Microcontroller Compensated Micromachined Oscillator

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Sponsored by:
Dr. Reza Abdolvand

Oscillators Overview

- Oscillators are heartbeat of electronics
- Necessary for stable signals and proper clocking
- Clock signals ensure data is not lost in delays
- Crystal oscillators are most common

Micromachined Oscillator Overview

- Micromachined oscillators: easier to create and smaller
- Human hair is between 20 and 200μm
- Issues arise with temperature stability

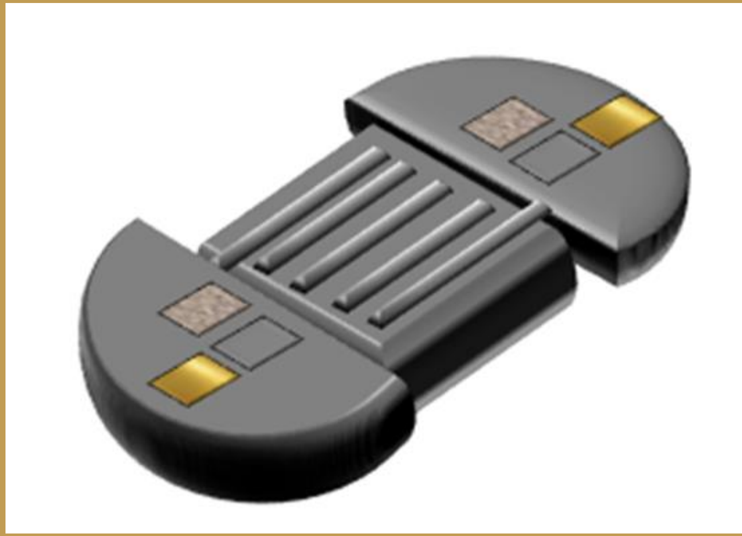


Figure 1: 3D rendering of micromachined oscillator

Motivation

- Researchers at UCF work with thin-film piezoelectric-on-silicon (TPoS) micromachined resonators
- TPoS resonators: respond uniquely to temperature changes
- Project sponsor: Dr. Abdolvand

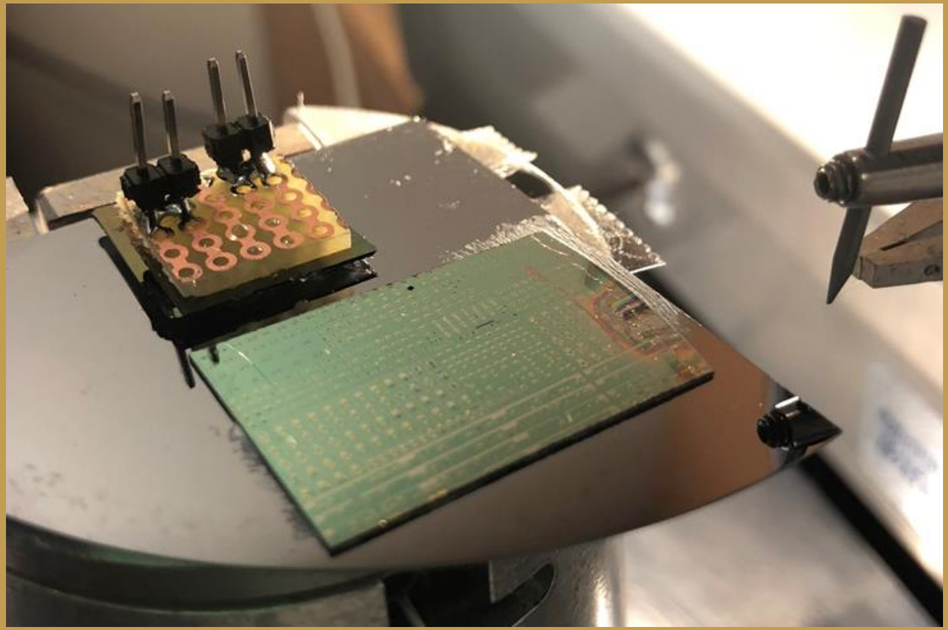


Figure 2: Actual oscillator image

Goals and Objectives

- Goal: to build a PCB that stabilizes temperature of TPoS oscillator

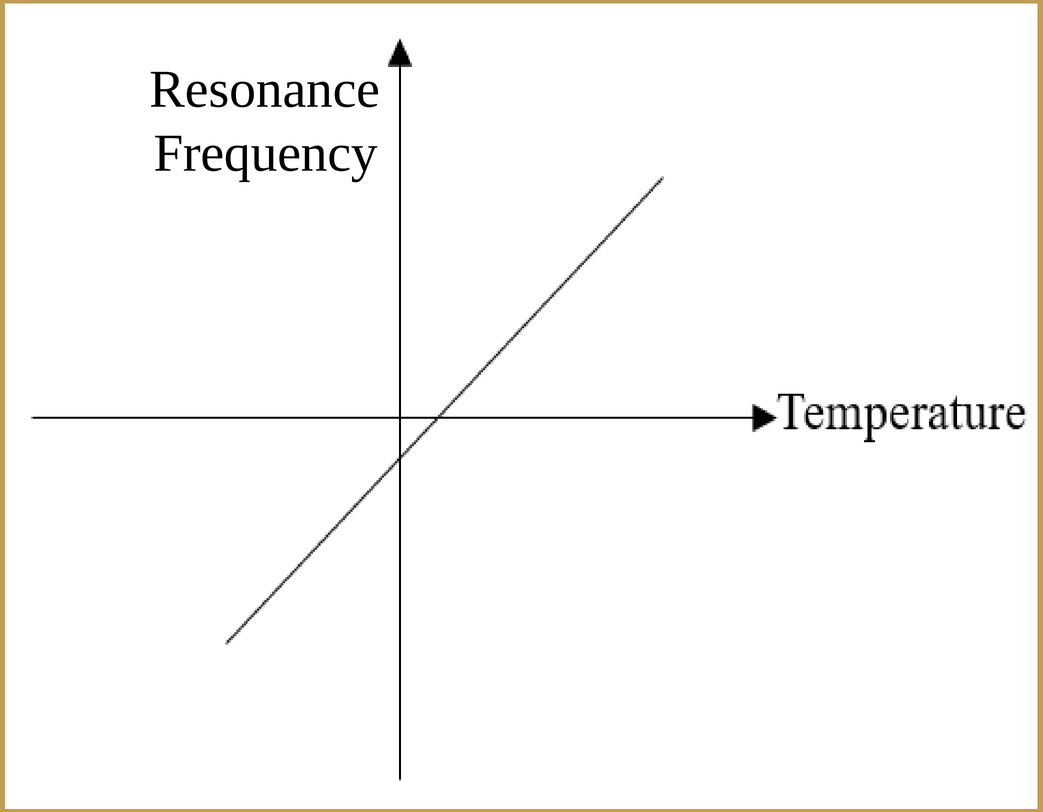


Figure 3: Example typical TCF curve of micromachined oscillators

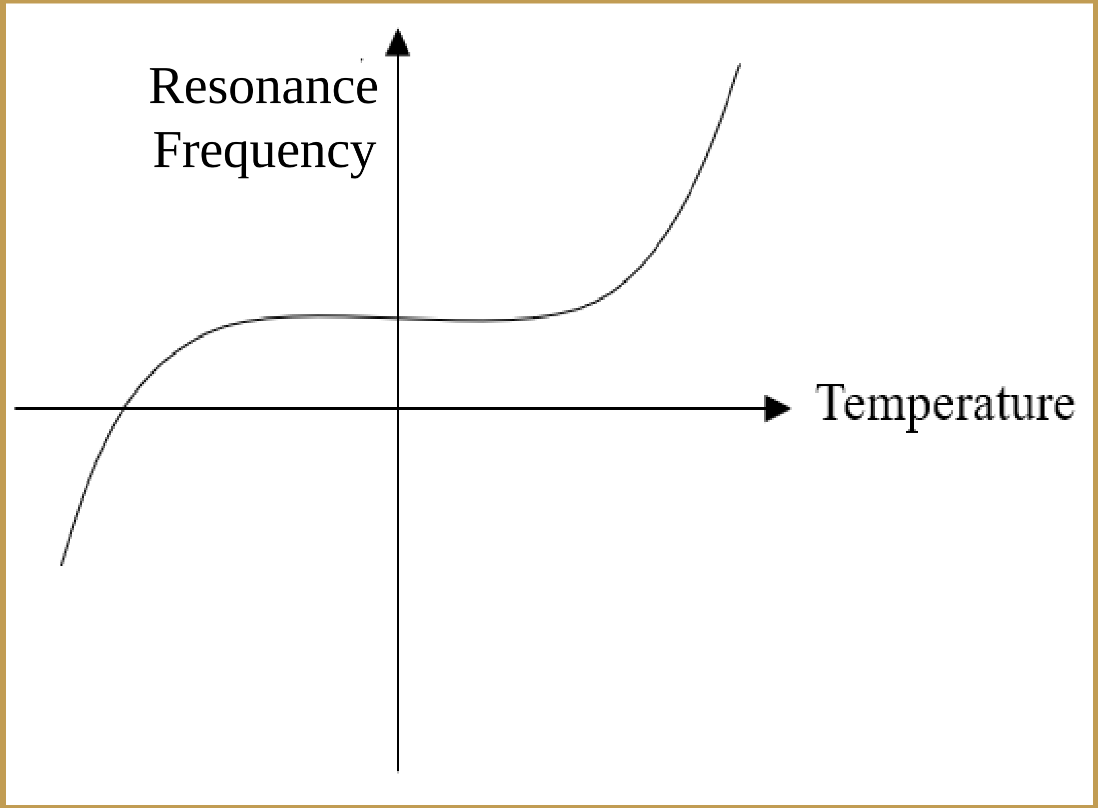
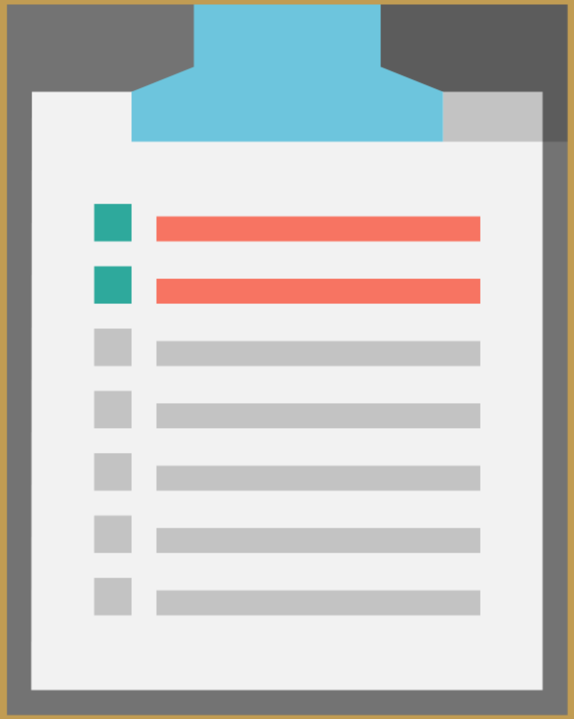


Figure 4: Example typical TCF curve for micromachined TPoS oscillator

Requirements

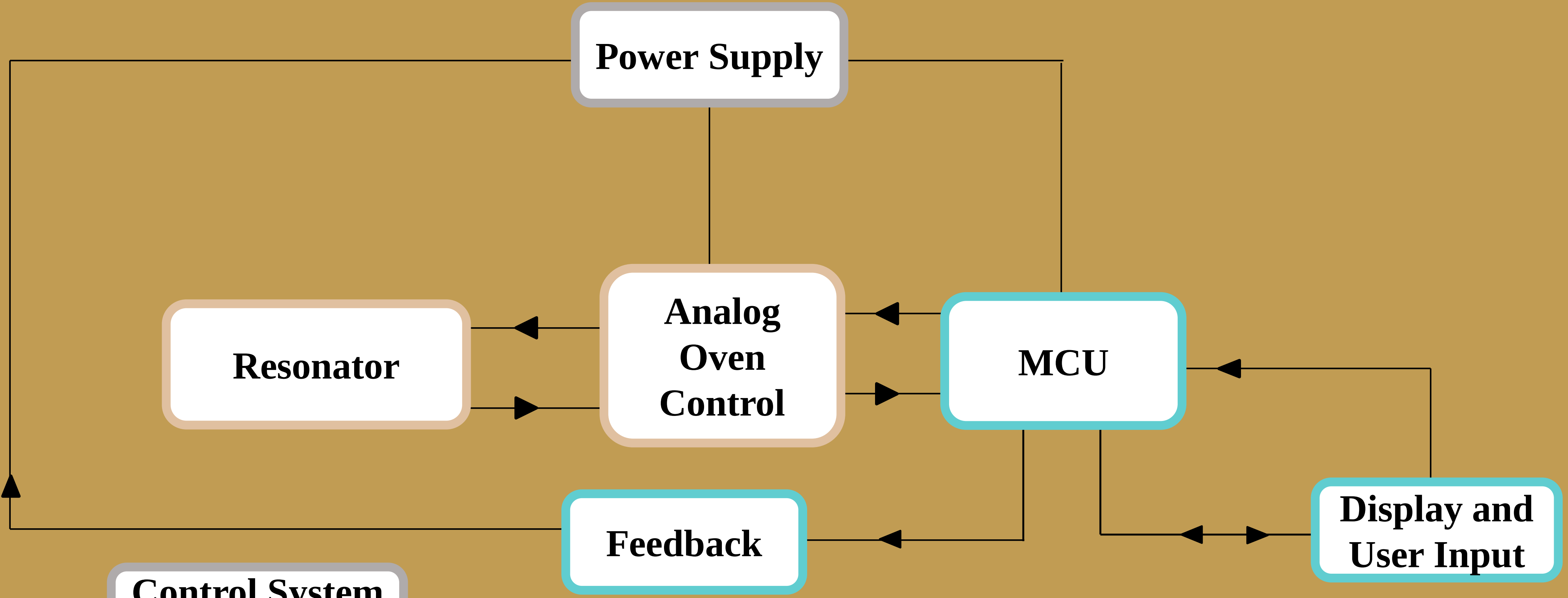
- Hardware Deliverables:
  - Low power
  - Parts per billion (ppb) frequency stability
  - Communication
    - Relay temperature and resistance to user
- Software Deliverables:
  - Controls within ppb accuracy (0.1 – 0.2 ^{o}C)
  - Correct speed of program for stability
  - Efficient code



Specifications

Feature	Value
Project Budget	$100
Completion Time	31 weeks total
Accuracy	Parts per billion (less than ~0.07Hz per 1°C of temperature change)
Operating Temperatures	System: ambient room temperature (approximately 23 °C) Resonator: greater than 85 °C (approximately 90 °C)
Resonance Frequency Deviation	2Hz
Start up time	<1second
Low Power	<20W

Overall System Design



Other Tasks:

- Control System Design
- Team Coordination
- PCB Design

Responsibility of:

- Heather
- Megan
- Michaela

COMPONENT SELECTION

Microcontroller Series Selection

Feature	MSP430	MSP432	PIC24F	Gecko
Operating Voltage	1.8 V – 3.6 V	1.62 V to 3.7 V	2.0 V – 3.6 V	1.98 V – 3.8 V
Manufacturer	Texas Instruments	Texas Instruments	Microchip Tech.	Silicon Labs
Comm. Interfaces	UART, SPI, I^2C	UART, SPI	UART, SPI, I^2C	UART, SPI
Pin Count	24	40	26	32
Bit Count	16-bit	32-bit	16-bit	32-bit
Low Power	Yes	Yes	Yes	Yes
Power Consumption in Active Mode	330 µA/MHz	95 µA/MHz	300 µA/MHz	63-225 µA/MHz
Approx. Board Price	$14.99	$12.99	$4.99	$29.99

The **MSP430** series microcontroller was chosen because:

- Simple 16-bit device
- Encompasses desired communication interfaces
- Battery life for portable measurement application
- Familiarity with the family of microcontrollers
- Low cost

Microcontroller Product Selection

Feature	MSP430FG47x	MSP430G2x	MSP430F552x
Pin Count	48	20	63
Analog-to-Digital Resolution	16-bit	10-bit	12-bit
Digital-to-Analog Resolution	12-bit	N/A	N/A
Additional features	Five low-power modes, digitally controlled oscillator	On-board buttons and LEDs, modules for added functionality	On-board emulation for programming and debugging
Board Price	$6.20	$9.99	$12.99

The **MSP430FG47x** microcontroller was chosen because:

- Provides enough pins to connect LCD, buttons, and voltage readings
- Highest A/D resolution
- Contains a D/A convertor
- Allows for an external crystal oscillator to increase clock speed
- Low cost

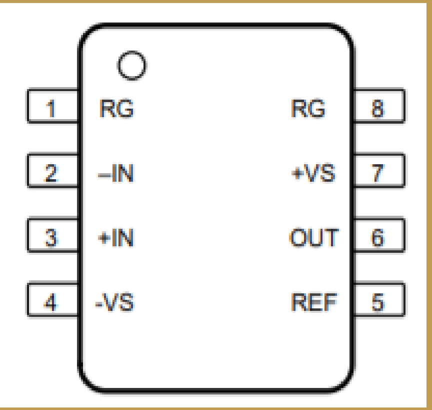
Microcontroller Voltage Readings

Resonator

Inside Microcontroller

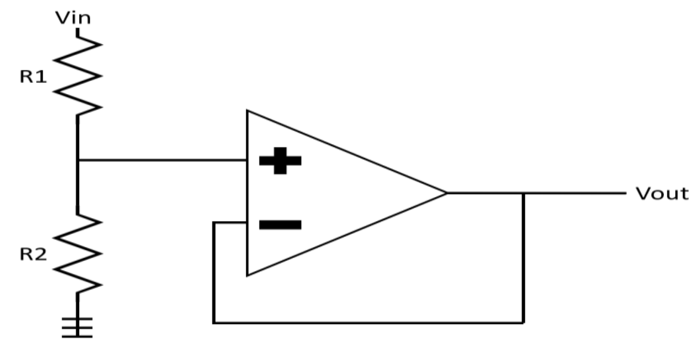
16-bit ADC

- **Goal:** Maximize resolution of voltage readings through 16-bit A/D Convertor
- **How:** Manipulate input voltages to span over the entire microcontroller's input voltage range (0V to 3.3V)
- Max resistor voltage of 0.5→gain of 6
- Max resonator voltage of 6→gain of 0.5



INA828 Op-Amp Gain Resistor

$$\text{Gain} = 6 = 1 + \frac{50k\Omega}{R_G}$$



Voltage Divider Circuit Gain

$$\text{Gain}=0.5=\frac{R_1}{R_1+R_2}$$

Other Components

- Liquid Crystal Display (LCD)
  - Low power solution to display textual information from the MSP430
  - LCD technology will be used to present various resonator readings to the user

Product	Manufacturer	Driver Voltage	Character Arrangement	Number of pins	Display Type	Price
LCM-H01604DSF	Lumex	5V	16x4	16	STN, Transflective	$27.92
EA 8081-A3N	Electronic Assembly	5V	8x2	14	Neutral, Blu-Contrast, STN, Reflective	$16.97
TC1602A-09T	TinSharp	5V	16x2	16	STN, Transmissive, Negative, Blue	$9.95
NMTC-S20200BMNHSGW-12	Microtips Technology	4.5V	20x2	16	STN, Transmissive, Negative	$15.74
LCD-20x4Y	Gravitech	4.7V	20x4	16	STN yellow green	$14.35
NHD-0216K1Z-FL-YBW	Newhaven Display	5V	16x2	16	STN yellow green, Transflective	$10.50

Other Components

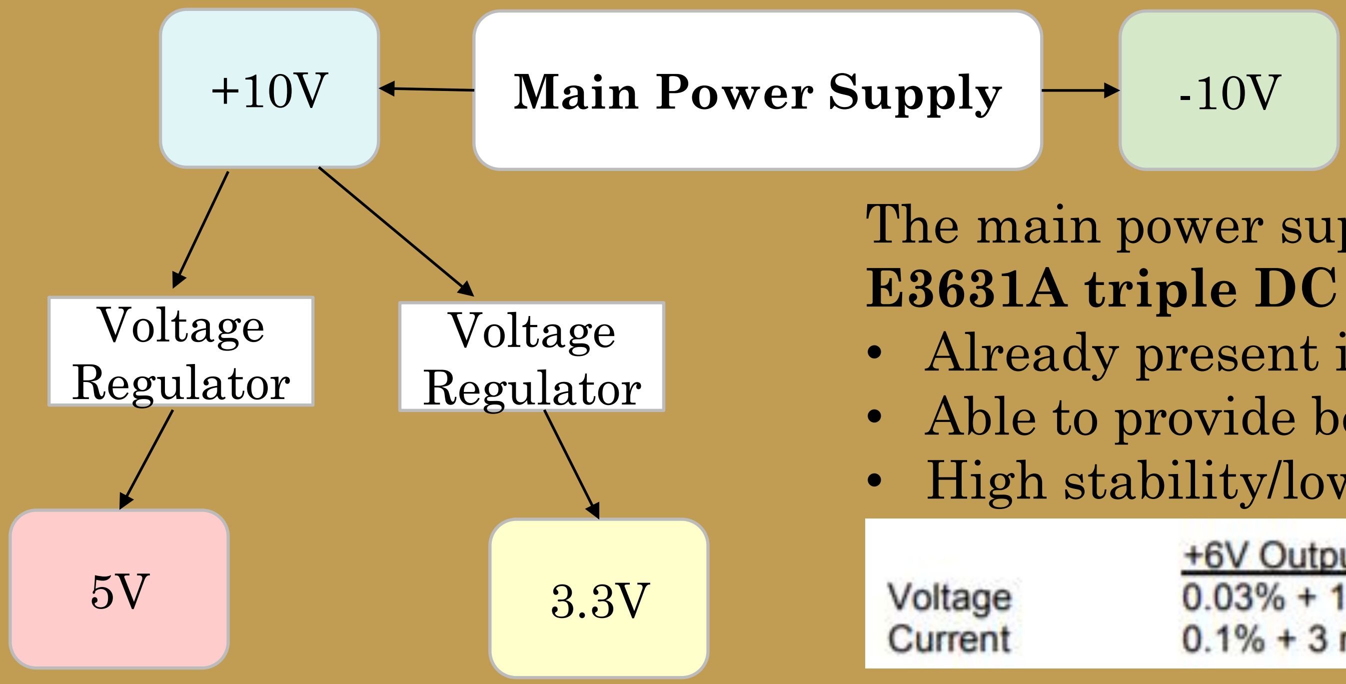
- 0 TCR resistor
  - To ensure precision when calculating the voltage passing through the resonator
  - The options below are manufactured by Vishay Foil Resistors (a division of Vishay Precision Group) and have a TCR value of 0.2 ppm/°C

Product	**Resistance**	**Case Code (inches)**	**Price**
Y16285R00000D0W	5Ω	2512	$16.75
Y1625100R000Q9R	100Ω	1206	$12.75
Y402310R0000C9R	10Ω	1206	$17.64
Y1630250R000T9R	250Ω	1206	$11.56
Y11191R00000D9W	1Ω	Non-standard	$13.60
Y162910R0000C9R	10Ω	0805	$9.48

POWER SUPPLY

Power Supply

Component	Supply Voltages	
Instrumentation Amplifiers	+10V	-10V
Operational Amplifier	+10V	-10V
LCD Display	5V	
Microcontroller	3.3V	



The main power supply was chosen to be the **Agilent E3631A triple DC voltage output** because:

- Already present in Dr. Abdolvand's Lab (Free)
- Able to provide both +10V and -10V rails
- High stability/low voltage variation:

	+6V Output	+25V Output	-25V Output
Voltage	0.03% + 1 mV	0.02% + 2 mV	0.02% + 2 mV
Current	0.1% + 3 mA	0.05% + 1 mA	0.05% + 1 mA

Voltage Regulators

The most important aspect of voltage regulation for our project:

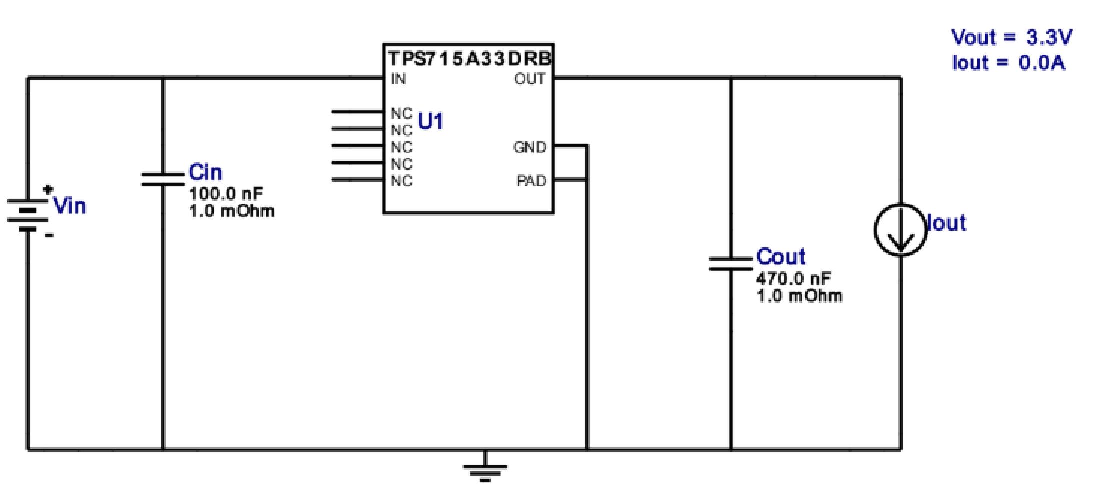
- ***Low noise***
- High efficiency
- Acceptable power capacity

	Comparison of Voltage Regulator Types		
	Linear	Switching	Zener
Noise	Low	High	High
Efficiency	Medium	High	Low
Power Capacity	High	High	Low

Linear voltage regulators would be the best option

DC to DC Conversions

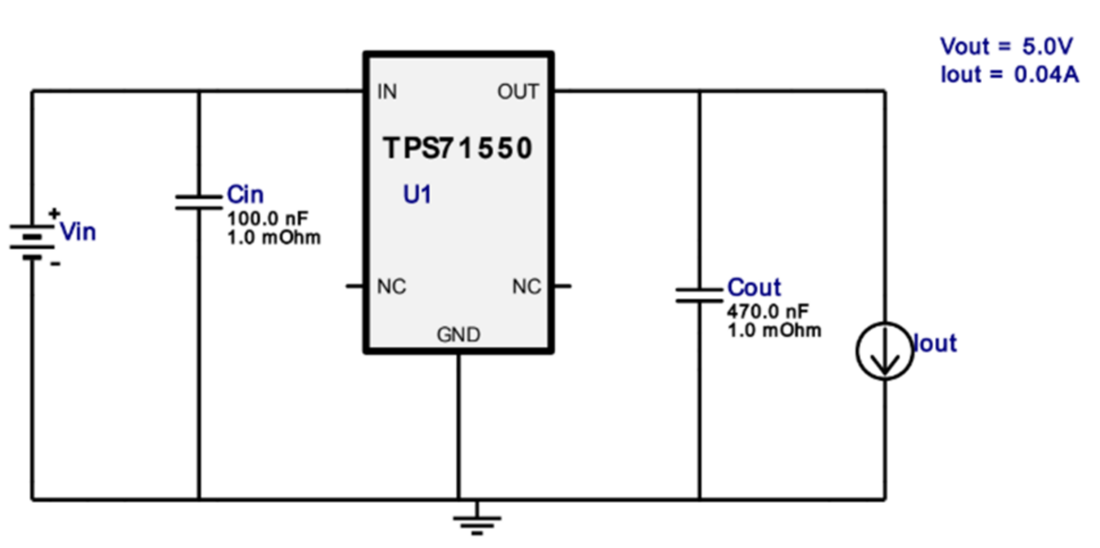
Main Power Supply (10V) to Microcontroller Power Supply (3.3V)



The **TPS715A33DRB** was chosen for this design because:

- Linear regulator (low noise)
- Highest efficiency of linear regulator designs (33%)

Main Power Supply (10V) to LCD Power Supply (5V)



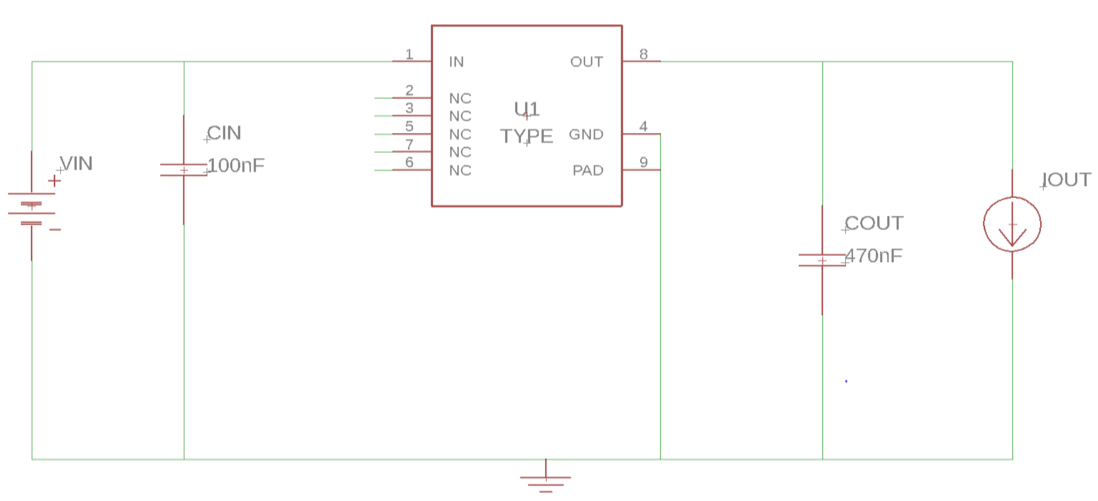
The **TPS71550** was chosen for this design because:

- Linear regulator (low noise)
- Highest efficiency of linear regulator designs (50%)

EAGLE SCHEMATIC AND BOARD DESIGN

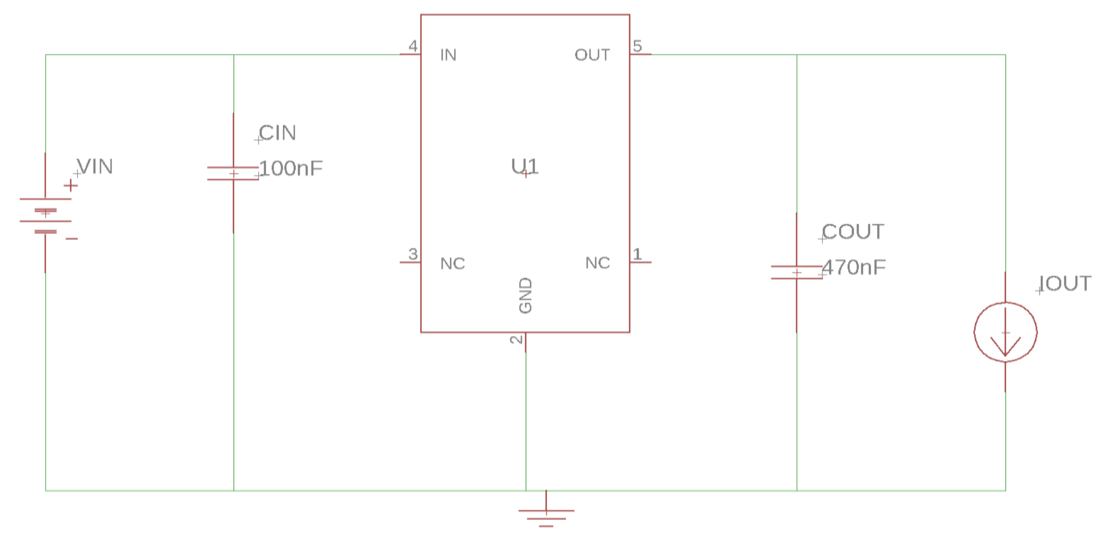
DC to DC EAGLE Schematics

Main Power Supply (10V) to Microcontroller Power Supply (3.3V)



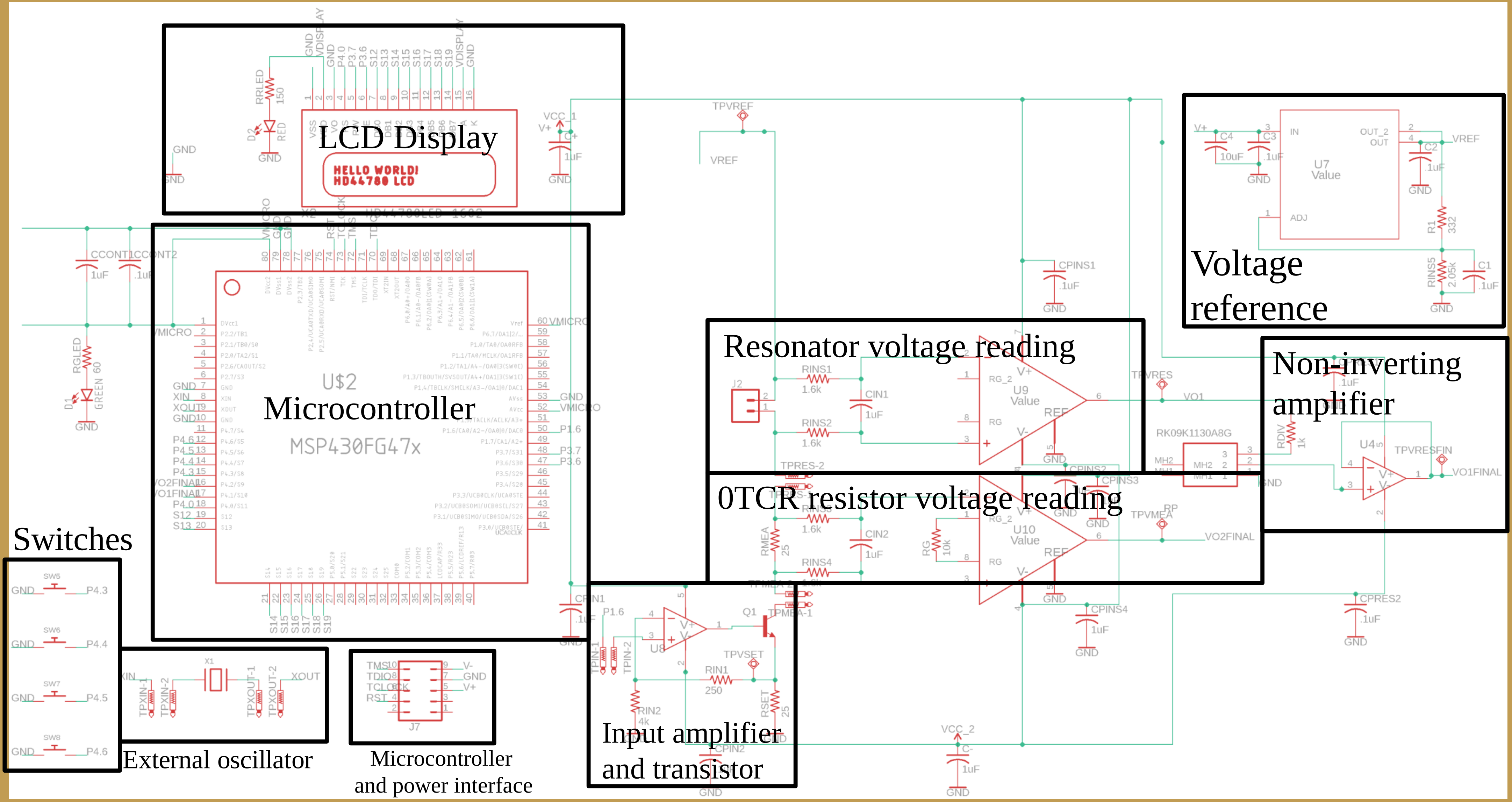
- The input voltage V_{in} (10V) comes from the Agilent E3631A which is the main power supply
- The output voltage V_{out} goes to the Microcontroller's analog and digital power supplies (3.3V)

Main Power Supply (10V) to LCD Power Supply (5V)

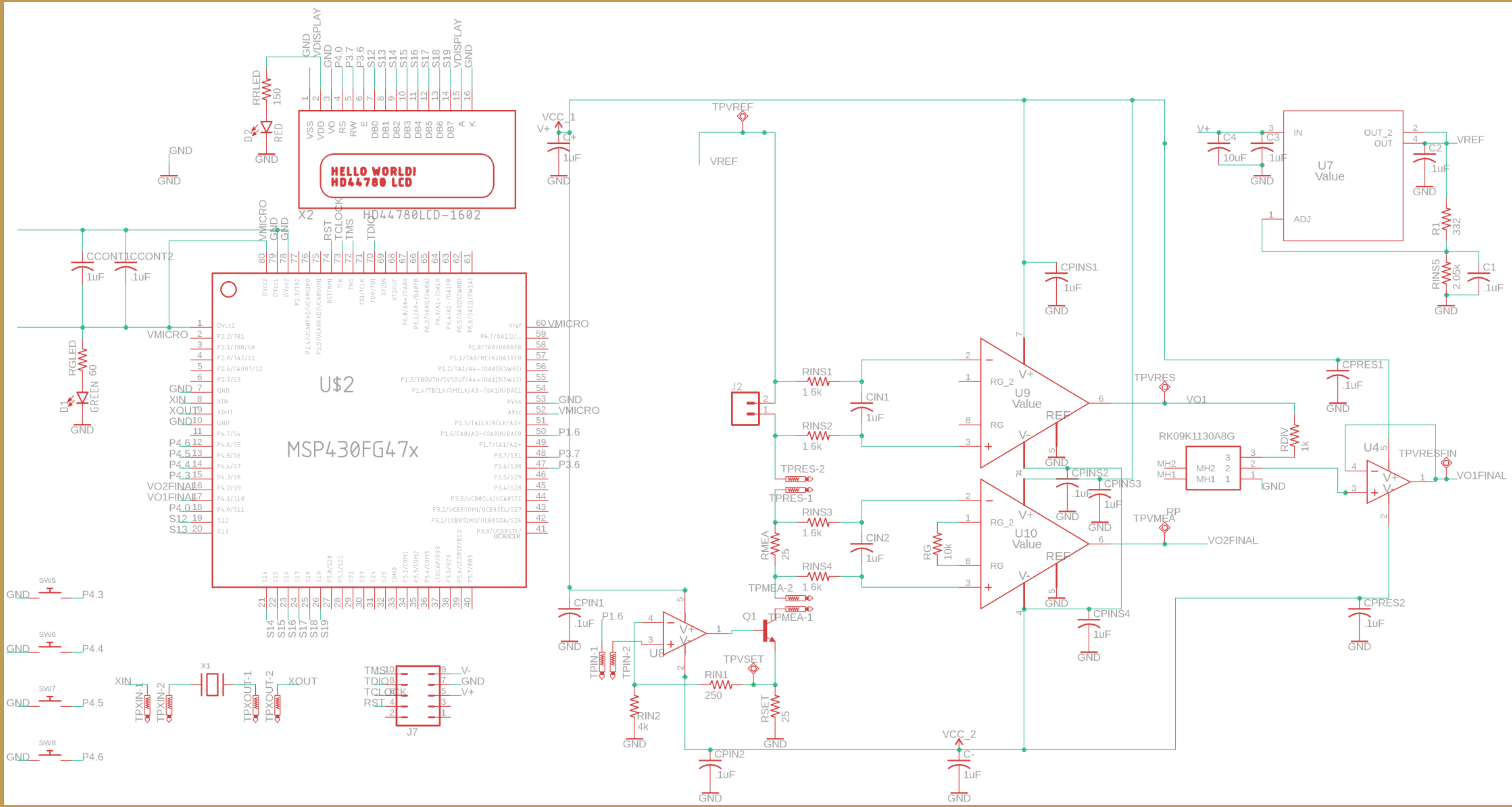


- The input voltage V_{in} (10V) comes from the Agilent E3631A which is the main power supply
- The output voltage V_{out} goes to the LCD's power supply (5V)

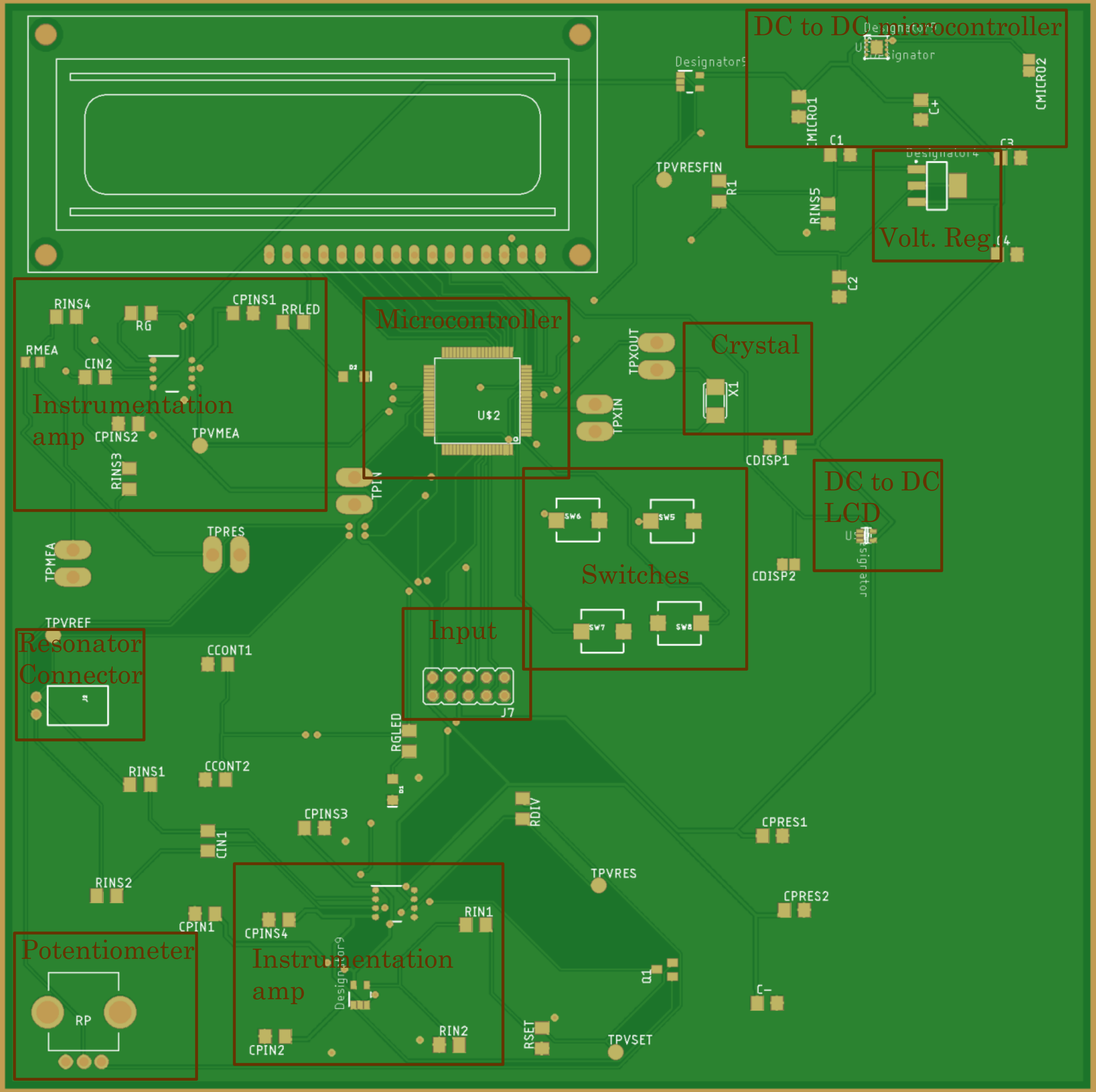
EAGLE Design



EAGLE Design



Prototype Board



SOFTWARE

Software Functionality

- The purpose of the software is illustrated in the tasks below:
  - Calculating the resistance and temperature of the resonator
  - Displaying the desired information to the user
  - Controlling the current passed into the resonator
- Other requirements include:
  - Operating in two modes: standby and operational
  - Scalable and efficient code

Programming Environment

- The selected software environment is the Code Composer Studio
  - An integrated development environment designed for TI's microcontrollers and embedded processors
  - Contains a multitude of tools for development and debugging embedded applications

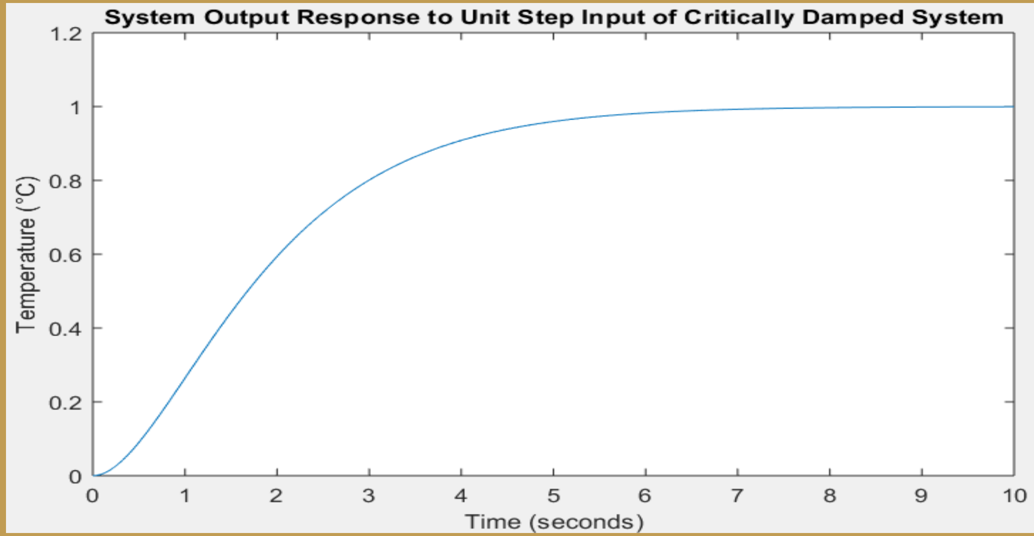
Environment	**Description**	**Operating Systems**	**Programming Languages**	**Additional Support**
CCS Cloud	Cloud-based IDE	N/A – Web browser	C/C++	Cloud-hosted workspace and TI Resource Explorer
Energia	Intuitive, easy-to-use and Open Source	Windows, Mac and Linux	In-line C, assembly	Framework of APIs and code examples
Code Composer Studio	Full-featured, eclipse-based IDE	Windows and Linux	C/C++	Energy Trace and ULP Advisor tools

Programming Language

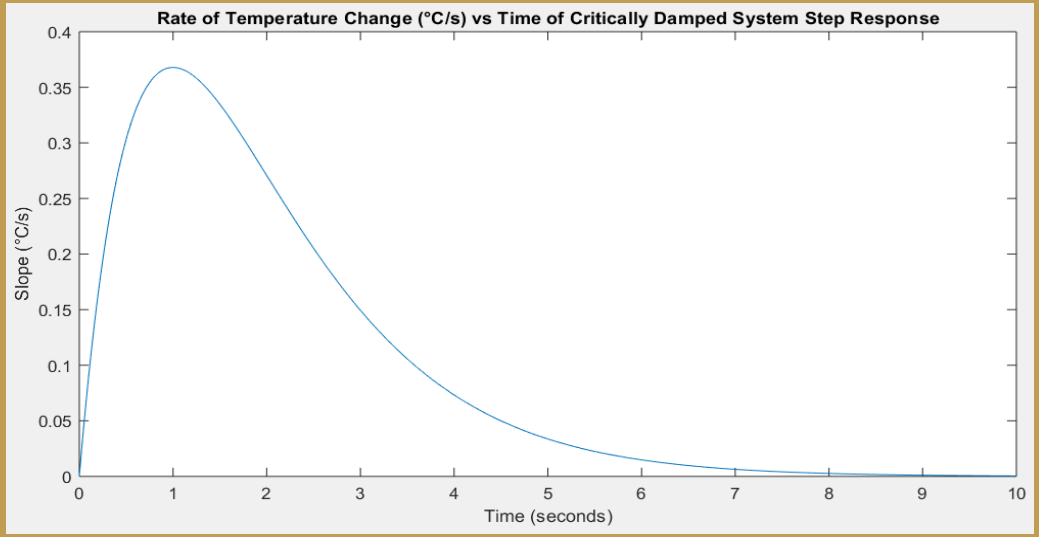
- The programming language chosen for this project is C
  - Often the language of choice for this type of application
  - High-level languages produce more efficient code with respect to low-level languages
  - Previous background in C programming

Temperature Control System

Control System Unit Step Output



Control System Unit Step Output Slope

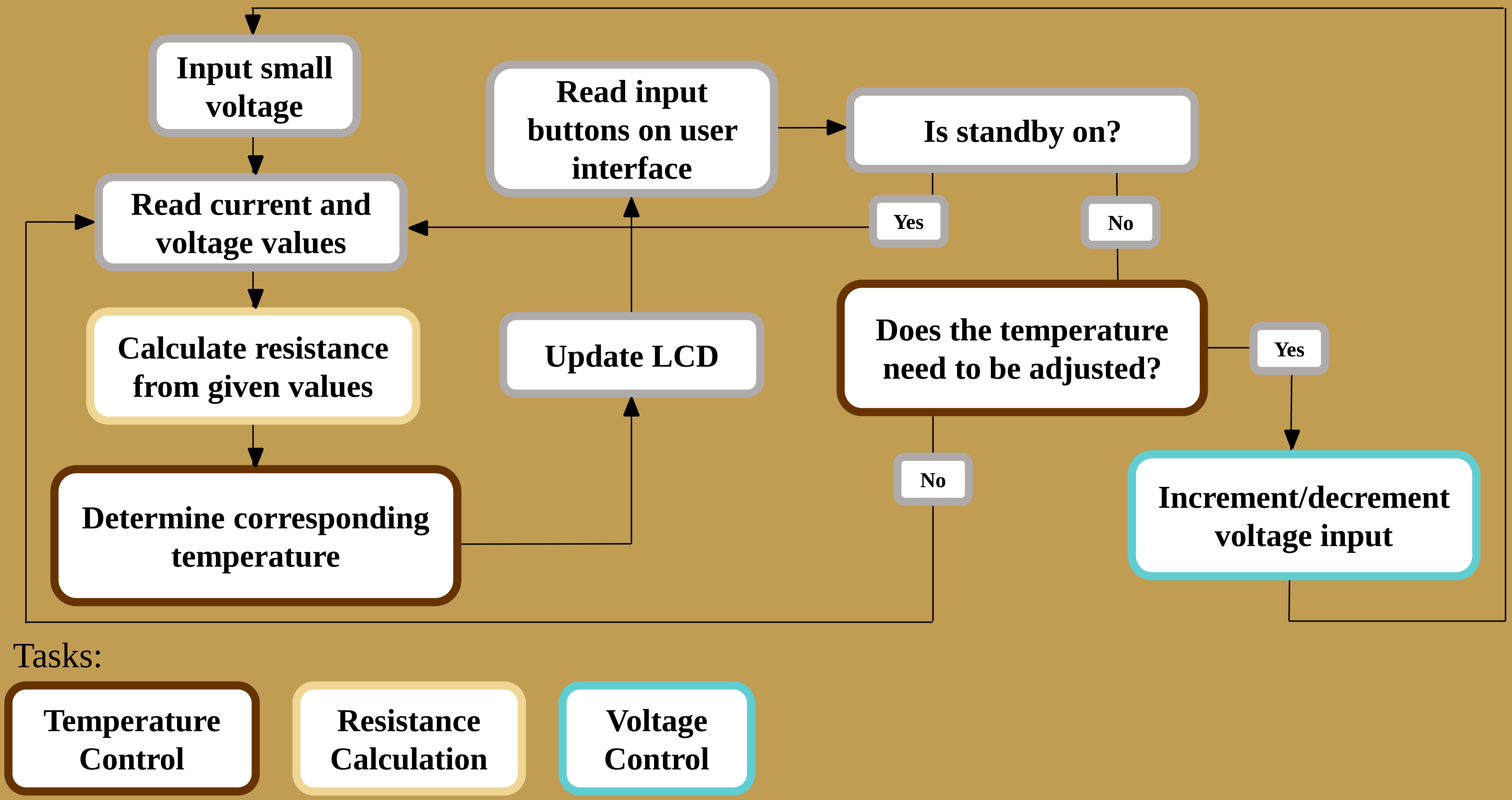


- Control the rate at which the resonator goes from its current to desired temperature
- Second-order critically damped system
- Designed to heat up no faster than R °C/s such that the resonator's temperature stabilizes as temperature increases

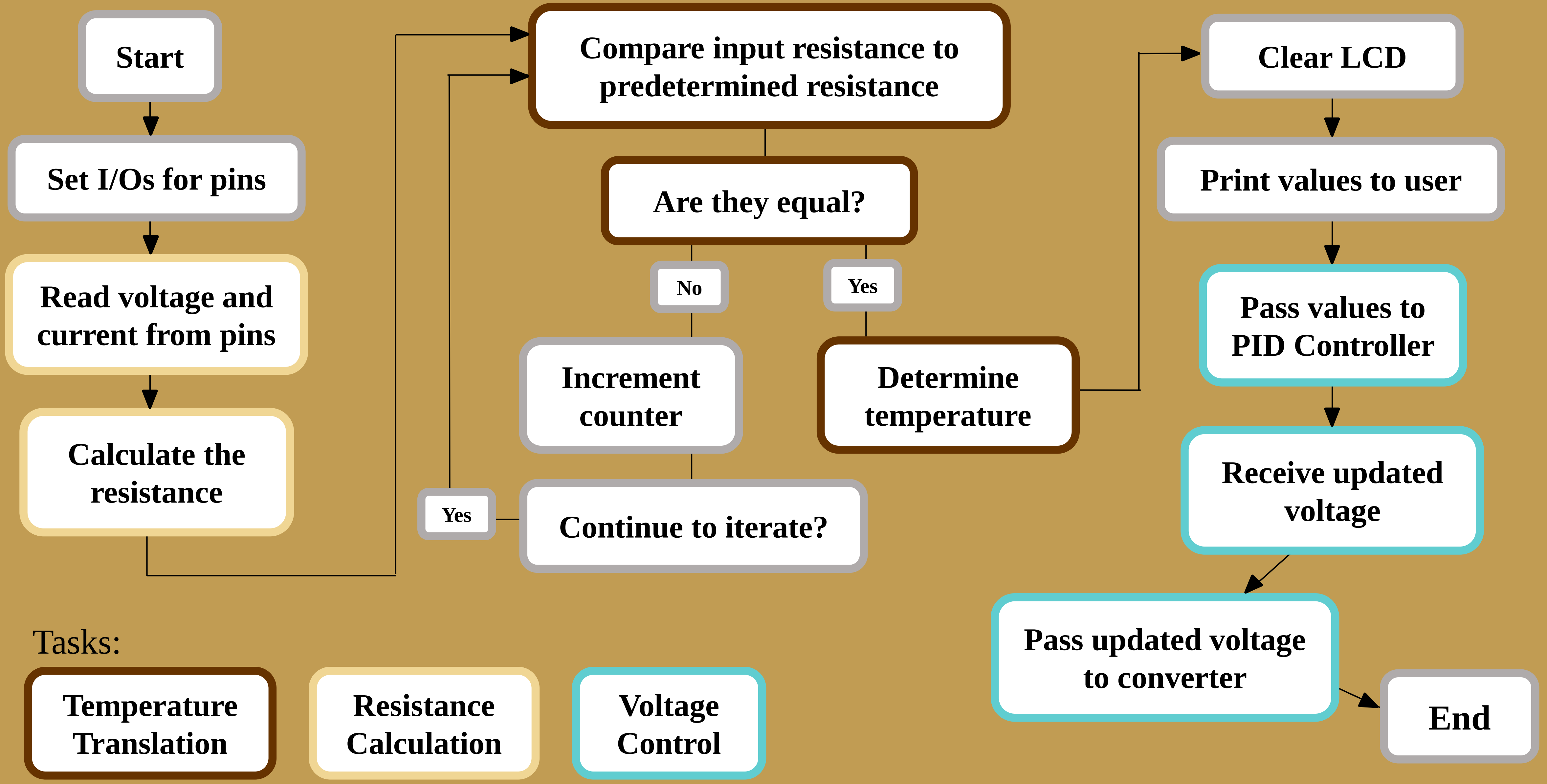
Temperature Control Algorithm

- Lookup table will be implemented to utilize data regarding the relationship between resistance and temperature
  - Often faster than calculation algorithms
  - Implemented in the temperature translation algorithm in the program
- PID controller will be used to implement control loop feedback to control a specific variable (voltage)
  - Advantages include the yield of simple and precise calculations
  - Voltage will be repeatedly recalculated and passed back into the resonator to maintain constant temperature
  - Chosen over predictive implementations as to not compromise simplicity

Program Flow



Program Flow cont.



LCD Testing

- The evaluation of the software is critical for verifying the correct performance of the application
- The software component of this system will need to receive accurate voltage and current inputs and perform calculations and conversions appropriately
- The LCD will be used to debug and present measurements to the tester during program development

ADMINISTRATIVE

Work Distribution

	Team Member		
Tasks	Megan	Heather	Michaela
Team Coordination		P	
Resonator Testing		P	
Overall Schematic	S	P	
PCB Schematic Design	P	S	
PCB Board Design	S	P	
Power Supplies	P		
Control System Design	P		S
Display and User Input			P
Microcontroller Programming			P
Component Selection	P	P	P
Key: P=Primary, S=Secondary			

Estimated Budget

Part	Manufacturer	Part Number	Quantity	Estimated Cost
Microcontroller	Texas Instruments	MSP430	1	$9.99
PCB Boards	Element 14	N/A	3	$66
Display	Adafruit	TC1602A-09T	1	$9.95
Miscellaneous parts for resonator	N/A	N/A	N/A	$50
Miscellaneous parts for DC to DC conversions and power supply	N/A	N/A	N/A	$25
Miscellaneous Parts for measuring voltage	N/A	N/A	N/A	$30
Shipping Costs				$25
				Estimated Total Cost: $215.94
				Remaining Budget: $784.06

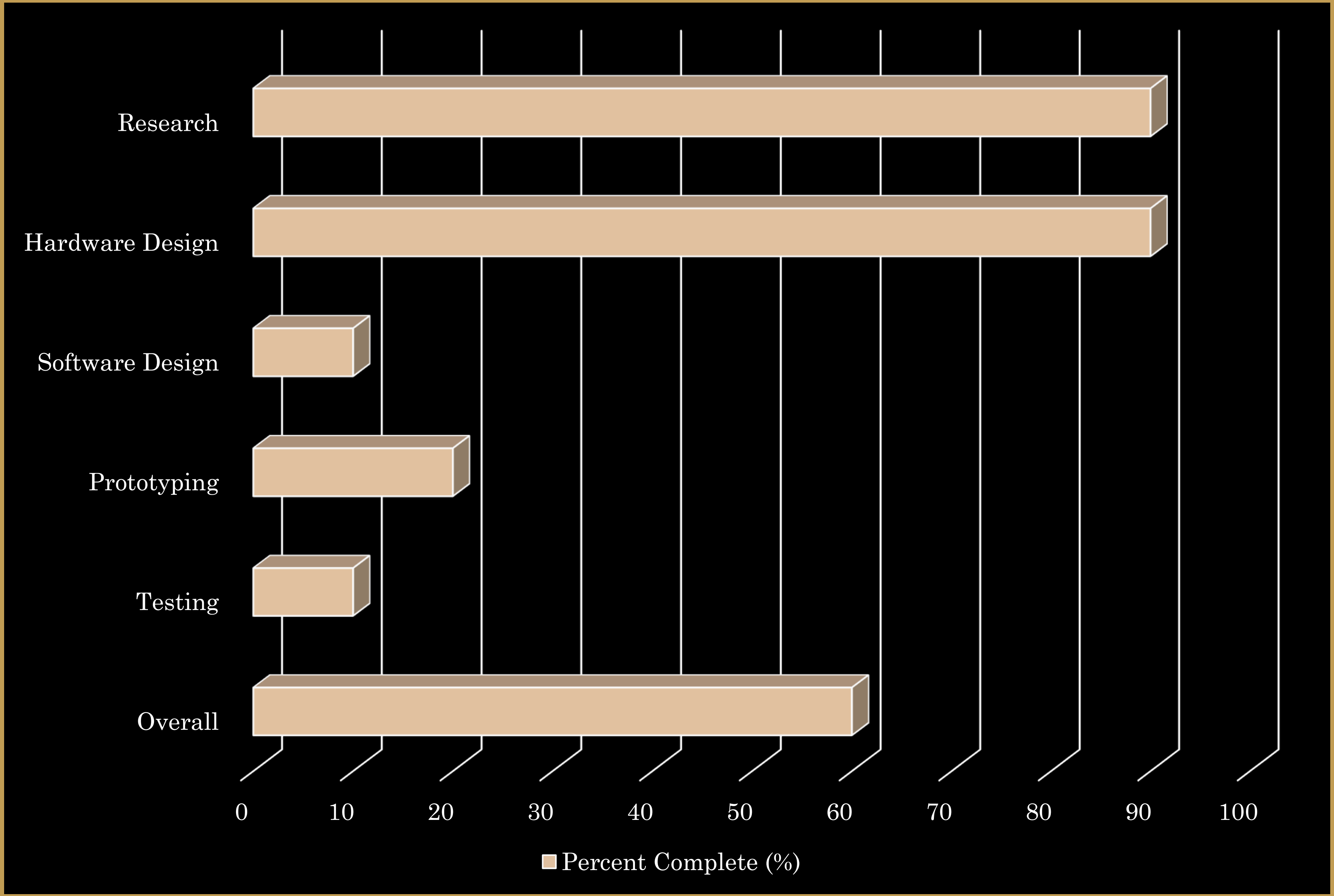
Current Budget

Company	Component	Price/Component	Qty. ordered	Total price
Advanced Circuits	PCB Board	$33.00	2	$66.00
	Shipping and handling	N/A	N/A	$23.77
Digi-Key	0TCR Resistor	$9.48	3	$28.44
	Crystal oscillator	$1.09	3	$3.27
	Shipping and taxes	N/A	N/A	$12.06
Mouser	Capacitors	$0.12-$0.52	38	$6.66
	Resistors	$0.10-$0.19	31	$3.77
	Wire connectors	$0.76	3	$2.28
	Switches	$0.57	8	$4.56
	Transistor	$0.20	3	$0.60
	Microcontroller	$11.46	3	$34.38
	LEDs	$0.40-$0.43	6	$2.49
	Voltage regulators	$0.78-$1.33	9	$8.94
	Potentiometers	$0.57	2	$1.14
	Instrumentation and operational amplifiers	$2.39-$5.01	6	$24.82
	Shipping	N/A	N/A	$7.99
Amazon	120 Jumper wire set	$8.99	1	$8.99
	LCD	$5.99	1	$5.99
				Total Price: $246.15

Concerns and Difficulties

- Difficulties: Component selection, PCB design, little experience
- Concerns: Software and hardware integration
- Lessons: Teamwork, research carefully, be flexible

Current Progress



Next Steps

- Continued testing of microcontroller/LCD
- PCB testing and reorder to improve design
- Write up user instructions

Questions?