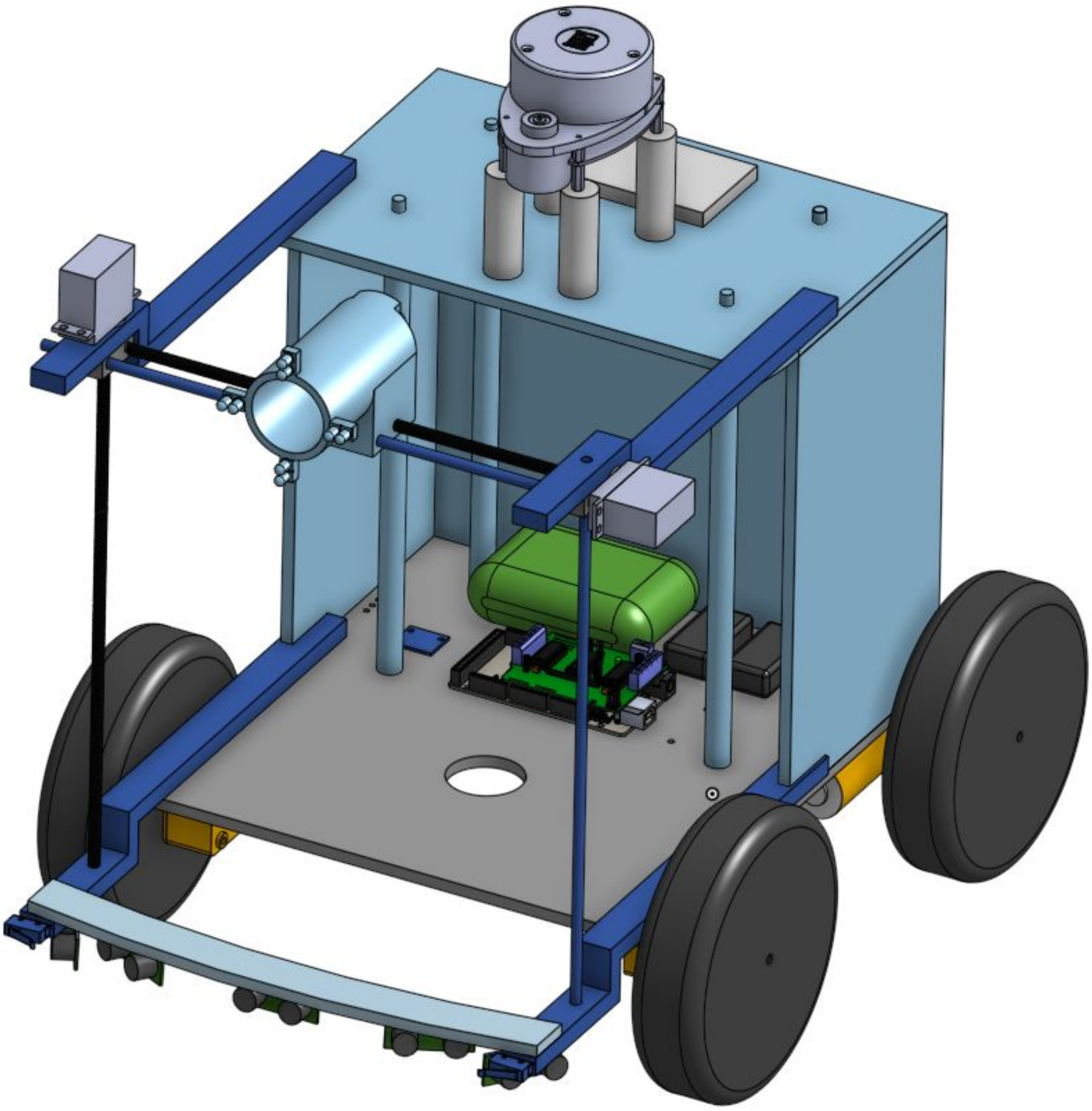
Final Paper
Fire-breathing Rubber Duckies



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Abstract

An autonomous mobile robot was designed for the fall 2020 ME412 Autonomous Mobile Robots course in the Cooper Union for the Advancement of Science and Art. The robot is designed to accomplish several tasks while operating autonomously in an unknown environment. The robot is expected to navigate through a dirt/gravel surface, while detecting and avoiding obstacles such as large rocks and bonsai of various sizes. The ultimate goal of the robot is to attack enemy robots by launching a ping pong ball "warhead" or slot a ping pong ball "warhead" in a circular cavity located on an enemy home base, after which the robot would return to its own home base.

The robot is equipped with various sensors, including ultrasonic sonar sensors, infrared sensors, limit switches, and LIDAR. It also has four DC motors that control translational and rotational movement, two servo motors to carry out object slotting tasks, and a solenoid to launch a ping pong ball "warhead." The robot is controlled with an Arduino Mega 2560, which is used to read sensors' signal inputs and actuate motors and a solenoid with the help of a L293D motor driver shield.

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1. Introduction

a. Objectives

The objective of the robot is to slot (deliver) a 40mm ping pong ball "warhead" through a circular hole cut into an enemy home base while securely aligning to the home base, after which the robot would return to its home base. At the same time, the robot is expected to attack an enemy robot by launching the warhead towards the enemy robot whenever possible. The robot should additionally be able to navigate through the arena without colliding with any of the obstacles.

b. Arena

The battlefield is a 12 feet by 20 feet rectangular enclosure with 2-foot wooden wall. The ground of the arena is a dirt and gravel surface populated with larger rocks and bonsai of various sizes.
Each home base is 2 feet wide, built in a recession of 1 to 4 inches from the arena wall, and textured with twelve zig zags. The home base also has a 120-millimeter hole centered 4 to 16 inches from the ground and 6 to 18 inches from its left border, through which the warhead is to be delivered.

c. Rules

The robot's maximum dimension is limited to a 2-foot length, a 2-foot width, and a 20-inch height in any mode of operation. It may not have mechanisms intended to damage any part of the arena or other robots. The robot is allowed to carry at most one ping pong ball warhead at any given time. The robot may be reloaded by the human operators only when it is docked to its home base, or if "teleported" in the case of an emergency. Before delivering the warhead through the hole, the robot must physically contact/align with the enemy home base on both the left and right side of the hole. If the robot shoots a warhead at an enemy robot, in order for the attack to be considered valid, the ping pong ball that is launched must hit the enemy robot before colliding with an object other than the ground or coming to a complete stop[1].

2. Robot Design
a. Mechanical Design
i. Chassis and Wheels

The chassis of the robot, shown in Figure 1 below, is built from two laser-cut acrylic sheets with a thickness of 0.25 inch. To allow for light-based sensory equipment to scan the arena without being obstructed by components of the object slotting mechanism, one of the acrylic sheets serves as an upper deck and is supported by four columns with a height of 10 inches each. The columns are built with ½-inch hex size/¼-20 thread standoff pieces with a combined height of 10 inches[2]. The centers of adjacent wheels are separated by a wheelbase of around 10.117 inches.

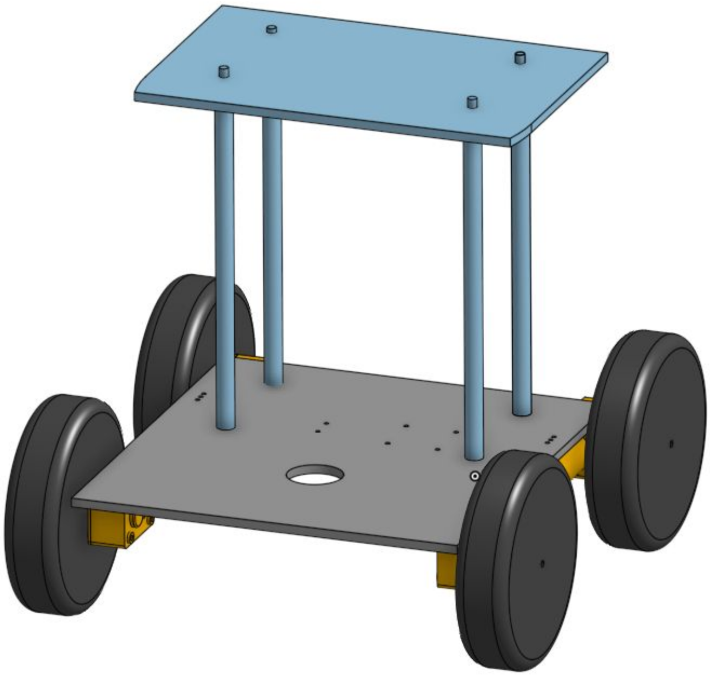

Figure 1: Chassis & wheels

ATR rubber-tired wheels, shown in Figure 2 below, were chosen for the wheels of the robot, as the rubber tires would allow the robot to traverse uneven, rocky ground. The wheels have a diameter of 6 inches and are attached to hubs (also shown in Figure 2 below), which are in turn attached to motors. The motors are attached to the lower deck of the robot.

Figure 2: ATR rubber-tired wheels & corresponding wheel hubs[3]

ii. Body

To shield the electronic components from dirt and gravel that may be disturbed and tossed around by the wheels, part of the rear of the robot is shielded with vertical walls - shown in Figure 3 - also made from acrylic sheets with a thickness of 0.25 inch. The walls also provide additional support for the upper deck, as well as additional weight for the rear portion of the robot to counter the heavy servo motors used in the object slotting mechanism in the front. Finally, four 3D-printed cylindrical supports with a diameter of 0.75 inch and a height of 2.25 inches were placed on the upper deck to raise the LIDAR and enable it to take unobstructed readings.

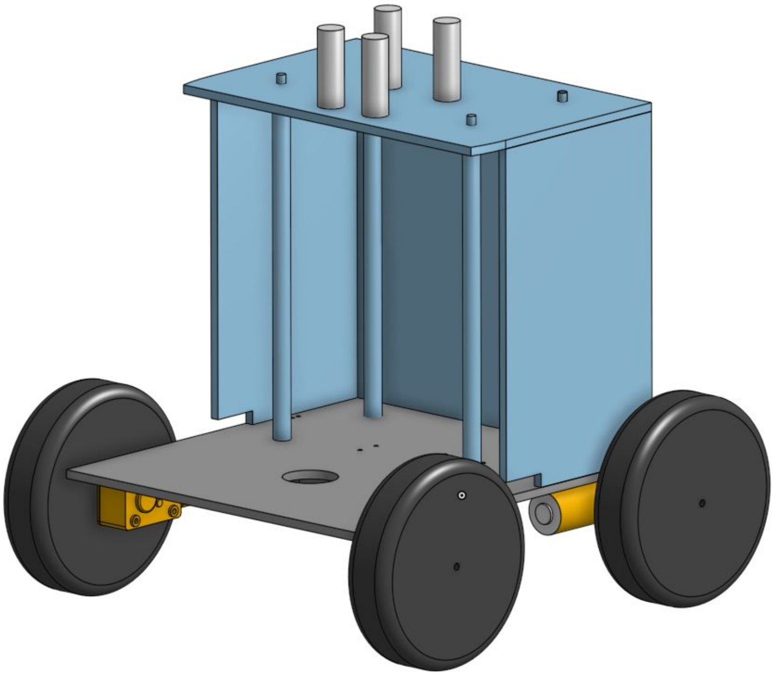

Figure 3: Chassis, wheels, & body

iii. Cannon/Object Slotting

The ping pong ball "warhead" is kept in a cylindrical tube that serves both as a cannon to shoot enemy robots and a compartment for slotting into the enemy's home base. To allow for object slotting, ¼"-20 threaded rods[4] actuated by servo motors are utilized in both the direction of the robot's width and height to allow the cylindrical tube to move vertically and horizontally to align the compartment with the hole of the enemy's base. The object slotting mechanism is attached to the rest of the robot by four long acrylic beams with a length of 11.8 inches, a width of ¾ inches, and a height of 0.4 inches to avoid interference with the lower level of the chassis. Two of the beams are attached to the top deck of the robot, and the other two are attached to the lower deck of the robot. At the end of the beams on the lower deck are two limit switches, shown in Figure 4. The limit switches are intended to verify aligned docking prior to slotting the ping pong ball warhead into the enemy home base. To allow for the placement of sonars for detecting smaller obstacles and enemy robots, an additional crossbeam, also shown more clearly in Figure 4, is placed near the front of the robot.

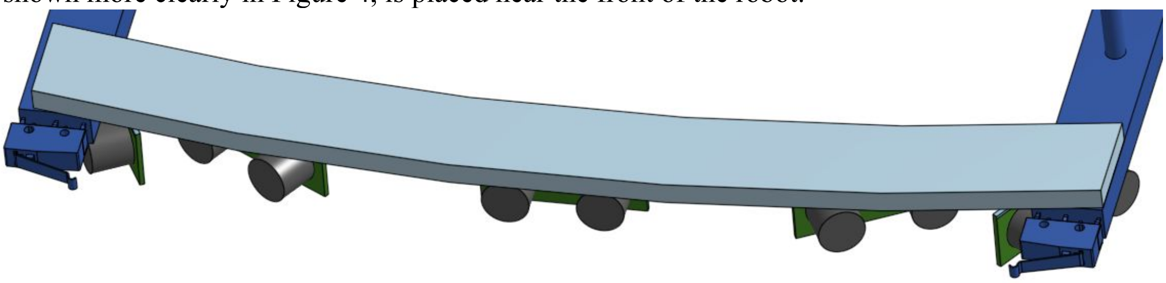

Figure 4: Sonar crossbeam & limit switches for aligned docking verification

The object slotting mechanism as a whole is shown in Figure 5.

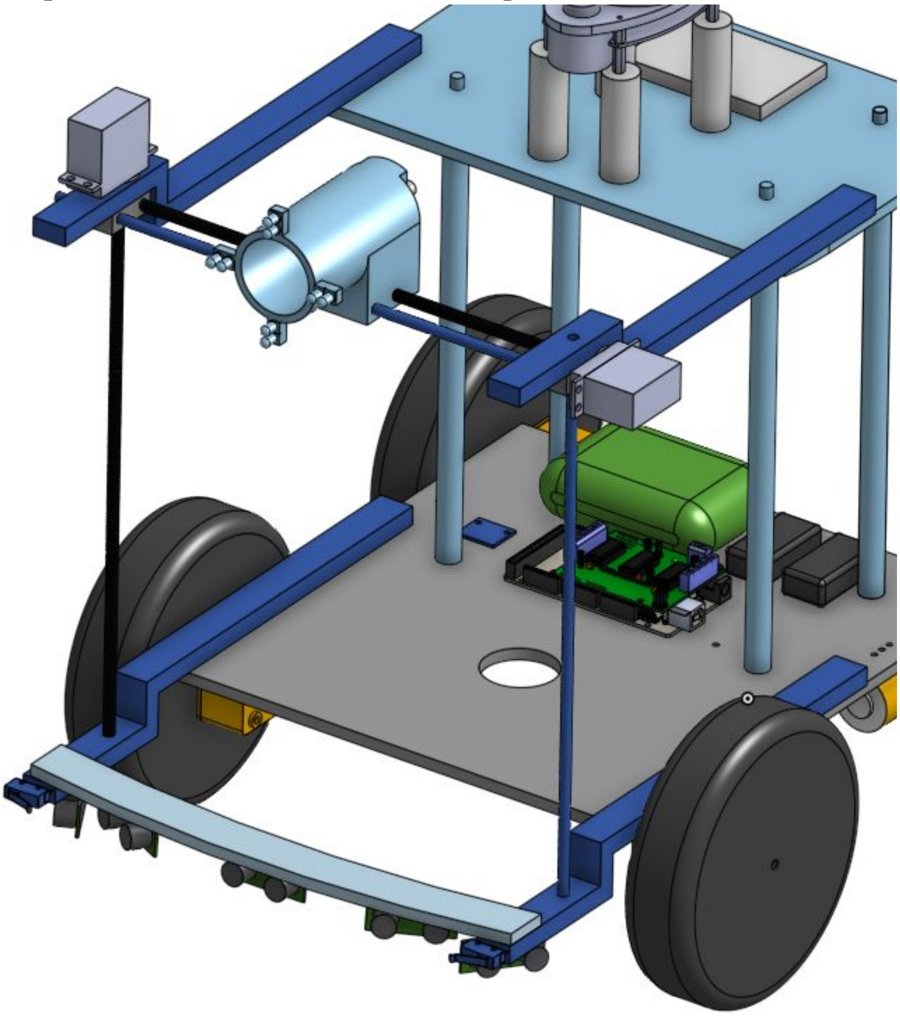

Figure 5: Object slotting mechanism

iv. Overall Assembly

Figure 6 shows a CAD model of the overall assembly, as well as relevant electronics.

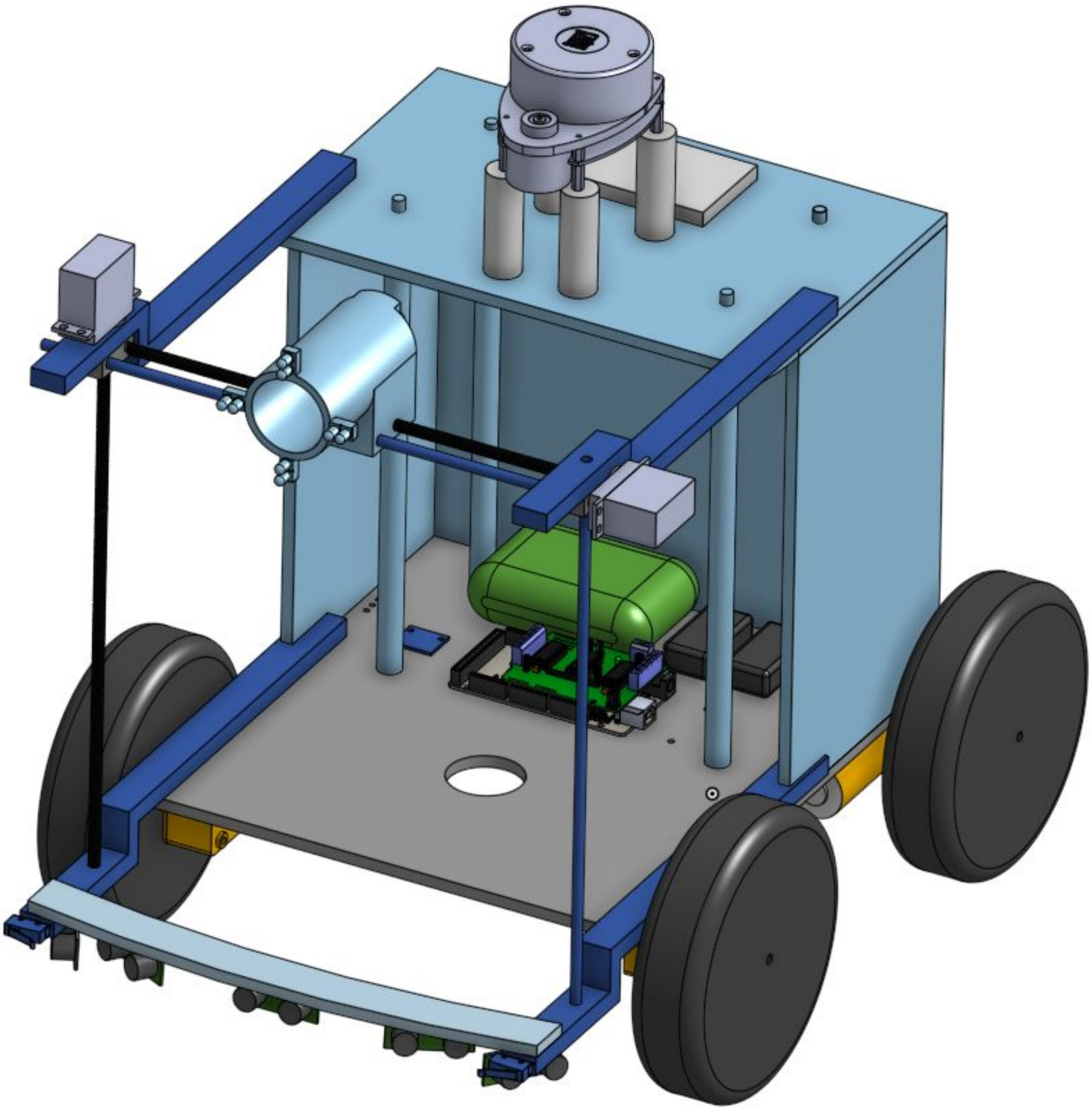

Figure 6: Overall assembly

b. Electrical Design

i. Microcontroller

An Arduino Mega 2560 was chosen as a microcontroller for the robot. The Arduino Mega is an 8-bit board that has 54 digital pins, 16 analog inputs, and 4 serial ports, enough pins for all sensors and actuators[5]. It uses the I2C communication protocol, which allows it to communicate with the IMU of motor drivers. It can perform serial communication on pins RX/TX, which will allow it to read sensor data, especially from the LIDAR. Finally, the Arduino Mega 2560 is capable of generating a pulse-width modulation (PWM) signal, which adds more precision to the actuation of the motors. It can output 5V to power sensors.

ii. Obstacle Avoidance

- **RPLIDAR-A1**

The Slamtec RPLIDAR-A1, shown in Figure 7, is a light detection and ranging (LIDAR) sensor capable of performing omnidirectional laser range scanning of its surrounding environment[6]. It is placed on the top of the robot to generate an outline map that can be used for obstacle avoidance and enemy home base detection. The RPLIDAR-A1 is capable of detecting objects located as far as 12

meters and can sample 8000 points at frequencies up to 10 Hz.
The RPLIDAR-A1 requires 5 volts of power input, and uses RX and TX pins for serial communication - all of which can be supplied by the Arduino Mega 2560 microcontroller.
The core of the RPLIDAR-A1 rotates clockwise while emitting lasers. It measures the time that the lasers take to reflect back in order to calculate the distance to the object. From LIDAR distance and angle data, the robot can decide if there are any objects in its vicinity. Since the RPLIDAR-A1 is situated at the top of the robot, it does not detect objects above the robot. This selective detection of objects based on its height allows the robot to navigate below the taller bonsai whose branches are above the height of the robot, resulting in nimble and effective navigation.
The sensor data from the RPLIDAR-A1 can also be used for detecting the enemy home base; the home base's jagged edges on the surrounding wooden walls are the only objects in the arena that will have a cluster of parallel straight lines. This means that a Hough line transform technique algorithm can be applied to the outline map to detect surrounding wooden walls[7]. Because the zig zag pattern will be filtered out by the line transform, the robot can look for two line segments with identical slopes that have few discontinuities in between.

Figure 7: Slamtec RPLIDAR-A1[7]

- **SRF04 Sonar Rangefinders**

Because the RPLIDAR-A1 is only capable of detecting taller obstacles, it is impossible to detect the ground obstacles such as rocks with only the RPLIDAR-A1. Therefore, five SRF04 sensors were chosen to detect ground-level obstacles.
The Devantech SRF04, shown in Figure 8, is a single-transducer ultrasonic rangefinder with a 2-pin serial interface, which returns a pulse that is proportional to the distance to the object[8]. By measuring the time difference between the pulse generation and the detection of the reflected pulse, the SRF04 can calculate the distance to objects. It is capable of detecting an object as close as 3 centimeters and as far away as 3 meters, which allows for avoidance by the robot of obstacles before it can collide with any obstacle.
The SRF04 requires 5 volts of input voltage, and two digital I/O pins for the trigger and the echo pins. Having 54 digitals pins, the Arduino Mega 2560 is capable of operating five SFR04 sonar rangefinders simultaneously. However, the Arduino Mega 2560 is not capable of providing enough power to all SRF04 sonar rangefinder units. Thus, an external power supply is introduced to evenly distribute the input voltage to each sonar.

Figure 8: Devantech SRF04 ultrasonic rangefinder/sonar[8]

iii. Navigation

- **MPU6050 Magnetic Compass**

The MPU6050 magnetic compass, shown in Figure 9, contains a MEMS accelerometer and a MEMS gyro that can return yaw, pitch, and roll angle[9]. It can orient the robot either to the enemy home base for the delivery of a ping pong ball warhead, or back to the home base after the accomplishment of the mission and/or for the reloading the robot with another ping pong ball warhead.
The MPU6050 can communicate with the Arduino Mega 2560 through SCL and SDA pins connected to the I2C communication bus. It also requires a 5-volt power input, which can be supplied by the Arduino Mega 2560.

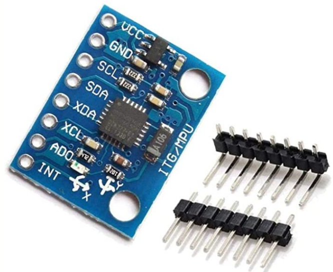

Figure 9: MPU6050 magnetic compass[9]

- **L293D Motor Driver Shield**

The L293D motor driver shield, shown in Figure 10, is used to actuate motors. It supplies up to 10 volts of input power[10], and is capable of driving four DC motors (connected to the robot's wheels) and two servo motors (connected to the robot's object slotting mechanism) at once, which will facilitate the operation of the motors. As a result, the L293D in a sense controls the robot's motion, as well as object slotting. The motor driver shield can be directly installed onto the Arduino Mega 2560.

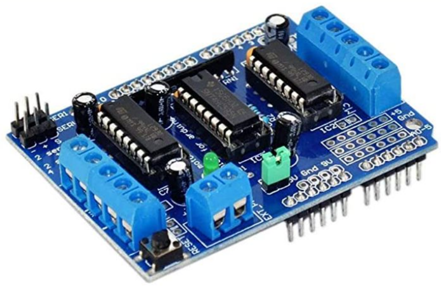

Figure 10: L293D motor driver shield[10]

- **IG32 Right-angle Gear Motor**

The IG32 right-angle gear motor, shown in Figure 11, is a brushed permanent magnet DC motor that has a right angle gearbox. It has a rated torque of 12kgf-cm and a rated speed of 9.5 RPM[9]. Although the gear motor requires 12V of input, 10V of input from L293D will be sufficient to drive the robot for the accomplishment of the task, since the objective of the robot does not lie in speed.

Figure 11: IG32 right-angle gear motor[11]

iv. Attacking and Object Slotting

- **XRN-0530 Solenoid**

The Aexit XRN-0530, shown in Figure 12, is a pull-push solenoid that will be used to launch the ping pong ball warhead. It has a rated force of 50g and a course of 10 millimeters[12]. The XRN-0530 requires 12 volts of input voltage, which is unable to be supplied by Arduino Mega 2560; therefore, an external 12-volt battery will be used, whose power supply will be controlled by a transistor. Additionally, in order to prevent the sudden change in voltage during the operation of the transistor, a flyback diode will be included in the circuit for the solenoid.

Figure 12: Aexit XRN-0530 solenoid[12]

- **MG92-series Servo Motors**

Two Adafruit MG92-series servo motors, shown in Figure 13, were chosen for actuating object slotting. One motor each will control the horizontal and vertical position of the cannon. The servo motors will be connected to and powered by the L293D motor driver shield.

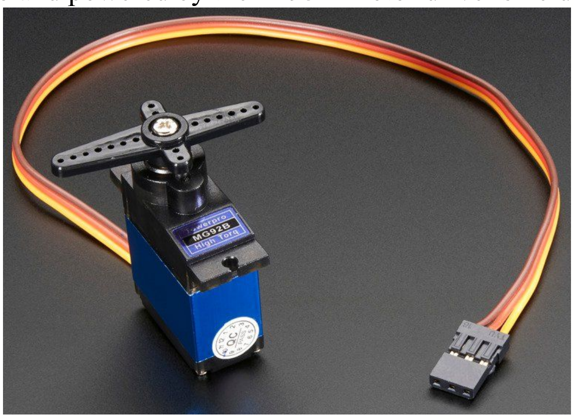

Figure 13: Adafruit MG92-series servo motors[11]

- **GP2Y0D805Z0F Infrared (IR) Rangefinders**

The Sharp GP2Y0D805Z0F infrared rangefinder, shown in Figure 14 with a corresponding carrier board, is a distance-measuring sensor unit. It operates at a supply voltage from 2.7 to 6.2V, and returns a digital output of "high" for a distance larger than 50 millimeters and "low" for a distance smaller than 50 millimeters[13]. Eight of these units are attached at the front of the cannon. Four are arranged in an inner circular pattern within the diameter of the object slotting hole on the enemy home base, and the other four are arranged in an outer circular pattern larger than the diameter of the object slotting hole. The two circular patterns will allow for fine adjustment of the position of the cannon.

Figure 14: Sharp GP2Y0D805Z0F IR rangefinder[13]

- **SS-3GL13PD Limit Switch**

Two Omron Electronics SS-3GL13PD limit switches, shown in Figure 15, are attached to the frontmost part of the robot, specifically on the front end of the beams attached to the lower deck of the robots. The switches are intended to certify aligned docking to the enemy's home base; the switches would be pressed if the robot contacts and aligns with the wall of the base. Once a signal is sent from both limit switches, object slotting can be performed.

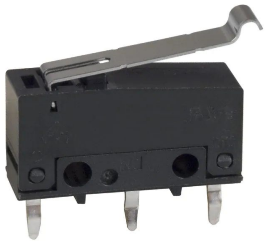

Figure 15: Omron Electronics SS-3GL13PD limit switch[14]

v. Power

Two different types of batteries will be used to power operations on the robot.
Two general 9-volt batteries will be used, with one powering the Arduino Mega 2560 and the other powering the L293D motor driver shield.
One 12-volt NiMH battery pack with a charge of 3.8 Amp-hours will be used as a power supply for the rest of the units[16]. The battery pack will provide power directly to components that require 12 volts of input, such as the solenoid and the gear motors for the wheels. It will also provide power to the sensors via a 5-volt step-down regulator manufactured by Wolfwhoop, shown in Figure 16.

Figure 16: Wolfwhoop 6-24 V to 5 V step-down voltage regulator[17]

vi. Circuit Diagram

Figure 17 shows a diagram of all electronics involved in the robot and how they will be wired.

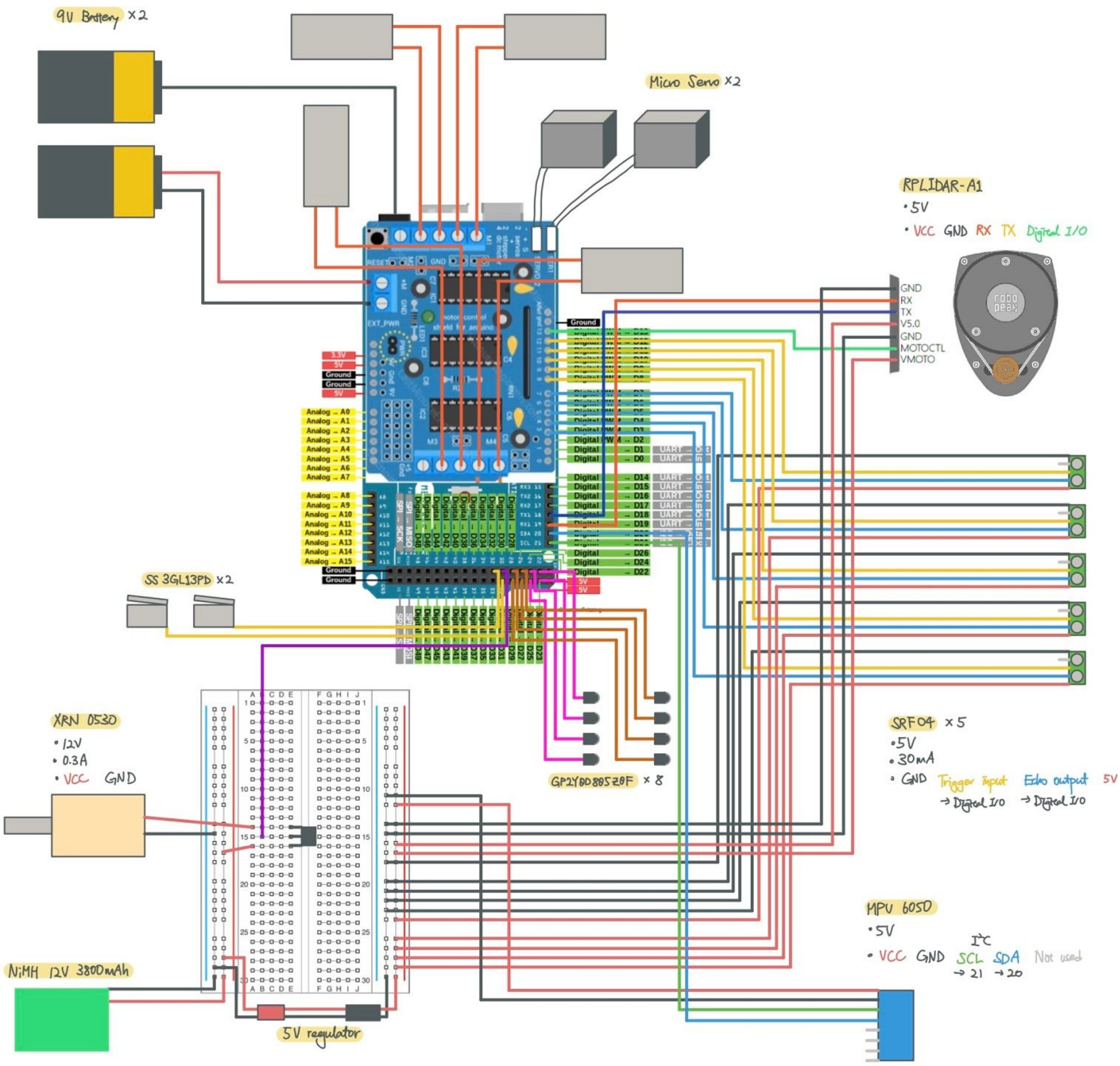

Figure 17: Circuit Diagram

3. Strategy

The robot is expected to carry out the object slotting and enemy-attacking based on the subsumption architecture. The robot is assigned one of six hierarchical states at each given time, each of which corresponds to a specific behavior designed to accomplish a task that will be implemented completely independently from any other behaviors. States with higher numbers occupy higher priority than states with lower numbers. Thus, the higher level state will be assigned to the robot whenever the condition for the higher level states is met. The subsumption structure for the robot is shown in Figure 18. Each arrow indicates that the higher level states will take over the lower states when triggered. However, state 1 and state 2 are hierarchically equivalent in that both will subsume state 0 when triggered and will be subsumed by either state 3 or state 4 whenever possible. Similarly, state 3 and state 4 are hierarchically equivalent.

The lowest state of the robot is a “navigating forward” state, which is triggered when there is no active target found. The robot will be navigating forward in the direction of the enemy home base, while avoiding the obstacles and actively searching for the targets. The states above this bottommost state are “Moving towards enemy robot” and “Moving towards enemy homebase.” Whenever the enemy robot or the enemy homebase are found while navigating, the robot will stop navigating around and actively move towards the identified target. Above these states are “Enemy attacking” and “Object slotting.” Both states possess equal priority in the subsumption architecture and will be triggered when the robot is in a reasonably close distance to the identified target - if the robot has detected an enemy robot and gets close enough to it, the robot will launch the ping pong ball warhead, thereby setting the robot’s state to 5; alternatively, if an enemy home base is set as a target and the robot aligns and docks onto it, object slotting will be performed, followed by the change in the state to 5. Finally, the highest state is “Returning to the homebase” which is triggered when the robot completes the task designated in state 3 and 4. When the robot is in state 5, it will turn around and navigate back to the homebase while avoiding the obstacles.

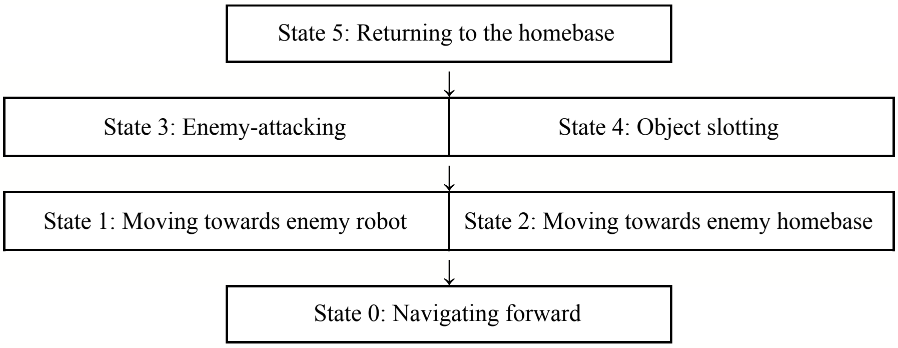

Figure 18: Subsumption architecture

4. Results/Conclusion

Ultimately, the aforementioned design is currently a theoretical model, due to limited resources at the Cooper Union for the Advancement of Science and Art being made more inaccessible due to the 2020 SARS-CoV-2 pandemic. Therefore, no testing was able to be done to verify that the design works electrically, mechanically, and coding-wise with little to no flaws. Similarly, no conclusions can yet be made on the robot’s design.

5. Future Work

In the future, the design can be physically conceived and tested to verify the coding, electrical circuitry, and mechanical designs of the robot.

In addition to eventually constructing the robot, additional future work can comprise the addition of “stealth” systems on the robot. It is proposed to add a bright light source (LED lightbulb) on the top of the robot to create a bright spot around the robot to possibly skew enemy robots’ light-based readings from such mechanisms as LIDARs and ToF cameras. Additionally, it is proposed to add soft sound-absorbing material around the robot to possibly skew enemy robots’ sound-based readings from such mechanisms as sonars. In order to not confuse the robot’s own light-based readings when the light source is turned on, it is proposed to activate the light source for several seconds, during which the robot’s LIDAR system would be deactivated to avoid skewed readings due to the bright light source.

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7. Appendices

Appendix A. Bill of Materials

Manufacturer	Part number	#	Description	Unit price	Total cost
SuperDroid Robots	TD-160-008	2	ATR Wheel Shaft Pair 8mm Bore - 6inch pneumatic DM	$38.92	$77.84
Arduino	A000067	1	Arduino Mega 2560 Rev3	$40.30	$40.30
Slamtec	RB-Rpk-03	1	RPLidar A1M8 - 360 Degree Laser Scanner Development Kit	$99.00	$99.00
Devantech	R93-SRF04	5	Devantech SRF04 Sonar Rangefinder	$18.00	$90.00
HiLetgo	GY-521	1	MPU6050 3 Axis Accelerometer Gyroscope Module 6 DOF 6-axis Accelerometer Gyroscope Sensor Module	$4.99	$4.99
HiLetgo	B01DG61YRM	1	Arduino L293D Motor Driver Shield	$5.89	$5.89
Shayang Ye Industrial Co., Ltd	TD-035-010	4	IG32 Right Angle 12VDC 010 RPM Gear Motor	$49.85	$199.40
Aexit	9c6f7bd9-2a46-62107ccd054a4d	1	Aexit XRN-0530 DC 12V 1.7A 50g Pull Type Open Frame Solenoid Electromagnet Magnet	$9.95	$9.95
Adafruit	2307	2	Micro Servo - High Powered, High Torque Metal Gear	$11.95	$23.90
Sharp	1132	8	Pololu Carrier with Sharp GP2Y0D805Z0F Digital Distance Sensor 5cm	$9.52	$76.16
Omron Electronics Inc-EMC Div	SS-3GL13P	2	Switch Snap Action SPDT 3A 125V	$1.72	$3.44
Wolfwhoop	5824093032	1	Wolfwhoop PW-D Control Buck Converter 6-24V to 5V 1.5A Step-Down Regulator Module Power Inverter Volt Stabilizer	$9.99	$9.99
Canal Plastics	N/A	4	12” x 12” acrylic sheet with ¼” thickness	$10.00	$40.00
McMaster Carr	91075A199	20	Male-Female Threaded Hex Standoff 18-8 Stainless Steel, 1/2" Hex, 2" Long, 1/4"-20 to 1/4"-20 Thread	$8.03	$160
McMaster Carr	3313N11	1	High-Strength Steel Threaded Rod Zinc Yellow-Chromate Plated, 1/4"-20 Thread Size, 3 Feet Long	$17.15	$17.15
Small Parts	N/A	1	Acetal Copolymer Round Rod, Opaque Black, Standard Tolerance, ASTM D6778, 1/4" Diameter, 36" Length	$12.35	$12.35
AA Portable Power	PR-CU-R525	1	12 V 3800 mah (10x4/3A, Hump) Battery Pack	$59.85	$59.85
Energizer	N/A	1	9V Batteries, Premium Alkaline, 2 Count	$6.75	$6.75
				TOTAL	$936.96

Appendix B. Arduino Pseudo-Code

```
#include <RPLidar.h>
#include <MPU6050_tockn.h>
#include <AF_DCMotor.h>
#include <Servo.h>

RPLidar lidar;
MPU6050 mpu6050(Wire);
AF_DCMotor motor1(1);
AF_DCMotor motor2(2);
AF_DCMotor motor3(3);
AF_DCMotor motor4(4);
Servo servoH;
Servo servoV;

// Define pin number for LIDAR motor
const int lidarMotor = 13;

// Define pin numbers for the sonars
const int trig1 = 12;
const int trig2 = 11;
const int trig3 = 10;
const int trig4 = 9;
const int trig5 = 8;
const int echo1 = 7;
const int echo2 = 6;
const int echo3 = 5;
const int echo4 = 4;
const int echo5 = 3;

// Define pin numbers for the IR Rangefinders
const int IR_in1 = 22;
const int IR_in2 = 23;
const int IR_in3 = 24;
const int IR_in4 = 25;
const int IR_out1 = 26;
const int IR_out2 = 27;
const int IR_out3 = 28;
const int IR_out4 = 29;

// Define pin number for the solenoid
const int solenoid = 30;

// Define pin numbers for the limit switches
const int limit1 = 31;
const int limit2 = 32;

// Basic movements
void moveForward(int t){};
void moveBackward(int t){};
void turnCW(float angle){};
void turnCCW(float angle){};
void rotateTowards(float targetDir){};

// Reading sensors
void readLidar(float[] &lidarDistances, float[] &lidarAngles){};
void readSonar(float[5] &sonarDistances){};
void readCompass(float &roll, float &pitch, float &yaw){};

// Target Finding
bool findEnemyHomeBase(float[] &lidarDistances, float[] &lidarAngles, float
&targetDir){};
bool findEnemyRobot(float[5] &sonarDistances, float &targetDir){};
```

```
// Navigation, when there is no target found
void navigateForward(float[] &lidarDistances, float[] &lidarAngles, float[5]
&sonarDistances){};

// Proceeding, when there is an active target found
void proceedToward(float[] &lidarDistances, float[] &lidarAngles, float[5]
&sonarDistances, float &targetDir){};

// Attacking
void launch(){};

//Object Slotting
void dock(){};
void alignCanon(){};

// State of robot. 0-5
// Subsumption architecture
// Higher number state corresponds to higher priority
// 0: No target found. Proceeds forward while avoiding obstacles
// 1: Enemy Robot found. Move towards the target while avoiding obstacles
// 2: Enemy Home Base found. Move towards the target while avoiding obstacles
// 3: Attacking enemy robot
// 4: Object slotting
// 5: Return home base
byte robotState;

// Global variables for the threshold values
byte maxAng;
byte maxDist;
byte minAng;
byte minDist;

void setup()
{
  // Begin serial communication of LIDAR
  lidar.begin(Serial);

  // Set pinmode of the LIDAR, and start rotating at maximum speed
  pinMode(lidarMotor, OUTPUT);
  digitalWrite(lidarMotor, 255);

  // Begin serial communication of compass
  Wire.begin();
  mpu6050.begin();

  // Set pinmode of the compass
  pinMode(20, OUTPUT);
  pinMode(21, OUTPUT);

  // Set pinmode of the sonars
  pinMode(trig1, OUTPUT);
  pinMode(trig2, OUTPUT);
  pinMode(trig3, OUTPUT);
  pinMode(trig4, OUTPUT);
  pinMode(echo1, INPUT);
  pinMode(echo2, INPUT);
  pinMode(echo3, INPUT);
  pinMode(echo4, INPUT);

  // Set pinmode of IR Rangefinders
  pinMode(IR_in1, INPUT);
  pinMode(IR_in2, INPUT);
  pinMode(IR_in3, INPUT);
  pinMode(IR_in4, INPUT);
  pinMode(IR_out1, INPUT);
```

```
  pinMode(IR_out2, INPUT);
  pinMode(IR_out3, INPUT);
  pinMode(IR_out4, INPUT);

  // Set pinmode of the solenoid
  pinMode(solenoid, OUTPUT);
  digitalWrite(solenoid, LOW);

  // Set robot state
  robotState = 0;
}

void loop()
{
  float targetDir; // Stores the direction of the target

  float[] lidarDistances; // Distance values for a single revolution of LIDAR
  float[] lidarAngles; // Angle values for a single revolution of LIDAR

  float[5] sonarDistances; // Distance values from the sonars

  float roll, pitch, yaw; // Stores the roll, pitch, yaw angles of the robot

  // If return home
  if (robotState == 5)
  {
    proceedToward(homeBase, lidarDistances, sonarDistances);
  }

  // If object slotting
  else if (robotState == 4)
  {
    dock();
    alighCanon();
    launch();
    // Set robot state to return home base
    robotState = 5;
  }

  // If attacking
  else if (robotState == 3)
  {
    launch();
    // Set robot state to return home base
    robotState = 5;
  }

  // If enemy home base found
  else if (robotState == 2)
  {
    while (all sonarDistances > minDist)
    {
      proceedToward(targetDir, lidarDistances, sonarDistances);
    }
    // Set robot state to object slotting
    robotState = 4;
  }

  // If enemy robot found
  else if (robotState == 1)
  {
    // Until both the angle and the distance becomes small enough
    while (targetDir >= maxAng && sonarDistances[2] >= maxDist)
    {
      // Rotate towards the enemy robot
```

```
      rotateTowards(255, targetDir);
      // Proceed towards the enemy robot for the time that is proportional to the
distance
      moveForward(sonarDistances[2]*timeFactor);

      // Update the direction of enemy robot before repeating the while loop
      // If enemy robot not found this time, go back to state 0
      if (!findEnemyRobot(sonarDistances, targetDir))
      {
        robotState = 0;
        break;
      }
    }
    robotState = 3;
  }
  // If no target is found
  else if (robotState == 0)
  {
    // Read sensors
    readLidar(lidarDistances, lidarAngles);
    readSonar(sonarDistances);
    readCompass(roll, pitch, yaw);

    // If enemy robot found
    if (findEnemyRobot(sonarDistances, targetDir)
    {
      robotState = 1;
    }

    // If enemy home base found
    if (findEnemyHomeBase(lidarDistances, lidarAngles, targetDir)
    {
      robotState = 2;
    }

    // If nothing found
    else
    {
      navigateForward(lidarDistances, lidarAngles, sonarDistances);
    }
  }
}

void moveForward(int t)
{
  motor1.run(FORWARD);
  motor2.run(FORWARD);
  motor3.run(FORWARD);
  motor4.run(FORWARD);
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor3.setSpeed(255);
  motor4.setSpeed(255);
  delay(time);
}
void moveBackward(int t)
{
  motor1.run(BACKWARD);
  motor2.run(BACKWARD);
  motor3.run(BACKWARD);
  motor4.run(BACKWARD);
  motor1.setSpeed(255);
  motor2.setSpeed(255);
  motor3.setSpeed(255);
  motor4.setSpeed(255);
```

```
  delay(time);
}
void turnCW(float angle)
{
  while ( abs(mpu6050.getAngleZ() - angle) >= maxAng )
  {
    motor1.run(FORWARD);
    motor2.run(FORWARD);
    motor3.run(BACKWARD);
    motor4.run(BACKWARD);
    motor1.setSpeed(angle*speedFactor);
    motor2.setSpeed(angle*speedFactor);
    motor3.setSpeed(angle*speedFactor);
    motor4.setSpeed(angle*speedFactor);
    delay(time);
  }
}
void turnCCW(float angle)
{
  while ( abs(mpu6050.getAngleZ() - angle) >= maxAng )
  {
    motor1.run(BACKWARD);
    motor2.run(BACKWARD);
    motor3.run(FORWARD);
    motor4.run(FORWARD);
    motor1.setSpeed(angle*speedFactor);
    motor2.setSpeed(angle*speedFactor);
    motor3.setSpeed(angle*speedFactor);
    motor4.setSpeed(angle*speedFactor);
    delay(time);
  }
}
void rotateTowards(float targetDir)
{
  if (targetDir > 0)
  {
    turnCW(targetDir);
  }
  else
  {
    turnCCW(targetDir);
  }
}
void readLidar(float[] &distances, float[] &angles)
{
  for a single revolution:
    distances[i] = lidar.getCurrentPoint().distance; //distance value in mm unit
    angle[i] = lidar.getCurrentPoint().angle; //anglue value in degree
}
void readSonar(float[5] &sonarDistances)
{
  for (int i = 0; i < 5; i++)
  {
    sonarDistances[i] = digitalRead(12 - i);
  }
}
void readCompass(float &roll, float &pitch, float &yaw)
{
  mpu6050.update();
  roll = mpu6050.getAngleX();
  pitch = mpu6050.getAngleY();
  yaw = mpu6050.getAngleZ();
}

// Target Finding
```

```
bool findEnemyHomeBase(float[] &lidarDistances, float[] &lidarAngles, float &targetDir)
{
  float[][] lines = lineDetect(lidarDistances, lidarAngles);
  for (angles between (-getAngleZ() - 45°) and (-getAngleZ() + 45°))
  {
    if (any 2 lines have same slope && no abrupt change in distance is observed
inbetween the lines)
    {
      targetDir = (midpoint of startpoint of one line and endpoint of another line);
      return true;
    }
  }
  return false;
}
float[] houghLineTransform(float x0, float y0)
{
  float[] r;
  /* find r as a function of theta */
  return r;
}
float[][] lineDetect(float[] x, float[] y)
{
  /* use houghTransform to detect lines*/
  return lines; // lines is a 2-D array in which (slope, intercept, startpoint,
endpoint) tuples are stored
}
bool findEnemyRobot(float[5] &sonarDistances, float &targetDir)
{
  for (int i = 0; i < 5; i++)
  {
    // If any of the sonar reading is below the minDist
    if (sonarDistances[i] < minDist)
    {
      // Strop the motors
      motor1.run(RELEASE);
      motor2.run(RELEASE);
      motor3.run(RELEASE);
      motor4.run(RELEASE);

      int sum = 0;
      // Store the sonar distance values
      float[5] previousSonarDistances = sonarDistances;
      // Wait for 3 seconds
      delay(3000);
      // Retrieve the sonar data again
      readSonar(sonarDistances);
      // Calculate the sum of the difference
      for (int j = 0; j < 5; j++)
      {
         sum += (sonarDistances[i] - previousSonarDistances[i])^2;
      }
      // If the difference is significant, there must be an object that is moving around
      if (sum > thres)
      {
        robotState = 1;
        return true;
      }
      else
      {
        return false;
      }
    }
  }
}
```

```
// Navigation, when there is no target found
void navigateForward(float[] &lidarDistances, float[] &lidarAngles, float[5]
&sonarDistances)
{
  while( min(lidarDistances) > minDist && min(sonarDistances) > minDist )
  {
    moveForward();
  }
  // If minimum distance threshold is violated by the lidar
  if (min(lidarDistances) <= minDist)
  {
    minAngle = lidarAngles[indexOf(min(lidarDistances))];
  }
  // If minimum distance threshold is violated by the sonar
  if (min(sonarDistances) <= minDist)
  {
    minAngle = indexOf(min(sonarDistances));
  }

  // If minimum angle occurs on the left side of the robot
  if (minAngle < 0)
  {
    // Rotate until the minimum distance is directly on the left of the robot
    // Assumption: minAngle < 90, since the minimum angle is encoutnered while traveling
forward
    rotateCW(90 - minAngle);
    moveForward(100);
    // Face front and begin navigating again
    rotateTowards(0);
  }
  // If minimum angle occurs on the right side of the robot
  else if (minAngle > 0)
  {
    // Rotate until the minimum distance is directly on the right of the robot
    rotateCCW(90 - minAngle);
    moveForward(100);
    // Face front and begin navigating again
    rotateTowards(0);
  }
}

// Proceed Towards is exacly the same as navitage forward, but the only difference is
that
// the robot tries to rotate towards the target direction after each detour
void proceedToward(float[] &lidarDistances, float[] &lidarAngles, float[5]
&sonarDistances, float &targetDir)
{
  while( min(lidarDistances) > minDist && min(sonarDistances) > minDist )
  {
    moveForward();
  }
  // If minimum distance threshold is violated by the lidar
  if (min(lidarDistances) <= minDist)
  {
    minAngle = lidarAngles[indexOf(min(lidarDistances))];
  }
  // If minimum distance threshold is violated by the sonar
  if (min(sonarDistances) <= minDist)
  {
    minAngle = indexOf(min(sonarDistances));
  }

  // If minimum angle occurs on the left side of the robot
  if (minAngle < 0)
  {
```

```
    // Rotate until the minimum distance is directly on the left of the robot
    // Assumption: minAngle < 90, since the minimum angle is encoutnered while traveling
forward
    rotateCW(90 - minAngle);
    moveForward(100);
    // Rotate towards the target direction and begin navigating again
    rotateTowards(targetDir);
  }
  // If minimum angle occurs on the right side of the robot
  else if (minAngle > 0)
  {
    // Rotate until the minimum distance is directly on the right of the robot
    rotateCCW(90 - minAngle);
    moveForward(100);
    // Rotate towards the target direction and begin navigating again
    rotateTowards(targetDir);
  }
  // Update the direction of enemy home base
  // If enemy home base not found this time, go back to state 0
  if (!findEnemyHomeBase(targetDir))
  {
    robotState = 0;
    break;
  }
}

void launch()
{
  digitalWrite(solenoid, HIGH);
}

void dock()
{
  // Keep accelerate forward until the robot is in full contact with the enemy home base
  while( digitalRead(limit switch) == HIGH ) // HIGH means not in contact
  {
    moveForward(100); // Proceed gradually until both limit switches are pressed
  }
  // Strop the motors
  motor1.run(RELEASE);
  motor2.run(RELEASE);
  motor3.run(RELEASE);
  motor4.run(RELEASE);
}

void alignCanon()
{
  initPos(); // Initializes the position of the canon to the bottom left
  while(all digitalRead(inner IR sensor)==LOW)
  {
    swipe();  // Swipe the bottom row -> elevate 30 -> swipe the middle row -> elevate
30 -> swipe the top row
            // If any IR sensor reads HIGH, break
  }
  while ( any digitalRead(inner IR sensor) == HIGH and digitalRead(corresponding outer
IR sensor) == HIGH )
  {
    moveServo(inner IR sensor); // Move the servo towards the direction where both inner
and outer IR sensor readings are HIGH
  }
}
```

Appendix C. Hardware Datasheets

XRN-0530 DC 12V/DC24V 5.1KG/10mm Pull Type Open Frame Solenoid Electromagnet

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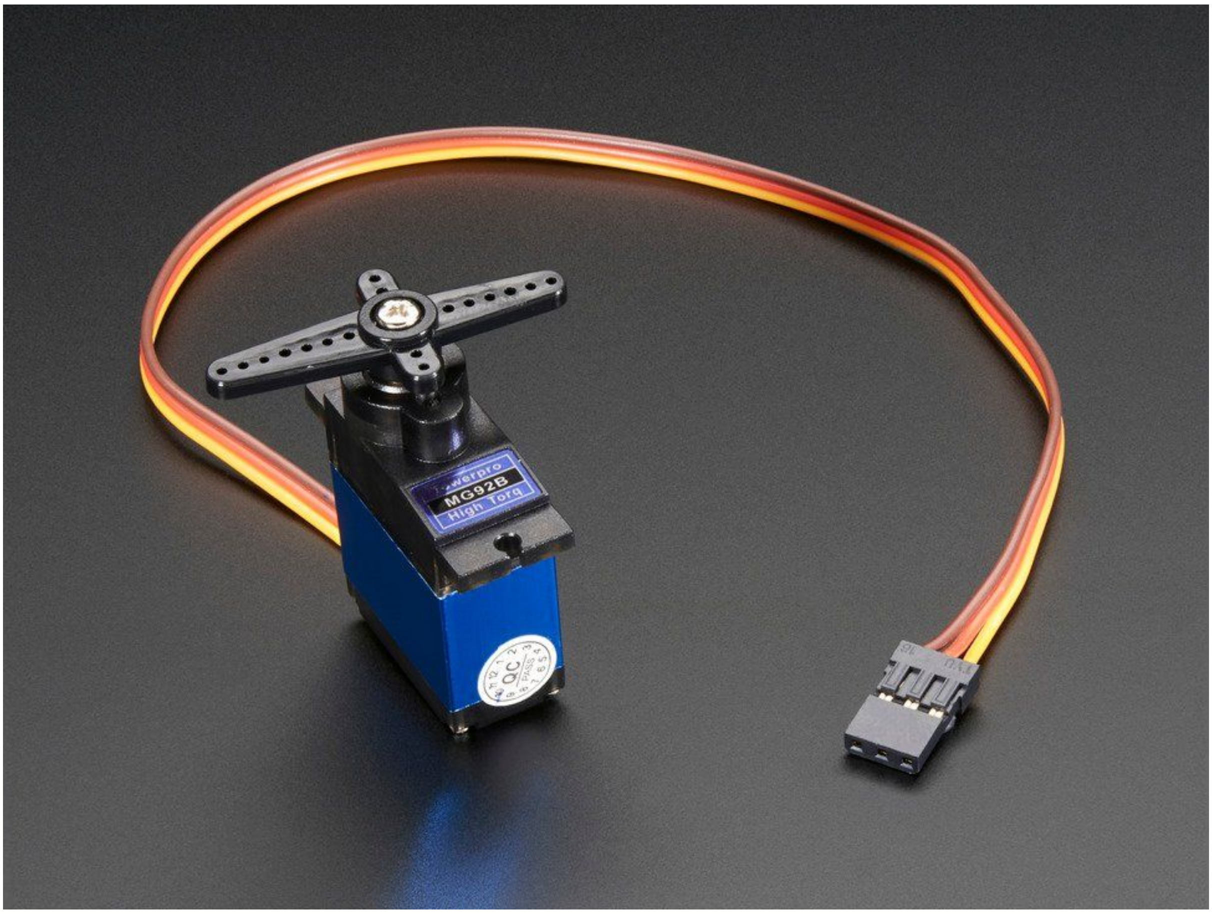
Model	XRN-0530
Rated Voltage	DC 12V/DC24V
Type	Pull
Force& Stroke	5.1KG/10mm
Body Size	30 x 16 x 14mm / 1.2" x 0.63" x 0.55" (L*W*T)
Plunger Bar Size	6 x 58mm / 0.24" x 2.3" (D*L)
Mounting Hole Dia.	2.2mm/ 0.09"
Cable Length	19cm / 7.5"
Material	Metal, Electronic Parts



TECHNICAL DETAILS

- Stall Torque (4.8v): 3.1kg/cm
- Stall Torque (6.0v): 3.5kg/cm
- Operating Speed (4.8v): 0.13sec/60°
- Operating Speed (6.0v): 0.08sec/60°
- Operating Voltage: 5.0~6.6v
- 36mm x 12mm x 31mm / 1.4" x 0.5" x 1.2"
- Wire Length: 257mm / 10.1"
- Weight: 14g
- Spline Count: 20

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1 ADD TO CART

L293D Motor Driver Shield Compatible to Duemilanove Mega UNO R3 AVR ATMEL

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产品详情

Specification:

1.Up to 4 bi-directional DC motors with individual 8-bit speed selection.
2.Up to 2 stepper motors (unipolar or bipolar) with single coil, double coil or interleaved stepping.
3.4 H-Bridges: per bridge provides 0.6A (1.2A peak current) with thermal protection, can run motors on 4.5V to 12V DC.
4.Pull down resistors keep motors disabled during power-up.
5.2 external terminal power interface, for seperate logic/motor supplies.
6.Tested compatible for Arduino Mega, Diecimila & Duemilanove.

L293x Quadruple Half-H Drivers

1 Features

- Wide Supply-Voltage Range: 4.5 V to 36 V
- Separate Input-Logic Supply
- Internal ESD Protection
- High-Noise-Immunity Inputs
- Output Current 1 A Per Channel (600 mA for L293D)
- Peak Output Current 2 A Per Channel (1.2 A for L293D)
- Output Clamp Diodes for Inductive Transient Suppression (L293D)

2 Applications

- Stepper Motor Drivers
- DC Motor Drivers
- Latching Relay Drivers

3 Description

The L293 and L293D devices are quadruple high-current half-H drivers. The L293 is designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36 V. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. Both devices are designed to drive inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN.

The L293 and L293D are characterized for operation from 0°C to 70°C.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
L293NE	PDIP (16)	19.80 mm × 6.35 mm
L293DNE	PDIP (16)	19.80 mm × 6.35 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Logic Diagram

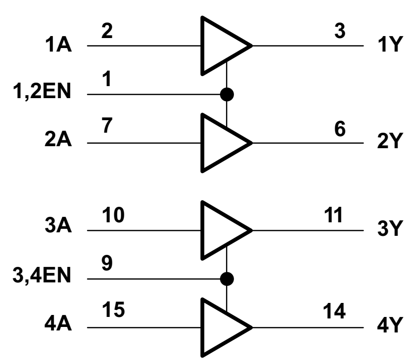


Table of Contents

4 Revision History

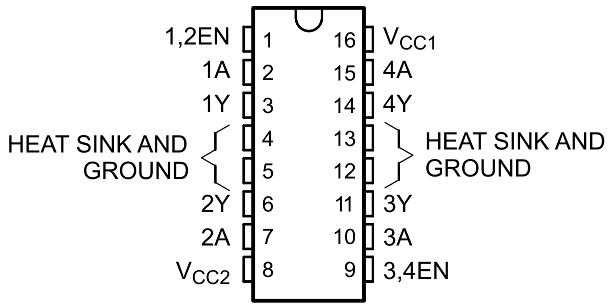
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (November 2004) to Revision D — **Page**

- Removed *Ordering Information* table 1
- Added *ESD Ratings* and *Thermal Information* tables, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section. 1

5 Pin Configuration and Functions

NE Package
16-Pin PDIP
Top View



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
1,2EN	1	I	Enable driver channels 1 and 2 (active high input)
<1:4>A	2, 7, 10, 15	I	Driver inputs, noninverting
<1:4>Y	3, 6, 11, 14	O	Driver outputs
3,4EN	9	I	Enable driver channels 3 and 4 (active high input)
GROUND	4, 5, 12, 13	—	Device ground and heat sink pin. Connect to printed-circuit-board ground plane with multiple solid vias
V_{CC1}	16	—	5-V supply for internal logic translation
V_{CC2}	8	—	Power VCC for drivers 4.5 V to 36 V

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

	MIN	MAX	UNIT
Supply voltage, V_{CC1} (2)		36	V
Output supply voltage, V_{CC2}		36	V
Input voltage, V_I		7	V
Output voltage, V_O	–3	V_{CC2} + 3	V
Peak output current, I_O (nonrepetitive, t ≤ 5 ms): L293	–2	2	A
Peak output current, I_O (nonrepetitive, t ≤ 100 µs): L293D	–1.2	1.2	A
Continuous output current, I_O: L293	–1	1	A
Continuous output current, I_O: L293D	–600	600	mA
Maximum junction temperature, T_J		150	°C
Storage temperature, T_{stg}	–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to the network ground terminal.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			MIN	NOM	MAX	UNIT
	Supply voltage	V_{CC1}	4.5		7	V
		V_{CC2}	V_{CC1}		36	
V_{IH}	High-level input voltage	V_{CC1} ≤ 7 V	2.3		V_{CC1}	V
		V_{CC1} ≥ 7 V	2.3		7	V
V_{IL}	Low-level output voltage		–0.3(1)		1.5	V
T_A	Operating free-air temperature		0		70	°C

(1) The algebraic convention, in which the least positive (most negative) designated minimum, is used in this data sheet for logic voltage levels.

6.4 Thermal Information

THERMAL METRIC(1)		L293, L293D NE (PDIP) 16 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance (2)	36.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	22.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	16.5	°C/W
ψ_{JT}	Junction-to-top characterization parameter	7.1	°C/W
ψ_{JB}	Junction-to-board characterization parameter	16.3	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.
(2) The package thermal impedance is calculated in accordance with JESD 51-7.

6.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER			TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{OH}	High-level output voltage		L293: I_{OH} = −1 A		V_{CC2} – 1.8	V_{CC2} – 1.4		V
			L293D: I_{OH} = − 0.6 A					
V_{OL}	Low-level output voltage		L293: I_{OL} = 1 A			1.2	1.8	V
			L293D: I_{OL} = 0.6 A					
V_{OKH}	High-level output clamp voltage		L293D: I_{OK} = –0.6 A			V_{CC2} + 1.3		V
V_{OKL}	Low-level output clamp voltage		L293D: I_{OK} = 0.6 A			1.3		V
I_{IH}	High-level input current	A	V_I = 7 V			0.2	100	µA
		EN				0.2	10	
I_{IL}	Low-level input current	A	V_I = 0			–3	–10	µA
		EN				–2	–100	
I_{CC1}	Logic supply current		I_O = 0	All outputs at high level		13	22	mA
				All outputs at low level		35	60	
				All outputs at high impedance		8	24	
I_{CC2}	Output supply current		I_O = 0	All outputs at high level		14	24	mA
				All outputs at low level		2	6	
				All outputs at high impedance		2	4	

6.6 Switching Characteristics

over operating free-air temperature range (unless otherwise noted) V_{CC1} = 5 V, V_{CC2} = 24 V, T_A = 25°C

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{PLH}	Propagation delay time, low-to-high-level output from A input	L293NE, L293DNE	C_L = 30 pF, See Figure 2		800		ns
		L293DWP, L293N L293DN			750		
t_{PHL}	Propagation delay time, high-to-low-level output from A input	L293NE, L293DNE			400		ns
		L293DWP, L293N L293DN			200		
t_{TLH}	Transition time, low-to-high-level output	L293NE, L293DNE			300		ns
		L293DWP, L293N L293DN			100		
t_{THL}	Transition time, high-to-low-level output	L293NE, L293DNE			300		ns
		L293DWP, L293N L293DN			350		

6.7 Typical Characteristics

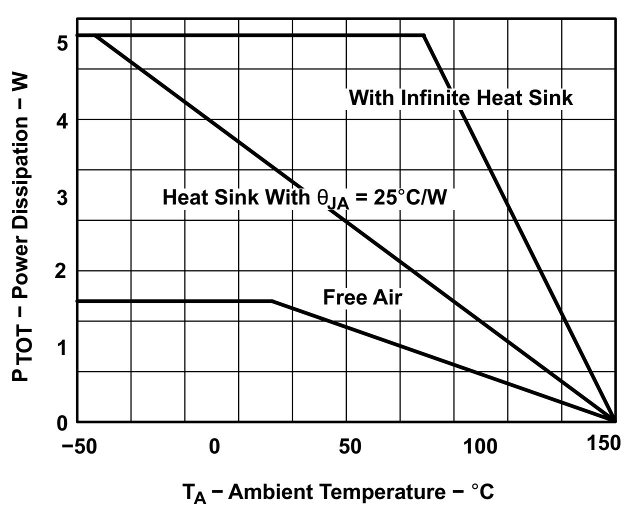
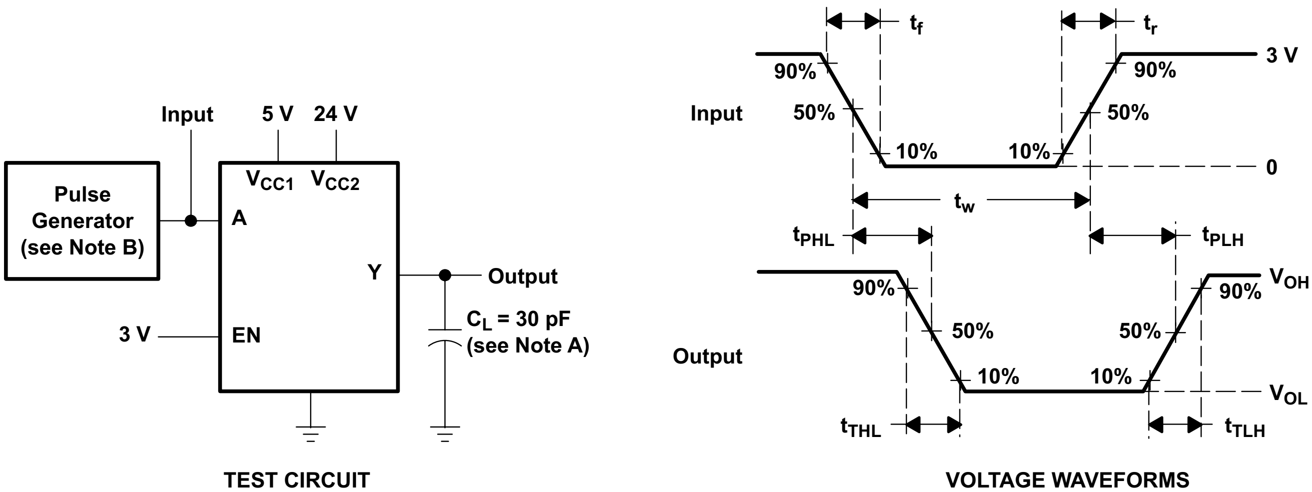


Figure 1. Maximum Power Dissipation vs Ambient Temperature

7 Parameter Measurement Information



NOTES: A. C_L includes probe and jig capacitance.

B. The pulse generator has the following characteristics: $t_r \leq 10$ ns, $t_f \leq 10$ ns, $t_w = 10$ μs, PRR = 5 kHz, $Z_O = 50\ \Omega$.

Figure 2. Test Circuit and Voltage Waveforms

8 Detailed Description

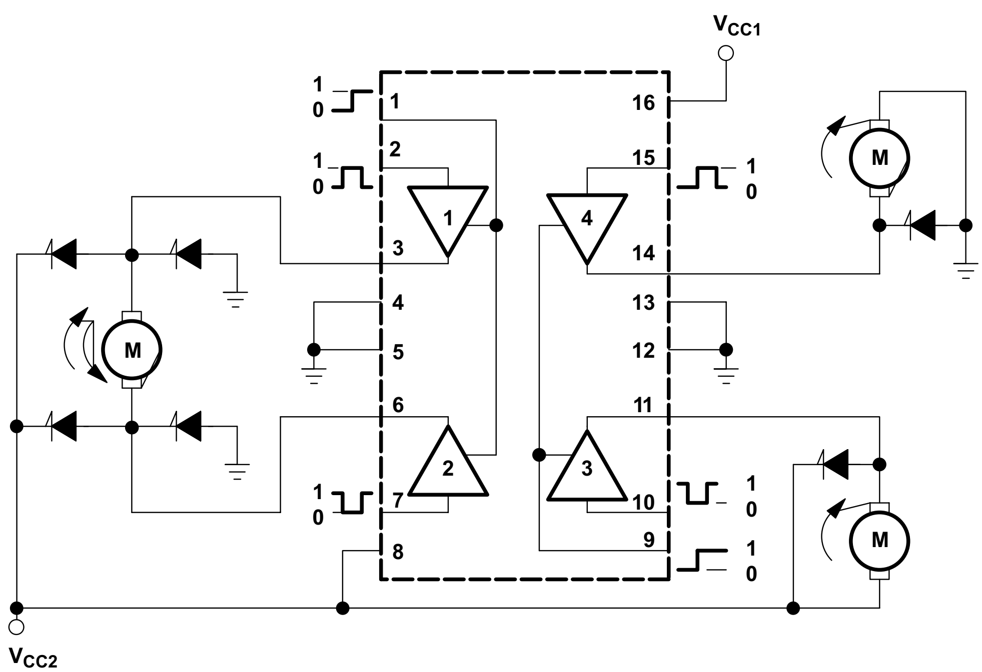
8.1 Overview

The L293 and L293D are quadruple high-current half-H drivers. These devices are designed to drive a wide array of inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current and high-voltage loads. All inputs are TTL compatible and tolerant up to 7 V.

Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled, and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled, and their outputs are off and in the high-impedance state. With the proper data inputs, each pair of drivers forms a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

On the L293, external high-speed output clamp diodes should be used for inductive transient suppression. On the L293D, these diodes are integrated to reduce system complexity and overall system size. A V_{CC1} terminal, separate from V_{CC2}, is provided for the logic inputs to minimize device power dissipation. The L293 and L293D are characterized for operation from 0°C to 70°C.

8.2 Functional Block Diagram



Output diodes are internal in L293D.

8.3 Feature Description

The L293x has TTL-compatible inputs and high voltage outputs for inductive load driving. Current outputs can get up to 2 A using the L293.

8.4 Device Functional Modes

Table 1 lists the fuctional modes of the L293x.

Table 1. Function Table (Each Driver)(1)

INPUTS (2)		OUTPUT (Y)
A	EN	
H	H	H
L	H	L
X	L	Z

(1) H = high level, L = low level, X = irrelevant, Z = high impedance (off)
(2) In the thermal shutdown mode, the output is in the high-impedance state, regardless of the input levels.

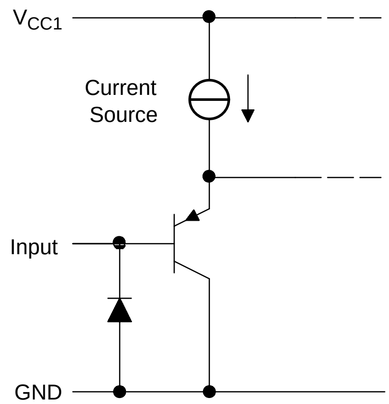


Figure 3. Schematic of Inputs for the L293x

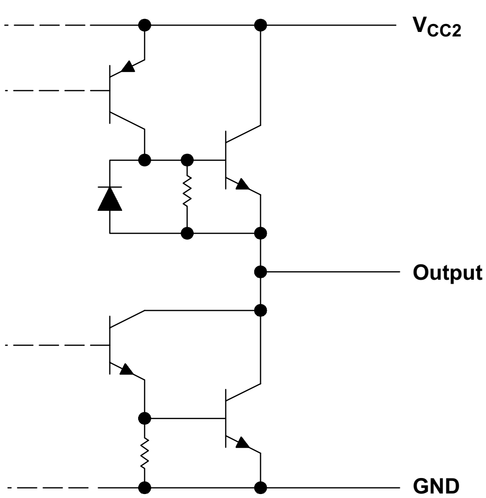


Figure 4. Schematic of Outputs for the L293

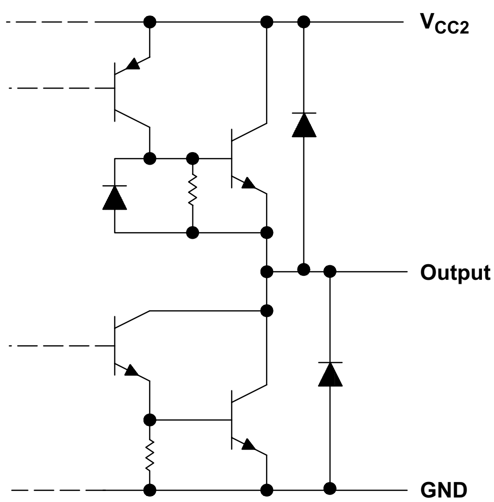


Figure 5. Schematic of Outputs for the L293D

9 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

A typical application for the L293 device is driving a two-phase motor. Below is an example schematic displaying how to properly connect a two-phase motor to the L293 device.

Provide a 5-V supply to V_{CC1} and valid logic input levels to data and enable inputs. V_{CC2} must be connected to a power supply capable of supplying the needed current and voltage demand for the loads connected to the outputs.

9.2 Typical Application

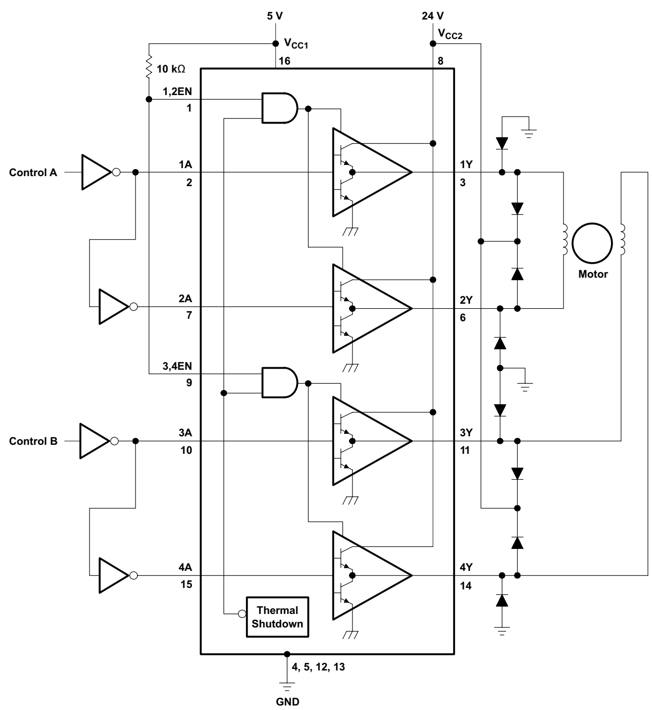


Figure 6. Two-Phase Motor Driver (L293)

9.2.1 Design Requirements

The design techniques in the application above as well as the applications below should fall within the following design requirements.

1. V_{CC1} should fall within the limits described in the *Recommended Operating Conditions*.
2. V_{CC2} should fall within the limits described in the *Recommended Operating Conditions*.
3. The current per channel should not exceed 1 A for the L293 (600mA for the L293D).

9.2.2 Detailed Design Procedure

When designing with the L293 or L293D, careful consideration should be made to ensure the device does not exceed the operating temperature of the device. Proper heatsinking will allow for operation over a larger range of current per channel. Refer to the *Power Supply Recommendations* as well as the *Layout Example*.

Typical Application (continued)

9.2.3 Application Curve

Refer to *Power Supply Recommendations* for additional information with regards to appropriate power dissipation. Figure 7 describes thermal dissipation based on Figure 14.

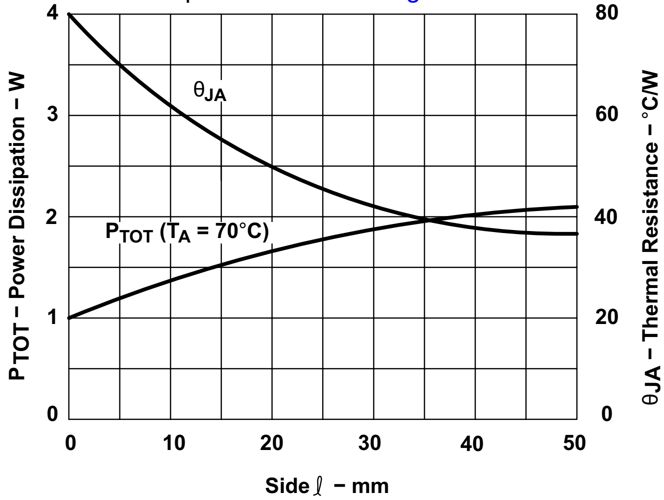


Figure 7. Maximum Power and Junction vs Thermal Resistance

9.3 System Examples

9.3.1 L293D as a Two-Phase Motor Driver

Figure 8 below depicts a typical setup for using the L293D as a two-phase motor driver. Refer to the *Recommended Operating Conditions* when considering the appropriate input high and input low voltage levels to enable each channel of the device.

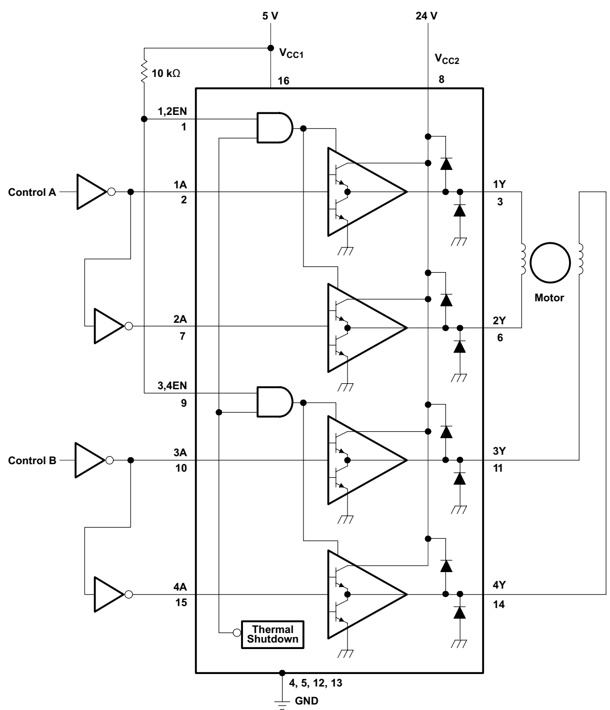
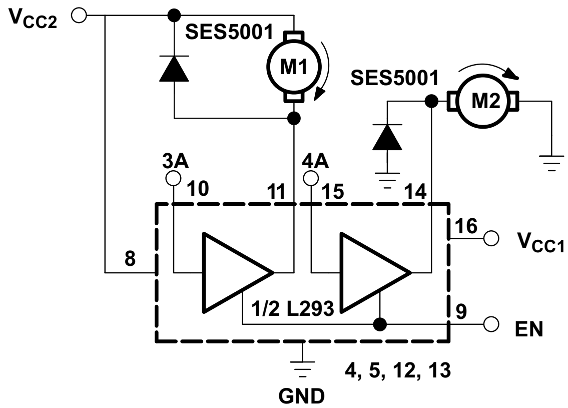


Figure 8. Two-Phase Motor Driver (L293D)

System Examples (continued)

9.3.2 DC Motor Controls

Figure 9 and Figure 10 below depict a typical setup for using the L293 device as a controller for DC motors. Note that the L293 device can be used as a simple driver for a motor to turn on and off in one direction, and can also be used to drive a motor in both directions. Refer to the function tables below to understand unidirectional vs bidirectional motor control. Refer to the *Recommended Operating Conditions* when considering the appropriate input high and input low voltage levels to enable each channel of the device.



Connections to ground and to supply voltage

Figure 9. DC Motor Controls

Table 2. Unidirectional DC Motor Control

EN	3A	M1 (1)	4A	M2
H	H	Fast motor stop	H	Run
H	L	run	L	Fast motor stop
L	X	Free-running motor stop	X	Free-running motor stop

(1) L = low, H = high, X = don't care

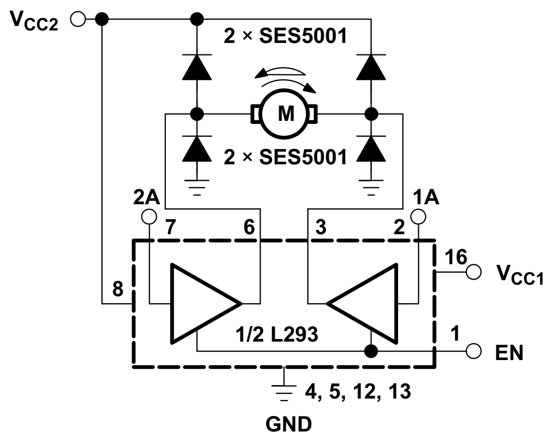


Figure 10. Bidirectional DC Motor Control

Table 3. Bidrectional DC Motor Control

EN	1A	2A	FUNCTION (1)
H	L	H	Turn right
H	H	L	Turn left

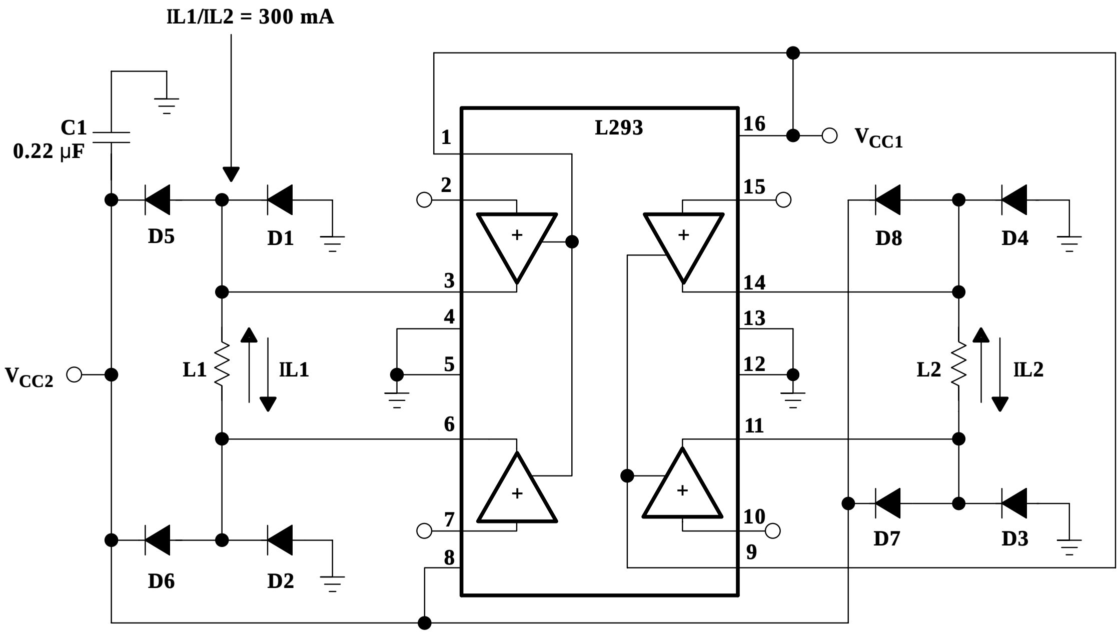
(1) L = low, H = high, X = don't care

Table 3. Bidirectional DC Motor Control (continued)

EN	1A	2A	FUNCTION (1)
H	L	L	Fast motor stop
H	H	H	Fast motor stop
L	X	X	Free-running motor stop

9.3.3 Bipolar Stepping-Motor Control

Figure 11 below depicts a typical setup for using the L293D as a two-phase motor driver. Refer to the *Recommended Operating Conditions* when considering the appropriate input high and input low voltage levels to enable each channel of the device.



D1−D8 = SES5001

Figure 11. Bipolar Stepping-Motor Control

10 Power Supply Recommendations

V_{CC1} is 5 V ± 0.5 V and V_{CC2} can be same supply as V_{CC1} or a higher voltage supply with peak voltage up to 36 V. Bypass capacitors of 0.1 uF or greater should be used at V_{CC1} and V_{CC2} pins. There are no power up or power down supply sequence order requirements.

Properly heatsinking the L293 when driving high-current is critical to design. The Rthj-amp of the L293 can be reduced by soldering the GND pins to a suitable copper area of the printed circuit board or to an external heat sink.

Figure 14 shows the maximum package power PTOT and the θJA as a function of the side of two equal square copper areas having a thickness of 35 µm (see Figure 14). In addition, an external heat sink can be used (see Figure 12).

During soldering, the pin temperature must not exceed 260°C, and the soldering time must not exceed 12 seconds.

The external heatsink or printed circuit copper area must be connected to electrical ground.

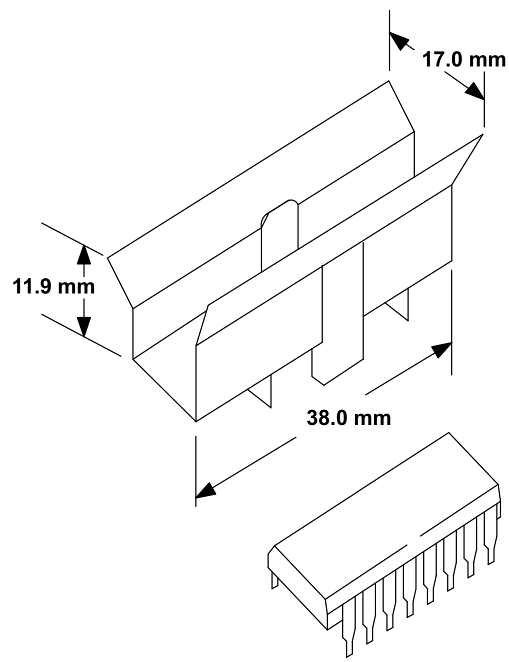


Figure 12. External Heat Sink Mounting Example (θ_{JA} = 25°C/W)

11 Layout

11.1 Layout Guidelines

Place the device near the load to keep output traces short to reduce EMI. Use solid vias to transfer heat from ground pins to ground plane of the printed-circuit-board.

11.2 Layout Example

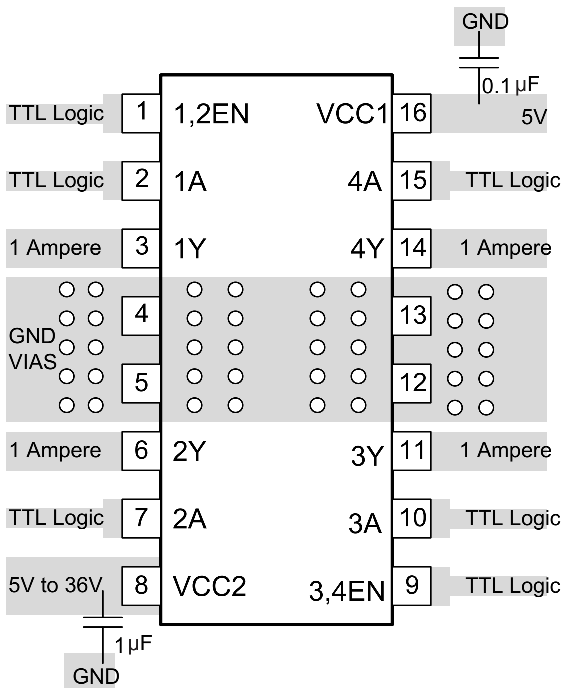


Figure 13. Layout Diagram

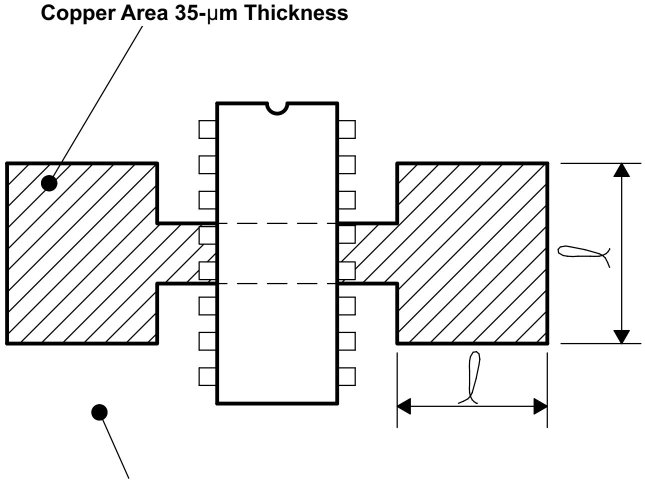


Figure 14. Example of Printed-Circuit-Board Copper Area (Used as Heat Sink)

12 Device and Documentation Support

12.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 4. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
L293	Click here	Click here	Click here	Click here	Click here
L293D	Click here	Click here	Click here	Click here	Click here

12.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.3 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

12.4 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

12.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
L293DNE	ACTIVE	PDIP	NE	16	25	RoHS & Non-Green	NIPDAU	N / A for Pkg Type	0 to 70	L293DNE	Samples
L293DNEE4	ACTIVE	PDIP	NE	16	25	RoHS & Non-Green	NIPDAU	N / A for Pkg Type	0 to 70	L293DNE	Samples
L293NE	ACTIVE	PDIP	NE	16	25	RoHS & Non-Green	NIPDAU	N / A for Pkg Type	0 to 70	L293NE	Samples
L293NEE4	ACTIVE	PDIP	NE	16	25	RoHS & Non-Green	NIPDAU	N / A for Pkg Type	0 to 70	L293NE	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

SS-P

Subminiature Basic Switch

SS Series Compatible Mounting with a Simple Construction and Easy-to-Use Design Concept

- One-piece terminal construction to keep out flux.
- A single leaf movable spring construction.
- Conforms to North American and European safety Standards.
- 1 mm MIN Contact Gap Models available for Interlock applications

RoHS Compliant

Model Number Legend

SS - [1] G [2] P [3]

1. Ratings

3 : 125 VAC 3 A
01: 30 VDC 0.1 A

2. Actuator

None : Pin plunger
L : Hinge lever
L13 : Simulated roller lever
L111 : Long hinge lever

3. Terminals

None : Solder terminals
T : Quick-connect terminals (#110)
D : PCB terminals

List of Models

●0.5 mm Contact Gap Models

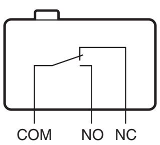
Ratings	Actuator (Terminals)	Solder terminals	Quick-connect terminals (#110)	PCB terminals
3A	Pin plunger	**SS-3GP**	**SS-3GPT**	**SS-3GPD**
	Hinge lever	**SS-3GLP**	**SS-3GLPT**	**SS-3GLPD**
	Simulated roller lever	**SS-3GL13P**	**SS-3GL13PT**	**SS-3GL13PD**
0.1A	Pin plunger	**SS-01GP**	**SS-01GPT**	**SS-01GPD**
	Hinge lever	**SS-01GLP**	**SS-01GLPT**	**SS-01GLPD**
	Simulated roller lever	**SS-01GL13P**	**SS-01GL13PT**	**SS-01GL13PD**

●1 mm MIN Contact Gap Models

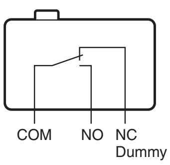
Ratings	Actuator	Terminals / Contact form	Solder terminals	Quick-connect terminals (#110)
3A	Long hinge lever	SPST-NO	**SS-3FL111P-3**	**SS-3FL111P-3T**

Contact Form

●SPDT



●SPST-NO (SS-3FP models)



Separator (Sold Separately), Terminal Connector (Sold Separately) ➡ Refer to "**Basic Switch Common Accessories**"

Contact Specifications

Item / Model		SS-3P models	SS-01P models	SS-3FP models
Contact	Specification	Rivet	Crossbar	Rivet
	Material	Silver	Gold alloy	Silver
	Gap (standard value)	0.5 mm	0.5 mm	1 mm min.
Inrush current	NC	9 A max.	-	9 A max.
	NO			
Minimum applicable load (reference value) *		5 VDC 160 mA	5 VDC 1 mA	5 VDC 160 mA

* Please refer to "**Using Micro Loads**" in "**●Precautions**" for more information on the minimum applicable load.

Ratings

Rated voltage / Item / Model	SS-3P / SS-3FP models	SS-01P models
	Resistive load	
125 VAC	3 A	0.1 A
30 VDC	3 A	0.1 A

Note 1. The above rating values apply under the following test conditions.
(1) Ambient temperature: 20±2°C
(2) Ambient humidity: 65±5%
(3) Operating frequency: 20 operations/min
Note 2. Consult your OMRON sales representative for information on models for other loads.

Approved Safety Standards

UL (UL1054/CSA C22.2 No.55)

Rated voltage / Item / Model	SS-3P / SS-3FP	SS-01P
	Resistive load	
125 VAC	3 A	0.1 A
30 VDC	3 A	0.1 A

VDE (EN61058-1)

Rated voltage / Model	SS-3P / SS-3FP	SS-01P
125 VAC	3 A	0.1 A
30 VDC	3 A	0.1 A

Testing conditions: 5E4 (50,000 operations) T55 (0 to 55°C)

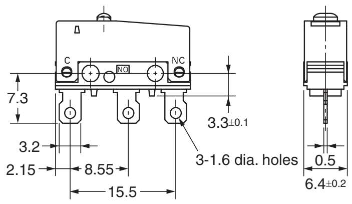
Characteristics

Item / Model		SS-3P models	SS-01P models	SS-3FP models
Permissible operating speed		0.1 mm to 1 m/s (for pin plunger models)		
Permissible operating frequency	Mechanical	300 operations/min		
	Electrical	30 operations/min		
Insulation resistance		100 MΩ min. (at 500 VDC with insulation tester)		
Contact resistance (initial value)		50 mΩ max.	100 mΩ max.	50 mΩ max.
Dielectric strength *1	Between terminals of the same polarity	1,000 VAC 50/60 Hz for 1 min		
	Between current-carrying metal parts and ground	1,500 VAC 50/60 Hz for 1 min		
	Between each terminals and non-current-carrying metal parts	1,500 VAC 50/60 Hz for 1 min		
Vibration resistance *2	Malfunction	10 to 55 Hz, 1.5 mm double amplitude		
Shock resistance	Durability	1,000 m/s² {approx. 100G} max.		
	Malfunction *2	300 m/s² {approx. 30G} max.		
Durability *3	Mechanical	1,000,000 operations min. (60 operations/min)		100,000 operations min. (60 operations/min)
	Electrical	70,000 operations min. (20 operations/min, 125 VAC) 100,000 operations min. (20 operations/min, 30 VDC)	200,000 operations min. (20 operations/min)	100,000 operations min. (20 operations/min, 30 VDC)
Degree of protection		IEC IP40		
Degree of protection against electric shock		Class I		
Proof tracking index (PTI)		250		
Ambient operating temperature		-25°C to +85°C (at ambient humidity of 60% max.) (with no icing or condensation)		
Ambient operating humidity		85% max. (for +5 to +35°C)		
Weight		Approx. 1.6 g (pin plunger models)		

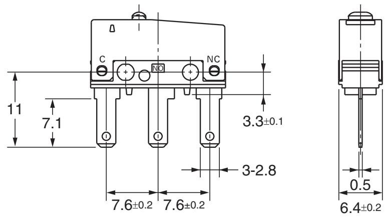
Note. The data given above are initial values.
*1. The values for dielectric strength shown are for models with a Separator (refer to "**Micro Switch Common Accessories**").
*2. The values are at Free Position and Total Travel Position values for pin plunger, and Total Travel Position value for lever. Close or open circuit of the contact is 1 ms max.
*3. For testing conditions, consult your OMRON sales representative.

Terminals/Appearances (Unit: mm)

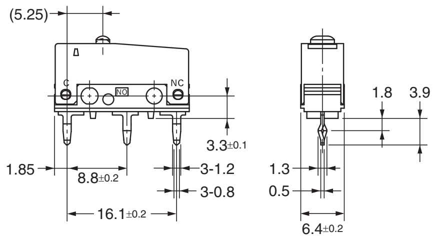
●Solder terminals



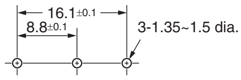
●Quick Connect Terminals (#110)



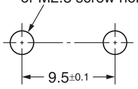
●PCB terminals



<PCB Mounting Dimensions (Reference)>



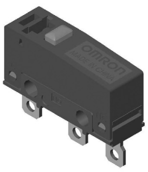
Mounting Holes (Unit: mm)

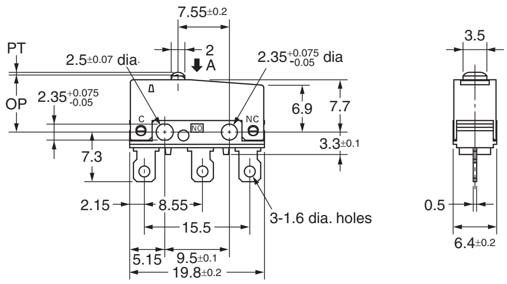


Dimensions (Unit: mm) and Operating Characteristics

The illustrations and dimensions are for models with solder terminals. Refer to **"Terminals/Appearances"** for details on models with quick connect terminals (#110) or PCB terminals.

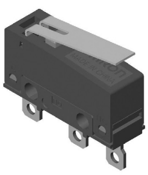
●Pin plunger
SS-3GP
SS-01GP

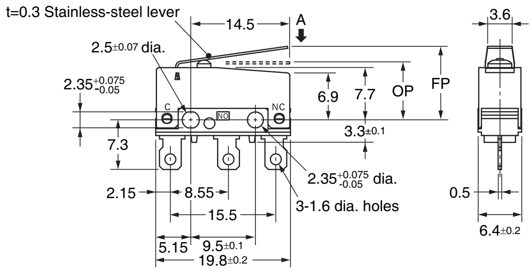




Operating characteristics		Model	SS-3GP	SS-01GP
Operating Force	OF	Max.	1.50 N {153 gf}	
Releasing Force	RF	Min.	0.2 N {20 gf}	
Pretravel	PT	Max.	0.6 mm	
Overtravel	OT	Min.	0.4 mm	
Movement Differential	MD	Max.	0.15 mm	
Operating Position	OP		8.4±0.3 mm	

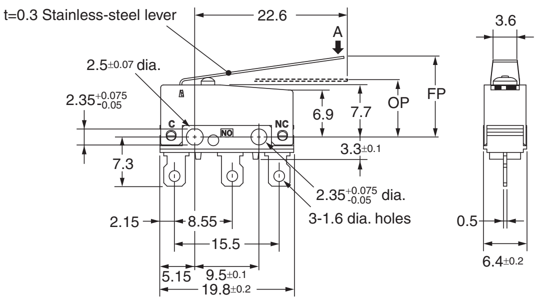
●Hinge lever
SS-3GLP
SS-01GLP





Operating characteristics		Model	SS-3GLP	SS-01GLP
Operating Force	OF	Max.	0.5 N {51 gf}	
Releasing Force	RF	Min.	0.05 N {5 gf}	
Overtravel	OT	Min.	1.0 mm	
Movement Differential	MD	Max.	0.8 mm	
Free Position	FP	Max.	13.6 mm	
Operating Position	OP		8.8±0.8 mm	

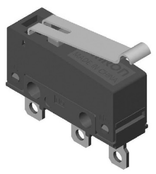
●Long hinge lever
SS-3FL111P-3

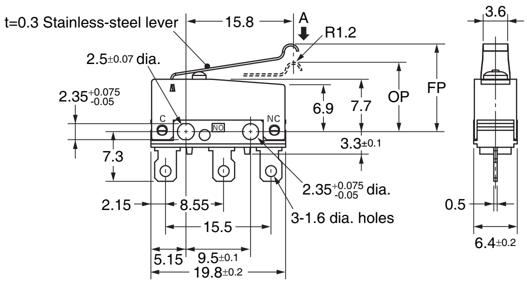


Operating characteristics		Model	SS-3FL111P-3
Operating Force	OF	Max.	0.55 N {56 gf}
Releasing Force	RF	Min.	0.01 N {1 gf}
Overtravel	OT	Min.	1.0 mm
Movement Differential	MD	Max.	3.0 mm
Free Position	FP	Max.	16.8 mm
Operating Position	OP		8.8±1.5 mm

Note 1. Unless otherwise specified, a tolerance of ±0.4 mm applies to all dimensions.
Note 2. The operating characteristics are for operation in the A direction (⬇).

●**Simulated roller lever**
SS-3GL13P
SS-01GL13P





Operating characteristics		Model	SS-3GL13P	SS-01GL13P
Operating Force	OF	Max.	0.5 N {51 gf}	
Releasing Force	RF	Min.	0.05 N {5 gf}	
Overtravel	OT	Min.	1.0 mm	
Movement Differential	MD	Max.	0.8 mm	
Free Position	FP	Max.	15.5 mm	
Operating Position	OP		10.7±0.8 mm	

Note 1. Unless otherwise specified, a tolerance of ±0.4 mm applies to all dimensions.
Note 2. The operating characteristics are for operation in the A direction (⬇).

Precautions

★**Please refer to "Common Precautions" for correct use.**

Cautions

●**Soldering**

• Connecting to Solder Terminals

Complete the soldering at the iron tip temperature of 350 to 400°C within 5 seconds, and do not apply any external force for 1 minute after soldering. Soldering at an excessively high temperature or soldering for more than 5 seconds may deteriorate the characteristics of the Switch.

• Connecting to PCB terminals

When using automatic soldering baths, we recommend soldering at 260±5°C within 5 seconds. Make sure that the liquid surface of the solder does not flow over the edge of the board.

When soldering terminals manually, complete the soldering at the iron tip temperature between 350 to 400°C within 3 seconds, and do not apply any external force for 1 minute after soldering. When applying solder, keep the solder away from the case of the Switch and do not allow solder or flux to flow into the case.

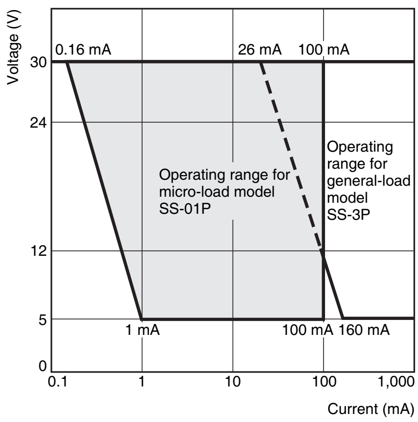
Correct Use

●**Mounting**

Use M2.3 mounting screw with plane washers or spring washers to securely mount the Switch. Tighten the screws to a torque of 0.23 to 0.26 N·m {2.3 to 2.7 kgf·cm}.

●**Using Micro Loads**

Using a model for ordinary loads to open or close the contact of a micro load circuit may result in faulty contact. Use models that operate in the following range. However, even when using micro load models within the following operating range, if inrush current occurs when the contact is opened or closed, it may increase the contact wear and so decrease durability. Therefore, insert a contact protection circuit where necessary. The N-level reference value applies for the minimum applicable load. This value indicates the malfunction reference level for the reliability level of 60% (λ_{60}).
(JIS C5003)
The equation, $\lambda_{60}=0.5\times10^{-6}$/operation indicates that the estimated malfunction rate is less than $\frac{1}{2,000,000}$ operations with a reliability level of 60%.



- Application examples provided in this document are for reference only. In actual applications, confirm equipment functions and safety before using the product.
- Consult your OMRON representative before using the product under conditions which are not described in the manual or applying the product to nuclear control systems, railroad systems, aviation systems, vehicles, combustion systems, medical equipment, amusement machines, safety equipment, and other systems or equipment that may have a serious influence on lives and property if used improperly. Make sure that the ratings and performance characteristics of the product provide a margin of safety for the system or equipment, and be sure to provide the system or equipment with double safety mechanisms.

Note: Do not use this document to operate the Unit.

OMRON Corporation
Electronic and Mechanical Components Company

Contact: www.omron.com/ecb

Cat. No.B108-E1-05
0716(0207)(O)

GP2Y0D805Z0F

Distance Measuring Sensor Unit Digital output (50 mm) type

■Description

GP2Y0D805Z0F is a distance measuring sensor unit, composed of an integrated combination of PD (photo diode) , IRED (infrared emitting diode) and signal processing circuit.
The variety of the reflectivity of the object, the environmental temperature and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method.
The output voltage of this sensor stays high in case an object exists in the specified distance range. So this sensor can also be used as proximity sensor.

■Features

1. Digital output type
2. Short distance type
   Detecting distance : Typ. 50 mm
3. Low profile
   Package size : 13.6×7×7.95 mm
4. Consumption current : Typ. 5 mA
5. Battery drive possible
   Supply voltage : 2.7 to 6.2 V
6. Sunlight tolerance
7. Add Vin terminal, and an external transistor of Vcc line is unnecessary at intermittent operating.

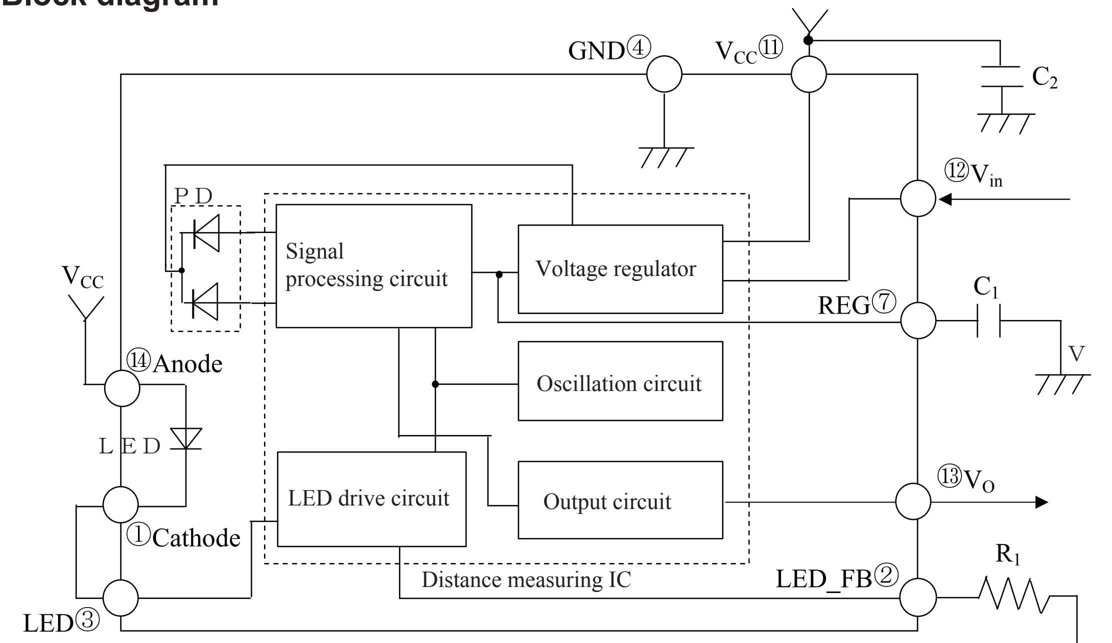
■Agency approvals/Compliance

1. Compliant with RoHS directive (2002/95/EC)

■Applications

1. Touch-less switch
   (Sanitary equipment, Control of illumination, etc.)
2. Robot cleaner

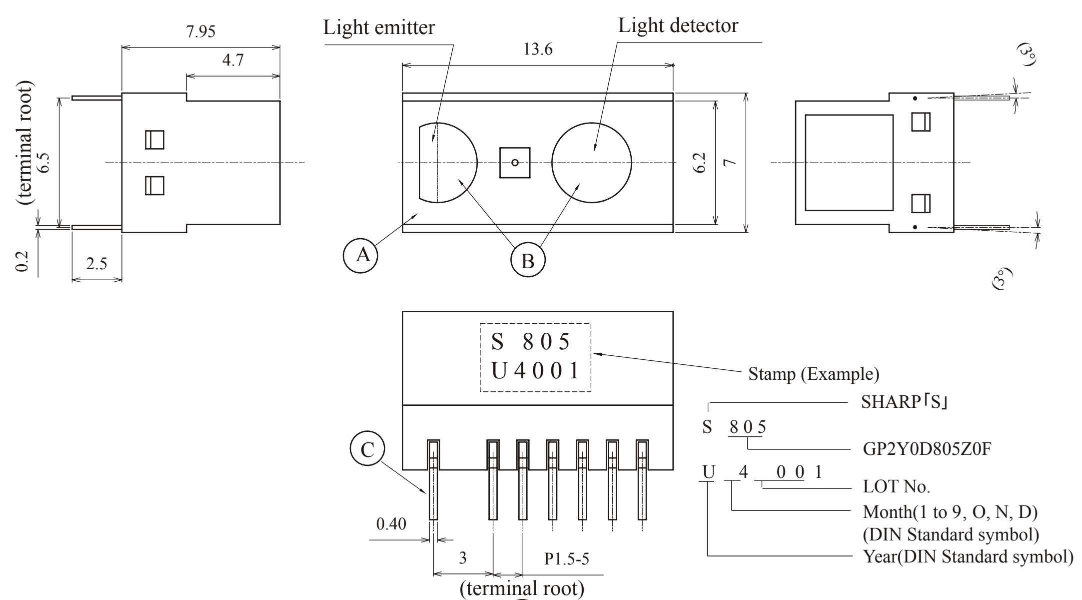
■Block diagram

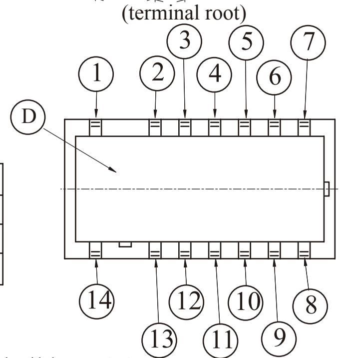


R_1 (LED current adjustment resistance = 4.3 Ω) (LED Pulse current Typ. 70 mA)
$C_1 \cdot C_2$ = 0.1 μF

■Outline Dimensions

(Unit : mm)





Material

A	Case	PC (Color:Black)
B	Lens	PC(Visible light cut type)
C	Device coating	PPS(Color:Black)
D	Lead pin	42ALLOY(Pd-Au plating)

DIN Standard year production
(Remove G, I, O, Q, Y, Z)
(It repeats itself by a period for 20 years)

year	Mark
2006	U
2007	V
2008	W
2009	X
⋮	⋮
2025	T
2026	U

	Symbol
①	Cathode
②	LED_FB
③	LED
④	GND
⑤	—
⑥	—
⑦	REG
⑧	—
⑨	—
⑩	—
⑪	V_{CC}
⑫	V_{in}
⑬	V_O
⑭	Anode

— : No contact

(Note1) Unspecified tolerances shall be ± 0.3 mm.
(Note2) ( ) : Reference value

Product mass : approx. 0.7g

■Absolute Maximum Ratings

	Parameter	Symbol	Rating	Unit
	Supply voltage	V_{CC}	-0.3 to +7	V
	Output terminal voltage	V_O	-0.3 to V_{CC}+0.3	V
	Input terminal voltage	V_{in}	-0.3 to V_{CC}+0.3	V
	Operating temperature	T_{opr}	-10 to +60	℃
	Storage temperature	T_{stg}	-20 to +70	℃
*	Soldering temperature	T_{sol}	260	℃

* 5s or less/time up 2times
t = 1.0 mm One side board mounting

■Electro-optical Characteristics

(T_a=25℃,V_{CC}=5V)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Average supply current	I_{CC1}	V_{CC}=5V, V_{in}=5V, R_1=4.3Ω (*1)	—	5	6.5	mA
Average supply current	I_{CC2}	V_{CC}=5V, V_{in}=5V, R_1=4.3Ω (*1)	—	9	10.5	mA
Stand-by supply current	I_{CC3}	V_{CC}=5V, V_{in}=0V	—	5	8	μA
Output voltage	V_{OH}	Output voltage at high level	V_{CC}-0.6	—	—	V
	V_{OL}	Output voltage at low level	—	—	0.6	V
Detecting distance	L	(*2)(*3)	40	50	60	mm

(*1) I_{CC1} : (LED Emitting time : Typ. 20 μs × 8 times), I_{CC2} : (Emitting time : Typ. 20 μs × 15 times),
LED Pulse Current : Typ. 70 mA
(*2) Using reflective object : White paper (Made by Kodak Co., Ltd. gray cards R-27·white face, reflectance ; 90%)
(*3) Output voltage switch has a hysteresis width. The distance specified by L should be the distance which the output turns from L to H in case an object moves to the sensor.

■Recommended operating conditions

Parameter	Symbol	Conditions	Rating	Unit
Supply voltage	V_{CC}		2.7 to 6.2	V
High level input voltage	V_{inH}	CMOS level signal. Operating	MIN V_{CC}-0.2	V
Low level input voltage	V_{inL}	CMOS level signal. Standby state	MAX 0.2	V

Fig. 1 Timing chart

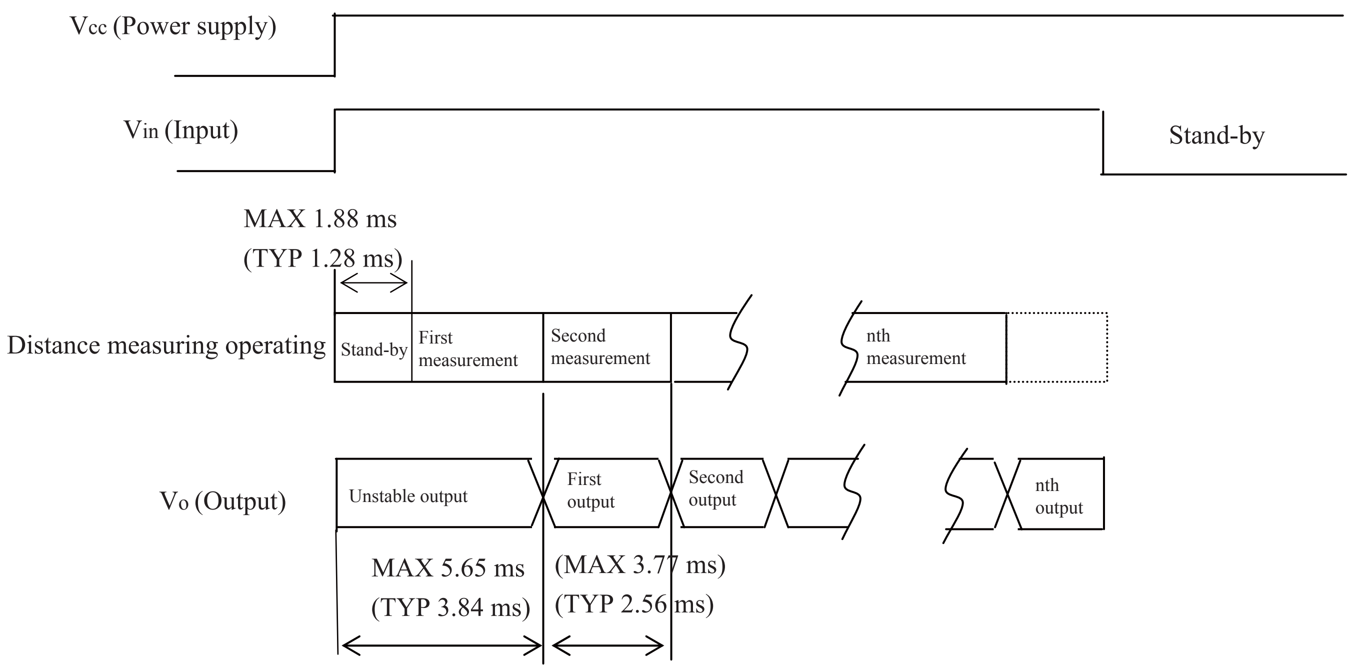
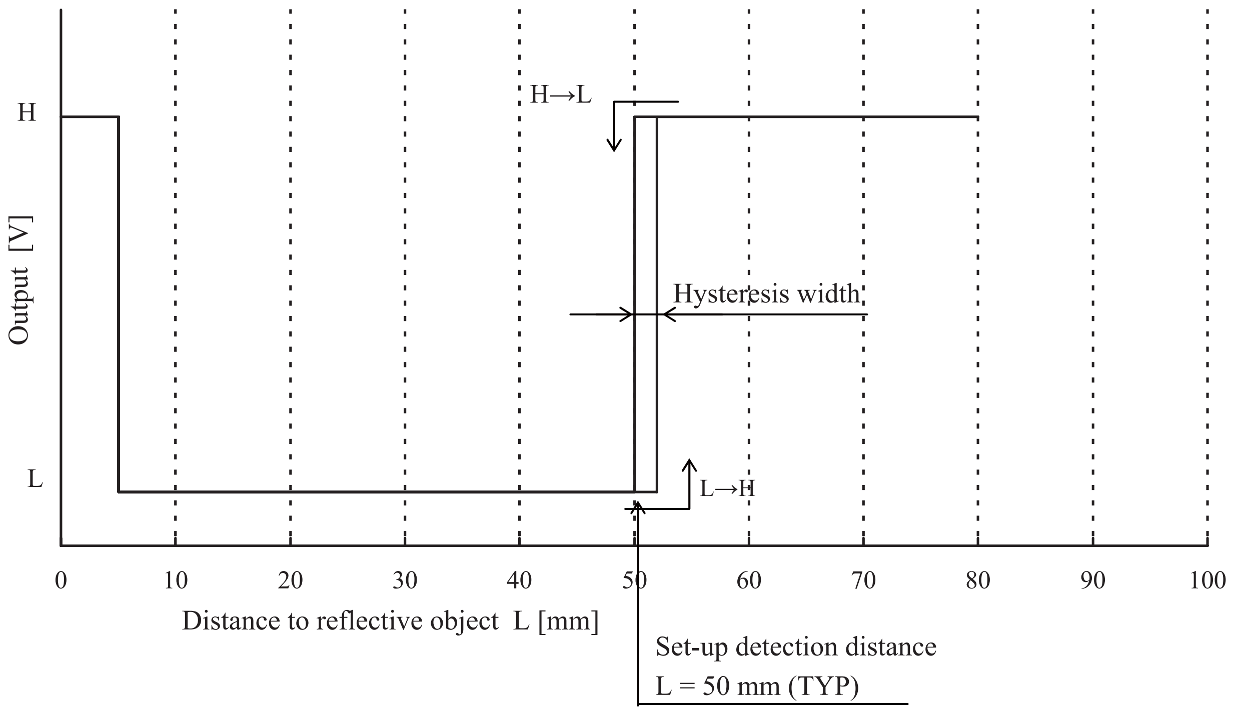


Fig. 2 Example of distance measuring characteristics (output)



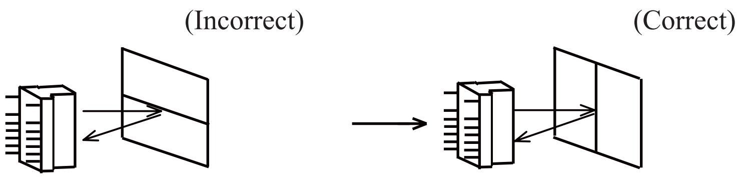
■Notes

●Advice for the optics

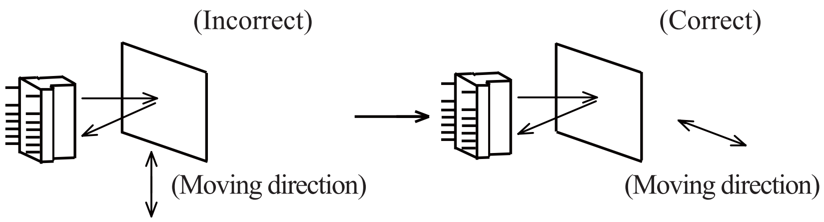
• The lens of this device needs to be kept clean. There are cases that dust, water or oil and so on deteriorate the characteristics of this device. Please consider in actual application.
• Please don't do washing. Washing may deteriorate the characteristics of optical system and so on. Please confirm resistance to chemicals under the actual usage since this product has not been designed against washing.

●Advice for the characteristics

• In case that an optical filter is set in front of the emitter and detector portion, the optical filter which has the most efficient transmittance at the emitting wavelength range of LED for this product ($\lambda = 870 \pm 70$nm), shall be recommended to use. Both faces of the filter should be mirror polishing. Also, as there are cases that the characteristics may not be satisfied according to the distance between the protection cover and this product or the thickness of the protection cover, please use this product after confirming the operation sufficiently in actual application.
• In case that there is an object near to emitter side of the sensor between sensor and a detecting object, please use this device after confirming sufficiently that the characteristics of this sensor do not change by the object.
• When the detector is exposed to the direct light from the sun, tungsten lamp and so on, there are cases that it can not measure the distance exactly. Please consider the design that the detector is not exposed to the direct light from such light source.
• Distance to a mirror reflector can not be sometimes measured exactly.
In case of changing the mounting angle of this product, it may measure the distance exactly.
• In case that reflective object has boundary line which material or color etc. are excessively different, in order to decrease deviation of measuring distance, it shall be recommended to set the sensor that the direction of boundary line and the line between emitter center and detector center are in parallel.



• In order to decrease deviation of measuring distance by moving direction of the reflective object, it shall be recommended to set the sensor that the moving direction of the object and the line between emitter center and detector center are vertical.



●Notes on handling

• There are some possibilities that the internal components in the sensor may be exposed to the excessive mechanical stress. Please be careful not to cause any excessive pressure on the sensor package and also on the PCB while assembling this product.
• Soldering shall be done with a soldering iron and below 260℃, less than 5s and maximum 2 times.
Also, please pay attention not to put outer force on lead terminals while soldering.
Please do not apply flow soldering because it may damage optical lens of the device.

●Presence of ODC etc.

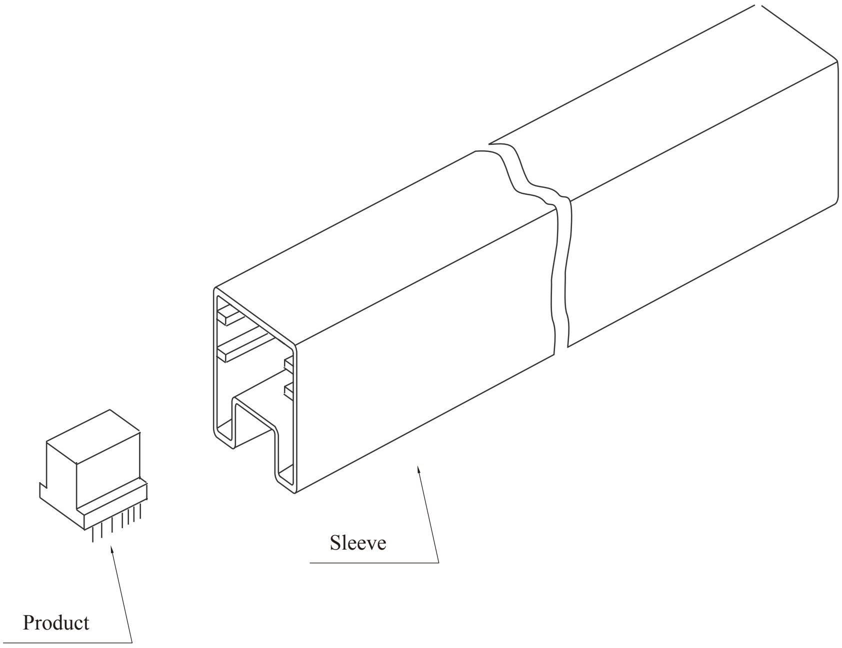
This product shall not contain the following materials.
And they are not used in the production process for this product.
Regulation substances : CFCs, Halon, Carbon tetrachloride, 1.1.1-Trichloroethane (Methylchloroform)

Specific brominated flame retardants such as the PBB and PBDE are not used in this product at all.

This product shall not contain the following materials banned in the RoHS Directive (2002/95/EC).

- Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls (PBB), Polybrominated diphenyl ethers (PBDE).

■Package specification



Put products of 40 pieces in sleeve.

■Important Notices

· The circuit application examples in this publication are provided to explain representative applications of SHARP devices and are not intended to guarantee any circuit design or license any intellectual property rights. SHARP takes no responsibility for any problems related to any intellectual property right of a third party resulting from the use of SHARP's devices.

· Contact SHARP in order to obtain the latest device specification sheets before using any SHARP device. SHARP reserves the right to make changes in the specifications, characteristics, data, materials, structure, and other contents described herein at any time without notice in order to improve design or reliability. Manufacturing locations are also subject to change without notice.

· Observe the following points when using any devices in this publication. SHARP takes no responsibility for damage caused by improper use of the devices which does not meet the conditions and absolute maximum ratings to be used specified in the relevant specification sheet nor meet the following conditions:

(i) The devices in this publication are designed for use in general electronic equipment designs such as:

--- Personal computers
--- Office automation equipment
--- Telecommunication equipment [terminal]
--- Test and measurement equipment
--- Industrial control
--- Audio visual equipment
--- Consumer electronics

(ii) Measures such as fail-safe function and redundant design should be taken to ensure reliability and safety when SHARP devices are used for or in connection with equipment that requires higher reliability such as:

--- Transportation control and safety equipment (i.e., aircraft, trains, automobiles, etc.)
--- Traffic signals
--- Gas leakage sensor breakers
--- Alarm equipment
--- Various safety devices, etc.

(iii) SHARP devices shall not be used for or in connection with equipment that requires an extremely high level of reliability and safety such as:

--- Space applications
--- Telecommunication equipment [trunk lines]
--- Nuclear power control equipment
--- Medical and other life support equipment (e.g., scuba).

· If the SHARP devices listed in this publication fall within the scope of strategic products described in the Foreign Exchange and Foreign Trade Law of Japan, it is necessary to obtain approval to export such SHARP devices.

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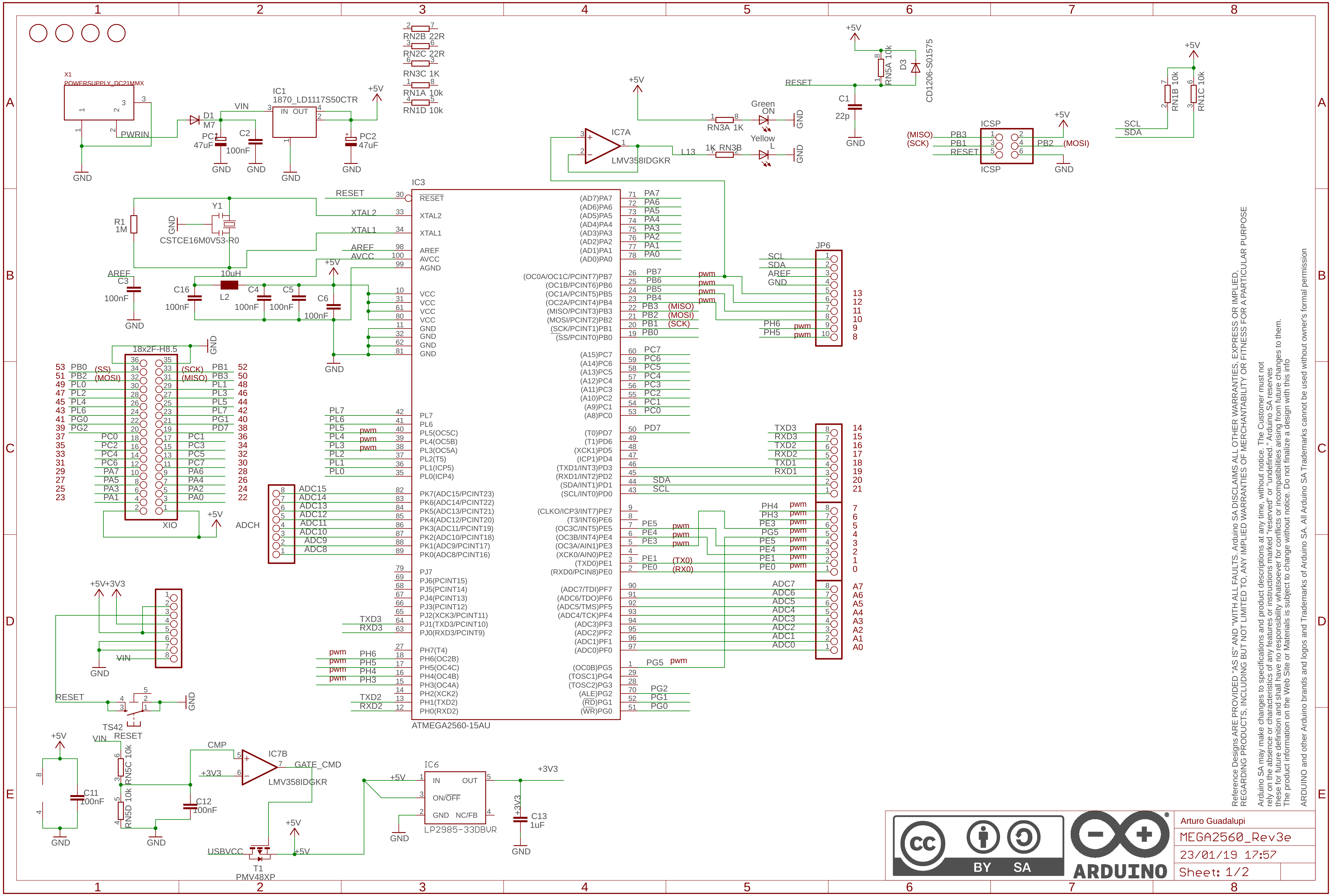

X1 POWERSUPPLY_DC21MMX
IC1 1870_LD1117S50CTR
IC3 ATMEGA2560-15AU
IC6 LP2985-33DBVR
IC7A LMV358IDGKR
IC7B LMV358IDGKR
T1 PMV48XP
Y1 CSTCE16M0V53-R0
D3 CD1206-S01575
ICSP
JP6
XIO 18x2F-H8.5
ADCH
TS42
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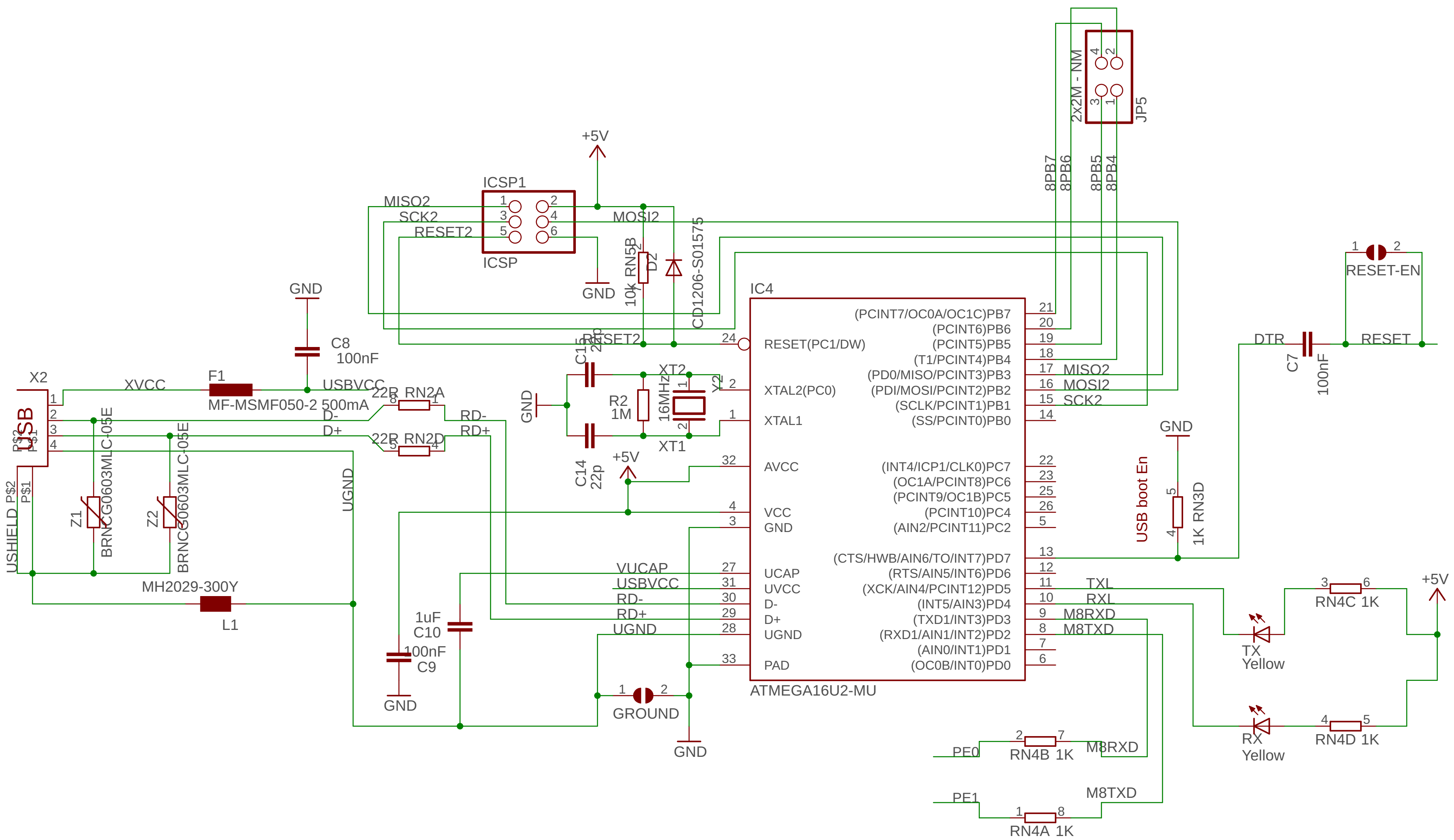

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MEGA2560_Rev3e

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Sheet: 2/2

MPU-6000 and MPU-6050 Product Specification Revision 3.4

CONTENTS

1 Revision History

Revision Date	Revision	Description
11/24/2010	1.0	Initial Release
05/19/2011	2.0	For Rev C parts. Clarified wording in sections (3.2, 5.1, 5.2, 6.1-6.4, 6.6, 6.9, 7, 7.1-7.6, 7.11, 7.12, 7.14, 8, 8.2-8.4, 10.3, 10.4, 11, 12.2)
07/28/2011	2.1	Edited supply current numbers for different modes (section 6.4)
08/05/2011	2.2	Unit of measure for accelerometer sensitivity changed from LSB/m*g* to LSB/*g*
10/12/2011	2.3	Updated accelerometer self test specifications in Table 6.2. Updated package dimensions (section 11.2). Updated PCB design guidelines (section 11.3)
10/18/2011	3.0	For Rev D parts. Updated accelerometer specifications in Table 6.2. Updated accelerometer specification note (sections 8.2, 8.3, & 8.4). Updated qualification test plan (section 12.2).
10/24/2011	3.1	Edits for clarity Changed operating voltage range to 2.375V-3.46V Added accelerometer Intelligence Function increment value of 1m*g*/LSB (Section 6.2) Updated absolute maximum rating for acceleration (any axis, unpowered) from 0.3ms to 0.2ms (Section 6.9) Modified absolute maximum rating for Latch-up to Level A and ±100mA (Section 6.9, 12.2)
11/16/2011	3.2	**Updated self-test response specifications for Revision D parts dated with date code 1147 (YYWW) or later.** Edits for clarity Added Gyro self-test (sections 5.1, 6.1, 7.6, 7.12) Added Min/Max limits to Accel self-test response (section 6.2) Updated Accelerometer low power mode operating currents (Section 6.3) Added gyro self test to block diagram (section 7.5) Updated packaging labels and descriptions (sections 11.8 & 11.9)
5/16/2012	3.3	Updated Gyro and Accelerometer self test information (sections 6.1, 6.2, 7.12) Updated latch-up information (Section 6.9) Updated programmable interrupts information (Section 8) Changed shipment information from maximum of 3 reels (15K units) per shipper box to 5 reels (25K units) per shipper box (Section 11.7) Updated packing shipping and label information (Sections 11.8, 11.9) Updated reliability references (Section 12.2)
8/19/2013	3.4	Updates section 4

2 Purpose and Scope

This product specification provides advanced information regarding the electrical specification and design related information for the MPU-6000™ and MPU-6050™ MotionTracking™ devices, collectively called the MPU-60X0™ or MPU™.

Electrical characteristics are based upon design analysis and simulation results only. Specifications are subject to change without notice. Final specifications will be updated based upon characterization of production silicon. For references to register map and descriptions of individual registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

The self-test response specifications provided in this document pertain to Revision D parts with date codes of 1147 (YYWW) or later. Please see Section 11.6 for package marking description details.

3 Product Overview

3.1 MPU-60X0 Overview

MotionInterface™ is becoming a "must-have" function being adopted by smartphone and tablet manufacturers due to the enormous value it adds to the end user experience. In smartphones, it finds use in applications such as gesture commands for applications and phone control, enhanced gaming, augmented reality, panoramic photo capture and viewing, and pedestrian and vehicle navigation. With its ability to precisely and accurately track user motions, MotionTracking technology can convert handsets and tablets into powerful 3D intelligent devices that can be used in applications ranging from health and fitness monitoring to location-based services. Key requirements for MotionInterface enabled devices are small package size, low power consumption, high accuracy and repeatability, high shock tolerance, and application specific performance programmability – all at a low consumer price point.

The MPU-60X0 is the world's first integrated 6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 4x4x0.9mm package. With its dedicated I^2C sensor bus, it directly accepts inputs from an external 3-axis compass to provide a complete 9-axis MotionFusion™ output. The MPU-60X0 MotionTracking device, with its 6-axis integration, on-board MotionFusion™, and run-time calibration firmware, enables manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers. The MPU-60X0 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port. The MPU-60X0 is footprint compatible with the MPU-30X0 family.

The MPU-60X0 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*.

An on-chip 1024 Byte FIFO buffer helps lower system power consumption by allowing the system processor to read the sensor data in bursts and then enter a low-power mode as the MPU collects more data. With all the necessary on-chip processing and sensor components required to support many motion-based use cases, the MPU-60X0 uniquely enables low-power MotionInterface applications in portable applications with reduced processing requirements for the system processor. By providing an integrated MotionFusion output, the DMP in the MPU-60X0 offloads the intensive MotionProcessing computation requirements from the system processor, minimizing the need for frequent polling of the motion sensor output.

Communication with all registers of the device is performed using either I^2C at 400kHz or SPI at 1MHz (MPU-6000 only). For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20MHz (MPU-6000 only). Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the MPU-60X0 package size down to a revolutionary footprint of 4x4x0.9mm (QFN), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000*g* shock tolerance, and has programmable low-pass filters for the gyroscopes, accelerometers, and the on-chip temperature sensor.

For power supply flexibility, the MPU-60X0 operates from VDD power supply voltage range of 2.375V-3.46V. Additionally, the MPU-6050 provides a VLOGIC reference pin (in addition to its analog supply pin: VDD), which sets the logic levels of its I^2C interface. The VLOGIC voltage may be 1.8V±5% or VDD.

The MPU-6000 and MPU-6050 are identical, except that the MPU-6050 supports the I^2C serial interface only, and has a separate VLOGIC reference pin. The MPU-6000 supports both I^2C and SPI interfaces and has a single supply pin, VDD, which is both the device's logic reference supply and the analog supply for the part. The table below outlines these differences:

Primary Differences between MPU-6000 and MPU-6050

Part / Item	MPU-6000	MPU-6050
VDD	2.375V-3.46V	2.375V-3.46V
VLOGIC	n/a	1.71V to VDD
Serial Interfaces Supported	I^2C, SPI	I^2C
Pin 8	/CS	VLOGIC
Pin 9	AD0/SDO	AD0
Pin 23	SCL/SCLK	SCL
Pin 24	SDA/SDI	SDA

4 Applications

- *BlurFree*™ technology (for Video/Still Image Stabilization)
- *AirSign*™ technology (for Security/Authentication)
- *TouchAnywhere*™ technology (for “no touch” UI Application Control/Navigation)
- *MotionCommand*™ technology (for Gesture Short-cuts)
- Motion-enabled game and application framework
- InstantGesture™ iG™ gesture recognition
- Location based services, points of interest, and dead reckoning
- Handset and portable gaming
- Motion-based game controllers
- 3D remote controls for Internet connected DTVs and set top boxes, 3D mice
- Wearable sensors for health, fitness and sports
- Toys

5 Features

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-60X0 includes a wide range of features:

- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.6mA
- Standby current: 5µA
- Factory calibrated sensitivity scale factor
- User self-test

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-60X0 includes a wide range of features:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g*
- Integrated 16-bit ADCs enable simultaneous sampling of accelerometers while requiring no external multiplexer
- Accelerometer normal operating current: 500µA
- Low power accelerometer mode current: 10µA at 1.25Hz, 20µA at 5Hz, 60µA at 20Hz, 110µA at 40Hz
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

5.3 Additional Features

The MPU-60X0 includes the following additional features:

- 9-Axis MotionFusion by the on-chip Digital Motion Processor (DMP)
- Auxiliary master I^2C bus for reading data from external sensors (e.g., magnetometer)
- 3.9mA operating current when all 6 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.375V-3.46V
- Flexible VLOGIC reference voltage supports multiple I^2C interface voltages (MPU-6050 only)
- Smallest and thinnest QFN package for portable devices: 4x4x0.9mm
- Minimal cross-axis sensitivity between the accelerometer and gyroscope axes
- 1024 byte FIFO buffer reduces power consumption by allowing host processor to read the data in bursts and then go into a low-power mode as the MPU collects more data
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I^2C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers (MPU-6000 only)
- 20MHz SPI serial interface for reading sensor and interrupt registers (MPU-6000 only)

- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

5.4 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports 3D MotionProcessing and gesture recognition algorithms
- The MPU-60X0 collects gyroscope and accelerometer data while synchronizing data sampling at a user defined rate. The total dataset obtained by the MPU-60X0 includes 3-Axis gyroscope data, 3-Axis accelerometer data, and temperature data. The MPU's calculated output to the system processor can also include heading data from a digital 3-axis third party magnetometer.
- The FIFO buffers the complete data set, reducing timing requirements on the system processor by allowing the processor burst read the FIFO data. After burst reading the FIFO data, the system processor can save power by entering a low-power sleep mode while the MPU collects more data.
- Programmable interrupt supports features such as gesture recognition, panning, zooming, scrolling, tap detection, and shake detection
- Digitally-programmable low-pass filters
- Low-power pedometer functionality allows the host processor to sleep while the DMP maintains the step count.

5.5 Clocking

- On-chip timing generator ±1% frequency variation over full temperature range
- Optional external clock inputs of 32.768kHz or 19.2MHz

6 Electrical Characteristics

6.1 Gyroscope Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
GYROSCOPE SENSITIVITY						
Full-Scale Range	FS_SEL=0		±250		º/s	
	FS_SEL=1		±500		º/s	
	FS_SEL=2		±1000		º/s	
	FS_SEL=3		±2000		º/s	
Gyroscope ADC Word Length			16		bits	
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(º/s)	
	FS_SEL=1		65.5		LSB/(º/s)	
	FS_SEL=2		32.8		LSB/(º/s)	
	FS_SEL=3		16.4		LSB/(º/s)	
Sensitivity Scale Factor Tolerance	25°C	-3		+3	%	
Sensitivity Scale Factor Variation Over Temperature			±2		%	
Nonlinearity	Best fit straight line; 25°C		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	25°C		±20		º/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		º/s	
Power-Supply Sensitivity (1-10Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (10 - 250Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (250Hz - 100kHz)	Sine wave, 100mVpp; VDD=2.5V		4		º/s	
Linear Acceleration Sensitivity	Static		0.1		º/s/*g*	
SELF-TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	1
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (100Hz)		0.05		º/s-rms	
Low-frequency RMS noise	Bandwidth 1Hz to10Hz		0.033		º/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		º/s/ √ Hz	
GYROSCOPE MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	
Y-Axis		27	30	33	kHz	
Z-Axis		24	27	30	kHz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		256	Hz	
OUTPUT DATA RATE						
	Programmable	4		8,000	Hz	
GYROSCOPE START-UP TIME	**DLPFCFG=0**					
ZRO Settling (from power-on)	to ±1º/s of Final		30		ms	

1. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		m*g*	1
	Z axis		±80		m*g*	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		m*g*	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		$\mu g/\sqrt{Hz}$	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		260	Hz	
OUTPUT DATA RATE						
	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		m*g*/LSB	

1. Typical zero-g initial calibration tolerance value after MSL3 preconditioning
2. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

6.3 Electrical and Other Common Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
TEMPERATURE SENSOR						
Range			-40 to +85		°C	
Sensitivity	Untrimmed		340		LSB/ºC	
Temperature Offset	35°C		-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)		±1		°C	
VDD POWER SUPPLY						
Operating Voltages		2.375		3.46	V	
Normal Operating Current	Gyroscope + Accelerometer + DMP		3.9		mA	
	Gyroscope + Accelerometer (DMP disabled)		3.8		mA	
	Gyroscope + DMP (Accelerometer disabled)		3.7		mA	
	Gyroscope only (DMP & Accelerometer disabled)		3.6		mA	
	Accelerometer only (DMP & Gyroscope disabled)		500		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		70		µA	
	40 Hz update rate		140		µA	
Full-Chip Idle Mode Supply Current			5		µA	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	
VLOGIC REFERENCE VOLTAGE	MPU-6050 only					
Voltage Range	VLOGIC must be ≤VDD at all times	1.71		VDD	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			3	ms	
Normal Operating Current			100		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

6.4 Electrical Specifications, Continued

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
SPI Operating Frequency, All Registers Read/Write	MPU-6000 only, Low Speed Characterization		100 ±10%		kHz	
	MPU-6000 only, High Speed Characterization		1 ±10%		MHz	
SPI Operating Frequency, Sensor and Interrupt Registers Read Only	MPU-6000 only		20 ±10%		MHz	
I^2C Operating Frequency	All registers, Fast-mode			400	kHz	
	All registers, Standard-mode			100	kHz	
I^2C ADDRESS	AD0 = 0		1101000			
	AD0 = 1		1101001			
DIGITAL INPUTS (SDI/SDA, AD0, SCLK/SCL, FSYNC, /CS, CLKIN)						
V_{IH}, High Level Input Voltage	MPU-6000	0.7*VDD			V	
	MPU-6050	0.7*VLOGIC			V	
V_{IL}, Low Level Input Voltage	MPU-6000			0.3*VDD	V	
	MPU-6050			0.3*VLOGIC	V	
C_I, Input Capacitance			< 5		pF	
DIGITAL OUTPUT (SDO, INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000	0.9*VDD			V	
	R_{LOAD}=1MΩ; MPU-6050	0.9*VLOGIC			V	
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000			0.1*VDD	V	
	R_{LOAD}=1MΩ; MPU-6050			0.1*VLOGIC	V	
$V_{OL.INT1}$, INT Low-Level Output Voltage	OPEN=1, 0.3mA sink Current			0.1	V	
Output Leakage Current	OPEN=1		100		nA	
t_{INT}, INT Pulse Width	LATCH_INT_EN=0		50		µs	

6.5 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Typical	Units	Notes
Primary I²C I/O (SCL, SDA)				
V_{IL}, LOW-Level Input Voltage	MPU-6000	-0.5 to 0.3*VDD	V	
V_{IH}, HIGH-Level Input Voltage	MPU-6000	0.7*VDD to VDD + 0.5V	V	
V_{hys}, Hysteresis	MPU-6000	0.1*VDD	V	
VIL, LOW Level Input Voltage	MPU-6050	-0.5V to 0.3*VLOGIC	V	
VIH, HIGH-Level Input Voltage	MPU-6050	0.7*VLOGIC to VLOGIC + 0.5V	V	
Vhys, Hysteresis	MPU-6050	0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	3mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	3	mA	
	V_{OL} = 0.6V	5	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	
Auxiliary I²C I/O (AUX_CL, AUX_DA)	**MPU-6050: *AUX_VDDIO*=0**			
V_{IL}, LOW-Level Input Voltage		-0.5V to 0.3*VLOGIC	V	
V_{IH}, HIGH-Level Input Voltage		0.7*VLOGIC to VLOGIC + 0.5V	V	
V_{hys}, Hysteresis		0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	VLOGIC > 2V; 1mA sink current	0 to 0.4	V	
V_{OL3}, LOW-Level Output Voltage	VLOGIC < 2V; 1mA sink current	0 to 0.2*VLOGIC	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V V_{OL} = 0.6V	1 1	mA mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	

6.6 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

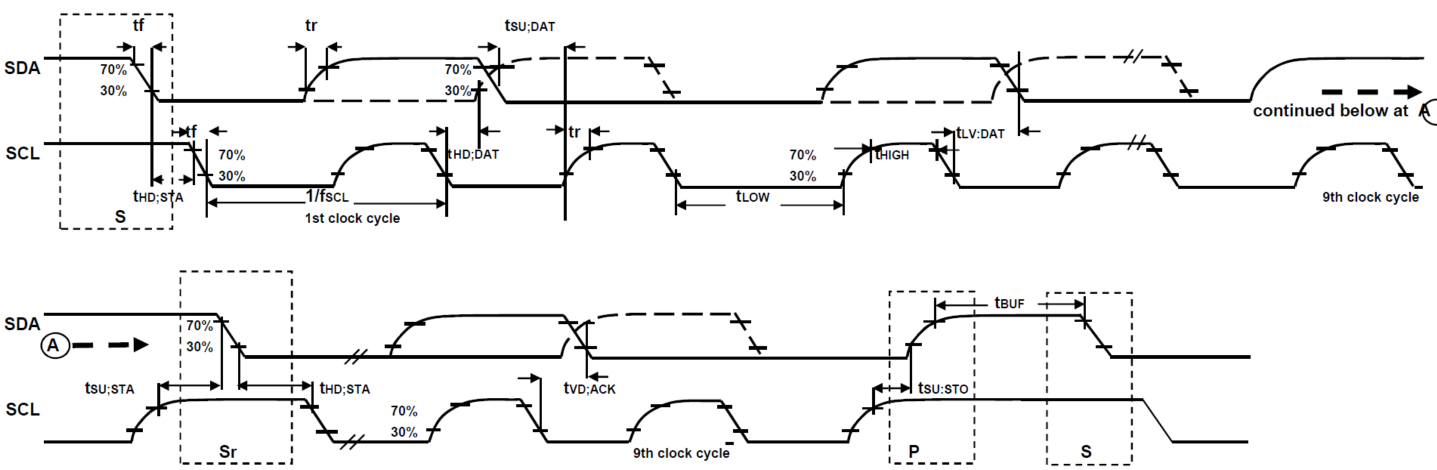
Parameters	Conditions	Min	Typical	Max	Units	Notes
INTERNAL CLOCK SOURCE	**CLK_SEL=0,1,2,3**					
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
Clock Frequency Initial Tolerance	CLK_SEL=0, 25°C	-5		+5	%	
	CLK_SEL=1,2,3; 25°C	-1		+1	%	
Frequency Variation over Temperature	CLK_SEL=0		-15 to +10		%	
	CLK_SEL=1,2,3		±1		%	
PLL Settling Time	CLK_SEL=1,2,3		1	10	ms	
EXTERNAL 32.768kHz CLOCK	**CLK_SEL=4**					
External Clock Frequency			32.768		kHz	
External Clock Allowable Jitter	Cycle-to-cycle rms		1 to 2		µs	
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8.192		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1.024		kHz	
Accelerometer Sample Rate			1.024		kHz	
PLL Settling Time			1	10	ms	
EXTERNAL 19.2MHz CLOCK	**CLK_SEL=5**					
External Clock Frequency			19.2		MHz	
Gyroscope Sample Rate	Full programmable range	3.9		8000	Hz	
Gyroscope Sample Rate, Fast Mode	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow Mode	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
PLL Settling Time			1	10	ms	

6.7 I²C Timing Characterization

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Min	Typical	Max	Units	Notes
I²C TIMING	**I²C FAST-MODE**					
f_{SCL}, SCL Clock Frequency				400	kHz	
$t_{HD.STA}$, (Repeated) START Condition Hold Time		0.6			µs	
t_{LOW}, SCL Low Period		1.3			µs	
t_{HIGH}, SCL High Period		0.6			µs	
$t_{SU.STA}$, Repeated START Condition Setup Time		0.6			µs	
$t_{HD.DAT}$, SDA Data Hold Time		0			µs	
$t_{SU.DAT}$, SDA Data Setup Time		100			ns	
t_r, SDA and SCL Rise Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
t_f, SDA and SCL Fall Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
$t_{SU.STO}$, STOP Condition Setup Time		0.6			µs	
t_{BUF}, Bus Free Time Between STOP and START Condition		1.3			µs	
C_b, Capacitive Load for each Bus Line			< 400		pF	
$t_{VD.DAT}$, Data Valid Time				0.9	µs	
$t_{VD.ACK}$, Data Valid Acknowledge Time				0.9	µs	

Note: Timing Characteristics apply to both Primary and Auxiliary I²C Bus

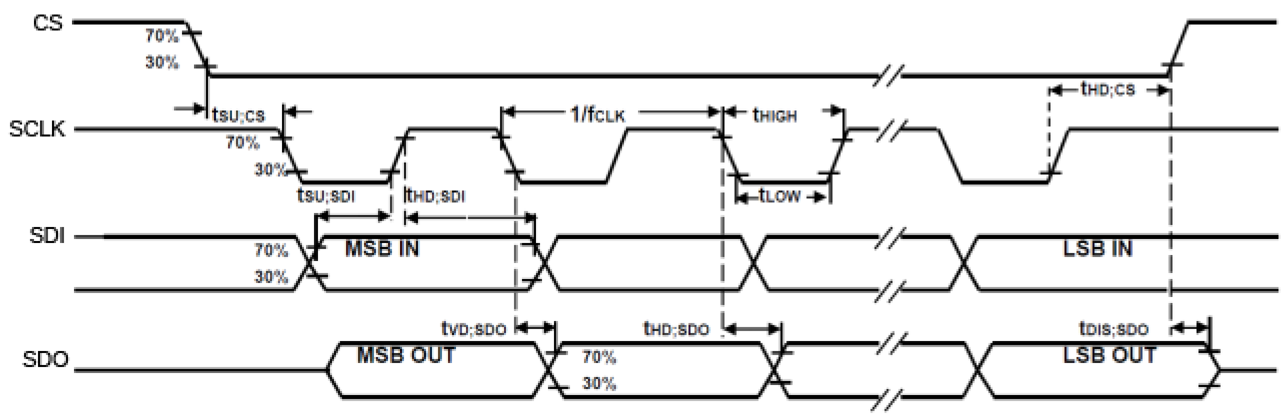


I²C Bus Timing Diagram

6.8 SPI Timing Characterization (MPU-6000 only)

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency				1	MHz	
t_{LOW}, SCLK Low Period		400			ns	
t_{HIGH}, SCLK High Period		400			ns	
$t_{SU.CS}$, CS Setup Time		8			ns	
$t_{HD.CS}$, CS Hold Time		500			ns	
$t_{SU.SDI}$, SDI Setup Time		11			ns	
$t_{HD.SDI}$, SDI Hold Time		7			ns	
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF			100	ns	
$t_{HD.SDO}$, SDO Hold Time	C_{load} = 20pF	4			ns	
$t_{DIS.SDO}$, SDO Output Disable Time				10	ns	



SPI Bus Timing Diagram

6.9 Absolute Maximum Ratings

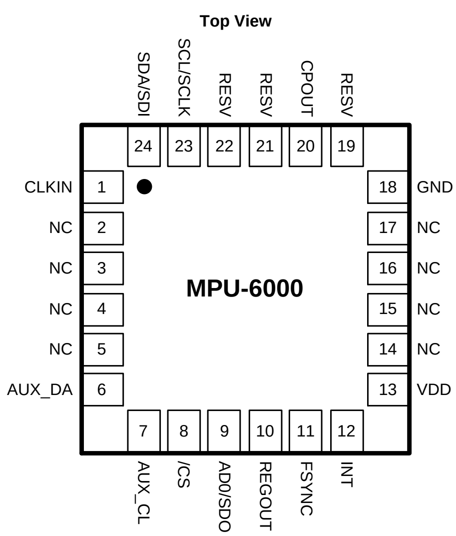
Stress above those listed as “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions is not implied. Exposure to the absolute maximum ratings conditions for extended periods may affect device reliability.

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level (MPU-6050)	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 250V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

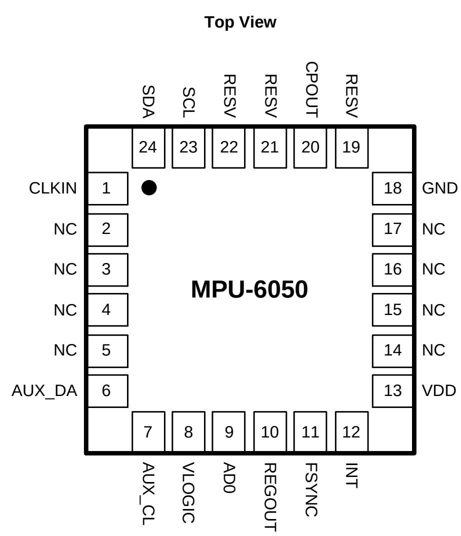
7 Applications Information

7.1 Pin Out and Signal Description

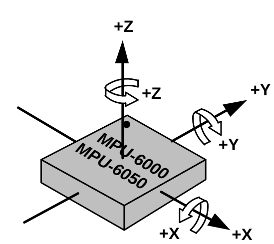
Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
1	Y	Y	CLKIN	Optional external reference clock input. Connect to GND if unused.
6	Y	Y	AUX_DA	I^2C master serial data, for connecting to external sensors
7	Y	Y	AUX_CL	I^2C Master serial clock, for connecting to external sensors
8	Y		/CS	SPI chip select (0=SPI mode)
8		Y	VLOGIC	Digital I/O supply voltage
9	Y		AD0 / SDO	I^2C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I^2C Slave Address LSB (AD0)
10	Y	Y	REGOUT	Regulator filter capacitor connection
11	Y	Y	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	Y	Y	INT	Interrupt digital output (totem pole or open-drain)
13	Y	Y	VDD	Power supply voltage and Digital I/O supply voltage
18	Y	Y	GND	Power supply ground
19, 21	Y	Y	RESV	Reserved. Do not connect.
20	Y	Y	CPOUT	Charge pump capacitor connection
22	Y	Y	RESV	Reserved. Do not connect.
23	Y		SCL / SCLK	I^2C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I^2C serial clock (SCL)
24	Y		SDA / SDI	I^2C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I^2C serial data (SDA)
2, 3, 4, 5, 14, 15, 16, 17	Y	Y	NC	Not internally connected. May be used for PCB trace routing.



QFN Package
24-pin, 4mm x 4mm x 0.9mm

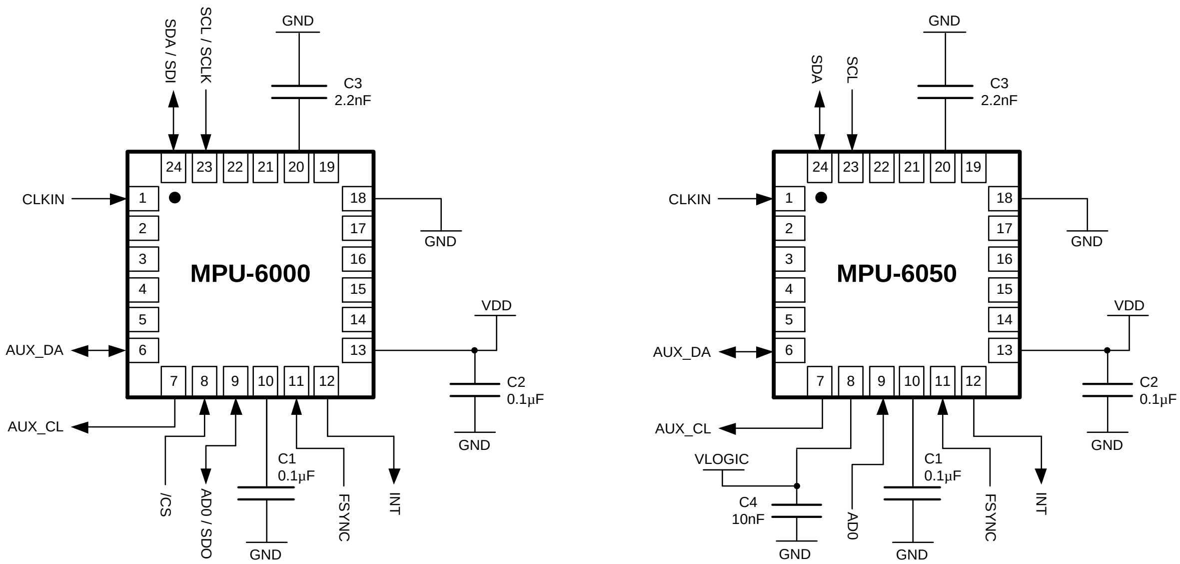


QFN Package
24-pin, 4mm x 4mm x 0.9mm



Orientation of Axes of Sensitivity and Polarity of Rotation

7.2 Typical Operating Circuit



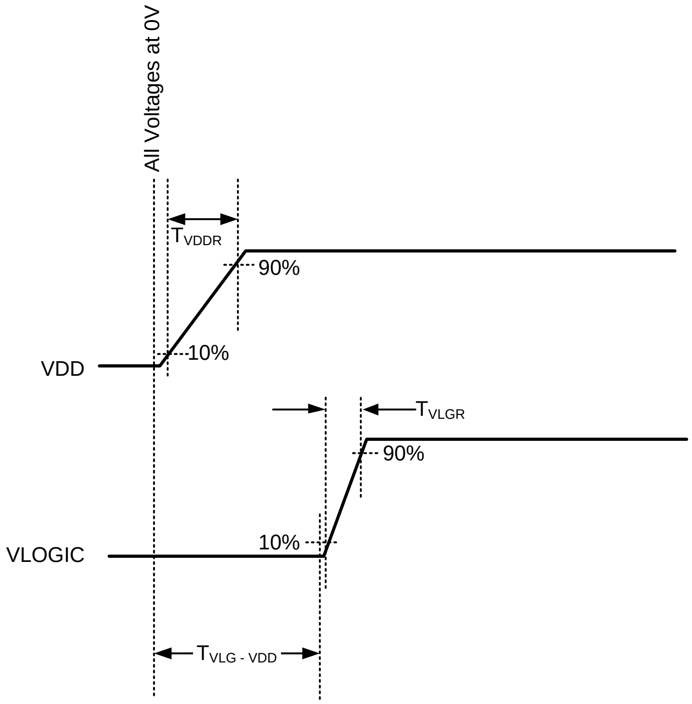
Typical Operating Circuits

7.3 Bill of Materials for External Components

Component	Label	Specification	Quantity
Regulator Filter Capacitor (Pin 10)	C1	Ceramic, X7R, 0.1µF ±10%, 2V	1
VDD Bypass Capacitor (Pin 13)	C2	Ceramic, X7R, 0.1µF ±10%, 4V	1
Charge Pump Capacitor (Pin 20)	C3	Ceramic, X7R, 2.2nF ±10%, 50V	1
VLOGIC Bypass Capacitor (Pin 8)	C4*	Ceramic, X7R, 10nF ±10%, 4V	1

* MPU-6050 Only.

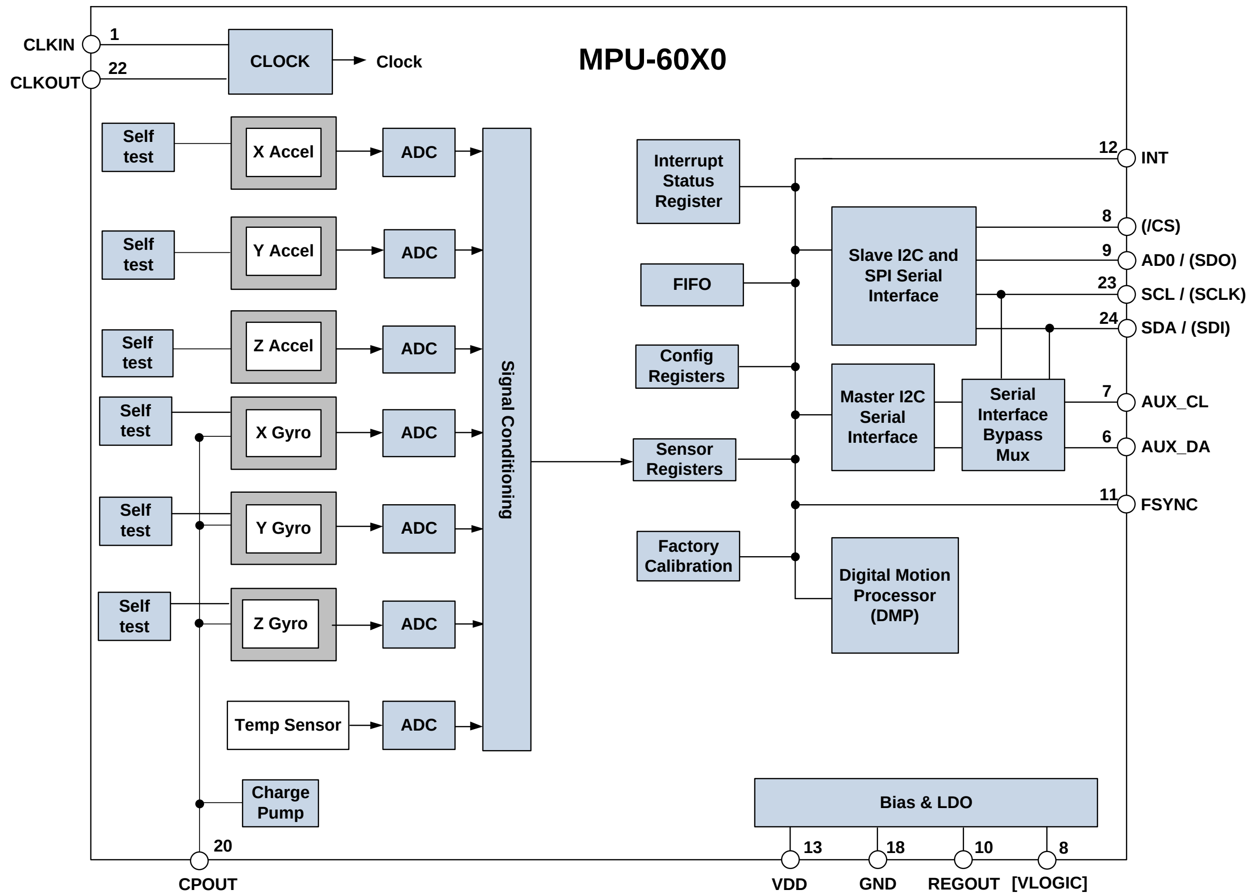
7.4 Recommended Power-on Procedure



Power-Up Sequencing

1. VLOGIC amplitude must always be ≤VDD amplitude
2. T_{VDDR} is VDD rise time: Time for VDD to rise from 10% to 90% of its final value
3. T_{VDDR} is ≤100ms
4. T_{VLGR} is VLOGIC rise time: Time for VLOGIC to rise from 10% to 90% of its final value
5. T_{VLGR} is ≤3ms
6. $T_{VLG\text{-}VDD}$ is the delay from the start of VDD ramp to the start of VLOGIC rise
7. $T_{VLG\text{-}VDD}$ is ≥0
8. VDD and VLOGIC must be monotonic ramps

7.5 Block Diagram



Note: Pin names in round brackets ( ) apply only to MPU-6000
Pin names in square brackets [ ] apply only to MPU-6050

7.6 Overview

The MPU-60X0 is comprised of the following key blocks and functions:

- Three-axis MEMS rate gyroscope sensor with 16-bit ADCs and signal conditioning
- Three-axis MEMS accelerometer sensor with 16-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I^{2}C and SPI (MPU-6000 only) serial communications interfaces
- Auxiliary I^{2}C serial interface for 3rd party magnetometer & other sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope & Accelerometer Self-test
- Bias and LDO
- Charge Pump

7.7 Three-Axis MEMS Gyroscope with 16-bit ADCs and Signal Conditioning

The MPU-60X0 consists of three independent vibratory MEMS rate gyroscopes, which detect rotation about the X-, Y-, and Z- Axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis. The full-scale range of the gyro sensors may be digitally programmed to ±250, ±500, ±1000, or ±2000 degrees per second (dps). The ADC sample rate is programmable from 8,000 samples per second, down to 3.9 samples per second, and user-selectable low-pass filters enable a wide range of cut-off frequencies.

7.8 Three-Axis MEMS Accelerometer with 16-bit ADCs and Signal Conditioning

The MPU-60X0's 3-Axis accelerometer uses separate proof masses for each axis. Acceleration along a particular axis induces displacement on the corresponding proof mass, and capacitive sensors detect the displacement differentially. The MPU-60X0's architecture reduces the accelerometers' susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0*g* on the X- and Y-axes and +1*g* on the Z-axis. The accelerometers' scale factor is calibrated at the factory and is nominally independent of supply voltage. Each sensor has a dedicated sigma-delta ADC for providing digital outputs. The full scale range of the digital output can be adjusted to ±2*g*, ±4*g*, ±8*g*, or ±16*g*.

7.9 Digital Motion Processor

The embedded Digital Motion Processor (DMP) is located within the MPU-60X0 and offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, and additional 3^{rd} party sensors such as magnetometers, and processes the data. The resulting data can be read from the DMP's registers, or can be buffered in a FIFO. The DMP has access to one of the MPU's external pins, which can be used for generating interrupts.

The purpose of the DMP is to offload both timing requirements and processing power from the host processor. Typically, motion processing algorithms should be run at a high rate, often around 200Hz, in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate; for example, a low power user interface may update as slowly as 5Hz, but the motion processing should still run at 200Hz. The DMP can be used as a tool in order to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in the application.

7.10 Primary I^2C and SPI Serial Communications Interfaces

The MPU-60X0 communicates to a system processor using either a SPI (MPU-6000 only) or an I^2C serial interface. The MPU-60X0 always acts as a slave when communicating to the system processor. The LSB of the of the I^2C slave address is set by pin 9 (AD0).

The logic levels for communications between the MPU-60X0 and its master are as follows:

- MPU-6000: The logic level for communications with the master is set by the voltage on VDD
- MPU-6050: The logic level for communications with the master is set by the voltage on VLOGIC

For further information regarding the logic levels of the MPU-6050, please refer to Section 10.

7.11 Auxiliary I²C Serial Interface

The MPU-60X0 has an auxiliary I²C bus for communicating to an off-chip 3-Axis digital output magnetometer or other sensors. This bus has two operating modes:

- I²C Master Mode: The MPU-60X0 acts as a master to any external sensors connected to the auxiliary I²C bus
- Pass-Through Mode: The MPU-60X0 directly connects the primary and auxiliary I²C buses together, allowing the system processor to directly communicate with any external sensors.

Auxiliary I²C Bus Modes of Operation:

- I²C Master Mode: Allows the MPU-60X0 to directly access the data registers of external digital sensors, such as a magnetometer. In this mode, the MPU-60X0 directly obtains data from auxiliary sensors, allowing the on-chip DMP to generate sensor fusion data without intervention from the system applications processor.

  For example, In I²C Master mode, the MPU-60X0 can be configured to perform burst reads, returning the following data from a magnetometer:

  - X magnetometer data (2 bytes)
  - Y magnetometer data (2 bytes)
  - Z magnetometer data (2 bytes)

  The I²C Master can be configured to read up to 24 bytes from up to 4 auxiliary sensors. A fifth sensor can be configured to work single byte read/write mode.

- Pass-Through Mode: Allows an external system processor to act as master and directly communicate to the external sensors connected to the auxiliary I²C bus pins (AUX_DA and AUX_CL). In this mode, the auxiliary I²C bus control logic (3rd party sensor interface block) of the MPU-60X0 is disabled, and the auxiliary I²C pins AUX_DA and AUX_CL (Pins 6 and 7) are connected to the main I²C bus (Pins 23 and 24) through analog switches.

  Pass-Through Mode is useful for configuring the external sensors, or for keeping the MPU-60X0 in a low-power mode when only the external sensors are used.

  In Pass-Through Mode the system processor can still access MPU-60X0 data through the I²C interface.

Auxiliary I²C Bus IO Logic Levels

- MPU-6000: The logic level of the auxiliary I²C bus is VDD
- MPU-6050: The logic level of the auxiliary I²C bus can be programmed to be either VDD or VLOGIC

For further information regarding the MPU-6050's logic levels, please refer to Section 10.2.

7.12 Self-Test

Please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document for more details on self test.

Self-test allows for the testing of the mechanical and electrical portions of the sensors. The self-test for each measurement axis can be activated by means of the gyroscope and accelerometer self-test registers (registers 13 to 16).

When self-test is activated, the electronics cause the sensors to be actuated and produce an output signal. The output signal is used to observe the self-test response.

The self-test response is defined as follows:

Self-test response = Sensor output with self-test enabled – Sensor output without self-test enabled

The self-test response for each accelerometer axis is defined in the accelerometer specification table (Section 6.2), while that for each gyroscope axis is defined in the gyroscope specification table (Section 6.1).

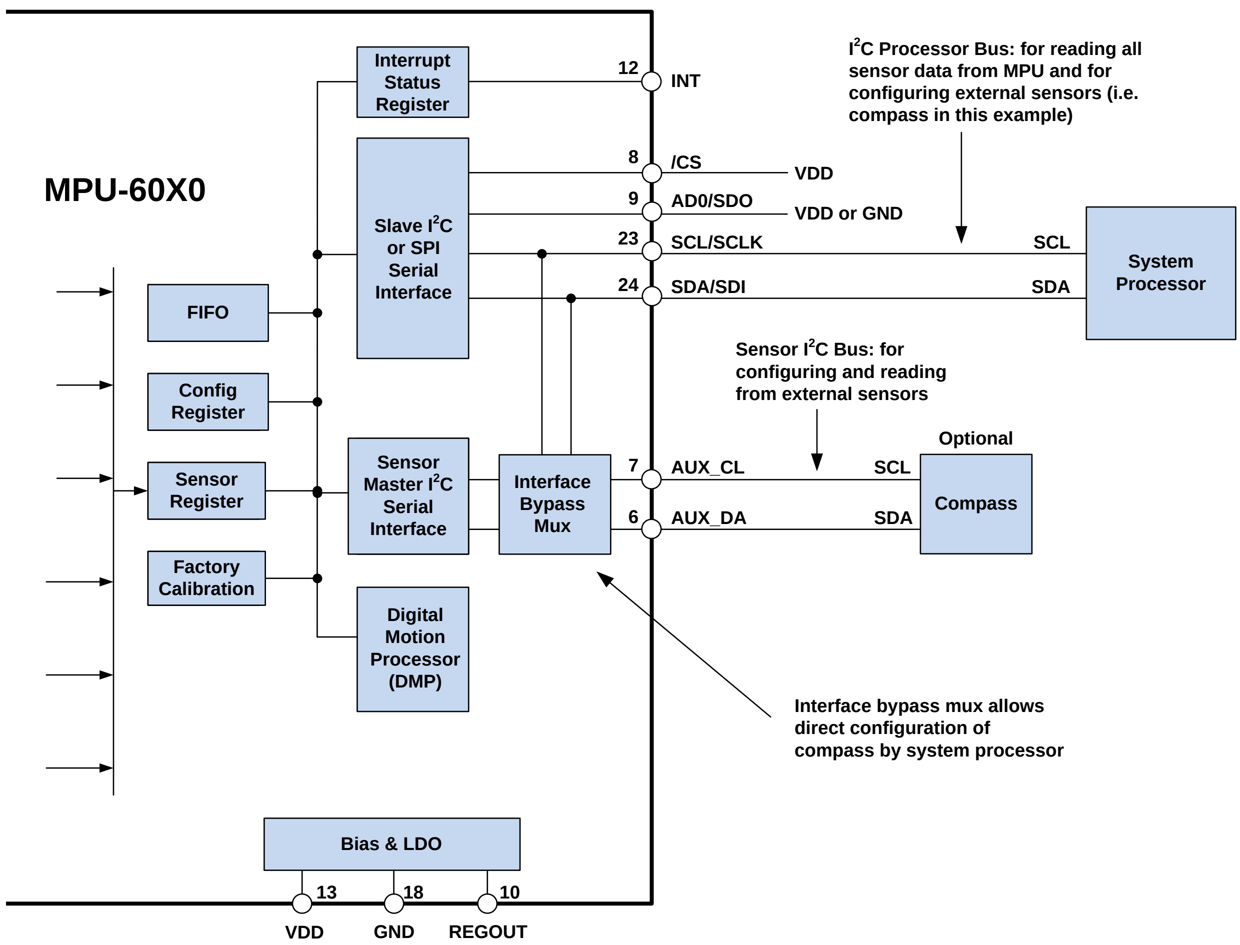
When the value of the self-test response is within the min/max limits of the product specification, the part has passed self test. When the self-test response exceeds the min/max values, the part is deemed to have failed self-test. Code for operating self test code is included within the MotionApps software provided by InvenSense.

7.13 MPU-60X0 Solution for 9-axis Sensor Fusion Using I²C Interface

In the figure below, the system processor is an I²C master to the MPU-60X0. In addition, the MPU-60X0 is an I²C master to the optional external compass sensor. The MPU-60X0 has limited capabilities as an I²C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors. The MPU-60X0 has an interface bypass multiplexer, which connects the system processor I²C bus pins 23 and 24 (SDA and SCL) directly to the auxiliary sensor I²C bus pins 6 and 7 (AUX_DA and AUX_CL).

Once the auxiliary sensors have been configured by the system processor, the interface bypass multiplexer should be disabled so that the MPU-60X0 auxiliary I²C master can take control of the sensor I²C bus and gather data from the auxiliary sensors.

For further information regarding I²C master control, please refer to Section 10.



7.14 MPU-6000 Using SPI Interface

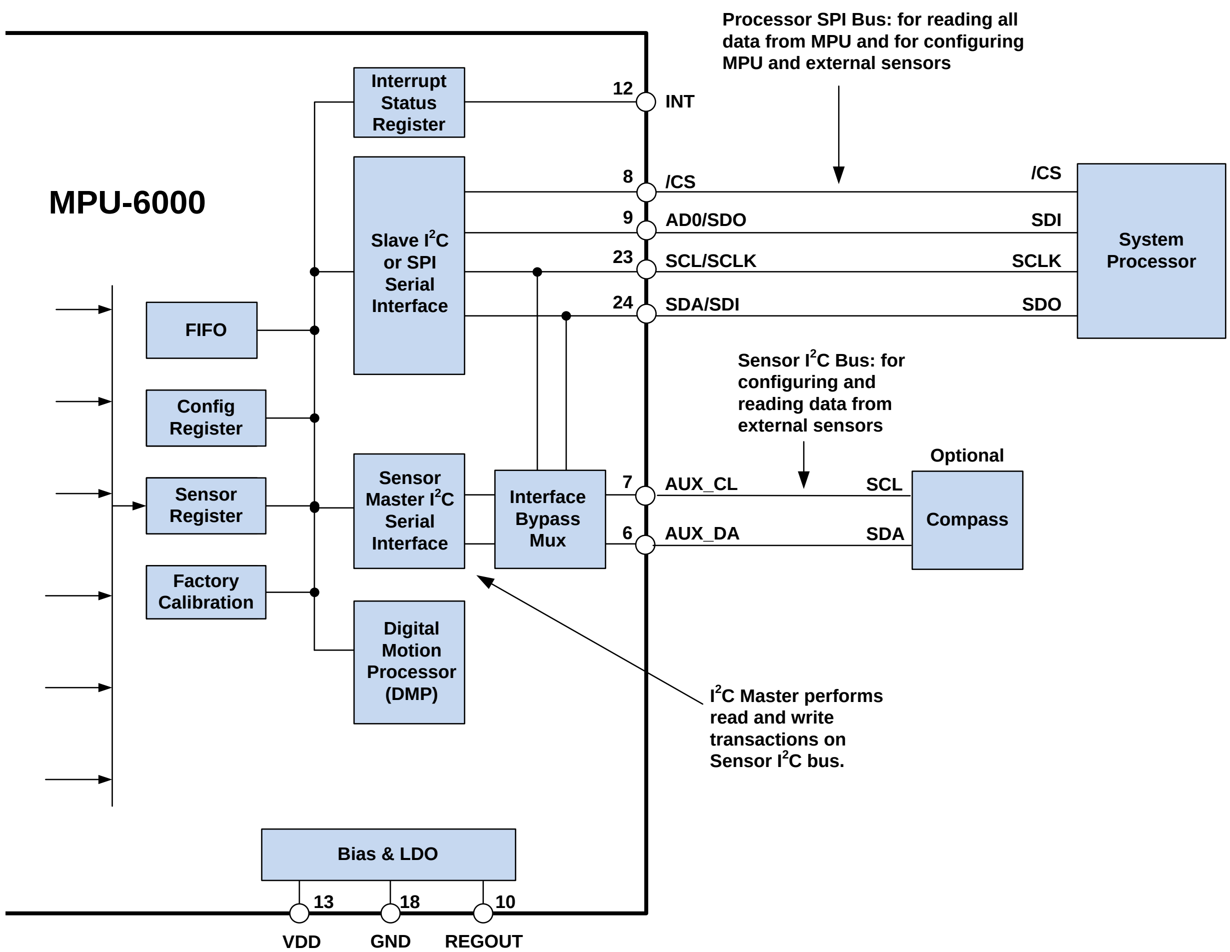
In the figure below, the system processor is an SPI master to the MPU-6000. Pins 8, 9, 23, and 24 are used to support the /CS, SDO, SCLK, and SDI signals for SPI communications. Because these SPI pins are shared with the I²C slave pins (9, 23 and 24), the system processor cannot access the auxiliary I²C bus through the interface bypass multiplexer, which connects the processor I²C interface pins to the sensor I²C interface pins.

Since the MPU-6000 has limited capabilities as an I²C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors, another method must be used for programming the sensors on the auxiliary sensor I²C bus pins 6 and 7 (AUX_DA and AUX_CL).

When using SPI communications between the MPU-6000 and the system processor, configuration of devices on the auxiliary I²C sensor bus can be achieved by using I²C Slaves 0-4 to perform read and write transactions on any device and register on the auxiliary I²C bus. The I²C Slave 4 interface can be used to perform only single byte read and write transactions.

Once the external sensors have been configured, the MPU-6000 can perform single or multi-byte reads using the sensor I²C bus. The read results from the Slave 0-3 controllers can be written to the FIFO buffer as well as to the external sensor registers.

For further information regarding the control of the MPU-60X0's auxiliary I²C interface, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.



7.15 Internal Clock Generation

The MPU-60X0 has a flexible clocking scheme, allowing a variety of internal or external clock sources to be used for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning and ADCs, the DMP, and various control circuits and registers. An on-chip PLL provides flexibility in the allowable inputs for generating this clock.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator
- Any of the X, Y, or Z gyros (MEMS oscillators with a variation of ±1% over temperature)

Allowable external clocking sources are:

- 32.768kHz square wave
- 19.2MHz square wave

Selection of the source for generating the internal synchronous clock depends on the availability of external sources and the requirements for power consumption and clock accuracy. These requirements will most likely vary by mode of operation. For example, in one mode, where the biggest concern is power consumption, the user may wish to operate the Digital Motion Processor of the MPU-60X0 to process accelerometer data, while keeping the gyros off. In this case, the internal relaxation oscillator is a good clock choice. However, in another mode, where the gyros are active, selecting the gyros as the clock source provides for a more accurate clock source.

Clock accuracy is important, since timing errors directly affect the distance and angle calculations performed by the Digital Motion Processor (and by extension, by any processor).

There are also start-up conditions to consider. When the MPU-60X0 first starts up, the device uses its internal clock until programmed to operate from another source. This allows the user, for example, to wait for the MEMS oscillators to stabilize before they are selected as the clock source.

7.16 Sensor Data Registers

The sensor data registers contain the latest gyro, accelerometer, auxiliary sensor, and temperature measurement data. They are read-only registers, and are accessed via the serial interface. Data from these registers may be read anytime. However, the interrupt function may be used to determine when new data is available.

For a table of interrupt sources please refer to Section 8.

7.17 FIFO

The MPU-60X0 contains a 1024-byte FIFO register that is accessible via the Serial Interface. The FIFO configuration register determines which data is written into the FIFO. Possible choices include gyro data, accelerometer data, temperature readings, auxiliary sensor readings, and FSYNC input. A FIFO counter keeps track of how many bytes of valid data are contained in the FIFO. The FIFO register supports burst reads. The interrupt function may be used to determine when new data is available.

For further information regarding the FIFO, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

7.18 Interrupts

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Items that can trigger an interrupt are (1) Clock generator locked to new reference oscillator (used when switching clock sources); (2) new data is available to be read (from the FIFO and Data registers); (3) accelerometer event interrupts; and (4) the MPU-60X0 did not receive an acknowledge from an auxiliary sensor on the secondary I^2C bus. The interrupt status can be read from the Interrupt Status register.

For further information regarding interrupts, please refer to the MPU-60X0 Register Map and Register Descriptions document.

For information regarding the MPU-60X0's accelerometer event interrupts, please refer to Section 8.

7.19 Digital-Output Temperature Sensor

An on-chip temperature sensor and ADC are used to measure the MPU-60X0 die temperature. The readings from the ADC can be read from the FIFO or the Sensor Data registers.

7.20 Bias and LDO

The bias and LDO section generates the internal supply and the reference voltages and currents required by the MPU-60X0. Its two inputs are an unregulated VDD of 2.375 to 3.46V and a VLOGIC logic reference supply voltage of 1.71V to VDD (MPU-6050 only). The LDO output is bypassed by a capacitor at REGOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

7.21 Charge Pump

An on-board charge pump generates the high voltage required for the MEMS oscillators. Its output is bypassed by a capacitor at CPOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

8 Programmable Interrupts

The MPU-60X0 has a programmable interrupt system which can generate an interrupt signal on the INT pin. Status flags indicate the source of an interrupt. Interrupt sources may be enabled and disabled individually.

Table of Interrupt Sources

Interrupt Name	Module
FIFO Overflow	FIFO
Data Ready	Sensor Registers
I^2C Master errors: Lost Arbitration, NACKs	I^2C Master
I^2C Slave 4	I^2C Master

For information regarding the interrupt enable/disable registers and flag registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document. Some interrupt sources are explained below.

9 Digital Interface

9.1 I²C and SPI (MPU-6000 only) Serial Interfaces

The internal registers and memory of the MPU-6000/MPU-6050 can be accessed using either I²C at 400 kHz or SPI at 1MHz (MPU-6000 only). SPI operates in four-wire mode.

Serial Interface

Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
8	Y		/CS	SPI chip select (0=SPI enable)
8		Y	VLOGIC	Digital I/O supply voltage. VLOGIC must be ≤ VDD at all times.
9	Y		AD0 / SDO	I²C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I²C Slave Address LSB
23	Y		SCL / SCLK	I²C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I²C serial clock
24	Y		SDA / SDI	I²C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I²C serial data

Note:

To prevent switching into I²C mode when using SPI (MPU-6000), the I²C interface should be disabled by setting the *I2C_IF_DIS* configuration bit. Setting this bit should be performed immediately after waiting for the time specified by the "Start-Up Time for Register Read/Write" in Section 6.3.

For further information regarding the *I2C_IF_DIS* bit, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

9.2 I²C Interface

I²C is a two-wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I²C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The MPU-60X0 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400 kHz.

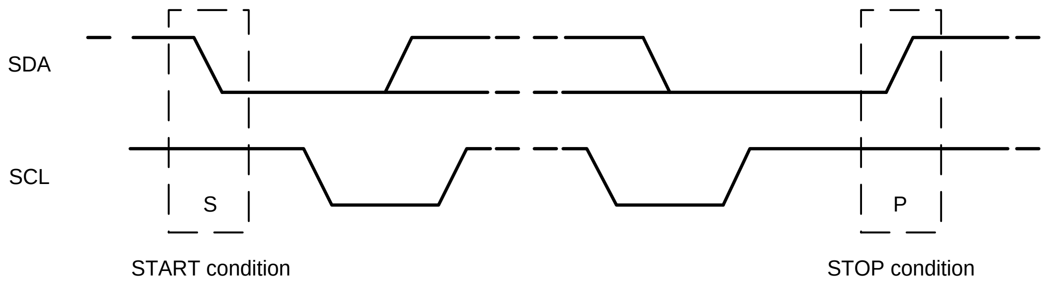
The slave address of the MPU-60X0 is b110100X which is 7 bits long. The LSB bit of the 7 bit address is determined by the logic level on pin AD0. This allows two MPU-60X0s to be connected to the same I²C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin AD0 is logic low) and the address of the other should be b1101001 (pin AD0 is logic high).

9.3 I²C Communications Protocol

START (S) and STOP (P) Conditions

Communication on the I²C bus starts when the master puts the START condition (S) on the bus, which is defined as a HIGH-to-LOW transition of the SDA line while SCL line is HIGH (see figure below). The bus is considered to be busy until the master puts a STOP condition (P) on the bus, which is defined as a LOW to HIGH transition on the SDA line while SCL is HIGH (see figure below).

Additionally, the bus remains busy if a repeated START (Sr) is generated instead of a STOP condition.

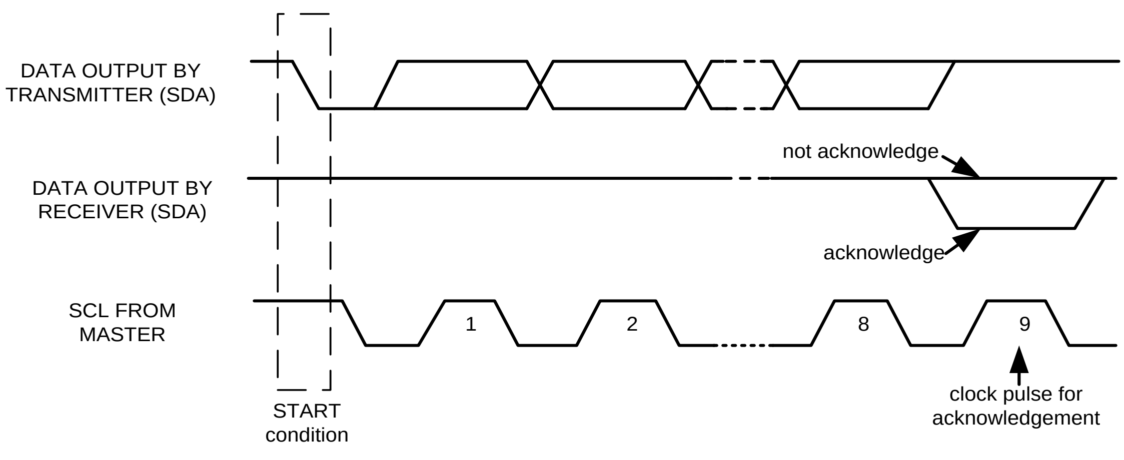


START and STOP Conditions

Data Format / Acknowledge

I^2C data bytes are defined to be 8-bits long. There is no restriction to the number of bytes transmitted per data transfer. Each byte transferred must be followed by an acknowledge (ACK) signal. The clock for the acknowledge signal is generated by the master, while the receiver generates the actual acknowledge signal by pulling down SDA and holding it low during the HIGH portion of the acknowledge clock pulse.

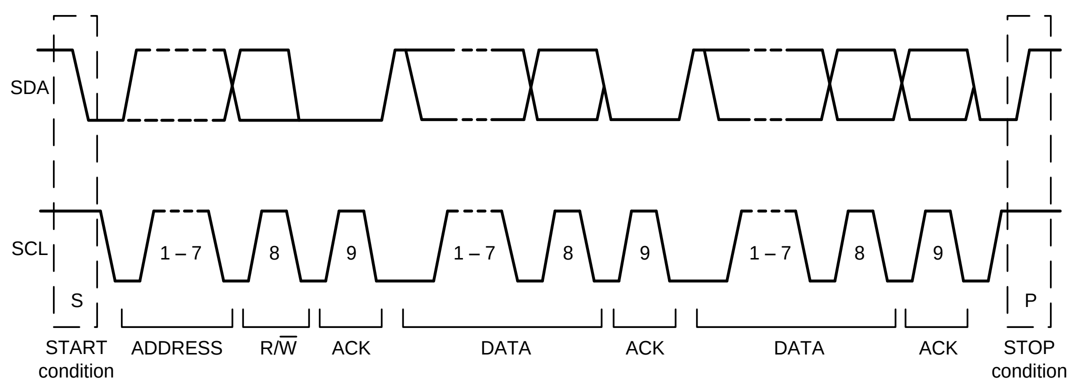
If a slave is busy and cannot transmit or receive another byte of data until some other task has been performed, it can hold SCL LOW, thus forcing the master into a wait state. Normal data transfer resumes when the slave is ready, and releases the clock line (refer to the following figure).



Acknowledge on the I^2C Bus

Communications

After beginning communications with the START condition (S), the master sends a 7-bit slave address followed by an 8th bit, the read/write bit. The read/write bit indicates whether the master is receiving data from or is writing to the slave device. Then, the master releases the SDA line and waits for the acknowledge signal (ACK) from the slave device. Each byte transferred must be followed by an acknowledge bit. To acknowledge, the slave device pulls the SDA line LOW and keeps it LOW for the high period of the SCL line. Data transmission is always terminated by the master with a STOP condition (P), thus freeing the communications line. However, the master can generate a repeated START condition (Sr), and address another slave without first generating a STOP condition (P). A LOW to HIGH transition on the SDA line while SCL is HIGH defines the stop condition. All SDA changes should take place when SCL is low, with the exception of start and stop conditions.



Complete I²C Data Transfer

To write the internal MPU-60X0 registers, the master transmits the start condition (S), followed by the I²C address and the write bit (0). At the 9th clock cycle (when the clock is high), the MPU-60X0 acknowledges the transfer. Then the master puts the register address (RA) on the bus. After the MPU-60X0 acknowledges the reception of the register address, the master puts the register data onto the bus. This is followed by the ACK signal, and data transfer may be concluded by the stop condition (P). To write multiple bytes after the last ACK signal, the master can continue outputting data rather than transmitting a stop signal. In this case, the MPU-60X0 automatically increments the register address and loads the data to the appropriate register. The following figures show single and two-byte write sequences.

Single-Byte Write Sequence

Master	S	AD+W		RA		DATA		P
Slave			ACK		ACK		ACK	

Burst Write Sequence

Master	S	AD+W		RA		DATA		DATA		P
Slave			ACK		ACK		ACK		ACK	

To read the internal MPU-60X0 registers, the master sends a start condition, followed by the I^2C address and a write bit, and then the register address that is going to be read. Upon receiving the ACK signal from the MPU-60X0, the master transmits a start signal followed by the slave address and read bit. As a result, the MPU-60X0 sends an ACK signal and the data. The communication ends with a not acknowledge (NACK) signal and a stop bit from master. The NACK condition is defined such that the SDA line remains high at the 9^{th} clock cycle. The following figures show single and two-byte read sequences.

Single-Byte Read Sequence

Master	S	AD+W		RA		S	AD+R			NACK	P
Slave			ACK		ACK			ACK	DATA		

Burst Read Sequence

Master	S	AD+W		RA		S	AD+R			ACK		NACK	P
Slave			ACK		ACK			ACK	DATA		DATA		

9.4 I^2C Terms

Signal	Description
S	Start Condition: SDA goes from high to low while SCL is high
AD	Slave I^2C address
W	Write bit (0)
R	Read bit (1)
ACK	Acknowledge: SDA line is low while the SCL line is high at the 9^{th} clock cycle
NACK	Not-Acknowledge: SDA line stays high at the 9^{th} clock cycle
RA	MPU-60X0 internal register address
DATA	Transmit or received data
P	Stop condition: SDA going from low to high while SCL is high

9.5 SPI Interface (MPU-6000 only)

SPI is a 4-wire synchronous serial interface that uses two control lines and two data lines. The MPU-6000 always operates as a Slave device during standard Master-Slave SPI operation.

With respect to the Master, the Serial Clock output (SCLK), the Serial Data Output (SDO) and the Serial Data Input (SDI) are shared among the Slave devices. Each SPI slave device requires its own Chip Select (/CS) line from the master.

/CS goes low (active) at the start of transmission and goes back high (inactive) at the end. Only one /CS line is active at a time, ensuring that only one slave is selected at any given time. The /CS lines of the non-selected slave devices are held high, causing their SDO lines to remain in a high-impedance (high-z) state so that they do not interfere with any active devices.

SPI Operational Features

1. Data is delivered MSB first and LSB last
2. Data is latched on the rising edge of SCLK
3. Data should be transitioned on the falling edge of SCLK
4. The maximum frequency of SCLK is 1MHz
5. SPI read and write operations are completed in 16 or more clock cycles (two or more bytes). The first byte contains the SPI Address, and the following byte(s) contain(s) the SPI data. The first bit of the first byte contains the Read/Write bit and indicates the Read (1) or Write (0) operation. The following 7 bits contain the Register Address. In cases of multiple-byte Read/Writes, data is two or more bytes:

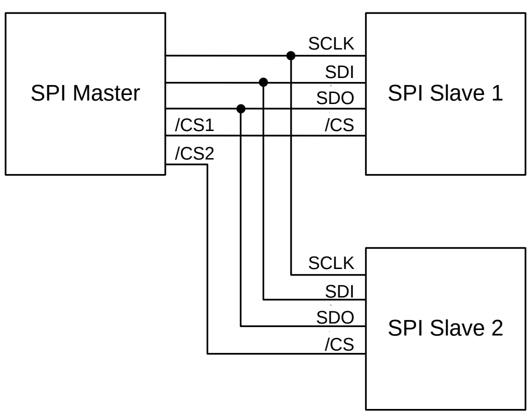
SPI Address format

MSB							**LSB**
R/W	A6	A5	A4	A3	A2	A1	A0

SPI Data format

MSB							**LSB**
D7	D6	D5	D4	D3	D2	D1	D0

6. Supports Single or Burst Read/Writes.



Typical SPI Master / Slave Configuration

10 Serial Interface Considerations (MPU-6050)

10.1 MPU-6050 Supported Interfaces

The MPU-6050 supports I^2C communications on both its primary (microprocessor) serial interface and its auxiliary interface.

10.2 Logic Levels

The MPU-6050's I/O logic levels are set to be VLOGIC, as shown in the table below. AUX_VDDIO must be set to 0.

I/O Logic Levels vs. *AUX_VDDIO*

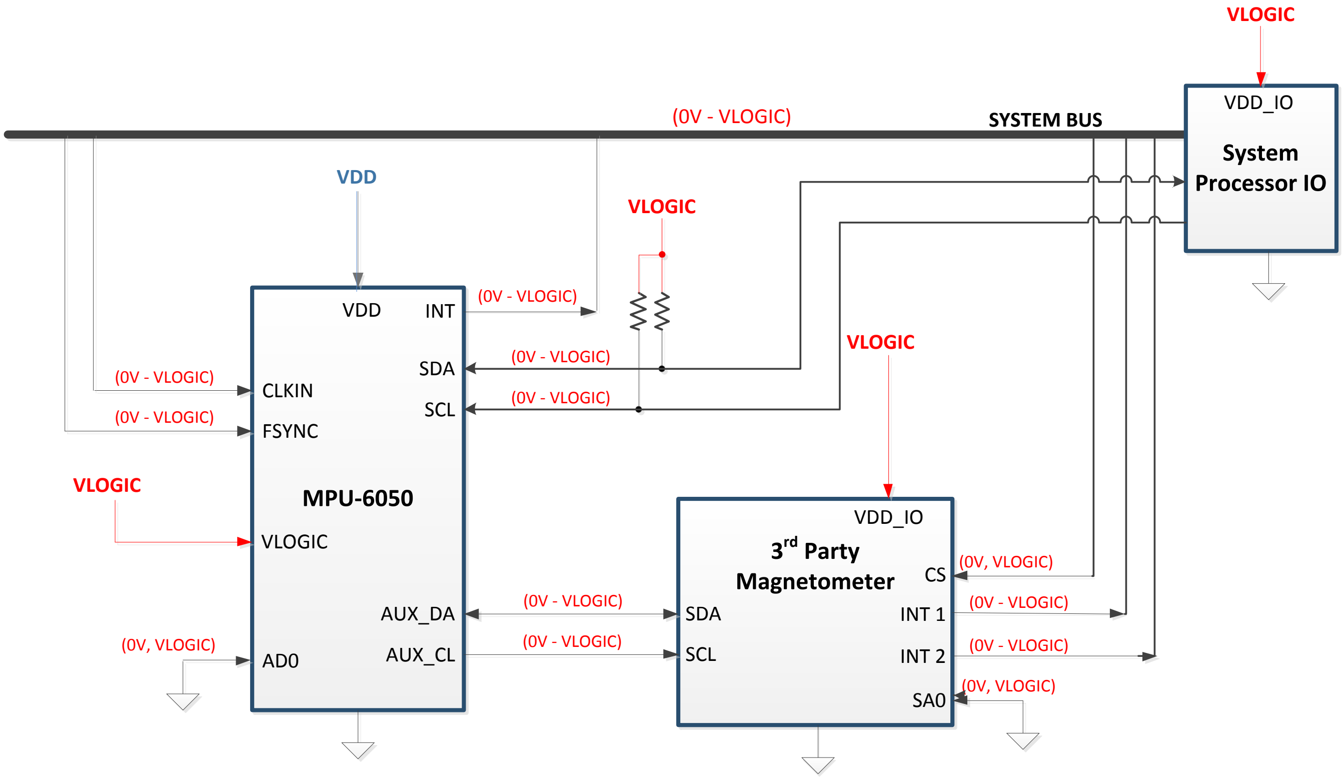
AUX_VDDIO	**MICROPROCESSOR LOGIC LEVELS** (Pins: SDA, SCL, AD0, CLKIN, INT)	**AUXILLARY LOGIC LEVELS** (Pins: AUX_DA, AUX_CL)
0	VLOGIC	VLOGIC

Note: The power-on-reset value for *AUX_VDDIO* is 0.

When *AUX_VDDIO* is set to 0 (its power-on-reset value), VLOGIC is the power supply voltage for both the microprocessor system bus and the auxiliary I^2C bus, as shown in the figure of Section 10.3.

10.3 Logic Levels Diagram for AUX_*VDDIO* = 0

The figure below depicts a sample circuit with a third party magnetometer attached to the auxiliary I^{2}C bus. It shows logic levels and voltage connections for *AUX_VDDIO* = 0. Note: Actual configuration will depend on the auxiliary sensors used.



I/O Levels and Connections for *AUX_VDDIO* = 0

Notes:

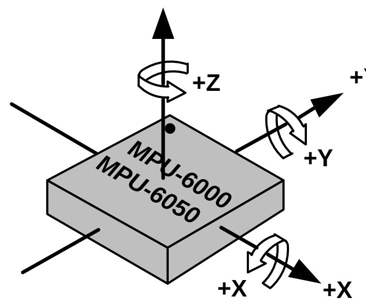
1. AUX_VDDIO determines the IO voltage levels of AUX_DA and AUX_CL
   (0 = set output levels relative to VLOGIC)
2. All other MPU-6050 logic IOs are referenced to VLOGIC.

11 Assembly

This section provides general guidelines for assembling InvenSense Micro Electro-Mechanical Systems (MEMS) gyros packaged in Quad Flat No leads package (QFN) surface mount integrated circuits.

11.1 Orientation of Axes

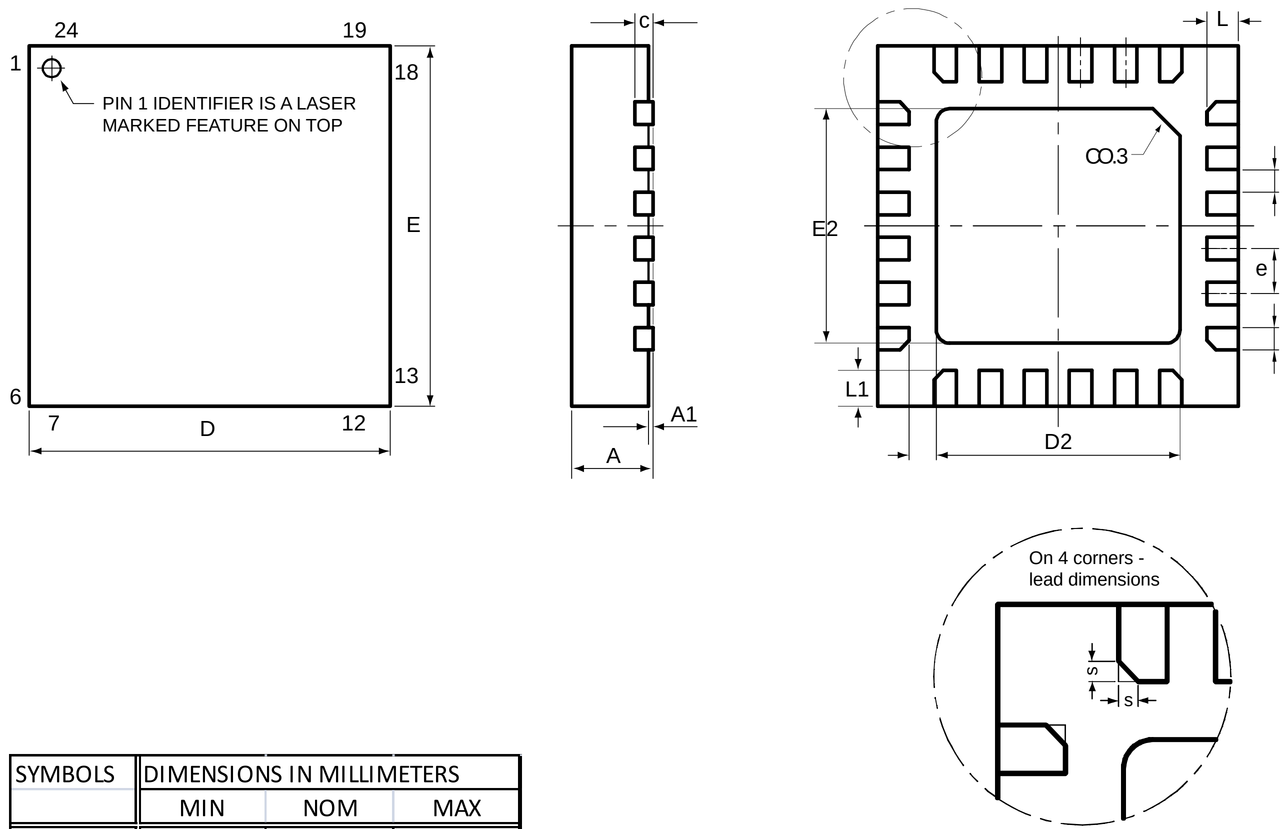
The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier (•) in the figure.



Orientation of Axes of Sensitivity and Polarity of Rotation

11.2 Package Dimensions

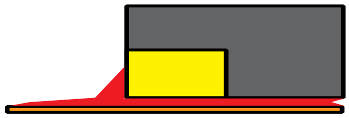
24 Lead QFN (4x4x0.9) mm NiPdAu Lead-frame finish



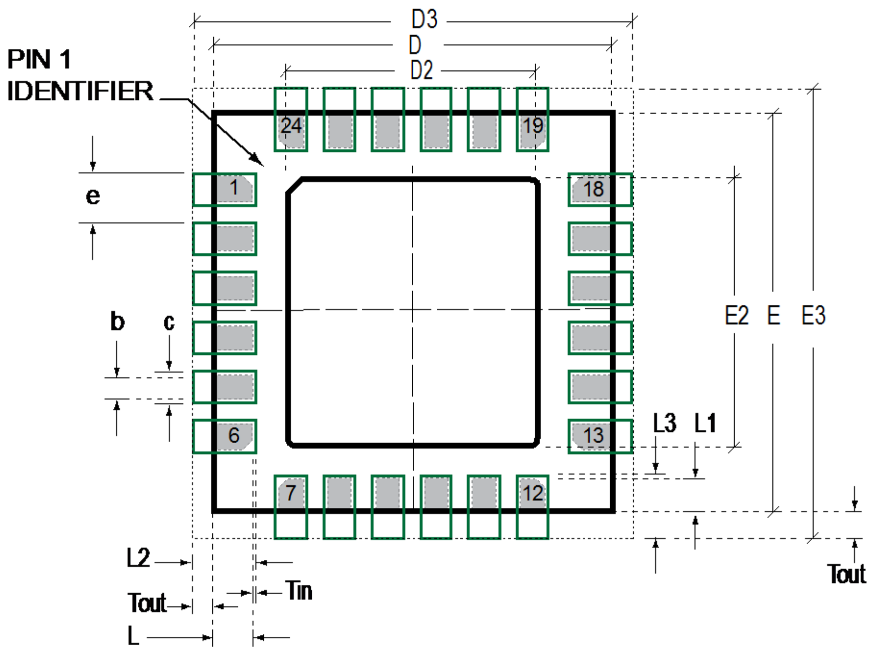
SYMBOLS	DIMENSIONS IN MILLIMETERS		
	MIN	NOM	MAX
A	0.85	0.90	0.95
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
c	---	0.20 REF	---
D	3.90	4.00	4.10
D2	2.65	2.70	2.75
E	3.90	4.00	4.10
E2	2.55	2.60	2.65
e	---	0.50	---
f (e-b)	---	0.25	---
K	0.25	0.30	0.35
L	0.30	0.35	0.40
L1	0.35	0.40	0.45
s	0.05	---	0.15

11.3 PCB Design Guidelines

The Pad Diagram using a JEDEC type extension with solder rising on the outer edge is shown below. The Pad Dimensions Table shows pad sizing (mean dimensions) recommended for the MPU-60X0 product.



JEDEC type extension with solder rising on outer edge



PCB Layout Diagram

SYMBOLS	DIMENSIONS IN MILLIMETERS	NOM
	Nominal Package I/O Pad Dimensions	
e	Pad Pitch	0.50
b	Pad Width	0.25
L	Pad Length	0.35
L1	Pad Length	0.40
D	Package Width	4.00
E	Package Length	4.00
D2	Exposed Pad Width	2.70
E2	Exposed Pad Length	2.60
	I/O Land Design Dimensions (Guidelines)	
D3	I/O Pad Extent Width	4.80
E3	I/O Pad Extent Length	4.80
c	Land Width	0.35
Tout	Outward Extension	0.40
Tin	Inward Extension	0.05
L2	Land Length	0.80
L3	Land Length	0.85

PCB Dimensions Table (for PCB Lay-out Diagram)

11.4 Assembly Precautions

11.4.1 Gyroscope Surface Mount Guidelines

InvenSense MEMS Gyros sense rate of rotation. In addition, gyroscopes sense mechanical stress coming from the printed circuit board (PCB). This PCB stress can be minimized by adhering to certain design rules:

When using MEMS gyroscope components in plastic packages, PCB mounting and assembly can cause package stress. This package stress in turn can affect the output offset and its value over a wide range of temperatures. This stress is caused by the mismatch between the Coefficient of Linear Thermal Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting.

Traces connected to pads should be as symmetric as possible. Maximizing symmetry and balance for pad connection will help component self alignment and will lead to better control of solder paste reduction after reflow.

Any material used in the surface mount assembly process of the MEMS gyroscope should be free of restricted RoHS elements or compounds. Pb-free solders should be used for assembly.

11.4.2 Exposed Die Pad Precautions

The MPU-60X0 has very low active and standby current consumption. The exposed die pad is not required for heat sinking, and should not be soldered to the PCB. Failure to adhere to this rule can induce performance changes due to package thermo-mechanical stress. There is no electrical connection between the pad and the CMOS.

11.4.3 Trace Routing

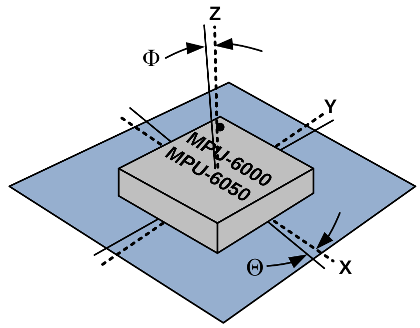
Routing traces or vias under the gyro package such that they run under the exposed die pad is prohibited. Routed active signals may harmonically couple with the gyro MEMS devices, compromising gyro response. These devices are designed with the drive frequencies as follows: X = 33±3Khz, Y = 30±3Khz, and Z=27±3Khz. To avoid harmonic coupling don't route active signals in non-shielded signal planes directly below, or above the gyro package. Note: For best performance, design a ground plane under the e-pad to reduce PCB signal noise from the board on which the gyro device is mounted. If the gyro device is stacked under an adjacent PCB board, design a ground plane directly above the gyro device to shield active signals from the adjacent PCB board.

11.4.4 Component Placement

Do not place large insertion components such as keyboard or similar buttons, connectors, or shielding boxes at a distance of less than 6 mm from the MEMS gyro. Maintain generally accepted industry design practices for component placement near the MPU-60X0 to prevent noise coupling and thermo-mechanical stress.

11.4.5 PCB Mounting and Cross-Axis Sensitivity

Orientation errors of the gyroscope and accelerometer mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro or accel responds to rotation or acceleration about another axis, respectively. For example, the X-axis gyroscope may respond to rotation about the Y or Z axes. The orientation mounting errors are illustrated in the figure below.



Package Gyro & Accel Axes (– – –) Relative to PCB Axes (——) with Orientation Errors (Θ and Φ)

The table below shows the cross-axis sensitivity as a percentage of the gyroscope or accelerometer's sensitivity for a given orientation error, respectively.

Cross-Axis Sensitivity vs. Orientation Error

Orientation Error (θ or Φ)	Cross-Axis Sensitivity (sinθ or sinΦ)
0º	0%
0.5º	0.87%
1º	1.75%

The specifications for cross-axis sensitivity in Section 6.1 and Section 6.2 include the effect of the die orientation error with respect to the package.

11.4.6 MEMS Handling Instructions

MEMS (Micro Electro-Mechanical Systems) are a time-proven, robust technology used in hundreds of millions of consumer, automotive and industrial products. MEMS devices consist of microscopic moving mechanical structures. They differ from conventional IC products, even though they can be found in similar packages. Therefore, MEMS devices require different handling precautions than conventional ICs prior to mounting onto printed circuit boards (PCBs).

The MPU-60X0 has been qualified to a shock tolerance of 10,000*g*. InvenSense packages its gyroscopes as it deems proper for protection against normal handling and shipping. It recommends the following handling precautions to prevent potential damage.

- Do not drop individually packaged gyroscopes, or trays of gyroscopes onto hard surfaces. Components placed in trays could be subject to *g*-forces in excess of 10,000*g* if dropped.
- Printed circuit boards that incorporate mounted gyroscopes should not be separated by manually snapping apart. This could also create *g*-forces in excess of 10,000*g.*
- Do not clean MEMS gyroscopes in ultrasonic baths. Ultrasonic baths can induce MEMS damage if the bath energy causes excessive drive motion through resonant frequency coupling.

11.4.7 ESD Considerations

Establish and use ESD-safe handling precautions when unpacking and handling ESD-sensitive devices.

- Store ESD sensitive devices in ESD safe containers until ready for use. The Tape-and-Reel moisture-sealed bag is an ESD approved barrier. The best practice is to keep the units in the original moisture sealed bags until ready for assembly.

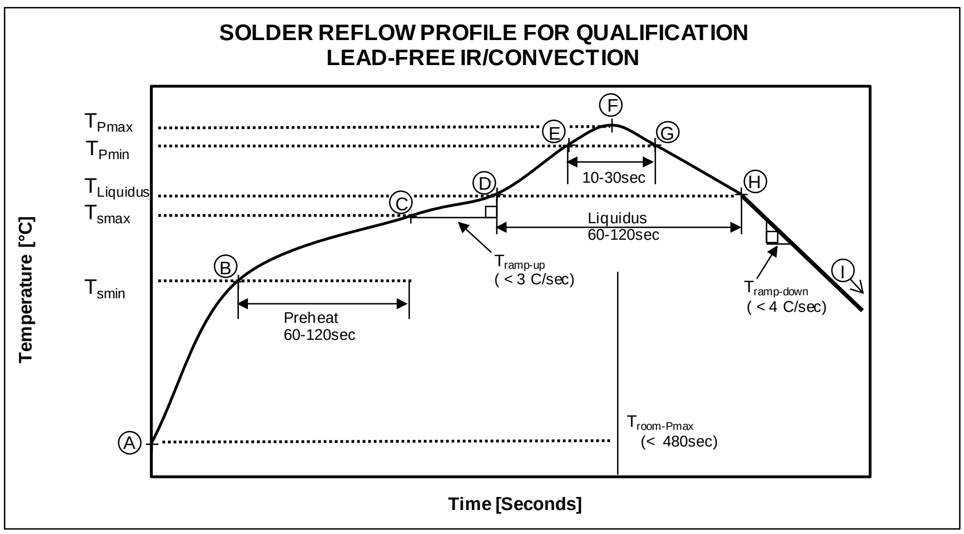
Restrict all device handling to ESD protected work areas that measure less than 200V static charge. Ensure that all workstations and personnel are properly grounded to prevent ESD.

11.4.8 Reflow Specification

Qualification Reflow: The MPU-60X0 was qualified in accordance with IPC/JEDEC J-STD-020D.1. This standard classifies proper packaging, storage and handling in order to avoid subsequent thermal and mechanical damage during the solder reflow attachment phase of PCB assembly.

The qualification preconditioning process specifies a sequence consisting of a bake cycle, a moisture soak cycle (in a temperature humidity oven), and three consecutive solder reflow cycles, followed by functional device testing.

The peak solder reflow classification temperature requirement for package qualification is (260 +5/-0°C) for lead-free soldering of components measuring less than 1.6 mm in thickness. The qualification profile and a table explaining the set-points are shown below:



Temperature Set Points Corresponding to Reflow Profile Above

Step	Setting	CONSTRAINTS		
		Temp (°C)	Time (sec)	Max. Rate (°C/sec)
A	T_{room}	25		
B	T_{Smin}	150		
C	T_{Smax}	200	$60 < t_{BC} < 120$	
D	$T_{Liquidus}$	217		$r_{(TLiquidus\text{-}TPmax)} < 3$
E	T_{Pmin} [255°C, 260°C]	255		$r_{(TLiquidus\text{-}TPmax)} < 3$
F	T_{Pmax} [260°C, 265°C]	260	$t_{AF} < 480$	$r_{(TLiquidus\text{-}TPmax)} < 3$
G	T_{Pmin} [255°C, 260°C]	255	$10 < t_{EG} < 30$	$r_{(TPmax\text{-}TLiquidus)} < 4$
H	$T_{Liquidus}$	217	$60 < t_{DH} < 120$	
I	T_{room}	25		

Notes: Customers must never exceed the Classification temperature (T_{Pmax} = 260°C).
All temperatures refer to the topside of the QFN package, as measured on the package body surface.

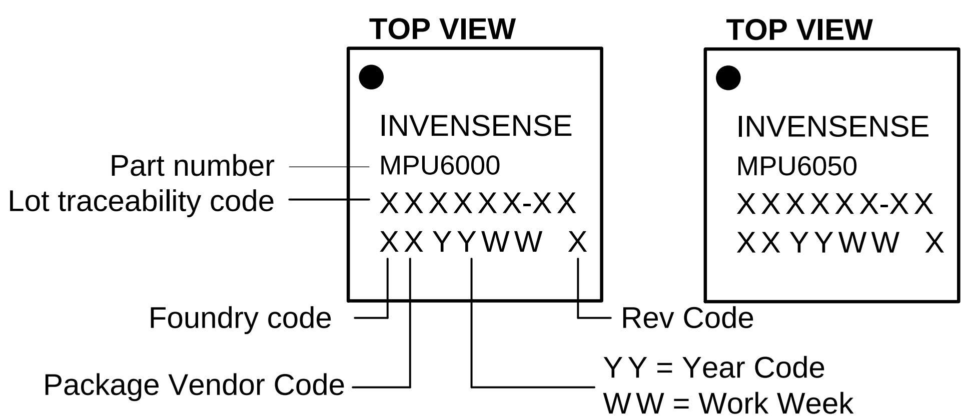
Production Reflow: Check the recommendations of your solder manufacturer. For optimum results, use lead-free solders that have lower specified temperature profiles (Tp_{max} ~ 235°C). Also use lower ramp-up and ramp-down rates than those used in the qualification profile. Never exceed the maximum conditions that we used for qualification, as these represent the maximum tolerable ratings for the device.

11.5 Storage Specifications

The storage specification of the MPU-60X0 conforms to IPC/JEDEC J-STD-020D.1 Moisture Sensitivity Level (MSL) 3.

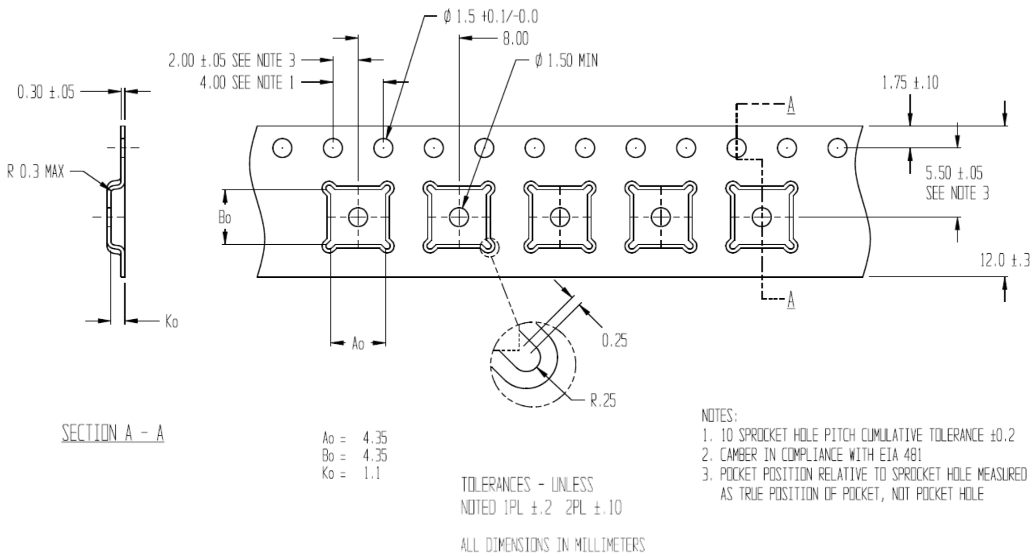
Calculated shelf-life in moisture-sealed bag	12 months -- Storage conditions: <40°C and <90% RH
After opening moisture-sealed bag	168 hours -- Storage conditions: ambient ≤30°C at 60%RH

11.6 Package Marking Specification

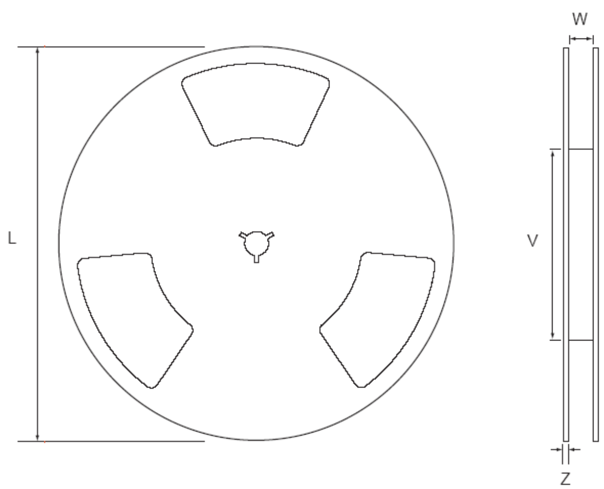


Package Marking Specification

11.7 Tape & Reel Specification



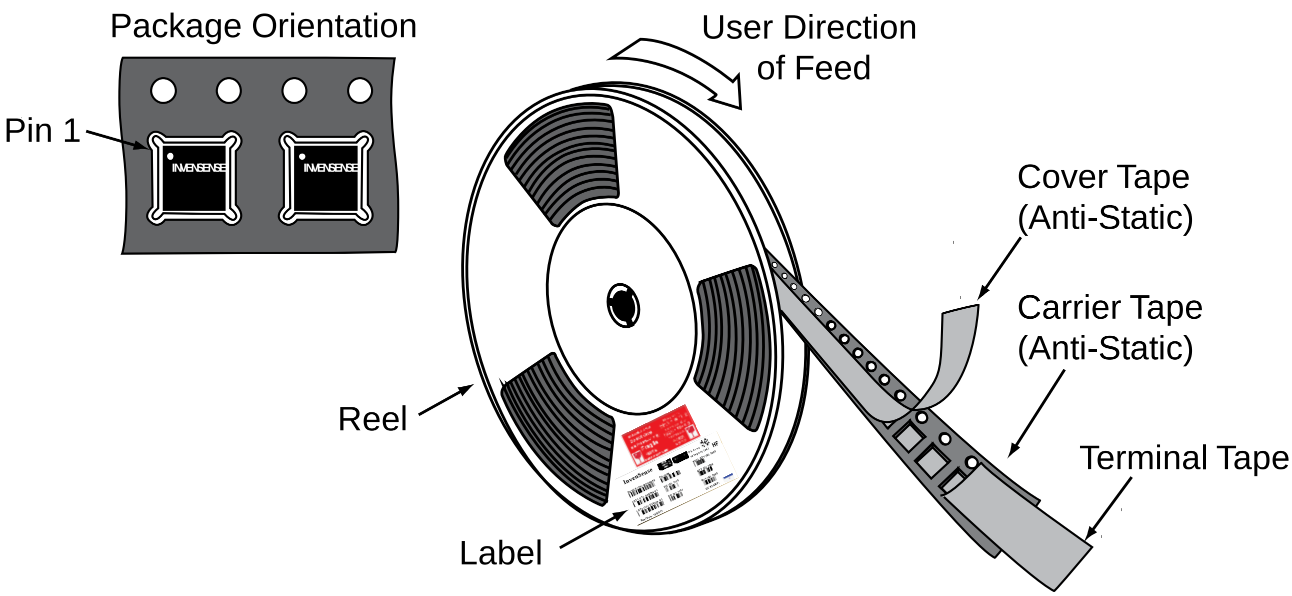
Tape Dimensions



Reel Outline Drawing

Reel Dimensions and Package Size

PACKAGE SIZE	REEL (mm)			
	L	V	W	Z
4x4	330	102	12.8	2.3



Tape and Reel Specification

Reel Specifications

Quantity Per Reel	**5,000**
Reels per Box	**1**
Boxes Per Carton (max)	**5**
Pcs/Carton (max)	**25,000**

11.8 Label

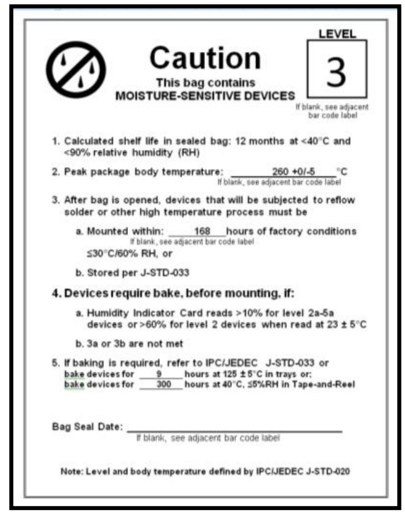
Barcode Label

Location of Label on Reel

11.9 Packaging

REEL – with Barcode & Caution labels

Vacuum-Sealed Moisture Barrier Bag with ESD, MSL3, Caution, and Barcode Labels



MSL3 Label

Caution Label

ESD Label

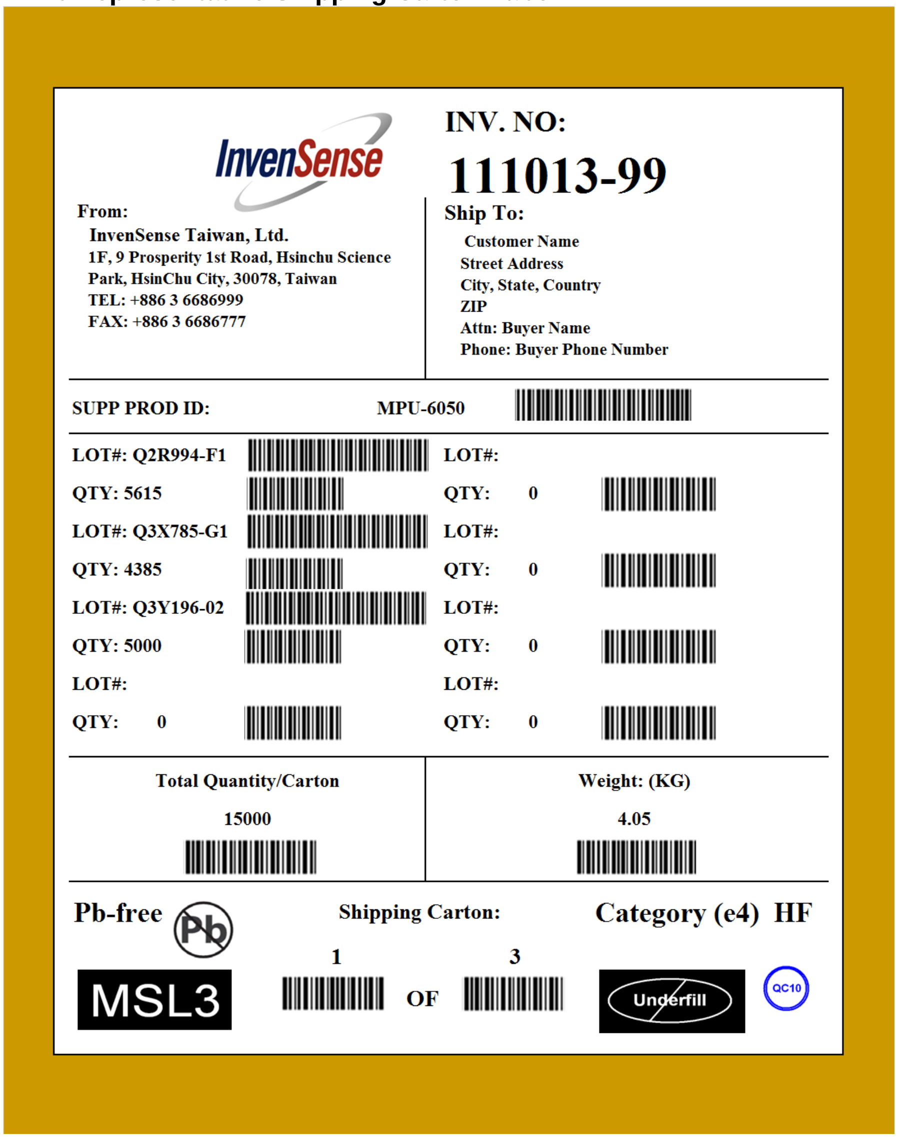
Inner Bubble Wrap

Pizza Box

Pizza Boxes Placed in Foam-Lined Shipper Box

Outer Shipper Label

11.10 Representative Shipping Carton Label



INV. NO:

111013-99

From:
InvenSense Taiwan, Ltd.
1F, 9 Prosperity 1st Road, Hsinchu Science Park, HsinChu City, 30078, Taiwan
TEL: +886 3 6686999
FAX: +886 3 6686777

Ship To:
Customer Name
Street Address
City, State, Country
ZIP
Attn: Buyer Name
Phone: Buyer Phone Number

SUPP PROD ID: MPU-6050

LOT#: Q2R994-F1	LOT#:
QTY: 5615	QTY: 0
LOT#: Q3X785-G1	LOT#:
QTY: 4385	QTY: 0
LOT#: Q3Y196-02	LOT#:
QTY: 5000	QTY: 0
LOT#:	LOT#:
QTY: 0	QTY: 0

Total Quantity/Carton	Weight: (KG)
15000	4.05

Pb-free Pb

Shipping Carton: 1 OF 3

Category (e4) HF

MSL3

Underfill

QC10

12 Reliability

12.1 Qualification Test Policy

InvenSense's products complete a Qualification Test Plan before being released to production. The Qualification Test Plan for the MPU-60X0 followed the JESD47I Standards, "Stress-Test-Driven Qualification of Integrated Circuits," with the individual tests described below.

12.2 Qualification Test Plan

Accelerated Life Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(HTOL/LFR) High Temperature Operating Life	JEDEC JESD22-A108D, Dynamic, 3.63V biased, Tj>125°C [read-points 168, 500, 1000 hours]	3	77	(0/1)
(HAST) Highly Accelerated Stress Test (1)	JEDEC JESD22-A118A Condition A, 130°C, 85%RH, 33.3 psia. unbiased, [read-point 96 hours]	3	77	(0/1)
(HTS) High Temperature Storage Life	JEDEC JESD22-A103D, Cond. A, 125°C Non-Bias Bake [read-points 168, 500, 1000 hours]	3	77	(0/1)

Device Component Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(ESD-HBM) ESD-Human Body Model	JEDEC JS-001-2012, (2KV)	1	3	(0/1)
(ESD-MM) ESD-Machine Model	JEDEC JESD22-A115C, (250V)	1	3	(0/1)
(LU) Latch Up	JEDEC JESD-78D Class II (2), 125°C; ±100mA	1	6	(0/1)
(MS) Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883, Method 2002.5, Cond. E, 10,000*g's*, 0.2ms, ±X, Y, Z – 6 directions, 5 times/direction	3	5	(0/1)
(VIB) Vibration	JEDEC JESD22-B103B, Variable Frequency (random), Cond. B, 5-500Hz, X, Y, Z – 4 times/direction	3	5	(0/1)
(TC) Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak Mode 2 [5'], 1000 cycles	3	77	(0/1)

Board Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(BMS) Board Mechanical Shock	JEDEC JESD22-B104C,Mil-Std-883, Method 2002.5, Cond. E, 10000*g's*, 0.2ms, +-X, Y, Z – 6 directions, 5 times/direction	1	5	(0/1)
(BTC) Board Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak mode 2 [5'], 1000 cycles	1	40	(0/1)

(1) Tests are preceded by MSL3 Preconditioning in accordance with JEDEC JESD22-A113F

13 Environmental Compliance

The MPU-6000/MPU-6050 is RoHS and Green compliant.

The MPU-6000/MPU-6050 is in full environmental compliance as evidenced in report HS-MPU-6000, Materials Declaration Data Sheet.

Environmental Declaration Disclaimer:

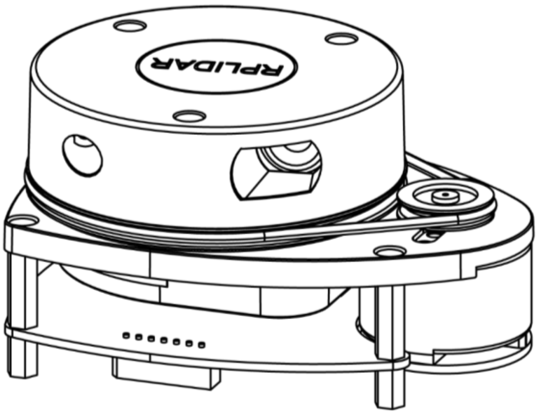
InvenSense believes this environmental information to be correct but cannot guarantee accuracy or completeness. Conformity documents for the above component constitutes are on file. InvenSense subcontracts manufacturing and the information contained herein is based on data received from vendors and suppliers, which has not been validated by InvenSense.

RPLIDAR A1

Low Cost 360 Degree Laser Range Scanner

Introduction and Datasheet

Model: A1M8



2016-07-04 rev.1.0

www.slamtec.com

Shanghai Slamtec.Co.,Ltd

RPLIDAR A1 is a low cost 360 degree 2D laser scanner (LIDAR) solution developed by SLAMTEC. The system can perform 360degree scan within 6meter range. The produced 2D point cloud data can be used in mapping, localization and object/environment modeling.

RPLIDAR A1's scanning frequency reached 5.5 hz when sampling 360 points each round. And it can be configured up to 10 hz maximum.

RPLIDAR A1 is basically a laser triangulation measurement system. It can work excellent in all kinds of indoor environment and outdoor environment without sunlight.

System connection

RPLIDAR A1 contains a range scanner system and a motor system. After power on each sub-system, RPLIDAR A1 start rotating and scanning clockwise. User can get range scan data through the communication interface (Serial port/USB).

Figure 1-1 RPLIDAR A1 System Composition

RPLIDAR A1 comes with a speed detection and adaptive system. The system will adjust frequency of laser scanner automatically according to motor speed. And host system can get RPLIDAR A1's real speed through communication interface.

The simple power supply schema saves LIDAR system's BOM cost and makes RPLIDAR A1 much easier to use. Detailed specification about power and communication interface can be found in the following sections.

Mechanism

RPLIDAR is based on laser triangulation ranging principle and uses high-speed vision acquisition and processing hardware developed by SLAMTEC. The system measures distance data in more than 2000 times' per second and with high resolution distance output (<1% of the distance).

RPLIDAR emits modulated infrared laser signal and the laser signal is then reflected by the object to be detected. The returning signal is sampled by vision acquisition system in RPLIDAR A1 and the DSP embedded in RPLIDAR A1 start processing the sample data and output distance value and angle value between object and RPLIDAR A1 through communication interface.

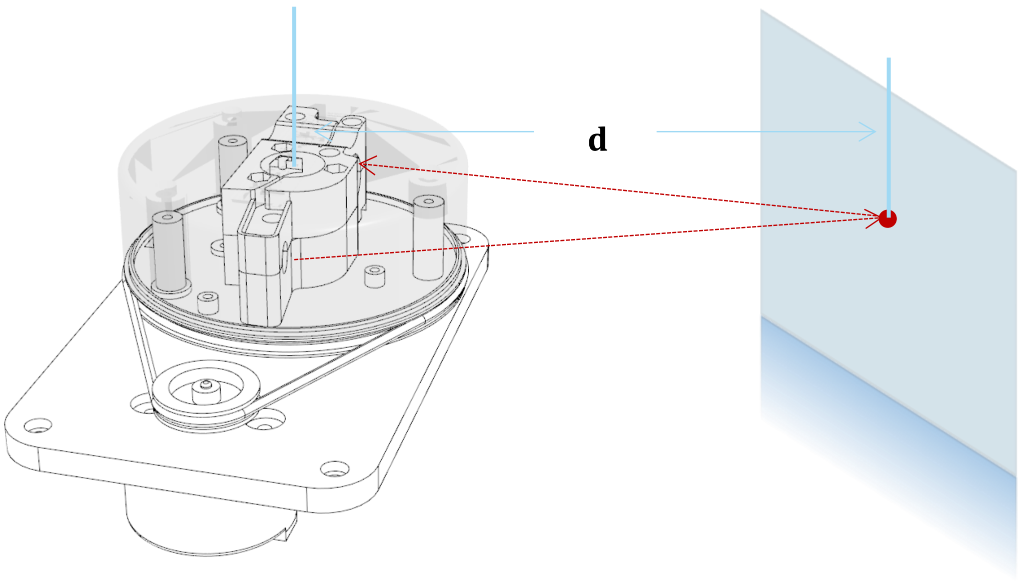
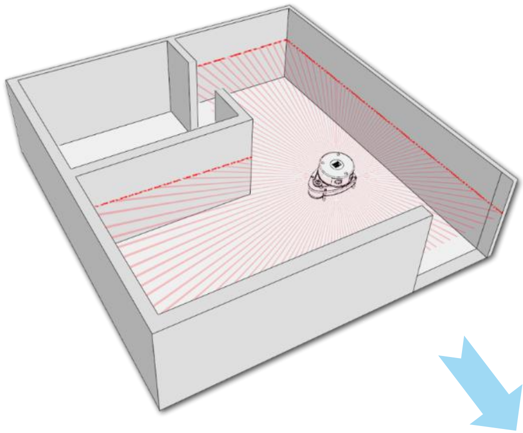


Figure 1-2 The RPLIDAR A1 Working Schematic

The high-speed ranging scanner system is mounted on a spinning rotator with a build-in angular encoding system. During rotating, a 360 degree scan of the current environment will be performed.



*Note：The LIDAR scan image is not directly relative to the environment showed here. Illustrative purpose only.

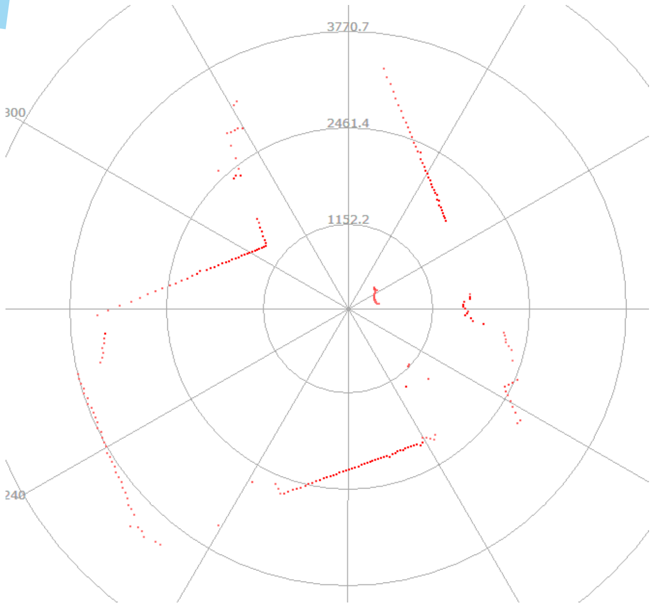


Figure 1-3 The Obtained Environment Map from RPLIDAR A1 Scanning

Safety and Scope

Class I

RPLIDAR A1 system use a low power (<5mW) infrared laser as its light source, and drives it using modulated pulse. The laser emits in a very short time frame which can make sure its safety to human and pet and reach Class I laser safety standard.

The modulated laser can effectively prevent ambient light and sunlight during ranging scanning process. This make RPLIDAR A1 work excellent in all kinds of indoor environment and outdoor environment without sunlight.

Data Output

When RPLIDAR A1 is working, sampling data will output to communication interface. Each sample point contains below information. RPLIDAR A1 outputs sampling data continuously. Host systems can configure output format and stop RPLIDAR A1 by sending stop command. If you need detailed data format and communication protocol, please contact with SLAMTEC.

Data Type	Unit	Description
Distance	mm	Current measured distance value between the rotating core of the RPLIDAR A1 and the sampling point
Heading	degree	Current heading angle of the measurement
Quality	level	Quality of the measurement
Start Flag	(Boolean)	Flag of a new scan

Figure 1-4 The RPLIDAR A1 Sample Point Data Information

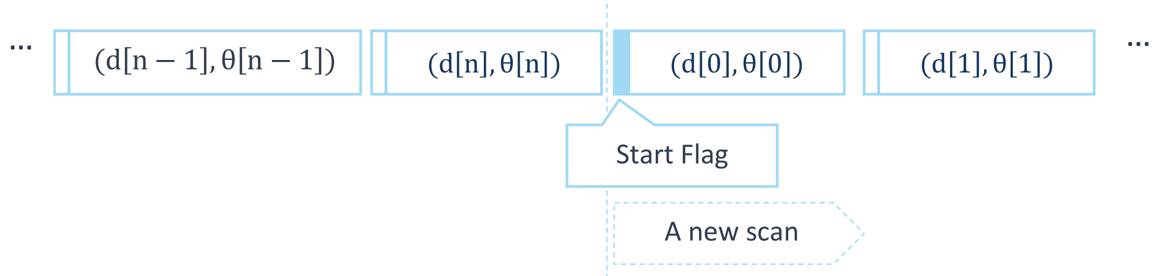


Figure 1-5 The RPLIDAR A1 Sample Point Data Frames

Application Scenarios

The RPLIDAR A1 can be used in the following application scenarios:

- Home service /cleaning robot navigation and localization
- General robot navigation and localization
- Smart toy's localization and obstacle avoidance
- Environment scanning and 3D re-modeling
- General simultaneous localization and mapping (SLAM)

Measurement Performance

- For Model A1M8 Only

Item	Unit	Min	Typical	Max	Comments
Distance Range	Meter(m)	TBD	0.15 - 6	TBD	White objects
Angular Range	Degree	n/a	0-360	n/a	
Distance Resolution	mm	n/a	<0.5	n/a	<1.5 meters
			<1% of the distance		All distance range*
Angular Resolution	Degree	n/a	≤1	n/a	5.5Hz scan rate
Sample Duration	Millisecond(ms)	n/a	0.5	n/a	
Sample Frequency	Hz	n/a	≥2000	2010	
Scan Rate	Hz	1	5.5	10	Typical value is measured when RPLIDAR A1 takes 360 samples per scan

Figure 2-1 RPLIDAR A1 Performance

Note: the triangulation range system resolution changes along with distance, and the theoretical resolution change of RPLIDAR A1 is shown as below:

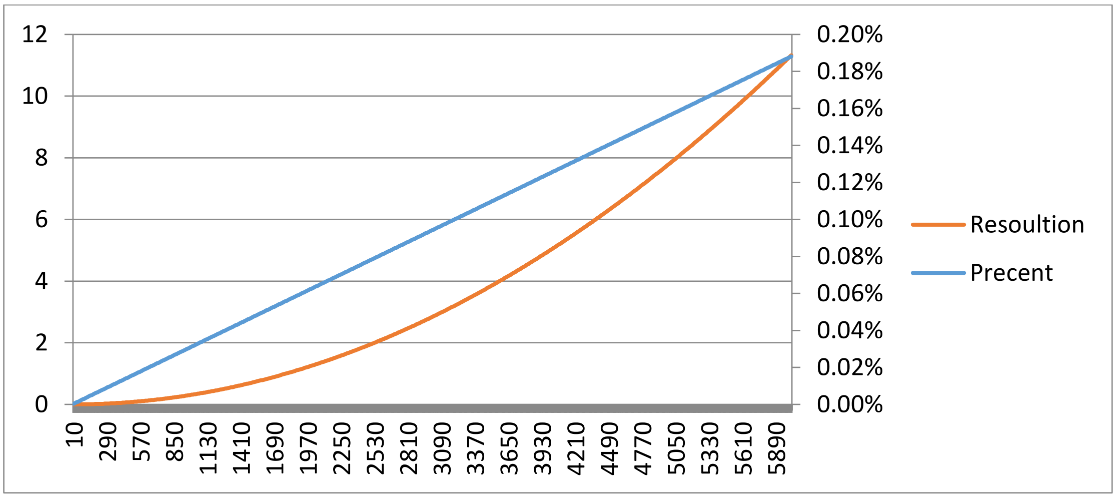


Figure 2-2 The Trend Graph of RPLIDAR A1 Resolution

Laser Power Specification

- For Model A1M8 Only

Item	Unit	Min	Typical	Max	Comments
Laser wavelength	Nanometer(nm)	775	785	795	Infrared Light Band
Laser power	Milliwatt (mW)	TBD	3	5	Peak power
Pulse length	Microsecond(us)	TBD	110	300	

Figure 2-3 RPLIDAR A1 Optical Specification

Communication interface

RPLIDAR A1 uses 3.3V-TTL serial port (UART) as the communication interface. Other communication interface such as USB can be customized according to customer's requirement. The table below described specification for serial port interface. Please contact SLAMTEC if you want detailed communication protocol and SDK.

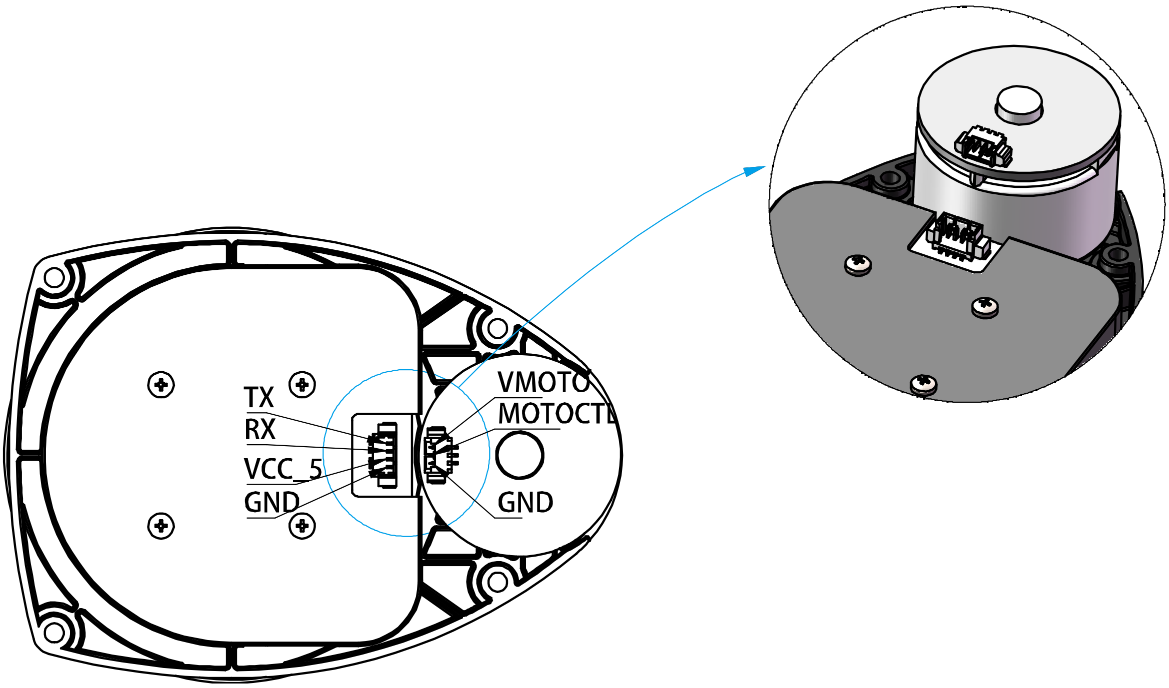


Figure 2-4 RPLIDAR A1 Power Interface

Item	Unit	Min	Typical	Max	Comments
Band rate	bps	-	115200	-	
Working mode	-	-	8N1	-	8n1
Output high voltage	Volt (V)	2.9	-	3.5	Logic High
Output low voltage	Volt (V)	-	-	0.4	Logic Low
Input high voltage	Volt (V)	1.6*	-	3.5	Logic High
Input low voltage	Volt (V)	-0.3	-	0.4	Logic Low

Figure 2-5 RPLIDAR External Interface Signal Definition

Note: the RX input signal of A1M8 is recognized by the current. In order to ensure the reliable signal identification inside the system, the actual control node voltage of this pin will not be lower than 1.6v.

Interface	Signal Name	Type	Description	Min	Typical	Max
Motor Interface	VMOTO	Power	Power for RPLIDAR A1 Motor	-	5V	9V
	MOTOCTL	Input	Enable signal for RPLIDAR A1 Motor/PWM Control Signal	0V	-	VMOTO
	GND	Power	GND for RPLIDAR A1 Motor	-	0V	-
Core Interface	VCC_5	Power	Power for RPLIDAR A1 Range Scanner Core	4.9V	5V	6V
	TX	Output	Serial output for Range Scanner Core	0V	-	5V
	RX	Input	Serial input for Range Scanner Core	0V	-	5V
	GND	Power	GND for RPLIDAR A1 Range Scanner Core	-	0V	V5.0

Figure 2-6 RPLIDAR A1 External Interface Specifications

Note: for the motor interface and core interface of batch version, they use the PH1.25-3P horizontal pitch connector and PH1.25-4P vertical pitch connector respectively. Please refer to the mechanical dimensions in Chapter 5 for details of signals and their matched pins. But the RPLIDAR development kit uses the PH2.54-7P pitch connector. Please refer to *RPLIDAR Development Kit User Manual* for detailed specifications.

Power Supply and Consumption

Ranging scanner system and motor system are powered separately in RPLIDAR A1. External system should provide power supply for them separately in order to ensure data accuracy. Below chart showed a recommended power mode. More specification is provided in the following table.

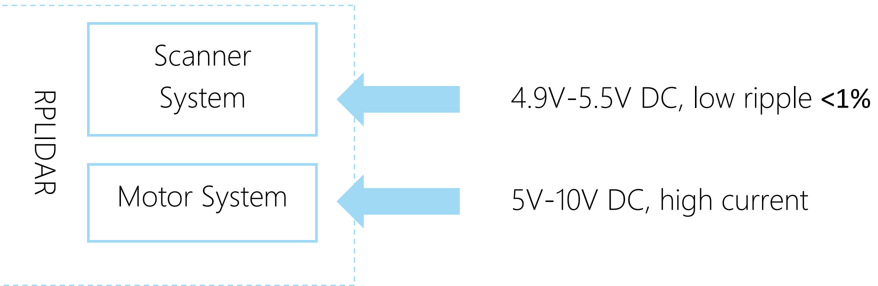


Figure 2-7 RPLIDAR A1 Power Recommended Power Mode

Item	Unit	Min	Typical	Max	Comments
Scanner system voltage	Volt (V)	4.9	5	5.5	If the voltage exceeds the max value, it may damage the core.
Scanner system voltage ripple	Millivolt(mV)		20	50	High ripple may cause the core working failure.
Scanner system start current	Milliampere (mA)	TBD	500	600	Underpower may cause the startup failure.
Scanner system current	Milliampere (mA)	TBD	80	100	Sleep mode, 5V input
		TBD	300	350	Work mode, 5V input
Motor system voltage	Volt (V)	5	5	10	Adjust voltage according to speed
Motor system current	Milliampere (mA)	TBD	100	TBD	5V input

Figure 2-8 RPLIDAR A1 Power Supply Specification

MISC

- For Model A2M3/A2M4 Only

Item	Unit	Min	Typical	Max	Comments
Weight	Gram (g)	TBD	190	TBD	
Temperature range	Degree Celsius (°C)	0	TBD	45	

Figure 2-9 RPLIDAR A1 MISC Specification

To make sure RPLIDAR A1's laser always working in the safety range (<5mW) and avoid any other damage caused by device, RPLIDAR A1 comes with laser power detection and sensor healthy check feature. RPLIDAR A1 will shut down the laser and stop working when any of below errors has been detected.

- Laser transmit power exceeds limited value
- Laser cannot power on normally
- Scan speed of Laser scanner system is unstable
- Scan speed of Laser scanner system is too slow
- Laser signal sensor works abnormally

Host systems can inquiry the RPLIDAR A1's status through communication interface and restart RPLIDAR A1 to try to recovery from error.

SLAMTEC provides debug GUI tool and SDK (available for Windows, x86 Linux and Arm Linux) to speed up the product development for users. Please contact SLAMTEC for detail information.

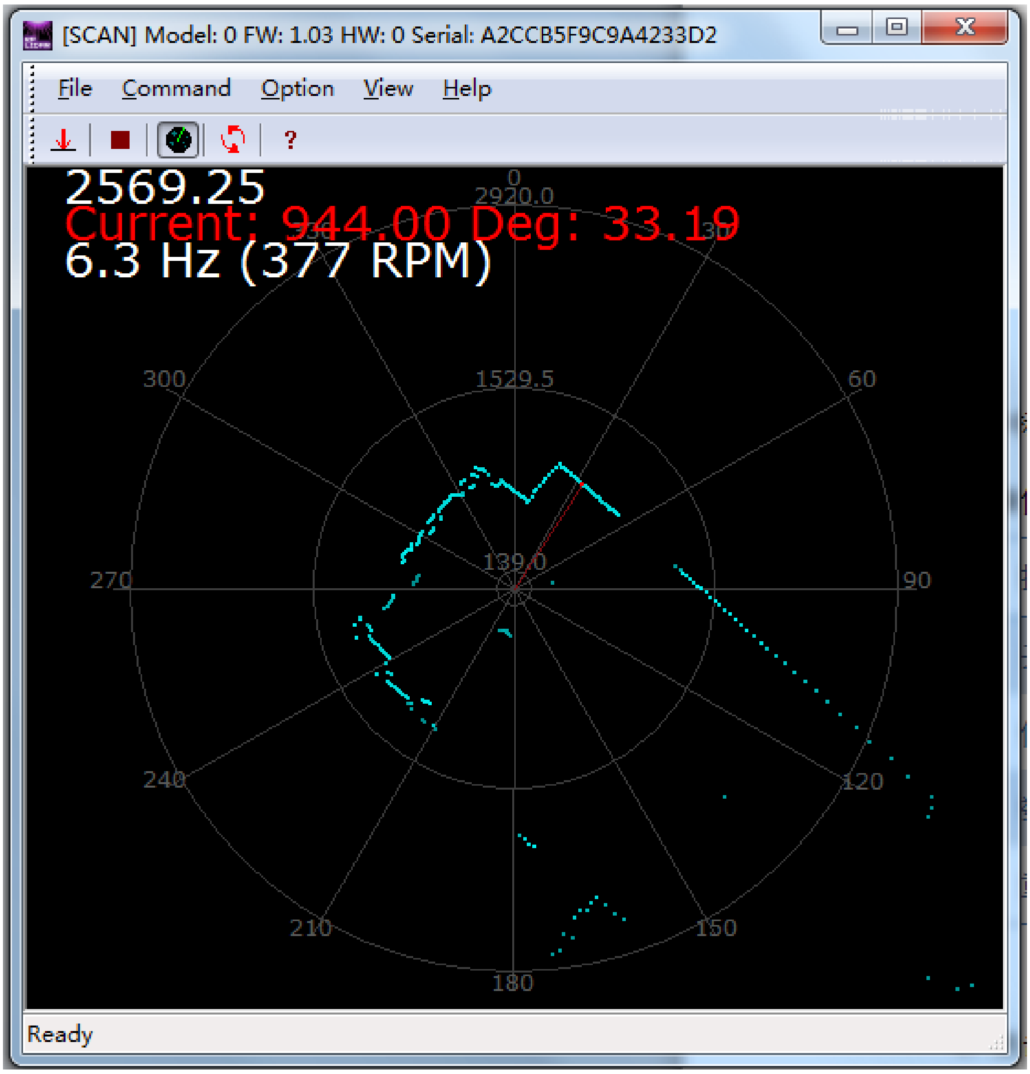


Figure 4-1 the Debugging GUI of RPLIDAR A1

To facility customer's integration, RPLIDAR A1's structure is designed to decouple the core ranging system and fixed platform which can be customized. The part marked red in the below figure is the fixed platform that can be customized according to customer requirement.

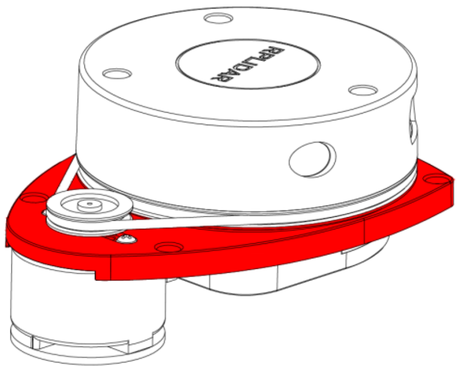


Figure 5-1 The fixd platform of RPLIDAR A1

The RPLIDAR A1-A1M8 assemble size showed below:

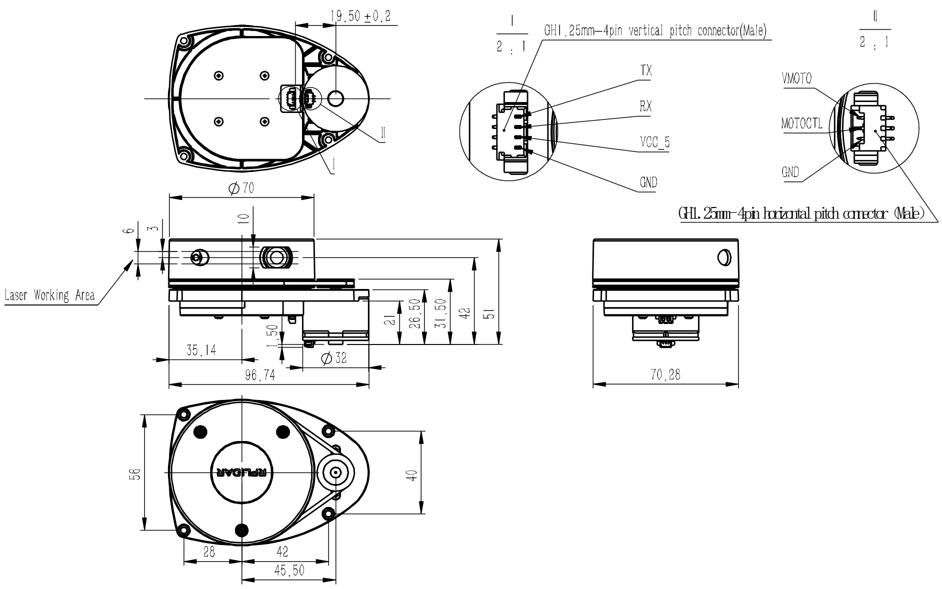
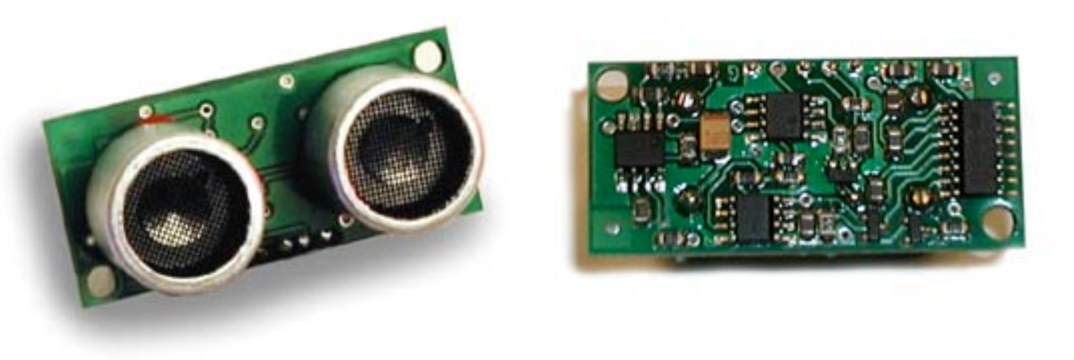


Figure 5-2 The Mechanical Dimensions of RPLIDAR A1

Date	Description
2013-3-13	Initial draft
2013-5-16	1. Updated the laser class information 2. Updated motor voltage range 3. Updated size chart according to Rev1.5 sample design
2013-8-9	Updated power consumption
2013-11-23	Updated product specification
2013-12-29	Updated product specification
2014-2-9	Added model name: A1M1
2014-4-17	Added weight and temperature range description
2014-5-6	Changed the measurement distance range based on the new design
2015-6-3	Update Mechanical parameter figure. Modify model name to A1M3
2016-3-29	Update Mechanical parameter figure. Modify model name to A1M8
2016-04-25	Added startup current requirement of A1M8 and corrected some parameter errors
2016-04-28	Added connection information for batch version
2016-05-19	Replaced obsolete images.
2016-07-04	Updated the description about RX input signal and added a note about it.

Image and Table Index

Devantech SRF04 Ultrasonic Ranger



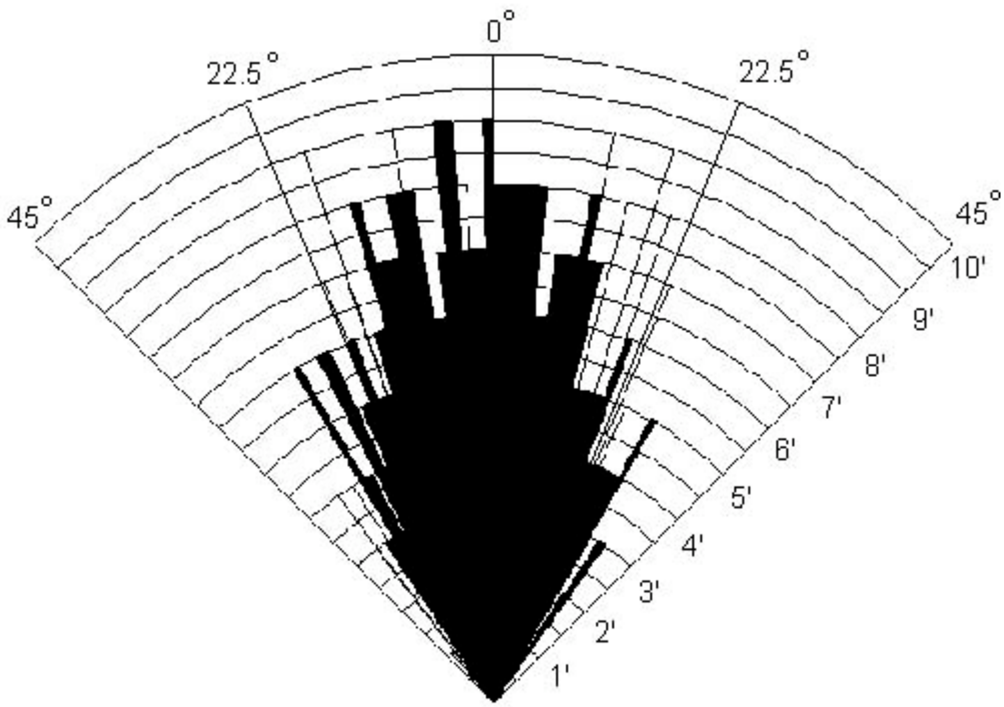
This high performance ultrasonic range finder is compact and measures an amazingly wide range from 3cm to 3m. This ranger is a perfect for your robot or any other projects requiring accurate ranging information.

Specifications

Beam Pattern	see below
Voltage	5v
Current	30mA Typ. 50mA Max
Frequency	40KHz
Maximum Range	3 m
Minimum Range	3 cm
Sensitivity	Detect a 3cm diameter stick at > 2 m
Input Trigger	10uS Min. TTL level pulse
Echo Pulse	Positive TTL level signal, width proportional to range.
Weight	0.4 oz.
Size	1.75" w x 0.625" h x 0.5" d

Specifications subject to change without notice

Beam Pattern



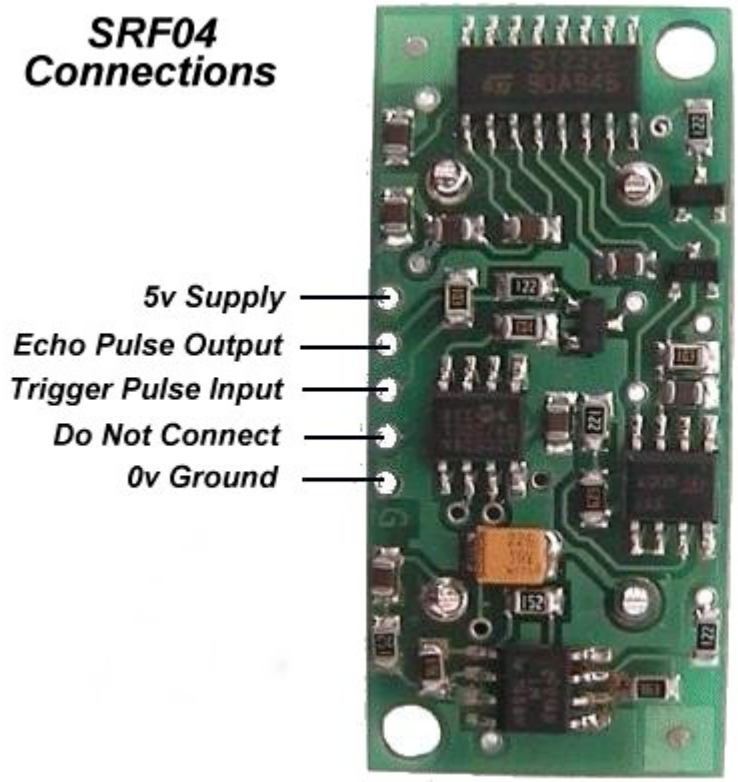
Theory of Operation

The ranger works by transmitting a pulse of sound outside the range of human hearing. This pulse travels at the speed of sound (roughly 0.9 ft/msec) away from the ranger in a cone shape and the sound reflects back to the ranger from any object in the path of this sonic wave. The ranger pauses for a brief interval after the sound is transmitted and then awaits the reflected sound in the form of an echo. The controller driving the ranger then requests a ping, the ranger creates the sound pulse, and waits for the return echo. If received, the ranger reports this echo to the controller and the controller can then compute the distance to the object based on the elapsed time.

Connections

We have many programs using the OOPic with the SRF04 with the Trekker. Also, Devantech has examples using the SRF04 module with a wide range of popular controllers.

Want to know the history of this little module, and even more information?

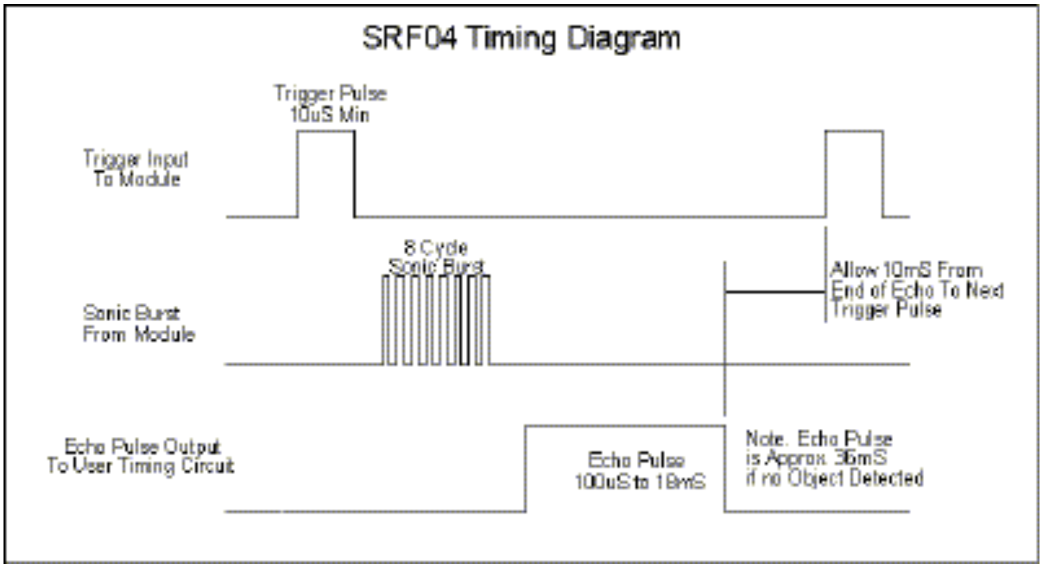


The ranger requires four connections to operate. First are the power and ground lines. The ranger requires a 5V power supply capable of handling roughly 5OmA of continuous output. The remaining two wires are the signal wires. The connections can be made by soldering wire leads to the board or header pins/sockets.

Basic Timing

There are a couple of requirements for the input trigger and output pulse generated by the ranger. The input line should be held low (logic 0) and then brought high for a minimum of 10usec to initiate the sonic pulse. The pulse is generated on the falling edge of this input trigger. The ranger's receive circuitry is held in a short blanking interval of 100usec to avoid noise from the initial ping and then it is enabled to listen for the echo. The echo line is low until the receive circuitry is enabled. Once the receive circuitry is enabled, the falling edge of the echo line signals either an echo detection or the timeout (if no object echo is detected).

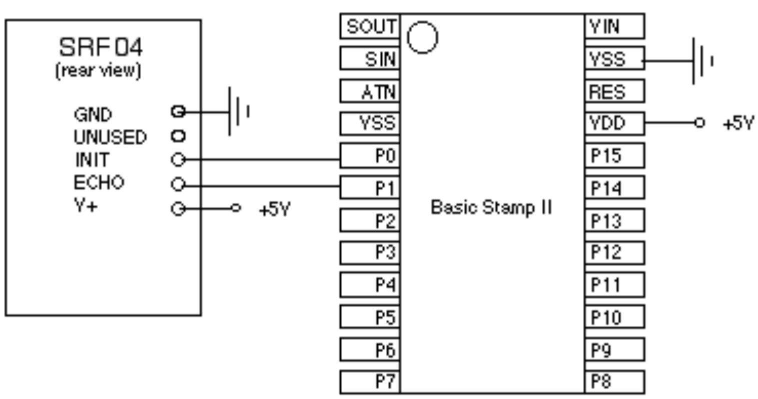
Your controller will want to begin timing the falling edge of your trigger input and end timing on the falling edge of the echo line. This duration determines the distance to the first object the echo is received from.



Interface Example

This example demonstrates the SRFO4 interface to a Basic Stamp II. Interfacing with the OOPic is a lot easier! For an OOPic example follow this link.

This example uses the Basic Stamp II carrier board and debug output capability to take continuous readings from the SRFO4 and display them in the debug console of the Stamp development environment.



Example; Code:

```
' Devantec SRFO4/Basic Stamp II Example
wDist    var     word
INIT     con     1

' CONVERSION FACTORS
' The PULSIN command returns the round-trip
'echo time in 2us units which is equivalent to
' the one-way trip time in 1 us units
' distance = (echo time)/ conversion factor)
' use 74 for inches
' use 29 for centimeters

convfac    con    74     'use inches

main
   gosub sr_sonar
   debug dec wDist,cr
   pause 200
   go to main

sr_sonar:
   pulsout INIT, 5                    '10us pulse
   pulsin ECHO,I,wDist wDist          'measure echo time
   wDist/convfac                      'convert to inches
   pause 10
   return

sr_sonar_2:
   pulsout INIT, 5                    '10us init pulse
   output INT                         'dummy command (delay)
   rctime ECHO,I,wDist                'measure echo time
   wDist = wDist/convfac              'convert to inches
   pause 10
return
```

The execution time of the pulsin instruction will be slightly different for different pins. If you change the pin assignments, the pulsin command in the sr_sonar subroutine listed above may miss the rising edge of the ECHO input and return some readings of O. Using rctime instead of pulsin may fix this problem. Another trick is to introduce a small delay with a dummy command before measuring the echo time with the rctime command. This is illustrated in the alternate subroutinesr_sonar_2. You may need to experiment to determine the best code for your application. Or just use the OOPic and skip all this mess!