws.
7. Remove the RS232 circuit card from bus position #2 along with its connector plate.

NOTE: In the IC/4 there is a second RS232 card in bus position 3. **DO NOT** remove this card.

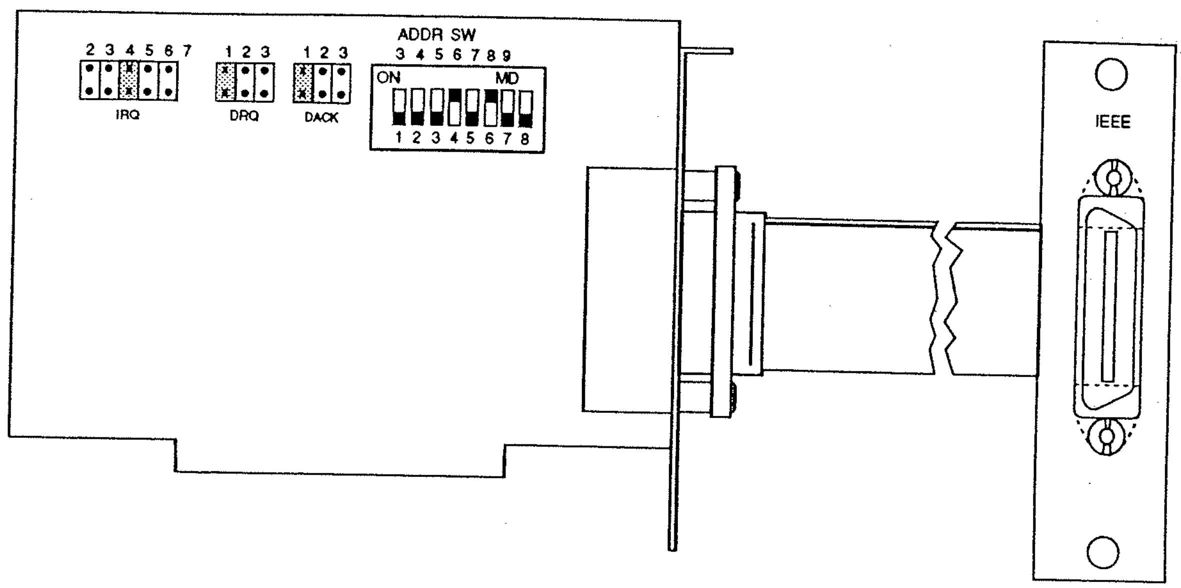


Figure 10.8 IEEE Communications Module

8. Position the IEEE circuit card over bus location #2 and insert firmly.

9. Attach the connector plate to the far right opening using the screws saved in step 6.

10. Secure the connector side of IEEE circuit card to the brace with the brace screw included in the upgrade ship kit.

11. Reverse steps 1 through 5 to return the unit to service.

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INFICON

Section 11
Calibration Procedures

Contents

11.1 Importance of Density, Tooling and Z-ratio

The quartz crystal microbalance is capable of precisely measuring the mass added to the face of the oscillating quartz crystal sensor. The instrument's knowledge of the density of this added material (specified in the density parameter in material set up) allows conversion of the mass information into thickness. In some instances, where highest accuracy is required, it is necessary to make a density calibration as outlined in Section 11.2.

Because the flow of material from a deposition is not uniform, it is necessary to account for the different amount of material flow onto the sensor compared to the substrates. This factor is accounted for in the tooling parameter in material set up. The tooling factor can be experimentally established by following the guidelines in Section 11.3

In the IC/4 only if the Z-ratio is not known, it should be estimated from the procedures outlined in Section 11.4. In the IC/4 PLUS, typically the Auto Z function can be used to determine the Z-ratio. If it is not desirable to use the Auto Z function, the procedure in Section 11.4 can also be used.

11.2 Determining Density

NOTE: The bulk density values retrieved from the Material Library are sufficiently accurate for most applications.

Follow the steps below to determine density value:

1. Place a substrate (with proper masking for film thickness measurement) adjacent to the sensor, so that the same thickness will be accumulated on the crystal and this substrate.
2. Set density to the bulk value of the film material or to an approximate value.
3. Set Z-ratio to 1.000 and tooling to 100%.
4. Place a new crystal in the sensor and make a short deposition (1000-5000 Å), using manual control.
5. After deposition, remove the test substrate and measure the film thickness with either a multiple beam interferometer or a stylus-type profilometer.
6. Determine the new density value with the following equation:

$$\text{Density (g/cm}^3\text{)} = D_1 \frac{T_x}{T_M}$$

where

D_1	=	Initial density setting
T_x	=	Thickness reading on IC/4
T_M	=	Measured thickness

7. A quick check of the calculated density may be made by programming the instrument with the new density value and observing that the displayed thickness is equal to the measured thickness, provided that the instrument's thickness has not been zeroed between the test deposition and entering the calculated density.

NOTE: Slight adjustment of density may be necessary in order to achieve $T_X = T_M$.

11.3 Determining Tooling

1. Place a test substrate in the system's substrate holder.
2. Make a short deposition and determine actual thickness.
3. Calculate tooling from the relationship:

$$\text{Tooling (\%)} = TF_i \times \frac{T_M}{T_x}$$

where

T_M	=	Actual thickness at substrate holder
T_x	=	Thickness reading in the IC/4
TF_i	=	Initial tooling factor

4. Round off percent tooling to the nearest 0.1 %.
5. When entering this new value for tooling into the program, T_M will equal T_X if calculations are done properly.

NOTE: It is recommended that a minimum of three separate evaporations be made when calibrating tooling. Variations in source distribution and other system factors will contribute to slight thickness variations. An average value tooling factor should be used for final calibrations.

11.4 Laboratory Determination of Z-ratio

NOTE: On the IC/4 PLUS, the Auto Z function is available to automatically calculate the Z-ratio. Especially when precise Z-ratio values are significant, Auto Z is recommended.

A list of Z-values for materials commonly used is available in the Material Library. For other materials, Z can be calculated from the following formula:

$$Z = (d_q \mu_q / d_f \mu_f)^{1/2}$$

$$= 9.378 \times 10^5 (d_f \mu_f)^{-1/2}$$

where

d_f = density (g/cm³) of deposited film

μ_f = shear modulus (dynes/cm²) of deposited film

d_q = density of quartz (crystal) (2.649 gm/cm³)

μ_q = shear modulus of quartz (crystal) (3.32×10^{11} dynes/cm²)

The densities and shear moduli of many materials can be found in a number of handbooks.

Laboratory results indicate that Z-values of materials in thin-film form are very close to the bulk values. However, for high stress producing materials, Z-values of thin films are slightly smaller than those of the bulk materials. For applications that require more precise calibration, the following direct method is suggested:

1. Using the calibrated density and 100% tooling, make a deposition such that the percent crystal life display will read approximately 50%, or near the end of crystal life for the particular material, whichever is smaller.
2. Place a new substrate next to the sensor and make a second, short deposition (1000-5000Å).
3. Determine the actual thickness on the substrate (as suggested in density calibration).
4. Adjust Z-ratio value in the instrument to bring the thickness reading in agreement with actual thickness.

For multiple layer deposition (for example, two layers), the Z-value used for the second layer is determined by the relative thickness of the two layers. For most applications the following three rules will provide reasonable accuracies:

If the thickness of layer 1 is large compared to layer 2, use material 1 Z-value for both layers.

If the thickness of layer 1 is thin compared to layer 2, use material 2 Z-value for both layers.

If the thickness of both layers is similar, use a value for Z-ratio which is the weighted average of the two Z values for deposition of layer 2 and subsequent layers.

11.5 Determining Cross Sensitivity Correction For Co-Deposition (IC/4 PLUS Only)

The Cross Sensitivity correction feature of the IC/4 PLUS is beneficial to applications involving the simultaneous deposition of two materials. When depositing two materials it is not always possible to isolate each crystal so that it samples material from a single source. The Cross Sensitivity feature is used to eliminate this "cross talk" of material from the second source being deposited onto the crystal intended to control the deposition rate from the first source.

Procedure Overview

The procedure consists of steps to deposit on both crystals having only one source turned on and then to calculate the interference at Sensor "B" as a percentage of the rate at Sensor "A". The first source is then turned off and a deposit is made on both crystals having only the second source turned on. The interference at Sensor "A" is then calculated as a percentage of the rate at Sensor "B".

Having calculated and entered the cross sensitivity values a co-deposition can then be run with the cross talk corrected for each crystal. A detailed procedure on how to accomplish this is outlined below. The amount of cross talk at each sensor must be less than 100%.

> **NOTE:** Due to the way the cross sensitivity parameter is implemented in the IC/4 PLUS, the density and Z-ratio values for both materials are required to be the same when calculating the cross sensitivity values. After calculating the proper cross sensitivity values, the density and Z-ratio parameters are returned to their proper values.

Procedure Assumptions and Requirements

The procedure assumes the instrument is configured for Co-Deposition. This may require the installation of optional equipment. Co-Deposition requires a second measurement board. Each board requires a crystal sensor (single, CrystalSix, or dual sensor heads). Two source control voltage outputs must be connected to the appropriate source power supplies. If these items are not configured refer to Section 10 for further information. It is also assumed the operator is familiar with the operation and programming of the instrument.

Use Source 1 and Sensor 1 for the Material specified by the first Layer. Use Source 2 and Sensor 3 for the Material specified by the second Layer.

The Tooling Factors for each sensor must be determined prior to calculating the Cross Sensitivity values. If this has not been done, refer to Section 11.3.

Set the User Level to 2 in the Utility Display. The extended features of the IC/4 PLUS are required. Also, set the Stop on Max Power parameter in the Utility Display to NO.

Set the Co-Deposition parameter to YES in the Layer definition display. This will activate the Cross Sensitivity parameters.

Program the Final Thickness value for each Layer to be 999.9 kÅ.

Program the pre-deposition and post-deposition phases for the Materials and the desired deposition Rates for the Layers you wish to co-deposit.

Program all source and sensor shutters to their appropriate values.

Use the detailed procedure to calculate the Cross Sensitivity values to be entered into the respective Layer Definitions.

Detailed Procedure

To calculate the amount of cross talk at Sensor 1 due to material from Source 2:

1. Enter 0.1 into the Rate parameter for Layer 1. Enter zero into the Maximum Power parameter for the Material in Layer 1.

2. Enter zero into the Cross Sensitivity parameter for Layer 2. The value in the Cross Sensitivity parameter for Layer 1 should also be zero.

3. Enter the Density and Z-ratio for the Material in Layer 2 into the Density and Z-ratio parameters for both materials. Enter a value of one for the Z-ratio type parameter for both Sensor 1 and Sensor 3 in the Edit Sensor Display.

4. Start the co-deposition, allowing Layers 1 and 2 to sequence through the pre-deposition phases. The power for source 2 should be ramped to the appropriate levels while the power for source 1 should be held at 0 %.

5. After Layers 1 and 2 enter DEPOSIT and the rate from source 2 is stable at the desired deposition rate, manually zero the thickness accumulation for both Layers. This may be done from the Operate Display by pressing the panel keys- **Zero Thickness 1**(F1), **Key Switch 2**(F4), **Zero Thickness 2**(F1) in rapid succession or by using the Zero Thickness commands via the remote communications, external input or internal logic.

6. Allow a thickness to accumulate for Layers 1 and 2 (on both sensors) for at least 1 minute. Longer thickness accumulations may be necessary for low rates and/or to reduce the error introduced by not being able to zero the thickness for both Layers concurrently. Larger thickness accumulations will result in a more accurate calculated value.

7. Calculate the Cross Sensitivity value for Layer 1 using the following equation:

   CS1 = (Thickness at Sensor 1 / Thickness at Sensor 3) X 100 %

8. Enter the calculated value, CS1, as the Cross Sensitivity parameter's value for Layer 1. Zero the thickness accumulation for both Layers concurrently and monitor the thickness accumulation for both Layers.

9. The thickness for Layer 1 should remain at 0.000 kÅ. Small adjustments of the value for the Cross Sensitivity may be necessary in order to obtain a zero thickness accumulation for Layer 1.

10. Stop the deposition, allowing the material in source 2 to cool sufficiently so that no material is being deposited. Place the instrument into the Ready state by pressing Reset.

To calculate the amount of cross talk at Sensor 3 due to material from Source 1:

1. Enter the desired Rate parameter's value for Layer 1. Enter the appropriate Maximum Power value into the Material definition for the Layer 1 material.

2. Enter a Rate of 0.1 into the rate parameter for Layer 2. Enter zero as the value of the Maximum Power parameter for the Material in Layer 2.

3. Enter the density and Z-ratio for the Material in Layer 1 into the Density and Z-ratio parameters for both materials. Enter a value of 1 into the Z-ratio type parameter for both Sensor 1 and Sensor 3 in the Edit Sensor Display.

4. Enter a value of zero into the Cross Sensitivity parameter for Layer 1. The value in the Cross Sensitivity parameter for Layer 2 should also be zero.

5. Start the co-deposition, allowing Layers 1 and 2 to sequence through the pre-deposition phases. The power for source 1 should be ramped to the appropriate levels while the power to source 2 should be held at 0 %.

6. After Layers 1 and 2 enter the DEPOSIT state and the rate from source 1 is stable at the desired deposition rate, zero the thickness accumulation for both Layers. This may be done from the Operate Display by pressing the panel keys- **Zero Thickness 1**(F1), **Key Switch 2**(F4), and **Zero Thickness 2**(F1) in rapid succession or by using the Zero Thickness command via the remote communications, external input or internal logic.

7. Allow the thickness to accumulate for Layers 1 and 2 (on both sensors) for at least 1 minute. Longer thickness accumulations may be necessary for low rates and/or to reduce the error introduced by not being able to zero the thickness for both Layers concurrently. Larger thickness accumulations will result in a more accurate calculated value.

8. Calculate the Cross Sensitivity value for Layer 2 using the following equation:

   CS2 = (Thickness at Sensor 3 / Thickness at Sensor 1) X 100 %

9. Enter the calculated value, CS2, as the Cross Sensitivity parameter's value for Layer 2. Zero the thickness accumulation for both Layers concurrently and monitor the thickness accumulation for both Layers.

10. The thickness for Layer 2 should remain at 0.000 kÅ. Small adjustments of the value for the Cross Sensitivity may be necessary in order to obtain a zero thickness accumulation for Layer 2.

11. Stop the deposition and place the instrument into the READY state by pressing Reset. Enter the desired deposition rate into the Rate parameter for Layer 2. Enter the appropriate Maximum Power value into the Material definition for the material specified for Layer 2. Also enter the appropriate Final Thickness values into Layers 1 and 2 and set the Stop on Max Power parameter in the Utility display to the desired value. Enter the correct values for Density and Z-ratio into the Material Display for the materials specified in Layers 1 and 2. Enter the desired value into the Z-ratio type parameter for Sensors 1 and 3 in the Edit Sensor Display.

12. Enter the appropriate Cross Sensitivity values into the definitions for Layers 1 and 2. This completes the calculation of Cross Sensitivity values. The instrument is now ready for co-depositions.

11.6 AutoTuning

The AutoTune feature of the IC/4 is used to automatically characterize the response of a system. AutoTune examines the rate change response after executing step changes in power. Control parameters are calculated for algorithms designed for either slow responding systems or fast responding systems, with PID parameters determined for slow systems and a process gain coefficient determined for fast sources.

- Operate
  - AutoTune Parameters
    - AutoTune Manual
      - AutoTune Tuning

There are two subsets of AutoTune. A shortened version called "Quick Tune", calculates the required values from a fixed change in source power. The "Complete Tune" process first incorporates the Quick Tune procedure and then refines the parameters' values by operating at a set of rates established about the desired operating point.

AutoTune operation is initiated by selecting the AUTOTUNE panel (F5) in the Operate display while in the READY state. This will invoke the AutoTune Parameters display upon entry, the cursor will be placed at the last referenced parameter.

An AutoTune parameter is edited by positioning the box cursor at the desired parameter value and then using the data entry panel to input a new parameter value. By using the panel keys the manual state of AutoTune can be started or you may return to the Operate Display.

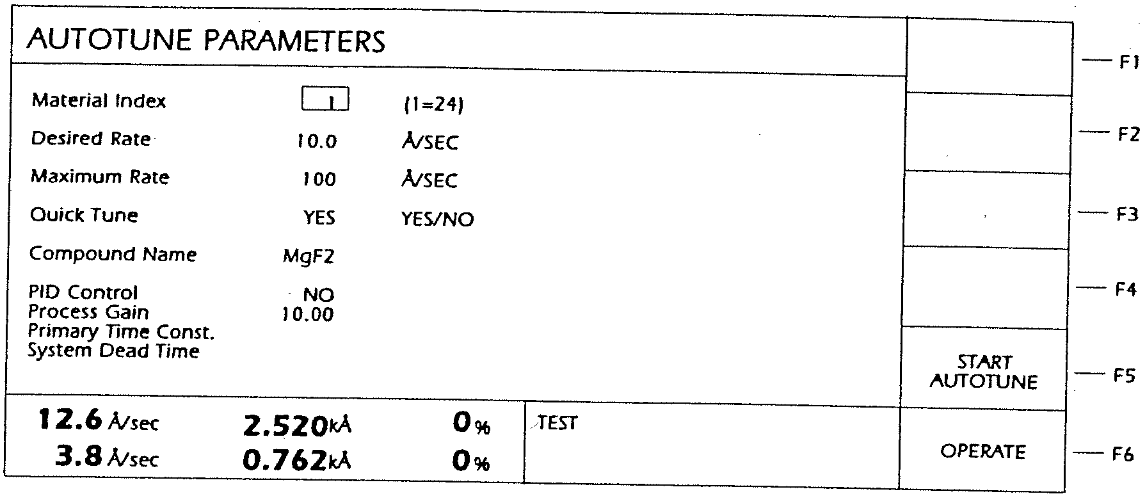


Figure 11.1 AutoTune Parameter Display

11.6.1 AutoTune Parameters

MATERIAL INDEX 1 to 12 (24 for the IC/4 PLUS)

This parameter is used to select the Material (from the MATERIAL DIRECTORY) that is to be "AutoTuned". Values range from 1 to 12 (24 for the IC/4 PLUS). The default value is 1.

DESIRED RATE 0.1 to 999 Å/s

For a Complete Tune, this parameter determines the Rate for which the AutoTuned control loop parameters will be calculated. For Quick Tune this parameter is ignored. Values range from 0.1 to 999 Å/s. The default value is 10.0 Å/s.

MAXIMUM RATE 0.2 to 999 Å/s

This parameter is used to set the maximum deposition Rate allowed during an AutoTune session. The events which will occur upon exceeding this value are dependent upon whether a Quick Tune or a Complete Tune is designated. The range of values permitted for this parameter is dependent on the value chosen for the Desired Rate. The maximum allowed value will always be 999 Å/s. The minimum allowed value is 2 times the Desired Rate value.

QUICK TUNE YES/NO

This parameter is used to chose between a Quick Tune or a Complete Tune. Permissible values are YES and NO. A value of YES selects Quick Tune. The default value is YES.

MATERIAL NAME

This is a read-only parameter that represents the chemical being deposited.

PID CONTROL

This is a read-only parameter that indicates whether PID control was specified during material definition. A YES indicates that this material is slow responding and a PID control loop is used for source control.

PROCESS GAIN

This is a read-only parameter that represents the rate of change of % source power for a given rate deviation.

PRIMARY TIME CONSTANT

This is a read-only parameter that represents the source's time constant. It is valid only for a PID control loop.

SYSTEM DEAD TIME

This is a read-only parameter that represents the source's lag time. It is valid only for a PID control loop.

11.6.2 AutoTune Manual Display

The AutoTune Manual display is entered from the AutoTune Parameters display by selecting **START AUTOTUNE** (F6).

The AutoTune Manual display is similar to the general Operate display with the exception that Thickness and Process information will be absent. The AutoTune Manual display automatically places the instrument in the MANUAL state. Just like the normal MANUAL state, the power level can be adjusted via the handheld controller.

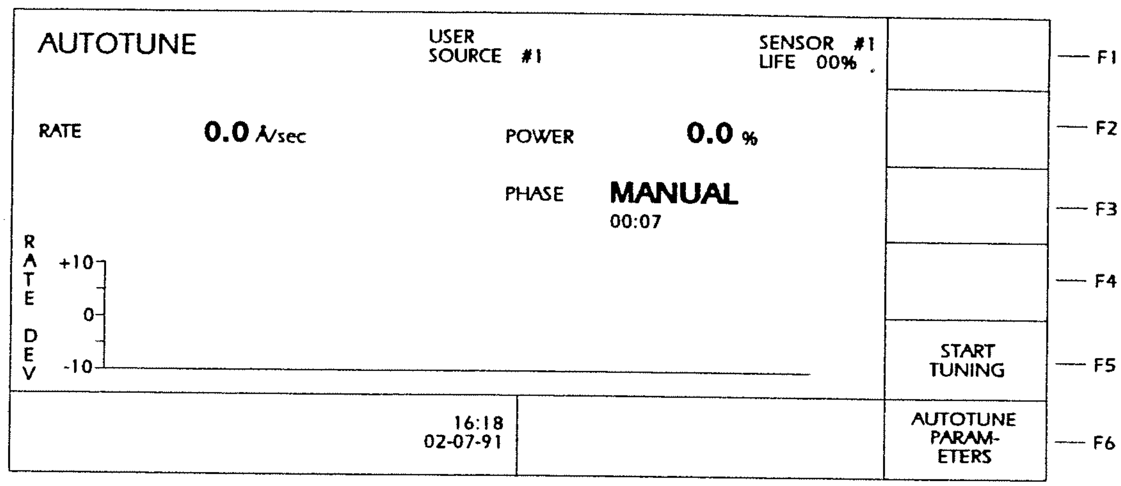


Figure 11.2 AutoTune Manual Display

11.6.3 AutoTune Tuning Display and AutoTune Description

The AutoTune Tuning display is entered from the AutoTune Manual display by selecting **START TUNING** (F5).

AutoTune tuning is executed automatically by the instrument. *Operator intervention is not required.*

The tuning process can be stopped by pressing the EXIT AUTOTUNE panel.

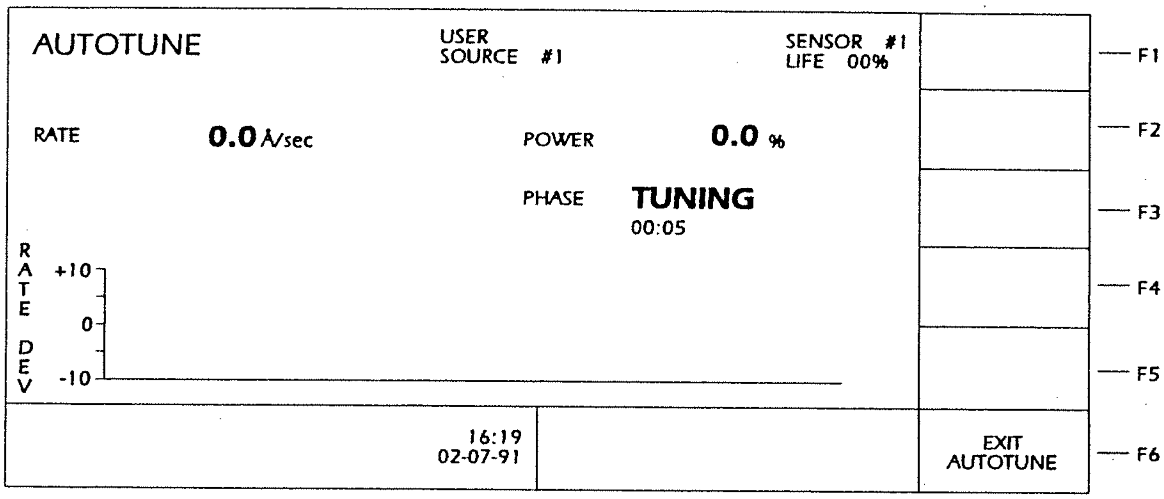


Figure 11.3 AutoTune Tuning Display

The instrument goes through the following algorithm when AutoTuning:

The first portion of Tuning is the Speed Test. The Speed Test calculates how quickly the system reacts to an instantaneous increase in source power level. The results of the Speed Test determine whether the system is fast or slow. Consequently, this designation of fast or slow determines what action is to follow.

For Quick Tune, the increment in power level is a pre-determined percentage of the power, while for a Complete Tune the increment in power level is calculated to try to obtain a specific rate increase.

If Quick Tune is chosen, the instrument will begin the AutoTune procedure by first recognizing an initial power setting. This initial power setting is the power level the operator adjusts to while in the Manual state of AutoTune. Next, the instrument will increase the power level to a value

5% greater than the initial level. If the rate of deposition exceeds the Maximum Rate value during this transition, the power level is returned to the initial power setting and the instrument will increase the power level to a value of 2.5% greater than the initial level.

Again, if the Maximum Rate value is exceeded, the power level is returned to the initial power setting and the instrument will increase the power level to a value of 1.25% greater than the initial level. If the Maximum Rate is exceeded this final time a Quick Tune Failure message will appear and the control loop parameters must be determined manually. If the rate does not exceed the Maximum Rate value during any one of these power increments then the rate transition for this pre-determined power increment is used to calculate the control loop parameters. There is no Rate control feedback during Quick Tune.

If a Complete Tune is chosen, a Quick Tune is done first and will proceed as described above. These Quick Tune values are used as backup parameters in the event a Complete Tune fails. After completing the Quick Tune, the instrument will initially establish rate control to one-half the Desired Rate, then increment the power level to obtain a rate at 2 times the Desired Rate.

If the Maximum Rate is exceeded, the power level will be adjusted to re-establish rate control at one-half the desired rate and then increased to obtain a rate at the Desired Rate. If the Maximum Rate is again exceeded, the instrument will leave AutoTune and return the values calculated with Quick Tune. If the Maximum Rate is not exceeded, the control loop parameters will be calculated based on the rate transition. There is rate feedback when doing a Complete Tune.

The major difference in the implementation of AutoTune for a fast source (typically an electron beam gun) as opposed to a slow source, is the way in which rate stability is determined. For a fast source there can be many rate instabilities, such as sweep frequency fluctuations and short term thermal shorts, therefore rate noise makes determination of when the rate is stable impractical.

To circumvent this problem the power level for both Quick Tune and Complete Tune is increased to the appropriate level and held for approximately 9 seconds. The rate transition over this time period is used to calculate the Process Gain parameter. Having calculated the Process Gain, the power level is returned to the initial power setting (or rate if in Complete Tune) and the procedure is repeated. The Process Gain value is again calculated and the two values compared. If the relative deviation between the two values is less than 40%, AutoTune is completed.

This procedure may be repeated up to 4 times to obtain agreement between calculated Process Gain values. If agreement can not be reached after four times, Quick Tune values will be returned. A failure message will be returned if a Quick Tune can not be accomplished. The time for a fast tune is typically no more than two minutes. A Quick Tune on a slow system typically takes 10 minutes, while a Complete Tune may take as long as 30 minutes.

11.6.4 Definition of AutoTune Messages

The following messages may appear while AutoTuning:

AutoTune Failure	Inconsistent Quick Tune results are not allowing control loop parameters to be determined.
AutoTune Successful	The instrument has determined the system's control loop parameters.
Complete Bump 1	The first increase of source power level. It is used to determine control loop parameters for the Complete Tune portion of AutoTune.
Complete Bump 2	The second increase of source power level.
Complete Bump 3	The third increase of source power level.
Complete Tune Failure	Indicates inconsistent results which do not allow the Complete tune control loop parameters to be calculated. The Quick Tune results will then be displayed.
Fast System	Indicates very short time delay between increase in power level and the corresponding rate increase.
Half Rate	The adjustment of the source's power level to establish a deposition rate which is one-half the desired rate.
Max Power Exceeded	Indicates that the power has exceeded the AutoTune MAXIMUM POWER. *Note: The AutoTune max power is 5% less than the max power programmed for the material being AutoTuned.*
Quick Bump 1	The first 5% increase of source power level. It is used to determine control loop parameters, for the Quick Tune portion of AutoTune.
Quick Bump 2	The second 5% increase of source power level.
Quick Bump 3	The third 5% increase of source power level.
Ramp	Indicates that the power level is being decreased to zero over a twenty second time period.
Slow System	Indicates that a measurable time delay between an increase in power level and the corresponding rate increase has been measured.
Speed Test	An instantaneous increase of source power. It is used to test the response time of the system in order to differentiate between fast and slow systems.

STOP Max Rate Exceeded	Indicates that tuning has stopped because the MAXIMUM RATE parameter was exceeded three times.
STOP Rate Too Low	Indicates that tuning has stopped because the initial rate was below 0.1Å/s.

11.6.5 AutoTune Preparation Instructions

The following procedure should be followed to perform an AutoTune:

1. Determine the Correct System Setup

   In order to ensure good AutoTune results and good source control, careful consideration should be given to eliminating system noise, thermal shorting, and any other factors that result in rate instabilities.

2. Determine the Correct Material and Source Parameters

   Because an evaporation source's behavior is material specific, careful attention should be given to choosing the correct material and source parameters.

   Choose the source's voltage range that best suits the material and evaporation technique. Generally, low meting point materials use smaller ranges (0 to ±2.5 or 0 to ±5.0 Volts), while high melting point materials use the larger range (0 to ±10.0 Volts). (Refer to Section 8.3)

3. Determine the Correct AutoTune Parameters

Material Index	Choose the index number of the desired chemical. (from the Material Directory)
Desired Rate	Choose the rate at which to control the deposition. This parameter is used only for a Complete Tune.
Maximum Rate	Choose the maximum rate the system can handle safely (i.e., source doesn't spit, equipment is not damaged).
Quick Tune	Choose either YES for Quick Tune or NO for a Complete Tune.

4. Press the START AUTOTUNE function key (F5) and increase the power level with the hand held controller until the rate is approximately one half the desired rate.

5. Allow the source to come to an equilibrium by leaving the power level constant for approximately three minutes.

6. When the source has reached equilibrium, press the START TUNING function key (F5), and observe the instrument as it goes through the "tuning" portion of AUTOTUNE.

7. When AutoTune is completed the instrument will automatically return to the AutoTune Parameters display and the newly calculated values will be displayed next to the old values. The operator then has the option of ACCEPTING CHANGES (F5) or REFUSING CHANGES (F6). Accepting the changes replaces the old parameters with the new values, while refusing the changes leaves the old values in place.

8. An AUTOTUNE failure means the IC/4 was unable to consistently measure the system's response characteristics.

NOTE: To ensure a successful AutoTune there are a few items to be considered:

A well conditioned source is imperative. Be certain the source will be able to withstand the automatic power increments without spitting or other damage occurring to the system.

A "quiet" crystal is essential. Rate noise and gun arcs will cause AutoTune Failures.

Use the Maximum Rate and Maximum Power limits to protect your equipment.

Do not set the Maximum Rate at exactly twice the Desired Rate. Allow for overshoot.

Section 12
Troubleshooting Guide, Status and Error Messages

Contents

12.1 Status and Error Messages

AUTOTUNE MAX POWER

The power setting in AutoTune has increased beyond the material's max power setting less 5%. (Autotune Max Power is set at 5% less than the maximum power programmed for the material being AutoTuned.)

AUTOTUNE SUCCESSFUL

Control loop parameters have been successfully established by AutoTune.

AUTOTUNE TIMEOUT

AutoTune was unable to maintain a stable deposition or complete the measurement of a deposition transition.

bb RAM LOCK

Indicates the battery backed RAM Lock feature is active. Shown in inverse video.

CANNOT EMPTY PROCESS

The last layer of a process may not be deleted.

CANNOT DELETE CO-DEP

A layer being co-deposited cannot be deleted. Set CO-DEP to NO prior to deleting the layer.

CANNOT INSERT CO-DEP

A layer cannot be inserted between two layers that are in co-dep.

CANNOT PARENTHESIZE

There must be at least 3 output events in the string to use parentheses.

CARD FORMATTED

The memory card was successfully formatted.

CARD NOT PRESENT

Save or Retrieve requires the memory card to be inserted; the card is not detected by the instrument.

CARD WRITE PROTECTED

The Save requested cannot be performed when the memory card is physically write protected.

COMPLETE BUMP #

AutoTune displays the change in the power supply setting.

DELAY
The instrument is in a 5 second delay between Hold and Sample of RateWatcher.

END OF PROCESS
Process has completed.

FAST SYSTEM
AutoTune has detected the response of the system to be fast.

HALF RATE
The system is being bumped toward half of the desired deposition rate in AutoTune.

HOLD
The process is in the Hold portion of RateWatcher.

I/0 EQUATIONS LOCKED
The strings comprising the I/0 equations cannot be accessed while they are locked.

I/0 LOCK
The instrument has been placed in I/0 lock; this prohibits entering I/0 or Source/Sensor parameters from the front panel unless the I/0 Lock Code is known.

ILLEGAL BAUD RATE
Baud rate selections are 1200, 2400, 4800, 9600 or 19200.

ILLEGAL DATE
The month or day entry is invalid; months should be in the 01 to 12 range; days should be in the correct range for the month specified.

ILLEGAL INPUT - VALUE TOO LARGE
Parameter entry is out of range.

ILLEGAL INPUT - VALUE TOO SMALL
Parameter entry is out of range.

ILLEGAL LOCK CODE
The correct lock code is necessary to unlock parameters.

ILLEGAL PARENTHESIS
Left and right parentheses in output strings must be balanced.

ILLEGAL SENSOR TYPE
Sensor type may only be 1, 2 or 6.

ILLEGAL TIME

Time is invalid; hours should be in the 00 to 23 range; minute should be in the 00 to 59 range.

INPUT IN USE

The input line in question has already been reserved for use.

INVALID EQUATION

Output strings must have connectors and required numerics before exiting output edit display.

LAYER UNDEFINED

The "Layer to Start" defined in Utility Set Up must correspond to a defined layer in the active process.

LESS THAN THICK LMT

Final Thickness must be greater than Thickness Limit

LOCK CODE ACCEPTED

Indicates that parameters have been successfully unlocked.

MATERIAL IN USE

A material referenced in any layer cannot be deleted.

MATERIAL UNDEFINED

Material must be previously defined in Material Set Up.

MAX POWER REACHED

Indicates that the specified maximum power has been reached on an active source.

MAXIMUM TERMS

No more than 5 terms are allowed in any one output or input string.

MEAS SYS COMM FAIL

Indicates that readings from the measurement card are not being received. If this error recurs, it indicates a cabling or hardware problem with the measurement card.

MEMORY CARD FAILURE

The instrument is unable to save or retrieve information on the memory card.

MORE THAN FINAL THK

Thickness Limit must be less than Final Thickness.

MUST ENTER OLD CODE

Utility Set Up requires the old I/0 lock code to be entered before updating a new I/0 lock code.

NO CONNECTOR TO EDIT
There must be at least two output events in the string to edit a connector.

NO LABELS DEFINED
Negate signs cannot be added without outputs being defined.

NO MATERIAL DEFINED
Materials must be defined to be used in a Process Layer.

NON-DEPOSIT HOLD
Indicates the non-deposit hold input is activated. Shown in inverse video.

NO SWITCH: IN LAYER
A crystal switch from the handheld controller cannot be done while a layer is running.

NO SWITCH: NO OUTPUT
No output was set for crystal switching in the sensor display, so switch cannot be done.

NO SWITCH: SINGLE
A crystal switch cannot be requested while using a single head crystal.

NO SWITCH: NO XTALS
Indicates that a crystal switch was requested on a multi head, but there are no good crystals left.

NOT IN READY
Indicates that the instrument cannot perform the requested function unless it is in READY.

NOW ENTER NEW CODE
After verifying an old I/0 lock code, this is a prompt in Utility Set Up to enter a new code.

OUTPUT IN USE
Indicates that the output relay in question has already been reserved for use in Sensor or Source Set Up.

PARAMETERS RETRIEVED
This is an acknowledgement that parameters have been successfully retrieved from the memory card.

PARAMETERS SAVED
This is an acknowledgement that parameters have been successfully saved on the memory card.

PROCESS UNDEFINED
The Active Process defined in Utility Set Up must correspond to a defined process.

PROGRAM LOCK
Indicates that the instrument is in Program Lock. This prohibits any parameter from being entered from the front panel until the Program Lock Code is entered on the Program display.

QUICK BUMP #
Indicates the particular number of the Source Power Change used to measure the system response values.

RAMP 1 MORE THAN 2
Start Ramp 1 value must be less than Start Ramp 2 value.

RAMP 2 LESS THAN 1
Start Ramp 2 value must be greater than Start Ramp 1 value.

RATE ABOVE MAX
Indicates that the deposition rate has increased beyond the maximum allowed in AutoTune.

REMOTE LOCK
Indicates that the instrument has been placed in Remote Lock from an external computer. This prohibits any parameters from being entered via the front panel.

SAMPLE
Indicates that the instrument is in the Sample portion of RateWatcher.

SENSOR NOT PRESENT
Indicates that sensor 3 or 4 are not part of the instrument's present configuration. In order to use sensor 3 or 4, the hardware must be present to do so.

SLOW SYSTEM
Indicates that AutoTune has determined the response of the system to be slow.

SOURCE NOT PRESENT
Indicates that source 3 or 4 is not part of the instrument's configuration. In order to use source 3 or 4, a second source control board must be installed.

SPEED TEST
The system's speed of response is being determined by AutoTune. The power supply power increases during this period.

STOP - COMMUNICATIONS
STOP command received from remote communications.

STOP - COMPLETE TUNE FAIL

Indicates the complete tune portion of the AutoTune process did not determine reliable system response results.

STOP - HALF RATE FAIL

Indicates that AutoTune was unable to vary the source to half the desired rate.

STOP - HANDHELD

STOP executed from handheld controller.

STOP - INPUT n

STOP executed from external input line number n.

STOP - INTERNAL LOGIC n

STOP executed from internal logic statement number n.

STOP - MAX POWER

Indicates the instrument has been stopped because Max Power has been exceeded for over 5 seconds. The stop on max power parameter is entered in the Utility Set Up.

STOP - MAX POWER ERROR

Indicates that AutoTune was unable to finish the complete tune without exceeding the material's maximum power setting.

STOP - MAX POWER < 5

AutoTune has been stopped because the material's maximum power setting is less than 5%. AutoTune maximum power is set at 5% less than the material maximum power.

STOP - MEAS SYS COMM FAIL

Indicates that readings from the measurement card are not being received. If this error records, it indicates a cabling or hardware problem with the measurement card.

STOP - POWER LOSS

Indicates that the instrument has been stopped due to a prior power loss.

STOP - QUICK TUNE FAIL

Indicates that the quick tune portion of the AutoTune process did not get repeatable system response results.

STOP - RATE TOO LOW

AutoTuning is terminated when the deposition rate at the start of the tuning, is below 0.1 Å/s.

STOP - SHUTTER DELAY

Indicates that the instrument has been in shutter delay for more than 60 seconds without achieving rate control to within 5% of the desired rate.

STOP - SOURCE CONFLICT
Indicates that the instrument has been stopped because a request has been made for two layers to execute using the same source.

STOP - SENSOR CONFLICT
Indicates that the instrument has been stopped because a request has been made for two layers to be executing a deposition state using the same sensor, or two sensors on the same measurement board.

STOP - SOURCE SWITCH
Indicates that the instrument has been stopped due to a source switcher mechanical failure.

STOP - SWITCHER FAIL
Indicates the instrument has been stopped due to a CrystalSix sensor switcher mechanical failure.

STOP - TIME POWER
Indicates that the instrument has stopped because a layer completed in time power.

STOP - XTAL FAIL
Indicates the instrument has been stopped due to crystal fail while in pre- or post-deposit, or while in deposit. This is determined in the Utility Set Up by programming "not to complete on time power".

SWITCHER FAIL
Indicates that a mechanical failure of the crystal switcher has been detected.

TEST
Indicates the instrument is in Test mode as determined in the Utility Set Up.

UNABLE TO AUTO Z (IC/4 PLUS Only)
Indicates that the requested Auto Z measurement cannot be completed due to the crystal condition. This is caused by a weak or unstable first anharmonic measurement. Also may be caused by the instrument not recognizing the crystal as a new crystal, or inserting a used crystal.

UNABLE TO START
A START cannot be processed while the display is on the I/0 screens.

XTAL FAIL x
Indicates that the crystal at Sensor x has failed.

XTAL SWITCHING
Indicates that a crystal switch is in progress.

12.2 Troubleshooting Guide

If the instrument fails to work, or appears to have diminished performance, the following Symptom/Cause chart may be helpful.

WARNING!!

THERE ARE NO USER SERVICEABLE COMPONENTS WITHIN THE INSTRUMENT CASE.

POTENTIALLY LETHAL VOLTAGES ARE PRESENT WHEN THE LINE CORD, SYSTEM I/O OR AUX I/O ARE CONNECTED.

REFER ALL MAINTENANCE TO QUALIFIED PERSONNEL.

CAUTION: *This instrument contains delicate circuitry which is susceptible to transients. Disconnect the line cord whenever making any interface connections. Refer all maintenance to qualified personnel.*

12.2.1 Major Instrument Components, Assemblies and Mating Connectors

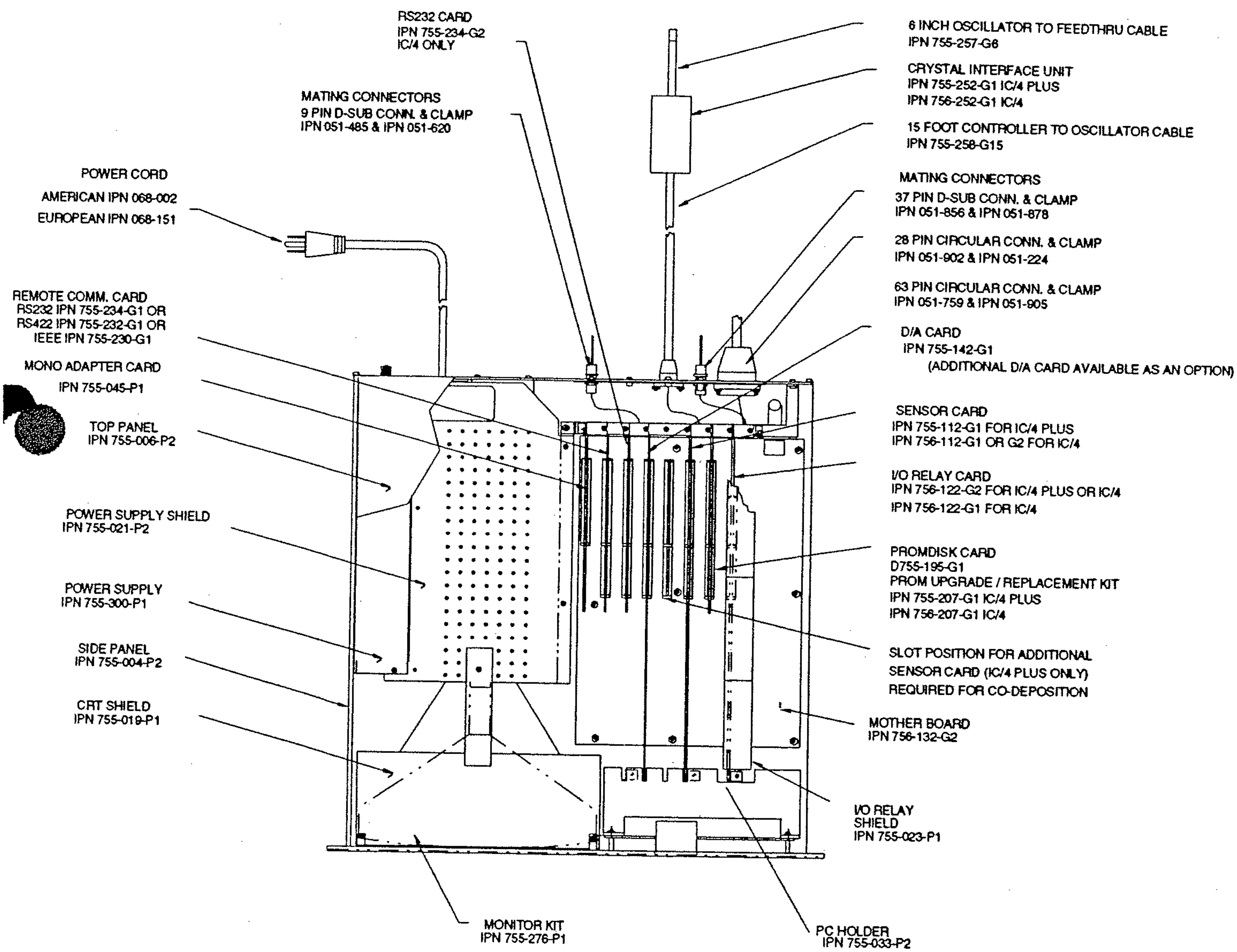


Figure 12.1a IC/4 Schematic Assembly (Rev.A)

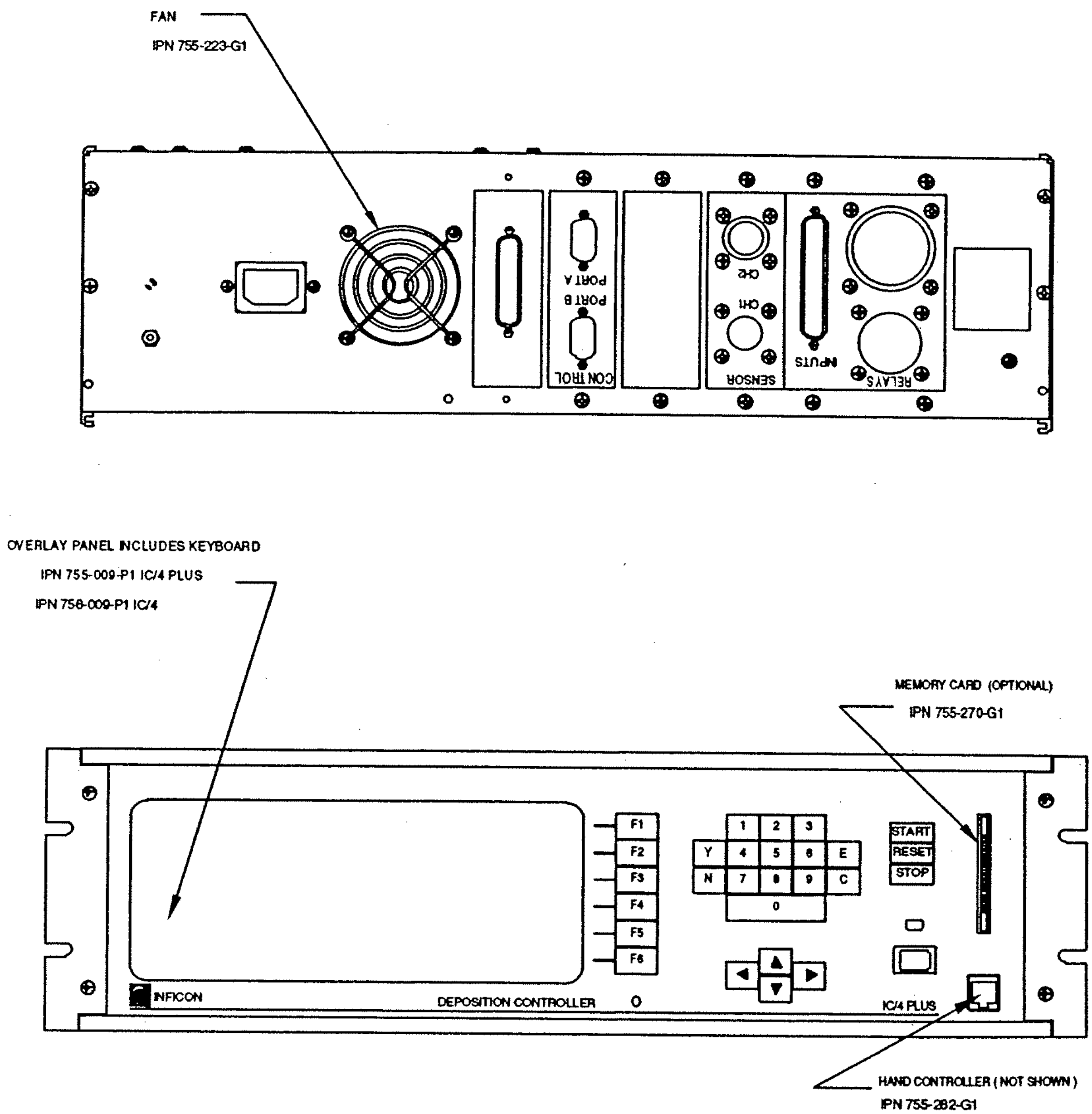


Figure 12.1b IC/4 Schematic Assembly (Rev. A)

12.2.2 Troubleshooting the Instrument

SYMPTOM	CAUSE	REMEDY
1. power on LED not lighted	a. blown fuse/circuit breaker tripped	a. have qualified personnel replace fuse/reset circuit breaker
	b. electrical cord unplugged from wall or back of instrument	b. re-connect power cord
	c. incorrect line voltage	c. have qualified personnel verify line voltage, verify the instrument is configured for the correct voltage
2. unit "locks" up	a. cover or back panels not attached to the instrument	a. ensure all covers and panels are in place and securely fastened
	b. high electrical noise environment	b. re-route cables to reduce noise pickup (1 ft away from high power conducting lines makes a sizable reduction in the amount of noise entering the instrument), keep all ground wires short with large surface area to minimize ground impedance
	c. poor grounds or poor grounding practice	c. verify proper earth ground, use appropriate ground strap, eliminate ground loops by establishing the correct system grounding, verify proper instrument grounding
3. instrument does not retain parameters on power down (loss of parameters on power up)	a. faulty static RAM	a. SRAM battery has a normal life expectancy of ten years, contact Inficon service department
	b. power supply problem	b. contact Inficon service department
4. some keys on front panel function while others do not	a. faulty keypad or faulty keypad ribbon cable	a. contact Inficon service department

SYMPTOM	CAUSE	REMEDY
5. all keys on the front panel fail to function	a. instrument is "locked" up	a. turn power to OFF or to STBY, then to ON, see item 2 above
6. control voltage output does not function properly	a. DAC board damaged from applying voltage to the control voltage output	a. ensure cable connection to the DAC board does not have a potential across the contacts, contact Inficon service department
	b. reversed polarity of control voltage relative to that accepted by the source power supply	b. verify source output polarity of DAC and the required input polarity of the source power supply, refer to the instruction manual to reconfigure the instrument if necessary
	c. improper control cable fabrication	c. check for correct cable wiring in the appropriate section of the manual
7. CRT or LCD display dull or blank	a. brightness/contrast adjustment required	a. refer to manual for location of adjustment potentiometer, adjust as desired
	b. LCD or CRT/power supply problem	b. contact Inficon service department
8. poor rate control	a. control loop parameters improperly selected	a. refer to the instruction manual section on tuning control loop parameters
	b. electron beam sweep frequency "beating" with the instrument's measurement frequency	b. adjust the sweep frequency so it is not a multiple of the instrument's measurement frequency
9 crystal fail always on	a. XIU/oscillator not connected	a. verify proper sensor/oscillator connections
	b. XIU/oscillator malfunctioning	b. if available, insert a known working XIU/oscillator in place of suspect one; if XIU/oscillator is confirmed bad, contact Inficon service department

SYMPTOM	CAUSE	REMEDY
	c. defective cable from feedthrough to XIU/oscillator or from instrument to XIU/oscillator	c. use an ohm meter or DVM to check electrical continuity or isolation as appropriate
	d. poor electrical contact in the transducer, feedthroughs, or in-vacuum cable	d. use an ohm meter or DVM to check electrical continuity or isolation as appropriate
	e. failed crystal/no crystal	e. replace crystal/insert crystal
	f. two crystals placed into the crystal holder	f. remove one of the crystals

12.2.3 Troubleshooting Transducers/Sensors

NOTE: The most useful tool for diagnosing sensor head problems is the DVM (Digital Volt Meter). Disconnect the short oscillator cable from the feedthrough and measure the resistance from the center pin to ground. If the reading is less than 1-2 megaohms, the source of the leakage should be found and corrected. Likewise, with the vacuum system open check for center conductor continuity, a reading of more than 1 ohm from the feedthrough to the transducer contact indicates a problem. Cleaning contacts or replacing the in-vacuum cable may be required.

NOTE: A more detailed troubleshooting guide is shipped with the sensor. Refer to that manual for more detailed information in some cases.

SYMPTOM	CAUSE	REMEDY
1. large jumps of thickness reading during deposition	a. mode hopping due to defective crystal	a. replace crystal, use ModeLock™ measurement system
	b. stress causes film to peel from crystal surface	b. replace crystal or use high performance RunSaver crystal; consult factory
	c. particulate or "spatter" from molten source striking crystal	c. thermally condition the source thoroughly before deposition, use a shutter to protect the crystal during source conditioning
	d. scratches or foreign particles on the crystal holder seating surface (improper crystal seating)	d. clean and polish the crystal seating surface on the crystal holder
	e. small pieces of material fell on crystal (for crystal facing up sputtering situation)	e. check the crystal surface and blow it off with clean air
	f. small pieces of magnetic material being attracted by the sensor magnet and contacting the crystal (sputtering sensor head)	f. check the sensor cover's aperture and remove any foreign material that may be restricting full crystal coverage

SYMPTOM	CAUSE	REMEDY
2. crystal ceases to oscillate during deposition before it reaches its "normal" life	a. crystal struck by particulate or "spatter" from molten source	a. thermally condition the source thoroughly before deposition, use a shutter to protect the crystal during source conditioning
	b. material on crystal holder partially masking crystal cover aperture	b. clean crystal holder
	c. existence of electrical short or open condition	c. using an ohm meter or DVM, check for electrical continuity in the sensor cable, connector, contact springs, connecting wire inside sensor, and feedthroughs..
	d. check for thermally induced electrical short or open condition	d. see "c" above
NOTE: Crystal life is highly dependent on process conditions of rate, power radiated from source, location, material, and residual gas composition.		
3. crystal does not oscillate or oscillates intermittently (both in vacuum and in air)	a. intermittent or poor electrical contact (contacts oxidized)	a. use an ohm meter or DVM to check electrical continuity, clean contacts
	b. leaf springs have lost retentivity (ceramic retainer, center insulator)	b. rebend leafs to approx. 45°
	c. RF interference from sputtering power supply	c. verify earth ground, use ground strap adequate for RF ground, change location of instrument and oscillator cabling away from RF power lines, connect instrument to a different power line
	d. cables/oscillator not connected, or connected to wrong sensor input	d. verify proper connections, and inputs relative to programmed sensor parameter

SYMPTOM	CAUSE	REMEDY
4. crystal oscillates in vacuum but stops oscillation after open to air	a. crystal was near the end of its life; opening to air causes film oxidation which increases film stress	a. replace crystal
	b. excessive moisture accumulates on the crystal	b. turn off cooling water to sensor prior to venting, flow warm water through sensor while chamber is open
5. thermal instability: large changes in thickness reading during source warm-up (usually causes thickness reading to decrease) and after the termination of deposition (usually causes thickness reading to increase)	a. inadequate cooling water/ cooling water temperature too high	a. check cooling water flow rate, be certain that cooling water temperature is less than 30oC; refer to appropriate sensor manual
	b. excessive heat input to the crystal	b. if heat is due to radiation from from the evaporation source, move sensor further away from source and use sputtering crystals for better thermal stability; install radiation shield
	c. crystal not seated properly in holder	c. clean or polish the crystal seating surface on the crystal holder
	d. crystal heating caused by high energy electron flux (often found in RF sputtering)	d. use a sputtering sensor head
	e. poor thermal transfer from water line to body (CrystalSix sensor)	e. use a new water tube whenever the clamping assembly has been removed from the body; if a new water tube is not available, use a single layer of aluminum foil between the cooling tube and sensor body, if your process allows
	f. poor thermal transfer (Bakeable)	f. use Al or Au foil washer between crystal holder and sensor body

SYMPTOM	CAUSE	REMEDY
6. poor thickness reproducibility	a. variable source flux distribution	a. move sensor to a more central location to reliably sample evaporant, ensure constant relative pool height of melt, avoid tunneling into the melt
	b. sweep, dither, or position where the electron beam strikes the melt has been changed since the last deposition	b. maintain consistent source distribution by maintaining consistent sweep frequencies, sweep amplitude and electron beam position settings
	c. material does not adhere to the crystal	c. make certain the crystal surface is clean; avoid touching crystal with fingers, make use of an intermediate adhesion layer
	d. cyclic change in rate	d. make certain source's sweep frequency is not "beating" with the instrument's measurement frequency
7. large drift in thickness (greater than 200 Å for a density of 5.00 g/cc) after termination of sputtering	a. crystal heating due to poor thermal contact	a. clean or polish the crystal seating surface on the crystal holder
	b. external magnetic field interfering with the sensor's magnetic field (sputtering sensor)	b. rotate sensor magnet to proper orientation with external magnetic field, refer to the sputtering sensor manual IPN 074-157
	c. sensor magnet cracked or demagnetized (sputtering sensor)	c. check sensor magnetic field strength, the maximum field at the center of the aperture should be 700 gauss or greater

SYMPTOM	CAUSE	REMEDY
8. CrystalSix, crystal switch problem (does not advance or not centered in aperture)	a. loss of pneumatic supply, or pressure is insufficient for proper operation	a. ensure air supply is regulated at 80-90 psi
	b. operation has been impaired as a result of material accumulation on cover	b. clean material accumulation as needed, refer to CrystalSix manual IPN 074-155 for maintenance
	c. improper alignment	c. realign as per instructions in CrystalSix manual IPN 074-155
	d. 0.0225" diameter orifice not installed on the supply side of solenoid valve assembly	d. install orifice as shown in the CrystalSix manual IPN 074-155

12.2.4 Troubleshooting Computer Communications

SYMPTOM	CAUSE	REMEDY
1. communications cannot be established between the host computer and the instrument	a. improper cable connection	a. verify for correct cable wiring as described in the manual
	b. BAUD rate in host computer not the same as the instrument	b. verify BAUD rate in the host's applications program, verify BAUD rate in the instrument
	c. incompatible protocols being used	c. verify that the instrument protocol: RS232, SECS, GPIB, DATALOG, CHECKSUM, matches host
	d. incorrect device address (GPIB or SECS protocol)	d. verify device address in host's applications program, (or in IBCONF file for National Instrs. GPIB) and verify instrument address
2. error code returned	a. A = illegal command	a. the command sent was not valid; verify command syntax as shown in the instrument's manual (placement of spaces within the command string are important)
	b. B = illegal value	b. the parameter's value sent is outside the range for the given parameter, verify parameter's range
	c. C = illegal ID	c. the command sent was for a parameter which doesn't exist; verify the correct parameter number
	d. D = illegal command format	d. the command sent is not valid; verify command syntax as shown in the instrument's manual (placement of spaces within the command string are important)
	e. E = no data to retrieve	e. some parameters may not be in use, depending on the value of other parameters

SYMPTOM	CAUSE	REMEDY
	f. F = cannot change value now	f. the command sent is for a parameter that cannot be changed while the instrument is executing a Process; place the instrument in the READY state in order to change the value
	g. G = bad checksum	g. checksum value does not match the value sent by the host's application program, may be caused by noise on the RS232 cable or the checksum is not calculated properly by the applications program
	h. O = data overrun	h. I/O port unable to keep up with data transfer rate; lower BAUD rate, increase speed of host's applications program by; using a compiled version of the program, stream lining program execution, use a faster CPU

12.3 Replacing the Crystal

The procedure for replacing the crystal is basically the same with all transducers, except the CrystalSix.

CAUTIONS: *Always use clean nylon lab gloves and plastic tweezers for handling the crystal (to avoid contamination which may lead to poor adhesion of the film to the electrode).*

Do not rotate the ceramic retainer assembly after it is seated (as this will scratch the crystal electrode and cause poor contact).

Do not use excessive force when handling the ceramic retainer assembly since breakage may occur.

NOTES: Certain materials, especially dielectrics, may not adhere strongly to the crystal surface and may cause erratic readings.

Thick deposits of some materials, such as SiO, Si, and Ni will normally peel off the crystal when it is exposed to air, as a result of changes in film stress caused by gas absorption. When you observe peeling, change the crystals.

12.3.1 Standard and Compact

Follow the procedure below to replace the crystal in the Standard and Compact sensor:

1. Gripping the crystal holder with your fingers, pull it straight out of the sensor body.
2. Gently pry the crystal retainer from the holder (or use crystal snatcher; see Figure 12.5).
3. Turn the retainer over and the crystal will drop out.
4. Install a new crystal, with the patterned electrode face up.
5. Push the retainer back into the holder and replace the holder in the sensor body.

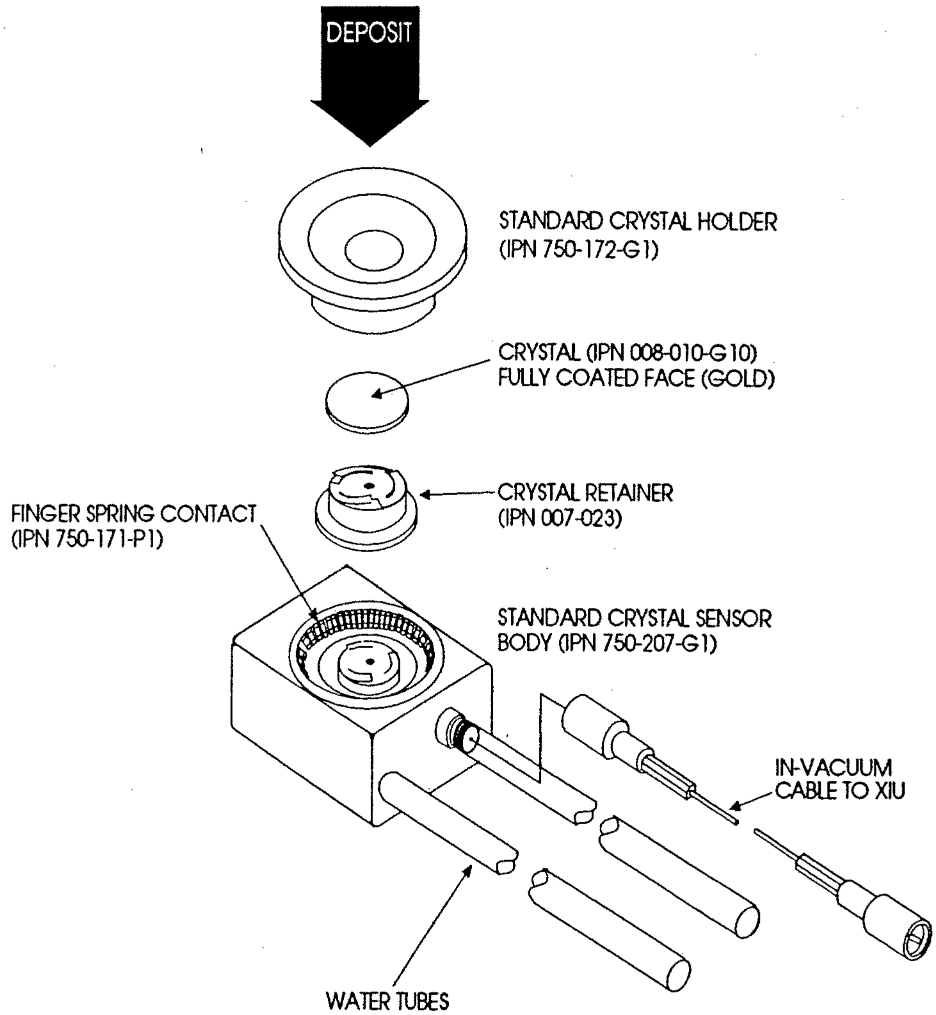


Figure 12.2 Standard Crystal Sensor (Exploded)

12.3.2 Shuttered and Dual Sensors

There is no difference in the crystal changing procedure between shuttered and non-shuttered Standard and Compact sensors, since the shutter pivots away from the crystal opening when the shutter is in the relaxed state.

12.3.3 Bakeable Sensor

For the Bakeable sensor, the procedure is the same as the regular crystal except that you must first unlock the cam assembly by flipping it up. Once the crystal has been replaced, place a flat edge of the holder flush with the cam mechanism and lock it in place with the cam (Figure 12.3).

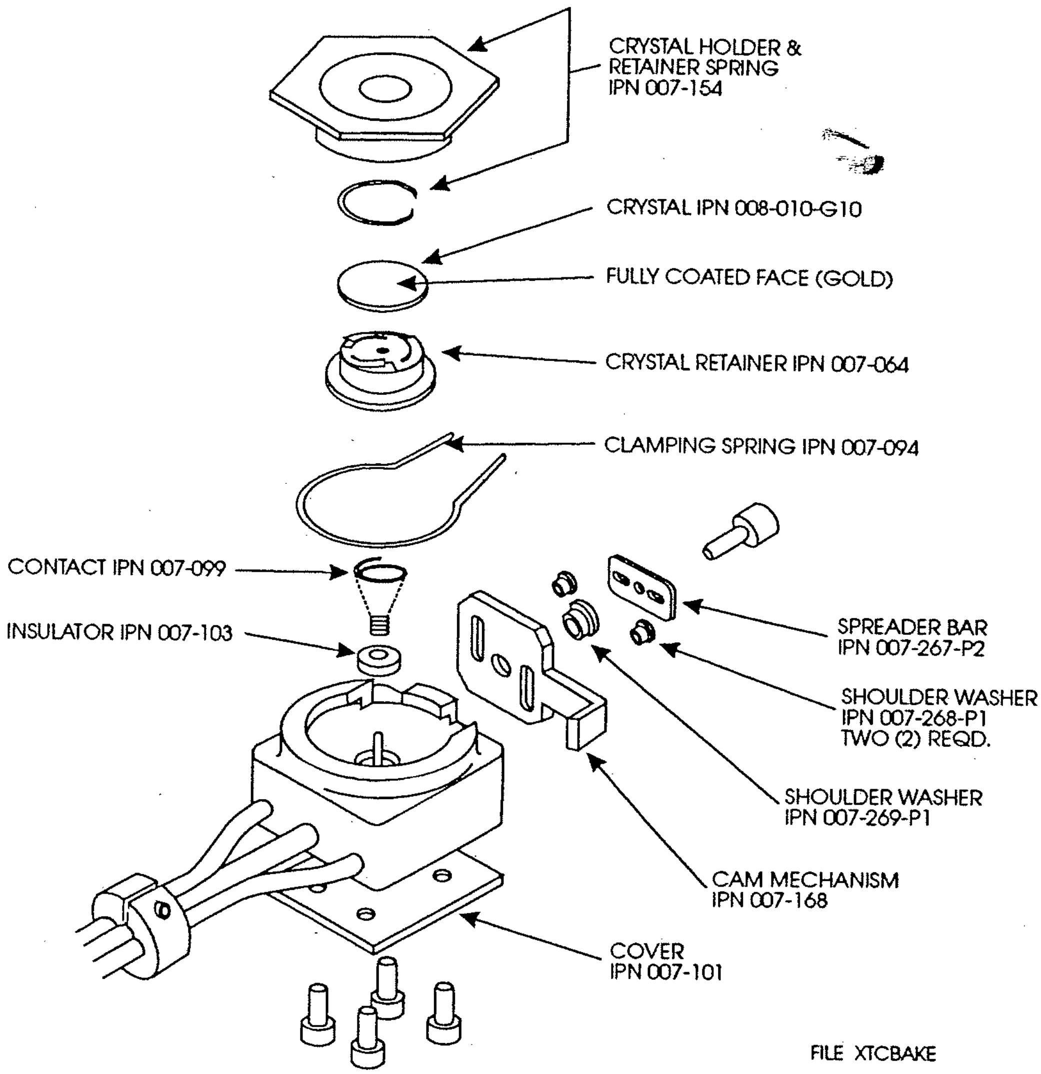


Figure 12.3 Bakeable Crystal Sensor (Exploded)

12.3.4 Sputtering Sensor

Observe the general precautions (Section 12.3) for replacing crystals and follow the instructions below to replace the crystal in a sputtering sensor.

1. Grip the body assembly with your fingers and pull it straight out to separate it from the water-cooled front part. (You may have to disconnect the sensor cable in order to separate the parts.) See Figure 12.4.
2. Pull the crystal holder straight out from the front of the sensor.
3. Remove the ceramic retainer from the crystal holder by pulling it straight out with the crystal snatcher (Section 12.4.5 - Using the Crystal Snatcher).
4. Turn the crystal holder over so that the crystal drops out.
5. Install a new crystal into the crystal holder with the patterned electrode facing the back and contacting the leaf springs on the ceramic retainer. (Use only special crystals for sputtering, IPN 008-009-G10.)
6. Put the ceramic retainer back into the crystal holder and put the holder into the front cover of the sensor.
7. Align the position of the back part so that the connector matches with the notch on the front of the sensor. Snap the two parts together. Reconnect the sensor cable if it has been disconnected.

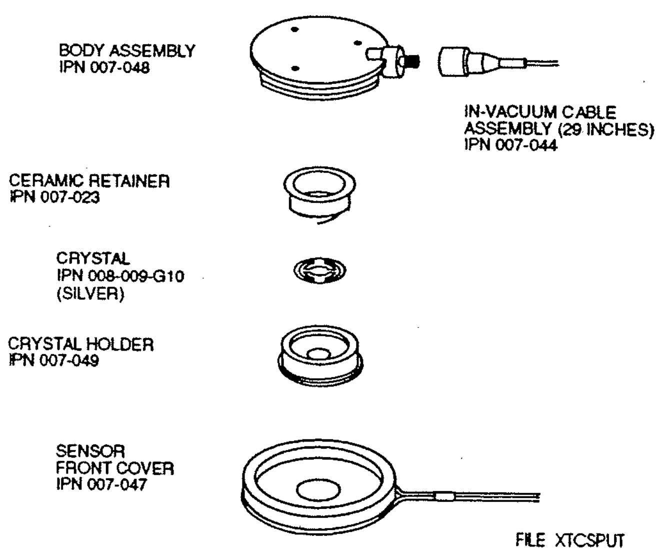


Figure 12.4 Sputtering Crystal Sensor (Exploded)

12.3.5 Crystal Snatcher (IPN 007-035)

To use the crystal snatcher supplied with the sensor follow the instructions below:

1. Insert crystal snatcher into ceramic retainer (1) and apply a small amount of pressure. This locks the retainer to the snatcher and allows the retainer to be pulled straight out (2).
2. Re-insert the retainer into the holder after the crystal has been changed.
3. Release the crystal snatcher with a slight side-to-side motion.

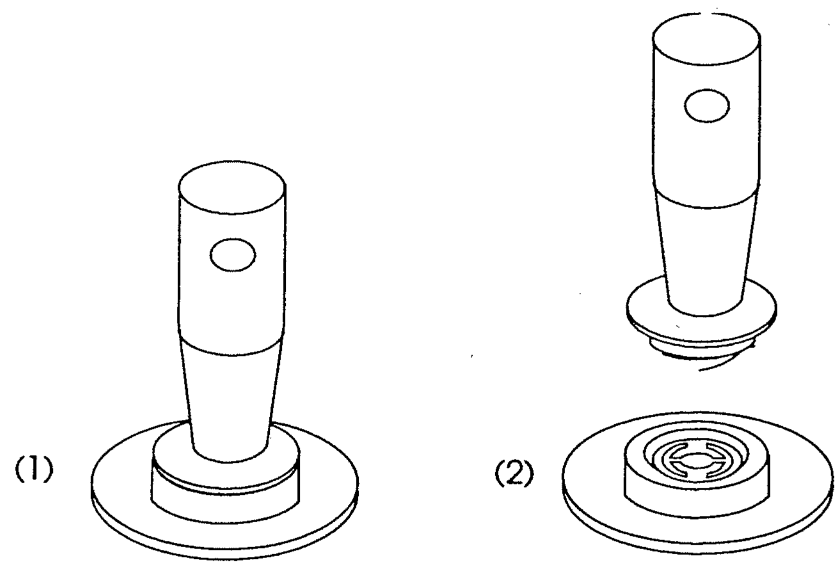


Figure 12.5 Use of Crystal Snatcher

12.3.6 CrystalSix

See the manual (IPN 074-155) for specific instructions for this device.

Appendix A - Material Table

The following table represents the content of the instrument's material library. The list is alphabetical by chemical formula.

The communications facility utilizes the code value to represent a specific material. An * is used to indicate that a Z-ratio has not been established for a certain material. A value of 1.000 is defaulted in these situations.

Code	Formula	Density	Z-Ratio	Material Name
0	Ag	10.500	0.529	Silver
1	AgBr	6.470	1.180	Silver Bromide
2	AgCl	5.560	1.320	Silver Chloride
3	Al	2.700	1.080	Aluminum
4	Al_2O_3	3.970	0.336	Aluminum Oxide
5	Al_4C_3	2.360	*1.000	Aluminum Carbide
6	AlF_3	3.070	*1.000	Aluminum Fluoride
7	AlN	3.260	*1.000	Aluminum Nitride
8	AlSb	4.360	0.743	Aluminum Antimonide
9	As	5.730	0.966	Arsenic
10	As_2Se_3	4.750	*1.000	Arsenic Selenide
11	Au	19.300	0.381	Gold
12	B	2.370	0.389	Boron
13	B_2O_3	1.820	*1.000	Boron Oxide
14	B_4C	2.370	*1.000	Boron Carbide
15	Ba	3.500	2.100	Barium
16	BaF_2	4.886	0.793	Barium Fluoride
17	BaN_2O_6	3.244	1.261	Barium Nitrate
18	BaO	5.720	*1.000	Barium Oxide
19	$BaTiO_3$	5.999	0.464	Barium Titanate (Tetr)
20	$BaTiO_3$	6.035	0.412	Barium Titanate (Cubic)
21	Be	1.850	0.543	Beryllium
22	BeF_2	1.990	*1.000	Beryllium Fluoride
23	BeO	3.010	*1.000	Beryllium Oxide
24	Bi	9.800	0.790	Bismuth
25	Bi_2O_3	8.900	*1.000	Bismuth Oxide
26	Bi_2S_3	7.390	*1.000	Bismuth Trisulphide
27	Bi_2Se_3	6.820	*1.000	Bismuth Selenide
28	Bi_2Te_3	7.700	*1.000	Bismuth Telluride
29	BiF_3	5.320	*1.000	Bismuth Fluoride
30	BN	1.860	*1.000	Boron Nitride

Code	Formula	Density	Z-Ratio	Material Name
31	C	2.250	3.260	Carbon (Graphite)
32	C	3.520	0.220	Carbon (Diamond)
33	C_8H_8	1.100	*1.000	Parlyene (Union Carbide)
34	Ca	1.550	2.620	Calcium
35	CaF_2	3.180	0.775	Calcium Fluoride
36	CaO	3.350	*1.000	Calcium Oxide
37	$CaO-SiO_2$	2.900	*1.000	Calcium Silicate (3)
38	$CaSO_4$	2.962	0.955	Calcium Sulfate
39	$CaTiO_3$	4.100	*1.000	Calcium Titanate
40	$CaWO_4$	6.060	*1.000	Calcium Tungstate
41	Cd	8.640	0.682	Cadmium
42	CdF_2	6.640	*1.000	Cadmium Fluoride
43	CdO	8.150	*1.000	Cadmium Oxide
44	CdS	4.830	1.020	Cadmium Sulfide
45	CdSe	5.810	*1.000	Cadmium Selenide
46	CdTe	6.200	0.980	Cadmium Telluride
47	Ce	6.780	*1.000	Cerium
48	CeF_3	6.160	*1.000	Cerium (III) Fluoride
49	CeO_2	7.130	*1.000	Cerium (IV) Dioxide
50	Co	8.900	0.343	Cobalt
51	CoO	6.440	0.412	Cobalt Oxide
52	Cr	7.200	0.305	Chromium
53	Cr_2O_3	5.210	*1.000	Chromium (III) Oxide
54	Cr_3C_2	6.680	*1.000	Chromium Carbide
55	CrB	6.170	*1.000	Chromium Boride
56	Cs	1.870	*1.000	Cesium
57	Cs_2SO_4	4.243	1.212	Cesium Sulfate
58	CsBr	4.456	1.410	Cesium Bromide
59	CsCl	3.988	1.399	Cesium Chloride
60	CsI	4.516	1.542	Cesium Iodide
61	Cu	8.930	0.437	Copper
62	Cu_2O	6.000	*1.000	Copper Oxide
63	Cu_2S	5.600	0.690	Copper (I) Sulfide(Alpha)
64	Cu_2S	5.800	0.670	Copper (I) Sulfide (Beta)
65	CuS	4.600	0.820	Copper (II) Sulfide
66	Dy	8.550	0.600	Dysprosium
67	Dy_2O_3	7.810	*1.000	Dysprosium Oxide
68	Er	9.050	0.740	Erbium
69	Er_2O_3	8.640	*1.000	Erbium Oxide
70	Eu	5.260	*1.000	Europium
71	EuF_2	6.500	*1.000	Europium Fluoride
72	Fe	7.860	0.349	Iron
73	Fe_2O_3	5.240	*1.000	Iron Oxide

Code	Formula	Density	Z-Ratio	Material Name
74	FeO	5.700	*1.000	Iron Oxide
75	FeS	4.840	*1.000	Iron Sulphide
76	Ga	5.930	0.593	Gallium
77	Ga_2O_3	5.880	*1.000	Gallium Oxide (B)
78	GaAs	5.310	1.590	Gallium Arsenide
79	GaN	6.100	*1.000	Gallium Nitride
80	GaP	4.100	*1.000	Gallium Phosphide
81	GaSb	5.600	*1.000	Gallium Antimonide
82	Gd	7.890	0.670	Gadolinium
83	Gd_2O_3	7.410	*1.000	Gadolinium Oxide
84	Ge	5.350	0.516	Germanium
85	Ge_3N_2	5.200	*1.000	Germanium Nitride
86	GeO_2	6.240	*1.000	Germanium Oxide
87	GeTe	6.200	*1.000	Germanium Telluride
88	Hf	13.090	0.360	Hafnium
89	HfB_2	10.500	*1.000	Hafnium Boride
90	HfC	12.200	*1.000	Hafnium Carbide
91	HfN	13.800	*1.000	Hafnium Nitride
92	HfO_2	9.680	*1.000	Hafnium Oxide
93	$HfSi_2$	7.200	*1.000	Hafnium Silicide
94	Hg	13.460	0.740	Mercury
95	Ho	8.800	0.580	Holminum
96	Ho_2O_3	8.410	*1.000	Holminum Oxide
97	In	7.300	0.841	Indium
98	In_2O_3	7.180	*1.000	Indium Sesquioxide
99	In_2Se_3	5.700	*1.000	Indium Selenide
100	In_2Te_3	5.800	*1.000	Indium Telluride
101	InAs	5.700	*1.000	Indium Arsenide
102	InP	4.800	*1.000	Indium Phosphide
103	InSb	5.760	0.769	Indium Antimonide
104	Ir	22.400	0.129	Iridium
105	K	0.860	10.189	Potassium
106	KBr	2.750	1.893	Potassium Bromide
107	KCl	1.980	2.050	Potassium Chloride
108	KF	2.480	*1.000	Potassium Fluoride
109	KI	3.128	2.077	Potassium Iodide
110	La	6.170	0.920	Lanthanum
111	La_2O_3	6.510	*1.000	Lanthanum Oxide
112	LaB_6	2.610	*1.000	Lanthanum Boride
113	LaF_3	5.940	*1.000	Lanthanum Fluoride
114	Li	0.530	5.900	Lithium
115	LiBr	3.470	1.230	Lithium Bromide
116	LiF	2.638	0.778	Lithium Fluoride

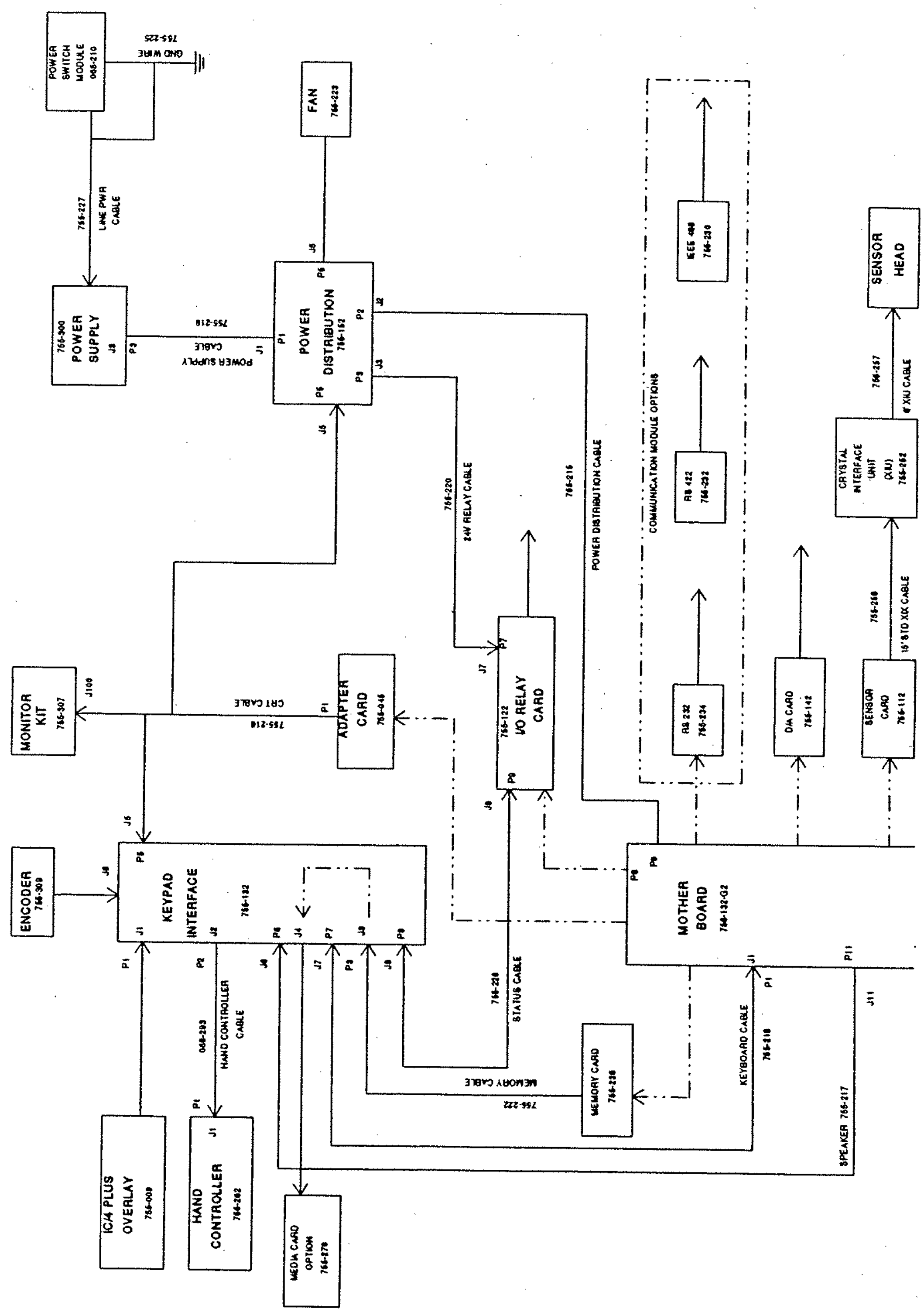
Code	Formula	Density	Z-Ratio	Material Name
117	$LiNbO_3$	4.700	0.463	Lithium Niobate
118	Lu	9.840	*1.000	Lutetium
119	Mg	1.740	1.610	Magnesium
120	$MgAl_2O_4$	3.600	*1.000	Magnesium Aluminate
121	MgF_2	3.180	0.637	Magnesium Fluoride
122	MgO	3.580	0.411	Magnesium Oxide
123	$MgO_3Al_2O_3$	8.000	*1.000	Spinel
124	Mn	7.200	0.377	Manganese
125	MnO	5.390	0.467	Manganese Oxide
126	MnS	3.990	0.940	Manganese (II) Sulfide
127	Mo	10.200	0.257	Molybdenum
128	Mo_2C	9.180	*1.000	Molybdenum Carbide
129	MoB_2	7.120	*1.000	Molybdenum Boride
130	MoO_3	4.700	*1.000	Molybdenum Trioxdide
131	MoS_2	4.800	*1.000	Molybdenum Disulfide
132	Na	0.970	4.800	Sodium
133	Na_3AlF_6	2.900	*1.000	Cryolite
134	$Na_5Al_3F_{14}$	2.900	*1.000	Chiolite
135	NaBr	3.200	*1.000	Sodium Bromide
136	NaCl	2.170	1.570	Sodium Chloride
137	$NaClO_3$	2.164	1.565	Sodium Chlorate
138	NaF	2.558	0.949	Sodium Fluoride
139	$NaNO_3$	2.270	1.194	Sodium Nitrate
140	Nb	8.578	0.492	Niobium (Columbium)
141	$Nb2O_3$	7.500	*1.000	Niobium Trioxide
142	$Nb2O_5$	4.470	*1.000	Niobium (V) Oxide
143	NbB_2	6.970	*1.000	Niobium Boride
144	NbC	7.820	*1.000	Niobium Carbide
145	NbN	8.400	*1.000	Niobium Nitride
146	Nd	7.000	*1.000	Neodynium
147	$Nd2O_3$	7.240	*1.000	Neodynium Oxide
148	NdF_3	6.506	*1.000	Neodynium Fluoride
149	Ni	8.910	0.331	Nickel
150	NiCr	8.500	*1.000	Nichrome
151	NiCrFe	8.500	*1.000	Inconel
152	NiFe	8.700	*1.000	Permalloy
153	NiFeMo	8.900	*1.000	Supermalloy
154	NiO	7.450	*1.000	Nickel Oxide
155	P_3N_5	2.510	*1.000	Phosphorus Nitride
156	Pb	11.300	1.130	Lead
157	$PbCl_2$	5.850	*1.000	Lead Chloride
158	PbF_2	8.240	0.661	Lead Fluoride
159	PbO	9.530	*1.000	Lead Oxide

Code	Formula	Density	Z-Ratio	Material Name
160	PbS	7.500	0.566	Lead Sulfide
161	PbSe	8.100	*1.000	Lead Selenide
162	$PbSnO_3$	8.100	*1.000	Lead Stannate
163	PbTe	8.160	0.651	Lead Telluride
164	Pd	12.038	0.357	Palladium
165	PdO	8.310	*1.000	Palladium Oxide
166	Po	9.400	*1.000	Polonium
167	Pr	6.780	*1.000	Praseodymium
168	Pr_2O_3	6.880	*1.000	Praseodymium Oxide
169	Pt	21.400	0.245	Platinum
170	PtO_2	10.200	*1.000	Platinum Oxide
171	Ra	5.000	*1.000	Radium
172	Rb	1.530	2.540	Rubidium
173	RbI	3.550	*1.000	Rubidium Iodide
174	Re	21.040	0.150	Rhenium
175	Rh	12.410	0.210	Rhodium
176	Ru	12.362	0.182	Ruthenium
177	S_8	2.070	2.290	Sulphur
178	Sb	6.620	0.768	Antimony
179	Sb_2O_3	5.200	*1.000	Antimony Trioxide
180	Sb_2S_3	4.640	*1.000	Antimony Trisulfide
181	Sc	3.000	0.910	Scandium
182	Sc_2O_3	3.860	*1.000	Scandium Oxide
183	Se	4.810	0.864	Selenium
184	Si	2.320	0.712	Silicon
185	Si_3N_4	3.440	*1.000	Silicon Nitride
186	SiC	3.220	*1.000	Silicon Carbide
187	SiO	2.130	0.870	Silicon (II) Oxide
188	SiO_2	2.648	1.000	Silicon Dioxide
189	Sm	7.540	0.890	Samarium
190	Sm_2O_3	7.430	*1.000	Samarium Oxide
191	Sn	7.300	0.724	Tin
192	SnO_2	6.950	*1.000	Tin Oxide
193	SnS	5.080	*1.000	Tin Sulfide
194	SnSe	6.180	*1.000	Tin Selenide
195	SnTe	6.440	*1.000	Tin Telluride
196	Sr	2.600	*1.000	Strontium
197	SrF_2	4.277	0.727	Strontium Fluroide
198	SrO	4.990	0.517	Strontium Oxide
199	Ta	16.600	0.262	Tantalum
200	Ta_2O_5	8.200	0.300	Tantalum (V) Oxide
201	TaB_2	11.150	*1.000	Tantalum Boride
202	TaC	13.900	*1.000	Tantalum Carbide

Code	Formula	Density	Z-Ratio	Material Name
203	TaN	16.300	*1.000	Tantalum Nitride
204	Tb	8.270	0.660	Terbium
205	Tc	11.500	*1.000	Technetium
206	Te	6.250	0.900	Tellurium
207	TeO_2	5.990	0.862	Tellurium Oxide
208	Th	11.694	0.484	Thorium
209	ThF_4	6.320	*1.000	Thorium (IV) Fluoride
210	ThO_2	9.860	0.284	Thorium Dioxide
211	$ThOF_2$	9.100	*1.000	Thorium Oxyfluoride
212	Ti	4.500	0.628	Titanium
213	Ti_2O_3	4.600	*1.000	Titanium Sesquioxide
214	TiB_2	4.500	*1.000	Titanium Boride
215	TiC	4.930	*1.000	Titanium Carbide
216	TiN	5.430	*1.000	Titanium Nitride
217	TiO	4.900	*1.000	Titanium Oxide
218	TiO_2	4.260	0.400	Titanium (IV) Oxide
219	Tl	11.850	1.550	Thallium
220	TlBr	7.560	*1.000	Thallium Bromide
221	TlCl	7.000	*1.000	Thallium Chloride
222	TlI	7.090	*1.000	Thallium Iodide (B)
223	U	19.050	0.238	Uranium
224	U_4O_9	10.969	0.348	Uranium Oxide
225	UO_2	10.970	0.286	Uranium Dioxide
226	U_3O_8	8.300	*1.000	Tri Uranium Octoxide
227	V	5.960	0.530	Vanadium
228	V_2O_5	3.360	*1.000	Vanadium Pentoxide
229	VB_2	5.100	*1.000	Vanadium Boride
230	VC	5.770	*1.000	Vanadium Carbide
231	VN	6.130	*1.000	Vanadium Nitride
232	VO_2	4.340	*1.000	Vanadium Dioxide
233	W	19.300	0.163	Tungsten
234	WC	15.600	0.151	Tungsten Carbide
235	WB_2	10.770	*1.000	Tungsten Boride
236	WO_3	7.160	*1.000	Tungsten Trioxide
237	WS_2	7.500	*1.000	Tungsten Disulphide
238	WSi_2	9.400	*1.000	Tungsten Silicide
239	Y	4.340	0.835	Yttrium
240	Y_2O_3	5.010	*1.000	Yttrium Oxide
241	Yb	6.980	1.130	Ytterbium
242	Yb_2O_3	9.170	*1.000	Ytterbium Oxide
243	Zn	7.040	0.514	Zinc
244	Zn_3Sb_2	6.300	*1.000	Zinc Antimonide
245	ZnF_2	4.950	*1.000	Zinc Fluoride

Code	Formula	Density	Z-Ratio	Material Name
246	ZnO	5.610	0.556	Zinc Oxide
247	ZnS	4.090	0.775	Zinc Sulfide
248	$ZnSe$	5.260	0.722	Zinc Selenide
249	$ZnTe$	6.340	0.770	Zinc Telluride
250	Zr	6.490	0.600	Zirconium
251	ZrB_2	6.080	*1.000	Zirconium Boride
252	ZrC	6.730	0.264	Zirconium Carbide
253	ZrN	7.090	*1.000	Zirconium Nitride
254	ZrO_2	5.600	*1.000	Zirconium Oxide
255		10.000	*1.000	USER

Appendix B - IC/4 PLUS Interconnection Diagram



Appendix B - IC/4 Interconnection Diagram