EEE193A/CPE190A Senior Design
Instructor:Professor Fethi Belkhouche

Team 8: Smart Life Vest System

Assignment 7 : Laboratory Prototype Documentation

Fall 2015

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Abstract: Team Smart Life Vest is a project that focuses on reducing drowning, an underrated problem in society. The team hopes to accomplish this by accelerating the response time between rescuers and potential victims by designing a life vest with implemented wearable technology. This report will go over the technical details of our design and the team's thought process throughout the period of designing the Smart Life Vest. Some of the important documentation includes the Design Contract, the Work Breakdown Structure, and the Risk Assessment.

Index Terms: **Arduino, Microcontroller, GPS, GSM, IMU, Android, PHP, MYSQL, Database**

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I. PROBLEM STATEMENT

A. Introduction
The increased need to maintain a healthy lifestyle has been apparent throughout our society. Exercise including aquatic activities show exceptional health benefits for remaining active. However, engaging in aquatic activities may also inevitably cause an increase in drowning deaths.

B. The Drowning Crisis
In most countries around the world, drowning is the leading cause of injury-related death. Drowning is a serious and underestimated health and social problem worldwide. According to the WHO (World Health Organization), drowning is the third leading cause of unintentional injury death, accounting for 7% of all injury-related deaths. There are an estimated 372,000 annual drowning deaths worldwide. There are various negative effects including emotional, psychological, physiological, sociological, legal and financial consequences.

C. Consequences
There are many variables that can contribute to cause drowning, with some areas and certain demographics being more susceptible. Negative effects of drowning go beyond not only a growing number in fatalities, but can also affect all of those involved in the incident, the community, and on a larger scale also affect the economy.

D. Possible Solutions
Many methods and policies have been placed in order to tackle this issue, with some being more successful than others. For this reason, we proposed to create a "Smart Life Vest" system that will combat drowning as a societal problem. This smart life vest will not only increase the chance of survival, but also aide the rescuer in finding the victim easier and faster.

II. DESIGN IDEA CONTRACT

A. Elevator Pitch
We are creating a smart life vest that will guide rescuers to a drowning victim.

B. The Smart Life Vest
Our smart life vest will increase the likelihood of survival of the user stranded in water through the use of: a GPS (Global Positioning System) tracking device, an IMU (Inertial Measurement Unit) motion sensor, a GSM (Global system for mobile communications) module, as well as software that will program the microcontroller and create the user application interface.

The application will show the location coordinates of the wearer as well as a "status" that shows whether the user is in danger. This status will be based upon if the user is moving or not and will be determined by the IMU. These components will need to be connected to our GSM module in order to transmit data to the application software. To achieve this, the GSM will first transmit data through a website host that will then send that data to the smart phone application. The data will not only appear on the application, but also on the website. In an effort to minimize space and maximize efficiency, all three components (GPS, IMU, GSM) will programmed and integrated together on the same Arduino microcontroller. In addition, all of the components will need to be waterproofed as they will be embedded into the life vest. However, for our prototype we will not integrate our components into the life vest just yet. We will simply ensure that all components can communicate together and send the appropriate data to show on our application. We will work on designing the life vest with our components during the spring semester.

III. OUR DESIGN IDEA:

A. GPS (Global Positioning System) Implementation:
The GPS module will track the location of the life vest so that the location coordinates (longitude and latitude) can be seen on the application.

This will increase the efficiency for rescuers as well as save time drastically if the exact location of the victim is known. Implementation of this feature requires the Adafruit ultimate GPS breakout shield. It will be programmed using the Arduino Uno microcontroller in conjunction with the open source Arduino software IDE.

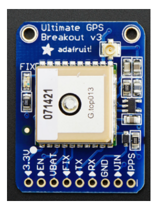

Figure 1. Adafruit Ultimate GPS Breakout-Version 3

B. IMU (Inertial Measurement Unit) Implementation
The IMU sensor within the jacket will be able to track the wearer's orientation. This will be instrumental in determining whether the user is in trouble or not.

We plan to designate a range of values of the orientation and acceleration of the wearer. If these several warning checkpoints are passed, this will trigger warning signals to the controller that the wearer is in an unsafe state and will require help.

Our assumptions will be generalized in the first semester with more accuracy planned for the spring semester. Based on the orientation angle of the IMU, we will simply set two statuses that will show on the application if the user is moving or not moving.

For the spring semester we plan to have the IMU capable of tracking different swim patterns and moving speeds. We also looked into the possible need of adding another IMU sensor. In an attempt to minimize lifejacket space and save money, we will implement the IMU on the same microcontroller for testing sake. Eventually we will attempt to improve upon simply using an Arduino, possibly in favor or something more compact and better secure.

Figure 2. SparkFun 9 Degrees of Freedom Breakout – MPU-9150 (IMU)

C. GSM (Global system for mobile communication)

A GSM module will be necessary in receiving data from the GPS and IMU and then transmitting that data to the online database of our website. Once the information has been seen on the server, it will then be sent to the Android based studio application software. This data must be received accurately in real time with minimum delays, and then outputted to the user interface.

The hardware used will be an Arduino GSM shield 2 with an integrated antenna. This shield also has text and call capabilities. If for whatever reason the application crashes, the GSM will be able to send text messages containing the data as a backup plan.

Adding calling and voice activation is a feature we will explore in the spring semester. The GSM module is a pivotal component throughout our entire project. Much of our success in senior design relies on this GSM module working properly.

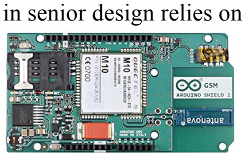

Figure 3. Arduino GSM Shield 2 A000105

D. Smartlifevest.com

Through extensive research and after communicating with another team in senior design, we concluded that it would be more efficient to create a website in order to transmit data from the GSM to the application.

This information will be stored in the database of our website and then sent to the application using PHP (a server scripting language) commands integrated with MySQL (an open source database). The location and status of the wearer will show on the application in addition to the website.

As a starting point the website is used simply as a proxy to transmit our data. However in the spring semester we will work on formatting the website to have a cleaner and more user friendly look.

E. User Interface

With the immense use of smartphones and in an effort to make our system more user friendly, creating a smartphone application was an obvious choice. This will make our product more accessible to everyday people.

The application or "map app" will be designed to take the longitude and latitude emitted from the GPS receiver to show where it is on a map. Using the data acquired from the IMU, the app will also need to have a feature that shows whether or not the victim is in immediate danger or not.

The software associated with the app will be designed using the "Android Studio:"
https://developer.android.com/sdk/index.html.
Tools and platforms given from its SDK manager:
https://developer.android.com/tools/help/sdkma nager.html.

Using this setup is ideal for keeping cost low since it is free and will give us access to Google Maps, which we will use to show the location of the wearer.

We also keep in mind the use of more than one smart life vest. Being able to differentiate between data coming from multiple vests is an added feature we would like to place on the application during the spring semester. Some kind of color coded system will be implemented in order for the user of the application to distinguish between different vests and their respective locations/statuses.

IV. FUNDING

The Smart Life Vest system was fully funded by the members of the team. However, our budget will be more expensive during the spring semester. Therefore, we will make our efforts to look into outside resources for funding.

Table 1. Fall 2015 Project Budget

Adafruit Ultimate GPS Breakout – 66 channel w/10 Hz updates – Version 3	$39.95
Arduino GSM Shield 2 A000105	$89.95
Sim card phone plan with AT&T	$25.00/month
SparkFun 9 Degrees of Freedom Breakout – MPU-9150 (IMU)	$34.95
Arduino Uno Microcontroller	$29.95
Website Domain	$69.95
TOTAL	$289.75

Table 2. Spring 2016 Project Budget

Adafruit Ultimate GPS Breakout – 66 channel w/10 Hz updates – Version 3	$39.95
Arduino GSM Shield 2 A000105	$89.95
Sim card phone plan with AT&T	$25.00/month ≈ $150.00 total
SparkFun 9 Degrees of Freedom Breakout – MPU-9150 (IMU)	$34.95
Arduino Uno Microcontroller	$29.95
Power Supply	≈ $30.00
Website Domain	$69.95
Life Jacket Materials	≈ $25.00
TOTAL	$469.75

V. WORK BREAKDOWN STRUCTURE

A. Overview

Planning the break down of our project, the "Smart Life Vest" was necessary in order to fully envision our system. Each feature is broken down into sub features and then activities.

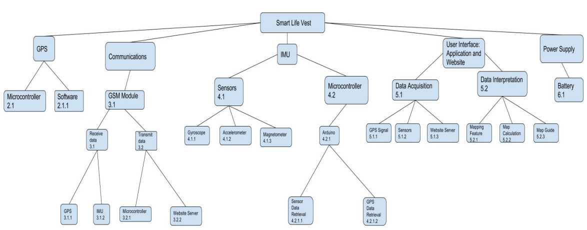

Figure 4. Work Breakdown structure diagram

B. Locating the User

The GPS device will be used to determine the location coordinates of the user. The module itself has a red light in place as a visual indicator to show when it is fully implemented. We know that a signal has been reached once the red light stops flashing.

The GPS will then transmit the signal to the GSM device. (2.1) This will be implemented using an Arduino Uno microcontroller and (2.1.1) the Arduino open source software IDE.

C. System Communications

We must also ensure that the individual components of our design will be able to communicate and work with one another. This is vital for the functioning of the entire system. (3.1) The GSM must have adequate reception and power to be able to receive the data and then (3.2) transmit that data to the user interface. Information will be received from the (3.1.1) GPS as well as the (3.1.2) IMU. The GSM will then transmit after being programmed through the (3.2.1) microcontroller. We will connect the GSM to the (3.2.2) website server, in which the data will then go to the application.

D. Status of the User

With the IMU motion sensor, the status of the user will be determined. The status indicates whether the wearer is in danger or not. For testing purposes, this will be simplified and will only determine whether the user is moving or not.

Integrated within the IMU device are sensors, (4.1.1) gyroscope, (4.1.2) accelerometer and (4.1.3) magnetometer. These are used to detect object orientation, angle and speed. We will once again be implementing the IMU with the (4.2.1) Arduino microcontroller.

The microcontroller will (4.2.1.1) receive the data from the sensors in addition to (4.2.1.2) receiving data from the GPS.

E. User Interface

After the user's location and status has been determined, it is vital that this information can be seen and interpreted in a user friendly manner. For this reason, we will create a smart phone application that will first need the data parsed through a website server.

The website itself will also be able to show the status and location coordinates as well for the user. (5.1) Data from the GSM will be acquired by the server (5.2) and then interpreted by the application.

The acquired data includes information from the (5.1.1) GPS signal, (5.1.2) sensors, and (5.1.3) website server. Through coding of the application, this data will be interpreted to create a (5.2.1) mapping feature, (5.2.2) map calculation, and (5.2.3) map guide.

F. Power Supply

Of course it is necessary to power our system in a portable and efficient manner. The power supply will obviously need to be water proofed as well. We will be implementing a waterproof and portable (6.1) battery that can provide enough power for our system

VI. PROJECT TIMELINE

A. Milestone 1: Confirm Arduino Measurement Components Working Properly

The first milestone for our project mainly consisted of testing the Inertial Measurement Unit and the GPS to determine their effectiveness and reliability. The GPS was easy to implement and test, but reliable locations were difficult to determine.

The GPS signal gets blocked when inside tall buildings, therefore for testing purposes, it was done outdoors. Similar to the GPS, the IMU was easy to setup. A breakout board containing several sensors was used for our IMU.

During testing however, the IMU required lots of research to decipher the data. An algorithm was needed to filter out noise and pass through reliable data. Additionally, the IMU needed to integrate all three of its sensors: accelerometer, gyroscope, and magnetometer in order to offset error accumulation.

Afterwards, a lot of testing was to be done to capture data that accurately represented the motions our users would commonly act. Precision was key in determining the user state.

B. Milestone 2: Establish Stable Connection between GSM & Web Server

The second major milestone for our project was making sure we had a good reliable way of communicating between the lifejacket and wherever the GPS was needed in order to reach the user. Suffice to say, the GSM was the backbone of our design. Without it, there is no help that can come to save our potential user.

We had many issues with finding a good GSM shield that worked well with the Arduino microcontroller we were already using with our measurement components.

Because not many people have tried integrating GSM and Arduino data transfer, there wasn't much documentation to go on.

Additionally, like the GPS, location was a prominent factor in determining how well the device worked. A lot of moving around had to be done, to find a location where the GSM worked reliably. Even then, the GSM takes a while to warm up and begin sending data.

That's the price that has to be paid however, in order to achieve long range communications. By the end we were able to use the GSM to send hard-coded "data" to our online web server.

C. Milestone 3: Integration of Components & GSM

The third major milestone for our project is integrating all of our components together. The main issue we had with integrating Arduino components in general was wondering how to properly simultaneously initialize all the components.

For Arduino components in general, we weren't sure if we needed several open serial monitors for each component to start working, so to confirm we started testing with integrating the GPS and the GSM together without implementing any serial monitor.

We had it set up to send GPS coordinates to a cell phone. We were successful, to our pleasant surprise as we were able to send the coordinates as planned, which was followed by sending GPS coordinates to our Website. This was followed by combining the IMU code with the GSM & GPS code.

With the IMU, we had it set so during particular motions or user "states", it would trigger the GSM to start sending GPS coordinates to the website along with the user state.

D. Milestone 4: Integration of Web Database & Android Application

The fourth milestone was the integration of the web database and the android application. Because this was not part of our original design, we were initially quite overwhelmed with the extra workload, not to mention that none of us had any experience whatsoever with the database language MySql, or the web programming language PHP.

This milestone consisted of three major parts: firstly, we had to create a database inside of a web server. Next, we had to write code in order to push the data into a "JSON" array. Next we had to write code into the application to access and parse the JSON array.

In this section, we would like to extend a special thanks to Belal Khan of "Simplified Coding," his article "Android JSON Tutorial to Get Data from MySql Database." We used his tutorial for the basis of our android application coding.

VII. RISK ASSESSMENT

A. Overview

The figure below is a risk matrix reflecting the probability of certain risks compared with their relative damages:

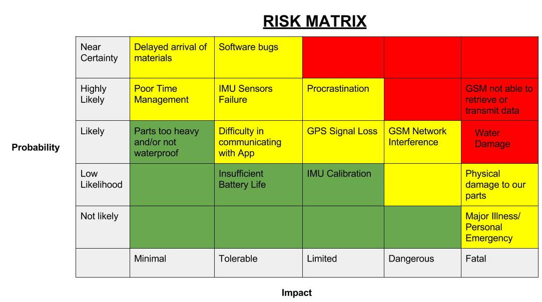

Figure 5. Risk Matrix

Risks that are common to all components include possible water and or general equipment damage, as well as an incompatibility from one component to another. The mitigation plan to avoid water and equipment damage is to first and foremost, simply be careful with our equipment.

Our plan is to encapsulate the entire device into a single plastic, waterproof box when we apply it to an actual lifejacket. The mitigation plan to avoid incompatibility is to simply start piecing our project together early, this way we have time to identify potential issues.

B. GPS (Low Risk)

I. Risks
GPS signals can be affected by multipath issues, where the radio signals reflect off surrounding terrain such as tall buildings and walls. These delayed signals cause measurement errors that are different for each type of GPS signal.

II. Mitigation Plan
Therefore, a specialized external antenna may be used to improve the sensitivity and reduce the signal power as received by the antenna. An external antenna will help by providing an additional gain and maximize our signal strength.

C. IMU (Medium Risk)

I. The Risks
The most likely risk with the IMU is human error. Incorrect connections and lack of experience will increase the likelihood of something going wrong. Another risk, while not as likely but potentially dangerous is hardware failure. Faulty hardware will need to be replaced resulting in more money and delay progress during developmental stages, while a faulty product will result in jeopardizing the user's safety.

Some other risks associated with the IMU is that it must be calibrated correctly upon power up every time. If state parameters aren't precise, the lifejacket will not be able to detect when user is in trouble, which is the key function of the lifejacket. This is another dangerous risk that needs to be avoided.

One risk that is easily manageable of IMU's is data drift from the IMU. Data drift are errors in the data that accumulate proportionally over time and will end up with inaccurate data. The more the IMU is in use, the more the error accumulates. While this is an innate issue with IMU's, it is also supplanted by the fact that IMUs make use of several different sensors to help offset the error.

II. Mitigation Plan
The biggest mitigation strategy for the IMU is good experimental practices. That means being organized in the data collection, conducting many trials for data acquisition, and giving oneself enough time to complete the tasks.

If hardware fails due to human error or by some supernatural act, it's important to make sure backup and replacement hardware to be able to replace the faulty hardware. Lastly, to make sure the state parameters are working correctly, many additional tests will be need to ran to confirm their accuracy.

D.GSM (High Risk)
Within the GSM module lies our biggest risk. If the GSM can not communicate with the other components, this will ultimately be the demise of our project. Our project relies heavily on the stable operation of the GSM module.

I. Risks
The first obstacle will be to get the GSM activated with the microcontroller and recognizing the IMU and GPS device. The GSM will then need to transmit the data to our application. The connection between the microcontroller and the application has to be communicated in nearly real time.

If there are any delays with receiving or transmitting of any information, this could have fatal consequences to the user. Because the GSM modem communicates over the mobile network, the operation of our life vest system is limited to areas only within range of the mobile network.

In addition, lack of experience working with communication devices such as the GSM attributes to the high risk factor with this feature.

II. Mitigation Plan
In order to overcome these challenges, we need to designate a large amount of time for not only coding but also the knowledge behind how the connection works. This part requires extensive research. Efficient time management and effective communication among all team members is necessary for success with this feature especially.

Safety is obviously of the highest importance in our project. The risk of having faulty or delayed data transmitted to our user interface will affect the safety of the user, especially when swimming in unpredictable conditions. The output from the GSM must be tested and verified. For this reason, we must be prepared and become familiar with the GSM device. Ultimately, through adequate use of our time and attention to detail we can begin to take on any issues that may arise with the GSM device

E. Application (Medium High Risk)

I. Risks
Seemingly the most obvious, an application malfunction, meaning that the application would be detrimental to the survival of the victim. Furthermore, a bug in a software program is inevitable in nature so the best mitigation plan is to ensure that the application is functioning properly.

Unfortunately, although this is a good plan to shoot for, as previously mentioned, there will eventually be a malfunction in the application, whether it is the phone or the app.

With technology changing every second, it is possible that there may an incompatibility with other pieces of technology within the life vest. Because the technology in the vest has no foreseeable changes, this risk lies exclusively with the phone that is at risk

II. Mitigation Plan
The easiest and inconspicuous solution to a software bug is simply start the programming process early. The only way to ensure proper functioning of the application, when lives are on the line, is a rigorous testing plan early in the process.

This way, as many as possible of the possible bugs in the application can be weaned from the system.

As a backup, to take care of possible errors that may surface in the case of an emergency, the GSM will automatically send the coordinates and the current state of the the victim every thirty seconds.

F. Power Supply (Low Risk)

I. Risks
The power supply does not have enough power the system to run for at least 12 hours straight. Moreover, the power supply is too heavy, so it will put the victim in danger of drowning. Also, water can wet the power supply and make the system be corrupted.

II. Mitigation Plan
The power supply should be designed to have enough power to support the system for at least 12 hours straight. Moreover, the battery must be light in weight and portable. The user should not feel a heavy load on their back while swimming. It would be ideal if the battery was waterproof, however the battery could be sealed with durable water proof materials.

VIII. TASK ASSIGNMENTS

Provided below are tables indicating tasks completed by each team member. These tasks are broken up into sections pertaining to each team members' assigned component.

Table 3 – Joseph Joslin Work Breakdown Hours	
Research	3
Assignments	19
Application	31
Communication	12
Server	38
Meetings	13
Total	116

Table 4 – King Nguyen Work Breakdown Hours	
IMU	30
Assignments	15
GPS	5
GSM	5
Power Supply	5
Meetings	13
Total	73

Table 5 – Trieu Pham Work Breakdown Hours	
Research	10
Assignments	15
GPS	10
Power Supply	5
Meetings	13
Total	53

Table 6 – Kristie Sihombing Work Breakdown Hours	
Research	13
Assignments	11
Server	15
Communication	13
Total	52

Table 7 – Team Work Breakdown Hours	
Assignments	60
Application	31
GPS	15
IMU	30
Server	53
Communication	25
Total	214

IX. USER MANUAL

At this point, the “Smart Life Vest” is still in its prototype stage, therefore, many of it’s features are not functional yet. We do not recommend use of this project in water due to its external power source being a non water-proofed battery.

Step 1: The Smart Life Vest

Although the Arduino, GSM, GPS and IMU are not currently attached to the life vest, each component is fully functional both individually and together. As the product is delivered, each component is fully assembled together. The only work required is to plug the included battery into the Arduino and to power both the Arduino and the GSM unit. Once they receive power and the GSM and GPS find their satellites to begin sending data, the unit is ready to be used.

Step 2: The Application

The application is still in its prototype stage, and still shows the inter-workings of the application. Below, figure 6 shows the current home screen as well as its data parsed into usable numbers in the screen to the right.

In Reference to Figure 6 on the right:

To access the current status of the life vest wearer, simply press the “Get JSON “ button on the home screen (currently labeled JSON STUFF) and the array of data below the button will appear. To access the data, simply press the “PARSE JSON” button to be able to toggle through each datapoint. To check for new data, press the backwards arrow button at the top, then the “GET JSON” button to refresh the data array. Then repeat the process.

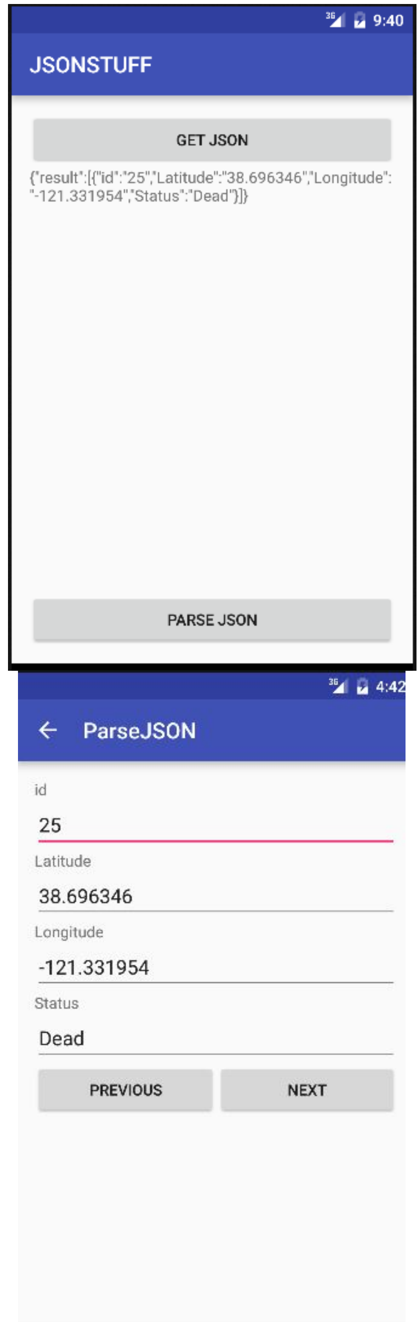

Figure 6. Home Screen

X. DESIGN DOCUMENTATION

The design of the "Smart Life Vest" can be broken down into 6 major components: IMU, GPS, GSM, Arduino, Server, Application. As discussed previously, the arduino along with the GSM will transmit GPS and IMU data to an online server.

Then, the user of the product will monitor the potential victim through a cell phone application, which streams data from the server.

A. Hardware

This is shown below in figure 1:

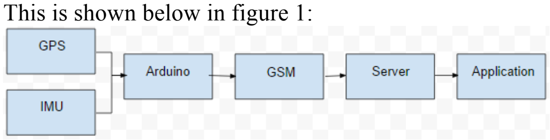

Figure 7. Hardware flow chart

B. Software

Although the "Smart Life Vest" has several hardware components, the way that they function is almost entirely based on software.

An extremely simple block diagram overview of the flow of software decision making is shown below in figure 2:

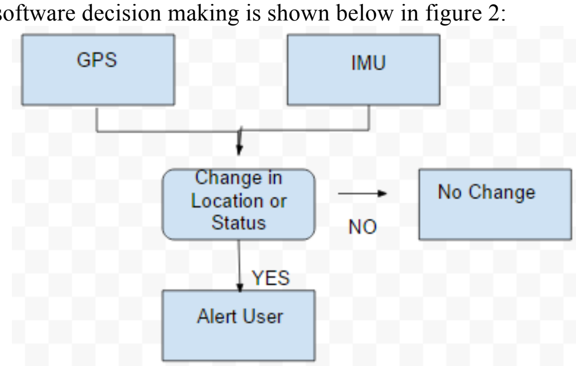

Figure 8. Software Decision Making Process

The above diagram essentially shows that if there is a change in either the location or the status of the potential victim, this data will be transferred to the application to alert the user.

If neither the location or status has changed, then there will be no update, this way, the database will not be clogged with too many data points and it will run much more smoothly.

The pseudocode below shows the outline of how the GPS, IMU and GSM communicate with each other.

```
//*******************************************PseudoCode****
*****************************
import TINYGPS++ Library
import GSM Library
#define URL formatting constants
setup loop
{
Setup IMU Sensor;
Connect gps to satellite;
Connect GSM shield to internet;

if(GSM connects)
{setup complete;}
else
{try to reset connection;}
}
while (GSM connected)
{
Receive GPS coordinates;
From IMU coordinates, determine status of the
potential victim;
if (change in GPS)
{
upload coordinates and status to server through:
www.smartlifevest.com/gps/thankyou.php?Latitude=
(getLatitude)?Longitude=(getLongitude)?Status=(get
Status);
}
else if (change in GPS)
{
upload coordinates and status to server through:
www.smartlifevest.com/gps/thankyou.php?Latitude=
(getLatitude)?Longitude=(getLongitude)?Status=(get
Status);
}
else
{repeat loop;}
}
//*************************END OF PSEUDO
CODE************************************
```

XI. TEST PLAN HARDWARE

This fall, most of the testing that took place was meant to test each individual component.

A. GPS

The most important aspect of the of the GPS is its ability to find satellites. This is reflected in time and also the versatility of its location. To test this, we simply observed the GPS as we turned it on throughout the semester.

We found that it is extremely unreliable indoors, but outside, it can generally find satellites as long as we are not under a tree or shadowed by a tall building. We also found that it can take between 5 and 60 seconds to locate satellites.

This spring we plan to test this further by purposefully using the GPS in a variety of locations and attempting to map the correlation between location and the time to find satellites.

B. GSM

Similar to the GPS, the GSM's most important factors are its ability to find satellites combined with the time to do so. This semester, we had much trouble with the GSM unit in regards to the signal strength. We attempted to solve this problem in a variety of ways including an external power source, and an extra antenna.

Although both of these supplements helped the GSM find a signal, the unit was still having trouble sending data. To combat this, we have ordered a new GSM unit, one that has a better repertoire for signal strength. This spring, we plan to test the new GSM for the correlation between time and signal strength.

C. Battery

This fall, we did not perform testing of the battery. Through datasheets on both the GSM and the GPS we found that it needed to be able to supply at least 2A of current to the Arduino (which powers the GSM and the GPS) at approximately 6 to 9V.

Further testing this spring will include how long the battery can power the unit until it can no longer provide enough power for the unit to transfer data to the server.

D. Server

The server is an almost instantaneous connection for the Arduino and the application. It can transfer data as quickly as the GSM can upload it and the application can download it.

XII. TEST PLAN SOFTWARE

This fall, most of the testing that took place pertained to making sure all of the components were fully functional with each other.

Communication between the GPS, GSM, and the Arduino was one of the biggest problems this semester. This mainly consisted of the initialization of the GPS and the GSM, it seemed that when one was working the other wasn't.

Eventually, we discovered that the reason that the GPS and GSM couldn't be initialized together was that they both used the same serial ports of the Arduino. To combat this, we switched to a different library so that they could be used together.

Implementing the server between the GSM and the Android app was a necessary but unplanned endeavor. This is due to the fact that both the GSM and the Android app will receive a different IP address each time they are turned on.

Because the server has a static IP address, both the GSM and the application will not need to connect to a different IP address when they turn on.

XIII. INTEGRATION PLAN

A. Spring 2016 Implementation

Troubleshooting and testing the hardware and software led us to several conclusions. Firstly, the need of the online server. Although this was mentioned earlier, the website server acts as a midway point between the Application and the GSM.

But, because there is a now a website server, this allows us to create a website page for our product. With this, we can now display information about our product in order to advertise, as well as display up to date information about the user of the life vest.

This spring we will also need to demo our product inside of an actual life vest. To do this we will need to obtain a waterproof case for our equipment. This will require further testing, because the equipment in expensive we will not want to immediately submerge our product. We will have to perform stress testing as well as the ability of the waterproof case to be submerged.

XIV. REFERENCES

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XV. APPENDIX

Included in the following appendix are data sheets of all components used as well as resumes of all team members.

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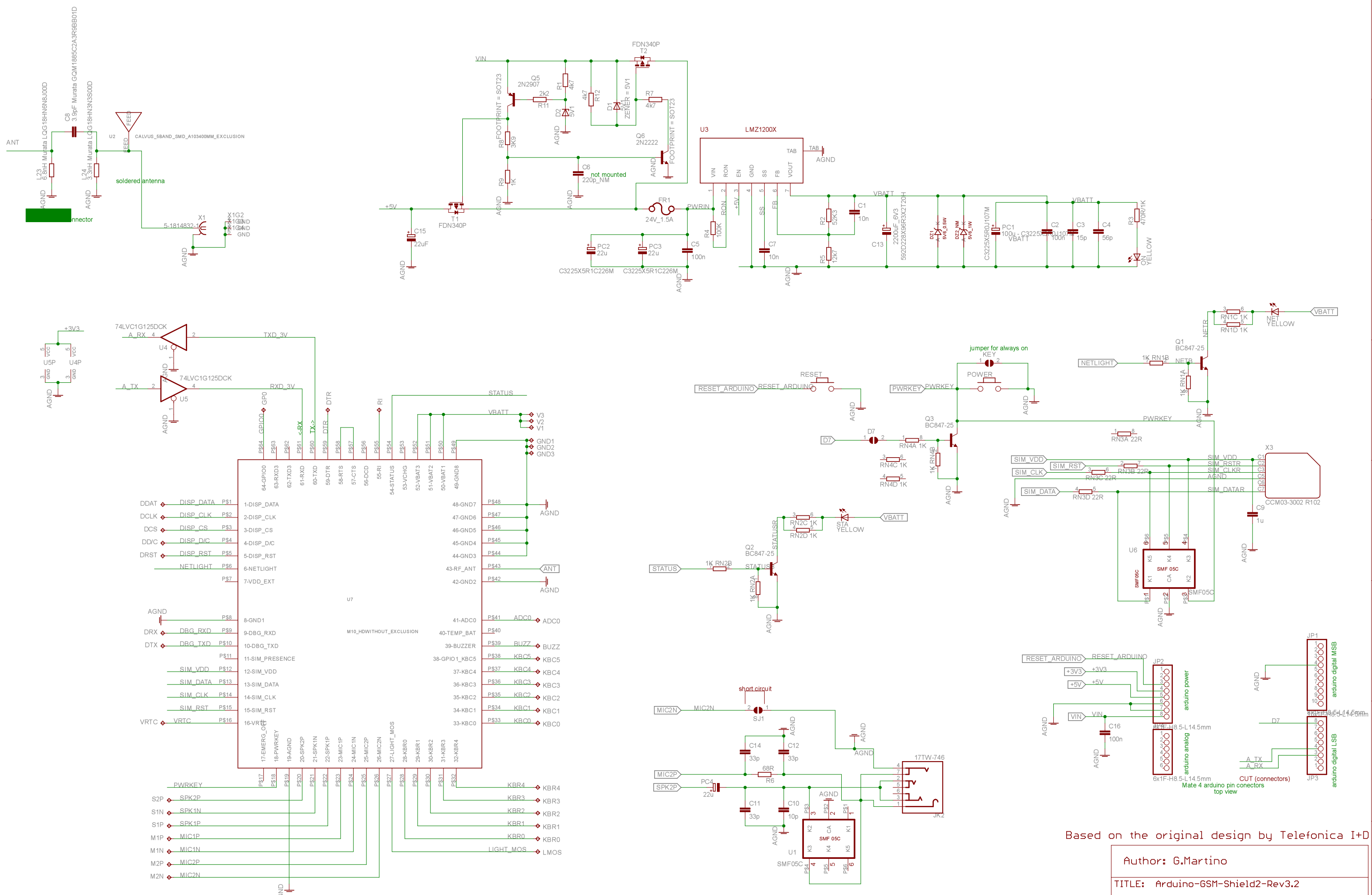


Based on the original design by Telefonica I+D

Author: G.Martino

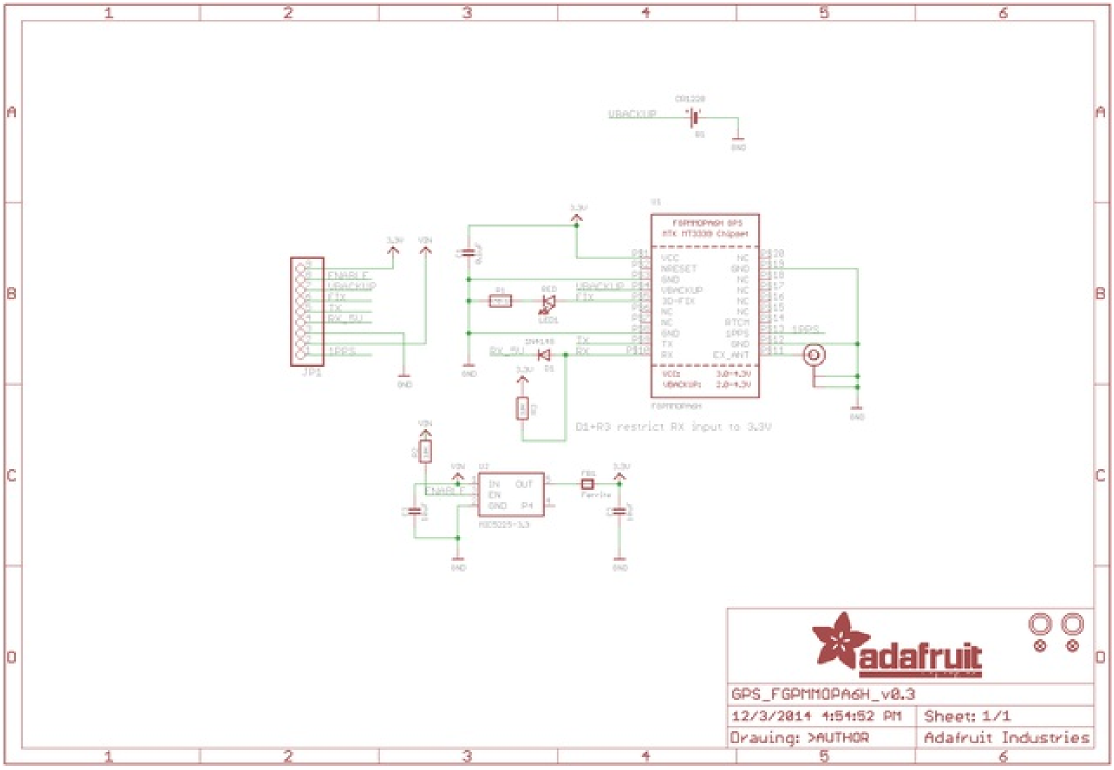
TITLE: Arduino-GSM-Shield2-Rev3.2

Document Number:

REV: 3.2

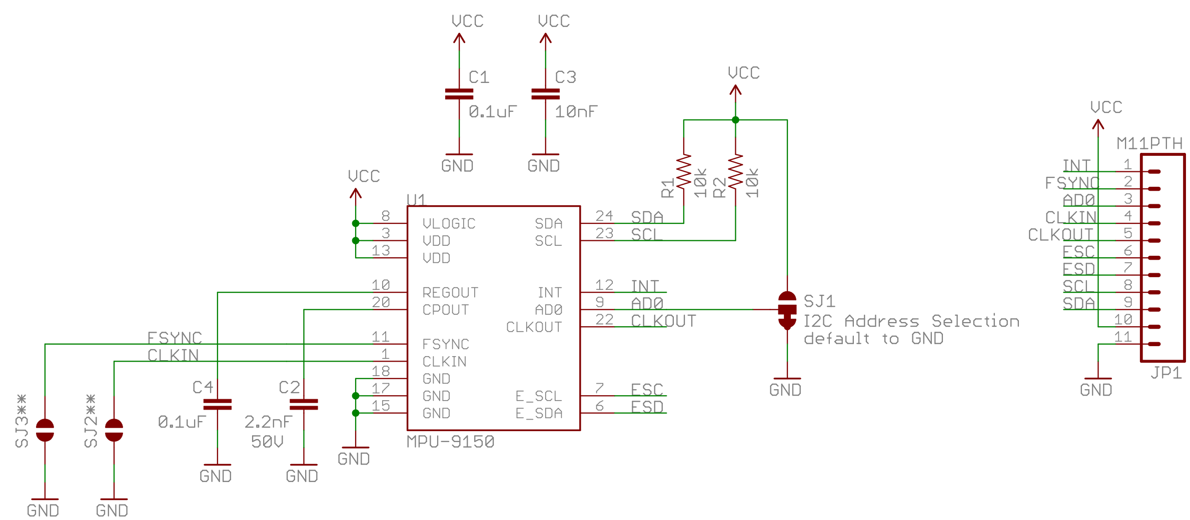
Date: 04.03.2015 12:45:55

Sheet: 1/1



Ultimate GPS Fabrication Print

Dimensions in Inches



*2.375V < VCC < 3.465V

*The LSB bit of the 7 bit address is determined by the logic level on pin AD0.
Default Address = 0x68 (pin AD0 is logic low)
Alternative Address =0x69 (pin AD0 is logic high)

**Optional external reference clock input or synchronization digital input.
Connected to GND by default. Cut trace for external control

open hardware

SFE SFE

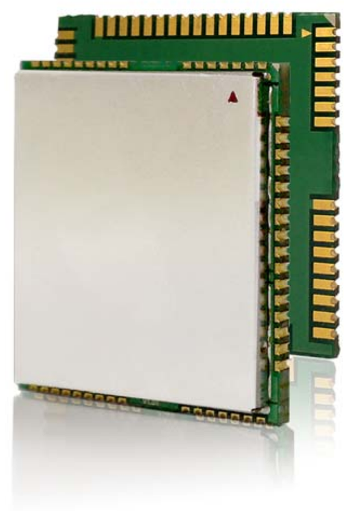
TITLE: mpu-9150_breakout

Design by: REV:

Date: 5/13/2014 11:39:26 AM Sheet: 1/1

M10

Quectel Cellular Engine



Hardware Design

M10_HD_V2.0

Document Title	M10 Hardware Design
Revision	2.0
Date	2010-07-30
Status	Release
Document Control ID	M10_HD_V2.0

General Notes

Quectel offers this information as a service to its customers, to support application and engineering efforts that use the products designed by Quectel. The information provided is based upon requirements specifically provided for Quectel by the customers. Quectel has not undertaken any independent search for additional relevant information, including any information that may be in the customer's possession. Furthermore, system validation of this product designed by Quectel within a larger electronic system remains the responsibility of the customer or the customer's system integrator. All specifications supplied herein are subject to change.

1 Introduction

This document defines the M10 module series and describes the hardware interface of the Quectel's M10 module that connects to the customer application and the air interface.

This document can help customer quickly understand module interface specifications, electrical and mechanical details. With the help of this document, associated application notes and user guide, customer can use M10 module to design and set up mobile applications quickly.

1.1 Related documents

Table 1: Related documents

SN	Document name	Remark
[1]	M10_ATC	AT command set
[2]	ITU-T Draft new recommendation V.25ter	Serial asynchronous automatic dialing and control
[3]	GSM 07.07	Digital cellular telecommunications (Phase 2+); AT command set for GSM Mobile Equipment (ME)
[4]	GSM 07.10	Support GSM 07.10 multiplexing protocol
[5]	GSM 07.05	Digital cellular telecommunications (Phase 2+); Use of Data Terminal Equipment – Data Circuit terminating Equipment (DTE – DCE) interface for Short Message Service (SMS) and Cell Broadcast Service (CBS)
[6]	GSM 11.14	Digital cellular telecommunications (Phase 2+); Specification of the SIM Application Toolkit for the Subscriber Identity module – Mobile Equipment (SIM – ME) interface
[7]	GSM 11.11	Digital cellular telecommunications (Phase 2+); Specification of the Subscriber Identity module – Mobile Equipment (SIM – ME) interface
[8]	GSM 03.38	Digital cellular telecommunications (Phase 2+); Alphabets and language-specific information
[9]	GSM 11.10	Digital cellular telecommunications (Phase 2); Mobile Station (MS) conformance specification; Part 1: Conformance specification
[10]	GSM_UART_AN	UART port application notes
[11]	M10_HD_AN01	M10 hardware design application notes
[12]	GSM_FW_Upgrade_AN01	GSM Firmware upgrade application note
[13]	M10_EVB_UGD	M10 EVB user guide application notes

1.2 Terms and abbreviations

Table 2: Terms and abbreviations

Abbreviation	Description
ADC	Analog-to-Digital Converter
AMR	Adaptive Multi-Rate
ARP	Antenna Reference Point
ASIC	Application Specific Integrated Circuit
BER	Bit Error Rate
BOM	Bill Of Material
BTS	Base Transceiver Station
CHAP	Challenge Handshake Authentication Protocol
CS	Coding Scheme
CSD	Circuit Switched Data
CTS	Clear To Send
DAC	Digital-to-Analog Converter
DRX	Discontinuous Reception
DSP	Digital Signal Processor
DCE	Data Communications Equipment (typically module)
DTE	Data Terminal Equipment (typically computer, external controller)
DTR	Data Terminal Ready
DTX	Discontinuous Transmission
EFR	Enhanced Full Rate
EGSM	Enhanced GSM
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
ETS	European Telecommunication Standard
FCC	Federal Communications Commission (U.S.)
FDMA	Frequency Division Multiple Access
FR	Full Rate
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HR	Half Rate
I/O	Input/Output
IC	Integrated Circuit
IMEI	International Mobile Equipment Identity
Imax	Maximum Load Current
Inorm	Normal Current
kbps	Kilo Bits Per Second
LED	Light Emitting Diode

Abbreviation	Description
Li-Ion	Lithium-Ion
MO	Mobile Originated
MS	Mobile Station (GSM engine)
MT	Mobile Terminated
PAP	Password Authentication Protocol
PBCCH	Packet Switched Broadcast Control Channel
PCB	Printed Circuit Board
PDU	Protocol Data Unit
PPP	Point-to-Point Protocol
RF	Radio Frequency
RMS	Root Mean Square (value)
RTC	Real Time Clock
RX	Receive Direction
SIM	Subscriber Identification Module
SMS	Short Message Service
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TX	Transmitting Direction
UART	Universal Asynchronous Receiver & Transmitter
URC	Unsolicited Result Code
USSD	Unstructured Supplementary Service Data
VSWR	Voltage Standing Wave Ratio
Vmax	Maximum Voltage Value
Vnorm	Normal Voltage Value
Vmin	Minimum Voltage Value
VIHmax	Maximum Input High Level Voltage Value
VIHmin	Minimum Input High Level Voltage Value
VILmax	Maximum Input Low Level Voltage Value
VILmin	Minimum Input Low Level Voltage Value
VImax	Absolute Maximum Input Voltage Value
VImin	Absolute Minimum Input Voltage Value
VOHmax	Maximum Output High Level Voltage Value
VOHmin	Minimum Output High Level Voltage Value
VOLmax	Maximum Output Low Level Voltage Value
VOLmin	Minimum Output Low Level Voltage Value
Phonebook abbreviations	
FD	SIM Fix Dialing phonebook
LD	SIM Last Dialing phonebook (list of numbers most recently dialed)
MC	Mobile Equipment list of unanswered MT Calls (missed calls)
ON	SIM (or ME) Own Numbers (MSISDNs) list
RC	Mobile Equipment list of Received Calls

SM	SIM phonebook

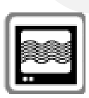
1.3 Safety caution

The following safety precautions must be observed during all phases of the operation, such as usage, service or repair of any cellular terminal or mobile incorporating M10 module. Manufactures of the cellular terminal should send the following safety information to users and operating personnel and to incorporate these guidelines into all manuals supplied with the product. If not so, Quectel does not take on any liability for customer failure to comply with these precautions.

When in a hospital or other health care facility, observe the restrictions about the use of mobile. Switch the cellular terminal or mobile off. Medical equipment may be sensitive to not operate normally for RF energy interference.

Switch off the cellular terminal or mobile before boarding an aircraft. Make sure it switched off. The operation of wireless appliances in an aircraft is forbidden to prevent interference with communication systems. Forget to think much of these instructions may lead to the flight safety or offend against local legal action, or both.

Do not operate the cellular terminal or mobile in the presence of flammable gas or fume. Switch off the cellular terminal when you are near petrol station, fuel depot, chemical plant or where blasting operations are in progress. Operation of any electrical equipment in potentially explosive atmosphere can constitute a safety hazard.



Your cellular terminal or mobile receives and transmits radio frequency energy while switched on. RF interference can occur if it is used close to TV set, radio, computer or other electric equipment.

Road safety comes first! Do not use a hand-held cellular terminal or mobile while driving a vehicle, unless it is securely mounted in a holder for hands-free operation. Before making a call with a hand-held terminal or mobile, park the vehicle.

GSM cellular terminals or mobiles operate over radio frequency signal and cellular network and cannot be guaranteed to connect in all conditions, for example no mobile fee or an invalid SIM card. While you are in this condition and need emergent help, Please Remember using emergency call. In order to make or receive call, the cellular terminal or mobile must be switched on and in a service area with adequate cellular signal strength.

Some networks do not allow for emergency call if certain network services or phone features are in use (e.g. lock functions, fixed dialing etc.). You may have to deactivate those features before you can make an emergency call.

Also, some networks require that a valid SIM card be properly inserted in cellular terminal or mobile.

2 Product concept

The M10 is a Quad-band GSM/GPRS engine that works at frequencies GSM850MHz, GSM900MHz, DCS1800MHz and PCS1900MHz. The M10 features GPRS multi-slot class 12 and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4. For more detail about GPRS multi-slot classes and coding schemes, please refer to Appendix A and Appendix B.

With a tiny profile of 29mm x 29mm x 3.6 mm, the module can meet almost all the requirements for M2M applications, including Tracking and Tracing, Smart Metering, Wireless POS, Security, Telematics, Remote Controlling, etc.

The M10 is an SMD type module, which can be embedded in customer application through its 64-pin pads. It provides all hardware interfaces between the module and customer's host board.

The module is designed with power saving technique so that the current consumption is as low as 1.1 mA in SLEEP mode when DRX is 5.

The M10 is integrated with Internet service protocols, which are TCP/UDP, FTP and HTTP. Extended AT commands have been developed for customer to use these Internet service protocols easily.

The modules are fully RoHS compliant to EU regulation.

2.1 Key features

Table 3: Module key features

Feature	Implementation
Power supply	Single supply voltage 3.4V – 4.5V
Power saving	Typical power consumption in SLEEP mode to 1.1 mA@ DRX=5 0.7 mA@ DRX=9
Frequency bands	● Quad-band: GSM850, GSM900, DCS1800, PCS1900. ● The module can search these frequency bands automatically ● The frequency bands can be set by AT command. ● Compliant to GSM Phase 2/2+
GSM class	Small MS
Transmitting power	● Class 4 (2W) at GSM850 and GSM900 ● Class 1 (1W) at DCS1800 and PCS1900
GPRS connectivity	● GPRS multi-slot class 12 (default) ● GPRS multi-slot class 1~12 (configurable) ● GPRS mobile station class B
Temperature range	● Normal operation: -35°C ~ +80°C

	• Restricted operation: -45°C ~ -35°C and +80°C ~ +85°C [1)] • Storage temperature: -45°C ~ +90°C
DATA GPRS: CSD:	• GPRS data downlink transfer: max. 85.6 kbps • GPRS data uplink transfer: max. 85.6 kbps • Coding scheme: CS-1, CS-2, CS-3 and CS-4 • Support the protocols PAP (Password Authentication Protocol) usually used for PPP connections • Internet service protocols TCP/UDP/FTP/HTTP/MMS • Support Packet Switched Broadcast Control Channel (PBCCH) • CSD transmission rates: 2.4, 4.8, 9.6, 14.4 kbps non-transparent • Unstructured Supplementary Services Data (USSD) support
SMS	• MT, MO, CB, Text and PDU mode • SMS storage: SIM card
FAX	Group 3 Class 1 and Class 2
SIM interface	Support SIM card: 1.8V, 3V
Antenna interface	Connected via 50 Ohm antenna pad
Audio features	Speech codec modes: • Half Rate (ETS 06.20) • Full Rate (ETS 06.10) • Enhanced Full Rate (ETS 06.50 / 06.60 / 06.80) • Adaptive Multi-Rate (AMR) • Echo Cancellation • Echo Suppression • Noise Reduction
Serial interface	• Serial Port: Seven lines on serial port interface • Use for AT command, GPRS data and CSD data • Multiplexing function • Support autobauding from 4800 bps to 115200 bps • Debug Port: Two lines on second serial port interface DBG_TXD and DBG_RXD • Debug Port only used for software debugging
Phonebook management	Support phonebook types: SM, FD, LD, RC, ON, MC
SIM Application Toolkit	Support SAT class 3, GSM 11.14 Release 99
Real time clock	Implemented
Alarm function	Programmable via AT command
Physical characteristics	Size: 29±0.15 x 29±0.15 x 3.6±0.3mm Weight: 6g
Firmware upgrade	Firmware upgrade over Serial Port

1) When the module works in this temperature range, the deviations from the GSM specification might occur. For example, the frequency error or the phase error could increase.

Table 4: Coding schemes and maximum net data rates over air interface

Coding scheme	1 Timeslot	2 Timeslot	4 Timeslot
CS-1:	9.05kbps	18.1kbps	36.2kbps
CS-2:	13.4kbps	26.8kbps	53.6kbps
CS-3:	15.6kbps	31.2kbps	62.4kbps
CS-4:	21.4kbps	42.8kbps	85.6kbps

2.2 Functional diagram

The following figure showes a block diagram of the M10 module and illustrates the major functional parts:

- The GSM baseband part
- Flash and SRAM
- The GSM radio frequency part
- The SMT pads interface

  —LCD interface
  —SIM card interface
  —Audio interface
  —Key-board interface
  —UART interface
  —Power supply
  —RF interface

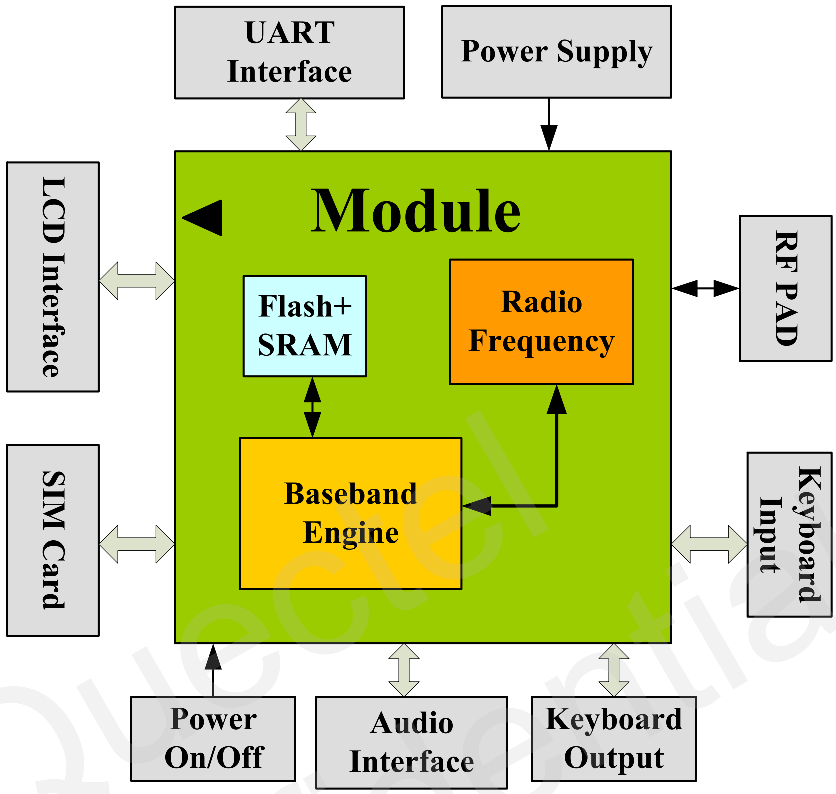


Figure 1: Module functional diagram

2.3 Evaluation board

In order to help customer on the application of M10, Quectel supplies an Evaluation Board (EVB) that hosts the module directly with appropriate power supply, SIM card holder, RS-232 serial interface, handset RJ11 port, earphone port, antenna and other peripherals to control or test the module. For details, please refer to the *document [13]*.

Note: GPRS Class 12 is the default setting. The module can be configured from GPRS Class 1 to Class 12 by "AT+QGPCLASS". Setting to lower GPRS class would make it easier to design the power supply for the module.

5.6 Electro-static discharge

Although the GSM engine is generally protected against Electrostatic Discharge (ESD), ESD protection precautions should still be emphasized. Proper ESD handling and packaging procedures must be applied throughout the processing, handling and operation of any applications using the module.

The measured ESD values of module are shown as the following table:

Table 42: The ESD endurance (Temperature:25℃,Humidity:45 %)

Tested point	Contact discharge	Air discharge
VBAT,GND	±5KV	±10KV
PWRKEY	±4KV	±8KV
SIM Card Interface	±4KV	±8KV
Antenna port	±5KV	±10KV
SPK1P/1N, SPK2P/2N, MIC1P/1N, MIC2P/2N	±4KV	±8KV

6 Mechanical dimension

This chapter describes the mechanical dimensions of the module.

6.1 Mechanical dimensions of module

Figure 45: M10 top and side dimensions（Unit: mm）

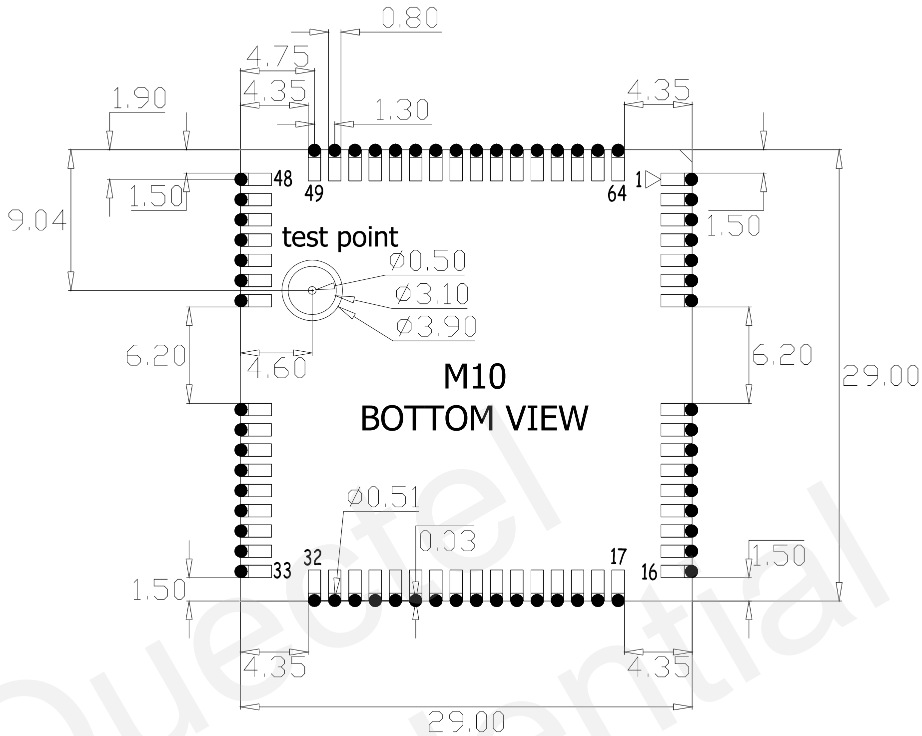


Figure 46: M10 bottom dimensions（Unit: mm）

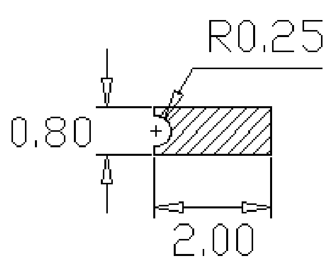
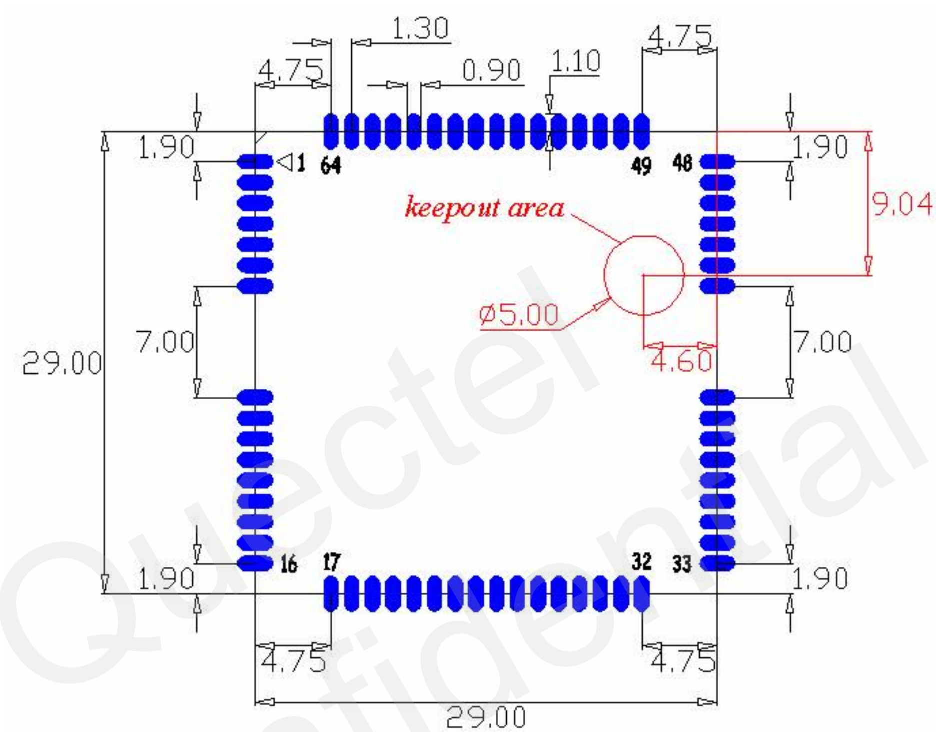
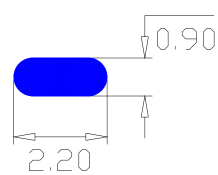


Figure 47: PAD bottom dimensions（Unit: mm）

6.2 Footprint of recommendation





single pad

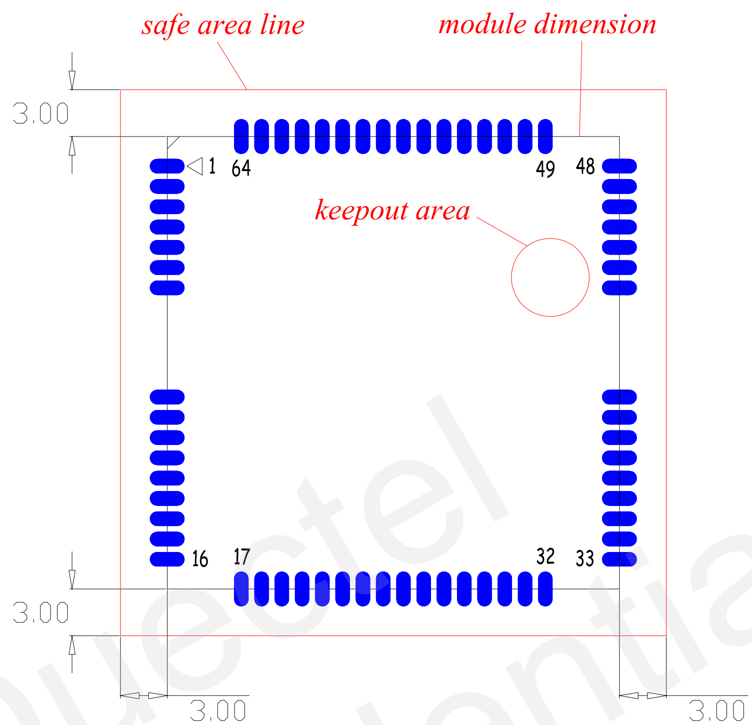


Figure 48: Footprint of recommendation（Unit: mm）

Note1：Keep out the area below the test point in the host PCB. Place solder mask.
Note2：In order to maintain the module, keep about 3mm between the module and other components in host PCB.

6.3 Top view of the module

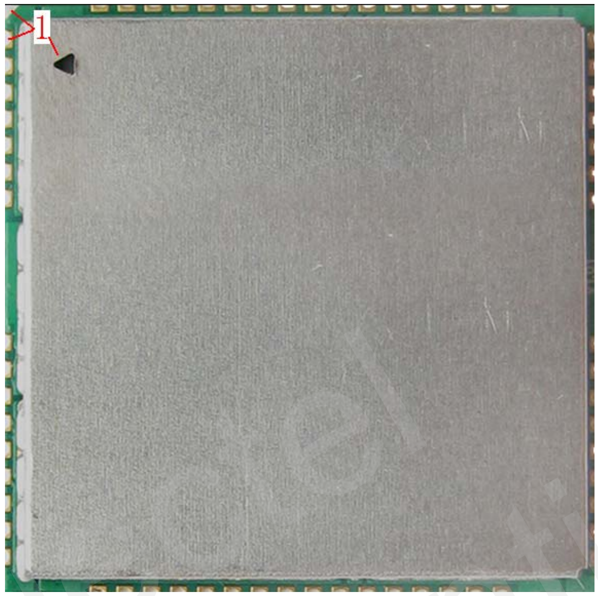


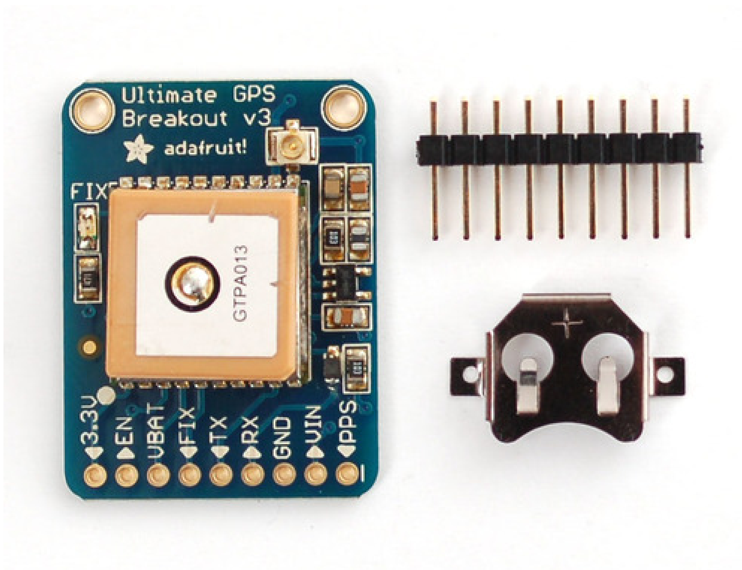
Figure 49: Top view of the module

6.4 Bottom view of the module

Figure 50: Bottom view of the module

Adafruit Ultimate GPS

Created by lady ada

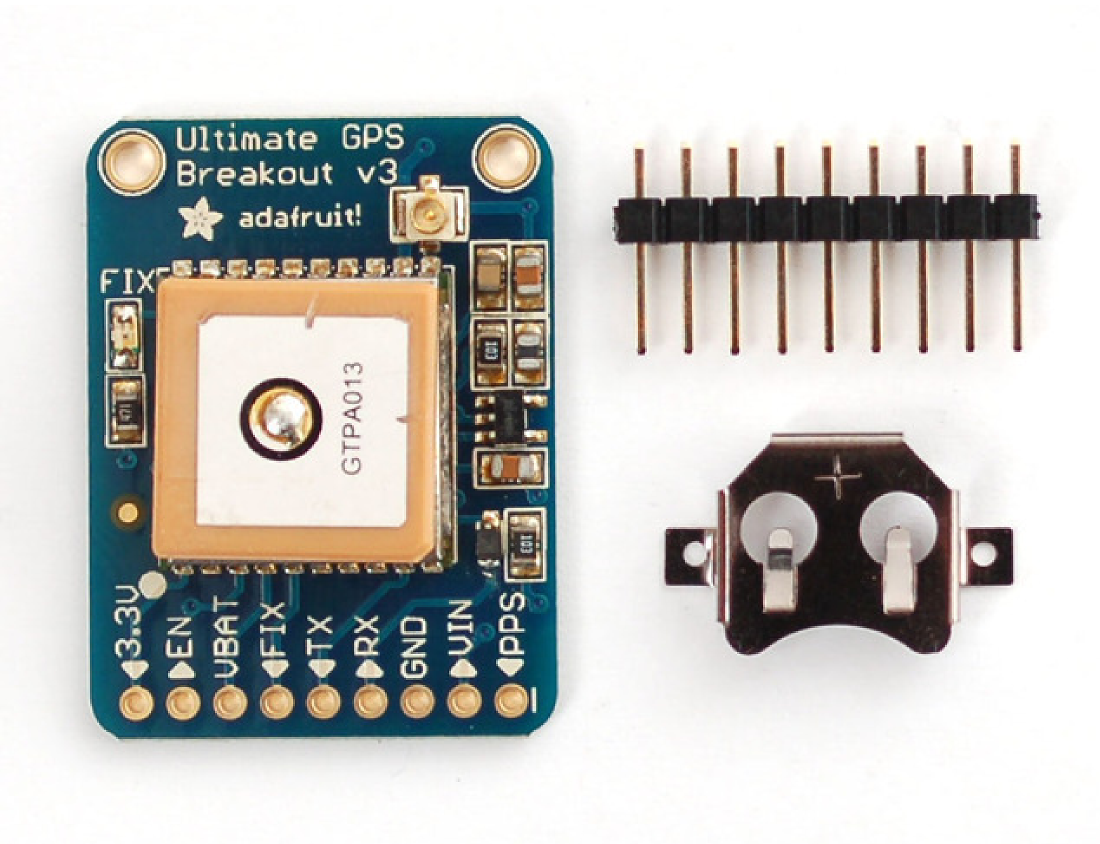


Last updated on 2015-01-17 06:30:26 PM EST

Overview

We carry a few different GPS modules here in the Adafruit shop, but none that satisfied our every desire - that's why we designed this little GPS breakout board. We believe this is the **Ultimate** GPS module, so we named it that. It's got everything you want and more:

- -165 dBm sensitivity, 10 Hz updates, 66 channels
- 5V friendly design and only 20mA current draw
- Breadboard friendly + two mounting holes
- RTC battery-compatible
- Built-in datalogging
- PPS output on fix
- Internal patch antenna + u.FL connector for external active antenna
- Fix status LED



The breakout is built around the MTK3339 chipset, a no-nonsense, high-quality GPS module that can track up to 22 satellites on 66 channels, has an excellent high-sensitivity receiver (-165 dB tracking!), and a built in antenna. It can do up to 10 location updates a second for high speed, high sensitivity logging or tracking. Power usage is incredibly low, only 20 mA during navigation.

Best of all, we added all the extra goodies you could ever want: a ultra-low dropout 3.3V regulator so you can power it with 3.3-5VDC in, 5V level safe inputs, ENABLE pin so you can turn off the module using any microcontroller pin or switch, a footprint for optional CR1220 coin cell to keep the RTC running and allow warm starts and a tiny bright red LED. The LED blinks at about 1Hz while it's searching for satellites and blinks once every 15 seconds when a fix is found to conserve power. If you want to have an LED on all the time, we also provide the FIX signal out on a pin so you can put an external LED on.

Two features that really stand out about version 3 MTK3339-based module is the external antenna functionality and the the built in data-logging capability. The module has a standard ceramic patch antenna that gives it -165 dB sensitivity, but when you want to have a bigger antenna, you can snap on any 3V active GPS antenna via the uFL connector. The module will automatically detect the active antenna and switch over! Most GPS antennas use SMA connectors so you may want to pick up one of our uFL to SMA adapters. (http://adafru.it/851)

The other cool feature of the new MTK3339-based module (which we have tested with great success) is the built in datalogging ability. Since there is a microcontroller inside the module, with some empty FLASH memory, the newest firmware now allows sending commands to do internal logging to that FLASH. The only thing is that you do need to have a microcontroller send the "Start Logging" command. However, after that message is sent, the microcontroller can go to sleep and does not need to wake up to talk to the GPS anymore to reduce power consumption. The time, date, longitude, latitude, and height is logged every 15 seconds and only when there is a fix. The internal FLASH can store about 16 hours of data, it will automatically append data so you don't have to worry about accidentally losing data if power is lost. It is not possible to change what is logged and how often, as its hardcoded into the module but we found that this arrangement covers many of the most common GPS datalogging requirements.

Pick one up today at the Adafruit shop! (http://adafru.it/746)

Specifications:

Module specs:

- Satellites: 22 tracking, 66 searching
- Patch Antenna Size: 15mm x 15mm x 4mm
- Update rate: 1 to 10 Hz
- Position Accuracy: 1.8 meters
- Velocity Accuracy: 0.1 meters/s
- Warm/cold start: 34 seconds
- Acquisition sensitivity: -145 dBm
- Tracking sensitivity: -165 dBm
- Maximum Velocity: 515m/s
- Vin range: 3.0-5.5VDC
- MTK3339 Operating current: 25mA tracking, 20 mA current draw during navigation
- Output: NMEA 0183, 9600 baud default
- DGPS/WAAS/EGNOS supported
- FCC E911 compliance and AGPS support (Offline mode : EPO valid up to 14 days)

- Up to 210 PRN channels
- Jammer detection and reduction
- Multi-path detection and compensation

Breakout board details:

- Weight (not including coin cell or holder): 8.5g
- Dimensions (not including coin cell or holder): 25.5mm x 35mm x 6.5mm / 1.0" x 1.35" x 0.25"

If you purchased a module before March 26th, 2012 and it says MTK3329 on the silkscreen, you have the PA6B version of this breakout with the MT3329 chipset. The MTK3329 does not have built in datalogging. If your module has sharpie marker crossking out the MTK3329 text or there is no text, you have a PA6C MTK3339 with datalogging ability. If you have the version with "v3" next to the name, you have the PA6H which has PPS output and external-antenna support

This tutorial assumes you have a '3339 type module.

Direct Computer Wiring

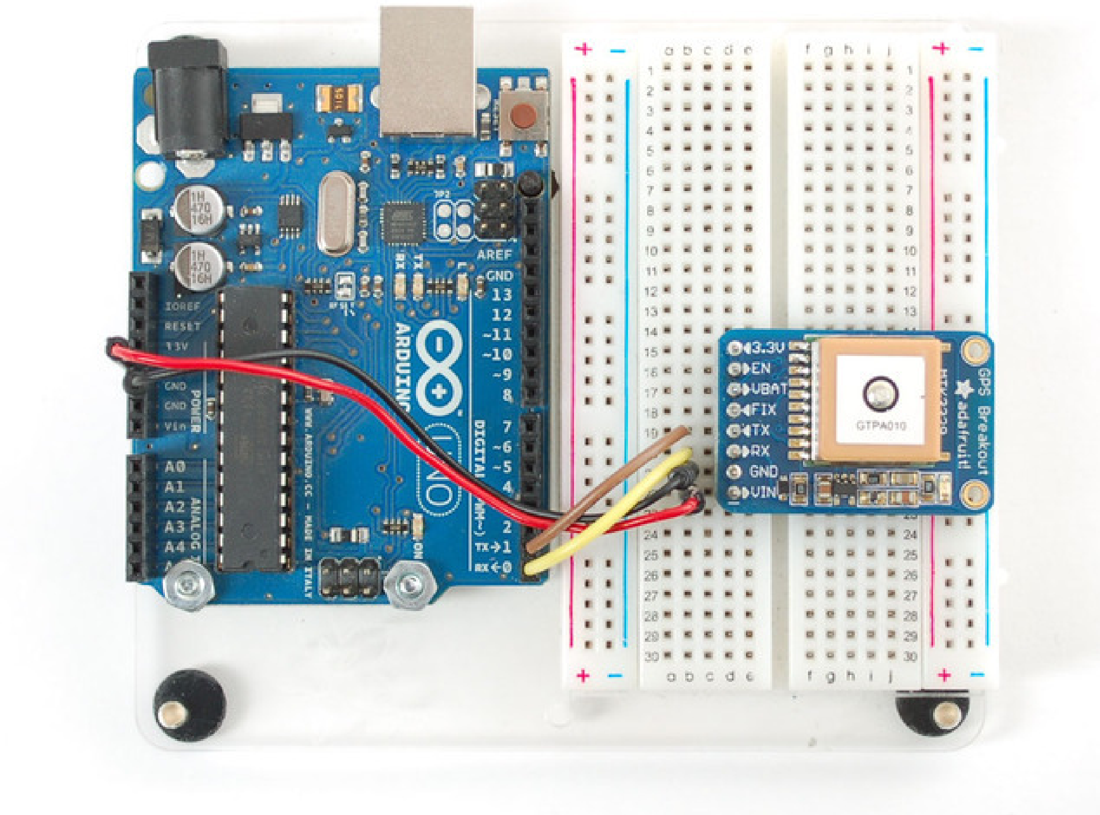
GPS modules are great in that the moment you turn them on, they'll start spitting out data, and trying to get a 'fix' (location verification). Like pretty much every GPS in existence, the Adafruit Ultimate GPS uses TTL serial output to send data so the best way to first test the GPS is to wire it directly to the computer via the TTL serial to USB converter on an Arduino. You can also use an FTDI Friend or other TTL adapter but for this demonstration we'll use a classic Arduino.

> Leonardo Users: This tutorial step won't work with a Leonardo. Go on to the next step, "Arduino Wiring", but refer back here for this discussion of the GPS data!

First, load a 'blank' sketch into the Arduino:

```
// this sketch will allow you to bypass the Atmega chip
// and connect the Ultimate GPS directly to the USB/Serial
// chip converter.

// Connect VIN to +5V
// Connect GND to Ground
// Connect GPS RX (data into GPS) to Digital 0
// Connect GPS TX (data out from GPS) to Digital 1

void setup() {}
void loop() {}
```

This is will free up the converter so you can directly wire and bypass the Arduino chip. Once you've uploaded this sketch, wire the GPS as follows. Your module may look slightly different, but as long as you are connecting to the right pin names, they all work identically for this part

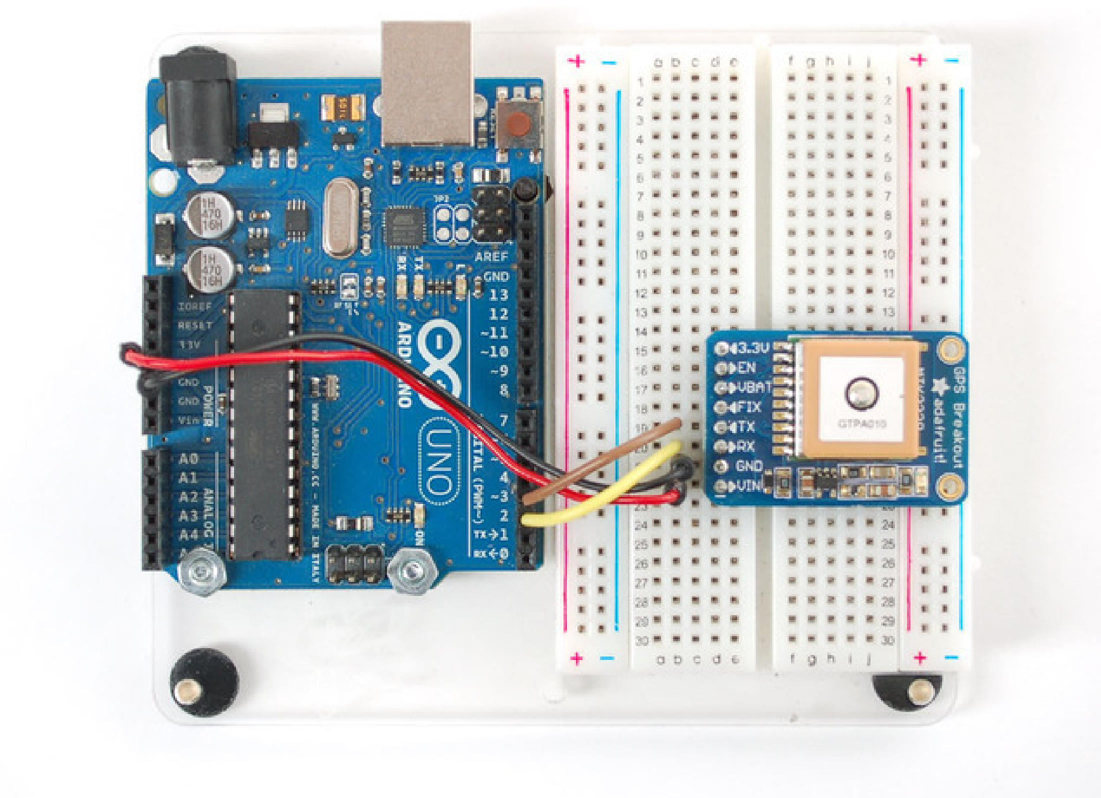


Now plug in the USB cable, and open up the serial monitor from the Arduino IDE and be sure to select **9600 baud** in the drop down. You should see text like the following:

Arduino Wiring

Once you've gotten the GPS module tested with direct wiring, we can go forward and wire it up to a microcontroller. We'll be using an Arduino but you can adapt our code to any other microcontroller that can receive TTL serial at 9600 baud.

Connect **VIN** to +5V, **GND** to Ground, **RX** to digital 2 and **TX** to digital 3.



Next up, download the Adafruit GPS library. This library does a lot of the 'heavy lifting' required for receiving data from GPS modules, such as reading the streaming data in a background interrupt and auto-magically parsing it. To download it, visit the GitHub repository (http://adafru.it/aMm) or just click below

Download the Adafruit GPS Library from github

http://adafru.it/emg

rename the uncompressed folder **Adafruit_GPS**. Check that the **Adafruit_GPS** folder contains **Adafruit_GPS.cpp** and **Adafruit_GPS.h**

Move **Adafruit_GPS** to your Arduino/Libraries folder and restart the Arduino IDE. Library installation is a frequent stumbling block...if you need assistance, our All About Arduino Libraries (http://adafru.it/dSk) guide spells it out in detail!

> Leonardo & Micro Users: We have special example sketches in the Adafruit_GPS library that work with the Micro/Leo!

Open up the **File→Examples→Adafruit_GPS→echo** sketch and upload it to the Arduino. Then open up the serial monitor. This sketch simply reads data from the software serial port (pins 2&3) and outputs that to the hardware serial port connected to USB.

Open up the Arduino IDE Serial Console and make sure to set the Serial baud rate to **115200**

You can configure the GPS output you see by commenting/uncommenting lines in the **setup()** procedure. For example, we can ask the GPS to send different sentences, and change how often it sends data. 10 Hz (10 times a second) is the max speed, and is a lot of data. You may not be able to output "all data" at that speed because the 9600 baud rate is not fast enough.

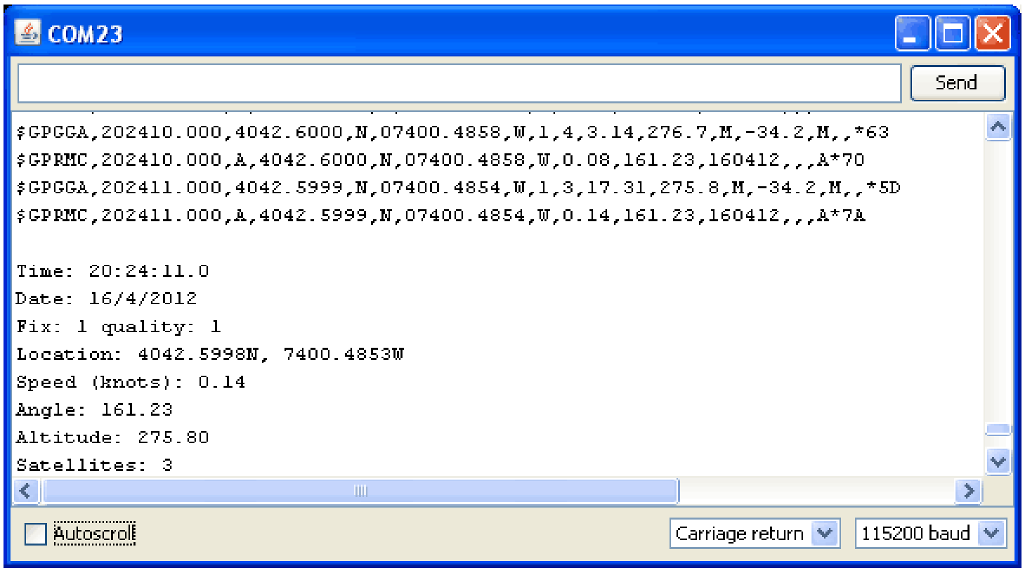
```
// You can adjust which sentences to have the module emit, below

  // uncomment this line to turn on RMC (recommended minimum) and GGA (fix data) including altitu
  GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCGGA);
  // uncomment this line to turn on only the "minimum recommended" data for high update rates!
  //GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCONLY);
  // uncomment this line to turn on all the available data - for 9600 baud you'll want 1 Hz rate
  //GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_ALLDATA);

  // Set the update rate
  // 1 Hz update rate
  //GPS.sendCommand(PMTK_SET_NMEA_UPDATE_1HZ);
  // 5 Hz update rate- for 9600 baud you'll have to set the output to RMC or RMCGGA only (see above)
  GPS.sendCommand(PMTK_SET_NMEA_UPDATE_5HZ);
  // 10 Hz update rate - for 9600 baud you'll have to set the output to RMC only (see above)
  //GPS.sendCommand(PMTK_SET_NMEA_UPDATE_10HZ);
```

In general, we find that most projects only need the RMC and GGA NMEA's so you don't need ALLDATA unless you have some need to know satellite locations.

Parsed Data Output

Since all GPS's output NMEA sentences and often for our projects we need to extract the actual data from them, we've simplified the task tremendously when using the Adafruit GPS library. By having the library read, store and parse the data in a background interrupt it becomes trivial to query the library and get the latest updated information without any icky parsing work.

Open up the **File→Examples→Adafruit_GPS→parsing** sketch and upload it to the Arduino. Then open up the serial monitor.



In this sketch, we call **GPS.read()** within a once-a-millisecond timer (this is the same timer that runs the **millis()** command). Then in the main loop we can ask if a new chunk of data has been received by calling **GPS.newNMEAreceived()**, if this returns **true** then we can ask the library to parse that data with **GPS.parse(GPS.lastNMEA())**.

We do have to keep querying and parsing in the main loop - its not possible to do this in an interrupt because then we'd be dropping GPS data by accident.

Once data is parsed, we can just ask for data from the library like **GPS.day**, **GPS.month** and **GPS.year** for the current date. **GPS.fix** will be 1 if there is a fix, 0 if there is none. If we have a fix then we can ask for **GPS.latitude**, **GPS.longitude**, **GPS.speed** (in knots, not mph or k/hr!), **GPS.angle**, **GPS.altitude** (in centimeters) and **GPS.satellites** (number of satellites)

This should make it much easier to have location-based projects. We suggest keeping the update rate at 1Hz and request that the GPS only output RMC and GGA as the parser does not keep track of other data anyways.

Downloads & Resources

Datasheets

- MTK3329/MTK3339 command set sheet (http://adafru.it/e7A) for changing the fix data rate, baud rate, sentence outputs, etc!
- PMTK 'complete' data (http://adafru.it/d2Q)sheet (like the above but with even more commands)
- Datasheet for the PA6B (MTK3329) GPS module itself (http://adafru.it/aMo)
- Datasheet for the PA6C (MTK3339) GPS module itself (http://adafru.it/aMp)
- Datasheet for the PA6H (MTK3339) GPS module itself (http://adafru.it/aPO)
- MT3339 GPS PC Tool (windows only) (http://adafru.it/aMq) and the PC Tool manual (http://adafru.it/aMr)
- Sample code and spec sheet for the LOCUS built-in logger (http://adafru.it/aTi)
- LOCUS (built-in-datalogging system) user guide (http://adafru.it/dL2)
- Mini GPS tool (windows only) (http://adafru.it/aMs)

More reading:

- Trimble's GPS tutorial (http://adafru.it/emh)
- Garmin's GPS tutorial (http://adafru.it/aMv)

EPO files for AGPS use

Data format for EPO files (http://adafru.it/eb0)

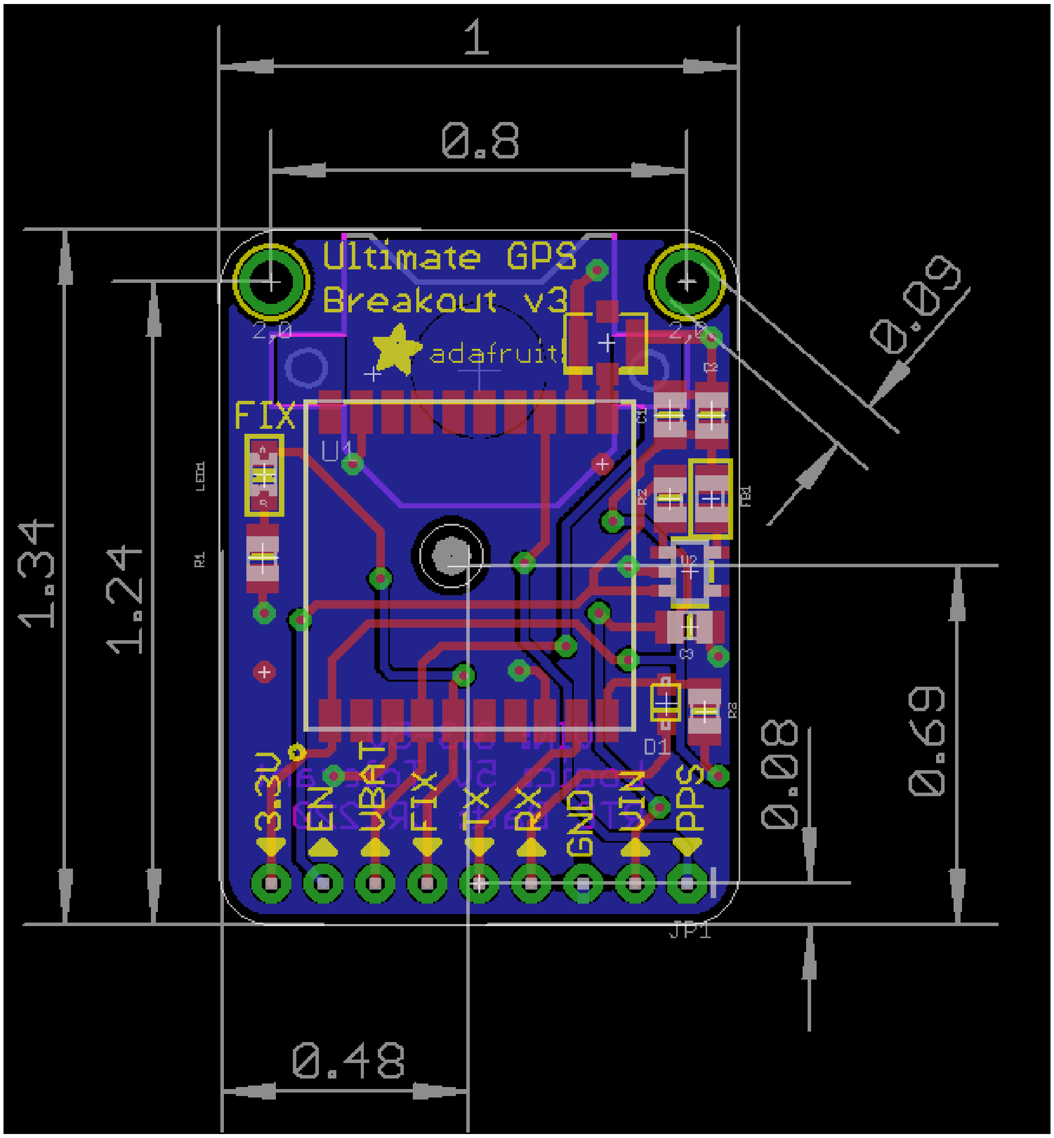
Adafruit GPS Library for Arduino

https://github.com/adafruit/Adafruit-GPS-Library/ (http://adafru.it/emi)

MTK_EPO_Nov_12_2014.zip

http://adafru.it/eb1

Ultimate GPS v3 Schematic


1
0.8
1.34
1.24
0.09
0.69
0.08
0.48
Ultimate GPS
Breakout v3
adafruit!
FIX
U1
D1
JP1
3.3V
EN
VBAT
FIX
TX
RX
GND
VIN
PPS

MPU-9150
Product Specification
Revision 4.3

1 Revision History

Revision Date	Revision	Description
05/27/2011	1.0	Initial Release of Product Specification
06/14/2011	2.0	Modified for Rev C Silicon (sections 5.2, 6.2, 6.4, 6.6, 8.2, 8.3, 8.4) Edits for clarity (several sections)
10/21/2011	2.1	Updated Supply current vs. operating modes (sections 5.3, 5.4, 6.4) Modified Self-Test Response of Accelerometers (section 6.2) Modified absolute maximum rating for acceleration (section 6.9) Updated latch up current rating (sections 6.9, 12.2) Modified package dimensions and PCB design guidelines (sections 11.2, 11.3) Updated assembly precautions (section 11.4) Updated qualification test plan (section 12.2) Edits for clarity (several sections)
10/24/2011	3.0	Modified for Rev D Silicon (sections 6.2, 8.2, 8.3, 8.4) Edits for Clarity (several sections)
12/23/2011	3.1	Updated package dimensions (section 11.2)
05/14/2012	4.0	Added Gyroscope specifications (section 6.1) Added Accelerometer specifications (section 6.2) Updated Electrical Other Common Specifications (section 6.3) Updated latch-up information (section 6.9) Updated Block Diagram (section 7.5) Update Self-Test description (section 7.13) Updated PCB design guidelines (section 11.3) Updated packing and shipping information (sections 11.8, 11.9, 11.10, 11.11) Updated reliability references (section 12.2)
8/28/2013	4.1	Removed “Advanced Information” watermark. Updated section 2.0, 6.5, 6.7, 1.7, 7.2, 7.15, 8, 10.3 and 11.8. Removed section 8.1.
9/13/2013	4.2	Updated Section 6.
9/18/2013	4.3	Updated Section 5.5 & 8.

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2 Purpose and Scope

This product specification provides information regarding the electrical specification and design related information for the MPU-9150™ Motion Processing Unit™ or MPU™.

Electrical characteristics are based upon design analysis and simulation results only. Specifications are subject to change without notice. For references to register map and descriptions of individual registers, please refer to the MPU-9150 Register Map and Register Descriptions document.

3 Product Overview

3.1 MPU-9150 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-9150 is the world’s first integrated 9-axis MotionTracking device that combines a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer, a 3-axis MEMS magnetometer and a Digital Motion Processor™ (DMP™) hardware accelerator engine. The MPU-9150 is an ideal solution for handset and tablet applications, game controllers, motion pointer remote controls, and other consumer devices. The MPU-9150’s 9-axis MotionFusion combines acceleration and rotational motion plus heading information into a single data stream for the application. This MotionProcessing™ technology integration provides a smaller footprint and has inherent cost advantages compared to discrete gyroscope, accelerometer, plus magnetometer solutions. The MPU-9150 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port to produce a 10-Axis sensor fusion output. The MPU-9150 is a 3rd generation motion processor and is footprint compatible with the MPU-60X0 and MPU-30X0 families.

The MPU-9150 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs, three 16-bit ADCs for digitizing the accelerometer outputs and three 13-bit ADCs for digitizing the magnetometer 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), a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*, and a magnetometer full-scale range of ±1200µT.

The MPU-9150 is a multi-chip module (MCM) consisting of two dies integrated into a single LGA package. One die houses the 3-Axis gyroscope and the 3-Axis accelerometer. The other die houses the AK8975 3-Axis magnetometer from Asahi Kasei Microdevices Corporation.

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-9150 uniquely supports a variety of advanced motion-based applications entirely on-chip. The MPU-9150 thus enables low-power MotionProcessing in portable applications with reduced processing requirements for the system processor. By providing an integrated MotionFusion output, the DMP in the MPU-9150 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 I^2C at 400 kHz. 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-9150 package size down to a revolutionary footprint of 4x4x1mm (LGA), 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, magnetometers, and the on-chip temperature sensor.

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
- Pedestrian based navigation
- Navigation
- Electronic Compass

5 Features

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-9150 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
- Factory calibrated sensitivity scale factor
- User self-test

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-9150 includes a wide range of features:

- Digital-output 3-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
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

5.3 Magnetometer Features

The triple-axis MEMS magnetometer in MPU-9150 includes a wide range of features:

- 3-axis silicon monolithic Hall-effect magnetic sensor with magnetic concentrator
- Wide dynamic measurement range and high resolution with lower current consumption.
- Output data resolution is 13 bit (0.3 µT per LSB)
- Full scale measurement range is ±1200 µT
- Self-test function with internal magnetic source to confirm magnetic sensor operation on end products

5.4 Additional Features

The MPU-9150 includes the following additional features:

- 9-Axis MotionFusion via on-chip Digital Motion Processor (DMP)
- Auxiliary master I^2C bus for reading data from external sensors (e.g., pressure sensor)
- Flexible VLOGIC reference voltage supports multiple I^2C interface voltages
- Smallest and thinnest package for portable devices: 4x4x1mm LGA
- Minimal cross-axis sensitivity between the accelerometer, gyroscope and magnetometer 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
- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

5.5 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports 3D MotionProcessing and gesture recognition algorithms
- The MPU-9150 collects gyroscope, accelerometer and magnetometer data while synchronizing data sampling at a user defined rate. The total dataset obtained by the MPU-9150 includes 3-Axis gyroscope data, 3-Axis accelerometer data, 3-Axis magnetometer data, and temperature data.
- 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.

5.6 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

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 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	-40°C to +85°C		±0.04		%/°C	
Nonlinearity	Best fit straight line; 25°C		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	Component level (25°C)		±20		º/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		º/s	
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (92Hz)		0.06		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	to ±1º/s of Final		30		ms	

6.2 Accelerometer Specifications

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 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		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±80		m*g*	
	Z axis		±150		m*g*	
Change over specified temperature – Component level -25°C to 85°C	X & Y Axis		±0.75		mg/°C	
	Z Axis		±1.50		mg/°C	
NOISE PERFORMANCE						
Power Spectral Density	X, Y & Z Axes, @10Hz, AFS_SEL=0 & ODR=1kHz		400		μ*g*/ √Hz	
Total RMS Noise	AFS = 0 @100Hz		4		mg-rms	
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	

6.3 Magnetometer Specifications

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

The information in the following table is from the AKM AK8975 datasheet.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
MAGNETOMETER SENSITIVITY						
Full-Scale Range			±1200		µT	
ADC Word Length	Output in two's complement format		13		bits	
Sensitivity Scale Factor		0.285	0.3	0.315	µT /LSB	
ZERO-FIELD OUTPUT						
Initial Calibration Tolerance		-1000		1000	LSB	

6.4 Electrical and Other Common Specifications

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 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	35ºC			-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)			±1		°C	
VDD POWER SUPPLY							
Operating Voltages			2.375		3.465	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value				100	ms	
OPERATING CURRENT							
Normal Operating Current	Gyro at all rates	Gyro + Accel (Magnetometer and DMP disabled)		3.9		mA	
	Accel at 1kHz sample rate	Accel + Magnetometer (Gyro and DMP disabled)		900		µA	
	Magnetometer at 8Hz repetition rate	Magnetometer only (DMP, Gyro, and Accel disabled)		350		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	
Magnetometer Full Power Mode Current	100% Duty Cycle			6		mA	
Full-Chip Idle Mode Supply Current				6		µA	
VLOGIC REFERENCE VOLTAGE							
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	

6.5 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
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 (SDA, AD0, SCL, FSYNC, CLKIN)						
V_{IH}, High Level Input Voltage		0.7*VLOGIC			V	
V_{IL}, Low Level Input Voltage				0.3*VLOGIC	V	
C_I, Input Capacitance			< 5		pF	
DIGITAL OUTPUT (INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ	0.9*VLOGIC			V	
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ			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	

6.6 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Typical	Units	Notes
Primary I²C I/O (SCL, SDA)				
VIL, LOW Level Input Voltage		-0.5V to 0.3*VLOGIC	V	
VIH, HIGH-Level Input Voltage		0.7*VLOGIC to VLOGIC + 0.5V	V	
Vhys, Hysteresis		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 (ES_CL, ES_DA)				
V_{IL}, LOW-Level Input Voltage		-0.5 to 0.3*VDD	V	
V_{IH}, HIGH-Level Input Voltage		0.7*VDD to VDD+0.5V	V	
V_{hys}, Hysteresis		0.1*VDD	V	
V_{OL1}, LOW-Level Output Voltage	1mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	1	mA	
	V_{OL} = 0.6V	1	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus cap. in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	

6.7 Electrical Specifications, Continued

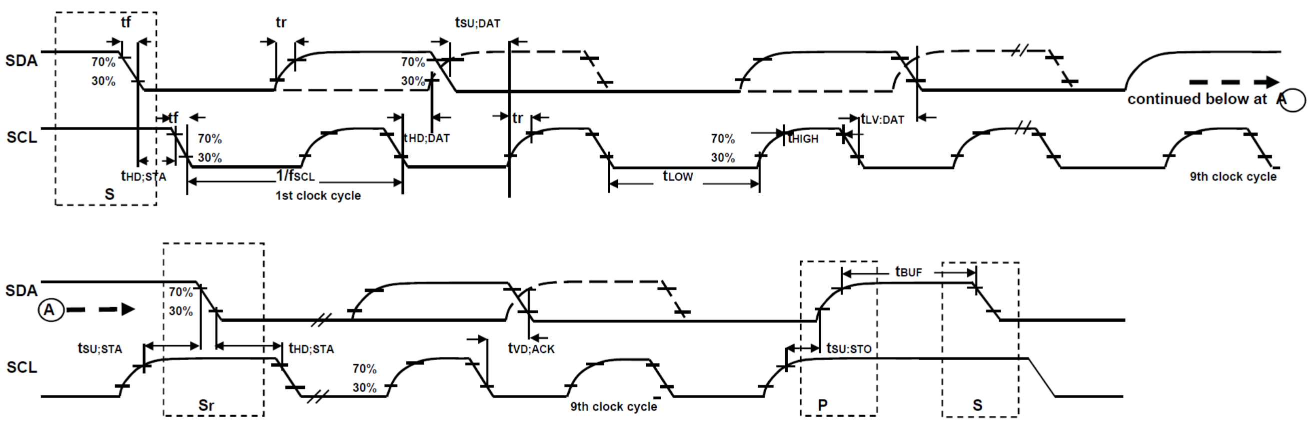
Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

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		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		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		ms	

6.8 I²C Timing Characterization

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 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	



I²C 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.

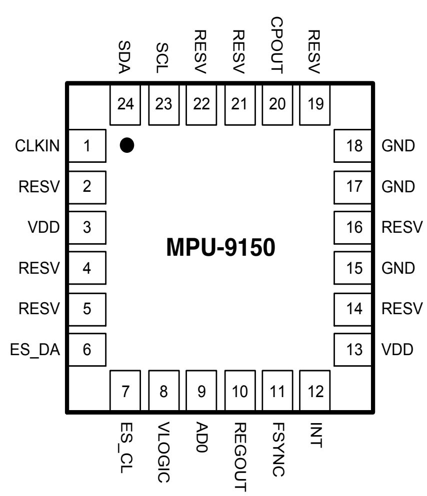
Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +85°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

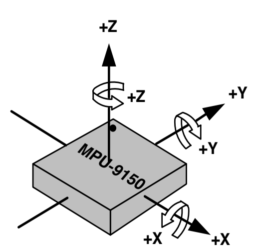
7.1 Pin Out and Signal Description

Pin Number	Pin Name	Pin Description
1	CLKIN	Optional external reference clock input. Connect to GND if unused.
6	ES_DA	Auxiliary I^2C master serial data
7	ES_CL	Auxiliary I^2C Master serial clock
8	VLOGIC	Digital I/O supply voltage
9	AD0	I^2C Slave Address LSB (AD0)
10	REGOUT	Regulator filter capacitor connection
11	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	INT	Interrupt digital output (totem pole or open-drain)
3, 13	VDD	Power supply voltage and Digital I/O supply voltage
15, 17,18	GND	Power supply ground
20	CPOUT	Charge pump capacitor connection
22	RESV	Reserved. Do not connect
23	SCL	I^2C serial clock (SCL)
24	SDA	I^2C serial data (SDA)
2, 4, 5, 14, 16, 19, 21	RESV	Reserved. Do not connect.

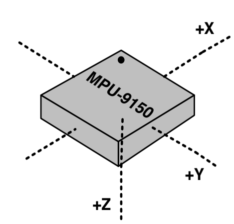
Top View



LGA Package
24-pin, 4mm x 4mm x 1mm

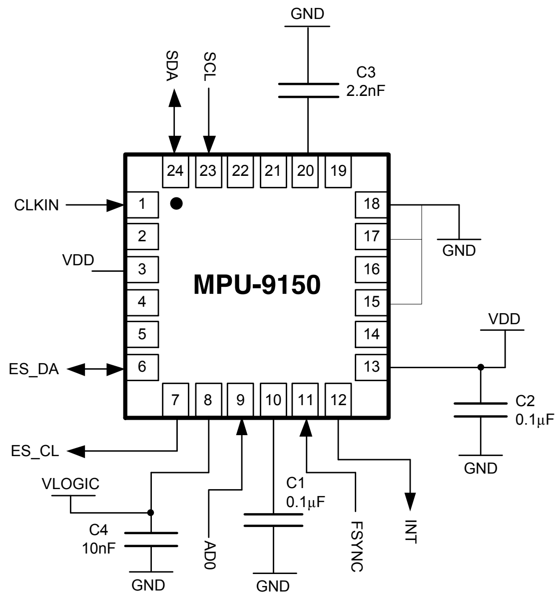


Orientation of Axes of Sensitivity and Polarity of Rotation for Accel & Gyro



Orientation of Axes of Sensitivity for Magnetometer

7.2 Typical Operating Circuit

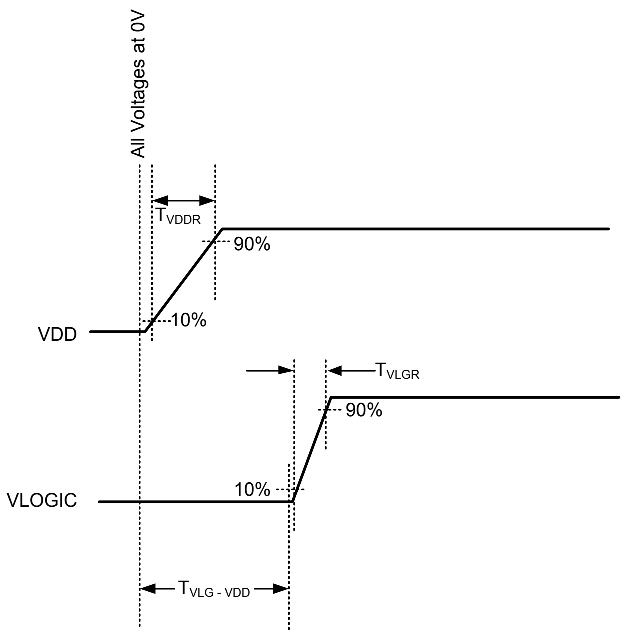


Typical Operating Circuit

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

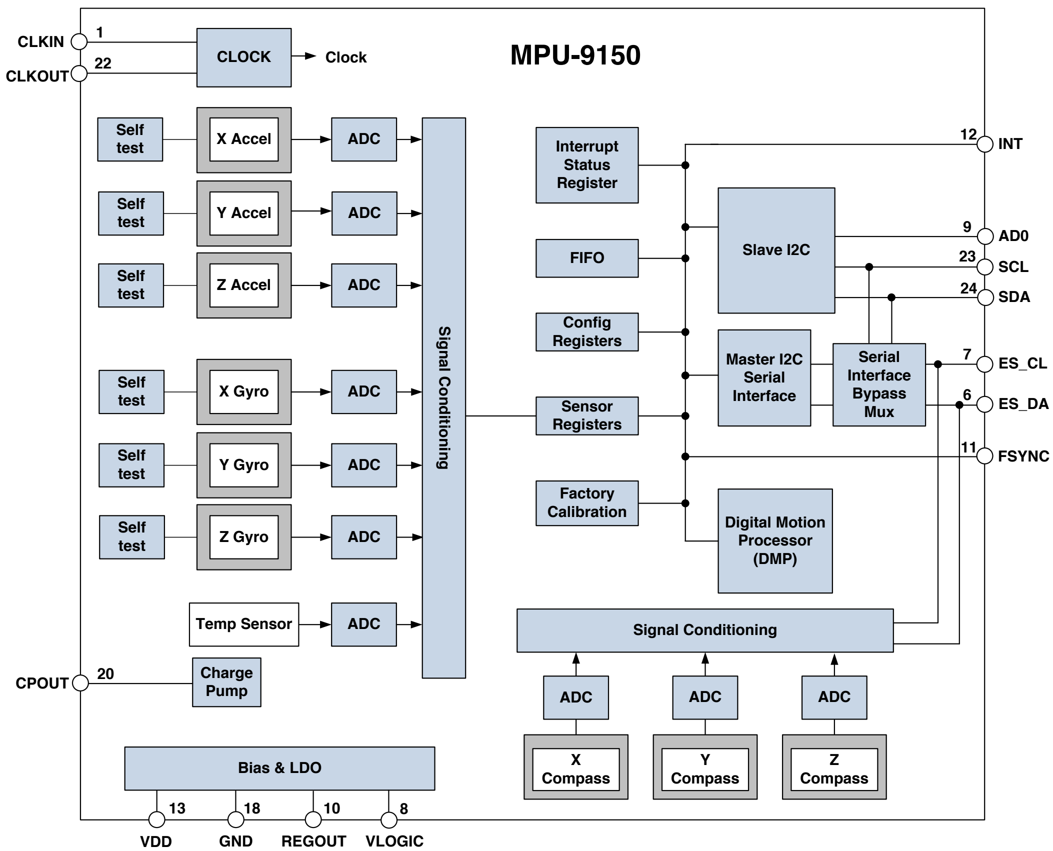
7.4 Recommended Power-on Procedure



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

7.5 Block Diagram



7.6 Overview

The MPU-9150 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
- Three-axis MEMS magnetometer sensor with 13-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I^{2}C serial communications interface
- Auxiliary I^{2}C serial interface for 3rd party sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope, Accelerometer and Magnetometer Self-test
- Bias and LDO
- Charge Pump

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-9150 followed the JESD 47I 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 Condition 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	1	5	(0/1)
(TC) Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak Mode 2 [5'], [Read-Points 1000 cycles]	3	77	(0/1)

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

Joseph M. Joslin

916-778-8010

3602 Amethyst Dr.

jmjoslin19@gmail.com

OBJECTIVE

To obtain an Electrical Engineering Position

EDUCATION

Bachelors, Electrical Engineering, CSU Sacramento

Related Courses

Electronics I, II *	Intro to Feedback Systems	Intro to Logic Design
Robotics *	Power Systems Analysis	
Modern Communication Systems *	Network Analysis	
Probability + Random Signals *	Electro-Mechanical Conversion	
Intro to Microprocessors	Signals and Systems	

** In progress as of Fall 2015*

SKILLS

Computer Languages:
C++, Java, Verilog HDL, Matlab

Computer Skills:
PSpice, Multisim, Cadence, Circuit Maker, Primavera P6, MS Office, MS Project, MS Database

Project Management:
Scheduling, Banquet Captain, Leadership Skills

Tools:
Oscilloscope, Arduino, Multimeter

WORK EXPERIENCE

Scheduling Intern	Kiewit Power Constructors	6/15- 8/15
Banquet Server	Whitney Oaks Golf Club	8/10- 5/15

PROJECTS

Motion Tracking Security System
Designed and led a group to design a security system using 3 motion sensors, a Raspberry Pi, a servo motor, and a micro controller. The system was designed to follow 1 or more objects through 180 degrees of motion, and to be transmitted to a remote location for observation. A report was written and presentation given.

Power Plant Scheduling Template
With a fellow intern, we designed a template with all the engineering deliverables used to create a power plant. We consulted with experienced engineers for the most efficient design and created the template in Primavera. It is currently being used by Kiewit Power Constructors.

ACCOMPLISHMENTS and ACTIVITIES

· Kiewit Internship
· Presidents Honor Role, Deans List
· 2015 Tahoe Brazilian Jiu-Jitsu First Place Winner
· 4 Years High-school Golf

Working 30 hours per week, while carrying 15 units per semester and maintaining a 3.6 GPA

Trieu Pham

5525 San Juan Ave. Citrus Heights, CA 95610 (916) 671-9304 trieupdh@gmail.com

OBJECTIVE:

To obtain an internship in Electrical/Electronic Engineering industry

EDUCATION:

In progress, B.S., Electrical and Electronic Engineering, CSU Sacramento; GPA: 3.40; May 2016

RELATED COURSES:

Electronics I	Signal and Systems
Electronics II *	Digital Control Systems
Robotics *	Introduction to Feedback Systems
Introduction to Microprocessors	Wireless Communication Systems *

** In progress as of Fall 2015*

KNOWLEDGE AND SKILLS

Tools:
MATLAB, Design Entry CIS, Visual Studio, MS Office

Programming:
C/C++, Verilog, Java, VB.NET

Communication/Organization/Leadership:
Strong written and verbal communication skills; self-motivated, dependable and willing to work in teams and individually.

Problem Solving:
Skilled at troubleshooting complex or challenging problems and finding solutions.

PROJECT EXPERIENCE:

Straight Line Robot Movement
Developed and built a four-wheeled mobile robot moving straight line. The direction of robot is controlled by servo motor to two steering wheels. Arduino micro-controller was selected as PID controller due to react and respond to the data received from potentiometer sensor to identify and figure out desired position and direction.

Water Temperature and Level Control System
A member of three-person team that designed, simulated a control system that maintained water temperature and water level using Arduino micro-controller. Using a waterproof temperature sensor, the servo of hot water container was programmed to close its valve and stop releasing water once cold water container had reached the desired temperature. A valve of cold water container that was connected to another servo released water out once its water level had reached above capacity, triggering the float switch.

WORK EXPERIENCE:

Quality Checker — **Softfile** — 9/14 to present
Checking and fixing scanned documents to ensure legible and high quality for the customer.

Customer Service Assistant — **HMSHost at Sacramento Int'l Airport** — 7/10- 3/15
Completing customer transactions, cleaning the food or stock areas, and maintaining inventory. Transferring supplies between storage and work areas by hand or cart.

Office Clerk — **Brandidas Communications** — 5/08- 11/09
Answering telephones, directing calls and taking messages. Compiling, copying and sorting customers' documents. Operating office machines, voice mail systems and personal computers.

ACTIVITIES AND ACCOMPLISHMENTS:

Dean's Honor List, Spring 2014, Spring 2015

Working 20 hours per week, while carrying 12 units per semester and maintaining a 3.40 GPA

Kristie Sihombing

(916) 533-2085   kristiesihombing@gmail.com

Objective: To obtain a position as an Electrical Engineering student where I can utilize my technical skills while gaining valuable work experience.

Education:
In progress: Bachelor of Science, Electrical and Electronic Engineering, CSUS
Expected Graduation Date: Spring 2016

Related Courses:

*Electronics II	Microprocessors	Power System Analysis
Circuit Analysis	Logic Design	*Electric Power Distribution
Network Analysis	C Programming	Modern Communication Systems

**In progress as of Fall '15*

Knowledge and skills:

Leadership:
Strong leadership, organizational, and planning skills. Organized a singing competition event involving over 100 people. Efficiently run and organize various church social events and activities. Consistently encourage participation.

Communication:
Excellent networking and socializing skills. Led call to worship in front of over 900 people. Good written and verbal communication skills. Ability to work individually as well as with a group.

Computer skills:
PSPICE, Multisim, Matlab, Simulink, ADS, PSCAD, Excel, Mac and Windows operating system

Project Experience:

Water Temperature and Level Control System
A member of three-person team that designed and simulated a control system that maintained water temperature and water level using the Arduino microcontroller.

Work Experience:

AppleCare At-Home Advisor **Apple Inc.** May 2011-June 2012; June 2015-Present
Involved in work that provides telephone technical support for Apple computers and devices while working independently from home. Demonstrated discipline and motivation by remaining on task while working remotely from management. Collaborated in team building activities. Exercised multitasking skills. Managed multiple systems and applications. Analyzed and resolved a variety of complex technical issues. Effectively developed communication skills and consistently met quotas. Drove sales for AppleCare Protection Plan and all other Apple products. Demonstrated customer service.

Cashier/Server **California State Fair 2012** July 2012
Operated cash register. Provided customer service.
Developed ability to work in a fast paced environment.

Volunteer Work:

- 2009-Present: President of Parkview Presbyterian Church-GKI Youth/Young Adult Group
- July 2013-Present: N.A.P.C (National Asian Presbyterian Council) Steering Committee Young Adult Representative

- October 2013-Present: Interim Coordinator for youth and young adults of N.I.P.C (National Indonesian Presbyterian Council)
- Raised over 700$ for World Vision Organization Famine Fundraiser

King Nguyen, E.I.T.

king.nd.nguyen@gmail.com (916)230-6654

Education

California State University, Sacramento June 2016
Bachelor of Science, Electrical & Control Engineering

Work Experience

Engineering Intern at Intarcia Therapeutics, Inc. June - August 2015
Worked with Allen-Bradley PLCs and HMIs

- Performed backup and inventory procedures on systems
- Conducted GxP 21 CFR Part 11 ERES Assessments on systems
- Setup and configured PLC (Controllogix) and HMI(Panelview Plus) station for testing.
- Tested domain authentication for future implementation on HMIs.

Technical Skills

Programming Languages: C, C++, Matlab, Verilog, SPIN, SQL
Software: Altera Quartus II, AUTOCAD, Keysight ADS
Cadence Pspice, Multisim, RsLogix, FactoryTalk View, SOLIDWORKS
Microcontroller: Arduino, Parallax, PICkit
Other: Oscilloscope, Function Generator, Raspberry Pi

Projects

Water Control System Fall 2014
Worked in a group to design and construct a water control system. Water in a tank is optimized to user defined temperature and volume by a microcontroller.

- Configured Arduino microcontroller to control servos and sensors
- Calibrated feedback sensors
- Assembled a heated water source and a reservoir to hold drained water

Coursework

Computer Science: Discrete Mathematics, Object-Oriented Programming
Electrical Engineering: Device Physics, Digital Systems
Electronics Circuits, Signals and Systems, Control Systems
Applied Electromagnetics, Electromechanic Conversion