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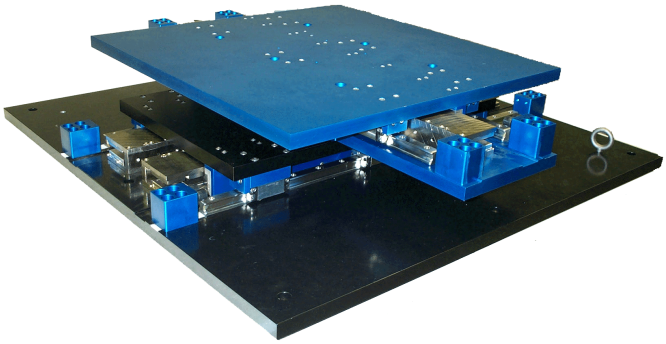
# *XY Shake Table III*



## User Manual

ST III

Quanser Inc.
2014

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# 1 PRESENTATION

The Quanser XY Shake Table III (ST III) shown in Figure 1.1 is a high-powered planar stage system that can move a load of up to 100 kg at high-accelerations and velocities. The stage itself is capable of moving in either the $x$ or $y$ directions and has a total travel greater than 20 cm on each axis. To minimize the amount of moving parts and achieve optimal performance, the table is actuated using linear motors. This increases the reliability of the system and keeps the operation of the system quiet.

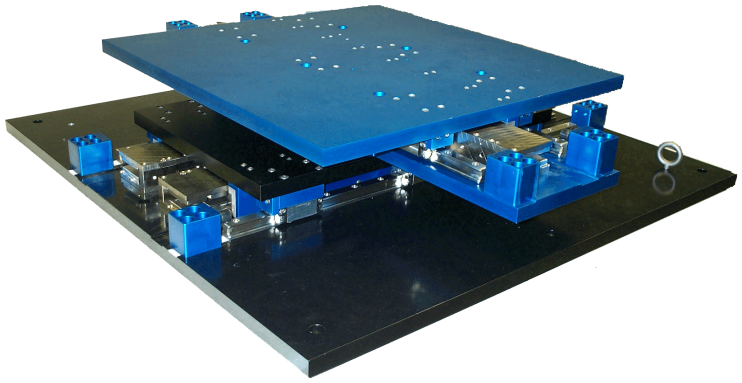


Figure 1.1: Quanser XY Shake Table IIIsystem

The system is comprised of:

1. Quanser XY Shake Table III
2. Power amplifier
3. Data acquisition (DAQ) device
4. PC running the real-time control (e.g. QUARC®)

The interaction between the different system components is shown in Figure 1.2. Using a software such as QUARC® on the PC/laptop, the user specifies a command signal to the shake table (e.g., sine wave, earthquake). The current needed to move the stage at the desired position is calculated in QUARC® and sent through the analog output channel of the DAQ device to the power amplifier. The amplifier applies the current and drives the motor on the XY Shake Table III. The table tracking the commanded signal and the resulting displacement and acceleration of the stage are measured by the on-board encoder and the accelerometer sensors. The encoder and accelerometer are connected to the DAQ and their signals can be displayed and processed further. Plotted data can be also be saved for later analysis.

**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.

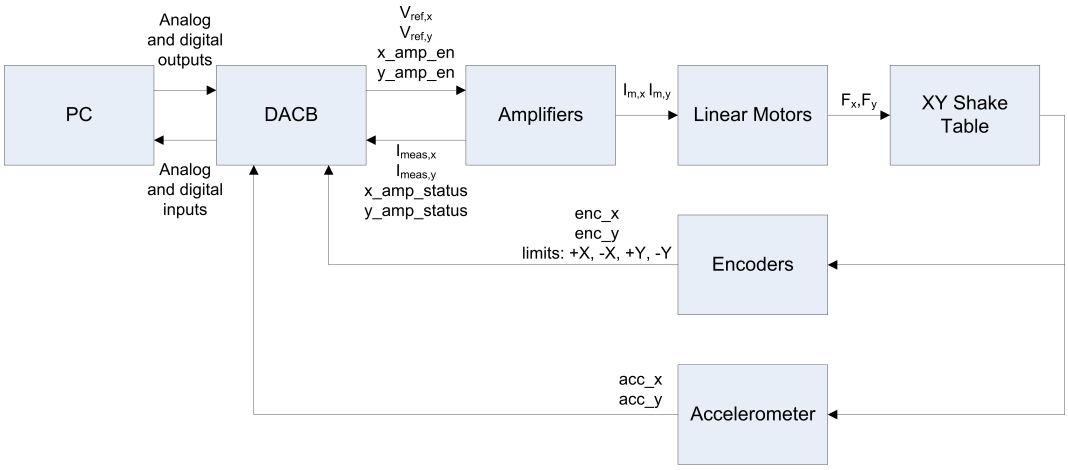



Figure 1.2: Interaction between main XY Shake Table III components

# 2 COMPONENTS

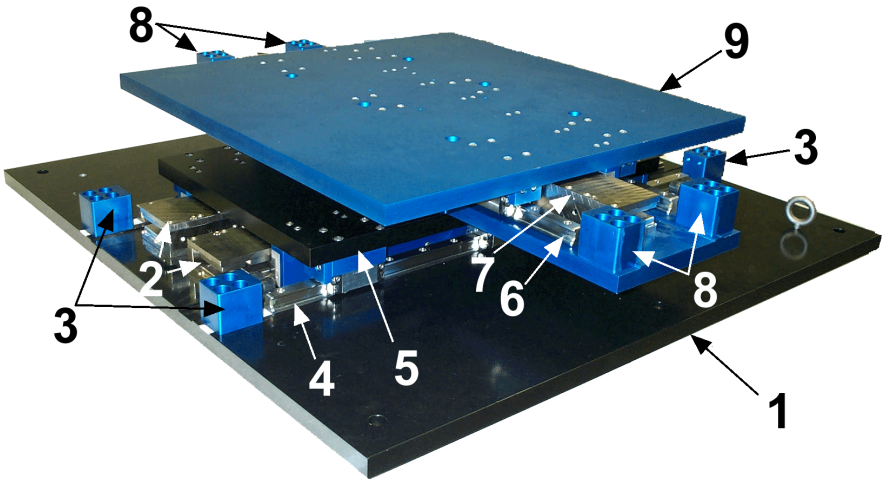
The high-powered XY Shake Table III system is depicted in Figure 1.1. The table is actuated using a total of three linear motors. Two motors power the x-axis on the bottom of the table, and one motor powers the y-axis on the top of the table. They together allow for XY planar motion in the Cartesian arrangement. The top motor is a mounted on a stage where experiments and test fixtures can be attached. The XY Shake Table III components are identified in Section 2. Some of the those components are then described in Section 2.2.

## 2.1 Nomenclature

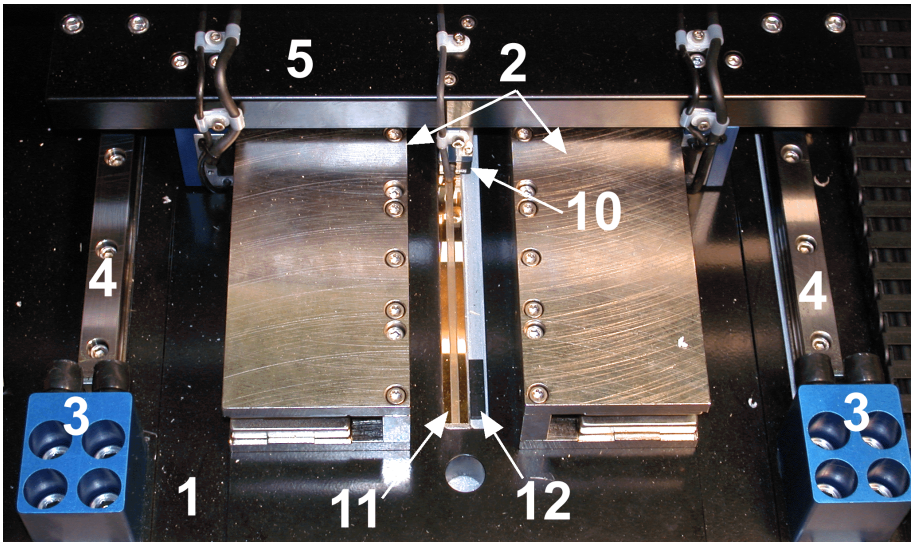
The components listed in Table 2.1 are labeled in Figure 2.1.

| ID | Component | ID | Component |
|---|---|---|---|
| 1 | Ground support stage | 7 | Top axis linear motor |
| 2 | Bottom axis linear motor | 8 | Top axis hard stops |
| 3 | Bottom axis hard stops | 9 | Top axis stage |
| 4 | Bottom axis linear bearing guide | 10 | Encoder scanning head |
| 5 | Bottom axis stage | 11 | Encoder scale tape |
| 6 | Top axis linear bearing guide | 12 | Magnet for limit switch |

Table 2.1: Components




(a) Top View




(b) Top Corner View

Figure 2.1: XY Shake Table III Components

## 2.2 Description

### 2.2.1 Linear Motor

The XY Shake Table III has two linear motors actuating the bottom axis and a single linear motor actuating the top axis. Each linear motor is the same. The specifications are given in Table 2.2.

**Caution:** Input 36.0 A peak, 12.0 A continuous.

**Caution:** Exposed moving parts.

| Symbol | Description | Value |
|---|---|---|
| $F_{max,peak}$ | Maximum peak force | 2642 N |
| $F_{max,cont}$ | Maximum continuous force | 880.7 N |
| $P_{max,peak}$ | Maximum peak power | 4554 W |
| $I_{max,peak}$ | Maximum peak current | 36.0 A |
| $I_{max,cont}$ | Maximum continuous current | 12.0 A |
| $k_t$ | Motor current-force constant | 72.95 N-m/A (16.4 lb/A) |
| $k_m$ | Motor back-emf constant | 83.86 V/(m/s) |
| $R_m$ | Electrical resistance | 3.60 $\Omega$ |
| $L_m$ | Electrical inductance | 4.40 mH |
| $\tau_e$ | Electrical time constant | 1.30 ms |
| | Motor force power constant | 39.14 N/W |
| $V_{max}$ | Maximum DC voltage | 330 V |
| | Thermal Dissipation Constant | 6.75 W/$^o$C |
| | Thermal Time Constant | 15.10 min |
| | Max Winding Temperature | 100.00 $^o$C |
| | Coil Mass | 5.67 kg [12.5 lb] |
| | Coil Length | 71.12 cm [28 inch] |

Table 2.2: Linear Motor Specifications

### 2.2.2 Amplifiers

The linear motors are driven using current-controlled PWM amplifiers from Advanced Motion Controls (AMC). The amplifiers for each axis is different: the x-axis uses an the AMC B060A400AC drive and the y-axis uses the B30A40AC drive. The main specifications for the x-axis amplifiers is given in Table 2.3 and the y-axis amplifier specifications are summarized in Table 2.4. The current reference pin on each amplifier has a maximum output of $\pm$7.25V (i.e., command signal to current loop). This is used to calculate the amplifier gain. For example in the x-axis, the maximum peak current is 60 A so the gain is 60 A/ 7.25 V = 8.28 A/V.

| Symbol | Description | Value |
|---|---|---|
| | Max continuous power at rated voltage | 10630 W |
| $I_{max,x}$ | Maximum peak current | 60.0 A |
| | Maximum continuous current | 30.0 A |
| $K_{a,x}$ | Motor current-force constant | 8.28 A/V |
| | Current monitor scaling | 10 A/V |

Table 2.3: X-Axis Amplifier Specifications

| Symbol | Description | Value |
|---|---|---|
| | Maximum peak power | 5700 W |
| $I_{max,x}$ | Maximum peak current | 30.0 A |
| | Maximum continuous current | 15.0 A |
| $K_{a,x}$ | Motor current-force constant | 4.14 A/V |
| | Current monitor scaling | 4.2 A/V |

Table 2.4: Y-Axis Amplifier Specifications

### 2.2.3 Hard Stops

The bottom and top stages of the shake table are equipped with a pair of hard stops. They are located at the each end of the linear guides on the bottom and top stages, as shown in Figure 2.1. The hard stops are equipped with rubber dampers that can absorb a great amount of impact force should the table become unstable.

### 2.2.4 Linear Bearing Guides

The bottom and top stages ride along a pair of linear guides using ball bearings. They enable the stages to have a total travel length of 8.50 inches, or 21.59 cm. They are shown in both Figure 2.1.

### 2.2.5 Bottom and Top Stage

The top axis stage weighs a total of 210 lbs and the moving weight is 105 lbs. The bottom stage axis weighs a total of 387 lbs and the moving weight is 307 lbs. The moving weight is the sum of the bottom moving table, 97 lbs, and the total top axis weight, 210 lbs.

The bottom support plate, shown in Figure 2.1, is 42 $\times$ 41 5/6 inch$^2$, or 106.7$\times$ 106.4 cm$^2$. The bottom linear motor drives are installed onto this plate. The plate has 4 large screw holes at each corner and smaller screw holes along the sides. These can be used to fasten the shake table onto a ground floor support to prevent the shake table system from moving, or at least reduce the amount of vibration. Although this is not necessary, it is recommended in order to yield more precise results when, for instance, measuring acceleration.

The top stage on the XY Shake Table III, shown in Figure 2.1, 28 $\times$ 28 inch$^2$, or 71.1 $\times$ 71.1 cm$^2$. The top stage has many screw holes that can be used to mount structures and other objects, e.g., Quanser Active Mass Damper. The mass of both stages along with their travel and dimensions are summarized in Table 2.5.

| Symbol | Description | Value |
|---|---|---|
| | Total top axis mass | 95.22 kg |
| $M_{p,y}$ | Moving top axis mass | 47.61 kg |
| | Total bottom axis mass | 175.48 kg |
| $M_{p,x}$ | Moving bottom axis mass | 139.21 kg |
| | Entire stage mass | 272.1 kg |
| | Total bottom axis travel distance | 21.59 cm |
| | Total top axis travel distance | 21.59 cm |
| | Dimensions of base | 106.7 $\times$ 106.4 cm$^2$ |
| | Dimensions of top stage | 71.1 x 71.1 cm$^2$ |

Table 2.5: Bottom and Top Stage Specifications

### 2.2.6 Encoder

There is a LIDA 477/487 Heidenhain encoder mounted on the ground stage base plate that measures the bottom axis or x-axis position. The encoder read head scans along the scaling strip and outputs 250,000 counts per meter in 1X mode. The encoder resolution is therefore 250 nm/count. Similarly there is encoder setup on the top stage to measure the y-axis position.

**Note:** The encoders can output 1,000,000 counts per meter when used in quadrature mode. The lower-resolution 1X mode was used to reduce sensor noise.

### 2.2.7 Accelerometer

A dual-axis ADXL210E accelerometer is mounted underneath the stage of the Shake Table II to measure the acceleration of the stage in both the $x$ and $y$ directions. It is shown with ID #15 label in Figure 2.1. The sensor has a range of $\pm$10 g and its noise, in the operating range of the shake table, is approximately $\pm$5.0 mV, i.e., $\pm$5.0 mg. The analog sensor is calibrated such that 1 V equals 1 g, or 9.81 m/s$^2$. See the ADXL210E accelerometer specification sheet [1] for more details.

**Caution:** The accelerometer readings can be misleading and lead to unexpected results. Please use caution when using them as they are generally used as indicators.

### 2.2.8 Limit Switches

There is a total of four limit switches installed to detect when the bottom or top stage approaches the limit of their travel the safety hard stops. There is a +X and -X limit switch at each end of the bottom x-axis stage and a +Y and -Y limit switch at each end of the top y-axis stage.

The limit sensors are magnetically triggered. They are located approximately 1 cm from all the safety hard stops which limits the travel as described in Table 2.6.

The limit sensors are active low, as summarized in Table 2.6. Thus when the stage goes over the +X switch, it outputs 0. However, when +X is not being pressed down (i.e., triggered) it normally outputs 1. This signal can then be used to calibrate the stage to center or to stop the control software and prevent the table from hitting the hard stops.

| Description | Value |
|---|---|
| X-Axis travel distance between limit sensors | 20.15 cm |
| Y-Axis travel distance between limit sensors | 20.15 cm |
| Output value when +X switch pressed down (active low) | 0 |
| Output value when -X switch pressed down (active low) | 0 |
| Output value when +Y switch pressed down (active low) | 0 |
| Output value when -Y switch pressed down (active low) | 0 |

Table 2.6: Limit Switch Specifications

# 3 SYSTEM SETUP

In this section, the interaction between the data acquisition (DAQ) device and the various devices on the XY Shake Table III is explained. When setting up the system, go through the wiring described in Section 3.2.

The following is a listing of the hardware components used in this experiment:

1. **Power Amplifier**: PWM current-controlled amplifiers.
2. **Data Acquisition Device**: Quanser Q8.
3. **Shake table plant**: XY Shake Table III.

For reference purposes, Section 5 contains detailed drawings that describe the connections between the various signals of XY Shake Table III and the DAQ board. Figure 5.1 gives an overview of the system wiring. The x and y-axis amplifiers wiring is described in Figure 5.2 and Figure 5.3, respectively. Figure 5.4 illustrates the encoder connections of the system. The power system connections are summarized in Figure 4.5 and the start/stop logic wiring is detailed in Figure 5.5.

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

**Caution:** The XY Shake Table III is a high-powered system: setup and installation should be left to qualified personnel only.

## 3.1 Cable Nomenclature

The cables listed in Table 3.1 are used to connect the XY Shake Table III to the amplifier / control box. Depending on your configuration, not all these cables are necessary. The Analog Cable and E-Stop are used with the standard XY Shake Table III system. The RCA, Encoder, and Motor cables are only used with the Active Mass Damper (AMD) system, which is optional.

| Cable | Type | Description |
|---|---|---|
|  (a) Analog Cable | 6-pin-mini-DIN to 6-pin-mini-DIN | Connects an external analog sensor (e.g., accelerometer) to the control box *S1&S2*, *S3&S4*, and *S5&S6* connectors. The cable also supplies ± 12 VDC to power the sensor. |
|  (b) E-Stop | E-Stop | The Remote E-Stop must be connected to the amplifier for proper operation. The E-Stop button locks in the disabled position when pressed. To release the E-Stop, twist the red button clockwise. |
|  (c) RCA Cable | 2xRCA to 2xRCA | Connect the Analog Output channel on the DAQ to the *Amplifier Command* connectors on the VoltPAQ (note: only used with AMD system). |
|  (d) Encoder Cable | 5-pin-stereo-DIN to 5-pin-stereo-DIN | This cable carries the encoder signals between the Active Mass Damper (AMD) Cart *Encoder* connector and the DAQ (note: only used with AMD system). |
|  (e) Motor Cable | 4-pin-DIN to 6-pin-DIN | This cable connects the output of the amplifier to the Active Mass Damper Cart DC motor (note: only used with AMD system). |

Table 3.1: Cables used to connect the XY Shake Table III experiment

## 3.2 Connections

This section describes the connections between the amplifier/control box and the Quanser XY Shake Table III experiment. The connections are summarized in Table 3.2, and pictured in Figure 3.1.

| Cable | From | To | Signal |
|---|---|---|---|
| 1 | ST III: Bottom Left Motor Cable | Amplifier: **Bottom Left Motor** Connector | Connects motor leads from amplifier to bottom left motor. |
| 2 | ST III: Bottom Right Motor Cable | Amplifier: **Bottom Right Motor** Connector | Connects motor leads from amplifier to bottom right motor. |
| 3 | ST III: Top Axis Motor Cable | Amplifier: **Top Axis Motor** Connector | Connects motor leads from amplifier to bottom left motor. |
| 4 | ST III: Top Axis Hall Cable | Amplifier: **Top Axis Hall** Connector | Top axis hall-effect sensor feedback to top-axis amplifier. |
| 5 | ST III: Bottom Axis Hall Cable | Amplifier: **Bottom Axis Hall** Connector | Bottom axis hall-effect sensor feedback to bottom axis amplifier. |
| 6 | ST III: Top Axis Encoder Cable | Amplifier: **Top Axis Encoder** Connector | Top-axis encoder fed-back to data-acquisition board. Used to measured y-axis position. |
| 7 | ST III: Bottom Axis Encoder Cable | Amplifier: **Bottom Axis Encoder** Connector | Bottom-axis encoder fed-back to data-acquisition board. Used to measured y-axis position. |
| 8 | ST III: Limits Cable | Amplifier: **Limits** Connector | Stage limits +X, -X, +Y, and -Y fed-back to DAQ. Used to detect when x and y stage reach their maximum position. |
| 9 | ST III: Accelerometer 6-pin-mini-DIN Connector | Amplifier: **S1&S2** 6-pin-mini-DIN Connector | Connects the accelerometer using the 5-pin-mini-DIN to 5-pin-mini-DIN cable. This caries both the x and y acceleration signals of the top stage. |

Table 3.2: Connections between the XY Shake Table III and the amplifier (back panel)

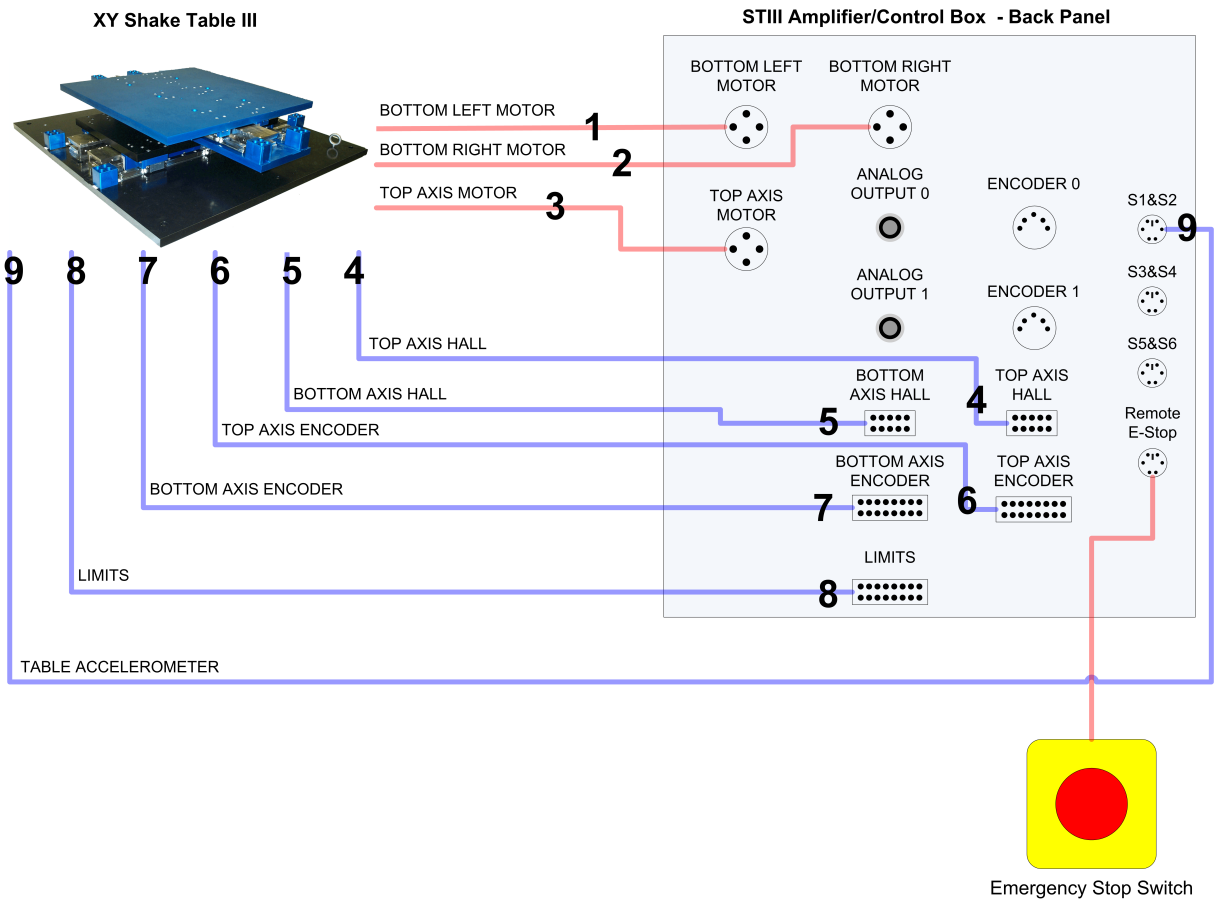



Figure 3.1: XY Shake Table III connections

## 3.3 Two-Floor Active Mass Damper Setup and Connections

**Note:** The Two-Floor Active Mass Damper is an optional system and may not have been supplied with your system.

### 3.3.1 Setup

The Two-Floor Active Mass Damper (with two carts) is shown in Figure 3.2. As indicated, **make sure that the x-axis of the accelerometers on the AMD floors are in-line with the x-axis of the shake table and that the connector sides are on the same side**.

As illustrated in Figure 3.3, align the three holes of the AMD base floor to the three screw holes on the top of the shake table stage. Then, using three 8-32 screws fasten the base of the bottom floor to the top of the stage.

Note that you can also configure the two floor dual cart system (2xAMD-1) as a two floor one cart active mass damper (AMD-2) or a one floor active mass damper (AMD-1). See the the *AMD-1 User Manual* and the *AMD-2 User Manual* for information on these systems. Using these AMD systems with the Quanser Shake Table II is described in *Shake Table II with AMD-1 User Manual*, *Shake Table II with AMD-2 User Manual*, and *Shake Table II with 2xAMD-1 User Manual*.

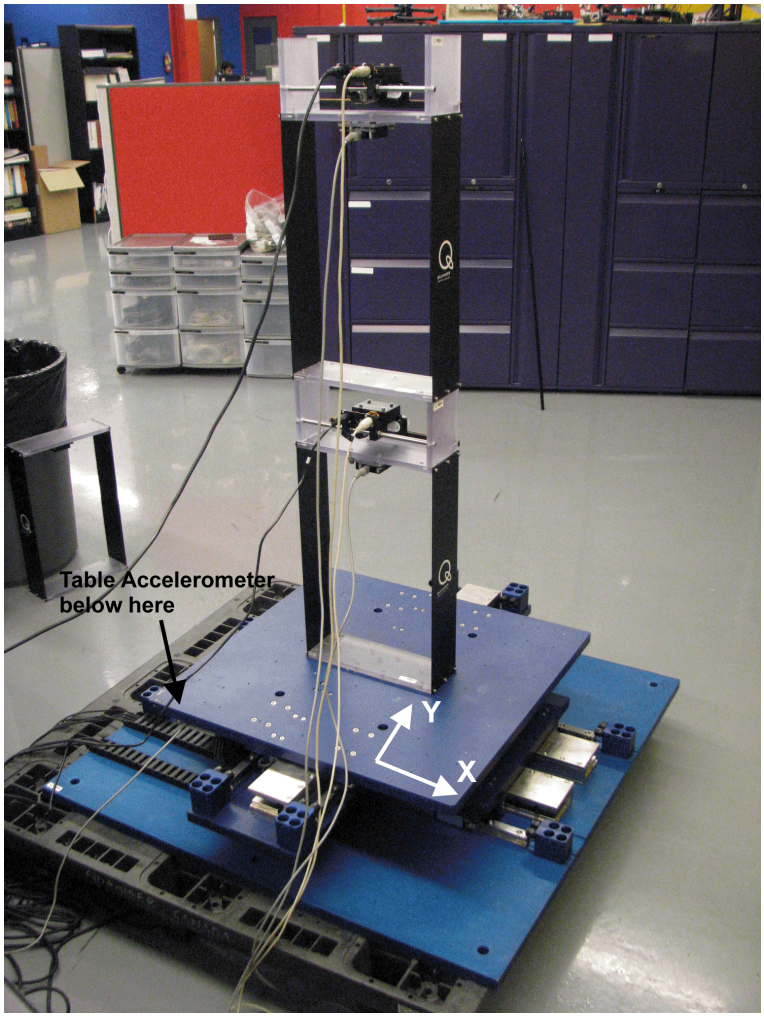



Figure 3.2: Two-Floor Active Mass Damper on XY Shake Table III

### 3.3.2 Connections

When using the Two-Floor Active Mass Damper device, additional connections are required. These extra connections are shown in Figure 3.4 and listed in Table 3.3.

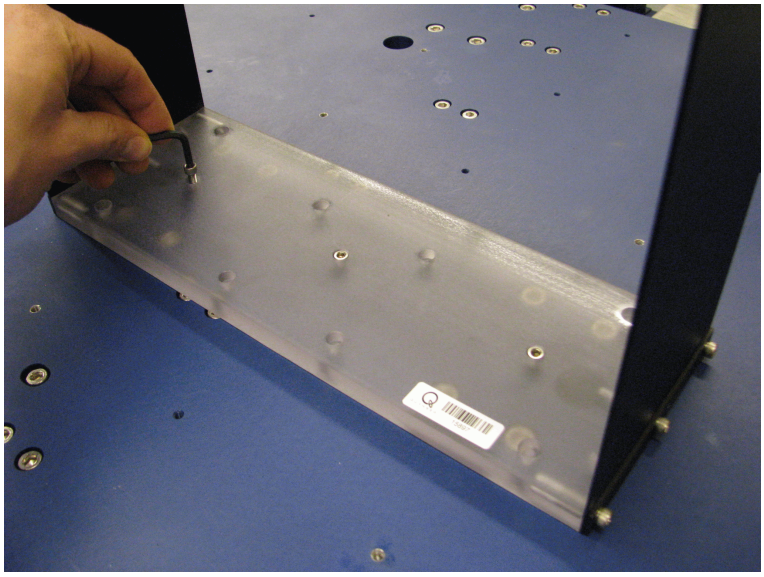


Figure 3.3: Fasten base of AMD floor to stage

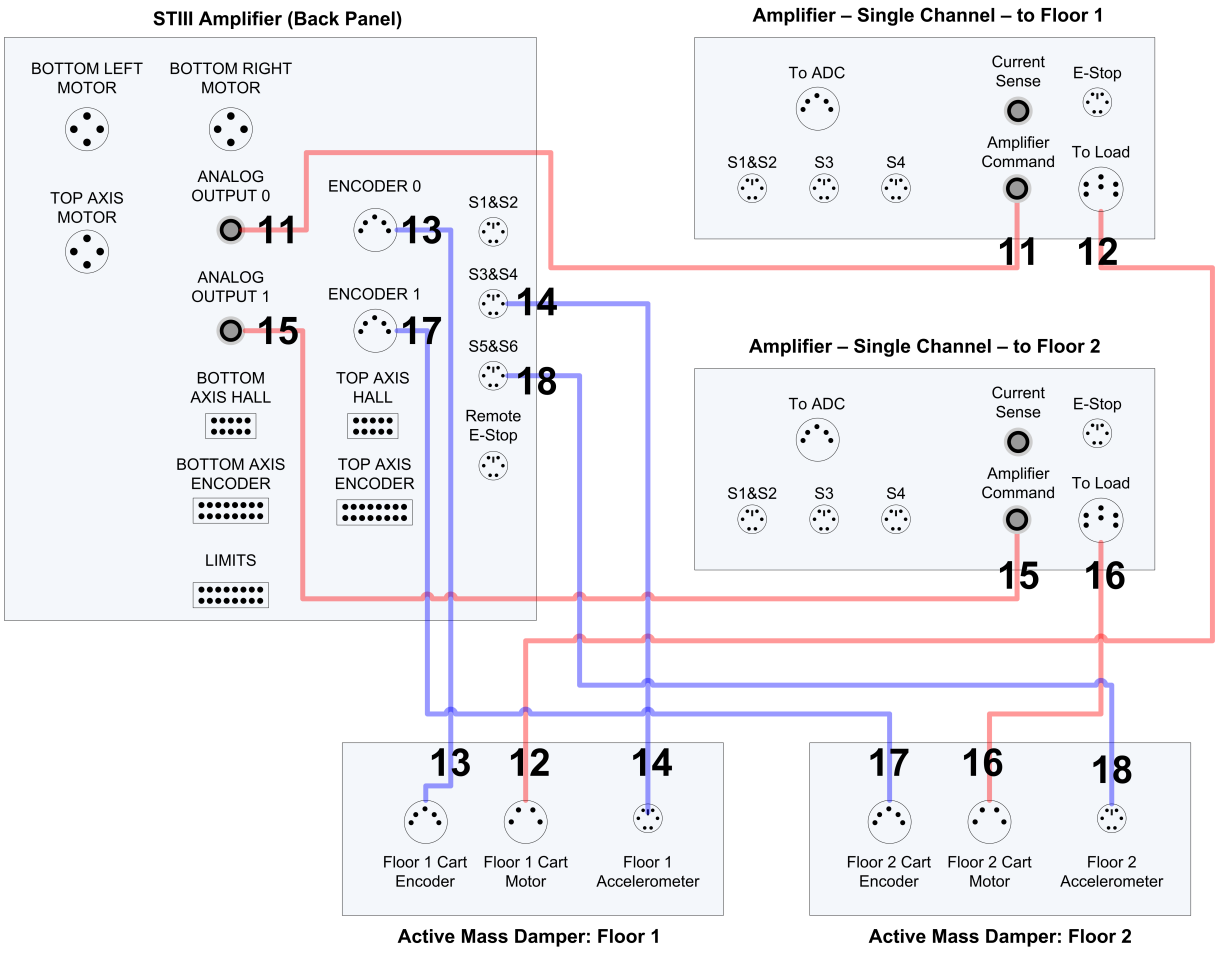



Figure 3.4: Connecting the Two-Floor Active Mass Damper plant to the ST III amplifier/control box

| Cable | From | To | Signal |
|---|---|---|---|
| 11 | ST III Amplifier: **ANALOG OUTPUT 0** | Floor 1 VoltPAQ: **Amplifier Command** Connector | Bottom cart control signal generated by controller running on PC. |
| 12 | Floor 1 VoltPAQ: **To Load** Connector | AMD Floor 1: **Cart Motor** Connector | Amplified control signal applied to IP02 motor on bottom floor, $V_{m1}$. |
| 13 | ST III Amplifier: **ENCODER 0** | AMD Floor 1: **Encoder** Connector | Measures the linear position of the bottom floor cart, $x_{c1}$. |
| 14 | AMD Floor 1 **Accelerometer** Connector | ST III Amplifier: **S3&S4** Connector | Floor 1 measured acceleration (x-axis available on S3 and y-axis on S4. |
| 15 | ST III Amplifier: **ANALOG OUTPUT 1** | Floor 2 VoltPAQ: **Amplifier Command** Connector | Top cart control signal generated by controller running on PC. |
| 16 | Floor 2 VoltPAQ: **To Load** Connector | AMD Floor 2: **Cart Motor** Connector | Amplified control signal applied to IP02 motor on top floor, $V_{m2}$. |
| 17 | ST III Amplifier: **ENCODER 1** | AMD Floor 2: **Cart Encoder** Connector | Measures the linear position of the top floor cart, $x_{c2}$. |
| 18 | AMD Floor 2 **Accelerometer** Connector | ST III Amplifier: **S5&S6** Connector | Floor 2 measured acceleration (x-axis is on S5 and y-axis on S6). |

Table 3.3: Connections between Two-Floor Active Mass Damper system and ST III amplifier/control box

# 4 SYSTEM HARDWARE DESCRIPTION

This section details how the amplifier, encoder, accelerometer, and power systems are connected.

## 4.1 Amplifier Wiring

The Drive A amplifier supplies current in the x-axis linear motor and Drive B amplifier drives current in the y-axis motor. The connections between the amplifiers and the data acquisition (DAQ) device are illustrated in Figure 4.1. The connections are made such that the current monitor and amplifier status signals can be read by the PC. See Figure 5.2 and Figure 5.3 for the wiring details of the x-axis and y-axis amplifiers.

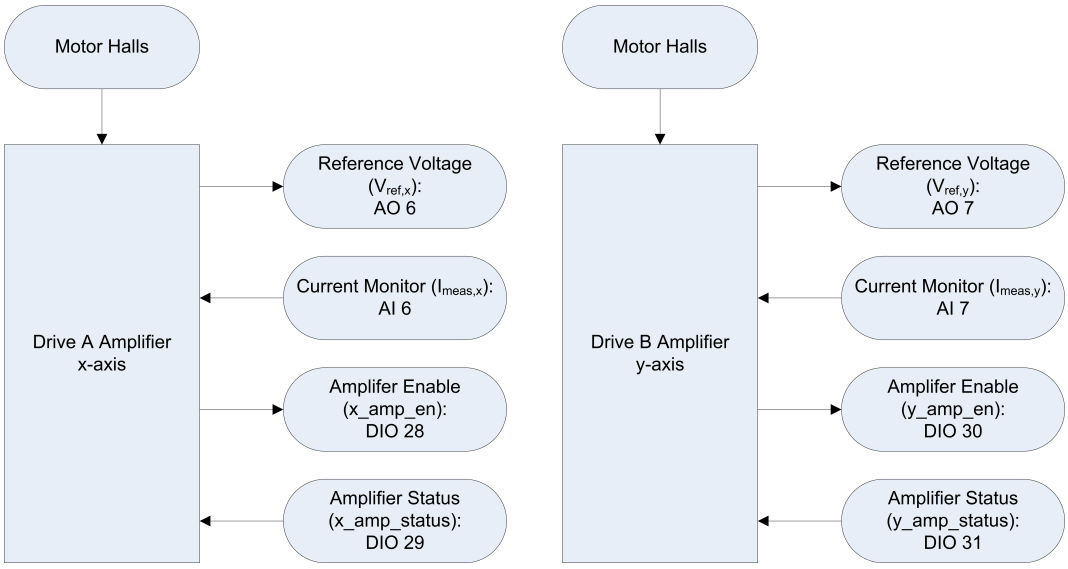



Figure 4.1: Amplifier drive A and B wiring

## 4.2 Encoder Wiring

The x-axis and y-axis differential encoders are connected to a line driver to output a single-ended signal. These signals are then connected to the data acquisition device , as illustrated in Figure 4.2. The limit switch output is connected directly to the digital inputs on the data acquisition system. See Figure 5.4 for the details on the encoder wiring.

## 4.3 Accelerometer Wiring

As illustrated in Figure 11, up to three X-Y accelerometers can be connected to the data acquisition device. Accelerometer #1 is connected to the *S1&S2* connector and the x and y acceleration signals are available on Analog Input channels #0 and #1 on the DAQ. Accelerometer #2 is wired to *S3&S4* connector and the x and y accelerations are measured on AI channel #2 and #3, respectively. Finally, accelerometer #3 is connected to *S5&S6* and read on AI channels #4 and #5.

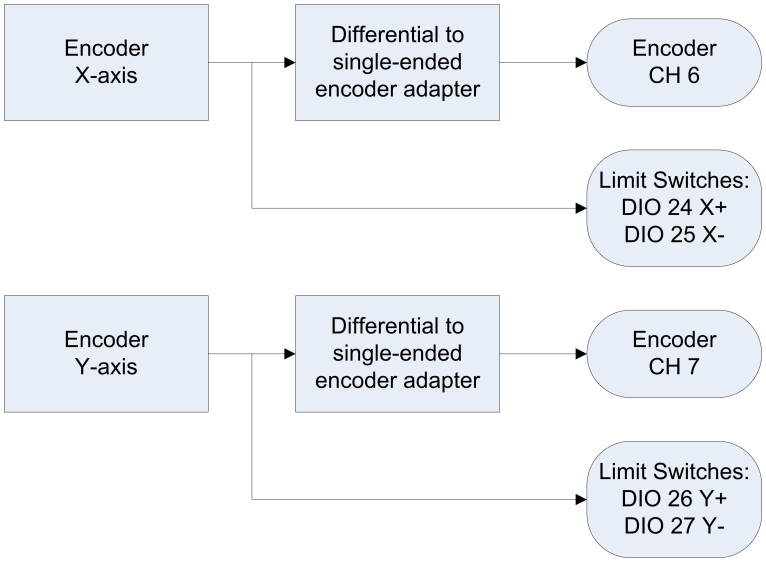



Figure 4.2: Encoder wiring

## 4.4 System Power

The amplifiers can only be enabled if the E-Stop switches are in the released position and the ARM button has been pressed.

To engage the system, follow this procedure:

1. Turn ON the main power supply that is connected to the amplifier (three-phase or single-phase).
2. Release the E-Stop button located on the front panel of the amplifier/control box, shown in Figure 4.4, by turning it clockwise.
3. Release the switch on the remote E-Stop, shown in Figure 3.1b.
4. Press on the green ARM button on the front panel of the amplifier box, pictured in Figure 4.4.
5. The POWER and ARMED LEDs should both be ON. This means the amplifiers are ready-to-be-enabled. When the digital output lines #28 and #30 are set to low, the amplifiers are enabled and can drive the shake table motors.

**Note: After Pressing an E-Stop**: When either of the E-Stop switches is pressed down, the amplifiers can no longer be enabled until you release that E-Stop and press the ARM button again.

As shown by Figure 4.5, the amplifiers are typically powered by a three-phase power supply. However, this can also be driven using single-phase. The system power connections are detailed in Figure 4.5.

**Caution:** The three-phase power supply voltage is 120/208 VAC. **Regions using 230 VAC should apply single-phase supply only! Any voltage input applied greater than 240 VAC will damage the amplifiers.**

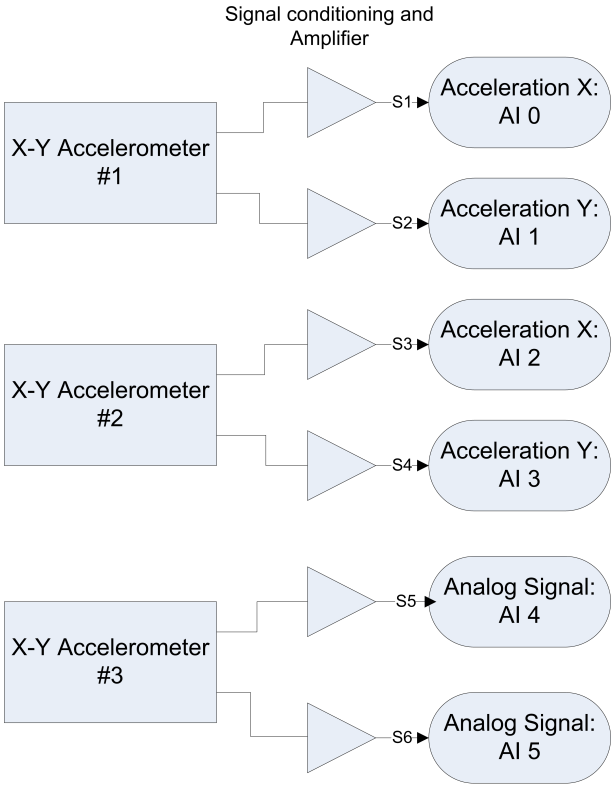



Figure 4.3: Accelerometer and analog sensor connections


Figure 4.4: Front panel of amplifier control box

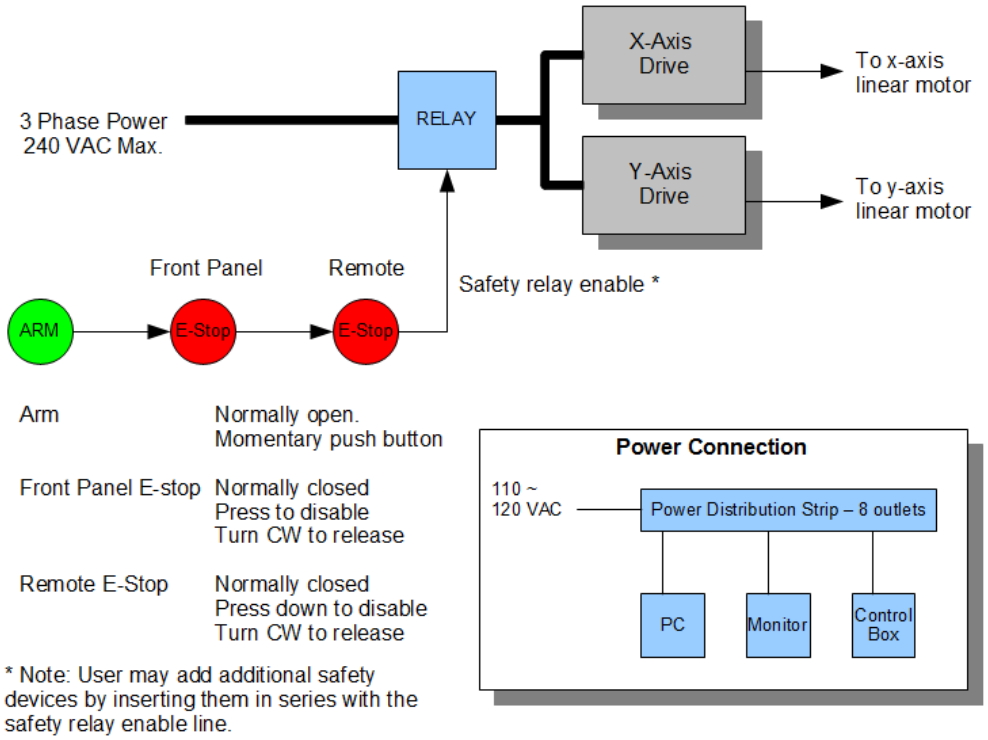



Figure 4.5: Power connections schematic

# 5 SYSTEM SCHEMATICS

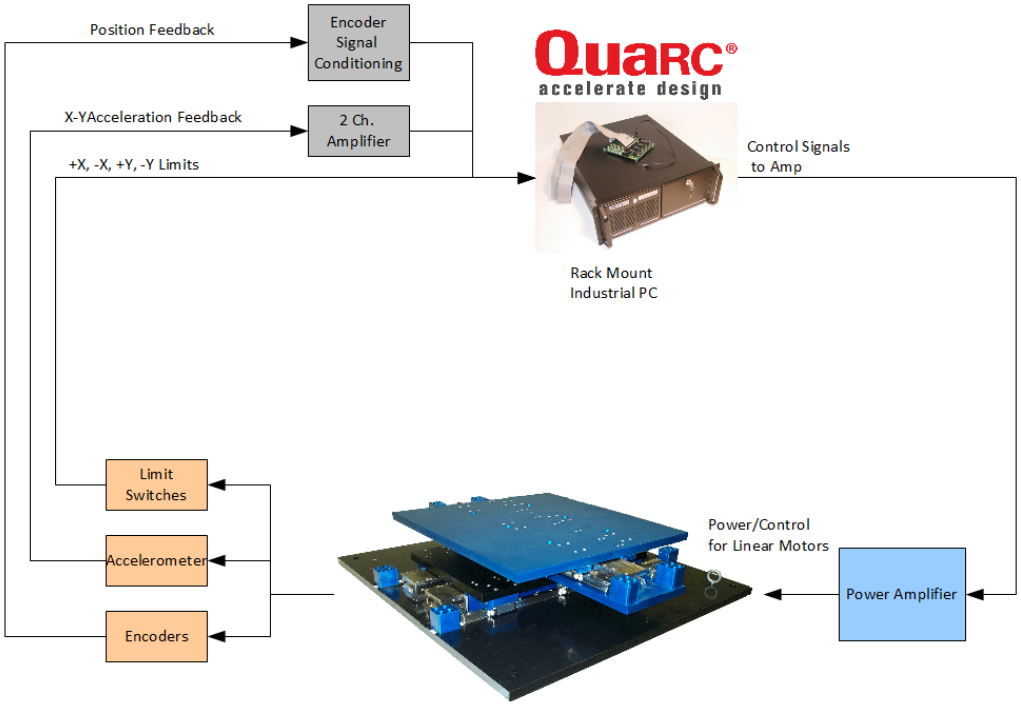



Figure 5.1: XY Shake Table III connection overview

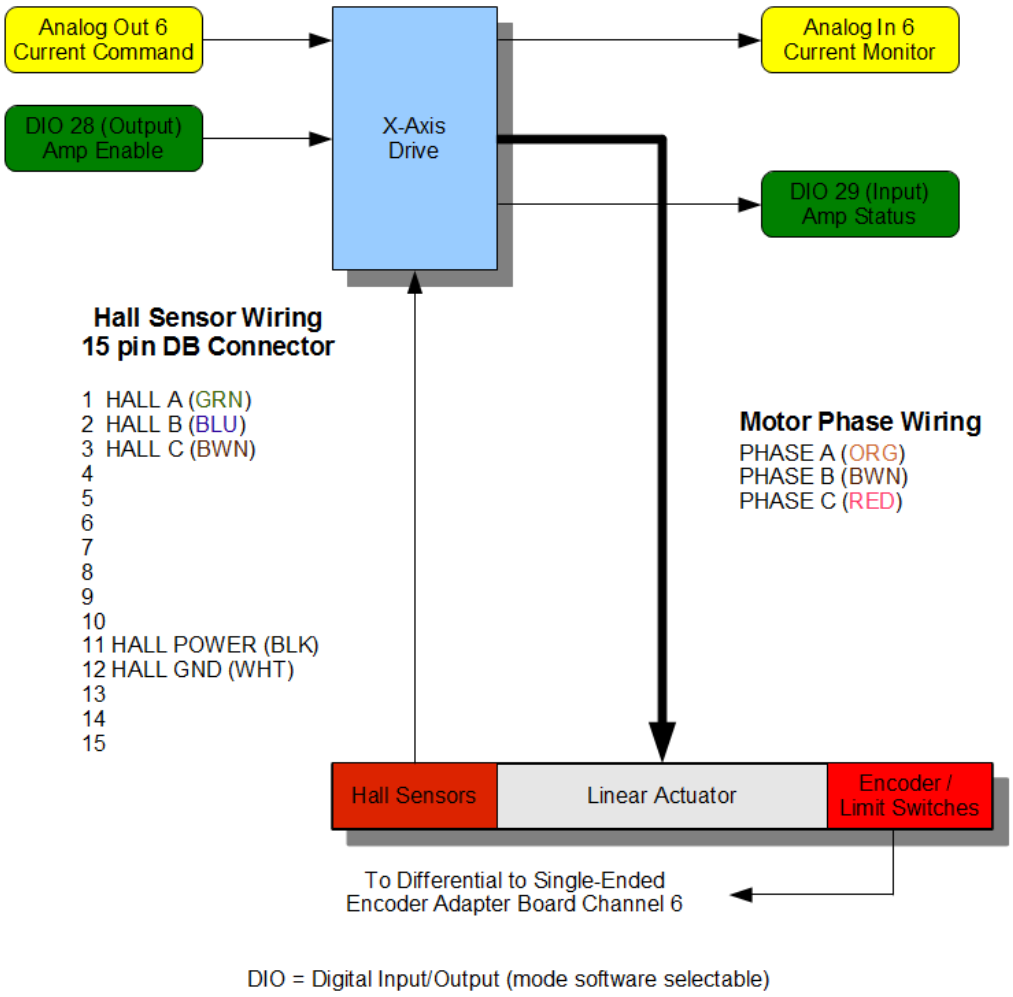



Figure 5.2: X-Axis amplifier wiring details

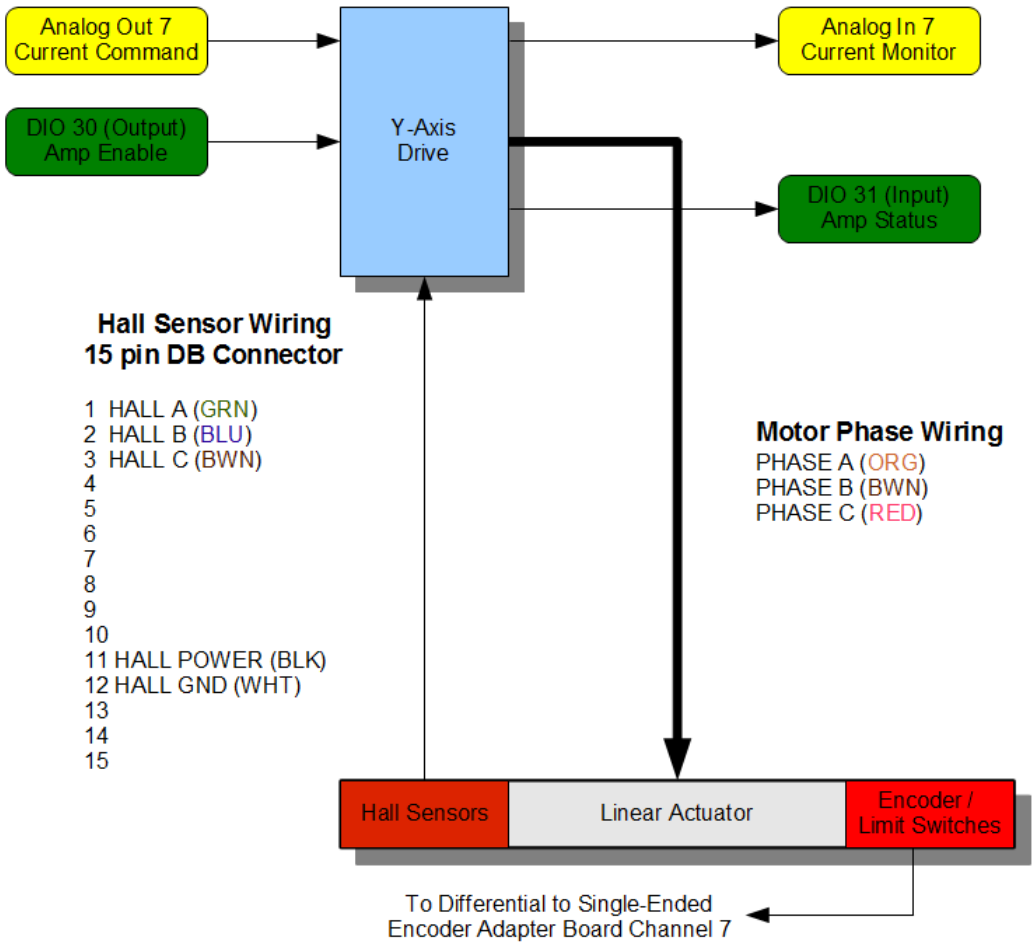
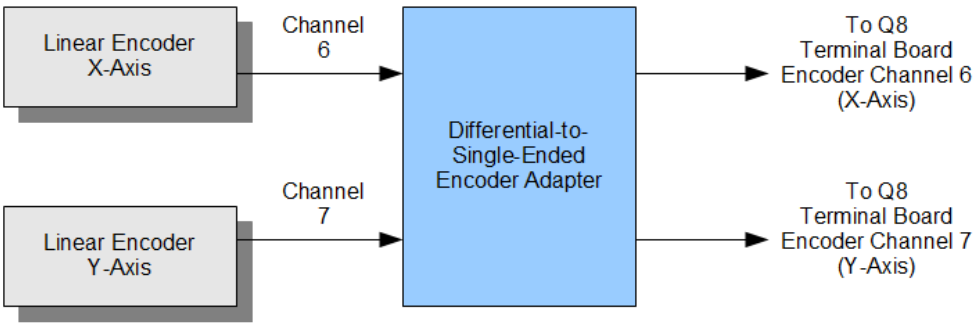
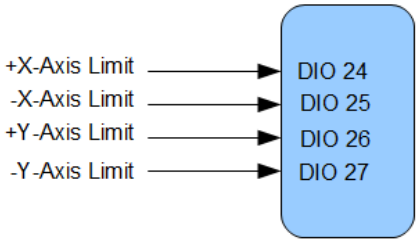



Figure 5.3: Y-Axis amplifier wiring details




**Encoder Cable Pinouts**

| | | |
|---|---|---|
| 1 | A+ | (BWN) |
| 2 | GND | (WHT/GRN) |
| 3 | B+ | (GREY) |
| 4 | +5V | (GREEN/BWN) |
| 5 | | |
| 6 | LIMIT 2 | (BLK/YEL) |
| 7 | I- | (BLK) |
| 8 | LIMIT 1 | (BLK/GRN) |
| 9 | A- | (GRN) |
| 10 | GND | (WHT) |
| 11 | B- | (PNK) |
| 12 | +5V | (BLU) |
| 13 | | |
| 14 | I+ | (RED) |

**Differential Board Connection**

| | |
|---|---|
| 1 | A- |
| 2 | A+ |
| 3 | B- |
| 4 | B+ |
| 5 | I- |
| 6 | I+ |
| 7 | GND |
| 8 | +5V |

Figure 5.4: Encoder and limit switch connections

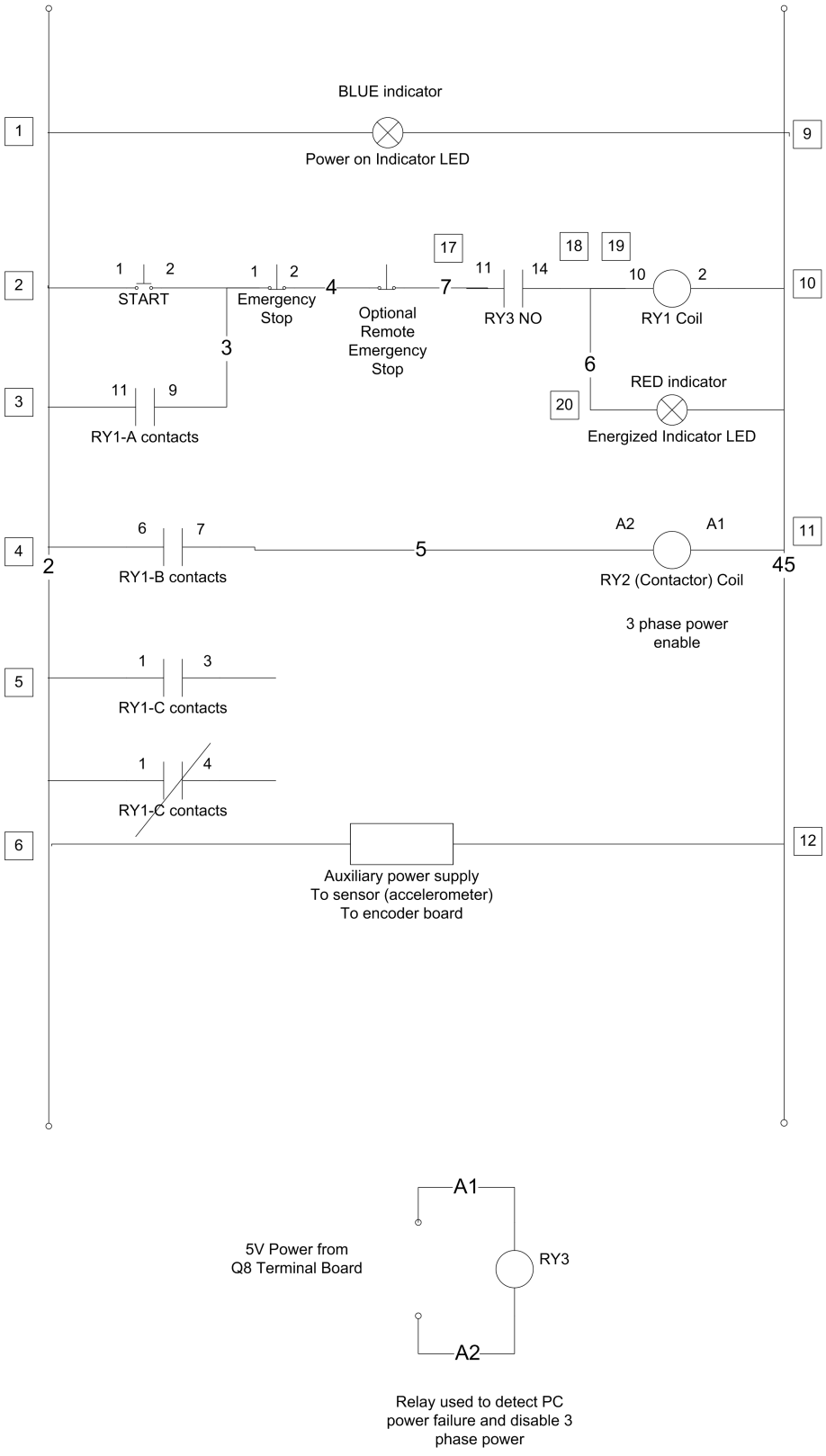



Figure 5.5: Start/stop logic of 110 VAC wiring

# 6 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] Analog Devices. Adxl210e. 2002.