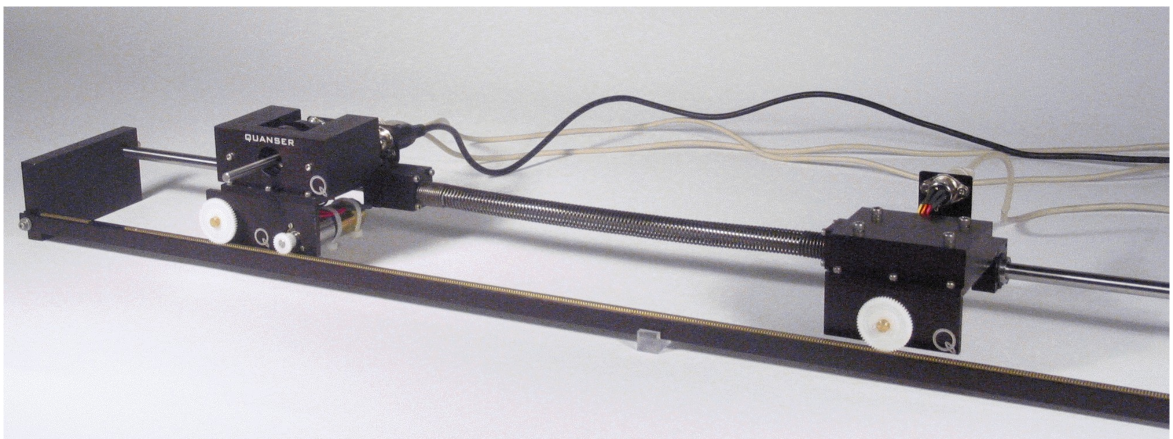
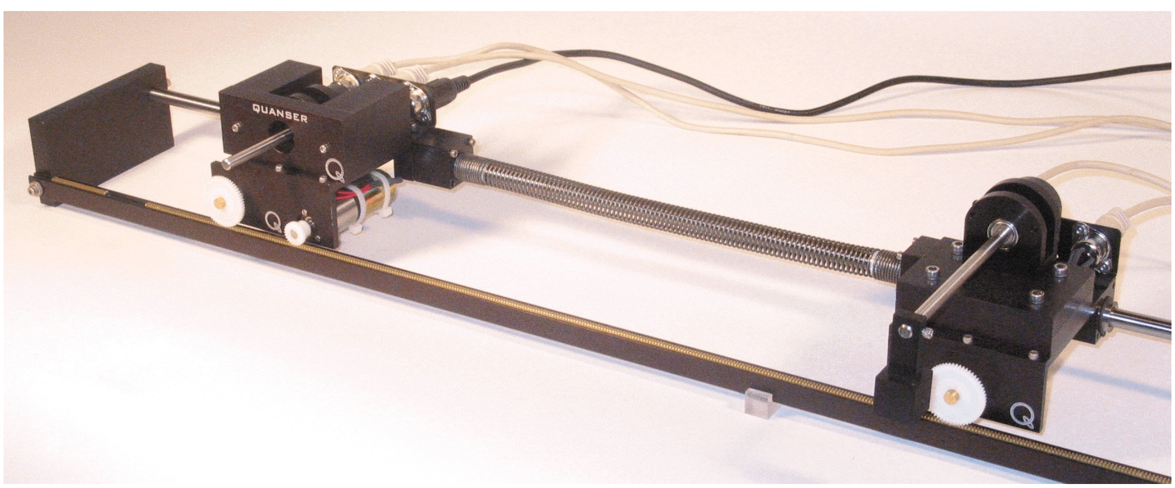
Linear Motion Servo Plants: IP01 and IP02

Single Linear Flexible Joint (SLFJ)





User Manual

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1. Single Linear Flexible Joint (SLFJ)

1.1. Single Linear Flexible Joint: System Description

The Single Linear Flexible Joint (SLFJ) experiment consists of a system of two carts sliding on an IP01 or IP02 track, as shown in Figures 1 and 2, below. While one of the two carts is motorized and drives the system (e.g. IP01 or IP02), the second cart is passive and coupled to the first one through a linear spring. The shafts of these elements are coupled to a rack and pinion mechanism in order to input the driving force to the system and to measure the two cart positions. When the motor turns, the torque created at the output shaft is translated to a linear force which results in the cart's motion. When the carts move, the potentiometer and/or encoder shafts turn and the resulting signals are calibrated to obtain the actuated and load carts' positions.

As illustrated in Figures 1 and 2, the cart on the left is an IP02 cart with the extra weight mounted atop of it in order to reduce slippage. To run the SLFJ experiment, the cart on the right can be any of the three following Quanser's modules: LFJC, LFJC-E, or LFJC-PEN-E. All three modules consist of a linear flexible joint with cart (LFJC). As an example, Figure 1 shows the LFJC-E on the right-hand side, while Figure 2 depicts the LFJC-PEN-E. These carts are passive (i.e. not motor-driven) and made of solid aluminum. All of them use linear bearings to slide along a ground stainless steel shaft. Moreover, two masses are available for attachment to the cart. These two weights, mounting on the load cart, can be used for assessing the robustness of the controller and the effects of variations in parameters.

In case of the LFJC, the cart position is sensed by a potentiometer, whose shaft meshes with the IP01 or IP02 track via a pinion.
If the LFJC-E module is used instead, then the potentiometer, sensing the cart position, is replaced by a quadrature optical encoder.

In addition, the LFJC-PEN-E module can be used as well for the SLFJ experiment. In this case, the cart is also equipped with a rotary joint atop of it, whose axis of rotation is perpendicular to the direction of motion of the cart. A free-swinging rod can then be attached to it and suspends in front of the cart. This rod functions as an "inverted pendulum" as well as a regular pendulum in subsequent experiments. The LFJC-PEN-E module is instrumented with two quadrature optical encoders. Similarly to the LFJC-E, one encoder measures the position of the cart via a pinion which meshes with the track. The other encoder measures the angle of the rod optionally mounted on the cart and is thus unlimited in range and continuous over the entire circle.

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 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 Reference [1] for a complete description of both IP01 and IP02 systems.

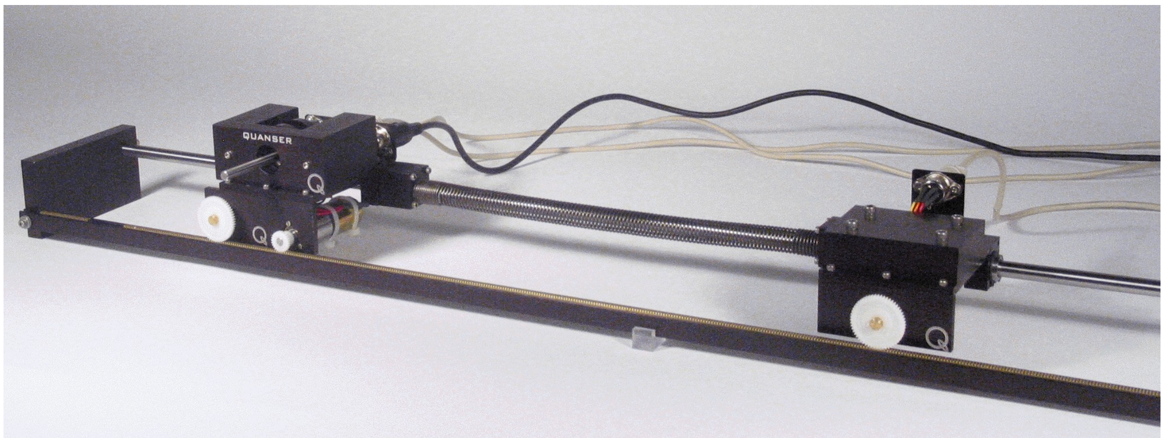


Figure 1 LFJC-E Coupled to an IP02

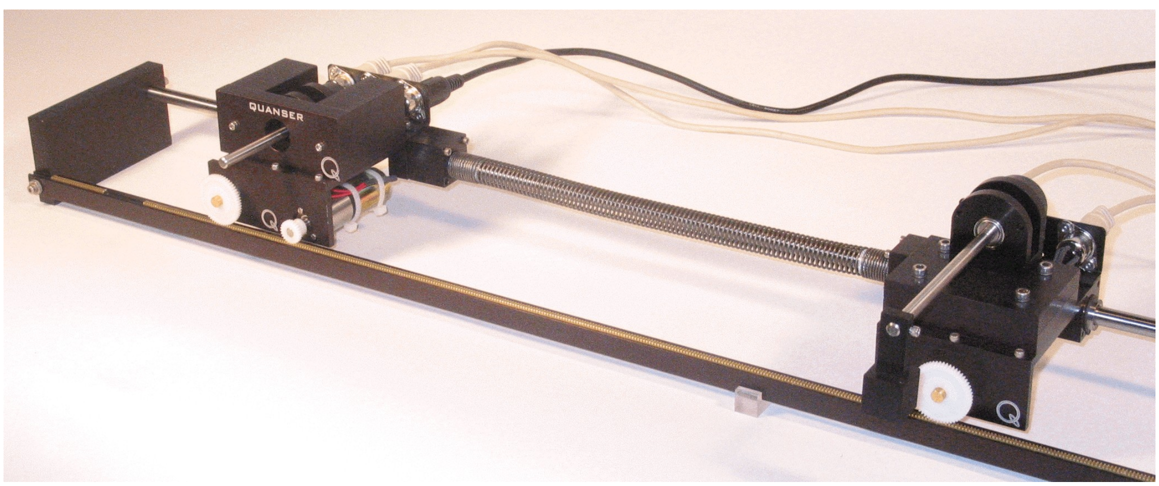


Figure 2 LFJC-PEN-E Coupled to an IP02

1.2. Single Linear Flexible Joint (SLFJ) Experiment: Control Challenge

As illustrated in Figures 1 and 2, above, the objective of the single linear flexible joint experiment is to design a control system to track the spring-driven cart to a desired position with minimum overshoot and maximum speed. Therefore, the desired outcome is to design a feedback controller such that the output cart (i.e. LFJC(-PEN)(-E)) tracks a position setpoint while minimizing joint deflection and resonance in the system.

The ability to vary parameters and the hardware configuration is also available should you wish to modify the dynamics of the challenge, like for example changing the cart mass and/or spring length. The system is supplied with a state-feedback controller but, of course, you may design any other controller you wish. The complete mathematical modelling and system parameters are provided to streamline the implementation of the control theory of your choice.

2. Linear Flexible Joint Cart (LFJC) 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 LFJC(-PEN)(-E) module. Quanser's basic linear motion servo plants are the IP01 and the IP02. The linear flexible joint cart can be used individually or in combination with other Quanser modules, as shown in Table 1.

Experiment Name	***Experiment Description***
Double Linear Flexible Joint (DLFJ)	Design of a control system to position the final stage of a linear flexible load consisting of two LFJ carts connected in series.
Linear Flexible Joint Cart with Single Inverted Pendulum (LFJ with SIP)	Design of a control system to balance a single inverted pendulum on a spring-driven linear cart.
Linear Flexible Joint Cart on a Seesaw (LFJ on Seesaw)	Design of a control system to balance a seesaw using a flexible structure mounted atop of it.

Table 1 IP01- and IP02-Based Experiments Involving the Linear Flexible Joint Cart Module

3. LFJC(-PEN)(-E) Description

3.1. Component Nomenclature

Figures 3 and 4, below, depict the LFJC-E and LFJC-PEN-E modules, respectively.

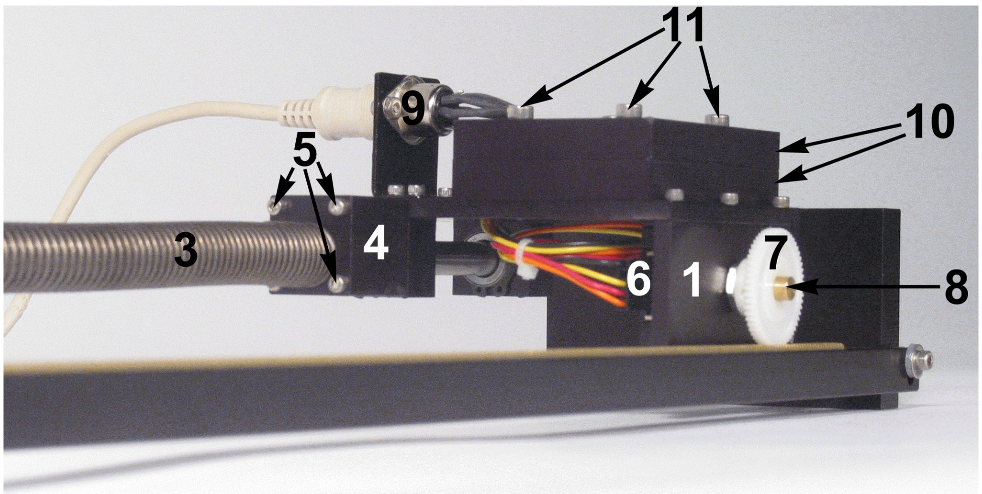


Figure 3 LFJC-E Nomenclature

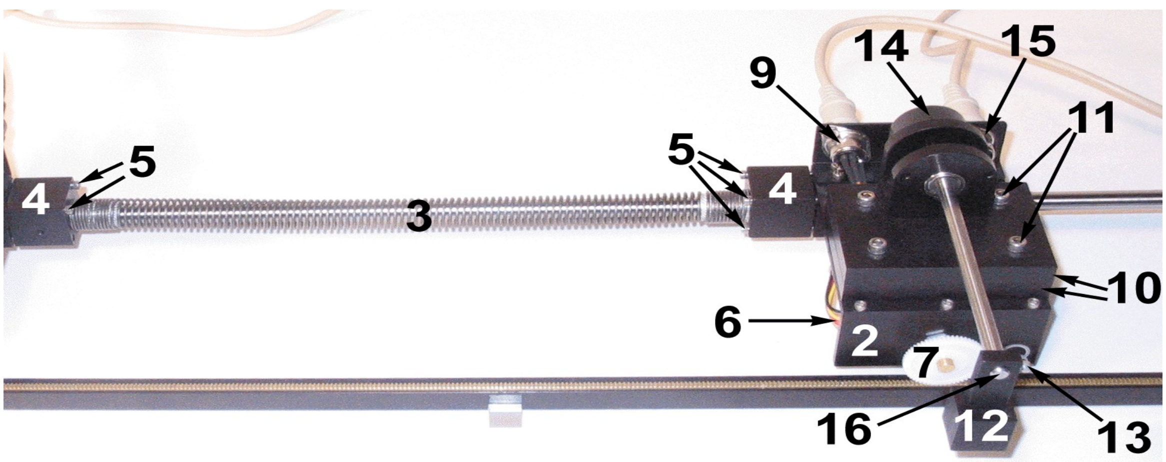


Figure 4 LFJC-PEN-E Nomenclature

As a component nomenclature, Table 2, below, provides a list of all the principal elements composing the LFJC(-PEN)(-E) systems. Each of these elements is located and identified, through a unique identification (ID) number, on both LFJC-E and LFJC-PEN-E systems as represented in Figures 3 and 4, above.

ID #	Description	ID #	Description
1	LFJC-E	**2**	LFJC-PEN-E
3	Compression Spring	**4**	Spring Fitting
5	Spring Fitting Set Screw: (7/64)"	**6**	Cart Encoder
7	Cart Position Pinion	**8**	Cart Position Axis
9	Cart Encoder Connector	**10**	Load Weight
11	Load Weight Set Screw: (9/64)"	**12**	Pendulum T-Fitting (a.k.a. Socket)
13	Pendulum T-Fitting Set Screw: (3/32)"	**14**	Pendulum Encoder
15	Pendulum Encoder Connector	**16**	Pendulum Axis

Table 2 LFJC(-PEN)-E Component Nomenclature

The two masses (i.e. component #10) supplied for the load cart can be used, for instance, for assessing the robustness of the controller and the effects of variations in parameters.
It is reminded that the LFJC module is basically identical to the LFJC-E except that a potentiometer replaces the optical encoder.

3.2. Component Description

3.2.1. Linear Spring (Component #3)

The linear spring used in the LFJC(-PEN)(-E) is a compression spring coiled left hand from **Ashfield Springs Limited (UK)**. It has the following dimensions: an outside diameter of 15.90mm (i.e. 0.625"), a wire diameter of 1.40 mm (i.e. 0.056"), with approximately 3.54 coils/cm (i.e. 9 coils/inch), for a length of around 304 mm (i.e. 12"). The part stock number is: **S.618**. Furthermore, both ends of the linear spring are equipped with a square fitting in order to mate with either the IP01 or IP02 cart on one side and the LFJ cart on the other; thus obtaining a linear spring-mass system.

3.2.2. LFJC Potentiometer

If the LFJC module is used (instead of the LFJC(-PEN)-E), the encoder depicted by component #6 in Figure 3 is replaced with a potentiometer to sense the spring-driven cart position. The LFJ cart position is sensed by a 10-turn black potentiometer, namely the **Vishay Spectrol model 534-1-1-103**. As illustrated by its wiring diagram in Figure 5, below, the LFJC potentiometer is connected to a ±12 Volt DC power supply (e.g. from the Quanser

VoltPAQ, see Reference [2]) through two bias resistors of 7.15 kÙ each. Under normal operations, potentiometer terminal 1 should measure +5VDC while terminal 3 should measure -5VDC. The actual position voltage is available at terminal 2. The total output range of the cart position potentiometer results to be ±5V over its 10 complete turns (i.e. 3600 degrees). The main specifications of the LFJC potentiometer are included in Appendix A.

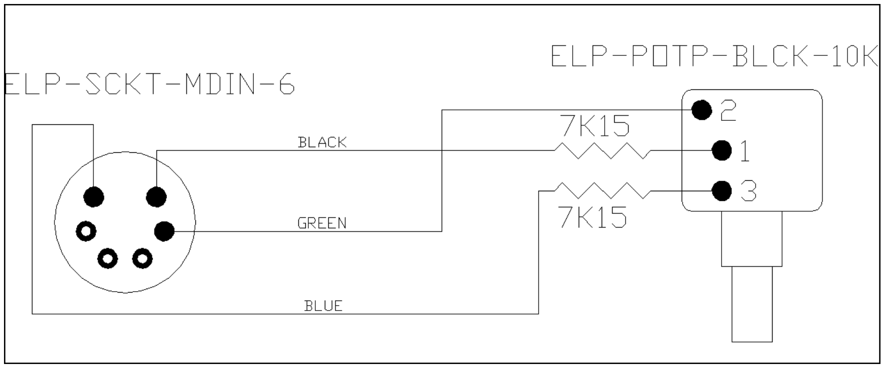


Figure 5 Wiring Diagram of the LFJC Potentiometer

If the LFJC 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) 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 potentiometer is powered with ±12VDC at the 6-pin-mini-DIN connector, as shown in Figure 5, above. 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 19 for information on contacting Quanser.

3.2.3. LFJC-E And LFJC-PEN-E Encoders (Components #6 and #14)

The LFJC-E has one optical encoder, which is used to measure the LFJC position, as represented in Figures 3, by component #6. The encoder measuring the LFJ cart linear position does so through a rack-pinion system. The encoder model mounted on the LFJC-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.

As previously stated, the LFJC-PEN-E module is very similar to the LFJC-E. However, the LFJC-PEN-E also offers a rotary joint atop of it, where a free-swinging rod can be attached to and suspend in front of the cart. It results that the LFJC-PEN-E module is instrumented with two quadrature optical encoders, as represented in Figure 4 by components #6 and #14. Similarly to the LFJC-E, one encoder measures the position of the cart via a pinion which meshes with the track. The other encoder measures the angle of the rod optionally mounted on the cart. Both encoders of the LFJC-PEN-E are typically identical. They are also **US Digital S1 single-ended optical shaft encoders**. They offer a high resolution of 4096 counts per revolution. Their specification sheet can be found in Appendix B.

The internal wiring diagram of the LFJC(-PEN)-E encoder(s) is depicted in Figure 6. The standard 5-pin DIN connector shown in Figure 6 is also pictured as components #9 and #15 in Figures 3 and 4.

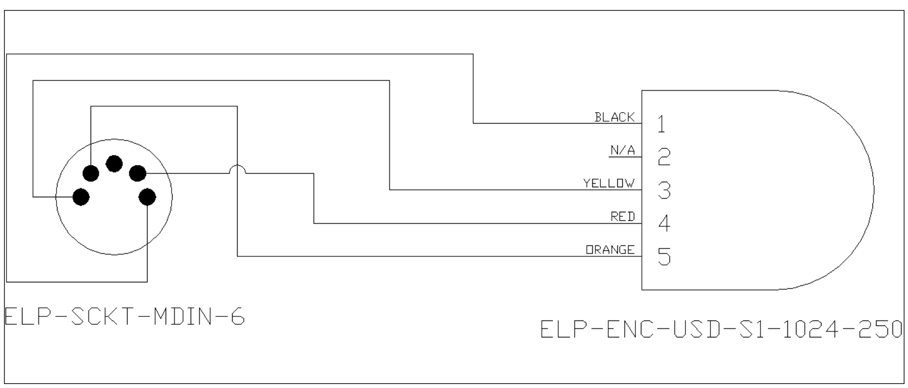


Figure 6 Wiring Diagram of the LFJC(-PEN)-E Encoder

If the LFJC(-PEN)-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. LFJC(-PEN)(-E) Model Parameters

Table 3, below, lists and characterizes the main parameters associated with the Quanser's LFJC, LFJC-E, and LFJC-PEN-E modules. These parameters are particularly useful for the mathematical modelling and simulation of the linear flexible joint systems.

Symbol	*Description*	*Value*	*Unit*
M_{c2_c}	LFJC(-E) Mass (Cart Alone)	0.220	kg
M_{c2_pc}	LFJC-PEN-E Mass (Cart Alone)	0.240	kg
M_{w2}	LFJC(-PEN)(-E) Weight Mass	0.120	kg
M_{pf2}	LFJC-PEN-E Pendulum Fixture Mass	0.135	kg
B_{eq2}	LFJC(-PEN)(-E) Equivalent Viscous Damping Coefficient as seen at the Cart Position Pinion	1.1	N.s/m
K_s	LFJC(-PEN)(-E) Spring Stiffness Constant	160	N/m
M_s	LFJC(-PEN)(-E) Spring Assembly Mass	0.145	kg
L_s	LFJC(-PEN)(-E) Spring Length	0.29	m
N_{pp2}	LFJC(-PEN)(-E) Position Pinion Number of Teeth	56	
r_{pp2}	LFJC(-PEN)(-E) Position Pinion Radius	1.48E-002	m
P_{pp2}	LFJC(-PEN)(-E) Position Pinion Pitch	1.664E-003	m/tooth
K_{PC_LFJC}	LFJC Potentiometer Sensitivity	0.0931	m/V
K_{EC_LFJC}	LFJC(-PEN)-E Position Encoder Resolution	2.275E-005	m/count
K_{EP_LFJC}	LFJC-PEN-E Pendulum Encoder Resolution	0.0015	rad/count

Table 3 LFJC(-PEN)(-E) System Parameters

5. Single Linear Flexible Joint (SLFJ): Configuration and Setup

Figures 7 and 8, below, illustrate the mounting and assembly in the default configuration of the LFJC-E and LFJC-PEN-E modules, respectively, with an IP02 cart-and-track system.

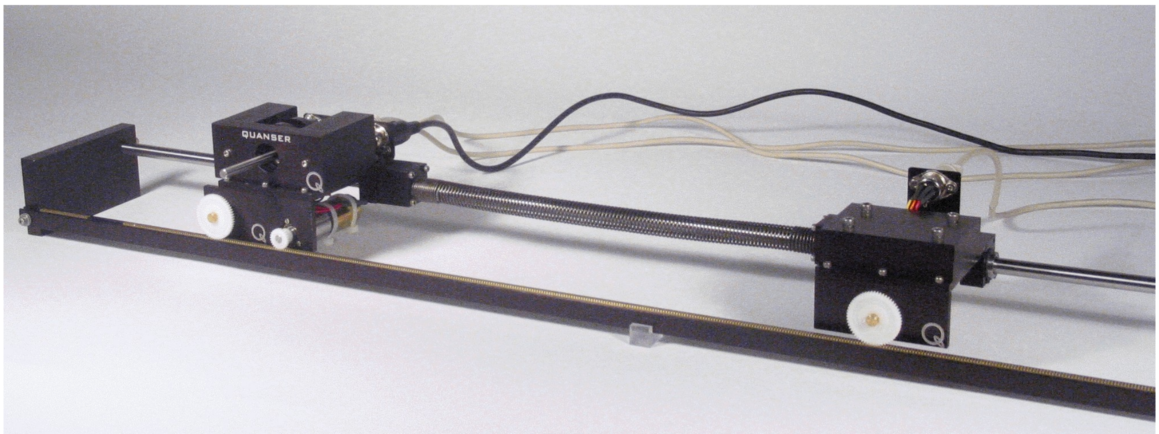


Figure 7 Coupling of the LFJC-E with the IP02 Cart

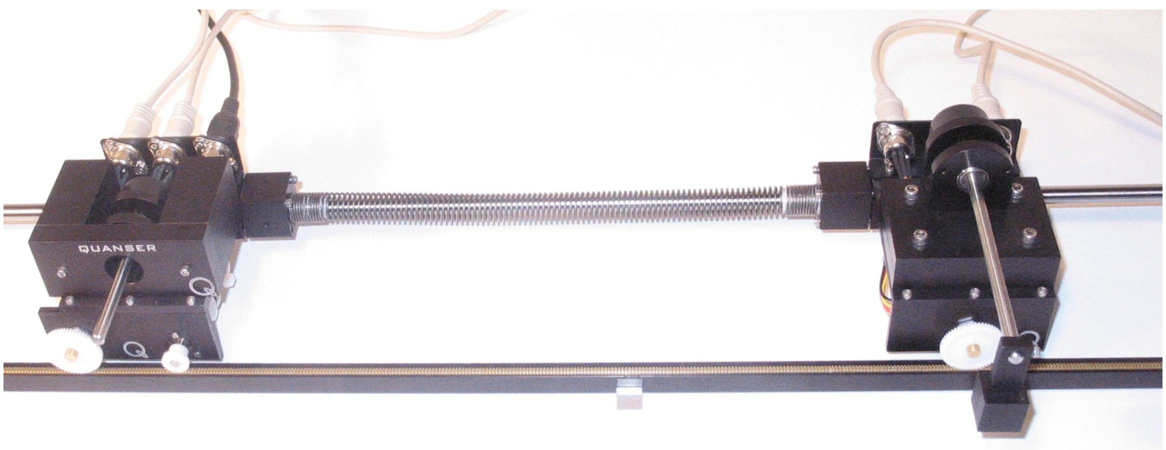


Figure 8 Coupling of the LFJC-PEN-E with the IP02 Cart

5.1. SLFJ: Default Configuration

The default configuration for the one-LFJC(-PEN)(-E)-plus-one-IP01-or-IP02 system is the one used in the Quanser single linear flexible joint laboratory, as decribed in References [5] and [6].

The default configuration is depicted in Figures 7 and 8, above, and can be described as follows:

Concerning both IP01 and IP02 cart-and-track systems, the default configuration consists of the cart with its additional weight mounted atop of it (the extra mass for the motorized cart reduces slippage). Besides, the two load weights provided for the LFJC(-PEN)(-E) should also be attached to the output cart.

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. Likewise, do not mount the pendulum rod on your LFJC-PEN-E system.

Step 2. Mount your LFJC(-PEN)(-E) module on your IP01 or IP02 track. To do so, first remove one of your IP01 or IP02 rack end plates by unfastening the two corresponding set screws. Consult Reference [1] if necessary. You can then slip both linear spring and the LFJC(-PEN)(-E) cart on the IP01 or IP02 stainless steel shaft. Finally once the LFJC(-PEN)(-E) system can slide smoothly on the guide rail, you can then mount the rack end plate back and tighten the two set screws.

Step 3. Attach the linear spring square fitting (component #4 in Figures 3 and 4) to your IP01 or IP02 cart. To do so, fasten the set screws numbered 5 in Figures 3 and 4.

Step 4. Place the additional weight on your IP01 or IP02 cart, if not already done.

Step 5. Mount the two additional weights (components #10 in Figures 3 and 4) on top of your LFJC(-PEN)(-E) system, if not already done. To that effect, fasten the set screws numbered 11 in Figures 3 and 4.

Step 6. Optionally, you can clamp the IP01 or IP02 track down to the table using its end plates.

Step 7. Wire both your IP01 or IP02 cart and LFJC(-PEN)(-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 single linear flexible joint laboratory described 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 9 and summarized in Table 4.

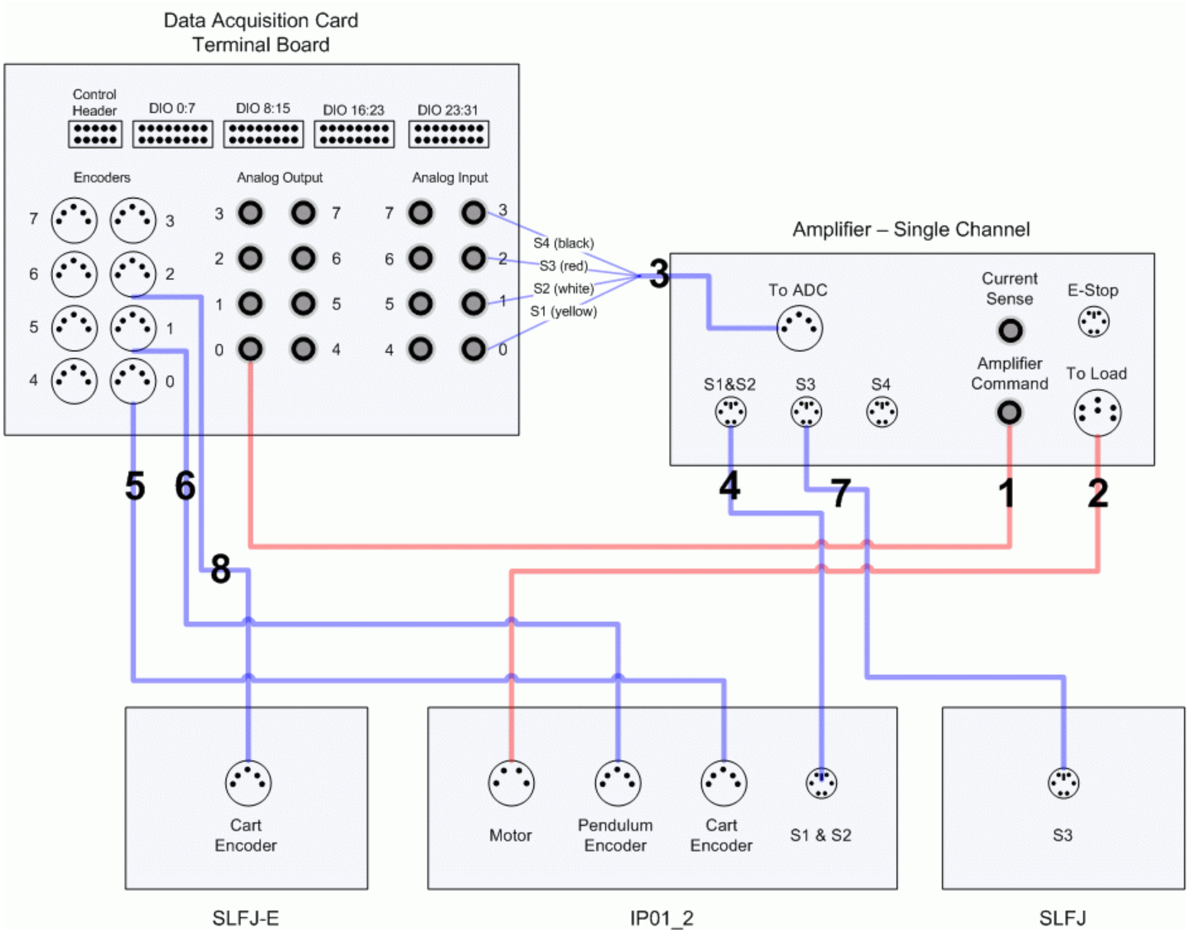


Figure 9: Connections between IP01_2, SLFJ (-E), data-acquisition board, and power amplifier.

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	IP01 “S3” connector	SLFJ cart (S3/AI #2) potentiometer measurements.
8	Terminal Board: Encoder Input #2	"IP02 Pendulum" encoder connector	SLFJ cart shaft angle measurement.

Table 4: IP01_2+SLFJ(-E) connection 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. LFJC Connections

The LFJC potentiometer is wired to one 6-pin mini DIN socket, as represented in the wiring schematic in Figure 5.

The standard cabling procedure of the LFJC 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 LFJC S3 (i.e. potentiometer) connector. Then connect its other end to the amplifier socket labelled **"S3"**, which is contained inside the amplifier, e.g. VoltPAQ, "From Analog Sensors" front panel. For a full description of your amplifier, review Reference [2].

- **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 ADC"**. 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 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 LFJC potentiometer voltage signal (proportional to its cart position).

5.3.3. LFJC(-PEN)-E Connections

To run, for example, the Quanser single linear flexible joint laboratory decribed in References [5] and [6] with either the LFJC-E or LFJC-PEN-E module the cart position encoder must be connected. However for the SLFJ experiment, connecting the LFJC-PEN-E's pendulum encoder is optional since no pendulum is used in this configuration.

Proceed according to the two following steps described below:

- **Connect the LFJC(-PEN)-E Position "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 **LFJC(-PEN)-E Encoder Connector**, which is shown as component #9 in Figures 3 and 4. Then connect the other cable end to the **Encoder Input 2** on your terminal board.

- **Optional: Connect the LFJC-PEN-E Pendulum Angle "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 **LFJC-PEN-E Pendulum Encoder Connector**, which is shown as component #15 in Figure 4. Then connect the other cable end to the **Encoder Input 3** on your 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!**

5.4. Special Case: Connecting DAQ w/ 2 Encoder Input to IP02 and SLFJ-E

When using a data-acquisition board with only two encoder inputs, e.g. Q2-USB or some NI DAQ devices,connect the system as shown in Figure 10and described in . The IP01_2 cart pendulum connection is not used, so it is not omitted from the wiring.

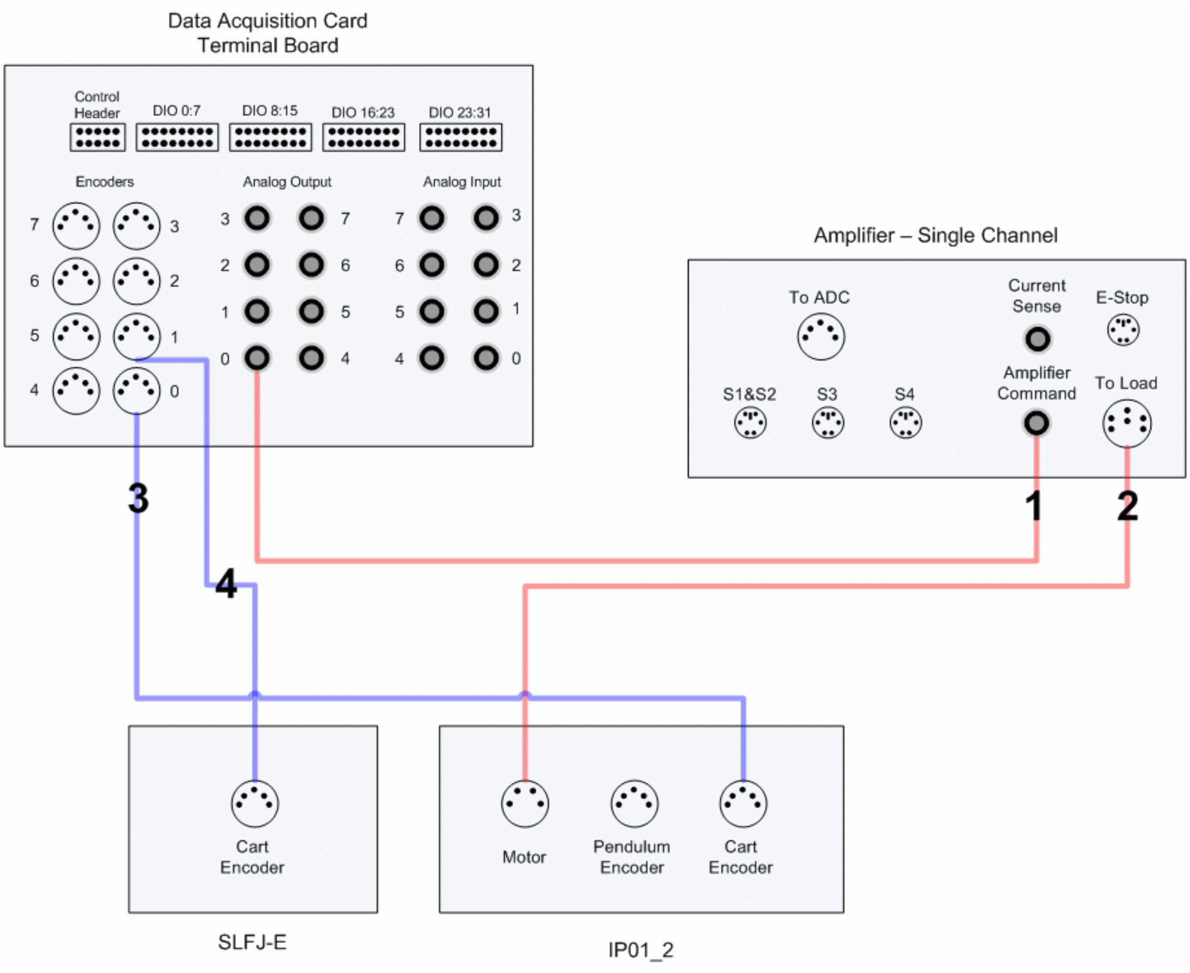


Figure 10: Connections for IP02, SLFJ-E, and a DAQ with only 2 encoder inputs (e.g. Q2-USB or NI board).

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	Terminal Board: Encoder Input #0	“IP02 Cart” encoder connector	IP02 cart position measurement.

Cable #	*From*	*To*	*Signal*
4	Terminal Board: Encoder Input #1	"IP02 Pendulum" encoder connector	SLFJ cart shaft angle measurement.

Table 5: Connection summary for IP02, SLFJ-E, and DAQ w/ 2 encoder inputs.

5.5. Typical Connection when using Q3 ControlPAQ-FW

The typical cabling connections detailed in this section are for the Quanser single linear flexible joint experiment when used with the Quanser Q3 ControlPAQ-FW device. The connections are illustrated in Figure 11 and summarized in Table 6.

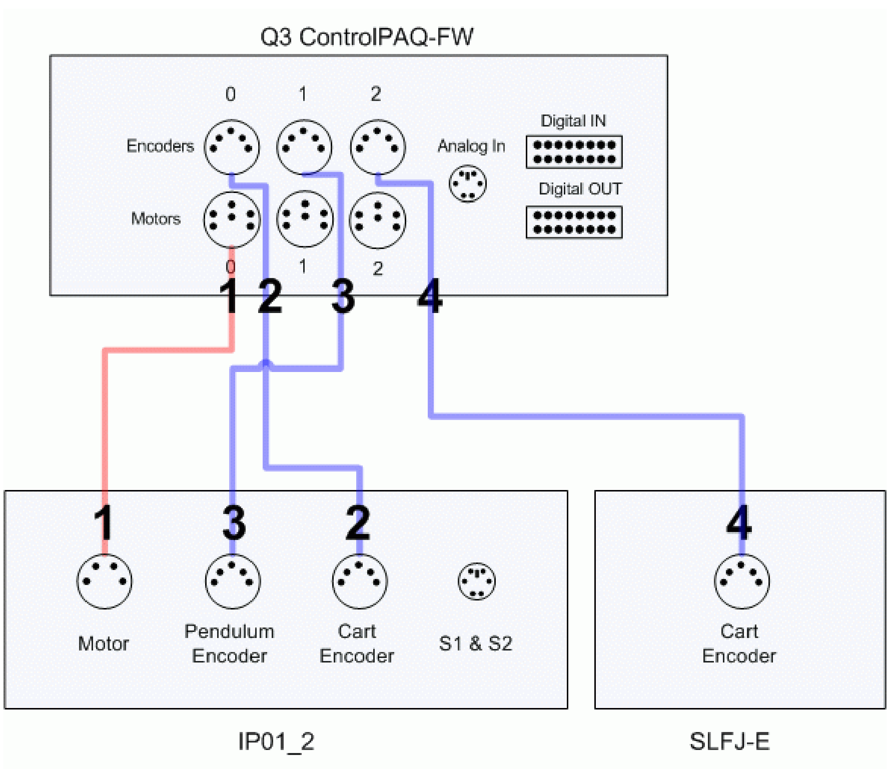


Figure 11: Connections for the IP02+SLFJ-E system with the Q3 ControlPAQ-FW.

Cable #	*From*	*To*	*Signal*
1	Q3: MOTOR 0	IP01_2 "Motor" connector	Power leads to the IP01_2 DC motor.
2	Terminal Board: Encoder Input #0	"IP02 Cart" encoder connector	IP02 cart position measurement.
3	Terminal Board: Encoder Input #1	"IP02 Pendulum" encoder connector	IP02 pendulum shaft angle measurement.
4	Terminal Board: Encoder Input #2	"IP02 Pendulum" encoder connector	SLFJ cart shaft angle measurement.

Table 6: IP02+SLFJ-E connection summary when using the Q3.

5.6. Other Possible SLFJ Configurations

As previously shown and discussed, the ability to vary parameters and change the hardware configuration is available should you wish to alter the system dynamics and therefore modify the control challenge.

For example, you could try any or a combination of the following:

- operate with or without the additional mass placed on your IP01 or IP02 cart.
- operate without or with one or with two additional weight(s) attached to your LFJC(-PEN)(-E) output system.
- change the linear spring characteristics (e.g. length, stiffness).
- incline your IP01 or IP02 track at an angle.
- add another Quanser module to your existing system (e.g. another LFJC(-PEN)(-E) stage, seesaw, pendulum).

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 - Single Linear Flexible Joint (SLFJ) – Linear Experiment #7: LQR Control - Student Handout.
[6] IP01 and IP02 - Single Linear Flexible Joint (SLFJ) – Linear Experiment #7: LQR Control – Instructor Manual.

Appendix A. LFJC Potentiometer Specification Sheet

7/8" (22mm) Precision Wirewound Potentiometer

FEATURES

- Special Resistance Tolerances to 1%
- Rear Shaft Extensions and Support Bearing
- Non Turn Lug
- Insulating Plastic Shaft
- Special Independent Linearity to ± 0.75%
- Dual Gang Configuration and Concentric Shafts
- High Torque and Center Tap
- Special Markings and Front Shaft Extensions
- Servo Unit available and Slipping Clutch

ELECTRICAL SPECIFICATIONS			
PARAMETER	**MODEL 533**	**MODEL 534**	**MODEL 535**
Resistance Range Standard Values	50Ω to 20KΩ	100Ω to 100KΩ	50Ω to 50KΩ
Capability Range	5Ω to 60KΩ	10Ω to 200KΩ	5Ω to 100KΩ
Standard Tol	± 5%	± 5%	± 5%
Linearity (Independent)	± 0.25%	± 0.25%	± 0.25%
Noise	100Ω ENR	100Ω ENR	100Ω ENR
Rotation (Electrical & Mechanical)	0° + 10°	0° + 10°	0° + 10°
Power Rating (@ 70°C)	1.0 watts	2.0 watts	1.5 watts
Additional Sections	75% of section 1		
Insulation Resistance	1000MΩ minimum 500VDC		
Dielectric Strength	1000V_{RMS} minimum 60Hz		
Absolute Minimum Resistance	Not to exceed linearity x total resistance or 1Ω, whichever is greater		
Tempco	20ppm/°C (standard values, wire only)		
End Voltage	0.25% of total applied voltage, maximum		
Phasing	CCW end points - section 2 phased to section 1 within ± 2°		
Taps	Center tap only		

MARKING	
Unit Identification	Manufacturer's name and model number, resistance value and tolerance, linearity specification date code and terminal identification

RESISTANCE VALUES	
Ohms	
533:	50R, 100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K
534:	100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K, 50K, 100K
535:	50R, 100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K, 50K

ORDERING INFORMATION

The Models 533 (3 turn), 534 (10 turn) and 535 (5 turn) can be ordered by stating

534	**1**	**2**	**XXX**
MODEL	MOUNTING	NUMBER OF SECTIONS	RESISTANCE EIA CODE SECTION #N
	1. Bushing **2**. Servo		(consult factory)

Appendix B. LFJC(-PEN)-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.

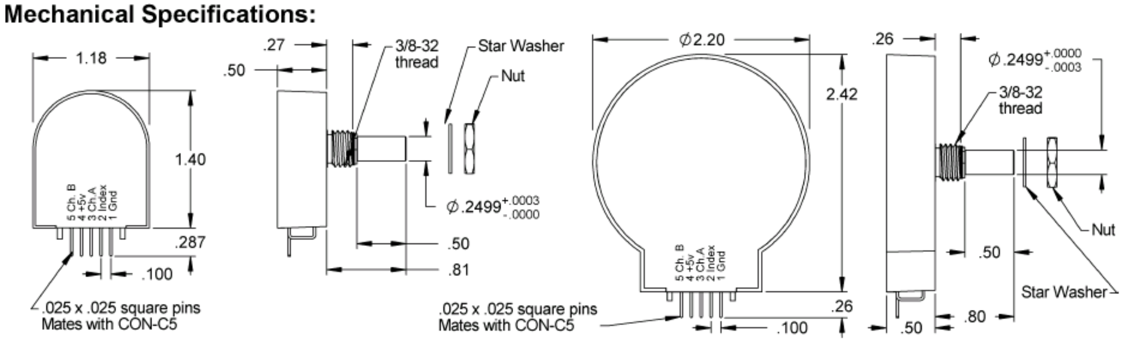
The **S1** and **S2** encoders are available with ball bearings for motion control applications or torque-loaded to feel like a potentiometer for front-panel manual interface.

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/sec²
Vibration	20 g. 5 to 2KHz
Shaft Speed	10,000 RPM max. continuous
Acceleration	50K rad/sec² 10K rad/sec² (**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/sec²
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.