

Wireless Sensing System for Intelligent Concrete Curing

Sponsor: Texas Instruments

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Introduction:

Concrete work, whether residential or commercial, is a costly investment that can impede on one's business or personal convenience during the curing process. Construction companies give an arbitrary duration of time to customers when they will be able to begin utilizing their investment. A 28-day strength diagram has been developed to estimate the time in which concrete has fully matured to offer its optimal strength. However, the maximum strength can be reached at different times based on the ambient temperature and humidity concentration in the environment and in the concrete. Hydration process is the chemical reaction that takes place in concrete, where the Portland cement reacts with water to form crystals that bonds and hardens the material. If concrete is poured in cold environments with temperatures less than 40 degrees Fahrenheit, the reaction will seize, causing the concrete to not settle properly and essentially freeze. High temperatures evaporate the water content too fast leaving the crystals with an insufficient amount of water to form uniformly throughout the concrete, which causes cracks. Given these varying set-up times, it would be very beneficial to know the exact time the concrete is cured to optimize business production and ensure maximum strength in a structure.

Texas Instruments has taken interest in designing a system that would relay information of two important parameters, temperature and humidity, to the customer that would inform them when they could begin utilizing their product. The desired specifications for this particular project are to produce wireless communication from the sensors that have been dispersed throughout the freshly poured concrete, to a centralized unit. This unit will calculate, through an algorithm, based on the information presented when the concrete is cured. The most imperative constraints for optimizing the designed system are power, accuracy, range and cost. Sensing modules must possess enough battery life to be able to transmit signals for the slowest settling times of concrete, established as three weeks. These signals need to have enough power to reach the centralized unit without any distortion in the information, and relay accurate levels. To ensure that this product will be of economic benefit to TI, it needs to be competitive with similar products currently on the market.

Background:

This idea has received plenty of attention over the past 15 years. Research papers such as, "Feasibility of Embedded Wireless Sensors for Monitoring of Concrete Curing and Structural Health," by B. Quinn and G. Kelly, have concluded that these sensing units are very achievable. Currently, there are a multitude of companies, such as Engius who developed IntelliRock systems that have released similar sensing units with varying amenities. The basis of these units require one to drill holes (around 5" by 1" diameter) in the hardened concrete in numerous areas, placing sensors in the holes that connect to a unit that receives information on temperature and humidity. The information about those parameters is then used to calculate when the concrete is properly cured from a central display unit. Mobility and

excessive work for implementation of the product are two major problems with these modules. The sensors are connected via wires to the central unit, constraining the product to only being able to test a small area of the concrete at one time. The other problem presented is the amount of time and work spent drilling and placing the probes in multiple regions for testing, then gathering the data from each section and computing the development of the concrete. These problems have inspired alternate options for a more efficient solution. Wireless sensing systems have been researched and developed to combat the issue, but come at a higher cost than wired systems. Texas Instruments is taking a new approach, by making a wireless transmitting system at a more feasible cost, that when completed has a great potential of generating abundant revenue.

Design Specifications:

For this project, we must design to and deliver end results in accordance with the specifications given below:

- Research, design, test, document and demonstrate a solution that will effectively measure the temperature and humidity inside a medium similar to concrete.
- The design will consist of two main components, the μ MAVRK and the MAVRK. These platforms will be provided by the Texas Instruments. The μ MAVRK will then be divided into three sub-components, a Sensor Module, Power Module and the Radio Module.
- The MAVRK, Power Module and Radio Module will be utilized without altering the circuitry. The Sensor module will need to be re-engineered in order to meet customer requirements and specifications.
- Sensor module with μ MAVRK must be enclosed by non-metal material in order to prevent damage due to pressure and humidity. Sensor should be exposed out of enclosure to achieve accurate condition of concrete.
- Test environment for demonstrating the performance of sensor module must be made.

Customer Requirements:

The MAVRK, Power Module and Radio Module will be utilized without altering the circuitry. The Sensor module will need to be re-engineered in order to meet customer requirements and specifications. Due to the devices' unattainability once placed into the concrete, the μ MAVRK platform must consume minimal amount of power to ensure all the necessary information is transmitted up to final curing time. A power source of 2 AA batteries have provided to us that will supply the sensing module. If the required tasks have been met, the customer has requested to merge the power supply, sensor board and μ MAVRK into a single printed circuit board. Lifespan of module needs to be at least 3 weeks, considering experimental time needed for full solidification of concrete was estimated at 2 weeks. Cost of module should be within range of reasonability. Criterion of defining solidification of the concrete is not an objective for this project, just accurate functionality between the parameters and MAVRK. Figure shown below analyzes the importance of each design factor.

		Parts Selection	High Level Design	Signal Conditioning	Time between Data Acquisition
Functionality	5				
Cost	2				
Accuracy	4				
Low Power	4				

Proposed Design Solution:

i. Component Selection

Temperature Sensor

Part Number	PTS1206
Manufacturer	VISHAY
Thermal response time	$t \leq 0.1s$
Operating Temperature Range	-55 to 150°C
R min(0°C)	100Ω
R max(60°C)	123.24Ω

Humidity Sensor

Part Number	CHS-UGS
Manufacturer	TDK
Operating Voltage	4.75V to 5.25V
Output Voltage	10mV per %RH

DC-DC Step up Booster

Part Number	TPS60241
Manufacturer	Texas Instrument
Supply Voltage	2.7 to 5.5V
Output Voltage	5V(fixed)
Current Output	25mA

40-Pin μEVM connector interface

Part Number	DF-40C-40DS-0.4V
Manufacturer	Hirose Electronics

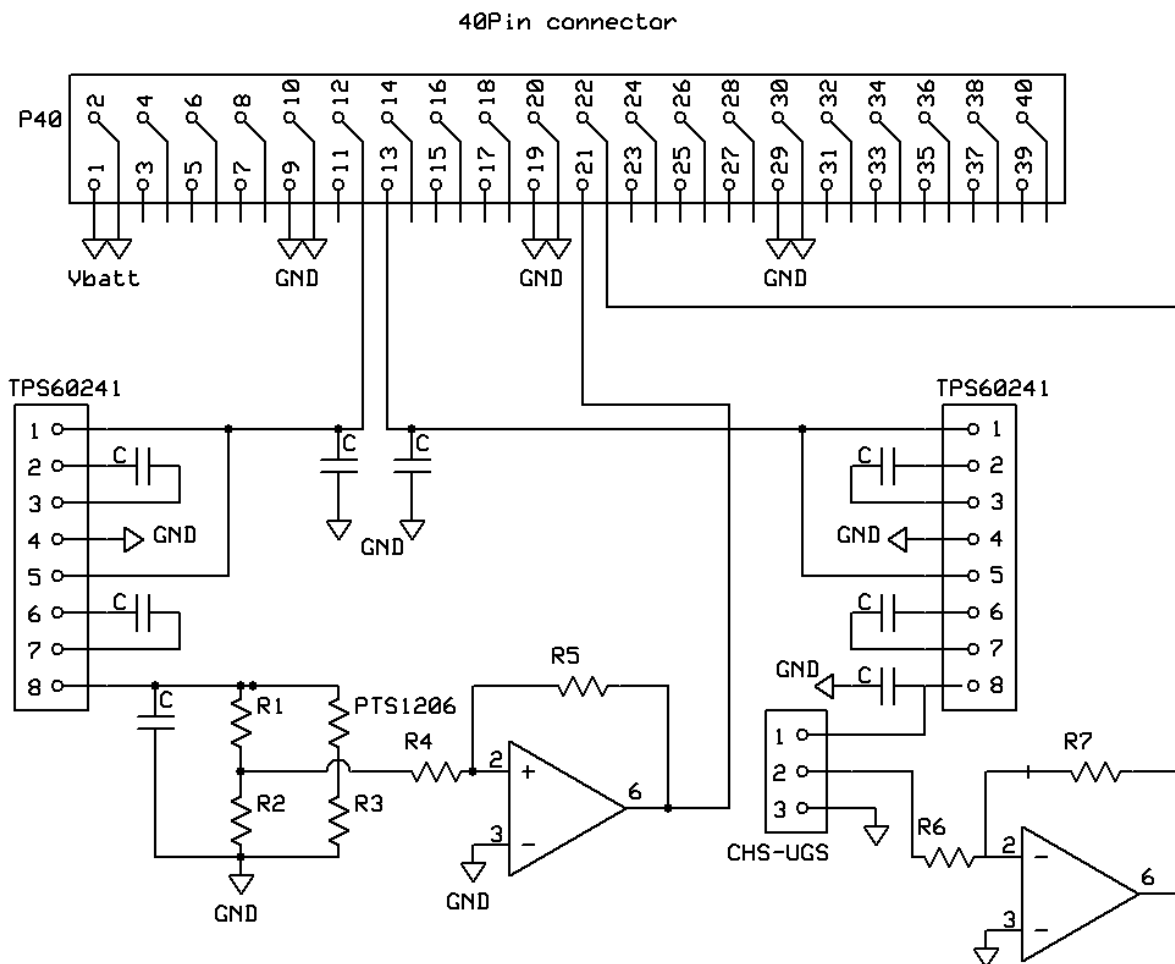
Operation Amplifier

Part Number	LM4250CN
Manufacturer	National Semiconductor
Type	Programmable Gain Amplifier

ii. Sensor module operation

From PIN 12 and 13, a 2.7 to 3.5V DC value will be supplied too PIN 1 of both TPS60241s. A 5V fixed DC Voltage will then be outputted to the RTD and humidity Sensor. For the RTD sensor, a Wheatstone Bridge will be used to eliminate the errors caused by the Resistive components of the circuit other than the RTD itself. The voltage from V bridge ranged from 0V to 0.306V will then be supplied to the Op Amp with a gain of 10 to reduce error in ADC conversion due to low resolution. V Out of the humidity Sensor, ranged from 0V to 1V will be also amplified by a gain factor of 3 for the same purpose. An amplified output will then be fed to Pin 21 and 22 accordingly, to communicate with the uMAVRK for 12-bit ADC conversion. Vref of the uMAVRK will be set to 3V by internal circuitry.

iii. Circuit Diagram



IV. Test environment

ii. Test environment

Due to time constraints, testing the design while embedded in concrete is not applicable. In order to simulate this action, we propose two possible approaches. The first approach involves placing the μ MAVRK platform into a fish bowl filled with sand. To simulate the temperature changes found in concrete, a heat lamp will be placed near the bowl. Also to achieve the humidity simulation that occurs in concrete, the sand will be dampened with water. The second approach involves the same method of simulation; however crushed up limestone will be used instead of sand.

iii. MPS programing requirements

- Powering module on and off in specific time interval to increase battery lifespan.
- Changing analog input from sensors to digital
- Sending data through RF antenna provided on μ MAVRK]

Risk Analysis:

Malfunctioning of development tool

- μ MAVRK and MAVRK is not a development tool in mass production state. There can be error within the development tool that cannot be fixed.

Life span of module

- Module must be in active state for minimum of two weeks. Using battery with large capacitance will solve the problem, but will increase the unit cost of module.

Field test

- Field tests are not likely to occur considering short time span of project. There can be issues which are not apparent on test environment level. Possible issues are :
 - o protection of module(pressure, temperature, humidity at practical environment might damage the circuit)
 - o frequency disturbance(due to low power nature of module, low frequency data transfer between μ MAVRK and MAVRK is likely to occur. Low frequencies are more likely to get distortion. Might limit signal range.

Software:

Mavrk Package Complications:

For Texas Instruments', we have agreed to produce a detailed report, which documents the issues and complications we encountered from the unboxing stage to the completion of our project. Here, we will describe the problem, and describe what we did to resolve the issue.

Upon the unboxing of our package, there were clear labels on each component. However, we realized that it did not include a Power Module or a Sensor Module. We have ordered these parts already. The set-up did not take long for us to find tutorials online for setting up and getting started. They were surprisingly straight forward. Although it was a long process, we did manage to get things moving.

1. First, we had to set up a software repository to receive the pre-written modules. Setting up this connection is the only way to receive their updates, as their code is not in a final-release form. There were several installations such as TortoiseGit, Msysgit, and Putty. This process is outlined in this tutorial: http://processors.wiki.ti.com/index.php/MAVRK_Software_Installation_Guide
2. In choosing the IDE, we ran into some problems. First, we decided to use the IAR Workbench. This was one of the options outlined in the tutorial. However, the user cannot use this software as it is currently. The free version given to us in CD is limited to only 8K. The modules will need much more than that. Next, we used Code Composer 4 (also given to us on CD). This also cannot be used. We get strange build errors. The version that can work with the Mavrk is **Code Composer 5**. This can be downloaded from TI's website without waiting for approval. Just make an account and proceed.
3. We cloned the modules into our repository. No problems here.
4. The next thing we did was to build and run the MCU application (UART Passthrough). This built and debugged fine.
5. We built the Sensor Demo Application on the uMavrk fine. However, upon Debugging, we get the following error: "The target setup (MSP430F5438A) does not match the actual target type (CC3430F5137)". Texas Instruments is currently working with us to figure out a solution to this problem.

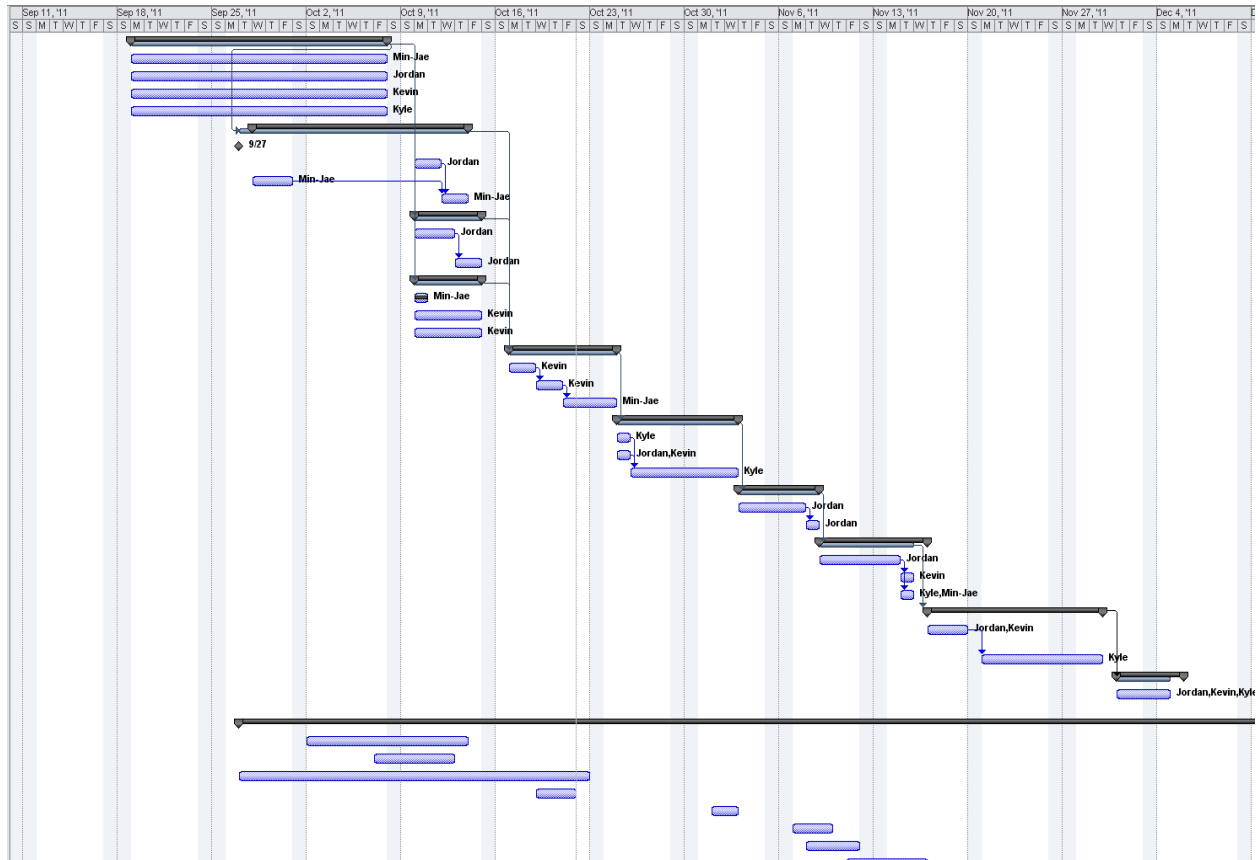
Project Management:

To optimize our project's duration of time, we assigned individual roles to our team members. These roles are designed to cover all aspects of the project that need a great deal of attention in order to meet our specifications in a timely manner. Each group member has a contributing role to tasks and deliverables outside the development of the circuit. Kevin Yeh has taken on the role of team manager, in which this intense position is responsible for ensuring group productivity and that assignments are met on time. This role also includes the organization and assigning of weekly tasks to group members, weekly team meetings and customer meetings. Kyle Shultz is the website prep that is in charge of creating and maintaining our team's website, which includes our objectives and relevant information about the process of our design. Jordan Bennett is the lab coordinator and document prep that is

responsible for reserving rooms for meetings and finalizing written documents. Our team's presentation prep is Min-Jae Lee, who organizes and structures oral presentation information.

While our professor allocated non-technical roles to us, we took it upon ourselves to assign technical areas which best utilize each of our strengths. These roles have been assigned to cut down on time wasted, and for each person to get firmly acquainted with an area to solve any problems if they are presented in the design phase. Kevin, a computer engineer, dealt with programming the μ MAVRK to translate the incoming sensor voltages to a known range that the MAVRK can interpret. Him and Kyle became acquainted with the Allegro program to take our prototype into a printed circuit board. Kyle also worked with TINA simulations to gain a theoretical perspective on how the prototype will act in different testing environments. Min-Jae and Jordan were in charge of the circuit, and what components were needed to provide accurate information for the MSP. A baseline reference was needed to compare the accuracy in the prototype, which Jordan researched and developed an effective method.

Our faculty member, Dr. Strangas, will be meeting with us every Wednesday. Working with him will help us move the project in the right direction. He will mainly be our point of contact in our questions about logistics. He will also provide suggestions on project management and how to allocate roles and resources.



Project Timeline

Listed below is a detailed timeline that Design Team 5 created and utilized during the project lifespan. In order for the team to accomplish the overall objective, checkpoints were established throughout the project.

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Research On project	16 days	Mon 9/19/11	Fri 10/7/11		
Temperature sensor	16 days	Mon 9/19/11	Fri 10/7/11		Min-Jae
humidity sensor	16 days	Mon 9/19/11	Fri 10/7/11		Jordan
uMAVRK interface	16 days	Mon 9/19/11	Fri 10/7/11		Kevin
Testing environment	16 days	Mon 9/19/11	Fri 10/7/11		Kyle
Design Tested on proto-board level	14 days	Wed 9/28/11	Thu 10/13/11 1		Jordan, Kyle, Min-

					Jae
Obtain Parts needed for building design	0 days	Tue 9/27/11	Tue 9/27/11		Kyle
Test Humidity sensor functionality	2 days	Mon 10/10/11	Tue 10/11/11		Jordan
Test Temperature sensor functionality	3 days	Wed 9/28/11	Fri 9/30/11		Min-Jae
Op-Amp Signal Conditioning(if necessary)	2 days	Wed 10/12/11	Thu 10/13/11	8,9	Min-Jae
Test Environment design	5 days	Mon 10/10/11	Fri 10/14/11	1	Jordan
Order Materials needed for Testing Environment	3 days	Mon 10/10/11	Wed 10/12/11		Jordan
Build testing environment	2 days	Thu 10/13/11	Fri 10/14/11	12	Jordan
MSP430 Programming	5 days	Mon 10/10/11	Fri 10/14/11	1	Kevin
uMAVRK pins Mapped out	1 day	Mon 10/10/11	Mon 10/10/11		Min-Jae
CC430 Programed	5 days	Mon 10/10/11	Fri 10/14/11		Kevin
MSP430 Programmed	5 days	Mon 10/10/11	Fri 10/14/11		Kevin
sensor board testing using uMAVRK	7 days	Mon 10/17/11	Mon 10/24/11	6,14,11	Kevin, Min-Jae
Test ADC conversion	2 days	Mon 10/17/11	Tue 10/18/11		Kevin
Test RF signal(Rx Tx)	2 days	Wed 10/19/11	Thu 10/20/11	19	Kevin
Circuit Modification for DSP difference	3 days	Fri 10/21/11	Mon 10/24/11	20	Min-Jae
PCB Board Fabrication(using Allegro)	7 days	Tue 10/25/11	Wed 11/2/11	18	
Circuit Simulation using TINA	1 day	Tue 10/25/11	Tue 10/25/11		Kyle
Grabber file created	1 day	Tue 10/25/11	Tue 10/25/11		Jordan, Kevin
sending& receiving PCB	6 days	Wed 10/26/11	Wed 11/2/11	23,24	Kyle
Enclosure Design	4 days	Thu 11/3/11	Tue 11/8/11	22	Jordan
Modify Enclosure to expose sensors	3 days	Thu 11/3/11	Mon 11/7/11		Jordan
Assemble Proto module	1 day	Tue 11/8/11	Tue 11/8/11	27	Jordan
Test 1st prototype sensor module	6 days	Wed 11/9/11	Wed 11/16/11	26	Jordan, Kevin, Kyle, Min-Jae
Gather Test Data	4 days	Wed 11/9/11	Mon 11/14/11		Jordan
MAVRK modification	1 day	Tue 11/15/11	Tue 11/15/11	30	Kevin
Circuit Modification	1 day	Tue 11/15/11	Tue 11/15/11	30	Kyle, Min-Jae
Fabricate Final Proto-board	10 days	Thu 11/17/11	Tue 11/29/11	29	
design Allegro PCB layout containing uMAVRK, Sensor module, power module	3 days	Thu 11/17/11	Sat 11/19/11		Jordan, Kevin
Send & Receive PCB	7 days	Mon 11/21/11	Tue 11/29/11	34	Kyle
Assemble final module	4 days	Thu 12/1/11	Mon 12/5/11	33	Jordan, Kevin, Kyle, Min-Jae
Final Demonstration of module with test environment	3 days	Thu 12/1/11	Sun 12/4/11		Jordan, Kevin, Kyle, Min-Jae
Non-technical tasks	62 days?	Tue 9/27/11	Mon 12/12/11		
update pre-proposal	11 days	Sun 10/2/11	Thu 10/13/11		
practice oral presentation	5 days	Fri 10/7/11	Wed 10/12/11		
Progress Report 1	23 days	Tue 9/27/11	Sat 10/22/11		
Oral Proposal Presentations	3 days	Wed 10/19/11	Fri 10/21/11		
First project demonstration for facilitator	2 days?	Tue 11/1/11	Wed 11/2/11		
Individual Application Notes due to facilitators	3 days?	Mon 11/7/11	Wed 11/9/11		
Team Technical Lectures	4 days?	Tue 11/8/11	Fri 11/11/11		
Progress Report # 2 and Demo #2 due to facilitators	4 days?	Fri 11/11/11	Wed 11/16/11		
Design Issues paper due	2 days?	Sat 11/19/11	Mon 11/21/11		
Professional self-assessment papers due	51 days?	Tue 9/27/11	Tue 11/29/11		
Final Proposal	5 days?	Mon 10/17/11	Fri 10/21/11		
Design Day Program Page	4 days	Tue 10/4/11	Fri 10/7/11		
Design Day Preparation + posters + Final Notebooks + CD	7 days?	Thu 12/1/11	Thu 12/8/11		
Technical Lecture Topic Form	3 days?	Sun 10/16/11	Tue 10/18/11		
Photocopy Of Engineering Notebooks	3 days?	Mon 10/24/11	Wed 10/26/11		
Final Reports, updates on website	3 days?	Sun 12/4/11	Tue 12/6/11		
Evaluation of individual Team members	2 days?	Sun 12/11/11	Mon 12/12/11		

Cost:

Fortunately, TI has provided all of the expensive components involved in this particular project. The compatible software, the centralized unit (MAVRK), the debugging module and the μ MAVRK sensing module has all been given to us. Since we already have these units, the components needed to meet design specifications are relatively low in cost but quantities were needed for most to test and fabricate multiple prototypes. Also, TI has a library of parts that can be obtained for free on their website, with restrictions to the quantity. The part that needed to be ordered is shown in the figure below.

Part Name	Quantity	Cost
40-pin Male Serial Adapter	3	\$12.50
Temperature Sensor	3	\$3.25
Humidity Sensor	3	\$96.30
Differential OP AMP	3	\$9.09
3 pin connector	6	\$3.03
Plastic Enclosure	3	\$4.15
Plastic Enclosure modification	1	Free(ECE SHOP)
Container	1	\$10(Estimate)
Heat Source	1	Free(Mech Lab)
Humidity source	1	Free
Material	1	\$5(Estimate)
PCB Fabrication Cost	3	\$150(estimate)
Total	29	\$293.32

