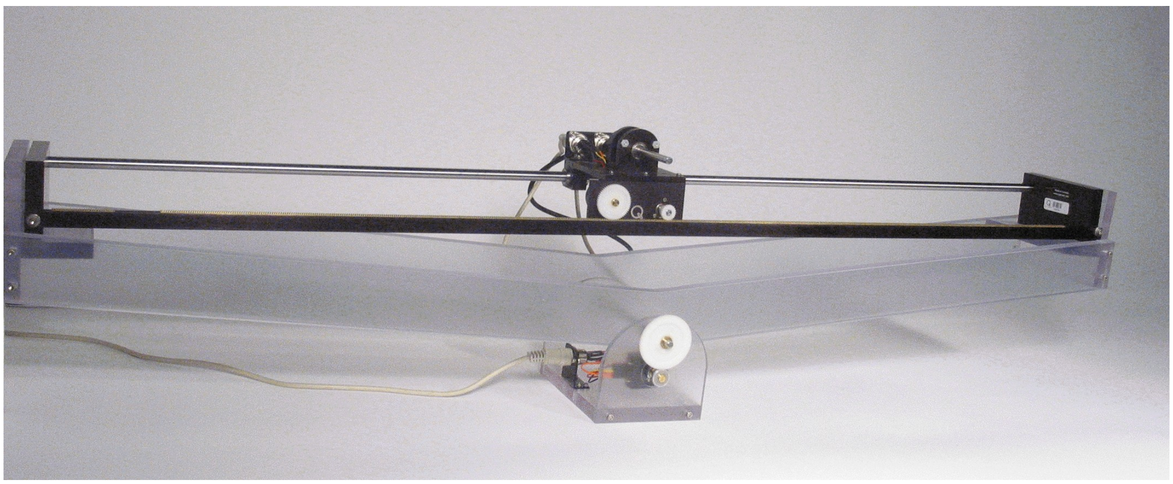
Linear Motion Servo Plants: IP01 and IP02

Seesaw



User Manual

Table of Contents

1. SEESAW(-E) Supporting a Linear Cart (IP01 or IP02)

1.1. SEESAW(-E): System Description

As illustrated in Figure 1, below, the SEESAW(-E) module is designed to accommodate either the IP01 or IP02 system, which is to say that the IP01 or IP02 cart and track can be placed on top of the seesaw. The Seesaw module per se is shown in Figure 2, below, and consists of two long arms hinged onto a support fulcrum. The system is manufactured of precisely machined polycarbonate with a durable matte finish. The seesaw can tilt freely about a rotation (a.k.a. pivot) axis mounted on an instrumented fulcrum. In order to measure the seesaw tilt angle, the rotation axis is coupled to either a potentiometer or an encoder through a pinion-and-anti-backlash-gear system. The resulting gear ratio is 3:1. If the SEESAW module is used, the tilt angle is measured using a potentiometer. If the SEESAW-E module is used, then the potentiometer is replaced with a 1024-line quadrature optical encoder to sense the position angle.

As previously mentioned, the IP01 or IP02 cart-and-rack system can easily be placed on top of the seesaw. The powered cart (e.g. IP01 or IP02) can then travel freely along the length of the seesaw. Both IP01 and IP02 are solid aluminum carts. They are driven by a rack and pinion mechanism using a 6-Volt DC motor, ensuring consistent and continuous traction. Such cart slides along a stainless steel shaft using linear bearings. The cart position is measured using a sensor coupled to the rack via an additional pinion. Please review Reference [1] for a complete description of both IP01 and IP02 systems.

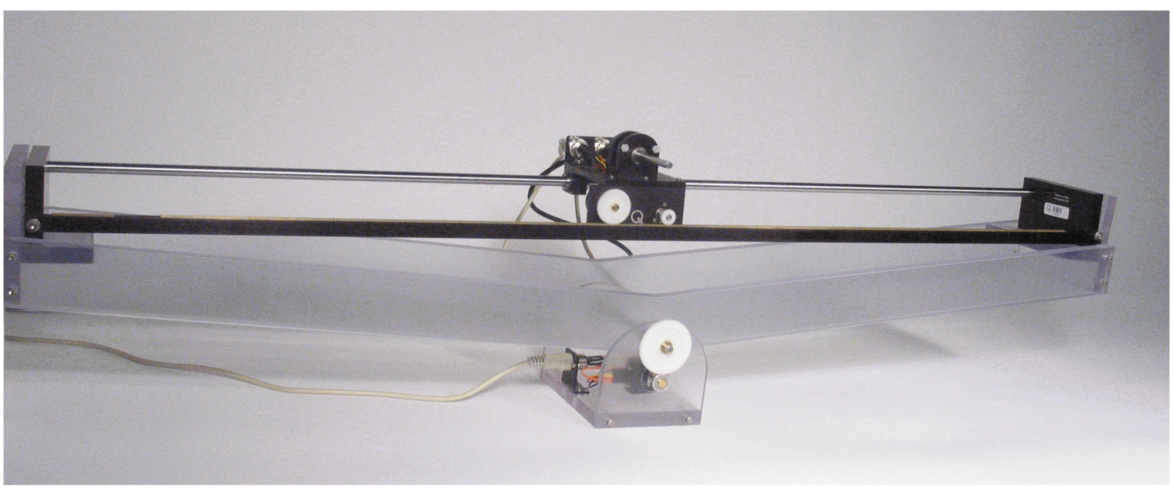


Figure 1 IP02 on the SEESAW-E

1.2. Seesaw Experiment: Control Challenge

As illustrated in Figure 1, above, the objective of the seesaw experiment is to design a control system to maintain the seesaw balanced using a sliding powered mass.

The system is supplied with a state-feedback controller but, of course, you may design any other controller you wish. The ability to vary parameters and the hardware configuration is also available should you wish to change the dynamics of the challenge. The complete mathematical modelling and system parameters are provided to streamline the implementation of the control theory of your choice.

2. SEESAW(-E) Module: Applications

Quanser values itself for the modularity of its experiments. This modular philosophy facilitates the change from one experimental setup to another with relative ease of work.

Table 1, below, provides a list of the Quanser linear motion experiments using the SEESAW(-E) module. Quanser's basic linear motion servo plants are the IP01 and the IP02. The seesaw can be used in combination with other Quanser modules, as described in Table 1.

Experiment Name	*Experiment Description*
Linear Flexible Joint Cart on Seesaw (LFJ on Seesaw)	Design of a control system to balance a seesaw using a flexible structure mounted atop of it.
Single Inverted Pendulum on a Seesaw (Seesaw / Pendulum)	Design of a control system to balance an inverted pendulum on top of a seesaw (MIMO system).

Table 1 IP01- and IP02-Based Experiments Involving the SEESAW(-E) Module

3. SEESAW(-E) Description

3.1. Component Nomenclature

Figures 2 and 3, below, depict the SEESAW-E module.

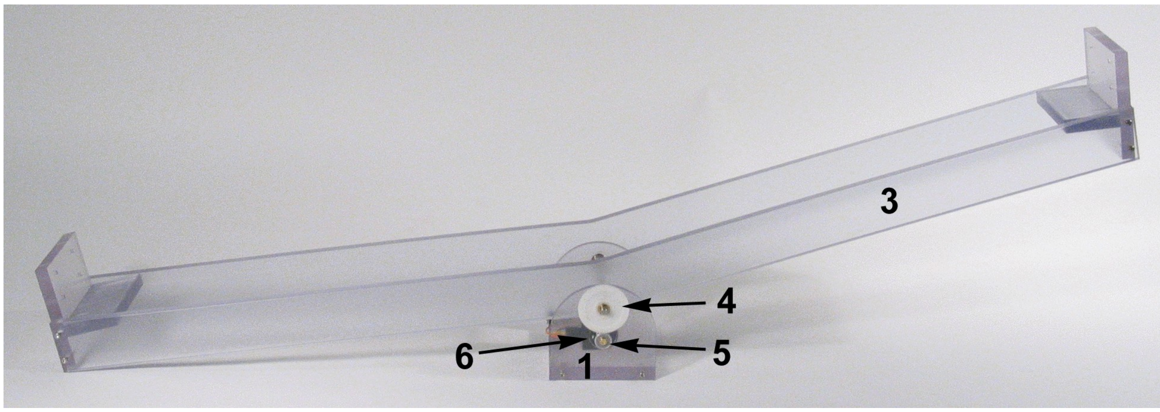


Figure 2 SEESAW-E Nomenclature

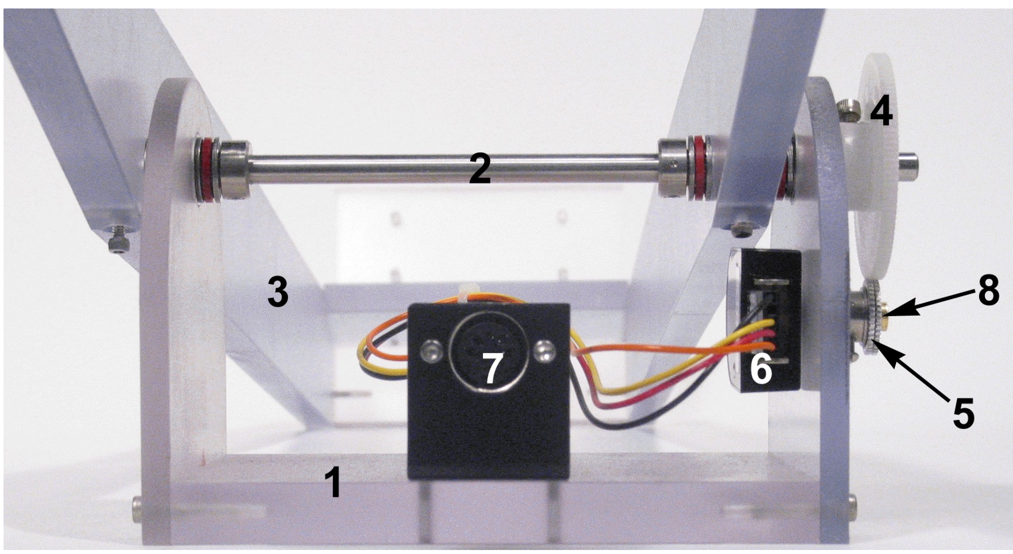


Figure 3 SEESAW-E Fulcrum Close-Up

As a component nomenclature, Table 2, below, provides a list of all the principal elements composing the SEESAW-E system. Each of these elements is located and identified, through a unique identification (ID) number, as represented in Figures 2 and 3, above.

ID #	Description	ID #	Description
1	Support Fulcrum	**2**	Pivot Axis
3	Seesaw Arm	**4**	Seesaw Position Pinion
5	Encoder Anti-Backlash Gear	**6**	Encoder
7	Encoder Connector	**8**	Encoder Shaft

Table 2 SEESAW-E Component Nomenclature

It is reminded that the SEESAW module is basically the same system as the SEESAW-E except that a potentiometer replaces the encoder.

3.2. Space Requirements

When mounted on the SEESAW(-E) module, both IP01 and IP02 systems require an overall space of 44-inch long by 16-inch high by 8-inch deep, as characterized in Table 3, below.

Description	Value	Unit
Overall SEESAW(-E)-plus-IP01_2 System Length	1.12	m
Overall SEESAW(-E)-plus-IP01_2 System Height	0.40	m
Overall SEESAW(-E)-plus-IP01_2 System Depth	0.20	m

Table 3 Overall Dimensions of the SEESAW(-E)-plus-IP01-or-IP02 System Space Requirements

3.3. Component Description

3.3.1. SEESAW Potentiometer

If the SEESAW module is used (instead of SEESAW-E), the encoder depicted by component #6 in Figure 3 is replaced with a potentiometer to sense the seesaw tilt angle. The SEESAW potentiometer is a **Vishay Spectrol model 138-0-0-103**. Its wiring diagram is depicted in Figure 4. No bias resistor is used. Under normal operations, the potentiometer's terminals 1 and 3 are connected to a ±12 Volt DC power supply from, for example, a Quanser VoltPAQ-X1 (see Reference [2]). The main specifications of the SEESAW potentiometer are included in Appendix A.

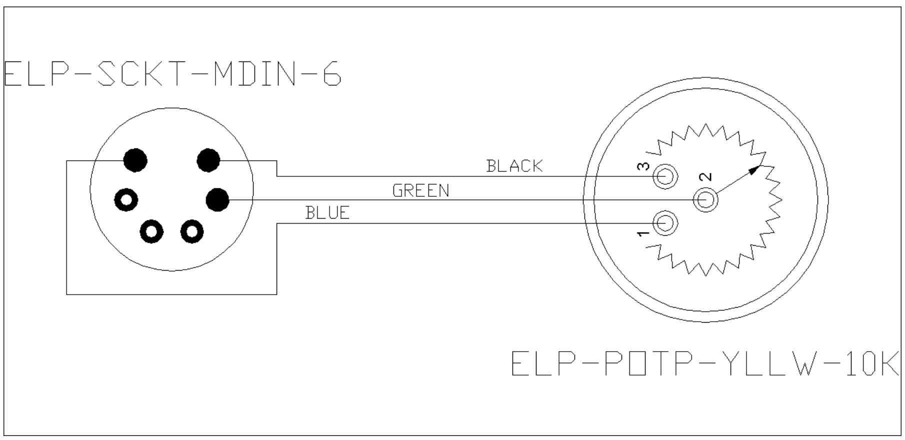


Figure 4 Wiring Diagram of the SEESAW Potentiometer

If the SEESAW potentiometer does not measure correctly, you should:

- Verify that your DAQ board is functional. In the case of the Q4 or Q8 Quanser HIL board, ensure the red LED on the board is on. If it is not, the fuse may be burnt and need replacement. Refer to Reference [4] as necessary. Also ensure that you are using the right driver corresponding to your type of DAQ. With the computer OFF, make sure the DAQ (or equivalent) is properly installed in the PC. To check the analog-to-digital conversion from the analog input channel that you are using on the, you could run an analog loopback example. See the corresponding example in the Q4/Q8 User Manual (Reference [3]) if using the Q4/Q8 HIL device.
- Ensure all cables are properly connected.
- Check that the power amplifier (e.g. VoltPAQ-X1) is functional. The power to the amplifier needs to be switched on in order for it to supply the potentiometer with ±12VDC.
- Measure the voltage across the potentiometer. Prior to doing that, ensure that the po-

tentiometer is powered with ±12VDC at the 6-pin-mini-DIN connector, as shown in Figure 5, below. You should observe ±12VDC at the potentiometer terminals 1 and 3. Moreover, if the voltage from the wiper does not change when you manually rotate the potentiometer shaft (measuring with, for example, a voltmeter or an oscilloscope), your potentiometer may need to be replaced. To obtain technical assistance, please refer to Section Obtaining Support on page 12 for information on contacting Quanser.

3.3.2. SEESAW-E Encoder (Component #6)

On the SEESAW-E, the seesaw tilt angle is measured with one optical encoder, which is represented in Figures 2 and 3, above, by component #6. The encoder model used in the SEESAW-E is a **US Digital S1 single-ended optical shaft encoder**. It offers a high resolution of 4096 counts per revolution (i.e. 1024 lines per revolution with two channels in quadrature). The complete specification sheet of the S1 optical shaft encoder is included in Appendix B.

The internal wiring diagram of the SEESAW-E encoder is depicted in Figure 5. The standard 5-pin DIN connector shown in Figure 5 is also pictured as component #7 in Figure 3.

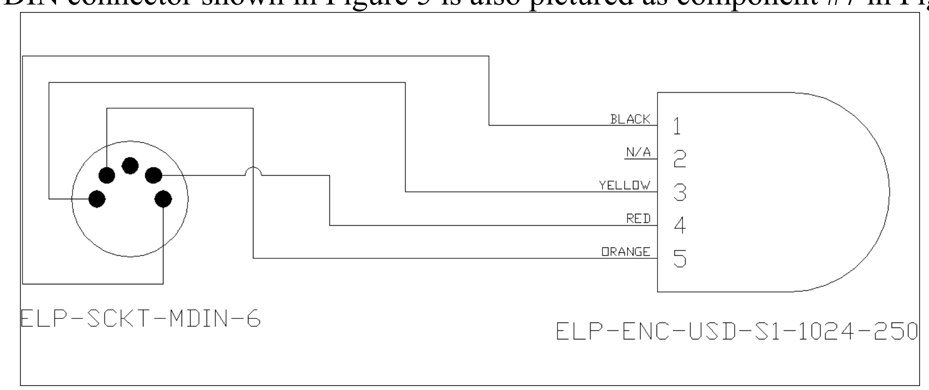


Figure 5 Wiring Diagram of the SEESAW-E Encoder

If the SEESAW-E encoder does not measure correctly, you should:

- Check that your DAQ board is functional. In the case of the Q4/Q8 HIL board, ensure the red LED on the board is lit. If it is not, the fuse may be burnt and need replacement. Refer to Reference [4] as necessary. Also ensure that you are using the right driver corresponding to your type of DAQ device and that you have an encoder chip that it is properly installed. Lastly, with the computer OFF make sure the DAQ is properly installed in the PC.
- Check that both signals from the encoder channels A and B are properly generated and fed to the DAQ (ensure all cables are properly connected). Using an oscilloscope, you should observe, when manually rotating the encoder shaft, two square

waves, representing channels A and B, with a phase shift of 90ºe (between the rising edge of the two channels). If you believe that your encoder is damaged and need to be replaced, refer to Section Obtaining Support, below, for information on contacting Quanser for technical support.

4. SEESAW(-E) Model Parameters

Table 4, below, lists and characterizes the main parameters associated with the Quanser's SEESAW(-E) module. These parameters are particularly useful for the mathematical modelling and simulation of the seesaw system(s).

Symbol	*Description*	*Value*	*Unit*
M_{sw}	Mass of the one-SEESAW(-E)-plus-one-IP01-or-IP02-Track System	3.6	kg
K_{gs}	SEESAW(-E) Geartrain Gear Ratio	3	
D_T	Distance from Pivot to the IP01 or IP02 Track	0.125	m
D_c	Distance from Pivot to the Centre Of Gravity of the one-SEESAW(-E)-plus-one-IP01-or-IP02-Track System	0.058	m
J_{sw}	Moment of Inertia of the one-SEESAW(-E)-plus-one-IP01-or-IP02-Track System, about its Center Of Gravity	0.395	$kg.m^2$
B_{sw}	Viscous Damping Coefficient as seen at the Seesaw Pivot Axis	≈0	N.m.s/rad
g	Gravitational Constant on Earth	9.81	m/s^2
K_{P_SW}	SEESAW Potentiometer Sensitivity	-0.2482	rad/V
K_{E_SW}	SEESAW-E Encoder Resolution	0.0015	rad/count
è_{range}	SEESAW(-E) Approximative Angular Range on a Flat Surface	±11.5	º

Table 4 SEESAW(-E) System Parameters

5. IP01 or IP02 on SEESAW(-E): Configuration and Setup

Figure 6, below, illustrates an IP02 cart-and-rack system mounted on top of a SEESAW-E, in the default configuration.

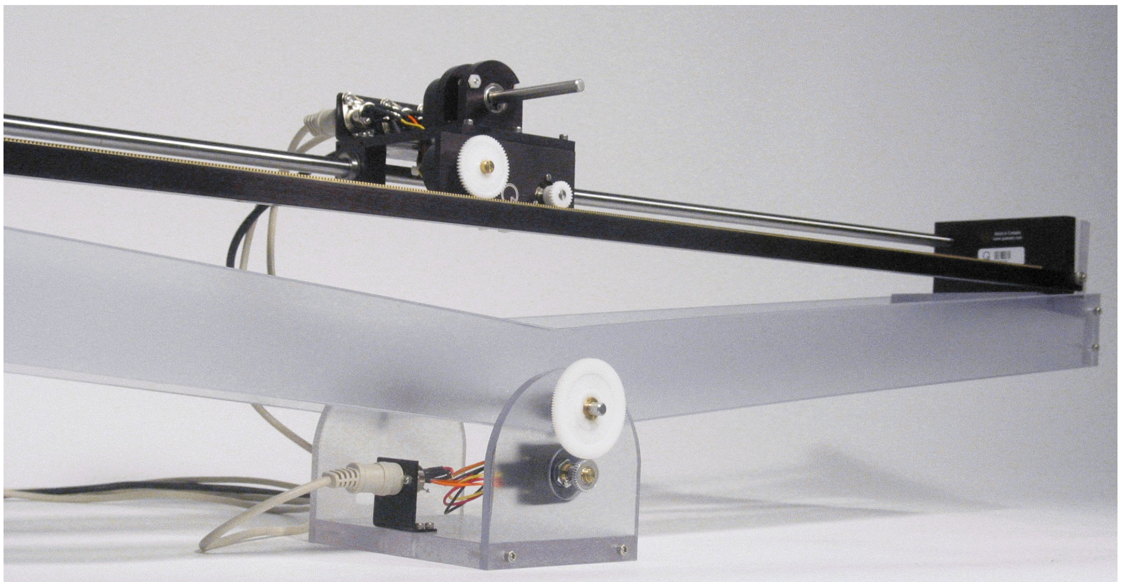


Figure 6 Configuration of the IP02 and SEESAW-E System

5.1. One-SEESAW(-E)-Plus-One-IP01-or-IP02 System: Default Configuration

The default configuration for the one-SEESAW(-E)-plus-one-IP01-or-IP02 system is the one used in the Quanser seesaw laboratory, as decribed in References [5] and [6].

The default configuration can be described as follows:

For both IP01 and IP02 cart-and-track systems, the default configuration consists of the cart without its additional weight on it. Also the pendulum rod itself is not used and should be removed. Lastly, the IP01 or IP02 rack should be located on top of the SEESAW(-E) in such a way that all the system's pinions face the same side, as shown in Figure 6.

5.2. Setup Procedure for the Default Configuration

The setup procedure for the default configuration, as previously described, is as follows:

Step 1. Do not mount the pendulum rod on your IP01 or IP02 cart. Remove it if necessary.

Step 2. Do not place the additional weight on your IP01 or IP02 cart. Remove it if necessary.

Step 3. Place your IP01 or IP02 cart and rack system on top of your SEESAW(-E) module. Make sure to locate the rack in such a way that the IP01 or IP02 cart pinions are on the same side as the SEESAW(-E) gears, as shown in Figure 6. Turn the rack around if necessary.

Step 4. Wire both your IP01 or IP02 cart and SEESAW(-E) module as described in the following Section, Typical Cabling Connections.

5.3. Typical Cabling Connections

The typical cabling connections detailed in this section are used by default in, for example, the Quanser seesaw laboratory decribed in References [5] and [6]. These cabling connections use standard cables, whose description and nomenclature can be found in Reference [1]. The connections are illustrated in Figure 7 and summarized in Table 5.

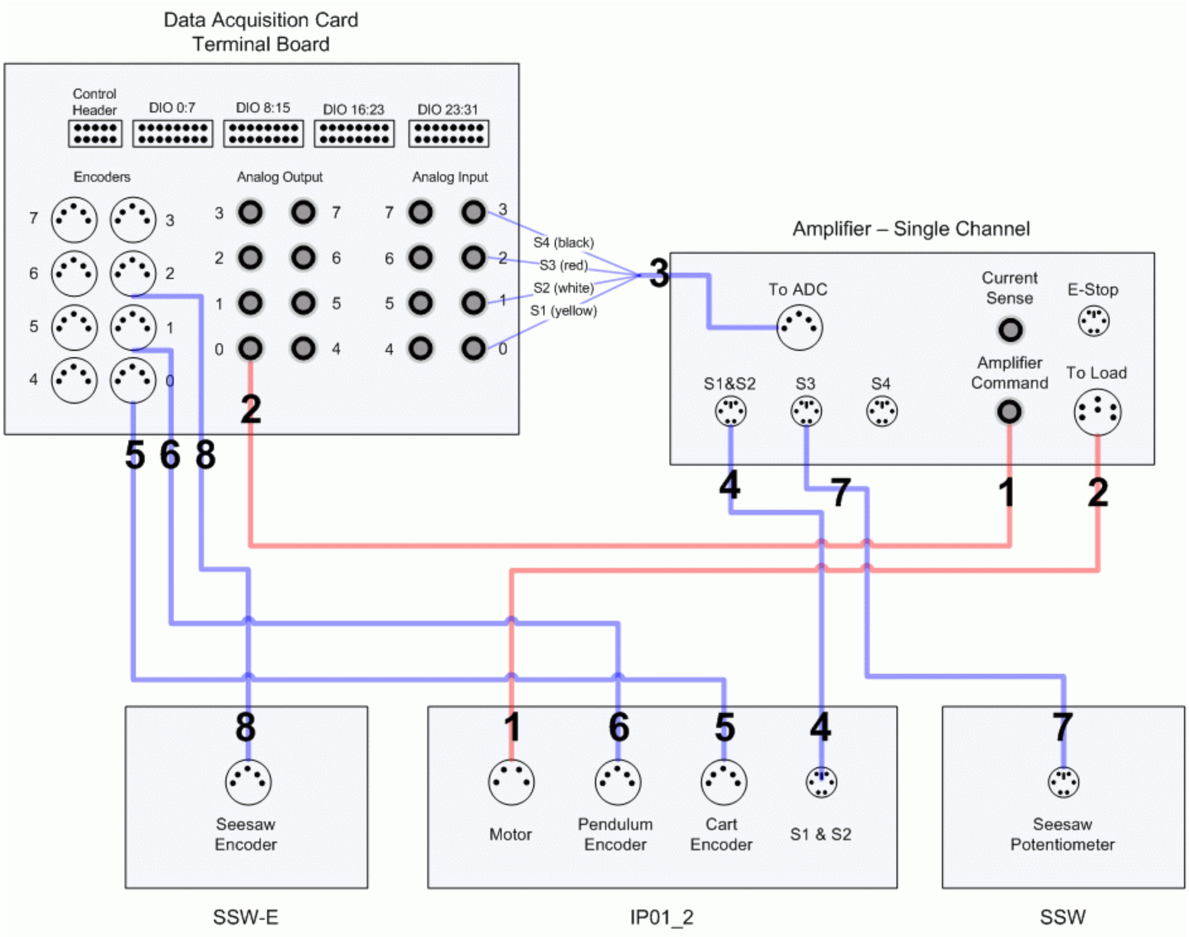


Figure 7: IP01_2 and SSW(-E) Connection diagram

Cable #	***From***	***To***	***Signal***
1	Terminal Board: Analog Output #0	Amplifier "Amplifier Command" connector	Control signal to the amplifier
2	Amplifier "To Load" connector	IP01_2 "Motor" connector	Power leads to the IP01_2 DC motor.
3	Amplifier "To ADC" connector	Terminal Board: S1 to Analog Input #0 S2 to Analog Input #1 S3 to Analog Input #2 S4 to Analog Input #3	Carries the analog signals connected to the S1 & S2, S3, and S4 connectors on the amplifier to the data-acquisition board.
4	Amplifier "S1 & S2" connector	IP01 "S1 & S2" connector	IP01 cart (S1/AI #0) and pendulum (S2/AI #1) potentiometer measurements.
5	Terminal Board: Encoder Input #0	"IP02 Cart" encoder connector	IP02 cart position measurement.
6	Terminal Board: Encoder Input #1	"IP02 Pendulum" encoder connector	IP02 pendulum shaft angle measurement.
7	Amplifier "S3" connector	SSW "Potentiometer" connector	Seesaw (S3/AI #2) angle potentiometer measurements.
8	Terminal Board: Encoder Input #2	SSW-E "Encoder" connector	Seesaw angle encoder measurement.

Table 5: IP01_2 and SSW(-E) connections summary

5.3.1. IP01 or IP02 Connections

Wire up your IP01 or IP02 cart as per dictated in Reference [1], where the Quanser's standard wiring conventions for the IP01 and IP02 systems are fully described.

5.3.2. SEESAW Connections

The SEESAW potentiometer is wired to one 6-pin mini DIN socket, as represented in the wiring schematic in Figure 4.

The standard cabling procedure of the SEESAW potentiometer is described below:

- **Connect the "From Analog Sensors" Cable**
  The "From Analog Sensors" cable is the 6-pin-mini-DIN-to-6-pin-mini-DIN cable described Reference [1]. First connect one end of the cable to the SEESAW S3 (i.e. potentiometer) connector. Then connect its other end to the amplifier socket labelled **"S3"**, which is contained inside the amplifier "From Analog Sensors" front panel. If you are using the Quanser VoltPAQ-X1, then review Reference [2] for a full description of your device.
- **Connect the "To Analog-To-Digital" Cable**
  The "To Analog-To-Digital" cable is the 5-pin-DIN-to-4xRCA cable described in Reference [1]. First if this is not already done, connect the cable 5-pin-DIN connector to the amplifier socket labelled **"To A/D"**. The other end of the cable is split into four RCA connectors, each one labelled with a single digit ranging from one to four. This numbering corresponds to the four possible analog sensor signals passing through the amplifier, namely S1, S2, S3 and S4. In order for the analog signals to be used in software, you should then connect all four RCA connectors to the first four analog input channels of your DAQ terminal board. Specifically, connect S1 to Analog Input 0, S2 to Analog Input 1, **S3 to Analog Input 2**, and S4 to Analog Input 3. Take particular care to connect S3 to Analog Input 2, since S3 carries the seesaw potentiometer voltage signal (proportional to its tilt angle).

5.3.3. SEESAW-E Connections

The SEESAW-E encoder should be directly connected to a Quanser terminal board. To do so, proceed as described below:

- **Connect the "Encoder" Cable**
  The "Encoder" cable is the 5-pin-stereo-DIN-to-5-pin-stereo-DIN cable described in Reference [1]. First connect one end of the cable to the **SEESAW-E Encoder Connector**, which is shown as component #7 in Figure 3. Then connect the other cable end to the **Encoder Input 2** on your DAQ terminal board.

CAUTION: Any encoder should be directly connected to the Quanser terminal board (or equivalent) using a standard 5-pin DIN cable. **DO NOT connect the encoder cable to the amplifier!**

6. Obtaining Support

Note that a support contract may be required to obtain technical support. To obtain support from Quanser, go to http://www.quanser.com and click on the *Tech Support* link. Fill in the form with all requested software version and hardware information and a description of the problem encountered. Submit the form. Be sure to include your email address and a telephone number where you can be reached. A qualified technical support person will contact you.

7. References

[1] *IP01 and IP02 User Manual*.
[2] Power Amplifier User Manual.
[3] *QUARC User Manual* (type doc quarc in Matlab to access).
[4] DAQ User Manual.
[5] *IP01 and IP02 - Seesaw – Linear Experiment #8: LQR Control - Student Handout*.
[6] *IP01 and IP02 - Seesaw – Linear Experiment #8: LQR Control – Instructor Manual*.

Appendix A. SEESAW Potentiometer Specification Sheet

1-5/16" (33.3mm) Low Cost Industrial Single Turn Wirewound, Conductive Plastic, Cermet

FEATURES

- Choice of Three Elements for Broad Resistance Range
- Center Tap Available
- Continuous Rotation & Mechanical Stops Both Standard
- High Power Rating (139)

ELECTRICAL SPECIFICATIONS

PARAMETER	MIL-PRF-12934/MIL-PRF-39023 TEST PROCEDURES APPLY	
	STANDARD	**SPECIAL**
Total Resistance: Model 132 Wirewound	5Ω to 20KΩ	to 35KΩ
Tolerance: 50Ω and above	± 3%	± 1%
Below 50Ω	± 5%	± 3%
Model 138 Conductive Plastic	1KΩ to 50KΩ	–
Tolerance:	± 10%	± 5%
Model 139 Cermet	500Ω to 2MΩ	–
Tolerance:	± 20%	± 5%
Linearity (Independent)	**STANDARD**	**BEST PRACTICAL**
Total Resistance (132)		
5Ω to 20Ω	± 1.0%	± 0.75%
20Ω to 200Ω	± 1.0%	± 0.50%
200Ω and above	± 0.5%	± 0.25%
138/139	± 0.5%	± 0.25%
Noise (132)	100Ω ENR	
Output Smoothness (138 & 139)	0.1% maximum	
Power Rating	40°C Ambient	
Model 132	2.75 watts	
Model 138	2 watts	
Model 139	5 watts	
	All Models derated to zero at 125°C	

Electrical Rotation	MODEL 132	MODEL 138	MODEL 139
Continuous	352° ± 2°	345° ± 4°	345° ± 4°
Stops	336° ± 2°	336° ± 4°	336° ± 4°

Insulation Resistance	1000MΩ minimum at 500VDC
Dielectric Strength	$1000V_{RMS}$, 60Hz
Absolute Minimum Resistance	1.0% of total resistance or 0.5Ω whichever is greater (132 only)
Minimum Voltage	0.5% maximum
Temperature Coefficient of Resistance	
132	Refer to standard resistance element data
138	± 500ppm/°C maximum
139	± 100ppm/°C maximum

MATERIAL SPECIFICATIONS

Housing	Molded glass filled thermoplastic
Rear Lid	Glass filled thermoset plastic
Shaft	Stainless steel, non-magnetic
Terminals	Brass, plated for solderability, Non-passivated
Mount Hardware	
Lockwasher Internal Tooth:	Steel, nickel plated
Panel nut:	Brass, nickel plated

ENVIRONMENTAL SPECIFICATIONS

Vibration	15Gs thru 2000 Hz
Shock	50g
Salt Spray	48 Hours
Rotational Life	
Shaft Revolutions	
Model 132	500,000
Model 138	2 million
Model 139	2 million
Operating Temperature Range	- 55°C to + 125°C
Moisture Resistance	–

ORDERING INFORMATION

The Models 132, 138 and 139 can be ordered from this specification sheet by stating. Example: **139 - 0 - 0 - 203**

139	**0**	**0**	**203**
MODEL	MECHANICAL OPTIONS	OTHER OPTIONAL FEATURES	RESISTANCE CODE
132, 138 or 139	**0**. Continuous **2**. Stops	**0**. Standard (End Taps) **1**. Center Tap (Within 5° of Electrical Center)	**2**: 1st Significant digit **0**: 2nd significant digit **3**: Number of Zero's

Other characteristics will be standard as described on this specification sheet. If special characteristics are required such as special linearity tolerance, special resistance tolerance, non-linear functions, etc., please state these on your order

Appendix B. SEESAW-E Encoder Specification Sheet

S1 & S2 Optical Shaft Encoders

Description:

The **S1** and **S2** series optical shaft encoders are non-contacting rotary to digital converters. Useful for position feedback or manual interface, the encoders convert real-time shaft angle, speed, and direction into TTL-compatible quadrature outputs with or without index. The encoders utilize an unbreakable mylar disk, metal shaft and bushing, LED light source, and monolithic electronics. They may operate from a single +5VDC supply.

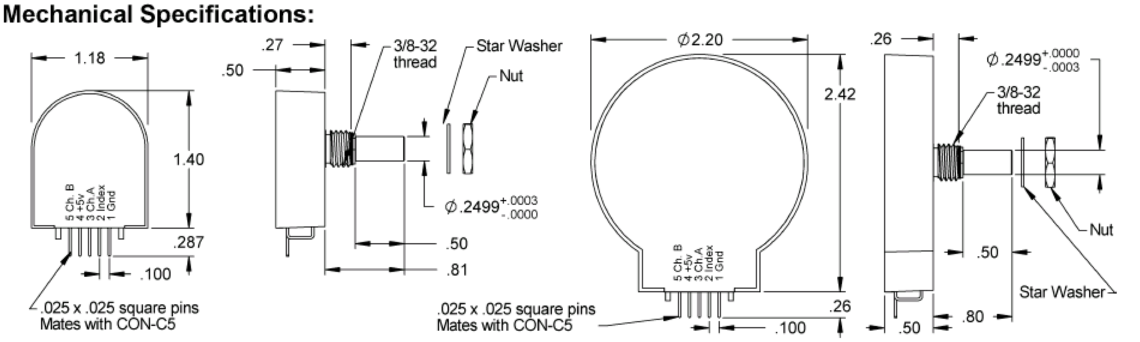
The **S1** and **S2** encoders are available with ball bearings for motion control applications or torque-loaded to feel like a potentiometer for front-panel manual interface.

Electrical Specifications:
B leads A for clockwise shaft rotation, A leads B for counter clockwise shaft rotation viewed from the shaft/bushing side of the encoder. For complete details see our **HEDS** data sheet.

Features:

- Small size
- Low cost
- 2-channel quadrature, TTL square wave outputs
- 3rd channel index option
- Tracks from 0 to 100,000 cycles/sec
- Ball bearing option tracks to 10,000 RPM
- -40 to +100°C operating temperature
- Single +5V supply
- US Digital warrants its products against defects and workmanship for two years. See complete warranty for details.

Mechanical Specifications:



Mechanical Notes: (ball bearing)

Acceleration	10,000 rad/sec^2
Vibration	20 g. 5 to 2KHz
Shaft Speed	10,000 RPM max. continuous
Acceleration	50K rad/sec^2 10K rad/sec^2 (**S2** series)
Shaft Torque	0.05 in. oz. max.
Shaft Loading	1 lb. max.
Bearing Life	$(40/P)^3$ = Life in millions of revs. P = radial load in pounds.
Weight	0.7 oz.
Shaft Runout	0.0015 T.I.R. max.

Mechanical Notes: (sleeve bushing)

Acceleration	10,000 rad/sec^2
Vibration	20 g. 5 to 2KHz
Shaft Speed	100 RPM max. continuous
Shaft Rotation	Continuous & reversible
Shaft Torque	0.5 ±0.2 in. oz. 0.3 in. oz. max. (**NT**-option)
Shaft Loading	2 lbs. max. dynamic 20 lbs. max. static
Weight	0.7 oz.
Shaft Runout	0.0015 T.I.R. max.

Materials & Mounting:

Shaft	Brass or stainless
Bushing	Brass
Connector	Gold plated
Hole Diameter	0.375 in. +0.005 - 0
Panel Thickness	0.125 in. max.
Panel Nut Max Torque	20 in.-lbs.