M600 SERVO TEST STAND
Makani Power

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Statement of Disclaimer

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Executive Summary

Tempest has designed and built a test stand to validate the servo selection for Makani Power's M600 prototype. The test stand tests the servo at a specified frequency and torque. It also includes an environmental housing that can later be used to incorporate a heater, cooler, and humidifier. The applied frequency, torque, and servo position is controlled by the operator. The stand also measures and provides a readout for temperatures throughout the chamber, humidity within the chamber, frequency felt by the servo, and load applied to the servo. The table has two tiers: the first tier supports all torque application components and the second tier supports the servo, vibration motor, and the chamber. The chamber table has the vibration motor attached underneath. The torque system is comprised of a linear pneumatic cylinder attached to rope which wraps around two pulleys (one attached to the servo shaft and one free spinning). The environmental chamber is constructed from rigid insulation walls and is a 9 cubic feet box. All of the sensors connect to a microcontroller and readout to an external computer. We are confident that our design satisfies the customer's needs and will assist them in choosing the appropriate servo for the M600.

Chapter 1: Introduction

1.1. Sponsor Background and Needs

Makani Power is designing the M600 airborne wind turbine, the second version of their energy collecting kite. Tempest has created a test stand to validate their selected servo motor which controls the wings during flight. Makani needs to monitor the servo's response to torque and frequency to determine the performance of the selected servo during flight conditions. Makani will also test the servo's reaction to humidity and temperatures faced during flight and perform life-cycle testing. To accommodate the time constraints of this project, Tempest was not required to specify heating, cooling and humidity elements. However, the test stand is designed with an environmental chamber, which will be compatible with heating, cooling, and humidity components that Makani can integrate at a later time.

Makani has tested servos for a 30 kW prototype turbine, the Wing7, using a mass and string test stand, but they decided they needed a more comprehensive test. Makani has provided a budget to design, build, and test a fully functional test stand. The 30 kW prototype is partially funded by a grant from the Department of Energy. The initial funding stemmed from Google as part of RE<C. This program has since been rolled into the green energy initiative. Makani has just been acquired by Google. They have just completed an autonomous all-modes flight with the Wing7. Makani's ultimate goal is a large scale deployment of 5 MW airborne turbines in offshore wind farms to make wind energy cost competitive with fossil fuels.

1.2. Formal Problem Definition

Makani needs a test stand to validate the servo for the M600 aileron, elevator, and rudder flaps. The servo is placed within a 9 ft^3 thermal housing that maintains the applied temperature and humidity seen by the servo during flight. A specified torque is applied to the servo and a support system must prevent a moment from being applied along the shaft of the servo. There must also be apparatus to apply a specified frequency and amplitude. Finally, the servo's reactions to temperature, humidity, frequency, servo position and applied torque must be monitored and controlled through a computer.

1.3. Objective/Specification Development

1.3.1 Design Specifications

1.3.1.1 Factor of Safety

a. Factor of Safety = 4

1.3.1.2 Torque Loading

a. Meet or exceed bode plot spec supplied by Makani power

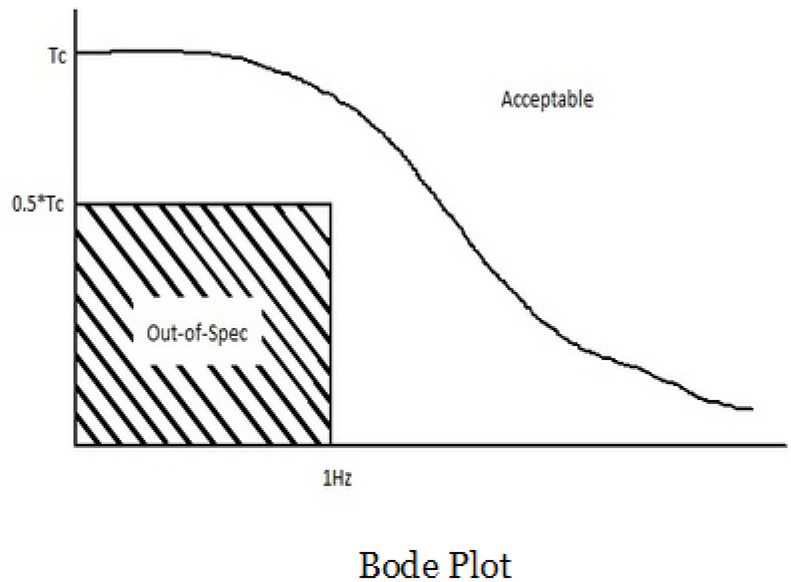


Figure 1.1. Makani's Specifications for Applied Frequency

b. 65 Nm continuous; 229 Nm max load for 20 s

1.3.1.3 Controls

a. Determined by user input array

b. Servo Position

c. Servo Load

1.3.1.4 Sensors

a. Servo Outputs
   - i. Position
   - ii. Load
   - iii. Temperature

b. External Inputs
   - i. Torque
   - ii. Frequency

c. External Outputs
   i. Temperature
   ii. Humidity
   iii. Strain on servo shaft
   iv. Frequency
   v. Position

1.3.1.5 Environmental chamber

a. Must interface with necessary heating, cooling, and humidifying apparatus
b. Must include sensors to monitor temperature and humidity

1.3.1.6 Output

a. MATLAB format array/spreadsheet
   i. Position vs. load
   ii. Temperature
   iii. Humidity
   iv. Frequency

1.3.1.7 Reliability

a. Calibrate sensors before each run

1.3.1.8 Durability

a. Servo should fail before the stand does
b. Must withstand all testing for M600
c. Must withstand environmental testing done in insulated chamber

1.3.1.9 Safety

a. Minimized pinch points
b. Moving parts are fully or partially enclosed
c. Non catastrophic failure
d. Not a fire/burn hazard

1.3.1.10 Size and weight

a. Envelope for chamber: 1m x 1m x 1m
b. Entire test stand must fit inside a standard trailer size and not exceed truck and trailer weight limits

1.3.1.11 Environmental chamber must support the application of temperature and humidity

a. Temperature
   i. -20°C minimum; 50°C maximum
   ii. 45°C/min desired; 10°C/min acceptable
b. Humidity
   i. 5% to 98% relative humidity; 50%/hour minimum

1.3.2 Designated Servo to Test

It was determined that the initial servo was not adequate to take the loads incurred during flight and adjusted for the factor of safety. Another servo has been chosen, and further details can be viewed in Appendix G. This information is only available with an NDA.

1.3.3 Design Considerations

During the design of the M600 Servo test stand, many factors were considered. First, the test stand must be transportable, meaning that its size and weight cannot exceed the maximum sizes for shipping. These limits are a maximum volume of 125 m^3 and a maximum weight of 150 N. The test stand also fits within a standard trailer of normal road width that can be driven without a class B license. The system can withstand the impacts and accelerations experienced during normal driving. Second, the test stand is adaptable to test different servos; although it is custom designed for the specified servo and must be retrofitted for another component. Third, the test stand is reliable and durable so that multiple tests can be completed with reproducible results.

Accuracy of the test stand is maintained by using calibration methods such as applying a known load in order to ensure that the test stand is reading and outputting correct values and comparing the outputs of the servo and the independent sensors. The specific elements of the servo test stand that ensure durability are a factor of safety of 4, oversized supports for the pulleys, and oversized rope. Last, the servo test stand is safe to use. This includes multiple factors, such as a limited number of pinch points, minimized possibility of electrical shock, ensured eye safety, negligible fire hazards, and no potential for a catastrophic failure to the test stand or injury to the user.

Chapter 2: Background

2.1. Current Test Machines (Existing Products)

There are many existing and ready-made products that test the parameters incorporated into our test stand (load, torque, temperature, humidity etc.). However, there are not any manufactured machines that test all of them at once. There are also very few machines that are specifically designed for testing servos. The existing servo test stands monitor high voltage and direct application of the servo (normal application for each type). They seem to be all electrical tests as shown in the Allen-Bradley Servo Motor Repair article on Servotech's website. However, we have found one man who has made his own test machine for a servo on his glider. He tested load, torque, sensitivity, deviation, accuracy, speed, and start/stop speed. Another company made a makeshift servo tester for load/torque and endurance. The following are the examples of existing testing apparatus:

2.1.1 HYCOM HSVTS Servo Valve Test Machine

Test machine for electrical components of servo valve. It tests the following:

- Pressure gain/proof pressure
- Polarity
- Null bias
- Full flow gain loaded and unloaded
- Threshold
- Frequency response
- Hysteresis
- Internal leakages
- Proof pressure test

Source: *Hydraulic Servo Valve Test Stands, HYCOM B.V.*

2.1.2 Hot Sell Temperature Humidity Test Bench, Dongguan Yuanyao Electronics Technology Co., Ltd.

Test machine for temperature and humidity. US $ 3,000 - 50,000 / Set

- Temperature Range: -73°C to +180°C
- Humidity Range: 20% ~98%

Source: *Hot sell Temperature humidity test bench, alibaba.com*

2.1.3 Instron – 8874 Axial-Torsion Fatigue Testing System

Fatigue test machine that has the following:

- Up to ±25 kN (5620 lbf) axial force capacity
- ±100 Nm (880 in-lb) torque capacity
- Wide range of axial-torsional grips, fixtures and accessories

Source: *Axial Torsion Fatigue Testing System, Instron*

2.1.4 Norwegian Glider Pilot

Ola Fremming designed and built a personalized servo test machine with the following components:

- PC-controlled (RS232) servo-pulse generator (BasicX BX24 µC)
- Precision potentiometer used to measure servo output angle
- Robust power to supply voltage to servo (PC PSU 5V 12A)
- Current-to-voltage sensor (to enable servo-current measurement), LEM LTS 6-NP
- Pulleys, wires and weights to generate torque in steps of 0.5[kg-cm]
- PC-connected data acquisition device (NI USB-6009) to measure current, voltage and position

This machine was able to test the following on a servo:

- Current consumption at static load
- Sensitivity
- Deviation/linearity
- Accuracy
- Speed
- Start-stop speed

Source: *Servo Testing, ofremmi.com*

2.1.5 Troy Built Models servo testing

This company built a makeshift servo test machine for comparison purposes. It tested fatigue and endurance.

Source: *Servos, Troy Built Models*

2.1.6 Existing Products Conclusions

Overall, there are currently no servo test machines on the market that will simultaneously test for all of our customer's specific requirements. We only discovered machines for specialized individual tests and test machines that people constructed at home. We also did not find machines that were specified for the high load that Makani has required.

2.2. Makani Research

Makani Power has designed a system similar to that of the Norwegian glider pilot and Troy Built Models based on weights and springs. Makani performed endurance testing and determined that the servos tested would overheat due to large internal forces on the gears. Maximum load testing showed that the servos tested could perform the design specified function. However, as the servos aged the sensed load also increased. It should be noted that Makani was testing servos for the smaller prototype, Wing7, and did not test the initially selected servo for the larger M600: the Moog 996 rotary servo actuator, or the finalized servo from Harmonic Drive.

2.3. Specific Technical Data

2.3.1 Aerodynamics

The product most closely resembles a glider, as defined by NASA. The kite experiences weight, lift, and drag forces during flight. Lift is created by differential pressure under and over the wing. Drag occurs due to frictional shear across the platform area. The wings are streamlined so as to maximize the angle of attack without experiencing stall. See the aerodynamic principles in the Appendix for further details. Aerodynamics is an important concept when considering the M600 in its entirety. However, for the scope of our project, the only aerodynamic analysis done will concern steady air flow through the environmental chamber.

2.3.2 Accelerated Life Testing

In order to fully test the servomotor in question, it must be tested for the full five years that has been specified by Makani. However, since this test span is not realistic the test cycle must be accelerated. Makani does not require that Tempest perform accelerated life testing. However, the test stand must be made to be compatible with this kind of testing at a later date. There are several types of accelerated life testing which result in different types of results.

2.3.2.1 Highly Accelerated Life Testing

Highly Accelerated Life Testing, HALT, is a series of tests with aggressive conditions that causes the weak points in the system to fail. This style of testing gives information on which parts of the system are the weakest, not whether the system will last the required five years.

2.3.2.2 Highly Accelerated Stress Screening

Highly Accelerated Stress Screening, HASS, tests a system to see if failure occurs within the given life period. It is generally used to identify units that have incipient flaws that will cause premature failure. This style of testing will also identify if the system as a whole will fail within the specified lifetime since it is a life cycle based test.

2.3.2.3 HALT vs. HASS

Both testing styles include a large temperature range, vibration introduced to the system, and accelerated and repeated loading. The main difference is the maximum and minimums applied to the system and the rate of application. HALT testing is more aggressive as its goal is to induce failures as fast as possible while the purpose of HASS is to test for the full life cycle of the unit. For this project both tests will be desired. HASS will be the baseline test to make sure that the servo being tested will survive flights it is expected to sustain. HALT will also be used separately to identify the weak points of the servo, what to look for when the servo is going to fail, and what to expect from the servo once it fails.

Source: *Life Cycle Testing Services, DTB*

2.3.3 Hydraulics

Hydraulics use nearly incompressible oil as the fluid in the system to apply loads. They are used in both linear and rotary orientations. Due to the incompressibility of oil, positioning can be very accurate and loads can be very large. Often hydraulics operate in the five to ten thousand psi range. While the oil allows for precise positioning it also results in shocks to the system which can result in leaks and errors in readings. Leaks can result in fire hazards if they are not stopped and cared for. One safety advantage of hydraulics is if the pressure needs to be released it can be done so immediately because of the incompressible nature of oil; there is no need to bleed off pressurized air to reduce the load.

2.3.4 Pneumatics

Pneumatics use air as the fluid in the system to apply loads. Pneumatics are used in both linear and rotary orientations. Due to the ease of flow and lack of viscosity of air pneumatics are able to perform faster than Hydraulics. However, because air is so compressible, precise positioning and loading is more difficult. Often pneumatics operate in the 80 to 100 psi range, but in specialized applications can operate up to 8000 psi. Pneumatic systems are generally much simpler and safer to operate. The compressibility of the air makes pneumatic systems last longer and more reliable because the air can absorb shocks to the system putting less pressure on seals and joints.

2.3.5 Electric Motors

Motors can come in a large number of sizes. They can utilize both direct and alternating current to produce mechanical energy from electrical energy. Motors have several different ratings including operating torque, torque speed, and stall torque. For the application required stall torque is the most important since the motor will not actually be moving while applying the torque. However, constantly applying stall torque to a motor causes overheating and failure. Overheating and failure during stall torque applications are caused by the maximum possible current being drawn through the motor for extended periods of time. Motors are not designed to handle the maximum current for such periods of time.

2.4. List of Applicable Standards

Makani does not require that Tempest abide by a specific set of standards, given the large scope of the project and its overall function. However the following standards have been investigated to further improve the design:

E4-10 - Standard Practices for Force Verification of Testing Machines
E74-06 - Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
E1319-98(2009) - Standard Guide for High-Temperature Static Strain Measurement
E1561-93(2009) - Standard Practice for Analysis of Strain Gage Rosette Data
E1928-07 - Standard Practice for Estimating the Approximate Residual Circumferential Stress in Straight Thin-walled Tubing
E2428-08 - Standard Practice for Calibration of Torque-Measuring Instruments for Verifying the Torque Indication of Torque Testing Machines
E2624-09 - Standard Practice for Torque Calibration of Testing Machines and Devices
D1761-06 - Standard Test Methods for Mechanical Fasteners in Wood
D3501-05a (2011) - Standard Test Methods for Wood-Based Structural Panels in Compression
D6874-03(2009) e1 - Standard Test Methods for Nondestructive Evaluation of Wood-Based Flexural Members Using Transverse Vibration
C447-03(2010) - Standard Practice for Estimating the Maximum Use Temperature of Thermal Insulations

Source: http://www.astm.org/DIGITAL_LIBRARY/COMMIT/PAGES/STDS_FULL/E28.htm

Chapter 3: Design Development

3.1. Loading and Positioning Design

3.1.1 Discussion of Conceptual Designs

Tempest chose 5 main techniques for loading the servo: a spring, motor, hydraulic or pneumatic pump, gear or gear train, chain or belt and any combination of these. Shown below are the concept drawings from our brainstorming sessions.

First we looked at linear motion applied to a lever to create torque. In these drawings, ‘S’ denotes the servo and ‘M’ denotes a separate motor:

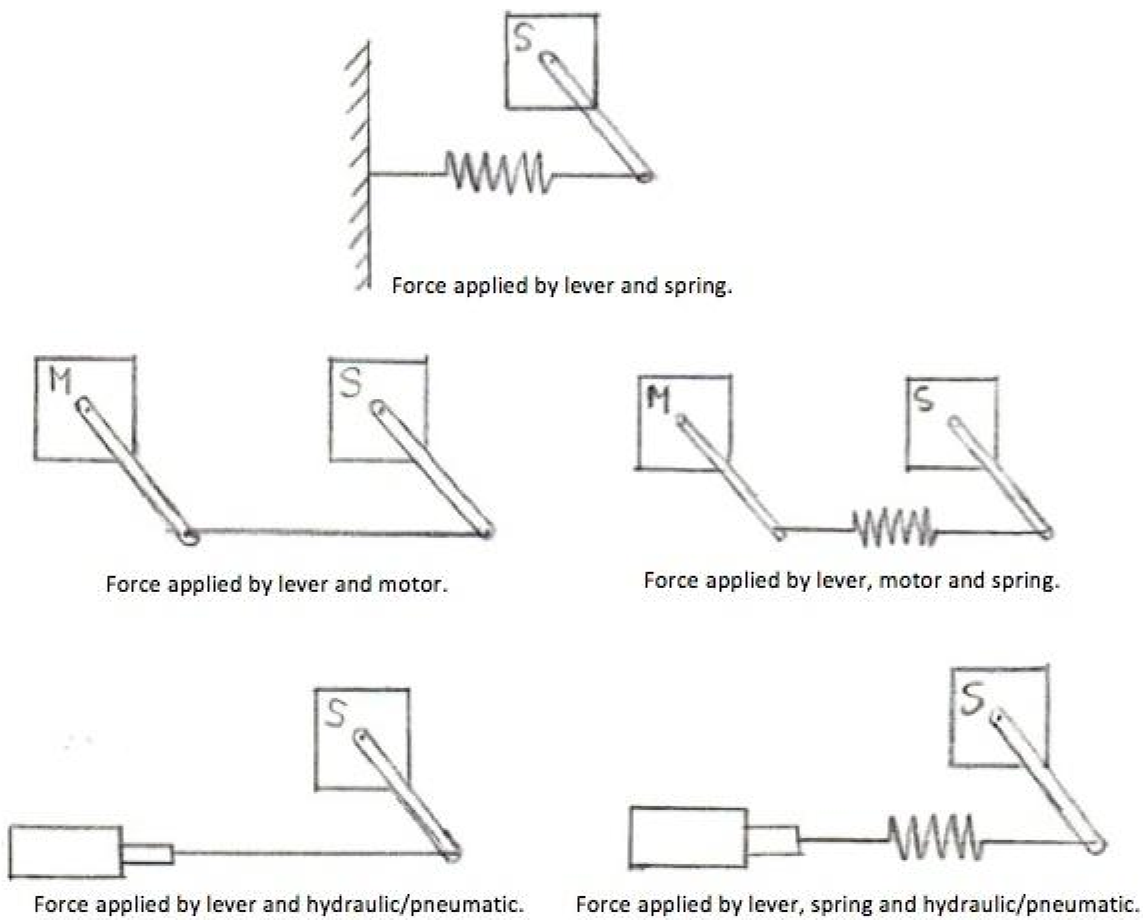


Figure 3.1. Sketches of Force Applied With Lever Arm

We then investigated linear hydraulic and pneumatic systems for creating torque with rotational motion:

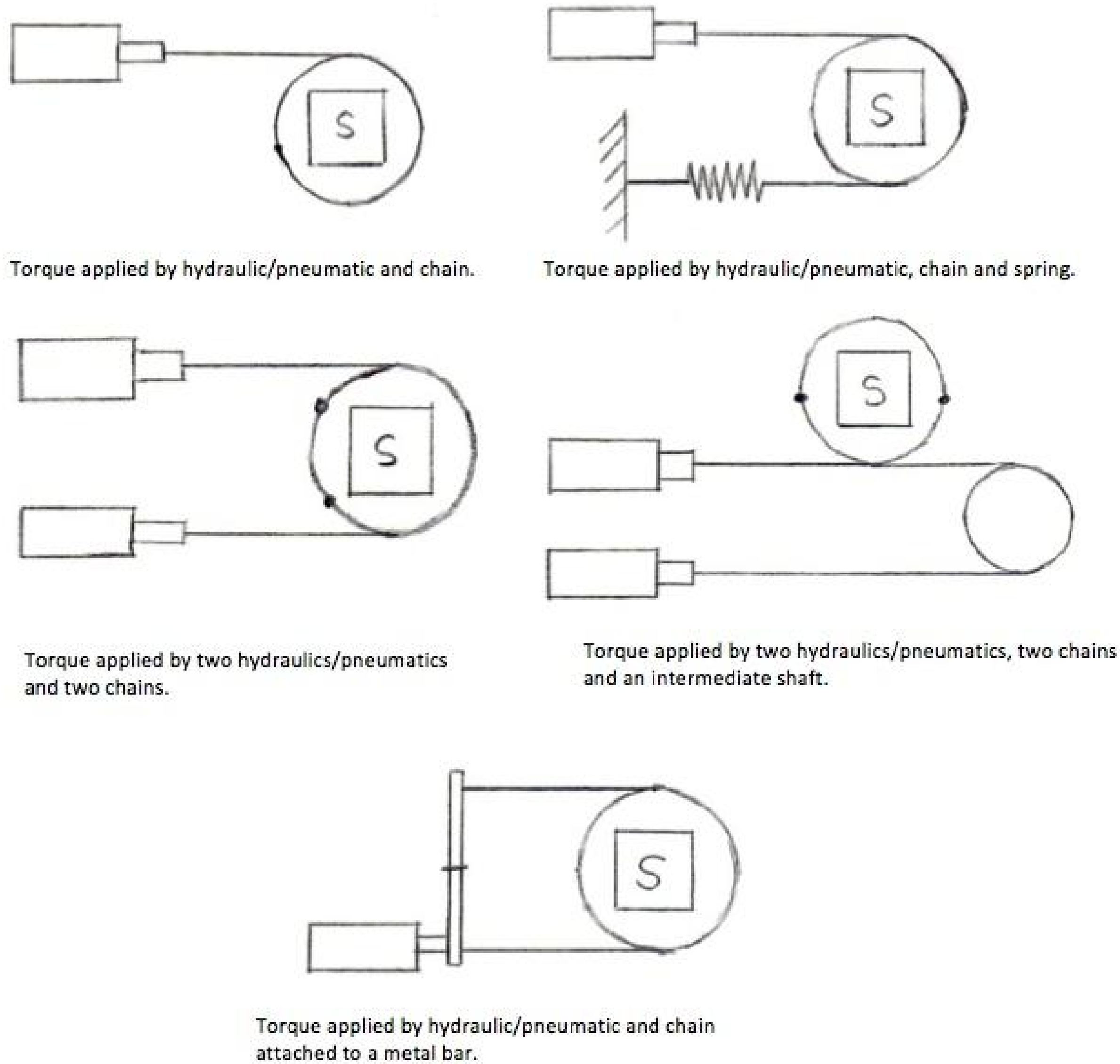
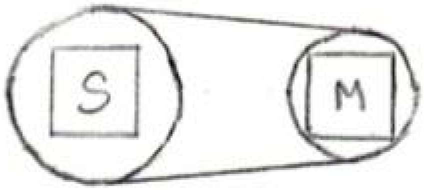
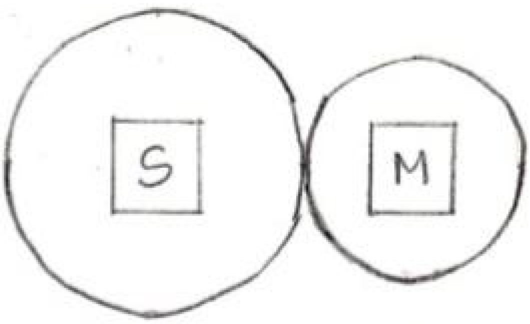


Figure 3.2. Sketches of Force Applied By Pneumatics

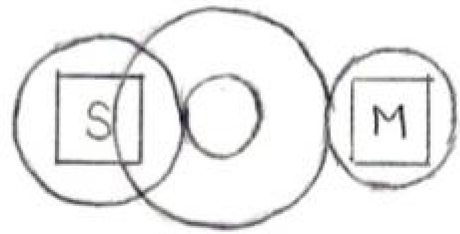
Last, we considered rotary hydraulics and pneumatics to create torque with rotational motion:



Torque applied by motor and sprocket and chain.



Torque applied by motor and two gears.



Torque applied by motor and gear train.

Figure 3.3. Sketches of Force Applied By Rotational Motion

We decided against using a lever arm and linear force, as depicted in Figure 3.1, because the torque varies depending on the angle of the lever. At any position where the lever arm is not perpendicular to the force, part of the resultant force is translated radially into the servo and no longer creates torque. As a result, the torque applied to the servo decreases as the angle from perpendicular increases. We decided against using gears or a gear train due to gears tendency to fail when under a large torque. Thus, the best options were a motor with a chain and sprocket or some type of hydraulic or pneumatic device.

After analyzing the hydraulic/pneumatic concepts, we determined the most effective designs were the double pneumatic system with two chains around two sprockets and the single pneumatic pushing on a rotating bar with a chain. After performing an analysis on these systems, we decided to use a pneumatic system over a hydraulic system, because pneumatic systems are simpler and safer. Also, pneumatics will allow for a quicker and better frequency. However, we must use caution not to overload the pneumatic, as pneumatics are generally used in low torque applications. More detailed drawings of the three top concepts are shown below.

Dual pneumatic design: $\tau_s = F_M r_s$ $\quad x = r_s(30^\circ)$

Rotary pneumatic sprocket and chain design: $T = \frac{d}{r}\tau$ $\quad x = r_s\,(30^\circ)$

Linear pneumatic, single bar design: $\tau = \frac{rd}{l}F$ $\quad \Theta = \frac{\sqrt{m^2+(l-r)^2}-\sqrt{(l\cos\alpha-r)^2+(m-Y)^2}}{r}$

3.1.2 Concept Selection

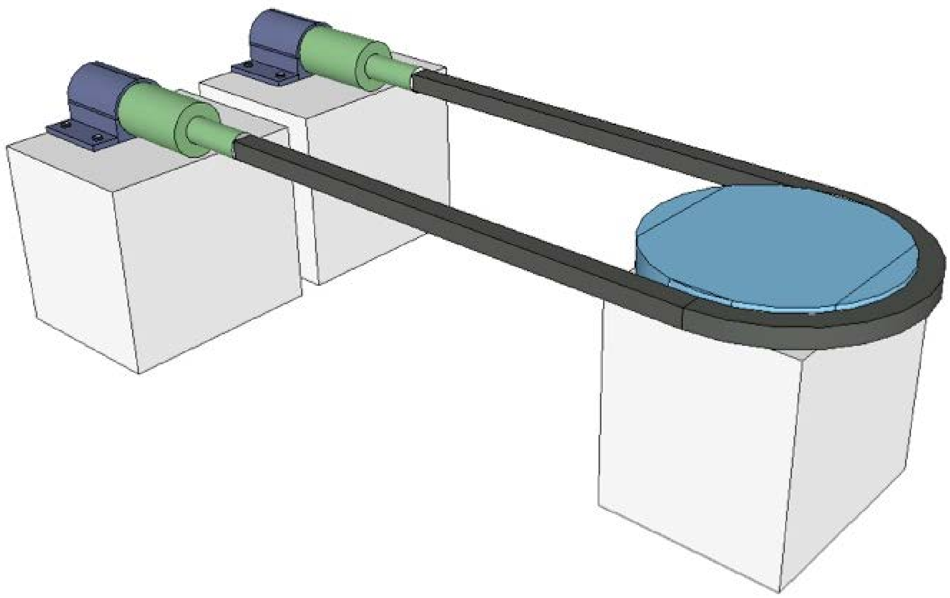


Figure 3.4. Design 1: Linear Pneumatic, Single Bar Design

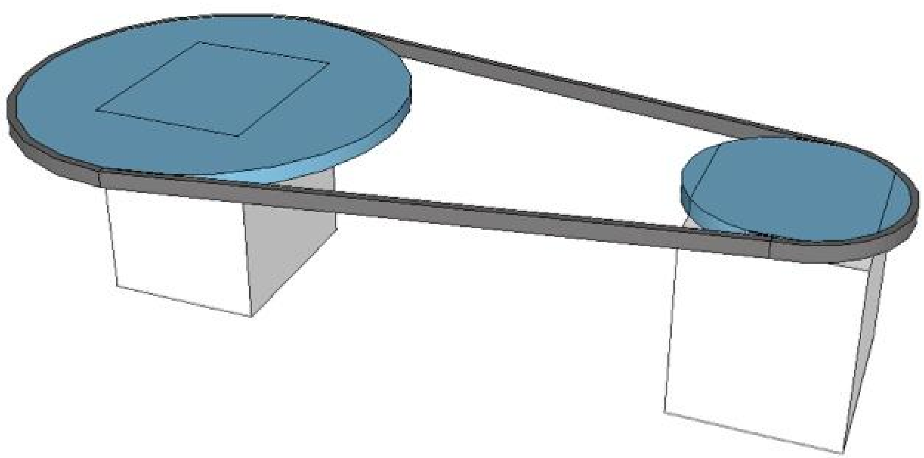


Figure 3.5. Design 2: Two Pneumatics Attached to a Chain and Sprocket on Servo

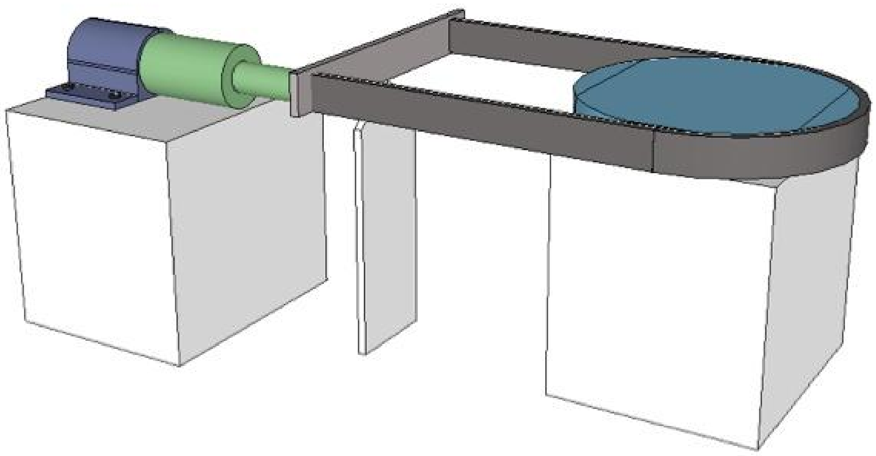


Figure 3.6. Design 3: Linear Pneumatic with Rotating Bar Attached to Chain

3.1.3 Analysis for Selected Top Concepts

We put the top concepts for torque application in a decision matrix. The objectives we chose are cost, frequency response, ease of setup, ability to apply force, manufacturability and safety. The datum for comparison is the simple weight system Makani had previously used, which is mentioned in research section 2.2.

Table 3.1. Decision Matrix for Torque Applications

		Motor with Chain and Sprocket		Two Pneumatic with Chain and Sprocket		Pneumatic with Bar and Chain and Sprocket		Datum: Weight System
	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating
Cost	3	-1	-3	-1	-3	-1	-3	0
Frequency response	4	0	0	1	4	1	4	0
Ease of setup	3	1	3	0	0	-1	-3	0
Ability to apply force	5	0	0	1	5	1	5	0
Manufacturability	4	1	4	-1	-4	-1	-4	0
Safety	3	0	3	-1	-3	0	0	0
Reliability	3	-1	-3	0	0	0	0	0
Total			4		5		-1	

The pneumatic with the rigid bar received a negative number, so this idea was eliminated. Otherwise, the decision was inconclusive. The simplicity and manufacturability of the motor and chain is not compromisable because of the time limits of this class. The force and the frequency response of a pneumatic device are not compromisable either because it is the main specification that we need to meet. So we brainstormed a little more and combined the two ideas. The final design has the layout of the motor and chain, but uses a rotary pneumatic instead of a motor. This allows us to apply the force needed and be simple enough so that the project is feasible for us to complete.

3.1.4 Further Design Analysis with Selected Final Design

During the specification of the pneumatic motor, pulley parts, and servo torque application components, it was found that the cost would be too high. In an effort to reduce costs, the sponsor asked for additional designs to be suggested. In addition, the servo torque specification was reduced.

After further analysis of the loading and positioning design, we settled on the design that incorporates one pneumatic motor with an extension stand-off, along with a second free-spinning pulley structure, and a servo torque applicator. Before, we had chosen the rotor pneumatic because it was the only feasible system for our design that could meet the desired torque load. However, as a result of the servo torque specification being reduced, we were able to go back to the design of a single pneumatic motor. Thus, we went through yet another design analysis for the loading device or contraption to transmit the pneumatic load to the servo. Figures 3.7 and 3.8 below show the design options that were formulated. Design option 1 shows a pneumatic with two loading ends that move back and forth to apply a torque load to the servo pulley. Design option 2 is also a pneumatic with two loading ends, but instead with an additional free-spinning pulley for the load cable to move around. Design option 3 is a pneumatic with only one load side and has the two options of either the use of the free-spinning pulley, or a long rod to apply the torque along the servo pulley.

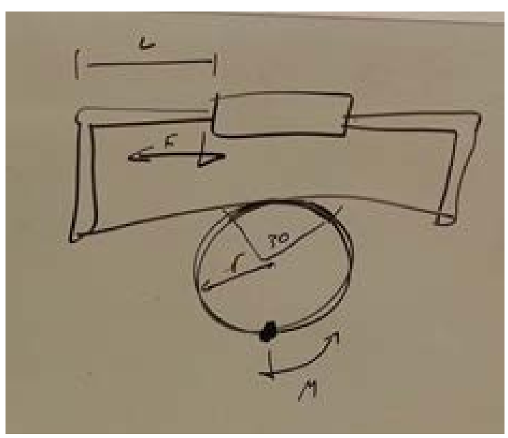


Figure 3.7. Design Option 1: Loading Device on Pneumatic to Servo Pulley

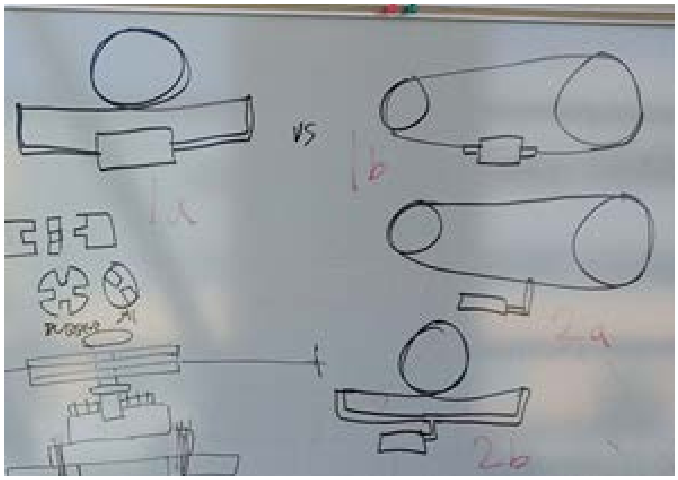


Figure 3.8. Design Option 2 & 3: Loading Device on Pneumatic to Servo Pulley

These design options were not used because they lacked feasible options for connecting the cable to the pneumatic. Rope cleats were considered and U-bolts were considered, but neither option yielded the required maximum strength required. Instead, other designs were formulated, such as the final selected design shown below in Figure 3.9.

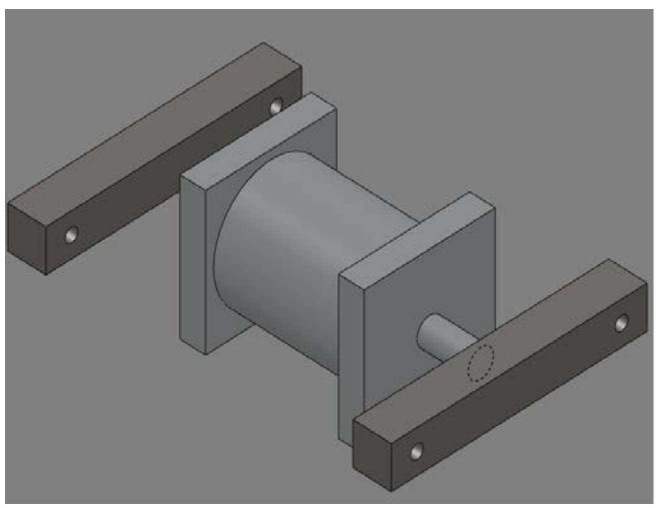


Figure 3.9. Selected Design for Loading Application on Pneumatic: Pneumatic Extension and Rope Aligning Add-on

This design allows for the load cable to be in line with the pneumatic motor. There are two similar pneumatic extensions that are in the back and front of the pneumatic that allow for an even loading. The cable goes through the holes on either side of the extensions, which allows for the cable to be parallel on either side of the pneumatic. This set up, in conjunction with the free-spinning pulley, allows for an evenly distributed load to be applied to the servo pulley from the pneumatic. The free-spinning pulley design can be seen in Figure 3.10 below.

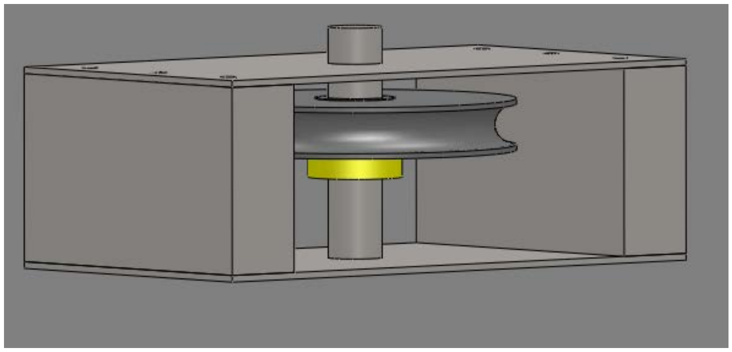


Figure 3.10. Second Free-spinning Pulley Design Drawing

The free-spinning drawing is housed within a support system that is then bolted down to the base table. We specified the side legs and the top and bottom plates to be able to handle the load from the cable without movement or failure. The shaft will be welded to the bottom plate, and a shaft collar will be used above and below the free-spinning pulley in order to keep the pulley at a constant height on the shaft. In addition, we also designed a shaft application setup, which can be seen below in Figure 3.11. The details of this setup can be found in the Final Design chapter.

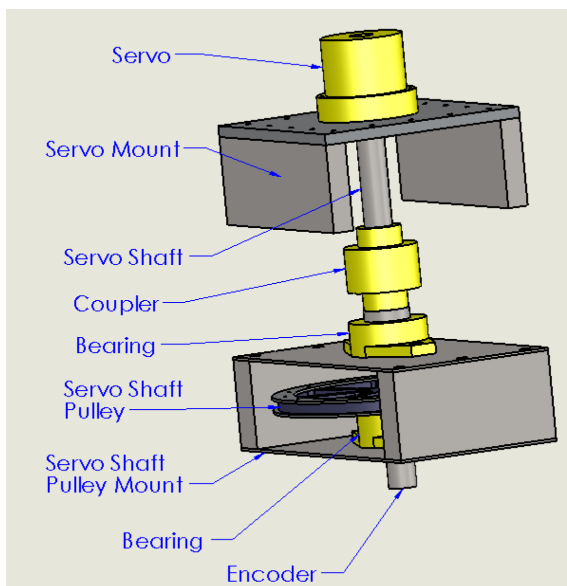


Figure 3.11. Setup for Servo Torque Loading Application

The final setup and layout of the loading and positioning design on the base table can be seen in the next section in Figure 3.17.

3.2. Mounting Design

3.2.1 Discussion of Conceptual Designs

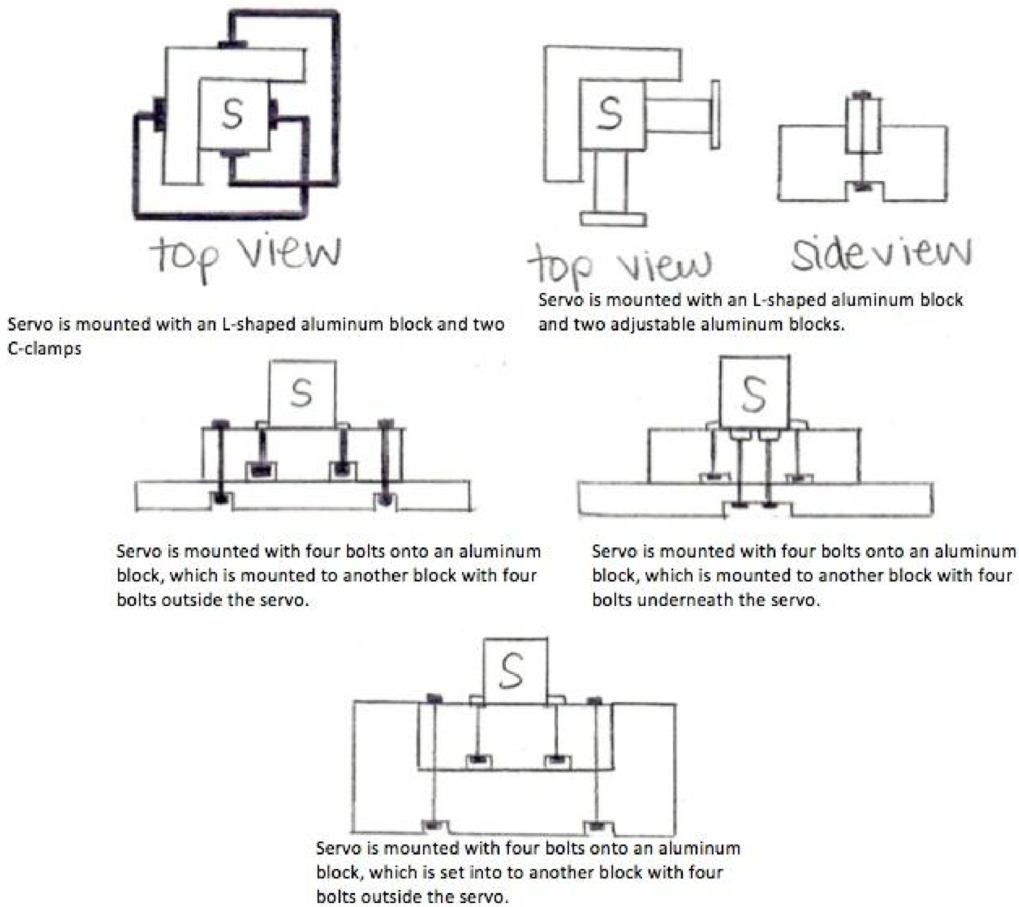


Figure 3.12. Sketches of Mounting Methods

Tempest decided against using C-clamps and the aluminum blocks because they are bulky and would get in the way during testing. We also decided against the bolted style with bolts directly underneath the servo because it makes assembly and disassembly difficult and requires more machining. The best two designs are very similar and more detailed drawings of them are shown below.

3.2.2 Concept Selection

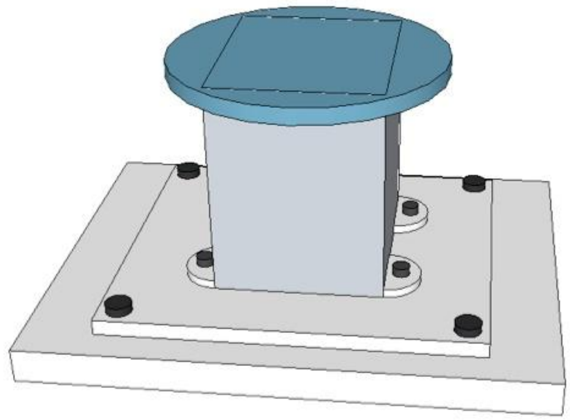


Figure 3.13. Design 1: Two Aluminum Blocks on Top of Each Other with 4 Bolts Each

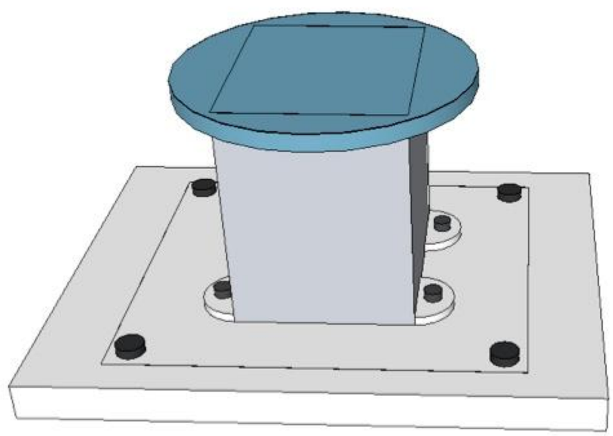


Figure 3.14. Design 2: Two Aluminum Blocks Nested in Each Other with 4 Bolts Each

3.2.3 Analysis for Selected Top Concept

Both Mount Design 1 and Mount Design 2 include a base plate made of steel, which is 1" thick. They both also use a 12" X 12" intermediate plate of aluminum, which is .5" thick. The bolts to attach the servo to the intermediate block in threaded holes for ease of disassembly. The bolts for the intermediate block to the base block will be countersunk under the base so the surface is flush. Base bolts are .5" in diameter and intermediate bolts are ⅜". These designs have two plates to make servo interchangeability easier: the base plate can be fixed always, and the intermediate plate can be changed depending on the servo. To decide between the stacked plates and the nested plates, we put them in a decision matrix with the datum of a single plate. The objectives for this application are cost, ease of setup, strength, manufacturability and safety.

Table 3.2. Decision Matrix for Mounting Applications

		Stacked Plates		Nested Plates		Datum: One Plate
	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating
Cost	3	-1	-3	-1	-3	0
Ease of setup	4	0	0	-1	-4	0
Strength	5	1	5	1	5	0
Manufacturability	4	0	0	-1	-4	0
Safety	3	0	0	0	0	0
Total			2		-6	

Design 1 will be simpler than the Design 2 to manufacture because of the machined base plate. Design 2 provides more support, but this is not necessary in the scope of our project. Design 2 will also provide problems in assembly because it will either be press fit or loose in the base plate. Press fit will mean it does not come out and cannot be replaced with other sizes if necessary. Loose means there is not the desired support for the purpose. Therefore we have decided that Design 1 will be the better option.

After further consideration and communication with Makani it has been decided that plywood plates will be used instead of metal plates. This is due to the significant price reduction and increase in ease of manufacturing. This will also result in a lighter weight baseplate that will vibrate easier. Due to the increased ease of manufacturability and reduction in cost the need for an intermediary plate has been eliminated.

In order to properly support the pulley mounted on the servo a support system has been added to the mounting arrangement. The mounting system will support the drive shaft both above and below the pulley. The system shown below is the design necessary to support the servo during maximum torque application.

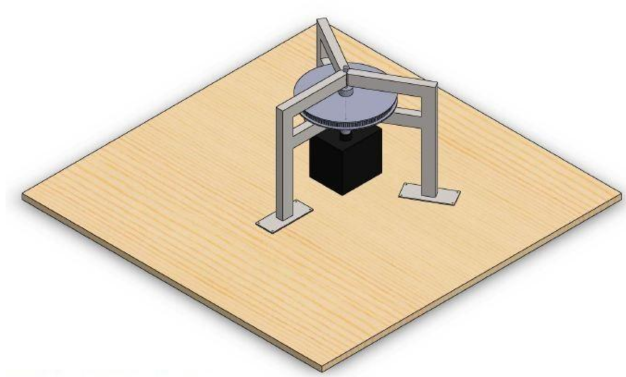


Figure 3.15. Mounting Design: Single Plywood Plate with Pulley Support

3.2.4 Further Design Analysis with Selected Final Design

After further analysis and deliberation with the project sponsor, our team found a major obstacle in our design process. Due to the initial layout of the components on the table, the plane of the load (the height of the cable, pulleys, and pneumatic motor) would be required to be at a relatively long height. This height is determined by the components on the servo shaft, which include the coupler, shaft collars, bearings, pulley, and mounting system (Figure 3.11). As a result of the large height required, a larger moment is created on the mounting systems, which then requires a more robust mounting design. A previous design with the large height can be seen below in Figure 3.16.

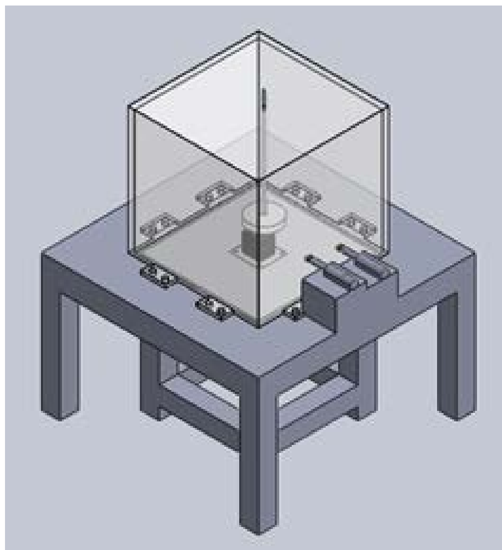


Figure 3.16. Previous Design to Demonstrate Height of Loading Plane

In order to eliminate the large, robust mounting structures that would be required to handle these large moments and loads, our team decided to lower the loading plane to be closer to the base table. As a result, there are smaller moments on the mounting structures, and the mounting structures can be simpler. In order to make the loading plane closer to the base table, we flipped the servo shaft and added another table on top to house the servo being tested. This can be seen in Figure 3.17 below.

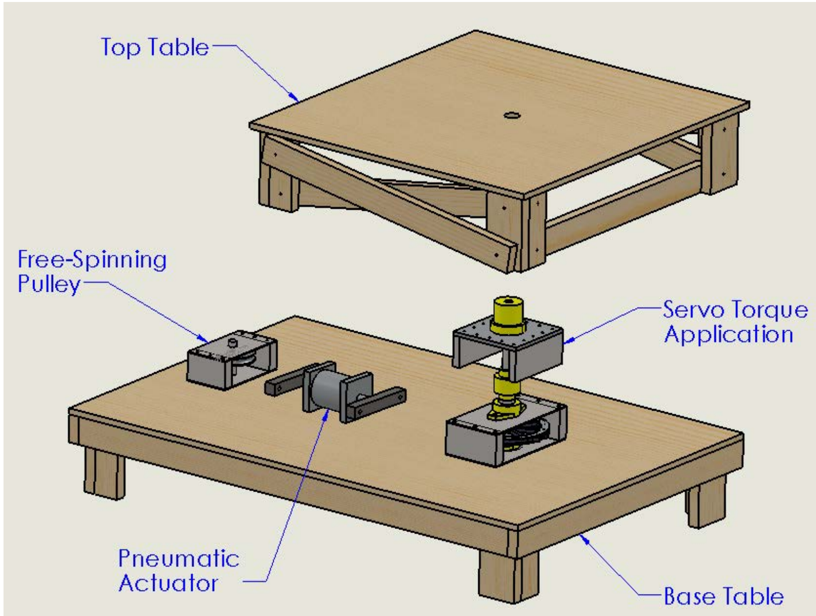


Figure 3.17. Selected Mounting Design Layout with Loading Plane Closer to Base Table

As a result of the lower moments, all of the mounting structures are simplified. This eliminates the need of the previous F-structure design. Instead, another wood top table was designed to handle the torque that will be applied to the torque and a simple servo mounting structure will be used to hold the servo.

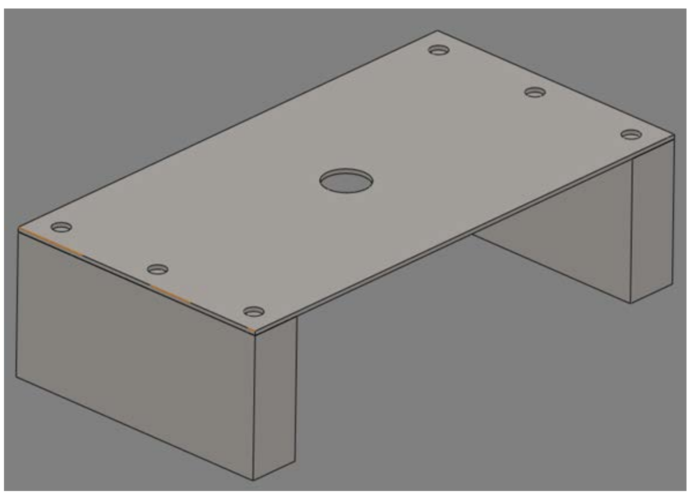


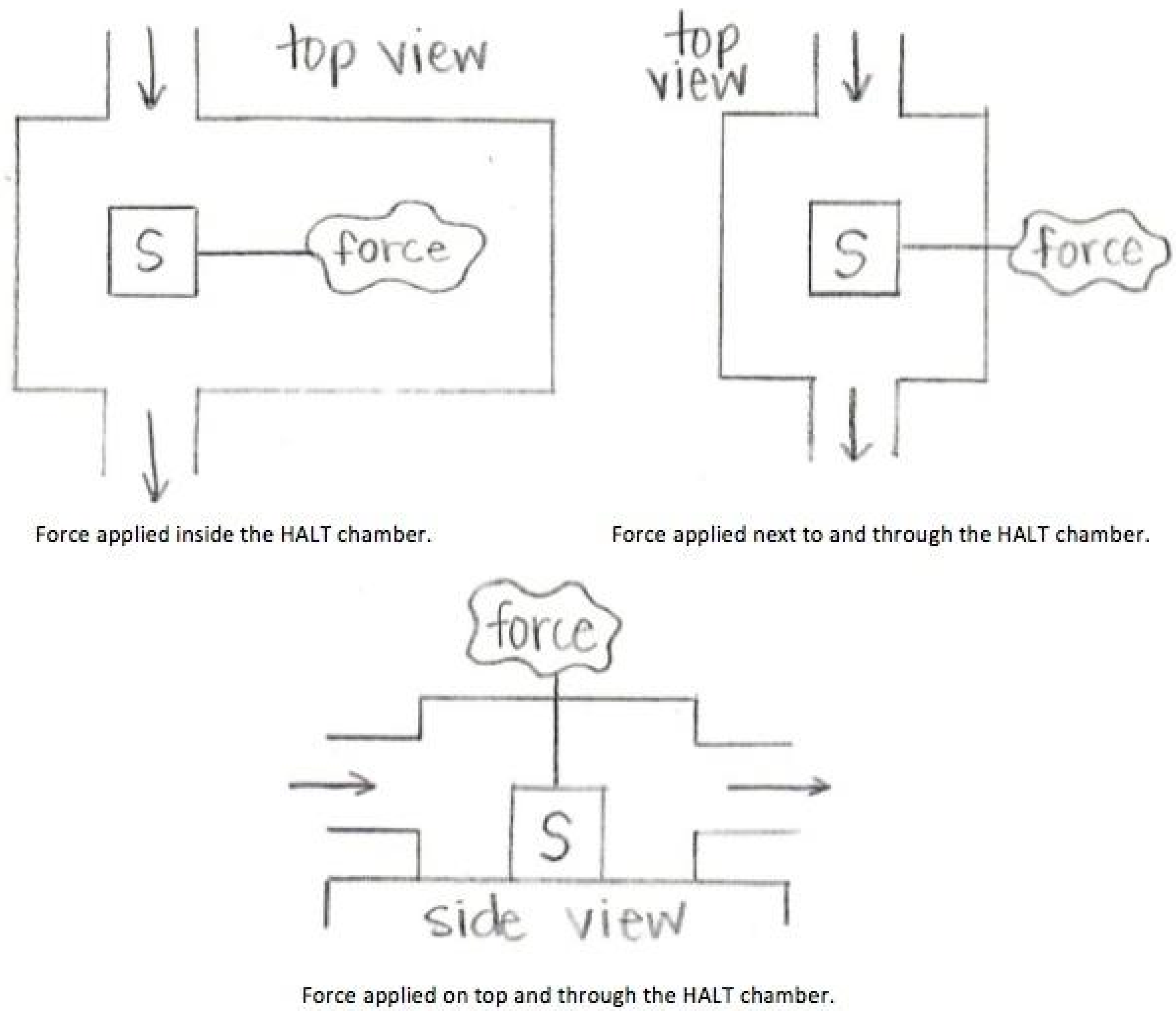
Figure 3.18. Selected Servo Mounting Structure

The servo mounting structure bolts straight to the top table and has a central hole and tapped holes to mount the servo inside. If a different servo must be tested, Makani Power only needs to construct a different top mounting plate that will fit the new servo. In addition, this top table will support the environmental chamber on top of it instead of the base table.

3.3. Environmental Chamber Design

3.3.1 Discussion of Conceptual Designs

For the environmental chamber, we first considered whether the torque application should be placed inside or outside the chamber.



Force applied inside the HALT chamber.

Force applied next to and through the HALT chamber.

Force applied on top and through the HALT chamber.

Figure 3.19. Sketches of Force Placement for Environmental Chamber

We then considered the placement of the actual heater and cooler:

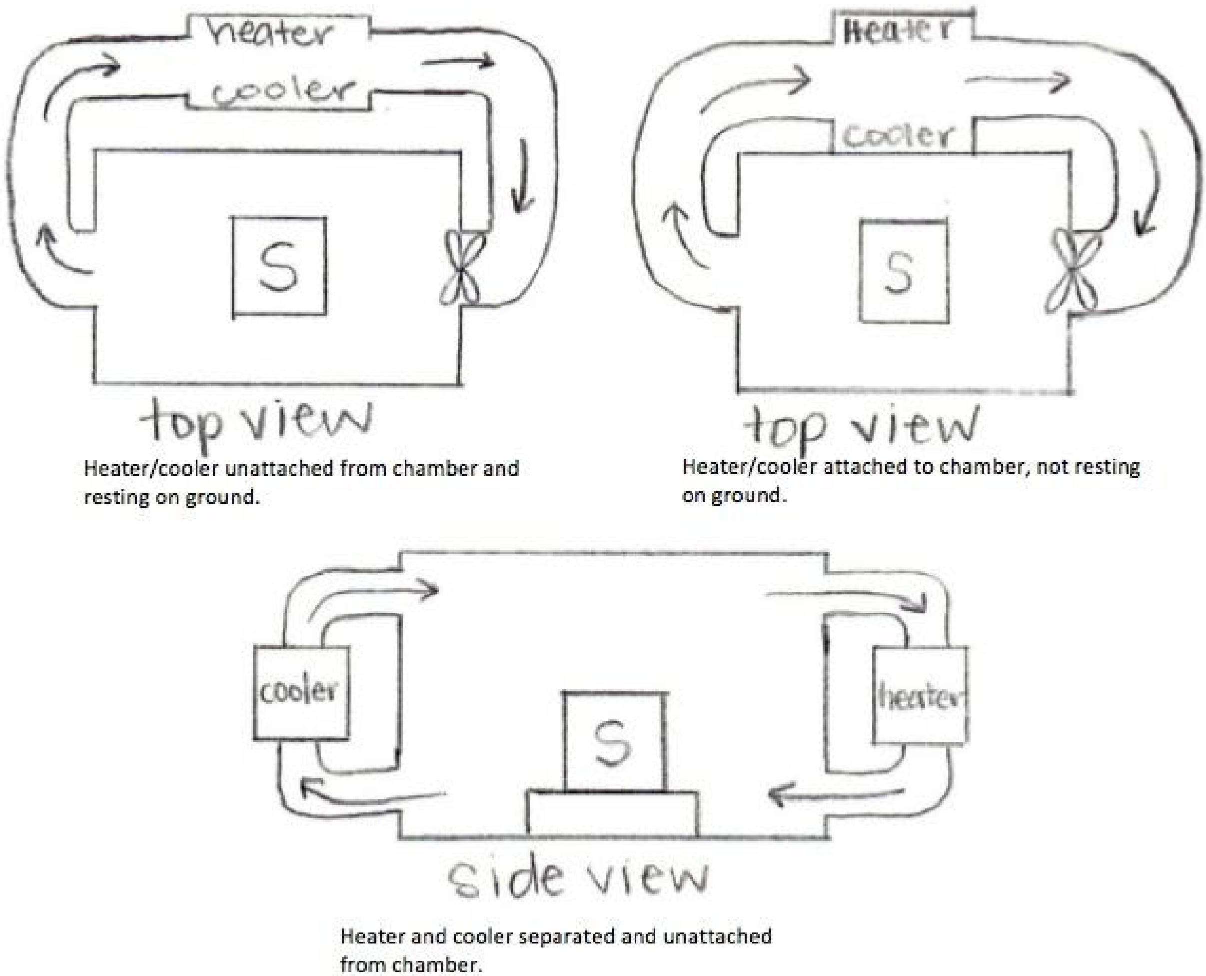


Figure 3.20. Sketches for Heater/Cooler Placement for Environmental Chamber

3.3.2 Concept Selection

For the placement of the force, it made most sense to place it outside the chamber off to the side. Out of the top will create unnecessary extra structures. Including the force inside the chamber exposes the force components to hot and cold temperatures as well as humidity. As for the placement of the heater and cooler, we first eliminated the heater/cooler element that was attached to the chamber because it would require the walls of the chamber to be strong enough to support it.

The remaining two designs are shown in more detail below:

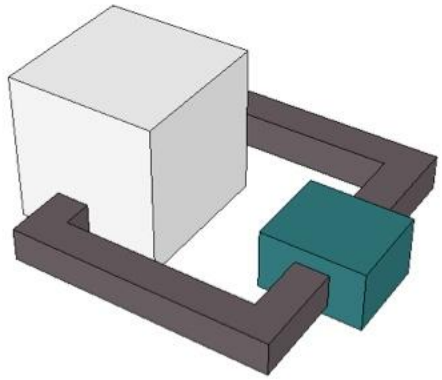


Figure 3.21. Chamber Design 1: Heater/Cooler Unit Together on Ground

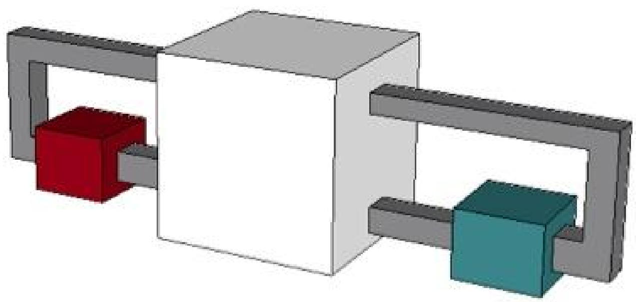


Figure 3.22. Chamber Design 2: Heater and Cooler Separated

3.3.3 Analysis for Selected Top Concept

Both of these designs have valves incorporated as a safety feature. Design 2 has vents located on either side to vent hot or cold air out when cooling or heating, respectively. To decide between the two, we put them in a decision matrix with a datum of heating/cooling inside the chamber. The objectives for this application are cost, ability to change temperatures quickly, ease of setup, manufacturability and safety.

Table 3.3. Decision Matrix for Environmental Chamber Applications

		Heater/cooler together, unattached from chamber		Heater/cooler separate, unattached from chamber		Datum: Heater/cooler inside chamber
	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating
Cost	3	-1	-3	-1	-3	0
Quick temperature change	4	1	4	1	4	0
Ease of setup	4	1	4	0	0	0
Manufacturability	5	0	0	0	0	0
Safety	3	1	3	1	3	0
Total			8		4	

This decision matrix indicates that a single system of heating and cooling would be best for our purposes. Although we have done extensive research on the environmental chamber design of our testing system, the priority is to complete the loading and positioning design. The insulating chamber will be constructed with all necessary temperature and humidity sensors. However, the actual heating and cooling apparatus will not be included.

3.3.4 Further Design Analysis with Selected Final Design

After consulting with the sponsor, it was concluded that our team would only be tasked with making the environmental chamber necessary for Highly Accelerated Life Testing (HALT), but will not be responsible for including the heating and cooling apparatus.

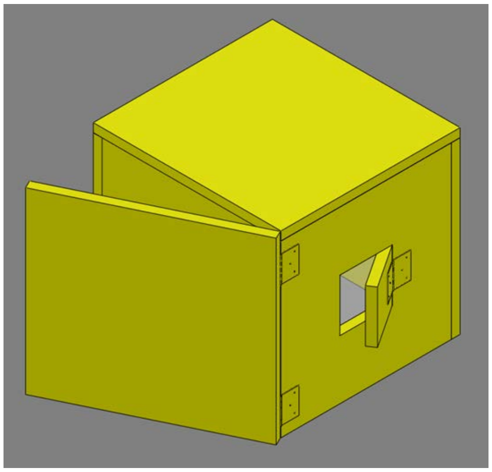


Figure 3.23. Selected Design for the Environmental Chamber

This design is easily constructed with rigid R-max insulation pieces and features a large door and convenient window to watch the servo inside being tested. If our sponsor would like to add on the heating and cooling apparatus, the back wall would be perfect to install the required hoses.

3.4. Vibration Table Design

3.4.1 Discussion of Conceptual Designs

The vibration table will be placed inside a cut-out slit of the larger support table. The vibration table will be used to provide vibrational loading to the servo during testing. The main use of vibrational loading will be during HALT testing of the servo to estimate the life expectancy and possible sources of failure.

The vibrational loading specifications have not yet been defined by the sponsor. However, we have done research on possible designs to implement in our testing table. The two main ideas to produce vibrational loading are listed below. The decision and final design is later defined.

3.4.1.1 Full vibration table

Figure 3.24. Vibration Table from: *Shop.Certifiedmtp.com*

The benefit of a full vibration table will be the simplicity of installation and use. However, these tend to be very expensive, ranging from around $2,000-$10,000. Once we acquire the vibration table specifications, we can research and locate a particular vibration table that will specifically meet the requirements. Installation of the vibration table into our system will be fairly simple, and all controls will already be implemented into the table. Additionally, using a ready-made commercial vibration table will increase the reliability and durability of the vibration element in our system.

3.4.1.2 Vibration motor

Figure 3.25. Vibration Motor from *historystones.com*

The benefits of a vibration motor compared to a full vibration table are the significantly lower price, ranging from around $50-$1000. However, implementing the vibration motor into our system will require much more research, time, and production from our team that may be better allocated to prioritized parts of the project, such as the loading design. The vibration motor can be mounted to the underside of a support plate (or the interface plate) and will vibrate the system. Another downside to this idea is that it is mainly used for vibrating concrete molds, rather than testing the vibrational capabilities of a system like our test stand. It is not specified for certain “G” loads, but instead for maximum weights that can be placed on top of the support plate and continue to vibrate. Additionally, using the vibration motor will require our team to redesign or build the table and supports for the vibrating plate, rather than it being all-inclusive as it is on the full vibration table.

3.4.2 Concept Selection

We selected the design of the vibration motor attached to a constructed table. A design option that our team formulated is to use a used car time for the suspension of the vibration table, which provides a cheap and efficient method to isolate the vibrations to the table area.

3.4.3 Analysis for Selected Top Concept

This design achieves the desired frequency at minimal cost. By purchasing an independent uniaxial vibration motor we cut costs immensely. However, we still needed a full vibration table to interface with our design. This design allowed us to integrate the vibe motor into a table we can easily construct. Additionally, the tire and plywood top provide ample support for the servo assembly on top. The plywood top is 0.75” thick to ensure that it will withstand the vibration and applied weight.

3.4.4 Further Design Analysis with Selected Final Design

As a result of the design change to include a top table to support the servo and servo pulley, our team decided to mount the vibration motor underneath the top table. This ensures that the servo will be able to “feel” enough of the amplitude and frequency from the vibration motor that will be necessary. In addition, vibration dampening pads will be placed underneath each of the table legs in order to dampen the vibrations that may be transmitted to the loading components and to eliminate rattling between the table legs and the floor.

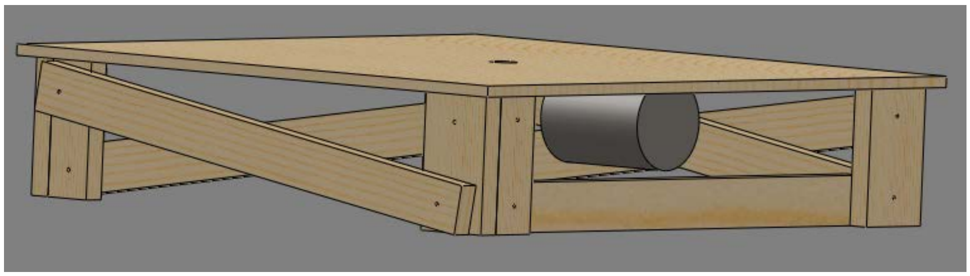


Figure 3.26. Vibration Table Final Design on Top Table

Chapter 4: Description of the Final Design

4.1. Overall Description/Layout

The final design is a set of tiered tables with the servo mounted to the top table with a shaft running through to the bottom table where the linear pneumatic applies the torque. The pneumatic is connected to this shaft via a pulley and cable, which wraps around a free-spinning pulley as well to apply the load. The pneumatic is controlled by a valve and regulator system. A vibration motor is attached to the underside of the top table to centralize the vibrations on the servo. The tiered-table assembly allows the servo to be inside the environmental chamber without the rest of the components.

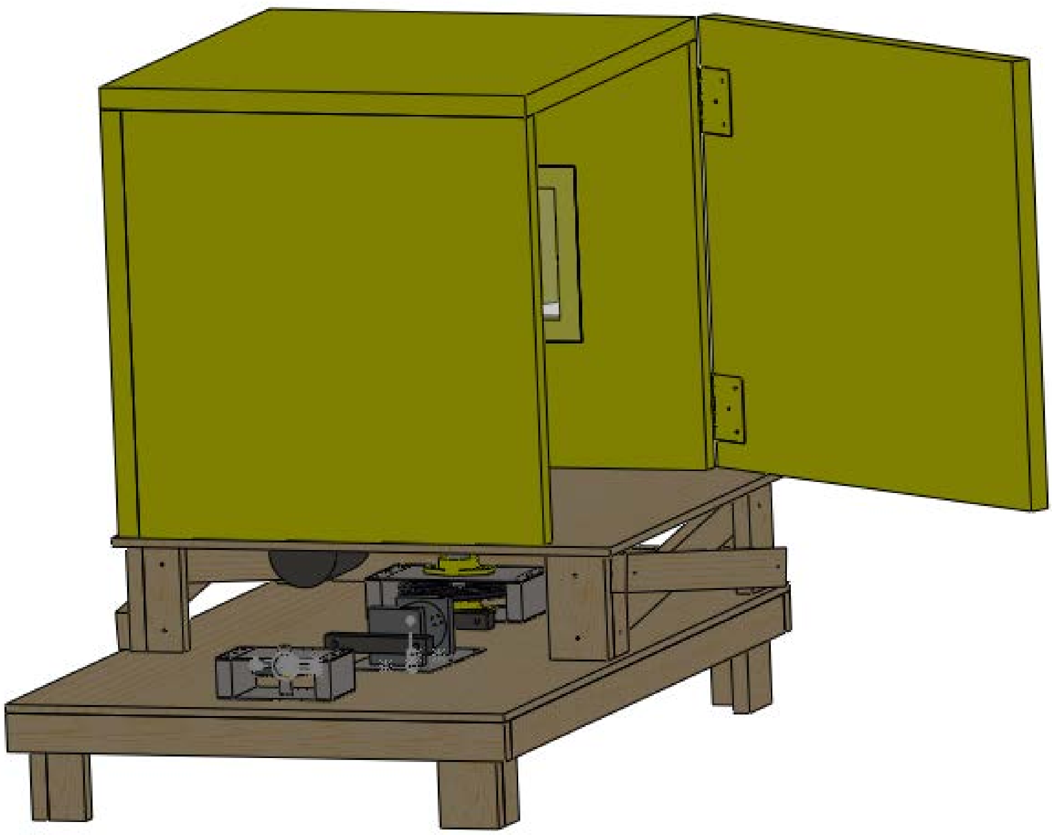


Figure 4.1. CAD of Final Design with Environmental Housing

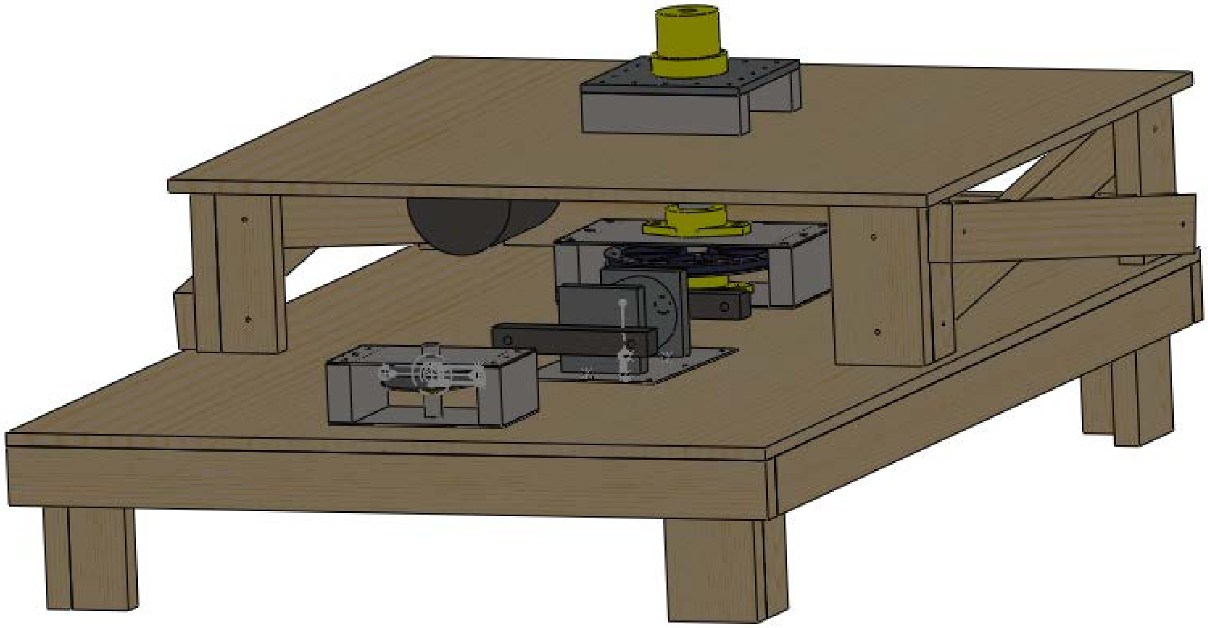


Figure 4.2. CAD of Final Design without Environmental Housing

Figure 4.3. Actual Photo of Assembled Test Stand

4.2. Detailed Design Description

4.2.1 Tables

4.2.1.1 Bottom Table

This table is made with douglas fir legs (2"x4" planks aligned with 2"x6" planks) and a cat fir plywood top (4'x6'x0.75"). There are also side panels on each side to strengthen the overall design. We used varying wood screw lengths to attach the legs to the table. We also used a wood stain and seal to cover the table to prevent water damage.

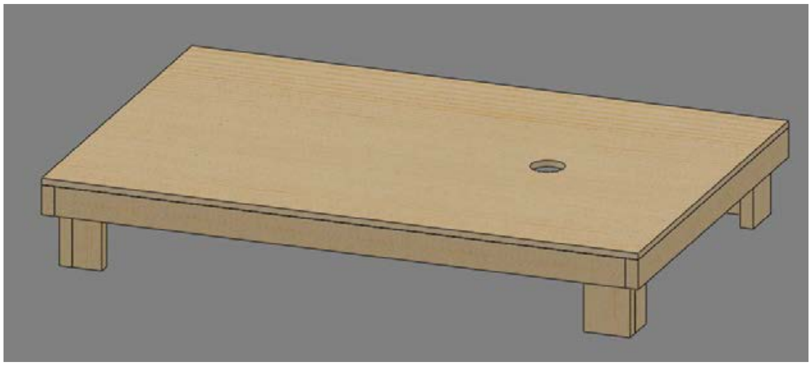


Figure 4.4. CAD of the Bottom Table

4.2.1.2 Top Table

This table is also made of douglas fir legs and cat fir top (4'x4'x0.75"). It also has cross beams on the sides and a side panel at the back to help with torsion between the two tables. The same stain and seal was used, as well as wood screws.

Figure 4.5. CAD of the Top Table

4.2.2 Servo Assembly

The servo sits on its mount on the top table, where it will be closed in by the environmental chamber. The servo is a Harmonic Drive, LLC SHA series servo.

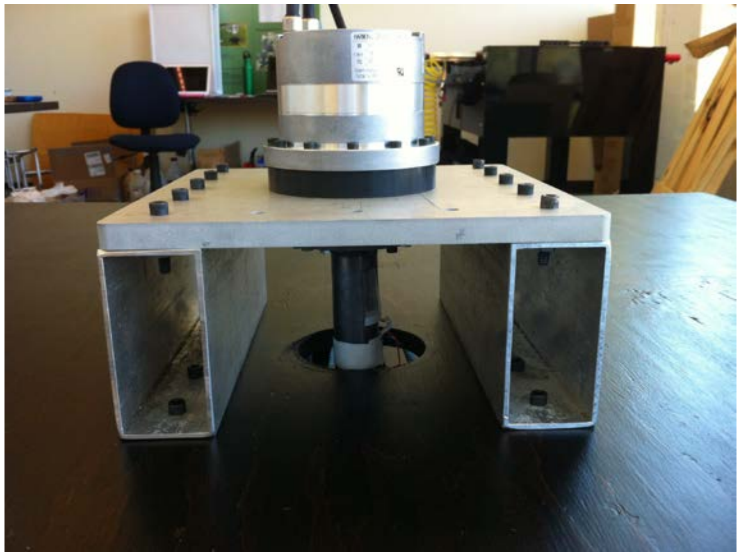


Figure 4.6. Servo Assembly Attached to Top Table

4.2.2.1 Shaft

The shaft is 1.25” in diameter with a ¼” keyway for the coupler and ⅛” keyway for the pulley. It is 6” long.

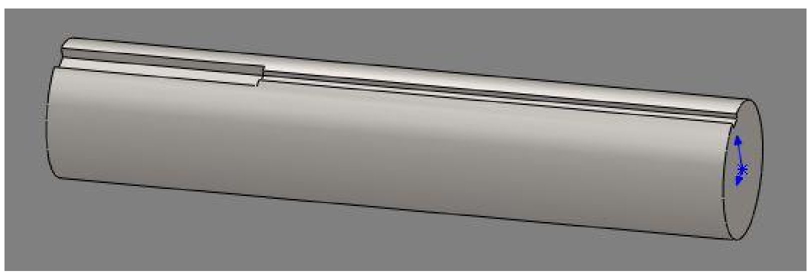


Figure 4.7. Shaft Attached to Servo Flange with Two Different Keyways

4.2.2.2 Flange

The flange is a 1” thick piece of standard steel with a 1.25” hole in the middle with a ⅛” keyway. There is a bolt pattern around the edge that matches the bolt pattern on the top of the servo, where it is attached. This piece was water-jet cut. The bolts that are used to attach this to the servo are M4x40 screws (the servo is threaded). We validated this material and geometry from calculations in Appendix #.

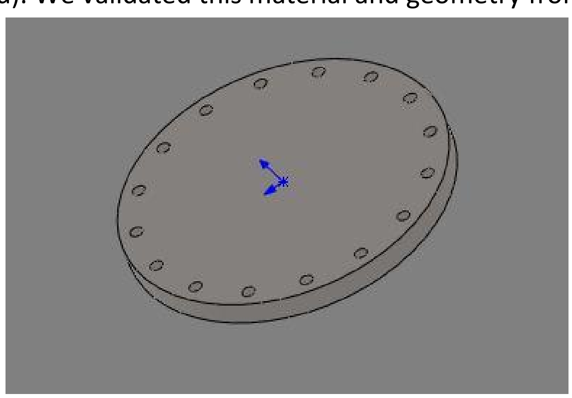


Figure 4.8. Servo Flange

4.2.2.3 Mount

The servo mount is an aluminum plate (8”x8”x0.5”) with bolt patterns for attachment to the table and for the servo attachment. The mount also has 2 legs made of hollow rectangular aluminum stock (4”x2”x8”). The bolts used to attach the servo to the mount are M4x40 and the bolts to attach the mount to the table are ¼”x1.25”.

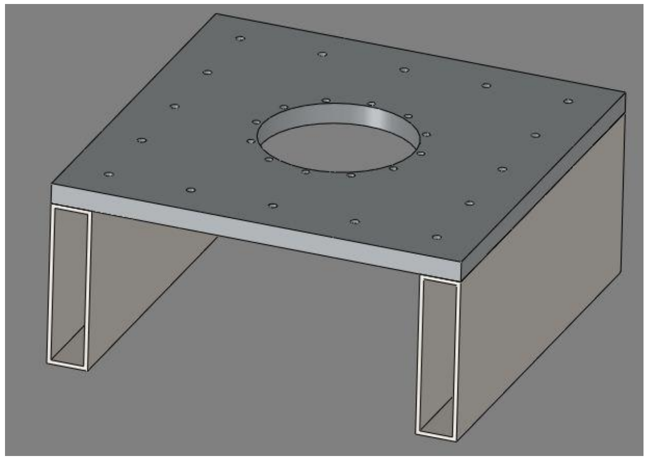


Figure 4.9. Servo Mount Including Plate and Legs

4.2.3 Pneumatic Assembly

The pneumatic is attached to a mount plate and has a standoff plus a rope support to attach the cable to. The valve and the regulator sit on the table next to the assembly.

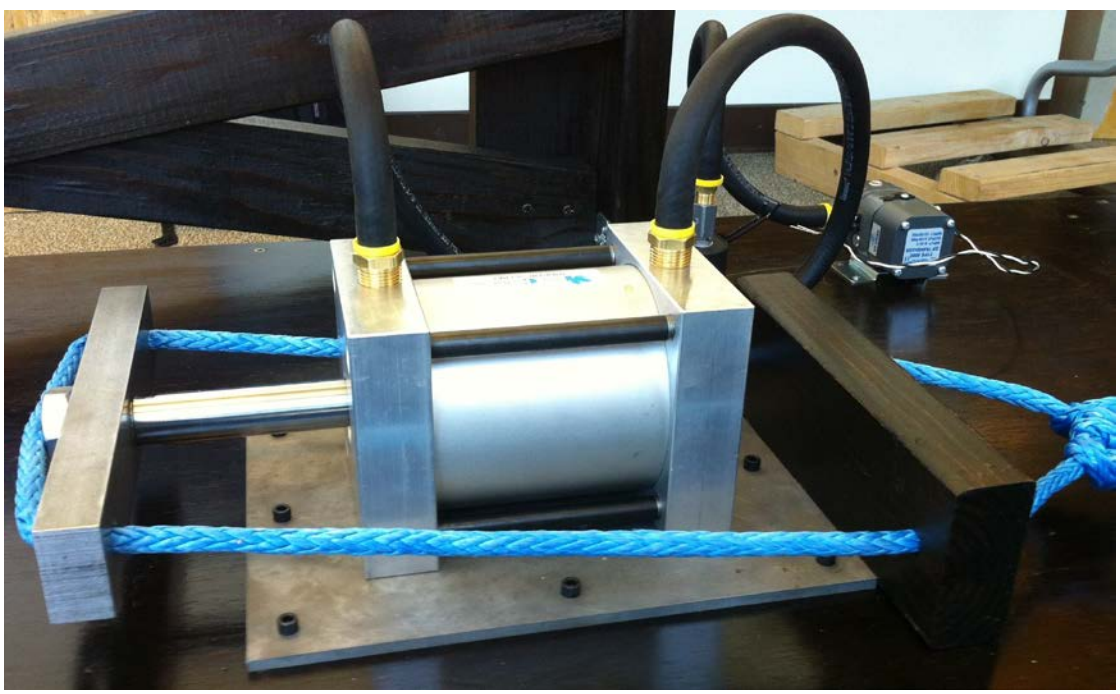


Figure 4.10. Pneumatic Assembly Including Hoses and Cable Attachment

4.2.3.1 Pneumatic
The pneumatic is an aluminum tie rod air cylinder with a stroke of 3”. It is shown above in Figure 4.10.

4.2.3.2 Mount
The pneumatic mount is a ¼” low carbon steel plate with bolt holes for the pneumatic and for attachment to the table.

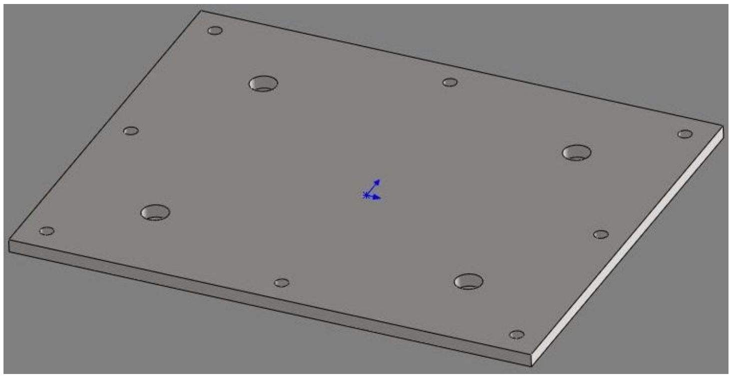


Figure 4.11. CAD of the Pneumatic Mount Showing Bolt Holes

4.2.3.3 Standoff and Cable Attachment
The standoff is attached to the end of the pneumatic shaft (1.5”x0.75”x10”) by a threaded hole and hex nut. It also has a hole on either end where the cable runs through. There is a matching piece at the back of the pneumatic (without the center hole) where the cable also runs through. The cable is zip tied at its proper location and tied using trucker’s hitch knots as shown in the photo below.

4.2.3.4 Electronic Proportional Regulator
The electronic proportional regulator is driven by the control board. The regulator controls how much by air pressure is passed to the pneumatic cylinder and thus how much load is applied to the servo.

4.2.3.5 Electronic Pneumatic Valve
The electronic pneumatic valve is also driven by the control board. This valve controls the direction in which the pneumatic loads the servo.

4.2.4 Servo Pulley Assembly

This pulley assembly consists of the shaft which has (from top to bottom) the coupler, a bearing, the top plate of the mount, the pulley, the shaft collar, the second bearing, the bottom plate of the mount, the table and finally the encoder. Shown below is the assembled servo pulley.

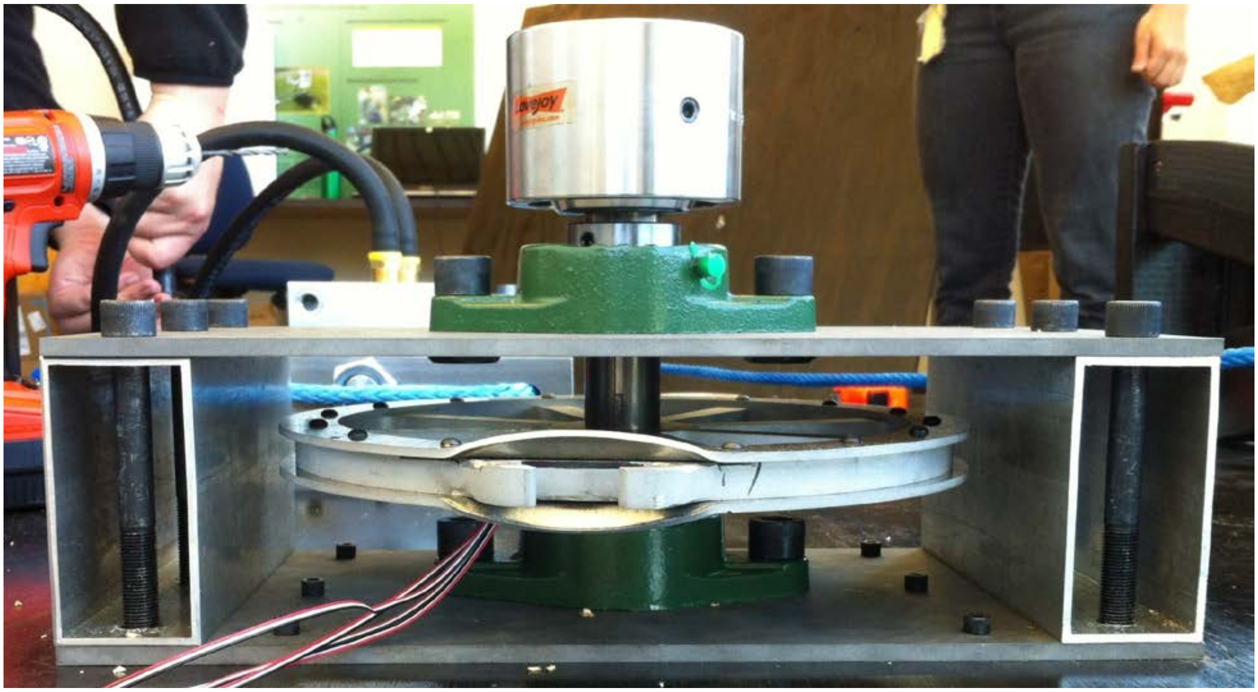


Figure 4.12. Assembly of the Pulley in its Support Structure with Half of the Coupler Attached. Not Seen is the Shaft Collar Sitting Underneath the Pulley

4.2.4.1 Pulley

The pulley for the servo is designed to hold ⅜” cable and a 1.25” shaft with a ⅛” keyway. The cable is attached here with a simple wrap around. The pulley is made of three separate parts: the middle section which is ⅜” thick and two washer sections that encase the inner part to prevent the cable from slipping out. The three pieces are bolted together.

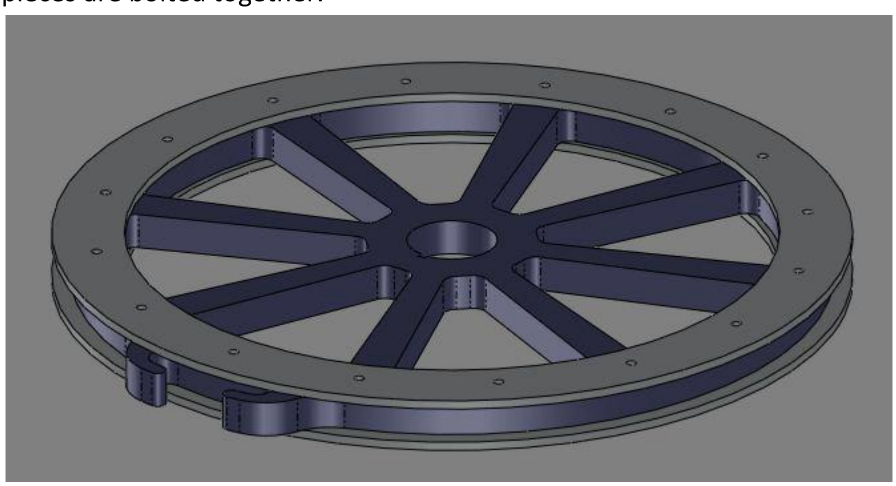


Figure 4.13. CAD of Pulley Design

4.2.4.2 Bearings

The bearings are mounted ball bearings compatible with 1.25” diameter shaft. They are mounted to the top and bottom plates of the pulley mount using ⅝” bolts and hex nuts. Both bearings have set screws to tighten around the shaft.

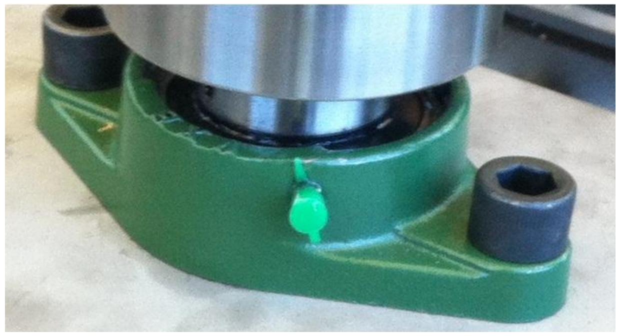


Figure 4.14. Image of One of the Bearings Mounted on a Pulley Plate

4.2.4.3 Coupler

The coupler is a LoveJoy continuous sleeve flexible gear coupler which is rated for our load. One side of the coupler will be attached to the top of the pulley shaft and the shaft from the servo will fit into the other side.

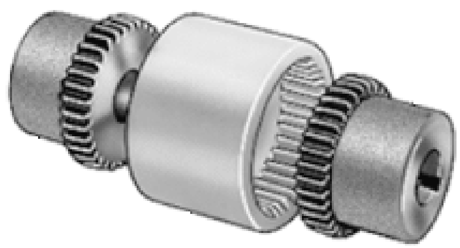


Figure 4.15. CAD of Coupler, Shown Expanded

4.2.4.4 Collar

The collar is set just below the pulley to keep it at the specified height. It is a clamping shaft collar made of black oxide steel tightened using an allen wrench.

Figure 4.16. Shaft Collar

4.2.4.5 Mount

The servo pulley mount is comprised of two steel plates with holes for the 1.25” shaft and two rectangular hollow aluminum legs. The mount is attached using ¼” steel bolts and hex nuts through the top plate and leg and through the bottom plate and table and leg (12 bolts total).

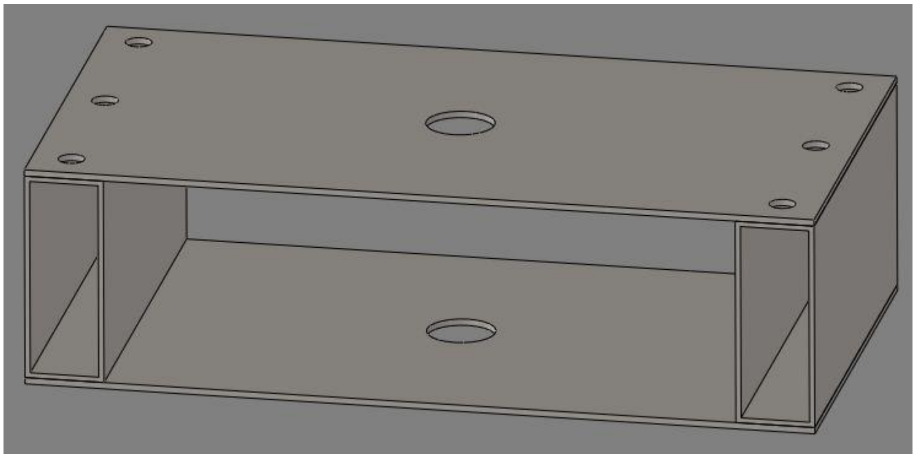


Figure 4.17. Pulley Mount with Two Plates and Two Legs

4.2.4.6 Shaft

The shaft is 1.25” in diameter with a ¼” keyway for the coupler and ⅛” keyway for the pulley. It is 10” long.

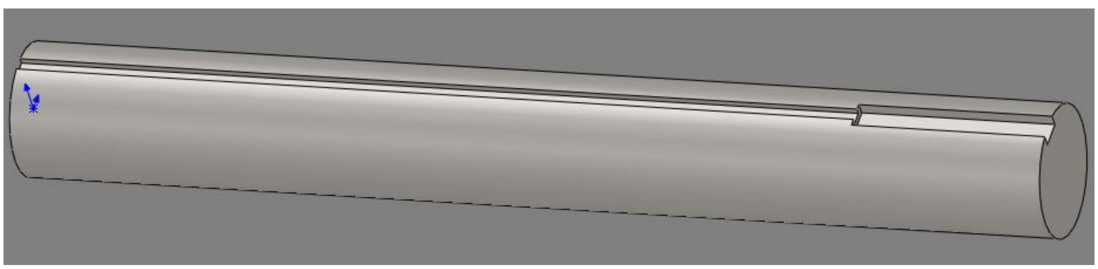


Figure 4.18. Shaft Attached To Pulley with Two Different Keyways

4.2.5 Second Pulley Assembly

The free spinning pulley is mounted in between two shaft collars on a 1” shaft welded to the bottom plate shown. The shaft also goes through the top plate with two aluminum legs.

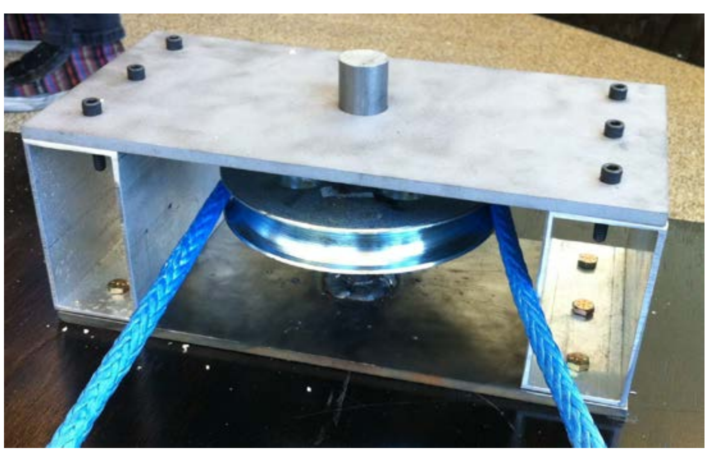


Figure 4.19. Second Pulley Assembly with Rope Attached

4.2.5.1 Pulley

The pulley is made of steel and fits a ⅜” cable. It has a very low friction bushing in the center which allows the pulley to rotate freely about the shaft.

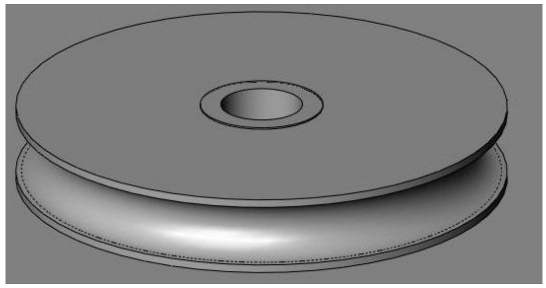


Figure 4.20. CAD of the Free Spinning Pulley

4.2.5.2 Shaft Collar

The collars in this assembly prevent the pulley from moving up or down. They are the same collars as on the other shaft except these fit a 1” diameter shaft. There is one located directly below and above the pulley.

Figure 4.21. Shaft Collar for Free Spinning Pulley

4.2.5.3 Shaft

The shaft is plain carbon steel 1” in diameter. It is 4.5” tall to allow for extra shaft above the top mount plate. It is welded to the bottom plate of the mount to create a rigid structure.

4.2.5.4 Mount

The mount consists of two ¼”thick steel plates with two hollow aluminum legs. The plates have holes for ¼” bolts through the legs.

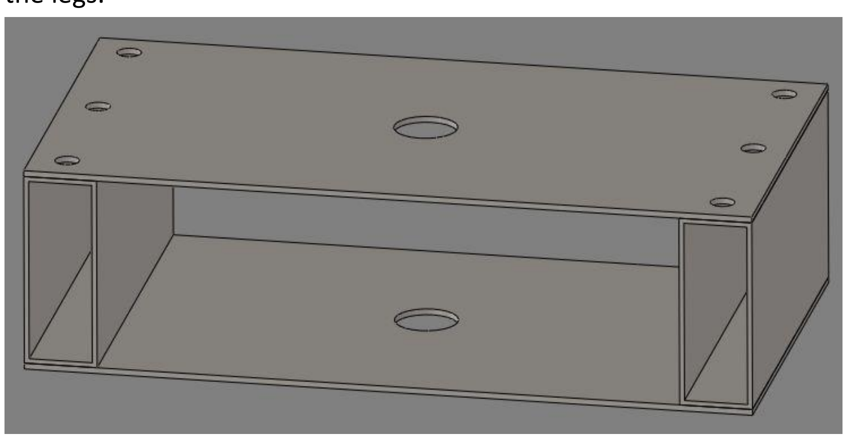


Figure 4.22. Free Spinning Pulley Mount with Plates and Legs

4.2.5.5 Cable

The cable is AmSteel Blue cable (3/8" thick) which is rated for our load plus the safety factor of 4. It is tied at the pneumatic and wrapped around both the pulleys as shown. It is tied with a trucker's hitch knot on both sides of the pneumatic.

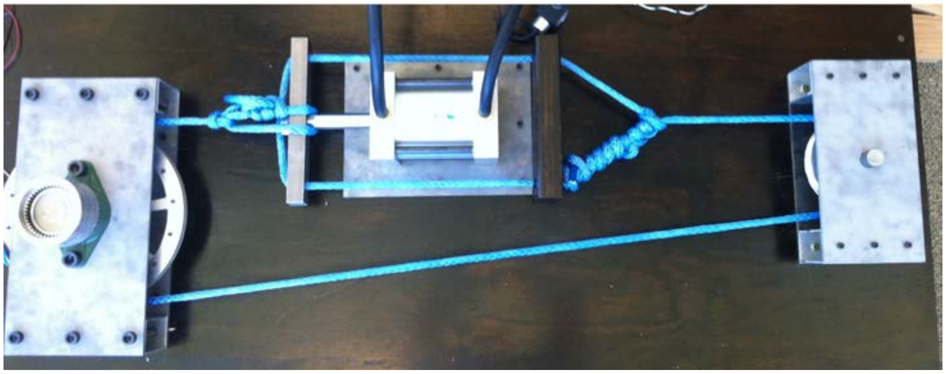


Figure 4.23. Cable Configuration

4.2.6 Environmental Chamber

The chamber is constructed of 2" thick rigid foam insulation. It is approximately 9 ft^3 and was constructed using aluminum tape and insulation caulk. One side has a door that fully opens with three hinges attached using wooden supports. The door also has latches to keep closed and a weather stripping lining to close off any gaps there are. There is a window cut from one side with a polycarbonate sheet to see through.

Figure 4.24. Assembled Environmental Chamber with Window

Since Makani took away the requirement to build a complete environmental chamber with heating, cooling and humidifying apparatuses this is the furthest we went with the chamber. This design allows for the inclusion of any devices Makani later adds.

4.2.7 Vibration Application

To apply the required frequency to the table, we have a vibration motor that is attached to the underside of the top table. It applies 60 Hz, which is in the acceptable range.

Figure 4.25. Vibration Motor on the Top Table

4.2.8 Data Acquisition System and Sensors

All sensors have been incorporated into a data acquisition system. This has allowed each component to be made into a control system which controls the load applied and relays data to a PC interface.

4.2.8.1 Data Acquisition System

The data acquisition system will consist of a PCB centered around an Atmega1284P microcontroller. This microcontroller will be programmed using a real-time operating system (RTOS) to control the data acquisition from the sensors below. The microcontroller will also control and operate the closed loop system for the pneumatic ram. Data from the sensors and control loop will be relayed back to a PC interface which will capture data

4.2.8.2 Temperature Sensors

The environmental testing chamber includes 4 temperature sensors: one on the servo and the other three spaced around the inside of the environmental chamber. The sensor on the servo will work in parallel with the thermocouple already inside the servo. This will allow for comparisons between how hot the servo thinks it is and how hot the servo actually is. In addition, the temperature sensors inside of the environmental chamber are used to measure the average temperature of the air in the chamber. The three sensors spread around the chamber are spaced to measure an accurate representation of the chamber temperature.

Digital temperature sensors were chosen for this project because they are inexpensive, accurate, and easy to implement and operate within the required temperature range.

Figure 4.26. Digital Temperature Sensor Breakout - TMP102
(https://www.sparkfun.com/products/9418)

4.2.8.3 Absolute Rotary Encoder

The testing system also requires position of the servo to be monitored externally of the servo. In order to do this an absolute rotary encoder has been mounted to the servo shaft. This allows for position data comparison between the servo and the encoder. Discrepancies between the encoder and the servo can be used by the sponsor to monitor when servo failure may occur.

An absolute rotary encoder was chosen because it allows for a simple implementation on the physical system and if power is lost the position of the servo is maintained.

Figure 4.27. Absolute Rotary Encoder
(http://www.rls.si/en/rm22-non-contact-5-v--15893)

The encoder assembly includes a small support underneath the bottom table to hold the shaft portion in place and provide a place to secure the free portion.

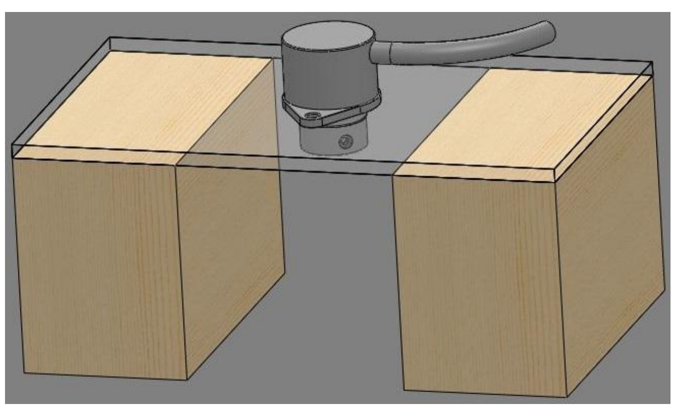


Figure 4.28. Support for the Encoder. The Bottom Portion of the Encoder is Attached to the Shaft

4.2.8.4 Humidity Sensor

In order to monitor the humidity in the environmental chamber a humidity sensor has been included in the system. The humidity sensor has been placed near the servo so that the humidity affecting the servo is the humidity being measured. Data from the humidity sensor is also relayed through the DAQ system to the PC interface.

We have chosen the following humidity sensor because of its relatively low cost, and capability to be incorporated in our system's DAQ.

Figure 4.28. Humidity Sensor HIH-4030 Breakout
(https://www.sparkfun.com/products/9569)

4.2.8.5 Accelerometer Sensor

In order to monitor how fast the vibration table is vibrating an accelerometer must be included. The accelerometer will need to communicate to the data acquisition system to have its data input into the final output data table.

The following three axis accelerometer has been chosen due to its ability to easily integrate into the system, its accuracy and low cost.

Figure 4.29. Triple Axis Accelerometer Breakout - MMA7361

(https://www.sparkfun.com/products/9652)

4.2.8.6 Strain Gage Sensor

To compensate for the fact that pneumatic motors do not have direct load control, strain gage sensors will be incorporated on the servo shaft and on the servo pulley to measure the torque being transferred to the servo. These sensors will be used in conjunction with an electronic proportional regulator and switch to create a closed loop system to control the actual torque being applied to the servo.

Strain gauges were chosen because they are the most direct way to measure the torque applied without introducing any additional resistance.

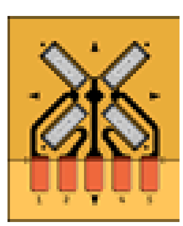


Figure 4.30. CEA-06-250US-120 Strain Gages
(http://www.vishaypg.com/micro-measurements/stress-analysis-strain-gages/all-shear-torque-rosettes/)

4.3. Cost Analysis

To analyze cost, we have separated the parts into assemblies as shown below. Any parts that do not appear here were not purchased, but were supplied by our sponsor. The total cost was $3495.93.

Tables			
Description	Unit Price	Quantity	Total
4'x8'x 19/32 Sanded Fir	$37.97	2	$75.94
2"x6"x10' Douglas Fir	$5.52	1	$5.52
2"x4"x8' Douglas Fir	$2.92	4	$11.68
4'x8'x0.75" AraucoPly wood	$40.97	1	$40.97
Sandpaper 3pk	$3.97	2	$7.94
Wood Screw 6x1/2	$3.82	1	$3.82
Wood Screw 10x3	$10.26	1	$10.26
Wood Screw 10x2 1/2	$8.91	1	$8.91
Wood Screw 10x2	$5.98	1	$5.98
Galv Steel Truss Clip	$0.68	6	$4.08
2x4 Douglas fir	$8.43	1	$8.43
Wood screws	$1.18	3	$3.54
Bent brackets	$0.67	10	$6.70
Screws	$5.58	1	$5.58
Flat brackets	$1.88	6	$11.28
Paint brush	$0.97	2	$1.94
zinc-plated alloy steel socket screw	$7.34	1	$7.34
grade 8 steel hex nut1/4" 20 thread	$6.74	1	$6.74
5/8"x1" steel socket screw 18-thread	$6.40	2	$12.80
5/8"x1-3/4" steel socket screw 18-thread	$9.77	2	$19.54
1/4"x1-1/4" steel socket screw 20-thread	$11.03	1	$11.03
#8x1-3/4" steel socket screw 32-thread	$7.75	1	$7.75
1/2"x5" steel socket screw 20-thread	$13.14	2	$26.28
1/2"x5" steel socket screw 20-thread	$7.34	2	$14.68
grade 8 steel hex nut1/2" 20 thread	$8.52	1	$8.52
black oxide hex nut 5/8" 18-thread	$1.77	4	$7.08
machine screw hex nut #8 32 thread	$1.49	1	$1.49
12.9 socket head cap screw M5 thread	$11.82	1	$11.82
12.9 socket head cap screw M4 thread	$9.13	1	$9.13
Hex nuts (3/8)	$0.12	4	$0.48
Washers (3/8)	$0.14	4	$0.56
Hex bolts (3/8)	$0.34	4	$1.36
Hex bolts (1/4)	$0.62	3	$1.86
Washers (1/2)	$1.18	1	$1.18
Hex bolts (4mm)	$0.35	8	$2.80
Washers (1/4)	$1.18	1	$1.18
		Total	$366.19

Chamber			
Description	**Unit Price**	**Quantity**	**Total**
DAP Insulation Caulk	$1.67	2	$3.34
Caulk Gun	$1.97	1	$1.97
Clear Polycarbonate sheet	$12.98	1	$12.98
Thermosheath Insulation	$30.98	3	$92.94
Minwax Polyacrylic	$18.32	1	$18.32
Hunter Green Satin Spray	$4.97	1	$4.97
Foil Tape	$3.25	2	$6.50
Wood Finish Espresso	$8.12	1	$8.12
Brushes	$1.15	4	$4.60
Hinges 2pk	$2.77	2	$5.54
Weather stripping	$7.59	3	$22.77
Poplar Board	$3.27	2	$6.54
Spray paint	$4.97	2	$9.94
Gate hook	$1.18	2	$2.36
Handle	$2.97	1	$2.97
Foil tape	$3.35	5	$16.75
Loctite Glue	$4.98	1	$4.98
		Total	$225.59

Vibration			
Description	**Unit Price**	**Quantity**	**Total**
Vibration motor	$218.00	1	$218.00
4 pack of anti vibration pads	$26.95	1	$26.95
		Total	$244.95

Pneumatic			
Description	**Unit Price**	**Quantity**	**Total**
Aluminum Tie Rod Air Cylinder 4.5" bore	$245.41	1	$245.41
directional control 3-port solenoid valve	$122.39	1	$122.39
precision electronic air regulator	$340.90	1	$340.90
Low Carbon steel rectangular bar	$56.33	1	$56.33
Cable ties	$2.38	1	$2.38
		Total	$767.41

Servo/Pulley Assembly			
Description	**Unit Price**	**Quantity**	**Total**
Steel drive shaft 1.25"x12"	$37.23	1	$37.23
Seal kit for coupler	$24.17	1	$24.17
Coupler hub	$100.24	1	$100.24
Coupler sleeve	$91.82	1	$91.82
One-Piece clamping shaft collar	$9.56	1	$9.56
1 1/4: bearing UCFL207-20 + 2	$9.95	2	$19.90
spring steel key stock 1/8"x1/8"	$2.07	1	$2.07
spring steel key stock 1/4"x1/4"	$3.70	1	$3.70
Power supply	$245.14	2	$490.28
Servo battery	$6.00	1	$6.00
		Total	$784.97

Second Pulley Assembly

Description	Unit Price	Quantity	Total
steel pulley for wire rope	$36.46	1	$36.46
Low carbon Steel rod	$10.69	1	$10.69
		Total	$47.15

Sensors

Description	Unit Price	Quantity	Total
Digital temperature sensor	$5.95	6	$35.70
Humidity sensor	$16.95	3	$50.85
Triple axis accelerometer	$11.95	2	$23.90
Strain Gages	$33.30	5	$166.50
		Total	$276.95

Miscellaneous

Description	Unit Price	Quantity	Total
Gas reimbursement for travel	$222.00	1	$222.00
Power cords	$9.97	2	$19.94
3/8 amsteel blue 20ft	$1.95	20	$39.00
Steel Tight Rectangular Bar 1/8" thick	$49.21	1	$49.21
low carbon steel rod 4"x1/2"	$9.53	1	$9.53
low carbon steel rectangular bar 3/16"	$11.99	1	$11.99
Low carbon steel bar 1.5" square	$16.45	1	$16.45
Allen wrench set	$10.86	1	$10.86
Power strip	$14.97	1	$14.97
		Total	$393.95

DAQ			
Description	**Unit Price**	**Quantity**	**Total**
FT232RL Debugger	$14.95	2	$29.90
Pocket AVR Programmer	$14.95	2	$29.90
SWITCH	$0.59	4	$2.36
24V REG	$3.57	3	$10.71
10V REG	$1.87	3	$5.61
25K RES	$0.98	4	$3.92
50K RES	$0.98	4	$3.92
3.3V REG	$2.79	3	$8.37
TRANSISTOR	$3.86	5	$19.30
LINEAR AMP	$3.63	1	$3.63
INST AMP G5-1000	$1.72	3	$5.16
ENCODER CONNECTOR	$2.58	2	$5.16
RS422	$4.26	3	$12.78
MICROCONTROLLER	$8.03	3	$24.09
PROGRAM HEADER	$0.99	2	$1.98
1X2 HEADER	$0.50	5	$2.50
1X3 HEADER	$0.78	2	$1.56
1X4 STRAIN GAUGE HEADER	$0.98	2	$1.96
1X6 HEADER	$1.41	6	$8.46
1X9 HEADER	$1.51	2	$3.02
DEBUG HEADER	$1.19	2	$2.38
CRYSTAL	$0.35	3	$1.05
10 MICROF CAP	$0.21	10	$2.08
0.1 MICROF CAP	$0.03	25	$0.63
22 PF CAP	$0.02	15	$0.36
DEBUG HEADER SCREW	$0.93	2	$1.86
RESET BUTTON	$0.35	3	$1.05
BLUE LED	$0.19	15	$2.91
GRN LED	$0.07	25	$1.70
RED LED	$0.07	25	$1.70
YLW LED	$0.07	25	$1.80
1K RES	$0.02	50	$0.86
250 RES	$1.08	5	$5.40
500 RES	$0.72	5	$3.60
FLYBACK DIODE	$0.14	15	$2.06
120 RES	$0.01	50	$0.46
STANDOFF	$0.18	6	$1.08
TWEEZERS	$5.75	1	$5.75
Blue wire	$0.27	5	$1.35
Red wire	$0.27	5	$1.35
Black wire	$0.27	5	$1.35
Green wire	$0.27	5	$1.35
Control Board	$58.70	1	$58.70
Red wire	$0.27	10	$2.70
Black wire	$0.27	10	$2.70
		Total	$290.51

4.4. Schematics/Wiring Diagrams

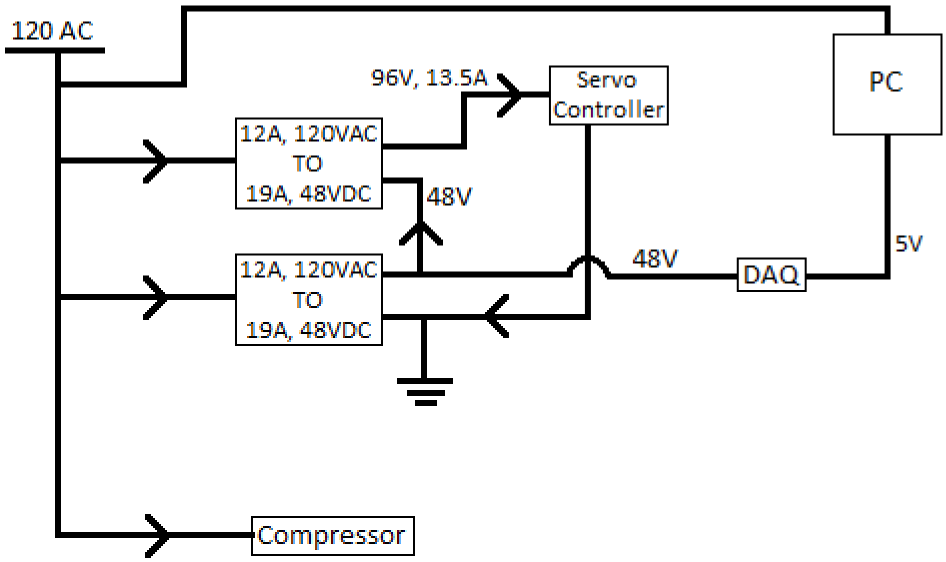


Figure 4.31. Preliminary Wiring Diagram

In order to operate the system power must be supplied to the servo motor and the DAQ board. The servo operates between 48 and 96 volts DC while the DAQ board operates at 5 volts. The 48 volts going into the DAQ is stepped down to 24V and 10V to operate the pneumatic switch and regulator respectively.

The data acquisition board schematic and drawing are included in appendix B. These depict the layout of the board and indicate which components are connected to which pins.

4.5. Safety Considerations

A failure modes and effects analysis was performed to determine the consequences of possible errors in the system. We broke down the possible failures of each part and all possible consequences of such a failure. This can be utilized to reduce weakness in the system. None of the failure effects endanger someone working with the equipment. Also, very few of the failure types are severe enough to damage the servo, or other equipment. The most severe consequence is compromised results, which would nullify the entire purpose of the test stand. There would be negligible consequences if any of the fluids spilled, as the only fluid used in the system is water. All of the failure effects should be easy to detect by a simple examination of the system periodically.

Table 4.1. Failure Modes and Effects Analysis

Part	Failure Type	Failure Effect
Pneumatic	Reverses Direction	Loss of control Overload/damage servo
Rope	Stretches/breaks Slips from Pulley	Loss of control Inaccurate displacement/torque readings Loss of control Inaccurate displacement/torque readings
Pulleys	Wear/Belt slips	Loss of control Inaccurate displacement/torque readings
Support Structure	Weld Fracture Bending	Moment is applied to servo Inaccurate displacement/torque readings
Vibration Motor	Overall malfunction	Compromised results
Insulated Chamber	Leak	Compromised results
Base Table	Fracture	Inaccurate displacement/torque readings

4.6. Maintenance and Repair Considerations

We have constructed the system from mostly raw materials that are easy to replace. The base table top and vibration table top are machined plywood. If the servo is changed out or the geometry of the system radically changes the table tops can easily be changed out. However, the servo support system is custom designed to fit the geometry of the selected servo. A change in the servo would require an adjusted support system. The insulated housing encompasses a much greater area than the servo and support system will take up, so the chamber will function for a wide range of servos. Also the chamber is simply bolted to the base table and slotted to allow the belts to slide through, so it is easily removed from transportation and maintenance. Additionally, one of the chamber walls is hinged and latched shut, so as to allow immediate access to the servo. The pneumatic is mounted externally so maintenance can be performed easily at any time.

Chapter 5: Product Realization

5.1. Specification Verification checklist or DVPR

Table 5.1 Product Realization

Specification	Desired	Actual
Safety Factor	4	4
Continuous torque	200 Nm (800 Nm with S.F.)	2400 Nm
Max torque	600 Nm (2400 Nm with S.F.)	3600 Nm
Loading frequency	See bode plot above	Met
Control	Servo position	Met
Servo output	Position, load, temperature	Met
External input	Torque, frequency	Met
External output	Temperature, humidity, position, frequency, strain	Met
Environmental chamber	Must encase servo for heating, cooling and humidifying	Fully enclosed with seals, does not enclose any other components
Durability	Must break servo before breaking stand	Designed to take a beating
Safety	Minimized pinch points, moving parts enclosed, Damped vibration	Only pneumatic and free spinning pulley exposed, vibration dampers
Chamber size	9 ft^3	Met
Test stand size	Must fit inside a standard trailer	Met
Environmental Chamber Temperature range	Should support -20°C to 50°C	Insulation and sensors specified to meet range
Humidity	Should support 5% to 98% relative humidity	Insulation and sensors specified to meet range

5.2. Manufacturing Process

The manufacturing process was dictated by availability of parts and machines in Mustang 60 and the Hangar. The first subassemblies fabricated were the first tier of the wood table and the environmental chamber. The focus during the first tier wood table was structural integrity and balance. The focus during construction of the environmental chamber was ease of disassembly and proper insulation. The window cover is a press fit in the wall of the chamber and can be removed while the machine is running. The door is held in place by a simple latch and should remain closed during operation of the machine.

Figure 5.1. Environmental Chamber Subassembly

The next subassembly created was the second tier of the wood table. The focus during construction of this subassembly was to provide ample space for the operator to view and access the torque application system, as well as provide proper support for the servo, environmental chamber, and vibration motor. After testing the vibration motor mounted on the second tier, we decided to provide additional support with two additional legs. This minimizes bending in the top of the second tier.

Figure 5.2. Wood Table Subassembly

The next subassembly fabricated was the torque application system. Each of the pulleys was pressed onto its respective shafts at a specified height. This ensures a truly horizontal plane of action. The servo shaft was attached to the coupling. There servo shaft was welded onto the servo flange. Next the pulley/shaft assemblies were mounted into their metal support structures. The shaft on the servo pulley is held in place by the bearings set screws and a shaft collar. Therefore, the height of this shaft may be adjusted at a later time. The shaft supporting the free spinning pulley is welded to the base plate of its support, and is not adjustable. The metal supports are attached by bolts and nuts, and can easily be disassembled at a later time. The rope is a single strand and has extra length stored at the rope support to allow later adjustments to geometry or tensioning. It is initially tied around the pneumatic in a trucker's hitch. This orientation allowed us to use a single ended linear pneumatic, while avoiding eccentricities in the plane of applied torque. The rope winds around the free spinning pulley without any rigid attachment. This pulley provides structure to the torque application, but does not need to support any of the torsional loads. The rope then ties around the servo pulley hooks. Finally the rope wraps back around to the pneumatic extension and is tied in another truckers hitch. We chose this method of mounting the rope, because it will fully translate the applied torque, but is easily removed and adjusted.

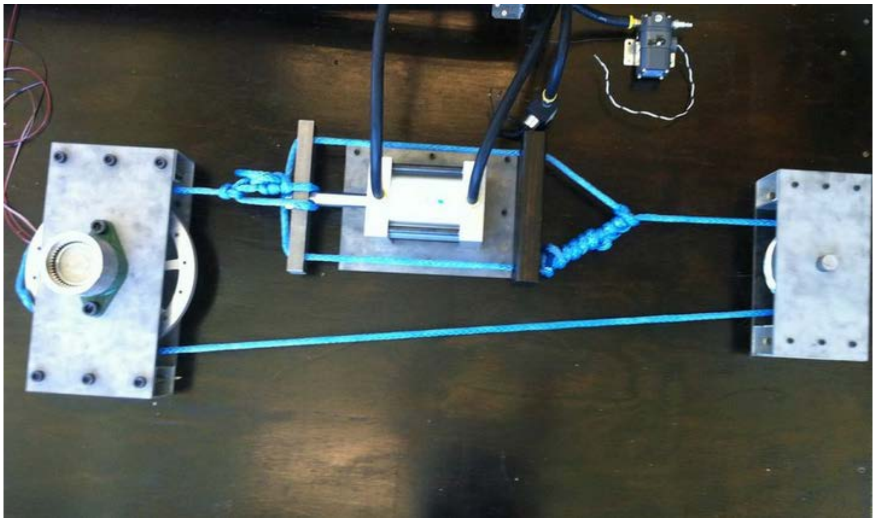


Figure 5.3. Torque System Subassembly

The final subassembly was the servo support system. The servo and servo support are attached with bolts and nuts, and can easily be disassembled. This was done intentionally to allow the operator to use this test machine with many different servo geometries. For a different servo, we suggest using a different servo flange, shaft, and top plate.

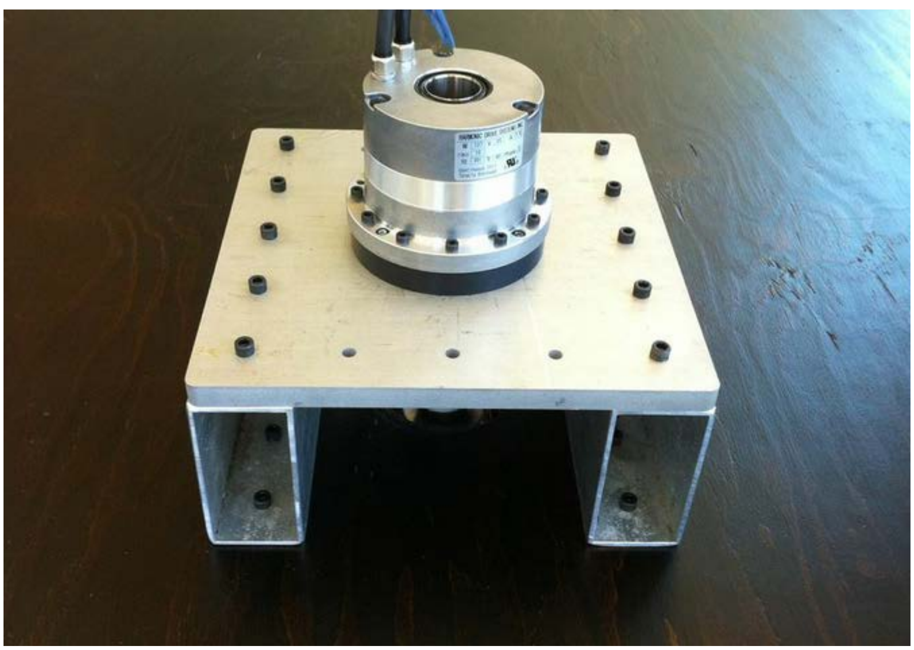


Figure 5.4. Servo subassembly

The final assembly was created by mounting the chamber on the table with hinges and screws and mounting all of the sensory equipment in the chamber. The DAQ is attached to the first tier table. We suggest containing the DAQ in an electrical box.

Figure 5.5. Final Assembly

Chapter 6: Design Verification/Testing

6.1. Test Descriptions

We tested the readout to each sensor independently of the entire system. Once the closed loop system was created we exposed each of the sensors to a known value and measured the sensor output, as a mode of calibration. This required known temperature, humidity, vibration, and strain sources.

We also tested the output of the vibration system with the associated weight on top of the table, which consists of the servo, servo support, and chamber. We decided to reinforce the second tier after preliminary testing. The main concern was bending in the top of the second tier. The frequency and amplitude output of our vibration system was within the range specified by Makani.

Finally we verified that the torque output from the pneumatic was as specified. This was determined from the outputs of the strain gages after they have been calibrated. As a working form of calibration, the output of the servo and the independent sensors can be compared during normal operation of the test stand.

Chapter 7: Conclusions and Recommendations

7.1. Design Overview

The final design is comprised of three main parts: the torque application system, the vibration system, and the DAQ and sensory equipment. A two tiered wood table supports the torque application system on the first tier and the thermal housing and vibration motor on the second tier. A microcontroller interfaces with the internal sensors and the computer to allow the operator to monitor and provide input to the test machine. The wood base table is constructed from fir planks and plywood. The thermal housing is 2” R-Max insulation composed into a 9 ft^3 cube. The pneumatic and regulator are being ordered from McMaster-Carr. The torque is applied with a high torque rope around a free spinning pulley and the pulley attached to the servo. A linear pneumatic provides the force. The servo is supported with an aluminum and steel table. The vibration table is constructed from a vibration motor attached directly to the plywood of the second tier. There is an insulating layer of weather stripping around the hole between the second tier and the insulated chamber. The internal sensors are bundled in the chamber and exit through this hole before connecting to the DAQ. The microcontroller integrates the external inputs and outputs into a closed loop function.

7.2. Recommendations

This test machine is custom designed to interface with the servo selected for the M600. The test stand can be retroactively fitted with another servo; however, the following changes must be made:

- Replace servo flange, shaft, and top plate of servo support table
- Encase DAQ in electrical box

We realized that Makani may want to make revisions to the test machine before beginning their formal testing of the specified servo. In order to allow changes to be made at a later date our team decided to leave the coupling spring unassembled. This will allow Makani to easily remove or adjust any element connected to the servo. The coupling functions without the spring and therefore the machine can be run as it is provided. However, once the coupling spring is installed, the coupling and shaft will be permanently attached. We have come up with additional suggestions to adapt the design for later uses:

- Replace DAQ with another custom designed or prefabricated DAQ to allow varied inputs and outputs
- Replace hollow aluminum legs with solid steel legs for higher torque applications
- Replace wood rope support with steel rope support (provided)
- Insert potentiometer to vary applied frequency and amplitude
- Integrate heating and cooling apparatus to perform HALT testing
- Increase thickness of table top

Appendix

Appendix A: QFD, Parameters and Relative Costs

Appendix B: Drawing Packet

Includes detailed part drawings, wiring diagrams and electrical schematics

Appendix C: Cost Analysis, Equipment and Material Quotes/Pricing

Appendix D: Vendor supplied Component Specifications and Data Sheets

Appendix E: Detailed Supporting Analysis

Appendix F: Project Gantt Chart

Appendix G: Servo Specifications (Omitted without NDA)

Appendix H. User's Manual

Your Project Name Here

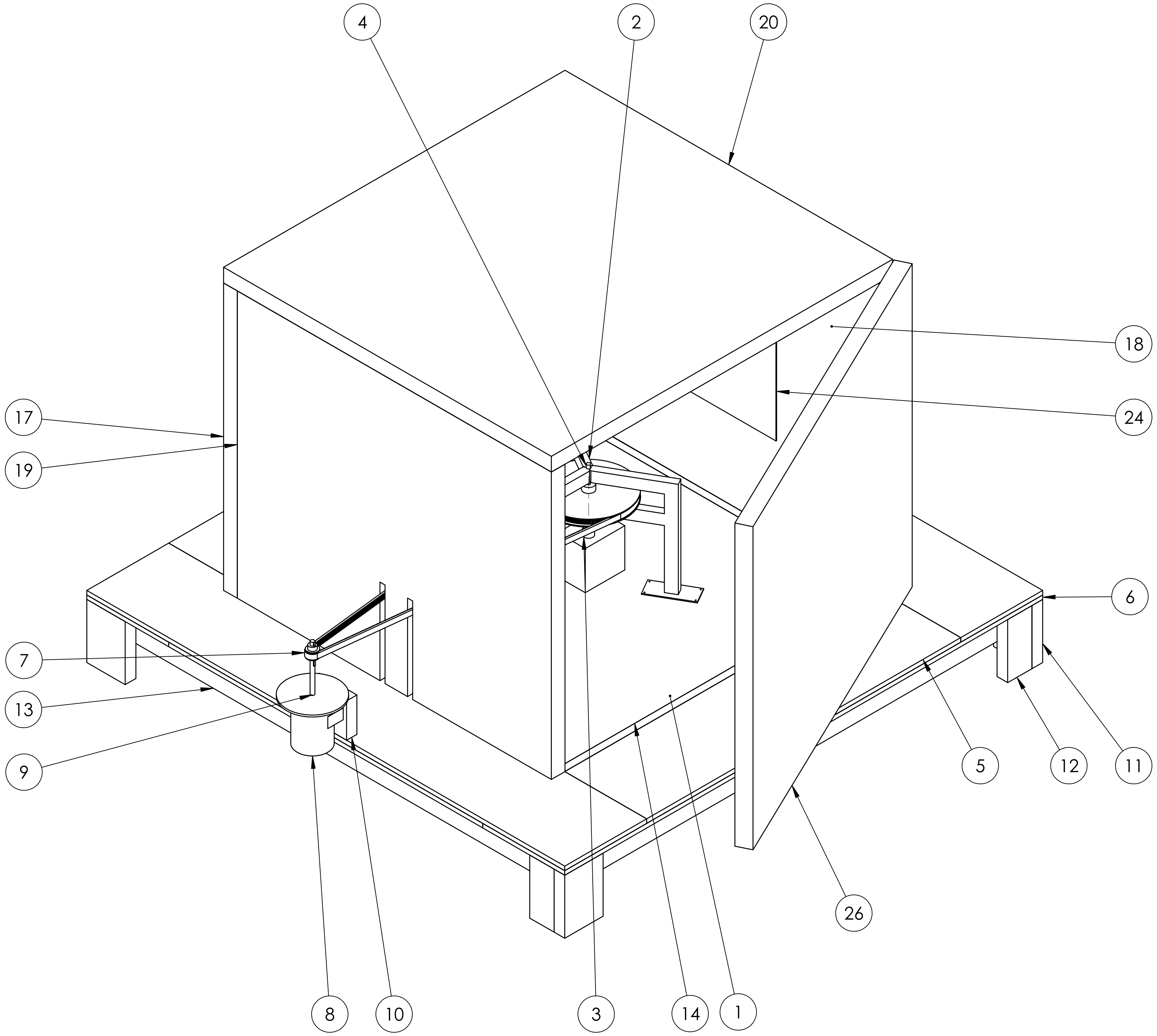
Makani Power, Servo Test Stand

Engineering Requirements (HOWS)

Customer Requirements (Step #2)	Weighting (Total 100)	Number of Pinch Points	Number of moving parts	Catastrophic Failure (go/nogo)	Size	Weight	Cost	Number of inputs	Number of readouts	Range of mounting size	Number of Torque Axes	Range of Torque	Range of input Voltage	Commands Servo (Go/No-go)	Range of Temperature	Range of Degrees	Range of wattage	Range of resistance	Range of torque	Range of Humidity	Range of Salinity	Number of Tests in life cycle	% of accurate tests	Go/No-Go	Benchmarks: Wing 7 Test stand		
Human Factors																											
Safe	11	●	●	o																							
Transportable	5				●	●																					
Ease of use	8							●	●																		
Function																											
Range of Servos	*									●																	
Full range of angular positions	14										●					●											
Emulate flight loads	*											o							●								
Emulate flight positions (voltage)	*										o		●			●											
Commands servo	*										Δ			●													
DAQ																											
measures temperature	*														●												
measures position	*										Δ					●			●								
measures power draw	11												●				●										
measures motor resistance	8																	●									
measures load	*											●															
Life																											
durable	14		o	o								Δ			Δ							●					
reliable	*																						●				
Controllables																											
measures humidity	5						Δ													●							
measures salinity	5						Δ														●						
Identify corner cases																											
Voltage Peaks	8												o											●			
Voltage zeros	11												o											●			
Units	100	#	#		m^3	N	$	#	#	cm^3	#	N	V		C	o	W	ohm	Nm	%	%	all	%				
Targets		x<2	7<x<2	No	1	150		array			3	0-1000		go	(-20)-80					5-95%	0-60	testing	95				
Benchmark #1																											
Benchmark #2																											

● = 9	Srong Correlation
○ = 3	Medium Correlation
Δ = 1	Small Correlation
Blank	No Correlation

Things to Test	How to Test (*Relate to # of cycles)	Cost	Time to Implement (scaled from 1 to 5; 5 being the most time to complete)	Feasibility/Practicality (1 to 5; 1 being most feasible)
Failure Temperature	Thermocouples *	> $4	1.5	1
	Temperature Guns	$20 - $50	1	3
	Imaging and Radiation	~ $2000	1	5
Motor Resistance	Ohmeter/Ammeter *	> $4	1.5	3
	Programmable Ohmeter (functionality with MATLAB)	~ $4	2	1
Load Applied (aileron	Weights	~ $30	2	3
	Springs	~ $30	2	3
	Hydraulics*	~ $100	3.5	2
	Friction Loading	~ $30	2.5	4
	Servo Motors*	~ $100	3.5	2.5
	Manual Loading	$0	2	5
Position of servo	Encoder	~ $3 - 50	1.5	2
	Hallifect	~ $5	2	1.5
	Manual Reading	~ $2	1	3
	Optical Reader	~ $100	2.5	3
Load felt	Load Cell	~ $150	2.5	2
	Strain Gauge	~ $7.50	3	2.5
	Weight Scale	$10 - 50	1.5	4
Reaction to Salinity (HALT oven)	Saline Humidifier (with cooling hoses)	$40 - 100	1.5	3
	Salinometer	$10 - 50	2	2
	Corrosion Meter (Corrometer)	$50 - 200	2	2
	Manual Inspection for corrosion (and affects on performance)	$0	1	1.5
Reaction to Humidity (HALT oven)	Humidifier/Dehumdifier	$30 - 50	1.5	3
	Humidimeter	$500 - 1000	2	2
	Corrosion Meter (Corrometer)	$50 - 200	2	2
	Manual Inspection for corrosion (and affects on performance)	$0	1	1.5
Control System	Computer Inputs	$20	3.5	1
	Manual Adjustments	$0	1	3



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Vibe Top		1
2	Servo Support		3
3	Servo		1
4	Servo Shaft		1
5	Table Top 1		4
6	Table Top 2		4
7	Loading Gears		1
8	Pnuematic		1
9	pnuematic shaft		1
10	Pnuematic support		1
11	2" x 6"		4
12	2" x 4"		4
13	Side panel		4
14	Bumper		4
15	vibe motor		1
16	tire		1
17	Back		1
18	Window Side		1
19	Side		1
20	Top		1
21	Hinge2		3
22	Hinge1		3
23	Hinge Bolt		3
24	Window		1
25	Window Cover		1
26	Door		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

REVISION

	NAME	SIGNATURE	DATE
DRAWN	ALEX SERVENTI		2/10/2013
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Servo Test Servo Test Stand

MATERIAL:

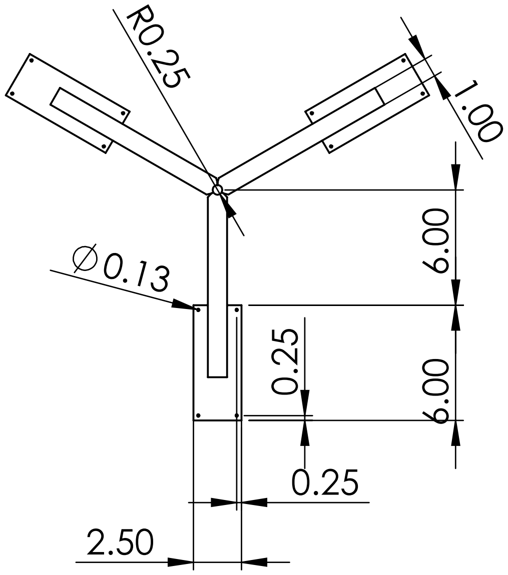
DWG NO.

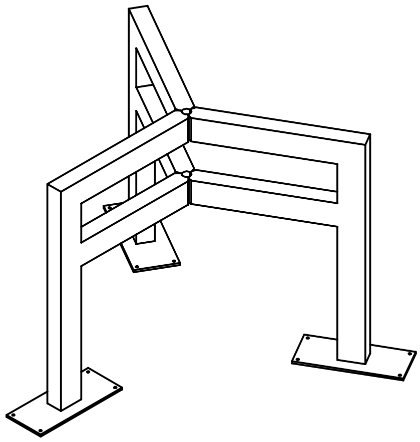
A2

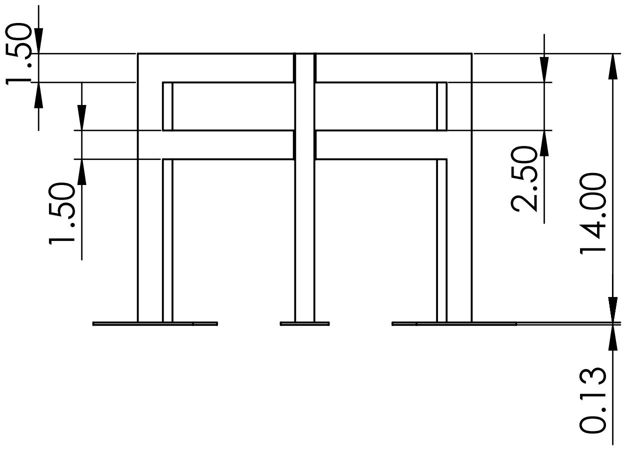
WEIGHT:

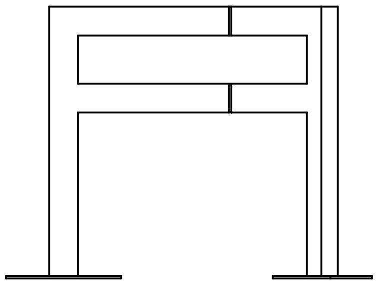
SCALE:1:10

SHEET 1 OF 1









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CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Cold Drawn Steel		DWG NO.	A4
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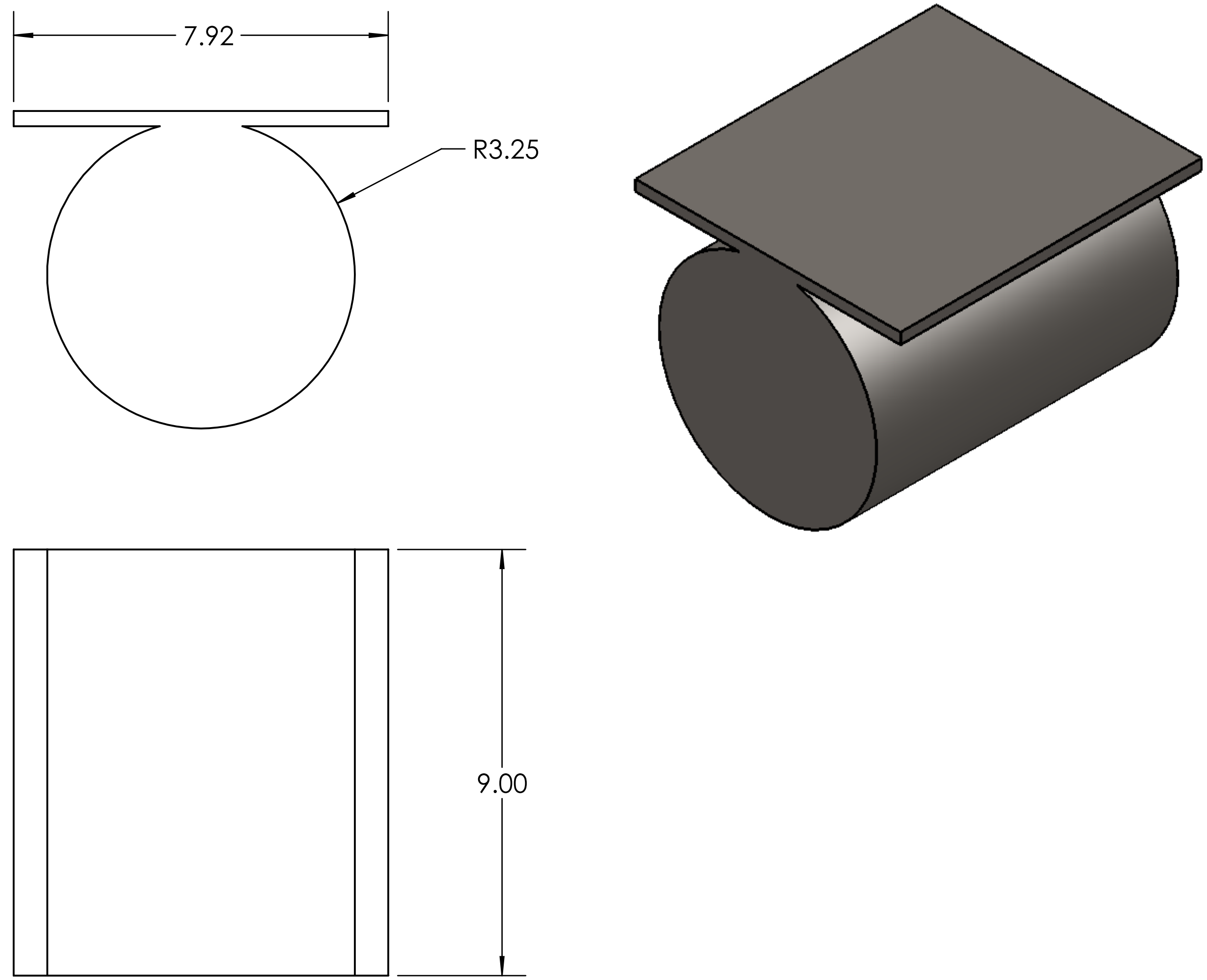

PROPRIETARY AND CONFIDENTIAL

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APPLICATION	

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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	vibe motor	

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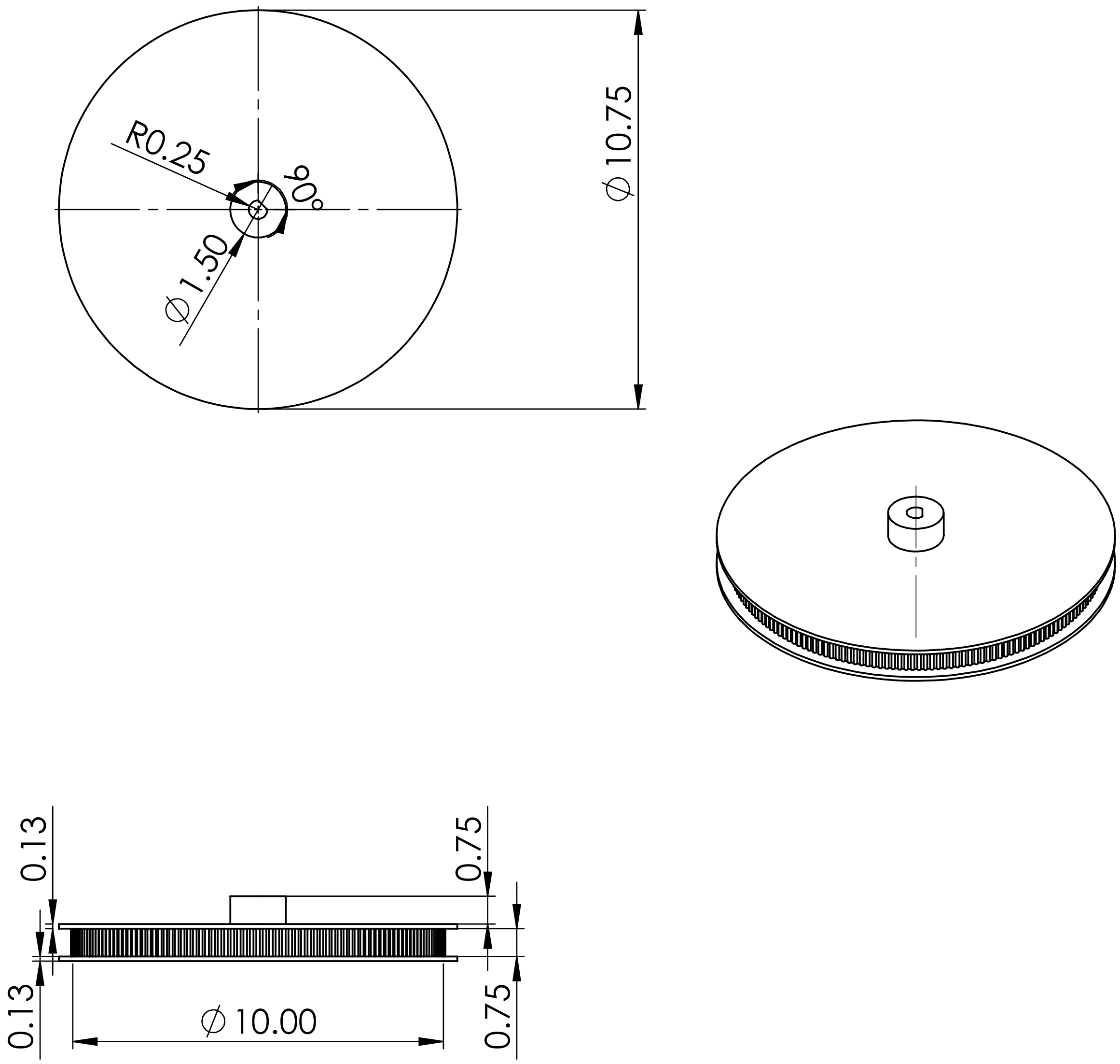

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CHK'D							
APPV'D							
MFG							
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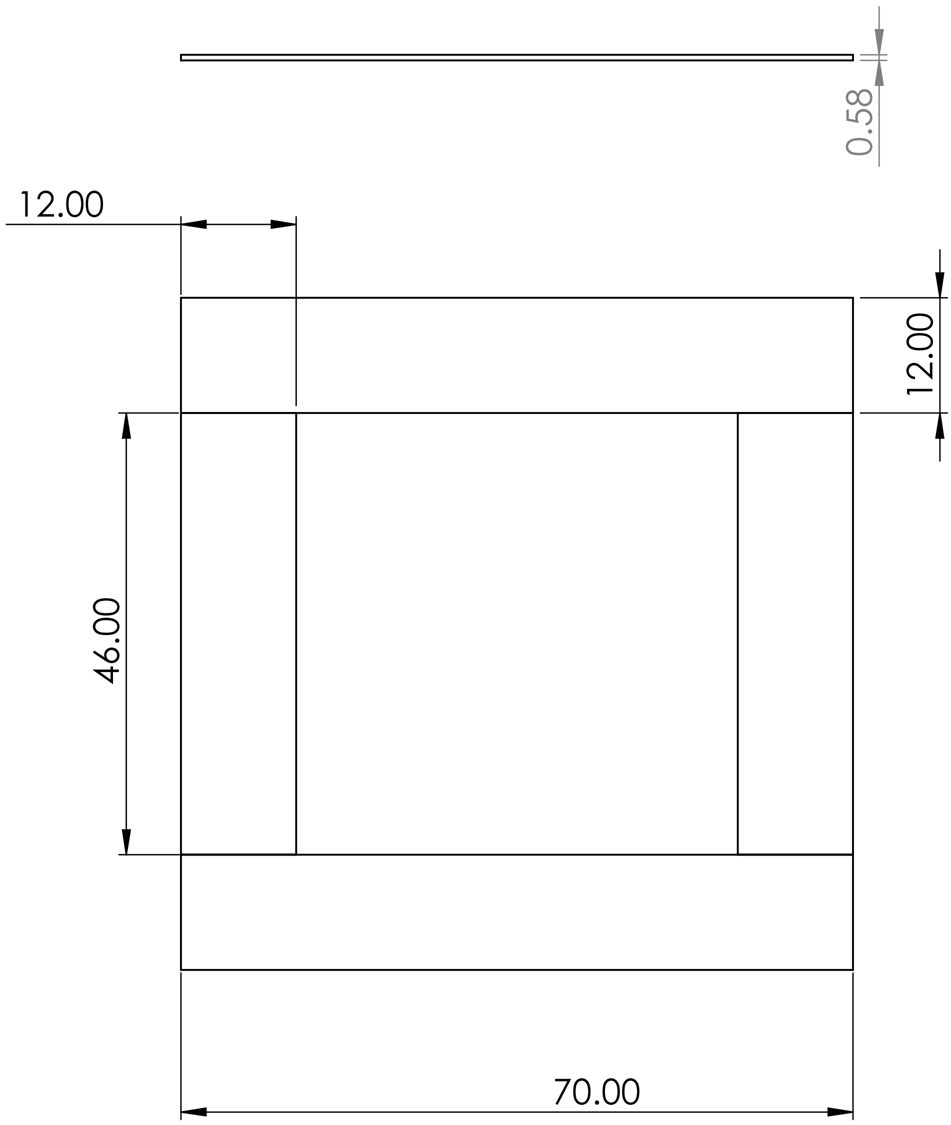

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CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: PLYWOOD			DWG NO. / A4
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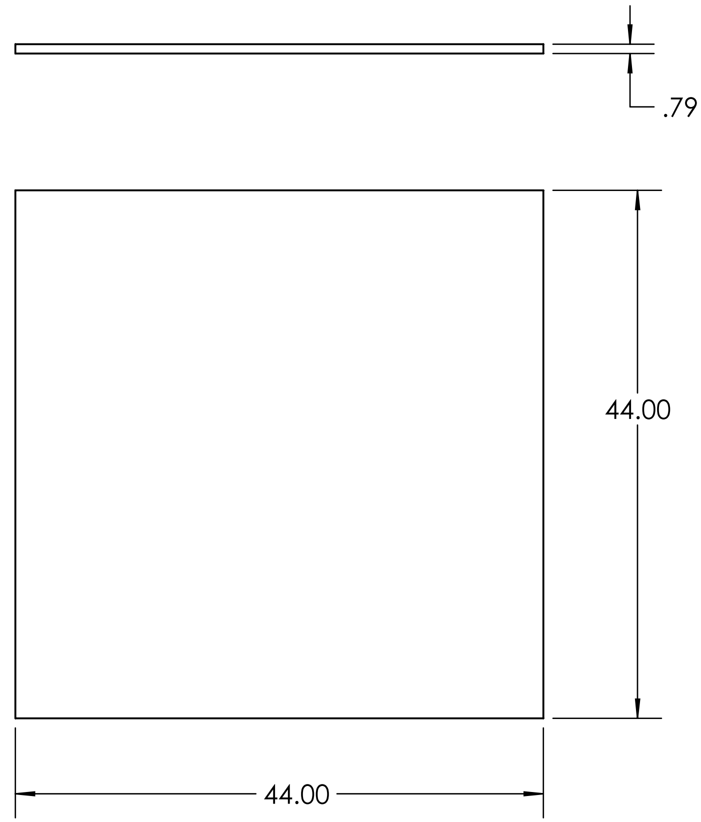

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ANGULAR: MACH ± BEND ±
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THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

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DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A | DWG. NO. Vibe Top | REV

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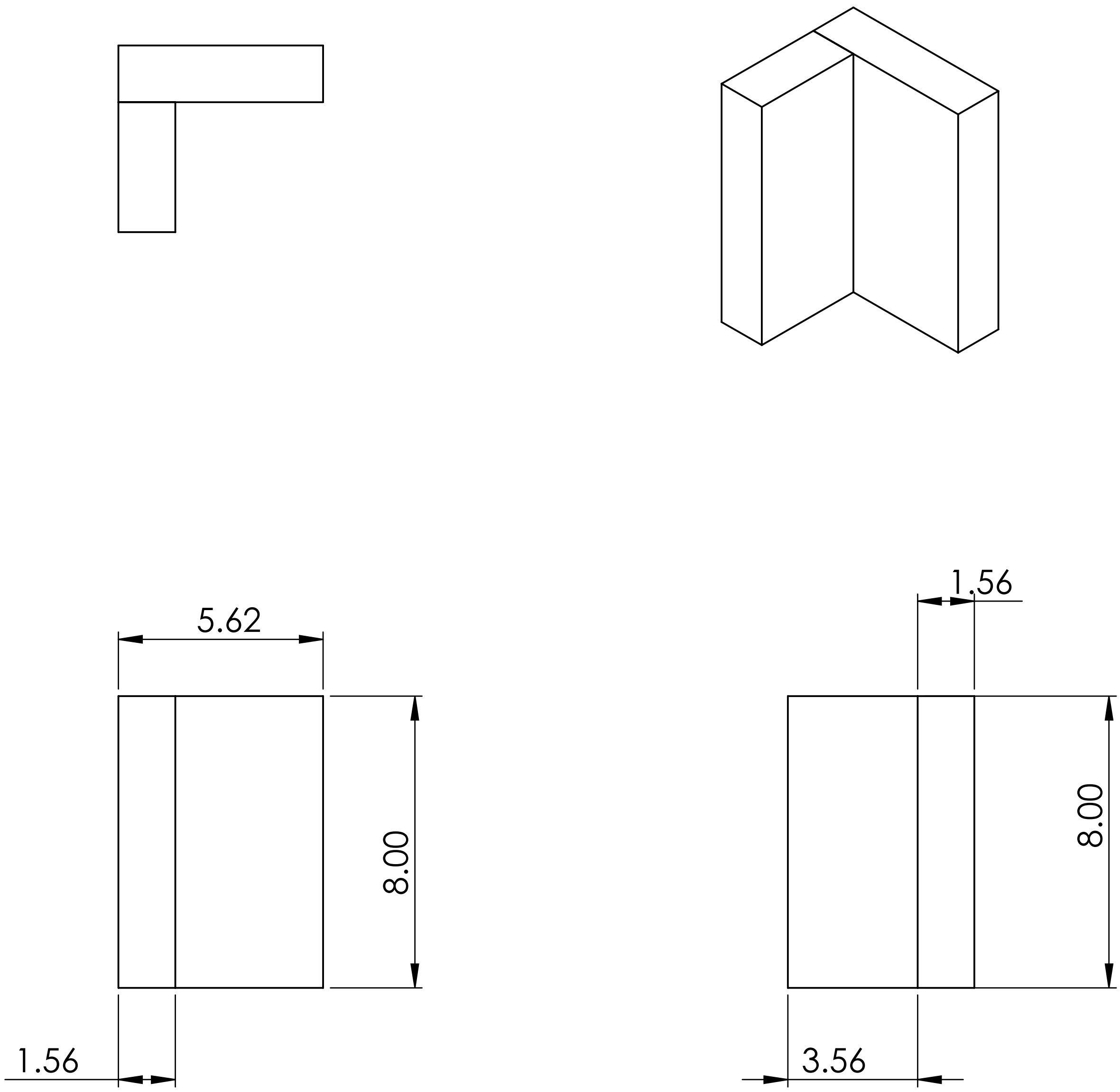

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	NAME	SIGNATURE	DATE		
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CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: PINE WOOD	
				WEIGHT:	

TITLE:

Table Legs

DWG NO.	A4
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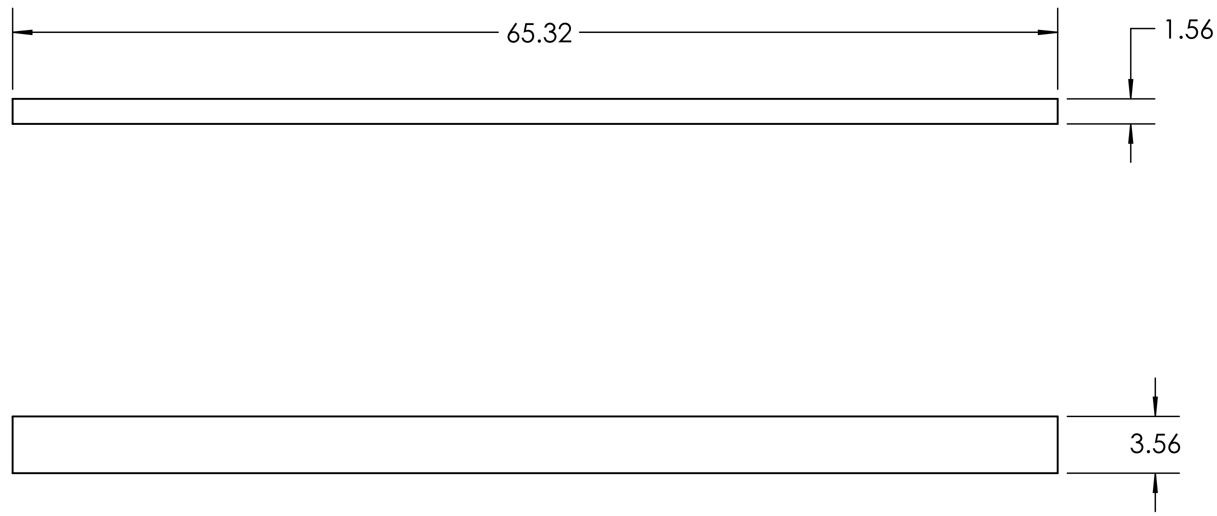

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

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DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

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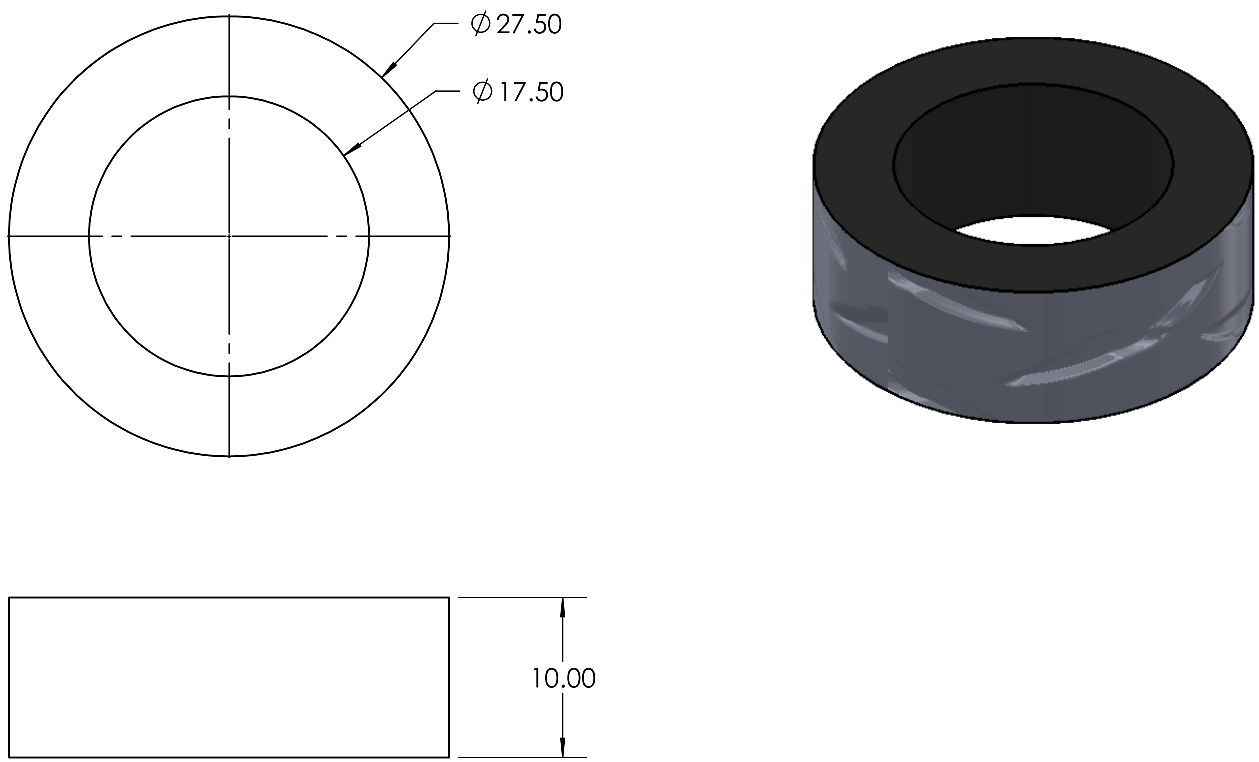

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			CHECKED			
			ENG APPR.			
			MFG APPR.			
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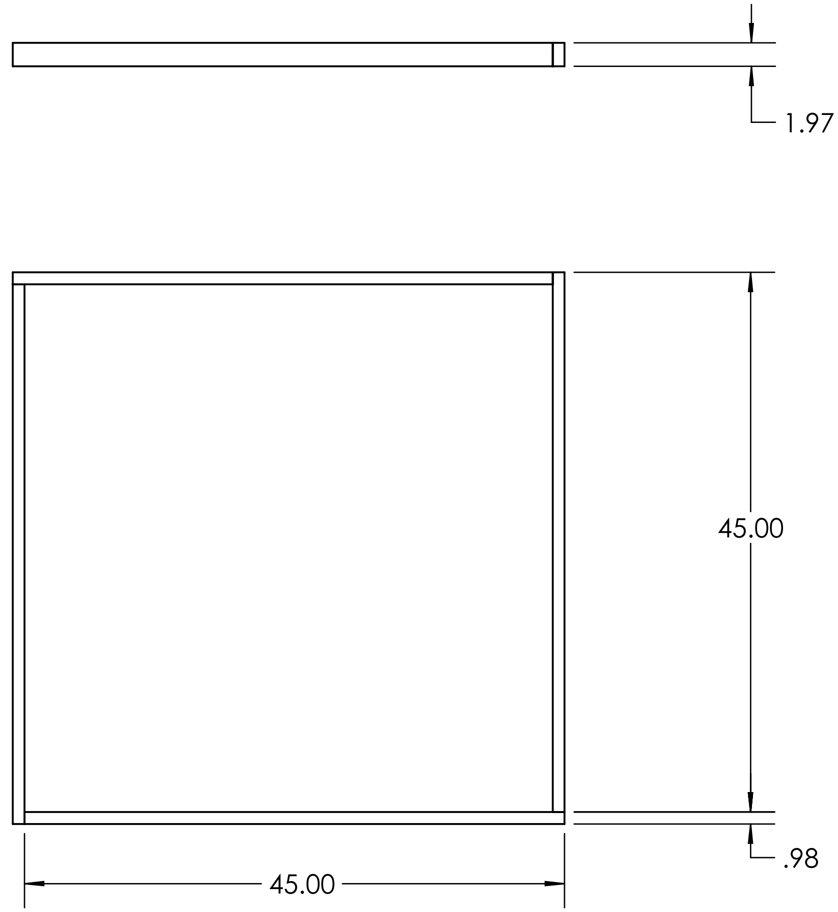
PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
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NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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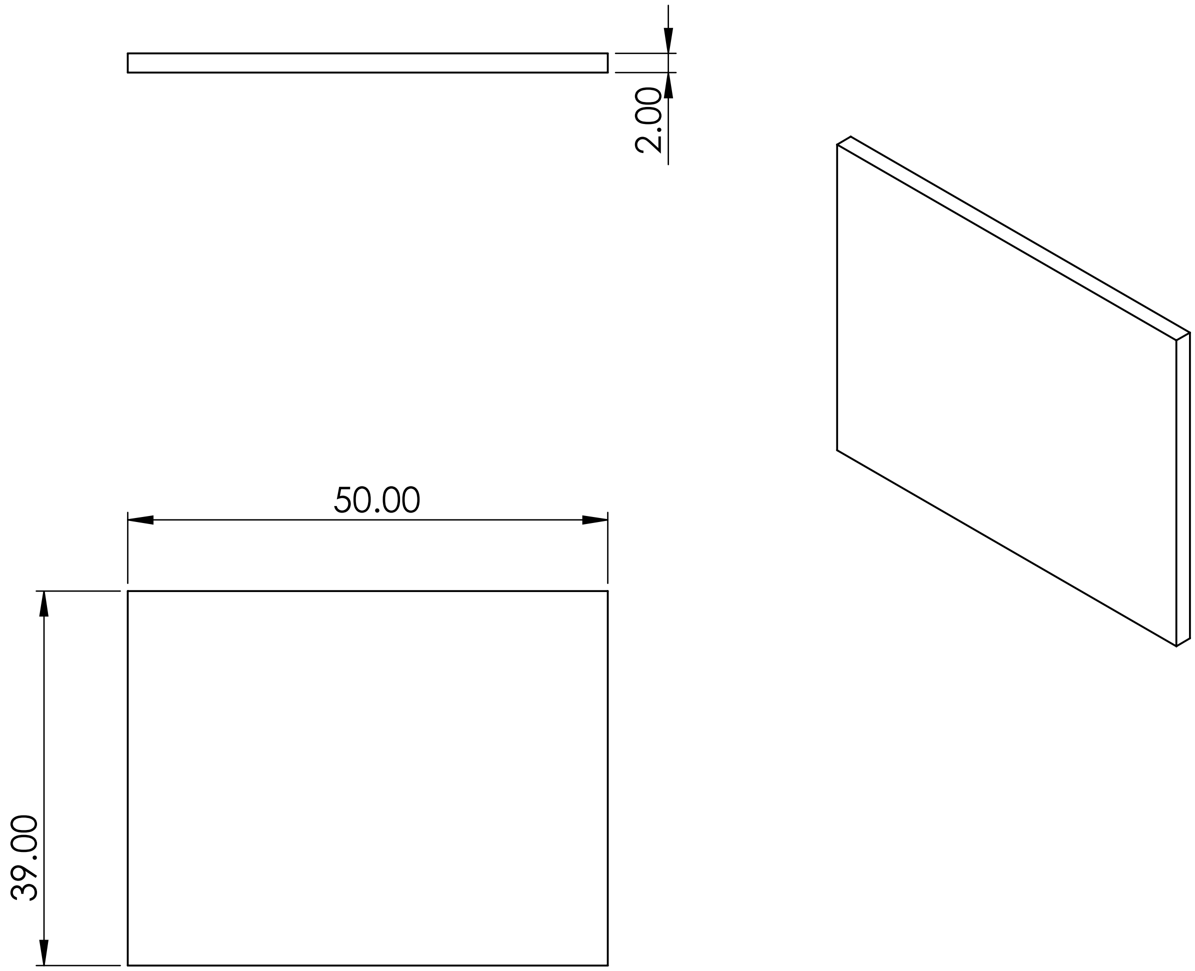

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CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: RMAX THERMOSHEET		DWG NO.	A4
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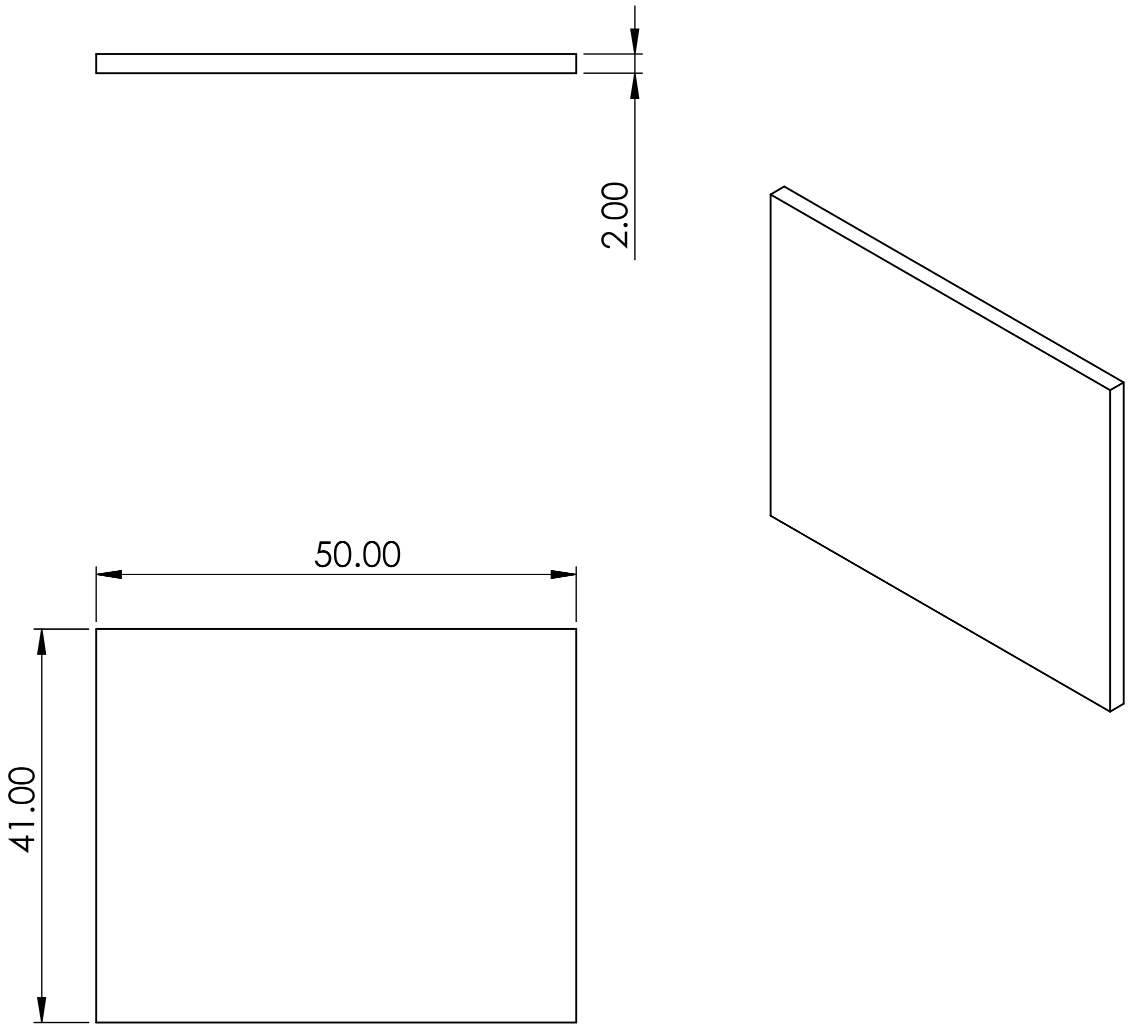

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DRAWN						Door
CHK'D						
APPV'D						
MFG						
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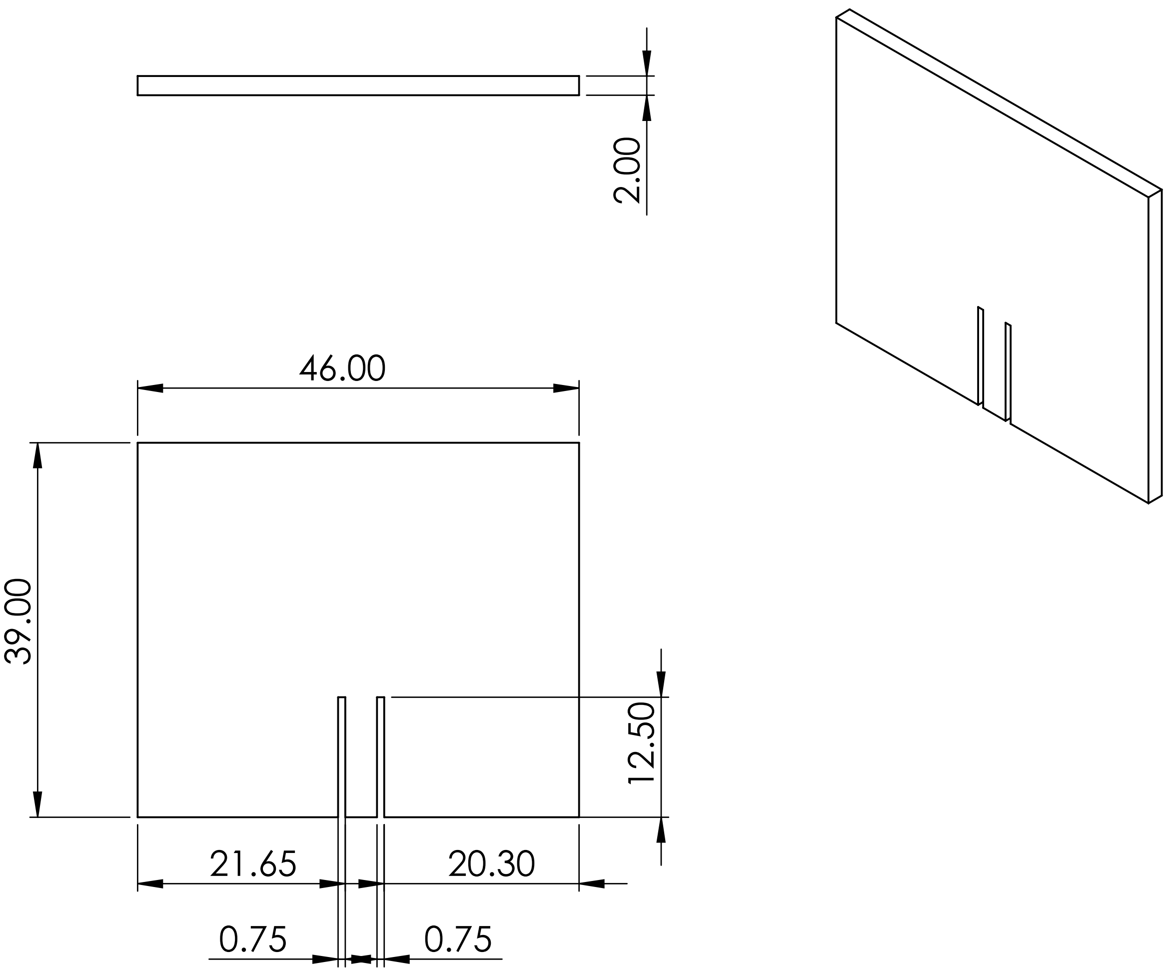

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CHK'D						
APPV'D						
MFG						
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				WEIGHT:		

TITLE:

Side

DWG NO.

A4

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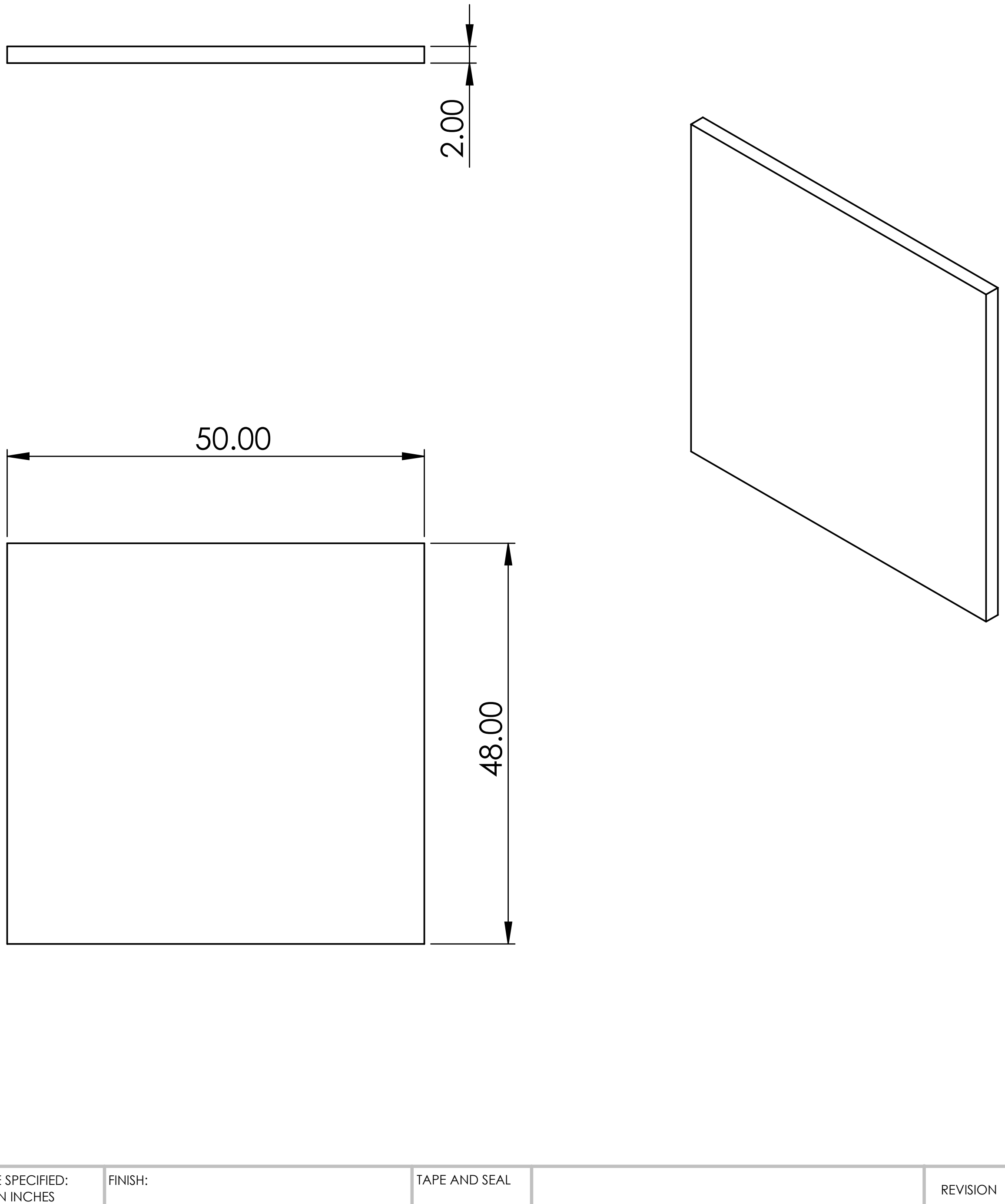

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CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: RMAX THERMOSHEET	DWG NO.	A4	
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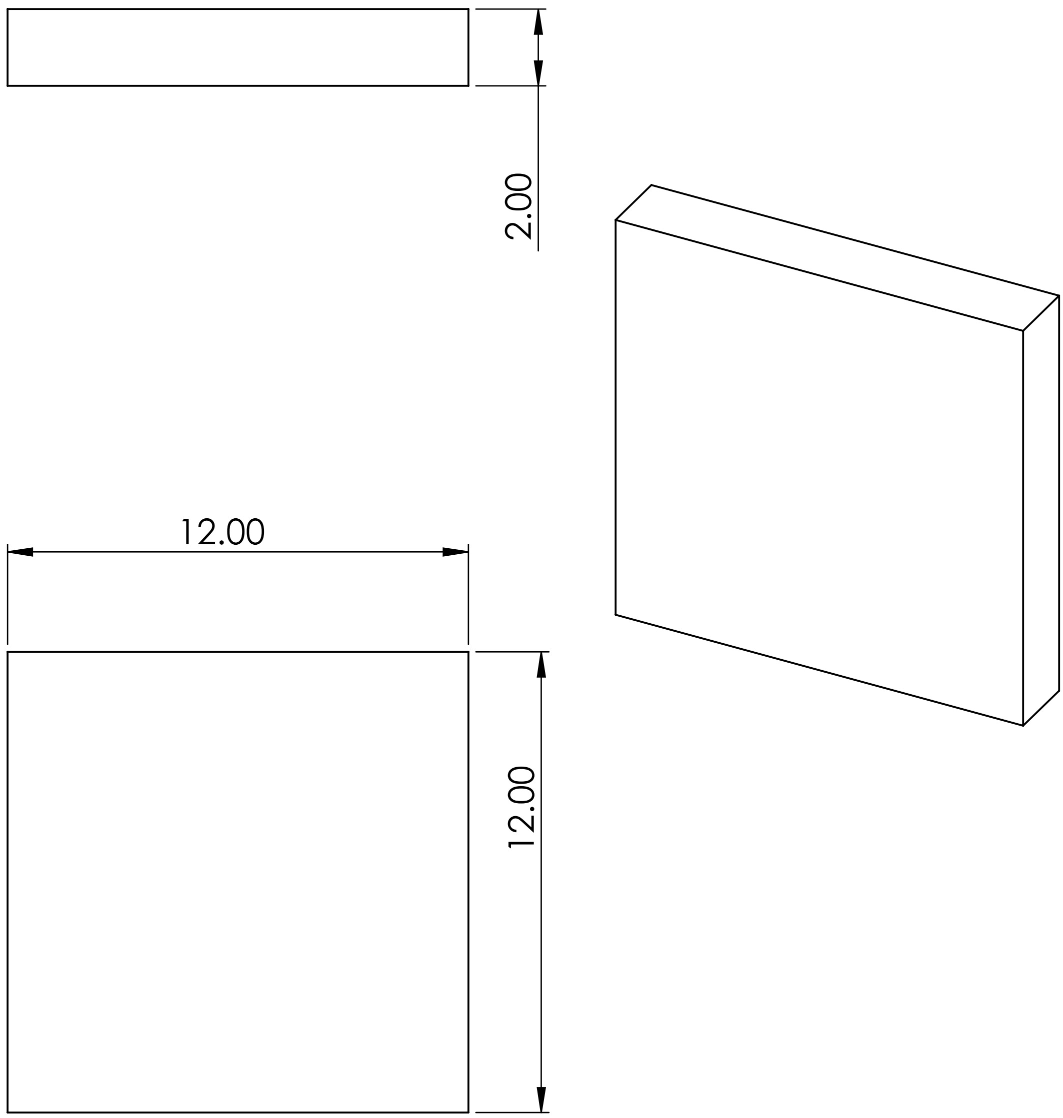


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

FINISH:

TAPE AND SEAL

REVISION

	NAME	SIGNATURE	DATE
DRAWN	ALEX SERVENTI		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: RMAX THERMOSHEET

WEIGHT:

TITLE:

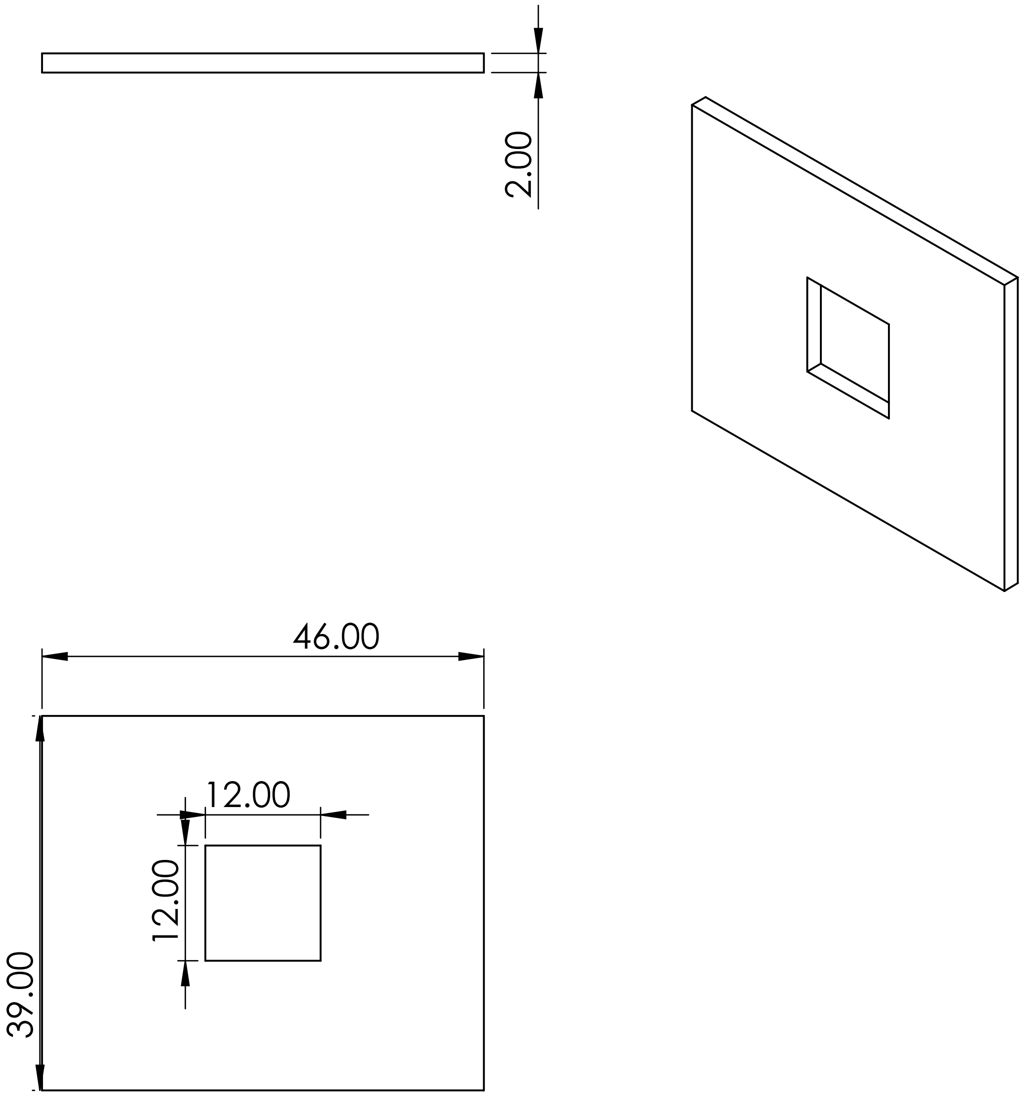
Window Cover

DWG NO.

A4

SCALE:1:5

SHEET 1 OF 1



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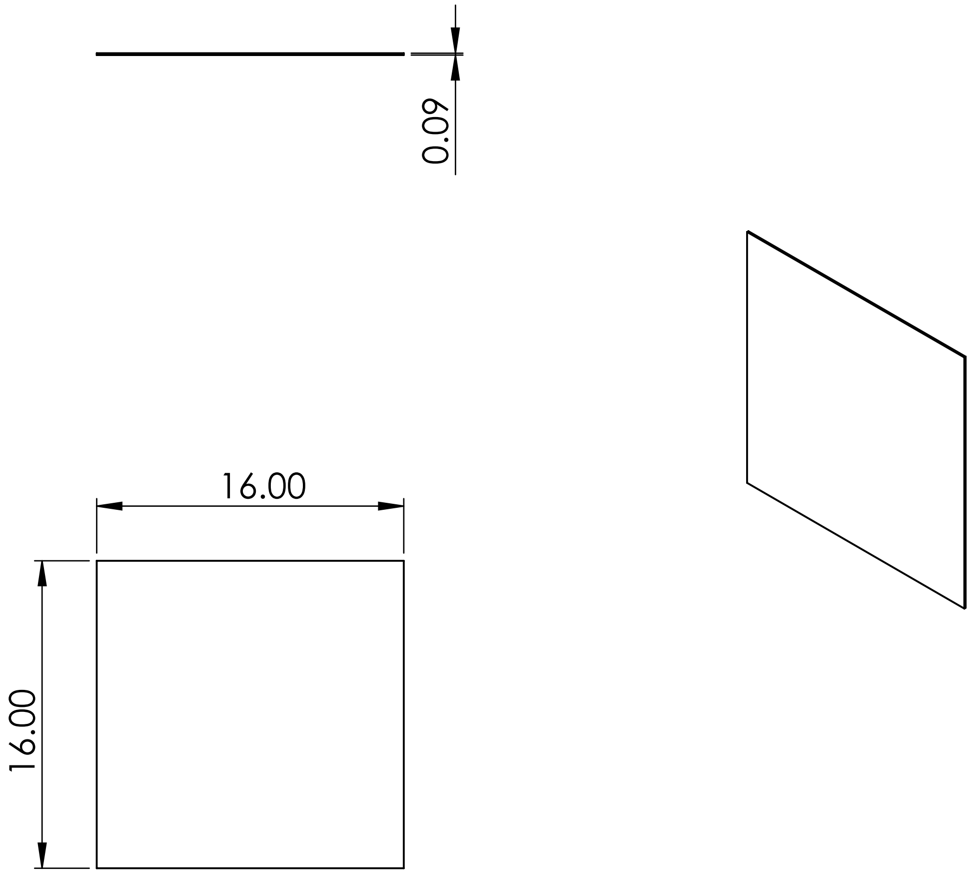
	NAME	SIGNATURE	DATE		TITLE:	Window Side
DRAWN	ALEX SERVENTI					
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: RMAX THERMOSHEET	DWG NO.	A4
				WEIGHT:	SCALE:1:20	SHEET 1 OF 1



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DIMENSIONS ARE IN INCHES

FINISH:

DEBUR AND BREAK SHARP EDGES

REVISION

	NAME	SIGNATURE	DATE
DRAWN	ALEX SERVENTI		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: POLYCARBONATE

WEIGHT:

TITLE:

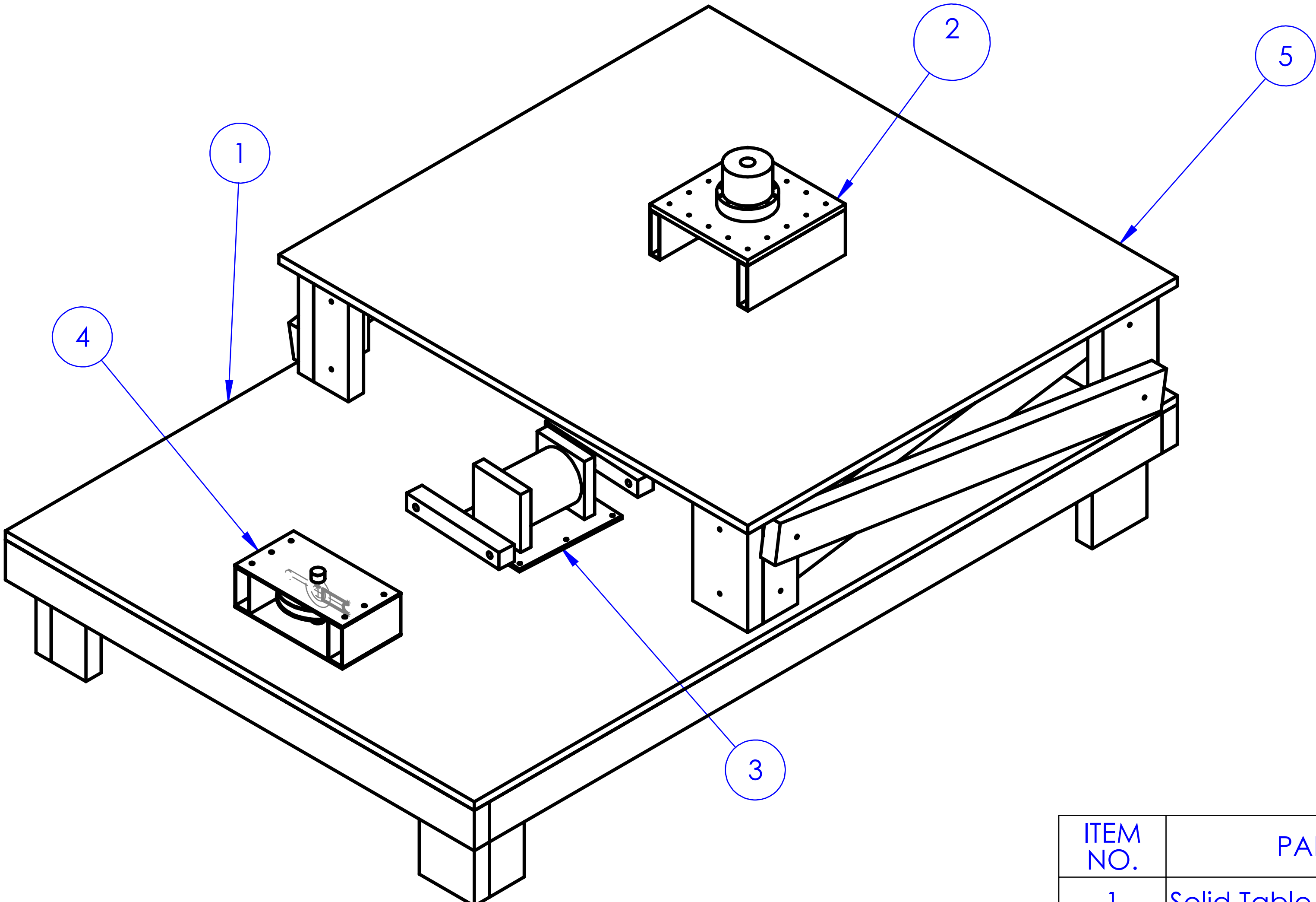
Window

DWG NO.

A4

SCALE:1:10

SHEET 1 OF 1



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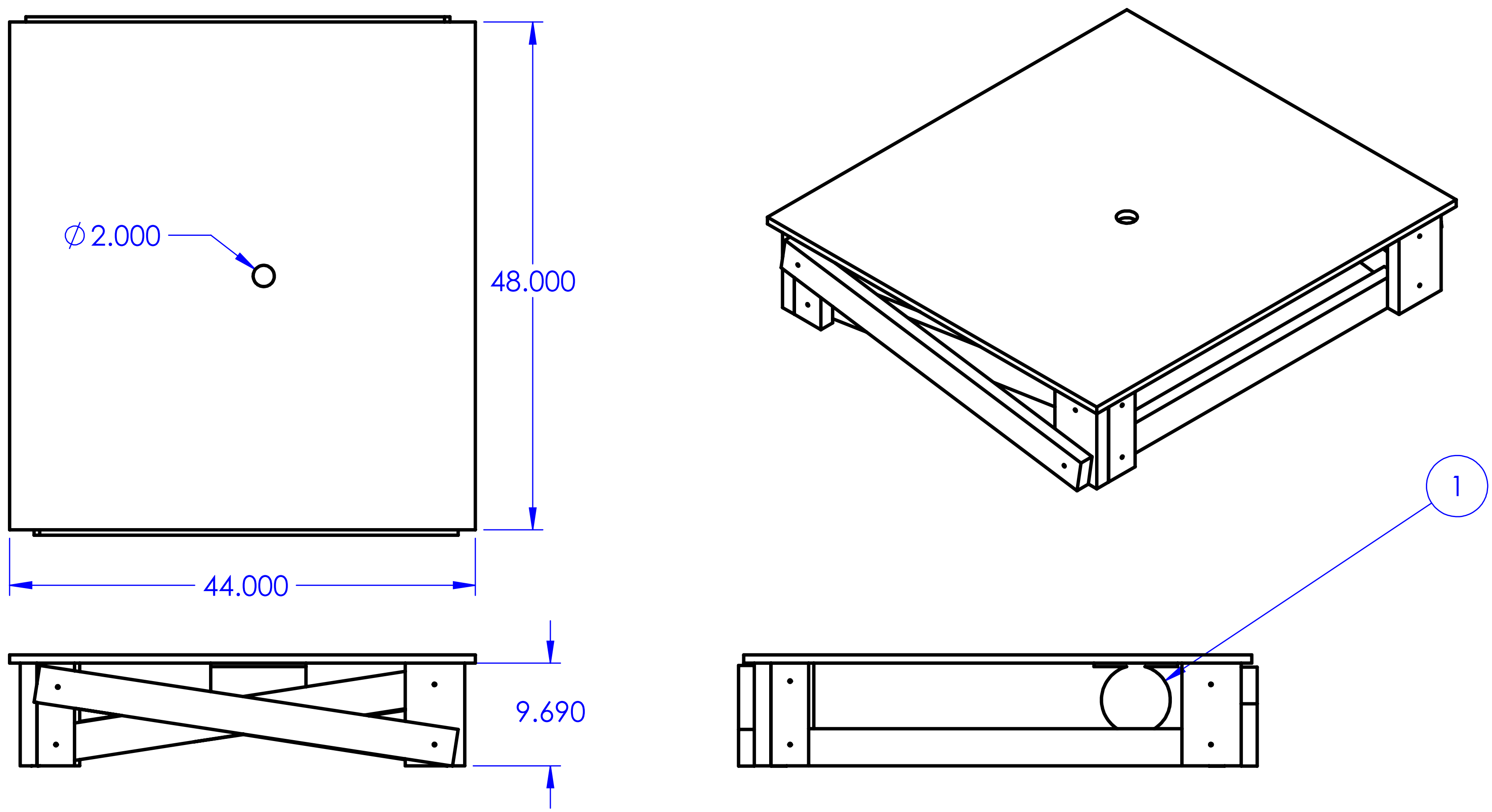
3	PneumaticAssembly	1
4	SecondPulleyAssembly	1
5	Chamber Table	1

Cal Poly Mechanical Engineering ME 251 - Winter 2013	Lab Section:	Assignment #	Title:		Drwn. By:
	Dwg. #:	Nxt Asb:	Date:	Scale:	Chkd. By:



ITEM NO.	PART NUMBER	QTY.
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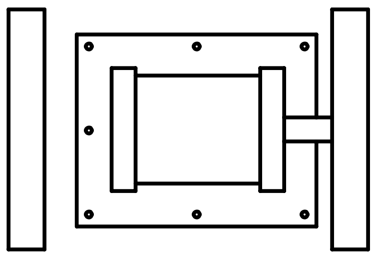
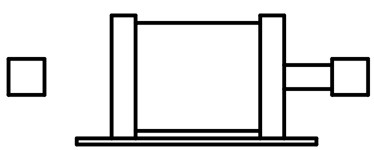
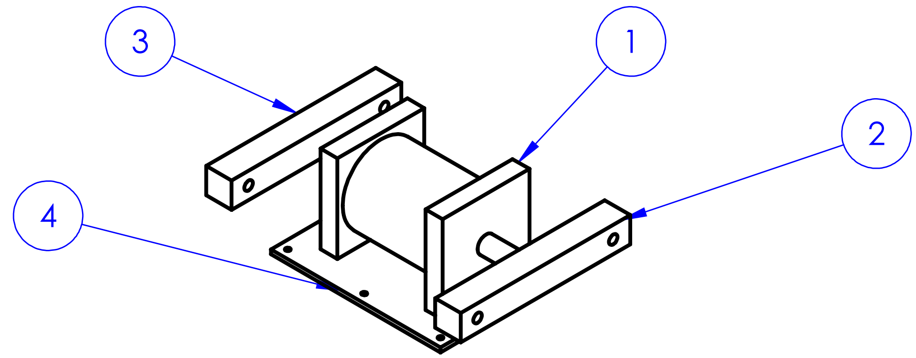
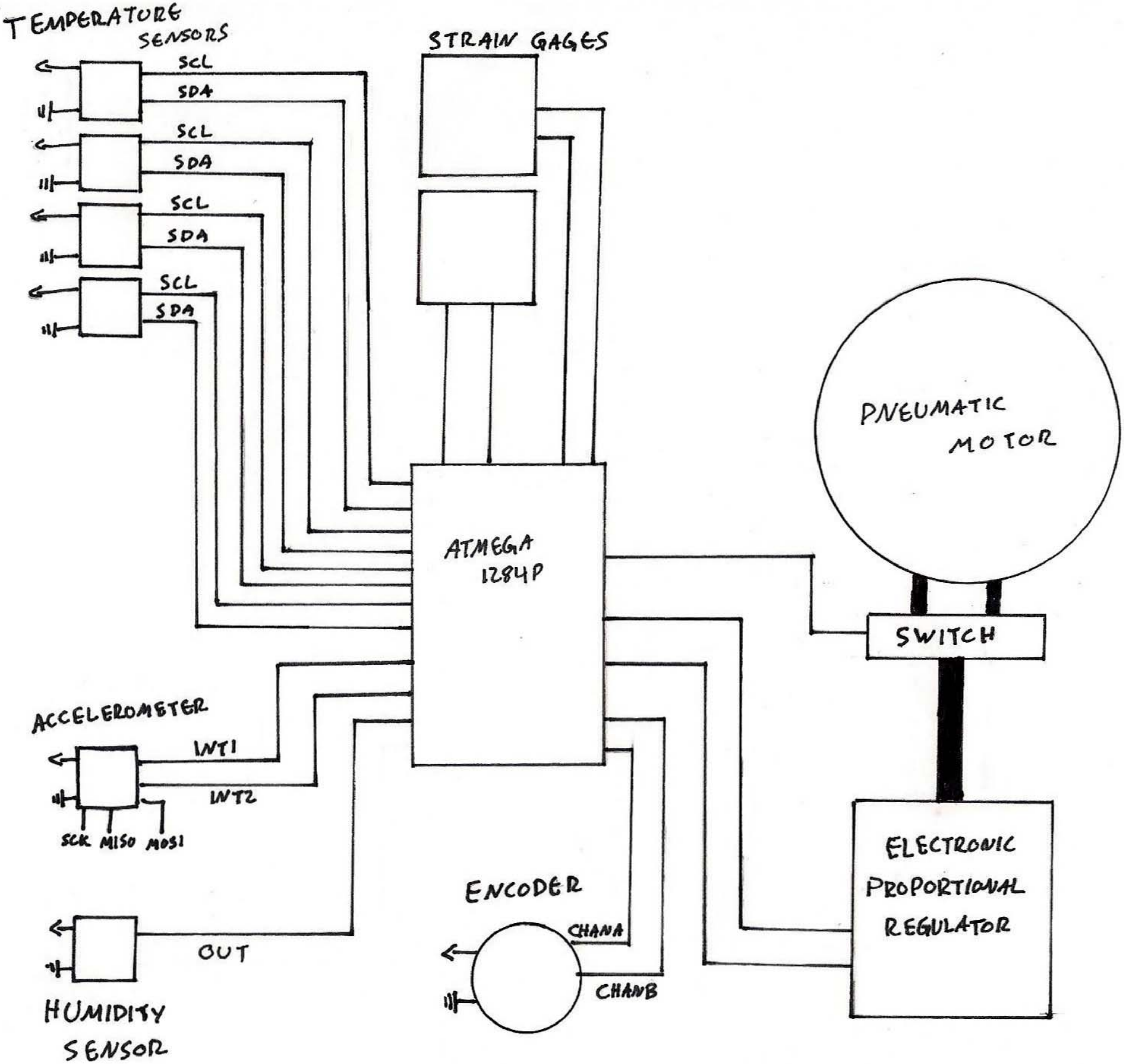






ITEM NO.	PART NUMBER	QTY.
1	Pneumatic	1
2	Pneumatic Extension	1
3	Free Rope Support	1
4	PneumaticMount	1

Cal Poly Mechanical Engineering ME 251 - Winter 2013	Lab Section:	Assignment #	Title:Pneumatic Assembly		Drwn. By:
	Dwg. #:	Nxt Asb:	Date:	Scale:	Chkd. By:


TEMPERATURE SENSORS
SCL
SDA
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SDA
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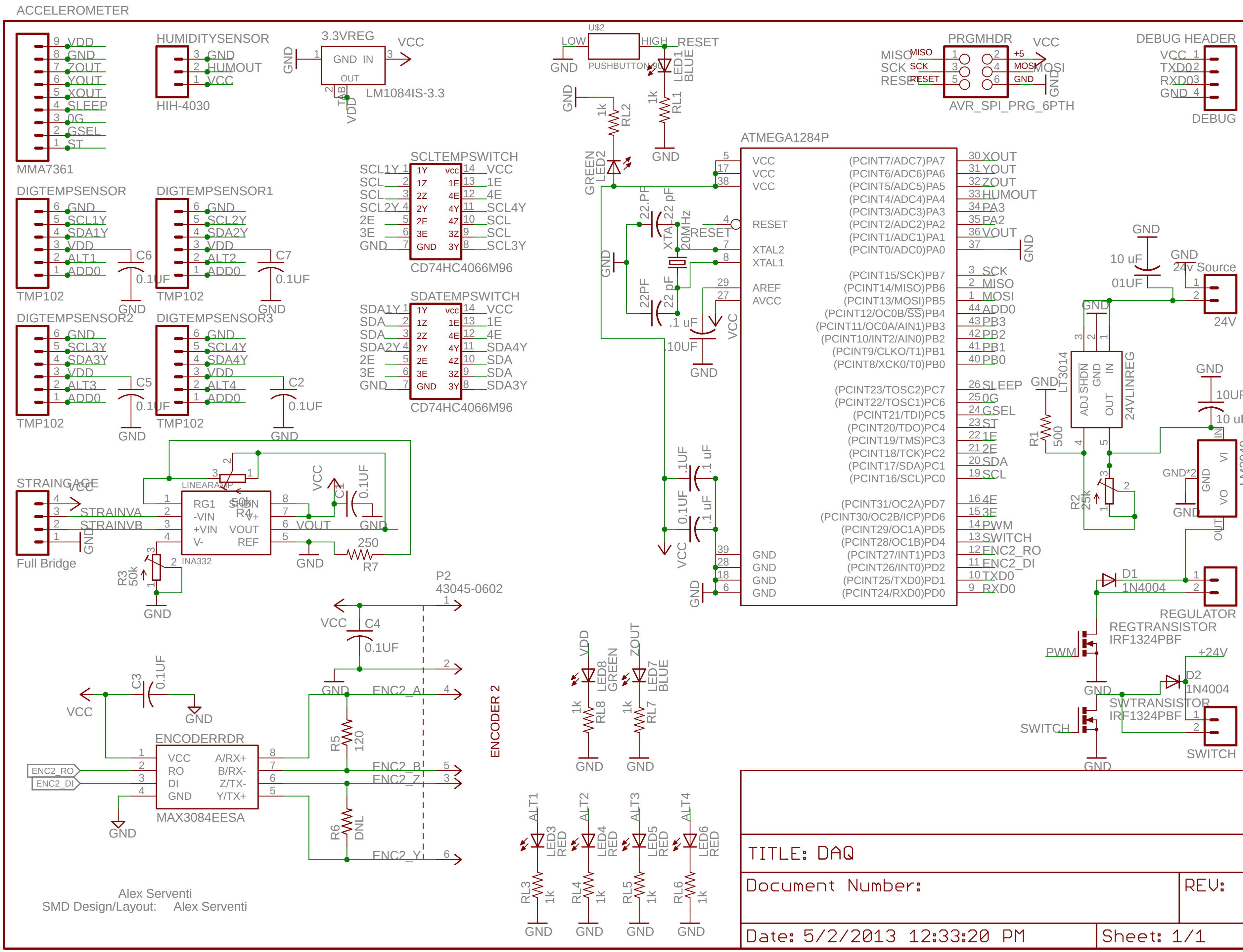
SDA
STRAIN GAGES
ATMEGA 1284P
PNEUMATIC MOTOR
SWITCH
ACCELEROMETER
INT1
INT2
SCK MISO MOSI
OUT
HUMIDITY SENSOR
ENCODER
CHANA
CHANB
ELECTRONIC PROPORTIONAL REGULATOR



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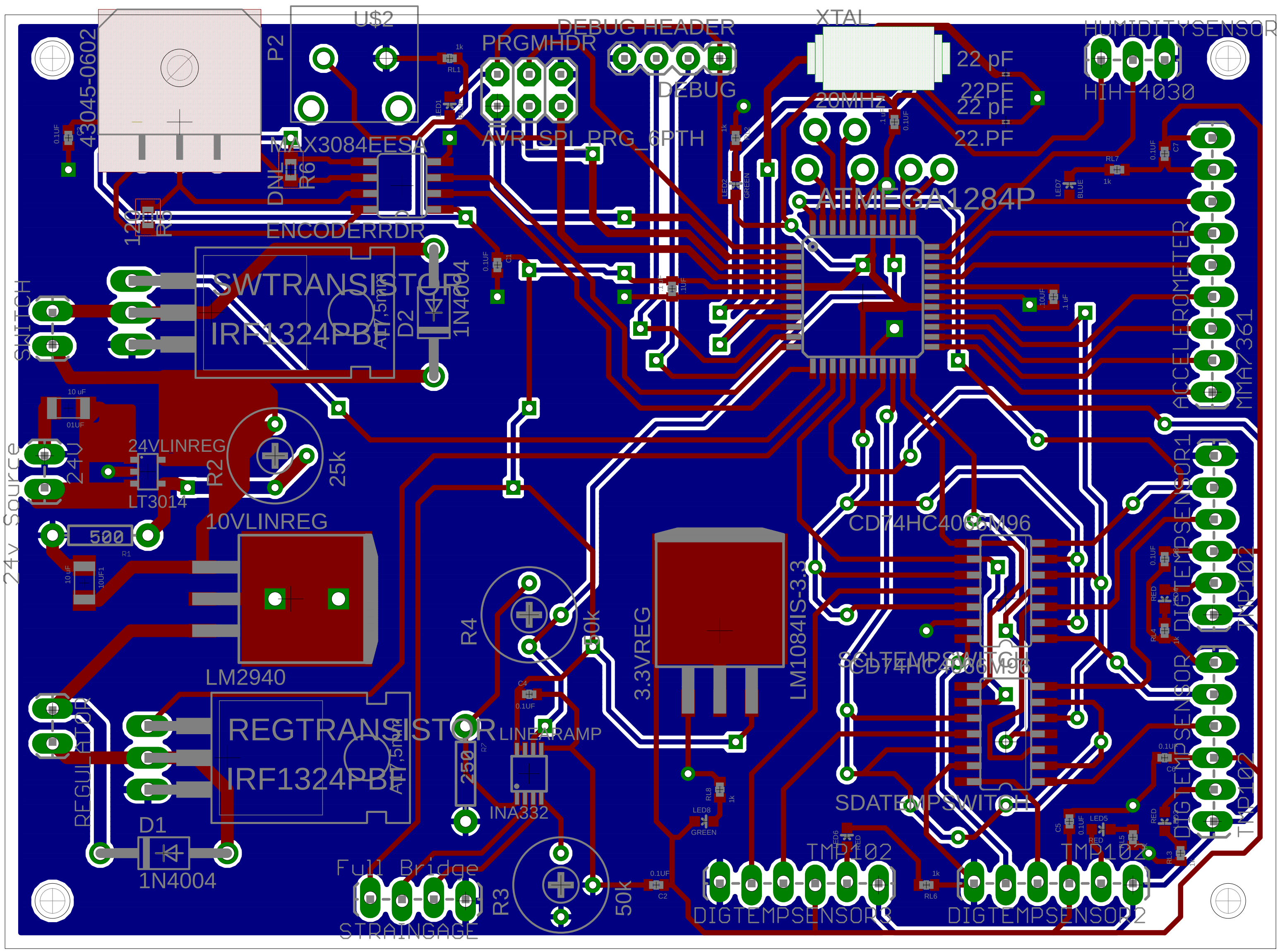

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Date Ordered	Date Reimbursed	Description	Model/Item Number	Unit Price	Quantity	Tax	Total	total
10/19/2012	3/4/2013	Gas reimbursement for travel	--	$222.00	1	$0.00	$222.00	$3,495.93
1/24/2013	1/24/2013	4'x8'x 19/32 Sanded Fir	578861	$37.97	2	$18.40	$75.94	
		2"x6"x10' Douglas Fir	603651	$5.52	1		$5.52	
		2"x4"x8' Douglas Fir	441317	$2.92	4		$11.68	
		4'x8'x0.75" AraucoPly wood	690053	$40.97	1		$40.97	
		DAP Insulation Caulk	18609	$1.67	2		$3.34	
		Caulk Gun	HD109	$1.97	1		$1.97	
		Clear Polycarbonate sheet	987359	$12.98	1		$12.98	
		Thermosheath Insulation	613010	$30.98	3		$92.94	
		Weather stripping	--	$7.59	3	$1.74	$22.77	
		Vibration motor	--	$218.00	1	--	$218.00	
3/9/2013		Sandpaper 3pk	51141941004	$3.97	2	$8.04	$7.94	
		Minwax Polyacrylic	27426633339	$18.32	1		$18.32	
		Hunter Green Satin Spray	20066773281	$4.97	1		$4.97	
		Foil Tape	716511102101	$3.25	2		$6.50	
		Wood Screw 6x1/2	30699208821	$3.82	1		$3.82	
		Wood Screw 10x3	30699212828	$10.26	1		$10.26	
		Wood Screw 10x2 1/2	30699212422	$8.91	1		$8.91	
		Wood Screw 10x2	30699212026	$5.98	1		$5.98	
		Galv Steel Truss Clip	707392297604	$0.68	6		$4.08	
		Wood Finish Espresso	27426700505	$8.12	1		$8.12	
		Brushes	77089150032	$1.15	4		$4.60	
		Hinges 2pk	30699153992	$2.77	2		$5.54	
		Loctite Glue	79340689428	$4.98	1		$4.98	
		Poplar Board	728927310292	$3.27	2		$6.54	
4/4/2013	4/4/2013	Digital temperature sensor	SEN-09418	$5.95	6	--	$35.70	
		Humidity sensor	SEN-09569	$16.95	3	--	$50.85	
		4 pack of anti vibration pads	X000CEWVX9	$26.95	1	--	$26.95	
		Aluminum Tie Rod Air Cylinder 4.5" bore	6491K513	$245.41	1	--	$245.41	
		Steel Tight Rectangular Bar 1/8" thick	9517K369	$49.21	1	--	$49.21	
		Low carbon Steel rod	8920K231	$10.69	1	--	$10.69	
		Low carbon steel bar 1.5" square	9143K23	$16.45	1	--	$16.45	
4/16/2013	4/16/2013	Steel drive shaft 1.25"x12"	1346K44	$37.23	1	--	$37.23	
		precision electronic air regulator	4993K4	$340.90	1	--	$340.90	
		low carbon steel rod 4"x1/2"	7786T52	$9.53	1	--	$9.53	
		directional control 3-port solenoid valve	7889K98	$122.39	1	--	$122.39	
		low carbon steel rectangular bar 3/16"	8910K546	$11.99	1	--	$11.99	
		steel pulley for wire rope	3164T82	$36.46	1	--	$36.46	
		Low Carbon steel rectangular bar	8910K841	$56.33	1	--	$56.33	
4/17/2013	4/17/2013	3/8 amsteel blue 20ft	38AMSTLBLU	$1.95	20	--	$39.00	
		USPS Priority Mail	FREIGHT	$6.00	1	--	$6.00	
4/23/2013	4/23/2013	Power supply	RSP-1000-48	$245.14	2	--	$490.28	
		shipping	--	$7.95	2	--	$15.90	
4/25/2013	4/25/2013	Seal kit for coupler	6454K33	$24.17	1	--	$24.17	
		Coupler hub	6454K23	$100.24	1	--	$100.24	
		Coupler sleeve	6454k13	$91.82	1	--	$91.82	
		Strain Gages	CEA-06-250US-120	$33.30	5	--	$166.50	
5/3/2013		Foil tape	716511102101	$3.35	5	$2.16	$16.75	
		Paint brush	77089850055	$0.97	2		$1.94	
		2x4 Douglas fir	73291324209	$8.43	1		$8.43	
5/4/2013		Wood screws	30699213610	$1.18	3	$3.76	$3.54	
		Bent brackets	44315823305	$0.67	10		$6.70	
		Screws	30699210428	$5.58	1		$5.58	
		Flat brackets	707392964209	$1.88	6		$11.28	
		Power cords	756847000252	$9.97	2		$19.94	
5/7/2013		Spray paint	20066773281	$4.97	2	$1.22	$9.94	
		Gate hook	30699158812	$1.18	2		$2.36	
		Handle	30699151844	$2.97	1		$2.97	
5/8/2013	5/8/2013	One-Piece clamping shaft collar	B0063KJFDY	$9.56	1	$0.72	$9.56	
		1 1/4: bearing UCFL207-20 + 2	kit7345	$9.95	2	$1.60	$19.90	
		shipping	--	$22.10	1	--	$22.10	
		FT232RL Debugger	BOB-00718	$14.95	2	--	$29.90	
		Pocket AVR Programmer	PGM09825	$14.95	2	--	$29.90	
		Triple axis accelerometer	SEN-09652	$11.95	2	--	$23.90	
		SWITCH	CD74HC4066M96	$0.59	4	--	$2.36	
		24V REG	LT3014ES5#TRMPBF	$3.57	3	--	$10.71	
		10V REG	LM2940SX-10/NOPB	$1.87	3	--	$5.61	
		25K RES	3362P-1-253LF	$0.98	4	--	$3.92	
		50K RES	3362P-1-503LF	$0.98	4	--	$3.92	
		3.3V REG	LM1084IS-3.3/NOPB	$2.79	3	--	$8.37	
		TRANSISTOR	IRF1324PBF	$3.86	5	--	$19.30	
		LINEAR AMP	INA156EA/250	$3.63	1	--	$3.63	
		INST AMP G5-1000	INA332AIDGKT	$1.72	3	--	$5.16	
		ENCODER CONNECTOR	430450602	$2.58	2	--	$5.16	
		RS422	MAX3084EESA+	$4.26	3	--	$12.78	
		MICROCONTROLLER	ATMEGA1284P-AU	$8.03	3	--	$24.09	
		PROGRAM HEADER	69168-106HLF	$0.99	2	--	$1.98	
		1X2 HEADER	1776275-2	$0.50	5	--	$2.50	
		1X3 HEADER	1776275-3	$0.78	2	--	$1.56	
		1X4 STRAIN GAUGE HEADER	1776275-4	$0.98	2	--	$1.96	
		1X6 HEADER	1776275-6	$1.41	6	--	$8.46	
		1X9 HEADER	OSTTE090161	$1.51	2	--	$3.02	
		DEBUG HEADER	534237-2	$1.19	2	--	$2.38	
		CRYSTAL	ATS20A	$0.35	3	--	$1.05	
		10 MICROF CAP	C3216Y5V1E106Z	$0.21	10	--	$2.08	
		0.1 MICROF CAP	C1005X5R1A104K050	$0.03	25	--	$0.63	

		22 PF CAP	C0603C0G1H220J030	$0.02	15	--	$0.36
		DEBUG HEADER SCREW	OSTTF040161	$0.93	2	--	$1.86
		RESET BUTTON	EVQ-PC205K	$0.35	3	--	$1.05
		BLUE LED	LB Q39E-N1P1-35-1	$0.19	15	--	$2.91
		GRN LED	LG Q971-KN-1	$0.07	25	--	$1.70
		RED LED	LS Q971-KN-1	$0.07	25	--	$1.70
		YLW LED	LY Q976-P1S2-36	$0.07	25	--	$1.80
		1K RES	ERJ-2GEJ102X	$0.02	50	--	$0.86
		250 RES	WHA250FET	$1.08	5	--	$5.40
		500 RES	CMF55500R00FEBF	$0.72	5	--	$3.60
		FLYBACK DIODE	1N4004	$0.14	15	--	$2.06
		120 RES	ERJ-3GEYJ121V	$0.01	50	--	$0.46
		STANDOFF	876	$0.18	6	--	$1.08
		TWEEZERS	18032EZ	$5.75	1	--	$5.75
5/14/2103	5/14/2103	zinc-plated alloy steel socket screw	90128A846	$7.34	1	--	$7.34
		grade 8 steel hex nut1/4" 20 thread	93827A211	$6.74	1	--	$6.74
		5/8"x1" steel socket screw 18-thread	91251A495	$6.40	2	--	$12.80
		5/8"x1-3/4" steel socket screw 18-thread	91251A400	$9.77	2	--	$19.54
		1/4"x1-1/4" steel socket screw 20-thread	91251A544	$11.03	1	--	$11.03
		#8x1-3/4" steel socket screw 32-thread	91251A082	$7.75	1	--	$7.75
		1/2"x5" steel socket screw 20-thread	91251A031	$13.14	2	--	$26.28
		1/2"x5" steel socket screw 20-thread	91251A090	$7.34	2	--	$14.68
		grade 8 steel hex nut1/2" 20 thread	93827A249	$8.52	1	--	$8.52
		black oxide hex nut 5/8" 18-thread	90475A035	$1.77	4	--	$7.08
		machine screw hex nut #8 32 thread	90480A009	$1.49	1	--	$1.49
		12.9 socket head cap screw M5 thread	91290A262	$11.82	1	--	$11.82
		12.9 socket head cap screw M4 thread	91290A168	$9.13	1	--	$9.13
		spring steel key stock 1/8"x1/8"	98535A130	$2.07	1	--	$2.07
		spring steel key stock 1/4"x1/4"	98535A150	$3.70	1	--	$3.70
5/14/2013		Control Board	TkWepQGX	$58.70	1	--	$58.70
		Shipping	--	$5.00	1		$5.00
5/24/2013		Allen wrench set	637634322057	$10.86	1	$3.25	$10.86
		Blue wire	0000-751-522	$0.27	5		$1.35
		Red wire	0000-320-266	$0.27	5		$1.35
		Black wire	0000-320-161	$0.27	5		$1.35
		Green wire	0000-320-242	$0.27	5		$1.35
		Cable ties	32076070335	$2.38	1		$2.38
		Hex bolts (1/4)	30699555185	$0.62	3		$1.86
		Washers (1/2)	30699198610	$1.18	1		$1.18
		Hex bolts (4mm)	30699356188	$0.35	8		$2.80
		Washers (1/4)	30699198214	$1.18	1		$1.18
		Power strip	6955837500077	$14.97	1		$14.97
5/25/2013		Hex nuts (3/8)	0000-655-449	$0.12	4	$0.19	$0.48
		Washers (3/8)	0000-655-570	$0.14	4		$0.56
		Hex bolts (3/8)	ARD	$0.34	4		$1.36
6/4/2013		Red wire	0000-320-226	$0.27	10	$0.43	$2.70
		Black wire	0000-320-161	$0.27	10		$2.70
6/4/2013		Servo battery	MAXER1733T	$6.00	1	--	$6.00
		Shipping	--	7.75	1		$7.75

Parker
Pneumatic

Air Motors

Series P1V-A

Catalogue 9127007652GB-ul

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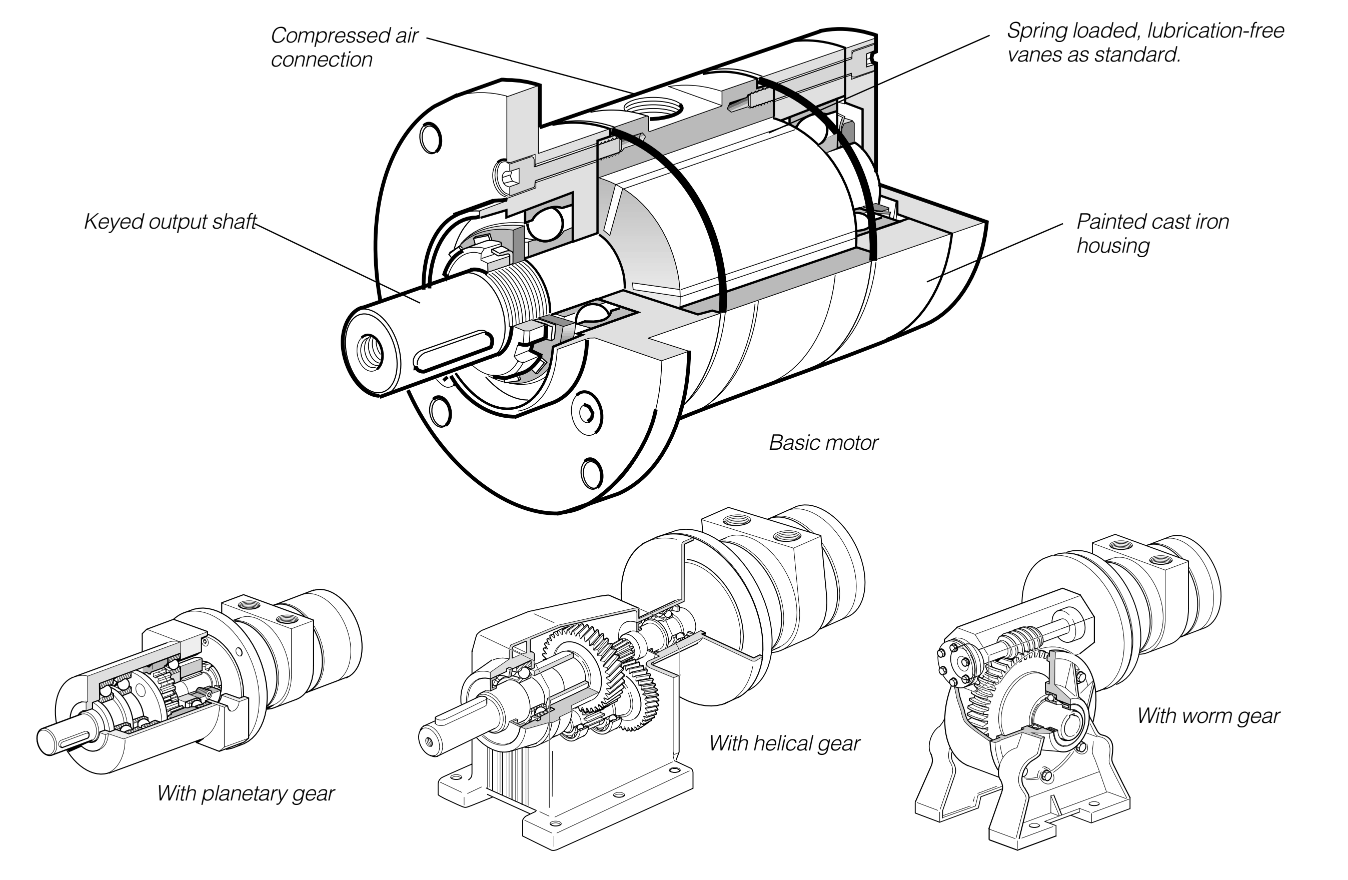


Air Motors, Series P1V-A

P1V-A is a range of reversible air motors intended for heavy and demanding applications. The motor housings are made from painted cast iron, and the components sealed to permit operation in damp and dirty environments.

The range contains three different sizes, P1V-A160, P1V-A260 and P1V-A360, with power ratings of 1600, 2600 or 3600 Watts. The basic motors can be supplied with built-in gearboxes, either planetary, helical or worm drive, to provide the correct speed of rotation and torque, and the correct installation mountings.

Basic motor

All pneumatic motors are equipped with spring loaded vanes as standard, which gives the motors very good starting and low speed running characteristics. They are also equipped with vanes for intermittent lube-free operation as standard. 100% lubrication-free vanes are obtainable as options. The simple construction of the motors makes them very reliable, with long service life and they are easy to service.

Motors with planetary gears

A P1V-A combined with a planetary gear has small installation dimensions, low weight in relation to performance, free installation position, flange mounting as standard, in line output shaft and high efficiency. They are available with shaft speeds ranging from 95 rpm to 1200 rpm, with torques ranging from 16 Nm to 160 Nm.

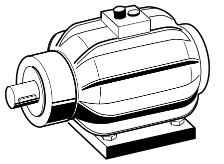
Motors with helical gears

A P1V-A combined with a helical gear has high efficiency, simple installation with flange or foot, and competitive pricing. They are available with shaft speeds ranging from 25 rpm to 1050 rpm, with torques ranging from 23 Nm to 1800 Nm. Oil-bath gears mean that the installation position must be decided beforehand. The installation position governs the amount of oil in the gear and the location of filling and drain plugs.

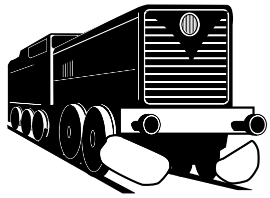
Motors with worm gears

A P1V-A combined with a worm drive gear has the following characteristics: gearboxes with high gear ratios are self-locking, which means that they can be used to maintain the output shaft in position, simple installation with the flange on the left or right sides or with a foot, small installation dimensions and competitive pricing. They are available with shaft speeds ranging from 62 rpm to 500 rpm, with torques ranging from 38 Nm to 670 Nm. Oil-bath gears mean that the installation position must be decided beforehand. The installation position governs the amount of oil in the gear and the location of filling and drain plugs.

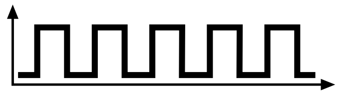
Products specially designed for mobile applications



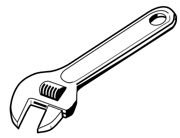
Air motors have much smaller installation dimensions than corresponding electric motors.



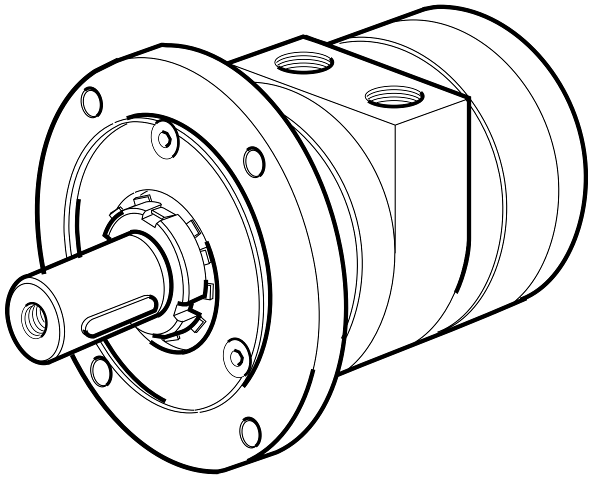
Air motors can be loaded until they stall, without damage. They are designed to be able to withstand the toughest heat, vibration, impact etc.

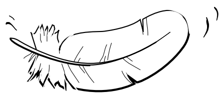


Air motors can be stopped and started continually without damage.

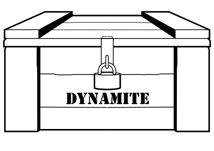


The simple design principle of air motors make them very easy to service.

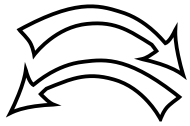




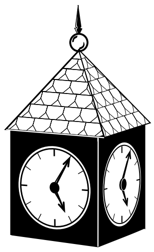
The weight of an air motor is several times less than corresponding electric motors.



Air motors can be used in the harshest environments.

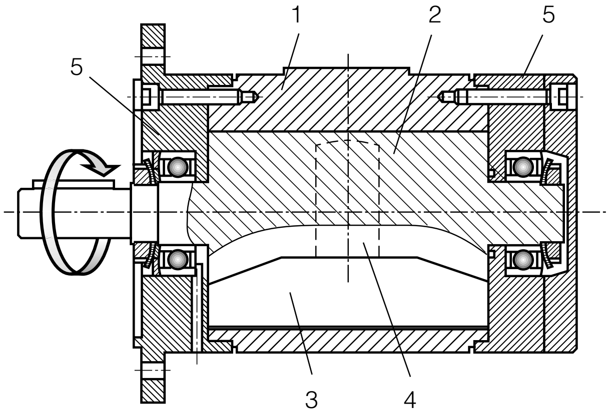


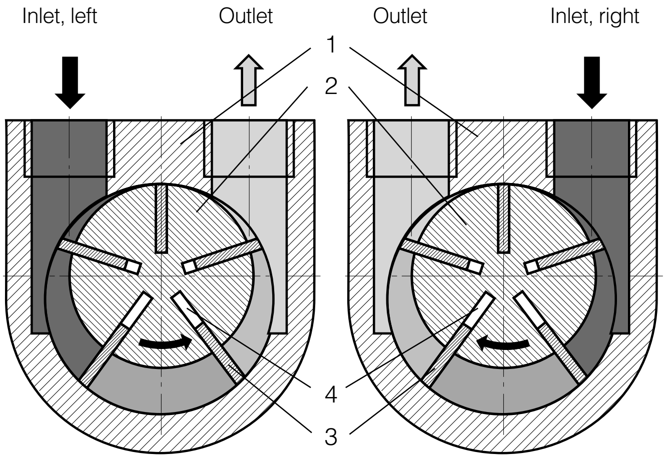
The motors are reversible as standard.



The reliability of air motors is very high, thanks to the design and the low number of moving parts.

Principles of air motor function



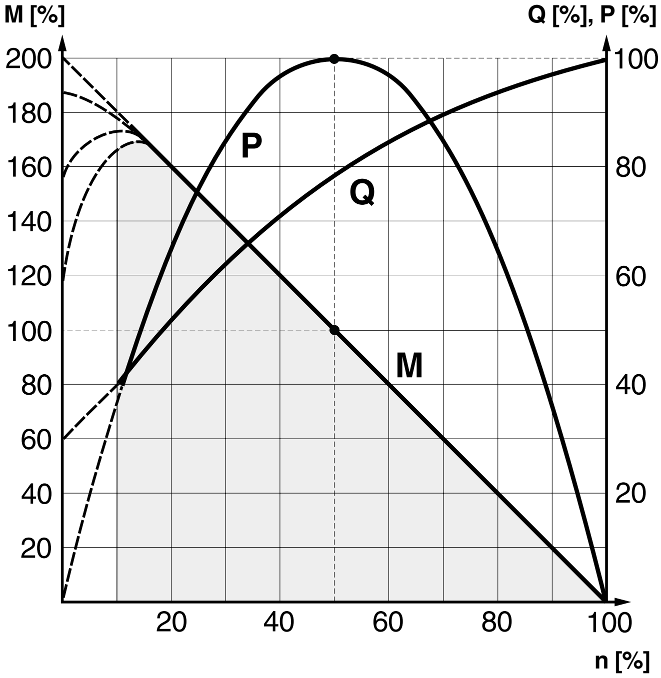


1	Rotor cylinder
2	Rotor
3	Vanes
4	Spring
5	End piece with bearing

There are a number of designs of air motor. Parker Pneumatic has chosen to use the vane rotor design, because of its simple design and reliable operation. The small external dimensions of vane motors make them suitable for all applications.

The principle of the vane motor is that a rotor with a number of vanes is enclosed in a rotor cylinder. The motor is supplied with compressed air through one connection and air escapes from the other connection. To give reliable starting, the springs press the vanes against the rotor cylinder. The air pressure always bears at right angles against a surface. This means that the torque of the motor is a result of the vane surfaces and the air pressure.

Torque, power and air consumption graphs



P = power
M = torque
Q = air consumption
n = speed

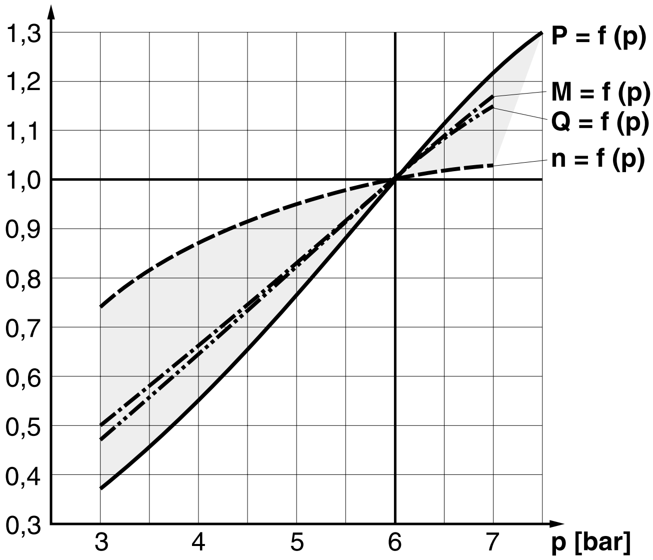
The performance characteristics of each motor are shown in a family of curves as above, from which torque, power and air consumption can be read off as a function of speed. Power is zero when the motor is stationary and also when running at free speed (100%) with no load. Maximum power (100%) is normally developed when the motor is driving a load at approximately half the free speed (50%).

Torque at free speed is zero, but increases as soon as a load is applied, rising linearly until the motor stalls. As the motor can then stop with the vanes in various positions, it is not possible to specify an exact torque. However, a minimum starting torque is shown in all tables.

Air consumption is greatest at free speed, and decreases with decreasing speed, as shown in the above diagram.

Correction diagrams

Correction factor



P = power
M = torque
Q = air consumption
n = speed

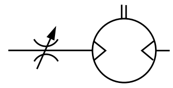
All catalogue data and curves are specified at a supply pressure of 6 bar to the motor. This diagram shows the effect of pressure on speed, specified torque, power and air consumption.

Start off on the curve at the pressure used and then look up to the lines for power, torque and air consumption. Read off the correction factor on the Y axis for each curve and multiply this by the specified catalogue data in the table, or data read from the torque and power graphs.

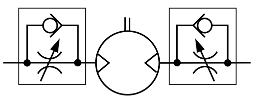
Example: at 4 bar supply pressure, the power is only 0.55 x power at 6 bar supply pressure.

This example shows how strongly power falls if supply pressure is reduced. You must therefore ensure that the motor is supplied through pipes of sufficient diameter to avoid pressure drop.

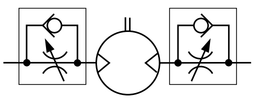
Speed regulation



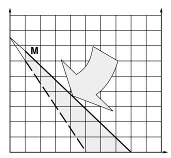
Supply throttling, non-reversible motor



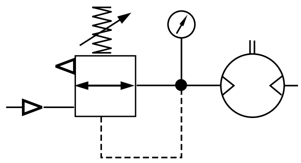
Supply throttling, reversible motor



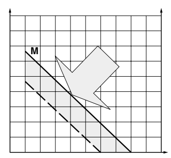
Exhaust throttling, reversible motor



Torque curve change caused by throttling



Pressure regulation at motor inlet



Torque curve change caused by pressure change

Throttling

The most common way to reduce the speed of a motor is to install a flow control valve in the air inlet. When the motor is used in applications where it must reverse and it is necessary to restrict the speed in both directions, flow control valves with by-pass should be used in both directions.

Inlet throttling

If the inlet air is restricted, the air supply is restricted and the free speed of the motor falls, but there is full pressure on the vanes at low speeds. This means that we get full torque from the motor at low speeds despite the low air flow.

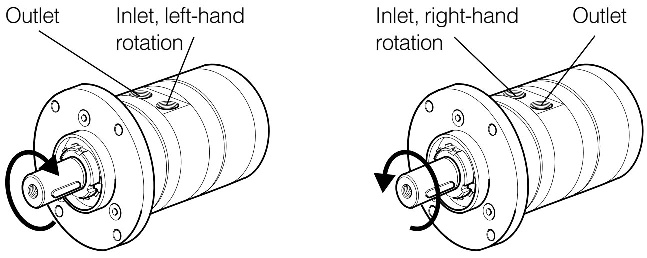
Since the torque curve becomes “steeper”, this also means that we get a lower torque at any given speed than would be developed at full air flow.

Pressure regulation

The speed and torque can also be regulated by installing a pressure regulator in the inlet pipe. This means that the motor is constantly supplied with air at lower pressure, which means that when the motor is braked, it develops a lower torque on the output shaft.

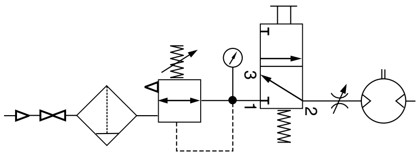
In brief: Inlet throttling gives reduced speed in one direction but maintains torque when braked. The torque curve becomes steeper. Pressure regulation in the inlet cuts torque when the motor is braked, and also reduced speed. The torque curve is moved parallel.

Direction of motor rotation

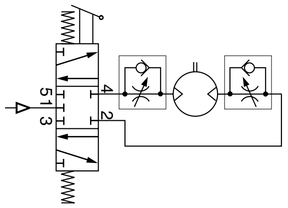


The direction of rotation of reversible motors is obtained by supplying inlet L or inlet R with compressed air. The motor can be stopped and started continually without damage occurring.

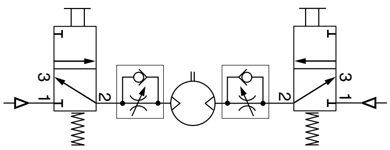
Air supply



Shut-off, filtering, pressure regulation and control valve



Reversible motor with 5/3 control valve



Reversible motor with two 3/2 control valves

The air with which the motor is supplied must be filtered and regulated. Directional valves are needed to provide it with air, to get the motor to rotate when we want it to. These valves can be equipped with several means of actuation, such as electric, manual and pneumatic control. When the motor is used in a non-reversible application, it is sufficient to use a 2/2 or 3/2 valve for supply. Either one 5/3 or two 3/2 valves are needed for a reversible motor, to ensure that the motor receives compressed air and the residual air outlet is vented. A flow control valve can be installed in the supply pipe to regulate the motor speed if the motor is not used as a reversible motor. One flow control valve with by-pass is needed to regulate each direction of rotation if the motor is used as a reversible motor. The built-in check valve will then allow air from the residual air outlet to escape through the outlet port in the control valve.

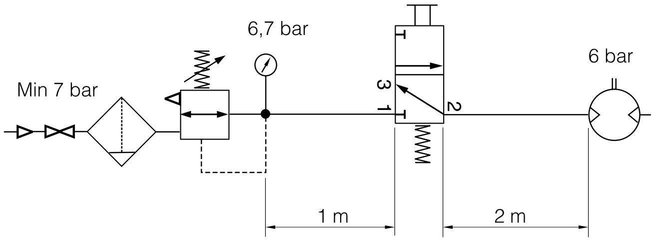
The compressed air supply must have sufficiently large pipes and valves to give the motor maximum power. The motor needs 6 bar at the supply port all the time. A reduction of pressure to 5 bar reduces the power developed to 77%, and to 55% at 4 bar.

Choice of components for air supply

Since the supply pressure at the air motor inlet port is of considerable importance for obtaining the power, speed and torque quoted in the catalogue, the recommendations below should be observed.

The following data must be complied with:
Supply pressure: 7 bar
Regulator pressure setting: 6.7 bar
Pipe length between air treatment unit and valve: max. 1 m
Pipe length valve and air motor: max. 2 m
The pressure drop through the air preparation unit, pipe, valve and pipe means that 6 bar pressure is obtained at the motor supply port.

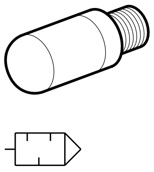
Please refer to the correction diagram on page 7, which shows what lower supply pressure means for power, speed and torque.

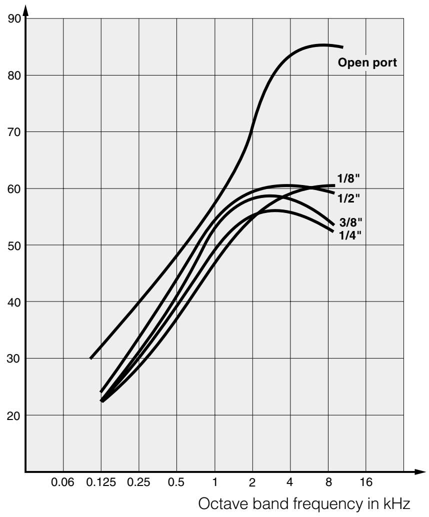


Air motor	P1V-A160	P1V-A260	P1V-A360
Air flow required, Nl/s	32	60	80
Min pipe ID, inlet, mm	19	19	22
Min pipe ID, outlet, mm	19	25	32
Recommended air treatment unit			
Maxi Modular G1/2 and G3/4			
Recommended valve series			
Valves with connections in valve housing			
VE42/43			
VE82/83			
Valves with connections in base plate			
Apollo, size 3			
Flexflow VG45			
Flexflow VE45			

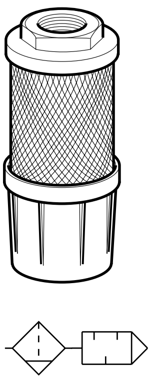
Silencing

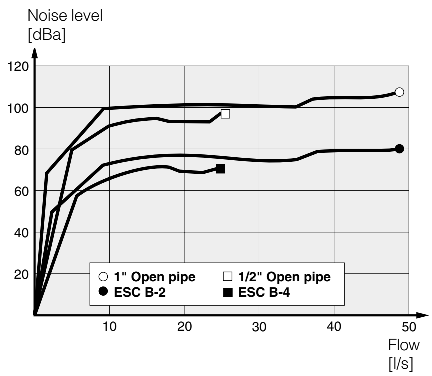
Exhaust silencer





Central silencer

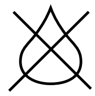




The noise from a air motor consists of both mechanical noise and a pulsating noise from the air flowing out of the outlet. The installation of the motor has a considerable effect on mechanical noise. It should be installed so that no mechanical resonance effects can occur. The outlet air creates a noise level which can amount to 115 dB(A) if the air is allowed to exhaust freely into the atmosphere. Various types of exhaust silencers are used to reduce this level. The most common type screws directly onto the exhaust port of the motor. Since the motor function causes the exhaust air to pulsate, it is a good idea to allow the air to exhaust into some kind of chamber first, which reduces the pulsations before they reach the silencer. The device which gives best silencing is to connect a soft plastic hose to a large central silencer which has the largest possible area, to reduce the speed of the out-flowing air as far as possible.

NOTE! Remember that a silencer which is too small or is blocked, generates back pressure on the outlet side of the motor, which reduces the motor power.

Lubrication and service life



Oil and oil mist are things which one tries to avoid to get the best possible working environment. In addition, purchasing, installation and maintenance of oil mist equipment costs money and, above all, time to achieve optimum lubrication effect. Users in all industries now try to avoid using components which have to be lubricated.

The P1V-A motor is equipped with vanes for intermittent operation as standard, which is the most common application of air motors. The motor is also available with optional hard vanes for continuous lubrication-free operation (option “C”).

Expected service life of P1V-A motors

Air treatment

Filtering	40 µm or better
Dew point	+3 to +4 °C
Air temperature	+20°C

Intermittent lubrication-free operation of P1V-A standard motors

Duty cycle	70%
Max. duration of intermittent use	15 minutes
Filtering 40 µm	app. 750 hours operation
Filtering 5 µm	app. 1,000 hours operation

Continuous operation of P1V-A standard motors, with lubrication

Oil volume	1 drop oil/Nm^3
Filtering 40 µm	app. 1,000 hours operation
Filtering 5 µm	app. 2,000 hours operation

Continuous lubrication-free operation of P1V-A motors equipped with hard vanes (option “C”)

Filtering 40 µm	app. 750 hours operation
Filtering 5 µm	app. 1,000 hours operation

Please refer to page 39 for service kits.

Choice of air motor, general

The motor to be used should be selected by starting with the torque needed at a specific spindle speed. In other words, to choose the right motor, you have to know the required speed and torque. Since maximum power is reached at half the motor's free speed, the motor should be chosen so that the point aimed at is as close as possible to the maximum power of the motor.

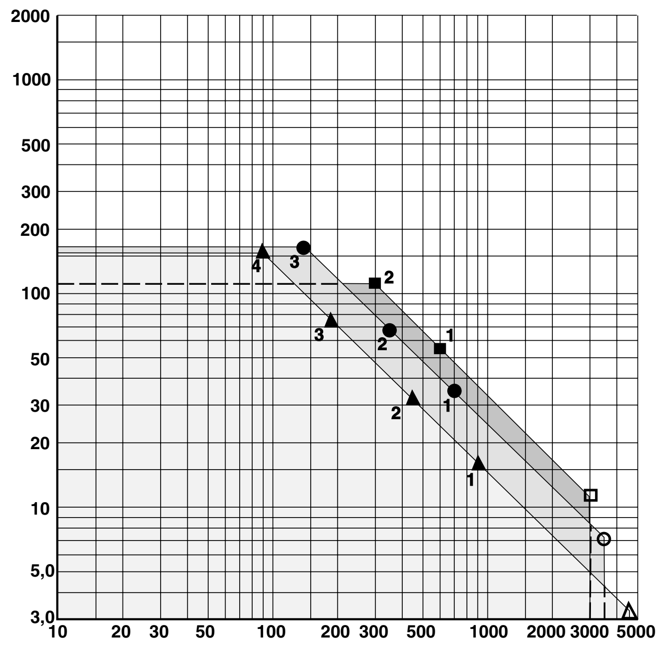
The design principle of the motor means that higher torque is generated when it is braked, which tends to increase the speed, etc. This means that the motor has a kind of speed self-regulation function built in.

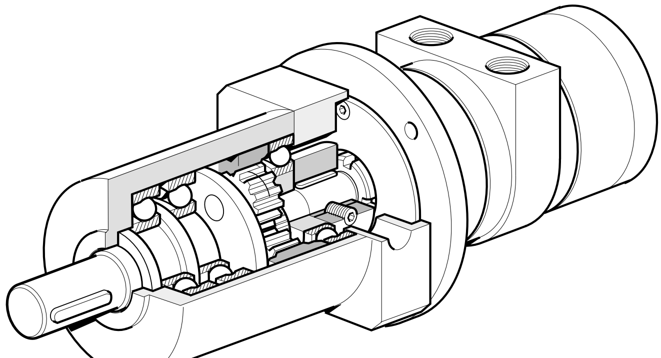
Use the following graph to choose the correct motor size and the correct type of gear as appropriate. The graph contains the points for the maximum torque of each motor at maximum power. Put in your point on the graph and select a marked point above and to the right of the point you need.

Then check the characteristic graph of each motor to find more accurate technical data. Always select a motor where the data required is in the grey field. Also use the correction diagram to see what it would mean to use different air supply pressures with the motor.

Tip: Select a motor which is slightly too fast and powerful, regulate its speed and torque with a pressure regulator and/or restriction to achieve the optimum working point.

Choice of motors with planetary gears





Planetary gears are characterised by high efficiency, low moment of inertia and can offer high gear ratios. The output shaft is always in the centre of the gearbox. Small installation dimensions relative to the torque provided. The gears are lubricated by grease, which means that it can be installed in all conceivable positions.

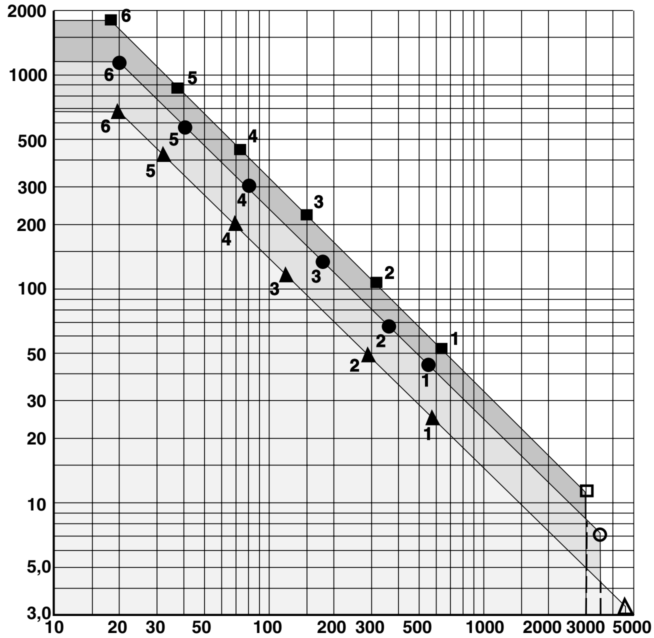
- Small installation dimensions
- Free installation position
- Simple flange installation
- Low weight
- Output shaft in centre
- High efficiency

Air motors in diagram above

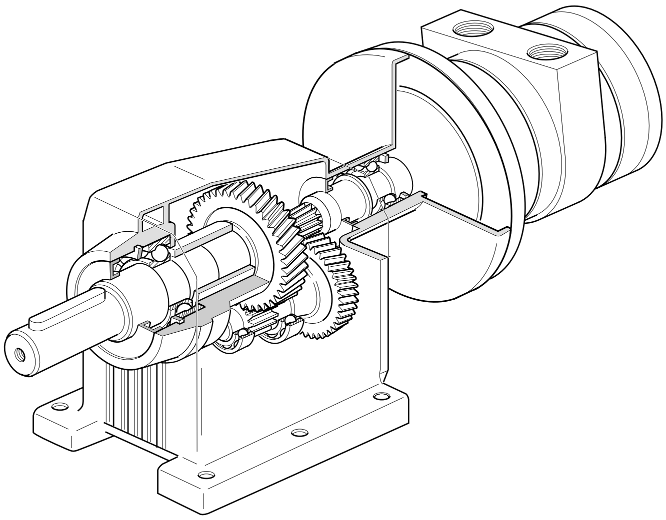
△	P1V-A160A0900, please refer to page 15
▲ 1	P1V-A160B0120, please refer to page 16
▲ 2	P1V-A160B0060, please refer to page 16
▲ 3	P1V-A160B0019, please refer to page 16
▲ 4	P1V-A160B0010, please refer to page 16
○	P1V-A260A0700, please refer to page 15
● 1	P1V-A260B0120, please refer to page 16
● 2	P1V-A260B0060, please refer to page 16
● 3	P1V-A260B0019, please refer to page 16
□	P1V-A360A0600, please refer to page 15
■ 1	P1V-A360B0096, please refer to page 16
■ 2	P1V-A360B0048, please refer to page 16

Choice of motors with helical gears

Torque at maximum power (Nm)



Speed at maximum power (rpm)



Helical gears are characterised by high efficiency. Several reduction stages permit relatively high gear ratios. Central output shaft and simple installation with flange or foot.

Oil-bath gearboxes mean that the installation position must be decided in advance. The installation position determines the volume of oil in the gearbox and location of oil filling and drain plugs.

- High efficiency
- Simple flange or foot installation
- Relatively low price

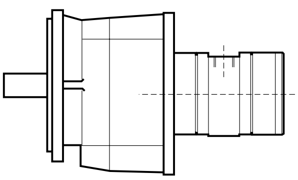
- – Installation position must be chosen in advance
- – Higher weight than planetary or worm drive gears.

Air motors in diagram above

△	P1V-A160A0900, please refer to page 15
▲ 1	P1V-A160•0066••, Choose installation below
▲ 2	P1V-A160•0032••, Choose installation below
▲ 3	P1V-A160•0014••, Choose installation below
▲ 4	P1V-A160•0008••, Choose installation below
▲ 5	P1V-A160•0004••, Choose installation below
▲ 6	P1V-A160•0003••, Choose installation below
○	P1V-A260A0700, please refer to page 15
● 1	P1V-A260•0080••, Choose installation below
● 2	P1V-A260•0052••, Choose installation below
● 3	P1V-A260•0025••, Choose installation below
● 4	P1V-A260•0011••, Choose installation below
● 5	P1V-A260•0006••, Choose installation below
● 6	P1V-A260•0003••, Choose installation below
□	P1V-A360A0600, please refer to page 15
■ 1	P1V-A360•0105••, Choose installation below
■ 2	P1V-A360•0052••, Choose installation below
■ 3	P1V-A360•0025••, Choose installation below
■ 4	P1V-A360•0013••, Choose installation below
■ 5	P1V-A360•0006••, Choose installation below
■ 6	P1V-A360•0003••, Choose installation below

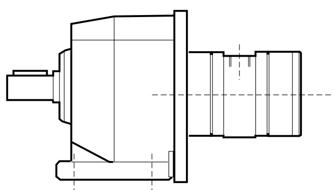
Installation, flange mounting

Please refer to page 18



Installation, foot mounting

Please refer to page 19



Technical data

Working pressure	Max 7 bar
Working temperature	-30 °C to +100 °C
Medium	40 µm filtered air with or without oil mist

Design data

Basic motor

- Robust design with few components
- Spring loaded vanes as standard give good starting and low speed characteristics
- Keyed output shaft
- Reversible operation

Planetary gear

- Precision made gears with efficiency over 95%
- Sealed, permanently grease lubrication gives free installation position
- Compact installation and low weight
- Central output shaft

Helical gear

- Two versions available, with flange or foot
- High efficiency, 90 to 95%
- Oil-bath gearboxes mean that the installation position must be decided in advance. The installation position determines the volume of oil in the gearbox and location of oil filling and drain plugs.

Worm gear

- Available in three versions, for installation with left-hand flange, right-hand flange or foot mounting.
- Compact size and low weight
- Self-locking in higher ratios
- Output shaft at 90° angle to motor spindle
- Hollow output shaft with key slot. Single-ended or "through" twin shaft as options.
- Oil-bath gearboxes mean that the installation position must be decided in advance. The installation position determines the volume of oil in the gearbox and location of oil filling and drain plugs.

Table and diagram data

All values are typical values, with a tolerance of ±10%

Options

Other variants on request.

Material specification

Basic motor

Housing	Cast iron, synthetic paint, black
Spindle, rotor	High grade steel
Key	Hardened steel
O-rings	Nitrile rubber, NBR
Screws	Zinc-coated steel

Planetary gear

Housing	Alloy steel, synthetic paint, black
Shaft	High grade steel
Key	Hardened steel
Shaft seals	Nitrile rubber, NBR
Screws	Zinc-coated steel

Helical gear

Housing	Aluminium or cast iron, synthetic paint, black
Shaft	High grade steel
Key	Hardened steel
Shaft seals	Nitrile rubber, NBR
Screws	Zinc-coated steel

Worm drive gear

Housing	Aluminium or cast iron, synthetic paint, black
Shaft	High grade steel
Key	Hardened steel
Pinion	Chill cast phosphor bronze
Worm	Alloyed, hardened steel
Shaft seals	Nitrile rubber, NBR
Screws	Zinc-coated steel

Accessories

Keyed shafts for worm gear

Shaft	High grade steel
Key	Hardened steel

Order key

P1V-A 160 E 0 066 B6

	Motor size
160	1600 W
260	2600 W
360	3600 W

	Function
A	Basic motor without gear-box, keyed shaft
B	With planetary gear, keyed shaft
D	With helical gear, flange, keyed shaft
E	With helical gear, foot, keyed shaft
F	With worm gear, flange left, hollow shaft with key slot
G	With worm gear, flange right, hollow shaft with key slot
H	With worm gear, foot, hollow shaft with key slot

	Free/max speed per min
000 | **900**	0000 | 9000

	Installation position
-	Free installation
	Horizontal installation
B3	Installation position B3
B5	Installation position B5
B6	Installation position B6
B7	Installation position B7
B8	Installation position B8
	Vertical installation
V1	Installation position V1
V3	Installation position V3
V5	Installation position V5
V6	Installation position V6

	Air motor family
P1V-A	Large vane motor, reversible

	Optional functions
0	Standard
C	Lubrication-free, continuous operation

Possible combinations

Please refer to pages 15 to 24

A: Free installation positions, basic motor

Please refer to page 15

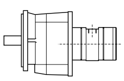
B: Free installation positions, planetary gear

Please refer to page 16

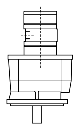
D: Free installation positions, helical gear and flange

Please refer to page 18

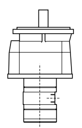
B5



V1



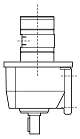
V3



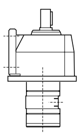
E: Installation positions, helical gear and foot

Please refer to page 19

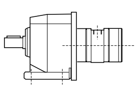
V5



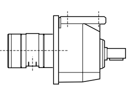
V6



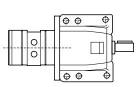
B3



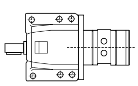
B8



B7



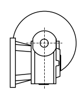
B6



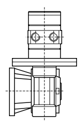
F: Installation pos., worm gear and flange, left-hand

Please refer to page 22

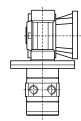
B3



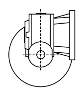
V6



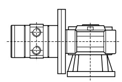
V5



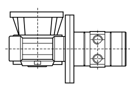
B8



B6



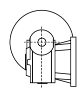
B7



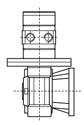
G: Installation pos., worm gear and flange, right-hand

Please refer to page 23

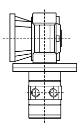
B3



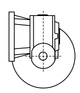
V6



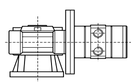
V5



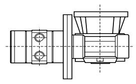
B8



B6



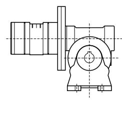
B7



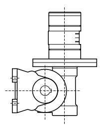
H: Installation positions, worm gear and foot

Please refer to page 24

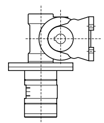
B3



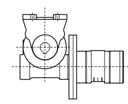
V6



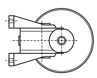
V5



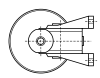
B8



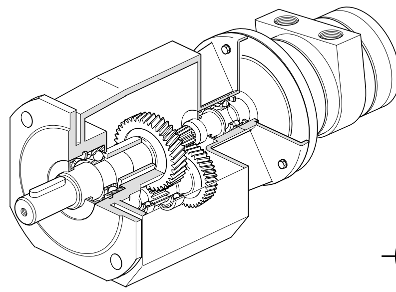
B6

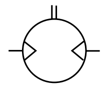


B7



NOTE! All technical data are based on a working pressure of 6 bar.





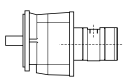
D: Motor with helical gear, flange mounting

Max power kW	Max speed rpm	Speed at max power rpm	Torque at max power Nm	Min start torque Nm	Max permitted torque Nm	Air consumption at max power l/s	Connection	Min pipe ID inlet/outlet mm	Weight Kg	Order code
Series P1V-A160										
1,600	660	590	23	35	70	32	G1/2	19/19	9,5	**P1V-A160D0066••**
1,600	320	280	49	74	125	32	G1/2	19/19	11,5	**P1V-A160D0032••**
1,600	140	120	113	170	200	32	G1/2	19/19	14,0	**P1V-A160D0014••**
1,600	80	70	200	300	430	32	G1/2	19/19	29,0	**P1V-A160D0008••**
1,600	37	32	415	623	750	32	G1/2	19/19	42,5	**P1V-A160D0004••**
1,600	25	20	685	1028	1200	32	G1/2	19/19	62,5	**P1V-A160D0003••**
Series P1V-A260										
2,600	800	565	42	63	70	60	G3/4	19/25	13,8	**P1V-A260D0080••**
2,600	520	365	65	98	125	60	G3/4	19/25	15,8	**P1V-A260D0052••**
2,600	250	175	135	203	200	60	G3/4	19/25	18,5	**P1V-A260D0025••**
2,600	110	80	302	453	430	60	G3/4	19/25	34,0	**P1V-A260D0011••**
2,600	60	40	565	848	750	60	G3/4	19/25	47,0	**P1V-A260D0006••**
2,600	30	20	1020	1530	1200	60	G3/4	19/25	67,0	**P1V-A260D0003••**
Series P1V-A360										
3,600	1050	625	52	78	125	80	G1	22/32	24,5	**P1V-A360D0105••**
3,600	520	310	105	158	125	80	G1	22/32	24,5	**P1V-A360D0052••**
3,600	250	150	215	323	430	80	G1	22/32	42,5	**P1V-A360D0025••**
3,600	125	74	440	660	750	80	G1	22/32	54,5	**P1V-A360D0013••**
3,600	62	37	850	1275	1200	80	G1	22/32	75,5	**P1V-A360D0006••**
3,600	30	18	1800	2700	4000	80	G1	22/32	149,5	**P1V-A360D0003••**

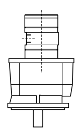
Note!
•• specify installation position in the order no. as in the illustrations below.
Example: P1V-A160D0066B5

D: Installation positions, helical gears and flange

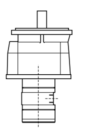
B5



V1



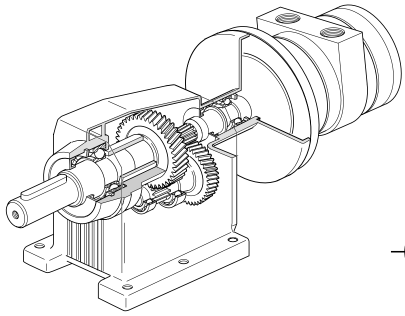
V3

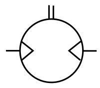


Torque and power graphs, please refer to pages 20-21

Permitted shaft loadings, please refer to page 38

Dimensions, please refer to pages 31





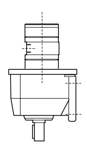
E: Motor with helical gear, foot mounting

Max power	Max speed	Speed at max power	Torque at max power	Min start torque	Max permitted torque	Air consumption at max power	Connection	Min pipe ID inlet/ outlet	Weight	Order code
kW	rpm	rpm	Nm	Nm	Nm	l/s		mm	Kg	
Series P1V-A160										
1,600	660	590	23	35	70	32	G1/2	19/19	9,8	**P1V-A160E0066••**
1,600	320	280	49	74	125	32	G1/2	19/19	11,5	**P1V-A160E0032••**
1,600	140	120	113	170	200	32	G1/2	19/19	14,5	**P1V-A160E0014••**
1,600	80	70	200	300	430	32	G1/2	19/19	31,2	**P1V-A160E0008••**
1,600	37	32	415	623	750	32	G1/2	19/19	44,5	**P1V-A160E0004••**
1,600	25	20	685	1028	1200	32	G1/2	19/19	65,2	**P1V-A160E0003••**
Series P1V-A260										
2,600	800	565	42	63	70	60	G3/4	19/25	13,8	**P1V-A260E0080••**
2,600	520	365	65	98	125	60	G3/4	19/25	15,8	**P1V-A260E0052••**
2,600	250	175	135	203	200	60	G3/4	19/25	18,5	**P1V-A260E0025••**
2,600	110	80	302	453	430	60	G3/4	19/25	34,0	**P1V-A260E0011••**
2,600	60	40	565	848	750	60	G3/4	19/25	47,0	**P1V-A260E0006••**
2,600	30	20	1020	1530	1200	60	G3/4	19/25	67,0	**P1V-A260E0003••**
Series P1V-A360										
3,600	1050	625	52	78	125	80	G1	22/32	24,5	**P1V-A360E0105••**
3,600	520	310	105	158	125	80	G1	22/32	24,5	**P1V-A360E0052••**
3,600	250	150	215	323	430	80	G1	22/32	42,5	**P1V-A360E0025••**
3,600	125	74	440	660	750	80	G1	22/32	54,5	**P1V-A360E0013••**
3,600	62	37	850	1275	1200	80	G1	22/32	75,5	**P1V-A360E0006••**
3,600	30	18	1800	2700	4000	80	G1	22/32	149,5	**P1V-A360E0003••**

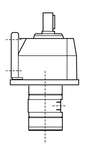
Note!
•• specify installation position in the order no. as in the illustrations below.
Example: P1V-A160E0066V5

E: Installation positions, helical gears and flange

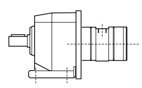
V5



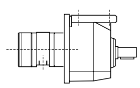
V6



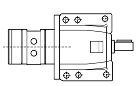
B3



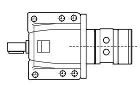
B8



B7



B6

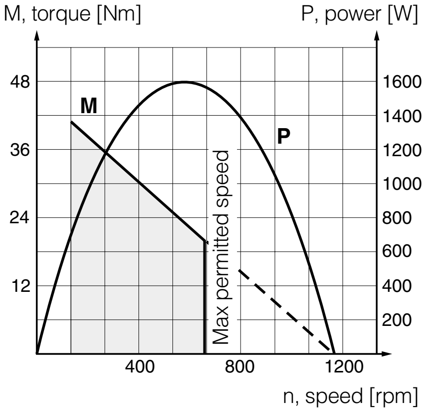


Torque and power graphs, please refer to pages 20-21

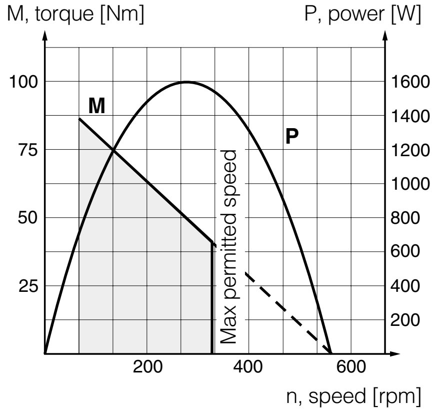
Permitted shaft loadings, please refer to page 38

Dimensions, please refer to pages 32

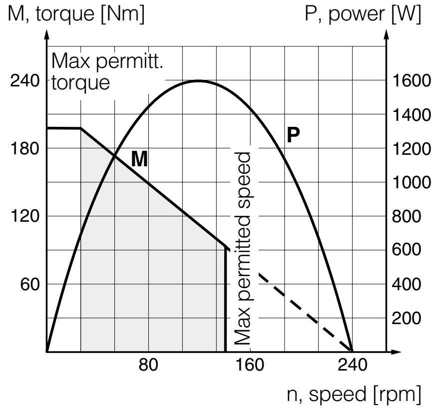
P1V-A160D0066••
P1V-A160E0066••



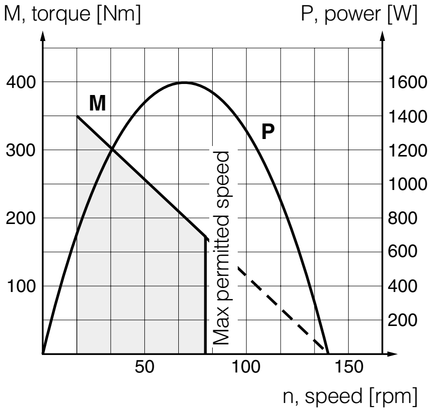
P1V-A160D0032••
P1V-A160E0032••



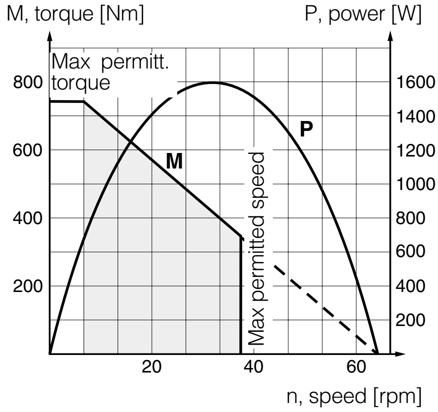
P1V-A160D0014••
P1V-A160E0014••



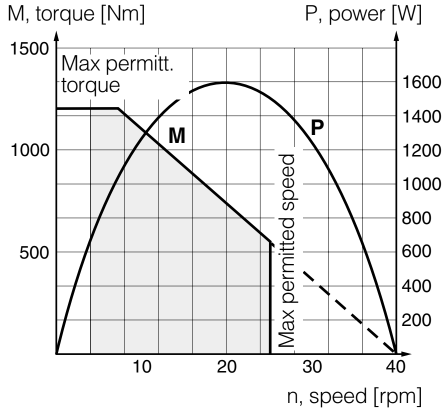
P1V-A160D0008••
P1V-A160E0008••



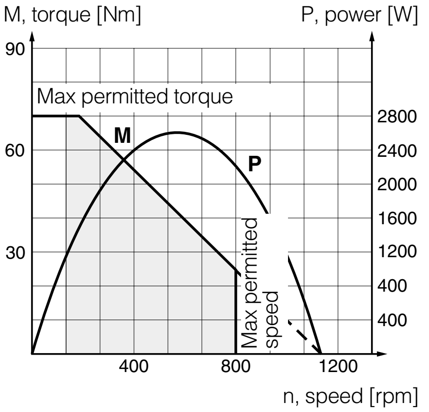
P1V-A160D0004••
P1V-A160E0004••



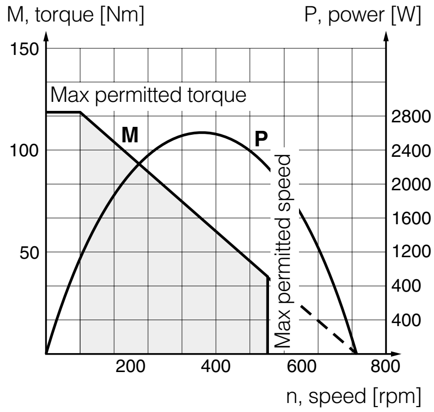
P1V-A160D0003••
P1V-A160E0003••



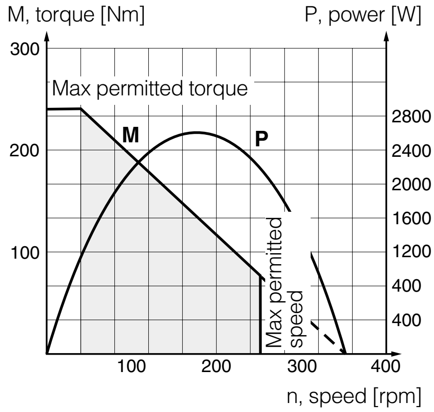
P1V-A260D0080••
P1V-A260E0080••



P1V-A260D0052••
P1V-A260E0052••

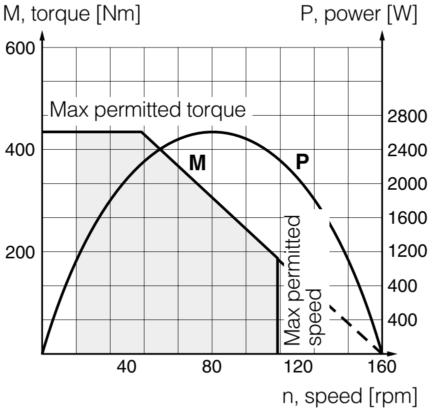


P1V-A260D0025••
P1V-A260E0025••

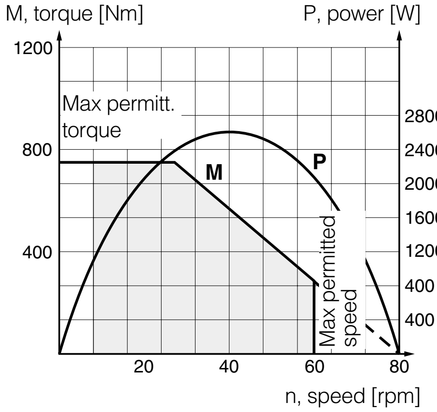


Working range of motor

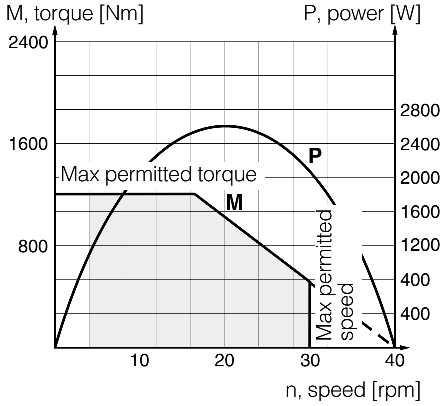
P1V-A260D0011••
P1V-A260E0011••



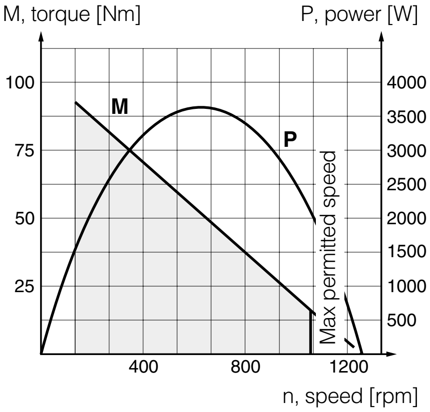
P1V-A260D0006••
P1V-A260E0006••



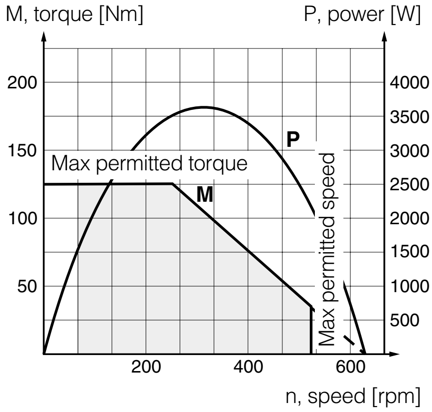
P1V-A260D0003••
P1V-A260E0003••



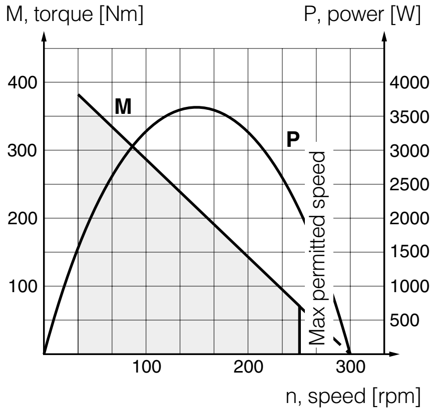
P1V-A360D0105••
P1V-A360E0105••



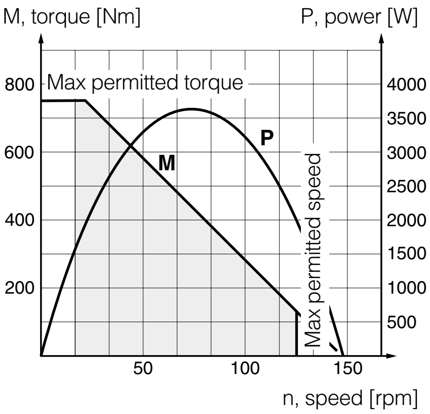
P1V-A360D0052••
P1V-A360E0052••



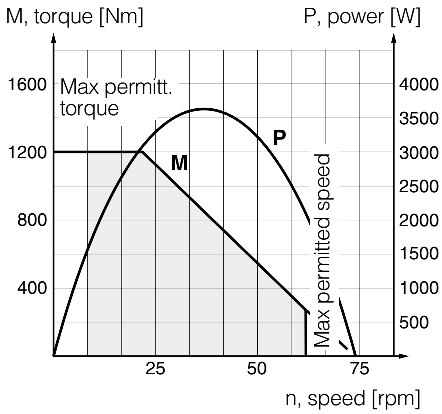
P1V-A360D0025••
P1V-A360E0025••



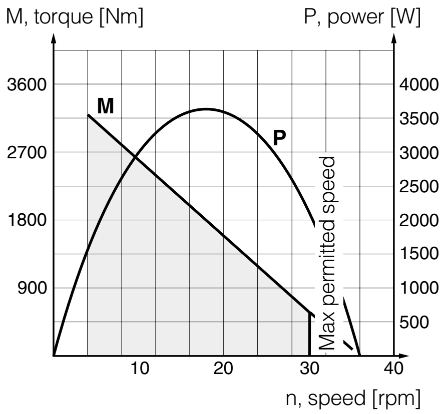
P1V-A360D0013••
P1V-A360E0013••



P1V-A360D0006••
P1V-A360E0006••



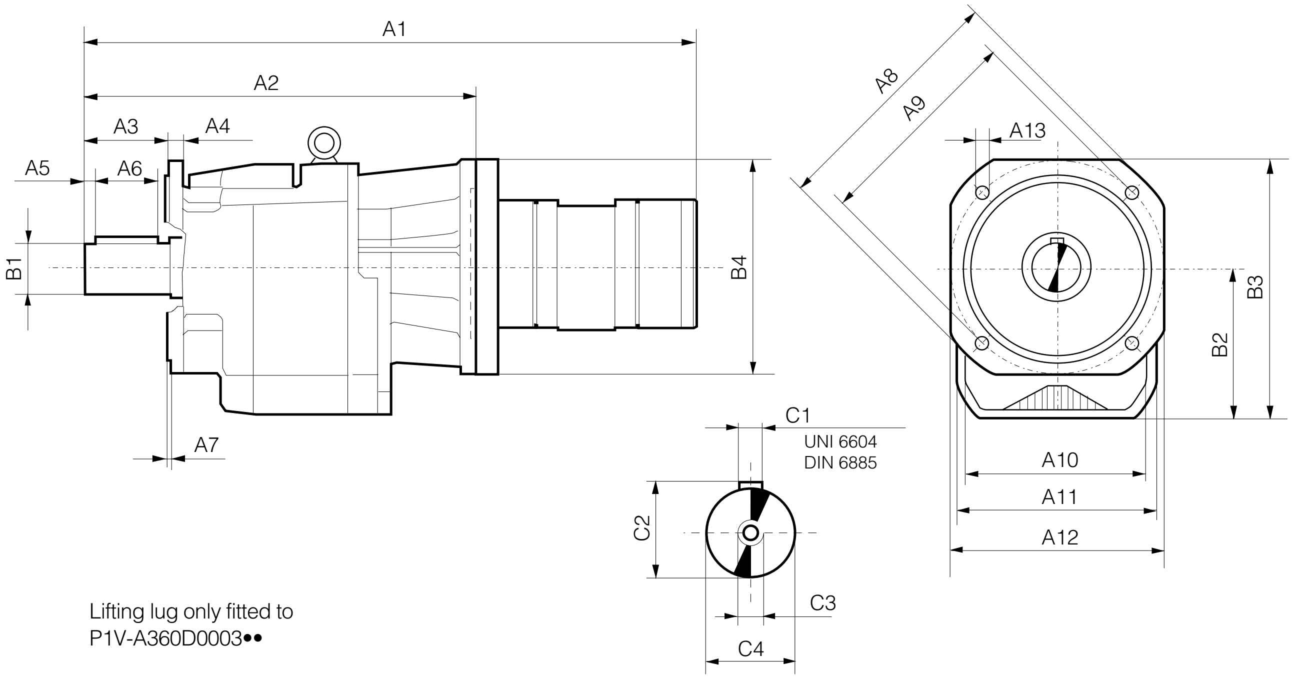
P1V-A360D0003••
P1V-A360E0003••



Working range of motor

Dimensions (mm)

Motor with helical gear, flange mounting



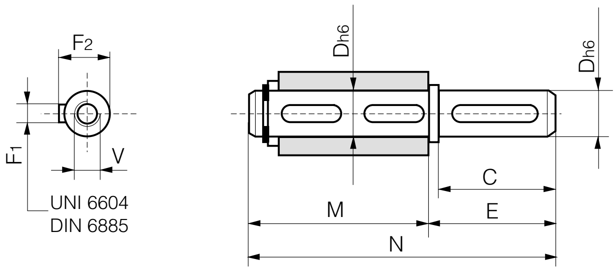
Lifting lug only fitted to
P1V-A360D0003••

Order code	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	B1	B2	B3
P1V-A160D0066••	370,5	244	40	8	5	30	3,0	140	115	95f7	95	105	9,5	20	82	138,0
P1V-A160D0032••	399,5	273	50	10	5	40	3,5	160	130	110f7	110	135	9,5	25	92	159,5
P1V-A160D0014••	433,5	307	60	12	5	50	3,5	200	165	130f7	130	150	11,5	30	108	183,0
P1V-A160D0008••	463,5	337	70	13	5	60	4,0	250	215	180 f7	155	210	14,0	35	128	233,0
P1V-A160D0004••	559,5	433	80	16	5	70	5,0	300	265	230 f7	185	260	14,0	40	152	282,0
P1V-A160D0003••	601,5	475	100	16	5	90	5,0	300	265	230 f7	210	260	14,0	50	190	320,0
P1V-A260D0080••	423,0	264	40	8	5	30	3,0	140	115	95f7	95	105	9,5	20	82	138,0
P1V-A260D0052••	451,0	292	50	10	5	40	3,5	160	130	110f7	110	135	9,5	25	92	159,5
P1V-A260D0025••	486,0	327	60	12	5	50	3,5	200	165	130f7	130	150	11,5	30	108	183,0
P1V-A260D0011••	515,0	356	70	13	5	60	4,0	250	215	180 f7	155	210	14,0	35	128	233,0
P1V-A260D0006••	612,0	453	80	16	5	70	5,0	300	265	230 f7	185	260	14,0	40	152	282,0
P1V-A260D0003••	634,0	475	100	16	5	90	5,0	300	265	230 f7	210	260	14,0	50	190	320,0
P1V-A360D0105••	458,0	292	50	10	5	40	3,5	160	130	110f7	110	135	9,5	25	92	159,5
P1V-A360D0052••	458,0	292	50	10	5	40	3,5	160	130	110f7	110	135	9,5	25	92	159,5
P1V-A360D0025••	521,0	356	70	13	5	60	4,0	250	215	180 f7	155	210	14,0	35	128	233,0
P1V-A360D0013••	547,0	382	80	16	5	70	5,0	300	265	230 f7	185	260	14,0	40	152	282,0
P1V-A360D0006••	640,0	475	100	16	5	90	5,0	300	265	230 f7	210	260	14,0	50	190	320,0
P1V-A360D0003••	699,0	534	140	20	15	110	5,0	400	350	300 f7	320	350	18,0	80	247	424,0

Order code	B4	C1	C2	C3	C4
P1V-A160D0066••	160	6x6x30	22,5	M8x19	20 h6
P1V-A160D0032••	160	8x7x40	28,0	M8x19	25 h6
P1V-A160D0014••	160	8x7x50	33,0	M10x22	30 h6
P1V-A160D0008••	160	10x8x60	38,0	M10x22	35 h6
P1V-A160D0004••	160	12x8x70	43,0	M12x28	40 h6
P1V-A160D0003••	160	14x9x90	53,5	M16x36	50 h6
P1V-A260D0080••	200	6x6x30	22,5	M8x19	20 h6
P1V-A260D0052••	200	8x7x40	28,0	M8x19	25 h6
P1V-A260D0025••	200	8x7x50	33,0	M10x22	30 h6
P1V-A260D0011••	200	10x8x60	38,0	M10x22	35 h6
P1V-A260D0006••	200	12x8x70	43,0	M12x28	40 h6
P1V-A260D0003••	200	14x9x90	53,5	M16x36	50 h6
P1V-A360D0105••	200	8x7x40	28,0	M8x19	25 h6
P1V-A360D0052••	200	8x7x40	28,0	M8x19	25 h6
P1V-A360D0025••	200	10x8x60	38,0	M10x22	35 h6
P1V-A360D0013••	200	12x8x70	43,0	M12x28	40 h6
P1V-A360D0006••	200	14x9x90	53,5	M16x36	50 h6
P1V-A360D0003••	200	22x14x110	85,0	M20x42	80 h6

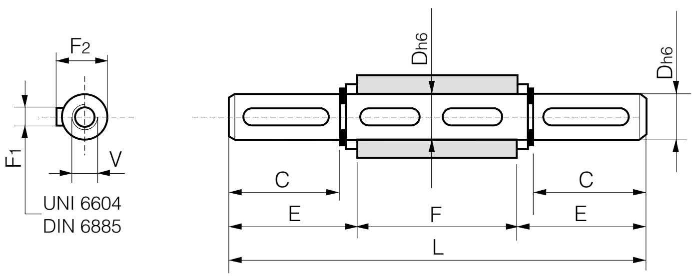
Dimensions (mm)

Shaft with keys for P1V-A motor with worm gear



Single-ended shaft

Order code	C	D	E	F1	F2	M	N	V
9121510242	60	25	65	8	28,0	89	154	M8x20
9121510243	60	25	65	8	28,0	127	192	M8x20
9121510244	60	35	65	10	38,0	149	214	M10x25
9121510245	75	42	80	12	45,0	164	244	M12x32
9121510246	80	45	85	14	48,5	176	261	M12x32



Double-ended shaft

Order code	C	D	E	F	F1	F2	L	V
9121510247	60	25	63,20	82	8	28,0	208,4	M8x20
9121510248	60	25	63,20	120	8	28,0	246,4	M8x20
9121510249	60	35	64,00	140	10	38,0	268,0	M10x25
9121510250	75	42	79,25	155	12	45,0	313,5	M12x32
9121510251	80	45	84,75	165	14	48,5	334,5	M12x32

NOTE!
Please refer to the table on page 25 for suitable motors with worm drive gears.

Permitted shaft loadings

Basic motors

Max permitted load on output shaft for basic motors (based on 10,000,000 revolutions of the output shaft, with 90% probable service life for ball bearings.

	F_{ax} N	F_{rad} N	a mm
P1V-A160A0900	600	1000	15
P1V-A260A0700	700	1400	20
P1V-A360A0600	900	1900	25

F_{rad} = Radial loading (N)
F_{ax} = Axial loading (N)

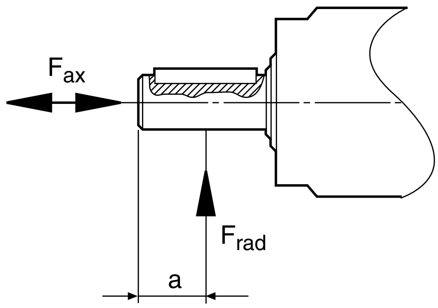


Fig. 1: Loading on output shaft.

Motors with planetary gears

The following calculations should be used to determine the loading on the output shaft bearing, if a service life of 10,000,000 revolutions of the output shaft is to be obtained with 90% probability.

F_{ax} = max $0,24 \times F_{rad}$

$M = \pm F_{ax} \times r \pm F_{rad} \times (X + K)$

Where M and K are found in the table below

	M Nm	K N
P1V-A160B120	2651	0,031
P1V-A160B060	2651	0,031
P1V-A160B019	7385	0,040
P1V-A160B010	7385	0,040
P1V-A260B120	2651	0,031
P1V-A260B060	2651	0,031
P1V-A260B019	7385	0,040
P1V-A360B096	7385	0,040
P1V-A360B048	7385	0,040

M Max. torque loading on output shaft (Nm)
r Distance from centre of output shaft to axial load (m)
X Distance from collar to radial load (m)
F_{rad} Radial loading (N)
F_{ax} Axial loading (N)

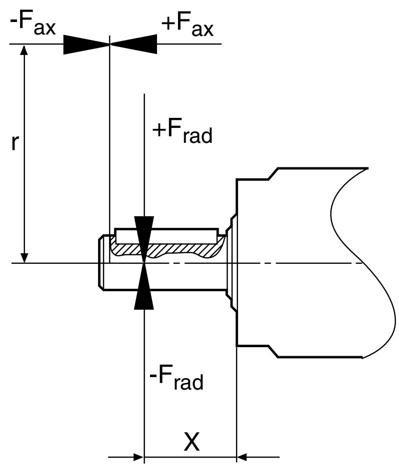


Fig 2: Load and braking torque on output shaft of planetary gear

Motors with helical gear or worm gear

Radial forces

Depending on the application, the drive shaft of the gearbox can be subjected to various radial forces, which can be calculated as follows:

$F_{rad} = 2000 \times M \times K_r / d$

F_{rad}	Radial force (N)
M	Torque (Nm)
d	Diameter of wheel, pulley, sprocket or gear wheel (mm)
Kr = 1	Sprocket constant
Kr = 1.25	Gear wheel constant
Kr = 1.5 - 2.5	Vee-belt pulley constant

Depending on the point of application of the force (please refer to the adjacent figure), the following two cases are found:

a. The force is applied to the centre of the output shaft, as in figure 3. This value can be read off on the table below, where consideration must be given to the following:

$F_{radc} \leq F_{rt}$

b. The force is applied at a distance x, as in figure 4. This value can be calculated as follows:

$F_{radx} = F_{rt} \times a / (b + X)$ gäller för $L/2 < X < c$

F_{rt}	Permissible radial force on centre of output-shaft (N)
a	Gear constant
b	Gear constant
c	Gear constant
X	Distance from shoulder on shaft to point of application of force (mm)

All values are found in the table below.
The following should be considered, however:

$F_{radc} \leq F_{radx}$

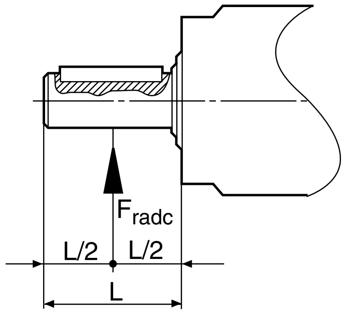


Fig. 3: Force applied at centre of shaft

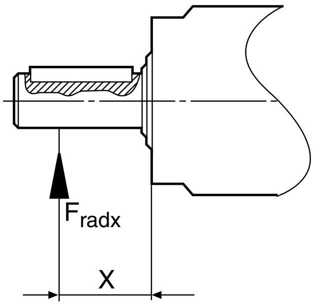


Fig. 4: Force applied at distance X

Axial forces

The maximum permissible axial force can be calculated as follows:

$F_{ax} = F_{rt} \times 0,2$

Table, Motor with helical gear

Motor	a	b	c	F_{rt} N
P1V-A160■0066••	46,0	26,0	450	1130
P1V-A160■0032••	54,5	29,5	550	2480
P1V-A160■0014••	60,5	30,5	750	4710
P1V-A160■0008••	69,0	34,0	850	6620
P1V-A160■0004••	80,5	40,5	900	10000
P1V-A160■0003••	98,5	48,5	1000	16000
P1V-A260■0080••	46,0	26,0	450	660
P1V-A260■0052••	54,5	29,5	550	2110
P1V-A260■0025••	60,5	30,5	750	3850
P1V-A260■0011••	69,0	34,0	850	5660
P1V-A260■0006••	80,5	40,5	900	10000
P1V-A260■0003••	98,5	48,5	1000	16000
P1V-A360■0105••	54,5	29,5	550	1640
P1V-A360■0052••	54,5	29,5	550	2110
P1V-A360■0025••	69,0	34,0	850	4280
P1V-A360■0013••	80,5	40,5	900	6890
P1V-A360■0006••	98,5	48,5	1000	16000
P1V-A360■0003••	131,0	61,0	1500	35000

Table, Motor with worm gear

Motor	a	b	F_{rt} N
P1V-A160■0043••	99	69	3450
P1V-A160■0020••	132	102	4700
P1V-A160■0010••	147	117	7000
P1V-A160■0008••	147	117	7000
P1V-A260■0050••	99	69	3450
P1V-A260■0022••	147	117	7000
P1V-A260■0013••	147	117	7000
P1V-A260■0008••	182	142	13800
P1V-A360■0050••	132	102	4700
P1V-A360■0022••	147	117	7000
P1V-A360■0013••	171	134	8000
P1V-A360■0006••	182	142	13800

Service kits for basic motor

The following kits are available for the basic motors, consisting of vanes, O-rings and springs:

Service kit, vanes for intermittent lubrication-free operation

For motor	Order code
P1V-A160A0900	**9121720630**
P1V-A260A0700	**9121720631**
P1V-A360A0600	**9121720632**

Service kit, vanes for continuous lubrication-free operation, option "C"

For motor	Order code
P1V-A160AC900	**9121720633**
P1V-A260AC700	**9121720634**
P1V-A360AC600	**9121720635**

Pneumatic Division
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Fax: +43 1 892 4546

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Tel: +32 67 280 900
Fax: +32 67 280 999

Czech and Slovak Republic - Prague
Tel: +420-396-630 111
Fax: +420-396-630 415

Denmark - Ishøj
Tel: +45 43 560 400
Fax: +45 43 733 107

England - Cannock
Tel: +44 1543 456 000
Fax: +44 1543 456 001

Finland - Vantaa
Tel: +358 9 4767 31
Fax: +358 9 4767 3201

France - Evreux
Tel: +33 232 233 400
Fax: +33 232 289 807

Germany - Mettmann
Tel: +49 2104 137 0
Fax: +49 2104 137 500

Hungary - Budapest
Tel: +36 1 252 8137
Fax: +36 1 252 8129

Italy - Corsico, Milan
Tel: +39 02 4519 21
Fax: +39 02 4479 340

Netherlands - Oldenzaal
Tel: +31 541 585 000
Fax: +31 541 585 459

Norway - Langhus
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Tel: +48 22 8634 942
Fax: +48 22 8634 944

Spain - Madrid
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Fax: +34 91 675 7711

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P31P / P32P Series

Electronic Proportional Regulator

0 to 10 volt, 4 to 20 mA

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Man-Machine Interface

High Visibility LED Display

Easy to Read Characters

All Controls on the Same Face

Energy Saving

Low Watt Power Consumption

No Unnecessary Loss of Air in Steady State

Total Flexibility

User Friendly and Easily Accessible Software Controls

One Basic Unit Suits All Customer Requirements - 0-10V Control Signal Standard 4-20mA Control Signal Software Selectable

Modular Mounting

10 bar & 2 bar Version

Special Applications

Clean Line Design

Suitable for Washdown: IP65

Forced Exhaust Option Available

4 Output Signal Versions Available

Compact and Light Weight

40 & 60 mm Body Sizes

Light Weight Aluminum Bodies

Flexible Mounting Options

Stand-alone or Modular Mounting

Foot Bracket Mounting

DIN-Rail Mounting

Outstanding Performance

Very Fast Response Times

Full Flow Exhaust

Excellent Linearity

High Flow

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Generic Industries

The new Proportional Regulator is designed to quickly and accurately adjust and maintain a set output pressure.

The unit will operate regardless of flow, in response to an electronic control signal. The media can be compressed air or an inert gas.

Applications for this technology are virtually unlimited; from paint spray control, paper manufacturing and printing to weaving and laser cutting control; in fact anywhere that requires accurate remote pressure control.

Automation

In the field of general automation, the need to control processes or movement via electronic signals is of paramount importance. The Proportional Regulator unit provides the facility to incorporate pressure control into a fully integrated control system.

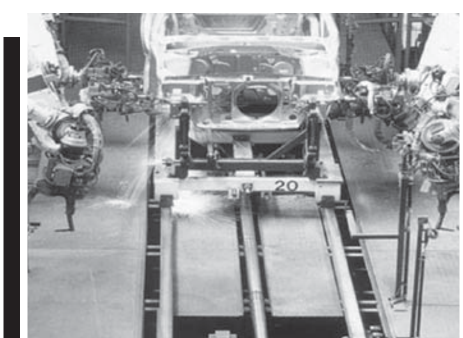
Packaging and Food

The Packaging and Food industry provides another ideal area for application of the Electronic Proportional Regulator, where fine control of tension on wrapping foils and paper is required. The degree of control and the ability to manually change parameters makes this unit ideally suited to the varying requirements of this industry.

Automotive

Applications for this innovative product in the Automotive industry can be seen in major manufacturers' "body-in-white" lines.

The control of clamping and welding forces during panel assembly is an ideal application, also accurate control in paint dipping and spraying can be achieved.



Why Proportional Technology?

The Difference Between Open or Closed Circuit Control

Standard pressure regulators go a long way towards meeting customers needs. In most cases these regulators work well in general pneumatic and automation applications. However, sometimes the application calls for more precise pressure control. The effects of time, cycling, input, back pressure or pressure and flow variation can all cause inconsistencies in pneumatic systems. Proportional Regulators are designed to eliminate those inconsistencies.

Open Control Circuit

In a normal pressure regulated control system, the inlet pressure (p1) is converted into the output pressure (p2) by the regulator. The set pressure (set value) is usually manually set by adjusting the control knob and in normal circumstances the regulator maintains the output pressure (actual value).

No facility for monitoring the output pressure is provided and there is consequently no way of checking that the set value and the actual value are the same. Also, no account is taken of external influences such as air consumption by the system, which can drastically alter the actual value.

Closed Loop Control Circuit

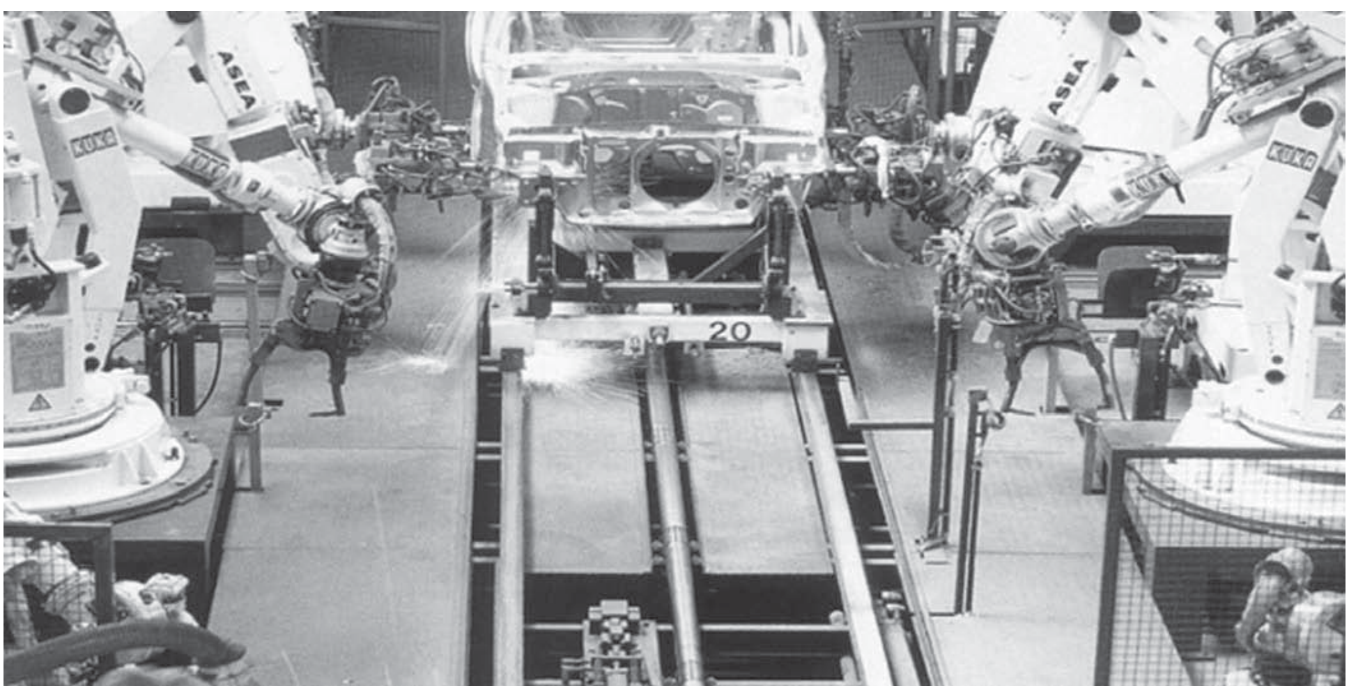
The input signal (Electronic Control Signal) is converted into the output value (P2 Output Pressure). This output value is continuously measured and compared with the input signal. If they are different, the unit adjusts the output value to correspond to the set value, to close the loop.

Proportional Pressure Regulators

The Proportional Regulators provide all the advantages of a closed circuit regulated system. When a set value is defined via the input signal (e.g. 0-10 V), the pressure regulator sets the corresponding output pressure (e.g. 0-150 PSI/0-10 bar). At the same time the integrated pressure sensor measures the actual pressure at the unit's outlet (actual value).

If the electronic regulation system finds that the actual value has deviated from the set value, it immediately corrects the actual value. This is a continuous process ensuring fast, accurate pressure regulation.

Typical Application in Automotive Body in White Welding Pressure Control



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P31P Series
Bottom exhaust

P32P Series
Bottom exhaust

Features

- Very fast response times
- Accurate output pressure
- Micro parameter settings
- Selectable I/O parameters
- Quick, full flow exhaust
- LED display indicates output pressure
- No air consumption in steady state
- Multiple mounting options
- Protection to IP65
- P31P flows to 19 dm^3/s (40 scfm)
- P32P flows to 57 dm^3/s (120 scfm)

Ordering Information

P 3 [ ] P A 1 [ ] A [ ] 2 [ ] [ ] 1 A

Body size	
Global Mini (1/4")	1
Global Compact (1/2")	2

Thread type	
BSPP	1
BSPT	2
NPT	9

Port size	
Global Mini (1/4")	2
Global Compact (1/2")	4

Version	
Bottom ported exhaust (NC)	A
Bottom ported forced exhaust (NO)*	E

* When the supply voltage is lost the unit will automatically exhaust the regulated pressure to 0 bar (atmospheric pressure)

Pressure Range	
0 - 2 bar (0-29 psig)	Z
0 - 10 bar (0-145 psig)	D

Power supply	
24 volts	2

Control Signal	
0-10 V†	V

† Factory setting is 0-10 V control signal. 4-20 mA control signal available via parameter 4 on keypad.

Output Signal	
Digital, PNP	D
PNP or 0-10V	P
NPN or 0-10V	N
4-20mA fixed	M

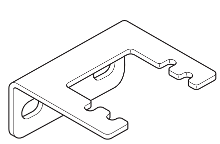
D) Digital PNP output only, no analog output selectable
P) Digital PNP and analogue 0-10V outputs selectable, by means of parameter 6. (Factory default 0-10V)
N) Digital NPN and analog 0-10 V outputs selectable by means of parameter 6. (Factory default 0-10V)
M) Analog 4-20mA output only.
Note: On all analog outputs the F.S. value can be adjusted by means of parameter 8

Input connector	
M12 (4 pin)	1

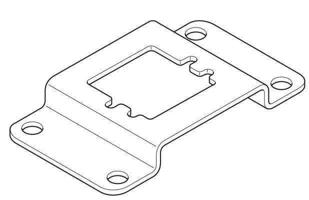
F
P31P / P23P
PAR15

P31P Mounting Brackets

Order Code	Description
P3HKA00ML	L-Bracket mounting kit
P3HKA00MC	Foot bracket mounting kit



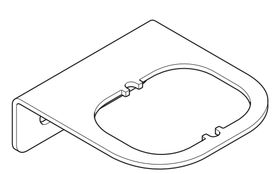
L-Bracket



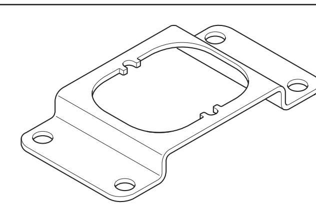
Foot Bracket

P32P Mounting Brackets

Order Code	Description
P3KKA00ML	L-Bracket mounting kit
P3KKA00MC	Foot bracket mounting kit



L-Bracket



Foot Bracket

Note:
These brackets fit both Proportional Regulators and Combined Soft Start & Dump Valves.

Cables

Order Code	Description
CB-M12-4P-2M	2 mtr. cable with moulded straight M12x1 connector

Technical Information

Working media

Compressed air or inert gasses, filtered to Min. 40µ, lubricated or non-lubricated, dried or un-dried, pressure dewpoint 3-5°C.

Operating pressure

	Max. Operating Pressure
2 bar unit	3 bar (43.5 PSI)
10 bar unit	10.5 bar (152 PSI)
Min. Operating Pressure	P2 Pressure + 0.5 bar

Pressure control range

Available in three pressure ranges, 0-2 bar, 0-7 bar or 0-10 bar. Pressure range can be changed through the software at all times. (parameter 19)

Temperature range

32°F to 122°F (0°C to 50°C)

Weight

P31P = 0.291 kg (0.64 lbs)
P32P = 0.645 kg (1.42 lbs)

Air consumption

No consumption in stable regulated situation.

Display

The regulator is provided with a digital display, indicating the output pressure, either in PSI or bar. The factory setting is as indicated on the label, can be changed through the software at all times (parameter 14).

Supply voltage

24 VDC +/- 10%

Power consumption

Max. 1.1W with unloaded signal outputs

Control signals

The electronic pressure regulator can be externally controlled through an analogue control signal of either 0-10V or 4-20mA. (parameter 4).

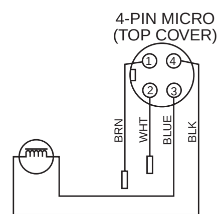
Output signals

As soon as the output pressure is within the signal band a signal is given of 24V DC, PNP Ri = 1 kOhm Outside the signal band this connection is 0V.

Connections

(In case of output signal (Option D)
Central M12 connector 4-pole

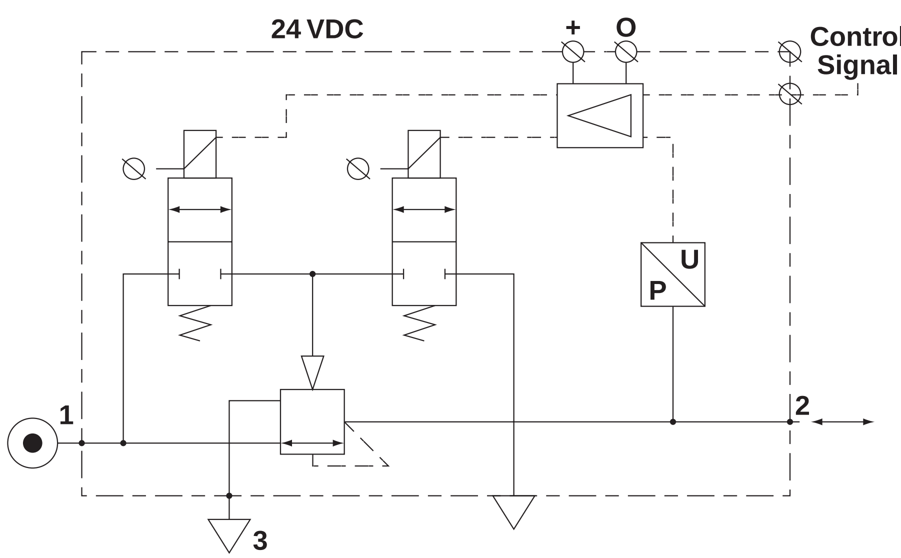
ISO 20401



The electrical connections are as follows:

Pin No.		Function	Color
1	24 V	Supply	Brown
2	0 to 10 V	Control Signal Ri = 100k Ω	White
	4 to 20mA	Control Signal Ri = 500k Ω	
3	0 V (GND)	Supply	Blue
4	24 V	Alarm Output Signal	Black

Schematic



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Technical Information

Dead Band
The dead band is preset at 1.3% of Full Scale*, adjustable via parameter 13.

Accuracy
Linearity: = < 0.3% of Full Scale.*

Proportional Band
The proportional band is preset at 10% of Full Scale.*

Fail Safe Operation
- If the P31P / P32P unit has an "0" or "A" in the 12th digit of the model number
  - When the supply voltage drops, the electronic control reverts to the fail safe mode. The last known output pressure air consumption. The digital display indicates the last known pressure setting.
  - When the supply voltage is reinstated to the correct level, the valve moves from the fail safe mode and the output pressure immediately follows the control signal requirement. The display indicates the actual output pressure.
  - Note: In the event of loss of both power and inlet pressure the unit will exhaust downstream pressure.
- If the P31P / P32P unit has an "E" in the 12th digit of the model number
  - When the supply voltage drops, the electronic control reverts to "Forced Exhaust Mode" and will automatically exhaust the downstream (regulated) pressure.
  - When the supply voltage is reinstated to the correct level the unit will return to normal operation and follows the control signal requirement. The display indicates the actual pressure.
- If the unit has been programmed in manual mode (not with a control signal) the unit will EXHAUST and the regulator will need to be reset when power is applied.

Full Exhaust
Complete exhaust of the regulator is defined as P2 ≤ 1% Full Scale

* Full Scale (F.S.)
For 2 bar (29 psig) versions this will be 2 barr (29 psig), for the 10 bar (145 psig) version full scale will be 10 bar (145 psig).

Degree of Protection
IP65

EU Conformity
CE: standard
EMC: according to directive 89/336/EEC
The new pressure regulator is in accordance with:

EN 61000-6-1:2001	**EN 61000-6-2:2001**
EN 61000-6-3:2001	**EN 61000-6-4:2001**

These standards ensure that this unit meets the highest level of EMC protection.

Mounting Position
Preferably vertical, with the cable gland on top.

Materials: P31P & P32P
- Magnet Core ....Steel
- Solenoid Valve Poppet .... FPM
- Solenoid Valve Housing .... Techno Polymer
- Regulator Body (P31P & P32P versions) .... Aluminium
- Regulator Top Housing ....Nylon
- Valve Head ....Brass & NBR
- Remaining Seals .... NBR

Advanced Functionality

Pilot valve protection
When the required output pressure can not be achieved because of a lack of input pressure the unit will open fully and will display NoP. Approximately every 10 seconds the unit will retry. The output pressure will then be approximately equal to the inlet pressure. As soon as the input pressure is back on the required level, the normal control function follows.

Safety exhaust
Should the **control signal** fall below 0.1 volts the valve will automatically dump downstream system pressure .

Input protection
The unit has built-in protection against failure and burnout resulting from incorrect input value, typically:

The 24VDC supply is incorrectly connected to the setpoint input, the display will show 'OL', as an overload indication. The unit will need to be rewired and when correctly connected will operate normally.

The overload indicator 'OL' will also appear should the wrong input value be applied or the wrong input value be programmed: 4 - 20m instead of 0 - 10V. To correct this a different set point value should be input or the unit reprogrammed to correct the set point value acceptance. (via parameter 4).

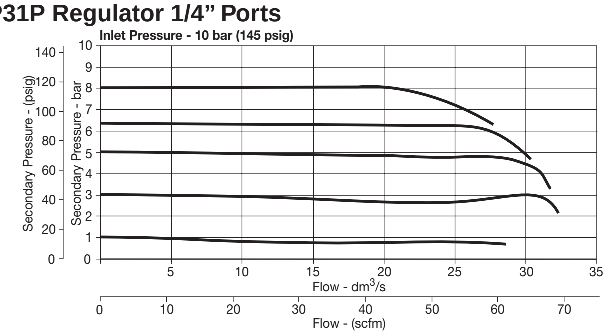
Response time	P31P	P32P
2 to 4 bar	25 msecs	35 msecs
1 to 6 bar	55 msecs	135 msecs
4 to 2 bar	70 msecs	85 msecs
6 to 1 bar	80 msecs	225 msecs

To fill volume of:
100cm^3 - P31P
330cm^3 - P32P
connected to the outlet of the regulator.

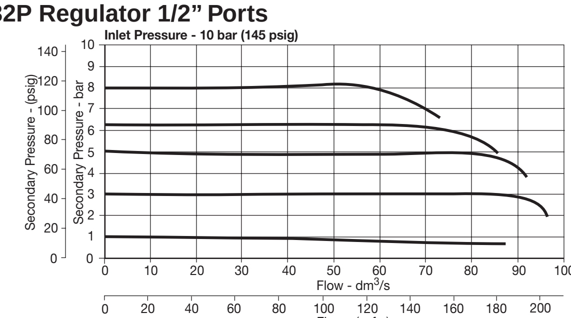
Settings
The regulator is pre-set at the factory. If required, adjustments can be made.

Flow Charts

P31P Regulator 1/4" Ports



P32P Regulator 1/2" Ports



Parker Hannifin Corporation
Pneumatic Division
Richland, Michigan
www.parker.com/pneumatics

Micropower, 3-Axis, ±2 *g*/±4 *g*/±8 *g* Digital Output MEMS Accelerometer

Data Sheet **ADXL362**

FEATURES

Ultralow power
- **Power can be derived from coin cell battery**
- **1.8 μA @ 100 Hz ODR, 2.0 V supply**
- **3.0 μA @ 400 Hz ODR, 2.0 V supply**
- **270 nA motion activated wake-up mode**
- **10 nA standby current**

High resolution: 1 m*g*/LSB

Built-in features for system-level power savings:
- **Adjustable threshold sleep/wake modes for motion activation**
- **Autonomous interrupt processing, without need for microcontroller intervention, to allow the rest of the system to be turned off completely**
- **Deep embedded FIFO minimizes host processor load**
- **Awake state output enables implementation of standalone, motion activated switch**

Low noise down to 175 μ*g*/√Hz

Wide supply and I/O voltage ranges: 1.6 V to 3.5 V
- **Operates off 1.8 V to 3.3 V rails**

Acceleration sample synchronization via external trigger

On-chip temperature sensor

SPI digital interface

Measurement ranges selectable via SPI command

Small and thin 3 mm × 3.25 mm × 1.06 mm package

APPLICATIONS

Hearing aids

Home healthcare devices

Motion enabled power save switches

Wireless sensors

Motion enabled metering devices

GENERAL DESCRIPTION

The ADXL362 is an ultralow power, 3-axis MEMS accelerometer that consumes less than 2 μA at a 100 Hz output data rate and 270 nA when in motion triggered wake-up mode. Unlike accelerometers that use power duty cycling to achieve low power consumption, the ADXL362 does not alias input signals by undersampling; it samples the full bandwidth of the sensor at all data rates.

The ADXL362 always provides 12-bit output resolution; 8-bit formatted data is also provided for more efficient single-byte transfers when a lower resolution is sufficient. Measurement ranges of ±2 *g*, ±4 *g*, and ±8 *g* are available, with a resolution of 1 m*g*/LSB on the ±2 *g* range. For applications where a noise level lower than the normal 550 μ*g*/√Hz of the ADXL362 is desired, either of two lower noise modes (down to 175 μ*g*/√Hz typical) can be selected at minimal increase in supply current.

In addition to its ultralow power consumption, the ADXL362 has many features to enable true system level power reduction. It includes a deep multimode output FIFO, a built-in micropower temperature sensor, and several activity detection modes including adjustable threshold sleep and wake-up operation that can run as low as 270 nA at a 6 Hz (approximate) measurement rate. A pin output is provided to directly control an external switch when activity is detected, if desired. In addition, the ADXL362 has provisions for external control of sampling time and/or an external clock.

The ADXL362 operates on a wide 1.6 V to 3.5 V supply range, and can interface, if necessary, to a host operating on a separate, lower supply voltage. The ADXL362 is available in a 3 mm × 3.25 mm × 1.06 mm package.

FUNCTIONAL BLOCK DIAGRAM

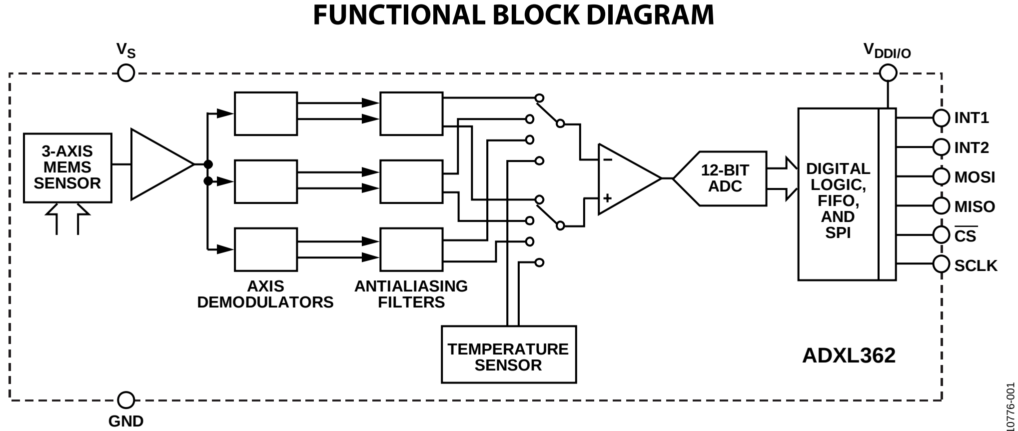


Figure 1.

Rev. A **Document Feedback**

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Tel: 781.329.4700

Technical Support **www.analog.com**

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REVISION HISTORY

9/12—Rev. 0 to Rev. A

Moved Revision History Section..3
Changes to Linking Activity and Inactivity Detection Section; Added Figure 31, Figure 32, and Figure 33, Renumbered Sequentially..16
Change to Table 13..29
Changes to Figure 44..36
Moved Power Supply Decoupling Section..37
Added Power Section, Power Supply Requirements Section, and Figure 47..37
Updated Outline Dimensions..43
Changes to Ordering Guide..43

8/12—Revision 0: Initial Version

SPECIFICATIONS

T_A = 25°C, V_S = 2.0 V, $V_{DD\ I/O}$ = 2.0 V, 100 Hz ODR, acceleration = 0 *g*, default register settings, unless otherwise noted.[1]

Table 1.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range	User selectable		±2, ±4, ±8		*g*
Nonlinearity	Percentage of full scale		±0.5		%
Sensor Resonant Frequency			3500		Hz
Cross Axis Sensitivity[2]			±1.5		%
OUTPUT RESOLUTION	Each axis				
All *g* Ranges			12		Bits
SENSITIVITY	Each axis				
Sensitivity Calibration Error				±10	%
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	2 *g* range		1		m*g*/LSB
	4 *g* range		2		m*g*/LSB
	8 *g* range		4		m*g*/LSB
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	2 *g* range		1000		LSB/*g*
	4 *g* range		500		LSB/*g*
	8 *g* range		250		LSB/*g*
Sensitivity Change Due to Temperature[3]	−40°C to +85°C		0.05		%/°C
0 *g* OFFSET	Each axis				
0 *g* Output	X_{OUT}, Y_{OUT}	−150	±35	+150	m*g*
	Z_{OUT}	−250	±50	+250	m*g*
0 *g* Offset vs. Temperature[3]					
Normal Operation	X_{OUT}, Y_{OUT}		±0.5		m*g*/°C
	Z_{OUT}		±0.6		m*g*/°C
Low Noise Mode and Ultralow Noise Mode	X_{OUT}, Y_{OUT}, Z_{OUT}		±0.35		m*g*/°C
NOISE PERFORMANCE					
Noise Density					
Normal Operation	X_{OUT}, Y_{OUT}		550		µ*g*/√Hz
	Z_{OUT}		920		µ*g*/√Hz
Low Noise Mode	X_{OUT}, Y_{OUT}		400		µ*g*/√Hz
	Z_{OUT}		550		µ*g*/√Hz
Ultralow Noise Mode	X_{OUT}, Y_{OUT}		250		µ*g*/√Hz
	Z_{OUT}		350		µ*g*/√Hz
	V_S = 3.5 V; X_{OUT}, Y_{OUT}		175		µ*g*/√Hz
	V_S = 3.5 V; Z_{OUT}		250		µ*g*/√Hz
BANDWIDTH					
Low Pass (Antialiasing) Filter, −3 dB Corner	HALF_BW = 0		ODR/2		Hz
	HALF_BW = 1		ODR/4		Hz
Output Data Rate (ODR)	User selectable in 8 steps	12.5		400	Hz
SELF TEST					
Output Change[4]	X_{OUT}	450	580	710	m*g*
	Y_{OUT}	−710	−580	−450	m*g*
	Z_{OUT}	350	500	650	m*g*
POWER SUPPLY					
Operating Voltage Range (V_S)		1.6	2.0	3.5	V
I/O Voltage Range ($V_{DD\ I/O}$)		1.6	2.0	V_S	V

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
Supply Current					
Measurement Mode	100 Hz ODR (50 Hz bandwidth)[5]				
Normal Operation			1.8		µA
Low Noise Mode			3.3		µA
Ultralow Noise Mode			13		µA
Wake-Up Mode			0.27		µA
Standby			0.01		µA
Power Supply Rejection Ratio (PSRR)	C_S = 1.0 µF, R_S = 100 Ω, C_{IO} = 1.1 µF, input is 100 mV sine wave on V_S				
Input Frequency 100 Hz to 1 kHz			−13		dB
Input Frequency 1 kHz to 250 kHz			−20		dB
Turn-On Time	100 Hz ODR (50 Hz bandwidth)				
Power-Up to Standby			5		ms
Measurement Mode Instruction to Valid Data			4/ODR		
TEMPERATURE SENSOR					
Bias	@ 25°C		350		LSB
Standard Deviation			290		LSB
Sensitivity Average	@ 25°C		0.065		°C/LSB
Standard Deviation			0.0025		°C/LSB
Sensitivity Repeatability	@ 25°C		±0.5		°C
Resolution			12		Bits
ENVIRONMENTAL					
Operating Temperature Range		−40		+85	°C

[1] All minimum and maximum specifications are guaranteed. Typical specifications may not be guaranteed.
[2] Cross axis sensitivity is defined as coupling between any two axes.
[3] −40°C to +25°C or +25°C to +85°C.
[4] Self test change is defined as the output change in *g* when self test is asserted.
[5] Refer to Figure 30 for current consumption at other bandwidth settings.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Acceleration (Any Axis, Unpowered)	5000 *g*
Acceleration (Any Axis, Powered)	5000 *g*
V_S	−0.3 V to +3.6 V
$V_{DD\ I/O}$	−0.3 V to +3.6 V
All Other Pins	−0.3 V to V_S
Output Short-Circuit Duration (Any Pin to Ground)	Indefinite
ESD	2000 V (HBM)
Short Term Maximum Temperature	
Four Hours	150°C
One Minute	260°C
Temperature Range (Powered)	−50°C to +150°C
Temperature Range (Storage)	−50°C to +150°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

Table 3. Package Characteristics

Package Type	θ_{JA}	θ_{JC}	Device Weight
16-Terminal LGA	150°C/W	85°C/W	18 mg

PACKAGE INFORMATION

Figure 2 and Table 4 provide details about the package branding for the ADXL362. For a complete listing of product availability, see the Ordering Guide section.

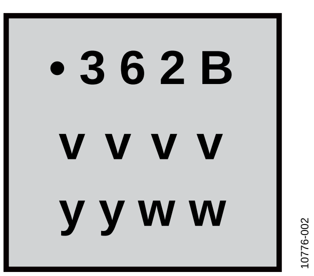


Figure 2. Product Information on Package (Top View)

Table 4. Package Branding Information

Branding Key	Field Description
●362B	Pin 1 indicator and part identifier
vvvv	Factory lot code
yyww	Date code

RECOMMENDED SOLDERING PROFILE

Figure 3 and Table 5 provide details about the recommended soldering profile.

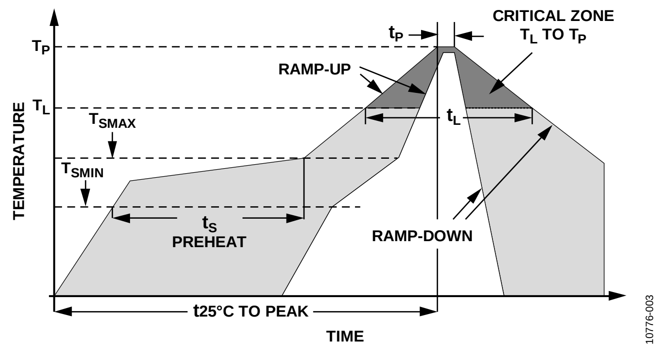
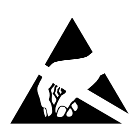


Figure 3. Recommended Soldering Profile

Table 5. Recommended Soldering Profile

	Condition	
Profile Feature	**Sn63/Pb37**	**Pb-Free**
Average Ramp Rate (T_L to T_P)	3°C/sec max	3°C/sec max
Preheat		
Minimum Temperature (T_{SMIN})	100°C	150°C
Maximum Temperature (T_{SMAX})	150°C	200°C
Time (T_{SMIN} to T_{SMAX})(t_S)	60 sec to 120 sec	60 sec to 180 sec
T_{SMAX} to T_L Ramp-Up Rate	3°C/sec max	3°C/sec max
Time Maintained Above Liquidous (T_L)		
Liquidous Temperature (T_L)	183°C	217°C
Time (t_L)	60 sec to 150 sec	60 sec to 150 sec
Peak Temperature (T_P)	240 + 0/−5°C	260 + 0/−5°C
Time Within 5°C of Actual Peak Temperature (t_P)	10 sec to 30 sec	20 sec to 40 sec
Ramp-Down Rate	6°C/sec max	6°C/sec max
Time 25°C to Peak Temperature	6 minutes max	8 minutes max

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

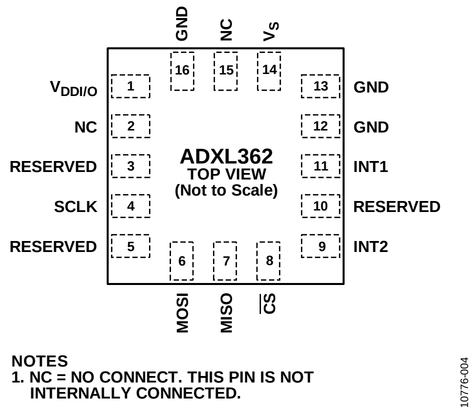


Figure 4. Pin Configuration (Top View)

Table 6. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	$V_{DD\ I/O}$	Supply Voltage for Digital I/O.
2	NC	No Connect. Not internally connected.
3	Reserved	Reserved. May be left unconnected or connected to GND.
4	SCLK	SPI Communications Clock.
5	Reserved	Reserved. Can be left unconnected or connected to GND.
6	MOSI	Master Output, Slave Input. SPI serial data input.
7	MISO	Master Input, Slave Output. SPI serial data output.
8	$\overline{CS}$	SPI Chip Select, Active Low. Must be low during SPI communications.
9	INT2	Interrupt 2 Output. INT2 also serves as an input for synchronized sampling.
10	Reserved	Reserved. Can be left unconnected, or connected to GND.
11	INT1	Interrupt 1 Output. INT1 also serves as an input for external clocking.
12	GND	Ground. This pin must be grounded.
13	GND	Ground. This pin must be grounded.
14	V_S	Supply Voltage.
15	NC	No Connect. Not internally connected.
16	GND	Ground. This pin must be grounded.

TYPICAL PERFORMANCE CHARACTERISTICS

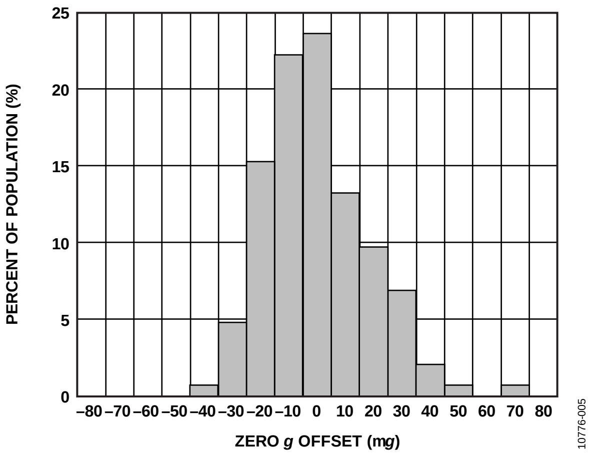


Figure 5. X-Axis Zero g *Offset at 25°C, V_S = 2 V*

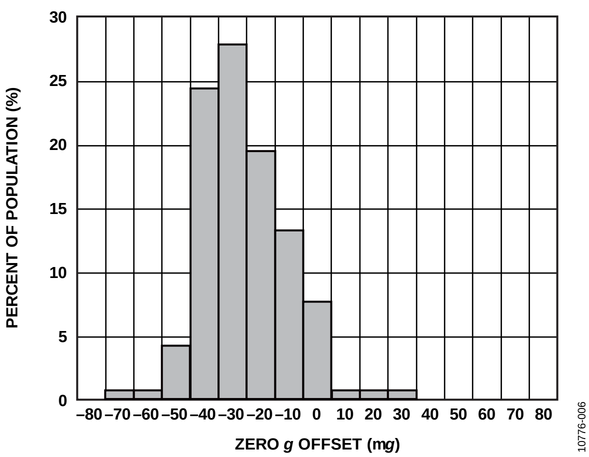


Figure 6. Y-Axis Zero g *Offset at 25°C, V_S = 2 V*

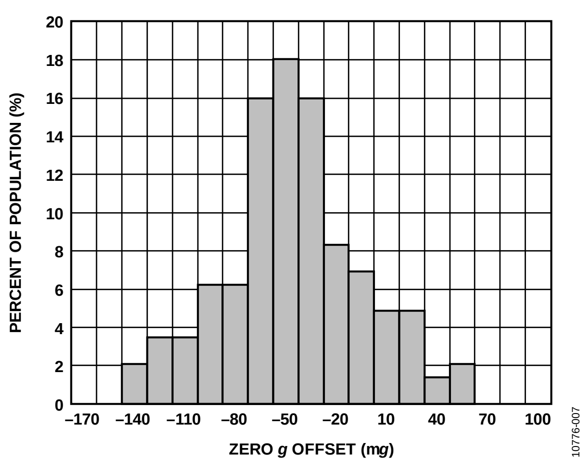


Figure 7. Z-Axis Zero g *Offset at 25°C, V_S = 2.5 V*

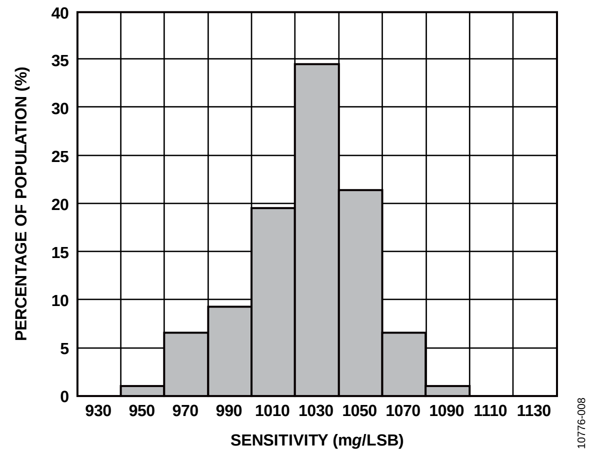


Figure 8. X-Axis Sensitivity at 25°C, V_S = 2 V, ±2 g *Range*

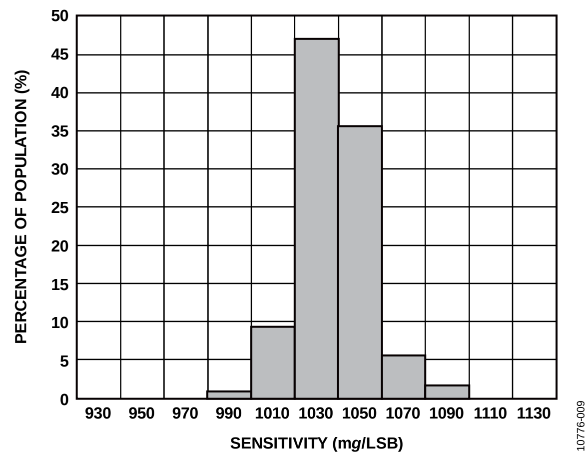


Figure 9. Y-Axis Sensitivity at 25°C, V_S = 2 V, ±2 g *Range*

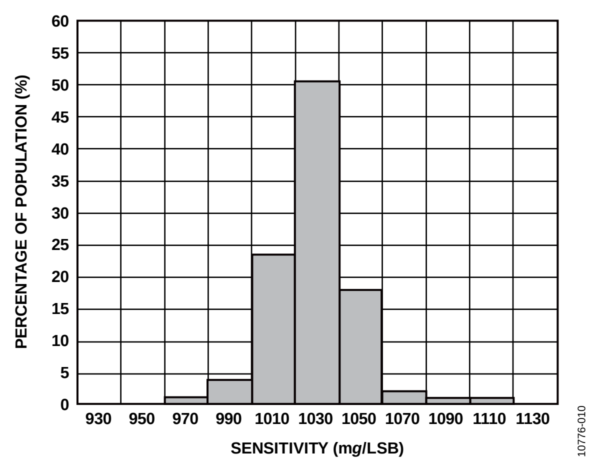


Figure 10. Z-Axis Sensitivity at 25°C, V_S = 2 V, ±2 g *Range*

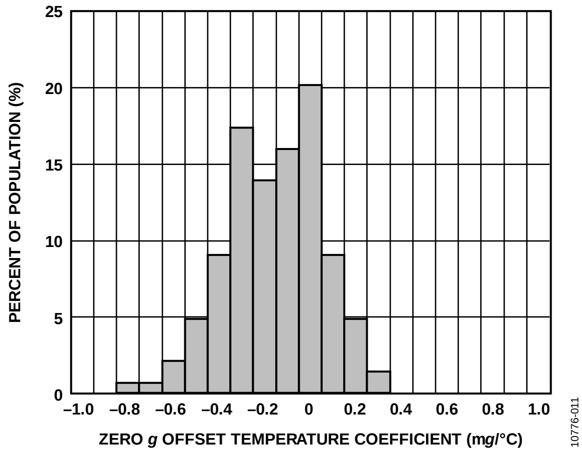


Figure 11. X-Axis Zero g Offset Temperature Coefficient, $V_S = 2.5$ V

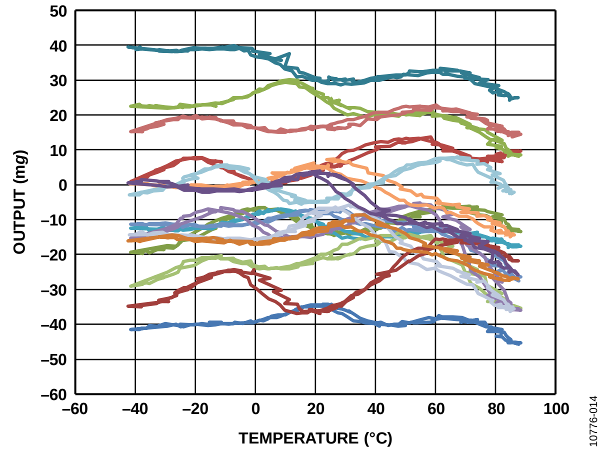


Figure 14. X-Axis Zero g Offset vs. Temperature—
16 Parts Soldered to PCB, ODR = 100 Hz, $V_S = 2$ V

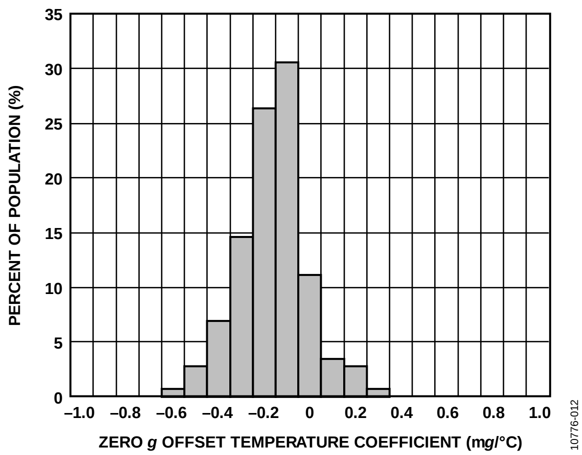


Figure 12. Y-Axis Zero g Offset Temperature Coefficient, $V_S = 2.5$ V

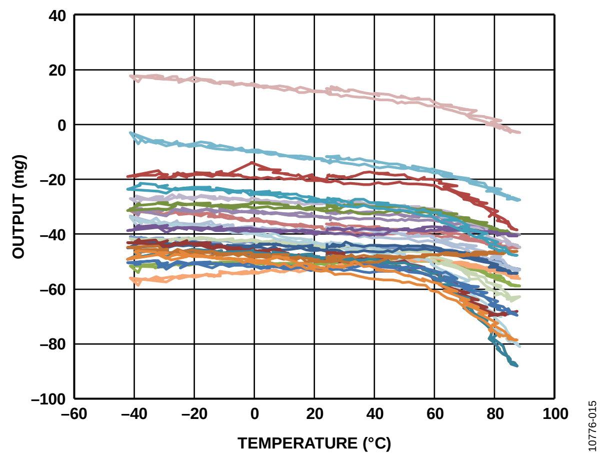


Figure 15. Y-Axis Zero g Offset vs. Temperature—
16 Parts Soldered to PCB, ODR = 100 Hz, $V_S = 2$ V

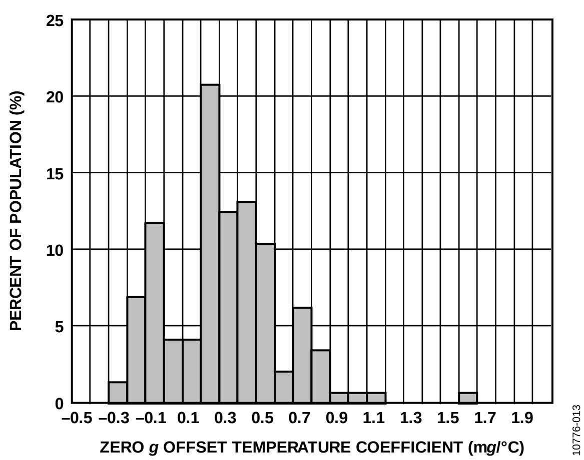


Figure 13. Z-Axis Zero g Offset Temperature Coefficient, $V_S = 2.5$ V

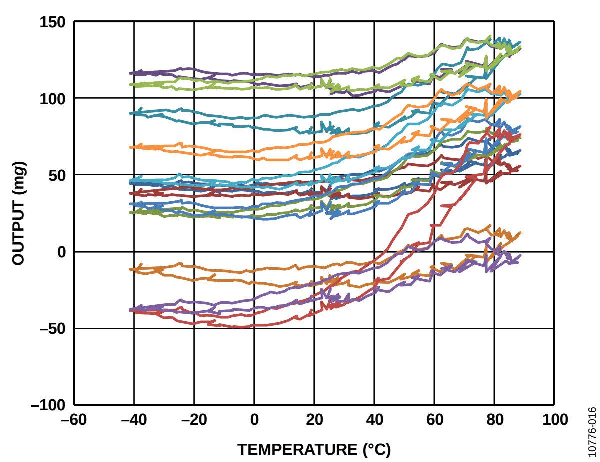


Figure 16. Z-Axis Zero g Offset vs. Temperature—
16 Parts Soldered to PCB, ODR = 100 Hz, $V_S = 2$ V

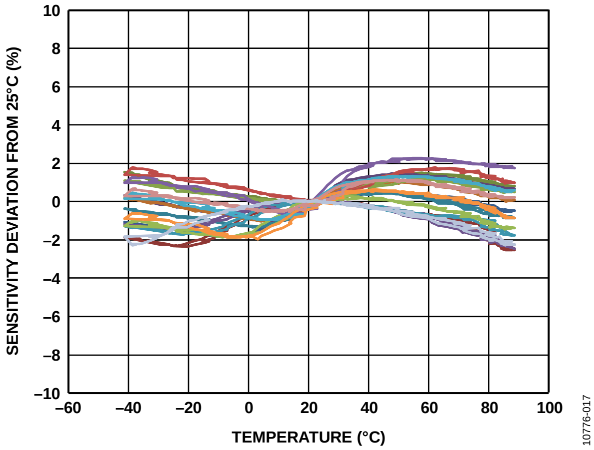


Figure 17. X-Axis Sensitivity Deviation from 25°C vs. Temperature—16 Parts Soldered to PCB, ODR = 100 Hz, V_S = 2 V

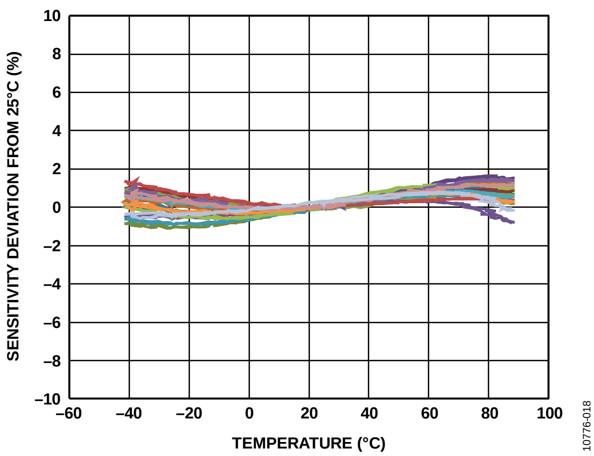


Figure 18. Y-Axis Sensitivity Deviation from 25°C vs. Temperature—16 Parts Soldered to PCB, ODR = 100 Hz, V_S = 2 V

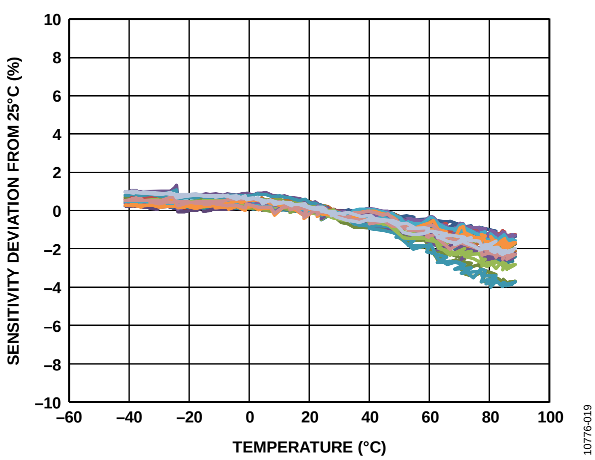


Figure 19. Z-Axis Sensitivity Deviation from 25°C vs. Temperature—16 Parts Soldered to PCB, ODR = 100 Hz, V_S = 2 V

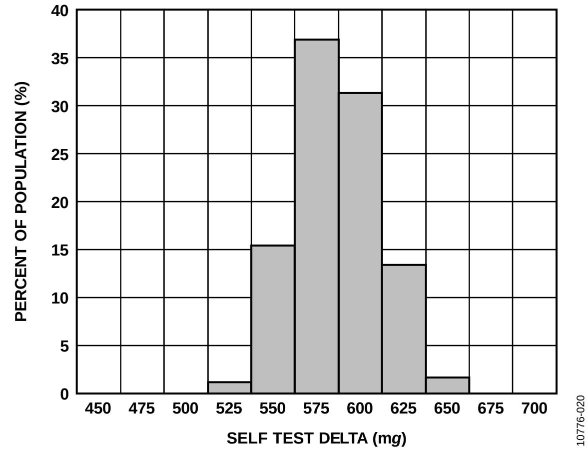


Figure 20. X-Axis Self Test Response at 25°C, V_S = 2 V

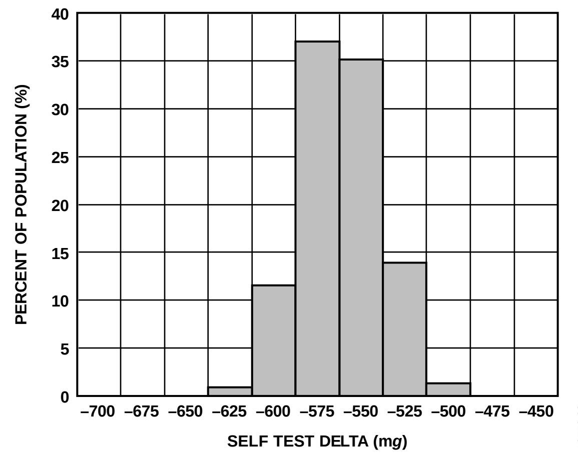


Figure 21. Y-Axis Self Test Response at 25°C, V_S = 2 V

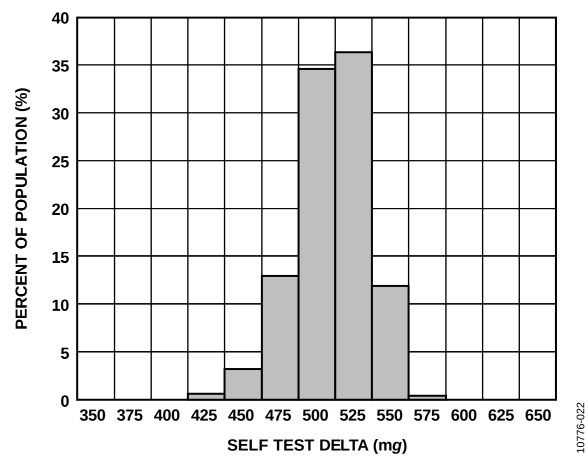


Figure 22. Z-Axis Self Test Response at 25°C, V_S = 2 V

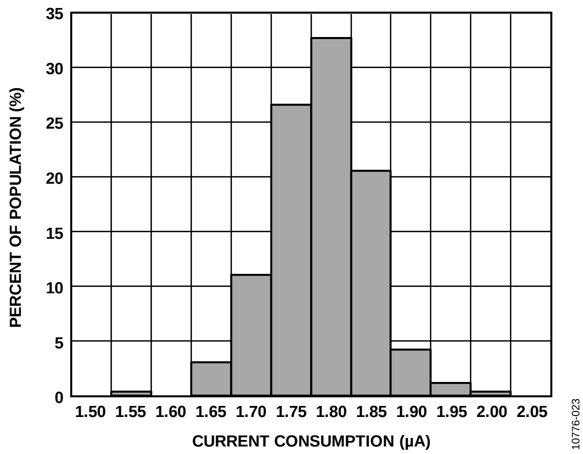


Figure 23. Current Consumption at 25°C, Normal Mode, ODR = 100 Hz, V_S = 2 V

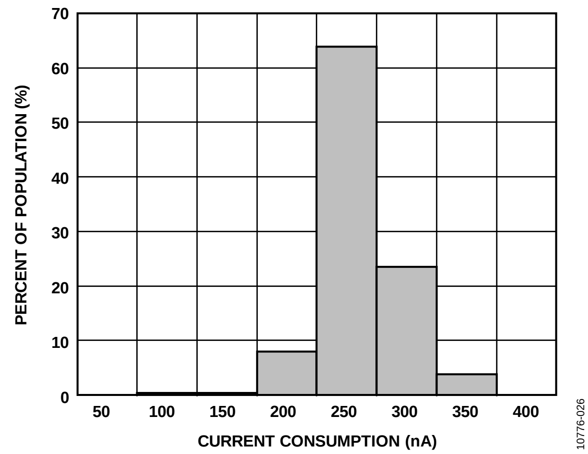


Figure 26. Current Consumption at 25°C, Wake-Up Mode, V_S = 2 V

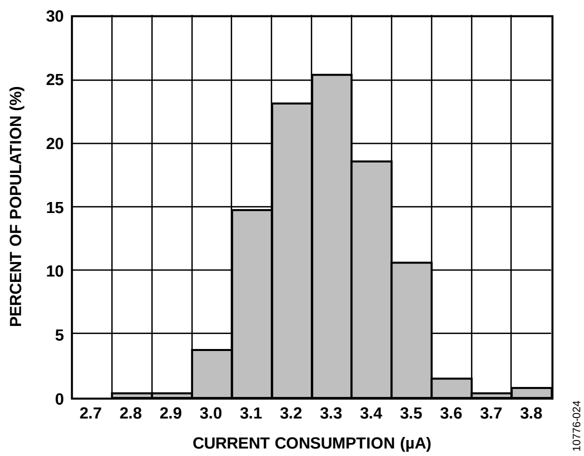


Figure 24. Current Consumption at 25°C, Low Noise Mode, ODR = 100 Hz, V_S = 2 V

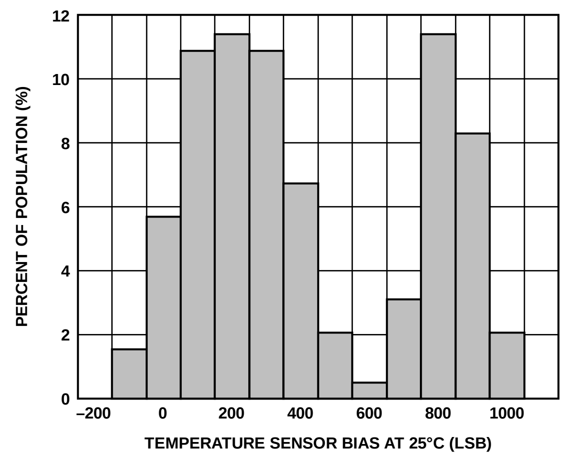


Figure 27. Temperature Sensor Response at 25°C, V_S = 2 V

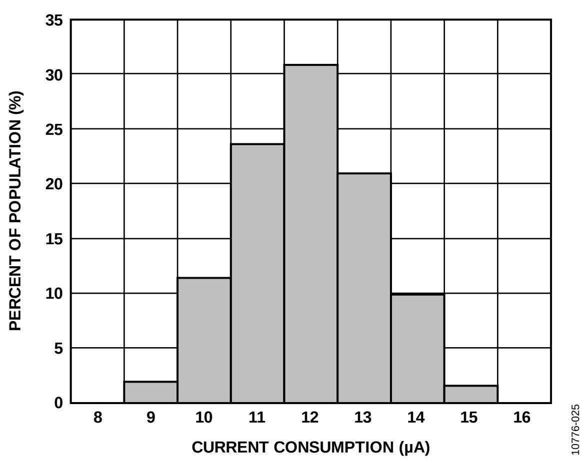


Figure 25. Current Consumption at 25°C, Ultralow Noise Mode, ODR = 100 Hz, V_S = 2 V

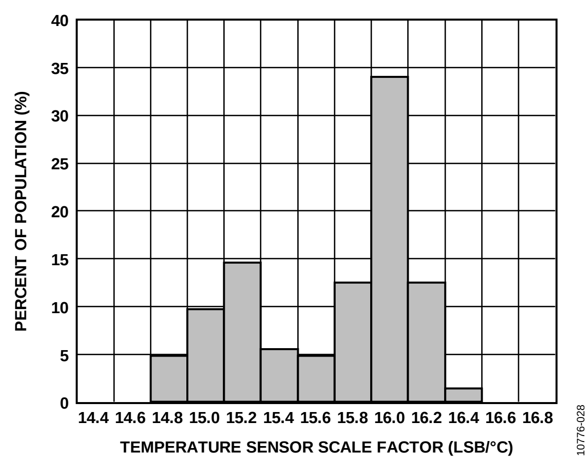


Figure 28. Temperature Sensor Scale Factor, V_S = 2 V

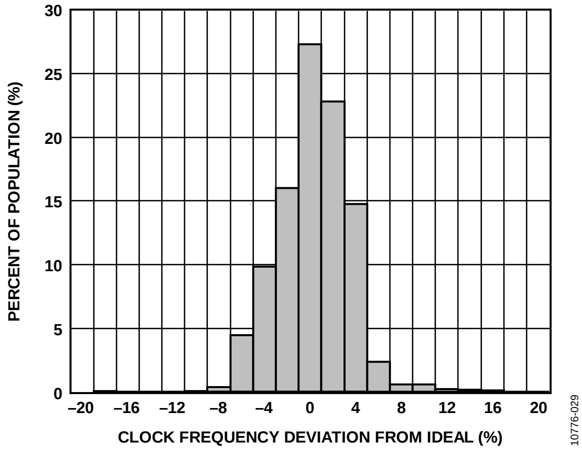


Figure 29. Clock Frequency Deviation from Ideal at 25°C, V_S = 2 V

THEORY OF OPERATION

The ADXL362 is a complete 3-axis acceleration measurement system that operates at extremely low power consumption levels. It measures both dynamic acceleration, resulting from motion or shock, and static acceleration, such as tilt. Acceleration is reported digitally and the device communicates via the SPI protocol. Built-in digital logic enables autonomous operation and implements functionality that enhances system level power savings.

MECHANICAL DEVICE OPERATION

The moving component of the sensor is a polysilicon surface-micromachined structure that is built on top of a silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces.

Deflection of the structure is measured using differential capacitors that consist of independent fixed plates and plates attached to the moving mass. Acceleration deflects the structure and unbalances the differential capacitor, resulting in a sensor output whose amplitude is proportional to acceleration. Phase sensitive demodulation determines the magnitude and polarity of the acceleration.

OPERATING MODES

The ADXL362 has two operating modes: measurement mode for continuous, wide bandwidth sensing; and wake-up mode for limited bandwidth activity detection. In addition, measurement can be suspended altogether by placing the device in standby.

Measurement Mode

Measurement mode is the normal operating mode of the ADXL362. In this mode, acceleration data is read continuously and the accelerometer consumes less than 3 µA (typical) across its entire range of output data rates of up to 400 Hz using a 2.0 V supply. All features described in this datasheet are available when operating the ADXL362 in this mode.

The ability to continuously output data from the minimum 12.5 Hz to the maximum 400 Hz data rate while still delivering less than 3 µA (typical) of current consumption is what defines the ADXL362 as an ultralow power accelerometer. Other accelerometers derive low current by using a specific low power mode that power cycles acceleration sensing. The result is a small effective bandwidth in the low power modes and undersampling of input data; therefore, unwanted aliasing can occur. Undersampling and aliasing do not occur with the ADXL362 because it continuously samples the full bandwidth of its sensor at all data rates.

Wake-Up Mode

Wake-up mode is ideal for simple detection of the presence or absence of motion at extremely low power consumption (270 nA at a 2.0 V supply voltage). Wake-up mode is useful particularly for implementation of a motion activated on/off switch, allowing the rest of the system to be powered down until activity is detected.

Wake-up mode reduces current consumption to a very low level by measuring acceleration only about six times per second to determine whether motion is present. If motion is detected, the accelerometer can respond autonomously in the following ways:

- Switch into full bandwidth measurement mode
- Signal an interrupt to a microcontroller
- Wake up downstream circuitry, depending on the configuration

In wake-up mode, all accelerometer features are available with the exception of the activity timer. All registers can be accessed, and real-time data can be read and/or stored in the FIFO.

Standby

Placing the ADXL362 in standby suspends measurement and reduces current consumption to 10 nA (typical). Pending interrupts and data are preserved and no new interrupts are generated.

The ADXL362 powers up in standby with all sensor functions turned off.

SELECTABLE MEASUREMENT RANGES

The ADXL362 has selectable measurement ranges of ±2 *g*, ±4 *g*, and ±8 *g*. Acceleration samples are always converted by a 12-bit ADC; therefore, sensitivity scales with *g* range. Ranges and corresponding sensitivity values are listed in Table 1.

When acceleration exceeds the measurement extremes, data is clipped at the full-scale value (0x0FFF), and no damage is caused to the accelerometer. Table 2 lists the absolute maximum ratings for acceleration, indicating the acceleration level that can cause permanent damage to the device.

SELECTABLE OUTPUT DATA RATES

The ADXL362 can report acceleration data at various data rates ranging from 12.5 Hz to 400 Hz. The internal low-pass filter pole is automatically set to ¼ or ½ the selected ODR (based on the HALF_BW setting) to ensure the Nyquist sampling criterion is met and no aliasing occurs.

Current consumption varies somewhat with output data rate as shown in Figure 30, remaining below 5.0 µA over the entire range of data rates and operating voltages.

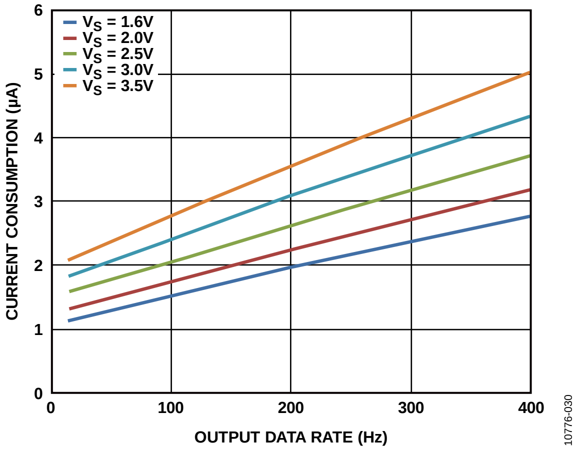


Figure 30. Current Consumption vs. Output Data Rate at Several Supply Voltages

Antialiasing

The analog-to-digital converter (ADC) of the ADXL362 samples at the (user selected) output data rate. In the absence of antialiasing filtering, it aliases any input signals whose frequency is more than half the data rate. To mitigate this, a two-pole low-pass filter is provided at the input of the ADC.

The user can set this antialiasing filter to a bandwidth that is at ½ the data rate or ¼ the data rate. Setting the antialiasing filter pole to ½ of the output data rate provides less aggressive antialiasing filtering, but maximizes bandwidth and is adequate for most applications. Setting the pole to ¼ of the data rate reduces bandwidth for a given data rate, but provides more aggressive antialiasing.

The antialiasing filter of the ADXL362 defaults to the more conservative setting, where bandwidth is set to one-fourth the output data rate.

POWER/NOISE TRADEOFF

The ADXL362 offers a few options for decreasing noise at the expense of only a small increase in current consumption.

The noise performance of the ADXL362 in normal operation, typically 7 LSB rms at 100 Hz bandwidth, is adequate for most applications, depending upon bandwidth and the desired resolution. For cases where lower noise is needed, the ADXL362 provides two lower noise operating modes that trade reduced noise for a somewhat higher current consumption.

Table 7 lists the current consumption and noise densities obtained for normal operation and the two lower noise modes at a typical 2.0 V supply.

Table 7. Noise and Current Consumption: Normal Operation, Low Noise Mode, and Ultralow Noise Mode @ V_S = 2.0 V

Mode	Noise (µg/√Hz) Typical	Current Consumption (µA) Typical
Normal Operation	550	1.8
Low Noise	400	3.0
Ultralow Noise	250	10

Operating the ADXL362 at a higher supply voltage also decreases noise. Table 8 lists the current consumption and noise densities obtained for normal operation and the two lower noise modes at the highest recommended supply, 3.3 V.

Table 8. Noise and Current Consumption: Normal Operation, Low Noise Mode, and Ultralow Noise Mode @ V_S = 3.3 V

Mode	Noise (µg/√Hz) Typical	Current Consumption (µA) Typical
Normal Operation	380	2.7
Low Noise	280	4.5
Ultralow Noise	175	15

POWER SAVINGS FEATURES

Designed for the most power conscious applications, the ADXL362 includes several features (as described in this section) for enabling power savings at the system level, as well as at the device level.

ULTRALOW POWER CONSUMPTION IN ALL MODES

At the device level, the most obvious power saving feature of the ADXL362 is its ultralow current consumption in all configurations. The ADXL362 consumes between 1.1 µA (typical) and 5 µA (typical) across all data rates up to 400 Hz and all supply voltages up to 3.5 V (see Figure 30). An even lower power, 270 nA (typical) motion triggered wake-up mode is provided for simple motion detection applications that require a power consumption lower than 1 µA.

At these current levels, the accelerometer consumes less power in full operation than the standby currents of many other system components, and is, therefore, optimal for applications that require continuous acceleration monitoring and very long battery life. Because the accelerometer is always on, it can act as a motion activation switch. The accelerometer signals to the rest of the system when to turn on, thereby managing power at the system level.

As important as its low operating current, the 10 nA (typical) standby current of the ADXL362 contributes to a much longer battery life in applications that spend most of their time in a sleep state and wake up via an external trigger.

MOTION DETECTION

The ADXL362 features built-in logic that detects activity (presence of acceleration above a threshold) and inactivity (lack of acceleration above a threshold). Activity and inactivity events can be used as triggers to manage the accelerometer mode of operation, trigger an interrupt to a host processor, and/or autonomously drive a motion switch.

Detection of an activity or inactivity event is indicated in the status register and can be configured to generate an interrupt. In addition, the activity status of the device, that is, whether it is moving or stationary, is indicated by the AWAKE bit, described in the Using the AWAKE Bit section.

Activity and inactivity detection can be used when the accelerometer is in either measurement mode or wake-up mode.

Activity Detection

An activity event is detected when acceleration remains above a specified threshold for a specified time period.

Referenced and Absolute Configurations

Activity detection can be configured as referenced or absolute.

When using absolute activity detection, acceleration samples are compared to a user set threshold to determine whether motion is present. For example, if a threshold of 0.5 *g* is set and the acceleration on the z-axis is 1 *g* for longer than the user defined activity time, the activity status asserts.

In many applications, it is advantageous for activity detection to be based not on an absolute threshold, but on a deviation from a reference point or orientation. This is particularly useful because it removes the effect on activity detection of the static 1 *g* imposed by gravity. When an accelerometer is stationary, its output can reach 1 *g*, even when it is not moving. In absolute activity, when the threshold is set to less than 1 *g*, activity is immediately detected in this case.

In the referenced configuration, activity is detected when acceleration samples are at least a user set amount above an internally defined reference for the user defined amount of time, as described in Equation 1.

$$ABS(Acceleration - Reference) > Threshold \qquad (1)$$

Consequently, activity is detected only when the acceleration has deviated sufficiently from the initial orientation. The reference for activity detection is calculated when activity detection is engaged in the following scenarios:

- When the activity function is turned on and measurement mode is engaged;
- If link mode is enabled: when inactivity is detected and activity detection begins; or
- If link mode is not enabled: when activity is detected and activity detection repeats.

The referenced configuration results in a very sensitive activity detection that detects even the most subtle motion events.

Fewer False Positives

Ideally, the intent of activity detection is to wake up a system only when motion is intentional, ignoring noise or small, unintentional movements. In addition to being sensitive to subtle motion events, the ADXL362 activity detection algorithm is designed to be robust in filtering out undesired triggers.

The ADXL362 activity detection functionality includes a timer to filter out unwanted motion and ensure that only sustained motion is recognized as activity. The duration of this timer, as well as the acceleration threshold, are user adjustable from one sample (that is, no timer) to up to 20 seconds of motion.

Note that the activity timer is operational in measurement mode only. In wake-up mode, one-sample activity detection is used.

Inactivity Detection

An inactivity event is detected when acceleration remains below a specified threshold for a specified time. Inactivity detection is also configurable as referenced or absolute.

When using absolute inactivity detection, acceleration samples are compared to a user set threshold for the user set time to determine the absence of motion. Inactivity is detected when enough consecutive samples are all below the threshold. The absolute configuration of inactivity should be used for implementing free fall detection.

When using referenced inactivity detection, inactivity is detected when acceleration samples are within a user specified amount of an internally defined reference (as described by Equation 2) for a user defined amount of time.

$$ABS(Acceleration - Reference) < Threshold \quad (2)$$

Referenced inactivity, like referenced activity, is particularly useful for eliminating the effects of the static acceleration due to gravity. With absolute inactivity, if the inactivity threshold is set lower than 1 *g*, a device resting motionless may never detect inactivity. With referenced inactivity, the same device under the same configuration detects inactivity.

The inactivity timer can be set to anywhere from 2.5 ms (a single sample at 400 Hz ODR) to almost 90 minutes (65,535 samples at 12.5 Hz ODR) of inactivity. A requirement for inactivity detection is that for whatever period of time the inactivity timer has been configured, the accelerometer detects inactivity only when it has been stationary for that amount of time.

For example, if the accelerometer has been configured for 90 minutes, the accelerometer detects inactivity when it has been stationary for 90 minutes. The wide range of timer settings means that in applications where power conservation is critical, the system can be put to sleep after very short periods of inactivity. In applications where continuous operation is critical, the system stays on for as long as any motion is present.

Linking Activity and Inactivity Detection

The activity and inactivity detection functions can be used concurrently and processed manually by a host processor, or they can be configured to interact in several other ways, as follows.

Default Mode

The user must enable the activity and inactivity functions because these functions are not automatically enabled by default. After the user enables the activity and inactivity functions, the ADXL362 exhibits the following behavior when it enters default mode: Both activity and inactivity detection remain enabled and all interrupts must be serviced by a host processor; that is, a processor must read each interrupt before it is cleared and can be used again.

Loop mode operation is illustrated in the flowchart in Figure 32.

Linked Mode

In linked mode, activity and inactivity detection are linked to each other such that only one of the functions is enabled at any given time. As soon as activity is detected, the device is assumed to be moving (or awake) and stops looking for activity; rather, inactivity is expected as the next event. Therefore, only inactivity detection operates.

Similarly, when inactivity is detected, the device is assumed to be stationary (or asleep). Thus, activity is expected as the next event; therefore, only activity detection operates.

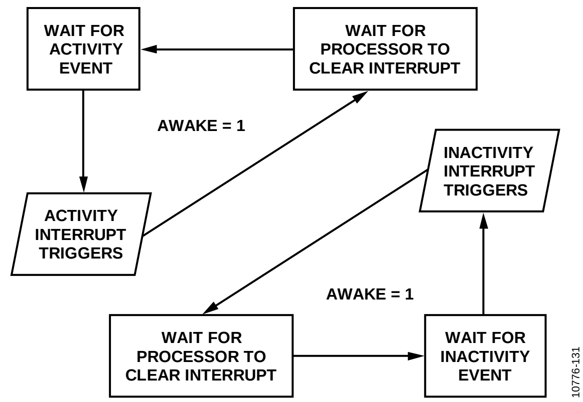


Figure 31. Flowchart Illustrating Activity and Inactivity Operation in Default Mode

In linked mode, each interrupt must be serviced by a host processor before the next interrupt is enabled.

Linked mode operation is illustrated in the flowchart in Figure 32.

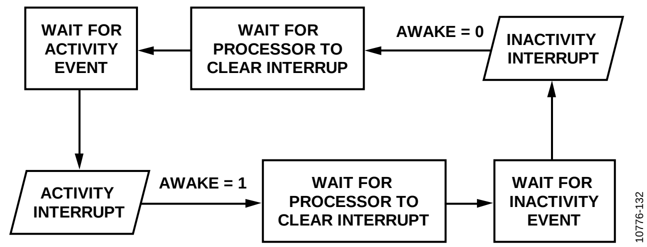


Figure 32. Flowchart Illustrating Activity and Inactivity Operation in Linked Mode

Loop Mode

In loop mode, motion detection operates as described in the Linked Mode section, but interrupts do not need to be serviced by a host processor. This configuration simplifies the implementation of commonly used motion detection and enhances power savings by reducing the amount of power used in bus communication.

Loop mode operation is illustrated in the flowchart in Figure 33.

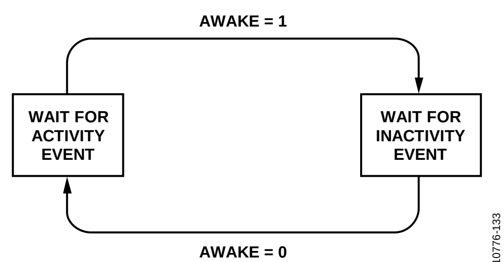


Figure 33. Flowchart Illustrating Activity and Inactivity Operation in Loop Mode

Autosleep

When in linked or loop mode, enabling autosleep causes the device to enter wake-up mode autonomously (see the Wake-Up Mode section) when inactivity is detected, and to reenter measurement mode when activity is detected.

The autosleep configuration is active only if linked or loop modes are enabled. In the default mode, the autosleep setting is ignored.

Using the AWAKE Bit

The AWAKE bit is a status bit that indicates whether the ADXL362 is awake or asleep. The device is awake when it has experienced an activity condition, and it is asleep when it has experienced an inactivity condition.

The awake signal can be mapped to the INT1 or INT2 pin, allowing the pin to serve as a status output to connect or disconnect power to downstream circuitry based on the awake status of the accelerometer. Used in conjunction with loop mode, this configuration implements a trivial, autonomous motion activated switch, as shown in Figure 43.

If the turn-on time of downstream circuitry can be tolerated, this motion switch configuration can save significant system level power by eliminating the standby current consumption of the remainder of the application. This standby current can often exceed the full operating current of the ADXL362.

FIFO

The ADXL362 includes a deep 512-sample first in, first out (FIFO) buffer. The FIFO provides benefits primarily in two ways, as follows.

System Level Power Savings

Appropriate use of the FIFO enables system level power savings by enabling the host processor to sleep for extended periods of time while the accelerometer autonomously collects data. Alternatively, using the FIFO to collect data can unburden the host while it tends to other tasks.

Data Recording/Event Context

The FIFO can be used in a triggered mode to record all data leading up to an activity detection event, thereby providing context for the event. In the case of a system that identifies impact events, for example, the accelerometer can keep the entire system off while it stores acceleration data in its FIFO and looks for an activity event. When the impact event occurs, data that was collected prior to the event is frozen in the FIFO. The accelerometer can then wake the rest of the system and transfer this data to the host processor, thereby providing context for the impact event.

Generally, the more context available, the more intelligent decisions a system can achieve, making a deep FIFO especially useful. The ADXL362 FIFO can store up to more than 13 seconds of data, providing a clear picture of events prior to an activity trigger.

All FIFO modes of operation, as well as the structure of the FIFO and instructions for retrieving data from it, are described in further detail in the FIFO Modes section of this data sheet.

COMMUNICATIONS

SPI Instructions

The digital interface of the ADXL362 is implemented with system level power savings in mind. The following features enhance power savings:

- Burst reads and writes reduce the number of SPI communication cycles required to configure the part and retrieve data.
- Concurrent operation of activity and inactivity detection enables “set it and forget it” operation. Linked and loop modes further reduce communications power by enabling the clearing of interrupts without processor intervention.
- The FIFO is implemented such that consecutive samples can be read continuously via a multibyte read of unlimited length; thus, one read FIFO instruction can clear the entire contents of the FIFO. In many other accelerometers, each read instruction retrieves a single sample only. In addition, the ADXL362 FIFO construction allows the use of direct memory access (DMA) to read the FIFO contents.

Bus Keepers

The ADXL362 includes bus keepers on all digital interface pins: MISO, MOSI, SCLK, $\overline{CS}$, INT1, and INT2. Bus keepers are used to prevent tristate bus lines from floating when nothing is driving them, thus preventing through current in any gate inputs that are on the bus.

MSB Registers

Acceleration and temperature measurements are converted to 12-bit values and transmitted via SPI using two registers per measurement. To read a full sample set of 3-axis acceleration data, six registers must be read.

Many applications do not require the accuracy that 12-bit data provides and prefer, instead, to save system level power. The MSB registers XDATA, YDATA, and ZDATA enable this tradeoff. These registers contain the eight MSBs of the x-, y-, and z-axis acceleration data; reading them effectively provides 8-bit acceleration values. Importantly, only three (consecutive) registers must be read to retrieve a full data set, significantly reducing the time during which the SPI bus is active and drawing current.

12-bit and 8-bit data are available simultaneously so that both data formats can be used in a single application, depending on the needs of the application at a given time. For example, the processor can read 12-bit data when higher resolution is required, and switch to 8-bit data (simply by reading a different set of registers) when application requirements change.

ADDITIONAL FEATURES

FREE FALL DETECTION

Many digital output accelerometers include a built-in free fall detection feature. In the ADXL362, this function can be implemented using the inactivity interrupt. Refer to the Applications Information section for more details, including suggested threshold and timing values.

EXTERNAL CLOCK

The ADXL362 has a built-in 51.2 kHz (typical) clock that, by default, serves as the time base for internal operations.

ODR and bandwidth scale proportionally with the clock. The ADXL362 provides a discrete number of options for ODR, such as 100 Hz, 50 Hz, 25 Hz, and so forth, in factors of 2, (see the Filter Control Register section for a complete listing). To achieve data rates other than those provided, an external clock can be used at the appropriate clock frequency. The output data rate scales with the clock frequency, as shown in Equation 3.

$$ODR_{ACTUAL} = ODR_{SELECTED} \times \frac{f}{51.2\ \text{kHz}} \quad (3)$$

For example, to achieve an 80 Hz ODR, select the 100 Hz ODR setting and provide a clock frequency that is 80% of nominal, or 41.0 kHz.

The ADXL362 can operate with external clock frequencies ranging from the nominal 51.2 kHz down to 25.6 kHz to allow the user to achieve any desired output data rate.

Alternatively, an external clock can be used to improve clock frequency accuracy. The distribution of clock frequencies among a sampling of >1000 parts has a standard deviation of approximately 3%. To achieve tighter tolerances, a more accurate clock can be provided externally.

Bandwidth automatically scales to ½ or ¼ of the ODR (based on the HALF_BW setting), and this ratio is preserved, regardless of clock frequency. Power consumption also scales with clock frequency: higher clock rates increase power consumption. Figure 34 shows how power consumption varies with clock rate.

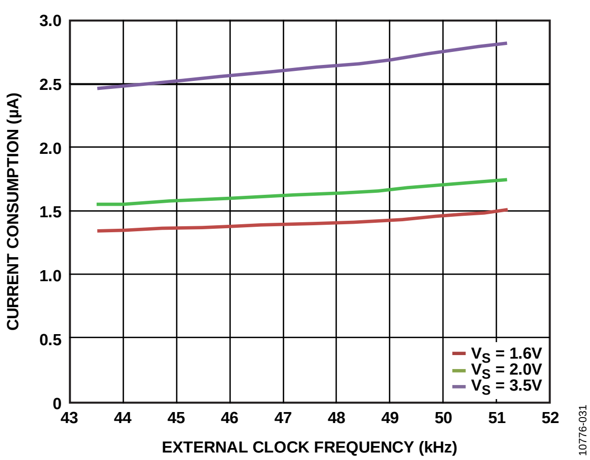


Figure 34. Current Consumption vs. External Clock Rate

SYNCHRONIZED DATA SAMPLING

For applications that require a precisely timed acceleration measurement, the ADXL362 features an option to synchronize acceleration sampling to an external trigger.

SELF TEST

The ADXL362 incorporates a self test feature that effectively tests its mechanical and electronic systems simultaneously. When the self test function is invoked, an electrostatic force is applied to the mechanical sensor. This electrostatic force moves the mechanical sensing element in the same manner as acceleration, and it is additive to the acceleration experienced by the device. This added electrostatic force results in an output change on all three axes.

USER REGISTER PROTECTION

The ADXL362 includes user register protection for single event upsets (SEUs). An SEU is a change of state caused by ions or electromagnetic radiation striking a sensitive node in a microelectronic device. The state change is a result of the free charge created by ionization in or close to an important node of a logic element (for example, a memory bit). The SEU, itself, is not considered permanently damaging to transistor or circuit functionality, but it can create erroneous register values. The ADXL362 registers that are protected from SEU are Register 0x20 to Register 0x2E.

SEU protection is implemented via a 99-bit error correcting (Hamming-type) code that detects both single- and double-bit errors. The check bits are recomputed any time a write to any of the protected registers occurs. At any time, if the stored version of the check bits is not in agreement with the current check bit calculation, the ERR_USER_REGS status bit is set.

The SEU bit in the status register is set on power-up prior to device configuration; it clears upon the first register write to that device.

TEMPERATURE SENSOR

The ADXL362 includes an integrated temperature sensor that can monitor internal system temperature or improve the temperature stability of the device via calibration. For example, acceleration outputs vary with temperature at a rate of ±0.5 m*g*/°C (typical), but the relationship to temperature is repeatable and can be calibrated.

To use the temperature sensor to monitor absolute temperature, it is recommended that its initial bias (its output at some known temperature) is measured and calibrated.

SERIAL COMMUNICATIONS

The ADXL362 communicates via a 4-wire SPI and operates as a slave. Ignore data that is transmitted from the ADXL362 to the master device during writes to the ADXL362.

As shown in Figure 36 to Figure 40, the MISO pin is in a high impedance state, held by a bus keeper, except when the ADXL362 is sending read data (to conserve bus power).

Wire the ADXL362 for SPI communication as shown in the connection diagram in Figure 35. The recommended SPI clock speeds are 1 MHz to 5 MHz, with 12 pF maximum loading.

The SPI timing scheme follows CPHA = CPOL = 0.

For correct operation of the part, the logic thresholds and timing parameters in Table 9 and Table 10 must be met at all times. Refer to Figure 41 and Figure 42 for visual diagrams of the timing parameters.

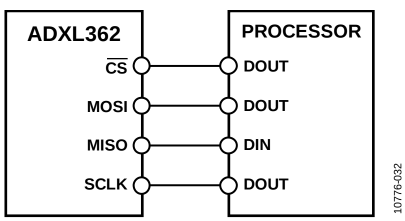


Figure 35. 4-Wire SPI Connection Diagram

SPI COMMANDS

The SPI port uses a multibyte structure wherein the first byte is a command. The ADXL362 command set is

- 0x0A: write register
- 0x0B: read register
- 0x0D: read FIFO

Read and Write Register Commands

The command structure for the read register and write register commands is as follows (see Figure 36 and Figure 37):

</CS down> <command byte (0x0A or 0x0B)> <address byte> <data byte> <additional data bytes for multi-byte> … </CS up>

The read and write register commands support multibyte (burst) read/write access. The waveform diagrams for multi-byte read and write commands are shown in Figure 38 and Figure 39.

Read FIFO Command

Reading from the FIFO buffer is a command structure that does not have an address.

</CS down> <command byte (0x0D)> <data byte> <data byte> … </CS up>

It is recommended that an even number of bytes be read (using a multibyte transaction) because each sample consists of two bytes: 2 bits of axis information and 14 bits of data. If an odd number of bytes is read, it is assumed that the desired data was read; therefore, the second half of the last sample is discarded so a read from the FIFO always starts on a properly aligned even-byte boundary. Data is presented least significant byte first, followed by the most significant byte.

MULTIBYTE TRANSFERS

Multibyte transfers, also known as burst transfers, are supported for all SPI commands: register read, register write, and FIFO read commands. It is recommended that data be read using multibyte transfers to ensure that a concurrent and complete set of x-, y-, and z-acceleration (and temperature, where applicable) data is read.

The FIFO runs on the serial port clock during FIFO reads and can sustain bursting at the SPI clock rate as long as the SPI clock is 1 MHz or faster.

Register Read/Write Auto-Increment

A register read or write command begins with the address specified in the command and auto-increments for each additional byte in the transfer. To avoid address wrapping and side effects of reading registers multiple times, the auto-increment halts at the invalid Register Address 63 (0x3F).

INVALID ADDRESSES AND ADDRESS FOLDING

The ADXL362 has a 6-bit address bus, mapping only 64 registers in the possible 256 register address space. The addresses do not fold to repeat the registers at addresses above 64. Attempted access to register addresses above 64 are mapped to the invalid register at 63 (0x3F) and have no functional effect.

Address 0x00 to Address 0x2E are for customer access, as described in the register map. Address 0x2F to Address 0x3F are reserved for factory use.

LATENCY RESTRICTIONS

Reading any of the data registers (0x08 to 0x0A or 0x0E to 0x15) clears the data ready interrupt. There can be as much as an 80 µs delay from reading a register to the clearing of the data ready interrupt.

Other register reads, register writes, and FIFO reads have no latency restrictions.

INVALID COMMANDS

Commands other than 0x0A, 0x0B, and 0x0D have no effect. The MISO output remains in a high impedance state, and the bus keeper holds the MISO line at its last value.

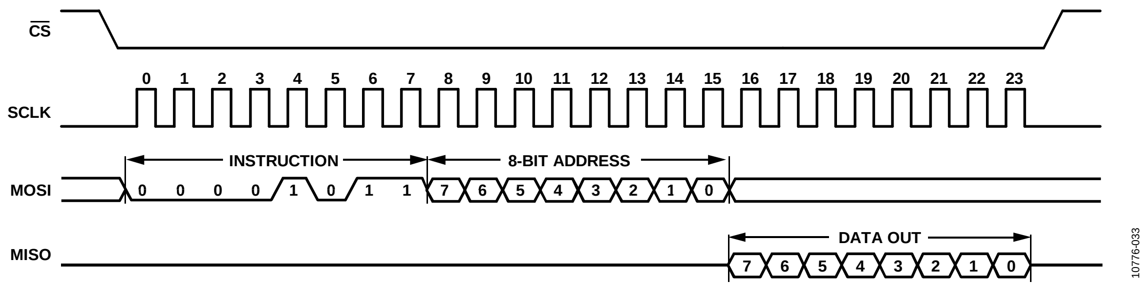


Figure 36. Register Read

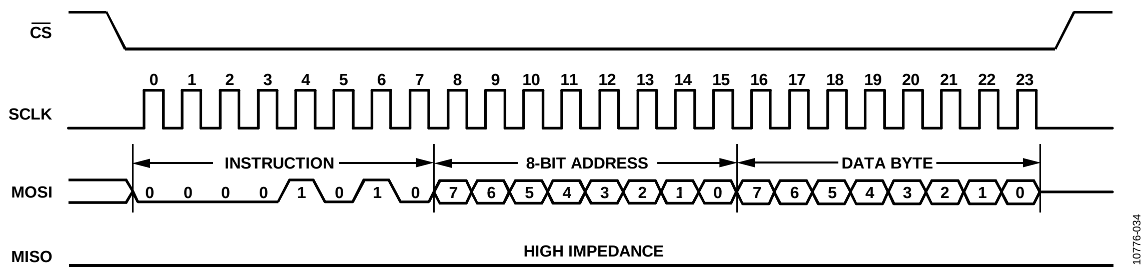


Figure 37. Register Write

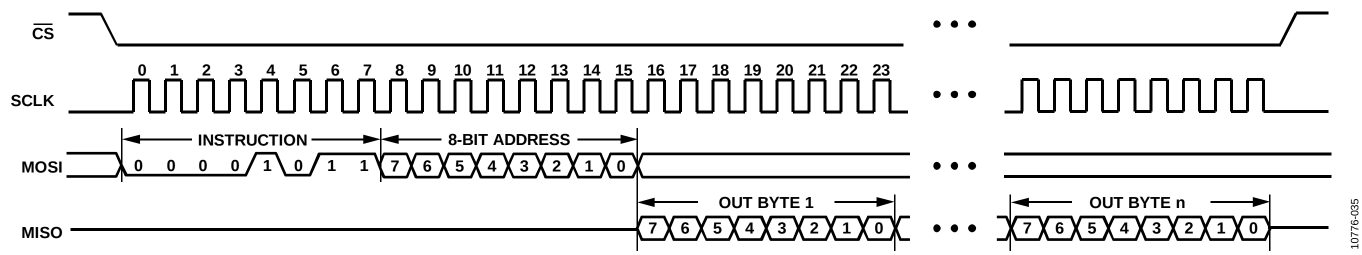


Figure 38. Burst Read

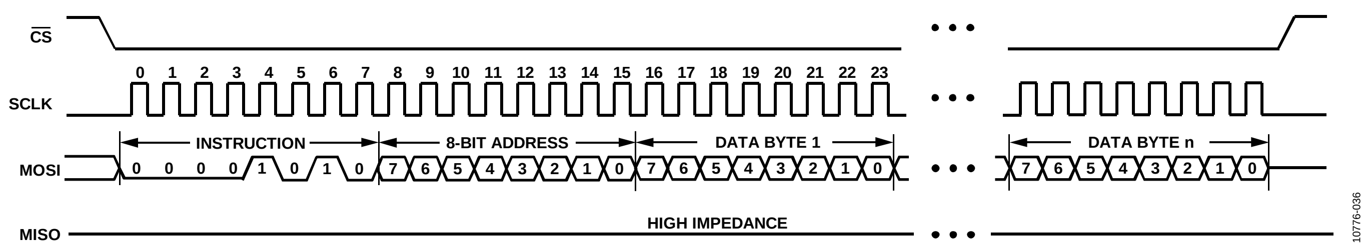


Figure 39. Burst Write

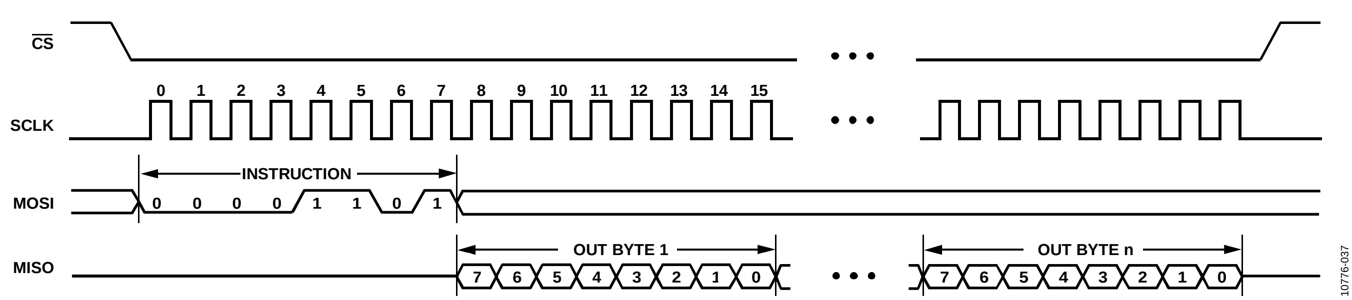


Figure 40. FIFO Read

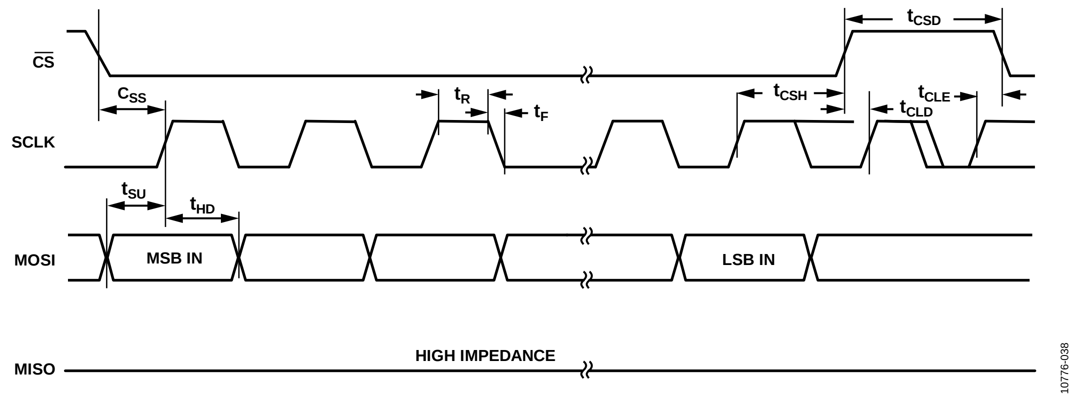


Figure 41. Timing Diagram for SPI Write Instructions

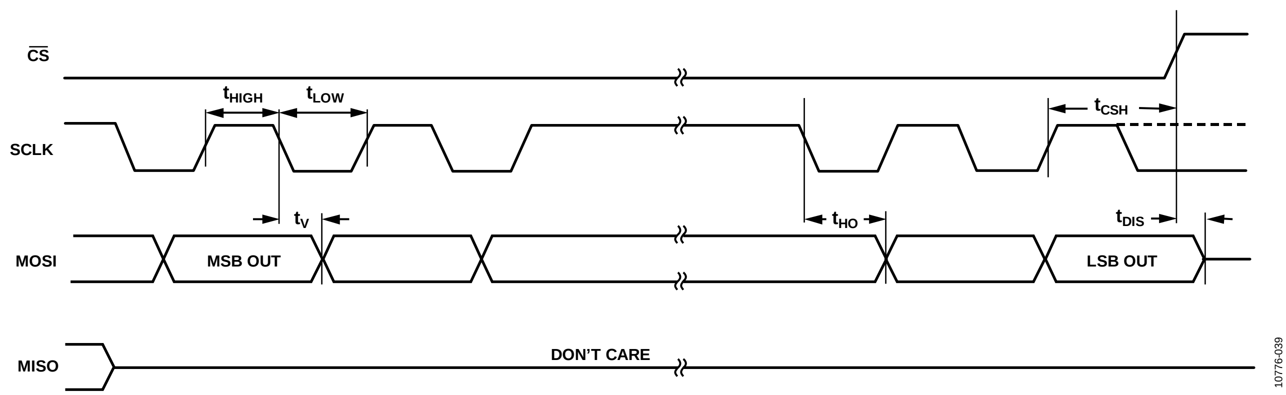


Figure 42. Timing Diagram for SPI Read Instructions

Table 9. SPI Digital Input/Output

Parameter	Test Conditions/Comments	Limit[1] Min	Max	Unit
Digital Input				
Low Level Input Voltage (V_{IL})			$0.3 \times V_{DD\ I/O}$	V
High Level Input Voltage (V_{IH})		$0.7 \times V_{DD\ I/O}$		V
Low Level Input Current (I_{IL})	$V_{IN} = V_{DD\ I/O}$		0.1	µA
High Level Input Current (I_{IH})	$V_{IN} = 0$ V	−0.1		µA
Digital Output				
Low Level Output Voltage (V_{OL})	$I_{OL} = 10$ mA		$0.2 \times V_{DD\ I/O}$	V
High Level Output Voltage (V_{OH})	$I_{OH} = -4$ mA	$0.8 \times V_{DD\ I/O}$		V
Low Level Output Current (I_{OL})	$V_{OL} = V_{OL,\ max}$	10		mA
High Level Output Current (I_{OH})	$V_{OH} = V_{OH,\ min}$		−4	mA

[1] Limits based on characterization results, not production tested.

Table 10. SPI Timing (T_A = 25°C, V_S = 2.0 V, $V_{DD\ I/O}$ = 2.0 V)[1]

Parameter	Limit[2, 3] Min	Max	Unit	Description
f_{CLK}		1	MHz	Clock Frequency
C_{SS}	100		ns	$\overline{CS}$ Setup Time
t_{CSH}	100		ns	$\overline{CS}$ Hold Time
t_{CSD}	10		ns	$\overline{CS}$ Disable Time
t_{SU}	50		ns	Data Setup Time
t_{HD}	50		ns	Data Hold Time
t_R	0	100	ns	SCLK Rise Time
t_F	0	100	ns	SCLK Fall Time
t_{HIGH}	100		ns	Clock High Time
t_{LOW}	100		ns	Clock Low Time
t_{CLD}	100		ns	Clock Delay Time
t_{CLE}	100		ns	Clock Enable Time
t_V	0		ns	Output Valid from Clock Low
t_{HO}	0	200	ns	Output Hold Time
t_{DIS}	0	200	ns	Output Disable Time

[1] The $\overline{CS}$, SCLK, MOSI, and MISO pins are not internally pulled up or down; they must be driven for proper operation.
[2] Limits based on design targets; not production tested.
[3] The timing values are measured corresponding to the input thresholds (V_{IL} and V_{IH}) given in Table 9.

REGISTER MAP

Table 11. Register Summary

Reg	Name	Bits	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset	RW
0x00	DEVID_AD	[7:0]	DEVID_AD[7:0]								0xAD	R
0x01	DEVID_MST	[7:0]	DEVID_MST[7:0]								0x1D	R
0x02	PARTID	[7:0]	PARTID[7:0]								0xF2	R
0x03	REVID	[7:0]	REVID[7:0]								0x01	R
0x08	XDATA	[7:0]	XDATA[7:0]								0x00	R
0x09	YDATA	[7:0]	YDATA[7:0]								0x00	R
0x0A	ZDATA	[7:0]	ZDATA[7:0]								0x00	R
0x0B	STATUS	[7:0]	ERR_USER_ REGS	AWAKE	INACT	ACT	FIFO_OVER-RUN	FIFO_WATER-MARK	FIFO_READY	DATA_READY	0x40	R
0x0C	FIFO_ENTRIES_L	[7:0]	FIFO_ENTRIES_L[7:0]								0x00	R
0x0D	FIFO_ENTRIES_H	[7:0]	UNUSED						FIFO_ENTRIES_H[1:0]		0x00	R
0x0E	XDATA_L	[7:0]	XDATA_L[7:0]								0x00	R
0x0F	XDATA_H	[7:0]	SX				XDATA_H[3:0]				0x00	R
0x10	YDATA_L	[7:0]	YDATA_L[7:0]								0x00	R
0x11	YDATA_H	[7:0]	SX				YDATA_H[3:0]				0x00	R
0x12	ZDATA_L	[7:0]	ZDATA_L[7:0]								0x00	R
0x13	ZDATA_H	[7:0]	SX				ZDATA_H[3:0]				0x00	R
0x14	TEMP_L	[7:0]	TEMP_L[7:0]								0x00	R
0x15	TEMP_H	[7:0]	SX				TEMP_H[3:0]				0x00	R
0x16	Reserved	[7:0]	Reserved[7:0]								0x00	R
0x17	Reserved	[7:0]	Reserved[7:0]								0x00	R
0x1F	SOFT_RESET	[7:0]	SOFT_RESET[7:0]								0x00	W
0x20	THRESH_ACT_L	[7:0]	THRESH_ACT_L[7:0]								0x00	RW
0x21	THRESH_ACT_H	[7:0]	UNUSED					THRESH_ACT_H[2:0]			0x00	RW
0x22	TIME_ACT	[7:0]	TIME_ACT[7:0]								0x00	RW
0x23	THRESH_INACT_L	[7:0]	THRESH_INACT_L[7:0]								0x00	RW
0x24	THRESH_INACT_H	[7:0]	UNUSED					THRESH_INACT_H[2:0]			0x00	RW
0x25	TIME_INACT_L	[7:0]	TIME_INACT_L[7:0]								0x00	RW
0x26	TIME_INACT_H	[7:0]	TIME_INACT_H[7:0]								0x00	RW
0x27	ACT_INACT_CTL	[7:0]	RES		LINKLOOP		INACT_REF	INACT_EN	ACT_REF	ACT_EN	0x00	RW
0x28	FIFO_CONTROL	[7:0]	UNUSED				AH	FIFO_TEMP	FIFO_MODE		0x00	RW
0x29	FIFO_SAMPLES	[7:0]	FIFO_SAMPLES[7:0]								0x80	RW
0x2A	INTMAP1	[7:0]	INT_LOW	AWAKE	INACT	ACT	FIFO_OVER-RUN	FIFO_WATER-MARK	FIFO_READY	DATA_READY	0x00	RW
0x2B	INTMAP2	[7:0]	INT_LOW	AWAKE	INACT	ACT	FIFO_OVER-RUN	FIFO_WATER-MARK	FIFO_READY	DATA_READY	0x00	RW
0x2C	FILTER_CTL	[7:0]	RANGE		RES	HALF_BW	EXT_SAMPLE	ODR			0x13	RW
0x2D	POWER_CTL	[7:0]	RES	EXT_CLK	LOW_NOISE		WAKEUP	AUTOSLEEP	MEASURE		0x00	RW
0x2E	SELF_TEST	[7:0]	UNUSED							ST	0x00	RW

REGISTER DETAILS

This section describes the functions of the ADXL362 registers. The ADXL362 powers up with default register values in the as shown in the Reset column of Table 11 in the Register Map section.

Note that any changes to the registers before the POWER_CTL register (Register 0x00 to Register 0x2C) should be made with the device in standby. If changes are made while the ADXL362 is in measurement mode, they may be effective for only part of a measurement.

DEVICE ID REGISTER

Address: 0x00, Reset: 0xAD, Name: DEVID_AD

This register contains the Analog Devices device ID, 0xAD.

B7	B6	B5	B4	B3	B2	B1	B0
1	0	1	0	1	1	0	1

DEVICE ID: 0x1D REGISTER

Address: 0x01, Reset: 0x1D, Name: DEVID_MST

This register contains the Analog Devices MEMS device ID, 0x1D.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	1	1	1	0	1

PART ID: 0xF2 REGISTER

Address: 0x02, Reset: 0xF2, Name: PARTID

This register contains the device ID, 0xF2 (362 octal).

B7	B6	B5	B4	B3	B2	B1	B0
1	1	1	1	0	0	1	0

SILICON REVISION ID REGISTER

Address: 0x03, Reset: 0x01, Name: REVID

This register contains the product revision ID, beginning with 0x01 and incrementing for each subsequent revision.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	1

X-AXIS DATA (8 MSB) REGISTER

Address: 0x08, Reset: 0x00, Name: XDATA

This register holds the eight most significant bits of the x-axis acceleration data. This limited resolution data register is used in power conscious applications where eight bits of data are sufficient: energy can be conserved by reading only one byte of data per axis, rather than two.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0

Y-AXIS DATA (8 MSB) REGISTER

Address: 0x09, Reset: 0x00, Name: YDATA

This register holds the eight most significant bits of the y-axis acceleration data. This limited resolution data register is used in power conscious applications where eight bits of data are sufficient: energy can be conserved by reading only one byte of data per axis, rather than two.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0

Z-AXIS DATA (8 MSB) REGISTER

Address: 0x0A, Reset: 0x00, Name: ZDATA

This register holds the eight most significant bits of the z-axis acceleration data. This limited resolution data register is used in power conscious applications where eight bits of data are sufficient: energy can be conserved by reading only one byte of data per axis, rather than two.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0

STATUS REGISTER

Address: 0x0B, Reset: 0x40, Name: STATUS

This register includes the following bits that describe various conditions of the ADXL362.

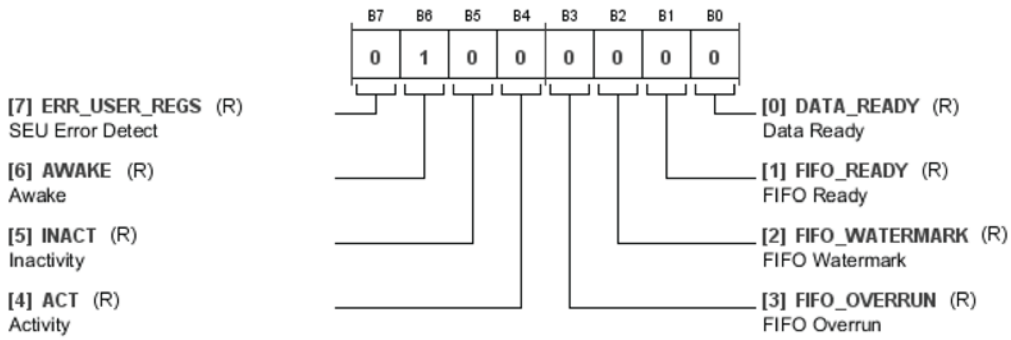


Table 12. Bit Descriptions for STATUS

Bits	Bit Name	Settings	Description	Reset	Access
7	ERR_USER_REGS		SEU Error Detect. 1 indicates one of two conditions: either an SEU event, such as an alpha particle of a power glitch, has disturbed a user register setting or the ADXL362 is not configured. This bit is high upon both startup and soft reset, and resets as soon as any register write commands are performed.	0x0	R
6	AWAKE		Indicates whether the accelerometer is in an active (AWAKE = 1) or inactive (AWAKE = 0) state, based on the activity and inactivity functionality. To enable autosleep, activity and inactivity detection must be in linked mode or loop mode (LINK/LOOP bits in the ACT_INACT_CTL register); otherwise, this bit defaults to 1 and should be ignored.	0x0	R
5	INACT		Inactivity. 1 indicates that the inactivity detection function has detected an inactivity or a free fall condition.	0x0	R
4	ACT		Activity. 1 indicates that the activity detection function has detected an overthreshold condition.	0x0	R
3	FIFO_OVERRUN		FIFO Overrun. 1 indicates that the FIFO has overrun or overflowed, such that new data replaces unread data. See the Using FIFO Interrupts section for details.	0x0	R
2	FIFO_WATERMARK		FIFO Watermark. 1 indicates that the FIFO contains at least the desired number of samples, as set in the FIFO_SAMPLES register. See the Using FIFO Interrupts section for details.	0x0	R
1	FIFO_READY		FIFO Ready. 1 indicates that there is at least one sample available in the FIFO output buffer. See the Using FIFO Interrupts section for details.	0x0	R
0	DATA_READY		Data Ready. 1 indicates that a new valid sample is available to be read. This bit clears when a FIFO read is performed. See the Data Ready Interrupt section for more details.	0x0	R

FIFO ENTRIES REGISTERS

These registers indicate the number of valid data samples present in the FIFO buffer. This number ranges from 0 to 512 or 0x00 to 0x200. FIFO_ENTRIES_L contains the least significant byte. FIFO_ENTRIES_H contains the two most significant bits. Bits[15:10] of FIFO_ENTRIES_H are unused (represented as X = don't care).

Address: 0x0C, Reset: 0x00, Name: FIFO_ENTRIES_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x0D, Reset: 0x00, Name: FIFO_ENTRIES_H

B15	B14	B13	B12	B11	B10	B9	B8
X	X	X	X	X	X	MSB	0

X-AXIS DATA REGISTERS

These two registers contain the sign extended (SX) x-axis acceleration data. XDATA_L contains the eight least significant bits (LSBs), and XDATA_H contains the four most significant bits (MSBs) of the 12-bit value.

The sign extension bits (B[15:12], denoted as SX in the XDATA_H bit map that follows) have the same value as the MSB (B11).

Address: 0x0E, Reset: 0x00, Name: XDATA_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x0F, Reset: 0x00, Name: XDATA_H

B15	B14	B13	B12	B11	B10	B9	B8
SX	SX	SX	SX	MSB	0	0	0

Y-AXIS DATA REGISTERS

These two registers contain the sign extended (SX) y-axis acceleration data. YDATA_L contains the eight LSBs and YDATA_H contains the four MSBs of the 12-bit value.

The sign extension bits (B[15:12], denoted as SX in the YDATA_H bit map that follows) have the same value as the MSB (B11).

Address: 0x10, Reset: 0x00, Name: YDATA_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x11, Reset: 0x00, Name: YDATA_H

B15	B14	B13	B12	B11	B10	B9	B8
SX	SX	SX	SX	MSB	0	0	0

Z-AXIS DATA REGISTERS

These two registers contain the sign extended (SX) z-axis acceleration data. ZDATA_L contains the eight LSBs, and ZDATA_H contains the four MSBs of the 12-bit value.

The sign extension bits (B[15:12], denoted as SX in the ZDATA_H bit map that follows) have the same value as the MSB (B11).

Address: 0x12, Reset: 0x00, Name: ZDATA_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x13, Reset: 0x00, Name: ZDATA_H

B15	B14	B13	B12	B11	B10	B9	B8
SX	SX	SX	SX	MSB	0	0	0

TEMPERATURE DATA REGISTERS

These two registers contain the sign extended (SX) temperature sensor output data. TEMP_L contains the eight LSBs, and TEMP_H contains the four MSBs of the 12-bit value. The value is sign extended; therefore, Bits[B15:B12] of TEMP_H are all 0s or all 1s, based on the value of Bit B11.

The sign extension bits (B[15:12], denoted as SX in the TEMP_H bit map that follows) have the same value as the MSB (B11).

Address: 0x14, Reset: 0x00, Name: TEMP_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x15, Reset: 0x00, Name: TEMP_H

B15	B14	B13	B12	B11	B10	B9	B8
SX	SX	SX	SX	MSB	0	0	0

SOFT RESET REGISTER

Address: 0x1F, Reset: 0x00, Name: SOFT_RESET

Writing Code 0x52 (representing the letter, R, in ASCII or unicode) to this register immediately resets the ADXL362. All register settings are cleared, and the sensor is placed in standby. Interrupt pins are configured to a high output impedance mode and held to a valid state by bus keepers.

This is a write-only register. If read, data in it is always 0x00.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0

ACTIVITY THRESHOLD REGISTERS

To detect activity, the ADXL362 compares the absolute value of the 12-bit (signed) acceleration data with the 11-bit (unsigned) THRESH_ACT value. See the Motion Detection section for more information on activity detection.

The term, THRESH_ACT, refers to an 11-bit unsigned value comprising the THRESH_ACT_L register, which holds its eight LSBs; and the THRESH_ACT_H register, which holds its three MSBs.

THRESH_ACT is set in codes; the value in *g* depends on the measurement range setting that is selected.

THRESH_ACT [*g*] = *THRESH_ACT* [codes]/*Sensitivity* [codes per *g*]

Address: 0x20, Reset: 0x00, Name: THRESH_ACT_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x21, Reset: 0x00, Name: THRESH_ACT_H

B15	B14	B13	B12	B11	B10	B9	B8
x	x	x	x	x	MSB	0	0

ACTIVITY TIME REGISTER

Address: 0x22, Reset: 0x00, Name: TIME_ACT

The activity timer implements a robust activity detection that minimizes false positive motion triggers. When the timer is used, only sustained motion can trigger activity detection. Refer to the Fewer False Positives section for additional information.

The value in this register sets the number of consecutive samples that must have at least one axis greater than the activity threshold (set by THRESH_ACT) for an activity event to be detected.

The time (in seconds) is given by the following equation:

Time = *TIME_ACT*/*ODR*

where:
TIME_ACT is the value set in this register.
ODR is the output data rate set in the FILTER_CTL register (Address 0x2C).

Setting the activity time to 0x00 has the same result as setting this time to 0x01: Activity is detected when a single acceleration sample has at least one axis greater than the activity threshold (THRESH_ACT).

When the accelerometer is in wake-up mode, the TIME_ACT value is ignored and activity is detected based on a single acceleration sample.

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0

INACTIVITY THRESHOLD REGISTERS

To detect inactivity, the absolute value of the 12-bit acceleration data is compared with the 11-bit (unsigned) THRESH_INACT value. See the Motion Detection section for more information.

The term, THRESH_INACT, refers to an 11-bit unsigned value comprised of the THRESH_INACT_L registers, which holds its eight LSBs and the THRESH_INACT_H register, which holds its three MSBs.

This 11-bit unsigned value sets the threshold for inactivity detection. This value is set in codes; the value (in *g*) depends on the measurement range setting selected:

THRESH_INACT [*g*] =
THRESH_INACT [codes]/*Sensitivity* [codes per *g*]

Address: 0x23, Reset: 0x00, Name: THRESH_INACT_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x24, Reset: 0x00, Name: THRESH_INACT_H

B15	B14	B13	B12	B11	B10	B9	B8
x	x	x	x	x	MSB	0	0

INACTIVITY TIME REGISTERS

The 16-bit value in these registers sets the number of consecutive samples that must have all axes lower than the inactivity threshold (set by THRESH_INACT) for an inactivity event to be detected.

The TIME_INACT_L register holds the eight LSBs and the TIME_INACT_H register holds the eight MSBs of the 16-bit TIME_INACT value.

The time in seconds can be calculated as

Time = *TIME_INACT*/*ODR*

where:
TIME_INACT is the 16-bit value set by the TIME_INACT_L register (eight LSBs) and the TIME_INACT_H register (eight MSBs).
ODR is the output data rate set in the FILTER_CTL register (Address 0x2C).

The 16-bit value allows for long inactivity detection times. The maximum value is 0xFFFF or 65,535 samples. At the lowest output data rate, 12.5 Hz, this equates to almost 90 minutes. In this configuration, the accelerometer must be stationary for 90 minutes before putting its system to sleep.

Setting the activity time to 0x00 has the same result as setting this time to 0x01: Activity is detected when a single acceleration sample has at least one axis greater than the activity threshold (THRESH_INACT).

Address: 0x25, Reset: 0x00, Name: TIME_INACT_L

B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	LSB

Address: 0x26, Reset: 0x00, Name: TIME_INACT_H

B15	B14	B13	B12	B11	B10	B9	B8
MSB	0	0	0	0	0	0	0

ACTIVITY/INACTIVITY CONTROL REGISTER

Address: 0x27, Reset: 0x00, Name: ACT_INACT_CTL

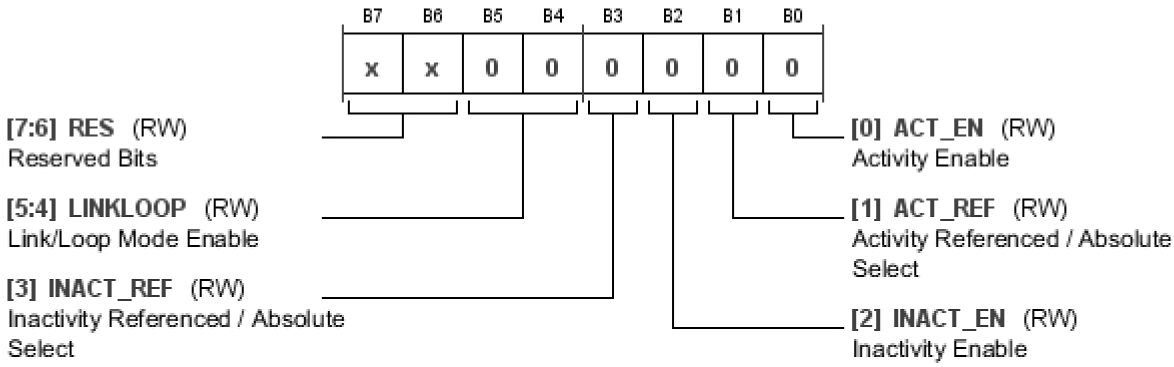


Table 13. Bit Descriptions for ACT_INACT_CTL

Bits	Bit Name	Settings	Description	Reset	Access
[7:6]	UNUSED		Unused Bits.	0x0	RW
[5:4]	LINK/LOOP	0X	Default Mode.	0x0	RW
			Activity and inactivity detection are both enabled, and their interrupts (if mapped) must be acknowledged by the host processor by reading the STATUS register. Autosleep is disabled in this mode. Use this mode for free fall detection applications.		
		01	Linked Mode.		
			Activity and inactivity detection are linked sequentially such that only one is enabled at a time. Their interrupts (if mapped) must be acknowledged by the host processor by reading the STATUS register.		
		11	Loop Mode.		
			Activity and inactivity detection are linked sequentially such that only one is enabled at a time, and their interrupts are internally acknowledged (do not need to be serviced by the host processor).		
			To use either linked or looped mode, both ACT_EN (Bit 0) and INACT_EN (Bit 2) must be set to 1; otherwise, the default mode is used. For additional information, refer to the Linking Activity and Inactivity Detection section.		
3	INACT_REF		Referenced/Absolute Inactivity Select.	0x0	RW
			1 = inactivity detection function operates in referenced mode.		
			0= inactivity detection function operates in absolute mode.		
2	INACT_EN		Inactivity Enable.	0x0	RW
			1 = enables the inactivity (underthreshold) functionality.		
1	ACT_REF		Referenced/Absolute Activity Select.	0x0	RW
			1 = activity detection function operates in referenced mode.		
			0 = activity detection function operates in absolute mode.		
0	ACT_EN		Activity Enable.	0x0	RW
			1 = enables the activity (overthreshold) functionality.		

FIFO CONTROL REGISTER

Address: 0x28, Reset: 0x00, Name: FIFO_CONTROL

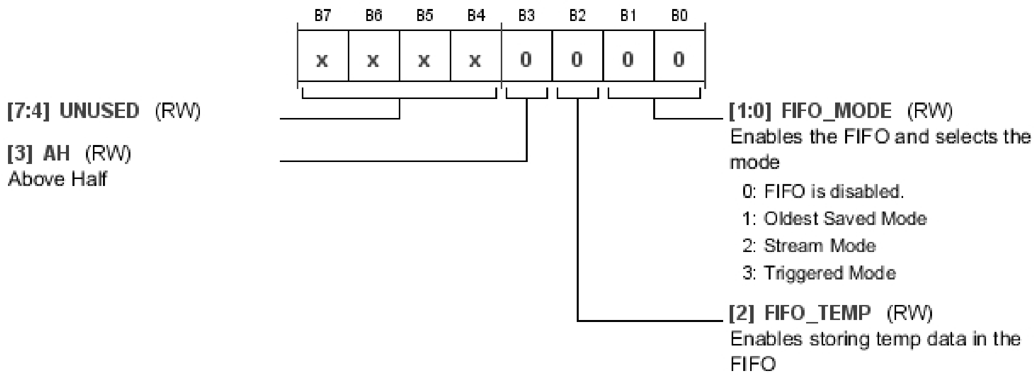


Table 14. Bit Descriptions for FIFO_CONTROL

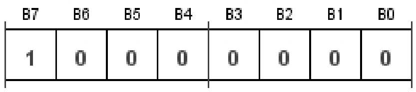
Bits	Bit Name	Settings	Description	Reset	Access
[7:4]	UNUSED		Unused Bits.	0x0	RW
3	AH		Above Half. This bit is the MSB of the FIFO_SAMPLES register, allowing FIFO samples a range of 0 to 511.	0x0	RW
2	FIFO_TEMP		Store Temperature Data to FIFO. 1 = temperature data is stored in the FIFO together with x-, y-, and z-axis acceleration data.	0x0	RW
[1:0]	FIFO_MODE		Enable FIFO and Mode Selection.	0x0	RW
		00	FIFO is disabled.		
		01	Oldest saved mode.		
		10	Stream mode.		
		11	Triggered mode.		

FIFO SAMPLES REGISTER

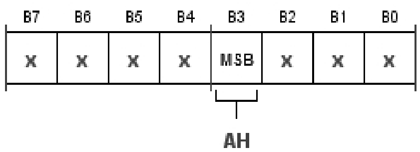
Address: 0x29, Reset: 0x80, Name: FIFO_SAMPLES

The value in this register specifies the number of samples to store in the FIFO. The AH bit in the FIFO_CONTROL register (Address 0x28) is used as the MSB of this value. The full range of FIFO samples is 0 to 511.

The default value of this register is 0x80 to avoid triggering the FIFO watermark interrupt (see the FIFO Watermark section for more information).



The following bit map is duplicated from the FIFO Control Register section to indicate the AH bit.



INT1/INT2 FUNCTION MAP REGISTERS

The INT1 and INT2 registers configure the INT1/INT2 interrupt pins, respectively. Bits[B6:B0] select which function(s) generate an interrupt on the pin. If its corresponding bit is set to 1, the function generates an interrupt on the INT pin. Bit B7 configures whether the pin operates in active high (B7 low) or active low (B7 high) mode.

Any number of functions can be selected simultaneously for each pin. If multiple functions are selected, their conditions are OR'ed together to determine the INT pin state. The status of each individual function can be determined by reading the STATUS register. If no interrupts are mapped to an INT pin, the pin remains in a high impedance state, held to a valid logic state by a bus keeper.

Address: 0x2A, Reset: 0x00, Name: INTMAP1

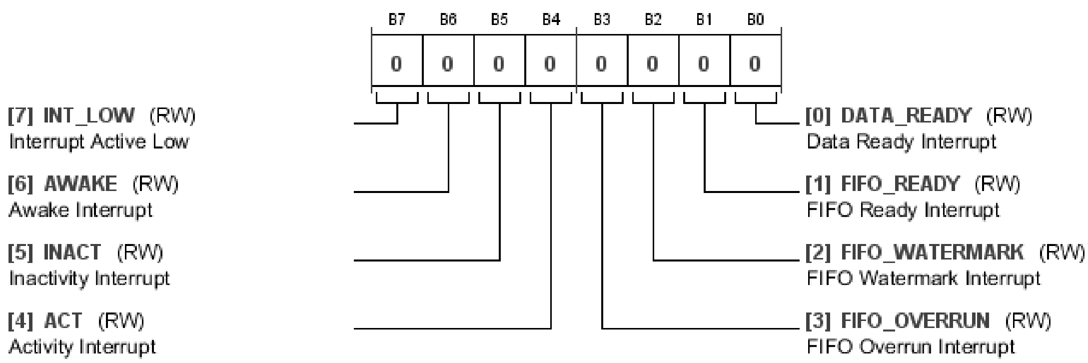


Table 15. Bit Descriptions for INTMAP1

Bits	Bit Name	Settings	Description	Reset	Access
7	INT_LOW		1 = INT1 pin is active low.	0x0	RW
6	AWAKE		1 = maps the awake status to INT1 pin.	0x0	RW
5	INACT		1 = maps the inactivity status to INT1 pin.	0x0	RW
4	ACT		1 = maps the activity status to INT1 pin.	0x0	RW
3	FIFO_OVERRUN		1 = maps the FIFO overrun status to INT1 pin.	0x0	RW
2	FIFO_WATERMARK		1 = maps the FIFO watermark status to INT1 pin.	0x0	RW
1	FIFO_READY		1 = maps the FIFO ready status to INT1 pin.	0x0	RW
0	DATA_READY		1 = maps the data ready status to INT1 pin.	0x0	RW

Address: 0x2B, Reset: 0x00, Name: INTMAP2

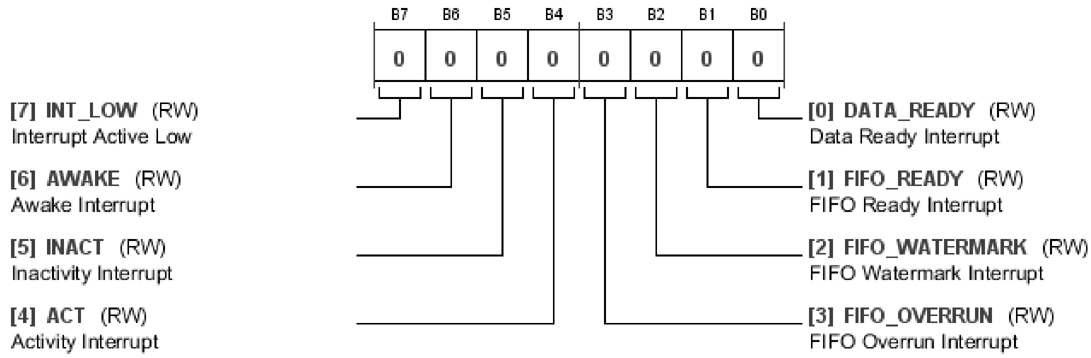


Table 16. Bit Descriptions for INTMAP2

Bits	Bit Name	Settings	Description	Reset	Access
7	INT_LOW		1 = INT2 pin is active low.	0x0	RW
6	AWAKE		1 = maps the awake status to INT2 pin.	0x0	RW
5	INACT		1 = maps the inactivity status to INT2 pin.	0x0	RW
4	ACT		1 = maps the activity status to INT2 pin.	0x0	RW
3	FIFO_OVERRUN		1 = maps the FIFO overrun status to INT2 pin.	0x0	RW
2	FIFO_WATERMARK		1 = maps the FIFO watermark status to INT2 pin.	0x0	RW
1	FIFO_READY		1 = maps the FIFO ready status to INT2 pin.	0x0	RW
0	DATA_READY		1 = maps the data ready status to INT2 pin.	0x0	RW

FILTER CONTROL REGISTER

Address: 0x2C, Reset: 0x13, Name: FILTER_CTL

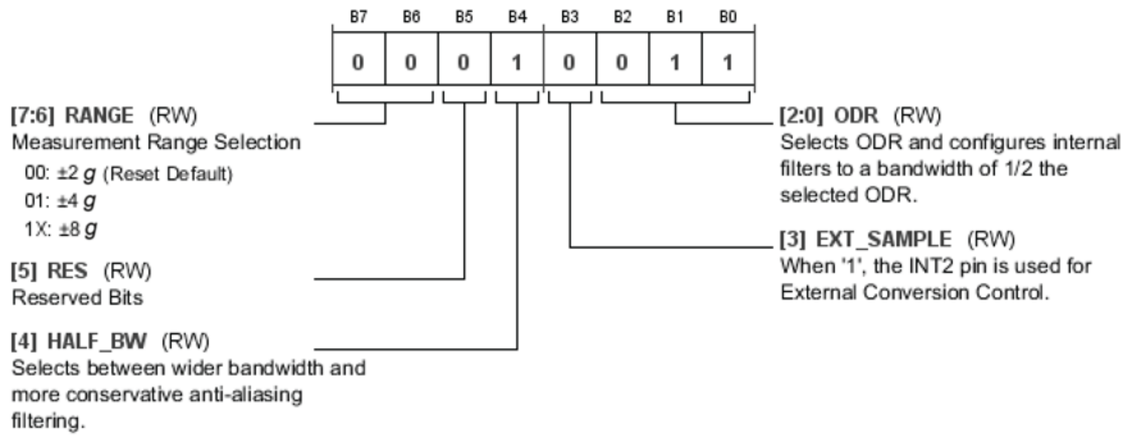


Table 17. Bit Descriptions for FILTER_CTL

Bits	Bit Name	Settings	Description	Reset	Access
[7:6]	RANGE		Measurement Range Selection.	0x0	RW
		00	±2 *g* (reset default)		
		01	±4 *g*		
		1X	±8 *g*		
5	RES		Reserved.	0x0	RW
4	HALF_BW		Halved Bandwidth. Additional information is provided in the Antialiasing section.	0x1	
			1 = the bandwidth of the antialiasing filters is set to ¼ the output data rate (ODR) for more conservative filtering.		
			0 = the bandwidth of the filters is set to ½ the ODR for a wider bandwidth.		
3	EXT_SAMPLE		External Sampling Trigger. 1 = the INT2 pin is used for external conversion timing control. Refer to the Using Synchronized Data Sampling section for more information.	0x0	RW
[2:0]	ODR		Output Data Rate. Selects ODR and configures internal filters to a bandwidth of ½ or ¼ the selected ODR, depending on the HALF_BW bit setting.	0x0	RW
		000	12.5 Hz		
		001	25 Hz		
		010	50 Hz		
		011	100 Hz (reset default)		
		100	200 Hz		
		101…111	400 Hz		

POWER CONTROL REGISTER

Address: 0x2D, Reset: 0x00, Name: POWER_CTL

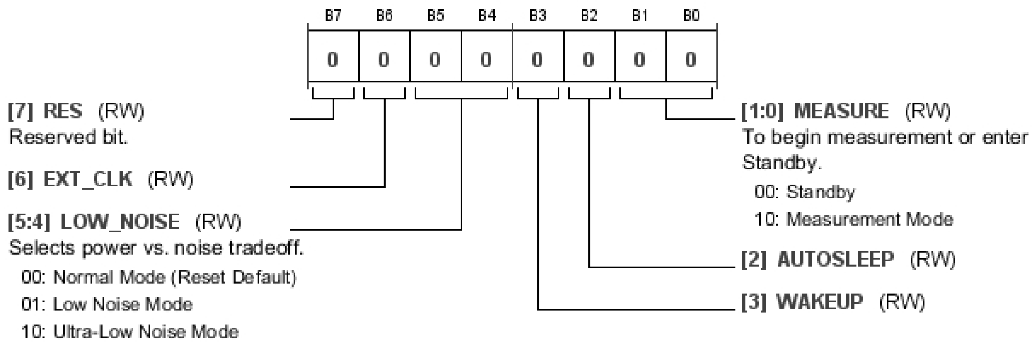


Table 18. Bit Descriptions for POWER_CTL

Bits	Bit Name	Settings	Description	Reset	Access
7	Reserved		Reserved.	0x0	RW
6	EXT_CLK		External Clock. See the Using an External Clock section for additional details.	0x0	RW
			1 = the accelerometer runs off the external clock provided on the INT1 pin.		
[5:4]	LOW_NOISE		Selects Power vs. Noise Tradeoff:	0x0	RW
		00	Normal operation (reset default).		
		01	Low noise mode.		
		10	Ultralow noise mode.		
		11	Reserved.		
3	WAKEUP		Wake-Up Mode. See the Operating Modes section for a detailed description of wake-up mode.	0x0	RW
			1 = the part operates in wake-up mode.		
2	AUTOSLEEP		Autosleep. Activity and inactivity detection must be in linked mode or loop mode (LINK/LOOP bits in ACT_INACT_CTL register) to enable autosleep; otherwise, the bit is ignored. See the Motion Detection section for details.	0x0	RW
			1 = autosleep is enabled, and the device enters wake-up mode automatically upon detection of inactivity.		
[1:0]	MEASURE		Selects Measurement Mode or Standby.	0x0	RW
		00	Standby.		
		01	Reserved.		
		10	Measurement mode.		
		11	Reserved.		

SELF TEST REGISTER

Address: 0x2E, Reset: 0x00, Name: SELF_TEST

Refer to the Self Test section for information on the operation of the self test feature, and see the Using Self Test section for guidelines on how to use this functionality.

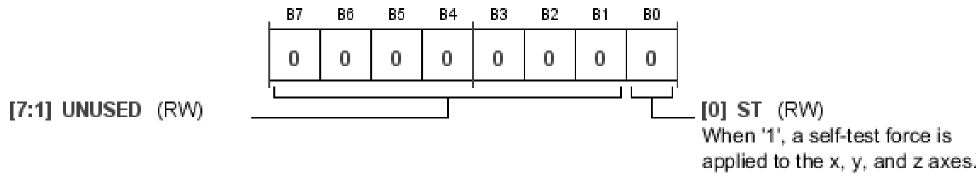


Table 19. Bit Descriptions for SELF_TEST

Bits	Bit Name	Settings	Description	Reset	Access
[7:1]	UNUSED			0x0	RW
0	ST		Self Test. 1 = a self test force is applied to the x-, y-, and z-axes.	0x0	RW

APPLICATIONS INFORMATION

APPLICATION EXAMPLES

This section includes a few application circuits, highlighting useful features of the ADXL362.

Device Configuration

This section outlines the procedure for configuring the device and acquiring data. In general, the procedure follows the sequence of the register map, starting with Register 0x20, THRESH_ACT_L.

1. Set activity and inactivity thresholds and timers.
   a. Write to Register 0x20 to Register 0x26.
   b. To minimize false positive motion triggers, set the TIME_ACT register greater than 1.
2. Configure activity and inactivity functions.
   a. Write to Register 0x27.
3. Configure FIFO.
   a. Write to Register 0x28 and Register 0x29.
4. Map interrupts.
   a. Write to Register 0x2A and Register 0x2B.
5. Configure general device settings.
   a. Write to Register 0x2C.
6. Turn measurement on.
   a. Write to Register 0x2D.

Settings for each of the registers vary based on application requirements. For more information, see the Register Details section.

Autonomous Motion Switch

The features of the ADXL362 make it ideal for use as an autonomous motion switch. The example outlined here implements a switch that, once configured, operates without the intervention of a host processor to intelligently manage system power. In this example, the awake signal, mapped to the INT2 pin, drives a high-side power switch, such as the ADP195, to control power to the downstream circuitry.

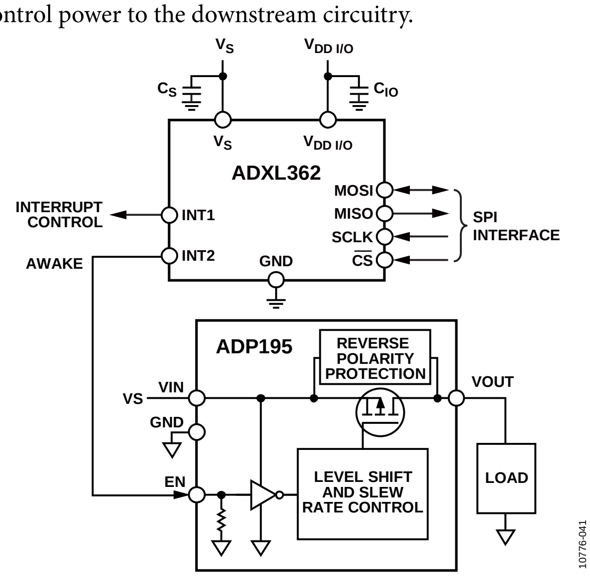


Figure 43. Awake Signal to Control Power to Downstream Circuitry

Startup Routine

This routine assumes a ±2 *g* measurement range and operation in wake-up mode.

1. Write 250 decimal (0xFA) to Register 0x20, and write 0 to Register 0x21: sets activity threshold to 250 m*g*.
2. Write 150 decimal (0x96) to Register 0x23, and write 0 to Register 0x24: sets inactivity threshold to 150 m*g*.
3. Write 30 decimal (0x1E) to Register 0x25: sets inactivity timer to 30 samples or about 5 seconds.
4. Write 0x3F to Register 0x27: configures motion detection in loop mode and enables referenced activity and inactivity detection.
5. Write 0x40 to Register 0x2B: map the AWAKE bit to INT2. The INT2 pin is tied to the gate of the switch.
6. Write 0x0A to Register 0x2D: begins the measurement in wake-up mode.

Using External Timing Triggers

Figure 44 shows an application diagram for using the INT1 pin as the input for an external clock. In this mode, the external clock determines all accelerometer timing, including the output data rate and bandwidth.

To enable this feature, at the end of the desired start-up routine, set Bit 6 in the POWER_CTL register; for example, write 0x42 to this register to enable the use of an external clock and place the accelerometer into measurement mode.

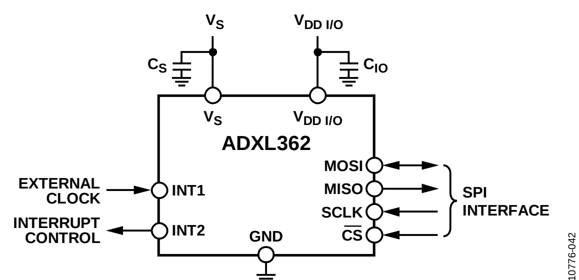


Figure 44. INT1 Pin as the Input for the External Clock

Figure 45 is an application diagram for using the INT2 pin as a trigger for synchronized sampling. Acceleration samples are produced every time this trigger is activated. To enable this feature, near the end of the desired start-up routine, set Bit 3 in the FILTER_CTL register; for example, write 0x4B to this register to enable the trigger and configure the accelerometer for ±8 *g* measurement range and 100 Hz ODR.

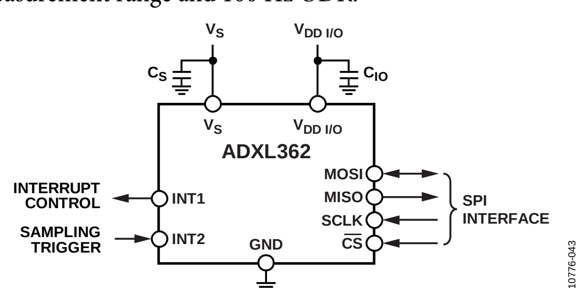


Figure 45. Using the INT2 Pin to Trigger Synchronized Sampling

Example: Implementing Free Fall Detection

Many digital output accelerometers include a built-in free fall detection feature. In the ADXL362, implement this function using the inactivity interrupt.

When an object is in true free fall, acceleration on all axes is 0 *g*. Thus, free fall detection is achieved by looking for acceleration on all axes to fall below a certain threshold (close to 0 *g*) for a certain amount of time. The inactivity detection functionality, when used in absolute mode, does exactly this.

To use inactivity to implement free fall detection, set the value in THRESH_INACT to the desired free fall threshold. Values between 300 m*g* and 600 m*g* are recommended; the register setting for these values varies based on the *g* range setting of the device, as follows:

THRESH_INACT =
Threshold Value [*g*] × *Scale Factor* [LSB per *g*]

Set the value in TIME_INACT to implement the minimum amount of time that the acceleration on all axes must be less than the free fall threshold to generate a free fall condition. Values between 100 ms and 350 ms are recommended; the register setting for this varies based on the output data rate.

TIME_INACT = *Time* [sec] × *Data Rate* [Hz]

When a free fall condition is detected, the inactivity status is set to 1 and, if the function is mapped to an interrupt pin, an inactivity interrupt triggers on that pin.

Startup Routine

The following startup routine configures the ADXL362 for a typical free fall application. This routine assumes a ±8 *g* measurement range and 100 Hz output data rate. Thresholds and timing values can be modified to suit particular application needs.

1. Write 0x58 (150 codes) to Register 0x23: sets free fall threshold to 600 m*g*.
2. Write 0x03 to Register 0x25: sets free fall time to 30 ms.
3. Write 0x0C to Register 0x27: enables absolute inactivity detection.
4. Write 0x20 to Register 0x2A or Register 0x2B to map the inactivity interrupt to INT1 or INT2, respectively.
5. Write 0x83 to Register 0x2C: configures the accelerometer to ±8 *g* range, 100 Hz ODR (output data rate).
6. Write 0x02 to Register 0x2D to begin measurement.

Implementation of a complete fall detection application is described in the AN-1023 Application Note, *Fall Detection Application by Using 3-Axis Accelerometer ADXL345*.

POWER

Power Supply Decoupling

Figure 46 shows the recommended bypass capacitors for use with the ADXL362.

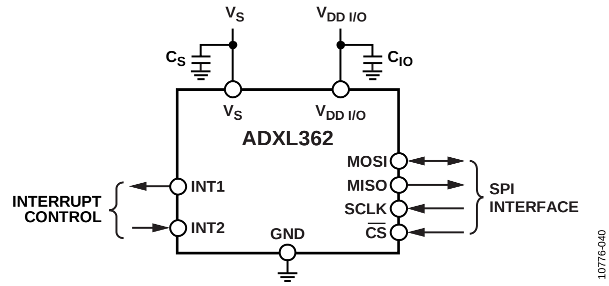


Figure 46. Recommended Bypass Capacitors

A 0.1 µF ceramic capacitor (C_S) at V_S and a 0.1 µF ceramic capacitor (C_{IO}) at $V_{DD\ I/O}$ placed as close as possible to the ADXL362. Supply pins are recommended to adequately decouple the accelerometer from noise on the power supply. It is also recommended that V_S and $V_{DD\ I/O}$ be separate supplies to minimize digital clocking noise on the V_S supply. If this is not possible, additional filtering of the supplies may be necessary.

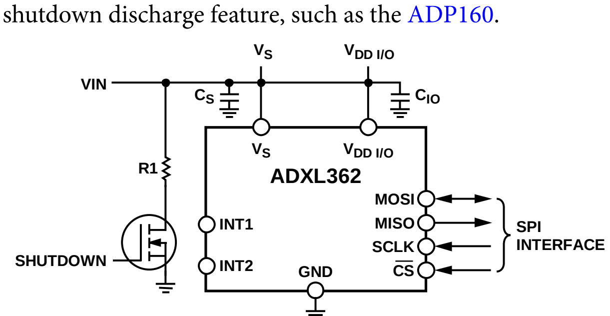
If additional decoupling is necessary, place a resistor or ferrite bead, no larger than 100 Ω, in series with V_S. Additionally, increasing the bypass capacitance on V_S to a 1 µF tantalum capacitor in parallel with a 0.1 µF ceramic capacitor may also improve noise.

Ensure that the connection from the ADXL362 ground to the power supply ground has low impedance because noise transmitted through ground has an effect similar to noise transmitted through V_S.

Power Supply Requirements

The ADXL362 is designed to operate using supply voltage rails ranging from 1.8 V to 3.3 V. The operating voltage range (V_S), specified in Table 1, ranges from 1.6 V to 3.5 V to account for inaccuracies and transients of up to ±10% on the supply voltage.

The ADXL362 does not require any particular startup transient characteristics, except that it must always be started up from 0 V. When the device is in operation, any time power is removed from the ADXL362, or falls below the operating voltage range, the supplies (V_S, $V_{DD\ I/O}$, and any bypass capacitors) must be discharged completely before power is reapplied. To enable supply discharge, it is recommended to power the device from a microcontroller GPIO, connect a shutdown discharge switch to the supply (Figure 47), or use a voltage regulator with a shutdown discharge feature, such as the ADP160.



NOTES
1. THE ADXL362 SUPPLIES MUST BE DISCHARGED FULLY EACH TIME THE VOLTAGE ON THEM DROPS BELOW THE SPECIFIED OPERATING RANGE. A SHUTDOWN SWITCH IS ONE WAY TO DISCHARGE THE SUPPLIES.

10776-141

Figure 47. Using a Switch to Discharge the ADXL362 Supplies

FIFO MODES

The FIFO is a 512-sample memory buffer that can be used to save power, unburden the host processor, and autonomously record data.

The 512 FIFO samples can be allotted as either:

- 170 sample sets of concurrent 3-axis data; or
- 128 sample sets of concurrent 3-axis and temperature data

The FIFO operates in one of the four modes described in this section.

FIFO Disabled

When the FIFO is disabled, no data is stored in it and any data already stored in it is cleared.

The FIFO is disabled by setting the FIFO_MODE bits in the FIFO_CONTROL register (Address 0x28) to Binary Value 0b00.

Oldest Saved Mode

In oldest saved mode, the FIFO accumulates data until it is full and then stops. Additional data is collected only when space is made available by reading samples out of the FIFO buffer. (This mode of operation is sometimes referred to as "First N.")

The FIFO is placed into oldest saved mode by setting the FIFO_MODE bits in the FIFO_CONTROL register (Address 0x28) to Binary Value 0b01.

Stream Mode

In stream mode, the FIFO always contains the most recent data. The oldest sample is discarded when space is needed to make room for a newer sample. (This mode of operation is sometimes referred to as "Last N.")

Stream mode is useful for unburdening a host processor. The processor can tend to other tasks while data is being collected in the FIFO. When the FIFO fills to a certain number of samples (specified by the FIFO_SAMPLES register along with the AH bit in the FIFO_CONTROL register), it triggers a FIFO watermark interrupt (if this interrupt is enabled). At this point, the host processor can read the contents of the entire FIFO and then return to its other tasks as the FIFO fills again.

The FIFO is placed into stream mode by setting the FIFO_MODE bits in the FIFO_CONTROL register (Address 0x28) to Binary Value 0b10.

Triggered Mode

In triggered mode, the FIFO saves samples surrounding an activity detection event. The operation is similar to a one-time run trigger on an oscilloscope. The number of samples to be saved prior to the activity event is specified in FIFO_SAMPLES (Register 0x29, along with the AH bit in the FIFO_CONTROL register, Address 0x28).

Place the FIFO into triggered mode by setting the FIFO_MODE bits in the FIFO_CONTROL register (Address 0x28) to Binary Value 0b11.

FIFO Configuration

The FIFO is configured via Register 0x28 and Register 0x29. Settings are described in detail in the FIFO Control Register section.

FIFO Interrupts

The FIFO can generate interrupts to indicate when samples are available, when a specified number of samples has been collected, and when the FIFO overflows and samples are lost. See the Using FIFO Interrupts section for more information.

Retrieving Data from FIFO

FIFO data is read by issuing a FIFO read command, described in the SPI Commands section. Data is formatted as a 16-bit value as represented in Table 20.

When reading data, the least significant byte (Bits[B7:B0]) is read first, followed by the most significant byte (Bits[B15:B8]). Bits[B11:B0] represent the 12-bit, twos complement acceleration or temperature data. Bits[B13:B12] are sign extension bits, and Bits[B15:B14] indicate the type of data, as listed in Table 20.

Table 20. FIFO Buffer Data Format

B15	B14	B13	B12	B11	B10	B9	B8
Data Type: 00: X-Axis 01: Y-Axis 10: Z-Axis 11: Temp		Sign Extension		MSB	Data		

B7	B6	B5	B4	B3	B2	B1	B0
Data							LSB

Because the data format is 16-bit, the data must be read from the FIFO two bytes at a time. When a multibyte read is performed, the number of bytes read should always be an even number. Multibyte reads of FIFO data can be performed with no limit on the number of bytes read. If additional bytes are read after the FIFO is empty, the data in the additional bytes are read as 0x00.

As each sample set is acquired, it is written into the FIFO in the following order:

- X-axis
- Y-axis
- Z-axis
- Temperature (optional)

This pattern repeats until the FIFO is full, at which point the behavior depends on the FIFO mode (see the FIFO section). If the FIFO has insufficient space for four data entries (or three entries if temperature is not being stored), then an incomplete sample set can be stored.

FIFO data is output on a per datum basis. As each data item is read, the same amount of space is freed up in the stack. Again, this can lead to incomplete sample sets being present in the FIFO.

For additional system level FIFO applications, refer to the AN-1025 Application Note, *Utilization of the First In, First Out (FIFO) Buffer in Analog Devices, Inc. Digital Accelerometers*.

INTERRUPTS

Several of the built-in functions of the ADXL362 can trigger interrupts to alert the host processor of certain status conditions. This section describes the functionality of these interrupts.

Interrupt Pins

Interrupts can be mapped to either (or both) of two designated output pins, INT1 and INT2, by setting the appropriate bits in the INTMAP1 and INTMAP2 registers, respectively. All functions can be used simultaneously. If multiple interrupts are mapped to one pin, the OR combination of the interrupts determines the status of the pin.

If no functions are mapped to an interrupt pin, that pin is automatically configured to a high impedance (high-Z) state. The pins are also placed in the high-Z state upon a reset.

When a certain status condition is detected, the pin that condition is mapped to is activated. The configuration of the pin is active high by default so that when it is activated, the pin goes high. However, this configuration can be switched to active low by setting the INT_LOW bit in the appropriate INTMAPx register.

The INT pins can be connected to the interrupt input of a host processor where interrupts are responded to with an interrupt routine. Because multiple functions can be mapped to the same pin, the STATUS register can be used to determine which condition caused the interrupt to trigger.

Clear interrupts in one of several ways, as follows:

- Reading the STATUS register (Address 0x0B) clears activity and inactivity interrupts.
- Reading from the data registers. Address 0x08 to Address 0x0A or Address 0x0E to Address 0x15 clears the data ready interrupt.
- Reading enough data from the FIFO buffer so that interrupt conditions are no longer met clears the FIFO ready, FIFO watermark, and FIFO overrun interrupts.

Both interrupt pins are push-pull low impedance pins with an output impedance of about 500 Ω (typical) and digital output specifications, as shown in Table 21. Both pins have bus keepers that hold them to a valid logic state when they are in a high impedance mode.

To prevent interrupts from being falsely triggered during configuration, disable interrupts while their settings, such as thresholds, timings, or other values, are configured.

Table 21. Interrupt Pin Digital Output

Parameter	Test Conditions	Limit[1]		Unit
		Min	Max	
Digital Output				
Low Level Output Voltage (V_{OL})	I_{OL} = 500 µA		0.2 × $V_{DD\ I/O}$	V
High Level Output Voltage (V_{OH})	I_{OH} = −300 µA	0.8 × $V_{DD\ I/O}$		V
Low Level Output Current (I_{OL})	$V_{OL} = V_{OL,\ max}$	500		µA
High Level Output Current (I_{OH})	$V_{OH} = V_{OH,\ min}$		−300	µA

[1] Limits based on design, not production tested.

Alternate Functions of Interrupt Pins

The INT1 and INT2 pins can be configured for use as input pins instead of for signaling interrupts. INT1 is used as an external clock input when the EXT_CLK bit (Bit 6) in the POWER_CTL register (Address 0x2D) is set. INT2 is used as the trigger input for synchronized sampling when the EXT_SAMPLE bit (Bit 3) in the FILTER_CTL register (Address 0x2C) is set. One or both of these alternate functions can be used concurrently; however, if an interrupt pin is used for its alternate function, it cannot simultaneously be used for its primary function, to signal interrupts.

External clocking and data synchronization are described in the Applications Information section.

Activity and Inactivity Interrupts

The ACT bit (Bit 4) and INACT bit (Bit 5) in the STATUS register are set when activity and inactivity are detected, respectively. Detection procedures and criteria are described in the Motion Detection section.

Data Ready Interrupt

The DATA_READY bit (Bit 0) is set when new valid data is available, and it is cleared when no new data is available.

The DATA_READY bit is not set while any of the data registers, Address 0x08 to Address 0x0A and Address 0x0E to Address 0x15, are being read. If DATA_READY = 0 prior to a register read and new data becomes available during the register read, DATA_READY remains at 0 until the read is complete and, only then, is set to 1.

If DATA_READY = 1 prior to a register read, it is cleared at the start of the register read.

If DATA_READY = 1 prior to a register read and new data becomes available during the register read, DATA_READY is cleared to 0 at the start of the register read and remains at 0 throughout the read. When the read is complete, DATA_READY is set to 1.

Using FIFO Interrupts

FIFO Watermark

The FIFO_WATERMARK bit (Bit 2) is set when the number of samples stored in the FIFO is equal to or exceeds the number specified in the FIFO_SAMPLES register (Address 0x29) together with the AH bit in the FIFO_CONTROL register (Bit 3, Address 0x28). The FIFO_WATERMARK bit is cleared automatically when enough samples are read from the FIFO, such that the number of samples remaining is lower than that specified.

If the number of FIFO samples is set to 0, the FIFO watermark interrupt is set. To avoid unexpectedly triggering this interrupt, the default value of the FIFO_SAMPLES register is 0x80.

FIFO Ready

The FIFO_READY bit (Bit 1) is set when there is at least one valid sample available in the FIFO output buffer. This bit is cleared when no valid data is available in the FIFO.

Overrun

The FIFO_OVERRUN bit (Bit 3) is set when the FIFO has overrun or overflowed, such that new data replaces unread data. This may indicate a full FIFO that has not yet been emptied or a clocking error caused by a slow SPI transaction. If the FIFO is configured to oldest saved mode, an overrun event indicates that there is insufficient space available for a new sample.

The FIFO_OVERRUN bit is cleared automatically when the contents of the FIFO are read. Likewise, when the FIFO is disabled, the FIFO_OVERRUN bit is cleared.

USING SYNCHRONIZED DATA SAMPLING

For applications that require a precisely timed acceleration measurement, the ADXL362 features an option to synchronize acceleration sampling to an external trigger. The EXT_SAMPLE bit (Bit 3) in the FILTER_CTL Register (Address 0x2C) enables this feature. When the EXT_SAMPLE bit is set to 1, the INT2 pin is automatically reconfigured for use as the sync trigger input.

When external triggering is enabled, it is up to the system designer to ensure that the sampling frequency meets system requirements. Sampling too infrequently causes aliasing. Noise can be lowered by oversampling; however, sampling at too high a frequency may not allow enough time for the accelerometer to process the acceleration data and convert it to valid digital output.

When Nyquist criteria are met, signal integrity is maintained. An internal antialiasing filter is available in the ADXL362 and can assist the system designer in maintaining signal integrity. To prevent aliasing, set the filter bandwidth to a frequency no greater than ½ the sampling rate. For example, when sampling at 100 Hz, set the filter pole to no higher than 50 Hz. The filter pole is set via the ODR bits in the FILTER_CTL register (Address 0x2C). The filter bandwidth is set to ½ the ODR and is set via these bits. Even though the ODR is ignored (as the data rate is set by the external trigger), the filter is still applied at the specified bandwidth.

Because of internal timing requirements, the trigger signal applied to pin INT2 must meet the following criteria:

- The trigger signal is active high.
- The pulse width of the trigger signal must be at least 25 µs.
- The trigger must be deasserted for at least 25 µs before it is reasserted.
- The maximum sampling frequency that is supported is 625 Hz (typical).
- The minimum sampling frequency is set only by system requirements. Samples need not be polled at any minimum rate; however, if samples are polled at a rate lower than the bandwidth set by the antialiasing filter, then aliasing may occur.

USING AN EXTERNAL CLOCK

The ADXL362 has a built-in clock that, by default, is used for clocked internal operations. If desired, an external clock can be provided and used.

To use an external clock, the EXT_CLK bit (Bit 6) in the POWER_CTL register (Address 0x2D) must be set. Setting this bit reconfigures the INT1 pin to an input pin on which the clock can be provided. The external clock must operate at or below 51.2 kHz. Further information is provided in the External Clock section.

USING SELF TEST

The self test function, described in the Self Test section, is enabled via the ST bit in the SELF_TEST register, Address 0x2E. The recommended procedure for using the self test functionality is as follows:

1. Read acceleration data for the x-, y-, and z-axes.
2. Assert self test by setting the ST bit in the SELF_TEST register, Address 0x2E.
3. Wait 1/ODR for the output to settle to its new value.
4. Read acceleration data for the x-, y-, and z-axes.
5. Compare to the values from Step 1, and convert the difference from LSB to m*g* by multiplying by the sensitivity. If the observed difference falls within the self test output change specification listed in Table 1, then the device passes self test and is deemed operational.
6. Deassert self test by clearing the ST bit in the SELF_TEST register, Address 0x2E.

The self test output change specification is given for V_S = 2.0 V. Because the electrostatic force is proportional to V_S^2 and the sensitivity of the device is ratiometric to V_S, the output change varies with V_S. The scale factors shown in Table 22 can be used to adjust the expected self test output limits for different supply voltages, V_S.

Note that at higher voltages, self test deltas may exceed 1 *g*. If the measurement is performed with one axis experiencing 1 *g* due to gravity, and if the accelerometer is configured for a ±2 *g* measurement range, the axis that is aligned with the field of gravity may reach 2 *g* and its output clips (saturates to its full-scale value). To alleviate this, self test can be measured with the y-axis aligned with gravity (where the y-axis self test output change is negative), or with the accelerometer configured for a ±4 *g* or ±8 *g* measurement range.

Table 22. Self Test Output Scale Factors for Different Supply Voltages, V_S

Supply Voltage, V_S (V)	Self Test Output Scale Factor
1.6	0.62
2.0	1.0
2.5	1.6
3.0	2.4
3.5	3.4

OPERATION AT VOLTAGES OTHER THAN 2.0 V

The ADXL362 is tested and specified at a supply voltage of V_S = 2.0 V; however, it can be powered with a V_S as high as 3.3 V nominal (3.5 V maximum) or as low as 1.8 V nominal (1.6 V minimum). Some performance parameters change as the supply voltage changes, including the supply current (see Figure 30), noise (see Table 7 and Table 8), offset, sensitivity, and self test output change (see Table 22).

Figure 48 shows the potential effect on 0 *g* offset at varying supply voltage. Data for this figure was calibrated to show 0 m*g* offset at 2.0 V.

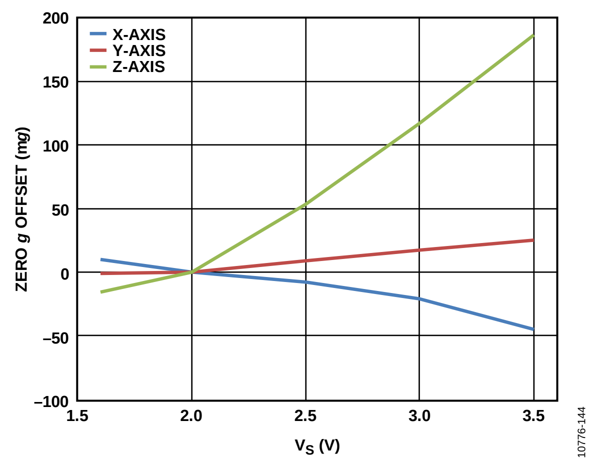


Figure 48. 0 g Offset vs. Supply Voltage

MECHANICAL CONSIDERATIONS FOR MOUNTING

Mount the ADXL362 on the printed circuit board (PCB) in a location close to a hard mounting point of the PCB to the case. Mounting the ADXL362 at an unsupported PCB location, as shown in Figure 49, can result in large, apparent measurement errors due to undampened PCB vibration. Locating the accelerometer near a hard mounting point ensures that any PCB vibration at the accelerometer is above the mechanical sensor resonant frequency of the accelerometer and, therefore, effectively invisible to the accelerometer. Multiple mounting points, close to the sensor, and/or a thicker PCB also help to reduce the effect of system resonance on the performance of the sensor.

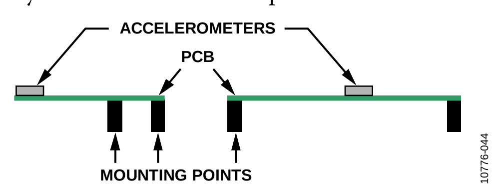


Figure 49. Incorrectly Placed Accelerometers

AXES OF ACCELERATION SENSITIVITY

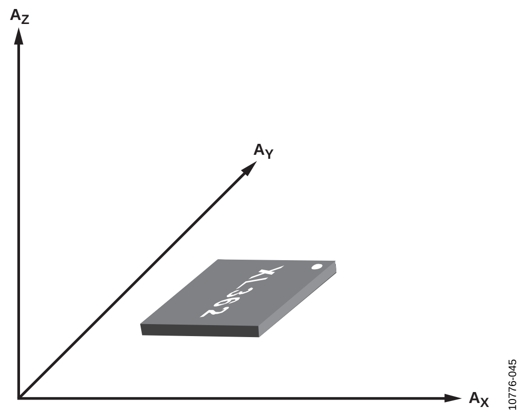


Figure 50. Axes of Acceleration Sensitivity (Corresponding Output Increases When Accelerated Along the Sensitive Axis)

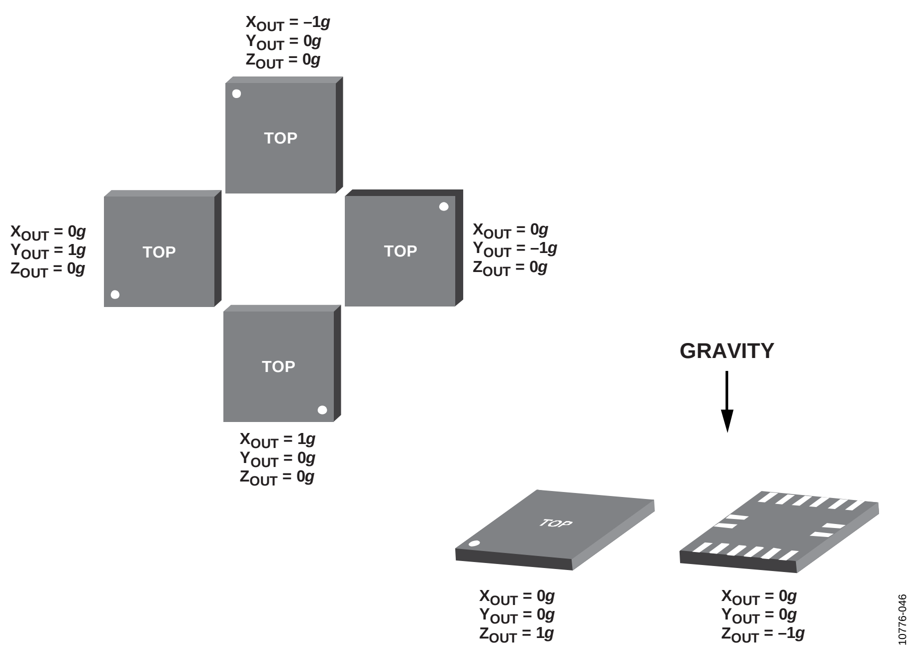


Figure 51. Output Response vs. Orientation to Gravity

LAYOUT AND DESIGN RECOMMENDATIONS

Figure 52 shows the recommended PCB land pattern.

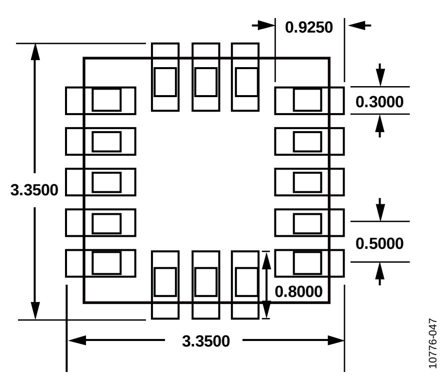


Figure 52. Recommended PCB Land Pattern (Dimensions shown in millimeters)

OUTLINE DIMENSIONS

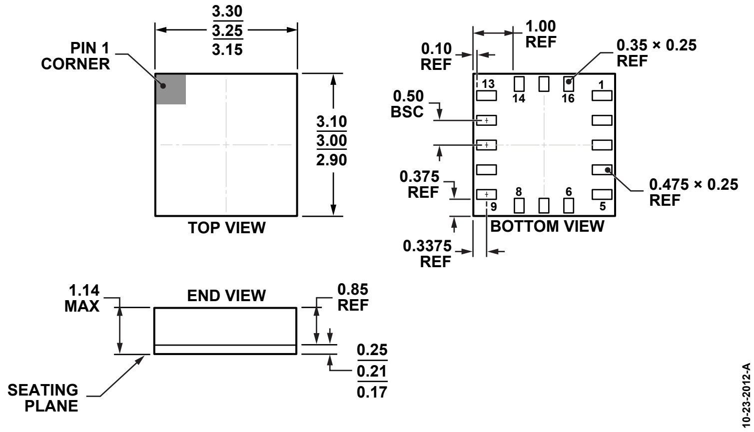


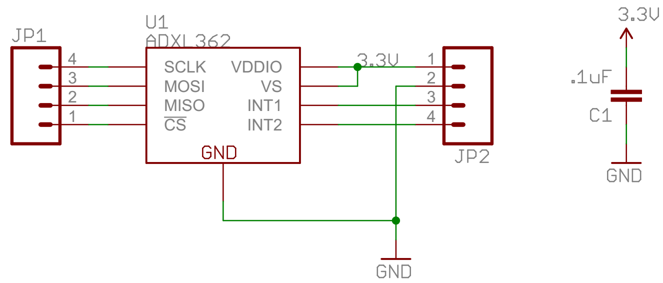
Figure 53. 16-Terminal Land Grid Array [LGA]
(CC-16-4)
Dimensions shown in millimeters

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option	Quantity
ADXL362BCCZ-RL	−40°C to +85°C	16-Terminal Land Grid Array [LGA]	CC-16-4	5,000
ADXL362BCCZ-RL7	−40°C to +85°C	16-Terminal Land Grid Array [LGA]	CC-16-4	1,500
ADXL362BCCZ-R2	−40°C to +85°C	16-Terminal Land Grid Array [LGA]	CC-16-4	250
EVAL-ADXL362Z	−40°C to +85°C	Breakout Board		
EVAL-ADXL362Z-DB	−40°C to +85°C	Datalogger and Development Board		
EVAL-ADXL362Z-MLP	−40°C to +85°C	Low Power Real-Time Evaluation System		
EVAL-ADXL362Z-S	−40°C to +85°C	Satellite Board for Evaluation System		

[1] Z = RoHS Compliant Part.

NOTES



open hardware

TITLE: ADXL362 BOB v01	SFE
Design by:	REV:
Date: 9/14/2012 12:13:12 PM	Sheet: 1/1

Data sheet
RM22D01_01
Issue 1, 13th January 2009

RLS®

RM22 series non-contact rotary encoders

The RM22 is a compact, high-speed rotary magnetic encoder designed for use in harsh environments. The non-contact two part design removes the need for seals or bearings ensuring long-term reliability and simple installation.

The encoder comprises a magnetic actuator and a separate encoder body. Rotation of the magnetic actuator is sensed by a custom encoder chip within the body, and processed to give the required output format.

The encoder chip processes the signals received to provide resolutions to 13 bit (8,192 positions per revolution) with high operational speeds. Output signals are provided in industry standard absolute, incremental, analogue or linear formats.

The compact encoder body is just 22 mm in diameter and provides dirt immunity up to IP68.

The RM22 can be used in a wide range of applications including marine, medical, print, converting, industrial automation, metal working, motor control and instrumentation.

Product range

RM22A - analogue with a single sine/cosine cycle per revolution

RM22B - complementary analogue outputs with a single sine/cosine cycle per revolution

RM22I - incremental with 80 to 2,048 pulses per revolution (320 to 8,192 counts per revolution with x 4 evaluation)

RM22S - synchro serial interface (SSI) with 320 to 8,192 positions per revolution

RM22P - absolute parallel interface with 512 positions per revolution (9 bit)

RM22V - linear voltage output in a range of variants

System features:

- **Excellent immunity to IP68**
- **Non-contact, frictionless design**
- **High speed operation to 30,000 rpm**
- **Compact - 22 mm diameter body**
- **Absolute - to 13 bit (8,192 positions per revolution)**
- **Industry standard absolute, incremental, analogue and linear output formats**
- **Accuracy to ±0.5°**
- **Simple installation**

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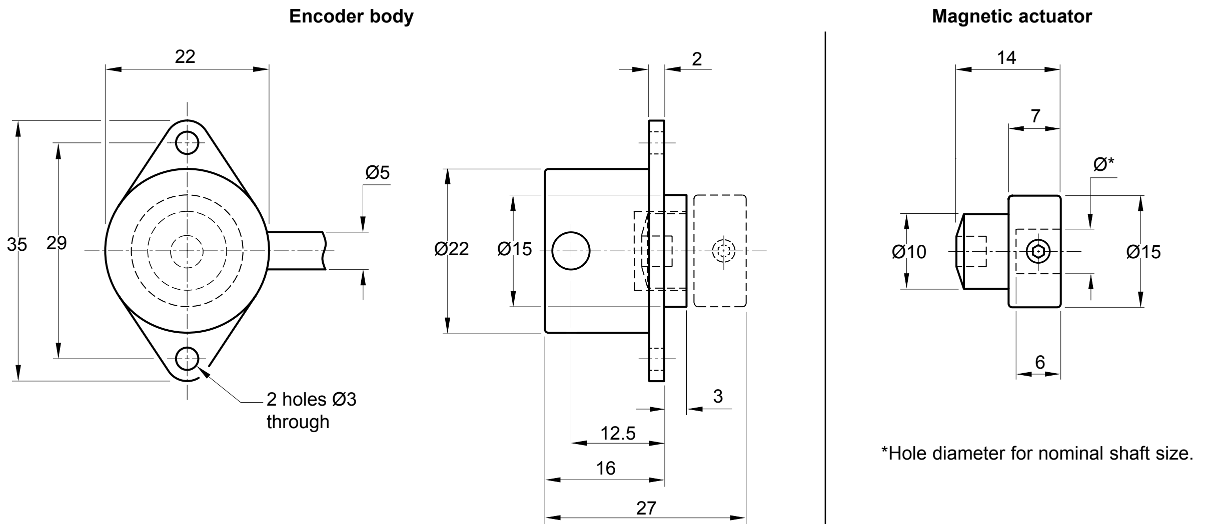
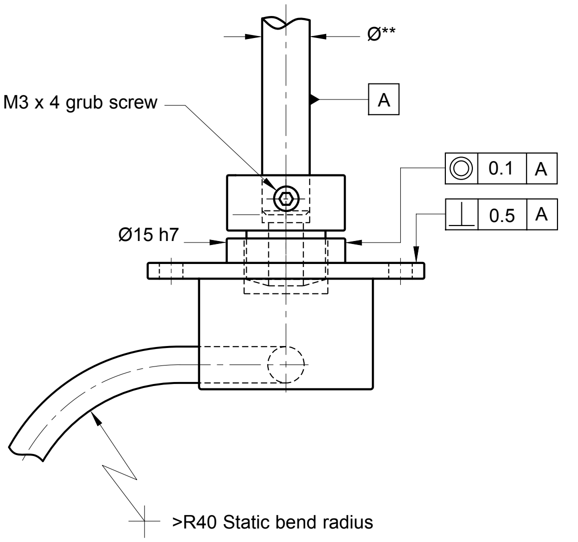
Data sheet
RM22D01_01

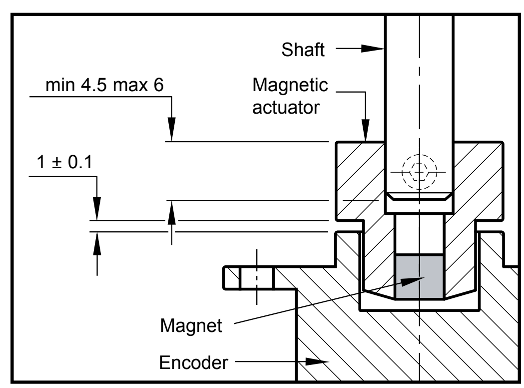
RM22 dimensions

Dimensions and tolerances in mm



RM22 installation drawing





**Nominal shaft size with tolerance h7.

Operating and electrical specifications

Humidity (for IP64 version)	Storage 95% maximum relative humidity (non-condensing) (IEC 61010-1) Operating 80% maximum relative humidity (non-condensing) (IEC 61010-1)
Acceleration	Operating 500 m/s² BS EN 60068-2-7:1993 (IEC 68-2-7:1983)
Shock (non-operating)	1000 m/s², 6 ms, 1/2 sine BS EN 60068-2-27:1993 (IEC 68-2-27:1987)
Vibration (operating)	100 m/s² max at 55 to 2000 Hz BS EN 60068-2-6:1996 (IEC 68-2-6:1995)
EMV compliance	BS EN 61326
Cable	Outside diameter 5 mm
Mass	Encoder unit 1 m cable (no connector) 48 g. Magnetic actuator 12 g
Environmental sealing	IP64 (IP68 optional) BS EN 60529

RM22I – Incremental outputs

Square wave differential line driver to RS422A

Power supply	V_{dd} = 5 V ± 5%
Power consumption	23 mA for 9 bit resolution 35 mA for all other resolutions
Output signals	A, B, Z, A-, B-, Z- (RS422A)
Max. cable length	50 m
Connector options	9 pin 'D' type plug (standard) Flying lead
Temperature	Operating -25 °C to +85 °C (-40 °C to +125 °C option 08)* Storage -40 °C to +125 °C
Edge separation	Min. 1 µs

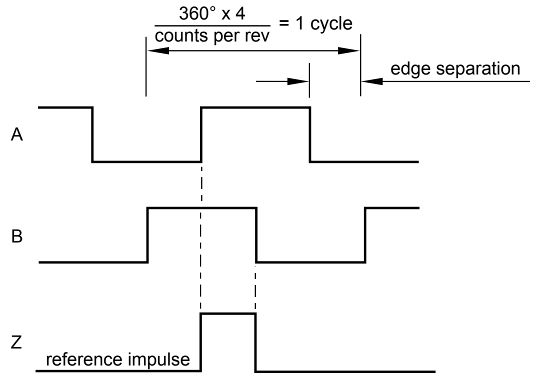
* Only available with IP64 sealing

Resolution options (counts per rev)	Maximum speed (rpm)	Accuracy*	Hysteresis
320, 400, 500	30,000	±0.7°	0.18°
512	30,000	±0.7°	0.45°
800, 1,000, 1,024	20,000	±0.5°	0.18°
1,600, 2,000, 2,048	10,000	±0.5°	0.18°
4,096	5,000	±0.5°	0.18°
8,192	2,500	±0.5°	0.18°

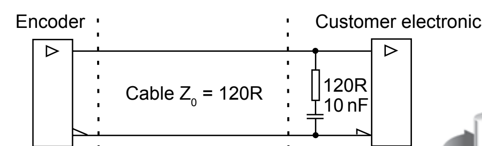
* Worst case within operational parameters including magnet position and temperature.

Timing diagram

(complementary signals not shown)



Recommended signal termination



B leads A for clockwise rotation of magnetic actuator

RM22S – Absolute binary synchro-serial interface (SSI)

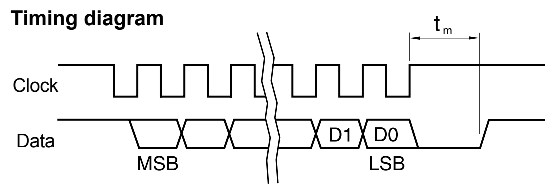
Serial encoded absolute position measurement

Output code	Natural binary
Power supply	V_{dd} = 5 V ± 5%
Power consumption	23 mA for 9 bit resolution 35 mA for all other resolutions
Repeatability	≤ 0.07°
Data outputs	Serial data (RS422A)
Data inputs	Clock (RS422A)
Max. cable length	100 m (at 1 MHz)
Connector options	9 pin 'D' type plug (standard) Flying lead
Temperature	Operating -40 °C to +125 °C (IP64) -40 °C to +85 °C (IP68) Storage -40 °C to +85 °C

Resolution options (positions per rev)	Maximum speed (rpm)	Accuracy*	Hysteresis
320, 400, 500	30,000	±0.7°	0.18°
512	30,000	±0.7°	0.45°
800, 1,000, 1,024	20,000	±0.5°	0.18°
1,600, 2,000, 2,048	10,000	±0.5°	0.18°
4,096	5,000	±0.5°	0.18°
8,192	2,500	±0.5°	0.18°

* Worst case within operational parameters including magnet position and temperature.

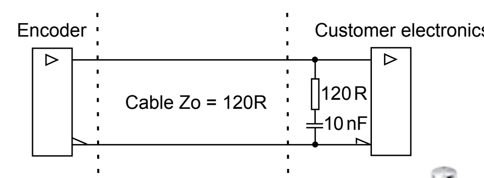
Timing diagram



Clock ≤ 900 kHz 16 µs ≤ t_m ≤ 22 µs (for 9 bit resolution)
Clock ≤ 4 MHz 12.5 µs ≤ t_m ≤ 20.5 µs (for all other resolutions)

Recommended signal termination

(For data output lines only)



Position increases for clockwise rotation of magnetic actuator

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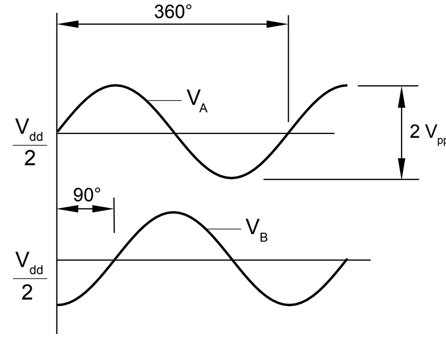
RM22A – Analogue sinusoidal outputs

2 channels V_A V_B sinusoids (90° phase shifted, single ended)

Power supply	V_{dd} = 5 V ± 5%	
Power consumption	20 mA	
Outputs	Signal amplitude Signal offset	2 ± 0.2 V_{pp} $\frac{V_{dd}}{2}$ ± 5 mV
Max. output frequency	500 Hz	
Max. cable length	3 m	
Connector options	9 pin ‘D’ type plug (standard) Flying lead	
Temperature	Operating	-40 °C to +125 °C (IP64) -40 °C to +85 °C (IP68)
	Storage	-40 °C to +85 °C
Maximum speed	30,000 rpm	
Internal serial impedance	720 Ω	

Timing diagram



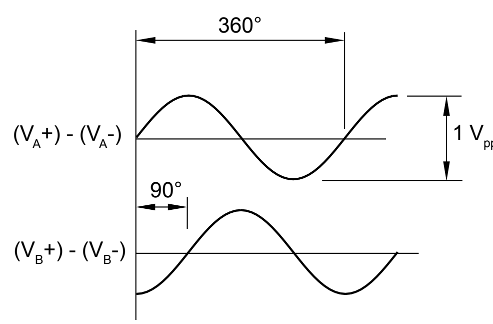
V_A leads V_B by 90° for clockwise rotation of magnetic actuator

RM22B – Analogue complementary sinusoidal outputs

2 channels V_A and V_B differential sinusoids in quadrature (90° phase shifted)

Power supply	V_{dd} = 5 V ± 5%	
Power consumption	20 mA	
Outputs	Signal amplitude Signal offset	0.5 ± 0.1 V_{pp} $\frac{V_{dd}}{2}$ ± 5 mV
Max. output frequency	500 Hz	
Max. cable length	20 m	
Connector options	9 pin ‘D’ type plug (standard) Flying lead	
Temperature	Operating Storage	-25 °C to +85 °C -25 °C to +85 °C
Maximum speed	30,000 rpm	
Internal serial impedance	100 Ω	

Timing diagram



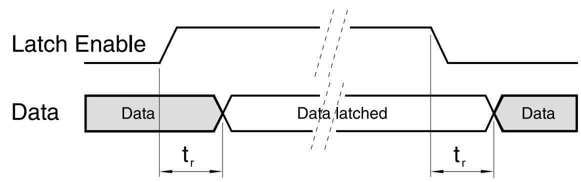
V_A leads V_B by 90° for clockwise rotation of magnetic actuator

RM22P – Absolute binary parallel interface

Parallel absolute position measurement

Output code	Natural binary	
Power supply	V_{dd} = 5 V ± 5%	
Power consumption	20 mA without load	
Output voltage	$V_H \geq 4$ V at $-I_H \leq 3$ mA $V_L \leq 1$ V at $I_L \leq 3$ mA	
Resolution	9 bit (512 positions per revolution)	
Hysteresis	0.45°	
Accuracy	±0.7°	
Repeatability	≤ 0.07°	
Data outputs	D0 (LSB) - D8 (MSB)	
Data inputs	LE - latch enable input signal, active high Maximum sampling rate 500 kHz	
Max. cable length	30 m	
Connector options	15 pin 'D' type plug (standard) Flying lead	
Temperature	Operating	-40 °C to +125 °C (IP64)
		-40 °C to +85 °C (IP68)
	Storage	-40 °C to +85 °C
Maximum speed	30,000 rpm	

Timing diagram



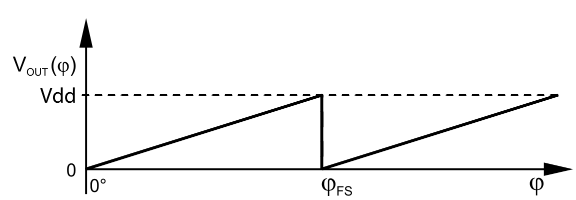
t_r (reaction time) ≤ 1µs

Position increases for clockwise rotation of magnetic actuator

RM22V – Linear voltage output

Power supply	V_{dd} = 5 V ± 5%	
Power consumption	20 mA typical	
Output voltage	0 V to V_{dd}	
Output loading	Max. 10 mA	
Nonlinearity	1 %	
Max. cable length	20 m	
Connector options	9 pin 'D' type plug (standard) Flying lead	
Temperature	Operating	-40 °C to +125 °C (IP64)
		-40 °C to +85 °C (IP68)
	Storage	-40 °C to +85 °C
Maximum speed	30,000 rpm	

Electrical output/shaft position



Output type and electrical variant

φ_{FS}	360°	180°	90°	45°
CW	**VA**	**VB**	**VC**	**VD**
CCW	**VE**	**VF**	**VG**	**VH**

Image shows clockwise rotation of magnetic actuator

RM22 ordering code

Encoder system = Encoder body + Magnetic actuator

 =  + 

Encoder body part number
eg **RM22SC0009B10A1B00**

Magnetic actuator
eg **RMA06A2A00**

RM22 SC 00 09B 10 A 1 B 00

Output type
AC - Analogue sinusoidal 2 V_{pp}
BC - Analogue complementary sinusoidal
IC - Incremental/RS422A
PC - Absolute binary parallel
SC - Absolute binary synchro - serial (SSI)
V_x - Linear voltage:

Analogue linear voltage output 0 V to 5 V, supply 5 V DC				
	360°	180°	90°	45°
CW	**VA**	**VB**	**VC**	**VD**
CCW	**VE**	**VF**	**VG**	**VH**

Shaft size
00 - N/A

Resolution
09B - 512 counts or positions per revolution (one sine/cosine wave per revolution – for output types **AC** and **BC**)

IC and SC only

Decimal
D32 – 320 **D80** – 800 **2D0** – 2,000
D40 – 400 **1D0** – 1,000
D50 – 500 **1D6** – 1,600

Binary
09B – 512 **11B** – 2,048 **13B** – 8,192
10B – 1,024 **12B** – 4,096

Special requirements
00 - None
08 - Extended operating temperature range (for output type **IC** and **IP64** only)

Environment
B - IP64, Aluminium body (standard)
C - IP68, Aluminium body
J - IP68, Stainless steel body

Body style and cable exit
1 - Flanged body, radial cable exit

Connector option
A - 'D' type connector - 9 way
B - 'D' type connector - 15 way (for output type **PC** only)
F - Flying lead (no connector)

Cable length
10 - 1 metre

NOTE: Not all combinations are valid.

For output resolutions of 9-bit (512 count per revolution), please select one of the following magnetic actuators:

RMA04A2A00 - 4 mm dia shaft
RMA05A2A00 - 5 mm dia shaft
RMA06A2A00 - 6 mm dia shaft
RMA08A2A00 - 8 mm dia shaft
RMA10A2A00 - 10 mm dia shaft
RMA19A2A00 - 3/16" dia shaft
RMA25A2A00 - 1/4" dia shaft
RMA37A2A00 - 3/8" dia shaft

For output resolutions of 10-bit (1024 count per revolution) or higher, please select one of the following magnetic actuators:

RMA04A3A00 - 4 mm dia shaft
RMA05A3A00 - 5 mm dia shaft
RMA06A3A00 - 6 mm dia shaft
RMA08A3A00 - 8 mm dia shaft
RMA10A3A00 - 10 mm dia shaft
RMA19A3A00 - 3/16" dia shaft
RMA25A3A00 - 1/4" dia shaft
RMA37A3A00 - 3/8" dia shaft

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Document issues

Issue	Date	Page	Corrections made

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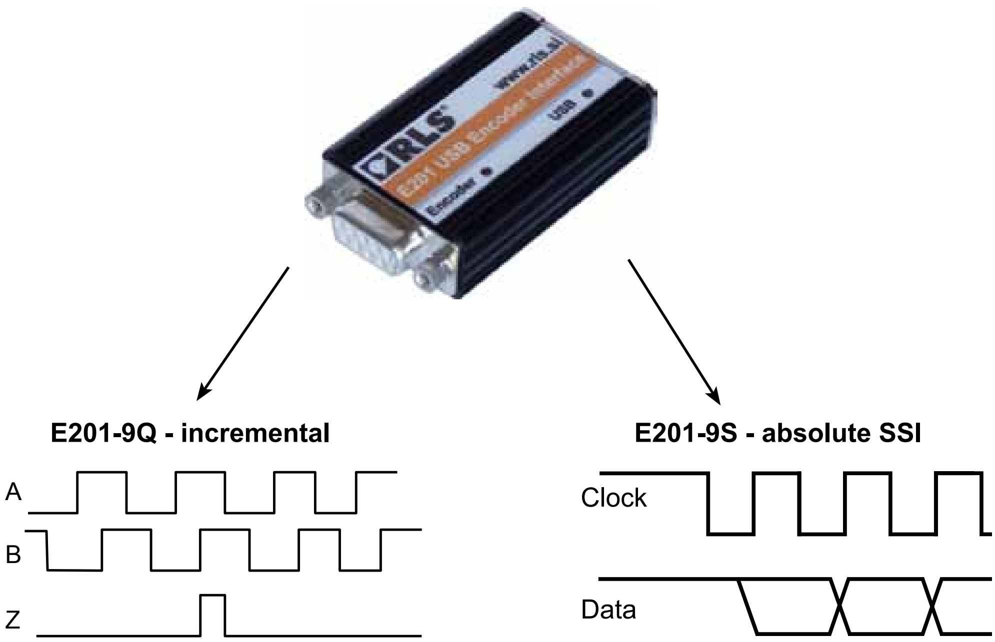
Data sheet
E201D01_01
Issue 1, 12th April 2011

E201 USB Encoder Interface



The E201 is a single channel USB encoder interface suitable for use with a wide variety of 5 V rotary and linear encoders.

It allows encoders to be easily interfaced and powered from a PC using only a USB cable. The E201 is available in 2 versions:

- **E201-9Q supporting incremental encoders**
- **E201-9S supporting absolute SSI encoders**

Both standard versions are pin compatible with RLS rotary and linear magnetic encoders. The interfaces can also be used with Renishaw encoders, however the encoder pin-out needs to be modified.

Two status LEDs are included to indicate USB status and encoder activity.

Demo software installation

Download and install the demo software from www.rls.si/E201. During the installation all necessary drivers are installed.

When installation is completed, connect the E201 interface and configure the software for the encoder that you will be using. Encoder supply voltage and current consumption can be read out by the software. Power supply to the encoder can be switched on / off by the software.

For custom development of a software, a detailed explanation of the ASCII commands can be found in this datasheet under the Programming commands section.

Applications

- Encoder functional test
- Encoder demonstration
- Metrology
- Gauging
- PC based machinery

E201-9Q - for 5 V incremental encoders

The E201-9Q counts edges from 5 V incremental encoders and allows the count value to be read by a PC using simple ASCII commands over a USB connection.

Technical specifications

Power supply	5 V
Power consumption	65 mA (without encoder connected)
Inputs	RS422 differential A, B, Z, A-, B-, Z- or single ended A, B, Z with 5 V TTL levels
Max. count rate	2 MHz, if using reference marks 30 MHz, if not using reference marks
USB connector	USB 1.1 Full Speed; USB 5 pin mini-B connector
Drivers Virtual Com Port (VCP) drivers available for:	Win 98, 98 SE, 2000/ME, XP, Vista, Win7
Cable length	1 meter standard A to mini-B USB cable (supplied)
Operating temperature	0 °C to +45 °C
Environmental sealing	IP20 - indoor use only
Dimensions	60 x 33 x 16 mm
Mass	Interface without USB cable 42 g

Connections

Encoder input
('D' type connector - 9 way)

Pin	Function
1	0 V
2	Z+
3	B+
4	A+
5	5 V
6	Z-
7	B-
8	A-
9	0 V

NOTE: Connections are directly compatible with the pin-out for RLS encoders. For Renishaw encoders, the encoder pin-out needs to be modified.

Status LEDs – E201-9Q

LED colour	USB	Encoder
red	disconnected	reference mark found
yellow	connected	encoder not moving
green	communication in progress	encoder moving

E201-9S - for 5 V absolute SSI encoders

The E201-9S interrogates an SSI encoder and allows the data to be read by a PC using simple ASCII commands over a USB connection.

Technical specifications

Power supply	5 V
Power consumption	65 mA (without encoder connected)
Data outputs	Clock (differential pair - RS422)
Data inputs	Data (differential pair - RS422)
USB connector	USB 1.1 Full Speed; USB 5 pin mini-B connector
Drivers Virtual Com Port (VCP) drivers available for:	Win 98, 98 SE, 2000/ME, XP, Vista, Win7
Cable length	1 meter standard A to mini-B USB cable (supplied)
Operating temperature	0 °C to +45 °C
Environmental sealing	IP20 - indoor use only
Dimensions	60 x 33 x 16 mm
Mass	Interface without USB cable 42 g

Connections

Encoder input
('D' type connector - 9 way)

Pin	Function
1	0 V
2	Clock+
3	Clock-
4	NC
5	5 V
6	Data+
7	Data-
8	NC
9	0 V

NOTE: Connections are directly compatible with the pin-out for RLS encoders. For Renishaw encoders, the encoder pin-out needs to be modified.

Status LEDs – E201-9S

LED colour	USB	Encoder
red	disconnected	encoder not connected
yellow	connected	-
green	communication in progress	encoder connected

Programming commands

NOTE: Note this section is only needed if you wish to develop your own software. The E201 is provided with simple display software.

This section contains detailed information on the communication between the E201 interface and PC which is needed to develop a customised software.

Installation of USB Drivers

Download the E201 software which includes the USB drivers from **www.rls.si/E201** and follow the installation steps. The drivers will be installed during the software installation. The E201 interface will appear as a new Virtual COM port on the computer. The actual port number assigned depends on how many COM ports are already in use on the PC. In Windows XP this can be found under:

Control Panel > System > Hardware tab > Device Manager > folder "Ports (COM & LPT)".

Communications

The E201 interface responds to ASCII commands received over the USB acting as a virtual serial port. No CR character is required after any command. Speed settings of the virtual serial port can be any value.

Command set E201-9Q

ASCII COMMAND	ACTION	INTERFACE RESPONSE (with example)
v	E201-9Q returns software version + CR	E201-9Q V1.15 + CR
s	Interface serial number in 8 Hex numbers	aaaaaaaa : bbbbbbbb : cccccccc + CR
?	E201-9Q returns 3 decimal values (not fixed width) separated by colons and terminated with CR	3412:2596:1 + CR nnnn:rrrr:ssss + CR where: n = encoder count r = count value when reference/index was last seen s = status (status value of 1 shows that a reference was detected—use 'c' command to clear)
>	E201-9Q returns 24 character hexadecimal string + CR comprising 3 sets of 8 character hexadecimal strings	00000d5400000a2400000001 + CR nnnnnnnnrrrrrrrrssssssss + CR where: n = encoder count (signed 32 bit) r = count value when reference/index last seen (signed 32 bit) s = status (status value of 1 shows that a reference was detected—use 'c' to clear)
c	E201-9Q clears the reference status flag	-
z	E201-9Q sets current count value to zero (this also affects reference mark position)	-
a	E201-9Q clears the zero offset value stored by the 'z' command	-
e	Read encoder supply status, voltage and current consumption (fixed width)	1 : 4.975 V : 0070 mA + CR s: a.aaa V : bbbb mA + CR
n	Enable power supply to the encoder (default at power-up)	ON + CR
f	Disconnect power supply to the encoder	OFF + CR
p	Status of hardware input pins to the interface (0 or 1)	110 + CR abz + CR
1	Begin auto transmission of encoder position in decimal form at 1 kHz rate	1234 + CR nnnn + CR
0	Stop auto transmission	-

Command set **E201-9S**

ASCII COMMAND	ACTION	INTERFACE RESPONSE (with example)
v	E201-9S returns software version + CR	E201-9S V1.15 + CR
s	Interface serial number in 8 Hex numbers	aaaaaaaa : bbbbbbbb : cccccccc + CR
?	E201-9S returns encoder position in decimal representation (not fixed width)	1234 + CR nnnn + CR where: n = encoder count
>	E201-9S returns 8 Hex digits with encoder position	00000d54 + CR nnnnnnnn + CR where: n = encoder count (signed 32 bit)
b	Read current word width that is read from the encoder	31 bit + CR nn bit + CR
Bnn+CR	Set word width; n can be one or two characters	OK 31 bit + CR or B param error + CR OK nn bit + CR N = 1 to 31
m	Read current encoder clock frequency	2 = 1.1 MHz + CR or 9 = ERROR n = xxx kHz + CR
Mn	Set SSI clock frequency: 7 = 2.2 MHz 6 = 1.1 MHz 5 = 560 kHz 4 = 280 kHz 3 = 140 kHz (default) 2 = 70 kHz 1 = 35 kHz	frequency 5 + CR or M param error + CR frequency n + CR where: n = 1 to 7
e	Read encoder supply status, voltage and current consumption (fixed width)	1 : 4.975 V : 0070 mA + CR s: a.aaa V : bbbb mA + CR
n	Enable power supply to the encoder (default at power-up)	ON + CR
f	Disconnect power supply to the encoder	OFF + CR
p	Status of hardware input pins to the interface	_11 + CR xcd + CR x = space character c = clock pin (0 or 1), should be 1 d = data pin (0 or 1), should be 1
1	Begin auto transmission of encoder position in decimal form at 1 kHz rate	1234 + CR nnnn + CR
0	Stop auto transmission	-

Ordering code

E201-9Q USB interface for use with **incremental** encoders

E201-9S USB interface for use with absolute **SSI** encoders

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Document issues

Issue	Date	Page	Corrections made
1	12. 4. 2011	-	New document

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Installation guide
RM22D02_01
Issue 1, 14th January 2009

RM22 series non-contact rotary encoders

EMC compliance

This encoder system conforms to the relevant harmonised European standards for electromagnetic compatibility as detailed below.

BS EN 61326

Further information

For further information relating to the installation of RM22 encoders see also the RM22 data sheet (part number RM22D01). This can be downloaded from our website www.rls.si and is also available from your local representative.

Disclaimer

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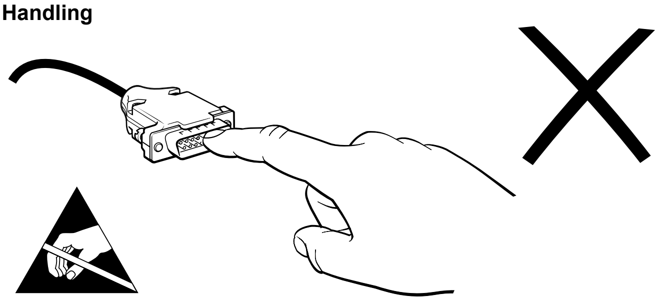
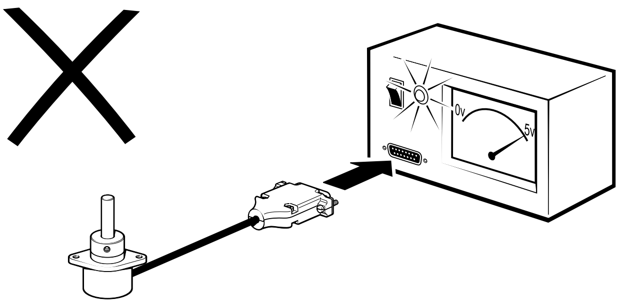
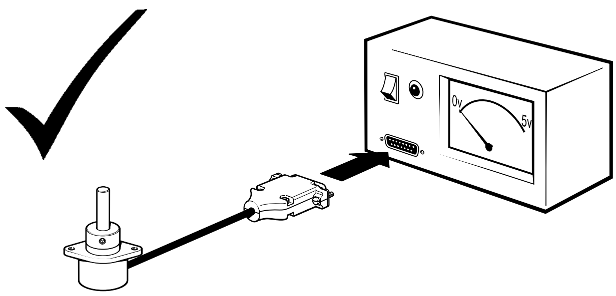
Handling







General specifications

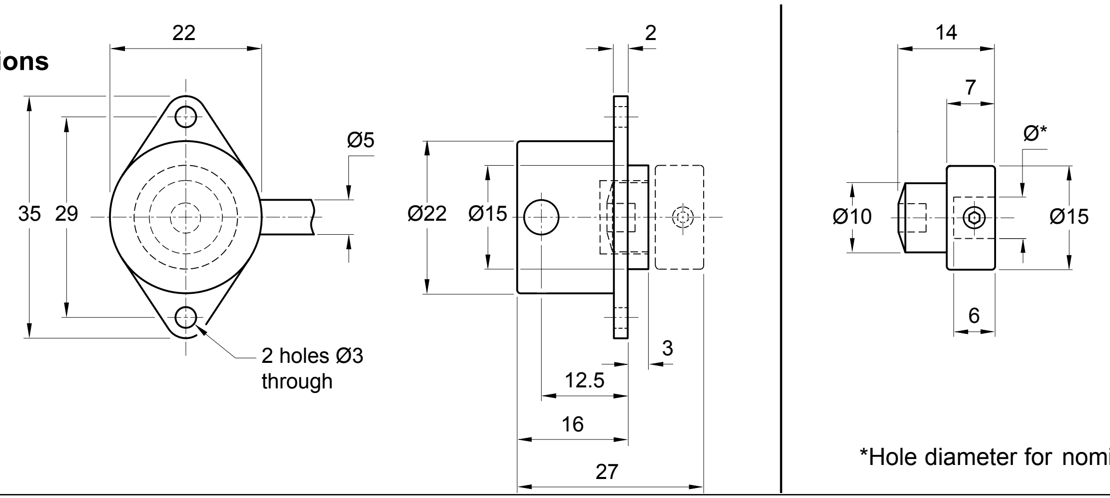
Power supply	5 V ± 5%	RM22 A/B/P/V 20 mA RM22 I/S 23mA - 9bit. 35mA for all other resolutions **NOTE:** Current consumption figures refer to unterminated encoders. When terminated with 120 Ω, RM22 S will draw an additional 25 mA, while RM22 I will draw an additional 25 mA per channel pair (A+, A-).
Sealing		IP64 (IP68 option available)
Operating temperature		RM22 IB -25 °C to +85 °C RM22 S/P/V/A -40 °C to +125 °C
Humidity	storage	95% maximum relative humidity (non-condensing) (BS EN 61010-1)
	operating	80% maximum relative humidity (non-condensing) (BS EN 61010-1)
Acceleration	operating	500 m/s^2 BS EN 60068-2-7:1993 (IEC 68-2-7:1983)
Shock	non-operating	1000 m/s^2, 6 ms, ½ sine BS EN 60068-2-27:1993 (IEC 68-2-27:1987)
Vibration	operating	100 m/s^2, 55 Hz to 2000 Hz BS EN 60068-2-6:1996 (IEC 68-2-6:1995)
Mass		RM22 inc. 1 m cable no connector 48 g magnetic actuator 12 g
Cable		Outside diameter 5 mm Maximum cable length 3 m (RM22A), 20 m (RM22B), 20 m (RM22V) 30 m (RM22P), 50 m (RM22I), 100 m (RM22S at 1MHz).

IMPORTANT: Power to RM22 encoders must be supplied from a DC SELV supply complying with the essential requirements of EN (IEC) 60950 or similar specification.

The RM22 series encoders have been designed to the relevant EMC standards, but must be correctly integrated to achieve EMC compliance. In particular, attention to shielding arrangements is critical.

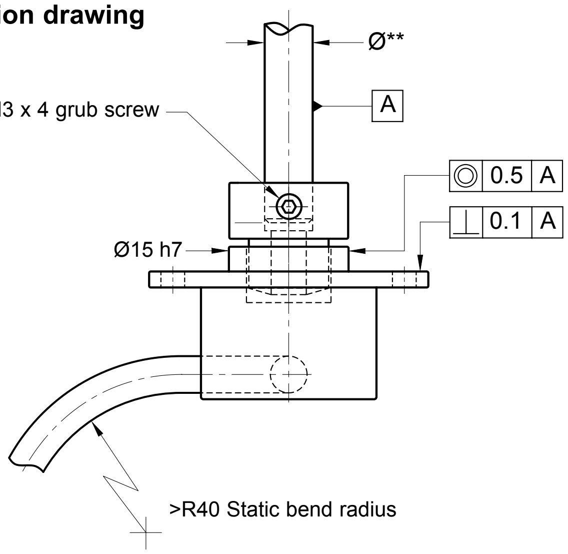
RM22 dimensions

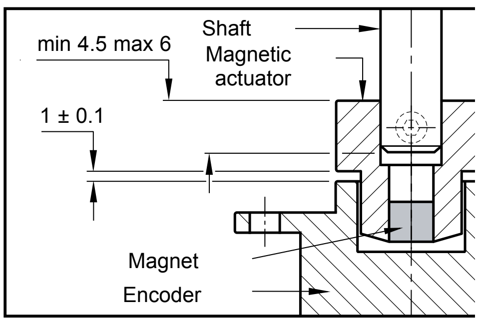
Dimensions and tolerances in mm



*Hole diameter for nominal shaft size

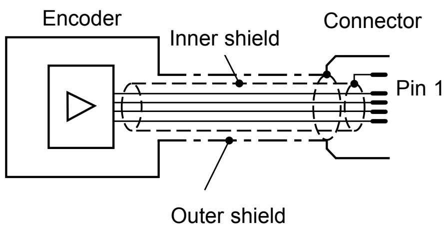
RM22 installation drawing



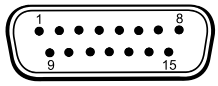


**Nominal shaft size with tolerance h7

Connections



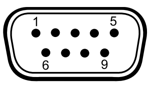
RM22 P



15 pin D plug

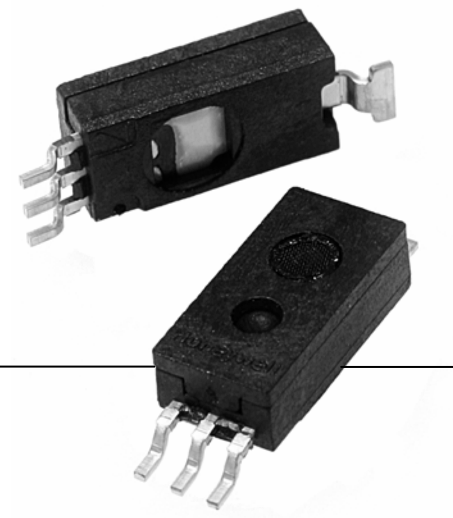
Pin Nr.	Function	Wire colour	Pin Nr.	Function	Wire colour
1	Shield - see connection diagram		9	D2	Black
2	D8	White	10	D1	Violet
3	D7	Brown	11	D0	Orange
4	D6	Green	12	NC	–
5	D5	Yellow	13	NC	–
6	D4	Grey	14	LE	Clear
7	D3	Pink	15	GND	Blue
8	V_{dd}	Red			

RM22 S/I/A



9 pin D plug

Pin Nr.	RM22 S		RM22 I		RM22 A		RM22 B		RM22 V	
	Function	Wire colour	Function	Wire colour	Function	Wire colour	Function	Wire colour	Function	Wire colour
1	Shield - see connection diagram		Shield - see connection diagram		Shield - see connection diagram		Shield - see connection diagram		Shield - see connection diagram	
2	Clock	White	Z	White	V_A	Green	V_A+	Green	NC	–
3	Clock-	Brown	B	Green	V_B	Brown	V_B+	Brown	V_{out}	Green
4	NC	–	A	Grey	NC	–	NC	–	NC	–
5	V_{dd}	Red	V_{dd}	Red	V_{dd}	Red	V_{dd}	Red	V_{dd}	Red
6	Data	Green	Z-	Brown	NC	–	V_A-	Yellow	NC	–
7	Data-	Yellow	B-	Yellow	NC	–	V_B-	White	NC	–
8	NC	–	A-	Pink	NC	–	NC	–	NC	–
9	GND	Blue	GND	Blue	GND	Blue	GND	Blue	GND	Blue



HIH-4030/31 Series

Humidity Sensors

DESCRIPTION

Honeywell has expanded our HIH Series to include an SMD (Surface Mount Device) product line: the new HIH 4030/4031. The HIH 4030/4031 complements our existing line of non-SMD humidity sensors. SMD packaging on tape and reel allows for use in high volume, automated pick and place manufacturing, eliminating lead misalignment to printed circuit board through-hole.

The HIH-4030/4031 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users.

Direct input to a controller or other device is made possible by this sensor’s near linear voltage output. With a typical current draw of only 200 μA, the HIH-4030/4031 Series is often ideally suited for low drain, battery operated systems.

Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4030/4031 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SMD.

The HIH-4030 is a covered integrated circuit humidity sensor. The HIH-4031 is a covered, condensation-resistant, integrated circuit humidity sensor that is factory-fitted with a hydrophobic filter allowing it to be used in condensing environments including industrial, medical and commercial applications.

The RH sensor uses a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning.

The sensing element's multilayer construction provides excellent resistance to most application hazards such as condensation, dust, dirt, oils and common environmental chemicals.

Sample packs are available. See order guide.

FEATURES

- Tape and reel packaging allows for use in high volume pick and place manufacturing (1,000 units per tape and reel)
- Molded thermoset plastic housing
- Near linear voltage output vs %RH
- Laser trimmed interchangeability
- Low power design
- Enhanced accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

POTENTIAL APPLICATIONS

- Refrigeration equipment
- HVAC (Heating, Ventilation and Air Conditioning) equipment
- Medical equipment
- Drying
- Metrology
- Battery-powered systems
- OEM assemblies

HIH-4030/31 Series

TABLE 1. PERFORMANCE SPECIFICATIONS (At 5 Vdc supply and 25 ºC [77 ºF] unless otherwise noted.)

Parameter	Minimum	Typical	Maximum	Unit	Specific Note
Interchangeability (first order curve)	–	–	–	–	–
0% RH to 59% RH	-5	–	5	% RH	–
60% RH to 100% RH	-8	–	8	% RH	–
Accuracy (best fit straight line)	-3.5	–	+3.5	% RH	1
Hysterisis	–	3	–	% RH	–
Repeatability	–	±0.5	–	% RH	–
Settling time	–	–	70	ms	–
Response time (1/e in slow moving air)	–	5	–	s	–
Stability (at 50% RH in a year)	–	±1.2	–	% RH	2
Stability (at 50% RH in a year)	–	±0.5	–	% RH	3
Voltage supply	4	–	5.8	Vdc	4
Current supply	–	200	500	µA	–
Voltage output (1st order curve fit)	V_{OUT}=(V_{SUPPLY})(0.0062(sensor RH) + 0.16), typical at 25 ºC				
Temperature compensation	True RH = (Sensor RH)/(1.0546 – 0.00216T), T in ºC				
Output voltage temp. coefficient at 50% RH, 5 V	–	-4	–	mV/ºC	–
Operating temperature	-40[-40]	See Figure 1.	85[185]	ºC[ºF]	–
Operating humidity (HIH-4030)	0	See Figure 1.	100	% RH	5
Operating humidity (HIH-4031)	0	See Figure 1.	100	% RH	–
Storage temperature	-50[-58]	–	125[257]	ºC[ºF]	–
Storage humidity	See Figure 2.			% RH	5

Specific Notes:
1. Can only be achieved with the supplied slope and offset. For HIH-4030/31-003 catalog listings only.
2. Includes testing outside of recommended operating zone.
3. Includes testing for recommended operating zone only.
4. Device is calibrated at 5 Vdc and 25 ºC.
5. Non-condensing environment. When liquid water falls on the humidity sensor die, output goes to a low rail condition indicating no humidity.

General Notes:
- Sensor is ratiometric to supply voltage.
- Extended exposure to ≥90% RH causes a reversible shift of 3% RH.
- Sensor is light sensitive. For best performance, shield sensor from bright light.

FACTORY CALIBRATION DATA

HIH-4030/31 Sensors may be ordered with a calibration and data printout. See Table 2 and the order guide on the back page.

TABLE 2. EXAMPLE DATA PRINTOUT

Model	**HIH-4030-003**
Channel	92
Wafer	030996M
MRP	337313
Calculated values at 5 V V_{OUT} at 0% RH V_{OUT} at 75.3% RH	 0.958 V 3.268 V
Linear output for 3.5% RH accuracy at 25 °C Zero offset Slope Sensor RH	 0.958 V 30.680 mV/%RH (V_{OUT} - zero offset)/slope (V_{OUT} - 0.958)/0.0307
Ratiometric response for 0% RH to 100% RH V_{OUT}	 V_{SUPPLY} (0.1915 to 0.8130)

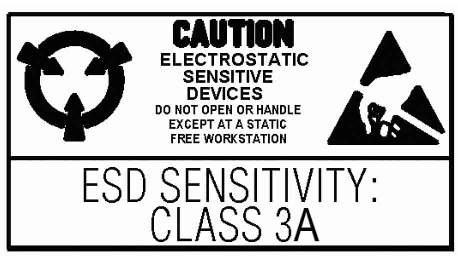


FIGURE 1. OPERATING ENVIRONMENT (Non-condensing environment for HIH-4030 catalog listings only.)

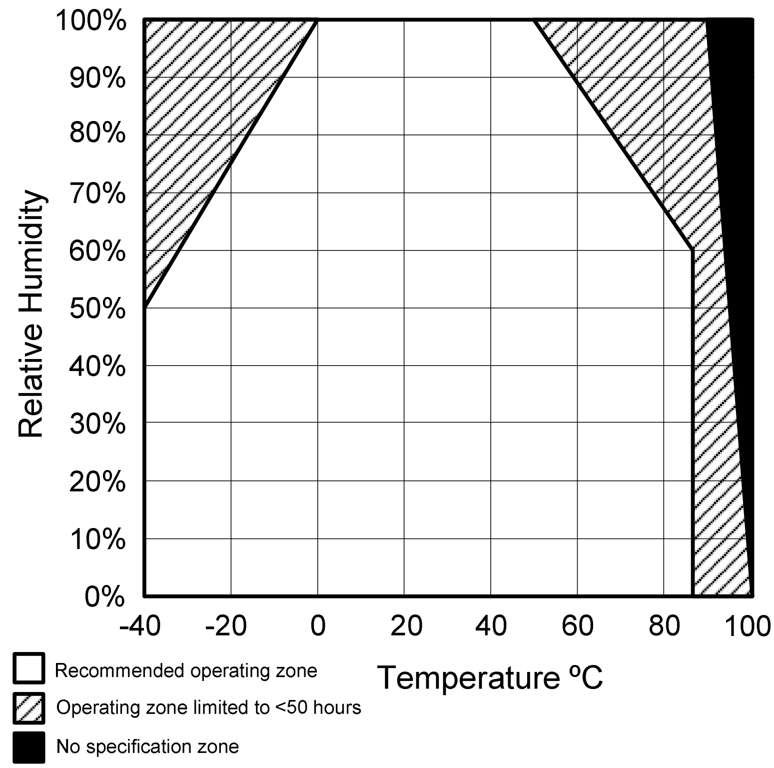


FIGURE 2. STORAGE ENVIRONMENT (Non-condensing environment for HIH-4030 catalog listings only.)

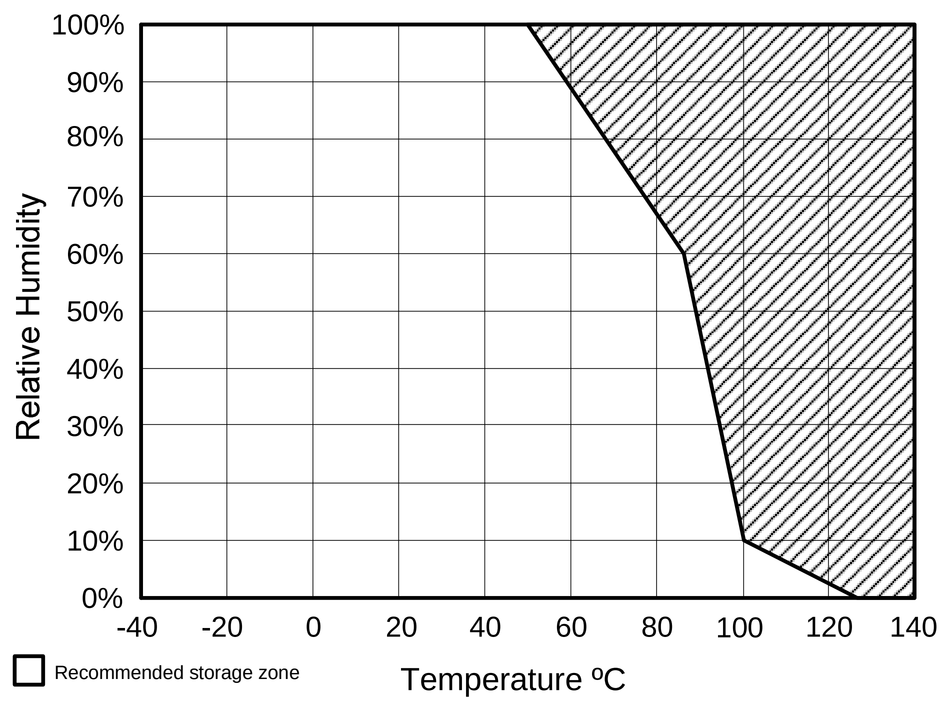


FIGURE 3. TYPICAL OUTPUT VOLTAGE VS RELATIVE HUMIDITY (At 25 ºC and 5 V.)

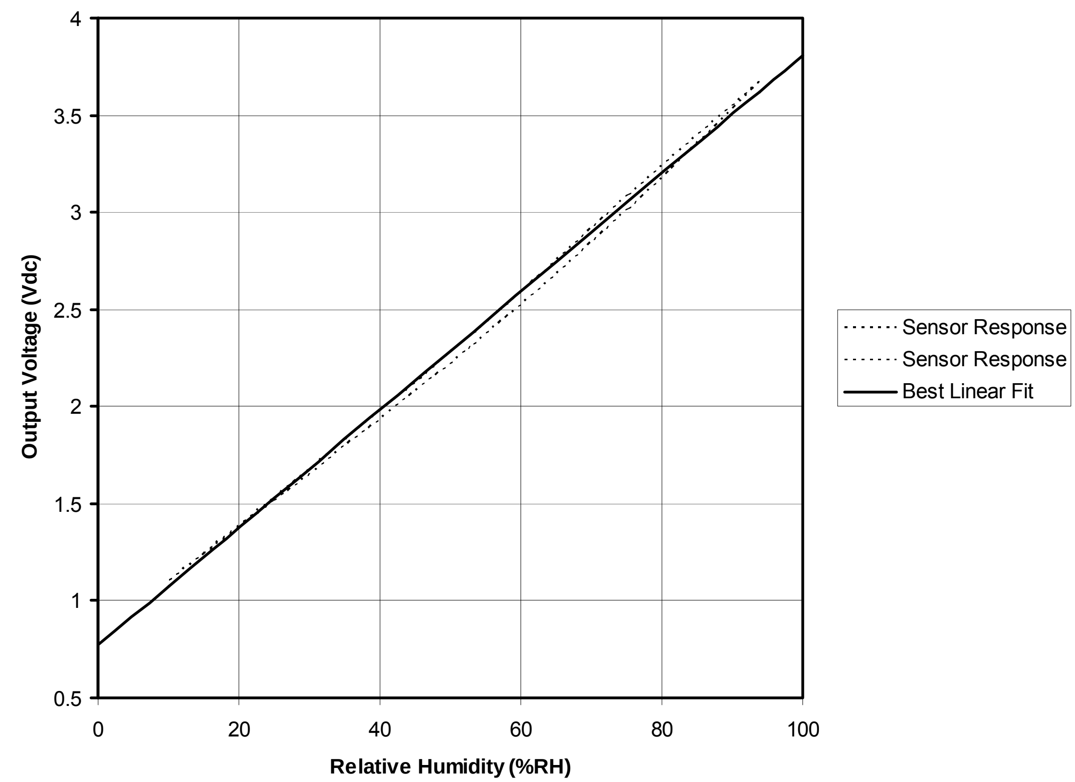


FIGURE 4. TYPICAL OUTPUT VOLTAGE (BFSL) VS RELATIVE HUMIDITY (At 0 ºC, 70 ºC and 5 V.)

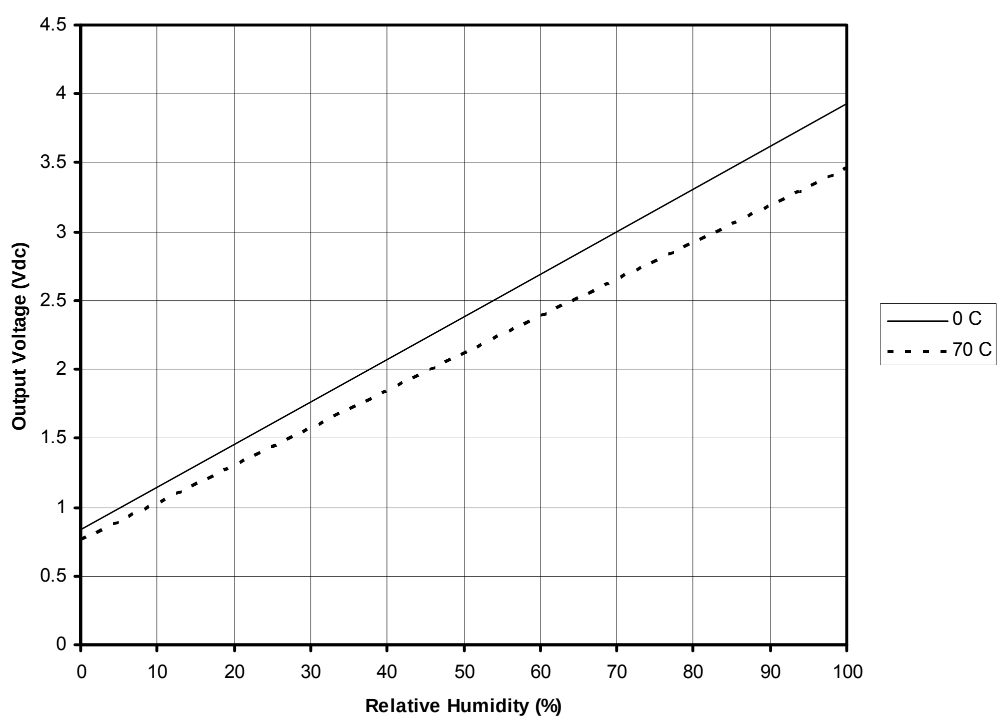


FIGURE 5. HIH-4030 MOUNTING DIMENSIONS (For reference only. mm/[in])

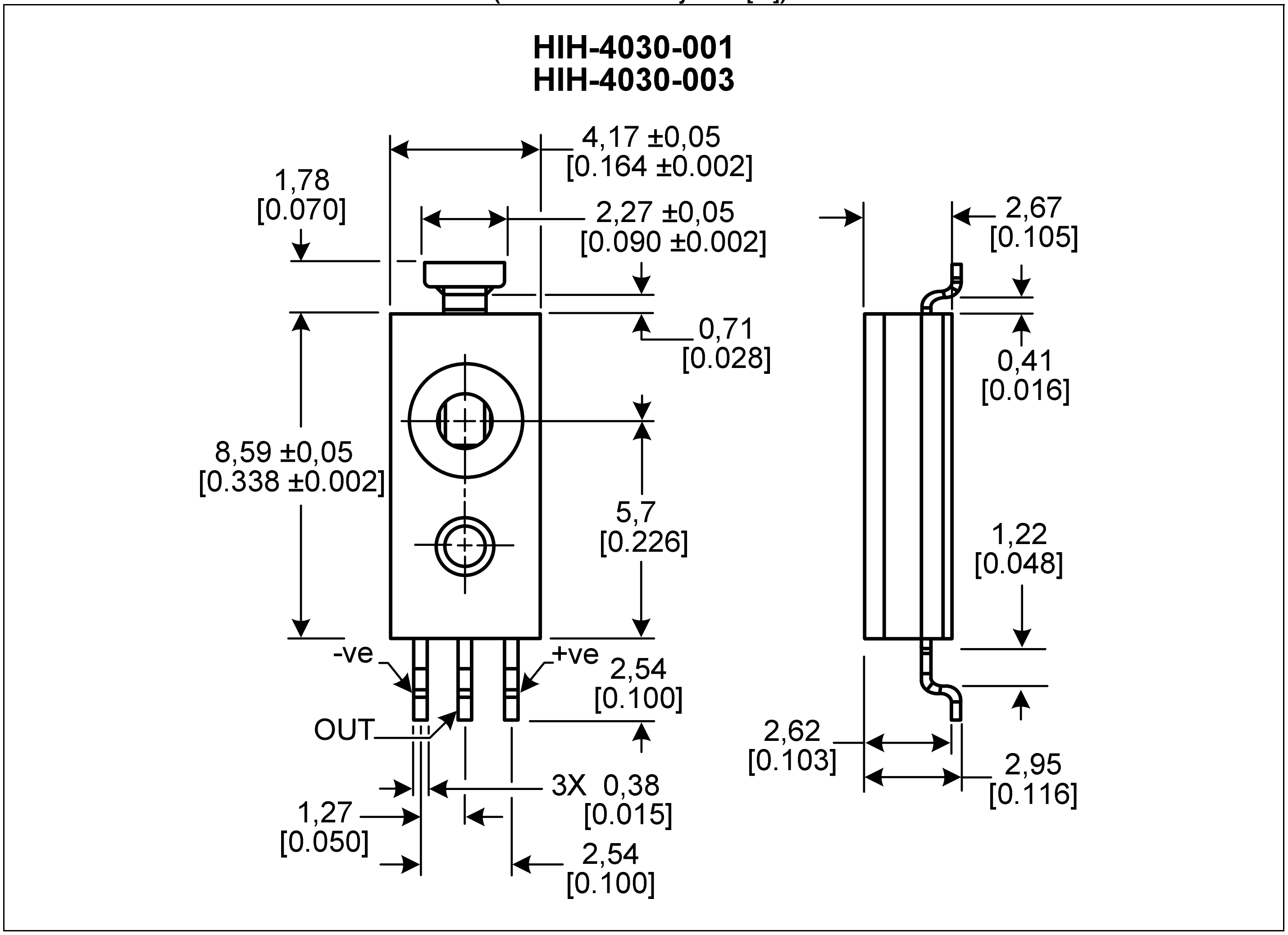


FIGURE 6. HIH-4031 MOUNTING DIMENSIONS (For reference only. mm/[in])

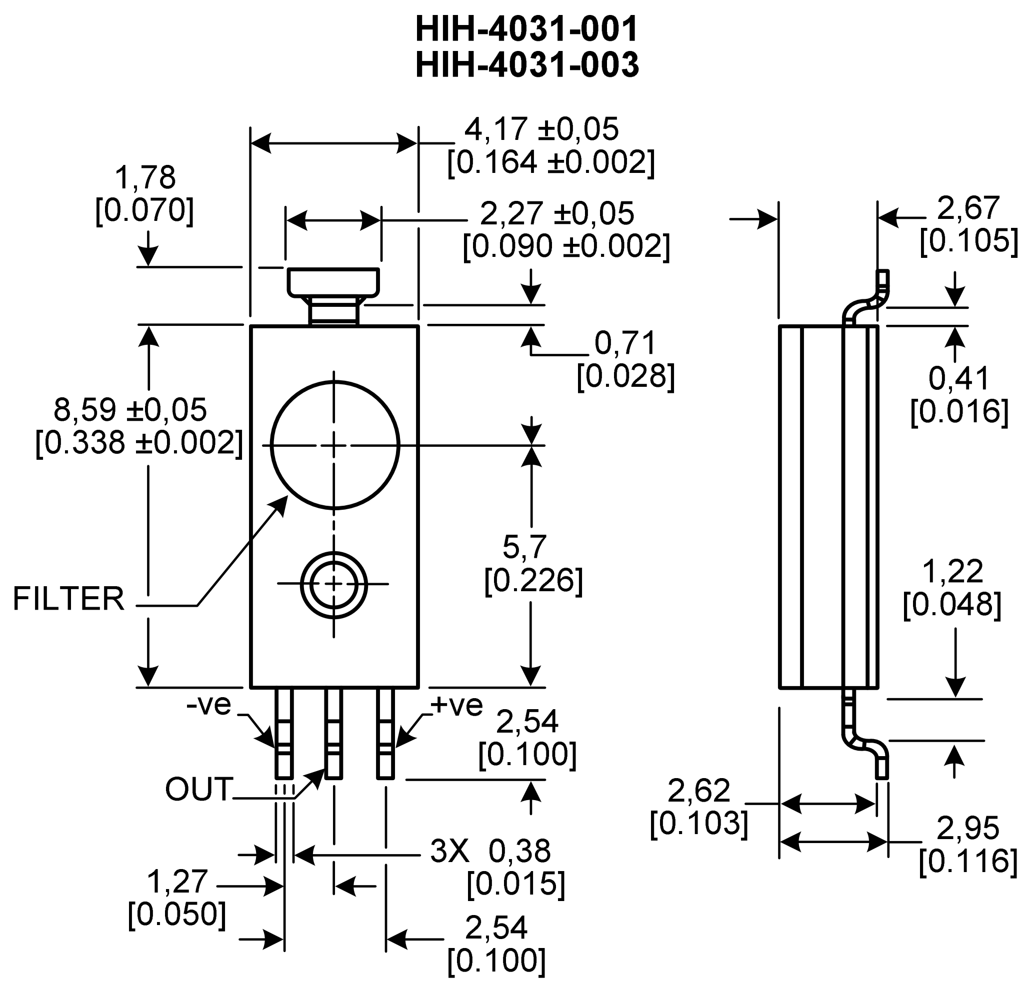


FIGURE 7. HIH-4031 PCB LANDING PATTERN (For reference only. mm/[in])

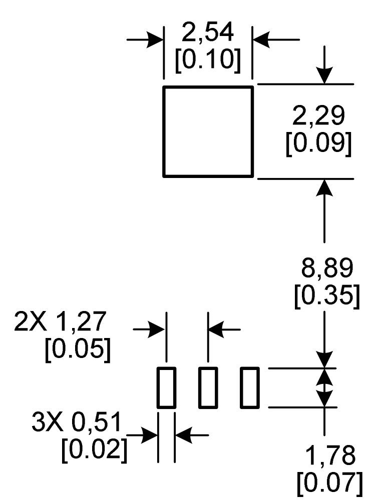


FIGURE 8. TAPE AND REEL DIMENSIONS (For reference only. mm/[in])

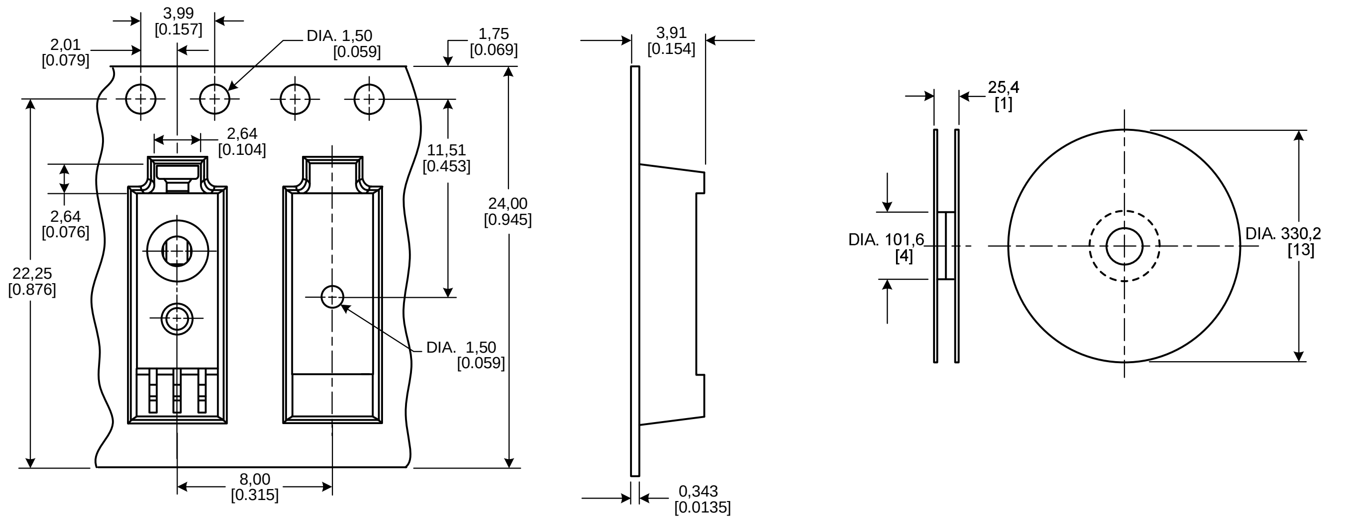
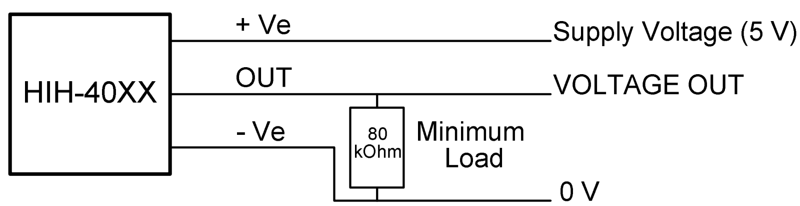


FIGURE 9. TYPICAL APPLICATION CIRCUIT



ORDER GUIDE

Catalog Listing	Description
HIH-4030-001	Covered integrated circuit humidity sensor, SMD, 1000 units on tape and reel
HIH-4030-003	Covered integrated circuit humidity sensor, SMD, calibration and data printout, 1000 units on tape and reel
HIH-4031-001	Covered, filtered integrated circuit humidity sensor, SMD, 1000 units on tape and reel
HIH-4031-003	Covered, filtered integrated circuit humidity sensor, SMD, calibration and data printout, 1000 units on tape and reel
HIH-4030-001S	Sample pack: covered integrated circuit humidity sensor, SMD, five units on tape
HIH-4030-003S	Sample pack: covered integrated circuit humidity sensor, SMD, calibration and data printout, five units on tape
HIH-4031-001S	Sample pack: covered, filtered integrated circuit humidity sensor, SMD, sample pack, five units on tape
HIH-4031-003S	Sample pack: covered, filtered integrated circuit humidity sensor, SMD, calibration and data printout, five units on tape

FURTHER HUMIDITY SENSOR INFORMATION

See the following associated literature is available on the Web**:**

- Product installation instructions
- Application sheets:
  - Humidity Sensor Performance Characteristics
  - Humidity Sensor Theory and Behavior
  - Humidity Sensor Moisture and Psychrometrics
  - Thermoset Polymer-based Capacitive Sensors

⚠ WARNING

MISUSE OF DOCUMENTATION

- The information presented in this product sheet is for reference only. Do not use this document as a product installation guide.
- Complete installation, operation, and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

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Honeywell warrants goods of its manufacture as being free of defective materials and faulty workmanship. Honeywell's standard product warranty applies unless agreed to otherwise by Honeywell in writing; please refer to your order acknowledgement or consult your local sales office for specific warranty details. If warranted goods are returned to Honeywell during the period of coverage, Honeywell will repair or replace, at its option, without charge those items it finds defective. **The foregoing is buyer's sole remedy and is in lieu of all other warranties, expressed or implied, including those of merchantability and fitness for a particular purpose. In no event shall Honeywell be liable for consequential, special, or indirect damages.**

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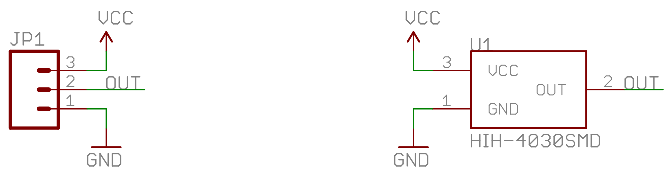

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Low Power Digital Temperature Sensor With SMBus™/Two-Wire Serial Interface in SOT563

FEATURES

- TINY SOT563 PACKAGE
- ACCURACY: 0.5°C (–25°C to +85°C)
- LOW QUIESCENT CURRENT:
  10μA Active (max)
  1μA Shutdown (max)
- SUPPLY RANGE: 1.4V to 3.6V
- RESOLUTION: 12 Bits
- DIGITAL OUTPUT: Two-Wire Serial Interface

APPLICATIONS

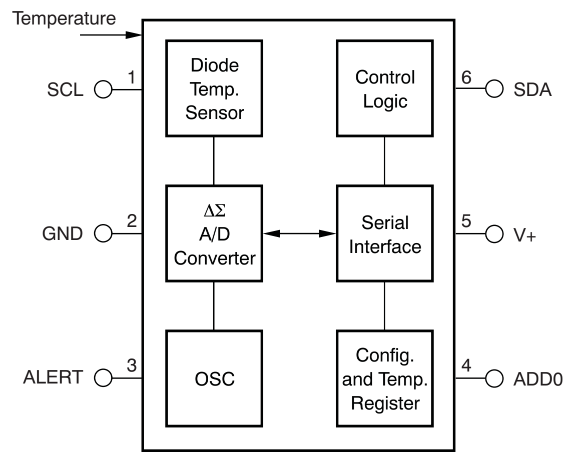
- PORTABLE AND BATTERY-POWERED APPLICATIONS
- POWER-SUPPLY TEMPERATURE MONITORING
- COMPUTER PERIPHERAL THERMAL PROTECTION
- NOTEBOOK COMPUTERS
- BATTERY MANAGEMENT
- OFFICE MACHINES
- THERMOSTAT CONTROLS
- ELECTROMECHANICAL DEVICE TEMPERATURES
- GENERAL TEMPERATURE MEASUREMENTS:
  Industrial Controls
  Test Equipment
  Medical Instrumentations

DESCRIPTION

The TMP102 is a two-wire, serial output temperature sensor available in a tiny SOT563 package. Requiring no external components, the TMP102 is capable of reading temperatures to a resolution of 0.0625°C.

The TMP102 features SMBus and two-wire interface compatibility, and allows up to four devices on one bus. It also features an SMB alert function.

The TMP102 is ideal for extended temperature measurement in a variety of communication, computer, consumer, environmental, industrial, and instrumentation applications. The device is specified for operation over a temperature range of –40°C to +125°C.



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This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
TMP102	SOT563	DRL	CBZ

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

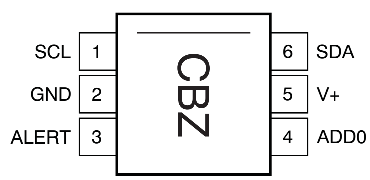
ABSOLUTE MAXIMUM RATINGS(1)

PARAMETER		TMP102	UNIT
Supply Voltage		3.6	V
Input Voltage(2)		–0.5 to +3.6	V
Operating Temperature		–55 to +150	°C
Storage Temperature		–60 to +150	°C
Junction Temperature		+150	°C
ESD Rating	Human Body Model (HBM)	2000	V
	Charged Device Model (CDM)	1000	V
	Machine Model (MM)	200	V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.
(2) Input voltage rating applies to all TMP102 input voltages.

PIN CONFIGURATION

DRL Package
SOT563
Top View



ELECTRICAL CHARACTERISTICS

At T_A = +25°C and V_S = +1.4V to +3.6V, unless otherwise noted.

PARAMETER		CONDITIONS	TMP102 MIN	TMP102 TYP	TMP102 MAX	UNIT
TEMPERATURE INPUT						
Range			–40		+125	°C
Accuracy (Temperature Error)		–25°C to +85°C		0.5	2	°C
		–40°C to +125°C		1	3	°C
vs Supply				0.2	0.5	°C/V
Resolution				0.0625		°C
DIGITAL INPUT/OUTPUT						
Input Logic Levels:						
V_{IH}			0.7 (V+)		3.6	V
V_{IL}			–0.5		0.3 (V+)	V
Input Current	I_{IN}	0 < V_{IN} < 3.6V			1	μA
Output Logic Levels:						
V_{OL} SDA		V+ > 2V, I_{OL} = 3mA	0		0.4	V
		V+ < 2V, I_{OL} = 3mA	0		0.2 (V+)	V
V_{OL} ALERT		V+ > 2V, I_{OL} = 3mA	0		0.4	V
		V+ < 2V, I_{OL} = 3mA	0		0.2 (V+)	V
Resolution				12		Bit
Conversion Time				26	35	ms
Conversion Modes		CR1 = 0, CR0 = 0		0.25		Conv/s
		CR1 = 0, CR0 = 1		1		Conv/s
		CR1 = 1, CR0 = 0 (default)		4		Conv/s
		CR1 = 1, CR0 = 1		8		Conv/s
Timeout Time				30	40	ms
POWER SUPPLY						
Operating Supply Range			+1.4		+3.6	V
Quiescent Current	I_Q	Serial Bus Inactive, CR1 = 1, CR0 = 0 (default)		7	10	μA
		Serial Bus Active, SCL Frequency = 400kHz		15		μA
		Serial Bus Active, SCL Frequency = 3.4MHz		85		μA
Shutdown Current	I_{SD}	Serial Bus Inactive		0.5	1	μA
		Serial Bus Active, SCL Frequency = 400kHz		10		μA
		Serial Bus Active, SCL Frequency = 3.4MHz		80		μA
TEMPERATURE RANGE						
Specified Range			–40		+125	°C
Operating Range			–55		+150	°C
Thermal Resistance, SOT563	θ_{JA}			260		°C/W

TYPICAL CHARACTERISTICS

At T_A = +25°C and V+ = 3.3V, unless otherwise noted.

QUIESCENT CURRENT vs TEMPERATURE (4 Conversions per Second)

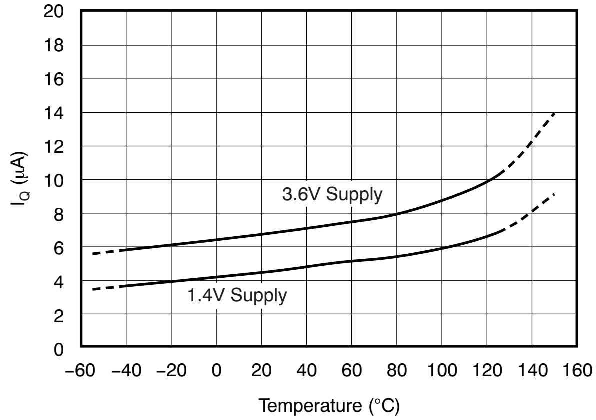


Figure 1.

SHUTDOWN CURRENT vs TEMPERATURE

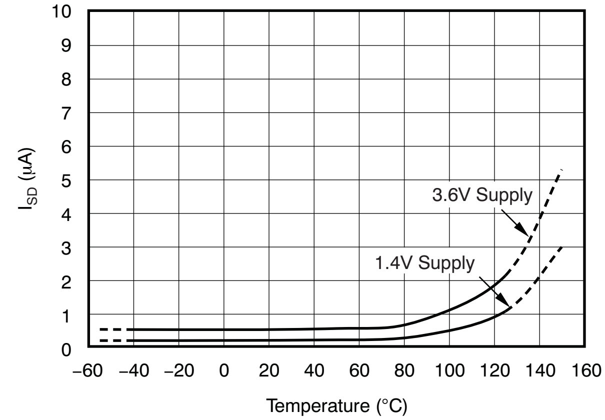


Figure 2.

CONVERSION TIME vs TEMPERATURE

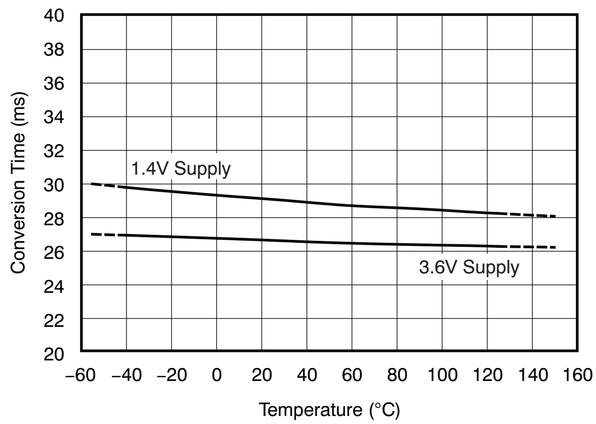


Figure 3.

QUIESCENT CURRENT vs BUS FREQUENCY (Temperature at 3.3V Supply)

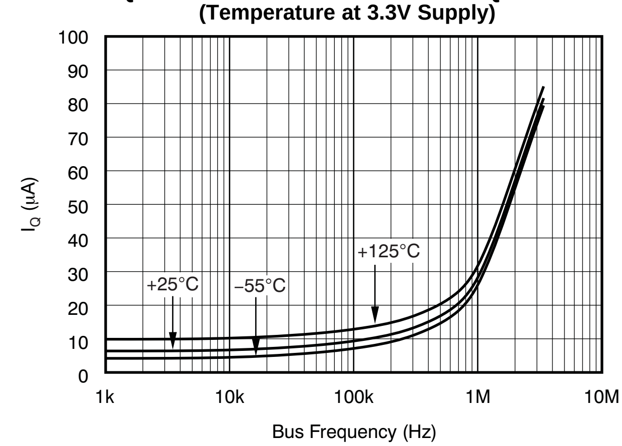


Figure 4.

TEMPERATURE ERROR vs TEMPERATURE

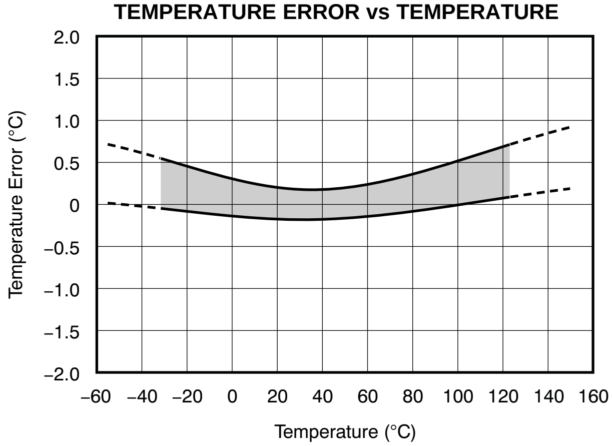


Figure 5.

TEMPERATURE ERROR AT +25°C

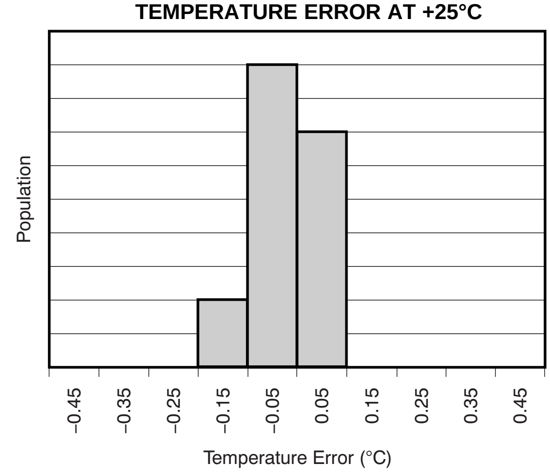


Figure 6.

APPLICATION INFORMATION

The TMP102 is a digital temperature sensor that is optimal for thermal-management and thermal-protection applications. The TMP102 is two-wire- and SMBus interface-compatible, and is specified over a temperature range of –40°C to +125°C.

Pull-up resistors are required on SCL, SDA, and ALERT. A 0.01μF bypass capacitor is recommended, as shown in Figure 7.

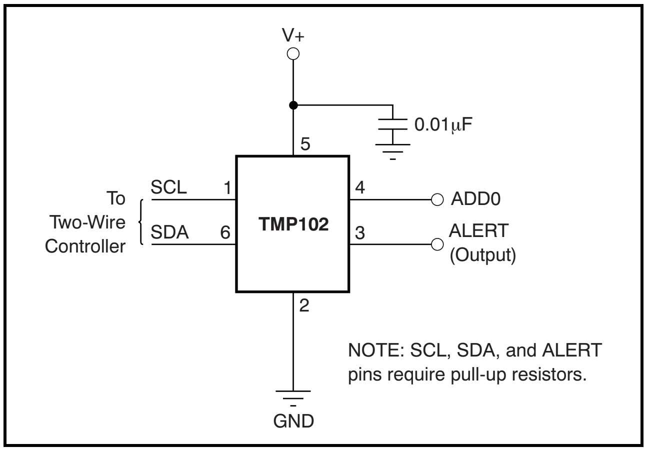


Figure 7. Typical Connections

The temperature sensor in the TMP102 is the chip itself. Thermal paths run through the package leads, as well as the plastic package. The lower thermal resistance of metal causes the leads to provide the primary thermal path.

To maintain accuracy in applications requiring air or surface temperature measurement, care should be taken to isolate the package and leads from ambient air temperature. A thermally-conductive adhesive is helpful in achieving accurate surface temperature measurement.

POINTER REGISTER

Figure 8 shows the internal register structure of the TMP102. The 8-bit Pointer Register of the device is used to address a given data register. The Pointer Register uses the two LSBs (see Table 11) to identify which of the data registers should respond to a read or write command. Table 1 identifies the bits of the Pointer Register byte. During a write command, P2 through P7 must always be '0'. Table 2 describes the pointer address of the registers available in the TMP102. Power-up reset value of P1/P0 is '00'. By default, the TMP102 reads the temperature on power-up.

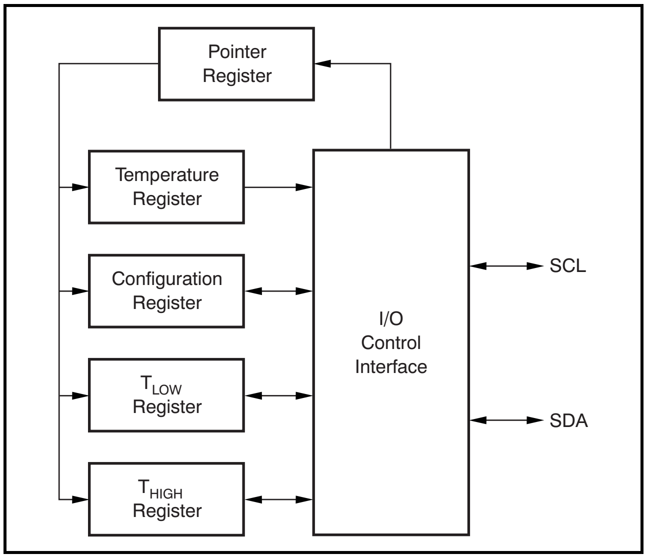


Figure 8. Internal Register Structure

Table 1. Pointer Register Byte

P7	P6	P5	P4	P3	P2	P1	P0
0	0	0	0	0	0	Register Bits	

Table 2. Pointer Addresses

P1	P0	REGISTER
0	0	Temperature Register (Read Only)
0	1	Configuration Register (Read/Write)
1	0	T_{LOW} Register (Read/Write)
1	1	T_{HIGH} Register (Read/Write)

TEMPERATURE REGISTER

The Temperature Register of the TMP102 is configured as a 12-bit, read-only register (Configuration Register EM bit = '0', see the *Extended Mode* section), or as a 13-bit, read-only register (Configuration Register EM bit = '1') that stores the output of the most recent conversion. Two bytes must be read to obtain data, and are described in Table 3 and Table 4. Note that byte 1 is the most significant byte, followed by byte 2, the least significant byte. The first 12 bits (13 bits in Extended mode) are used to indicate temperature. The least significant byte does not have to be read if that information is not needed. The data format for temperature is summarized in Table 5 and Table 6. One LSB equals 0.0625°C. Negative numbers are represented in binary twos complement format. Following power-up or reset, the Temperature Register will read 0°C until the first conversion is complete. Bit D0 of byte 2 indicates Normal mode (EM bit = '0') or Extended mode (EM bit = '1') and can be used to distinguish between the two temperature register data formats. The unused bits in the Temperature Register always read '0'.

Table 3. Byte 1 of Temperature Register(1)

D7	D6	D5	D4	D3	D2	D1	D0
T11 (T12)	T10 (T11)	T9 (T10)	T8 (T9)	T7 (T8)	T6 (T7)	T5 (T6)	T4 (T5)

(1) Extended mode 13-bit configuration shown in parenthesis.

Table 4. Byte 2 of Temperature Register(1)

D7	D6	D5	D4	D3	D2	D1	D0
T3 (T4)	T2 (T3)	T1 (T2)	T0 (T1)	0 (T0)	0 (0)	0 (0)	0 (1)

(1) Extended mode 13-bit configuration shown in parenthesis.

Table 5. 12-Bit Temperature Data Format(1)

TEMPERATURE (°C)	DIGITAL OUTPUT (BINARY)	HEX
128	0111 1111 1111	7FF
127.9375	0111 1111 1111	7FF
100	0110 0100 0000	640
80	0101 0000 0000	500
75	0100 1011 0000	4B0
50	0011 0010 0000	320
25	0001 1001 0000	190
0.25	0000 0000 0100	004
0	0000 0000 0000	000
–0.25	1111 1111 1100	FFC
–25	1110 0111 0000	E70
–55	1100 1001 0000	C90

(1) The resolution for the Temp ADC in Internal Temperature mode is 0.0625°C/count.

For positive temperatures (for example, +50°C):

Twos complement is not performed on positive numbers. Therefore, simply convert the number to binary code with the 12-bit, left-justified format, and MSB = 0 to denote a positive sign.

Example: (+50°C)/(0.0625°C/count) = 800 = 320h = 0011 0010 0000

For negative temperatures (for example, –25°C):

Generate the twos complement of a negative number by complementing the absolute value binary number and adding 1. Denote a negative number with MSB = 1.

Example: (|–25°C|)/(0.0625°C/count) = 400 = 190h = 0001 1001 0000

Twos complement format: 1110 0110 1111 + 1 = 1110 0111 0000

Table 6. 13-Bit Temperature Data Format

TEMPERATURE (°C)	DIGITAL OUTPUT (BINARY)	HEX
150	0 1001 0110 0000	0960
128	0 1000 0000 0000	0800
127.9375	0 0111 1111 1111	07FF
100	0 0110 0100 0000	0640
80	0 0101 0000 0000	0500
75	0 0100 1011 0000	04B0
50	0 0011 0010 0000	0320
25	0 0001 1001 0000	0190
0.25	0 0000 0000 0100	0004
0	0 0000 0000 0000	0000
–0.25	1 1111 1111 1100	1FFC
–25	1 1110 0111 0000	1E70
–55	1 1100 1001 0000	1C90

CONFIGURATION REGISTER

The Configuration Register is a 16-bit read/write register used to store bits that control the operational modes of the temperature sensor. Read/write operations are performed MSB first. The format and power-up/reset value of the Configuration Register is shown in Table 7. For compatibility, the first byte corresponds to the Configuration Register in the TMP75 and TMP275. All registers are updated byte by byte.

Table 7. Configuration and Power-Up/Reset Format

BYTE	D7	D6	D5	D4	D3	D2	D1	D0
1	OS	R1	R0	F1	F0	POL	TM	SD
	0	1	1	0	0	0	0	0
2	CR1	CR0	AL	EM	0	0	0	0
	1	0	1	0	0	0	0	0

EXTENDED MODE (EM)

The Extended mode bit configures the device for Normal mode operation (EM = 0) or Extended mode operation (EM = 1). In Normal mode, the Temperature Register and high- and low-limit registers use a 12-bit data format. Normal mode is used to make the TMP102 compatible with the TMP75.

Extended mode (EM = 1) allows measurement of temperatures above +128°C by configuring the Temperature Register, and high- and low-limit registers, for 13-bit data format.

ALERT (AL Bit)

The AL bit is a read-only function. Reading the AL bit will provide information about the comparator mode status. The state of the POL bit inverts the polarity of data returned from the AL bit. For POL = 0, the AL bit will read as '1' until the temperature equals or exceeds T_{HIGH} for the programmed number of consecutive faults, causing the AL bit to read as '0'. The AL bit will continue to read as '0' until the temperature falls below T_{LOW} for the programmed number of consecutive faults, when it will again read as '1'. The status of the TM bit does not affect the status of the AL bit.

CONVERSION RATE

The conversion rate bits, CR1 and CR0, configure the TMP102 for conversion rates of 8Hz, 4Hz, 1Hz, or 0.25Hz. The default rate is 4Hz. The TMP102 has a typical conversion time of 26ms. To achieve different conversion rates, the TMP102 makes a conversion and after that powers down and waits for the appropriate delay set by CR1 and CR0. Table 8 shows the settings for CR1 and CR0.

Table 8. Conversion Rate Settings

CR1	CR0	CONVERSION RATE
0	0	0.25Hz
0	1	1Hz
1	0	4Hz (default)
1	1	8Hz

After power-up or general-call reset, the TMP102 immediately starts a conversion, as shown in Figure 9. The first result is available after 26ms (typical). The active quiescent current during conversion is 40µA (typical at +27°C). The quiescent current during delay is 2.2µA (typical at +27°C).

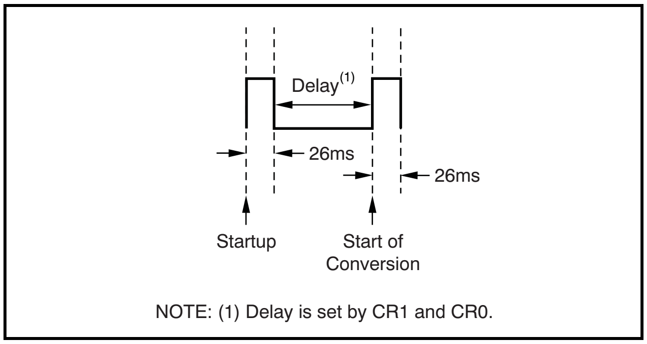


Figure 9. Conversion Start

SHUTDOWN MODE (SD)

The Shutdown mode bit saves maximum power by shutting down all device circuitry other than the serial interface, reducing current consumption to typically less than 0.5µA. Shutdown mode is enabled when the SD bit is '1'; the device shuts down when current conversion is completed. When SD is equal to '0', the device maintains a continuous conversion state.

THERMOSTAT MODE (TM)

The Thermostat mode bit indicates to the device whether to operate in Comparator mode (TM = 0) or Interrupt mode (TM = 1). For more information on comparator and interrupt modes, see the *High- and Low-Limit Registers* section.

POLARITY (POL)

The Polarity bit allows the user to adjust the polarity of the ALERT pin output. If POL = 0, the ALERT pin will be active low, as shown in Figure 10. For POL = 1, the ALERT pin will be active high, and the state of the ALERT pin is inverted.

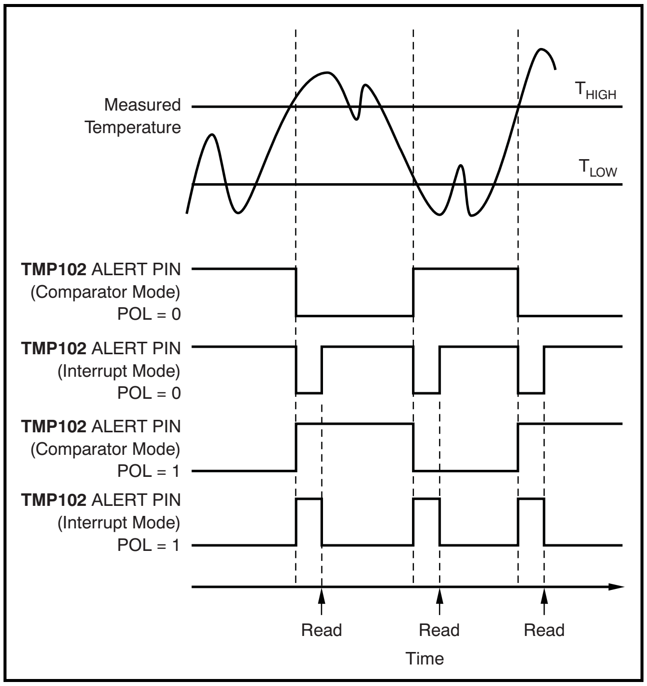


Figure 10. Output Transfer Function Diagrams

FAULT QUEUE (F1/F0)

A fault condition exists when the measured temperature exceeds the user-defined limits set in the T_{HIGH} and T_{LOW} registers. Additionally, the number of fault conditions required to generate an alert may be programmed using the fault queue. The fault queue is provided to prevent a false alert as a result of environmental noise. The fault queue requires consecutive fault measurements in order to trigger the alert function. Table 9 defines the number of measured faults that may be programmed to trigger an alert condition in the device. For T_{HIGH} and T_{LOW} register format and byte order, see the *High- and Low-Limit Registers* section.

Table 9. TMP102 Fault Settings

F1	F0	CONSECUTIVE FAULTS
0	0	1
0	1	2
1	0	4
1	1	6

CONVERTER RESOLUTION (R1/R0)

R1/R0 are read-only bits. The TMP102 converter resolution is set on start up to '11'. This sets the temperature register to a 12 bit-resolution.

ONE-SHOT/CONVERSION READY (OS)

The TMP102 features a One-Shot Temperature Measurement mode. When the device is in Shutdown mode, writing a '1' to the OS bit starts a single temperature conversion. During the conversion, the OS bit reads '0'. The device returns to the shutdown state at the completion of the single conversion. After the conversion, the OS bit reads '1'. This feature is useful for reducing power consumption in the TMP102 when continuous temperature monitoring is not required.

As a result of the short conversion time, the TMP102 can achieve a higher conversion rate. A single conversion typically takes 26ms and a read can take place in less than 20µs. When using One-Shot mode, 30 or more conversions per second are possible.

HIGH- AND LOW-LIMIT REGISTERS

In Comparator mode (TM = 0), the ALERT pin becomes active when the temperature equals or exceeds the value in T_{HIGH} and generates a consecutive number of faults according to fault bits F1 and F0. The ALERT pin remains active until the temperature falls below the indicated T_{LOW} value for the same number of faults.

In Interrupt mode (TM = 1), the ALERT pin becomes active when the temperature equals or exceeds the value in T_{HIGH} for a consecutive number of fault conditions (as shown in Table 9). The ALERT pin remains active until a read operation of any register occurs, or the device successfully responds to the SMBus Alert Response address. The ALERT pin will also be cleared if the device is placed in Shutdown mode. Once the ALERT pin is cleared, it becomes active again only when temperature falls below T_{LOW}, and remains active until cleared by a read operation of any register or a successful response to the SMBus Alert Response address. Once the ALERT pin is cleared, the above cycle repeats, with the ALERT pin becoming active when the temperature equals or exceeds T_{HIGH}. The ALERT pin can also be cleared by resetting the device with the General Call Reset command. This action also clears the state of the internal registers in the device, returning the device to Comparator mode (TM = 0).

Both operational modes are represented in Figure 10. Table 10 and Table 11 describe the format for the T_{HIGH} and T_{LOW} registers. Note that the most significant byte is sent first, followed by the least significant byte. Power-up reset values for T_{HIGH} and T_{LOW} are: T_{HIGH} = +80°C and T_{LOW} = +75°C. The format of the data for T_{HIGH} and T_{LOW} is the same as for the Temperature Register.

Table 10. Bytes 1 and 2 of T_{HIGH} Register(1)

BYTE	D7	D6	D5	D4	D3	D2	D1	D0
1	H11	H10	H9	H8	H7	H6	H5	H4
	(H12)	(H11)	(H10)	(H9)	(H8)	(H7)	(H6)	(H5)
BYTE	D7	D6	D5	D4	D3	D2	D1	D0
2	H3	H2	H1	H0	0	0	0	0
	(H4)	(H3)	(H2)	(H1)	(H0)	(0)	(0)	(0)

(1) Extended mode 13-bit configuration shown in parenthesis.

Table 11. Bytes 1 and 2 of T_{LOW} Register(1)

BYTE	D7	D6	D5	D4	D3	D2	D1	D0
1	L11	L10	L9	L8	L7	L6	L5	L4
	(L12)	(L11)	(L10)	(L9)	(L8)	(L7)	(L6)	(L5)
BYTE	D7	D6	D5	D4	D3	D2	D1	D0
2	L3	L2	L1	L0	0	0	0	0
	(L4)	(L3)	(L2)	(L1)	(L0)	(0)	(0)	(0)

(1) Extended mode 13-bit configuration shown in parenthesis.

BUS OVERVIEW

The device that initiates the transfer is called a *master*, and the devices controlled by the master are *slaves*. The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates the START and STOP conditions.

To address a specific device, a START condition is initiated, indicated by pulling the data-line (SDA) from a high to low logic level while SCL is high. All slaves on the bus shift in the slave address byte on the rising edge of the clock, with the last bit indicating whether a read or write operation is intended. During the ninth clock pulse, the slave being addressed responds to the master by generating an Acknowledge and pulling SDA low.

Data transfer is then initiated and sent over eight clock pulses followed by an Acknowledge Bit. During data transfer SDA must remain stable while SCL is high, because any change in SDA while SCL is high will be interpreted as a START or STOP signal.

Once all data have been transferred, the master generates a STOP condition indicated by pulling SDA from low to high, while SCL is high.

SERIAL INTERFACE

The TMP102 operates as a slave device only on the two-wire bus and SMBus. Connections to the bus are made via the open-drain I/O lines SDA and SCL. The SDA and SCL pins feature integrated spike suppression filters and Schmitt triggers to minimize the effects of input spikes and bus noise. The TMP102 supports the transmission protocol for both fast (1kHz to 400kHz) and high-speed (1kHz to 3.4MHz) modes. All data bytes are transmitted MSB first.

SERIAL BUS ADDRESS

To communicate with the TMP102, the master must first address slave devices via a slave address byte. The slave address byte consists of seven address bits, and a direction bit indicating the intent of executing a read or write operation.

The TMP102 features an address pin to allow up to four devices to be addressed on a single bus. Table 12 describes the pin logic levels used to properly connect up to four devices.

Table 12. Address Pin and Slave Addresses

DEVICE TWO-WIRE ADDRESS	A0 PIN CONNECTION
1001000	Ground
1001001	V+
1001010	SDA
1001011	SCL

WRITING/READING OPERATION

Accessing a particular register on the TMP102 is accomplished by writing the appropriate value to the Pointer Register. The value for the Pointer Register is the first byte transferred after the slave address byte with the R/$\overline{W}$ bit low. Every write operation to the TMP102 requires a value for the Pointer Register (see Figure 13).

When reading from the TMP102, the last value stored in the Pointer Register by a write operation is used to determine which register is read by a read operation. To change the register pointer for a read operation, a new value must be written to the Pointer Register. This action is accomplished by issuing a slave address byte with the R/$\overline{W}$ bit low, followed by the Pointer Register byte. No additional data are required. The master can then generate a START condition and send the slave address byte with the R/$\overline{W}$ bit high to initiate the read command. See Figure 14 for details of this sequence. If repeated reads from the same register are desired, it is not necessary to continually send the Pointer Register bytes, because the TMP102 remembers the Pointer Register value until it is changed by the next write operation.

Note that register bytes are sent with the most significant byte first, followed by the least significant byte.

SLAVE MODE OPERATIONS

The TMP102 can operate as a slave receiver or slave transmitter. As a slave device, the TMP102 never drives the SCL line.

Slave Receiver Mode:

The first byte transmitted by the master is the slave address, with the R/$\overline{W}$ bit low. The TMP102 then acknowledges reception of a valid address. The next byte transmitted by the master is the Pointer Register. The TMP102 then acknowledges reception of the Pointer Register byte. The next byte or bytes are written to the register addressed by the Pointer Register. The TMP102 acknowledges reception of each data byte. The master can terminate data transfer by generating a START or STOP condition.

Slave Transmitter Mode:

The first byte transmitted by the master is the slave address, with the R/$\overline{W}$ bit high. The slave acknowledges reception of a valid slave address. The next byte is transmitted by the slave and is the most significant byte of the register indicated by the Pointer Register. The master acknowledges reception of the data byte. The next byte transmitted by the slave is the least significant byte. The master acknowledges reception of the data byte. The master can terminate data transfer by generating a *Not-Acknowledge* on reception of any data byte, or generating a START or STOP condition.

SMBus ALERT FUNCTION

The TMP102 supports the SMBus Alert function. When the TMP102 operates in Interrupt mode (TM = '1'), the ALERT pin may be connected as an SMBus Alert signal. When a master senses that an ALERT condition is present on the ALERT line, the master sends an SMBus Alert command (00011001) to the bus. If the ALERT pin is active, the device acknowledges the SMBus Alert command and responds by returning its slave address on the SDA line. The eighth bit (LSB) of the slave address byte indicates if the ALERT condition was caused by the temperature exceeding T_{HIGH} or falling below T_{LOW}. For POL = '0', this bit is low if the temperature is greater than or equal to T_{HIGH}; this bit is high if the temperature is less than T_{LOW}. The polarity of this bit is inverted if POL = '1'. Refer to Figure 15 for details of this sequence.

If multiple devices on the bus respond to the SMBus Alert command, arbitration during the slave address portion of the SMBus Alert command determines which device will clear its ALERT status. The device with the lowest two-wire address wins the arbitration. If the TMP102 wins the arbitration, its ALERT pin becomes inactive at the completion of the SMBus Alert command. If the TMP102 loses the arbitration, its ALERT pin remains active.

GENERAL CALL

The TMP102 responds to a two-wire General Call address (0000000) if the eighth bit is '0'. The device acknowledges the General Call address and responds to commands in the second byte. If the second byte is 00000110, the TMP102 internal registers are reset to power-up values. The TMP102 does not support the General Address acquire command.

HIGH-SPEED (Hs) MODE

In order for the two-wire bus to operate at frequencies above 400kHz, the master device must issue an Hs-mode master code (00001xxx) as the first byte after a START condition to switch the bus to high-speed operation. The TMP102 does not acknowledge this byte, but switches its input filters on SDA and SCL and its output filters on SDA to operate in Hs-mode, allowing transfers at up to 3.4MHz. After the Hs-mode master code has been issued, the master transmits a two-wire slave address to initiate a data transfer operation. The bus continues to operate in Hs-mode until a STOP condition occurs on the bus. Upon receiving the STOP condition, the TMP102 switches the input and output filters back to fast-mode operation.

TIMEOUT FUNCTION

The TMP102 resets the serial interface if SCL is held low for 30ms (typ). The TMP102 releases the bus if it is pulled low and waits for a START condition. To avoid activating the timeout function, it is necessary to maintain a communication speed of at least 1kHz for SCL operating frequency.

NOISE

The TMP102 is a very low-power device and generates very low noise on the supply bus. Applying an RC filter to the V+ pin of the TMP102 can further reduce any noise the TMP102 might propagate to other components. R_F in Figure 11 should be less than 5kΩ and C_F should be greater than 10nF.

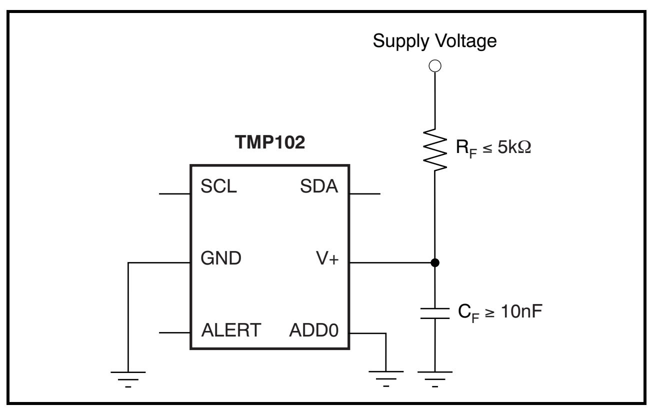


Figure 11. Noise Reduction

TIMING DIAGRAMS

The TMP102 is two-wire and SMBus compatible. Figure 12 to Figure 15 describe the various operations on the TMP102. Parameters for Figure 12 are defined in Table 13. Bus definitions are:

Bus Idle: Both SDA and SCL lines remain high.

Start Data Transfer: A change in the state of the SDA line, from high to low, while the SCL line is high, defines a START condition. Each data transfer is initiated with a START condition.

Stop Data Transfer: A change in the state of the SDA line from low to high while the SCL line is high defines a STOP condition. Each data transfer is terminated with a repeated START or STOP condition.

Data Transfer: The number of data bytes transferred between a START and a STOP condition is not limited and is determined by the master device. It is also possible to use the TMP102 for single byte updates. To update only the MS byte, terminate the communication by issuing a START or STOP communication on the bus.

Acknowledge: Each receiving device, when addressed, is obliged to generate an Acknowledge bit. A device that acknowledges must pull down the SDA line during the Acknowledge clock pulse in such a way that the SDA line is stable low during the high period of the Acknowledge clock pulse. Setup and hold times must be taken into account. On a master receive, the termination of the data transfer can be signaled by the master generating a *Not-Acknowledge* ('1') on the last byte that has been transmitted by the slave.

Table 13. Timing Diagram Definitions

PARAMETER	TEST CONDITIONS	FAST MODE		HIGH-SPEED MODE		UNIT
		MIN	MAX	MIN	MAX	
$f_{(SCL)}$	SCL Operating Frequency, V_S > 1.7V	0.001	0.4	0.001	3.4	MHz
$f_{(SCL)}$	SCL Operating Frequency, V_S < 1.7V	0.001	0.4	0.001	2.75	MHz
$t_{(BUF)}$	Bus Free Time Between STOP and START Condition	600		160		ns
$t_{(HDSTA)}$	Hold time after repeated START condition. After this period, the first clock is generated.	100		100		ns
$t_{(SUSTA)}$	Repeated START Condition Setup Time	100		100		ns
$t_{(SUSTO)}$	STOP Condition Setup Time	100		100		ns
$t_{(HDDAT)}$	Data Hold Time	0		0		ns
$t_{(SUDAT)}$	Data Setup Time	100		10		ns
$t_{(LOW)}$	SCL Clock Low Period, V_S > 1.7V	1300		160		ns
$t_{(LOW)}$	SCL Clock Low Period, V_S < 1.7V	1300		200		ns
$t_{(HIGH)}$	SCL Clock High Period	600		60		ns
t_F	Clock/Data Fall Time		300			ns
t_R	Clock/Data Rise Time		300		160	ns
t_R	Clock/Data Rise Time for SCLK ≤ 100kHz		1000			ns

TWO-WIRE TIMING DIAGRAMS

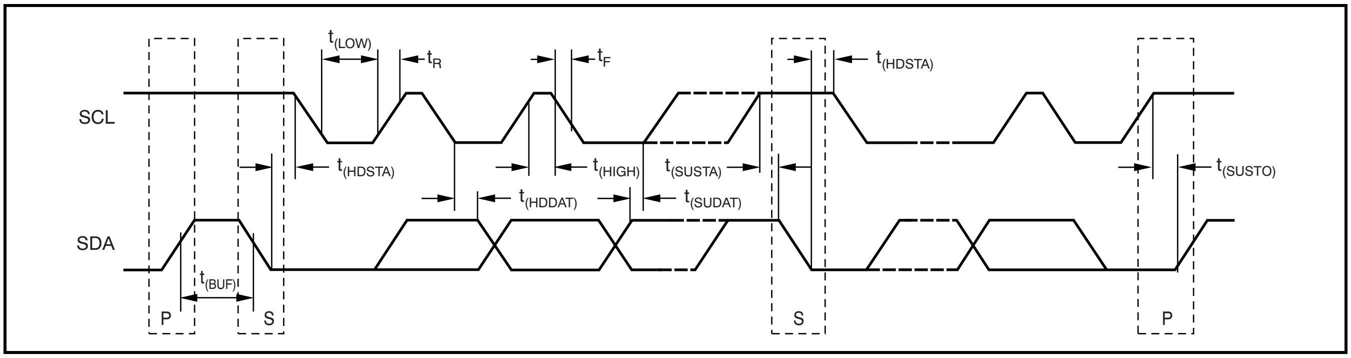


Figure 12. Two-Wire Timing Diagram

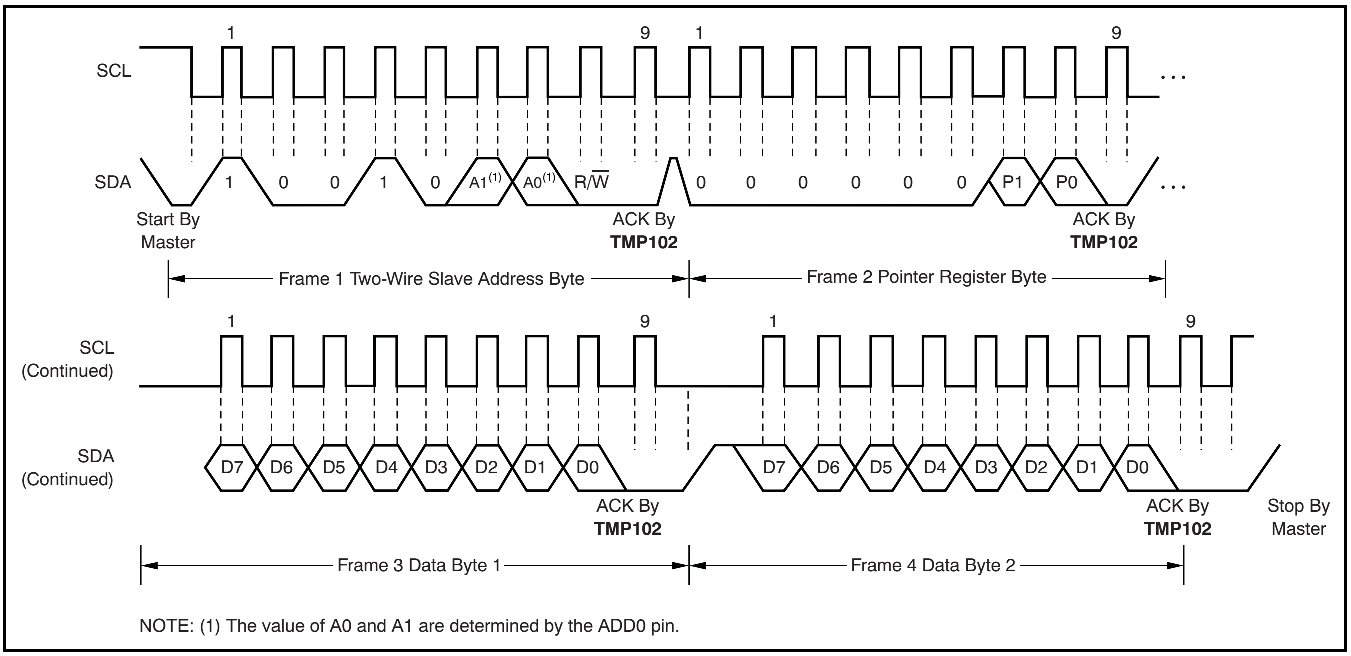


Figure 13. Two-Wire Timing Diagram for Write Word Format

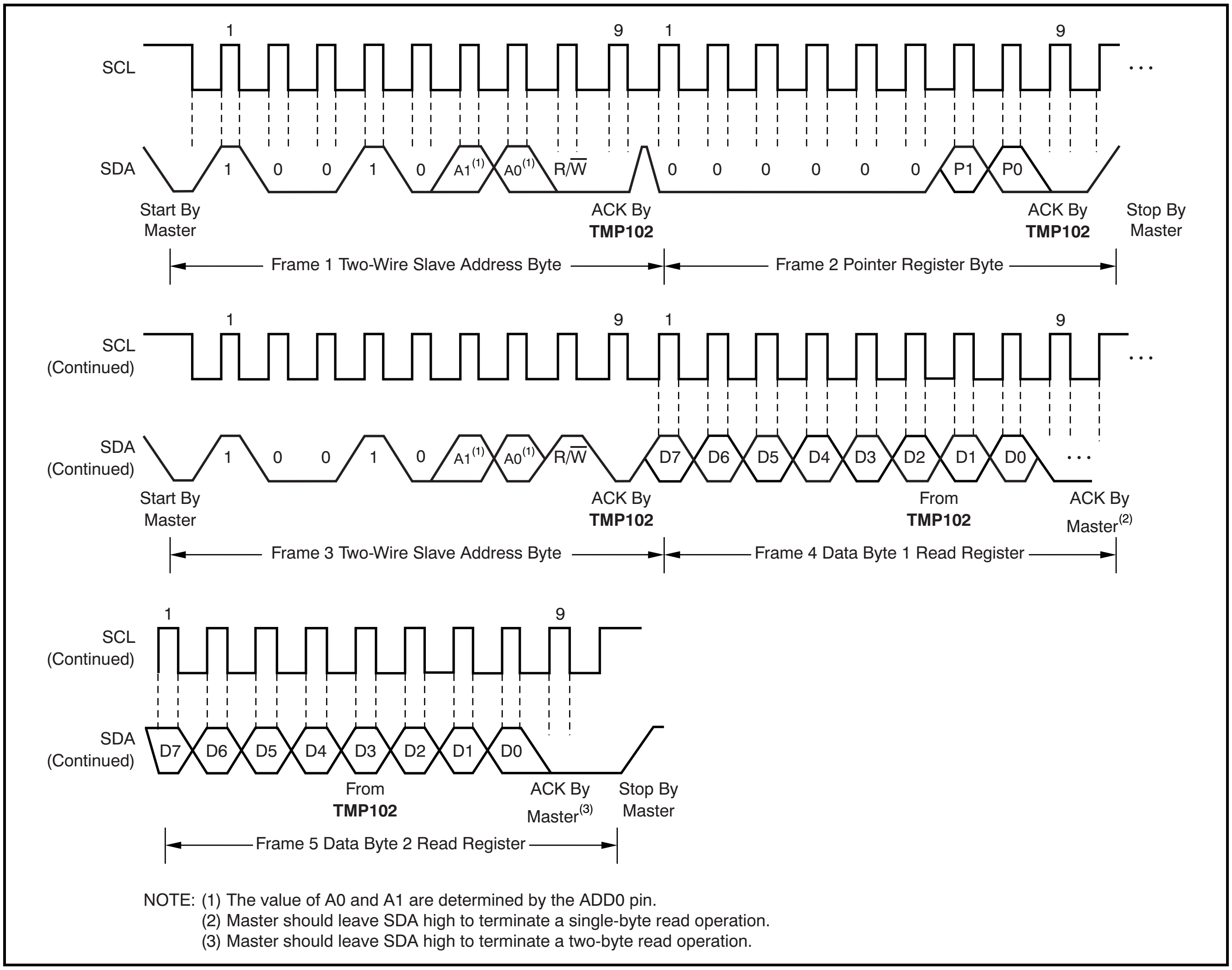


Figure 14. Two-Wire Timing Diagram for Read Word Format

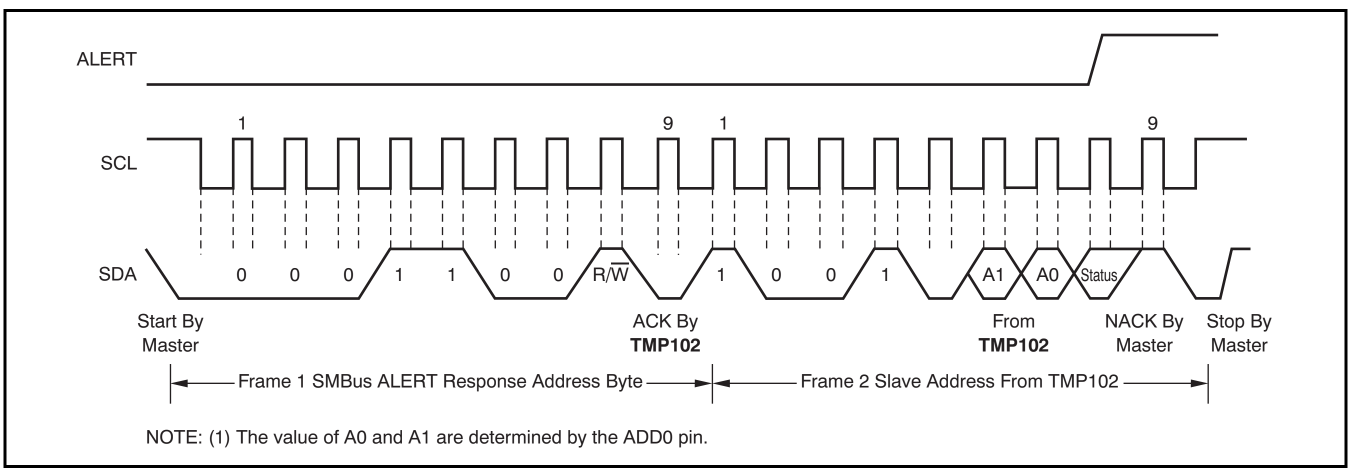


Figure 15. Timing Diagram for SMBus ALERT

PACKAGING INFORMATION

Orderable Device	Status [(1)]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [(2)]	Lead/Ball Finish	MSL Peak Temp [(3)]
TMP102AIDRLR	ACTIVE	SOT	DRL	6	4000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TMP102AIDRLRG4	ACTIVE	SOT	DRL	6	4000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TMP102AIDRLT	ACTIVE	SOT	DRL	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TMP102AIDRLTG4	ACTIVE	SOT	DRL	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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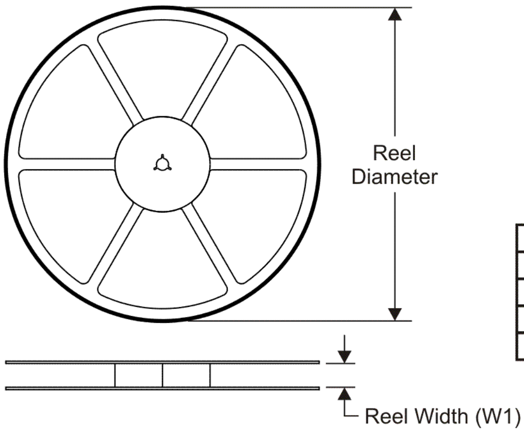
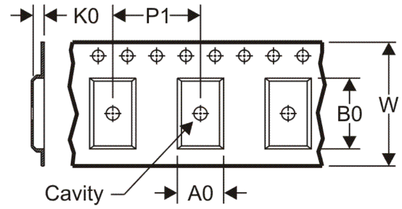
PACKAGE MATERIALS INFORMATION

TAPE AND REEL INFORMATION

REEL DIMENSIONS

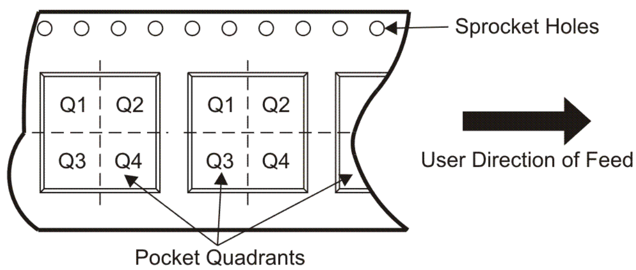


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

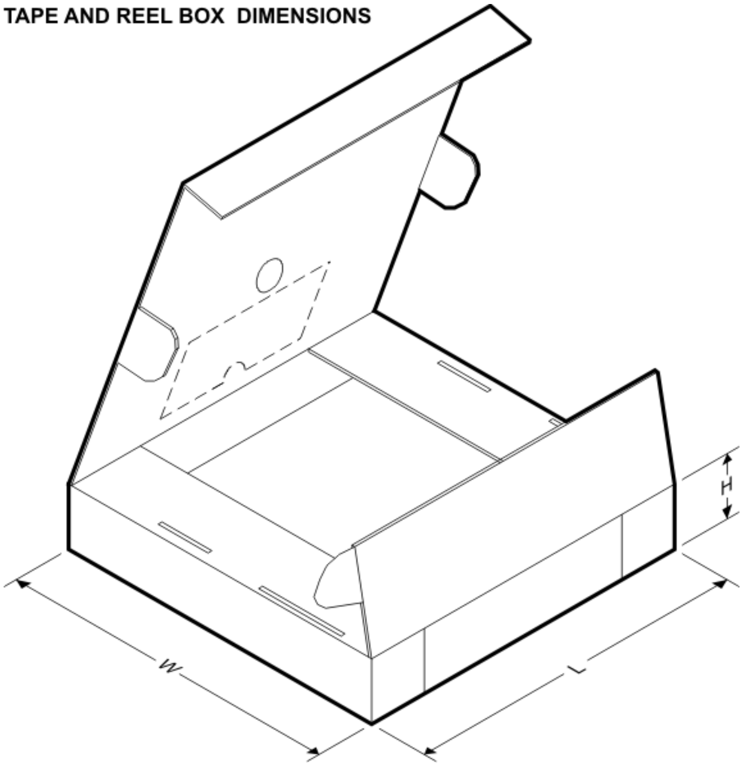
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

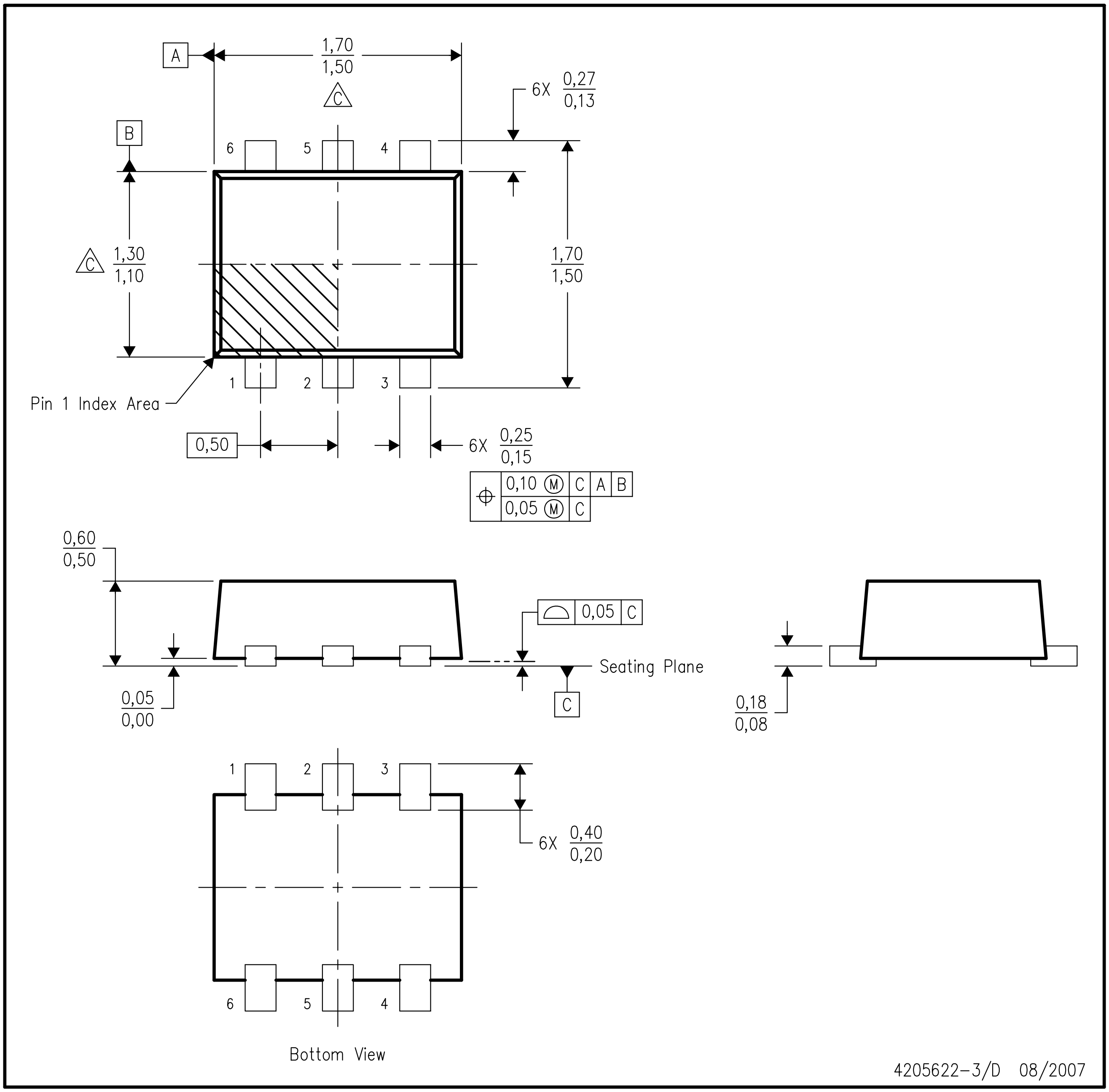
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TMP102AIDRLR	SOT	DRL	6	4000	180.0	9.2	1.78	1.78	0.69	4.0	8.0	Q3
TMP102AIDRLT	SOT	DRL	6	250	180.0	9.2	1.78	1.78	0.69	4.0	8.0	Q3

TAPE AND REEL BOX DIMENSIONS

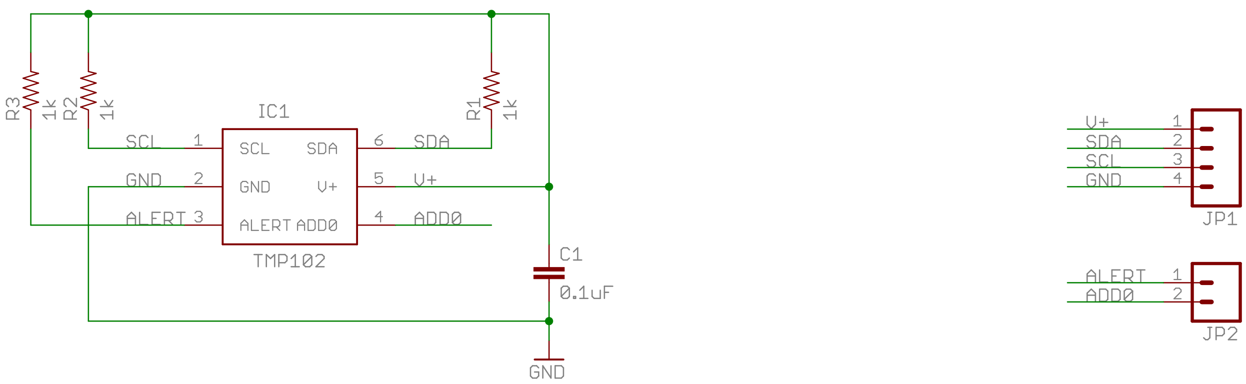


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TMP102AIDRLR	SOT	DRL	6	4000	202.0	201.0	28.0
TMP102AIDRLT	SOT	DRL	6	250	202.0	201.0	28.0



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash, interlead flash, protrusions, or gate burrs. Mold flash, interlead flash, protrusions, or gate burrs shall not exceed 0,15 per end or side.
D. JEDEC package registration is pending.



SFE

TITLE: TMP102_Breakout-v11

Document Number:

REV:

Date: 8/31/2009 1:09:43 PM

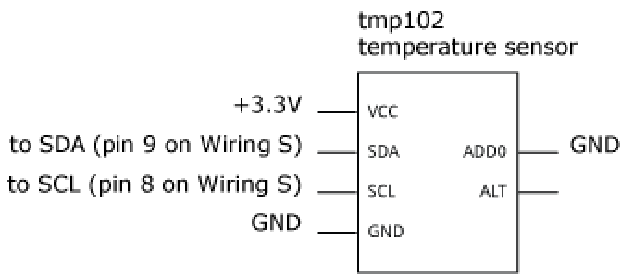
Sheet: 1/1

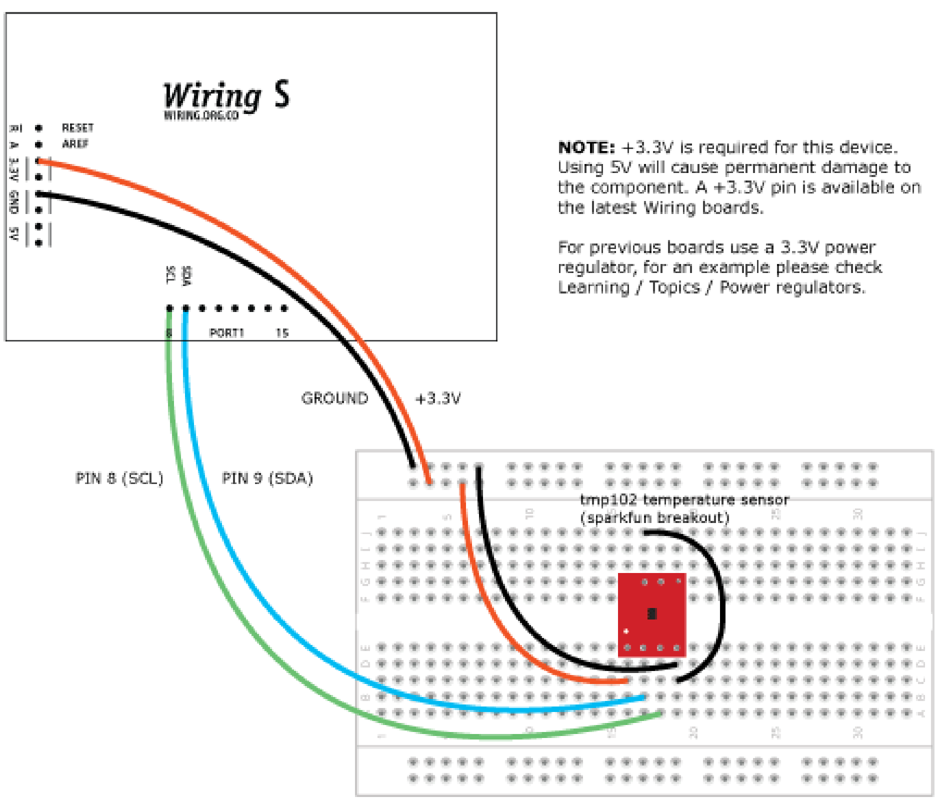
Temperature: Sparkfun tmp102

This example is for Wiring version 1.0 build 0100+. If you have a previous version, use the examples included with your software. *If you see any errors or have comments, please let us know.*

tmp102 temperature sensor by BARRAGAN (http://barraganstudio.com)

Demonstrates use of the Wire library reading data from the tmp102 temperature sensor On Wiring v1 boards the SCL and SDA pins are: 0 and 1 On Wiring S board the SCL and SDA pins are: 8 and 9





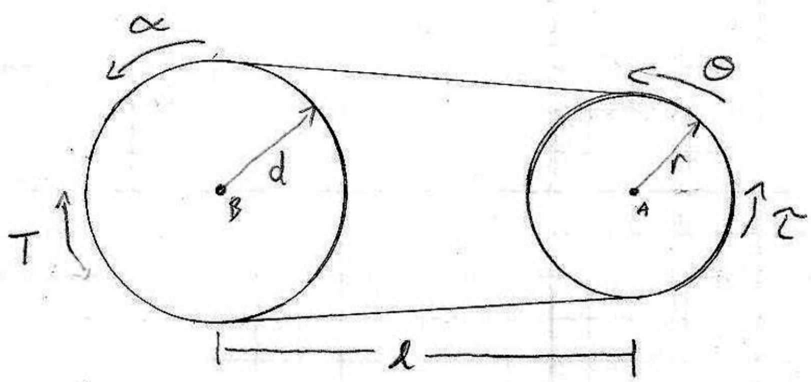
```
#include <Wire.h>

// From the datasheet the BMP module address LSB distinguishes
// between read (1) and write (0) operations, corresponding to
// address 0x91 (read) and 0x90 (write).
// shift the address 1 bit right (0x91 or 0x90), the Wire library only needs the 7
// most significant bits for the address 0x91 >> 1 = 0x48
// 0x90 >> 1 = 0x48 (72)

int sensorAddress = 0x91 >> 1;  // From datasheet sensor address is 0x91
                                // shift the address 1 bit right, the Wire library only needs the 7
                                // most significant bits for the address
byte msb;
byte lsb;
int temperature;

void setup()
{
  Serial.begin(9600);  // start serial communication at 9600bps
  Wire.begin();        // join i2c bus (address optional for master)
}

void loop()
{
  // step 1: request reading from sensor
  Wire.requestFrom(sensorAddress,2);
  if (2 <= Wire.available())  // if two bytes were received
  {
    msb = Wire.read();  // receive high byte (full degrees)
    lsb = Wire.read();  // receive low byte (fraction degrees)
    temperature = ((msb) << 4);  // MSB
    temperature |= (lsb >> 4);   // LSB
    Serial.print("Temperature: ");
    Serial.println(temperature*0.0625);
  }
  delay(500);  // wait for half a second
}
```



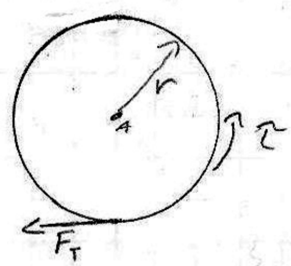
POSITIONING:

$$\alpha d = r\theta$$

$$\alpha = 30^\circ$$

$$\boxed{\theta = \frac{d}{r} 30^\circ}$$

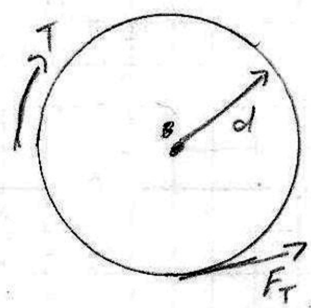
TORQUE:



$$\Sigma M_A = 0$$

$$\tau = r F_T$$

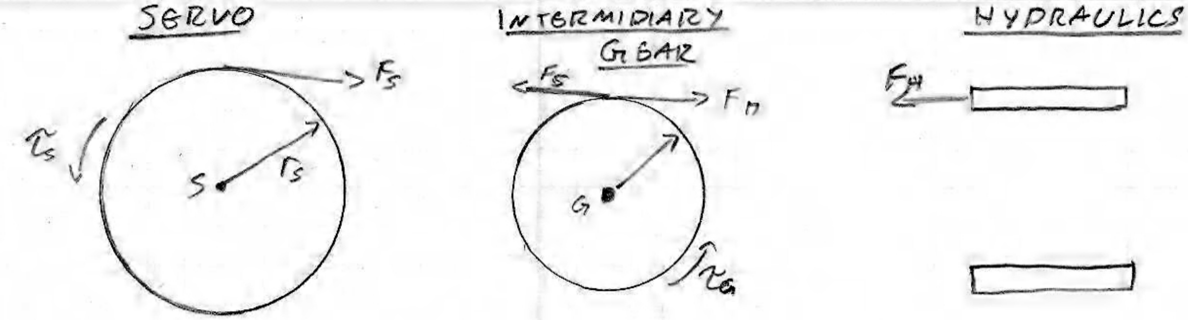
$$F_T = \frac{\tau}{r}$$



$$\Sigma M_B = 0$$

$$T = d F_T$$

$$\boxed{T = \frac{d}{r}\tau}$$



FORCE ANALYSIS

IDEALLY: $F_H = F_S$

$\Sigma M_S = 0$

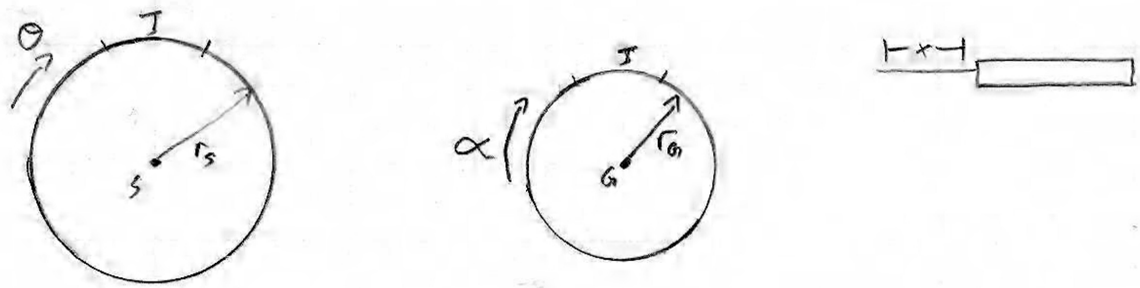
$\tau_S = F_S r_S$ $\qquad$ $\tau_G = F_S r_G$

$F_S = \frac{\tau_S}{r_S}$ $\qquad$ $F_S = \frac{r_G}{\tau_G}$ $\qquad$ $F_H = \frac{\tau_S}{r_S}$

$$\boxed{\tau_S = F_H r_S}$$

=> TORQUE ON SERVO ONLY DETERMINED BY HYDRAULIC FORCE AND SIZE OF SERVO GEAR

POSITION ANALYSIS

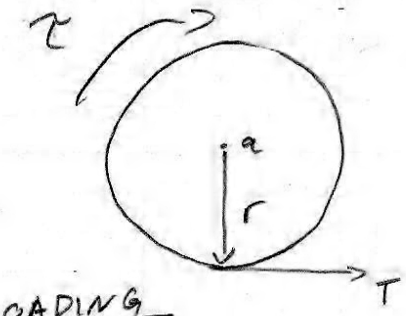


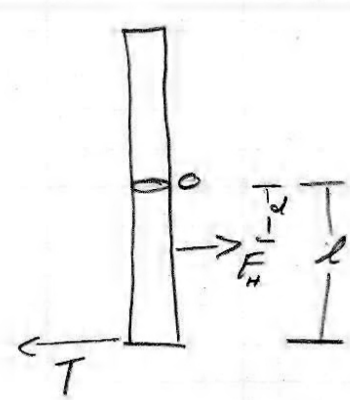
$T_S = \theta r_S$ $\qquad$ $T_G = \alpha r_G$ $\qquad$ $x = \theta r_S$

$\theta_{req} = 30°$

$T_S = T_G = x$

$$\boxed{x = r_S 30°}$$





LOADING

① $\Sigma M_a = 0$

$$rT - \tau_s = 0$$

$$T = \tau / r$$

② $\Sigma M_O = 0$

$$dF - lT = 0$$

$$T = \frac{d}{l} F_H$$

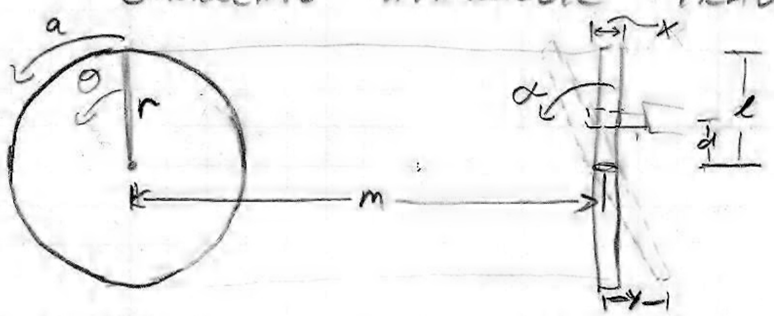
① -> ②

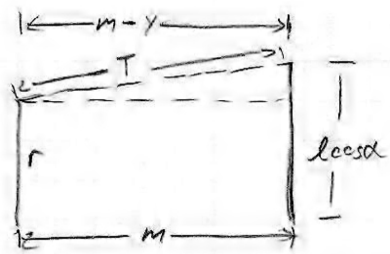
$$\tau / r = \frac{d}{l} F$$

③ $$\boxed{\tau = \frac{rd}{l} F}$$

POSITIONING

CORRELATE HYDRAULIC TRAVEL & SERVO ROTATION





$$a = \theta r$$

① $\theta = a/r$

$$\boxed{\theta = \frac{\sqrt{m^2 + (l-r)^2} - \sqrt{(l\cos\alpha - r)^2 + (m-y)^2}}{r}}$$

$$\frac{x}{d} = \frac{y}{l\cos\alpha}$$

$$y = l\cos\alpha \, \frac{x}{d}$$

$$a = T_0 - T$$

$$T = \sqrt{(l\cos\alpha - r)^2 + (m-y)^2}$$

$$\alpha = \tan^{-1} \frac{x}{d}$$

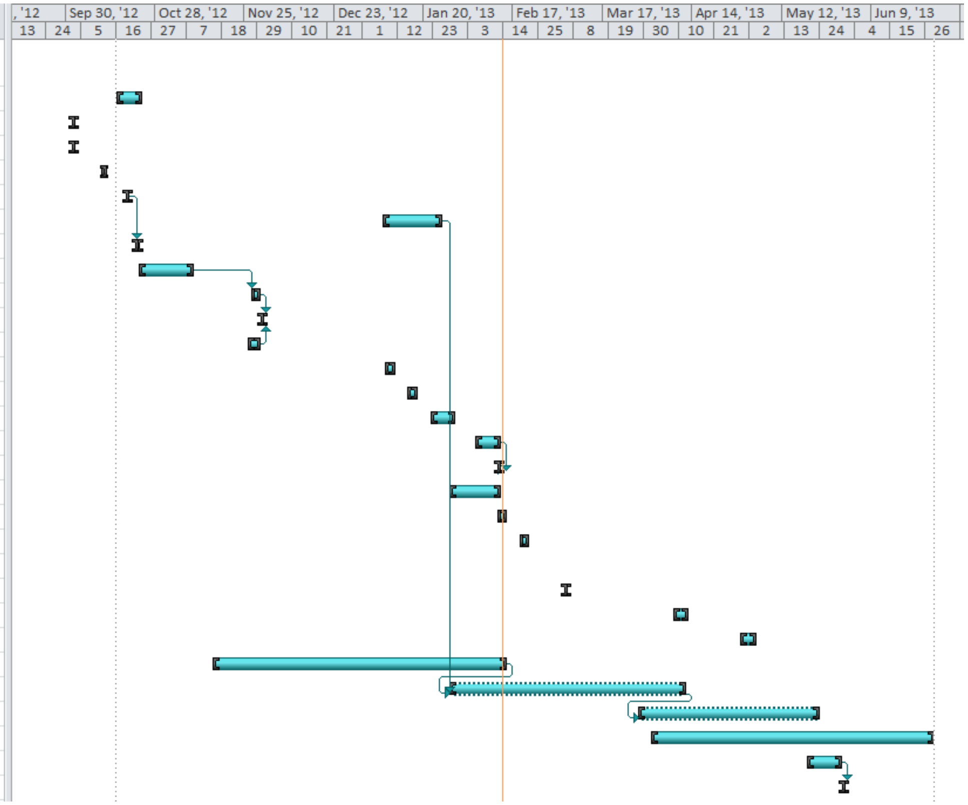
$$T_0 = \sqrt{(l-r)^2 + m^2}$$

$$y = l \frac{x}{d} \cos\alpha$$

$$\alpha = \tan^{-1}\left(\frac{x}{d}\right)$$

Appendix F: Project Gantt Chart

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Send introductory email to Makani				
2		Project Proposal	6 days	Tue 10/16/12	Tue 10/23/12	
3		Team contract	1 day	Tue 10/2/12	Tue 10/2/12	
4		NDA	1 day	Tue 10/2/12	Tue 10/2/12	
5		QFD	2 days	Thu 10/11/12	Fri 10/12/12	
6		Visit Makani	1 day	Fri 10/19/12	Fri 10/19/12	
7		Yellow Tag Test - Ari and Jeremy	15 days	Mon 1/7/13	Fri 1/25/13	
8		Turn in Logbooks	1 day	Mon 10/22/12	Mon 10/22/12	6
9		Conceptual model	13 days	Tue 10/23/12	Thu 11/8/12	
10		Concept Report	3 days	Tue 11/27/12	Thu 11/29/12	9
11		Concept Review	1 day	Fri 11/30/12	Fri 11/30/12	10,12
12		Concept Review Prep	4 days	Mon 11/26/12	Thu 11/29/12	
13		Analysis, drawing, BOM review	3 days	Tue 1/8/13	Thu 1/10/13	
14		Test plan development	3 days	Tue 1/15/13	Thu 1/17/13	
15		First Wave of Ordering Items	6 days	Tue 1/22/13	Tue 1/29/13	
16		Practice for Final Design Review with sponsor	6 days	Tue 2/5/13	Tue 2/12/13	
17		Final Design review with sponsor	1 day	Tue 2/12/13	Tue 2/12/13	16
18		Design Report	12 days	Mon 1/28/13	Tue 2/12/13	
19		Individual ethics memo	3 days	Tue 2/12/13	Thu 2/14/13	
20		Team ethics presentation	3 days	Tue 2/19/13	Thu 2/21/13	
21		Order Larger Parts (Pneumatic, DAQ system)	3 days	Sun 2/19/12	Tue 2/21/12	
22		Manufacturing and Test Review	1 day	Tue 3/5/13	Tue 3/5/13	
23		Project Update Memo	5 days	Mon 4/8/13	Fri 4/12/13	
24		Project Hardware/Assembly demo	5 days	Mon 4/29/13	Fri 5/3/13	
25		Manufacturing Drawings	66 days	Thu 11/15/12	Thu 2/14/13	
26		Manufacturing	54 days	Mon 1/28/13	Thu 4/11/13	25,7
27		Fixing Manufacturing Issues	41 days	Thu 3/28/13	Thu 5/23/13	26
28		Final Report	65 days	Mon 4/1/13	Fri 6/28/13	
29		Expo Prep	9 days	Mon 5/20/13	Thu 5/30/13	
30		Design Expo	1 day	Fri 5/31/13	Fri 5/31/13	29



Tempest Test Stand User's Manual

Jen Tibble

Jeremy Dong

Arianna Lasche

Alex Serventi

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

2013

Necessary Software/Equipment

- Matlab
- Laptop
- HDM Software http://harmonicdrive.net/support/hdm-downloads/
- 100 psi air supply
- 120 V Electrical Outlet

Start-up

1. Connect pneumatic hosing to air supply (100 psi)
2. Plug in provided power strip to 120 V electrical outlet
3. Check that power supplies and laptop are plugged into power strip
4. Start up HDM software on laptop
5. Start up Matlab
6. Check that environmental housing door is latched
7. Verify that pneumatic is in neutral position
8. Start up HDM and Matlab

Maintenance

- Keep bearings oiled (coupler oil if desired)
- Check tension in rope before each test
- Check and compare output of servo and independent sensors

Extra Components provided with Test Table

- Extra bolts for support structures and mounting
- Pneumatic Extension Steel rope support- Used for higher torque application (1”x1.75”x10” steel piece with two holes for rope)
- Plexiglass- Replacement window

- Steel rod- Replacement servo shaft for reconfigured geometry/swapped out servo
- Miscellaneous metal parts and hardware

Recommendations

- Run this machine up to the max rated servo torque with a safety factor of 4
- Replace hollow aluminum legs with solid steel for higher torques
- Replace wood rope support with provided steel support for higher torques
- Calibrate sensors intermittently