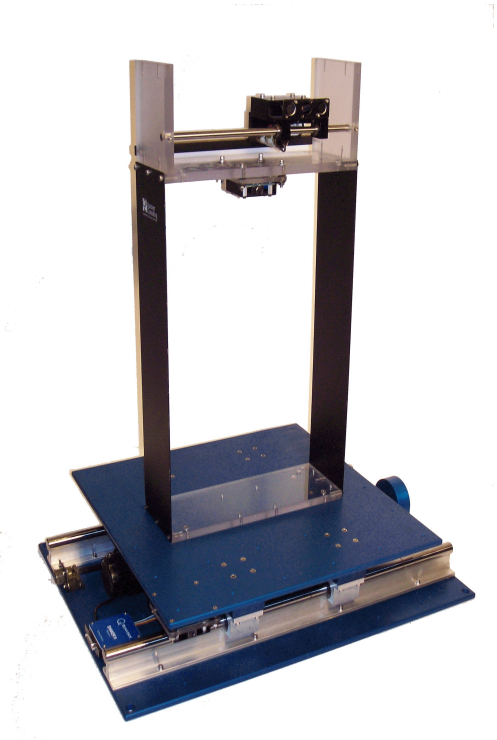
Specialty Linear Motion Servo Plant:
STII+AMD-1

Full-state Observer and LQR Control

Two-Floor Active Mass Damper and Shake Table II



All of Quanser's systems have an inherent open architecture design. It should be noted that the following experimental setup, accompanying files, and configuration are merely one of the many possible uses of this product.

User and Laboratory Manual

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1. Laboratory Objectives

The purpose of the experiment is to dampen the vibrations in the Quanser AMD-1 flexible structure that are introduced by the Quanser Shake Table II motions using the active mass, i.e. linear cart. An observer-based state-feedback cart controller that is similar to the one designed and implemented in References [3] and [4] is used. See References [1] and [2] for a complete description of the One-Floor Active Mass Damper (AMD-1) and the Shake Table II systems, respectively.

Section 2 goes through several laboratory requirements and Section 3 lists various Quanser documents that are referenced in this manual. The general system description, model parameters, wiring setup, and lab files overview is all given in Section 4. Section 5 describes the modeling of the system as well as the observer and control design. Finally the procedure to run the controller on the actual plant is discussed in Section 6.

2. Prerequisites

To successfully carry out this laboratory, the prerequisites are:

i) To have completed the laboratory described in Reference [3] and [4] to be familiar with the AMD system as well as with using QUARC to control and monitor the plant in real-time and in designing a controller through Simulink.
ii) To have undergone all the experiments described in the Reference [2] in order to be completely comfortable using the Shake Table II plant.
iii) To be familiar with full-state observer design as well as the LQR method enough to design a controller.

3. References

[1] Active Mass Damper - Two Floors (AMD-1) User Manual.
[2] Shake Table II User Manual.
[3] Active Mass Damper - Two Floor (AMD-1) - Linear Experiment #9: Vibration Control - Student Manual.
[4] Active Mass Damper - Two Floor (AMD-1) - Linear Experiment #9: Vibration Control - Instructor Manual.
[5] QUARC User Manual (type `doc quarc` in Matlab to access).

4. Experiment Setup

4.1. Main Components

To setup this experiment, the following hardware and software are required:

- **Power Amplifier:** Quanser UPM-180-25B for the Shake Table and a VoltPAQ-X1 (or -X2), or equivalent, for the AMD-1.
- **Data Acquisition Board:** Quanser Q4, Q8, or equivalent.
- **Active Mass Damper Plant:** Quanser IP01 or IP02.
- **Real-Time Control Software:** QUARC, as detailed in Reference [5], or equivalent.

For a complete and detailed description of the main components comprising this setup, please refer to the corresponding manuals.

If you are using the Quanser VoltPAQ-X1, make sure the Gain switch is set to 1.

4.2. Model and Sensor Parameters

See Reference [1] for the AMD-1 model parameters and Reference [2] for the Shake Table II specifications.

4.3. System Wiring and Hardware Setup

The wiring procedure for the Shake Table II with the AMD-1 system is summarized in Table 1, below. See references [1] and [2] for more information on these individual connections. The cable identification numbers in Table 1 correspond to the connection labels in figures 1, 2, 3, and 4.

Cable #	*Cable Type*	*From*	*To*	*Function*
1	25-pin Parallel Cable	"Table X" on the Terminal Board.	"From MultiQ" on the blue UPM-180-25B	Drives the amplifier to move the stage and receives the accelerometer, stage encoder, calibration, and limit detector signals from UPM.
2	15-pin Parallel Cable	"To Device" on the blue UPM-180-25B	Circuit board on the Shake Table II	Receives the encoder and limit detector signals from the shake table.
3	E-Stop Cable	E-Stop Connector on the blue UPM-180-25B (on the side).	E-Stop switch device.	Power amplifier can be disabled when E-Stop is pressed down.
4	4-pin Motor Cable	"Motor" Connector on the UPM-180-25B	Motor connector on the Shake Table II	Connects the shake table's motor leads to the amplifier on the UPM.
5	Analog Cable: 6-pin-mini-DIN to 6-pin-mini-DIN	"S1" Connector on the on the UPM-180-25B	Accelerometer on the Shake Table II	Carries ground acceleration signal to the UPM.
6	Analog Cable: 6-pin-mini-DIN to 6-pin-mini-DIN	"S2" Connector on the on the UPM-180-25B	Accelerometer on the structure.	Carries floor acceleration signal to the UPM.
7	RCA to RCA	Analog Output #1 on the Terminal Board	"Amplifier Command" Connector on Amplifier	AMD control signal generated by controller running on PC.
8	Motor Cable: 4-pin-DIN to 6-pin-DIN	"To Load" Connector on Amplifier	Motor Connector on IP02 cart.	Amplified control signal applied to IP02 motor, V_m.

Cable #	*Cable Type*	*From*	*To*	*Function*
9	Encoder Cable: 5-pin-stereo-DIN to 5-pin-stereo-DIN	Encoder #1 on the Terminal Board	IP02 Cart Encoder Connector	Measures the linear position of the cart, x_c.

Table 1 STII+AMD-1 Wiring Summary

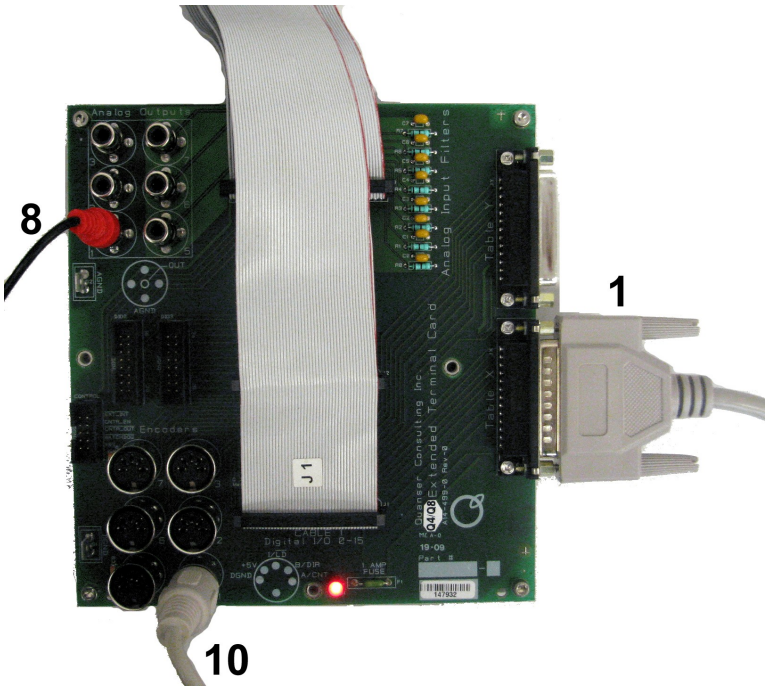

Figure 1: Connections on Q8 Extended Terminal Board.

Figure 2: Connections on VoltPAQ-X1 used for AMD-1 cart.

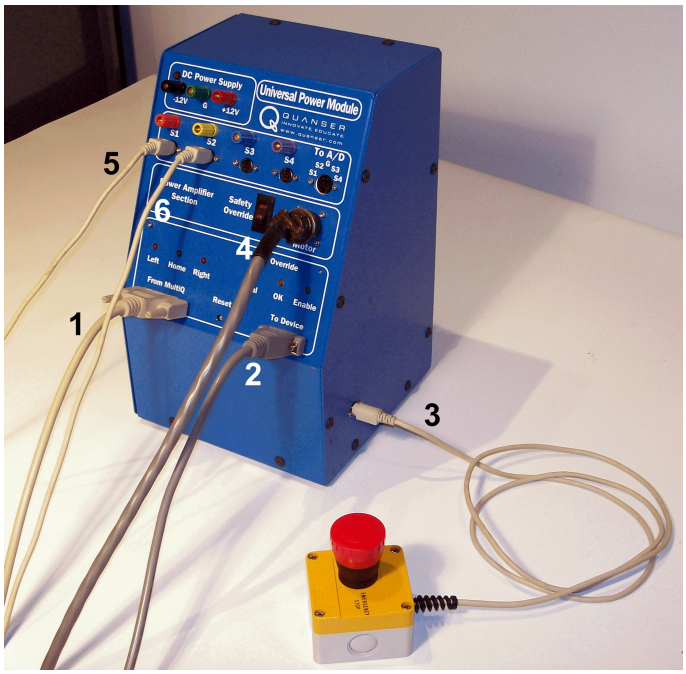

Figure 3 Connections on UPM-180-25B.

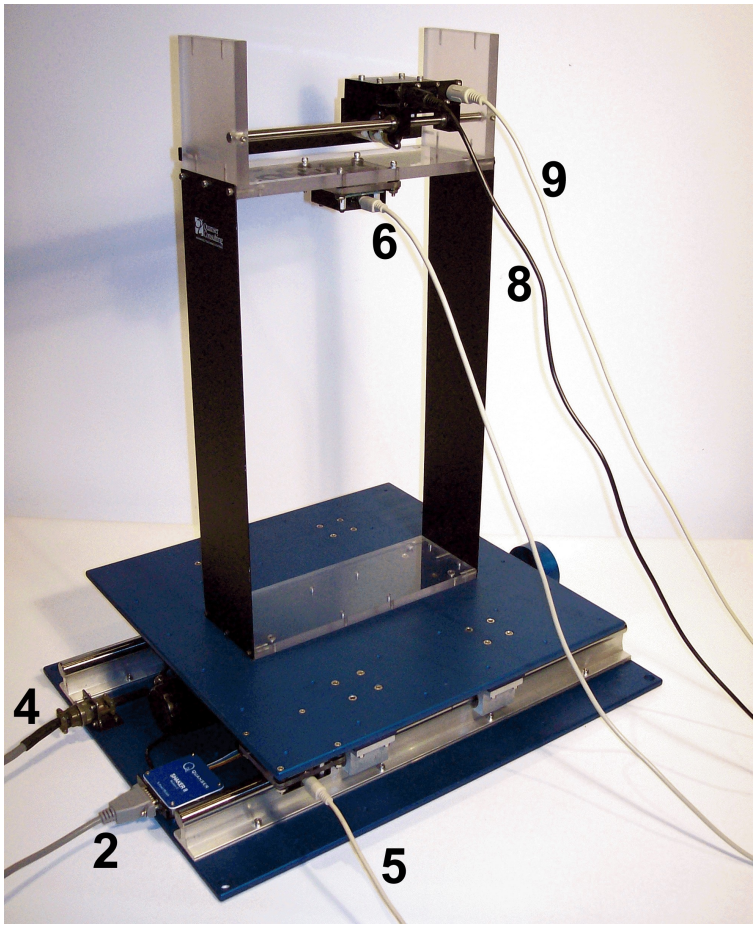

Figure 4 Connections on AMD-1 plant.

4.4. Experiment Design Files

Table 2, below, lists and describes some of files coming with the experiment. See Reference [1] for the remainder of the AMD-1 related files and Reference [2] for a listing of the Shake Table II related files.

File Name	*Description*
STII+AMD-1 User and Laboratory Manual.pdf	The user guide and experiment manual for the Shake Table II with AMD-1 system. It contains information about the setup, system modeling, control design, as well as the experimental procedure to implement the controller.
setup_stII_amd1.m	The main Matlab script that calls *setup_amd1_parameters.m*, *AMD1_ABCD_eqns.m*, *d_amd_pv.m*, and *d_shake_table_II.m* to set the model, control, and configuration parameters. **Run this file only to setup the laboratory.**
d_amd_pv.m	Matlab function that designs a PV controller to control the position of the AMD systems.
d_shake_table_II.m	Matlab function that designs a PD controller to control the position of the Shake Table II device.
q_amd1_e_stII.mdl	Simulink file that implements the real-time full-state observer and LQR state-feedback controller for the STII+AMD-1 plant (using the IP02).

Table 2 Laboratory Design Files

5. Modeling and Control Design

See the Maple Worksheet entitled *AMD-1 Equations.mws*, or its corresponding HTML output *AMD-1 Equations.html*, for the modeling of this device. Also see References [3] and [4] for the AMD-1 modeling diagrams as well as its full-state observer and feedback control design to dampen the vibrations.

6. In-Lab Procedure

This section explains the objective of the experiment as well as the procedure to control the STII+AMD-1 system using the QUARC software. Before proceeding, ensure all the connections have been made as instructed in Section 4.3.

6.1. Objectives

Implement with QUARC the designed full-state observer and pole-placement based control in order to dampen the vibrations introduced in the structure by the motions of the Shake Table II system.

6.2. Setting Up the Files

1. Open the Simulink diagram *q_amd1_stII.mdl,* shown in Figure 5. This model runs your actual STII+AMD-1 plant by directly interfacing with your hardware through the QUARC blocks, similarly as in references [3] and [4].

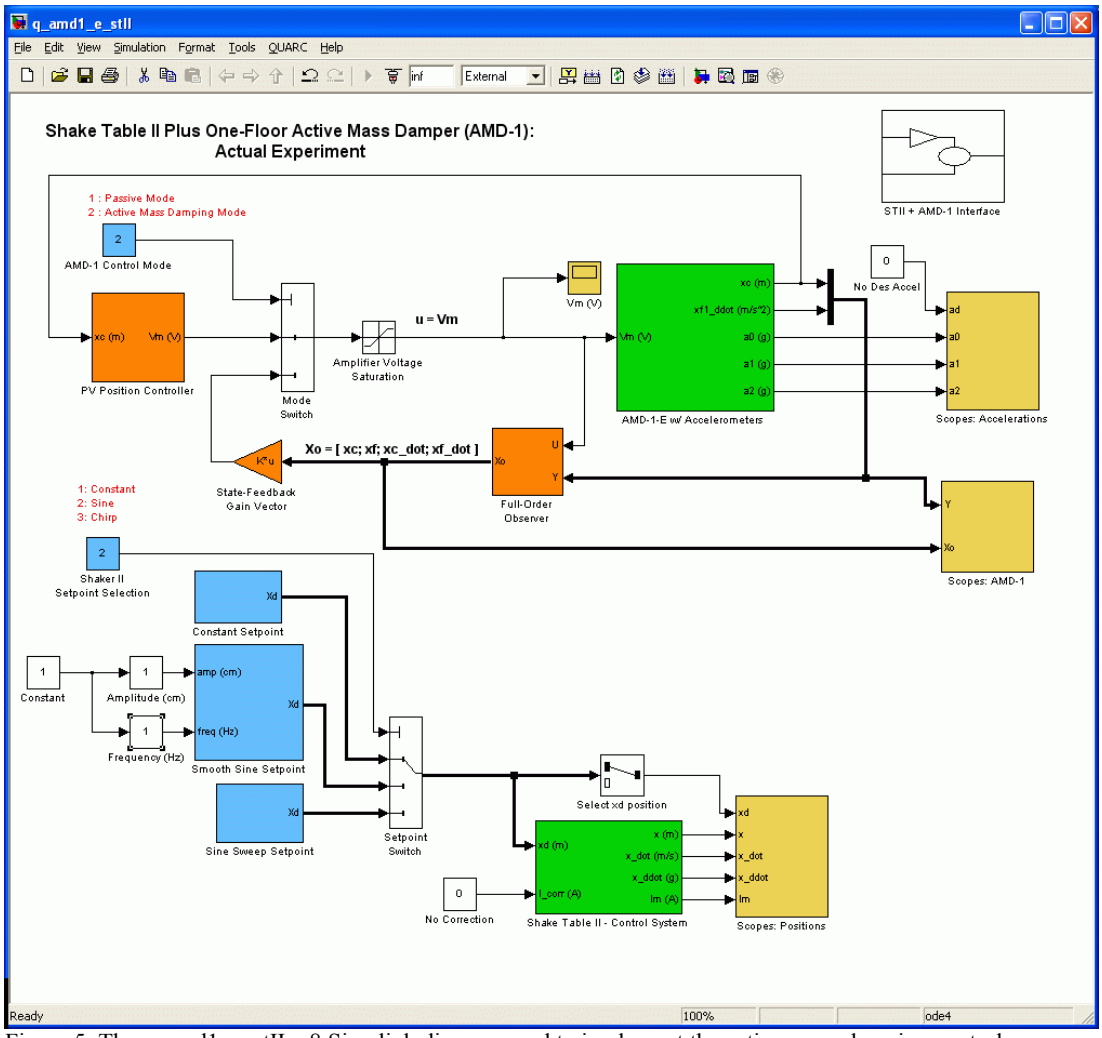

Figure 5: The q_amd1_e_stII_q8 Simulink diagram used to implement the active-mass damping control

2. **Configure script**: Open the Matlab script called *setup_stII_amd1.m*. Ensure the script is configured for the Shake Table II + AMD-1 configuration.
   - In the STII CONFIGURATION section, the users can change the Revision # of the Shake Table II, the payload mass, and whether or not to display shake table information and the setpoint limit plot. It is recommended that a load of 0 kg is used when using the AMD-1.

3. Execute the design file s*etup_stII_amd1.m* to setup the workspace before compiling the diagram and running it in real-time with QUARC.
   - This file sets the state-space model, calculates the cart PV position control gains, computes the observability matrix, *G*, and the feedback gain vector, *Kamd*, using the pole-placement algorithm.
   - Various other parameters such as the filter cutoff frequencies, cart and shake table position safety limits, and amplifier limits are also loaded into the workspace.
4. **Configure DAQ**: Double-click on the HIL Initialize block in the *STII+AMD-1* subsystem and ensure it is configured for the DAQ device that is installed in your system (e.g Q4 or Q8). See Reference [5] for more information on configuring the HIL Initialize block.
5. For safety reasons, a watchdog is placed that stops the controller when the Shake Table II goes beyond +/- 2.5 inches or when the bottom or top linear cart goes beyond +/- 8 cm. In addition, the UPM-180-25B power amplifier is disabled by the on-board PIC when the stage of the Shake Table II system hits either the left or right limit sensor.
6. As shown in Figure 5, there are three shake table setpoints that can be chosen: constant of 0, sine wave, or the chirp/sweep signal.

6.3. Running Sine Wave

Follow the steps described below to implement the designed controller in real-time and observe its effect on the actual STII+AMD-1 plant:

1. Turn on the power of the blue UPM-180-25B that is connected to the Shake Table II system.
2. Initialize the blue UPM-180-25B by running the q_boot_upm. See Reference [2] for the details.
3. **Ensure the stage of the Shake Table II is at the HOME position before performing the STII+AMD-1 experiment!** As in Reference [2], run the *q_cal* controller to center the table. Confirm that the green "Home" LED on the UPM-180-25B is lit after the procedure.
4. Turn on the amplifier that is connected to the AMD cart.
5. **Ensure the experiment is ran safely by manually moving the IP02 cart to the middle of the track so it is free to move on both sides.**
6. To run the system is passive mode, that is without active vibration dampening, set the Source block called *AMD-1 Control Model* to 1. This block in located in the the top-left corner of the *q_amd1_e_stII.mdl* Simulink diagram.
7. Set the *Shake Table II Setpoint Selection* constant block to 2 to select the sine sweep signal.

8. Click on QUARC | Build to compile the Simulink diagram.
9. Select QUARC | Start to begin running the controller. The shake table should begin moving back-and-forth as it tracks the sine wave.

   The controller can be stopped at any time by clicking on the *Stop* button located in the toolbar. Alternatively, the *Pause/Break* key on the keyboard can be used to stop the controller.

10. Increase the frequency of the sine wave to to 1.5 Hz. Your scopes should be similar to the readings shown below. The desired and measured shake table position is given in Figure 6, the measured cart position is shown in Figure 7, and the cart input voltage is given in Figure 8. Since the AMD is OFF, the cart is not moving very much at this point (plus the building does not sway much at this frequency).

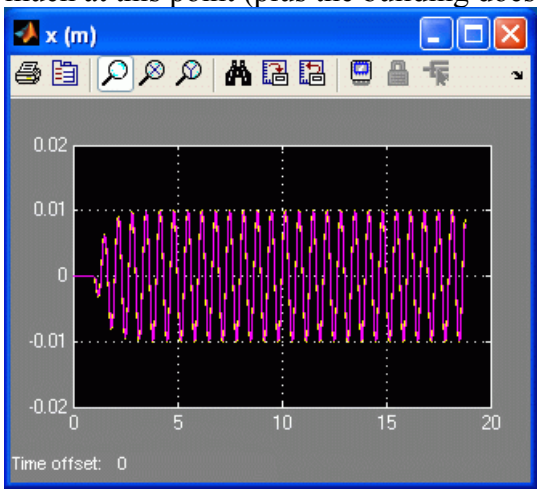

Figure 6: STII desired and measured position

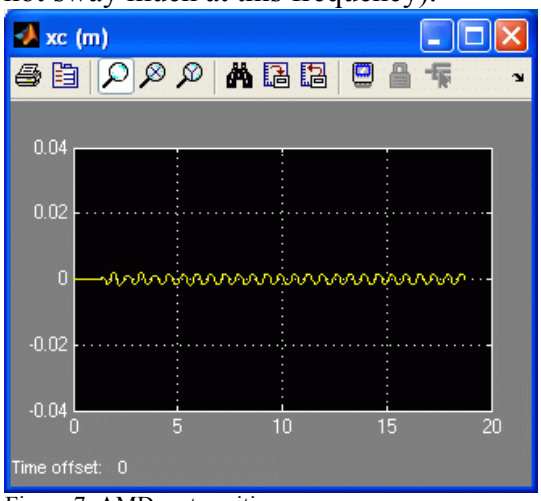

Figure 7: AMD cart position

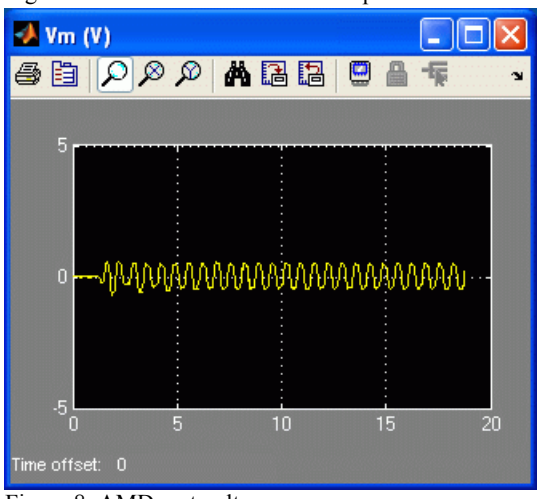

Figure 8: AMD cart voltage

11. The acceleration of the shake table (i.e. ground accleration) is in Figure 9 and the first floor acceleration scope is shown in Figure 10. Figure 11 shows the estimated deflection of the first floor.

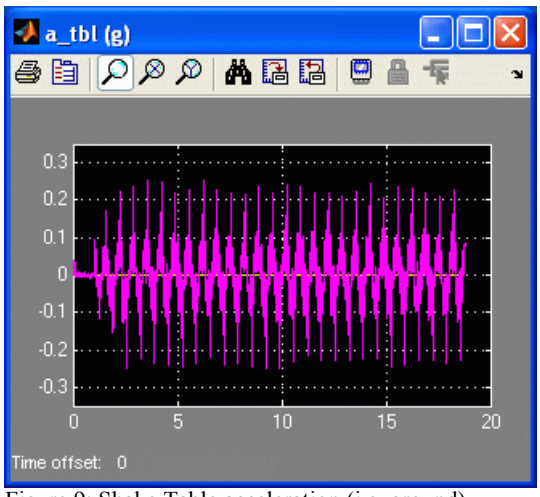

Figure 9: Shake Table acceleration (i.e. ground)

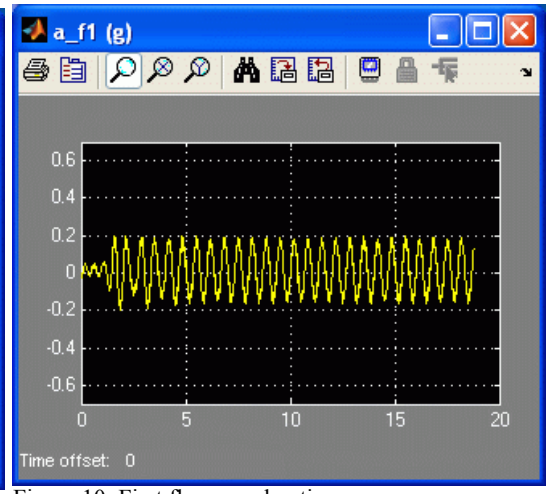

Figure 10: First floor acceleration

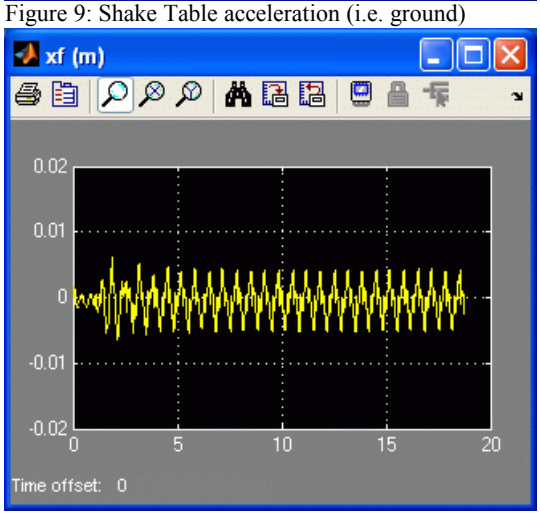

Figure 11: Estimated floor deflection

12. Click on QUARC | Stop to stop running the controller.

Try this...

- Run the sine wave at a frequency of 1.85 Hz when the AMD is on and off and examine the difference in the

6.4. Running Sine Sweep

Follow the steps described below to run a sine sweep through the table and examine its effect on the floor acceleration when the AMD is both on and off:

1. Set the *AMD-1 Control Model* to 1 for passive mode.
2. In the *Swine Sweep Setpoint* subsystem, set the *Sine Sweep Amplitude (m)* block to 0.01 meters and the ensure the chirp signal is going from 1 Hz to 2.0 Hz in 18 seconds.
3. Set the *Shake Table II Setpoint Selection* constant block to 2 to select the sine sweep signal.
4. Click on QUARC | Start to start running the controller.
5. The table should start moving back-and-forth at an increasing speed as the sine wave increases in frequency. The building structure will begin swaying more when the frequency begins to reach 2.0 Hz. Observe the movement of the structure and examine the response obtained in the opened scopes. The estimate floor deflection shown in the *x_f (mm)* scope and measured floor acceleration shown in the *a_f1 (g)* scope is given in Figure 12.

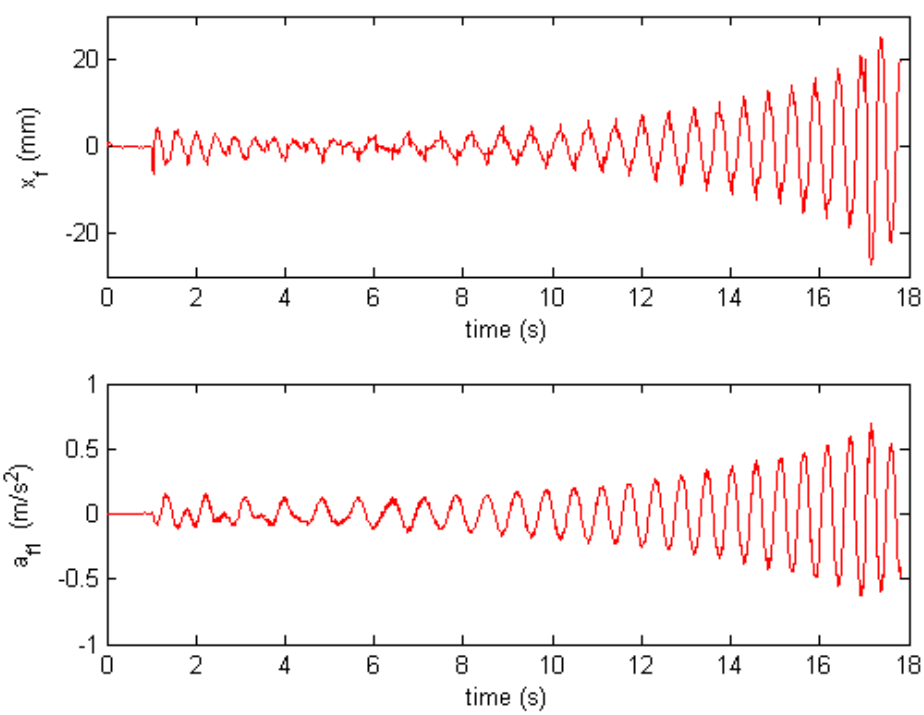

Figure 12: Floor response when AMD is off. Top plot: estimate floor deflection. Bottom plot: measured floor acceleration.

6. The sweep signal is automatically restarted. At the start of its next cycle, set the *AMD-1 Control Mode* Source block to 2 to investigate the effect of having the active mass damping. The floor deflection and acceleration when on active mode should be similar to response given in Figure 13. As illustrated, both the estimated deflection (top plot) and the measured acceleration (bottom plot) are attenuated when the active-mass damping in turned on. Remember that these effects are seen by simply looking at how much the structure sways when switching the AMD on and off.

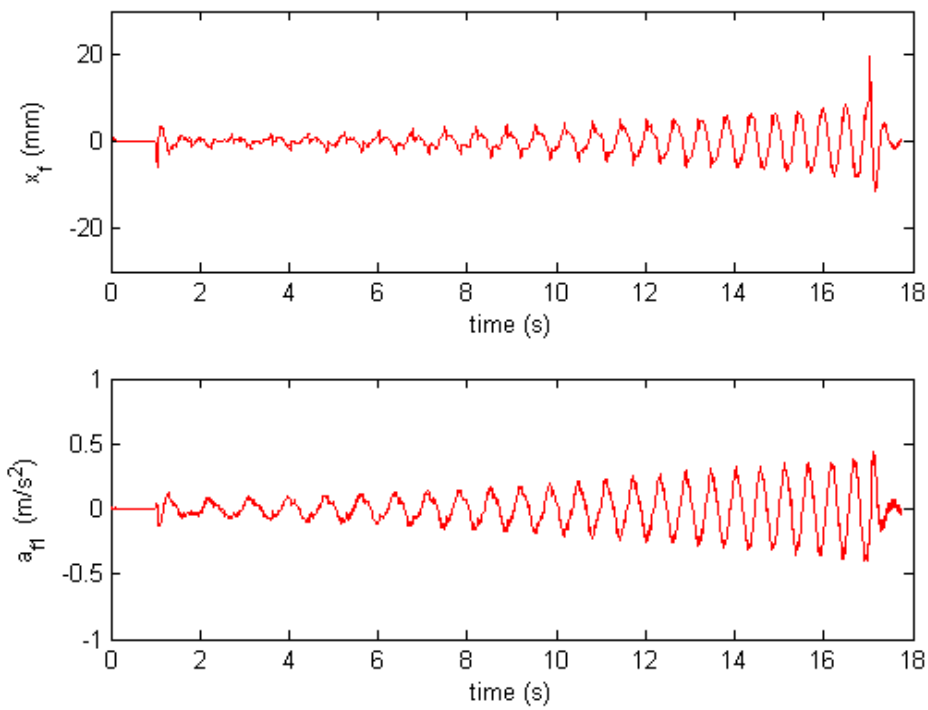

Figure 13: Floor response when AMD is on. Top plot: estimate floor deflection. Bottom plot: measured floor acceleration.

7. Stop running the QUARC controller by clicking on the *Stop* button.
8. Shut OFF the power on the both the blue UPM-180-25B used with the shake table and the amplifier connected to the linear cart (e.g. VoltPAQ-X1).

Plotting Data...

- Each scope is configured to save its last 10,000 points of data to a Matlab variable after the QUARC controller is stopped. You can use these variables to plot the data in Matlab figures as shown in Figure 12 and Figure 13.

- For example, the *a_f1 (g)* scope saves the last 10,000 points of data to the *data_af1* variable. When the controller runs at 0.002 seconds, this means its saves the last 10000 / 0.002 = 20 sec of data.
- See the Reference [5] for more information about this and the example given in the "saved response" folder.