LAMBDA 10®-2

Optical Filter Changer
Control System

Operation Manual

Rev. 2.05b (20210209)

$\mathsf{C}\,\mathsf{E}$ EU Declaration of Conformity

Application of Council Directives:
2014/30/EU (EMC), 2014/35/EU (LVD), and 2015/863/EU (RoHS 3)

Manufacturer's Name: Sutter Instrument Company

Manufacturer's Address:
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Equipment Tested: **Lambda 10-2** Optical Filter Switching & Shutter Control System

Model(s): **LB10-2, LB10-2S**

Conforms to Standards:		
	EMC Emissions:	EN 61326-1:2013, including: EN 55011: 2009 Class B; EN 50082-1:1992; EN 61000-3-2:2015, & EN 61000-3-3:2014
	EMC Immunity:	EN 61000-4-2:2009, EN 61000-4-3:2011, EN 61000-4-4:2012, EN 61000-4-5:2014, EN 61000-4-6:2014, EN 61000-4-8:2010, & EN 61000-4-11:2004
	LVD (Safety):	EN 61010-1:2010

Tested/Verified By:
C & C Laboratory
49000 Milmont Dr.
Freemont, CA 94538

Sutter Instrument

Sutter Instrument Company hereby declares that the equipment specified above was tested and conforms to the EU Directives and Standards listed above, and further certifies conformation to the requirements of the European Union's Restriction on Hazardous Substances in Electronic Equipment Directive 2015/863 (2011/65/EU Annex II) for RoHS 3.

Project Engineer: Mark Flaming
                                          President

DISCLAIMER

The **LAMBDA 10-2** Optical Filter Changer system is designed for the specific use of changing filters into and out of an optical pathway and no other use is recommended.

This instrument is designed for use in a laboratory environment. It is not intended for use, nor should it be used, in human experimentation or applied to humans in any way. This is not a medical device.

Do not open or attempt to repair the instrument. Extreme heat and high voltages are present and could cause injury.

Do not allow unauthorized and/or untrained operative to use this device.

Any misuse will be the sole responsibility of the user/owner and Sutter Instrument Company assumes no implied or inferred liability for direct or consequential damages from this instrument if it is operated or used in any way other than for which it is designed.

SAFETY WARNINGS AND PRECAUTIONS

Electrical

- Operate the Lambda 10-2 using 110-120 V AC, 60 Hz, or 220-240 V AC., 50 Hz line voltage. This instrument is designed for connection to a standard laboratory power outlet (Overvoltage Category II), and because it is a microprocessor--controlled device, it should be accorded the same system wiring precautions as any 'computer type' system. A surge protector and power regulator are recommended.

- ⚠️ Fuse Replacement: Replace only with the same type and rating:

Voltage Setting	Fuse: (Time Delay, 5mm x 20mm, glass tube)	
	Type and Rating	Manufacturer Examples
110V	1.5A, 250V	Bussmann GMC-1.5A or GMC-1.5-R (RoHS)
220V	T0.63A, 250V	Bussmann GDC-630mA or S506-630-R (RoHS); or Littelfuse: 218.630 or 218.063P (RoHS)

A spare fuse is located in the power input module. Please refer to the fuse-replacement appendix for more details on fuse ratings and for instructions on how to change the fuse.

Avoiding Electrical Shock and Fire-related Injury

- ⚠️ Always use the grounded power supply cord set provided to connect the system to a grounded outlet (3-prong). This is required to protect you from injury in the event that an electrical hazard occurs.

- Do not disassemble the system. Refer servicing to qualified personnel.

- ⚠️ To prevent fire or shock hazard do not expose the unit to rain or moisture.

Optical Radiation

This system is designed for use in conjunction with high-intensity light sources. Failure to comply with any of the following precautions may result in injury to the users of this device as well as those working in the general area near the device.

- ⚠ Never look into the optical pathway of the high intensity light sources typically used with this instrument. Doing so can cause permanent eye damage.

- ⚠ The high-intensity light sources typically used with this instrument also produce a significant amount of heat. Direct contact with the housing of those instruments can cause serious burns.

Electromagnetic Interference

To comply with FDA and CE electromagnetic immunity and interference standards; and to reduce the electromagnetic coupling between this and other equipment in your lab always use the type and length of interconnect cables provided with the unit for the interconnection of one or more filter wheels and/or shutters, host computer via serial RS-232 or parallel interface, or other equipment via TTL connections (see the TECHNICAL SPECIFICATIONS appendix for more details).

Operational

Failure to comply with any of the following precautions may damage this device.

- This instrument is designed for operation in a laboratory environment (Pollution Degree I).

- This unit is not designed for operation at altitudes above 2000 meters nor was it tested for safety above 2000 meters.

- ⚠ DO NOT CONNECT OR DISCONNECT THE CABLES BETWEEN THE CONTROLLER AND THE MECHANICAL UNITS (FILTER WHEELS AND/OR SHUTTERS) WHILE POWER IS ON.

  Please allow at least 20 seconds after turning the unit off before disconnecting the mechanical units. Failure to do this may result in damage to the electronics.

- ⚠ Operate only in a location where there is a free flow of fresh air on all sides. NEVER ALLOW THE FREE FLOW OF AIR TO BE RESTRICTED.

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1. GENERAL

1.1 Introduction

The Lambda 10-2 is an optical filter wheel system designed for rapid change of wavelength and comprises two subsystems: A controller and one or two filter wheels, each with or without a shutter, that are to be placed in the optical pathway of your existing experimental setup. Next is a description on how this manual is organized and the manner in which its use is intended, followed by a general and functional description of the system.

1.1.1 How to Use this Manual

This manual is organized in a manner that is best suited for the typical manner in which the reader would learn about the system, and then install, operate, and maintain it. Prior to the table of contents of this manual is a disclaimer and a series of cautionary and warning notes that should be read first. This first chapter provides an overall description of the system, leaving more in-depth technical information towards the end of the chapter. The next chapter describes how to install the system, followed by one or more chapters that provide operation instructions, and ending with a chapter on maintenance. Following the final chapter are several appendices that provide supplemental information. The installation chapter covers everything related to installation, from unpacking the equipment as received, through to ensuring that everything is correctly installed and is operating correctly. The operation chapters cover the two basic types of user interaction with the system: Manual (local) control and external computer control. Please take the time to read these instructions to assure the safe and proper use of this instrument.

1.1.2 Technical Support

Unlimited technical support is provided by Sutter Instrument Company at no charge to our customers. Our technical support staff is available between the hours of 8:00 AM and 5:00 PM (Pacific Time) at **(415) 883-0128**. You may also E-mail your queries to info@sutter.com.

1.2 General Description

The **LAMBDA 10-2** is a microprocessor controlled, high-speed optical filter wheel designed for microscopy and other applications, which require rapid and accurate wavelength switching. The **LAMBDA 10-2** supersedes the previous Lambda 10 filter wheel controller providing enhanced capability while retaining the same outstanding mechanical performance. The Lambda 10-2 controller can control up to two filter wheels and two high-speed shutters, and provides for both manual (local) control as well as external computer control (via either of the provided serial (RS-232) or parallel interfaces).

The controller system is designed around three embedded microcontrollers: one slave for each wheel and a master for control and communication. The electronics for two wheels and two shutters are already installed, even if you only ordered a single wheel system. If you add a second wheel or shutter later, there will be no additional electronics to buy. The embedded microcontrollers automatically determine the number of filter wheels that are installed, so there are no jumpers or switches to set.

The controller can run a single wheel and shutter under remote control through a parallel input using the same simple protocol as the original Lambda 10 controller. New commands have been added so that the 8-bit parallel input can efficiently control two wheels and two shutters without using any additional lines. The serial input uses the same command set as the parallel port, and provides full control of two wheels and two shutters. Either use the DB-25 cable provided to connect to the parallel port or the DB-9 cable provided to connect to the serial port.

The following instructions are meant to help you set up the Lambda 10-2 and become familiar with the manual mode of filter selection. Further details on controller functionality, filter installation, and remote communications can be found in other sections of this manual.

1.2.1 Systems

LB10-2: Includes one 25mm filter wheel without shutter, support base with mounting rods, rack mount[1] controller unit with wheel drive cable, parallel and serial interface cables for connection to PC, two drop-in filter holders, spanner wrench, 10 blanking discs, power cord, and manual.

LB10-2S: Same as above—with a Uniblitz®[2] shutter assembly and two slide-in filter holders.

LB10-232: Same as LB10-2 except with 32mm, T-mount threaded filter wheel (no drop-in filters) and modified 10-2 controller.

LB10-232S: Same as LB10-232 except with a Uniblitz® shutter (no drop-in or slide-in filters) and modified 10-2 controller.

LB10-250: Same as LB10-2 except with 50mm, 5 position wheel.

1.2.2 Filter Wheels and Shutters

When a Lambda 10-2 Filter Wheel system is purchased, its configuration may include one to two filter wheels, each one with or without a shutter. If the Lambda 10-2 system is purchased with only one 10-position 25mm (1-inch) filter wheel, you may wish to add a second filter wheel of the same type later, in which case the second filter wheel can be added without modification. A 10-position 32mm and a 5-position 50mm filter wheel are also available for use with the Lambda 10-2 controller. Each port of the controller to which a 32mm or 50mm filter wheel is to be connected, however, must be modified by Sutter Instrument Co. before said filter wheel can be connected. **Note that you must only use filter wheels manufactured by Sutter Instrument.**

The basic components of the filter wheel mechanical assembly are shown below in Figure 1-1 and Figure 1-2. The only components that are to be removed by the user are the drop-in or slide in filter holders and the plug in the loading port. At no time should the user remove the cover plate from the wheel housing.

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[1] Tabletop controller box is available upon request.

[2] Uniblitz® is a registered trademark of Vincent Associates.
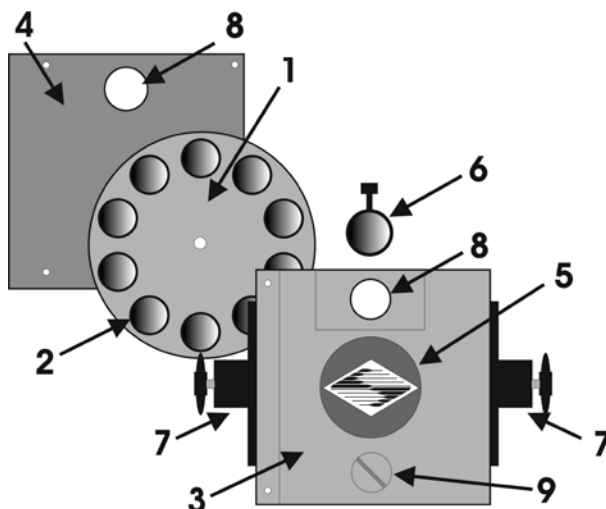
Figure 1-1. Lambda 10-2 Filter Wheel (without shutter)
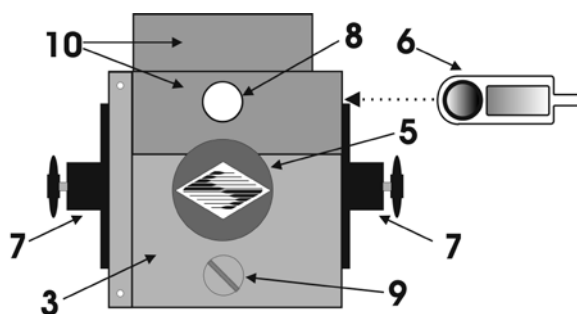
Figure 1-2. Lambda 10-2 filter wheel housing (with shutter)

1. 10-position wheel (removed from motor hub
2. Installed filter cup
3. Wheel housing
4. Cover plate (removed from wheel housing
5. Stepper motor
6. Drop-in filter holder (Figure 1-1) or slide-in filter holder (Figure 1-2)
7. Mounting ears
8. Optical port
9. Loading port (plug installed)
10. Shutter housing

All filter wheel options are listed in the Sutter Instrument catalogue and in the following list.

- **10-position, 25mm filter wheels:**
  LB10-NW (without shutter)
  LB10-NWS (with shutter)

    LB10-NWE (without shutter and set up for emission)

    LB10-WD (two wheels mounted back to back, without shutter)

    LB10-WDS (two wheels mounted back to back, with one shutter and one slide-in filter holder)

- **10-position 32mm filter wheels:**

    LB10-W32 (without shutter)

    LB10-W32S (with shutter)

- **5-position 50mm filter wheel:**

    LB10-W50 (without shutter).

NOTE: All shutters mentioned in this manual for use with the Lambda 10-2 are Uniblitz®[3] shutters.

1.2.3 Filters

The Lambda 10-2 filter changer is designed for use with any 1-inch or 25-mm filter with a thickness that does not exceed the following dimensions:

- **4.5 mm (0.18 in.) for Slide-in filter holders**
- **5.38 mm (0.21 in.) for Drop-in filter holders**
- **9 mm (0.35 in.) for filter cups**

Filter wheels designed for use with 32 mm filters will accept filters with a thickness that does not exceed the following dimensions:

- **9 mm (0.35 in.) for filter cups**

Instructions for installing filters into the filter wheel can be found in the FILTER WHEEL chapter of this manual. **Filters are not supplied by Sutter Instrument. However, filters conforming to the above specifications can be purchased from any filter manufacturer.**

1.2.4 Slide-In and Drop-In Filter Holders

Many users like to have extra Slide-in or Drop-in filter holders for more convenient replacement of these "fixed" filters. **Only use filter holders made by Sutter Instrument Company in the Lambda 10-2 Filter Wheel.** Extra filter holders are readily available from Sutter Instrument Company or their distributors and are listed as "SLIDE-IN" and "DROP-IN" in the Sutter catalogue. At this point, there are no slide-in filter holders for 32 mm systems, although a 32-mm Drop-in filter holder is available. In addition, there is a fixed filter position for a heat-blocking filter in most 32-mm microscope adapters offered by Sutter Instrument Company. Slide-in and drop-in filter holders are not available for the 50 mm filter wheels.

1.2.5 Shutters

If you purchase a Lambda 10-2 Filter Wheel system without a shutter and later decide to add one to the system, the Filter Wheel must be returned to the factory for the upgrade. The Lambda 10-2 Filter Wheel controller can support a retrofit shutter without modification.

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[3] Uniblitz® is a registered trademark of Vincent Associates.

However, **you must only use shutters installed by Sutter Instrument.** This upgrade is available only at Sutter Instrument's factory (or through their distributors) and is listed as "SHUTTER" in the Sutter catalogue (or "WHEEL" in older catalogues).

1.2.6 Adapters

Most microscopes, cameras, light sources and other optical instruments to which the Lambda 10-2 may be interfaced will require some sort of adapter to link the devices. Adapters for interfacing the filter wheel to most instruments are available from Sutter Instrument or can be custom built by Sutter Instrument. **Suitable adapters are available from other sources, as well, but Sutter Instrument assumes no responsibility for the performance, suitability and safety of adapters built by the user or other manufacturers.**

1.2.7 Other and Optional Accessories

1.2.7.1 Liquid Light Guide (LLG)

A 2-meter, 3mm diameter liquid light guide is optionally available from Sutter Instrument (P/N: LLG). The LLG includes a C-mount, lens, and lens tube.

1.3 Functional Description

1.3.1 Stepping Motor Operation

Stepping motors are not as familiar to most people as the common DC motor, but there are some similarities. The DC motor consists of an armature, an electromagnet mounted on a rotating shaft, which is located inside a permanent magnet. Current is supplied to the electromagnet through brushes that rub on contacts on the armature. When the electromagnet is energized, the armature rotates to align the poles of the electromagnet with the opposite poles of the permanent magnet. Of course, before this can occur, the rotation of the armature changes the contact plates rubbing on the brushes so that the current is reversed. This causes the poles of the electromagnet to reverse, establishing a force for continued rotation. This switching action is called commutation.

In stepping motors, the rotating element, called a rotor, is generally a permanent magnet while the fixed element, the stator, is the electromagnet. The key difference between stepping motors and DC motors, however, is the method of commutation. The DC motor commutates automatically as it rotates. Thus, the timing of the commutation is determined by the speed of rotation, which may vary with the load or applied power. The commutation of the stepping motor is set by external electronics, forcing the motor to rotate at a predetermined rate. If the load is such that the motor does not have the force to produce the correct rate of rotation, the rotation will become erratic and may even reverse.

The force exerted between two magnet poles is proportional to the square of the distance between the poles. A motor with a single electromagnet and only two poles would exhibit considerable loss of power when the distance between the poles of the permanent magnet and the electromagnet was greatest. It is understandable that, in most practical DC motors, the armature has more than two poles. This allows the commutation to occur over a smaller angle of rotation, so that the active poles can always be relatively close to the poles of the permanent magnet.

Stepping motors are also made with multiple poles on both the rotor and stator the exact arrangement determines the number of steps per revolution. The motor used in the Lambda 10-2 has 200 steps per revolution (1.8 degrees per step). There are usually two windings in the stator, and a single step of rotation is produced by reversing the current on one of the windings. Reversing the current on the second winding will then produce another step. If the first winding is then reversed again, returning to its original value, a third step will result. Finally, reversing the second winding, so that both windings are back to their original state, will produce a fourth step. This pattern may then be repeated to continue rotation in the same direction. Reversing the sequence produces steps of rotation in the opposite direction.

The rate and distance of rotation is determined by the rate and number of commutation steps. As long as the current is held constant in both windings, the rotor will not rotate. This makes the stepping motor ideal for producing fast start and stop movements. Some limitations should be considered. Given that there are only 4 states of the control electronics (2 polarities for each of the 2 windings) but 200 steps per revolution, it follows that, for each of these four states, there are 50 possible rotary positions. In order to establish the absolute position an external sensor must be added. Absolute position only needs to be determined once so long as the subsequent moves occur without errors.

Correct operation of stepping motors, which is outlined above, is not always obtained. If the motor lacks the torque to accelerate and decelerate the load at the rate indicated by the control electronics, the resulting move may differ from that commanded by the control electronics. For instance, if enough external force is applied, the motor shaft may be rotated even though the command signal has not changed. For small rotations (less than 3.6 degrees), the motor shaft will return to the correct position if the force is removed. For larger rotations, the shaft will stop at the nearest of the 50 correct positions for that command signal when the external force is removed.

2. INSTALLATION

2.1 Unpacking

The Lambda 10-2 and associated hardware comes packed in a single carton. The following is a list of the components found there. If two wheels were ordered, two of everything should have been received (except those items marked with an asterisk (*)). If you believe that any of these components are missing or show obvious signs of damage from shipping, please contact the factory.

- 1 or 2 Filter Wheels, each a 10 position 25 or 32 mm, or 5-position 50 mm, and each with or without a shutter (25 or 35 mm
- Lambda 10-2 Controller*
- Support Base per filter wheel
- 2 Support Rods per filter wheel
- 2 Base Clamps per filter wheel
- Filter Wheel to Controller Connecting Cable (1 per filter wheel)
- Parallel Interface Cable*
- Serial Interface Cable*
- Power Cord*
- 2 Individual Filter Holders (per filter wheel)
- Retaining Ring Driver*
- Manual*
- Microscope Adapters (if ordered)

Each 10-position filter wheel is shipped with nine positions of the wheel containing retaining rings, spacer rings and blanking discs. One of the individual filter holders contains the same three components. The second individual filter holder and one position of the wheel (position #1) contain only retainers and spacers.

The Lambda 10-2 is shipped to you in a prefabricated foam mold. Please take note of this method of packaging. Should it ever be necessary to ship the puller to another location, the same method of packaging should be employed. Additional packing material may be purchased from Sutter Instruments.

IMPORTANT: Improper packaging is a form of abuse and, as such, can be responsible for voiding the warranty where shipping damage is sustained because of such packing.

2.2 Pre-installation Considerations

2.2.1 Vibrations

The Lambda 10-2 filter wheel system was designed to produce fast filter changes with a minimum of vibration. The microprocessor controls the trajectory of each move using microsteps with programmed acceleration and deceleration profiles. The result is a system so smooth that customers using the Lambda 10 for the first time have called to report that their wheel isn't turning simply because they could not hear or feel anything.

Although the Lambda 10-2 is smooth and quiet, even the slightest vibration can produce problems for the electrophysiologist. Vibration can come from several sources. The most pronounced effects normally come from the high-speed shutter, if that option has been included. The shutter produces a very sharp impulse which is best avoided by finding another way of turning the light on and off such as turning to a blanked filter position.

When the motor accelerates and decelerates the filter wheel rapidly, the torque applied tends to turn the motor and the Lambda housing in the opposite direction. If the housing is not firmly attached, this may appear as vibration that increases with the selected speed and the weight of filters loaded. This is not usually a problem if the wheel is firmly mounted to a good solid surface.

Stepping motor-based systems can produce considerable vibration and noise if the rate at which steps are taken excites a system resonance. This problem is greatly reduced by reducing the step size with microstepping, as in the Lambda 10-2. Even when microstepping is used, it is possible to produce vibration by selecting a speed that is not optimal or by starting a new move within a few milliseconds of the end of the previous move. For example, with only two typical filters loaded speed 1 should give a very smooth move that stops with little vibration. Speed 2, 3, and 7 may all produce more vibration at the end of a move with this load even though they are slower speeds.

At a minimum, we recommend that the Lambda 10-2 should be firmly mounted to a solid surface by the support stand, which is included with each unit. Do not depend on the optical coupling between the microscope and the Lambda 10 to support and stabilize the Lambda 10. This configuration will be adequate in many cases. If there is still too much vibration, the wheel may be mounted using the support stand, but with an air gap between the Lambda 10 and the microscope.

The best cure for vibration is isolation. One simple approach is to mount the filter wheel to a wall or a separate table. If the microscope is on an air table, be aware that the microscope might drift relative to a filter wheel mounted on a separate, stable surface. In such cases, it may be better to couple the Lambda 10 to the microscope with a flexible light guide. Contact Sutter Instrument for detail of our light-guide adapter system.

2.3 Installing the Controller

2.3.1 Line Power (Mains)

The power cord provided with the Lambda 10-2 connects to the Power Entry Module located on the back of the unit (see Figure 2-1). This Module also includes the Line Fuse and Voltage Selector Switch.
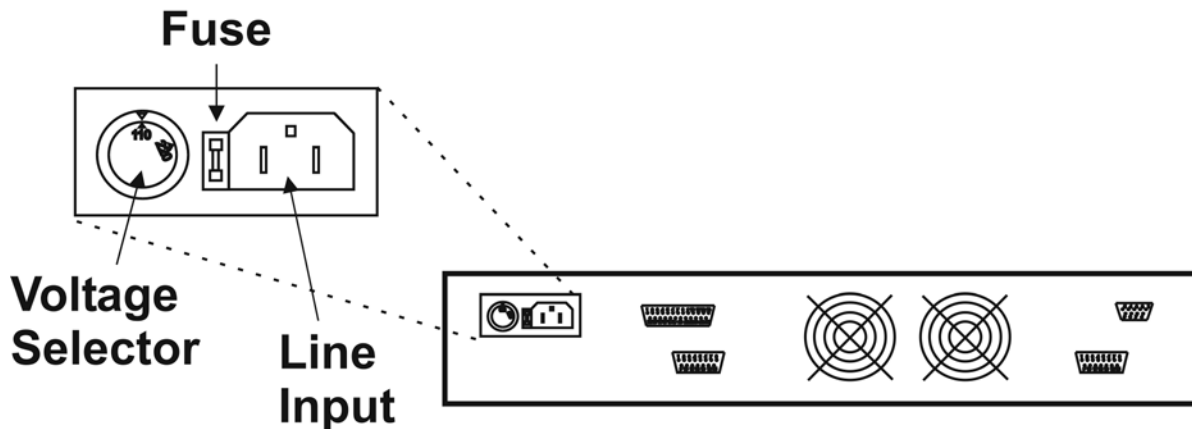
Figure 2-1. Lambda 10-2 Cabinet (rear view).

Confirm that the Voltage Selector Switch on the Power Entry Module is set to the proper value (110V a.c. or 220V a.c.). If it is not, turn the selector switch until the appropriate value is lined up with the indicator. You must also replace the fuse with the appropriate value (see the Technical Specifications), otherwise your protection from fire and electric shock may be compromised.

Make certain that the ON/OFF Switch located on the front panel of the Lambda 10-2 cabinet is turned OFF.
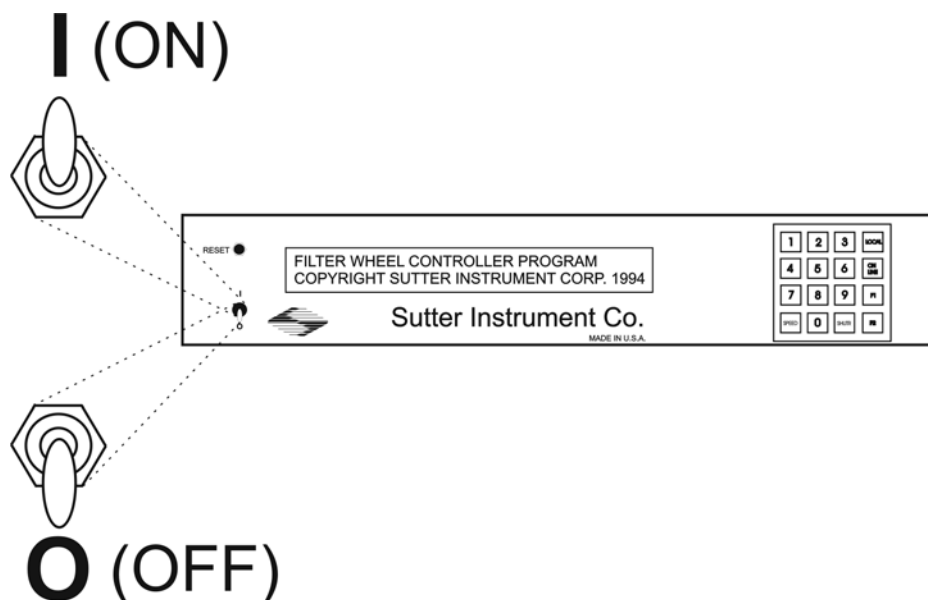
Figure 2-2. Lambda 10-2 Cabinet (front view)

Plug the power cord provided with the Lambda 10-2 into the Line Input socket on the Power Entry Module and then to a power source of the appropriate voltage and frequency.
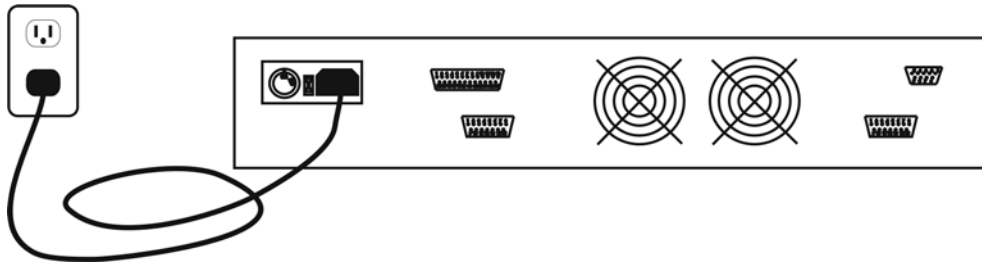
Figure 2-3. Power connection

2.4 Installing the Filter Wheel

If you have not yet mounted the filter wheel on the support hardware, please refer to the FIRST TIME USE chapter of this manual for instructions. Now move the mounted filter wheel to the approximate final location and adjust the filter wheel to the desired height. The filter wheel can be mounted on the posts in either orientation (optical port up or down), as required. The filter wheel can now be interfaced with other instruments (e.g. a microscope and a light source) using an appropriate adapter (Figure 2-4). If you need to purchase an adapter or require a custom adapter for your experimental setup, please contact the Technical Support staff at Sutter Instrument Company by phone (415 883-0128) or by E-mail (info@sutter.com).
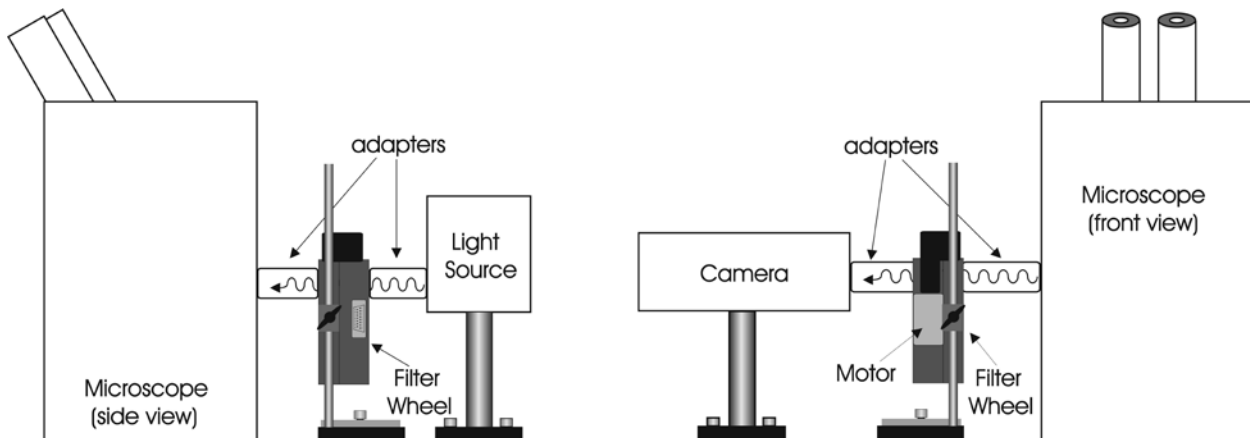
Figure 2-4. Schematic diagram of two possible experimental configurations

The optical ports in the filter wheel housing and cover plate are threaded 1-32 (standard C-mount) allowing direct connection of like-threaded devices (camera adapters, microscope adapters, etc.)

⚠️ *CAUTION: Care should be taken that any devices threaded into the ports <u>not</u> project more than 0.180 inches into the port. Allowing threaded devices to penetrate further could result in damage to the filter wheel or filter cups.*

Once the filter wheel has been attached to the other instrument(s), tighten the wing screws to lock the filter wheel at its final height. It is intended that the filter wheel be supported on the two posts included with your system. These posts can be screwed into the base provided or into any surface with ¼"-20 holes drilled on 6" centers at an appropriate position on the

tabletop or optical bench. When using the support rod base always secure it to the tabletop using the toe clamps provided with the system.

If a heavy light source is to be used (such as a vapor lamp with integral igniter) it should have its own separate support system.

If your filter wheel has a shutter, the side of the filter wheel on which the shutter is installed (the "motor side" as shown in Figure 2-4) would typically be mounted toward the light source. Placing the shutter between the lamp and filters limits the amount of heat and light to which the filters are exposed and increases the filters' useful lifetime.

2.4.1 Filter Wheel Assembly Set Up

1. Assemble the two Support Rods to the Support Base. Flats have been machined near the threaded end of these rods to facilitate tightening with a wrench. The pair of support base clamps should be used to anchor the base to some convenient location for testing. These clamps are designed to allow anchoring to any of the popular hole-patterns found in optical benches.

2. Slide the filter wheel down onto the support rods and lock it at a convenient height using the wing screws on the mounting ears of the filter wheel.
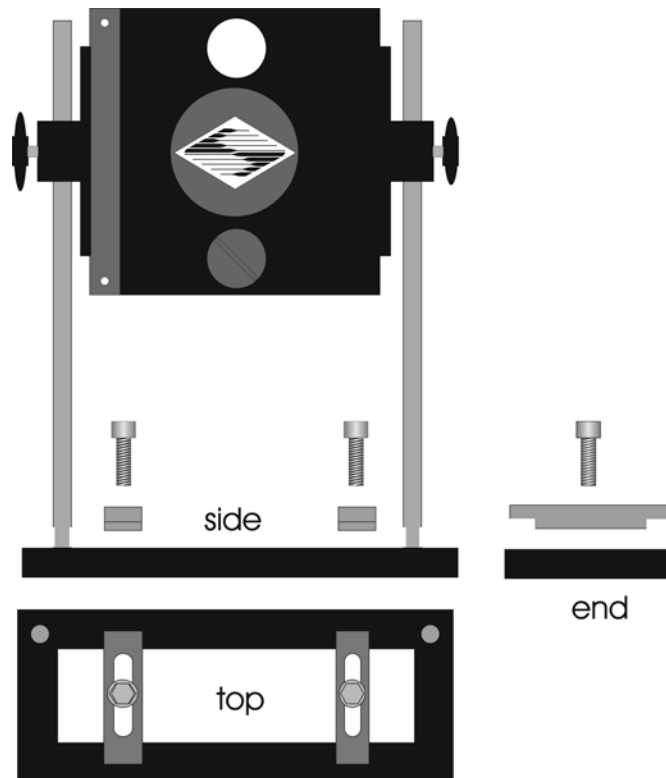
Figure 2-5. Filter wheel mounting stand

3. Connect the controller and filter wheel(s) with the appropriate cable(s) provided. It is important that the screws anchoring the cable ends be tight to ensure a good connection for the motor power leads and positioning signals.
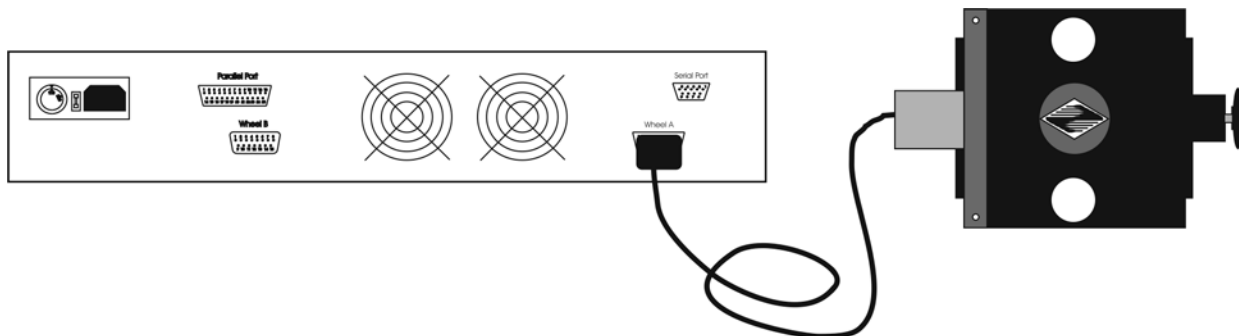
Figure 2-6. Filter wheel connection

⚠️ CAUTION: DO NOT CONNECT OR DISCONNECT THE CABLES BETWEEN THE CONTROLLER AND THE MECHANICAL UNITS (FILTER WHEELS AND/OR SHUTTERS) WHILE POWER IS ON.

Please allow at least 20 seconds after turning the unit off before disconnecting the mechanical units. Failure to do this may result in damage to the electronics.

2.5 First Time Use

Make certain that the Lambda 10-2 controller is properly connected to the mains power (refer to Section 2.3.1 and to Figure 2-1 and Figure 2-2).

2.5.1 Make It Go

1. Turn on the power using the ON/OFF switch on the front panel of the Lambda 10-2 controller cabinet (see Figure 2-2). The controller will briefly display an initialization screen and the filter wheel will automatically go to the "Home" (0) filter position. The current filter position will appear on the controller front panel display.

Filter position currently selected on Filter Wheel A

```
FILTER-A # 0 SP. 2  B NOT CONNECTED
PARALLEL          SHUTTER  A-OFF   B-OFF
```

Figure 2-7. Initialization screen.

2. The Lambda 10-2 will initially be set to respond to the parallel port as its input source. To manually select a filter you must first press the LOCAL key on the keypad. The display will now indicate that the MANUAL (keypad) input source is active.

```
FILTER-A # 0 SP. 2   B NOT CONNECTED
MANUAL-A              SHUTTER  A-OFF    B-OFF
```

**Input source currently
selected (MANUAL=keypad)**
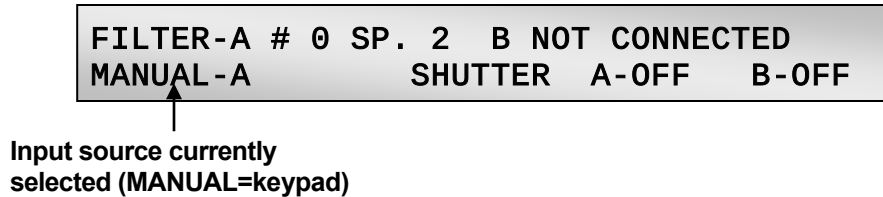
Figure 2-8. Initialization screen in local mode.

3. Press any numeric key on the keypad to manually select the corresponding filter position.

4. To select the filter wheel speed press the SPEED key on the keypad. The display will prompt you through the SPEED change routine. The smaller the number you enter (0 to 7), the faster the filter wheel will move. The default SPEED setting upon startup is 2.

5. If a shutter is installed, press the SHUTR key on the keypad to toggle the shutter open and closed. See the MANUAL CONTROL chapter for a more detailed description of shutter operation.

Now that you have completed this FIRST TIME USE section of this manual, you should be familiar with the basic components and the MANUAL operation of the Lambda 10-2. To get set up for an experimental application you will need to:

■   Install the desired filters into the FILTER WHEEL.
■   Install the filter wheel into the optical pathway using the appropriate adapter.
■   Establish the desired INTERFACE between the Lambda 10-2 and your computer.

Each of these steps is discussed in the following sections of the manual.

2.6 Loading Filters

2.6.1 Filter Orientation

The two sides of a filter are usually not identical due to differences in their surface coatings. Some form of labeling will be present to differentiate the two sides if this is the case. It is important to refer to the filter manufacturer's documentation to interpret the labeling and determine the proper orientation relative to the light source.

2.6.2 Filter Cups and Filter Holders

At each filter position on the filter wheel, is a filter cup assembly to hold one 1" filter. The Lambda 10-2 also comes with two removable 1" filter holders that can be placed into the optical pathway to accommodate "fixed" filters, such as neutral density filters. The filter holders will be either a "drop in" style if no shutter is installed (item 6 in Figure 1-1) or a "slide in" style if a shutter is installed (item 6 in Figure 1-2).

There are at least two components installed into each filter cup or holder before the Lambda 10-2 is shipped: a threaded retaining ring to secure the filter into the cup (or holder), and a spacer ring. In all but one of the filter cups, and in one of the filter holders, there will also be a blanking disc. Figure 2-9 depicts these items using the drop-in filter holder as an example.
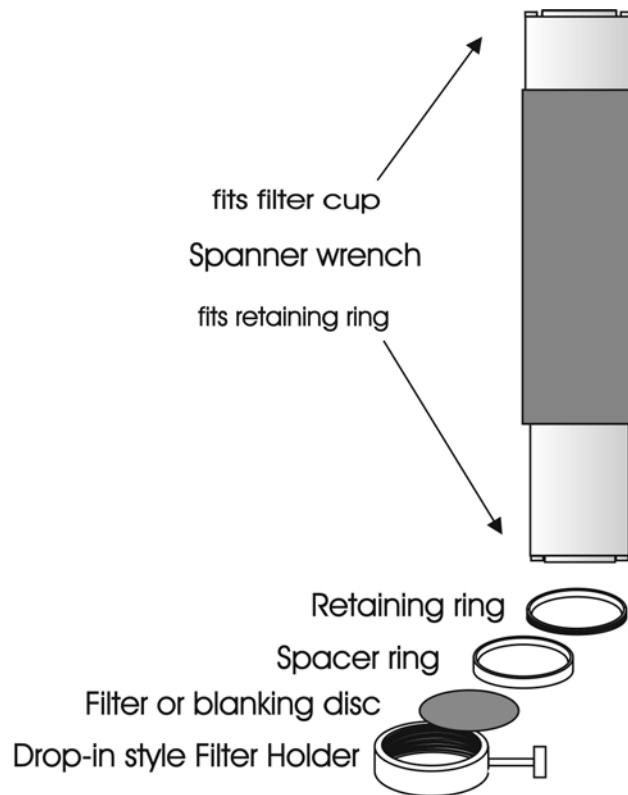
Figure 2-9. Filter holder components

- **Retaining Ring.** This ring is threaded on its outside surface and has two slots on its top edge. It is intended that the two slots be used for the removal and installation of the retaining ring when using the spanner wrench that is provided with the Lambda 10-2 (shown in Figure 2-9). Note how the design of the spanner wrench differs between 25, 32, and 50 mm filter sizes.
- **Spacer Ring.** This ring is unthreaded and serves to evenly carry the force of the retaining ring to the bottom of the filter cup or holder. It is recommended that the spacer be used anytime a blanking disc is installed or the filter cup or holder is. The spacer ring should also be used whenever the thickness of an installed filter allows its use. Maximum filter thicknesses for the filter cup and holders are specified below in Table 2-1.
- **Blanking Disc.** In all but one of the filter cups (and one of the filter holders), there will also be a blanking disc. These are meant to prevent transmission of the high intensity light to the microscope through unused filter positions. This is primarily a safety feature, which reduces the probability that the operator will look into the optical pathway when dangerous, high intensity, unfiltered light is present and magnified. A blanking disc in a filter cup can also function as a shutter in an experimental protocol.

Table 2-1. Maximum allowable filter thickness.

	With Spacer		Without Spacer	
	(Millimeters)	(Inches)	(Millimeters)	(Inches)
Slide-in holder	1.38	0.054	4.56	0.18
Drop-in holder	2.2	0.086	5.38	0.212
Filter cup	5.89	0.2315	9.07	0.3575

2.6.3 Installation of Filters into Filter Holders

Installation of filters into the filter holders requires care and patience to avoid damaging the threads as well as the filters. The following procedures describe this process and should be practiced with a drop-in (or slide-in) filter holder before attempting to load filters into the filter cups.
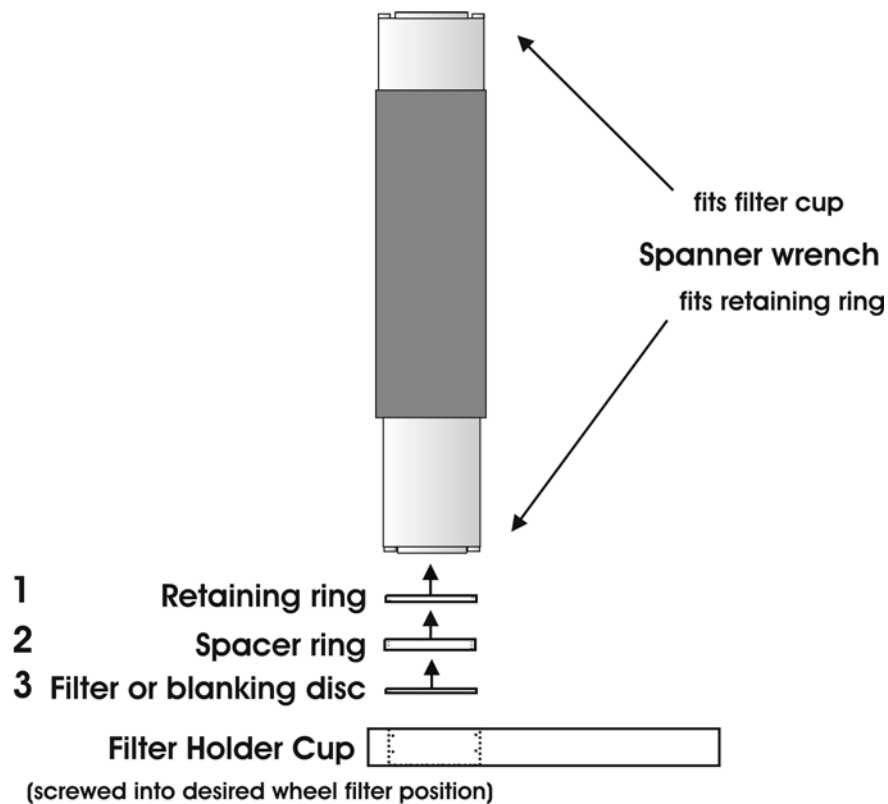
Figure 2-10. Removing the retaining ring

The threaded retaining ring has two notches cut into it, 180 degrees apart. Place the teeth (for 25mm; Figure 2-10) or notches (32 or 50 mm) of the spanner wrench into the notches on the retaining ring and carefully turn it counter-clockwise to unscrew it.

Once the retaining ring is removed, the spacer (and blank, if present) should be easily removed. You should become familiar with the assembly of this retaining system. In particular, you should develop a feel for turning the retaining ring without pushing down on the driver or wrench. This is important because if you forcefully push on the filter holder while you are trying to load a filter, you run the risk of scratching the filter if the tool slips out of place!
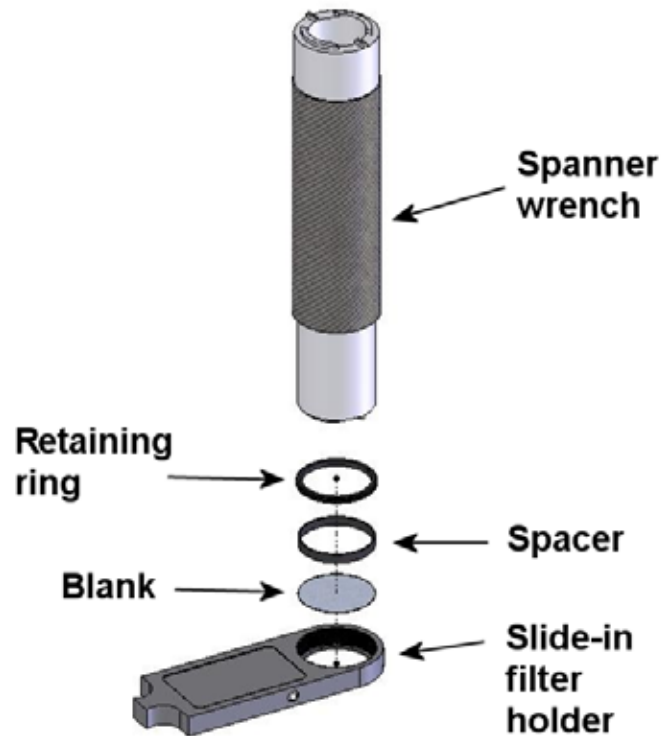
Figure 2-11. Installing a filter into a Slide-In Filter Holder.
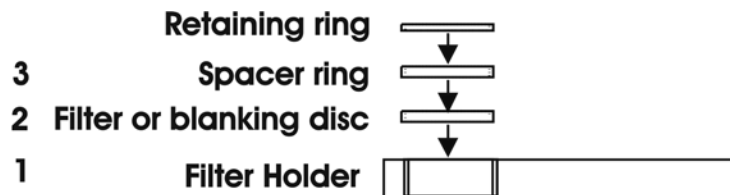
Figure 2-12. Assembly order of filter holder parts

Place the desired filter into the filter holder, first. With some 1" filters extra care must be taken to avoid getting the filters jammed at an angle.

Next, install the spacer ring into the filter holder. Unless the filter thickness precludes the use of the spacer ring (see Figure 2-12), always install the spacer. This helps to provide maximum separation between the filter surface and end of the tool that is used to turn the retaining ring.

Finally, install the threaded retaining ring. DO NOT OVER TIGHTEN THE RETAINING RING! It need only be tightened until it is firmly seated.

2.6.4 Installation of Filters into Filter Cups

Loading filters into the filter cups on the filter wheel follows the same procedure as described above for loading filters into filter holders. There is, however, the additional complication of working through the filter wheel housing. To gain access to the filter cups on the wheel, unscrew the access plug from the loading port on the motor housing (i.e., the motor side of

the filter wheel). A large coin or other suitable implement can be used to remove the plug. Once removed, the retaining ring in the underlying filter cup is accessible through that port.

To align the filter position you wish to load with the loading port, it is easiest to use the controller to identify and position the filter cups. To begin, connect the Filter Wheel to the controller (see the FIRST TIME USE chapter for a brief description of the principles of operation). When you first turn on the controller, the Filter Wheel will "HOME" itself, aligning the "0" filter position with the Optical Port and filter position #5 with the Loading Port. The filter being in the Loading Port is five positions removed from the one indicated by the controller display (i.e., the one at the OPTICAL PORT). This relationship between the filter position indicated by the controller and the filter position at the LOADING PORT is illustrated in Figure 2-13.

Filter position at optical port	0	1	2	3	4	5	6	7	8	9
Filter position at loading port	5	6	7	8	9	0	1	2	3	4
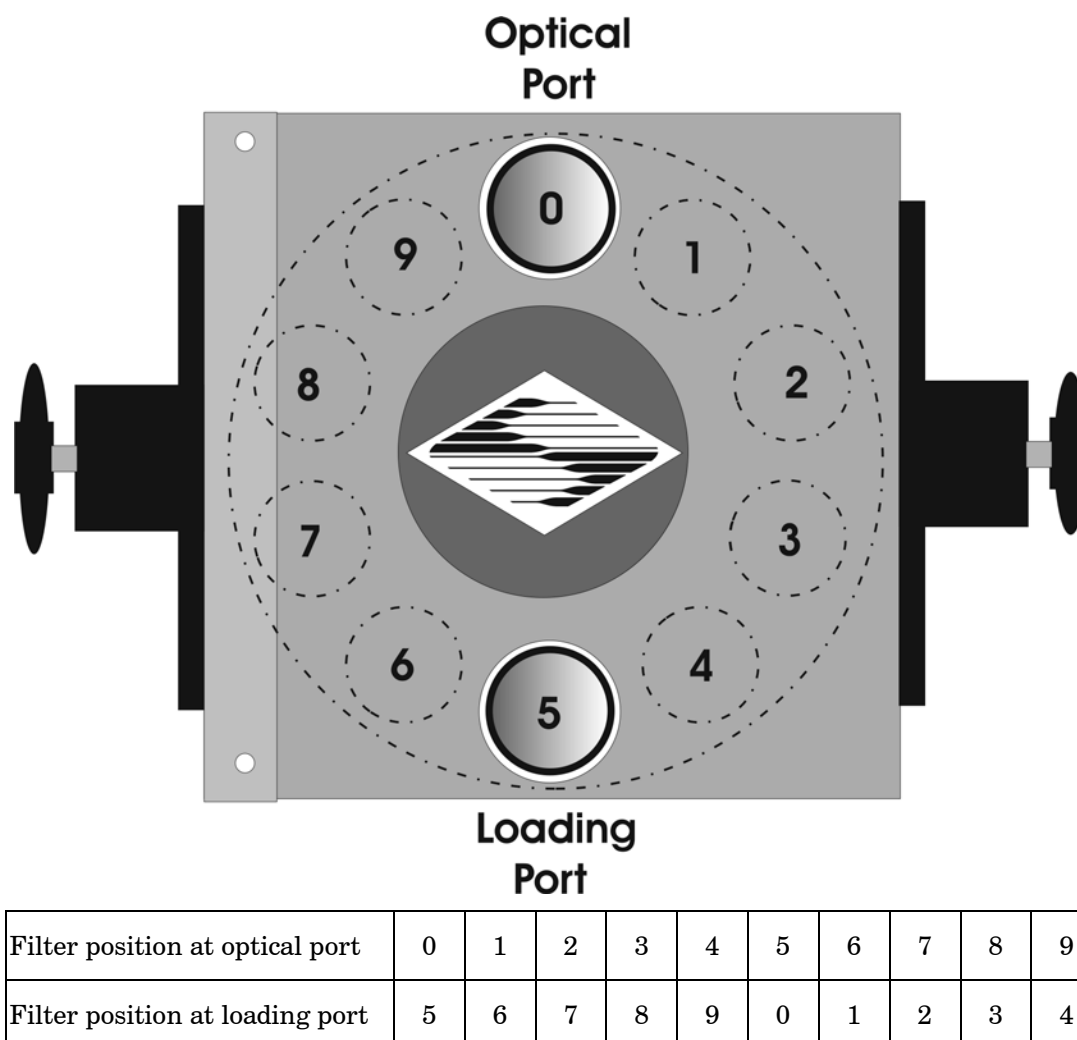
Figure 2-13. Filter ports (plug is removed from the loading port)

After identifying and positioning the filter cup to be loaded, it is advisable to turn off the controller before removing the retaining ring from the filter cup. Follow the procedures described above for installation of filters into filter holders.

⚠️ *CAUTION: An extra word of caution about excessive force is warranted at this point. DO NOT APPLY EXCESSIVE FORCE! Not only do you run the risk of damaging the filter but also the filter wheel itself can be permanently distorted by pushing too hard against the retaining ring with the driver or wrench. If you experience problems securing the retaining ring, back the ring off the filter cup and try again.*

After loading the filter(s), check each newly loaded filter position to make sure that the retaining ring is not projecting above the top edge of the filter cup then replace the loading port plug.

Another potential complication of loading filters into the filter cups can occur if the retaining ring has been previously over-tightened. In this case, it is possible that the filter cup itself will begin to unscrew from the wheel as the retaining ring is turned. If this occurs, STOP! Turn the spanner wrench so that the widest end is toward the filter cup and slip the wrench into the two notches in the edge of the cup. Then turn the wrench clockwise to screw the cup back into the slider. DO NOT push on the cup. Just screw it in until it seats firmly. It should then be possible to remove the retaining ring as described above without the cup turning.

It may appear that removal of the cover plate from the housing would facilitate loading filters. This is not the case! Removal of the cover plate will not give you access to the filter cup side of the wheel and may lead to misalignment of and damage to the Filter Wheel. **Under no conditions should you ever remove the cover plate or the filter wheel from the motor shaft**. Removal of the cover plate or the wheel from the shaft will void your warranty.

2.7 Filter Loading Tips

2.7.1 Selection of a Filter Position

In most cases any given filter could be installed at any of the ten FILTER POSITIONS. However, some minor considerations may improve performance of the system. Adjacent FILTER POSITIONS will require less switching time. Therefore, if an experiment will require rapid switching between 2 filters they should be located next to one another. If separation by one or more occupied filter positions is necessary, keep in mind that there will be brief transitions through, possibly, undesirable wavelengths as light transmits through those intervening filter(s) unless a shutter is installed and programmed for use.

2.7.2 Use of Blanking Discs

The blanking discs should only be removed from those positions that will contain a filter. The discs are intended as a safety device to reduce the risk of the user sustaining serious and permanent eye damage from looking in the microscope when dangerous high intensity light is present. We strongly urge that the discs be used. Please be careful and avoid the possibility of direct visualization of high intensity light.

2.7.3 Neutral Density Filters

The individual filter holders are typically used for neutral density filters and are installed as described above.

3. OPERATIONS

3.1 First Time Use

For first time use of the Lambda 10-2 during the installation process, please refer to Section 2.5 (First Time Use) in Chapter 2 (INSTALLATION).

3.2 Principles of Operation

The Lambda 10-2 controller can be operated locally (manually) from the controller keypad or remotely from a computer through either the parallel or serial port. These three operational modes (manual, parallel and serial) are functionally identical. Each allows the user to select:

- Active filter wheel
- Filter position
- Filter switching speed
- Shutter position (opened/closed state)

The remainder of this chapter provides a detailed description of the controller's rear panel connectors and front panel controls. Information needed to connect the power cord and filter wheel(s) is found in the FIRST TIME USE chapter. Instructions on operation of the controller and control of the filter wheel(s) manually from the keypad are presented in the MANUAL CONTROL chapter. The REMOTE CONTROL chapter explains control of the unit from a remote device, as well as supplying some technical details relevant to local operation. Technical details, which are not required for operation but which may help you understand the behavior of the unit, are found in APPENDIX A: Stepping Motor Operation.

⚠ CAUTION: DO NOT CONNECT OR DISCONNECT THE CABLES BETWEEN THE CONTROLLER AND THE MECHANICAL UNITS (FILTER WHEELS AND/OR SHUTTERS) WHILE POWER IS ON.

Please allow at least 20 seconds after turning the unit off before disconnecting the mechanical units. Failure to do this may result in damage to the electronics.

3.3 Rear Panel Connectors

All electrical connections are all made on the rear panel of the Lambda 10-2. See the FIRST TIME USE chapter for details on connecting the power cord and filter wheel cable(s).
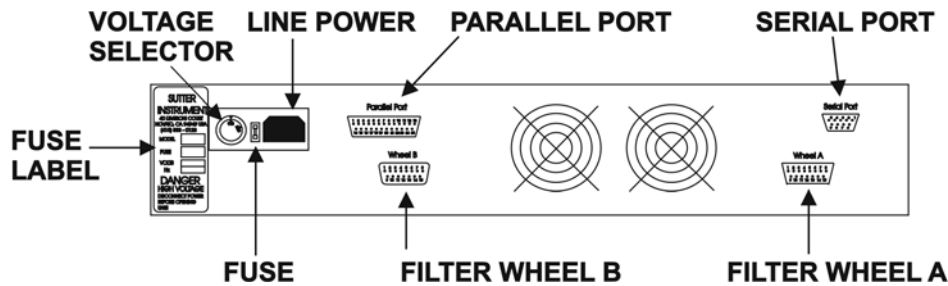
Figure 3-1. Electrical connections

FILTER WHEEL (A and B): These 15-pin DSUB connectors are used to link the Lambda 10-2 controller with the filter wheels (and shutters, if installed).

PARALLEL PORT: This 25-pin DSUB connector is used for establishing a parallel interface between the Lambda 10-2 and a remote device (computer) using the cable provided. This cable should not be used simultaneously with the serial port cable.

SERIAL PORT: This 9-pin DSUB connector is used for establishing a serial interface between the Lambda 10-2 and a remote device (computer) using the cable provided. This cable should not be used simultaneously with the parallel port cable.

VOLTAGE SELECTOR: This switch selects the appropriate line voltage, 110 or 220 volts at 50 or 60 Hz, and is typically set at the factory before shipping.

LINE POWER: This socket is used to connect the power cord to the Lambda 10-2.

FUSE LABEL: The information found on this label includes the model number of this instrument, the appropriate supply voltage(s), and the type(s) of fuse(s) required for the supply voltage(s).

FUSE: Fuse compartment containing the supply voltage fuse and an extra fuse. Replace blown fuses with a fuse of the appropriate value as given on the fuse label (back panel of the controller) or on the TECHNICAL SPECIFICATIONS page in this manual.

3.4 Front Panel Controls

3.4.1 Keypad
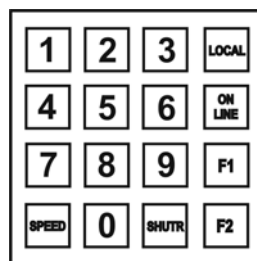
Figure 3-2. Lambda 10-2 Controller Keypad

 There are sixteen keys on the Lambda 10-2 keypad: Ten numerical keys (0 to 9), and six function keys. The microprocessor that controls the Lambda 10-2 reads the keys while they are depressed but the appropriate action will occur only when the key is released. If a key is pressed while a move is in progress but released after the move is over, the key will read normally. Keys pressed <u>and</u> released while a move is in progress are ignored.

0-9: These keys are used to manually select filter positions and, with the SPEED key, to choose between the eight pre-set speeds.

SHUTR: This key is used to manually open or close the shutter.

SPEED: This key is used to access the SPEED selection mode.

F1, F2: These keys are used in MANUAL mode to select which Filter Wheel you wish to command through the keypad. (F1=Wheel A; F2=Wheel B).

LOCAL: Pressing this key puts the unit under MANUAL (keypad) control. This function overrides all other input sources when pressed. This means that remote control through the parallel or serial port will be interrupted if this key is pressed and then released between executions of "ON LINE" commands.

ON LINE: This key transfers control of the Lambda 10-2 to an interfaced external source, such as a computer. This transfer can also be done by sending the correct signal from the external source as outlined under the interfacing section. The default input port is the PARALLEL PORT, so the display will indicate **PARALLEL** after the **ON LINE** key has been pressed. Both the parallel and serial ports are queried, however. Any time an appropriate command is received on the serial line, that port will then become the active input source, which will be reflected in the controller display.

3.4.2 RESET Button

Pressing the RESET button at any time causes the controller to re-initialize, clearing the display and returning to the initialization screen.

3.4.3 Display

During normal operation, the vacuum fluorescent display on the front panel of the controller provides the current position of the filter wheel(s), the status of any shutters that may be installed and the active input source.
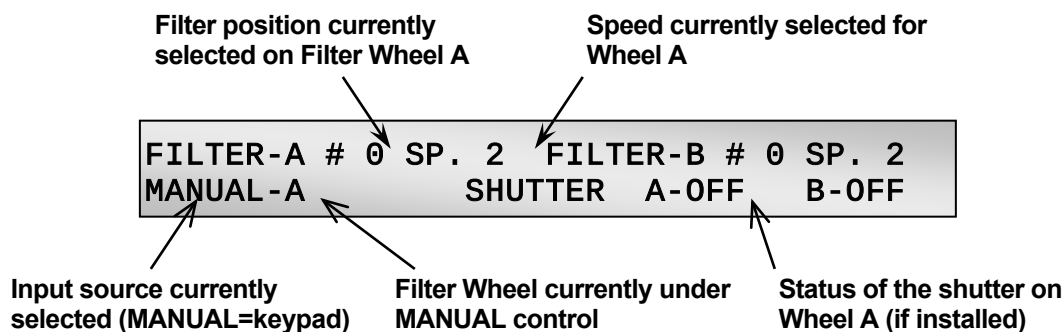
Figure 3-3. Status display screen

3.5 Power-Up Sequence

The control electronics for the filter changer are activated by the POWER switch (MAINS) on the front panel of the unit. Remember, when using an arc lamp with this system it is best to turn the lamp power supply on BEFORE turning on the Lambda 10-2. Lamp power

supplies are often electromagnetically "noisy" and can interrupt normal operation of microprocessor-controlled devices when they power up.

When power is applied, an initialization screen will be briefly displayed. Then each **LAMBDA 10-2** filter wheel installed will begin to rotate at a slow rate until sensors in the mechanical units signal that the "0" filter position is lined up with the optical port. The current filter position will then be displayed on the front panel. When initializing the following parameters will be set to the default values indicated:

- FILTER POSITION   0
- SPEED   2
- SHUTTER   OFF (closed)
- INPUT SOURCE   PARALLEL port

Filter position currently selected on Filter Wheel A　　　**Speed currently selected for Wheel A**

```
FILTER-A # 0 SP. 2  FILTER-B # 0 SP. 2
PARALLEL        SHUTTER  A-OFF   B-OFF
```

Input source currently selected is external control over parallel interface　　　**Status of the shutter on Wheel A (if installed)**
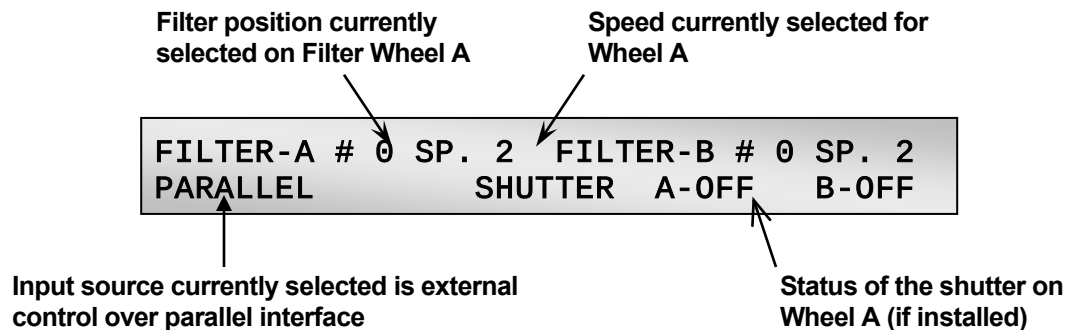
Figure 3-4. Status display defaults

The unit automatically selects the PARALLEL mode at power on. If the unit is under remote control, the display may change immediately to reflect the filter position, speed and shutter commands of the remote computer.

In order to manually select filter positions the MANUAL input source mode must be activated. The current INPUT mode will be indicated in the bottom left corner of the controller display. Press the LOCAL key to select the MANUAL mode.

3.5.1 Selecting the Wheel

If two Filter Wheels are installed, you must first select the wheel you wish to command by pressing the F1 or F2 key on the controller keypad.

- F1 = Wheel A

or

- F2 = Wheel B

The selected filter wheel (A or B) will be indicated in the lower left corner of the controller display after the word "MANUAL".

Filter position currently
selected on Filter Wheel A

Speed currently selected for
Wheel A

```
FILTER-A # 0 SP. 2  FILTER-B # 0 SP. 2
MANUAL-A          SHUTTER  A-OFF   B-OFF
```

Input source currently
selected (MANUAL=keypad)

Filter Wheel currently under
MANUAL control

Status of the shutter on
Wheel A (if installed)
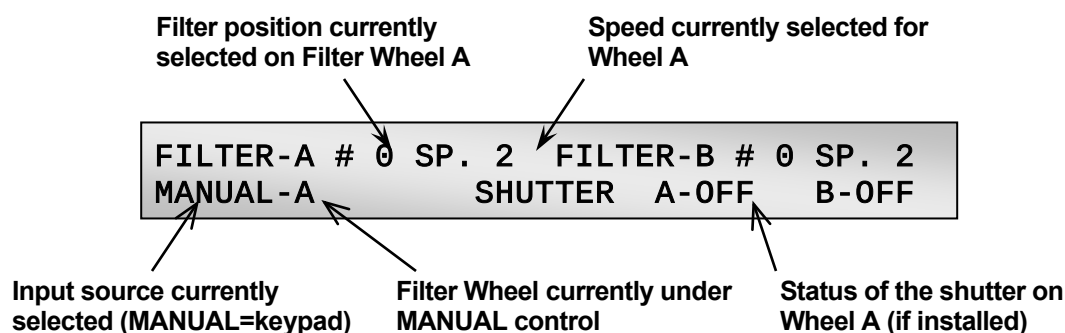
Figure 3-5. Display showing selected filter wheel

3.5.2 Selecting the Filter Position

Now any filter position on the selected wheel can be chosen by pressing the corresponding numeric key. Keys are read while depressed but the appropriate action will occur only when the key is released. If a key is pressed while a move is in progress but released after the move is over, the key will read normally. Keys pressed <u>and</u> released while a move is in progress are ignored. The filter position currently located in the optical port will be indicated on the display (see example above).

3.5.3 Selecting the Filter Switching Speed

To enter the SPEED selection mode, press the SPEED key on the keypad. The controller will prompt you to confirm entry into SPEED selection mode with the following display.

```
DO YOU WISH TO CHANGE THE FILTER WHEEL
SPEED? 1 = YES,  0 = NO
```

Figure 3-6. Screen showing prompt for speed selection

Entering 1 will allow the entry of the desired SPEED setting. Enter 0 to escape the SPEED selection mode and return to normal operation.

```
ENTER A SPEED VALUE FROM 0 TO 7
```

Figure 3-7. Entering the speed

Speed 0 is the fastest speed and speed 7 is the slowest. Speed selection under computer control is covered in a separate section.

The switching times (in milliseconds) for each of the 8 speeds is given in Table 3-1. Note that a 5-filter position move is the longest move on the 10-position filter wheel, since the controller will always rotate the correct direction to make the fastest change of position. For a given speed, the time for a move to a non-adjacent filter position will take about 1.8, 2.5, 3.3 or 4 times as long as a move to an adjacent filter position, depending on the number of filters to be skipped. The highest speed that can be used will depend on the weight of the filters mounted in the wheel. In a 25mm, 10-position filter wheel equipped with two typical filters

and eight blocking disks, adjacent filters can be changed in 55 milliseconds with a speed setting of 1. A correspondingly-equipped 32mm wheel may require a lower speed.

Table 3-1. Filter switching times (in milliseconds)

SPEED SETTING	NUMBER OF FILTER POSITIONS MOVED				
	1	2	3	4	5
0	50	90	125	165	200
1	55	99	138	182	220
2	63	113	158	208	252
3	78	140	195	257	312
4	106	191	265	350	424
5	164	295	410	541	656
6	264	475	660	871	1056
7	476	857	1190	1571	1904

3.5.4 Selecting the Shutter Position (Open/Close)

If you press the **LOCAL** key, the display's second line will contain the active input source, the wheel selected and the status of the shutter(s).

```
FILTER-A # 0 SP. 2  B NOT CONNECTED
MANUAL-A          SHUTTER  A-OFF   B-OFF
```

Input source currently selected (MANUAL=keypad)   **Filter Wheel currently under MANUAL control**   **Status of the shutter on Wheel A (if installed)**
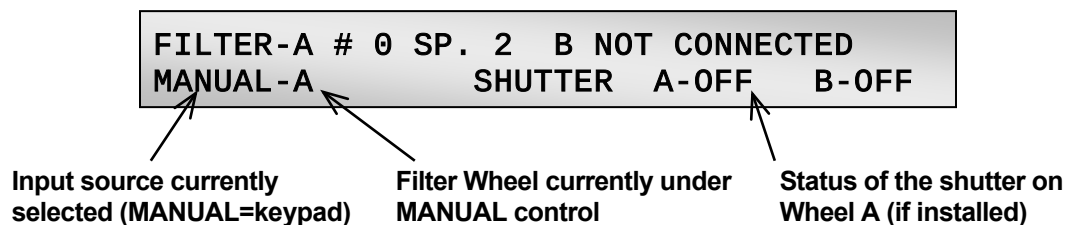
Figure 3-8. Status display screen after pressing LOCAL.

The above example indicates that both shutters are "OFF" (closed) and that Wheel and Shutter "A" are selected for "MANUAL" control. Going to the LOCAL mode from either REMOTE mode (parallel or serial) closes both shutters automatically. Once the MANUAL input source has been selected, pressing the shutter (SHUTR) key will toggle (open/close) the status of Shutter A. To control Wheel B and Shutter B, press the F2 key to select them as the active components. The display will change from "MANUAL-A" to "MANUAL-B". Pressing the SHUTR key will now toggle (open/close) Shutter B. In general, the shutter status will not change when going from LOCAL to ON LINE (to either SERIAL or PARALLEL control) until a new shutter command is sent from the remote computer.

3.5.5 Error Detection and Recovery

The Lambda 10-2 contains two sensor systems that are used to monitor the actual position of the filter wheel. After the controller sends the step sequence for a move to a new filter position, it compares the output of these sensors with the expected position. If there is no match, the error recovery sequence is started. First, the wheel is rotated until Filter 0 (zero)

is in position. Then the unit continues to rotate at a slow rate until the correct filter is in position. An ERROR signal is reported to the active interface.

3.5.6 Movement Errors: Causes and Solutions

3.5.6.1 Filter Weight vs. Speed

The Lambda 10-2 is optimized for the fastest exchange of two filters in research applications. One element of the Lambda 10-2's overall design that contributes to its superior performance is the acceleration and deceleration profiles that are pre-programmed into the microprocessor commanding the motor. There is a separate profile for each combination of *selected speed* and *number of positions to be moved*. The motor commands produced from these profiles result in exceedingly smooth and efficient filter wheel movements. The motor, however, is driven at its rated power which limits its ability to overcome the inertial load of the filter wheel if the weight of the wheel is increased by installing more (or heavier) filters. Increases in filter wheel weight, then, can lead to movement errors unless a slower *speed setting* is selected[1]. Detection of a movement error will initiate the RECOVERY routine described above, sending the wheel to the HOME (0) position.

3.5.6.2 Oscillation when Stopping

If the desired configuration of filters in your filter wheel results in a weight that is slightly excessive for the chosen speed, the filter wheel may oscillate instead of stopping quickly when the selected filter has rotated into position. Even though this may not be detected as an error by the controller, it is advisable to use a slower speed. This will cause a slower acceleration and deceleration profile to be used and, by eliminating the oscillations, may actually allow the move to be completed more quickly.

3.5.6.3 Oscillations when Moving

Selecting a slower speed will generally eliminate errors caused by excessive total filter wheel weight, but there are other considerations. For a given weight, some of the slow speeds may induce oscillations <u>during</u> movement. This is a result of stepping the motor near the resonance frequency (see Appendix A). Selecting a higher <u>or</u> lower speed will generally solve this problem.

3.5.6.4 Movement Errors after Successive Moves

With an <u>optimal</u> combination of speed and load-weight, it <u>may</u> be possible to give a new command as soon as the last move is complete. On the other hand, if the selected speed is improper for the load, as outlined above, oscillations (too small to be detected as movement errors) may be sufficient to carry-over from the end of one move to the beginning of the next. This can occur even when the delay between moves is more than 50 msec. It is possible, then, to experience movement errors after changing only the delay interval between moves. If you are making moves with a very short delay interval and errors are detected with some frequency, it is wise to consider this possibility before addressing the *selected speed*. Try

---

[1] WHY NOT JUST USE A LARGER MOTOR. As the inertia increases, an increase in the force required to achieve a given acceleration and deceleration becomes necessary. Since the step motor in the **LAMBDA 10-2** is operated at rated power, an increase in force could only be obtained by using a larger motor. This, in fact, is not a very satisfactory solution for the following reasons. First, larger motors have a higher *intrinsic inertia*. Second, if the larger motor has a larger diameter it would require that the filter wheel diameter also be expanded to move the filters radially so that the optical pathway clears the motor housing. Third, if the length (along the shaft) of the larger motor were longer, it would increase the optical path length, which is not desirable. At best, the net result of a larger motor might be a slight increase in speed when fully loaded, but at a cost of slowing the response when relatively few filters are loaded.

using a long time interval (1 second) between moves to test whether the length of the interval is contributing to the error rate.

3.5.7 Helpful Tips about Movement Errors

Always determine the appropriate speed by using the same filter wheel load weight and timing intervals that will be required in your experimental protocol. There is a tendency for users to test the Lambda 10-2 in their system using little, if any, delay between commands even though a pause occurs during an actual experiment.

If your application requires the delay between moves to be minimal experiment with small changes in the delay to find the best value and then keep the delay at that value. If your protocol precludes you from increasing the delay, use a slower speed to eliminate the oscillation. If you cannot use a slower speed, you must reduce the filter wheel weight to eliminate the movement errors.

If the weight is clearly excessive for the chosen speed select a slower speed. Make sure you also address the question of the delay interval before you become very serious about the speed of operation.

Remember, unless having a short delay interval is important, the solution to frequent movement errors will usually require some compromise between having fast filter switching speed and having the convenience of keeping many filters loaded.

4. EXTERNAL CONTROL OPERATIONS

4.1 General

The Lambda 10-2 microprocessor sets the PARALLEL port, by default, as the input source upon startup and anytime the ON LINE key is pressed. An appropriate command from the remote computer through the PARALLEL port will also set that port as the active input source and the display on the controller will reflect that change on its bottom line. The PARALLEL port will remain active until an appropriate command is sent from a remote computer through the SERIAL port <u>or</u> until the LOCAL key is pressed on the controller keypad. This chapter will discuss these connections and the structure of the data that is required from your computer for controlling the filter wheel(s) and shutter(s) through the PARALLEL port. Many of the details about the command structure will also apply to use of the SERIAL port for remotely controlling the Lambda 10-2.

4.2 Parallel Interface

The Lambda 10-2 microprocessor sets the PARALLEL port, by default, as the input source upon startup and anytime the ON LINE key is pressed. An appropriate command from the remote computer through the PARALLEL port will also set that port as the active input source and the display on the controller will reflect that change on its bottom line. The PARALLEL port will remain active until an appropriate command is sent from a remote computer through the SERIAL port <u>or</u> until the LOCAL key is pressed on the controller keypad. This chapter will discuss these connections and the structure of the data that is required from your computer for controlling the filter wheel(s) and shutter(s) through the PARALLEL port. Many of the details about the command structure will also apply to use of the SERIAL port for remotely controlling the Lambda 10-2.

4.2.1 Connecting to the Parallel Port Interface

The parallel interface connector on the back of the cabinet is a DB-25 connector. This port is designed for connection to a standard parallel port on a computer and is not to be connected to any other type of device. The pin assignments for this connector are, as viewed from the back of the unit, shown below.
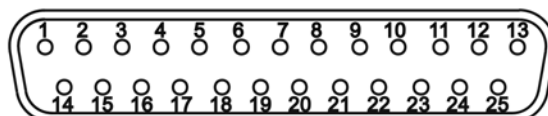
Figure 4-1. Parallel interface DB-25 connector on the Lambda 10-2.

Table 4-1. Lambda 10-2 Parallel Interface Pin Assignments

Pin #	Function
1	Not Connected (NC)
2	Bit 0 for Filter Position
3	Bit 1 for Filter Position
4	Bit 2 for Filter Position
5	Bit 3 for Filter Position
6	Bit 0 for Speed
7	Bit 1 for Speed
8	Bit 2 for Speed
9	Wheel Select Bit
10	NC
11	Busy Line Output
12	Error Line Output
13	NC
14	Shutter
15	NC
16	NC
17	NC
18	NC
19	NC
20	NC
21	NC
22	NC
23	NC
24	Ground
25	Ground

4.2.2 Input Command Structure

Input Commands to the controller via the parallel port are structured in a one-byte (8-bit) signal. These eight bits are transmitted to the Lambda 10-2 controller via the eight input lines (Pin 2 through Pin 9) of the parallel port connector. The eight bits can be used to convey two types of input commands.

- **Filter Commands:** These input commands select the desired filter position (0 – 9), switching speed (0 – 7), and filter wheel (A or B).
- **Special Commands:** These input commands are used to set the controller to the ON LINE (Remote) mode of operation, control the shutter(s) (when installed), and make BATCH TRANSFERS of input commands to the controller.

The microprocessor is programmed to distinguish between these two types of input commands based on the bit pattern of the command, and will respond accordingly. These two types of commands are discussed in more detail in the following sections.

4.2.2.1 Filter Commands

When the 8-bit command is identified by the controller as a filter command, the bit pattern is actually interpreted as three separate commands (or command parameters). The filter position is encoded in the four "least significant" bits, the speed is encoded in the "next three most significant" bits, and the wheel select is encoded in the "most significant" bit. These three functionally distinct filter command parameters are described in the following:

- **Filter Position Group (Pins 2 - 5)**. These four bits select the desired filter position and, in part, encode Special Commands. This group is treated as a four-place binary number, with the equivalent decimal values 0 through 9 corresponding to the selected filter position. Binary codes with decimal values greater than 9 are ignored, unless the binary value (in conjunction with the Speed Group Bits) corresponds with the decimal equivalent of one of the Special Command Codes listed later in this chapter.

- **Speed Group (Pins 6 - 8)**. These three bits select the speed of movement used in advancing to the next filter. The speed group is treated as a three-place binary number whose equivalent decimal value, 0 through 7, corresponds to the selected speed.

- **Wheel Bit (Pin 9).** This bit selects the filter wheel to which the filter position and speed commands will be directed. If this bit is low (0), Filter Wheel "A" will be selected. If this bit is high (1), Filter Wheel "B" will be selected. The filter position and speed values will be passed only to the wheel selected.

To send a filter command via the PARALLEL port the binary value must first be determined for the desired filter position, switching speed (4 bits and 3 bits, respectively), as well as the filter wheel (1 bit). Then these eight bits must be set, in the proper order, on the controller's PARALLEL port, as shown below.

Table 4-2. Filter command structure

Functional Bit Groups							
Byte Bit #	7	6	5	4	3	2	1	0
Group	Wheel	Speed			Filter Position			
Group Bit #	0	2	1	0	3	2	1	0
Decimal Group Values	0	0 - 7			0 - 9			
Decimal Group Value Examples	0	5			7			
Binary Group Values	0	000 - 111			0000 - 1001			
Binary Group Value Examples	0	101			0111			
Parallel Port Pin #	9	8	7	6	5	4	3	2

In Table 4-2, "Decimal Group Value Examples" are equivalent to the values of the desired filter wheel (0 = Wheel A), switching speed (5) and filter position (7). Their binary equivalents are shown as the "Binary Group Values". These eight bits are the raw data, then, that serve as a filter command to select the filter position, switching speed and filter wheel via the Lambda 10-2 controller's serial or parallel port.

When the controller is in the ON LINE (Remote) mode, the eight input lines on the parallel port are examined at 50 microsecond intervals. If the value on the 8-bit input lines (pins 2 - 9) has changed from the previous query, and if the new filter group value (pins 2 - 5) are in the range of 0 to 9, the controller will respond as commanded with a change in the filter position of the appropriate filter wheel. In the above example (Table 4-2), Filter Wheel A will move to Filter Position 7, using Speed 5.

4.2.2.2 Special Commands: ON LINE, BATCH, and SHUTTER Commands

When the 8-bit command is identified by the controller as a "Special Command", the bit pattern is interpreted as a single command encoded by all eight bits. The functions of the special commands are described below along with the decimal, hexadecimal, and binary values that encode them.

Table 4-3. Special command codes.

Command	Value (Decimal,, hexadecimal, binary)	Description
Transfer Control to Computer (On Line)	238 EE 11101110	When the controller is in the local mode, the unit will be forced to go ON LINE if this code is sent. The input port from which this command is received will become active. Sending this command via one input when the other input is active will cause the unit to change remote input modes. WARNING: If 238 is the current command of either input, do not send 238 via the other channel and do not attempt to go to the local mode! In either case, the controller will loop between modes continuously requiring the controller to be RESET.
Batch Transfer	223 DF 11011111	The controller reads the next four commands and acts on them in quick succession before acting on any subsequent command.
Open Shutter A	170 AA 10101010	Opens Shutter A
Open Shutter A Conditionally	171 AB 10101011	Opens Shutter A while Wheel A is stopped. The shutter will close each time the wheel moves and then will open again at the end of the move.
Close Shutter A	172 AC 10101100	Closes Shutter A

Command	Value (Decimal,, hexadecimal, binary)	Description
Open Shutter B	186 BA 10111010	Opens Shutter B
Open Shutter B Conditionally	187 BB 10111011	Opens Shutter B while Wheel B is stopped. The shutter will close each time Wheel B moves and then will open again at the end of the move.
Close Shutter B	188 BC 10111100	Closes Shutter B

Transfer Control to Computer (ON LINE). When sent via the parallel port this command will select the parallel port as the input source, setting the controller ON LINE. This change in input mode will be indicated in the bottom line of the controller's display.

Shutter Control using Special Commands. Six of the eight special commands described in Table 4-3 are used to control the status of the shutters. The functions of each of those commands are described there. For a description of an alternative method of remote shutter control, see the description of the **Dedicated TTL Line** later in this chapter.

Batch Transfer of Commands via the Parallel Port: In order to quickly transfer commands for both wheels and shutters, you should use the *BATCH TRANSFER* method. First, send the *BATCH TRANSFER* command, 223. When the **BUSY** signal drops low send the desired commands in the following order:

1. Shutter A command
2. Shutter B command
3. Filter/Speed/Wheel A command
4. Filter/Speed/Wheel B command

Make sure that the **BUSY** signal drops low after each command is sent before sending the next command. Once the controller has received the *BATCH TRANSFER* command, the unit will not respond until all four commands have been received. With this approach, the four commands can be passed in less than five (5) milliseconds. The values of each of the four types of command are distinct, so the controller may be able to respond correctly even if the four commands are sent in a different order. Sending the commands in the correct order assures the best performance.

The following listing lists a *Microsoft QuickBasic* program for batch transfer through a PC parallel (printer) port.

Listing 4-1. Batch transfer via PC parallel port program.

```
FOR I% = 0 TO 4                 'LOOP THROUGH 5 COMMAND VALUES
IF I% = 0 THEN X = 223          'SEND THE BATCH COMMAND NUMBER
IF I% = 1 THEN X = SHUTA        'SEND THE SHUTTER A COMMAND VALUE
IF I% = 2 THEN X = SHUTB        'SEND THE SHUTTER B COMMAND VALUE
IF I% = 3 THEN X = FILTERA + 16 * SPEEDA      'SEND FILTER, SPEED,
                                'SELECT BITS FOR WHEEL A
IF I% = 4 THEN X = FILTERB + 16 * SPEEDB + 128 ''SEND FILTER,
                                  'SPEED, SELECT BITS FOR WHEEL B
OUT BASEPORT, X                 'SEND TO PRINTER PORT
GOSUB BUSY                      'WAIT UNTIL THE LAMBDA IS READY
NEXT I%
```

4.2.2.3 Output Command Structure: BUSY and ERROR lines

The **LAMBDA 10-2** features two output lines; **BUSY** and **ERROR** (parallel port Pin #11 and #12, respectively). These lines report the status of the filter wheel movement as described below.

■ **Busy Line (Pin #11).** — The **BUSY** line indicates that a move is in progress. Upon receiving a new input command, the controller sets the BUSY output line high. The **BUSY** line will remain high until the controller is ready to accept new data. Changes in speed value or shutter status require <u>less than 1 msec</u> for the **BUSY** line to go low, again. Selection of a new filter position, however, requires the move to be completed before the **BUSY** line returns to low (even if in **ERROR** mode, see below). If both a speed and a filter change have occurred, the speed change will be processed and the unit will then read the input again. If the same speed value is still there, the new filter value will then be read and acted upon. It is unlikely that the speed will ever be changed in a given series of moves, so this protocol is not likely to result in filter move delays.

NOTE: The status of the eight (8) input lines is not checked while the **BUSY** line is high.

Additionally, a short period (as much as 50 microseconds) exists between the time the controller detects a new value and when the **BUSY** line is set high. Recall that the microprocessor queries the port for changes in the status of the Input Lines at about 50 microsecond intervals. Checking the status of the **BUSY** line within about 100 microseconds of sending an input command, then, may yield an anomalous "low" signal because of these two cumulative delays.

■ **Error Line (Pin #12).** — The **ERROR** signal indicates that an error has been detected and error recovery is in progress. The controller uses optical and magnetic sensors to verify that the correct filter is in position. If a command for a new filter is received and the correct new filter is not in position at the end of the change sequence, the sensors will indicate this to the controller. The controller will then set the **ERROR** signal high and enter the error recovery mode. The **BUSY** line will also be set high.

In the **ERROR** recovery mode, the wheel is rotated continuously until the sensors indicate that Filter 0 (zero) is in position. The wheel will then make a slow move to put the correct filter in position. The **BUSY** line will stay high until the correct filter is in position, but the **ERROR** signal will stay high only until Filter 0 (zero) is in position.

4.2.3 Strategies for Controlling the Lambda 10-2 via the Parallel Port

4.2.3.1 Using Input Lines Only

The filter wheel may be controlled using only the eight input lines and ignoring the **BUSY** and **ERROR** output lines from the controller. This may be desired to simplify the code

required to execute your experimental protocol and would be particularly easy when using a protocol that requires switching only between adjacent filter positions, since the time for each change would be the same. Successful use of this strategy requires the following:

- The fastest speed that allows execution of your protocol without errors must first be determined. If the filter wheel weight is not changed, the movement times will remain very consistent and the **ERROR** line can be ignored.
- The time required to complete the longest move must be estimated using the speed determined above. This estimate can be made using Table 3-1 in the previous chapter. Unless the number of filter positions moved is increased in the protocol, the **BUSY** line in a single wheel system can then be ignored.

NOTE: On power-up, the remote computer should not send its initial command until the filter wheel reaches its HOME position.

4.2.3.2 <u>Using Fewer than Eight Input Lines</u>

In some applications, not all of the eight input lines would have to be connected to the host computer. It is likely that the same speed will be used at all times with a given set of filters. Thus, the three lines that control speed could be directly wired so that the correct speed is always set. The direct wiring could even be made through a switch so that the speed could be changed if desired. If fewer than 9 of the ten filter positions will be used, it may be possible to direct wire some of the filter control lines, as well. With only one line, it is possible to select between two positions; with two lines, four positions are allowed, and three lines allows eight positions.

In the extreme case, then, where a protocol requiring the switching between only two filter positions is used, only a single logic level input line from the host computer to the controller (together with direct-wired connections to the other 7 lines) would be sufficient.

4.2.3.3 <u>Using the BUSY Line</u>

Reading the status of the **BUSY** line would allow the host computer to determine if the unit is ready to receive a command, if a command has been received, and when the new filter has been placed in position. Obviously, it is also possible for the host computer to control the timing of events based on the expected behavior of the Lambda 10-2 (as described above) using the **BUSY** line only to verify that the controller is in the expected state.

The status of the **BUSY** line could also be used as a condition for timing other events. For instance, the dropping of the **BUSY** line could be used as the trigger for opening a shutter or beginning data collection. Using the **BUSY** line to trigger other events automatically allows for time required to recover time from errors. The **BUSY** line can even be used as an indication that an error has occurred. If the **BUSY** line fails to go low at the expected time after a new command was issued, it may be assumed that the controller has detected an error and the filter wheel is in the process of recovering.

4.2.3.4 <u>Using the ERROR Line</u>

The **ERROR** line signals when an **ERROR** in Filter Wheel movement has been detected. The **ERROR** line normally would not be used to determine timing of program execution in the host computer, since it is active only <u>after</u> an error and, even then, it is not held high during the entire **ERROR** recovery process. The use of the **ERROR** line will depend on two factors

- **What are the consequences of an error?** Continuing normal program execution in the host computer during recovery from an error might cause problems such as wasted data storage, exposure of sensitive photo detectors, experimental preparation to strong light; or the recording of faulty data.

- **What is the burden placed on the host computer in checking the ERROR line.** The **ERROR** line will go high only after a move that has been completed incorrectly, and will remain high only during part of the recovery from that error. Thus, the host computer would have to read the status of the **ERROR** line just at the point in time at which data collection should begin.

4.2.4 Using a Computer's Parallel (Printer) Port

The standard PC parallel port provided for printer control may be used to control the Lambda 10-2. This, however, does not mean that instructions can be sent to the Lambda 10-2 in the same manner that they are sent to a printer. A printer is designed to print at its maximum rate and, if the computer generates output at a higher rate, the printer will store the output in a buffer until the mechanism is ready. If the buffer becomes full, the printer will indicate to the computer that it is not ready to accept more data. It follows that there is not a tight time relationship between the output of a command from the computer and the execution of that command by the printer.

The time relationship between output of data from the computer and response by the Lambda 10-2, in contrast, must be very tight. Thus, it is understandable that the mode with which the parallel port is used will differ somewhat for the Lambda 10-2 from that of a printer.

The details of the input and output signals were described in previous sections. Now we will discuss the way in which these signals may be used to control the Lambda 10-2 from a PC computer's parallel printer port. This information is provided as a limited example and is only intended to show the elements useful in controlling the Lambda 10-2 through a generic printer port. The user's individual requirements, hardware and software will dictate the actual program steps to be used. The approach in this example involves direct control over the state of input and output ports. The example programs have been run successfully on computers from several manufacturers without encountering any difficulties. However, given the wide range of hardware and software in use, it is impossible to anticipate all possible problems. **Sutter Instrument Company thus cannot be responsible for any damages that might result from use of the example programs.** The user should be particularly careful that the address used for each of the various I/O ports is correct for the user's system.

The parallel printer port is actually composed of three I/O ports at three consecutive addresses. The first address corresponds to an 8-bit output port, the second to a 4-bit input port, and the third to a 5-bit input/output port. The first two ports are used in our example. The address of the first (output) port, which is the base address, should be one of three possible values, depending on the individual system.

If the printer adapter is located on a display adapter, it will be called LPT 1 and will have a base address of 956 (3BC H). If there is no active printer adapter on a display adapter card, the primary printer adapter card will be called LPT1 and will have a base address of 888 (378 H). A second printer adapter card in the same system will be called LPT2 and will have a base address of 632 (278 H). Check the documentation of your system and the jumpers on the various adapter cards to be sure of the base address on the adapter you wish to use.

4.2.4.1 Connecting to the PC Parallel (Printer) Port

The connections to the parallel port are made through a DB 25 connector on your computer. The pin assignments for the parallel port socket are (as viewed from the plug side):
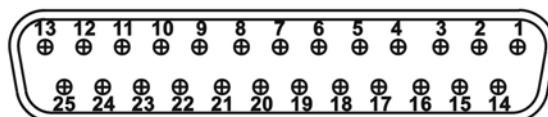
Figure 4-2. PC parallel (printer) port

Table 4-4. PC and Lambda 10-2 parallel port pin assignments

Pin #	PC PARALLEL PORT	Pin #	LAMBDA 10-2 CONTROLLER
1	Strobe	1	Not Connected (NC)
2	Bit 0 Data	2	Filter Position Bit 0
3	Bit 1 Data	3	Filter Position Bit 1
4	Bit 2 Data	4	Filter Position Bit 2
5	Bit 3 Data	5	Filter Position Bit 3
6	Bit 4 Data	6	Speed Bit 0
7	Bit 5 Data	7	Speed Bit 1
8	Bit 6 Data	8	Speed Bit 2
9	Bit 7 Data	9	Wheel Select Bit
10	ACK	10	NC
11	Busy	11	Busy Line Output
12	PE	12	Error Line Output
13	Select	13	NC
14	Autofeed	14	Shutter
15	Error	15	NC
16	Init	16	NC
17	Select In	17	NC
18	Ground	18	NC
19	Ground	19	NC
20	Ground	20	NC
21	Ground	21	NC
22	Ground	22	NC
23	Ground	23	NC
24	Ground	24	Ground
25	Ground	25	Ground

4.2.4.2 Input Command Structure

Input Commands may be sent through the printer adapter using an **OUT** command from basic, or an equivalent command from another language. In *Microsoft QuickBasic* the form of the command is:

OUT port, data

Where the decimal value of port would be 956, 888, or 632 depending on your system, and data would be a number indicating the desired speed and filter number.

The number to use for data can be generated from the desired speed and filter as follows:

data = wheel[0 for A; 128 for B] + (speed * 16) + filter position

Thus, to command a move to Wheel A, Filter Position 1, at Speed 1 (0 + 16 + 1 = 17), using a printer adapter having a base address of 888, you would use the following command:

```
OUT 888, 17
```

4.2.4.3 Output Command Structure: BUSY and ERROR Lines

The section Output Commands has a detailed explanation of the **BUSY** and **ERROR** signals. That section also describes some of the factors to consider in deciding whether to read the **BUSY** and **ERROR** signals. If you wish to read the status of the unit from your PC, this can be done through the 4-bit input port on the printer adapter. The address of this port will be the base address of the printer adapter, plus 1.

Table 4-5. PC printer adapter addresses

	Address	
	Base	**Input Port**
LPT1 on Graphics Adapter	956 (3BC hex)	957 (3BD hex)
LPT1 on Printer Adapter	888 (378 hex)	889 (379 hex)
LPT2 on Printer Adapter	632 (278 hex)	633 (279 hex)

The 4-bit input port only uses the 4 most significant bits at that address: bits 4, 5, 6, and 7. Bits 0, 1, 2, and 3 are not used by the printer adapter and will normally read as 1. Bit 7 in this input port is normally used by the printer to signal that it is "busy". That bit is set by the data signal from the printer to Pin 11 of the DB-25 parallel port connector on the back of the computer. The Lambda 10-2 uses this same bit in the computer's printer adapter to indicate that it is BUSY, although the polarity of this signal may differ from the corresponding printer BUSY signal.

With the Lambda 10-2 BUSY line connected to Pin 11 of the computer's parallel printer port, the input port can be read to obtain the status of the Lambda10-2. Using Microsoft QuickBasic, this would be done as follows:

Listing 4-2. Program to obtain the Lambda 10-2 status on the PC parallel port.

```
BUSY:  OUT BASEPORT+2, 16          'Required on some computers
                                   'before data can be read
       FOR U = 0 TO 5              'Delay to allow Lambda 10-2
            NEXT U                 'to set busy flag
LOOK:   STATUS = INP(INPORT)       'Read in from printer port
STATUS = STATUS AND 128            'Mask to read only bit 7
IF STATUS <> 128 THEN GOTO LOOK    'Still Busy so loop
RETURN                             'Not Busy so return
```

The example given will loop until the BUSY signal is low. When developing a program, it is advisable to insert an escape device in this loop, such as:

```
IF INKEY$<>"" THEN RETURN
```

If you are stuck in a tight, endless loop without an escape device, you will have to reset the computer. This statement may be removed once the program is operating correctly.

An alternative command to use in Microsoft QuickBasic is WAIT. This statement has the form:

WAIT *port*, AND*data*, XOR*data*

Where the port is the address of the input port, and data is an integer in the range 0 to 255. When the WAIT statement executes, program execution halts until the input port indicated by *port* reads as the indicated by data expressions. The ANDdata expression is evaluated as an AND operation. Thus, we may test to see if the BUSY line is set as follows:

```
WAIT 889, 128
```

The program will suspend operation until the value read for the most significant bit is 1. Since the printer adapter inverts this bit, this condition will be met only when the BUSY line is low. An XOR operation can be used as well, as noted in the Microsoft QuickBasic Language Reference. The WAIT statement will XOR the read data before the AND operation if a value for XORdata is provided. Consider the statement:

```
WAIT 889, 128, 128
```

The XOR of the read value of the port with 128 will invert the most significant bit. The program execution would thus be suspended until the BUSY signal went high, indicating that the unit was busy. Using the 2 statements in series would insure that the controller had time to assert the BUSY line in response to a command before the program began to test to see if the BUSY line had come back down:

```
WAIT 889, 128, 128
WAIT 889, 128,
```

IMPORTANT CONSIDERATION WHEN USING THE WAIT STATEMENT: The WAIT statement seems to be ideal because it provides a fast and easy way of directly testing input port bits. However, if the input port does not have the correct value, and you are unable to force the port to the correct value, you will need to reboot the computer. This should not be a significant problem in routine operation of a system, but it can provide considerable frustration when developing and testing the control program. Test the WAIT function with simple programs before you use it. Make sure that you will not lose important data if you are forced to reboot.

4.3 Dedicated TTL Line

Unlike the commands through the 8 bit port, the direct logic input lines will act even if the **BUSY** line is active. However, these lines only provide the conditional opening: the shutter will open while the wheel is stopped. It follows that the only advantage of the direct control lines is that, in a two-shutter system, the shutter associated with a wheel that was not moving could be opened or closed while the other wheel is moving. When the controller is in the manual mode, the dedicated TTL lines are ignored. If a valid 8-bit shutter command has been received by the controller, the dedicated TTL lines are ignored until the controller is reset.

The dedicated input lines are at pins 14 and 16 of the 25-pin parallel connector. Shutter A is opened by setting pin 14 high and closed by setting pin 14 low. Shutter B is opened by setting pin 16 high and closed by setting pin 16 low. Remember that this is a conditional opening: the shutter will be open only if the corresponding wheel is not moving.

If the 25-pin connector is brought to a PC parallel adapter, pins 14 and 16 correspond to the AUTOFEED and INITIALIZE control lines for a printer. These lines are controlled by setting bits in the command port of the printer adapter, which is at an address that is equal to the base port address + 2.

Pin 14 corresponds to the bit that encodes the value 2 and pin 16 corresponds to the bit that encodes the value 4. Sending a value of 2 to this port will set pin 14 low, which closes the shutter. Pin 14 can be set high to open the shutter by sending a value such as 0. The logic for pin 16 is the reverse of pin 14. To open shutter B, send a value of 4 to the port. To close shutter B, send 0 to the port. Since both shutters are controlled by the same port, you must combine the values for the two shutters by addition if you have two shutters installed.

Table 4-6. Commands for the dedicated TTL line

		SHUTTER A	
		OPEN	CLOSED
SHUTTER B	OPEN	4	6
	CLOSED	0	2

4.4 Serial RS-232 Interface

The Lambda 10-2 microprocessor sets the PARALLEL port, by default, as the input source upon startup and anytime the ON LINE key is pressed. An appropriate command from the remote computer through the SERIAL port will automatically set that port as the active input source and the display on the controller will reflect that change on its bottom line. The SERIAL port will remain active until an appropriate command is sent from a remote computer through the PARALLEL port <u>or</u> until the LOCAL key is pressed on the controller keypad.

There are some basic differences in the parallel and serial physical connections. There are also basic differences in the modes by which parallel and serial data are transmitted to the controller. The command code structures, however, are quite similar. The connection and Command Structure required to control the Lambda 10-2 via the Serial port are discussed in this chapter.

4.4.1 Connecting to the Serial Port

The serial interface connector on the back of the Lambda 10-2 controller cabinet is a DB-9 connector. The connections are arranged so a standard DB-9 serial cable can be used to connect the controller to a PC serial port. The port operates on a minimal RS-232 protocol where only the ground and the two data lines are connected; the hardware control lines are not connected. This port is designed for connection to a standard computer serial port. It should not be connected to any other type of interface or device. The pin assignments for this connector are, as viewed from the back of the controller:
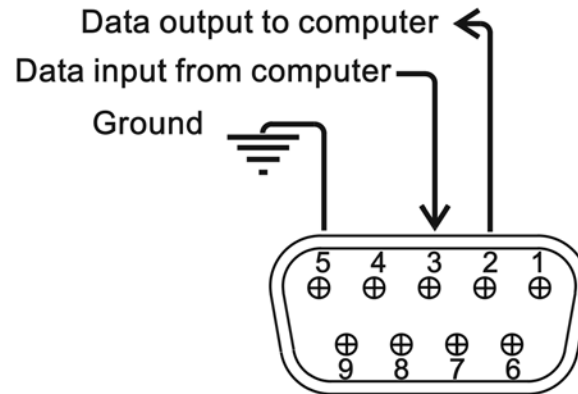
Figure 4-3. Serial port pin assignments.

Communication for the serial port requires the following settings:

- **Baud rate**   9600
- **Data bits**   8
- **Parity**   None
- **Stop bits**   1
- **Flow Control:**   None

No hardware control lines are connected. You must set the communication mode either so that these lines are ignored, or provide connections that will satisfy the mode of communication that you use. In Microsoft QuickBasic the communication channel may be opened with a statement such as:

```
OPEN "COM1:9600,N,8,1, CD0,CS0,DS0 " FOR RANDOM AS #1 LEN = 256
```

This sets COM1 to the correct mode for bi-directional communication through channel #1. The option list "CD0,CS0,DS0" causes BASIC to ignore the DCD, CTS and DSR control lines.

4.4.2 Input Command Structure

Input commands to the controller via the SERIAL port are structured as one byte (8-bits) each with the same function as the input commands (Filter and Special Commands) described in the PARALLEL port section of this chapter: Parallel port pin numbers 2 through 9 are analogous to bit numbers 1 through 8 in the one byte SERIAL port command.

4.4.2.1 Filter Commands

The binary value of an 8-bit serial port filter command defines the selected filter position, switching speed and filter wheel. To send a filter command via the serial port the binary value must first be determined for the Filter and Speed Groups (4 bits and 3 bits, respectively), as well as the Wheel bit. Then these binary values must be arranged in the proper order and converted as a group of 8-bits to its decimal equivalent.

Table 4-7. Creating a serial port filter command

	Functional Groups and Bit							
	Wheel	Speed			Filter			
Group Bit #	0	2	1	0	3	2	1	0
Decimal Group Example Values	0	5			7			
Binary Group Example Values	0	1	0	1	0	1	1	1
Binary Command Example Value	0	1	0	1	0	1	1	1
Decimal Command Example Value	87							

In Table 4-7, "Decimal Group Values" are equivalent to the values of the desired Filter Position (7), Switching Speed (5) and Filter Wheel (0 = Wheel A). The binary equivalent of each is referred to as the "Binary Group Value" and are arranged (as shown above) to yield a byte referred to as the "Binary Command Value" (the Wheel Bit is the "most significant bit"). This byte is the raw datum that serves as a Filter Command to select the Filter Position, Switching Speed and Filter Wheel on the Lambda 10-2 controller. Typically, this binary value is sent as its decimal equivalent as described below.

Since the serial data stream format is a single byte, each command can be sent as an ASCII character. If you have used a *BASIC* language open statement to establish serial communications the subsequent 8 bit command values may be sent using a *BASIC* PRINT # command such as:

```
PRINT #1, CHR$(DATANUM);
```

… where #1 is the file number used in the open statement, and DATANUM is the value of the command to be sent. Note that the CHR$ function allows the actual number to be sent rather than the ASCII numbers of the characters that represent the number. Sending ";" disables the automatic addition of characters such as a linefeed or a space.

4.4.3 Special Commands: ON LINE, SHUTTER and BATCH commands

The same Special Commands shown in the Parallel Port Chapter, Table 4-3, can be sent to the controller via the SERIAL port. The protocol used to transmit these commands is as described above in this chapter.

Transfer Control to Computer (ON LINE): When sent via the SERIAL Port this command will select the SERIAL port as the Input Source, setting the controller ON LINE. This change in Input mode will be indicated in the bottom line of the Controller display.

Shutter Control using Special Commands: Six of the eight Special Commands described in Table 4-3 are used to control the status of the shutters. All of these commands are valid SERIAL port Special Commands. The functions of each of those commands are described there. For a description of an alternative method of remote shutter control, see the description of the **Dedicated TTL Line** later in this chapter.

Batch Transfer of Commands via the Serial Port: In order to quickly transfer commands for both wheels and shutters, you should use the *BATCH TRANSFER* method. The controller will wait for commands for both wheels and both shutters before executing any of those four commands.

First send the *BATCH TRANSFER* command, 223, and then send the four commands for the 2 wheels and the 2 shutters. Send the desired commands in the following order:

1. 223
2. Shutter A command
3. Shutter B command
4. Filter/Speed/Wheel A command
5. Filter/Speed/Wheel B command

The controller will echo each command as it is sent. Once the controller has received the *BATCH TRANSFER* command, the unit will not respond with a carriage return or mechanical action until all four commands have been received. The carriage return will be sent when both wheels and shutters are in the state required by the commands. The batch transfer command must be sent each time a new batch of commands is sent. Once the batch commands have been executed as signaled by the carriage return, individual commands or additional batch commands may be sent.

With this approach, the five commands can be passed in less than 6 milliseconds. The values of each of the four types of command are distinct, so the controller may be able to respond correctly even if the four commands are sent in a different order. Sending the commands in the correct order assures the best performance.

The controller will echo each command with a delay of about 1 millisecond. If your hardware or software is not able to handle serial input and output at the same time, you may need to wait for each echoed command before sending the next command. In this case, the time to transmit the commands may increase to about 12 milliseconds.

4.4.4 Output Command Structure: Command Echo and <CR>

With the serial interface, the LAMBDA 10-2 controller responds to each command by echoing the command back to the host computer. This indicates that the command was received and will be executed promptly. If the command sent is the same as the last command received, it will not be echoed and the controller will take no action. Once the command has been executed completely, the controller will send a character with the value of 13, which is an ASCII CR (carriage return). In order to read the responses using *BASIC*, you can use a statement such as:

```
IF LOC(1) > 0 THEN SerialInput$ = INPUT$(1, #1)
```

LOC(1) > 0 indicates that characters are waiting in the received data buffer. INPUT$(1, #1) reads 1 character from the buffer, which is stored as SerialInput$. The following subroutine could be used to hold the computer in a loop until the command is properly echoed.

```
COMMANDCHECK:   IF LOC(1) > 0 THEN SerialInput$ = INPUT$(1, #1)
                IF DATANUM = ASC(SerialInput$) THEN RETURN
                GOTO COMMANDCHECK
```

A similar subroutine can be used to hold the computer in a loop until the carriage return (13) is received.

```
BUSYCHECK:      IF LOC(1) > 0 THEN SerialInput$ = INPUT$(1, #1)
                IF  ASC(SerialInput$)=13 THEN RETURN
                GOTO BUSYCHECK
```

5. MAINTENANCE

Routine cleaning of the Lambda 10-2 system is required to prevent excessive dust accumulations. This is done by wiping all exterior surfaces with a dry, soft, cotton cloth.

All retaining rings should be inspected occasionally to be certain that they are seated into the filter holders and cups.

The filter wheel is a precision-machined part mounted on a stepper motor shaft. As such, it DOES NOT REQUIRE LUBRICATION. Attempting to lubricate any part of the filter wheel or shutter assembly will void the warranty and may harm the motor or shutter.

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APPENDIX A. LIMITED WARRANTY

- Sutter Instrument Company, a division of Sutter Instrument Corporation, limits the warranty on this instrument to repair and replacement of defective components for two years from date of shipment, provided the instrument has been operated in accordance with the instructions outlined in this manual.

- Abuse, misuse, or unauthorized repairs will void this warranty.

- Limited warranty work will be performed only at the factory.

- The cost of shipment both ways is to be borne by the user.

- The limited warranty is as stated above and no implied or inferred liability for direct or consequential damages is intended.

- Consumables and Uniblitz®[1] shutters are exempt from this warranty.

- An extended warranty for up to 3 additional years can be purchased at the time of ordering, or until the original warranty expires. For pricing and other information, please contact Sutter Instrument.

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[1] Uniblitz® is a registered trademark of Vincent Associates.

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APPENDIX B. ACCESSORIES

B.1. Filter Wheels

LB10-NW	10-position 25mm filter wheel without shutter.
LB10-NWS	10-position 25mm filter wheel with Uniblitz® shutter.
LB10-NWE	10-position 25mm filter wheel set up for emission.
LB10-WD	Back-to-back mounting of two 25mm filter wheels (no drop-in filter holders).
LB10-WDS	Back-to-back mounting of two 25mm filter wheels with one Uniblitz® and one slide-in filter holder.
LB10-W32	10-position 32mm filter wheel without shutter.
LB10-W32S	10-position 32mm filter wheel with Uniblitz® shutter.
LB10-W50	5-position 50mm filter wheel without shutter.

B.2. Shutter

SHUTTER	25mm replacement Uniblitz® shutter (not an upgrade).
X100111	35mm replacement Uniblitz® shutter (not an upgrade)

B.3. Filter Holders and Liquid Light Guides

SL:IDE-IN[1]	Slide-in filter holder for 25mm filter wheel.
DROP-IN[2]	Drop-in filter holder for 25mm filter wheel.
LLG	Liquid light guide (2 meters, 3mm diameter). Includes C-mount, lens, and lens tube.

---

[1] Slide-in filter holders are for filter wheels equipped with a shutter.
[2] Drop-in filter holders are for filter wheels that are not equipped with a shutter.

B.4. Cables

W621510   15 pin shielded cable for standard filter wheel.

CSHUTTER   Shutter breakout cable (for Uniblitz® shutter).

W621505   DSUB 9 pin male/female for serial (RS-232) interface.

CMAC   DSUB 9-pin male to DIN serial cable for connecting a Macintosh (pre-Mac OS X Apple Macintosh systems only) to the serial RS-232 port.

CLAM10   25 pin breakout to BNC cable.

APPENDIX C. FUSE REPLACEMENT

In the event that the controller fails to power up when the power switch is turned on, check the line power fuse to see if it has blown. The fuse is located in the fuse holder on the power entry module on the back of the controller. To remove the fuse holder first unplug the power cord from the power entry module. This will reveal a slot just under the edge of the fuse holder. Use a screwdriver to pry the holder straight out of the power entry module.
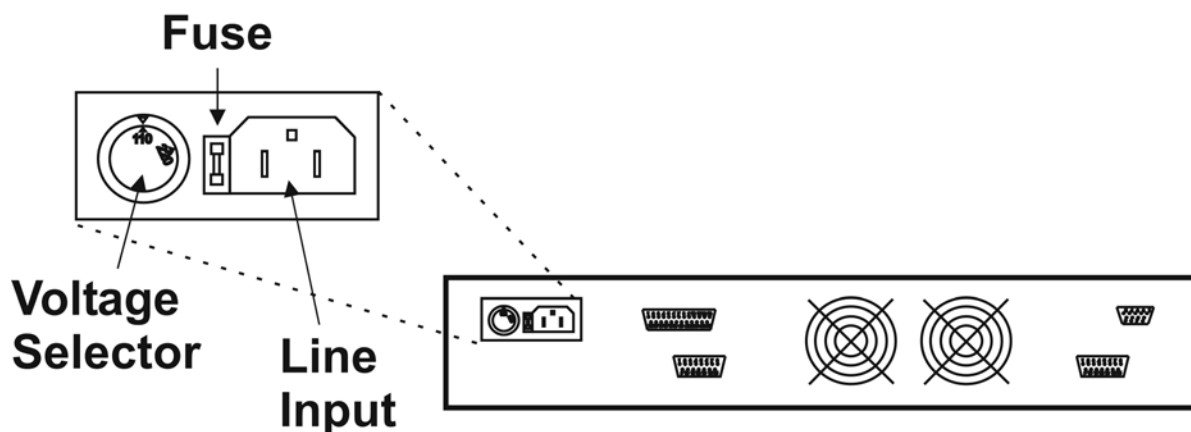
Figure 5-1. Power entry module

The fuse that is readily visible in the fuse holder when you take it out is the one that is "active" when the holder is installed. A spare fuse is also stored within the fuse holder. It is concealed in a compartment as shown in Figure 5-2. To remove the spare fuse, press down on the end of the compartment and push it out of the other end. The old fuse can serve as a convenient tool for pushing the spare fuse compartment out. Replace the active fuse with the spare and re-install the fuse holder and power cord. If the controller fails to power up with the new fuse installed, call Sutter Instrument technical support personnel for assistance.
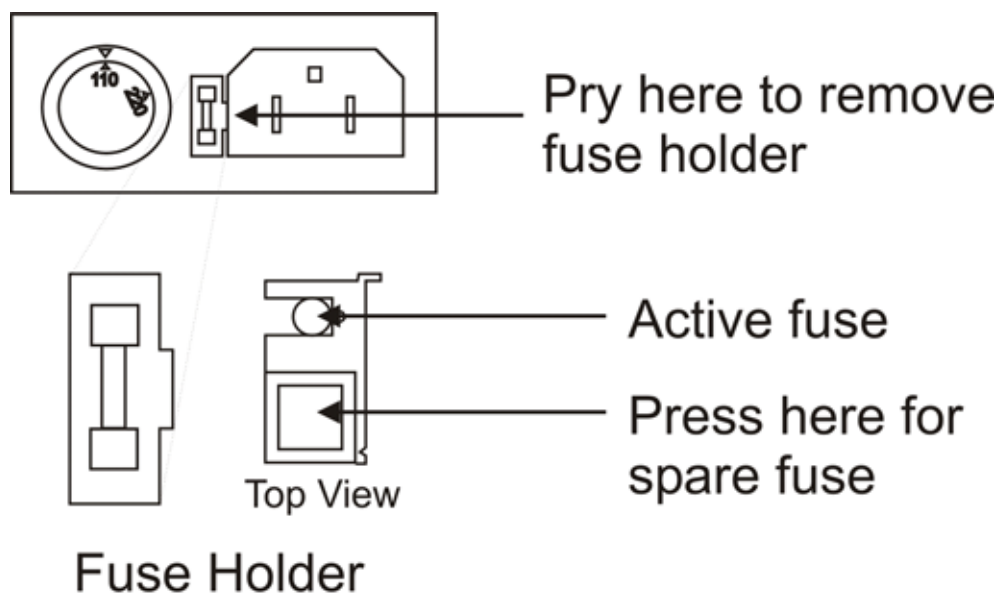
Figure 5-2. Fuse holder.

Make certain that the type and rating of the fuse being replaced are as indicated in Table C-1, according to the mains voltage setting being used.

Table C-1. Fuse type and rating.

Mains Voltage Setting	Fuse (Time Delay, 5mm x 20mm, glass tube)	
	Type and Rating	Manufacturer Examples
110V	1.5A, 250V	Bussmann GMC-1.5A or GMC-1.5-R (RoHS)
220V	T0.63A, 250V	Bussmann GDC-630mA or S506-630-R (RoHS); or Littelfuse: 218.630 or 218.063P (RoHS)

APPENDIX D. TECHNICAL SPECIFICATIONS

CE

D.1. Controller (rack mount)

Dimensions (H x W x D):   4 x 19 x 10.75 in (10 x 48.25 x 27 cm)

Weight: 9 lb., 4 oz. (4.2 kg)

Electrical:

Input voltage (Mains)   110 - 120 V at 60 Hz; or 220 – 240 V at 50 Hz

Maximum power consumption   149 VA

Mains fuse (rear of cabinet)

Table D-1. Mains fuse type and rating.

Mains Voltage Setting	Fuse (Time Delay, 5mm x 20mm, glass tube)	
	Type and Rating	Manufacturer Examples
110V	1.5A, 250V	Bussmann GMC-1.5A or GMC-1.5-R (RoHS)
220V	T0.63A, 250V	Bussmann GDC-630mA or S506-630-R (RoHS); or Littelfuse: 218.630 or 218.063P (RoHS)

Internal safety fuses (not operator accessible)

Orange line   Type T2.0A, 250V, 3AG

Orange/yellow line   Type T3.2A, 250V, 3AG

Yellow line   Type T3.2A, 250V, 3AG

Power cord   10A, 250V, with safety ground plug

Controller Cables

Table D-2. Cable specifications.

	Type	Max. Length	Ferrite at Controller End	Cabling
Filter Wheel	DB-15	6 feet	None required	Minimum of 26 awg stranded wire with 500 Volt
Parallel	DB-25	6 feet	*Fair-Rite #0443164-251	Dielectric separation of circuits. Foil shielding
Serial	DB-9	10 feet	*Fair-Rite #0443167-251	Connected to metal faceplates of connectors on both ends

* Fair-Rite Products Corp., P.O. Box J, One Commercial Row, Wallkill, NY, 12589, USA

D.2. Filter Wheel, 25 mm (1") (with Shutter, without Stand)

Dimensions (H x W x D):   6.25 x 7 x 2 in (15.88 x 17.75 x 5.8 cm)

Weight: 2 lb., 14 oz. (1.31 kg)

APPENDIX E. EXTERNAL CONTROL COMMAND REFERENCE

This appendix provides a complete list of remote control commands and return values.

Table E-1. Complete Remote-control command reference.

Command Byte Value			Keyboard Entry			Description			
Dec.	Hex.	Binary	Alt-keypad entry	Ctrl-char.	ASCII def./- char.	Filter Wheel Command			Shutter or Special Command
						W h e e l	S p e e d	F i l t e r	
0	00	00000000	Alt-0000	^@	(NUL)	A	0	0	
1	01	00000001	Alt-0001	^A	(SOH)			1	
2	02	00000010	Alt-0002	^B	(STX)			2	
3	03	00000011	Alt-0003	^C	(ETX)			3	
4	04	00000100	Alt-0004	^D	(EOT)			4	
5	05	00000101	Alt-0005	^E	(ENQ)			5	
6	06	00000110	Alt-0006	^F	(ACK)			6	
7	07	00000111	Alt-0007	^G	(BEL)			7	
8	08	00001000	Alt-0008	^H	(BS)			8	
9	09	00001001	Alt-0009	^I	(HT)			9	
10 - 15	0A - 0F	00001010 - 00001111	Alt-0010 - Alt-0015	^J - ^O	(LF) - (SI)				
16	10	00010000	Alt-0016	^P	(DLE)	A	1	0	
17	11	00010001	Alt-0017	^Q	(DC1)			1	
18	12	00010010	Alt-0018	^R	(DC2)			2	
19	13	00010011	Alt-0019	^S	(DC3)			3	
20	14	00010100	Alt-0020	^T	(DC4)			4	
21	15	00010101	Alt-0021	^U	(NAK)			5	
22	16	00010110	Alt-0022	^V	(SYN)			6	
23	17	00010111	Alt-0023	^W	(ETB)			7	
24	18	00011000	Alt-0024	^X	(CAN)			8	
25	19	00011001	Alt-0025	^Y	(EM)			9	
26 - 31	1A - 1F	00011010 - 00011111	Alt-0026 - Alt-0031	^Z - ^_	(SUB) - (US)				
32	20	00100000	Alt-0032		(space)	A	2	0	
33	21	00100001	Alt-0033		!			1	
34	22	00100010	Alt-0034		"			2	
35	23	00100011	Alt-0035		#			3	
36	24	00100100	Alt-0036		$			4	
37	25	00100101	Alt-0037		%			5	
38	26	00100110	Alt-0038		&			6	
39	27	00100111	Alt-0039		'			7	
40	28	00101000	Alt-0040		(			8	
41	29	00101001	Alt-0041		)			9	

Command Byte Value			Keyboard Entry			Description			
Dec.	Hex.	Binary	Alt-keypad entry	Ctrl-char.	ASCII def./-char.	Filter Wheel Command			Shutter or Special Command
						Wheel	Speed	Filter	
42	2A	00101010	Alt-0042		*				
-	-	-	–		–				
47	2F	00101111	Alt-0047		/				
48	30	00110000	Alt-0048		0			0	
49	31	00110001	Alt-0049		1			1	
50	32	00110010	Alt-0050		2			2	
51	33	00110011	Alt-0051		3			3	
52	34	00110100	Alt-0052		4			4	
53	35	00110101	Alt-0053		5	A	3	5	
54	36	00110110	Alt-0054		6			6	
55	37	00110111	Alt-0055		7			7	
56	38	00111000	Alt-0056		8			8	
57	39	00111001	Alt-0057		9			9	
58	3A	00111010	Alt-0058		:				
-	-	-	–		–				
63	3F	00111111	Alt-0063		?				
64	40	01000000	Alt-0064		@			0	
65	41	01000001	Alt-0065		A			1	
66	42	01000010	Alt-0066		B			2	
67	43	01000011	Alt-0067		C			3	
68	44	01000100	Alt-0068		D	A	4	4	
69	45	01000101	Alt-0069		E			5	
70	46	01000110	Alt-0070		F			6	
71	47	01000111	Alt-0071		G			7	
72	48	01001000	Alt-0072		H			8	
73	49	01001001	Alt-0073		I			9	
74	4A	01001010	Alt-0074		J				
-	-	-	–		–				
79	4F	01001111	Alt-0079		O				
80	50	01000000	Alt-0080		P			0	
81	51	01000001	Alt-0081		Q			1	
82	52	01000010	Alt-0082		R			2	
83	53	01000011	Alt-0083		S			3	
84	54	01000100	Alt-0084		T	A	5	4	
85	55	01000101	Alt-0085		U			5	
86	56	01000110	Alt-0086		V			6	
87	57	01000111	Alt-0087		W			7	
88	58	01001000	Alt-0088		X			8	
89	59	01001001	Alt-0089		Y			9	
90	5A	01001010	Alt-0090		Z				
-	-	-	–		–				
95	5F	01011111	Alt-0095		_				
96	60	01010000	Alt-0096		`			0	
97	61	01010001	Alt-0097		a	A	6	1	
98	62	01010010	Alt-0098		b			2	
99	63	01010011	Alt-0099		c			3	

| Command Byte Value | | | Keyboard Entry | | | Filter Wheel Command | | | Description |
Dec.	Hex.	Binary	Alt-keypad entry	Ctrl-char.	ASCII def./-char.	Wheel	Speed	Filter	Shutter or Special Command
100	64	01010100	Alt-0100		d			4	
101	65	01010101	Alt-0101		e			5	
102	66	01010110	Alt-0102		f			6	
103	67	01010111	Alt-0103		g			7	
104	68	01011000	Alt-0104		h			8	
105	69	01011001	Alt-0105		i			9	
106 - 111	6A - 6F	01011010 - 01011111	Alt-0106 – Alt-0111		j – o				
112	70	01110000	Alt-0112		p			0	
113	71	01110001	Alt-0113		q			1	
114	72	01110010	Alt-0114		r			2	
115	73	01110011	Alt-0115		s			3	
116	74	01110100	Alt-0116		t	A	7	4	
117	75	01110101	Alt-0117		u			5	
118	76	01110110	Alt-0118		v			6	
119	77	01110111	Alt-0119		w			7	
120	78	01111000	Alt-0120		x			8	
121	79	01111001	Alt-0121		y			9	
122 - 127	7A – 7F	01111010 - 01111111	Alt-0122 – Alt-0127		z – (DEL)				
128	80	10000000	Alt-0128					0	
129	81	10000001	Alt-0129					1	
130	82	10000010	Alt-0130					2	
131	83	10000011	Alt-0131					3	
132	84	10000100	Alt-0132			B	0	4	
133	85	10000101	Alt-0133					5	
134	86	10000110	Alt-0134					6	
135	87	10000111	Alt-0135					7	
136	88	10001000	Alt-0136					8	
137	89	10001001	Alt-0137					9	
138 - 143	8A - 8F	10001010 - 10001111	Alt-0138 - Alt-0143						
144	90	10010000	Alt-0144					0	
145	91	10010001	Alt-0145					1	
146	92	10010010	Alt-0146					2	
147	93	10010011	Alt-0147					3	
148	94	10010100	Alt-0148			B	1	4	
149	95	10010101	Alt-0149					5	
150	96	10010110	Alt-0150					6	
151	97	10010111	Alt-0151					7	
152	98	10011000	Alt-0152					8	
153	99	10011001	Alt-0153					9	

Command Byte Value			Keyboard Entry			Description			
Dec.	Hex.	Binary	Alt-keypad entry	Ctrl-char.	ASCII def./-char.	Filter Wheel Command			Shutter or Special Command
						Wheel	Speed	Filter	
154 - 159	9A - 9F	10011010 - 10011111	Alt-0154 - Alt-0159						
160	A0	10100000	Alt-0160			B	2	0	
161	A1	10100001	Alt-0161					1	
162	A2	10100010	Alt-0162					2	
163	A3	10100011	Alt-0163					3	
164	A4	10100100	Alt-0164					4	
165	A5	10100101	Alt-0165					5	
166	A6	10100110	Alt-0166					6	
167	A7	10100111	Alt-0167					7	
168	A8	10101000	Alt-0168					8	
169	A9	10101001	Alt-0169					9	
170	AA	10101010	Alt-0170						Open Shutter A
171	AB	10101011	Alt-0171						Open Shutter A conditionally
172	AC	10101100	Alt-0172						Close Shutter A
185 - 175	AD - AF	10101101 - 10101111	Alt-0185 - Alt-0175						
176	B0	10110000	Alt-0176			B	3	0	
177	B1	10110001	Alt-0177					1	
178	B2	10110010	Alt-0178					2	
179	B3	10110011	Alt-0179					3	
180	B4	10110100	Alt-0180					4	
181	B5	10110101	Alt-0181					5	
182	B6	10110110	Alt-0182					6	
183	B7	10110111	Alt-0183					7	
184	B8	10111000	Alt-0184					8	
185	B9	10111001	Alt-0185					9	
186	BA	10111010	Alt-0186						Open Shutter B
187	BB	10111011	Alt-0187						Open Shutter B conditionally
188	BC	10111100	Alt-0188						Close Shutter B
189 - 191	BD - BF	10111101 - 10111111	Alt-0189 - Alt-0191						
192	C0	11000000	Alt-0192			B	4	0	
193	C1	11000001	Alt-0193					1	
194	C2	11000010	Alt-0194					2	
195	C3	11000011	Alt-0195					3	
196	C4	11000100	Alt-0196					4	
197	C5	11000101	Alt-0197					5	
198	C6	11000110	Alt-0198					6	
199	C7	11000111	Alt-0199					7	
200	C8	11001000	Alt-0200					8	
201	C9	11001001	Alt-0201					9	

| Command Byte Value | | | Keyboard Entry | | | Filter Wheel Command | | | Description |
Dec.	Hex.	Binary	Alt-keypad entry	Ctrl-char.	ASCII def./-char.	Wheel	Speed	Filter	Shutter or Special Command
202 - 207	CA - CF	11001010 - 11001111	Alt-0202 - Alt-0207						
208	D0	11000000	Alt-0208					0	
209	D1	11000001	Alt-0209					1	
210	D2	11000010	Alt-0210					2	
211	D3	11000011	Alt-0211					3	
212	D4	11000100	Alt-0212			B	5	4	
213	D5	11000101	Alt-0213					5	
214	D6	11000110	Alt-0214					6	
215	D7	11000111	Alt-0215					7	
216	D8	11001000	Alt-0216					8	
217	D9	11001001	Alt-0217					9	
218 - 222	DA - DE	11001010 - 11001110	Alt-0218 - Alt-0222						
223	DF	11011111	Alt-0223						Batch Transfer of next 4 bytes (2 shutter and 2 filter wheel commands)
224	E0	11100000	Alt-0224					0	
225	E1	11100001	Alt-0225					1	
226	E2	11100010	Alt-0226					2	
227	E3	11100011	Alt-0227					3	
228	E4	11100100	Alt-0228			B	6	4	
229	E5	11100101	Alt-0229					5	
230	E6	11100110	Alt-0230					6	
231	E7	11100111	Alt-0231					7	
232	E8	11101000	Alt-0232					8	
233	E9	11101001	Alt-0233					9	
234 - 237	EA - ED	11101010 - 11101101	Alt-0234 - Alt-0237						
238	EE	11101110	Alt-0238						On Line
239	EF	11101111	Alt-0239						
240	F0	11110000	Alt-0240					0	
241	F1	11110001	Alt-0241					1	
242	F2	11110010	Alt-0242					2	
243	F3	11110011	Alt-0243					3	
244	F4	11110100	Alt-0244			B	7	4	
245	F5	11110101	Alt-0245					5	
246	F6	11110110	Alt-0246					6	
247	F7	11110111	Alt-0247					7	
248	F8	11111000	Alt-0248					8	
249	F9	11111001	Alt-0249					9	
250 - 255	FA - FF	11111010 - 11111111	Alt-0250 - Alt-0255						

NOTE 1: Bit 7 is used to select either Wheel A or B. The bit is set to 0 for Wheel , and is set to 1 for Wheel B.

NOTE 2: The "ASCII def./char." column for codes 128 through 255 (80 through FF hex) is left blank, since there are no ASCII character definitions for the codes in this range. However, many computers and operating systems do support characters within this range, although there is no single standard across all platforms. Furthermore, many operating systems, such as Microsoft Windows and Apple Mac OS X, have several "code pages" (character sets), many of which are country/language specific, from which the user can select. Therefore, this part of the table is left blank – if you wish, you may write in the characters defined in the character set you use on a regular basis.

Table 2. Filter command structure.

Byte Bit Positional #	7	6	5	4	3	2	1	0
Functional Bit Groups	Wheel	Speed			Filter Position			
Group Bit #	0	2	1	0	3	2	1	0
Decimal Group Values	0-1	0-7			0-9			
Binary Group Values	0-1	000-111			0000-1001			
Parallel Port Pin #	9	8	7	6	5	4	3	2

Encoding filter wheel commands into a single byte:

Command byte = (*wheel* * 128) + (*speed* * 16) + *position*

Where   *wheel*   =   0 (Wheel A) or 1 (Wheel B),
           speed   =   0 through 7, and
           position =   0 through 9.

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<u>NOTES</u>

NOTES