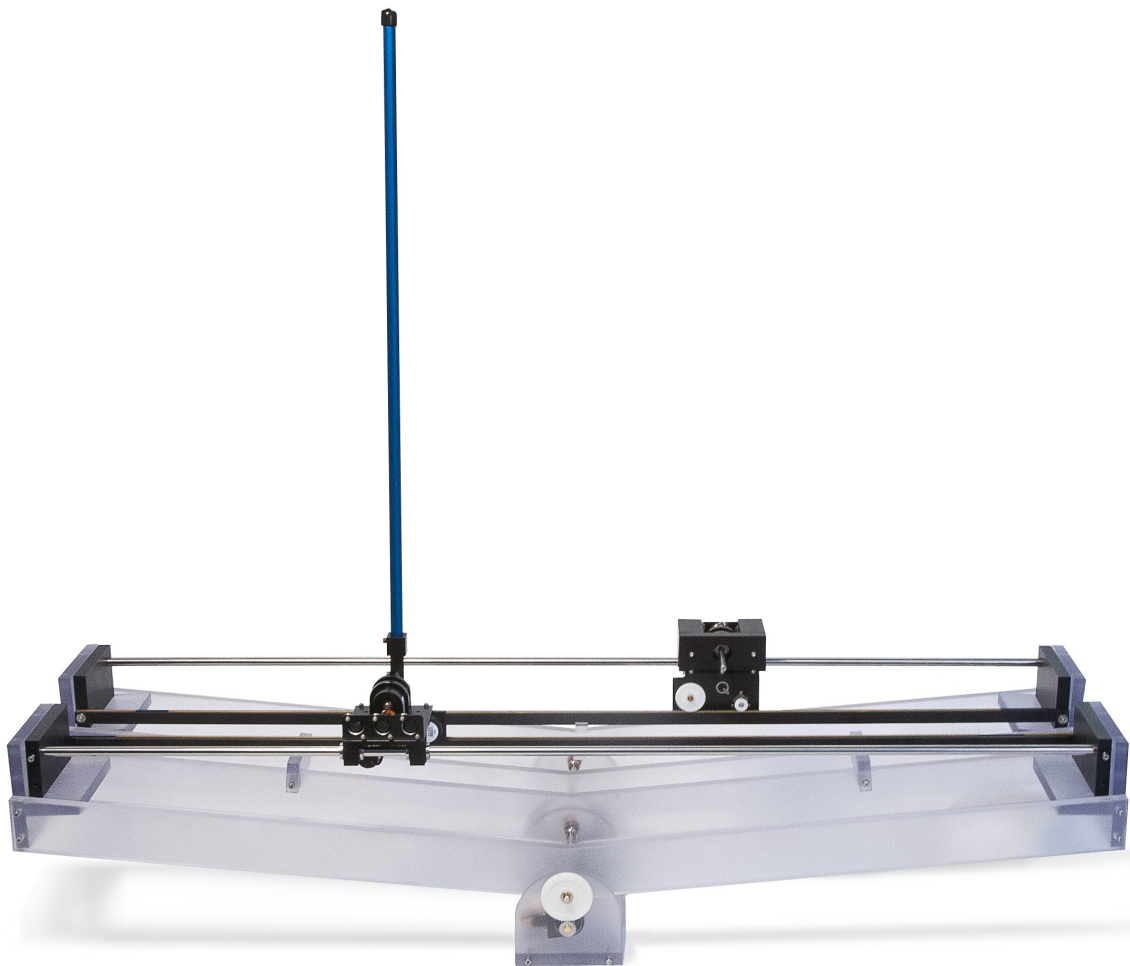




# USER MANUAL

## Seesaw Pendulum Experiment

Set Up and Configuration



CAPTIVATE. MOTIVATE. GRADUATE.

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Quanser Inc.  
119 Spy Court  
Markham, Ontario  
L3R 5H6  
Canada  
info@quanser.com  
Phone: 1-905-940-3575  
Fax: 1-905-940-3576

Printed in Markham, Ontario.

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#### Waste Electrical and Electronic Equipment (WEEE)



This symbol indicates that waste products must be disposed of separately from municipal household waste, according to Directive 2002/96/EC of the European Parliament and the Council on waste electrical and electronic equipment (WEEE). All products at the end of their life cycle must be sent to a WEEE collection and recycling center. Proper WEEE disposal reduces the environmental impact and the risk to human health due to potentially hazardous substances used in such equipment. Your cooperation in proper WEEE disposal will contribute to the effective usage of natural resources. For information about the available collection and recycling scheme in a particular country, go to [ni.com/citizenship/weee](http://ni.com/citizenship/weee).

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(For information about China RoHS compliance, go to [ni.com/environment/rohs\\_china](http://ni.com/environment/rohs_china))

#### CE Compliance

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

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# 1 PRESENTATION

The Seesaw Pendulum (SEEPEN) system consists of two carts on two separate IP02 tracks and each track is mounted on a SEESAW-E device, as shown in Figure 1.1. The SEESAW-E are attached together using two SP01 coupler attachments. The cart on the rear track is an IP02 cart with the extra weight. It is referred to as the mass cart and is used to stabilize the double seesaw assembly. The cart on the front track is also an IP02 cart. It does not have the additional mass and is has a single pendulum rod mounted. The pendulum cart is used to balance the pendulum in the upright vertical position.

Each IP02 cart is driven by a rack and pinion mechanism using a 6-Volt DC motor, ensuring consistent and continuous traction. Such cart slides along a ground stainless steel shaft using linear bearings. The cart position is measured using a sensor coupled to the rack via an additional pinion. Please review the Linear Servo Base Unit User Manual [?] for a complete description of the Linear Servo cart.

The Single Inverted Pendulum (SIP) module consists of a single rod mounted on the Pendulum Cart whose axis of rotation is perpendicular to the direction of motion of the cart. The SIP is free to fall along the Pendulum Cart's axis of motion. The default configuration of the SEEPEN uses the 24-inch "long" pendulum.

The SEESAW-E 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 Quanser SEESAW-E rotation axis is coupled to an encoder through a pinion-and-anti-backlash-gear system. For more information, see the SEESAW-E User Manual [?].

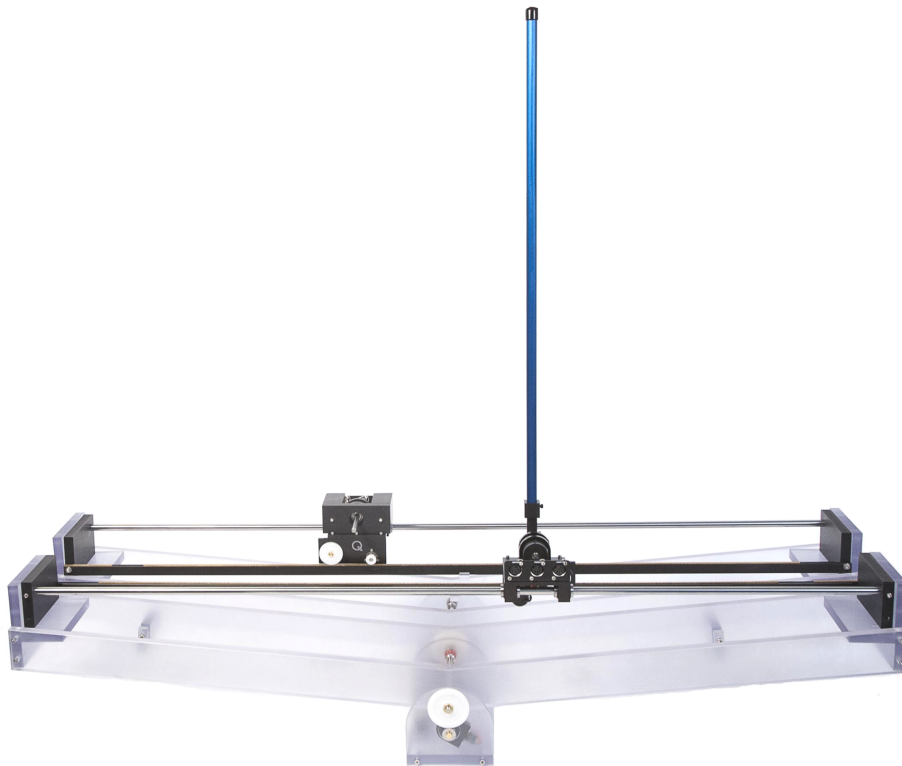


Figure 1.1: Seesaw Pendulum (SEEPEN)



**Caution:** This equipment is designed to be used for educational and research purposes and is not intended for use by the general public. The user is responsible to ensure that the equipment will be used by technically qualified personnel only.



## 2 COMPONENTS

The components of the Seesaw Pendulum (SEEPEN) are identified in Section 2.1. For more information of the components on the IP02 and SEESAW-E, please refer to their corresponding user manual (references [?], and [?]).

### 2.1 Components Nomenclature

The components of the SEEPEN are listed in Table 2.1 below and labeled in Figure 2.1 and Figure 2.2.

ID	Component	ID	Component
1	Front IP02 "Pendulum Cart"	4	Rear SEESAW-E
2	Rear IP02 "Mass Cart"	5	24-inches pendulum
3	Front SEESAW-E	6	SEESAW-E coupler

Table 2.1: Seesaw Pendulum Components.

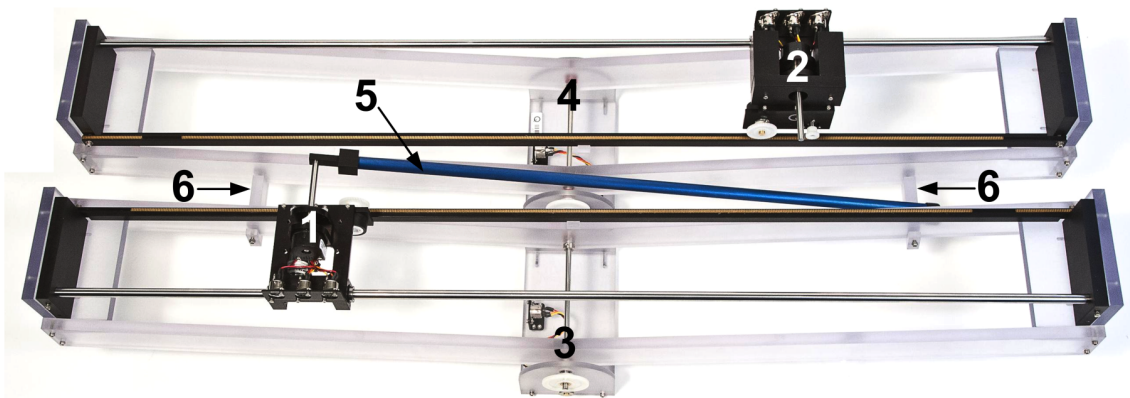


Figure 2.1: Seesaw Pendulum Components (SEEPEN).



Figure 2.2: SEESAW-E coupler attachment (SP01 module)

## 3 SPECIFICATION

Table 3.1, lists and characterizes the main parameters associated with Quanser's SEEPEN assembly. These parameters are particularly useful for the mathematical modeling and simulation of the system. The viscous damping of both carts ( $B_{c1}$  and  $B_{c2}$ ) the pendulum ( $B_p$ ), and the seesaw ( $B_{sw}$ ) were all considered negligible.

Symbol	Description	Value	Unit
$R_m$	Motor Armature Resistance	2.6	$\Omega$
$K_m$	Back-ElectroMotive-Force (EMF) Constant	0.00767	V-s/rad
$K_g$	Planetary Gearbox Gear Ratio	3.71	m
$r_{mp}$	Motor Pinion Radius	$6.35 \times 10^{-3}$	m
$M_{c1}$	"Mass cart" mass (IP02 with weight)	0.94	kg
$M_{c2}$	Pendulum cart mass (IP02 without weight)	0.57	kg
$M_{sw}$	Mass of <b>two</b> SEESAW-E	7.2	kg
$M_{gs}$	SEESAW Geartrain Gear Ratio	3	kg
$D_T$	Distance from Pivot to the IP02 Track	0.125	m
$D_c$	Distance from Pivot to the Center Of Gravity of the one-SEESAW-plus-one-IP02-Track System	0.058	m
$J_{sw}$	Moment of Inertia of the two-SEESAW-plus-one-IP02-Track System, about its Center Of Gravity	0.790	$\text{Kg}\cdot\text{m}^2$
$B_{sw}$	Viscous Damping Coefficient as seen at the SEESAW-E Pivot Axis	$\approx 0$	N-m-s/rad
<b>g</b>	Gravitational Constant on Earth	9.81	$\text{m}/\text{s}^2$
$M_p$	Pendulum Mass (with T-fitting)	0.230	Kg
$l_p$	Long Pendulum Length from Pivot to Center Of Gravity	0.3302	m
$J_p$	Long Pendulum Moment of Inertia, about its Center Of Gravity	$7.88 \times 10^{-3}$	$\text{Kg}\cdot\text{m}^2$
$B_p$	Viscous Damping Coefficient, as seen at the Pendulum Axis	0.0024	N-m-s/rad
$K_{EC}$	IP0 2 Cart Position Encoder Resolution	$2.275 \times 10^{-5}$	m/count
$K_{EP}$	Pendulum Encoder Resolution	0.0015	rad/count
$K_{E\_SW}$	Seesaw Position Encoder Resolution	0.0015	rad/count

Table 3.1: SEEPEN System Parameters

# 4 SYSTEM SETUP



**Caution:** If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Figure 4.1 illustrates the mounting and assembly, in the default configuration, of the Seesaw Pendulum system.

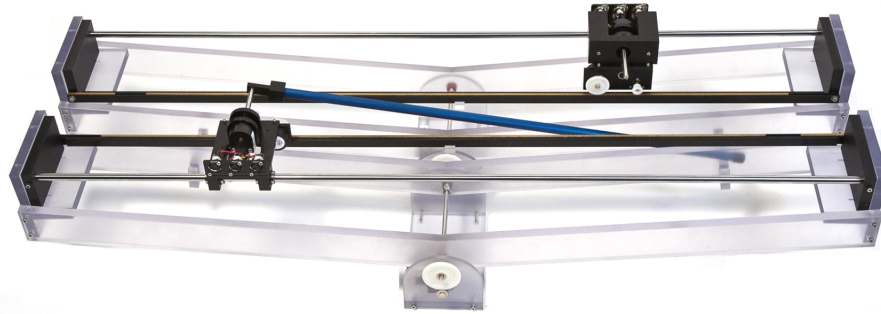


Figure 4.1: SEEPEN default configuration

**Note:** The default configuration consists of a "mass" cart (i.e. IP02 on the rear track) with an additional weight and a "pendulum" cart (i.e. IP02 on front track) without any additional weight.

Follow these procedure to setup the Seesaw Pendulum module for experimental use:

1. As depicted Figure 4.1, do not place the additional weight on the "pendulum" cart, but install additional weight on the "mass" cart. See reference [?] for more details.
2. Place the "pendulum" cart and rack on top of the SEESAW-E module. Make sure to locate the rack in such a way that the IP02 cart pinion are on the **opposite** side as the SEESAW-E gears, as shown in Figure 4.2.

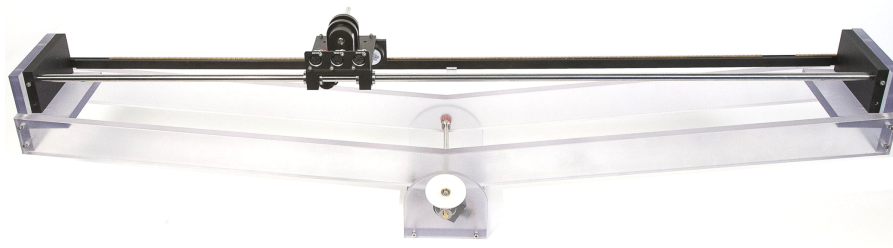


Figure 4.2: SEEPEN pendulum cart (front)

3. Place the "mass" cart and rack on top of the SEESAW-E module. make sure to locate the rack in such a way that the IP02 cart pinion are on the **same side** as the SEESAW-E gears, as shown in Figure 4.3.

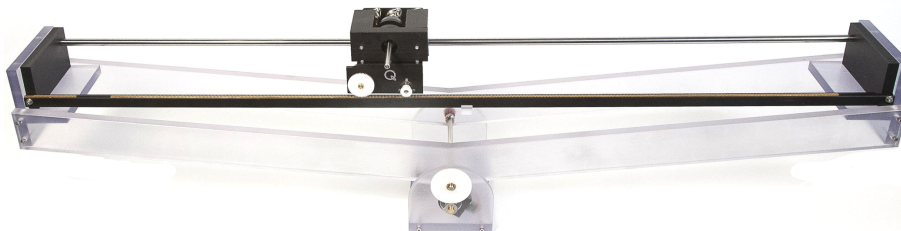


Figure 4.3: SEEPEN mass cart (rear)

- Slide the rod assembly onto the "pendulum" cart (front cart) and position this at the tip of the shaft, as shown in Figure 4.4. Tighten the screw to embrace the assembly to the shaft. **Do not over tighten the screw.**

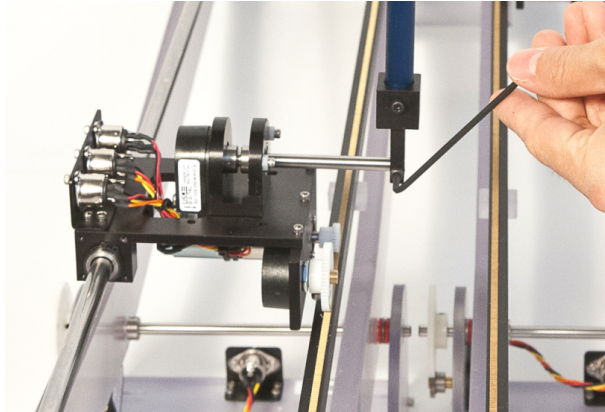


Figure 4.4: Attach rod to pendulum cart

- Place the two SEESAW systems side-by-side, as shown in Figure 4.5, and connect them together using the SP01 coupling attachments. Make sure you use two SP01 attachments - one for each side of the SEESAWs. Tighten the screws on each SP01 to secure the coupling.

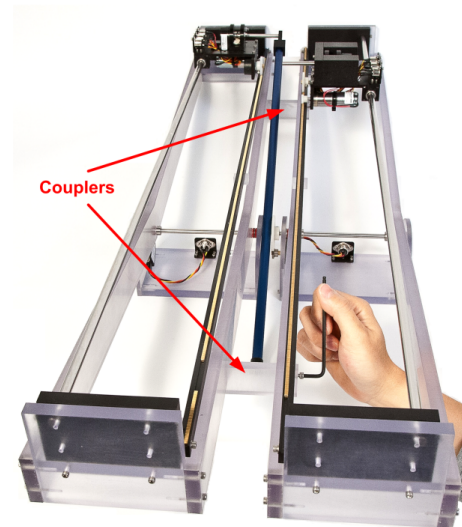


Figure 4.5: Coupling SEESAW-E systems

- Before running any experiments, it is recommended that the SEESAW-E modules are secured down onto the table.

# 5 WIRING PROCEDURE

The following is a listing of the hardware components used in the SEESAW Pendulum (SEEPEN) experiments:

1. **Power Amplifier:** Quanser VoltPAQ-X2, or equivalent.
2. **Data Acquisition Device:** NI CompactRIO with 2x Q1-cRio modules, Q8-USB, QPID/QPIDe, NI DAQ Devices, or equivalent.
3. **Linear Servo Plant:** 2x Quanser IP02 Base Unit.
4. **Module:** 2x Quanser SEESAW-E modules coupled together using the SP01 attachment.

See the references listed in Section 8 for more information on these components. The required cables are described in Section 5.1 and the procedure to connect the above components is given in Section 5.2.



**Caution:** When using the Quanser VoltPAQ power amplifier, **make sure set the Gain to 1!**

## 5.1 Cable Nomenclature

Table 5.1, below, provides a description of the standard cables used in the wiring of the IP02, and SEESAW-E.




Cable	Type	Description
 <p>(a) RCA Cable</p>	2xRCA to 2xRCA	Used to connect analog output of data acquisition device to amplifier. It carries amplifier command signal.
 <p>(b) Motor Cable</p>	4-pin-DIN to 6-pin-DIN	Applies the amplified command signal to the IP02 motor.
 <p>(c) Encoder Cable</p>	5-pin-stereo-DIN to 5-pin-stereo-DIN	This cable carries the encoder signals between an encoder connector and the data acquisition board (to the encoder counter). Namely, these signals are: +5 VDC power supply, ground, channel A, and channel B

Table 5.1: Cables Nomenclature

## 5.2 Typical Connections

This section explains how to connect the SEEPEN to the amplifier and the data acquisition device. See Reference [?] and [?] for the specifications and a description of the main components of the IP02 and SEESAW-E system.

The connections are given in Table 5.2 and illustrated in Figure 5.1. The detailed wiring procedure is given below.

Cable #	From	To	Signal
1	Data Acquisition Device: Analog Output #0	Amplifier Command #0 connector	Control signal to the amplifier for pendulum cart.
2	Data Acquisition Device: Analog Output #1	Amplifier Command #1 connector	Control signal to the amplifier for mass cart.
3	Amplifier # 0 To Load connector	"Pendulum cart" <b>Motor</b> connector	Power leads to the "pendulum" cart DC motor.
4	Amplifier # 1 To Load connector	"Mass cart" <b>Motor</b> connector	Power leads to the "mass" cart DC motor.
5	Data Acquisition Device: <b>Encoder Input #0</b>	"Pendulum cart" <b>Cart Encoder</b> connector	"Pendulum" cart position measurement.
6	Data Acquisition Device: <b>Encoder Input #1</b>	"Pendulum cart" <b>Pendulum Encoder</b> connector	Pivot shaft angular position.
7	Data Acquisition Device: <b>Encoder Input #2</b>	"Mass cart" <b>Cart Encoder</b> connector	"Mass" cart position measurement.
8	Data Acquisition Device: <b>Encoder Input #3</b>	"SEESAW-E" (back SEESAW) <b>Encoder</b> connector	SEESAW pivot angular position.
9	Emergency Stop Switch	E-Stop connector on VoltPAQ	The amplifier is deactivated when the E-Stop switch is pressed down.

Table 5.2: Seesaw Pendulum system wiring summary

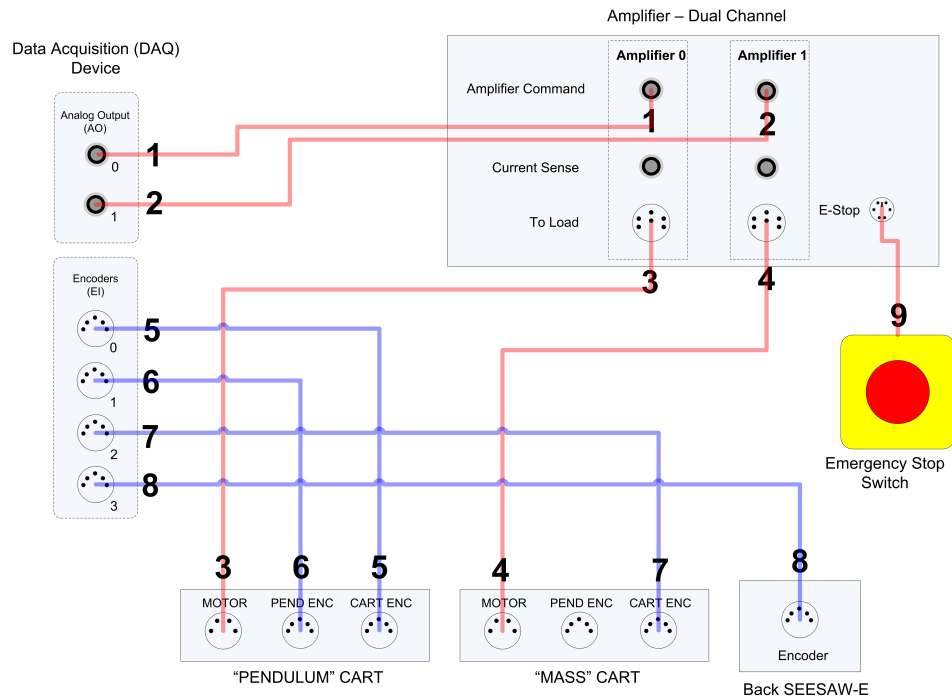


Figure 5.1: Seesaw Pendulum Wiring Diagram

The follow describes in detail the wiring procedure of the Seesaw Pendulum experiment to the amplifier and DAQ:

1. It is assumed that the data acquisition device is already installed as discussed in its User Manual.
2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the amplifier.
3. Connect one of the 2x RCA to 2x RCA cable from the *Analog Output Channel #0* on the Data Acquisition Device to the *Amplifier Command #0* Connector on the Quanser amplifier. See cable #1 shown in Figure 5.1. This carries the attenuated motor voltage control signal.
4. Connect another 2x RCA to 2x RCA cable from the *Analog Output Channel #1* on the Data Acquisition Device to the *Amplifier Command #1* Connector on the Quanser amplifier. See cable #2 shown in Figure 5.1. This carries the attenuated motor voltage control signal.
5. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *To Load* on the amplifier #0 to the *Motor* connector on the "pendulum cart". See connection #3 shown in Figure 5.1. The cable transmits the amplified voltage that is applied to the IP02 motor.
6. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *To Load* on the amplifier #1 to the *Motor* connector on the "mass cart". See connection #4 shown in Figure 5.1. The cable transmits the amplified voltage that is applied to the IP02 motor.
7. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *Cart Encoder* connector on the "pendulum cart" to *Encoder Input #0* on the Data Acquisition Device, as depicted by connection #5 in Figure 5.1. This carries the cart position measurement.



**Caution:** Connect the encoders directly to the data acquisition (DAQ) device using the standard 5-pin DIN cable. **Do NOT connect it to the amplifier.!**

8. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *Pendulum Encoder* connector on the "pendulum cart" to *Encoder Input #1* on the Data Acquisition Device, as depicted by connection #6 in Figure 5.1. This carries the shaft angular position measurement.
9. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *Cart Encoder* connector on the "mass cart" to *Encoder Input #2* on the Data Acquisition Device, as depicted by connection #7 in Figure 5.1. This carries the cart position measurement.
10. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *encoder* connector on the "back SEESAW-E" to the *Encoder Input #3* on the Data Acquisition Device, as depicted by connection #8 in Figure 5.1. This carries the SEESAW-E pivot angular position.
11. Connect the Emergency Stop Switch to the E-Stop connector on the VoltPAQ. This enable or disable the command output on the amplifier.



# 6 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your SEEPEN system is operating normally. It is assumed that the SEEPEN is connected as described in Section 5. To carry out these tests, it is preferable if the user can use a software such as **QUARC®** or **LabVIEW™** to read sensor measurements and feed voltages to the motor. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

## 6.1 IPO2 Motor and Sensors

Please refer to the Linear Servo Base Unit User Manual [?] for information on testing and troubleshooting the IPO2 separately.

## 6.2 Testing the SEESAW-E encoder

Please refer to the SEESAW-E User Manual [?] for information on testing and troubleshooting the SEESAW-E separately.

# 7 TECHNICAL SUPPORT

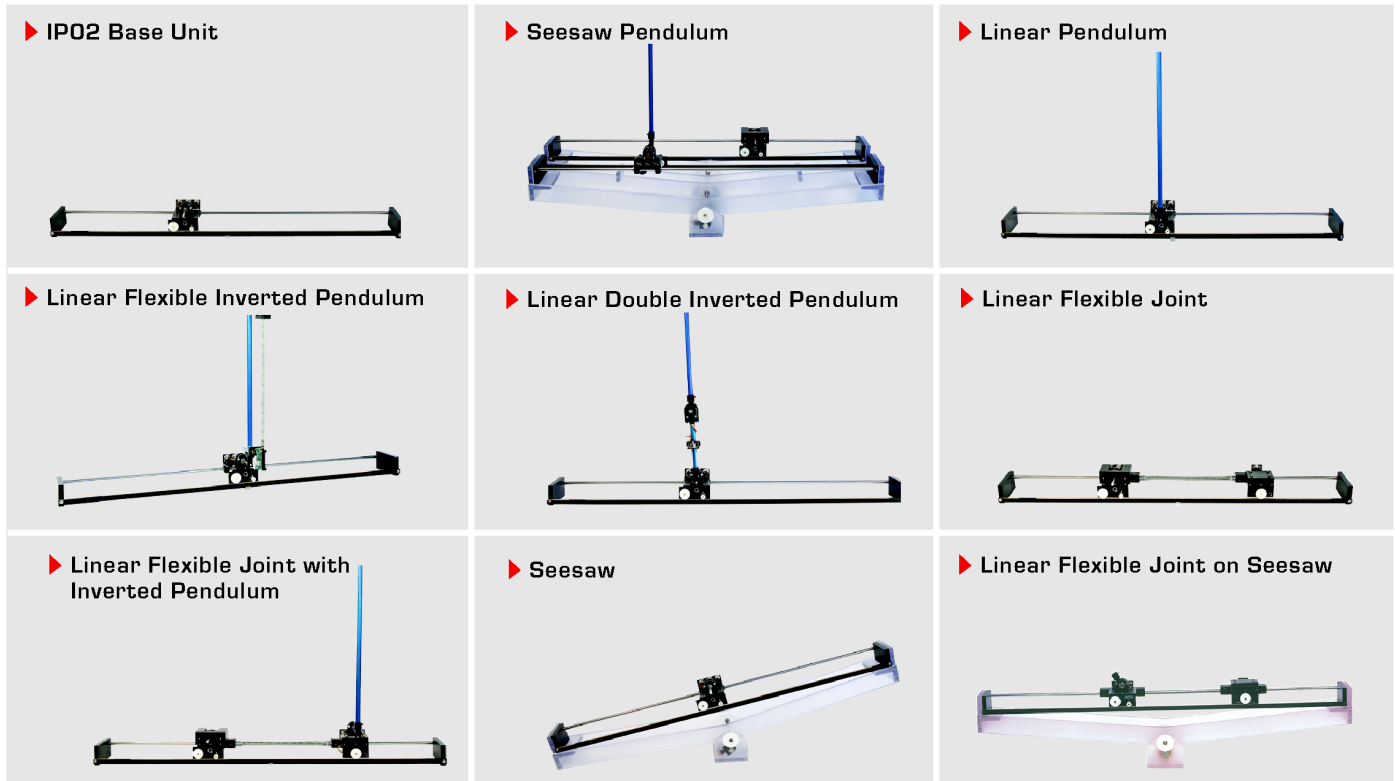
To obtain support from Quanser, go to <http://www.quanser.com/> and click on the Tech Support link. Fill in the form with all the requested software and hardware information as well as a description of the problem encountered. Also, make sure your e-mail address and telephone number are included. Submit the form and a technical support person will contact you.



# REFERENCES

- [1] Quanser Inc. *IP02 User Manual*, 2012.
- [2] Quanser Inc. *SEESAW-E User manual*, 2012.

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