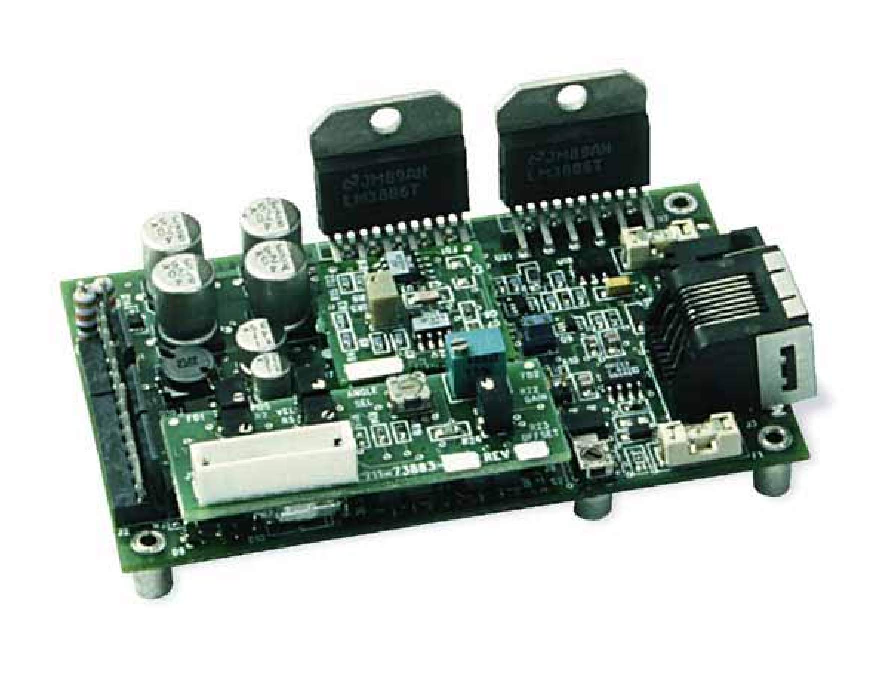
MiniSAX™ User's Manual



References found in this document to prior company and division names such as General Scanning Inc., GSI Lumonics, and GMAX now refer to General Scanning Optical Scanners, a member of GSI Group Inc.

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1 IMPORTANT INFORMATION

1.1 ESD WARNING

The OEM electronics that *General Scanning* manufactures - including galvanometers and servo controllers - are electrostatic discharge (ESD) sensitive. Improper handling could therefore damage these electronics. *General Scanning* has implemented procedures and precautions for handling these devices and we encourage our customers to do the same. Upon receiving your components, you should note that it is packaged in an ESD-protected container with the appropriate ESD warning labels. The equipment should remain sealed until the user is located at a proper static control station*.

Note: Any equipment returned to the factory must be shipped in anti-static packaging.

(*) A proper static control station **should** include:

1. A soft grounded conductive tabletop or grounded conductive mat on the tabletop.
2. A grounded wrist strap with the appropriate (1 Meg) series resistor connected to the tabletop mat and ground.
3. An adequate earth ground connection such as a water pipe or AC ground.
4. Conductive bags, trays, totes, racks or other containers used for storage.
5. Properly grounded power tools.
6. Personnel handling ESD items should wear ESD protective garments and ground straps.

1.2 Warranty Information

The Customer shall examine each shipment within 10 days of receipt and inform General Scanning of any shortage or damage. If no discrepancies are reported, General Scanning shall assume the shipment was delivered complete and defect free. General Scanning warrantees products against defects up to 1 year from manufacture date, barring unauthorized modifications or misuse. Repaired product is warranted 90 days after the repair is made, or one year after manufacture date - whichever is longer.

Contact Customer Service to obtain a Return Materials Authorization number *before returning any product for repair*.

All orders are subject to the General Scanning Terms and Conditions and Limited Warranty. Visit our website for the latest version of these documents and other useful information.

IMPORTANT: Optical Scanners are normally tuned, serialized and warranted as a matched set for optimized performance. Mismatched components negatively affect performance and void the warranty. A matched set typically consists of galvanometer motor, mirror load, electronic driver board and interface cable.

1.3 Customer Support

General Scanning has support services to address your questions or concerns with either the product or manual you are using. Before calling for assistance, be sure to refer to any appropriate sections in the manual that may answer your questions. Call General Scanning's Customer Service Department Monday through Friday between 8 A.M. and 5 P.M. local time (GMT –05:00 Eastern Time (US & Canada)).

The customer service personnel will be able to give you direct assistance and answers to your questions.

2 INTRODUCTION

The MiniSAX (**Mini**ature **S**ingle **AX**is) servo controller is one of *GSI Lumonics*' most recent developments in galvanometric servo control technology. By taking advantage of the newest surface mount components, the MiniSAX provides full-function scan electronics at a size and cost less than many stripped down servo amplifiers. Advanced servo filtering techniques together with a low-coupling design provide extended bandwidths and improved response times. The MiniSAX was engineered with system designers in mind, incorporating a simple yet comprehensive and flexible interface structure. For the first time, laser system manufactures can purchase a truly high performance, cost effective galvanometer servo controller that allows convenient, "in-head" packaging.

The MiniSAX uses a modular design, providing the ability to readily configure the driver for specific applications. An optional filter module is available in a variety of adjustable notch frequency ranges. The frequency response of this module can be optimized to handle a variety of customer-supplied loads. A thermal control module is available to support GSIL's thermally regulated scanners, allowing use of the industry's lowest drift galvanometers.

The MiniSAX product line includes a variety of accessories that ease the integration into your manufacturing process. The MiniSAX mounting bracket provides convenient mounting surfaces and mates with either of two optional heatsinks. A test interface board allows easy access to a variety of important test points. Mating connectors and inexpensive assembly tools are available directly from *GSI Lumonics*. The MiniSAX Startup Kit is recommended for first time users and includes many of these valuable accessories.

The purpose of this manual is to familiarize the user with the functionality of the MiniSAX driver. This manual also touches on topics such as servo tuning and troubleshooting. When buying a complete line scan engine (scanner, driver, and mirror) the servo should arrive with a factory tune. Do not attempt to retune the servo unless the tuning instructions in section 12 are fully understood.

3 SPECIFICATIONS

Command Input Characteristics

♦ Differential Voltage Range	±3 volts differential for full scale
♦ Input Impedance	5 KΩ differential

Position Output ±3 volts differential for full scale

Power Input

♦ Voltage	±15 to ±24 volts DC
♦ Quiescent Current	+170mA, -150mA (servo enabled, galvo resting w/o error, no thermal controller)

Motor Drive Power

♦ Dynamic Current max.	2.5 Amps RMS
♦ Peak Current	10.0 Amps

Note: U20/U21 mounting screws should be tightened to a torque of 16 in-lb (1.8 N-M).

Control I/O Characteristics

♦ Servo Ready	Open Drain, Active Low (50 mA max.)
♦ Servo Enable	TTL/CMOS Compatible, Active Low
♦ Temp OK*	Open Drain, Active Low (50 mA max.)

* Part of optional Temperature Controller Module

Protection

♦ Fully Fused	Motor Output, Automatic Gain Control, and Thermal Controller[1]
♦ Automatic Shutoff	Over-position, Supply Undervoltage, Position Detector Inactive

Temperature Range 0°C to 50°C Operating

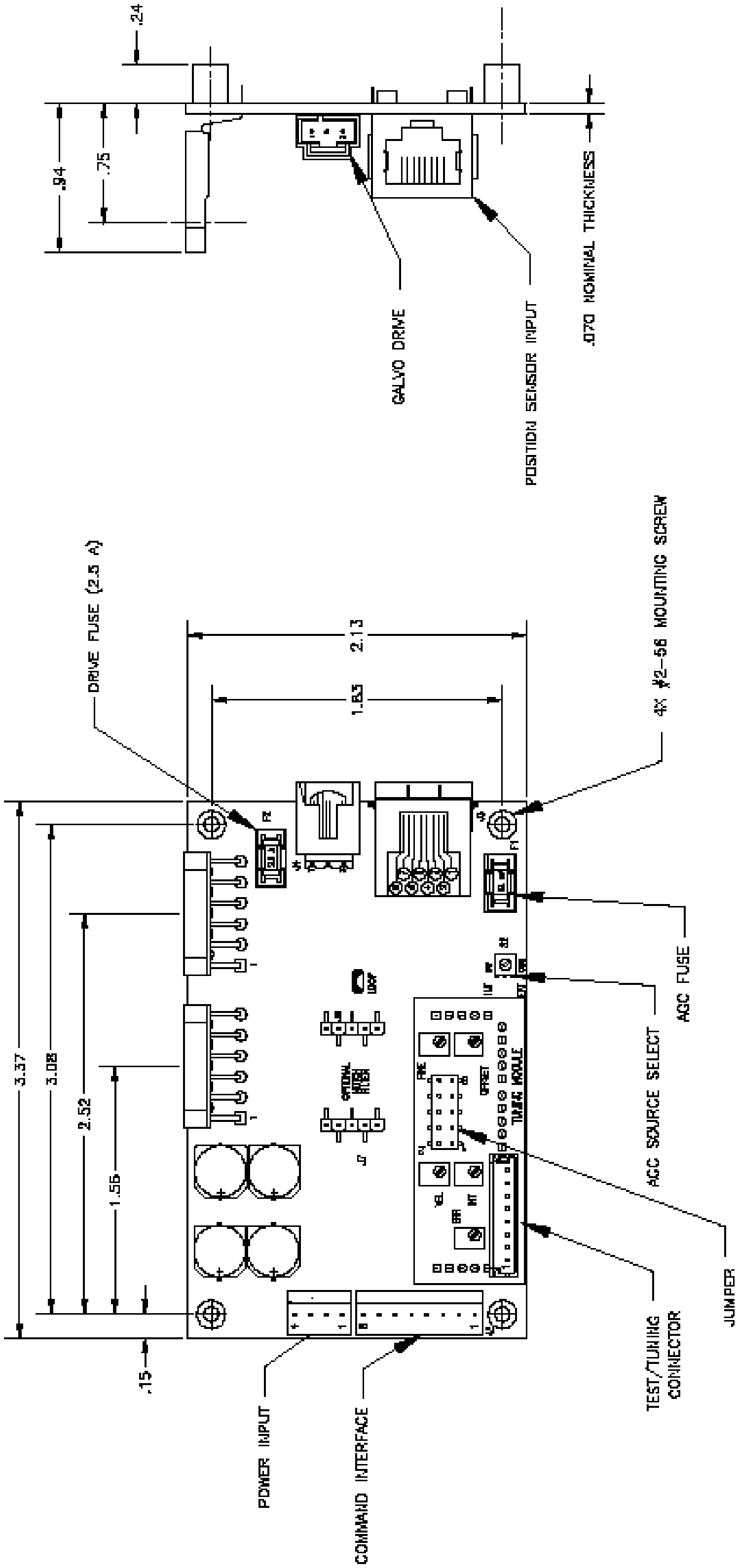
Size (not including mounting bracket)

W *x* **L** *x* **H**
$2\frac{1}{8}$” *x* $3\frac{3}{8}$” *x*$1\frac{1}{4}$”
(54.5mm *x* 86.5mm *x* 31.35mm)

Weight 66 grams
(Includes all optional modules. Does not include mounting bracket)

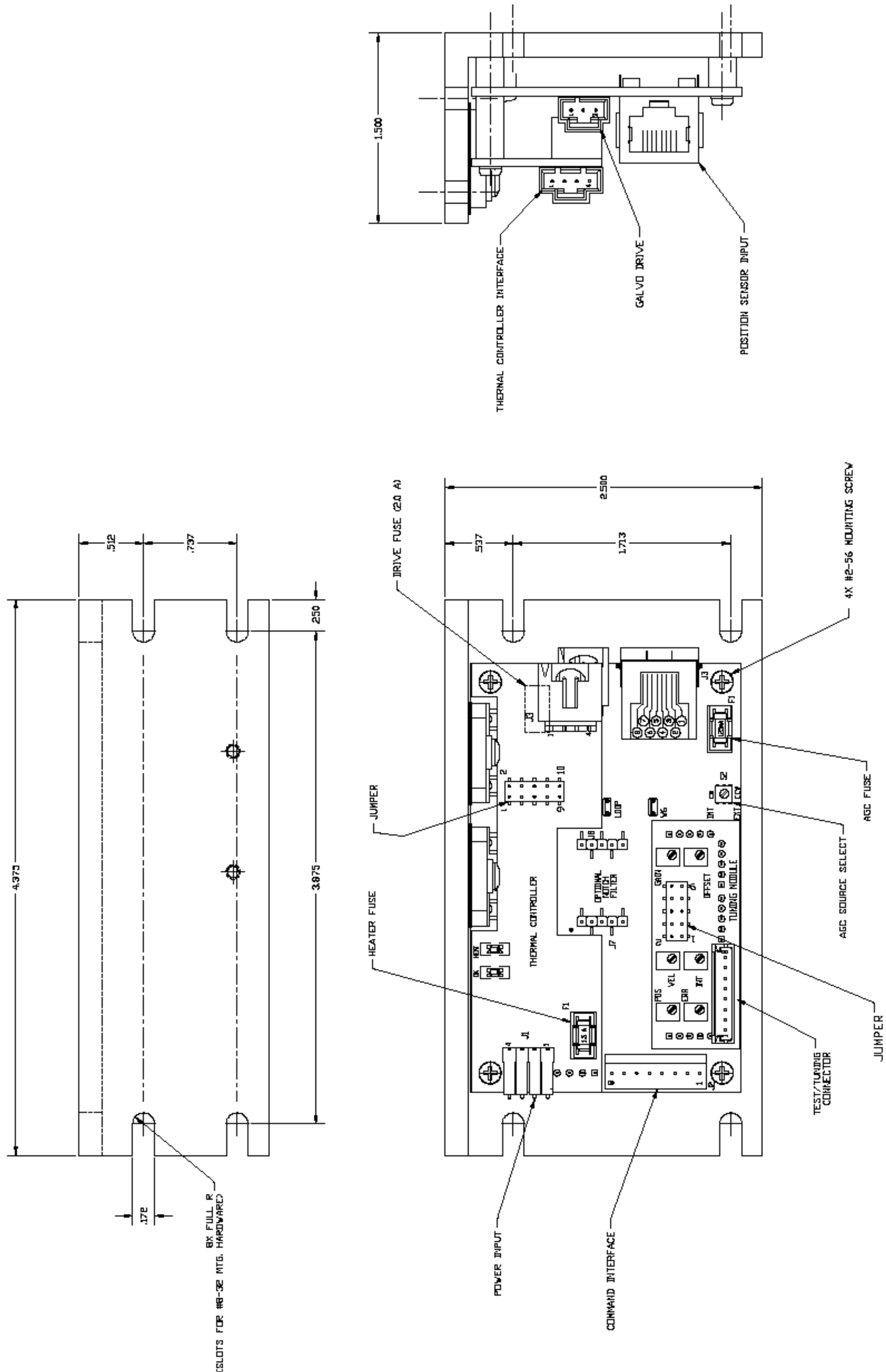
MiniSAX Outline

(without bracket, notch or temp. controller)



MiniSAX Outline with Bracket

(shown with thermal controller, notch and tuning module)



4 CONNECTIONS

4.1 Power Supply

Power is supplied to the MiniSAX through the J1 connector (See Figure 1). On controllers without the thermal regulator option, this connector is located on the baseboard. On systems with the thermal control option, the J1 connector is located on the thermal control module. The connector pin functions are shown in Table 1.

The power supply voltage requirement of the MiniSAX is application dependent. In most cases, +/-15V is recommended unless your application requires aggressive large signal response. Using higher voltage supplies can significantly increase the heatsinking requirements of the driver and scanner.

The power supply current requirement is application dependent and will vary as a function of the magnitude and duty cycle of scanner acceleration required. The MiniSAX driver is rated for a maximum ±2.5A RMS and 10A peak output currents. With all accessory modules installed and active, the maximum RMS supply current draw of the MiniSAX driver is 3A.

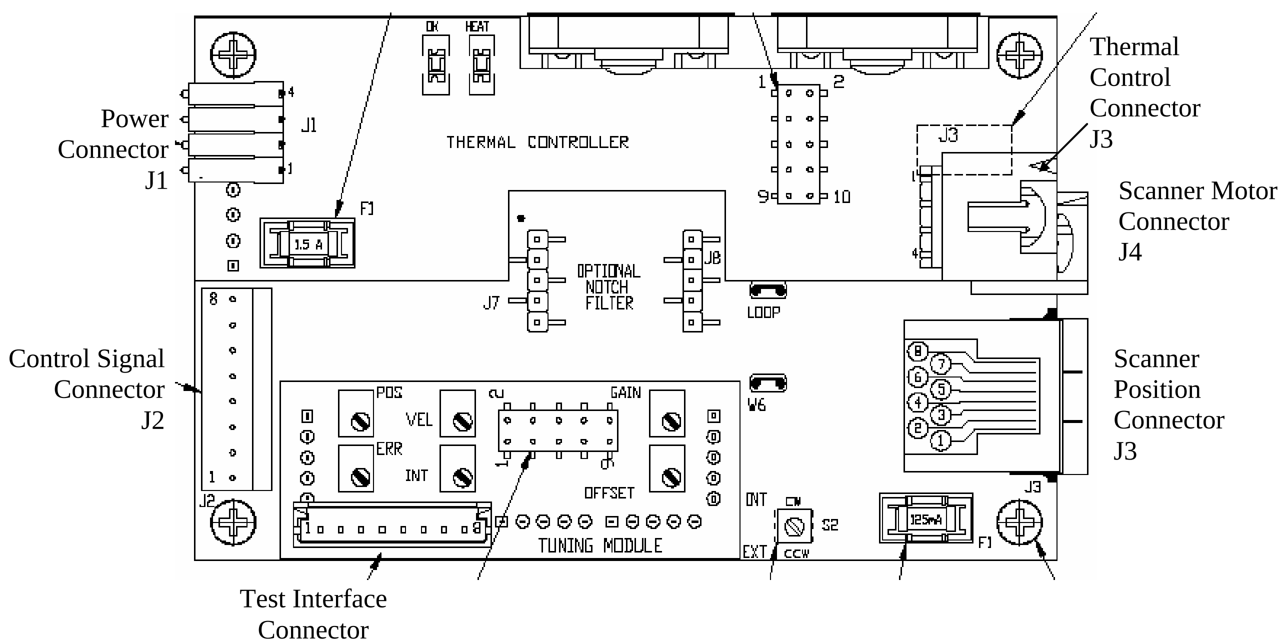


Figure 1: MiniSAX Connections

Table 1: Power Connector

Pin	Function
1	Reserved
2	Supply + (+15 to +24 V)
3	Supply Ground
4	Supply – (-15 to -24 V)

Mating Connector*: Panduit: CE100F22-4-D
Strain Relief*: Panduit: SCC100F-4-D
Assembly Tool*: Panduit: MRT-100F
Specified Wire Size: AWG #22 (Also available in #24, #26, #28)

**Contact your local GSI Lumonics Sales Representative for sample.*

4.2 Control Signal Interface

The control signal interface is provided on connector J2 located on the baseboard. System I/O including command input, position output, status feedback, and enable are located on this connector. The signal connector pin functions are provided in Table 2:

Table 2: Signal Interface Connector

Pin	Function
1	Command +
2	Command –
3	Ground
4	Temperature Status
5	Servo Enable
6	Servo Ready
7	Scanner Position +
8*	Scanner Position –

* Differential output- do not ground.

Mating Connector: Panduit CE100F22-8-D
Strain Relief: Panduit SCC100F-8-D
Assembly Tool: Panduit: MRT-100F
Specified Wire Size: AWG #22 (Also available in #24, #26, #28)

Command Input

The command input to the Mini-SAX is a true differential input that accepts a full-scale command of ±3V. For best noise immunity, GSIL suggests sending the analog command signal over a twisted shielded pair, grounding the shield at the MiniSAX ground, while allowing command (-) and (+) to float at the MiniSAX input.

Temperature Status

On drivers equipped with the optional temperature control module (TCM), this line provides a status signal indicating when the scanner temperature is in regulation. This is an active-low, open-drain output and will require an external pull-up resistor. The output is rated for a maximum sink current of 50 mA at a maximum 25 volts.

Careful consideration should be taken when using the temperature status signal to trigger a fault condition. This flag is set when the scanner temperature is within +/- 0.5^{o}C of the regulation set-point. Sudden increase in scanner power dissipation could increase the scanner temperature faster than the TCM can respond, causing an unwanted system shutdown.

Servo Enable

The SERVO_ENABLE input allows system-level control of galvo motion during startup or software reset. SERVO_ENABLE is an active low, TTL/CMOS compatible input. For systems not requiring this function, the SERVO_ENABLE input should be tied to a low logic level and can be connected directly to ground. **NOTE: The servo will not function while the SERVO_ENABLE is not at low logical level.**

Servo Ready

SERVO_READY is an active low output that indicates the servo is enabled and no fault conditions are detected. This is an open drain output, capable of sinking 50 mA at a maximum of 25V. An external pull up resistor is required. For more details on the fault conditions monitored by this output, see the section 5.1 "*Fault Detection*".

Scanner Position

The scanner position is provided as a true differential output with the same scale factor as the command input. *A true differential receiver is required for this signal.* ***The Scanner Position (-) output must not be tied to ground.*** If a single ended signal is desired, the + Scanner Position output can be used referenced to ground, but the full-scale voltage will be reduced by a factor of two.

4.3 Scanner Connections

The scanner is connected to the MiniSAX through two cables for standard scanners and through three cables for thermally regulated devices. The scanner position transducer signals connect through J3 and the motor interface is through J4, both on the baseboard. The optional thermal control is connected through J3 on the thermal control module. Each connector is unique and cannot be accidentally misconnected.

4.4 Test Interface Connector

A test interface connector is provided as J1 on the tuning module. This port is designed to connect with the MiniSAX Test Interface Board. The signals available on the test interface connector are not buffered or isolated and are not recommended for use other than with the recommended Test Interface

Board. If these signals are to be used in your laser system, we strongly recommend that they be buffered as close as possible to the MiniSAX controller and that care be taken not to introduce electrical noise into these lines. The signal locations for the test interface connector are provided in Table 3.

Table 3: Test Interface Connector

Pin	Signal
1	Reserved
2	Ground
3	Position Error
4	Position
5	Velocity
6	Integrator
7	+7V
8	–7V

Mating Connector: Molex 52484-0810

5 PROTECTION CIRCUITRY

5.1 Fault Detection

The MiniSAX contains protection circuitry that will disable the servo loop and set the SERVO_READY flag to a high logic level if any of several monitored error conditions are detected. Once an error is cleared, the servo will automatically reset in a controlled power-up sequence that enables the servo loop, resets the integrator, and then enables the command input and the SERVO_READY flag. The MiniSAX protection circuitry monitors SERVO_ENABLE status, scanner over-position, AGC out of regulation, and supply under-voltage. A fault condition is reported under the following circumstances:

- The SERVO_ENABLE status will cause a fault condition if it is at a TTL or CMOS HI logic level. (The SERVO_ENABLE is normally HI.)
- A scanner over-position fault is detected when the position voltage exceeds ±3.5 volts.
- An AGC out of regulation condition is detected if the AGC voltage level exceeds 11.8 volts or drops below 2.2 volts. The primary purpose of this feature is to disable the servo if the scanner position feedback cable is not connected, or if position detector fails.
- A supply under-voltage condition exists if either supply voltage drops below 13.2V.

5.2 Fuses

The Scanner drive output of the MiniSAX is fuse protected to prevent damage to either the scanner or the driver under fault or over-power conditions. The factory installed fuse (F2 on the baseboard) is a Littelfuse part number R45202.5, which is rated for 2.5A. For the VM500 and VM1000 scanners, the drive fuse (F2 on the baseboard) is a Littelfuse part number R452002 rated for 2A. This fuse will support the maximum rated drive current of the MiniSAX. *This current level is sufficient to cause damage to both the MiniSAX controller and the scanner if proper heatsinking is not provided.* For more information on this subject, refer to section 9.2 about heatsinking.

The AGC output is protected by a 250mA fuse, labeled F1 on the baseboard. The factory installed fuse is Littelfuse part number R451.250.

The optional Thermal Control Module is fuse protected against short circuit of the heater power output. The factory installed fuse is Littelfuse part number R45101.5, which is rated for 1.5A.

6 THERMAL CONTROL MODULE

6.1 Installation

The MiniSAX is available with an optional Thermal Control Module (TCM) for use with *GSIL's* family of thermally controlled scanners. The TCM plugs onto the MiniSAX baseboard power connector and connects to the four-pin connector on scanners equipped with thermal control hardware. When a TCM is installed on a MiniSAX controller, the system power must be connected to J1 on the TCM.

6.2 Indicator lights

The Thermal Control Module has two indicator lights for monitoring thermal status. The green LED will illuminate when the scanner temperature is within ±0.5°C of the regulation set point.

The duty cycle of the yellow LED is representative of the power being applied to the heater. When this LED is constantly lit, full power is being applied to the heater. When the LED is off, no power is being applied. Intermediate duty cycles indicate the relative power being applied to the heater. If the duty cycle of this LED is either very high or very low during normal scanner operating conditions, the thermal design of the scan system should be reviewed.

6.3 Temperature Set Point

The regulator set point is adjusted using Switch S1 (older version) or Jumper W1 (newer version) located on the TCM. The various settings are shown in Table 4. These are approximate set points, subject to the tolerance of the thermistor used to sense the scanner temperature.

The ability of the TCM to regulate scanner temperature is limited by the amount of power that can be provided to the scanner. In order to provide the greatest dynamic range, the set point should be as low as practical. Ideally, the set point would be just above the maximum unregulated scanner temperature encountered during operation at the maximum expected ambient temperature.

The amount of heater power available is a function of the supply voltage available to the TCM. Increasing this voltage improves the dynamic range of the TCM, but will cause increased power dissipation in the servo power amplifiers. TCM dynamic range can also be extended by thermally isolating the scanner from the ambient environment, however care must be taken to assure adequate scanner heatsinking is provided. For more information on this topic, refer to section 9.0: "Mounting Scanners".

6.4 Temperature Status Flag

A temperature status flag is available on the signal connector. A detailed description of this output is given in the Control Signal Interface section of this manual.

7 TEST INTERFACE BOARD

The Test Interface Board (TIB) provides a convenient mechanism for monitoring:

- Scanner Position
- Position Error
- Velocity
- Drive Voltage
- Drive Current

The Test Interface Board is connected to the MiniSAX test interface connector through an eight-pin ribbon cable (See Figure 2). This interface provides power to the TIB in addition to the test signals. In order to monitor scanner drive current and voltage, the scanner motor connector must be plugged into the TIB and the TIB then connected to the MiniSAX through a three-pin jumper cable.

Drive voltage and drive current signals are available either as a wideband output or as a RMS equivalent voltage for ease of calculating power dissipation in the scanner.

The Test Interface Board is a convenient tool when measuring MiniSAX filter module transfer functions. The filter module can be installed onto the TIB, which will provide power to the module and BNC connectors to the input and output ports of the module.

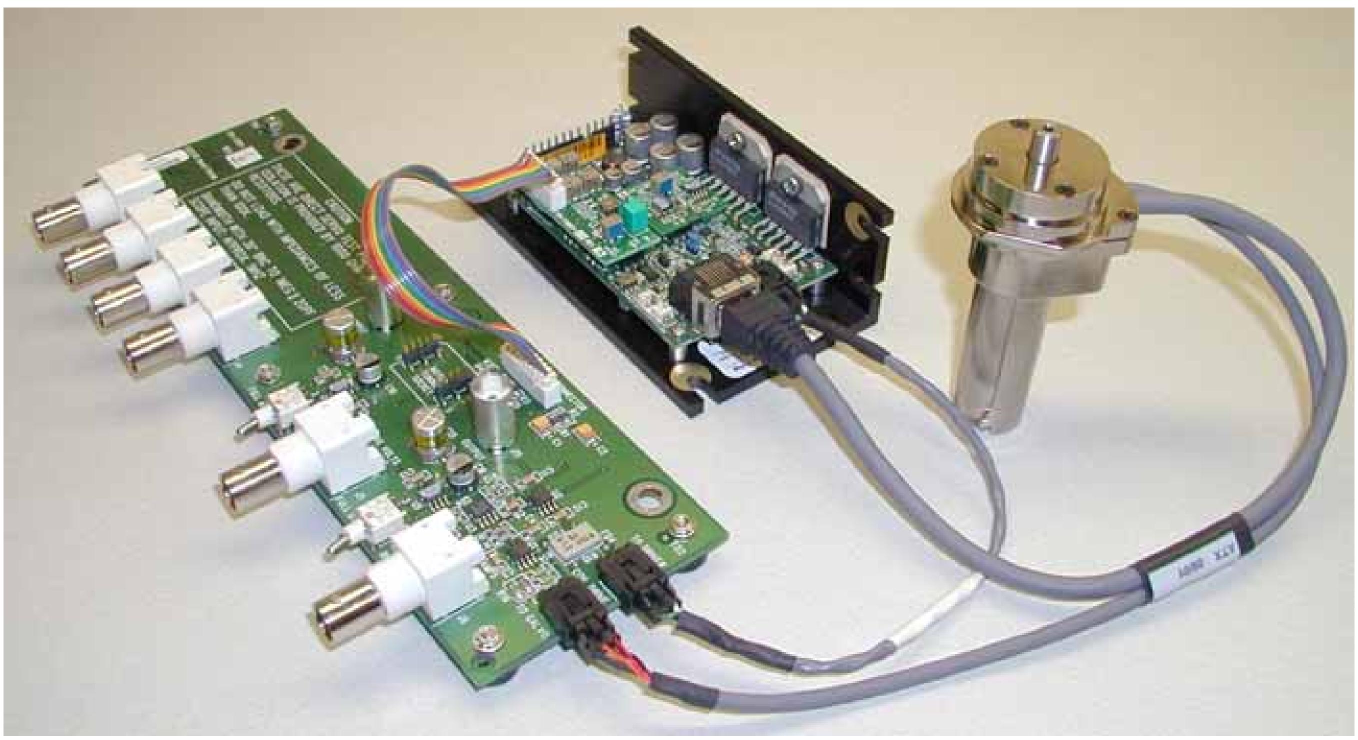


Figure 2: Test Interface Board Connection

8 SWITCH SETTINGS

The following switches and jumpers are preset at the factory. The only optional setting is the Temperature Set Point Switch / Jumper (only available with Thermal Control Option).

- On thermally regulated systems, the Temperature Set Point switch (S1 on the thermal control module) should be set for the desired temperature. See Table 4 for temperature setting.
- The AGC (Automatic Gain Control) Mode switch (S2 on the baseboard) must be set for the appropriate scanner family. These settings are shown in Table 5.
- Baseboard jumpers W1, W6, and W7 settings can be found in Table 6.
- The Course Gain switch (S1 on the tuning module) must be set for the each scanner type to reach the appropriate scan angle. These settings are shown in Table 7.

Note:
New version of the MiniSAX baseboard and TCM utilize a 5-position jumper instead of the previously used 5-position rotary switch (S1), as the later has been discontinued and cannot be purchased anymore.

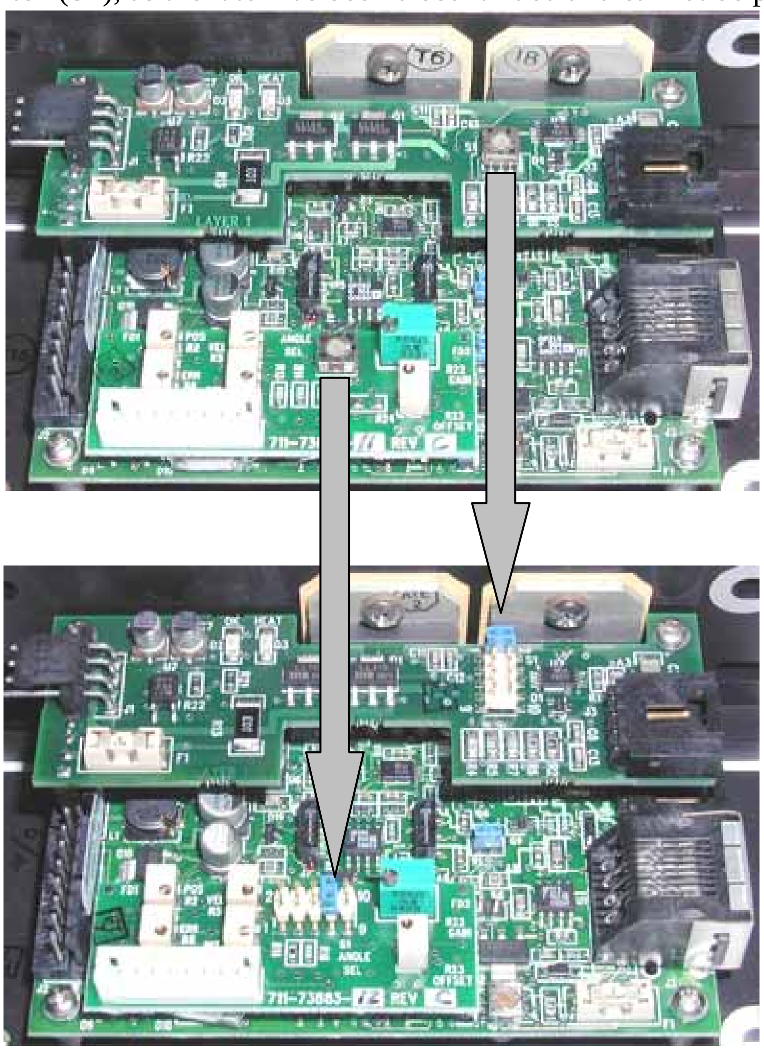


Table 4: Temperature Control Set Points (All Applicable Scanners)

Switch S1 Position (Older Version)	Jumper S1 Position (Newer Version)	Temperature Set Point
0	1-2	30° C
1	3-4	35° C
2	5-6	40° C
3	7-8	45° C
4	9-10	50° C

Table 5: AGC Switch Settings

Switch Position	Label	Scanner
CW	INT	VM2000, VM1000, VM500, FM3, M3, M2
Center	(None)	Not Used
CCW	EXT	G1

Table 6: Jumper Settings

Scanner	W1	W6	W7
VM2000, M2, M3, FM3, G1	IN	OUT	OUT
VM500, VM1000	IN	IN	IN

Table 7: Coarse Gain Settings

Switch S1 Position (Older Version)	Jumper S1 Position (Newer Version)	"Fine" Gain Scan Angle Adjustment Range				
		VM2000	VM1000	VM500	M2, M3	G1
1	7-8	±2° → ±8°	±9° → ±16°	±10° → ±19°	±7° → ±14°	±3° → ±13°
2	5-6	±8° → ±15°	±16° → ±24°	±19° → ±28°	±14° → ±21°	±13° → ±24°
3	3-4	±15° → ±22°	±24° → ±32°	±28° → ±38°	±21° → ±28°	±24° → ±34°
4	1-2	±22° → ±29°	±32° → ±41°	±38° → ±47°	±28° → ±35°	±34° → ±45°
0	9-10	±29° → ±36°	±41° → ±50°	±47° → ±57°	±35° → ±42°	±45° → ±55°

Notes:

1. Scanner position output sensitivity will vary. It may be necessary to use a coarse gain setting higher or lower than specified in Table 7 to reach desired scan angle using "Fine" gain potentiometer.

2. Contact your local technical support if you cannot reach desired scan angle. You may be using an incorrect tuning module.

3. Scanner may operate at scan angles larger than reported on spec sheet. Specs on spec sheet apply to the given maximum scan angle on spec sheet.

9 MOUNTING SCANNERS

Notice: Scanners should be clamped into a rigid mount. Failure to do so can cause an increase in jitter and wobble. Since the galvo is shielded using the MiniSAX ground, the MiniSAX must be electrically isolated from the mount to avoid noise caused by ground loops.

Figure 3 shows the mounting surfaces for some of *GSI Lumonics*' galvanometers. For VM2000, VM1000 and VM500 scanner mounting, see the corresponding scanner user manual. To request outline drawings, contact your local sales representative or applications support.

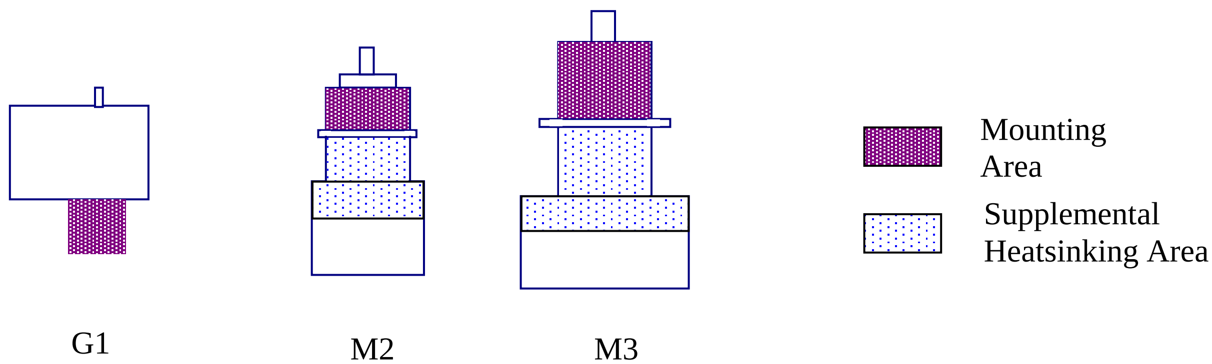


Figure 3. Scanner Mounting Area

Temperature-regulated galvanometers can provide a significant reduction of inaccuracies resulting from thermal drift. However, achieving this performance improvement requires careful consideration of the scanner's thermal environment and proper design of the scanner mount thermal impedance.

In applications requiring the highest available accelerations, the ability to conduct heat from the scan motor becomes a primary concern. Raster scanning and laser display applications are typically in this category. For these high-power applications, thermal management needs to be given careful consideration early in the system design process. Maximum scan acceleration and efficiency will be primarily a function of the heatsinking provided.

9.1 Temperature Regulation

Galvanometric scanners are typically exposed to temperature variations resulting from changes in both the ambient temperature and the power dissipated in the galvo motor. Scanner accuracy is adversely effected as the temperature of the position detector changes. Although these position detectors have been extensively engineered to minimize their sensitivity to temperature changes, the thermal effects cannot be entirely eliminated. By incorporating a temperature sensor and heater, the temperature of the position sensor can be regulated, thereby reducing the effects of scanner temperature changes.
Most low duty cycle or vector applications such as laser marking or rapid prototyping can readily achieve improved performance by using temperature- regulated scanners, provided the proper design analysis is performed.

While some level of thermal sensitivity reduction can usually be achieved with even a careless implementation of thermal regulation, maximum performance improvement will be realized only with appropriate design analysis, and then, only in certain applications. In general, high power scanning applications such as fast raster scanning or high duty cycle stepping are not well suited for thermally regulated scanners. This is due to the conflicting needs of good thermal conductivity to dissipate the heat generated in the scanner coil and appropriate thermal insulation required to isolate the scanner from changes in the ambient temperature.

The scanner coil is capable of dissipating much more power than the heater. This prevents the temperature regulating system being able to control the total power dissipated in the scanner if the coil power is varied over a wide range. If the scanner is operated at a *constant* high power level, thermal regulation *may* be possible.

9.2 Thermal Analysis

The first step in the thermal analysis is to determine the minimum and maximum power dissipation in the scanner coil and the minimum and maximum expected ambient temperatures. Using the maximum coil power dissipation and the maximum ambient temperature, the scanner-to-ambient thermal resistance is designed to provide sufficient heatsinking with the maximum allowable thermal isolation. This will give the largest useful operating range of the temperature regulation system. The maximum required heater power should then be calculated at the minimum expected ambient temperature and with the minimum motor power dissipation. This value should be compared to the maximum heater power available to assure the system has sufficient dynamic range to maintain regulation over all anticipated operating conditions.

The thermal time constant of galvanometric scanners is typically in excess of several minutes and the maximum power dissipation should be calculated as the average dissipation over this time period. The average dissipation, along with knowledge of the expected maximum ambient temperatures can now be used to design the optimum scanner-to-ambient thermal resistance.

A simplified electrical-equivalent model of the scanner thermal environment is shown in Figure 4. This circuit can be analyzed using Kirchoff's Laws and the following equation results:

$$T_H = P_H\,\theta_{HC} + (P_H + P_W)(\theta_{CS} + \theta_{SA}) + T_A \qquad [1]$$

Solving for the case-to-ambient thermal resistance yields:

$$\theta_{CS} + \theta_{SA} = \frac{T_H - T_A - P_H \bullet \theta_{HC}}{P_H + P_W} \qquad [2]$$

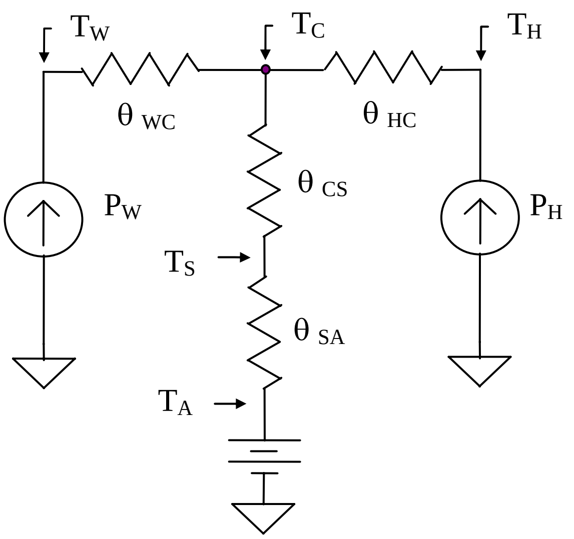


Figure 4. Thermal Model

P_W = motor winding power dissipation
P_H = heater power dissipation
T_H = heater temperature
T_W = motor winding temperature
T_C = motor case temperature
T_S = heatsink temperature
T_A = ambient temperature
θ_{WC} = motor thermal resistance (winding to case)
θ_{HC} = heater thermal resistance (heater to case)
θ_{CS} = interface thermal resistance (case to heatsink)
θ_{SA} = heatsink thermal resistance (heatsink to ambient)

If the following substitutions are made into Equation 2:

T_H = heater set-point temperature
T_A = maximum ambient temperature
P_H = minimum desired heater power dissipation (typically 1 to 3 W)
P_W = maximum motor winding power dissipation
θ_{HC} = heater thermal resistance from the scanner data sheet

Equation 2 can now be solved for the maximum allowable case-to-ambient thermal resistance.

By rearranging Equation 1:

$$P_H = \frac{T_H - T_A - P_W \cdot (\theta_{CS} + \theta_{SA})}{\theta_{HC} + (\theta_{CS} + \theta_{SA})} \qquad [3]$$

and making the following substitutions:

T_H = heater set-point temperature
T_A = minimum ambient temperature
P_W = minimum motor winding power dissipation
θ_{HC} = heater thermal resistance from the scanner data sheet
$(\theta_{CS} + \theta_{SA})$ = designed maximum case-to-ambient thermal resistance

The maximum required heater power dissipation can be evaluated. If this value is less than the rated maximum heater power dissipation, than the design is robust and can be implemented. If the calculated value exceeds the heater's maximum rated dissipation, then the expected range of thermal conditions exceeds the control range of the heating system and the desired temperature set point will not be maintained under all anticipated operating conditions.

9.3 Heatsink Design

After the desired case-to-ambient thermal resistance is determined, the heatsink (scanner mount) design can proceed. There are two components that can be adjusted to achieve the desired thermal resistance. The case-to-sink resistance can be increased by the addition of a controlled resistance insert, such as a machined glass-epoxy sleeve or a kapton film wrap. Alternatively, the sink-to-ambient resistance can be adjusted by varying the cross section or surface area of the scanner heatsink or mount.

9.4 Heatsinking

9.4.1 The Problems with Heat

The primary concern with high power operation of moving magnet scanners is controlling the motor coil temperature so that destructive failure does not occur. One failure mechanism associated with over-heating is a swelling of the stator until interference is created with the rotor. A second potential heat related failure is permanent thermal demagnetization of the rotor.

There are also less damaging problems associated with scanner heating, such as related gain and offset drift of the position detector. Improper heatsinking can adversely effect dynamic performance and in some cases convection currents created by excessively hot scanners and mirrors can cause optical path distortions.

9.4.2 Analyzing Heatsinking Requirements

Proper thermal analysis is essential to achieving high reliability and optimal performance in high power applications. The heat transfer from the scanner, through the heatsink, to the ambient environment can be modeled by an electrical circuit equivalent. The temperature difference between the motor winding and ambient can be equated to a potential difference, or voltage. The flow of heat is analogous to an electrical current. Thermal impedance is the ratio of temperature drop to power dissipation and is modeled as an electrical resistor. The typical model created is shown in Figure 5.

Winding temperature rise is dependent on the operating power level and the ability to heat to flow away from the winding to the motor cases, heatsink and the ambient atmosphere. The rate of heat removal depends primarily upon the thermal resistance of the materials involved. The temperature of the winding will increase until the rate of heat generated by the power dissipation is equal to the rate of heat flow away from the winding. At that point, thermal equilibrium is reached.

9.4.3 Power Dissipation

Power dissipation is an essential parameter in the determination of winding operating temperature. The power delivered to the scanner can be calculated by multiplying the RMS current and voltage measured using the Test Interface Board.

9.4.4 Thermal Runaway

The decrease in torque constant and increase in winding resistance as scanner temperature rises can work together to create a thermal runaway effect. Both the torque constant and resistance changes will increase power dissipation. This will, in turn, further increase the temperature of the scanner. If the scanner does not have sufficient heatsinking, it is possible that this cycle will not reach equilibrium at a temperature below the maximum specified winding temperature.

It is especially important during the evaluation phase to carefully monitor the power dissipation and scanner case temperature to assure steady state conditions are achieved at an acceptable winding temperature.

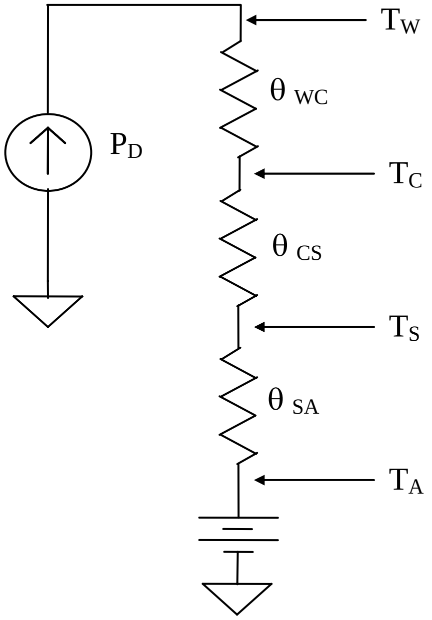


Figure 5. Thermal Model

This equivalent electrical circuit can be analyzed using Kirchoff's Laws and the following equation results:

$$T_W = P_D * (\theta_{WC} + \theta_{CS} + \theta_{SA}) + T_A \qquad [1]$$

Where:

T_W = motor winding temperature
T_C = motor case temperature
T_S = heatsink temperature
T_A = ambient temperature
P_D = power dissipation
θ_{WC} = motor thermal resistance (winding to case)
θ_{CS} = interface thermal resistance (case to heatsink)
θ_{SA} = heatsink thermal resistance (heatsink to ambient)

9.4.5 Scanner Mounting

Scanner mount design can strongly influence θ_{CS} and θ_{SA}. In high power applications the scanner should be mounted by the motor case in a manner that assures good thermal conductivity. Supplemental heatsinking can also be provided as indicated in Figure 3, but its effectiveness is usually small compared to the heatsinking provided by the scanner mount. A typical mount will utilize an aluminum bracket designed to clamp around the scanner body.

In order to maximize heat flow from the motor case to the heatsink, the surface area of the interface should be made as large as possible. The unclamped clearance between the mounting bracket and the scanner should be limited to 0.003" in order to prevent excessive air gaps or line-contact interfaces. Excessively rough surface finishes can also degrade heat flow and therefore should be kept to 64 microinches or better.

Thermal compound should be used between the scanner and heatsink, as well as in any additional interfaces between the scanner mount and the
environmental ambient. Thermal compound has an impedance approximately 20 times lower than that of air and will significantly reduce the effects of minor air gaps present even in well designed mounts. With the use of thermal compound, θ_{CS} can be reduced to 0.5°C/W or less.

10 TUNING STRATEGIES

For more aggressive scanning applications, the servo tuning plays a greater role in determining the speed and accuracy of a system. Sections 10 and 11 discuss alternative tuning methods, and describe the tuning procedures used by the factory. Servo tuning requires the user to be familiar with equipment such as the oscilloscope and function generator. If not familiar with this equipment, you should contact your sales representative to order a factory custom tuning.

10.1 Servo Architecture

The servo architecture used in *GSI Lumonics* drivers allows adjustment of four tuning parameters: *integrator gain, error gain, position-proportional gain, and damping* (or velocity gain). The function of each of these parameters is outlined in Table 8. A block diagram of the servo is shown in figure 7.

Table 8: Servo Parameters

Integrator Gain:	The integrator term provides high dc gain, allows the servo to achieve zero error for a constant position command, and maintains a constant tracking offset for a constant velocity command.
Error Gain:	The error gain term provides a current to the scanner proportional to the difference between the commanded and actual position. This allows quick acceleration of the scanner in response to large command transitions.
Position-Proportional:	The position-proportional term allows the use of high integrator gains and desensitizes the servo loop to small changes in the command size or motor parameters.
Damping (Velocity):	The damping term adds phase to the servo loop and is used to maintain loop stability.

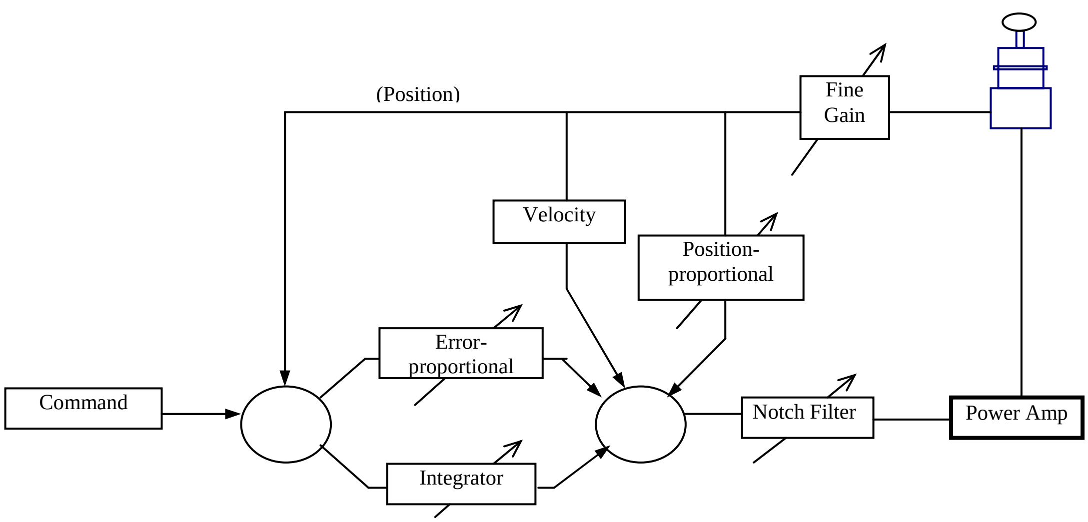


Figure 7: Servo Architecture

10.2 Notch Filter

When a guitar string is plucked, an oscillation occurs at a fixed frequency. This frequency is primarily a function of string thickness and tension. Each scanner and mirror also has a characteristic natural resonance. The frequency of resonance is a function of the rotor and bearing structure of the galvo, as well as the load dynamics. In most cases, if a notch filter is not used oscillation will occur at the resonant frequency.

GSI Lumonics uses notch filter technology to prevent oscillations from occurring in the servo loop. This allows the use of high bandwidth stages in the servo for fastest response times. Figure 6 shows an example of the scanner and mirror's characteristic transfer function along with the notch filter response.

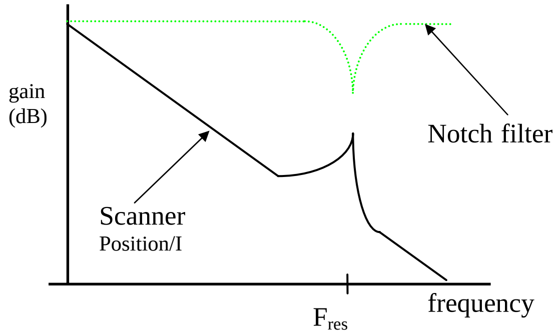


Figure 6: Notch Frequency Response

10.3 Accuracy and High Speed Tuning

Technicians at *GSI Lumonics* have achieved the best performance using three of the four servo terms. Applications requiring the highest accuracy are tuned using the *velocity*, *position-proportional* and *integrator* terms, leaving the *error-proportional* fully CCW. The large-signal response is slower when using the ***accuracy-optimized*** tuning method, although the response is more uniform with changes in commanded acceleration.

Applications requiring the maximum speed are tuned using the *velocity*, *error-proportional* and *integrator* terms, leaving the *position-proportional* fully CCW. This tuning is recommended in applications such as high-speed raster scanning which requires a minimum large-step time. The large-signal response is fastest using the ***speed-optimized*** tuning. For more information on tuning performance, see sections 11 and 12.

10.4 Large-Signal and Small-Signal Waveforms

Although optical scanners are used in a great variety of applications, the scan waveforms can be grouped into two broad categories: *small-signal* and *large-signal*. This nomenclature does not refer to the angular excursion of the scanner, but rather to signal levels internal to the servo amplifier. The servo amplifier will saturate if the commanded acceleration exceeds the system's linear range. This saturation level defines the transition between small- and large-signal commands. A full field step can be a small-signal command if the command is structured such that the maximum linear acceleration limit of the scanner/mirror/driver combination is not exceeded. This is illustrated in Figure 8.

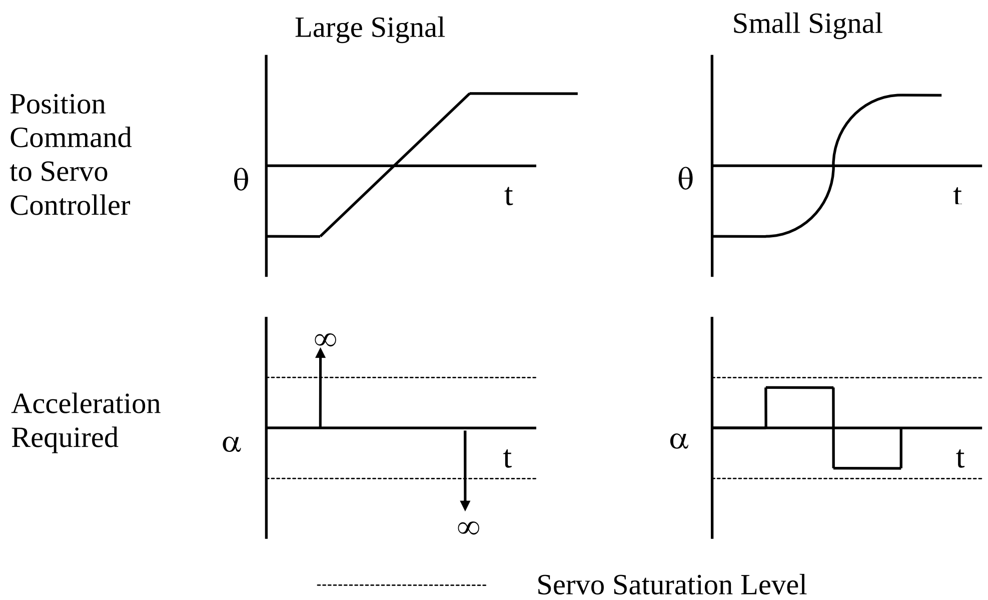


Figure 8: Large Signal and Small Signal Commands

10.5 Step Waveforms

The step waveform tuning can be adjusted to optimize the step time to the settling accuracy and step size (sizes) required by a particular application. Servo response to a step command can be characterized as overdamped, critically damped, or underdamped (See Figure 9). The small-signal *accuracy-optimized* tune will typically give a critically damped response for steps up to 10mR and either an overdamped or under-damped response for larger steps, depending upon their size.

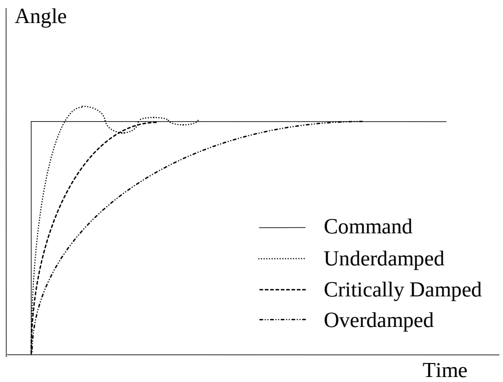


Figure 9: Step Response

With the scanner operating at the required step angle, the settling performance can be monitored on the position error test point with the aid of an oscilloscope. This signal is the difference between the command and actual position, and is equal to the position scale factor.

Rise times can be minimized by increasing the integrator and position proportional gains. Typically the smoothness of settling can be improved by increasing the *velocity* gain. For application requiring settling to very small tolerances (200 microradians or less) an overdamped response frequently gives the fastest overall settling, even though the rise time is slower. The overdamped tuning is gentler to the scanner and tends to excite less high frequency resonance, allowing the tight settling to be achieved more readily.

Since large step commands tend to saturate the servo controller, it is difficult to optimize the tuning for more than one large-signal step size. If consistent performance is required for a variety of different large steps, *GSI Lumonics* recommends that the large steps are broken up into a series of smaller steps, thereby eliminating the non-linearities associated with servo saturation. This is a process know as structuring the command, or micro-vectoring.

10.6 Raster Waveforms

There are three types of raster command waveforms (See Figure 10). The easiest to generate and lowest performance command is a waveform that commands an instantaneous retrace of the scanner. The scanner cannot follow an instantaneous retrace, which causes it to operate at an angle
That is smaller in amplitude than commanded. Performance can often be improved by the use of a dual slope command waveform. The slope of the retrace portion of the command is generally determined through trial and error, but a good starting point is 70% of the expected retrace time. The ideal raster command waveform is determined by taking the second integral of a square acceleration profile of a magnitude equal to the maximum unsaturated acceleration of the scan system.

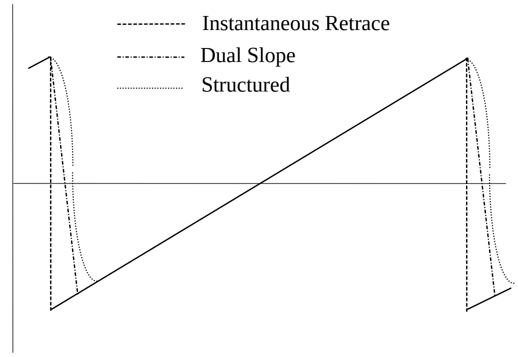


Figure 10: Raster Command Waveforms

The parameters of interest for a raster waveform are typically velocity linearity and retrace time. The velocity of the scanner can be observed by monitoring the velocity signal using an oscilloscope. Often a high gain amplifier with a low frequency filter (3-10kHz) is useful here. The position signal can be overlaid on the oscilloscope to determine the active scan angle.
Retrace time is typically minimized by increasing the *error* gain, while using the *damping* adjustment to maintain a smooth settling on the velocity
waveform. The integrator term is used to maintain a constant velocity over the active scan region.

10.7 Vector Waveforms

Vector waveforms consist of a series of small steps that are updated at a frequency high enough such that they create a waveform that appears continuous to the scan system. Vector waveforms should be structured so that the commanded acceleration and velocity do not exceed the scan system saturation limits. Typical vector applications include laser marking and rapid prototyping, where accurate tracking of complex waveforms is required.

It is frequently difficult to choose an optimization waveform for applications such as marking due to the complex, non-repetitive waveforms processed.
In these cases a typical optimization waveform is a constant velocity command broken by a series of stop and start points over the full field. (See Figure 11) The velocity chosen should be the maximum velocity expected in the application. If the vector waveform is repetitive, such as a structured raster or step, the actual scan waveform should be used during the tuning process.

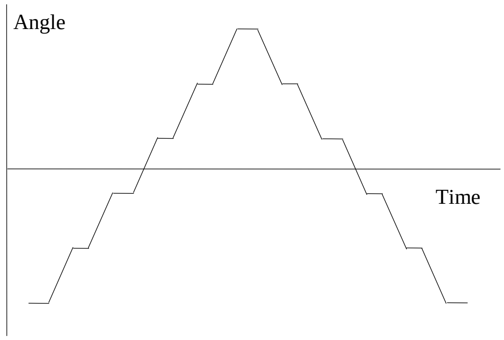


Figure 11: Vector Optimization Waveform

11 FACTORY TUNING

In aggressive scanning applications, the servo tuning is just as important to achieving high performance as the hardware. That is why *GSI Lumonics* offers four standard tunings as well as application-specific tuning for our OEM customers. The four tunings are described in Table 9:

Tuned for:	**Small Signal**	**Large Signal**
Accuracy-optimized **Terms used:** *-Velocity* *-Position* *-Integrator*	Part number: *000-PT101* - Fastest small-signal response - Slower large-signal response - Highest settling accuracy - May require structured commands for large steps - Ideal for high-accuracy marking	Part number: *000-PT102* - Fast small-signal response - Slower large signal response - High settling accuracy - Does not require command structuring for large steps - Ideal for step-and-stare
Speed-optimized **Terms used:** *-Velocity* *-Error* *-Integrator*	Part number: *000-PT500* - Fastest overall response - Lower settling accuracy - Requires structured commands for large steps	Part number: *000-PT104* - Fast overall response - Lower settling accuracy - Does not require command structuring for large steps - Ideal for raster applications

Table 9: Standard tuning matrix

12 TUNING INSTRUCTIONS

12.1 Equipment

The following equipment is required to properly tune the MiniSAX:

- Power Supply (see "MiniSAX Specifications")
- Oscilloscope (analog or digital, 2-channel minimum)
- Signal Generator
- Optical Scale
- HeNe Laser
- Scanner Mount
- Trimpot Adjustment Tool (Included in MiniSAX Startup kit)
- Test Interface Board (Included in MiniSAX Startup kit)

12.2 Do's and Don'ts

1. Do not attempt tuning without monitoring the position signal on an oscilloscope.
2. Do not set the scale factor so that a position signal of 6Vpp produces a greater deflection than the maximum recommended by the scanner's datasheet.
3. Do not allow the scanner to operate in an unstable manner. If the scanner looses control, turn the power off immediately to avoid damage.
4. Do not allow the scanner to be driven into the stops. If this occurs, turn the power off immediately to avoid damage.
5. Do have patience. Tuning can require a great deal of practice.

12.3 Rough Tuning

The term "Rough tuning" refers to a tune that is low in performance, but adequate to set the *notch filter*, *gain* and *offset*. These adjustments are made at the factory in cases where a complete line scan engine (scanner, driver and mirror) is ordered, or if the factory is supplied with a test load from the customer. If so, skip to the section on "Servo adjustment."

A. Mounting
- Mount the scanner using a fixture described in section 9.
- Clamp the mirror or load to the galvo shaft. Reflect a laser beam from the load onto a calibrated optical target, as shown in figure 12.
- Find mechanical center –
    - VM2000 & M-series: By rotating the shaft from one stop to the other, marking the center of the full excursion.
    - VM500 / VM1000: Not Applicable.
    - G-series: The mechanical center is the position that the scanner points to when the power is off.

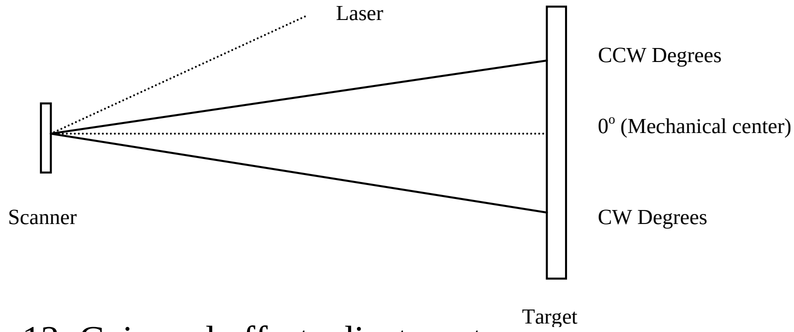


Figure 12: Gain and offset adjustment

B. Connect the *power, control signal, scanner* and *test interface board* to the MiniSAX as described in section 4 Connections. Monitor the position signal from the Test Interface Board on an oscilloscope. (If the test interface board is not available, a differential position signal is available on J2, pins 7&8.)

C. Remove the notch filter module from the MiniSAX. Turn the *velocity, error, position, integrator,* and *fine* gain pots fully CCW. Note that all pots have ten turns for full range, and there is no indication when at the end of the range. Up to 15 turns may be required to assure the gains are minimized. Confirm that all switch settings are correct.

D. Turn power on. (If oscillation or instability occurs, turn the power off immediately and adjust the *velocity, error, position* and *integrator* pots CCW a few more turns to be sure they are adjusted to the minimum gain. Turn power on.)

E. Input a 100mV$_{pp}$, 20 Hz step command into J2, pins 1&2. (Be sure the SERVO_ENABLE line is tied low.) Increase the velocity gain (CW) a few turns. **Note:** If the scanner begins to oscillate at high frequencies, reduce the *velocity* gain until it stops.

F. Increase the *error* gain. The scanner should begin to follow the command signal. Continue to increase the *velocity* and *error* gains until the position signal is following the command as shown in figure 13. A slightly under damped response will suffice.

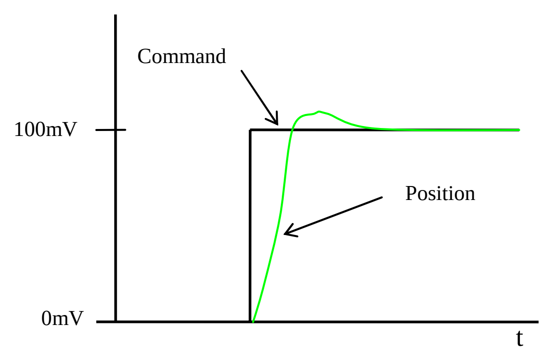


Figure 13: Rough tune response

12.4 Notch Filter Adjustment

There are many ways to adjust the notch filter. The first resonant frequency can be found using a spectrum analyzer by plotting the position/current transfer function. With the notch inserted onto the test interface board, a "real time" notch transfer function can be taken while adjusting the notch filter to the proper frequency. Many labs do not have a spectrum analyzer, so the procedure in this section describes a notch adjustment method that does not require this piece of test equipment.

Note: The servo must be "Rough Tuned" before the notch filter can be adjusted. If this has not been completed, go to section 12.3.

A. Input a 100mV$_{pp}$, 2KHz sine wave signal into the command interface connector. View the position signal on an oscilloscope (AC-coupling is recommended).

B. While viewing the amplitude of the position signal, gradually increase the frequency (for digital generator, use 100Hz increments) until the first peak amplitude is found. An audible increase in volume is usually heard at this frequency also. If the position signal cannot be seen, try increasing the *error* gain slightly.
Note: The oscilloscope will need to be set somewhere between 5 and 20 mV/Div to view the sinusoidal signal.

C. After finding the frequency giving the maximum peak-to-peak position deflection, turn the servo power off- leaving the frequency generator set. You have found the resonant frequency.

D. Plug the notch filter onto the MiniSAX board. Turn the power on. While viewing the position signal, adjust the notch filter to minimize this sinusoidal signal. The notch filter is now set.
Note: If proper adjustment is not possible, the notch filter frequency range may be incorrect for your line scan engine. Call your regional sales manager or Technical Support for help.

12.5 Gain and Offset adjustment

Before final tuning, the gain and offset should be adjusted to prevent possible damage to the scanner. Also, adjusting the gain after final tuning has been completed will change the response (adjusting the offset will not change the response).

If the servo is *rough tuned*, the position and command amplitudes may differ. The gain should be calibrated by comparing the position signal to the scan angle. Otherwise, inconsistent and inaccurate scaling as well as damage to the scanner may occur. Adjusting the gain and offset also sets the over-position shutdown angle.

A. With the servo power off, verify that the coarse gain switch / jumper is set to the correct position as shown in Table 7. Turn the *error-proportional* gain fully CCW. Input a 6V$_{pp}$, 20Hz square wave into the command interface connector.

B. Monitor the position signal on an oscilloscope, set to 1V/div. Apply power to the MiniSAX. Increase the *error-proportional* gain, while adjusting the *velocity* to maintain a critically-damped response as shown in figure 9. The position signal should approach 6V$_{pp}$. Increase the command voltage slightly so the position signal amplitude reads exactly $6V_{pp}$. Now adjust the *fine* gain to achieve the desired scale factor.

Note: If a smaller scan angle is desired, it may be possible to adjust the coarse gain setting to one position lower than recommended in Table 7. If this is done, return to step A.

C. Adjust the *offset* so that the scan is symmetrical about the mechanical center, found in step 12.3.A. You are now ready for final tuning.

12.6 Servo adjustment, Speed-optimized

Note: The *gain*, *offset* and *notch* adjustments must be complete before final tuning. The following tuning procedure is used when the maximum speed is required. This tuning method is the easier of the two. For more information on tuning methods, refer to section 10.3.

This procedure describes tuning the servo for the fastest step response. The same techniques may be used for other command waveforms as well.

A. Monitor the position signal on channel 1 and error on channel 2 (use DC coupling). The error signal is the most convenient to view while adjusting the servo for minimum step time. It gives the same information as the position signal, but allows much greater magnification of the settling since it revolves around zero volts.

B. Input a waveform that represents the largest step (or greatest acceleration) the galvo will be commanded.

Note: High bandwidth is achieved when the servo is adjusted to a small step of approximately 0.5 degrees. In this case, large steps will require command structuring.

C. Increase the *error-proportional* gain, while adjusting *velocity* to maintain a critically damped response. At some point, increasing the *error-proportional* causes a "bump" in the settling response which will not be removed with an increase in *velocity* gain (see Figure 14). When this occurs, you have reached the bandwidth or torque limit of your line scan engine.

Note: In cases where a lower settling accuracy is needed, higher speed can be achieved when tuning beyond the servo bandwidth limit, allowing the settling "bump" to exist.

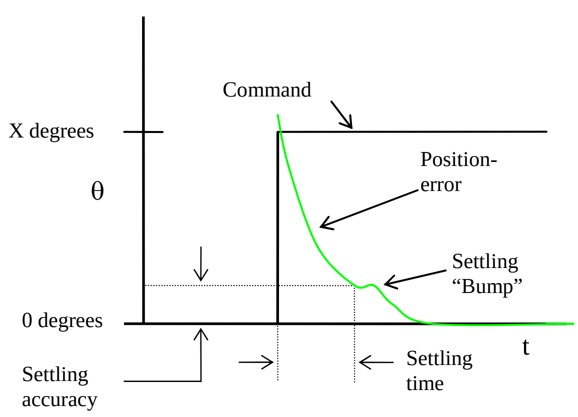


Figure 14: Settling "Bump"

D. For better settling accuracy, slowly increase the integrator gain until the constant settling level goes to 0V as shown in Figure 15. Re-adjustment of the *error-proportional* and *velocity* may be necessary.

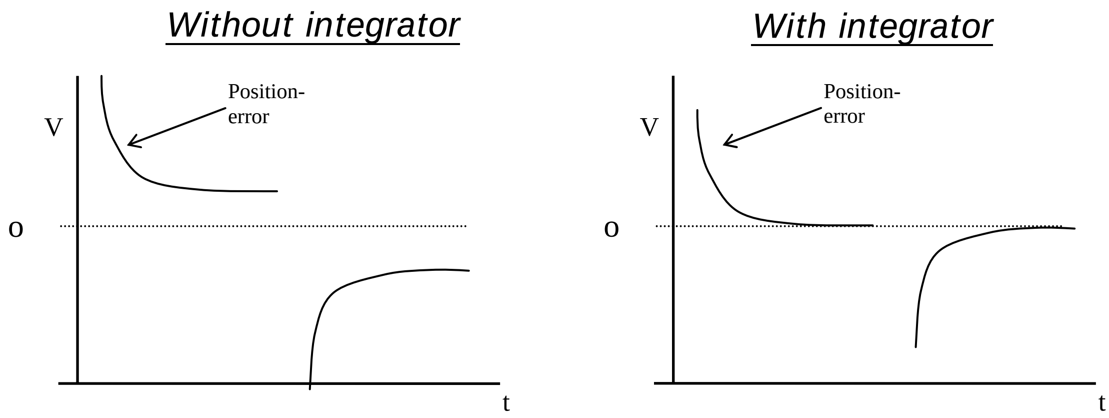


Figure 15: Integrator adjustment

12.7 Servo adjustment, Accuracy-optimized

Note: The *gain*, *offset* and *notch* adjustments must be complete before final tuning. The following tuning procedure is used when the maximum accuracy is required. This tuning method is more difficult than a *speed-optimized* tuning. For more information on tuning methods, refer to section 10.3.

This procedure describes tuning the servo for the highest settling accuracy. The same techniques may be used for other command waveforms as well.

A. Monitor the position signal on channel 1 and error on channel 2 (use DC coupling). The error signal is more convenient to view while adjusting the servo for minimum step time. It gives the same information as the position signal, but allows much greater magnification of the settling since revolves around zero volts.

B. Turn the *error-proportional*, position-proportional, integrator and *velocity* fully CCW. *Error-proportional* will not be used.

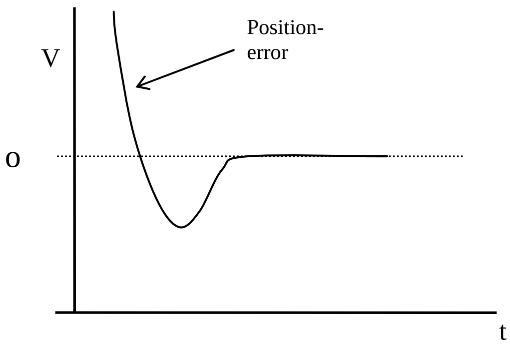
C. Input a waveform that represents the largest step (or greatest acceleration) the galvo will be commanded. Turn the *velocity* gain CW four or five turns. Turn the *position-proportional* gain 4 or 5 turns CW.

Note: High bandwidth is achieved when the servo is adjusted to a small step of approximately 0.5 degrees. In this case, large steps may require command structuring.

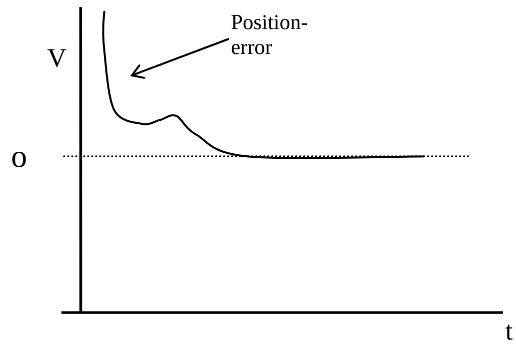
D. Increase the *integrator* and *position-proportional* gains alternately, while adjusting *velocity* to maintain a critically damped response. See Figure 16.

Note: Increasing the integrator gain causes a faster response. The position-proportional and velocity are used to maintain a critically damped response.

Step 1: Increase Integrator



Step 2: Increase position-proportional



Step 3: Increase velocity

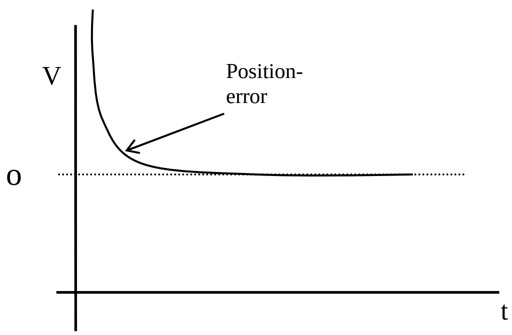


Figure 16: Tuning Steps

At some point, increasing the *integrator* causes a "bump" in the settling response which cannot be removed with *velocity* and *position-proportional* gain (see Figure 14). When this occurs, you have reached the bandwidth or torque limit of your line scan engine.

Note: In cases where a lower settling accuracy is needed, higher speed can be achieved when tuning beyond the servo bandwidth limit, allowing the settling "bump" to exist.

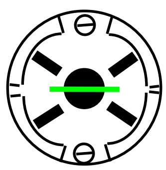
13 TROUBLESHOOTING (MOST COMMON CAUSES OF MALFUNCTION)

Before going further, check the following:

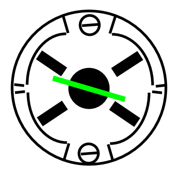
a. Verify that driver and scanner were tuned as a matched set by comparing the scanner serial number to the number written on the L-bracket tuning label.
b. Check the power supply connections and voltages.
c. Check to make sure the connections between the scanner and driver are properly seated.

1. ***On power up, scanner rotor pins to one side with no command signal.*** Warning: Turn the power supply off immediately. Failure to do so may result in the scanner overheating. Note: G-series scanners do not have a mechanical stop. In this case, damage to the rotor assembly is possible.

Top View- M-series Scanners



Correct



Incorrect

a. Remove jumper (W1) and apply power to verify that the position circuitry is functioning properly. To do so, observe the position signal on an oscilloscope. Rotating the mirror shaft should cause the position voltage to fluctuate between +3V and -3V.

2. ***On power up, the scanner does not "torque up" hard to the center position, with a 0V command signal.*** (There is a soft "electronic spring" which centers the rotor when the servo is disabled or not tuned.)

a. Be sure that SERVO_ENABLE (J2-5) is tied low.
b. Check for a blown fuse (F2) on the SAX baseboard.
c. Make sure the AGC switch (S2) is in the proper position. See the table in the setup section of this manual for the correct position. If not, it may be an indication that the driver was not tuned at the factory.

3. ***Scanner oscillates when powered up.*** Warning: Do not operate the scanner and driver without the load that it was tuned to. Changing the load inertia will most likely change the tuning performance and can cause oscillation or instability.
   a. Check to be sure that the load is securely fastened to the shaft.
   b. Check to see if the notch filter setting is correct. Try adjusting the trim pot a couple turns in each direction to see if the oscillation disappears. (See section 10.2 and 12.4 on notch filters.)
   c. If the incorrect notch filter module is used, it may not be possible to eliminate the oscillation. See the section on notch filters.

4. ***Scanner becomes unstable when powered up.*** Warning: Do not operate the scanner and driver without the load that it was tuned to.

    a. Check to be sure that the load is securely fastened to the scanner rotor.
    b. Be sure the power supply current ratings are enough to supply the scanner and driver-see section 4.1 on power supply requirements
    c. Could be an indication of an un-tuned servo.

5. ***Scanner becomes unstable when commanded to perform larger steps.*** Line scan engines tuned for vector and small-step applications may require a structured command (acceleration limited) to maintain stability over large steps.

    a. Be sure the power supply current ratings are enough to supply the scanner and driver. (See the section named "Power Supply Requirements".)

6. ***Scanner does not follow the command input adequately***. Tuning plays a critical role in determining scanner performance (see section 10 for discussion on tuning). Some applications require custom tuning, which could be performed by the factory or by a technical person using a procedure written in the tuning section of this manual.

    a. Some applications may require a structured command.

7. ***Scanner or driver becomes hot when operating.*** On scanners with the "thermal" option, it is normal for the scanner to become warm.

    a. Make sure scanner rotor is not pinned against the stop. If so, see 1 above.
    b. For high RMS power applications, review the heatsinking requirements discussed in section 9 of this manual.

8. ***Thermal Control Module (optional) indicator lights do not illuminate when the driver is powered up.***

    a. Check for a blown fuse (F1) on the TCM.
    b. Check to see that the temperature set point switch (S1) on the TCM is set to a position representing a temperature higher than the maximum unregulated scanner temperature (see the "Thermal Control Module" section of this manual for proper switch settings).

9. ***Scanner does not reach regulated temperature (green LED off, and yellow LED on).*** In cases where the set point is more than 10^o above ambient, it may be necessary to increase the thermal resistance between the scanner and mount or increase the power supply voltage to the SAX (See applications note AN104 "Using Temperature-Regulated Scanners". The power dissipated by the heater blanket is proportional to the power supply voltage.

    a. Change the set point (S1 on the TCM) to a lower temperature.
    b. Increase the power supply voltage
    c. Increase the thermal resistance between the scanner and mount

END OF DOCUMENT