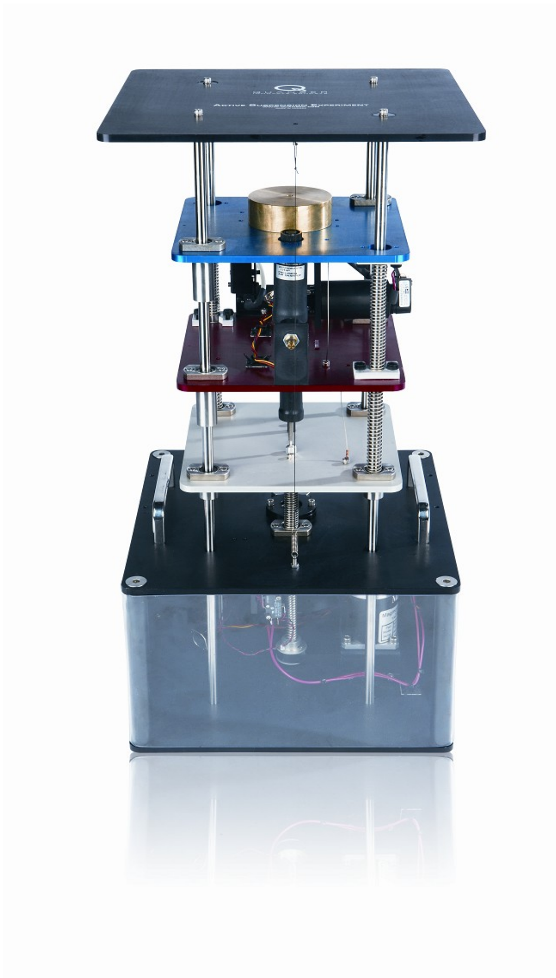
Advanced Mechatronics Collection:ASP

Active Suspension Plant

Active Suspension System



User Manual

Table of Contents

1. Active Suspension System - Presentation

The Active Suspension experiment comes complete with curriculum for undergraduate students and teaches cutting-edge technology that has brought a new generation of vehicles to life. Conventionally, automotive suspension designs have been a compromise between the three paradoxical criterion of road handling, suspension travel and passenger comfort. Active suspension technology is used in the automotive industry to continuously control the vertical movement of the wheel using an actively controlled actuator placed on the suspension axis. In recent years the use of this technology has allowed car manufacturers to achieve all three desired criterion independently. Similar technologies have also been used in train bogies to improve the curving behavior of the train and the decrease acceleration perceived by the passenger.

1.1. Active Suspension System: General Description

The Active Suspension plant is a bench-scale model to emulate a quarter-car model controlled by an Active Suspension mechanism. The plant consists of three floors/plates on top of each other. The top floor resembles the vehicle body and is suspended over the middle plate with two springs. A capstan drive high quality DC motor is also standing between the top and middle plates to emulate an active suspension mechanism.

The top floor is instrumented with an accelerometer to measure the acceleration of the vehicle body relative to the plant ground. The middle plate is in contact with the bottom plate, i.e. the road, through a spring and constitutes the tire in the quarter-car model. The bottom floor provides the road excitation in the system. It is connected to a fast response DC motor so that the designer can simulate different road profiles.

When the motor turns, the torque created at the output shaft is translated, through the lead screw and gearing mechanism, to a linear force which results in the bottom plate's motion. The structure is made of steel and the three plates can smoothly slide along a stainless steel shaft using linear bearings. The motion of the two bottom plates is tracked directly by two high resolution optical encoders while a third encoder measures the motion of the top plate relative to the middle one. Such a scaled quarter-car structure has been designed to study critical aspects of Active Suspension control implementations.

1.2. Active Suspension System: Control Challenge

This AS system consists of two masses, each supported by two springs as shown in the figure 1. The upper mass represents the vehicle body supported above the suspension while the lower mass corresponds to one of the vehicles wheels. The entire system represents the classic quarter car model. An LQG controller can be used to optimize a variety of performance parameters in this fourth order quarter-car model. The performance criteria can be formulated into a mathematical model. This mathematical representation is then optimized while considering the control actuator limitations. The performance measures to be controlled by students include:

- Ride Comfort - is related to vehicle body motion sensed by the passengers. It is measurable through an accelerometer located on the sprung mass.
- Suspension Travel - refers to relative displacement between the vehicle body and the wheel and is constrained within an allowable range of motion. The relative displacement between the sprung mass and the unsprung mass represents Suspension Travel and is measured using a linear capstan mechanism.
- Road Handling - is associated with the contact forces between the road surface and the vehicle tires. The contact forces between the road and the tires depend on the tire deflection. In the Active Suspension structure the relative displacement between the unsprung mass and the road represents the tire deflection.

2. Active Suspension System Components

2.1. Component Nomenclature

As a quick nomenclature, Table 1, below, provides a list of all the principal elements composing the Active Suspension system. Every element is located and identified, through a unique identification (ID) number (Table 1), on the Active Suspension plant represented in Figures 1, 2, 3, 4, and 5.

ID #	***Description***	***ID #***	***Description***
1	Top Plate (Blue, Vehicle Body Mass)	**2**	Accelerometer Gain Potentiometer
3	Middle Plate (Red, Vehicle Tire Mass)	**4**	Suspension Encoder
5	Bottom Plate (White, Road)	**6**	Suspension Motor Capstan Cable
7	2 Adjustable Springs (Vehicle Suspension Springs)	**8**	Spring Holder Set Screw
9	2 Adjustable Springs (Vehicle Tire Springs)	**10**	Linear Bearing Blocks

ID #	Description	ID #	Description
11	Bottom Plate Encoder Connector	12	Top Plate Encoder Connector
13	Bottom Plate Counter Weight Springs	14	Payload Mass (Brass)
15	Active Suspension DC Motor	16	Bottom Plate Encoder
17	Bottom Plate Servo Motor	18	Lead Screw
19	Encoder Thread	20	Stainless Steel Shafts
21	Accelerometer	22	Accelerometer Connector
23	Plant Top Cover	24	Limit Switch Safety Lights
25	Plant Handles	26	Bottom Plate Motor Connector
27	Limit Switch Push Key	28	Safety Rod
29	Movable Spring Holders	30	Safety Limit Switch
31	Suspension Motor Connector	32	Suspension Encoder Connector
33	Encoder Thread Anchor	34	Top Plate Encoder

Table 1 Active Suspension System Component Nomenclature

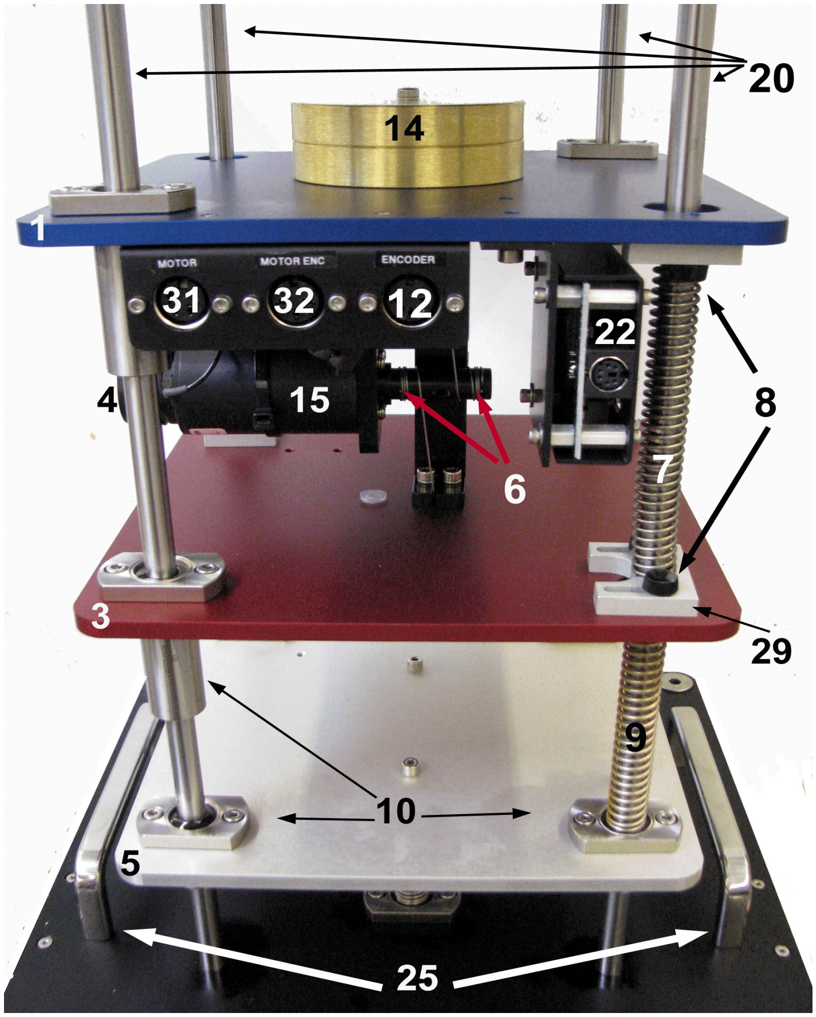


Figure 1: Active Suspension Plant. Front Top Panel View.

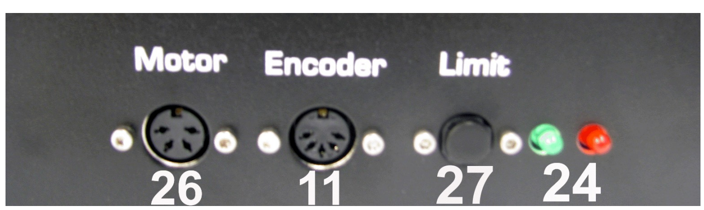


Figure 2: Active Suspension Plant. Front Bottom Panel View.

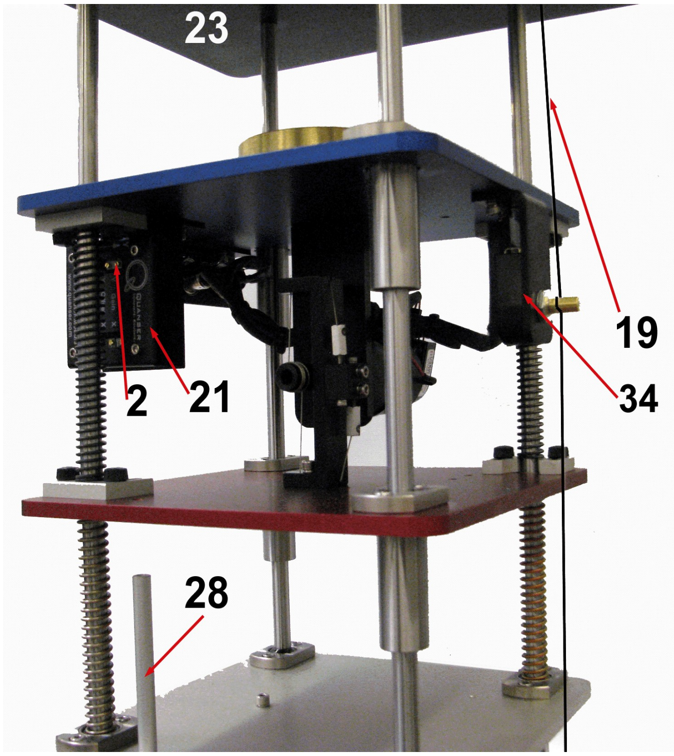


Figure 3: Active Suspension System. Side View.

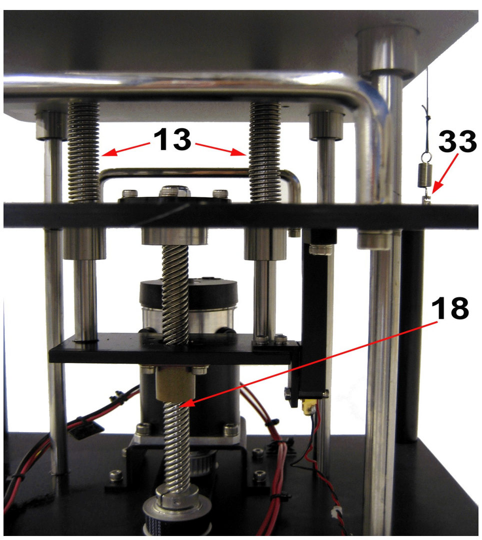


Figure 4: Active Suspension System. Bottom View.

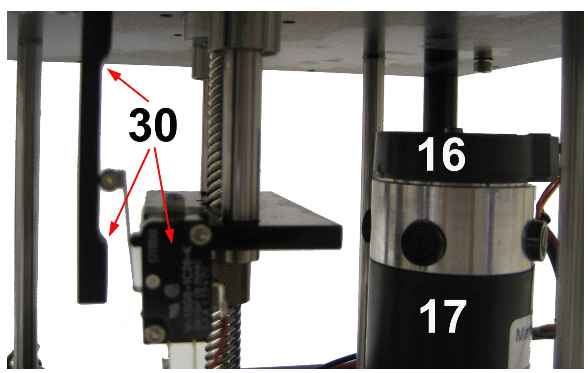


Figure 5: Active Suspension System. Bottom View

2.2. Component Description

2.2.1. Active Suspension DC Motor (Component #15)

The Active Suspension plant incorporates a **Faulhaber Coreless DC Motor (3863V006)**, as represented in Figures 1 and 2 by component #9. This model is a high efficiency low inductance motor resulting in a much faster response than a conventional DC motor.

CAUTION:
High Frequency signals applied to a motor will eventually damage the gearbox and/or the motor brushes. The most likely source for high frequency noise is derivative feedback. If the derivative gain is too high, a noisy voltage will be fed into the motor. To protect your motor, you should always band limit your signal (especially derivative feedback) to a value of **50Hz.**

2.2.2. Road Simulation Brushed Servo Motor (Component #17)

The Active Suspension incorporates a **Magmotor Brushed Servo Motor (S23-100 series)**, as shown in Figure 5 by ID #17. The motor has a power of 70 Watts. The motor is connected to the lead screw through the geared pinion and cable transmission. The lead screw translates the rotational motion of the motor to linear motion of the bottom plate. Some of the motor specifications are included in Table 2. More detailed motor specifications are available in Reference Error: Reference source not found.

FRAME SIZE	STACK LENGTH	PEAK STALL TORQUE (T_P) OZ-IN	CONT. STALL TORQUE (T_C) OZ-IN	ROTOR INERTIA (J_M) OZ-IN-SEC^2	FRICTION TORQUE (T_F) OZ-IN	THERMAL RESISTANCE (RM) ^{0}C/WATT	MAX RECOMMEND SPEED RPM	MAX WINDING TEMP. C^0	POWER RANGE W	WEIGHT LB
S23 --	100	500	50	0.006	5	4.5	4000	155	70	2

Table 2: Brushed Servo Motor Charactersitics.

2.2.3. Lead Screw (Component #18)

The lead screw, shown by ID #4 in Figure 2, circulates through a ball nut, component #5 in Figure 2, that is attached to the bottom of the bottom plate and is rotated by the motor. The lead screw has a pitch of 0.50 inches. Thus the road simulation plate moves 0.50 inches, or 1.24 cm, per single ball-screw revolution.

2.2.4. Middle Plate Encoder (Component #34)

Digital position measurement of middle plate vertical motion is obtained by using a high-resolution quadrature optical encoder. The encoder has a resolution of 1024 lines per revolution. In quadrature mode this gives 4096 counts per full rotation of the encoder shaft. The effective resolution, i.e. minimum linear position that can be detected, of the stage displacement is 4.87 μm.

The internal wiring diagram of the encoder is depicted in Figure 6. The encoder standard 5-pin DIN connector, shown in Figure 6, is also pictured as component #12 in Figure 1.

Refer to Section 4.3 for the encoder installation. Pushing the middle plate upwards should result in positive change of encoder reading.

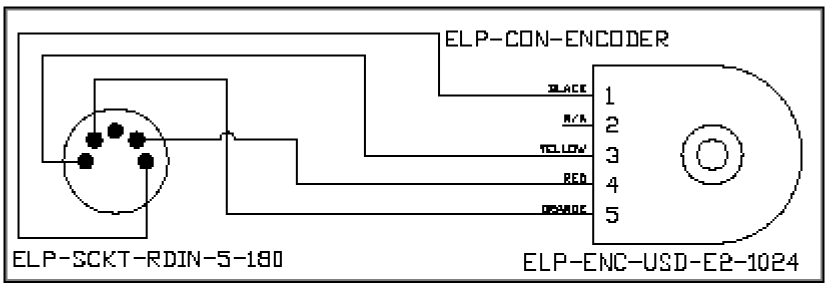


Figure 6: Active Suspension Encoders Internal Wiring

2.2.5. Suspension Encoder (Component #4)

Digital position measurement of suspension travel is obtained by using a high-resolution quadrature optical encoder. The optical encoder is directly mounted on the rear of the active suspension DC motor. The motor encoder has a resolution of 1000 lines per revolution. In quadrature mode this gives 4000 counts per full rotation of the encoder shaft.. The effective resolution, i.e. minimum linear position that can be detected, of the stage displacement is 9.42 μm.

The encoder standard 5-pin DIN connector is pictured as component #32 in Figure 1. Pushing the middle plate and top plate towards each other should result in negative change of encoder reading.

2.2.6. Bottom Plate Encoder (Component #16)

Digital position measurement of bottom plate is obtained by using a high-resolution quadrature optical encoder. The optical encoder is directly mounted on the rear of the brushed servo motor (Component #17). The motor encoder has a resolution of 2048 lines per revolution. In quadrature mode this gives 4096 counts per full rotation of the encoder shaft. The effective resolution, i.e. minimum linear position that can be detected, of the stage displacement is 2.19 µm. Refer to reference Error: Reference source not found for more details on this encoder.

The encoder standard 5-pin DIN connector is pictured as component #11 in Figure 2. Pushing the bottom plate upwards should result in a positive change of encoder reading.

2.2.7. Springs (Components #7 and #9)

The following sets of springs are supplied with the Active Suspension Plant as shown in Table 3.

Name	*Application*	*Length*	*Quantity*	*Color*	*Stiffness per spring*
FUF-14_128-A	Suspension	0.128m	2	Black (installed upon delivery)	490N/m
FUF-14_128-B	Suspension	0.128m	2	Orange	1020N/m
FUF-14_115-A	Tire	0.115m	2	Black	570N/m
FUF-14_115-B	Tire	0.115m	2	Orange (installed upon delivery)	1250N/m

Table 3 Active Suspension Spring Numenclature.

Moreover, two springs are installed on the device upon delivery (Component #13). These springs are used to compensate for the weight of the three moving plates and reducing the pressure on the servo motor (Component #17).

2.2.8. Linear Bearing Block (Component #10)

For smooth motion, the plates are fitted with low friction linear bearing blocks, shown by component #10 in Figure 1 , that glide on four ground hardened shafts, identified by component #20 in Figure 1.

2.2.9. Limit Switch (Components #24, 27, and 30)

The limit switch gets triggered when the bottom plate (Component #5) moves too close to its vertical range limits. In such a case this solenoid sensor directly deactivates the power of the servo motor (Component #17) and the red light will be on (see component #24 in Figure 2). In this situation the simulation should be stopped by the operator in the software and the bottom plate (Component #5) should be moved inside its working range. At this point the two red and green lights will be off meaning that the plate is inside its working range but the motor is still not active. Then one should press the limit switch push-key button (Component #27) in order to activate the servo motor (Component #17) again. Table describes different combinations of the limit switch lights.

Green Light	***Red Light***	***Description***
Off	Off	The bottom plate (Component #5) is inside its working range but the servo motor (Component #17) is not active. Push the limit switch button (Component #27) to activate the motor.
On	Off	The bottom plate (Component #5) is inside its working range and the servo motor (Component #17) is active.
Off	On	The bottom plate (Component #5) is outside its working range and the servo motor (Component #17) is not active. 1- Stop the simulation in the software. 2- Move the plate inside its working range to turn off the red light. 3- Push the limit switch button (Component #27) to activate the motor and to turn on the green light.
On	On	The limit switch circuit is not working properly. Contact Quanser's technical support.

Table 4 Limit Switch Lights Description.

2.2.10. Accelerometer (Component #21)

A dual-axis ADXL210E accelerometer is mounted underneath the top blue plate (Component #1) to measure the acceleration of the vehicle body along vertical direction. It is shown with ID #21 label in Figure 3.

The accelerometer has the capability to measure both AC/dynamic accelerations (e.g. vibrations) or DC/static accelerations (e.g. gravity). The arrows represented on the accelerometer, and depicted in Figure 3, show the positive direction of the AC acceleration sensor measurement on its axes of sensitivity. To best measure the Active Suspension top plate (vehicle body) vibration, the accelerometer is mounted such that its x-axis is longitudinal to vertical direction. Quickly pushing the top plate (component #1) upwards should result in an initial negative measured acceleration voltage. In order for the accelerometer reading to be consistent with the encoder measurements its sign should be negated in the control software.

The sensor has a range of ±10 *g* and its noise, in the operating range of the top plate, is approximately ±5.0 mV, i.e. ±5.0 m*g*. This analog sensor is calibrated such that 1 Volt equals 1 *g*, or 9.81 m/s^2. For more details about this sensor, see Reference Error: Reference source not found . Although the Active Suspension accelerometer has already been calibrated at the factory, the signal conditioning circuit properties may vary depending on the external conditions (e.g. humidity, temperature). Therefore, you may want to adjust the Offset potentiometer (shown as component #2 in Figure 3) such that it reads approximately zero Volts with zero acceleration (i.e. sensor resting flat/horizontally).

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.

2.2.11. AMPAQ Power Module

The AMPAQ Power Module, shown in Figure 7, is a pulse-width modulated current amplifier. It is used to drive the two motors of Active Suspension Plant. The power module's specifications are given in Table 5. The signals from the data-acquisition board are to be connected to the *Input* connector. The *Sense* connector outputs the current measured in the attached motors. The *Enable* connector socket of the AMPAQ receives digital input signals from the PC in order to enable or disable the power module. Finally, the amplified current is sent from the *Output* connector.

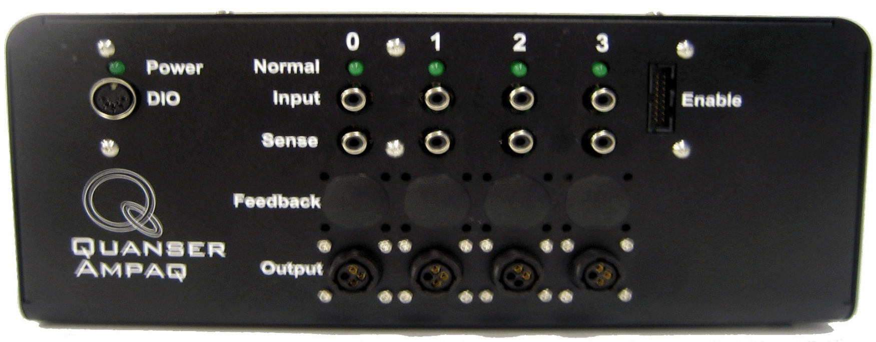


Figure 7: Quanser AMPAQ front view with the wired cables.

Each motor-driving amplifed current signal from each *Output* socket of the AMPAQ has its own indicator LED. When a particular *Output* signal is enabled, such that that its corresponding motor, to which it is connected, can be actuated, then its corresponding LED lights up. When a particular *Output* signal is disabled, that is its connected motor cannot be actuated, then its corresponding LED stays off. For example, if the AMPAQ's *Output* #2 is enabled, then a motor that is connected to the *Output* 2 socket will be actuated; furthermore, the *Normal* #2 LED will become lit. If, however, *Output* #2 is disabled, then LED 2 will not light up, and the corresponding motor to the *Output* #2 socket will not be actuated.

Symbol	*Description*	*Value*	*Unit*
	AMPAQ Maximum Input Voltage Range Note: This value is for reference only; particular control signal levels will result in unique voltage input levels.	±10	V
	AMPAQ Maximum Input Current Note: This value is for reference only; particular loading will result in unique electrical current use.	25	mA
	AMPAQ Enable Ribbon Cable Signals' Voltage Range	0 to 5	V
	AMPAQ Enable Ribbon Cable Signals Electrical Current (Absolute Maximum Value)	1	mA
	External Power Source RMS Voltage Required to Operate AMPAQ.	120/240	V
	External Power Source Voltage Frequency Required to Operate AMPAQ	60/50	Hz
V_{A_SUP}	AMPAQ Supply Voltage	27	V
V_{A_RNG}	AMPAQ Voltage Input Range	±10	V
K_a	AMPAQ Gain	0.5	A/V
I_{MAX}	AMPAQ Maximum Peak Output Note: This value is for reference only; particular motor resistance and loading will result in unique electrical current sourcing levels.	7	A
$I_{MAX,CONT}$	AMPAQ Continuous Output Current	2.15	A
B	Current Amplifier Bandwidth	500	Hz

Symbol	Description	Value	Unit
S_{AMP_SEN}	Current Sensor Sensitivity (for 0, 1, or 2; inside AMPAQ)	2.0	A/V

Table 5 AMPAQ specifications.

3. Active Suspension Model Parameters

Table 6, below, lists and characterizes the main parameters (e.g. mechanical and electrical specifications, convertion factors) associated with the Active Suspension System. Some of these parameters can be used for mathematical modeling of the plant as well as to obtain the system Equations Of Motion (EOM).

Symbol	Description	Value	Unit
	Structure Total Height	15.00	kg
M_s	Top Plate (Blue) with Attached Equipment Total Mass	2.45	kg
M_{us}	Middle Plate (red) with Attached Equipment Total Mass	1	kg
K_s	Suspension Passive Linear Stiffness Constant	Refer to Section 2.2.7	N/m
K_{us}	Tire Linear Stiffness Constant	Refer to Section 2.2.7	N/m
B_s	Suspension Damping Constant	Refer to Section 2.2.7	N.s/m
B_{us}	Tire Damping Constant	Refer to Section 2.2.7	N.s/m
	Suspension Motor Torque Constant	0.115	N.m/A
	Suspension Motor Shaft Radius	0.006	m
	Suspension Encoder Resolution	942E-6	m/count
	Bottom (White) Plate Encoder Resolution	219E-6	m/count
	Middle (Red) Plate Encoder Resolution	487E-6	m/count
	Suspension Travel Range	3.80E-002	m
	Middle (Red) Plate Travel Range	3.00E-002	m
	Bottom (White) Plate Travel Range	3.60E-002	m

Symbol	*Description*	*Value*	*Unit*
	Accelerometer Sensitivity	9.81	$m/s^2/V$

Table 6 Active Suspension System Paremeters.

4. Hardware Setup Procedure

This section describes the standard procedure to safely set up the mechanical components of the Active Suspension System. Follow the steps described below to set up the Active Suspension System mechanical assembly:

4.1. Unpacking and Routine Checkup

1. Cut the tie wraps that lock the bottom plate (component #5) to the plant handles (Component #25) .
2. Unscrew and take off the three safety screws as depicted with red arrows in Figure 8. The corresponding holes to these screws are shown in Figure 9 for more clarification. One screw is used to connect the rod (Component #28) to the red plate (Component #3) and thus keeps the white and red plates attached to each other. Two other screws connect the red plate to the motor cable holder so that the red and blue plates are attached to each other.

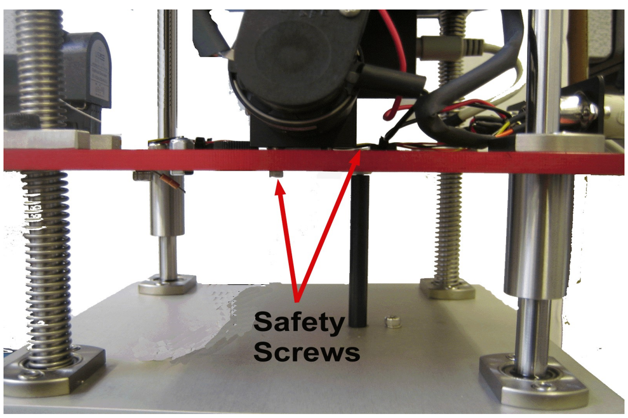


Figure 8: Safety screws that have to be opened before using the Active Suspension plant.

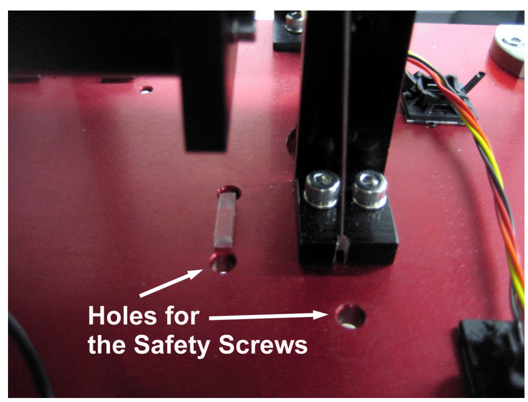


Figure 9: Safety screw holes.

3. Ensure that the linear bearings (Component #10) are well lubricated. To test this, move the bottom plate (Component #5) with your hand. This should result in smooth vertical motion of the three plates (Component #1, #3, and #5) on the linear bearings. If not, a

most probable cause of this issue is that the spring holders (Component #29) are engaged with the shafts. Refer to Section 4.2 to fix this problem.

4. Make sure that the safety cables (Component #26) are tightened well.
5. Make sure that the top cover plate (Component #23) is tightened with the four screws and the middle plate encoder cable (Component #19) is wrapped around the encoder shaft under enough tension. Refer to Section 4.3 for more details.
6. Before starting the controller, (assuming the system is wired properly), make sure the bottom plate (Component #5) is inside its working range by investigating the Component #30 in Figure 5 and the lights in Figure 2 (green should be On and red should be Off). **Refer to Section 2.2.9 and Table 4 for more details.**
7. Clear the Active Suspension plant workspace from anything other than the intended components.

4.2. Changing the Springs

1. Unscrew the two screws on the top cover plate (component #23) as shown in Figure 10. The two holes in the top cover are designed for replacing the springs. Take out the rings from the two holes.

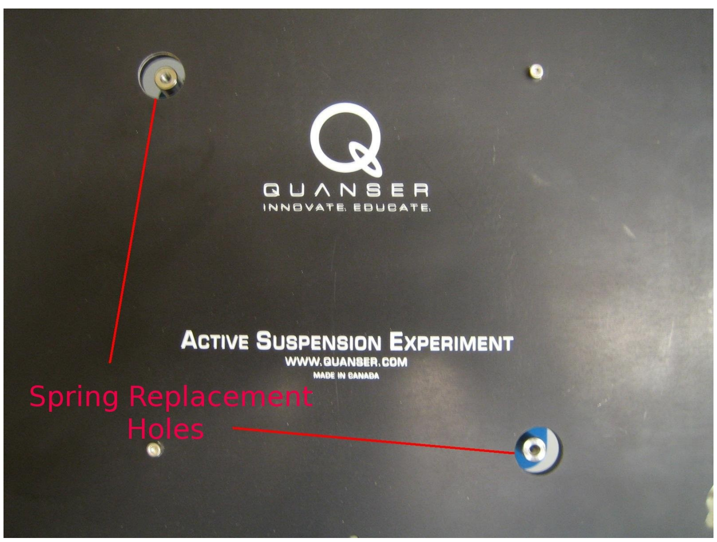


Figure 10: Active Suspension Plant. Top View.

2. Loosen the screws on the four movable spring holders (component #29) to the degree that one can freely slide the holders on the plates. It should be mentioned that opening the screws for half a turn should be enough to loosen them and to disengange the spring holders. See Figure 11 and 12. **For each spring to be replaced there are two spring holders on the corresponding shaft that have to be moved.**

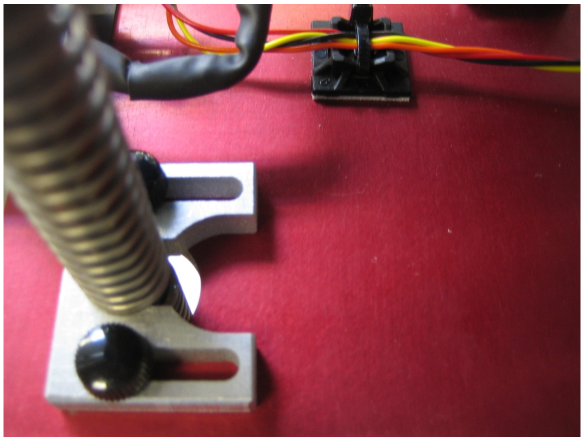


Figure 11: Spring Holder in Holding Mode.

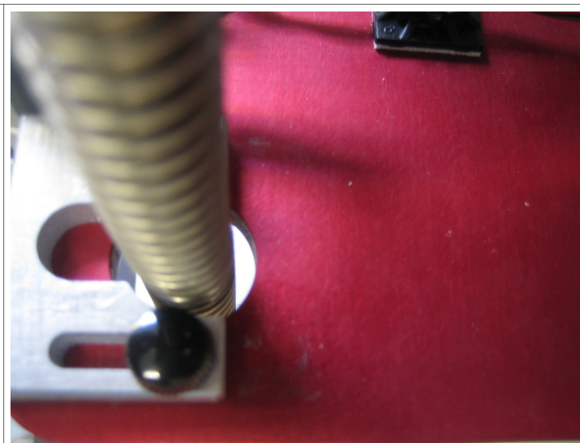


Figure 12: Spring Holder in Open Mode.

3. Slide the sping holders (component #29) on the plates carefully until the spring pops out on the shaft. See Figure 12.
4. Replace the springs with the desired ones. Make sure that the springs representing the tire stiffness stand between the bottom plate (component #1) and the middle plate (component #3). Also, make sure that the springs representing the vehicle suspension stiffness stand between the middle plate (component #3) and the top plate (component #5).
5. Slide the four spring holders (component #) until the springs are in contact with them and held well. Tighten the screws on the spring holders. **Make sure that all the four movable spring holders (component #) are tightened and are not engaged with the shafts.**

4.3. Installing the Top Cover Plate and the Middle Plate Encoder

In case the middle plate encoder thread or the structure top cover plate come off, follow these steps to install them back:

1. As shown in Figure 10, there are four screw holes on the top cover plate (Component #23). Align each hole near the center of their corresponding shaft (Component #20). Use an Allen key and the four screws to tighten the screws and fasten the top cover to the plant structure.
2. Wrap the encoder thread (Component #19) around the middle plate encoder shaft (Component #34). The rotation around the encoder shaft should be clock-wise when facing it. As a result, pushing the middle plate (Component #3) upwards will lead to a positive

change in the encoder reading.

3. Lock the end of the thread in the anchor (Component #33). The number of turns on the encoder shaft should be such that the thread (Component #19) is neither loose nor highly tensioned.

5. Wiring Procedure

This section describes the standard wiring procedure for the Active Suspension Plant

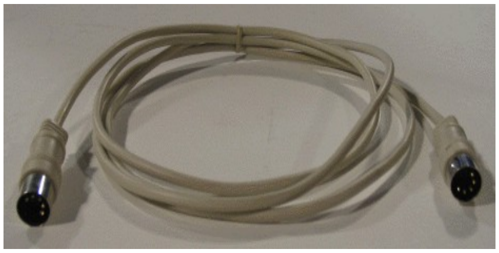
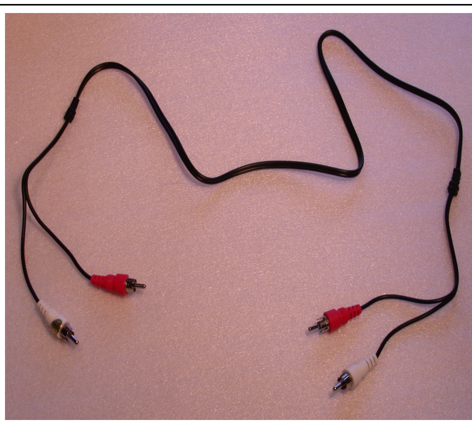
The following hardware, accompanying the Active Suspension System, is assumed:

- Power Amplifier: Quanser AMPAQ or equivalent.
- Data Acquisition Card: Quanser Q8 / Q4, or equivalent.(See Reference [5])
- External Analog Signal Conditioner

5.1. Cable Nomenclature

Table 7, below, provides a description of the standard cables used in the wiring of the Active Suspension System.

Cable	*Designation*	*Description*
 Figure 13 "From Analog-To-Analog" Cable	5-pin-DIN to 4-pronged male	This is a Motor Cable that connects the output of the power module (AMPAQ), after amplification, to the desired actuator (e.g. road simulation motor or active suspension motor). It has a 4-pronged male connector at one end and a 5-pin-DIN connector at the other end. Each of these connectors are keyed so that they can be plugged in only one way. This cable has a screwable rotating cover at its 4-pronged male connector that allows it to be screwed securely to AMPAQ connector. (2 supplied)

Cable	Designation	Description
 Figure 14 "Encoder" Cable.	5-pin-stereo-DIN to 5-pin-stereo-DIN	This cable carries the encoder signals between the encoder connectors and the data acquisition external terminal board (to the encoder counter). Namely, these signals are: +5VDC power supply, ground, channel A, and channel B. (3 supplied)
 Figure 15 "From Analog Sensors" Cable	6-pin-mini-DIN to 6-pin-mini-DIN	This cable carries analog signals from one or two plant sensors (e.g. accelerometer) to the external terminal box, where the signals can be either monitored and/or used by an analog controller. (1 supplied)
 Figure 16 Analog Input/Output Cable.	RCA to RCA	The "Analog Input/Output Cable" is actually two separate RCA cables. Each of these separate cables has a male connector at both ends. One of these separate cables has red connectors while the other has white connectors, to distinguish them from one another and to emphasize their independence. Two RCA connections carry analog signals between the DAQ terminal board and the AMPAQ. One RCA connection is used to interface DAQ board with the analog signal conditioning box. In commercial or industrial applications, the Analog Input/Output cable is sometimes referred to as "Stereo RCA Cables". (2 supplied)

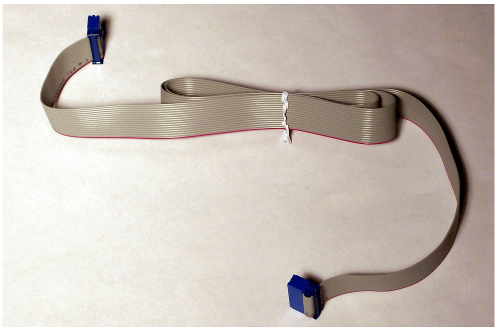
Cable	*Designation*	*Description*
 Figure 17 Ribbon cable.	16-pin to 16-pin	One 16 wire ribbon cables is supplied. The cable has identical female connectors at both ends and is keyed such that it can be plugged in only one way. The cable connects the AMPAQ to the DAQ terminal board. This carries the enable signals from the PC to the AMPAQ to enable and diable amplified motor signals to be available at the output sockets. (1 supplied)

Table 7 Cable Nomenclature

5.2. Hardware Requirements

Figures 18, 19, 20, 21, and 22 below, show, respectively, the DAQ External Terminal Board, the Active Suspension plant, the Analog Signal Conditioner Box, and the AMPAQ, all connected with the necessary cabling to interface and use the Active Suspension System.

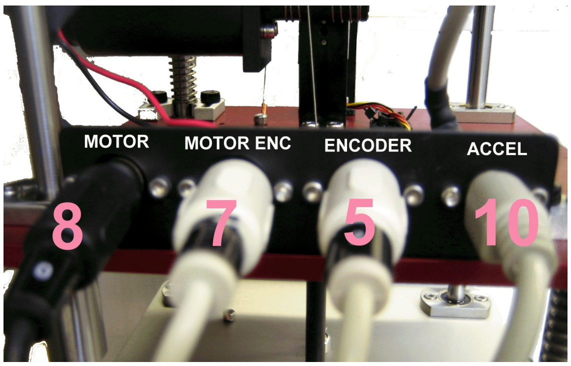


Figure 19: Active Suspension Plant Front Top View.

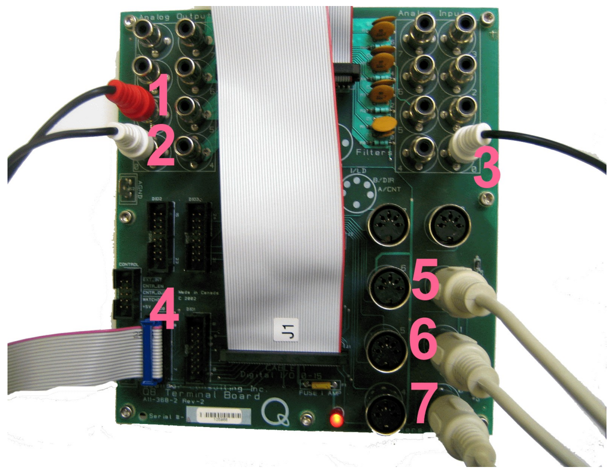


Figure 18: External Terminal Board.

Figure 20: Active Suspension Plant Front

Figure 21: External Analog Signal Conditioner.

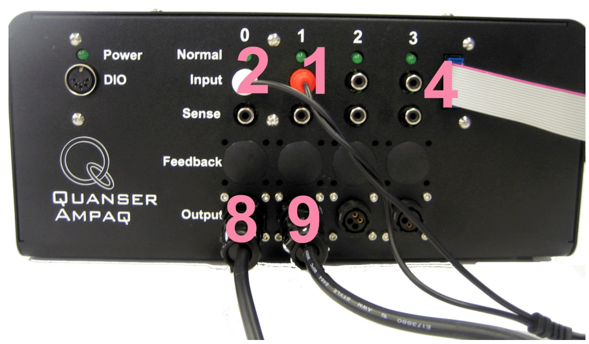


Figure 22: AMPAQ Front View.

Note: Wiring is demonstrated using the Q8 Terminal Board in Figure 18. Of course, other data-acquisition terminal boards can be used, e.g. Q4, QPID, QPIDe.

5.3. Typical Connections For the Active Suspension System

1. **CAUTION: Ensure the PC, the Analog signal conditioner, and the AMPAQ are powered off prior to making these connections!** In particular, never attempt to hot swap encoder signals. Encoder signals carry power from the PC to the encoder and thus are susceptible to current surge that could potentially damage the encoder, HIL card or the PC.
2. Figure 18 shows the DAQ terminal board, where digital I/O *Enable* ribbon cable, 3 Encoder cables, 2 Analog Output cables, and 1 Analog Input cables are to be attached. Make the cable connections to the DAQ terminal board as illustrated in Figure 18 and explained in Table 8. See Appendix.A for a listing of all the signals that are connected to DAQ terminal board.
3. Figure 19 shows the Active Suspension top front panel where one motor cable, 2 encoder cables, and one 6-pin-mini-DIN analog cable are to be connected according to Table 8.
4. Figure 20 shows the Active Suspension bottom front panel where one motor cable and one encoder cable are to be connected according to Table 8.
5. The Analog Signal Conditioner Box is depicted in Figure 21 where the 6-pin-mini-DIN to 6-pin-mini-DIN cable is connected to the input one of the signal conditioner box. An RCA cable is also connected to *S2* output of the box.
6. Figure 22 illustrates the front panel of the AMPAQ with the digital I/O *Enable* ribbon cable connection, 2 Motor cables, and 2 Analog Input cables are to be attached. Make the cable connections to the AMPAQ's front panel as shown in Figure 22 and described in Table 8. Ensure the 4-pronged male ends of the Motor cables connect to the AMPAQ.

5.3.1. Active Suspension Wiring Summary

Table 8, below, summarizes the electrical connections necessary to run the Active Suspension System.

Cable #	*Cable Type*	*From*	*To*	*Signal*
1	RCA Cable	Analog Output #0 on DAQ Terminal Board	*Input #0* on AMPAQ	Active Suspension DC Motor Amplifier Command.
2	RCA Cable	Analog Output #1 on DAQ Terminal Board	*Input #1* on AMPAQ	Road Simulation Servo Motor Amplifier Command.

Cable #	***Cable Type***	***From***	***To***	***Signal***
3	RCA Cable	Analog Input #0 on DAQ Terminal Board	Output *S2* on Analog Signal Conditioner	Carries the Analog Signal (Accelerometer Reading)
4	Ribbon cable	DIO1 on DAQ Terminal Board	*Enable I*nput on AMPAQ	Enable/Disable Motors
5	Encoder Cable: 5-pin-stereo-DIN to 5-pin-stereo-DIN	Middle Plate Encoder Connector	Encoder Input #2 on DAQ Terminal Board	The Middle Plate (Red) Position W.R.T is Measured and Transmitted Through This Cable to the Terminal Box.
6	Encoder Cable: 5-pin-stereo-DIN to 5-pin-stereo-DIN	Bottom Servo Motor Encoder Connector	Encoder Input #1 on DAQ Terminal Board	The Bottom Plate (White) Position W.R.T Base is Measured and Transmitted Through This Cable to the Terminal Box.
7	Encoder Cable: 5-pin-stereo-DIN to 5-pin-stereo-DIN	Top DC Motor Encoder Connector	Encoder Input #0 on DAQ Terminal Board	The Suspension Travel is Measured and Sent Through This Cable.
8	Motor Cable	*Output #0* on AMPAQ	*Motor* Connector on Plant top Front Panel	Amplified Signal – Active Suspension Motor
9	Motor Cable	*Output #1* on AMPAQ	*Motor* Connector on Plant Bottom Front Panel	Amplified Signal – Road Simulator Motor
10	6-pin-mini-DIN to 6-pin-mini-DIN	Plant Accelerometer Connector “ACCEL”	Input Related to *S1* and *S2* on Analog Signal Conditioner Box	Carries the Accelerometer Reading to the Analog Signal Conditioning Box

Table 8 Active Suspension Wiring Summary.

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. 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] Quanser. *DAQ User Manual*.
[2] Quanser. *QUARC User Manual* (type `doc quarc` in Matlab to access).
[3] Quanser. *QUARC Installation Manual*.
[4] Quanser. AMPAQ *User Manual*.
[5] Q4 or Q8 User Manual.