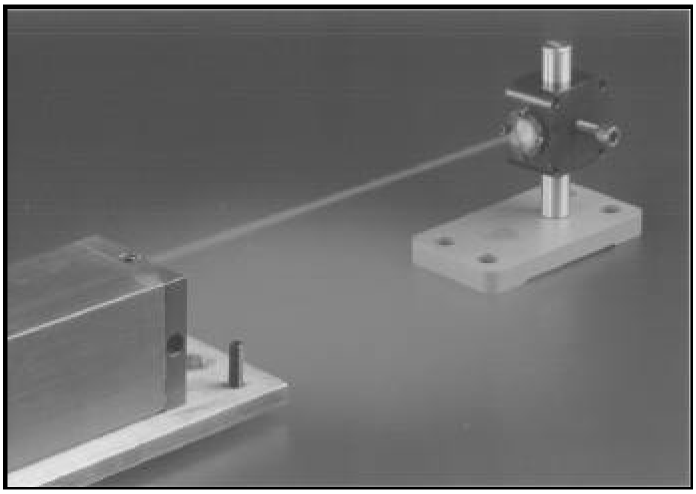
Laser Doppler Displacement Mete
Laser Doppler Scale



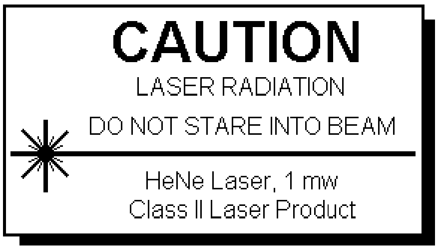
User's Guide

OPTODYNE, INC.
1180 Mahalo Place
Compton, CA 90220
Phone: 310-635-7481
Fax : 310-635-6301
Email : http//www.optodyne.com

1.1 Safety Precautions

This device is a Safety Class I system. It has been designed and tested acc to IEC Publication 348, "Safety Requirements for Electronic Measuring Appar This product is also a Class II Laser Product conforming to FDA Radi Performance Standard 21 CFR, subchapter J.

Warning: This equipment generates, uses, and can radiate radio frequ energy and if not installed and used in accordance with the instructions fo this manual, it may cause interference to radio communications. Tempo allowed by current regulations the equipment has been tested for compl within the limits for Class A computing devices pursuant to Subpart J of Part FCC rules (also CISPR 22, Class A), which are designed to provide reaso protection against such interference. Operation of this equipment in a resid area is likely to cause interference. The user, at his own expense, will be re to take whatever measures that may be necessary to correct the interfere



Warning: There is high voltage in the Laser Head Module. When the cover c module is removed, the operator is exposed to high voltage. Make sure t cables are firmly connected to both modules before turning on the laser p switch.

1.2 Patent

This device is patented- U.S. Patents 4,715,706, 5,116,126, 5,394,233 a 5,471,304 with other patents pending.

2.0 General Information

2.1 Introduction

There are several methods of measuring position, such as with inductive scales, magnetic scales, glass scales and laser interferometers. Inductive scales are known for ruggedness. Made of metal, they can withstand greater vibration and speed, and are perceived to be more reliable. Magnetic scales have the reputation for being less sensitive to contamination. Glass scales with higher resolution are more sensitive to hostile environmental conditions. Laser interferometers have the highest accuracy and resolution.

In general, encoder makers often process output signals through a special kind of circuitry known as interpolation electronics. This circuitry takes the two output sinusoidal signals from encoder and produces output signals of a higher frequency. These output signals can be used to measure distance traveled with more resolution than available from a non-interpolated encoder output.

However, imperfections in the scanning signals produce measuring errors on the order of 1% to a fraction of 1%, hence, the smaller the distance between encoder gratings or pitches, the smaller the interpolation error. Typical pitches, P for inductive scales is P=2 mm; for magnetic scales, P=200 µm, for glass scales, P=20 µm, and for laser interferometers a pitch of 0.6 µm is typical. Interferometers are the most expensive and difficult to use.

For more than two decades, traditional users of linear scales or transducers have had to settle for moderately accurate, glass or magnetic scales, or expensive and complex laser interferometers. As a result, the precision positioning industry has been locked behind a price/precision barrier.

Optodyne's innovative Dopplometry™ technology has broken through the technological barrier of bulky, cumbersome interferometer laser heads, time-consuming installation and alignment, and costly measurement methods. Optodyne has set a new industry standard for precision positioning and measurement equipment--a durable, compact, simple, and economical precise laser-based linear scale.

The Optodyne Laser Doppler Scales (LDS) are based on the firm's patented LDDM™ (Laser Doppler Displacement Meter). The LDS measures displacement by monitoring the phase shift of a laser beam reflected from a target. Recent progress in microelectronics, electro-optics, and computer and communication technologies, makes it possible to produce the surprisingly compact LDS with stunning performance at a very low cost.

The Laser Doppler Scale provides speed, high accuracy and long range positioning for 1, 2 and 3-axis applications, such as Linear Motors, CNC machine tools, CMM's, precision stages, supermicrometers and other linear measurement devices.

Major features of the LDS are:

- Inherent high accuracy and high resolution

3.0 Operation

3.1 General Applications

Optodyne's LDS is designed for applications requiring high accuracy, high spee long range in NC machine tools, X-Y stages, automatic equipment and positi where maximum performance is vital. The LDS has the advantage of small size weight and easy installation. The standard TTL output and the selectable incre provide direct interface to motion controllers. Because of the new techn breakthrough, the LDS provides laser interferometer performance, glass scale and linear transducer size. The LDS is designed for OEM applications. electronics board may be installed in the controller. Engineering support is available to help you design the LDS into your machine. If your needs are accuracy, high resolution, high speed or long range, an LDS system will mee requirements.

Compared to other position transducers such as glass or Inductosyn scales and frequency laser interferometers, the LDS requires less setup time and is complicated. Also, the total system accuracy is significantly better and conside more stable. For example, in the LDS, alignment shifts do not usually result in pc errors. If an alignment shift is so severe that a measurement is no longer possib user will be alerted with an error signal. In contrast, glass and Inductosyn scal prone to alignment shifts inducing positioning errors which may remain undet until either a recalibration is performed or improperly fabricated parts are disco

The LDS system is easily adapted to one, two, three, or multi-axis systems. benefits of the LDS for major areas of application are described below.

Major features for linear motor applications are:

1. Higher attainable stiffness because of the LDS's inherent mechanical sta
2. High slew rate (160 ips) does not limit linear motor control.
3. Isolates orthogonal disturbance to minimize axis cross coupling (for multi applications).
4. High device bandwidth.
5. High resolution (25 µin) promotes servo stiffness
6. Axis thrust centerline mounting capability.

Major features for 2-axis applications, such as X-Y stages, PC board drilling, gri IC fabrication and projector include:

1. Accuracy is independent of the X-Y stage for a low-cost, high-precision s
2. Center-mount reduces Abbé error, saves space.
3. Measurement scales are independent of ways for increased accuracy.
4. Detects and compensates for wobble along the X-axis.

Major Features for 3 -axis applications, such as precision machine center and C
are:

1. Centerline mounting improves accuracy by minimizing Abbé error.
2. Compensates for temperature to reduce effects of thermal expansion.
3. Electrical noise has minimal effect.
4. Increased servo stiffness for smooth cutting.
5. LDS characteristics minimize pitch error compensation.
6. Increase tool path and material removal accuracy.
7. Precision-machined surface not required for installation.
8. Wiring required for laser head only.
9. Minimal installation and alignment time.

3.2 Installation and Checkout

A properly installed LDS results in high accuracy and resolution, increased relia and less maintenance and calibration than other types of positioning transdu However, as with any measuring device, improper installation or operatio degrade the performance. Prior to installation of the equipment, it is import understand the basic measurement capabilities of the LDS along with considerations of relevant sources of errors.

The LDS is extremely easy to set up and operate. The laser head, placed on th of interest, is mounted in a fixed position. The retroreflector should be rigidly mo onto the moving objective or target. The final position of these two compone determined by targeting the laser beam while moving the objective. There limitation on the location of the processor module within the limits of its interconnecting cables; one to the laser head, the other to the controller on co and its AC power cord.

Mount the laser head by means of the two mounting holes on the front and back unit. This base plate may be secured to a work surface in any fashion that w generate and transmit excessive mechanical stresses to the laser head.

After the retroreflector is mounted onto the target, and the laser head is in p attach the cables between the laser head and processor module. Conne processor module to a DC power source.

Caution! Do not look directly into the beam aperture on the laser head face damage can result.

The laser light beam is most easily detected by holding a piece of white paper that the beam forms a visible spot on it. If the laser does not start, turn the p switch off and then on again. Adjust the positions of the laser head an retroreflector so that the return beam is visible on the laser head face. Conti adjust these two components until the spot of the return beam enters the rec aperture.

The outputs on the processor board are:

J3:	PIN 1	$\overline{\text{INT}}$	SIGNAL STRENGTH
	PIN 3	ERR	ERROR
	PIN 5	UP	UP PULSE
	PIN 7	DN	DOWN PULSE
	PIN 9	HR	ANALOG PHASE
	PIN 2		REFERENCE
	PIN 4		GROUND
	PIN 6		GROUND
	PIN 8		GROUND
	PIN 10		GROUND

J4:	PIN 1	$\overline{\text{INT}}$	SIGNAL STRENGTH
	PIN 3	ERR	ERROR
	PIN 5	A	SQUARE WAVE
	PIN 7	– B	SQUARE WAVE
	PIN 9	– B	SQUARE WAVE
	PIN 2	A	SQUARE WAVE
	PIN 4	– HR	N/C ANALOG PHAS
	PIN 6	I	HOME POSITION
	PIN 8	I	HOME POSITION
	PIN 10	GND	GROUND

For LDS systems with more options, such as reference mark (IHS), autor pressure and temperature compensation and AC power feed and enclosur interconnecting wire diagram is shown in APPENDIX E.

After all interconnecting cables are connected, turn on the DC power, and ther the laser beam parallel to the linear motion of the retroreflector over the displace range of interest.

The system will function immediately after turning power on, however, ult accuracy is achieved only after a warm-up period of 20-30 minutes during whi laser has a chance to reach its operating equilibrium. In a constant temper environment, drift is negligible after the laser reaches equilibrium. In an enviror having an ambient temperature variation of 5°C over 8 hours, system drift will be range of 1 to 2 counts per hour. When the retroreflector moves away from the head the output pulses are "up" pulses and when the retroreflector moves towa laser head the output pulses are "down" pulses.

For more specific installation instruction or trouble shooting, see **Install Instruction** shipped with the hardware.

3.3 Accuracy Considerations

The LDS system accuracy is determined by the accuracy of the instrumen environmental effects, and the optical installation effects. The instrument accur determined by the laser head frequency stability, the electronic accuracy and se of the automatic compensation (if needed). The environmental effects are chan atmospheric pressure, air temperature and material temperature. The o installation effects are dead path errors, cosine error and Abbé error.

3.3.1 Instrument Accuracy

The laser head accuracy is determined by the frequency stability of the laser The LDS uses an active frequency stabilization technique. Typical laser frequ stability is better than 0.005 ppm (see NIST Test Report No. 821/25461

November 14, 1994). The electronic accuracy is determined by the detector sig noise ratio, which is much smaller than the smallest resolution increment. Hen electronic accuracy is determined by the resolution used. Since the laser beam polarized, there is no interferometer non-linearity. If the automatic temperatur pressure compensation option is used, the accuracy of the compensati determined by the accuracy of the temperature and pressure sensors.

Without considering the material thermal expansion, typical system accuracy is than 1 ppm.

3.3.2 Environmental Effects

Laser measurements may be corrected for the two potential sources of measure errors when the highest accuracy is desired: the effect of atmosphere on the wavelength (or speed of light) and the effect of temperature on the material expa Usually, the effect due to material thermal expansion is much larger than the due to laser wavelength change. For example, a 1°C change in air temperatu cause a correction factor of 1 ppm, while a 1°C change in material temperatu cause a correction factor of 12 ppm for steel and 22 ppm for aluminum. specifically, for a measured distance of 10 meters, a 1°C material temperature c will cause an error of 120µm. However, a 1°C air temperature change will cau error of only 10 µm.

Hence, for most machine tool applications, it is not necessary to compensate t pressure and air temperature change, and material thermal expansion c compensated through the controller scale factor. A more detailed discussion automatic temperature and pressure compensation is in Appendix F.

3.3.3 Optical Installation Effects

When planning the installation of the laser head and optics on a specific mach number of factors must be considered to maintain the system accuracy. The imp points to consider are:

1. Installing the laser and retroreflector to minimize deadpath errors.
2. Align the laser beam path parallel to the axis of motion to minimize cos ine
3. Selecting the measurement paths to minimize Abbé error.
4. Both the laser head and the retroreflector should be solidly mounted to increase the stiffness.

In many cases, it may not be possible to completely eliminate these sources o but every effort should be made to minimize them. The following paragraphs d methods of installing and compensating for these errors.

Deadpath Errors

A deadpath error is an error introduced due to an unnecessary length of travel of light between the laser head and the retroreflector when the machine is at its position. To reduce the deadpath error, make sure the unnecessary length of between the laser head and the retroreflector is minimized.

Cosine Error

Misalignment of the laser beam path to the axis of motion of the translation s results in an error between the measured distance and the actual distance trav This is referred to as cosine error because the magnitude of the error is proportic the cosine of the misalignment angle.

As a rule of thumb, the cosine error is proportional to the square of the misaligr angle. For example, if the misalignment angle is 0.1°, the cosine error is (0.1/5 0.000003 or 3 ppm.

Cosine error can be reduced by makingthe laser beam parallel to the actual tra the axis.

Abbé Error

Abbé offset error occurs when the measuring point of interest is displaced fro actual measuring scale location and there are angular errors in the positioning sy

A very important advantage of the LDS system is that the Abbé error evident in a all positioning systems is very easily reduced.

Abbé offset error will make indicated position either shorter or longer than the a position, depending on the angular offset. The amount of measurement error res from Abbé offset is:

Offset distance x tangent of offset angle

To minimize the Abbé error, simply reduce the offset distance by directin measurement path as close as possible to the actual work area where measurement process takes place.

3.4 Air Turbulence and Thermal Gradient

Air turbulence and thermal gradients are important considerations when the tra longer than 5 meters. The air turbulence generated by the hot or cold air will d the laser beam and cause loss of signal strength. To minimize these effects, a direct air currents to the laser beam path or protect the laser beam with some ty cover. Since this would normally be done for protection against beam interruptic turbulence effects will usually not be a significant installation factor in ty environments.

For extremely high accuracy applications, thermal gradients created by localize sources (e.g. motors, electromagnetics, lamps, laser heads, etc.) located on c the machine will cause air turbulence or beam shift. Care must be taken to mir these effects.

- No need for periodic recalibration
- No wearing parts for non-contact devices
- Freedom to locate point of measurement close to measured object reduces Abbé error
- Orthogonality of positioning system determined by mirrors, not X-Y stages
- Electronics flexibility with variable increment and automatic temperature compensation
- No mounting stress on scale
- No thermal expansion on scale
- No need for machined flat surface for mounting scale saves installation costs
- Higher loop gain possible for closed loop servo control
- No coupling between X-axis and Y-axis motion
- Optional hermetic seals for hostile environments
- Rejection of vibration in two of three planes reduces structural resonance effects
- Immune to electronic noise and interference makes it suitable for linear servo motor drives

2.2 Product Description

Based on Optodyne's patented Laser Doppler Displacement Meter (LDDM™) technology, the LDS reflects a modulated laser beam off of a movable target. The beam is detected and processed for displacement information used by the control to determine position.

Installation is made easy with only three compact, ruggedized and light weight components. The helium neon (HeNe) laser head and retroreflector are installed under the way covers. The standard processor board, with TTL output, is available with either an A Quad B square wave or up/down pulses.

The LDS unit consists of three components; a Laser Head Module, Retroreflector and Processor Module as shown in Fig. 2-1, LDS System Block Diagram.

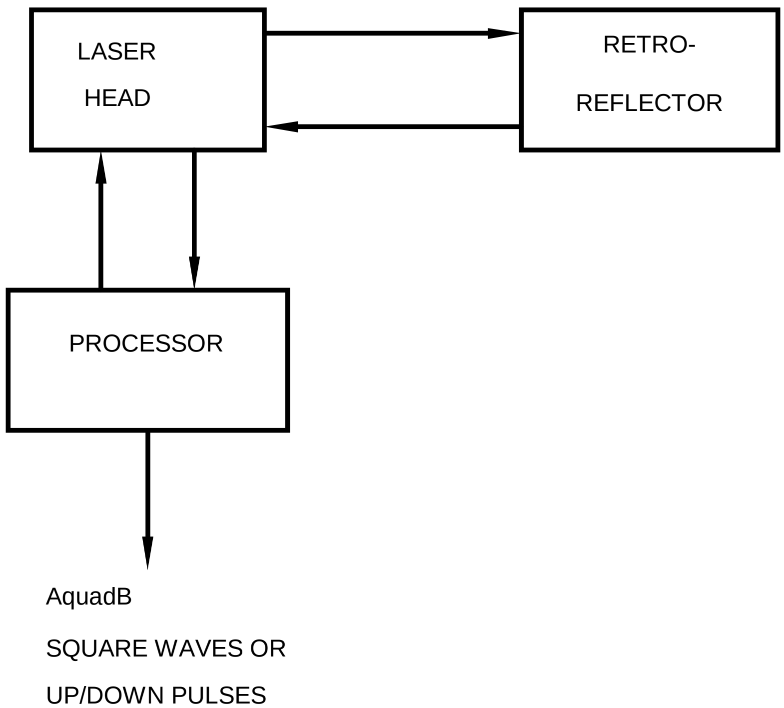


FIG. 2-1 LDS System Block Diagram

The following is a general description of these three components:

Laser Head Module

The Laser Head Module houses a stable HeNe laser source and electro-optic assembly and a photodetector which functions as a receiver. In a manner similar to the well known Doppler Radar, the Doppler shift of the return light beam is measured by an optical heterodyne technique. Three types of laser heads, L-109, L-102 and
L-101 are shown in Figs. 2.2a, 2.2b and 2.2d. Sugested mounting way illustrated in Fig.2.2c.

Retroreflector

The Retroreflector serves as a cooperative target. It is a corner cube, which reflects the laser beam back to the receiving aperture on a path parallel to the input beam, regardless of the angle of incidence. The use of a corner cube reflector provides significant advantages.

Its alignment during installation is not critical in that it may rotate during measurements. A Ø0.5 in. retroreflector with and without post and base are shown in Fig.2-3.

Processor Module

The Processor Module consists of a processor board and driver. The signal from the photodetector is processed by the phase-demodulator and converted to standard TTL up/down or AquadB square waves. A processor board and driver are shown in Fig. 2-4.

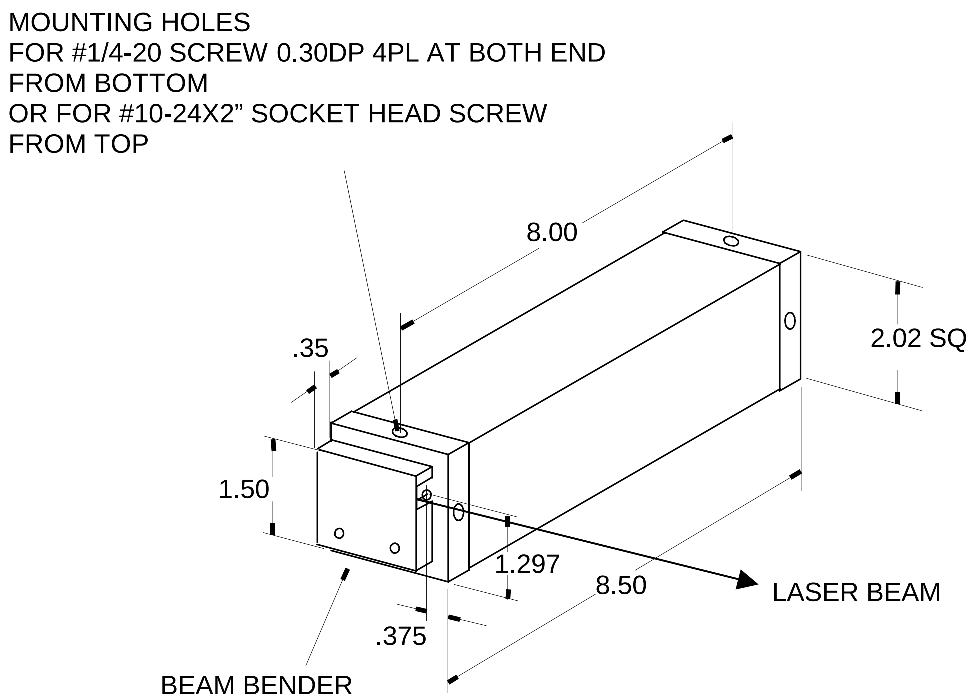
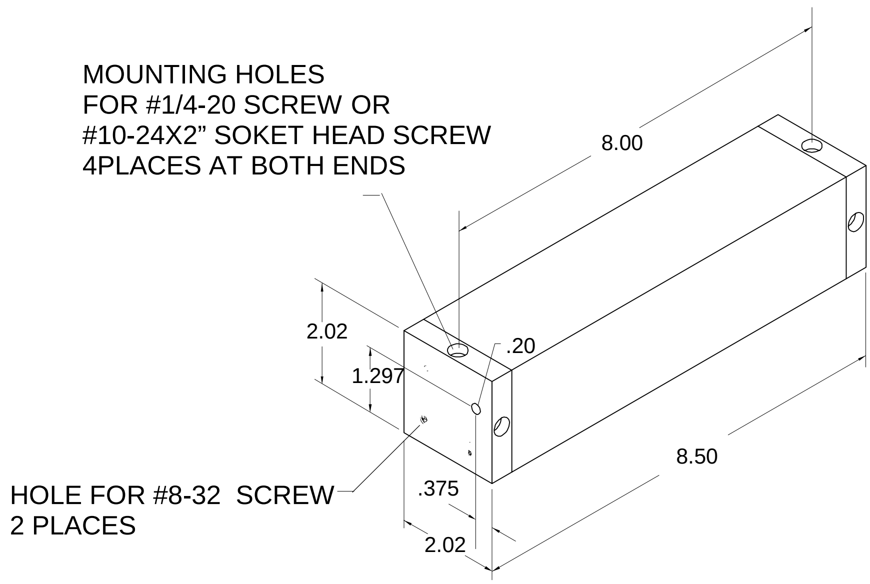
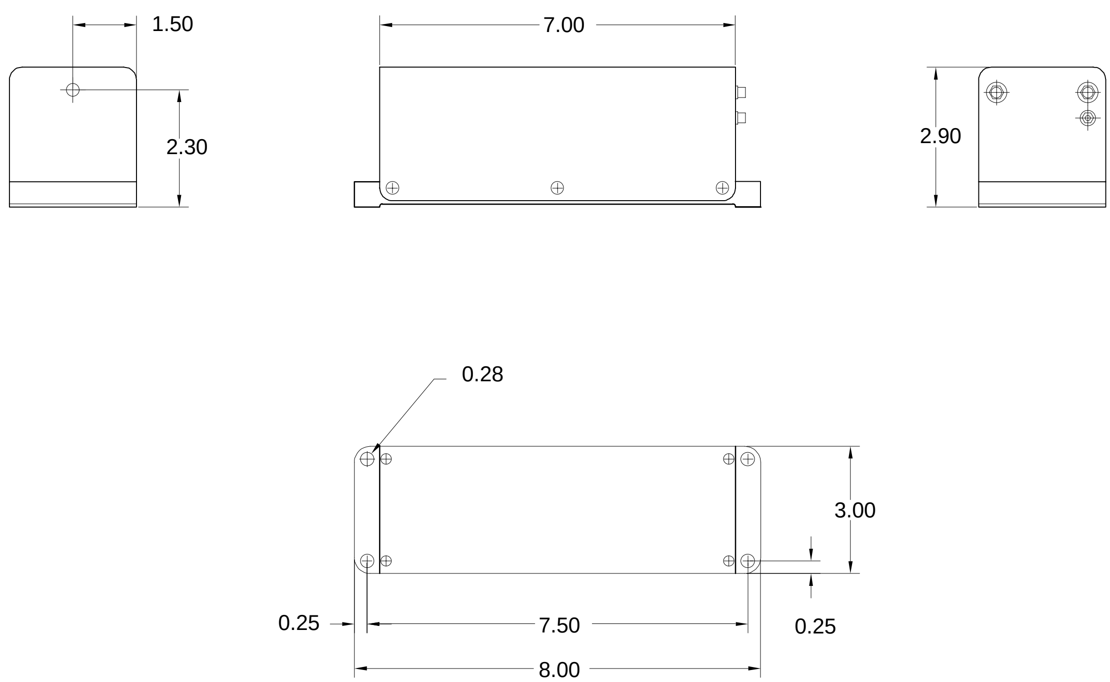


FIG.2.2a LASER HEAD (L-109)
WITH 90°BEAM BENDER (LD-51S)

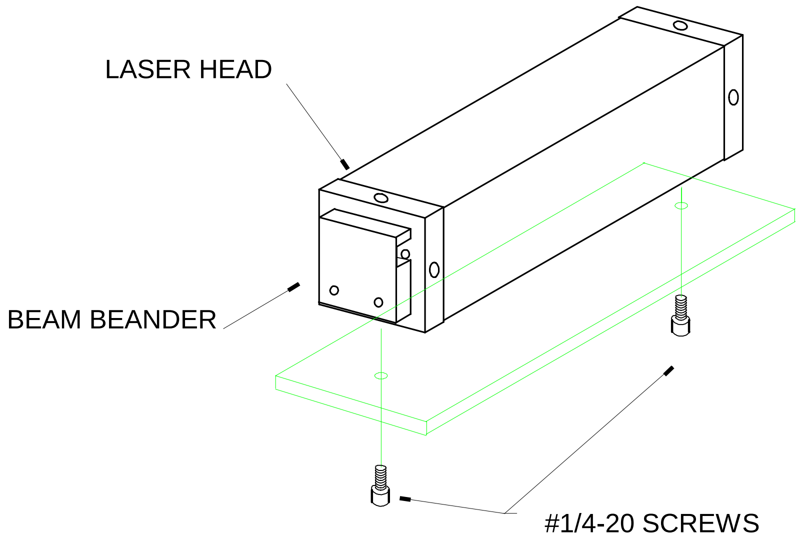


LASER HEAD (L-109)

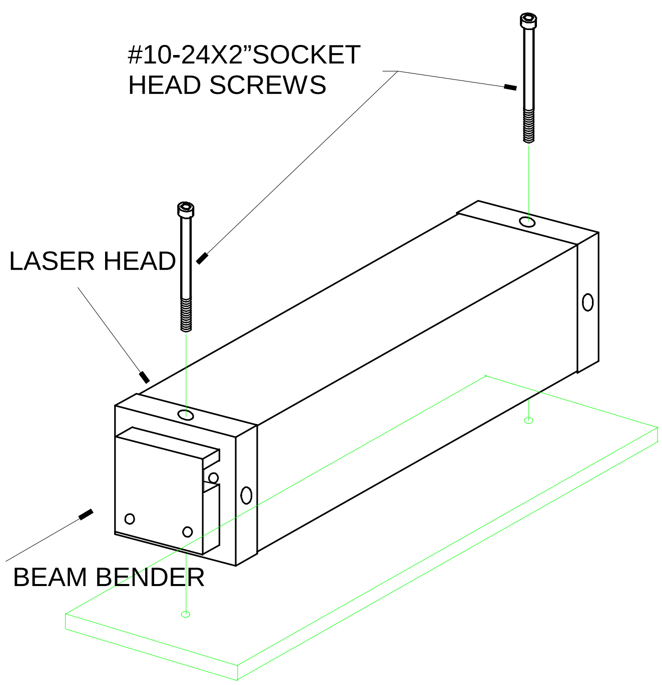


LASER HEAD (L-102)

FIG.2.2b STANDARD LASER HEAD (L-109,L-102)

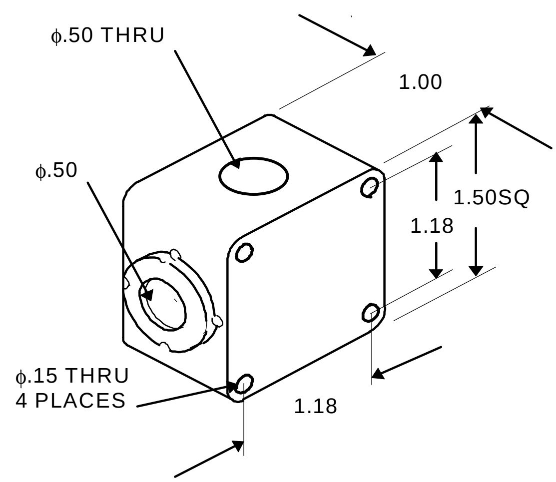


MOUNTING LASER HEAD FROM BOTTOM
WITH #1/4-20

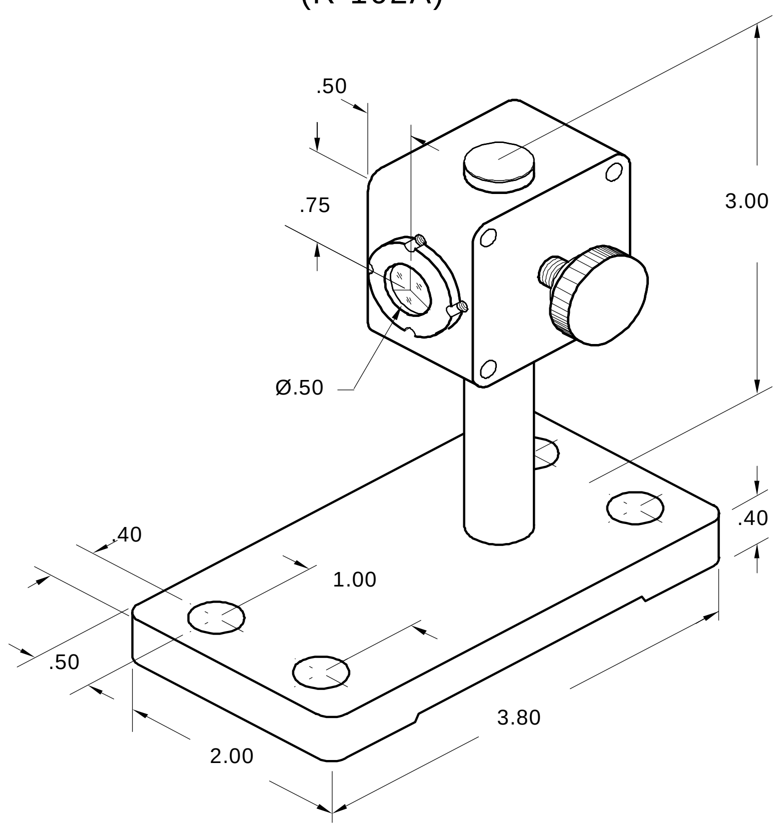


MOUNTING LASER HEAD FROM TOP
WITH #10-24X2" SOCKET HEAD SCREWS

FIG.2.2c LASER HEAD MOUNTING



1/2” RETROREFLECTOR
(R-102A)



ø1/2" CORNER CUBE WITH POST AND BASE (R- 102)

FIG. 2.3 1/2”RETROREFLECTOR

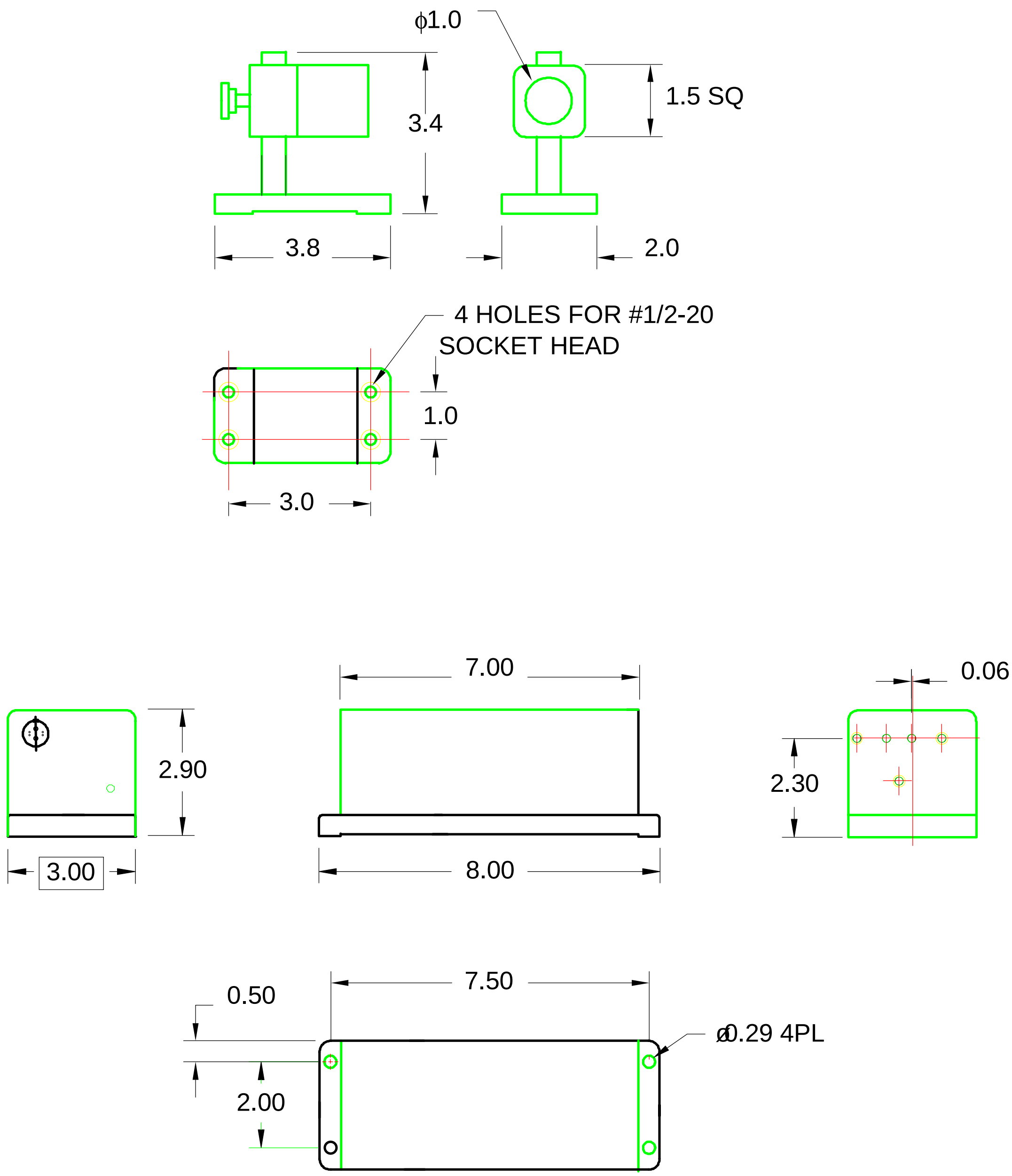


FIG.2.2d LASER HEAD (L-101)
AND 1” RETROREFLECTOR (R-106)

Fig. 2-4 LDS-1000

2.3 Theory of Operation

LDDM™ monitors the displacement of the objective or target, from an initial position, to any final position within the range of the instrument. Displacement is counted continuously as the target moves. Once set up the system operates without further adjustment.

The LDDM™ uses an electro-optical device which detects the Doppler shift of a laser frequency caused by a moving target to measure displacement with a high degree of accuracy. The range may be from a few microns to several tens of meters. Other precision displacement measuring devices use interferometric techniques, requiring a sophisticated and bulky laser. This approach calls for critical, time consuming alignments, and causes additional expense. LDDM™ is based on the principles used in radar. Its construction is simpler, less costly, more rugged and much easier to use than a conventional interferometer.

The frequency of the reflected laser beam is shifted by the motion of the Retroreflector and is proportional to its velocity. The phase shift is proportional to the displacement. A phase-detector is used to sense the phase shift. For each half wavelength of displacement a counter is incremented. A microprocessor is used to read the counter and the phase angle, and converts them to inches or centimeters.

The Doppler frequency shift can be expressed as:

$\Delta f = (2f/c)\ \Delta v$

or:

$\Delta\phi = 2\ \pi(2f/c)\ \Delta z$

Where Δf and $\Delta\phi$ are the frequency and phase shift and Δv and Δz are the velocity and displacement respectively of the Retroreflector, the variable f is the frequency of the laser and c is the speed of light.

A counter is used in conjunction with the phase detector to record the number of half-wave lengths, $\lambda/2$, detected. Compensation for changes in the speed of light due to temperature, pressure and humidity variations are available. Compensation for changes in material thermal expansion is also available.

2.4 System Description and Options

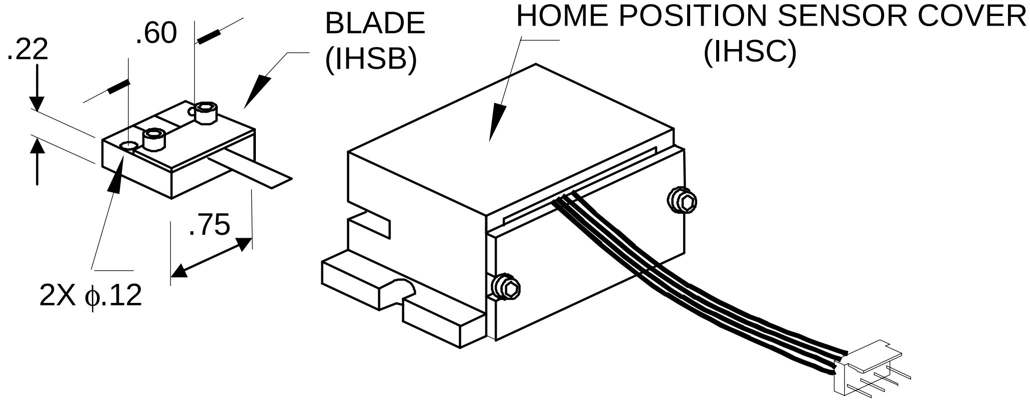
The basic LDS system, shown in Fig. 2.1, consists of a laser head module (L-109), a processor module (IPS1), a retroreflector (R-102) and a cable set (LD-21R). The inputs to the laser head module are 15V DC and driver signal, and the output is the detector signal. The inputs to the processor module are 15V DC, ±5V DC and the detector signal. The outputs are up/down pulses, AquadB square waves, and error signal. The retroreflector is a Ø½in. corner-cube. The cable set is comprised of three 12 ft. long co-axial cables. Accessories and options to the LDS system are described below.

2.4.1 Reference Mark (IHS)

The reference mark shown in Fig. 2.5a provides a home position signal. The output is a TTL signal and the position repeatability is better than 1 μm. Figure 2-5b shows the reference mark with cover.

2.4.2 High Resolution Output

The standard resolution is 12.45 μin (one-half wavelength, $\lambda/2$) or 24.9 μin (one wavelength, λ). For a higher resolution output, a divided by 8 board (IPPD2) will provide a resolution of 3.11 μin ($\lambda/8$), or a divided by 64 board (IPPD1) will provide a resolution of 0.39 μin ($\lambda/64$).



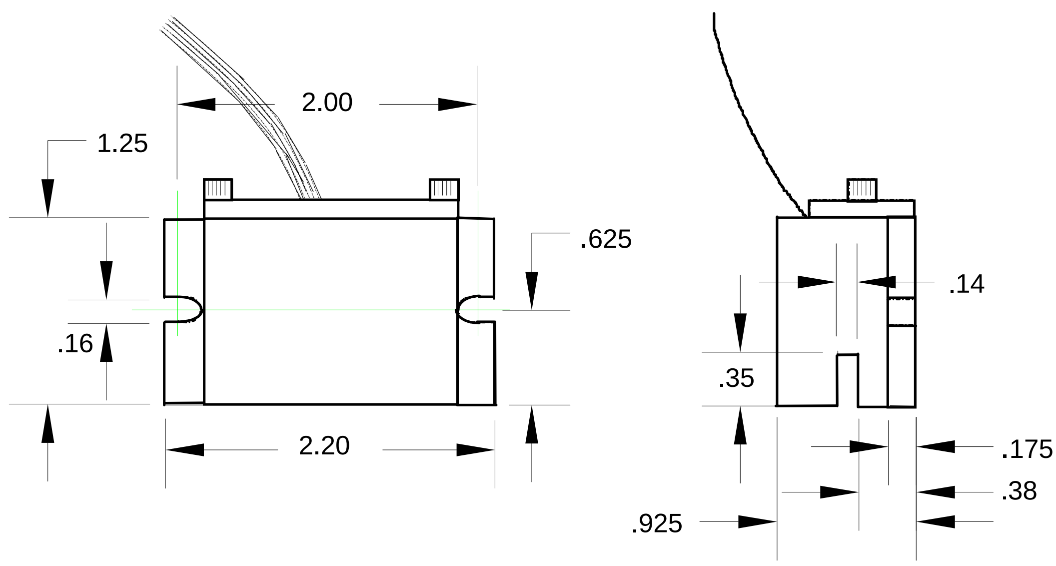


FIG.2.5a HOME POSITION SENSOR
WITH COVER

BLADE

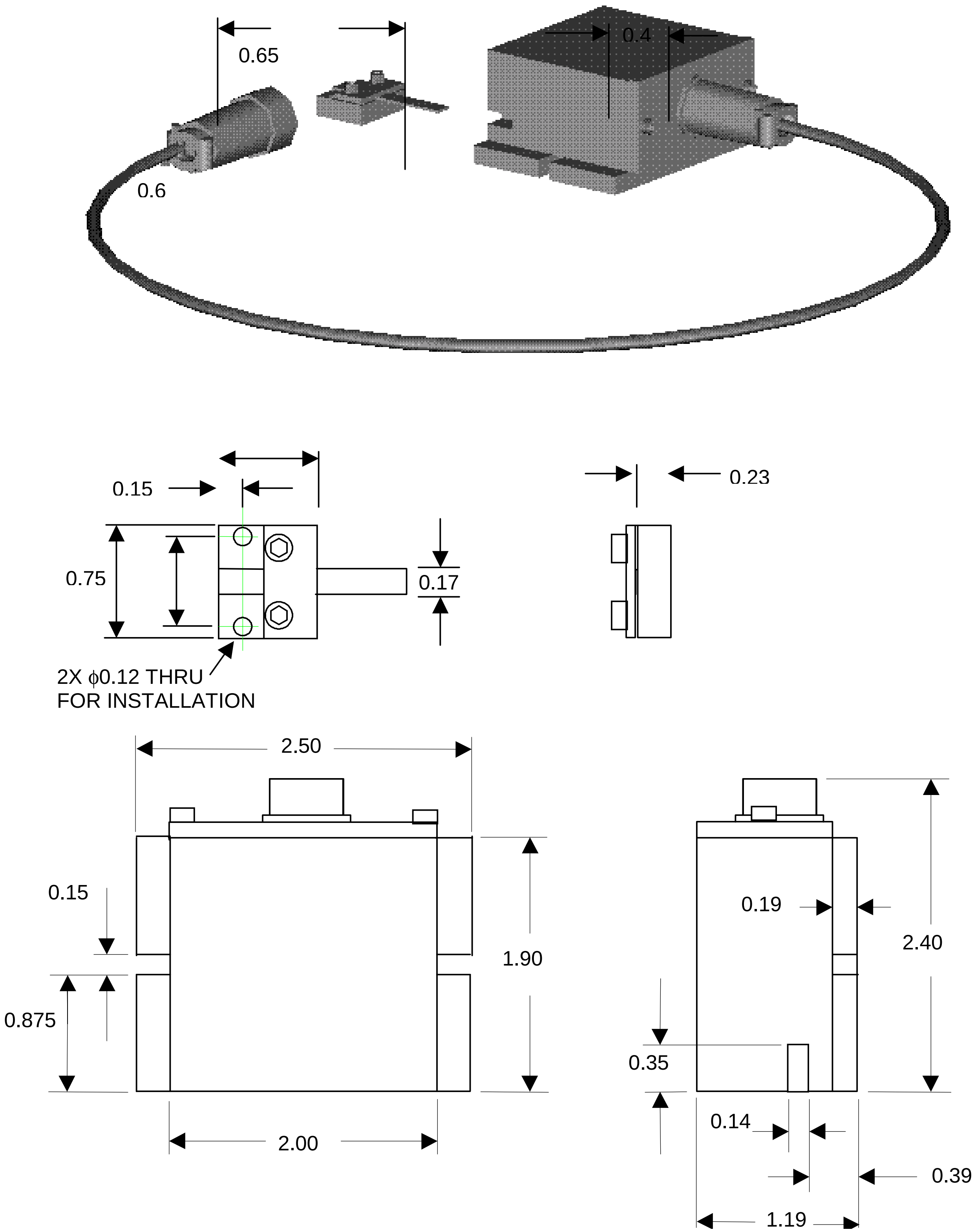


FIG. 2.5b HOME POSITION SENSOR WITH COVER

2.4.3 Selectable Increment (IPC3)

2.00 0.14

For some applications when a specific increment is required, a pulse converter board can be used to meet the requirement. The selectable increment board will provide an increment ranging from 24.9 µin divided by 0.999999 to 0.000001. This selectable increment can also be controlled by an automatic pressure and temperature compensation board.

2.4.4 Automatic Pressure and Temperature Compensation (IPC4)

For automatic compensation of atmospheric pressure, air temperature and material temperature changes, the automatic pressure and temperature compensation option can be added. This addition consists of an atmospheric pressure sensor, an air temperature sensor and a material temperature sensor (ATC, shown in Fig. 2.6), a data processing board and a selectable increment board. For multiple axis machines, only one ATC is needed.

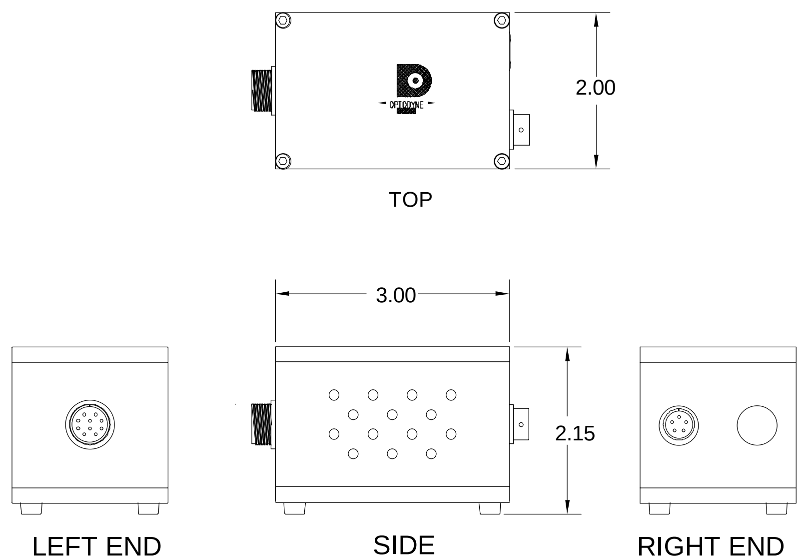


FIG. 2.6 ATC SENSOR

2.4.5 32-bit Parallel Output Board (IPACX)

This is a plug-in board to an IBM PC compatible computer. The board provides a 32-bit position counter with a resolution of 0.1 µin and can be read directly by a PC. It is a standard XT/AT board with 8-bit data transfer compatible to ISA specifications.

2.4.6 AC Power Feed and Enclosure

For stand alone operation, this option will provide a panel-mount enclosure for the processor board and driver, a DC power supply and a terminal strip for the output signals, as shown in Fig. 2.7a and Fig.2.7b.

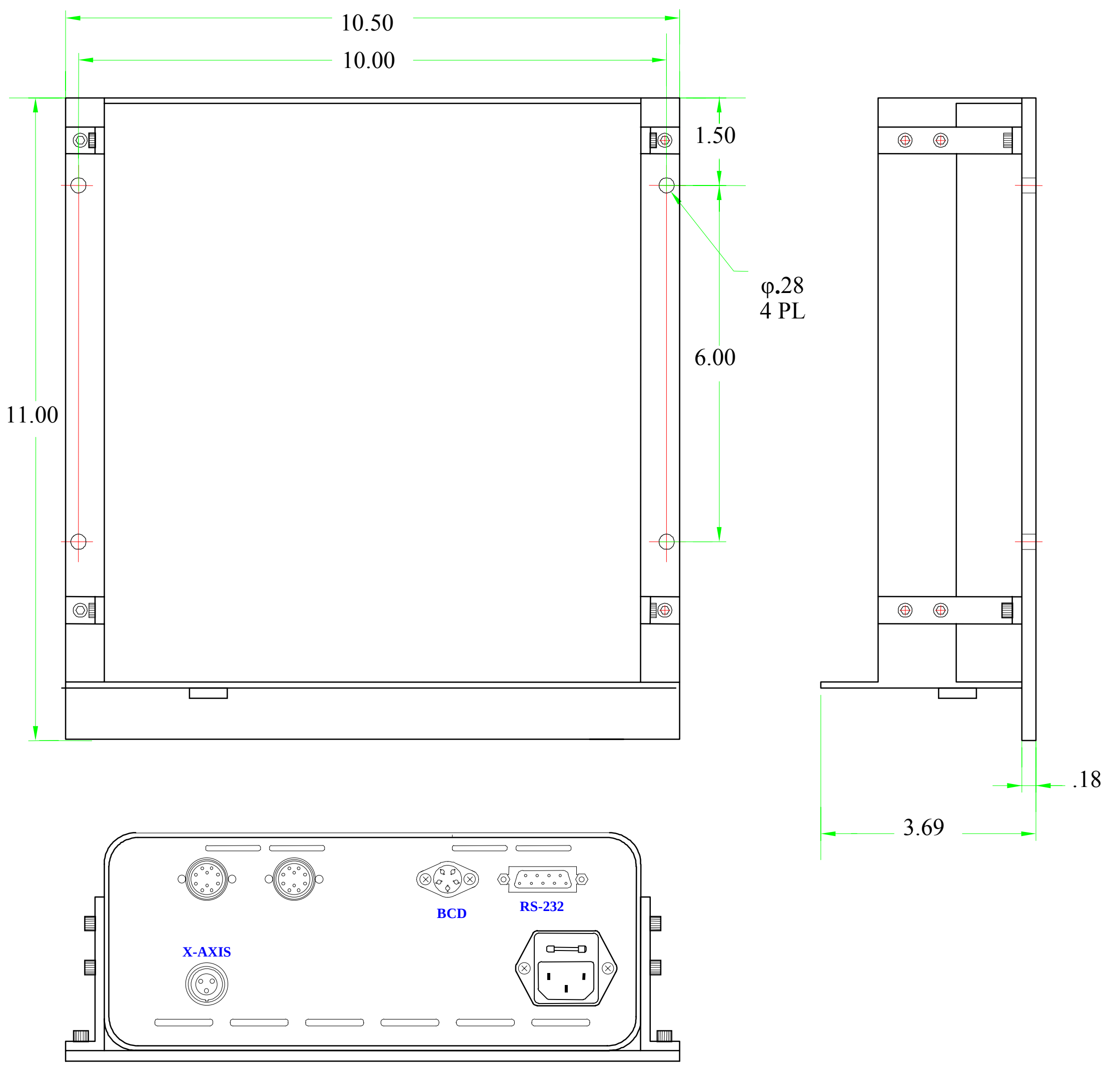


FIG.2.7a PROCESSOR BOX (P-301)

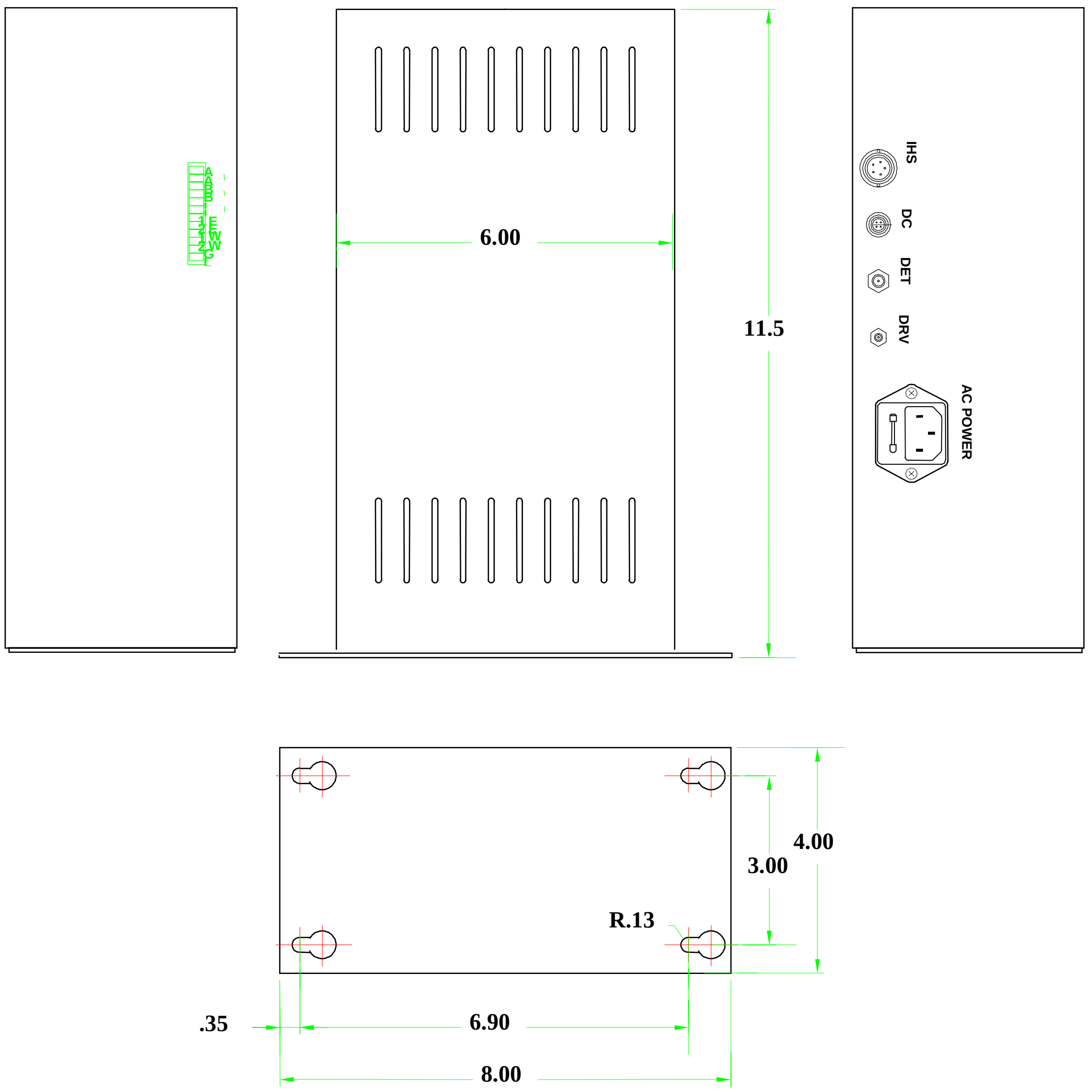
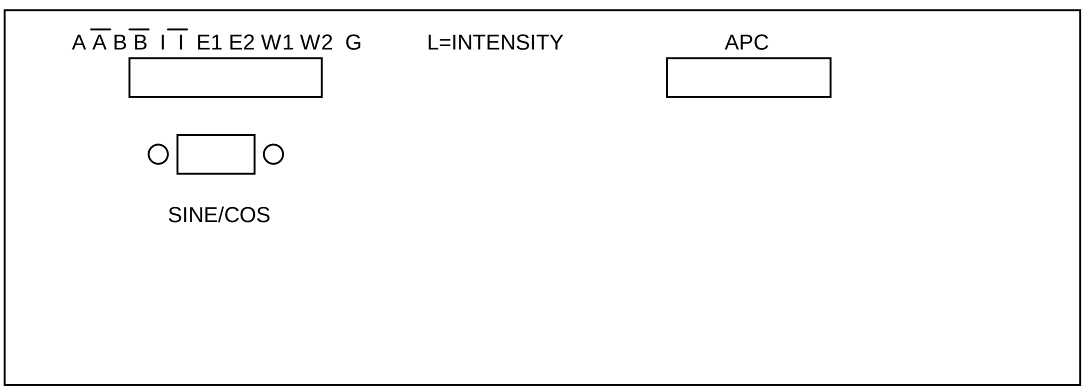


FIG. 2.7b PROCESSOR BOX (P-108)

A : A quadrature square wave signal
$\overline{A}$: $\overline{A}$ quadrature square wave signal
B : B quadrature square wave signal
$\overline{B}$: $\overline{B}$ quadrature square wave signal
I : Home position switch
$\overline{I}$:
E1: Error relay
E2:
W1: Warning relay
W2:
G : Ground
L : Intensity

(I, $\overline{I}$, E1, E2, W1, W2 — Option)



Processor Output Signal

(ICB) and a 10 digit LED display (D-101) to display the position can also be added (optional).

2.4.7 Accessories for Hostile Environments

The laser head can be hermetically sealed (except the connectors) (LHS1). The aperture of the laser head and the retroreflector may be protected by a beam protection gun barrel as shown in Fig. 2-8. (LD-57). A gun barrel for the retroreflector is also available, as shown in Fig. 2-9. For increased beam protection, the gun barrel can also be air purged. To bend the laser beam 90°, a turret beam bender (LD-15T), as shown in Fig. 2-10, is available.

2.4.8 Cooling Plate for Heat Removal from Laser Head

The Laser head generates 10 to 20 W of heat. This heat is dissipated through the base plate or through the air by convection. For machine tool applications the heat source negligible. This heat source is much smaller than other heat sources, such as the motor drive or spindle. However, for other applications this heat source may generate temperature gradients in the structure and cause positioning errors. For these critical applications, the laser head may be mounted on a cooling plate (liquid coolant or compressed air can be used). This cooling plate will remove the heat generated by the laser head. The dimensions of the cooling plate are 3" x 8" x 0.5" with mounting holes.

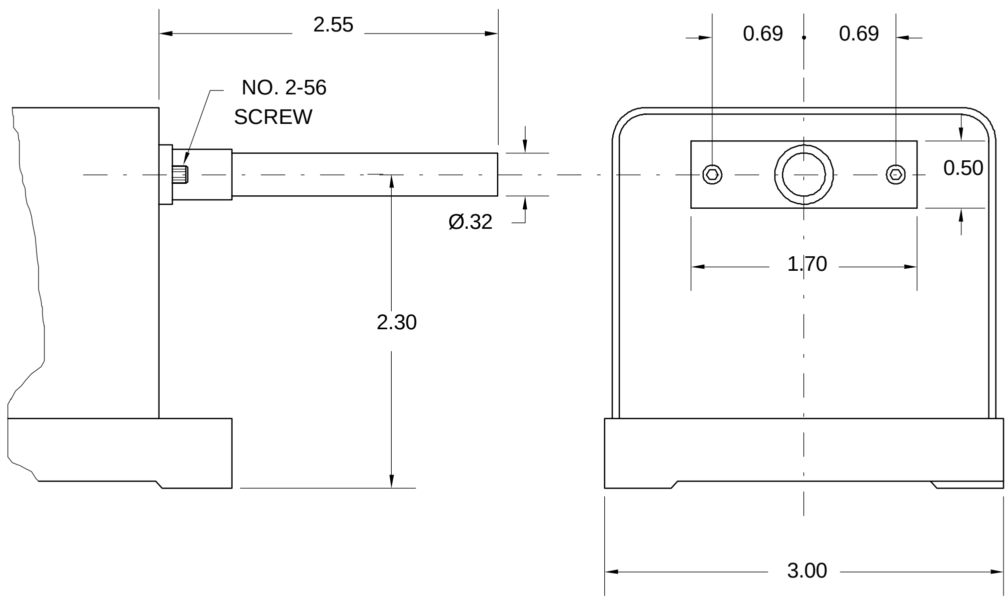


FIG. 2.8 BEAM PROTECTION GUN BARREL FOR LASER HEAD

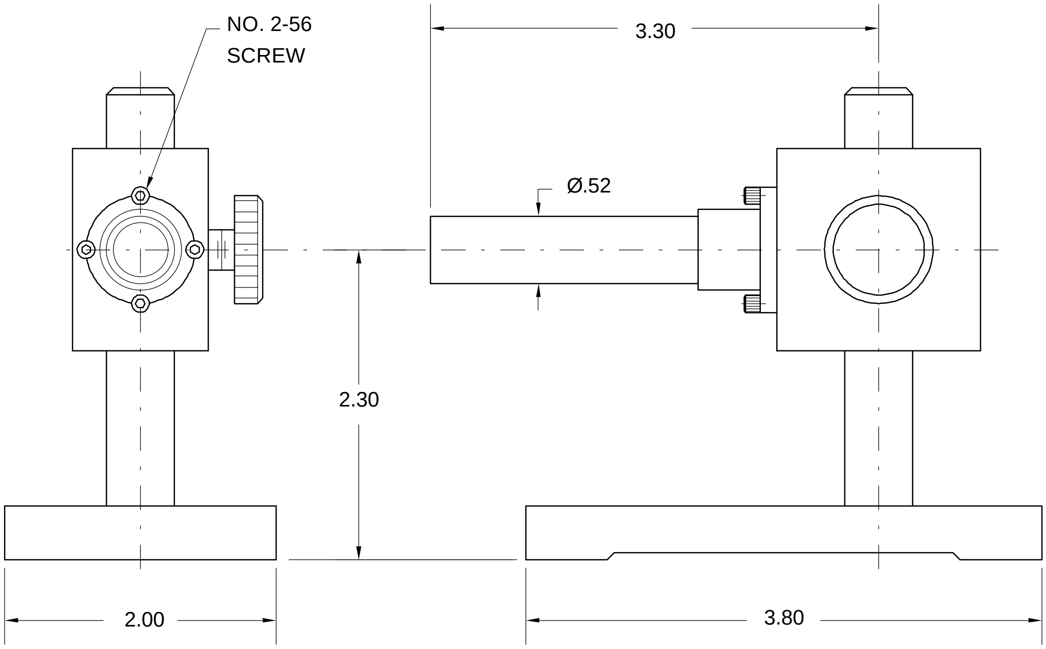


FIG. 2.9 BEAM PROTECTION GUN
BARREL FOR RETROREFLECTOR

Standard range for the LDS system is 40 inches. The standard range can be extended to 400 inches (ER-400) and 2000 inches (ER-2000) without changes to the overall physical dimensions of the laser head.

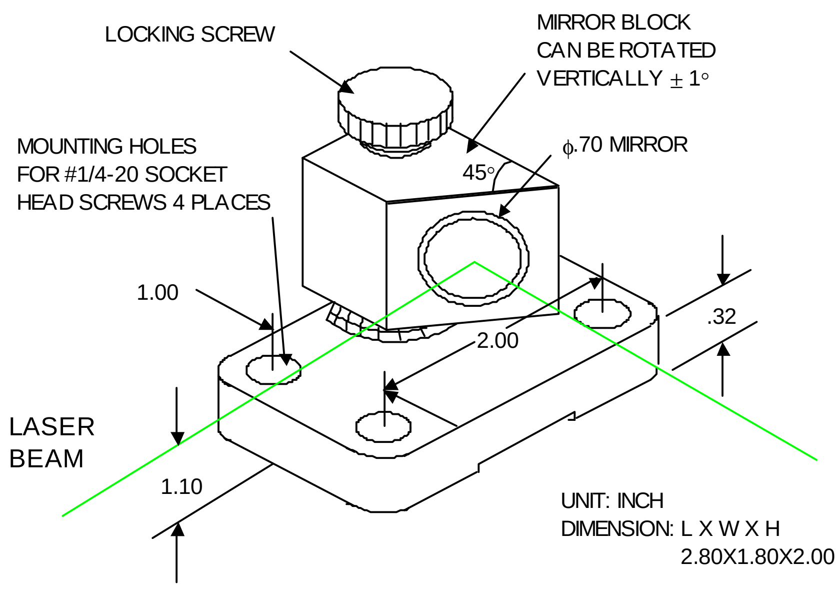


FIG.2-10 90° BEAM BENDER (LD-15TT)

2.4.9 Flat-mirror Target

Since some applications would use a flat mirror as a target, a narrow beam laser head (L-109N) is available. Applications for this option include X-Y stages and servo track writers.

2.5 Technical Specifications

2.5.1 System Performance

Resolution:	25 µin (24.914155 µin) 3.1 µin with divided by 8 board 0.38 µin with divided by 64 board 0.1 µin with 32-bit parallel board	
Laser Stability:	0.1 ppm	
Accuracy:	1 ppm (typical)	
Maximum Range:	up to 2,000 inches	
Maximum Speed:	up to 160 ips	
Maximum Acceleration:	laser head	10g
	retroreflector	100,000g
Power:	90-230VAC 50-60 Hz	
Operating Environment:	Temperature	60 to 90 °F.
	Altitude	0 to 10,000 ft.
	Humidity	0 to 95% non-condensing

2.5.2 Laser Head p/n L-109 (Fig. 2.2a)

Dimensions:	2 x 2 x 8.5 inches
Weight:	2 lb.
Mounting Holes Separation:	8 inch, 4 sides
Alignment Tolerance:	lateral ±0.05 inches
Warm-up Time:	20 minutes
Magnetic Field Strength:	no permanent magnetic field
Power Requirement:	15V DC, 2.2A
Laser Type:	HeNe laser, CW
Wavelength:	632.8nm
Output Power:	0.2 to 0.4 mW
Beam Diameter:	Ø0.2 inches
Wavelength Stability:	0.1 ppm

Safety Classification: Class 2 laser product conforming to US National center for Devices and Radiological Health, Regulations 21 CFR 1040.10, 1040.11

Lifetime: 20,000 hours MTBF

Connectors:
Gold SMA is signal output
Silver SMA is 15V DC input
Gold SMB is driver input

2.5.3 Retroreflector p/n R-102 (Fig. 2.3)

Dimensions: Ø½ inch
Weight: 0.05 oz., (0.4 oz with housing)

2.5.4 Processor Board and Driver p/n IPS1, ID1 (Fig. 2.4)

Dimensions:

Processor Board	0.5 x 4.5 x 8 inches
Driver	1 x 2 x 4.5 inches
with mounting plate, overall dimensions	2 x 4.5 x 8 inches

Weight: 1 lb.
Power Required: (including laser head)
15V DC at 2.5A
5V DC at 0.5A
-5V DC at 0.1A

Output:
AquadB square waves
up/down pulses, TTL compatible

Connectors:
Gold SMA is signal input
Silver SMA is 15V DC output
Silver SMA is driver output
Molex 3-pin is 15V DC input
Molex 5-pin is ±5V DC input
DIN 10-pin is AquadB, u/down pulses and error

1.3 Unpacking and Inspection

As soon as you have unpacked the system please check for the follc components:

1. Processor Module
2. Laser Head Module
3. Retroreflector
4. Cable Assemblies
5. User's Guide
6. Options and Accessories

Please check the condition of all components. Fill out the Warranty Registr Appendix D, and return it to Optodyne, Inc., at the address shown on the page of this manual. All equipment should be tested as soon as it is recei accordance with the installation instructions, page 3.2. If any component f operate properly or is damaged in any way, a warranty claim should be file the carrier. A full report of the damage should be filed with the claim agent, copy made available to Optodyne, Inc., Service Department. Optodyne wi advise you of the disposition of the equipment and arrange for its rep replacement. Include model number and serial number when corresponding this equipment for any reason.

If a warranty claim is necessary, please provide detailed information conce equipment type, serial number, nature ofthe problem, etc. Send the claim Optodyne Service Department on the address at the front of this mar Instructions for the disposition of the equipment will be returned to you. ordering replacement components from the factory, always give the type anc number of the equipment and the values, tolerances, ratings and Optc designation of all electrical components required. Please refer to the Part where applicable.

4.0 Maintenance

4.1 Trouble Shooting

1. No Laser Beam Output or Weak Beam

Check Connectors. Make sure the laser is connected properly. Check ca make sure they are in good condition. Check the AC power line int processor module, and make sure the power is on.

Sometimes when the machine is cold (< 50° F or < 10° C), it may take than 1 minute before the laser beam is emitted. If the laser still does not on line, return the laser head to the factory for repair.

2. Error Signal On

a. Check laser output beam
b. Check alignment, make sure the return beam enters the receiving ape
c. Check signal intensity, it should be more than 3.3V DC. If the intensity i than 3.3V, check the RF signal, it should be more than 0.8 peak-to-pe the RF signal is less than 0.8V, the laser head may be damaged and s be replaced. Return both the laser head and processor for repair.

3. Warning Signal On

a. The warning signal indicates that the laser is not locked or the signal and the laser needs either realignment or its optics need to be clea

b. If the light stays on continuously after realignment and cleaning, the head should be returned for repair.

4.2 Preventive Maintenance

There is no preventive maintenance required for the LDS. The system is des to operate for an extended time without attention. The laser tube has an esti life of 20,000 operating hours. Replacement of this tube is indicated by eit laser beam or a warning signal. The laser head must be returned to the fact laser tube replacement. Please contact your local sales representative for n charges associated with this repair when done out of warranty.

For the duration of the warranty period, repairs must be performed by Optod order to maintain the validity of the warranty. The case of the laser head is s with foil seals to prevent tampering. **BREAKING OF THESE SEALS VOIDS WARRANTY**. After warranty expiration, Optodyne strongly recommends defective components be returned to the factory for authorized service. Sp tools, test equipment and know-how are required to evaluate the LDS comp

APPENDIX A. WARRANTY

Optodyne, Inc. warrants that each new instrument which it manufactures an from defects in material and workmanship under recommended use conditions. Liability under this warranty is limited to servicing or adjusti returned to the factory for that purpose and replacing any defective parts th case that a problem is limited to a single module it is preferred that only t module be returned to Optodyne. This warranty is effective for 1 year fron delivery to the original purchaser. When the unit is returned (transportat prepaid by original purchaser) and when upon examination, it is disclosed to then if the fault has been caused by misuse or abnormal conditions of opera will be billed at the then prevailing repair rates and component replacement case, an estimate will be submitted before the work is started. Optodyne, Inc liable for damages by reason of failure of the instrument to perform proper consequential damage. This warranty does not apply to any unit that has be neglect, accident, misuse, improper operation or that in any way has been ta altered or repaired by any person other than an authorized Optodyne person unit whose serial number has been altered, defaced, or removed.

Exclusive Remedies: the remedies provide herein are the buyer's sole a remedies. Optodyne, Inc. shall not be liable for any direct, indirect, special, consequential damages, whether based on contract, tort or any other leg

This warranty only covers equipment manufactured by Optodyne, Inc. Acce as computers, printers, etc. are not covered by this warranty, but by manufacturer.

APPENDIX B. CERTIFICATION

Optodyne, Inc. certifies that this product meets its published specification, see at the time of shipment from the factory.

APPENDIX C. CALIBRATION

The fundamental accuracy of the LDDM™ is based upon the wavelength of th in the system. This wavelength has been measured to 632.8195 ± 0.0001 nr conditions defined as follows:

Temperature:	20° C
Pressure:	29.92 in Hg
Relative Humidity:	40%

A calibration constant of 80275.65 counts per inch has been programn microprocessor within the processor module. Recalibration service is av Optodyne, Inc. for a nominal charge. A certificate ofcalibration, which is trac NIST, formerly the National Bureau of Standards, is provided upon reque

APPENDIX D. WARRANTY REGISTRATION

Please complete this sheet as soon as the system is unpacked and return it t Inc. at the address listed below. Registration establishes the warranty period Optodyne to keep you informed of changes or upgrades.

End user's name:______________

Title: **Dept.:**

Company:____________________ **Phone Number:** (   )________ **ext.:**__________

Address:______________________

City:________________________ **State:**____ **ZIP:**__________

Date of Purchase:______________

Model Number:_______________

Laser head S/N:______________ **Processor S/N:**______________ **Display S/N:**______________

Description of intended use or application:

____

____

____

____

Mail to:

Optodyne, Inc.
1180 Mahalo Place
Compton, CA 90220

or FAX to 310-635-6301.

APPENDIX E. DESCRIPTION OF INTERFACES

The LDDM™ Processor Unit can be configured to give the following outputs:

- Up/Down Count pulses
- Analog Phase
- A Quad B Quadrature square wave
- Laser error signal
- BCD

Up/Down Count

The Up/Down pulses are high going TTL level pulses with a minimum pulse w ns, and a maximum pulse rate of 10 MHz. The inactive pulse output is held low other is active. The output buffer can source 15 ma (output high current) and si (output low current). In some configurations an RSV-422 buffer provides sing outputs with 50 ma source and sink.

Analog Phase

The Analog Phase signal is voltage which is used to interpolate values betweer pulses. With movement in the up direction, this voltage changes from 1.7 to between two up pulses; with movement in the down direction, the voltage chan 3.1 to 0.6 volts between down pulses. The voltage ranges are different because output has hysteresis when the direction changes. The leading edges of the pulses are coincident with the respective extremes of the analog voltage ranges.

A Quad B

The quadrature square wave signals are at TTL levels. In the normal configuratic 422 buffer provides 50 ma differential outputs. In some configurations the outpu single ended output buffer which can source 15 ma (output high current) and si (output low current).

Error Signal

The Error Signal is a TTL level digital output which is LOW to indicate that the la level is too low, and HIGH to indicate that the laser signal level is sufficient. D error condition, the position pulse outputs should be disabled.

APPENDIX F. AUTOMATIC TEMPERATURE AND PRESSURE COMPENSATION (ATC)

Accurate measurement is dependent upon the measuring system's ability adjust to environmental changes and upon the user's/operator's ability to set-u and operate the system properly.

Environmental changes affect the wavelength of the laser beam and th material's physical properties. The wavelength of the laser beam is th standard for distance measurements and is proportional to the velocity of lig in air.

The velocity of light in air changes due to varying air temperature, pressure a relative humidity.

As a rule of thumb, a 1°C increase in temperature corresponds to an increase laser beam wavelength of 1 ppm. A 1°C increase in temperature is equivale to a 3.3 mbar (0.1 in Hg) decrease in pressure, or 60% decrease in relati humidity.

THUS, FOR ACCURATE MEASUREMENTS, AIR TEMPERATUR PRESSURE AND RELATIVE HUMIDITY SHOULD BE MEASURED AN THEIR EFFECTS COMPENSATED.

Most materials undergo expansion or contraction due to change in temperatu If a part is measured at two different temperatures, two different values w result. Sometimes this difference can be as great as 100 ppm and can be t most significant source of error in distance measurements.

Ideally a distance measurement made with the LDDM™ should be done in temperature controlled room held at the standard temperature of 68°F (20°C Then all parts will be at their "true" size as defined by the Internation Committee on Weights and Measures.

Since a temperature controlled room is not always available, there should be compensation factor (Material Thermal Expansion Coefficient) to compensa for the amount of change due to temperature variations. At the time of t measurement, the temperature of the material must be known. Materi temperature and the material's coefficient of expansion will allow determinati of the amount of change due to fluctuations in temperature.

THUS, FOR ACCURATE MEASUREMENTS, MATERIAL TEMPERATUR SHOULD BE MEASURED SO THAT THE EFFECT OF EXPANSIO CONTRACTION CAN BE COMPENSATED.

APPENDIX G. STABILITY OF LASERS

The amplitude and frequency fluctuations of an internal mirror HeNe laser a attributed to variations in the laser tube length due to thermal expansion. T standard LDDM™ laser heads are stabilized.

The laser output is locked to the gain curve. Thermal expansion ar contraction cause the resonant frequency of the cavity to drift through the ga profile and produce peak-to-bottom changes in the laser output. The pow generated by the laser head is about 14W at 75°F (21W at 60°F and 7W 90°F).

When the laser frequency is locked, it is operated at two axial modes. T mode separation is 1085 MHz and one axial mode is always less than 20% the other axial mode.

The short term (less than a few minutes) frequency stability is ±0.001 ppm a the long term (more than a few hours) frequency stability is ±0.004 ppr Furthermore, there is no permanent magnetic field inside the laser head and t frequency stability is not affected by any magnetic field near the laser hea The reflected light back to the laser resonator will not affect the frequen stability.

APPENDIX H. MEASUREMENT ACCURACY

The repeatability is defined as the maximum deviation between measuremen under the same conditions and with the same instrument. The repeatability the LDDM™ can be checked by repeatedly moving the target between two fix stops. The 3 σ distribution of the readings at each stop is a good indication how repeatable the instrument is.

The accuracy is defined as the maximum deviation of a measurement from known standard or true value. Hence, accuracy is the repeatability plu calibration. Since the wavelength of all HeNe lasers is certified by NIST to accurate to within ±1.5 ppm (See NBS technical note 1248), no calibration necessary for accuracy less than ±1.5 ppm once the repeatability of th instrument is established.

For certain applications, an NIST traceable number is required. An Optody LDDM™ system (s/n 9410001252, 9410001039, and 941001) was calibrated NIST on November 14, 1994, Test # 821/254610-95. A report was issu stating that the laser wavelength stability is ±0.0049 ppm, while the syste accuracy is less than 0.2 ppm without automatic temperature and pressu compensation, and is less than 0.8 ppm with automatic temperature a pressure compensation. For those who have the need, Optodyne, can prov a certificate that the LDDM™ system has been calibrated against the LDDM system (s/n 9410001252) and a copy of the test data.

The instrument accuracy is only part of the measurement accuracy. Th measurement accuracy is determined by the vector sum (root sum of th square of the individual components) of the error components in the system error budgets. There are three types of error sources, namely, measureme instrument, environmental changes and installation. Some of the errors a proportional to the measurement length and some of the errors are fix quantities.

Typical instrument errors are laser wavelength variation, electronic error a optical non-linearity. Typical error due to environmental changes atmospheric compensation error, material thermal expansion compensati error and optics thermal drift error. Typical errors caused by improp installation are dead-path error, Abbé error and cosine error. The following is more detailed description of these error sources.

1. Laser Wavelength

A laser system's accuracy is based on the laser's wavelength accuracy. F a standard LDDM™, the frequency stability is 0.005 ppm and the waveleng accuracy certified by NIST is better than 0.1 ppm.

APPENDIX I. USE OF FLAT-MIRROR TARGETS FOR X-Y STAGES

The LDDM™ narrow beam laser head can be used for plane mirror reflec applications. For example, in a two axis system (e.g. an X-Y stage), the reflector can be allowed to move in the Y directionwithout affecting the sig strength of the X-measurement. Consequently, both reflectors in a 2-a system can be mounted on the same moving part to minimize Abbé offset er Defining the measurement as the point where the axis beams intersect, measurement is essentially independent of yaw motion of the moving stage shown in Fig. I-1.

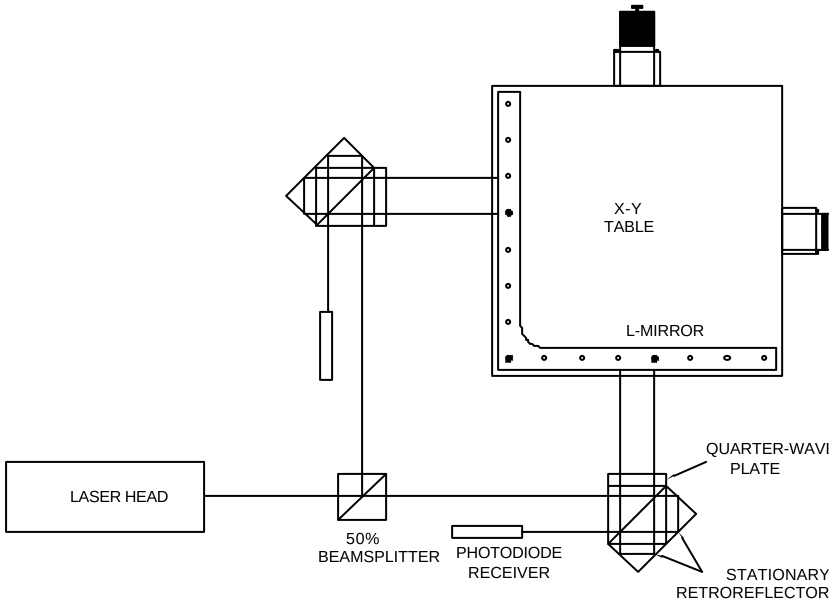


Fig. I-1 X-Y Stage Measurement with Interferometers

Contrast this system to a 2-axis system using retroreflectors. The X-a retroreflector must be mounted on a part of the stage that moves in the direction and not in the Y-direction. The Y-axis retroreflector must also mounted on a different part of the stage that is allowed to move in the Y-direct and not the X-direction. These constraints prevent 2-axis measurements fr

APPENDIX J. FASTENING, THERMAL AND VIBRATIO ISOLATION

The laser head is fastened through two through holes, one in the front and o in the back. The laser output beam is not at the center, hence the output bea location can be changed by rotation of the laser head. A 90° beam bend attached to the laser head is available to bend the output laser beam 90 There is some heat dissipation (10 to 20W) from the laser head. On smaller very accurate machines, care must be taken in the selection of a mountir configuration. A cooling plate is available to isolate the heat flux to tl machine. A circulatory coolant is needed for this cooling plate.

Vibration of the optics in a direction parallel to the beam can cause the readin to fluctuate rapidly, making it difficult to determine which number indicates t true position of the optics. When vibration occurs in a direction perpendicular the beam, the beam signal power can fluctuate. If this fluctuation is too gre insufficient beam signal will result indicated by an error signal.

Loose mounting can cause the optics to move inappropriately during measurement, causing a measurement error or loss of beam strength.

Elastic mounting can have the same effect as loose mounting. It can also l responsible for a "sag" offset in the optics' positions. If there is vibration in t machine, an elastic mounting can transmit and amplify the vibration to the attached optic,possibly causing additional errors.

APPENDIX K. LASER BEAM AND OPTICS PROTECTI

For most applications, the laser is inside the way cover or other protective co of the machine. For some applications, when the laser beam is not cove protection should be provided to prevent metal chips or cutting fluid f interfering with the measurements. The LDS requires protection aga unintentional laser beam blockage and air turbulence problems. Also, the op components usually require protection to prevent contamination of the op surfaces by oil or cutting fluid.

If protection of the laser beam and optical components is required, a sim cover can be provided. In many applications, the only moving component i reflector. In this case it is only necessary to provide fixed tubing for the la beam and some type of sealed enclosure for the optics. Since only one l beam of approximately Ø5.0 mm is involved, relatively small diameter tubing (ID) can be used. There is a wide variety of commercially available protec covers which are suitable for this purpose.

In some applications when the laser beam and optics are already protecte way covers or other means, oil vapor or small metal chips may still leak thr the cover. For this environment, usually a dust cover (gun barrel) in front o laser head and the retroreflector will provide adequate protection.

The laser system has been tested under oil vapor and oil mist condition extended periods without the need to clean the optics. This is because temperature of the laser head is higher than the environment temperature, s vapor will not condense on the laser head. There is some oil condensatio the retroreflector, but it will not interfere with the measurement. Of cou periodic cleaning of the retroreflector may be needed.

In certain environments, where excessive oil vapor and oil mist leaks throug way cover and also with large temperature fluctuations, adding an air purge t dust cover for the retroreflector, may reduce the frequency of cleaning the op For high velocity applications, the protection provided for the linear motors sh be more than adequate to protect the laser system.

When using air purge, care must be taken to minimize air turbulence, which disturb the laser beam.

APPENDIX L. PARTS LIST

LDS-1000

	P/N
1. LDS Laser Head (2”x2”)	L-109
2. 0.5”Retroreflector without Base and Post	R-102A
3. Processor Board with Driver	IPS1
4. 12 ft Cable Set, No BNC	LD-21R

Options:

1. AC Powerfeed and Enclosure with Terminal Strip(LDS)	P-107
2. AC Powerfeed and Enclosure without Terminal Strip(LDS)	P-107A
3. AC Powerfeed and Enclosure w/Strip, Lemo Connectrs	P-107L
4. AC Powerfeed and Enclosure w/o Strip, Lemo Connectors	P-107L
5. Home Position Transducer	IHS
6. Pulse Convertor	IPC3
7. Automatic ATC Converter Board & C4 Board(w/probes)	IPC4
8. Wavelength Divided by 8 Board	IPPD2
9. Wavelength Divided by 64 Board	IPD1
10. 32-bit Parallel Board (IPCAX)	IPP32
11. LDS Laser Head, Narrow Beam(2”x2”)	L-109N
12. Extended Range, 8mm Beam	L-109R
13. Counter Board with Microprocessor	ICB
14. 10 Digit LED Display	D-101
15. Extended Range to 400 in for L-109	ER-400
16. Extended Range to 2000 in for L-109	ER-2000
17. Hermetically Sealed (Except Connectors)	LHS1
18. 90 Degree Beam Bender LDS Model	LD-15C
19. Laser Head Gunbarrel	LD-57P
20. Retroreflector Gunbarrel	LD-57P
21. 90 Degree Beam Bender (Enternal +/- 1 Degree Adjustable)	LD-15T
22. 90 Degree Beam Bender (L-109, Fixed)	LD-51S
23. Sinusoidal Output	IPPS
24. IBM PC Interface	

APPENDIX M. REPRINTS OF PAPERS

HIGH SPEED AND HIGH ACCURACY MACHINE TOOLS USING
LASER ENCODER FEEDBACK

Dr. Charles Wang
President
Optodyne, Inc.
and
Jeff Porter
Product Line Manager
Ingersoll Milling

PRESENTED AT: Advances in Precision Machine Design
September 12, 1994
Chicago, Illinois

SPONSORED BY: Society of Manufacturing Engineers
Conferencing Division
One SME Drive, PO Box 930
Dearborn, MI 48121-0930
(313) 271-1500 FAX (313) 271-2861

I. Introduction

A revolutionary concept in the design of machine tools eliminated the lead screw increase the speed of the machine tool, as well as accuracy and rigidity. The le screw, as a machine's main source of inertia limits speed, so it has been replaced wit linear motor and motion control servo that uses a laser as feedback. The result is machine tool that is very fast when performing operations, such as moving betwe cuts, tool retraction and tool changes. The machine tool's path accuracy and settli time is improved, because of the benefits the laser provides for the machine's ser control system. The speed, power, and rigidity of the system makes both high me removal rate and high part accuracy possible at the same time. In addition, the hi acceleration and deceleration rates provided by this drive system make improved tc life at high feed rate possible because a constant chip load on the cutting tool maintained at all times.

II. High Velocity Manufacturing

Starting in 1985, Ingersoll Milling Machine Company, in conjunction with Ford Mot Company, began the development of a radically new machine tool technology whi utilized high thrust linear motors to drive the machine's linear axis. These linear mot replace the ball screws, ball nuts, gear boxes, servo motors, encoders, and end bearin traditionally used in a machine tool axis drive system. Magnetic force alone is used drive the machine axis and hold them in position. The objective of this developm was to produce a machine which would be several times more productive tha conventional machining centers with superior accuracy and reliability. Ultimatel flexible systems of these machines would be used to replace transfer lines for mid-t high volume production applications.

The result of this effort was the development of machines with the followi characteristics:

- Acceleration and deceleration rate which are 10 - 15 times higher than conventio machining centers (1-1.5 g).

- Rapid traverse and feed rates that are 3 - 4 times higher than convention machining centers (3,000 IPM, 76 m/min).

- A very stiff, stable machine platform capable of supporting new spindle technolo also developed by Ingersoll - high speed, high power, hydrodynamic bearin motorized spindles.

In order to achieve these results, every area of machine design needed to be rethoug A rigid machine structure with a first order resonant frequency three times higher th a conventional structure was required, but the structure had to weigh less than half th of a conventional steel or iron structure. Very high position and velocity loop gai were required for the machine's control system in order to maintain high path accura at high acceleration and feed rates. A photo of the Ingersoll high Velocity Machini Center is shown in Fig. 1. Ingersoll experimented with three different kinds of ax feedback systems and concluded that only one had all the capabilities needed for tl demanding application - laser encoder feedback.

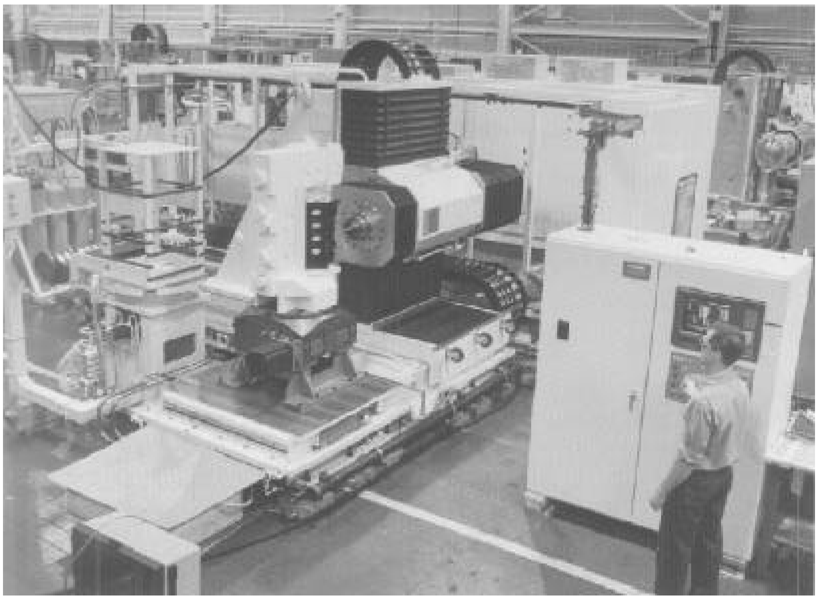


Fig. 1 Ingersoll High Speed Milling Center

III. Laser Doppler Displacement Technology

As described in Ref. 1, the LDDM™ is based on the principles of radar, the Dopp effect and optical heterodyne. Basically a target or retroreflector is illuminated by laser beam. The laser beam reflected by the retroreflector is frequency shifted by t motion of the retroreflector and the phase of the reflected laser beam is proportional the position of the retroreflector. That is

$$x = \frac{c}{2\mathrm{f}} \cdot (\mathrm{N} + \frac{f}{2 \cdot p}) \qquad ($$

Where x is the position of the retroreflector, c is the speed of light, f is the las frequency, N is the number of $2p$'s and f is the phase angle. For a typical output, N expressed as quadrature square waves and f is expressed as analog signal. Tl maximum speed for the phase detection is 8 MHz which corresponds to 2.5 m/s (96 i and the resolution per pulse is 0.63 micrometer (0.000012 inch). An LDDM™ las encoder is shown in Fig. 2.

Fig. 2   LDS Laser Head

Briefly, a laser beam is directed to a retroreflector. The retroreflector will reflect t laser beam back parallel to the output beam, and its position will he determined by t Doppler Shift. There are a number of advantages to working with a laser beam f precise positioning. The inherent accuracy of using a laser beam from a stabilized la as the measurement ruler is achieved with no periodic re-calibration. The measureme is non-contact eliminating mechanical linkages with the stage. One importa advantage is the freedom to locate the point of measurement close to the measur object. The retroreflector can be mounted closely in line with the location to measured reducing or eliminating the Abbé offset, (Ref. 2) or increasing the tightness the servo control. LDDM™ requires very little maintenance. There are no moving pa subject to wear. All machine mounted parts are of rugged design that insures long li The laser tube is small and rugged it can withstand 8 g of force and its laser beam nev needs re-calibration. When repairs are required, the modular design of the LDDM allows for rapid replacement of the defective module, thus minimizing down-time.

IV. Application of Laser Feedback to the High Velocity Module

A. Primary Drivers

1. Capable of high resolution feedback at high data rates. The ability of system provide 0.000012" positional resolution at velocities of 50"/second was a benefit this design.

2. Rejection of vibration in two of three planes reduced the effect of structur resonances. A linear motor (Ref. 3) machine must close the velocity feedback lo through the position feedback system since no rotating encoder or tachometer available. This introduces the machine structure into the velocity loop. In order achieve high servo stiffness and high acceleration and deceleration rates, hig velocity loop gains are required. The laser systems rejection of resonance in tw planes makes it possible to have high velocity loop gains without exciting t machine structure. A block diagram of the servo control is shown in Fig. 3.

3. Immune to electric noise or interference. Linear servo motors do not conta electrical noise or interference as well as rotary motors. The immunity of the las feedback system to the electrical noise created by a linear motor drive syste contributed to a clean feedback signal and stable machine control system.

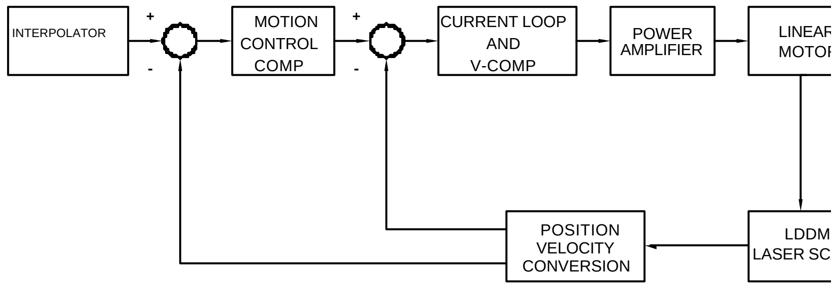


FIG. 3 BLOCK DIAGRAM OF A DIRECT DRIVE
AND LASER FEEDBACK SYSTEM

B. Secondary Benefits

1. Compensation for temperature related growth in the machine structure. Whe properly applied, a laser feedback system can provide compensation for therm growth in a machine structure because of its low coefficient of expansion compar with other scale designs (Ref. 4). The laser coefficient of expansion of 0.5 parts/million is approximately one-eight the coefficient for glass scales and on eleventh the coefficient of steel scales. As a result, the laser system is capable maintaining axis position despite growth of the machine structure.

2. Ease of installation and calibration. No precision machined surfaces are required mount the laser scale system. No time-consuming alignment and calibration proce is required. Wiring is required only for the laser head itself. The laser retroreflec is a passive device. If the laser head is mounted to an adjustment mechanism, t alignment procedure consists of reading a beam strength signal off a test point the laser controller card and adjusting the laser position to maximize the bea strength signal. No additional calibration or alignment is required.

V. Conclusion

While it would have been possible for High Velocity Machines to achieve the productivity and quality objectives using more conventional linear scales, our testi shows that the use of a laser feedback system materially improved machine stiffn and accuracy due to the benefits this system offers the machine's servo control syste The High Velocity Machines' combination of direct axis drive system and high cont gains for the position and velocity loops results in improved dynamic stiffnes acceleration/deceleration, and path accuracy. The use of laser feedback syster improved the servo system performance and thus the overall level of machi performance and accuracy.

References:

1. Wang, "Laser Doppler Displacement Measurement", Lasers and Optronics, 4 (N 9), pp. 69-71, Sept 1987.

2. Wang, "Abbé Error and Its Effect on Position Accuracy of an XY-Table", Motic 5, (No. 6) pp. 19-22, Nov/Dec 1989.

3. Chris Koepher, "Linear Motor Drive--- A Fast Track for Machine Tools", Mode Machine Shop, 67 (No. 2), pp. 64-7(), July 1994.

4. Rick Korte, "High-Tech Sensors Bring New Precision to Machine", America Machinist, 138, (No. 2) pp. 46-49, Feb 1994.

Figure Captions:

1. Photo of the Ingersoll High Velocity Machining Center
2. Photo of the LDDM™ laser encoder
3. Block diagram of the servo control loop

OPTODYNE, INC.
1180 Mahalo Place
Compton, CA 90220
310-635-7481

being made on the same part of the stage. Furthermore, there will be so geometry error inherent to the system if it is not perfectly rigid.

However, the flat-mirror arrangement needs a large space for the two la heads. The laser beams are also exposed making laser beam paths vulneral

The LDS laser head can be incorporated in a new design with the two la heads mounted underneath the X-Y stage (Fig. I-2). This laser he configuration allows measurement of the two flat-mirrors from inside the st rather than from outside as in the conventional flat mirror/laser he configuration.

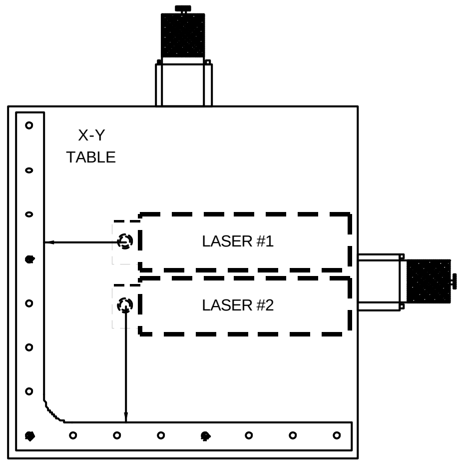


Fig I-2. X-Y Stage Measurement with LDS Narrow Beam Laser Beneath Stage.

This arrangement has all of the advantages of flat-mirror reflector but without disadvantages of the large external space requirement and beam vulnerabil

The laser head does produce heat (typically 10-20W), which may cause ther distortion of the stage. Care must be taken to either properly isolate the h source or allowance for the system to reach thermal equilibrium after power-

2. Electronic Error

The electronic error is a fixed e rror and is equal to the least resolution of tl system. For a standard LDDM™, the resolution is 1 µin (0.01 µm).

3. Optical Non-linearity

This error is referred to as optics non-linearity and occurs solely as a result the optical leakage of one polarization into the other polarization. F LDDM™, the laser beam is not polarized, hence there is no optical no linearity error.

4. Atmospheric Compensation Error

The magnitude of this error depends on the accuracy of the air temperatu and pressure sensor and how the atmospheric conditions change during t measurement. The index of refraction, n, of air is related to λ_V and λ_A by

$$n = \lambda_V / \lambda_A$$

where λ_V and λ_A are wavelength in vacuum and air, respectively. Change air density, which is a function of air temperature, pressure, humidity, a composition, affect the index of refraction. Assuming a standard ar homogeneous air composition, 1 ppm error results from any one of tl following conditions:

a. 1°C change in air temperature
b. 2.5 mm Hg change in air pressure
c. 60% change in relative humidity.

5. Material Thermal Expansion

Since the machine's dimensions are a function of temperature, a correcti for expansion or contraction may be required. This correction relates tl distance measurement back to a standard temperature of 20°C (68°F). achieve this correction, the temperature expansion coefficient must be know This correction or compensation term is known as Material Therm Expansion Compensation (MTE) and is defined as:

$$MTE = 1 - \alpha\Delta t$$

where

α = thermal expansion coefficient
Δt = T- 68°F

The magnitude of this error is a function of the object's temperature and t temperature sensor's measurement accuracy.

6. Optics Thermal Drift

Changes in temperature of the retroreflector during the measurement ca cause a change in optical path length which appears as an apparent distan change. A typical thermal drift is about 0.2µm/°C. To eliminate this optic thermal drift, you may use a mirror-type retroreflector.

7. Dead-path Error

Dead-path Error is caused by an uncompensated length, D, of the laser bea between the laser head and the retroreflector, with the positioning stage the zero position. In most applications, the dead-path errors can b minimized by reducing the dead-path distance D. The dead-path error c be added to the atmospheric compensation error by adding D to th measurement length L. That is, the effective length is D + L.

8. Abbé Error

The Abbé Error occurs when the measuring point of interest is displaced fro the actual measuring scale location, and when angular error exists in th positioning system. The Abbé error is equal to the offset distance, s, tim the tangent of the offset angle, ϕ.

9. Cosine Error

Misalignment of the laser beam to the mechanical axis of motion results in error between the measured distance and the actual distance traveled. Th is called Cosine Error. The cosine error is:

$$\text{Cosine Error} = 1 - \cos\theta$$

where

θ is the misalignment angle.

For small θ, the cosine error is approximately equal to $\theta^2/2$. For exampl when θ = 1 mrad (3 arcmin), the cosine error is 0.5 ppm.

For example, with the following variables:

controlled environment	T = ±0.5°C
total machine travel	L = 50 in.

dead-path	D = 3 in.
misalignment angle	θ = 1 mrad
machine guideway pitch angle	ϕ = 25 µrad
Abbé offset	s = 1 in.
material thermal expansion coefficient	α = 6.5 ppm
laser wavelength error	1 µin

The following errors would result:

The atmospheric compensation error:	1 ppm x 50 in x 0.5°C = 25 µin
The material thermal expansion:	6.5 x 50 in x 0.5°C = 162.5 µin
The dead-path error:	1 ppm x 3 in x 0.5°C = 1.5 µin.
The Abbé error:	1 in x 25 µrad = 25 µin.
The cosine error:	(1 mrad)^2/2 x 50 in = 25 µrad.

The total error, E would then be:

$$E = \sqrt{50^2 + 1^2 + 25^2 + 162.5^2 + 1.5^2 + 25^2 + 25^2}$$
$$\cong 175\ \mu in.$$

To achieve optimum measurement accuracy it is recommended that:

1. Whenever possible make the measurement in a tightly controlle environment and use appropriate compensation method to correct f atmospheric and material effects.

2. Position the laser head such that both the dead-path and Abbé offset a minimized.

Setup and measurement error is due to misalignment of the machine trav along the laser measurement axis (cosine error). For an accuracy of 1 ppm, t misalignment angle should be less than 1 mrad. There is also error due uncompensated measurement path length (dead path error).

In order to accurately correct the effects of environmental changes and mater temperature on the LDS output, the Automatic Temperature Compensati Factor and Material Thermal Expansion Coefficient should be keyed in. Th can be done manually if you can measure the temperatures and feed in t data. If your system has the ATC option, the ATC will automatica compensate for the environmental changes.

The ATC package comes with an ATC board, air pressure and temperatu sensor and material temperature sensor. In order to compensate for t temperature change, you must place the sensors where they can monitor t conditions that would influence the laser. The air sensor (continuously monito the atmospheric conditions) should be kept as close as possible to the actu measurement path, so that it can monitor the conditions the laser beam experiences. The material temperature sensor should be placed on the part the machine closest to its displacement measurement system. Do not place t air sensor on top of the processor box during a measurement. The process box heats up due to its power supply, and placing the air sensor on top of t processor could alter the air reading.

Important: Note that when you are using Optodyne's ATC package, you do n have to key-in air temperature; it will be compensated for automatically. But, the material thermal expansion, the material thermal expansion coefficient mu be loaded into the ATC board.

ATC Specifications:

Temperature:

	Range:	60-90°F (15-32°C)
	Accuracy:	0.18°F (0.1°C) for both air temperature anc material temperature sensor

Pressure:

	Range:	25-32 in Hg (635-813 mm Hg)
	Accuracy:	0.05 in Hg (1.3 mm Hg)

Cable:

4 ft., standard (1.25m)
12, 36 ft available (3.5, 11 m)

BCD

The BCD output is a bi-directional clocked serial port. The output data is in format for the LDDM™ BCD display unit. The port also accepts input data from buttons on the LDDM™ display unit.

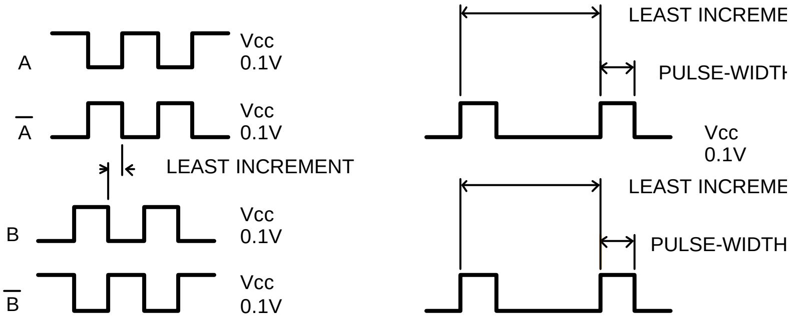
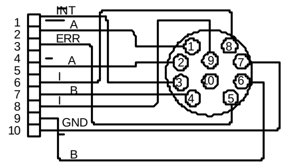


FIG. E-1 PROCESSOR OUTPUT SIGNALS

Output Signals

As shown in Fig. E-1, the output signals are up and down pulses, and Aquad waves. Each up/down pulse or leading edge of an AquadB square wave corres the resolution or least increment.



ADAPTER

10 DIN		10 H FEM
1	INT	3
2	A	1
3	ERR	5
4		
5	A	2
6	I	8
7	B	4
8	I	9
9	B	6
10	GND	7

CABLE 6' OPEN

10 HIR	MALE	7 COND.
1	A	BLUE
2	A	RED
3	INT	WHI
4	B	GRE
5	ERR	ORA
6	B	BRN
7	GND	BLK + S
8	HR or I	VIOLE
9	I	YELLOW
10	N/C	

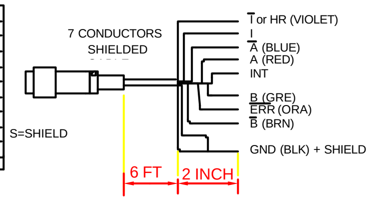
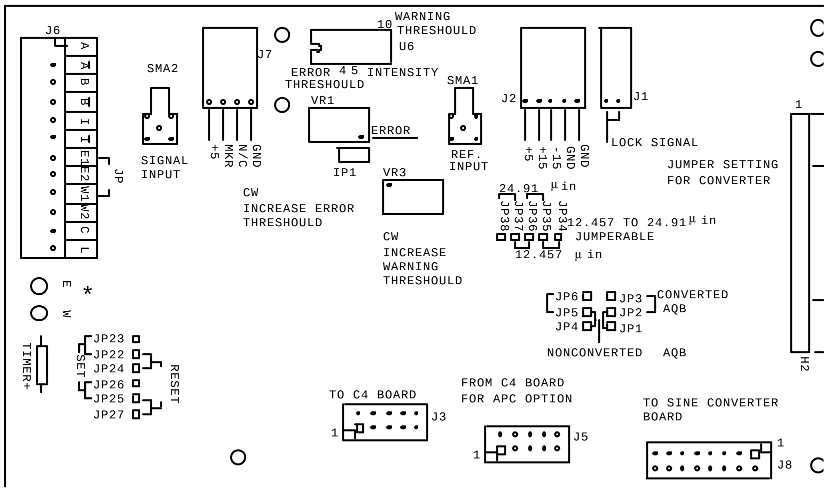


FIG. E-1A P4A/AQB, I / I ADAPTER AND CABLE

Interconnecting Wiring Diagram

The connectors on the processor board are shown in Figs. E-2a, single axis board. Fig.E-2b, P4ACVZ board and Fig.E-2c, SC4 board. The standard interc wiring diagrams are shown in Figs. E-3a and E-3b. The cable set connecting head and processor is shown in Fig. E-4, and the cable connecting the home sensor with pin-outs to the power feed enclosure is shown in Fig. E-5. Please your latest drawings. These connectors may be changed without notice.



* Error relay indicator: LED ON = Laser signal low or out of alignment.

* Warning relay indicator: LED ON = Laser signal low or unlock.

FIG.E-2a SCHEMATIC OF P3BCV BOARD CONNECTORS

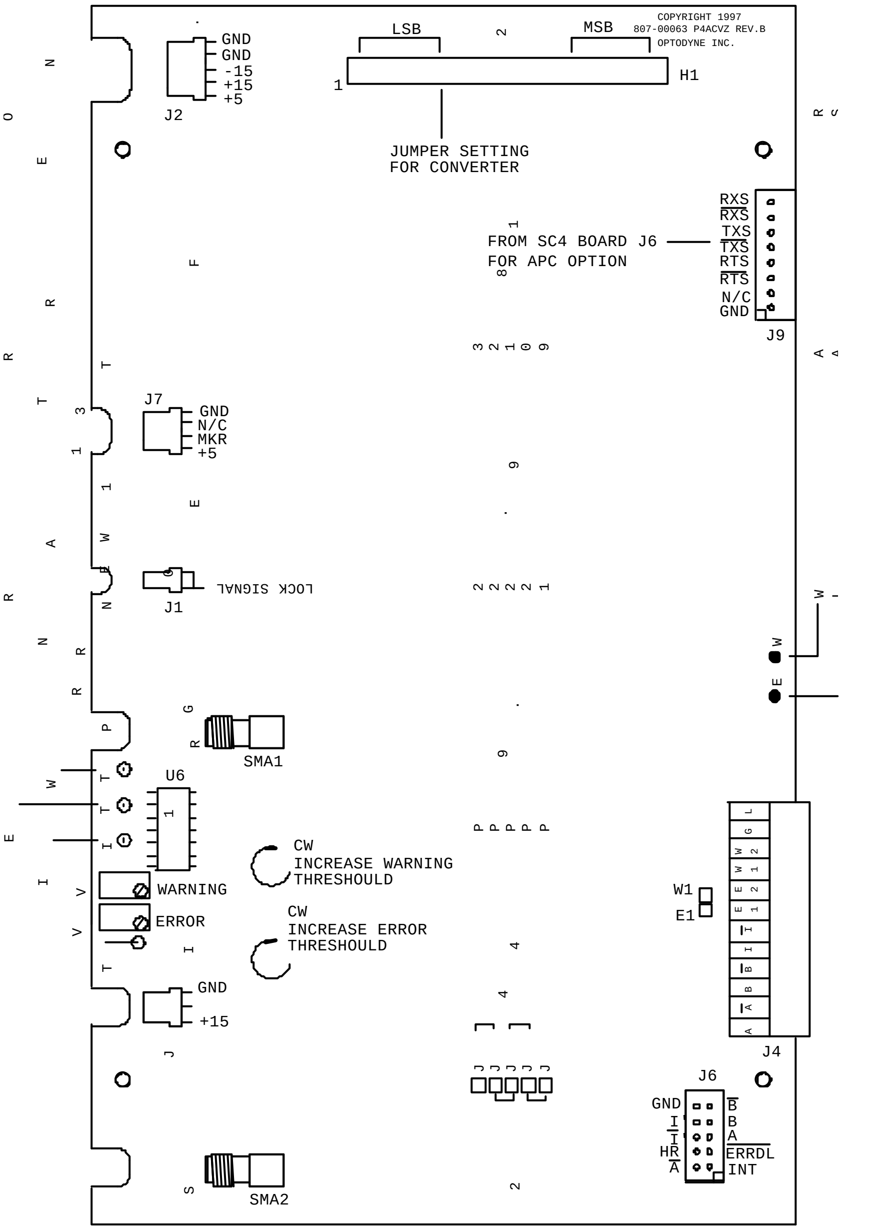


FIG.E-2b SCHEMATIC OF P4ACVZ REV.B
BOARD CONNECTORS

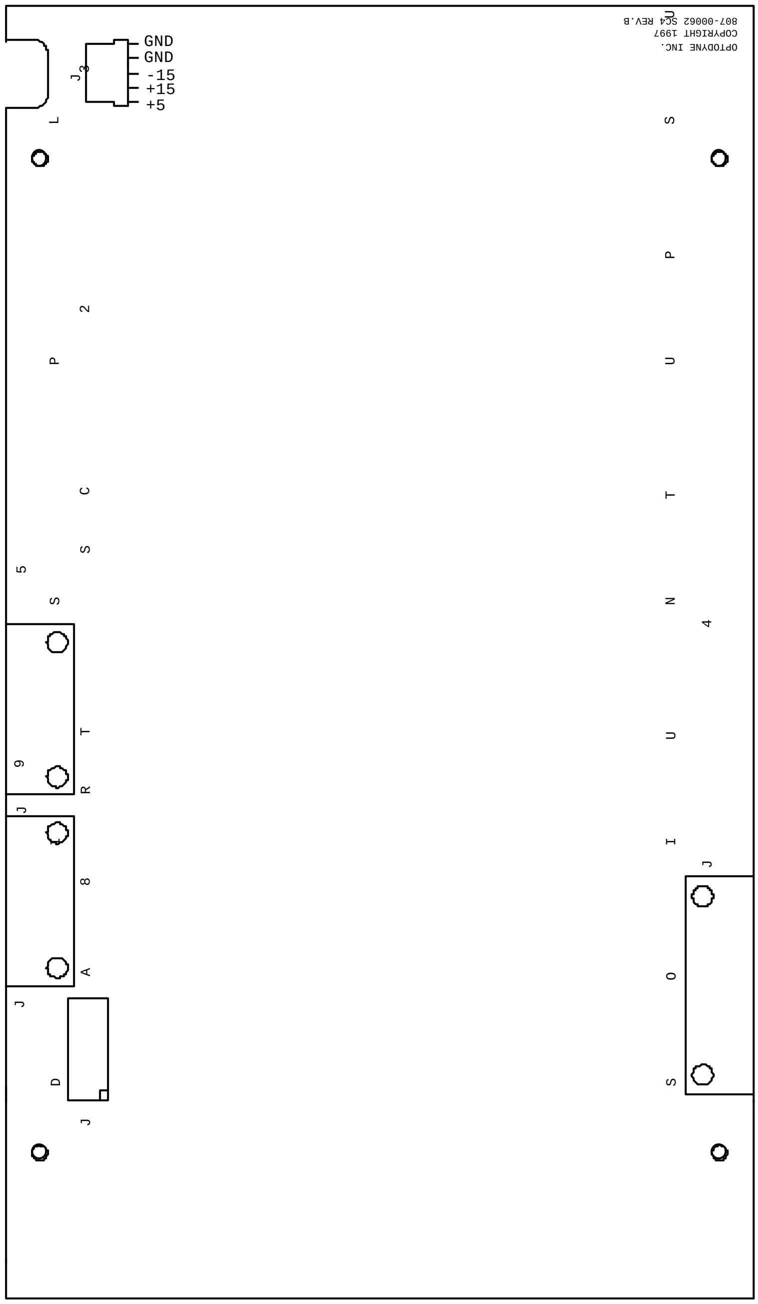


FIG. E-2c SCHEMATIC OF SC4 REB.B

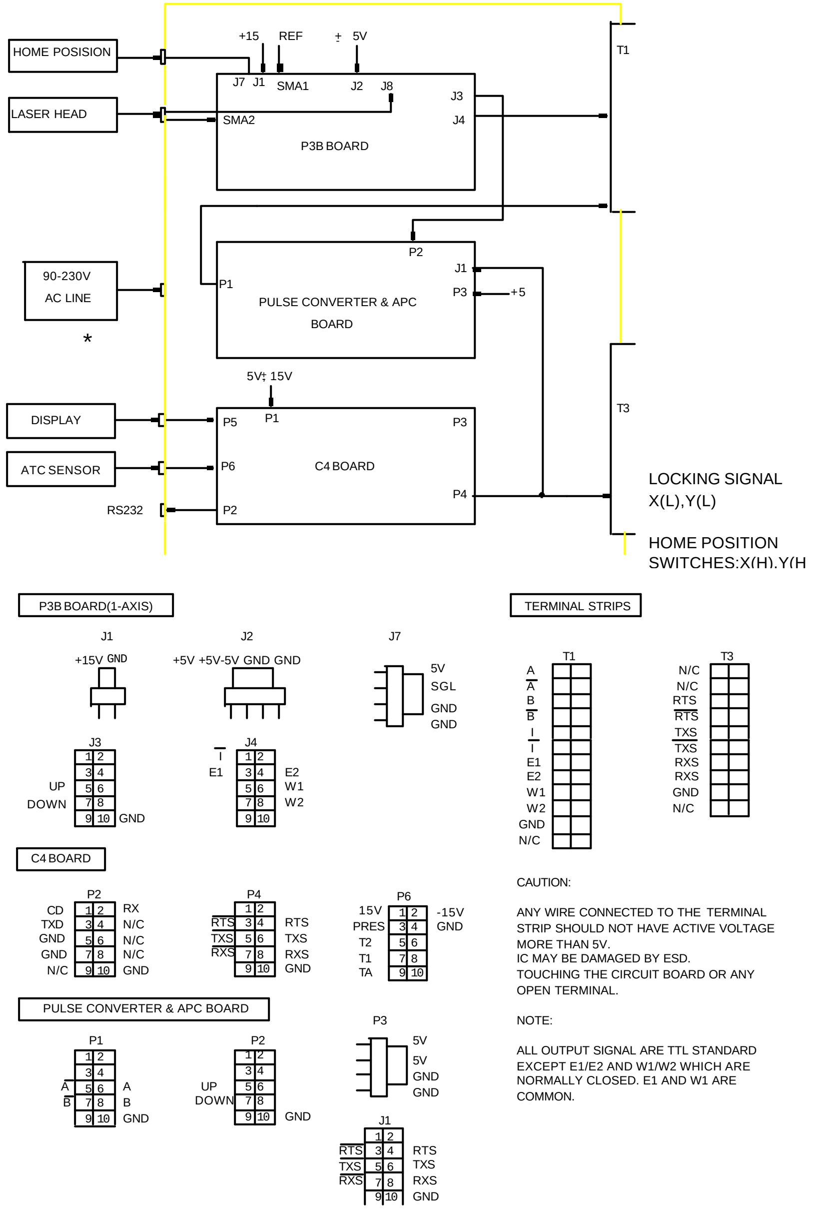
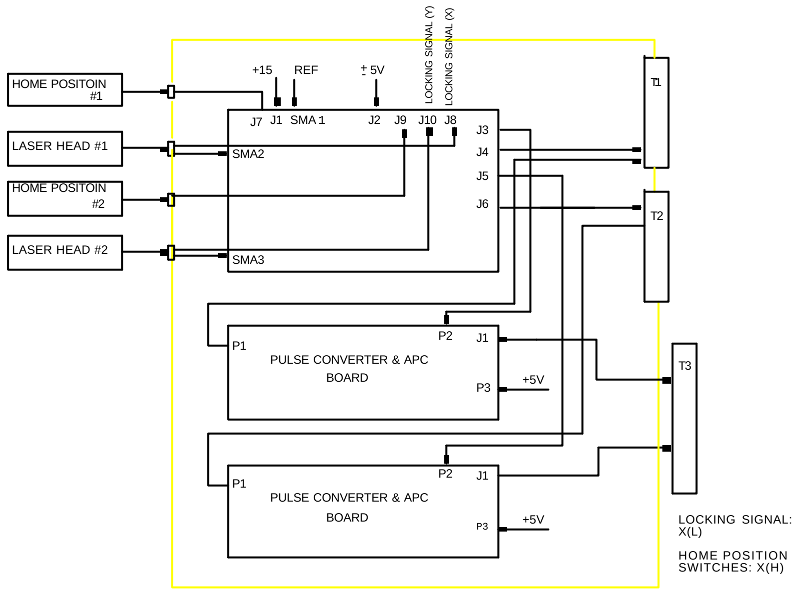
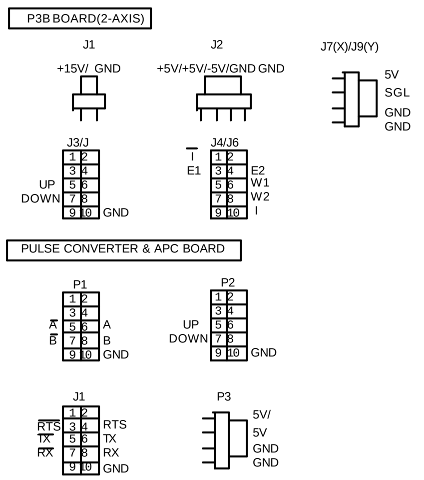
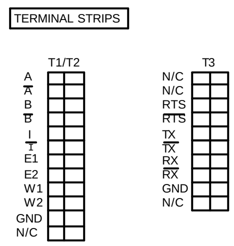


FIG.E-3a INTERCONNECTING WIRING DIAGRAM
WITH AC POWER FEED, ENCLOSURE AND ATC







CAUTION:

ANY WIRE CONNECTED TO THE TERMINAL STRIP SHOULD NOT HAVE ACTIVE VOLTAGE MORE THAN 5V.
IC MAY BE DAMAGED BY ESD.
TOUCHING THE CIRCUIT BOARD OR ANY OPEN TERMINAL.

NOTE:

ALL OUTPUT SIGNAL ARE TTL STANDARD EXCEPT E1/E2 AND W1/W2 WHICH ARE NORMALLY CLOSED. E1 AND W1 ARE COMMON.

FIG.E-3b 2-AXIS INTERCONNECTING WIRING DIAGRAM
WITH AC POWER FEED, ENCLOSURE AND ATC

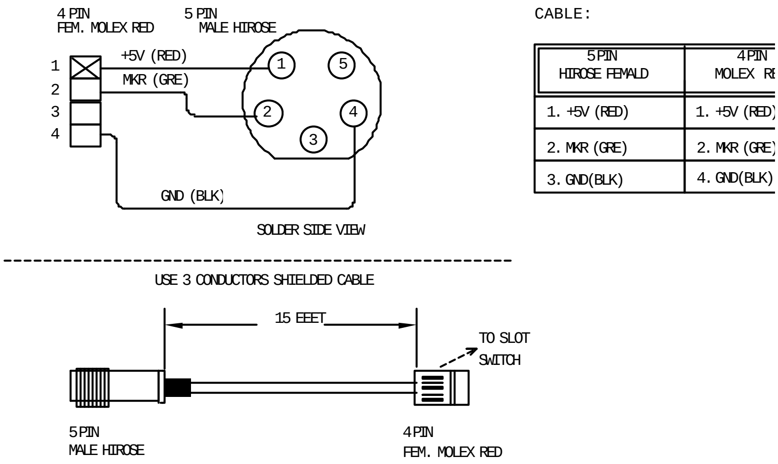
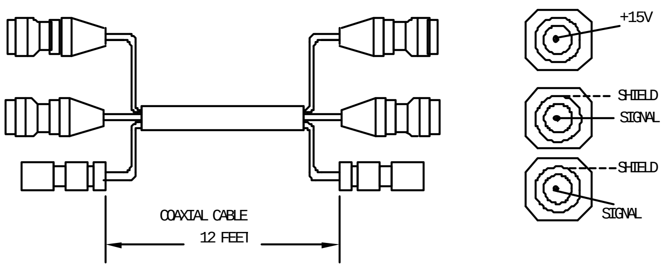
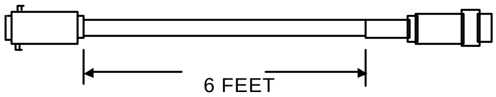


FIG. E-4 CABLE BETWEEN HOME POSITION SENSOR AND POWER FEED ENCLOSURE



NOTES:
P1 = NICKEL SMA MALE
P2 = GOLD SMA MALE
P3 = NICKEL SMB FEMALE

FIG. E-5 CABLE SET BETWEEN LASER HEAD AND PROCESSOR MODULE



USE 3 PAIRED, TWISTED, INDIVIDUALLY SHIELDED CABLE

DB9 MALE CONNECTOR	HIROSE 12 PLUG
1. GND	11. GND (ALL SHIELD)
2. SINE +	5. SINE + (RED)
3. SINE -	6. SINE - (BLK)
4. COS +	7. COS + (GRN)
5. COS -	8. COS - (BLK)
6. I -	10. I - (BLK)
7. I +	9. I + (WHT)

NOTE: PINS ARE NOT SHOWN, NOT CONNECTED

FIG. E-5a HIROSE TO DB SINE CABLE

Reference Mark, IHS

The reference mark is a electro-optic device used to determine home pos reference mark is provided with an IR light beam and a knife edge or razor-blac the razor-blade passes through the IR light beam, an output pulse is generated reference mark's receiver detects a drop in IR intensity by one-half. Repeatabi reference mark is better than 1 µm.

Divided by 8 Board, IPPD2 and Divided by 64 board, IPPD1

The standard increment of up/down pulses is 24.9 µin. For higher resolution c increments, a divided by 8 board and divided by 64 board are available. The d 8 board generates 8 additional output pulses based on the voltage of the anal signal. The divided by 8 board reduces the standard increment of 24.9 µin pe 3.11 µin per pulse. The maximum velocity is 10 ips. The maximum error is count. This error count is not accumulative and is corrected after each input pulse.

Similarly, the divided by 64 board will reduce the increment of each 24.9 µin width pulse to 0.39 µin. The maximum pulse rate for the divided by 64 board is 10 MHz or a maximum velocity of 3.9 ips.

Selectable Increment Board, IPC3

The selectable increment board is used to change the least input increment to a larger than the input increment. The selectable increment board can be used to cc least increment to an integer value, such as 25.00000 µin or 1 µm, or to compe temperature variations. The output increment divided by **F**, where **F** is a constant 0.000001 to 0.999999. The constant **F** is set by 22 jumpers (or 22-bit). Simply when the board is ordered, and Optodyne will set the board to the desired resolut factory. For different **F** values, call the Optodyne Service Department, and the 2 position settings will be supplied. Software may also be ordered ($50.00 per cop will aid in calculation of the jumper positions which correspond to the desired **F** val

The constant, **F** can also be controlled by an automatic pressure and tem compensation board.

Sinusoidal Output Board, IPPS

For controllers that require a sinusoidal feedback signal, a sinusoidal output boa can be purchased. Figure E-7 shows the signal voltage requirements, output frequ output period. Also shown is the reference or "Z-pulse" which is TTL compatible.

Automatic Pressure and Temperature Compensation, IPC4

The automatic pressure and temperature compensation consists of an air pressur an air temperature sensor, a material temperature sensor, and a CPU controlle The measured air pressure, air temperature and material temperature are calculate the compensation factor and convert to a 22-bit number to the s increment board (not included in the IPC4 package). The material thermal e coefficient in parts-per-million (ppm) per °C is loaded into the CPU through an RS by a notebook PC compatible computer. Software is provided to change the expansion coefficient which corresponds to the machines material composition. material sensor is available for the temperature and pressure compensation pa an option. Each automatic pressure and temperature compensation package ca up to 5 selectable incremental boards. The maximum cable length is 100 ft. F cable length' additional drivers are needed. Consult your authorized representative for details.

AUTOMATIC MATERIAL TEMPERATURE PULSE CONVERTER UTILITY SOFTWARE

Description

SAPCGP4C is a utility program that use to view and change the setting of material expansion factor (ppm°C) and base displacement per pulse (µinch/pulse

Installation and Operation

1. Connect an RS232 cable from the processor box to the computer. Make sure an APC cable is connected at all times.

2. At DOS prompt A> or C>, type SAPCGP4C * and press ENTER. It will prom you to select communication port. Press 1 for COM1 or 2 for COM2. The scre will be shown as follow :

OPTODYNE AUTOMATIC MATERIAL TEMPERATURE PULSE CONVERTER

PRESS NUMBER OF CHOICE

1. CHANGE EXPANSION FACTOR

2. CHANGE BASE DISPLACEMENT PER PULSE

3. CHECK SETTING

4. EXIT

LDDM SERIAL PORT

0000.000000 29.92 68

Displacement Pressure A. temperature

*** Make sure this software matches with your firmware. If not sure, check the Installation Instruction shipped with the hardware.**

Press 1 to change the material expansion factor in ppm°C (e.g. Aluminum =25ppm°C), (Manufacture default setting = 0 ppm°C) . Press ENTER after new value is selected.

Press 2 to change the base displacement per pulse.
(factor default setting = 25 µinch.)

Press 3 to view the setting.

Press 4 to exit.

The bottom left corner is LDDM serial reading coming from the processor box. After power on, the serial reading will show laser wavelength and signal intensity. Modes can be toggled pressing Y key. (Fig. E-6).

Press R to reset displacement.

Counter Board, ICB

The LDS can output displacement readings on a 10 digit LED display (D-101 Optodyne counter board. The counter board converts the up/down pulses an phase data to inches or mm, and gives a BCD output for the digital display.
The push-buttons on the display can be used to reset the inch or mm reading displacement units between inch and metric units, and select other functions su temperature, pressure, and material temperature(s) readouts.

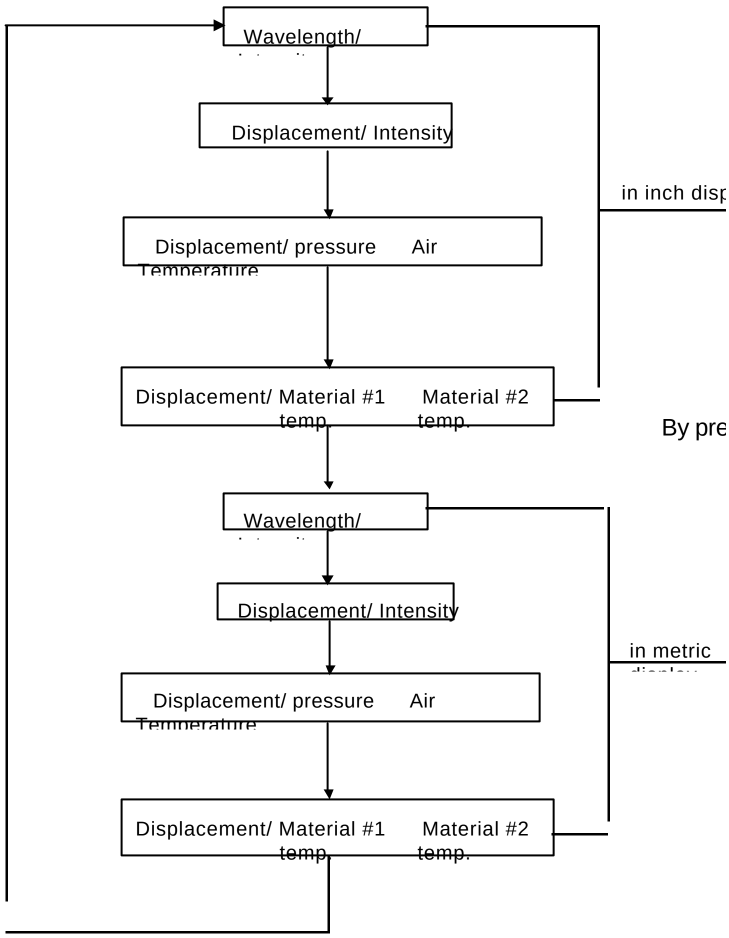
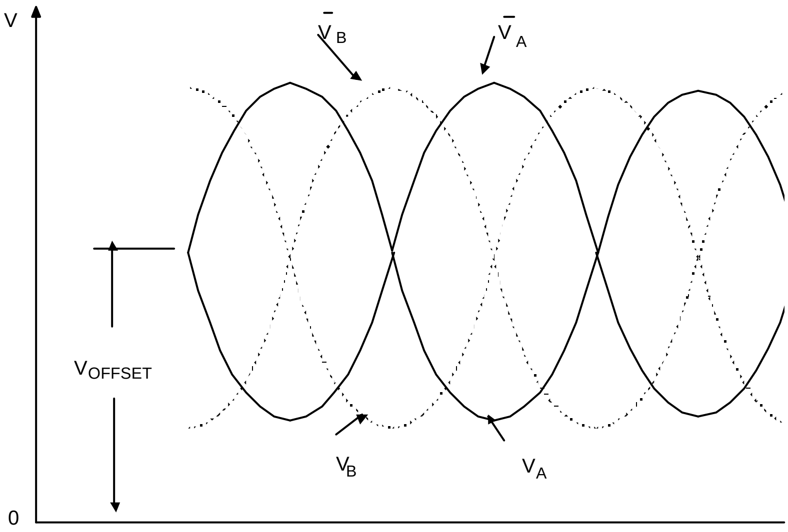


FIG. E-6 DISPLAY MODES BLOCK DIAGRAM

Sinusoidal signals



Amplitude: V_A-$\overline{V_A}$, 1V ± 0.2V
V_B-V_B, peak to peak

Offset: V_A, $\overline{V_A}$, V_B, $\overline{V_B}$, 2.5V± 0.2V
V_A-V_A, V_B-V_B, < 0.1V

Noise Level: 50 Mhz-100 Mhz, <30 mV
10 ns sppikes, < 0.2V

Output Frequency: 100 Khz

Output Period: 40.513167µm
(compatible to Fanuc's detector for linear motors)

Z-pulse (TTL)

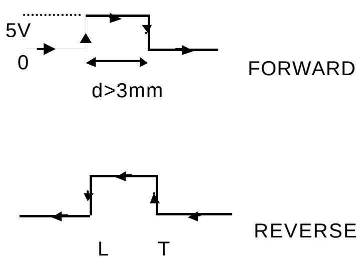


FIG. E-7 SINUSOIDAL OUTPUT SIGNAL

32-Bit Parallel Output Board (32BPO), p/n IPCAX

The Optodyne Model 32BPO PC Axis Board is a printed circuit board which one slot on a PC-compatible I/O bus. The board digitizes the output of an LDDM™ and outputs the target position in units of λ/512, or about 0.05 µin (1.2 position is maintained in a 32-bit counter which may be read over the PC b and/or output to the Position Error Connector on the top of the board (Fig. E-8).

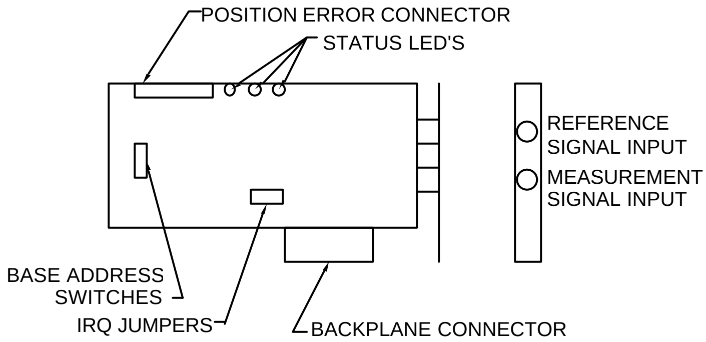


FIG. E-8 MODEL 32BPO PRINTED CIRCUIT BOARD

The Model 32BPO contains several command and status registers through operation may be controlled and interrogated. It is also capable of generating requests based on internal and external events.

The Model 32BPO provides an Offset Register which may be written by the register may be used to set the position counter to a predetermined value establish a reference for the position error output which then functions as the e input to an external servo loop.

The Optodyne Model 32BPO is designed for compatibility with the ISA speci making it suitable for use with almost all PC-compatible platforms.

The 32BPO employs 8-bit data transfers so that it may be used with XT-type AT-type computers. The board uses standard +5V, +12V and -12V power backplane.

The base address is &H210 with DIP switches 3 and 8 ON and the rest OFF. data consists of four 8-bit (1 byte) words. The addresses of these 4 bytes are:

b_0 = &H212

b_1 = &H612
b_2 = &HA12
b_3 = &HE12

A sample basic program is listed below.

```
CLS
begin:
OUT &AHA10, 1
'OUT &AHA10, 0
b0 = INP(&H212)
b1 = INP(&H612)
b2 = INP(&HA12)
b3 = INP(&HE12) AND &H7F
LOCATE 10, 10:  PRINT "Byte 0 = "; :  PRINT USING "###"; b0
LOCATE 12, 10:  PRINT "Byte 1 = "; :  PRINT USING "###"; b1
LOCATE 14, 10:  PRINT "Byte 2 = "; :  PRINT USING "###"; b2
LOCATE 16, 10:  PRINT "Byte 3 = "; :  PRINT USING "###"; b3
IF INKEY$ = CHR$(27) THEN END
GOTO begin
```

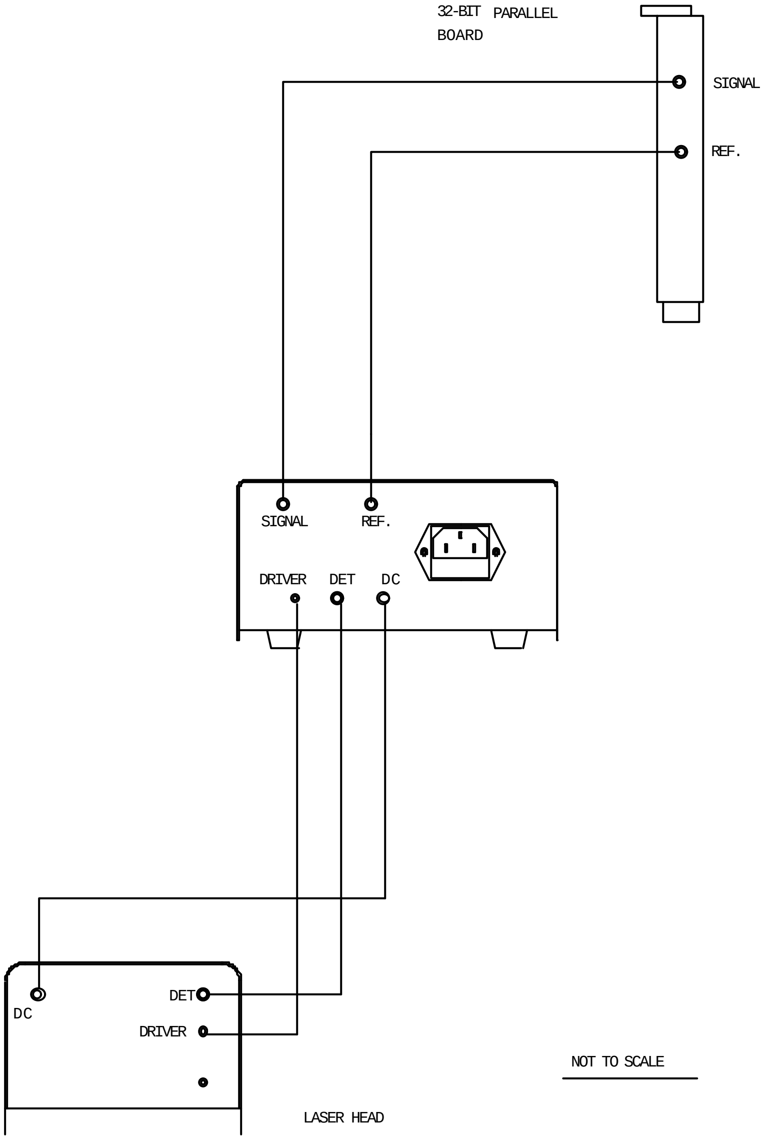


FIG. E-9 POWER SUPPLY AND DRIVER FOR THE 32-BIT

Position Error Connector Pinouts

Pin	Signal Name	Pin	Signal Name
1	(none)	33	GND
2	(none)	34	GND
3	FAULT/	35	GND
4	MEASUREMENT FAULT	36	REFERENCE FAULT
5	(none)	37	OVERFLOW
6	FORCE ZERO/	38	GND
7	POSITION RESET/	39	EXTERNAL SAMPLE/
8	OUTPUT ENABLE/	40	OUTPUT HOLD/
9	ERROR CLOCK	41	GND
10	(none)	42	GND
11	(none)	43	(none)
12	P1	44	P0
13	P3	45	P2
14	GND	46	P4
15	P6	47	P5
16	P8	48	P7
17	P10	49	P9
18	P12	50	P11
19	P13	51	GND
20	P15	52	P14
21	P17	53	P16
22	P19	54	P18
23	GND	55	P20
24	P22	56	P21
25	P24	57	P23
26	P26	58	P25
27	P28	59	P27
28	P29	60	GND
29	P31	61	P30
30	(none)	62	(none)
31	(none)	63	(none)
32	GND	64	GND

performance and to match replacement parts in order to achieve sy
performance per specification.