UNIVERSITY OF CENTRAL FLORIDA

Microcontroller Compensated Micromachined Oscillator Circuit

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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/resonators: fabrication and smaller
- Issues arise with temperature stability

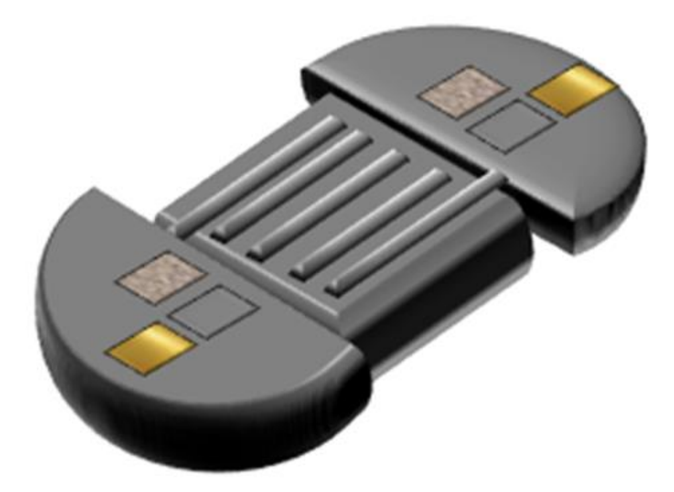


Figure 1: 3D rendering of micromachined oscillator

Motivation

- Researchers at UCF work with thin-film piezoelectric-on-silicon (TPoS) microsystems resonators
- TPoS resonators: active compensation
- Project sponsor: Dr. Abdolvand

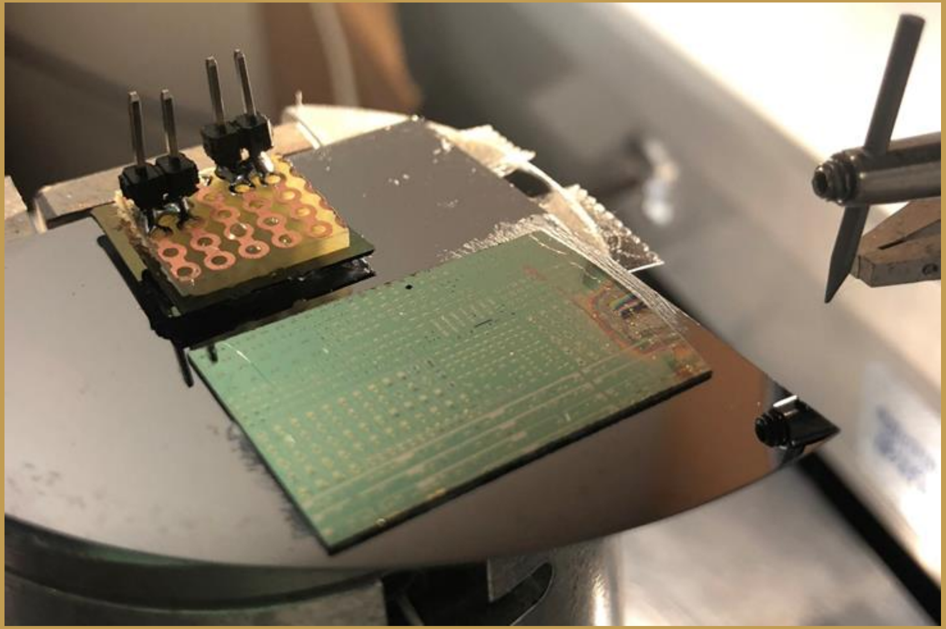


Figure 2: Fabricated oscillators on silicon

Goals and Objectives

- Goal: to build a PCB that stabilizes resistance of resistor
- Resistance → Temperature
- To be used in testing TPoS oscillators
- Unique temperature and resonance frequency characteristics

Requirements

- Hardware Deliverables:
  - Controls resistance within mΩ
  - Protection for resonator/functional checks
  - Communication
    - Relay temperature and resistance to user
- Software Deliverables:
  - Controls resistance within mΩ
  - Correct speed of program for stability

Specifications

Feature	**Value**
Project Budget	$1000
Completion Time	31 weeks total
Accuracy	Resistance within 1mΩ
Operating Temperatures	System: ambient room temperature (approximately 23 °C) Resonator: greater than 85 °C (approximately 90 °C)
Resistance Deviation	1mΩ
Start up time	<3second
Low Power	<20W

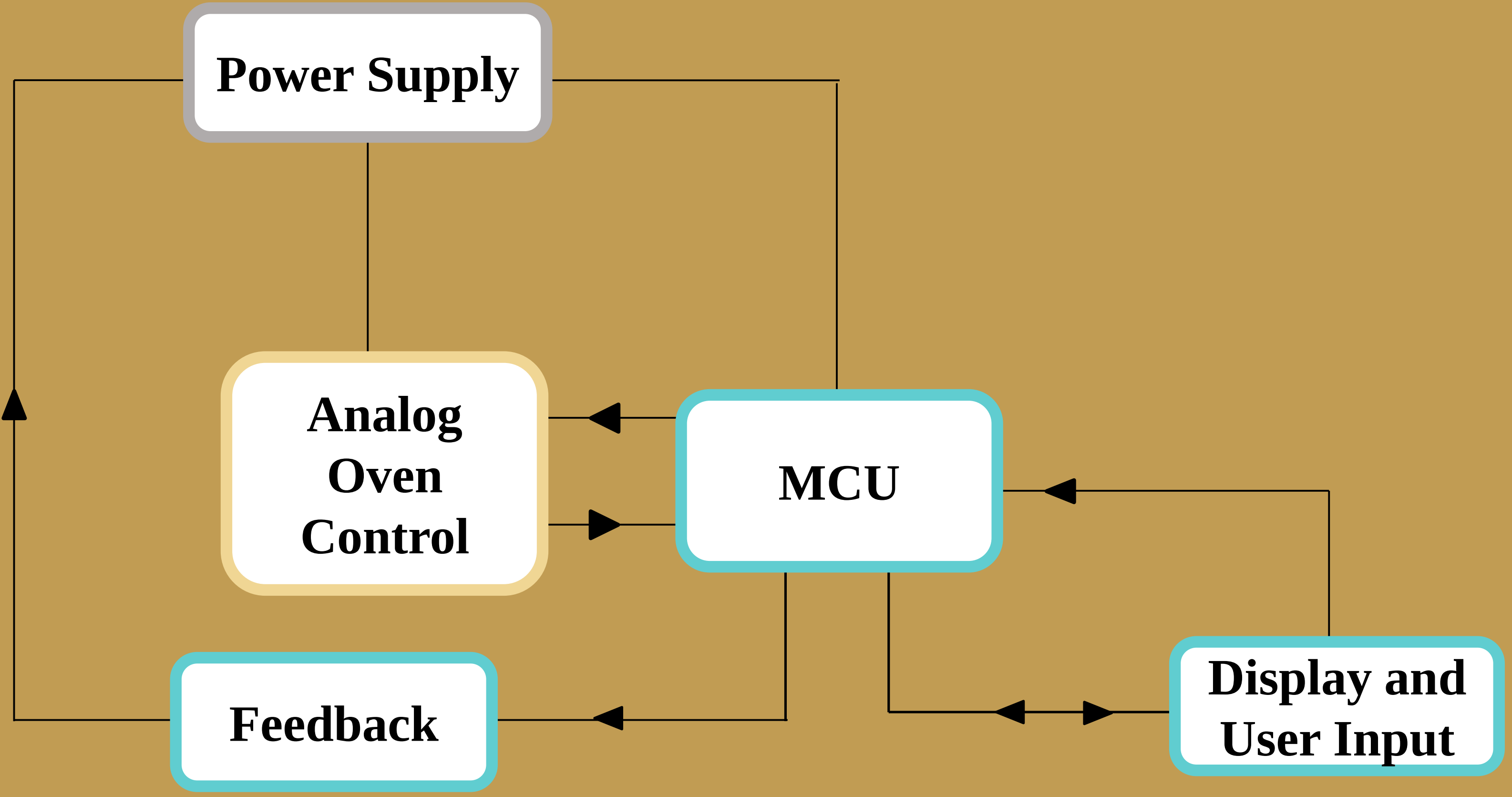
Overall System Design

Other Tasks:

Control System Design

Team Coordination

PCB Design and Assembly



Responsibility of:

Heather

Megan

Michaela

COMPONENT SELECTION

LCD Selection

- The **TinSharp 16x2 screen** was selected as the Liquid Crystal Display (LCD) because:
  - Its size allowed for flexibility in the presentation of results and user prompts
  - Compatibility and cost

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

0 TCR Resistor

- The **10Ω resistor** was chosen as the 0 TCR resistor because:
    - Considering the 10V power source, a resistance greater than 10Ω would pull too much voltage
    - Low price point and small and standard packaging
    - The options shown 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

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	20+	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. Price	$14.99	$12.99	$4.99	$29.99

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

- Familiarity with the family of microcontrollers
- Low cost
- High resolution A/D convertor options within series
- D/A convertor options within series

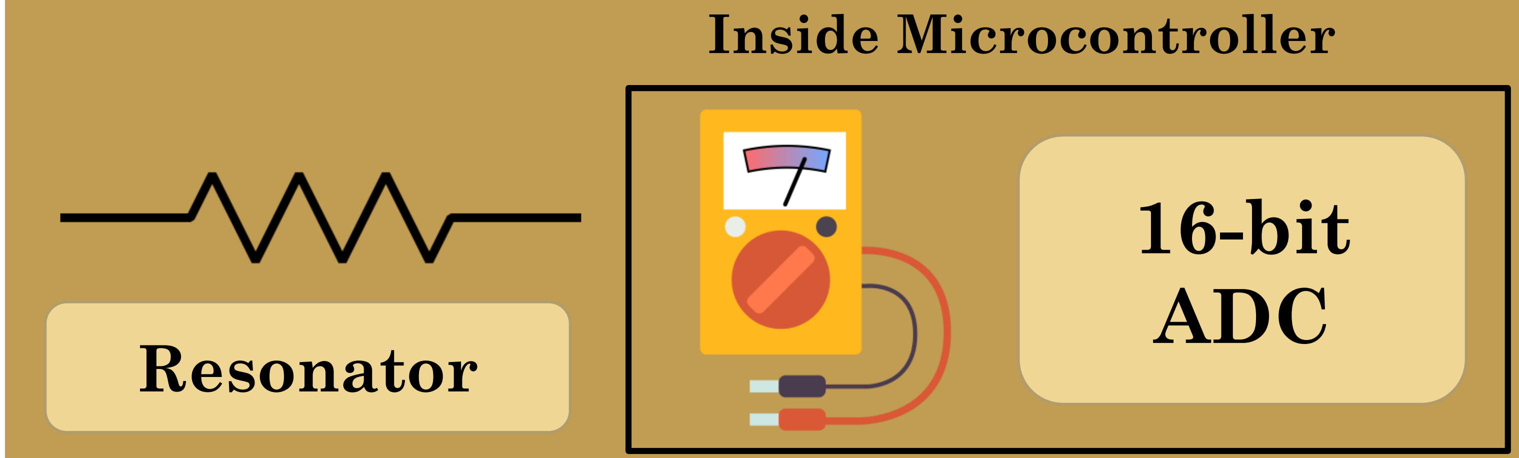
Microcontroller Product Selection

Feature	MSP430FG47x	MSP430G2x	MSP430F552x
Pin Count	80	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
Approx. Price	$9.99	$9.99	$12.99

The **MSP430FG47x** microcontroller was chosen because:

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

Microcontroller Voltage Readings



Inside Microcontroller

Resonator

16-bit ADC

Figure 3: Microcontroller ADC visual representation

- **Goal:** Maximize resolution of voltage readings through 16-bit A/D Convertor
- **How:** Manipulate input voltages to span over the entire microcontroller ADC input voltage range (0V to 1.5V)

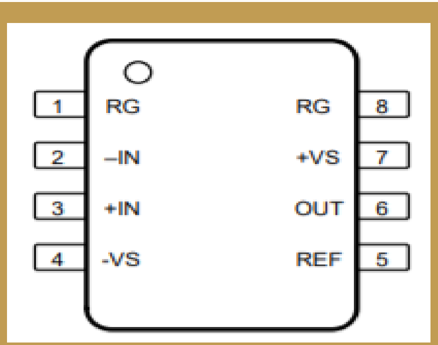


Figure 4: INA828 pin out
http://www.ti.com/lit/ds/symlink/ina828.pdf

INA828 Gain Resistor

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

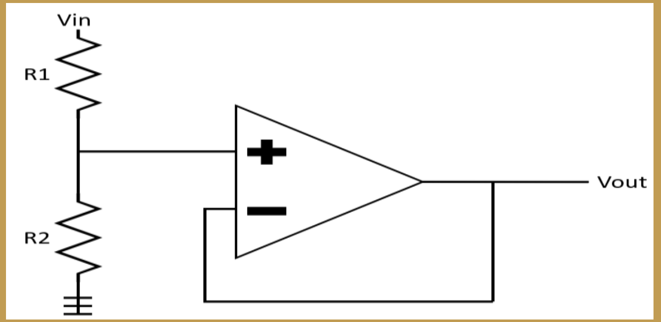


Figure 5: Voltage Divider Circuit

Voltage Divider Circuit Gain

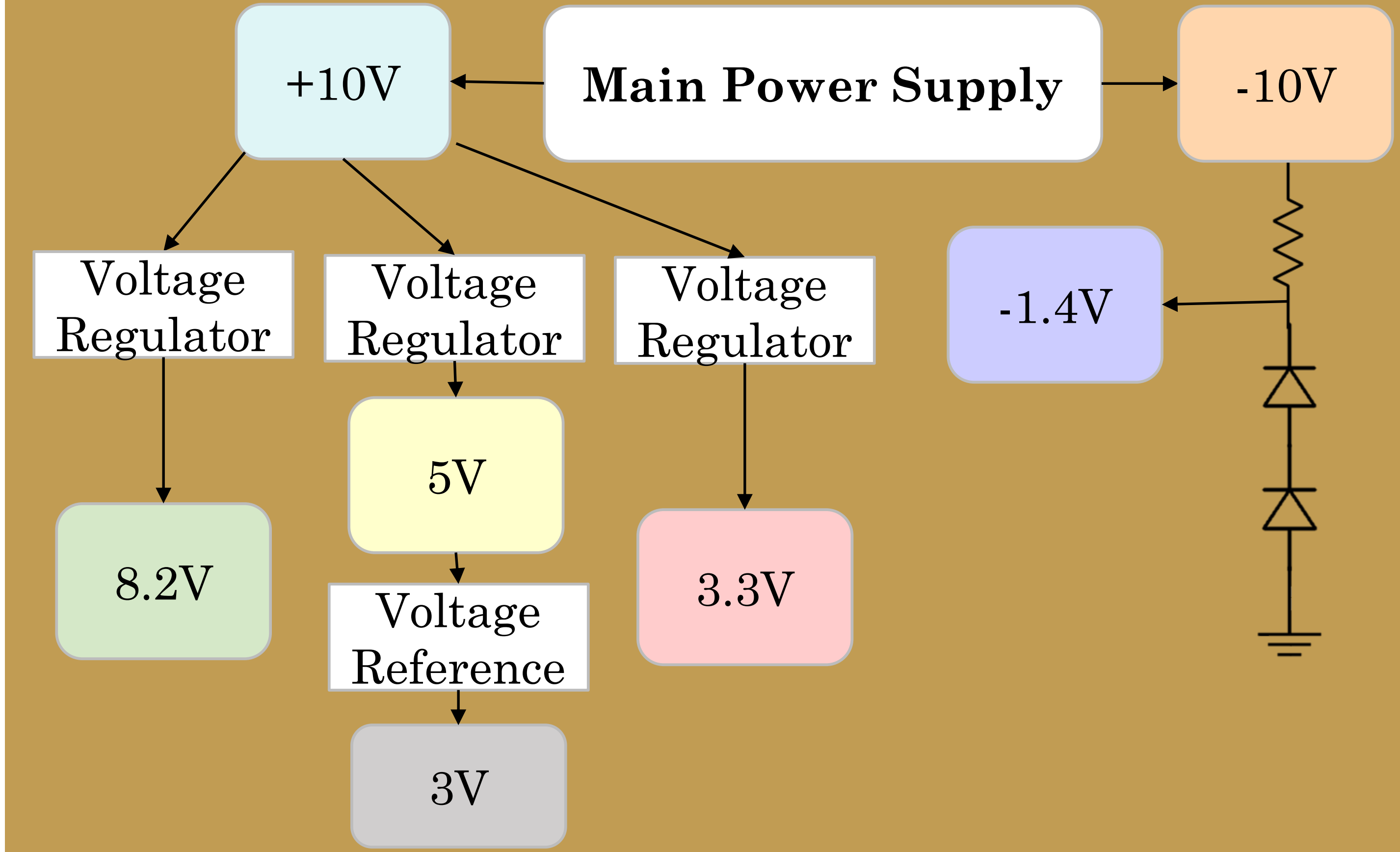
$$\text{Gain} = \frac{1}{7} = \frac{R_1}{R_1 + R_2}$$

POWER SUPPLY

Power Supply

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

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



Component	Supply Voltage(s)	
Instrumentation Amplifiers	+10V	-10V
Operational Amplifier	+10V	-10V
LCD Display	5V	
LCD Contrast Pin	-1.4V	
Microcontroller/ LCD Logic	3.3V	
ADC and DAC Reference Voltage	3V	
Circuit Input Voltage	8.2V	

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

EAGLE SCHEMATIC AND BOARD DESIGN

EAGLE Schematic Design

Main Power Supply (10V) to LCD Logic and Microcontroller Power Supply (3.3V)

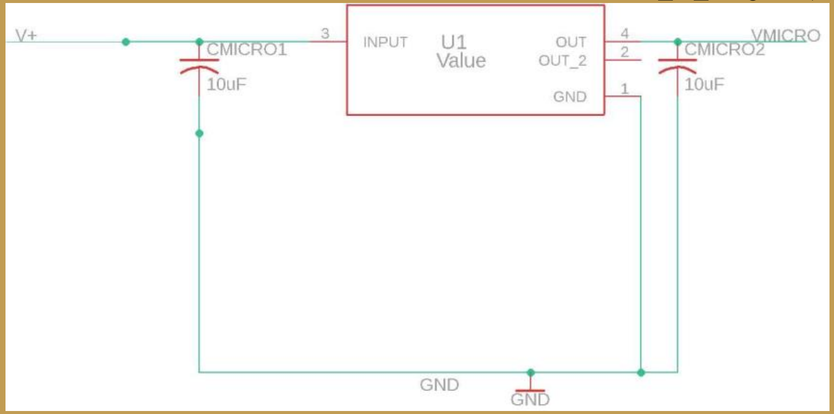


Figure 6: 10V to 3.3V conversion circuit

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

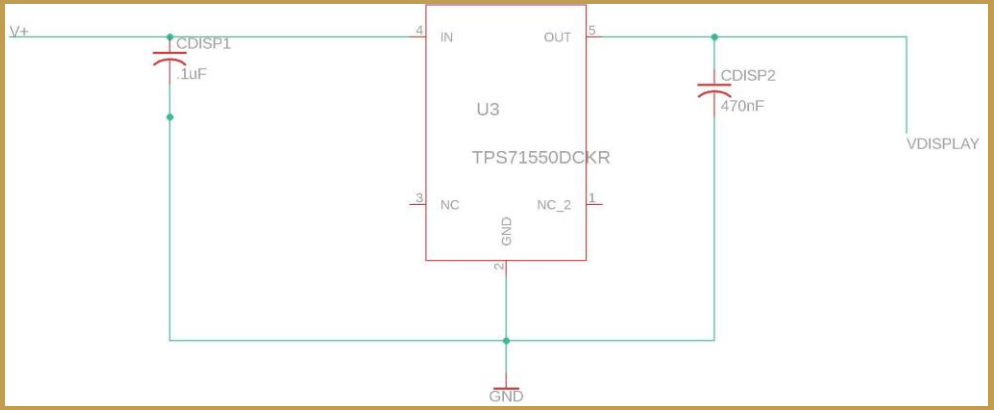


Figure 8: 10V to 5V conversion circuit

Main Power Supply (10V) to Circuit Input Voltage (8.2V)

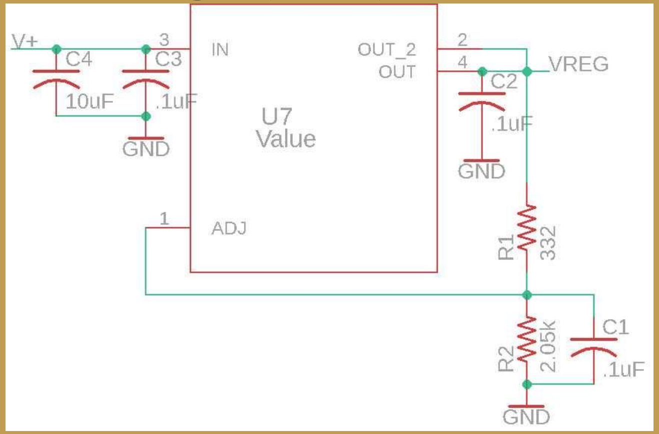


Figure 7: 10V to 8.2V conversion circuit

Voltage Reference (3V) for Microcontroller ADC and DAC

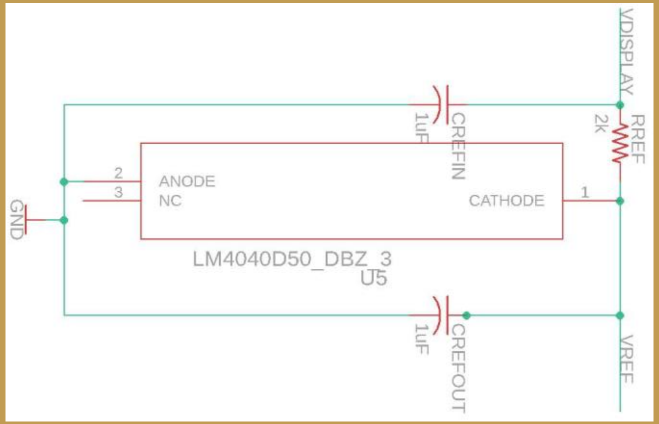


Figure 9: 3V voltage reference circuit

EAGLE Schematic Design

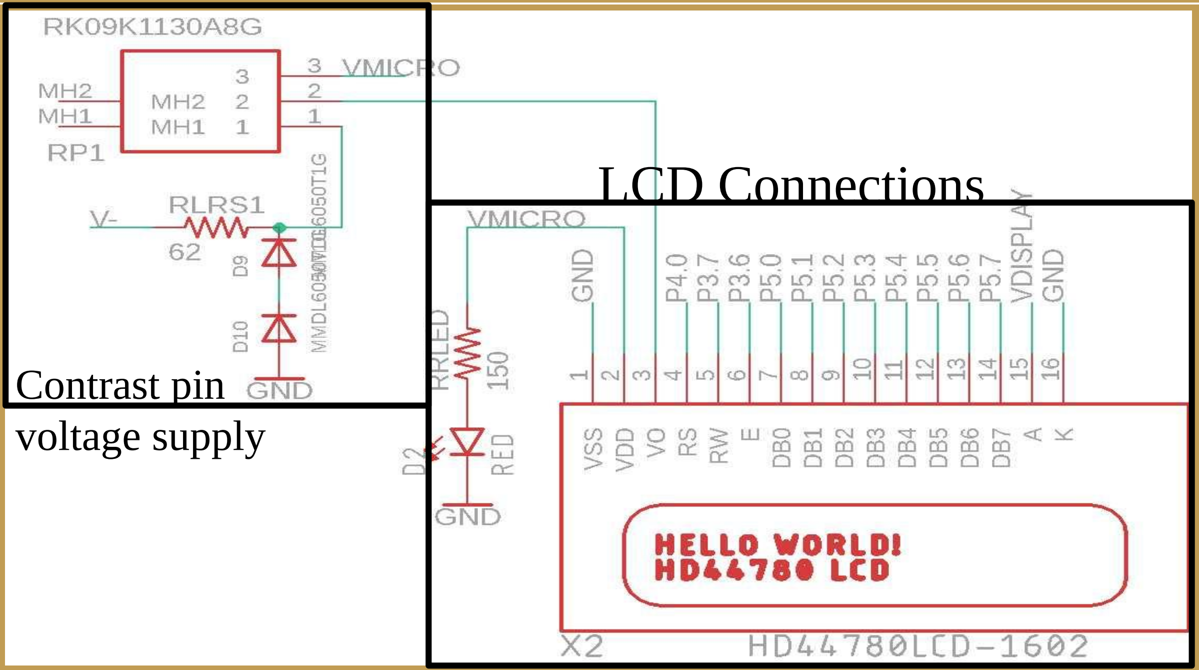


Figure 10: LCD schematic

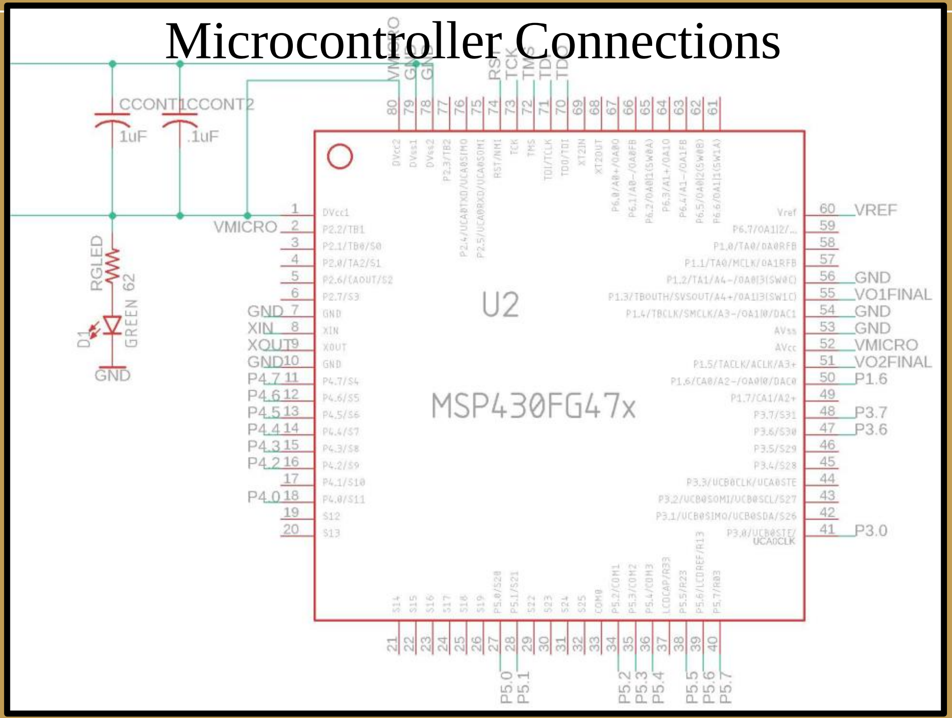


Figure 11: Microcontroller connections schematic

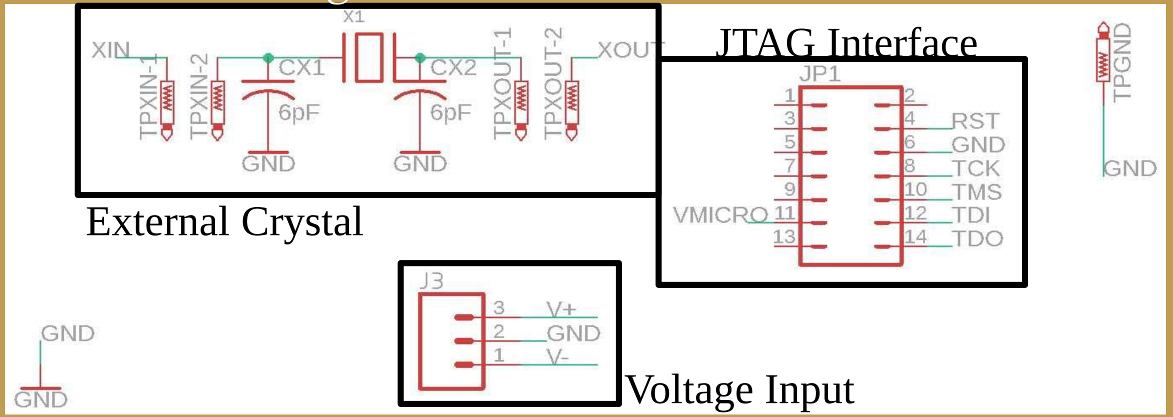


Figure 12: Voltage input, crystal, and programming interface schematic

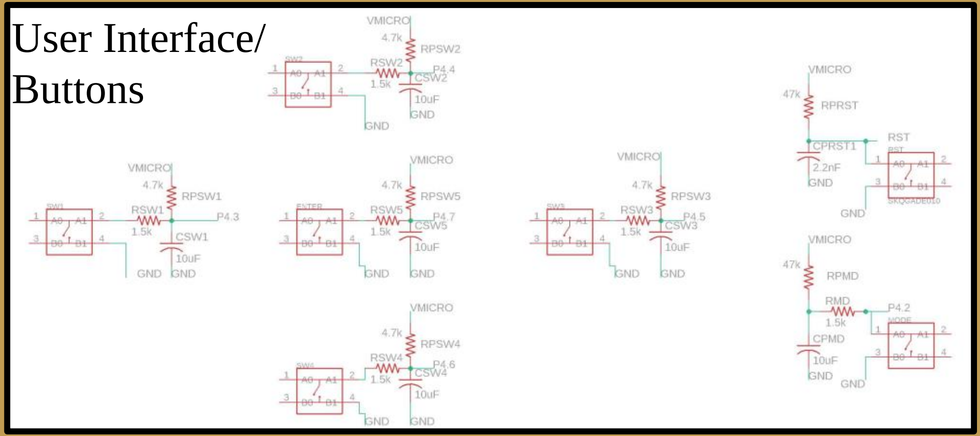


Figure 13: User interface schematic

EAGLE Analog Schematic Design

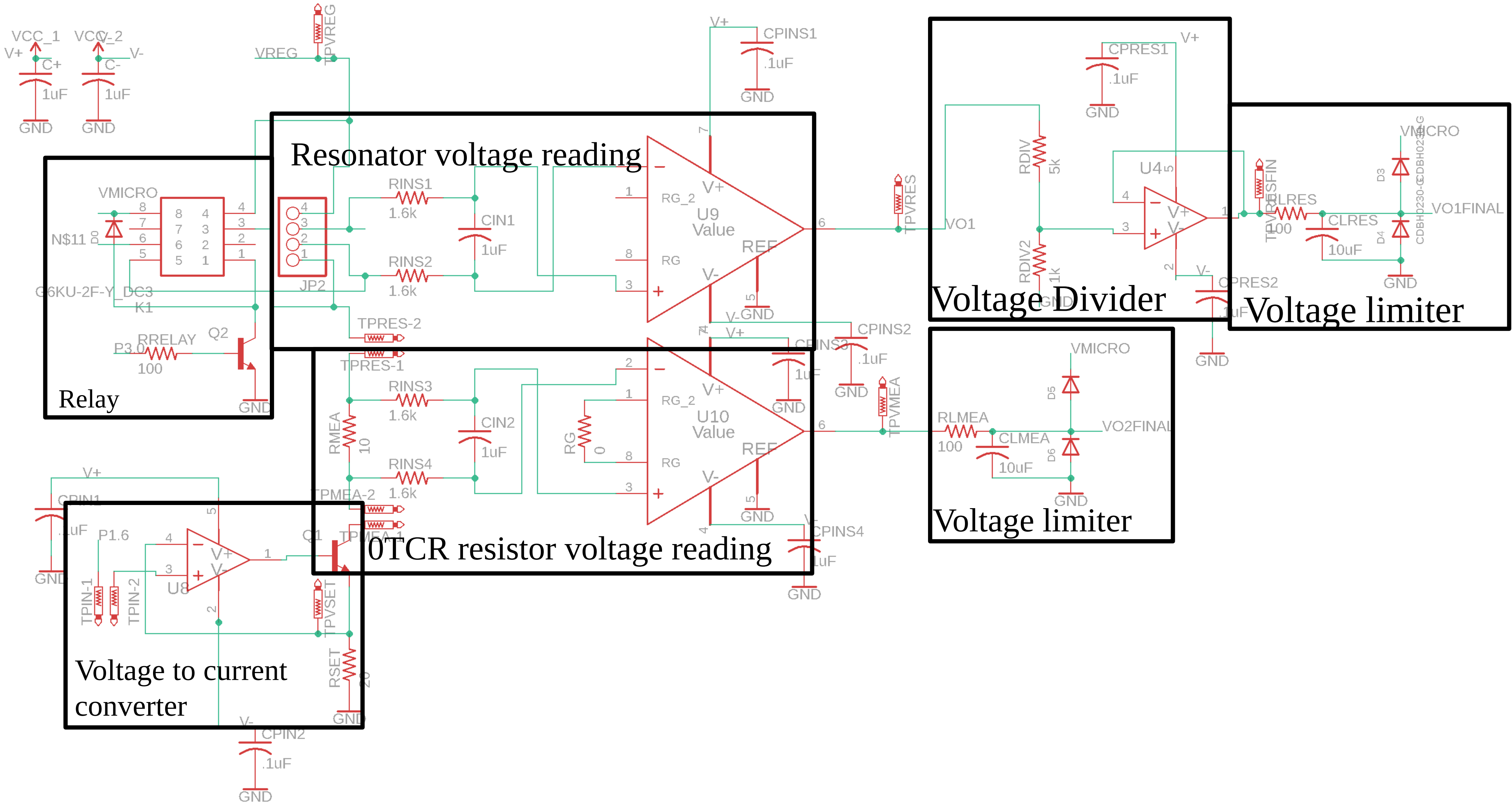


Figure 14: Analog schematic

EAGLE Analog Schematic Design

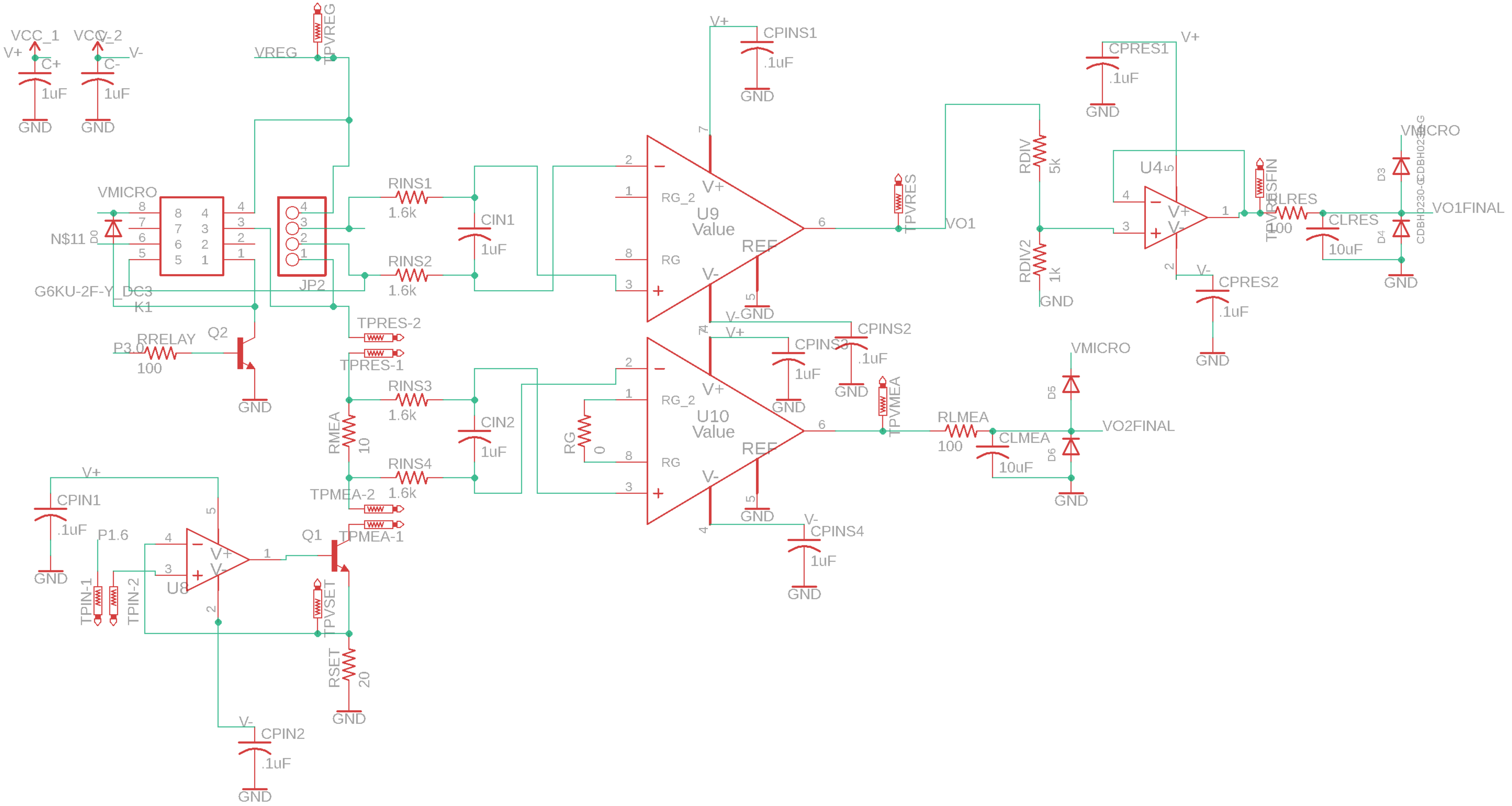


Figure 14: Analog schematic

EAGLE PCB Design

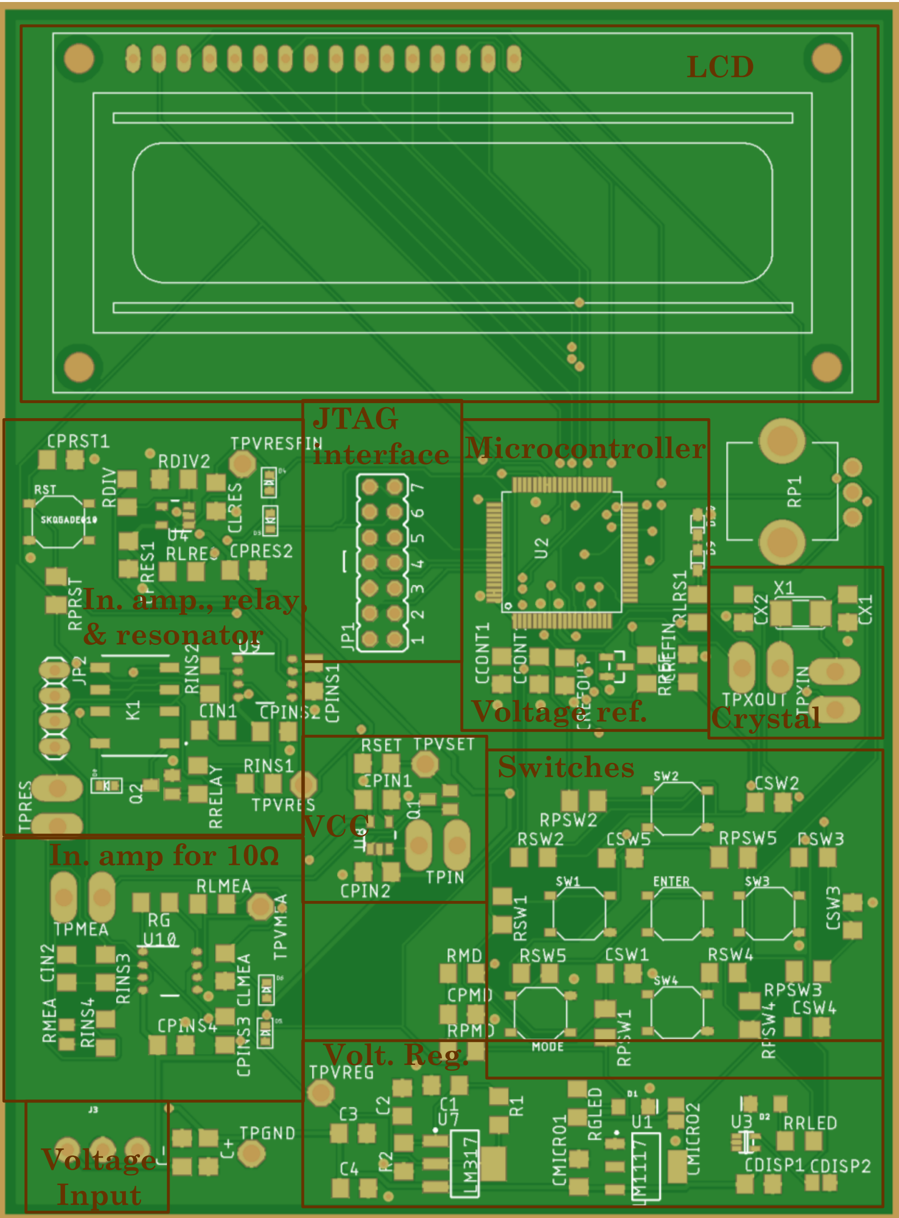


Figure 15: PCB design

Populated PCB

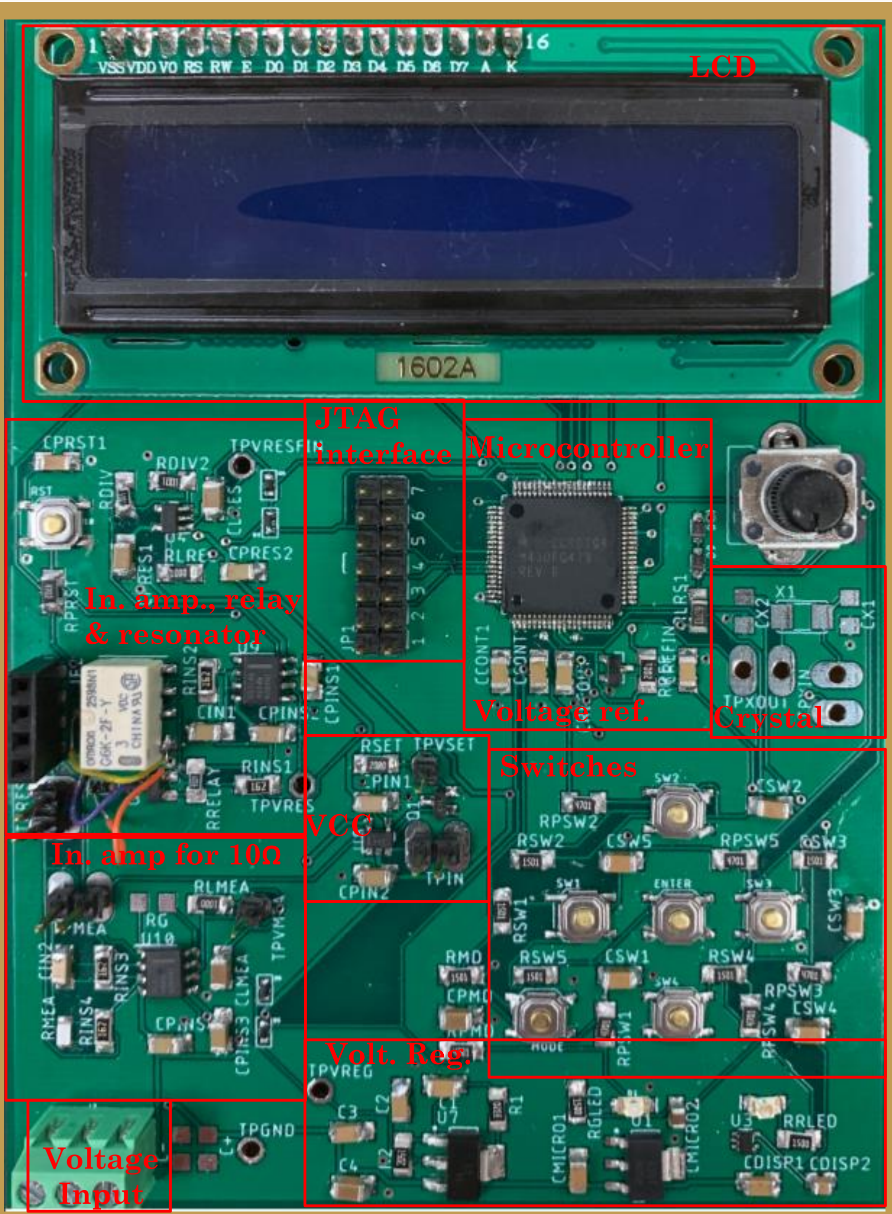


Figure 16: Populated PCB

Populated PCB

Figure 16: Populated PCB

SOFTWARE

Software Functionality

- The purpose of the software is illustrated in the tasks below:
  - Calculating the resistance of the resonator
  - Communicating information between the user and device
  - Controlling the current passed into the resonator
- Other requirements include:
  - Operating in three modes:
    - Standby
    - Characterization
    - Operational
  - Scalable and efficient code

Programming Language

- **C** was selected as the programming language for this project because:
  - Often the language of choice for this type of application
    - Programs for embedded applications tend to not be object-oriented
  - Build-in and user-defined types, data structures and flexible control flow (1)
  - Previous background in C programming

Programming Environment

- **Code Composer Studio** was selected as the software development environment because:
  - Designed for TI's microcontrollers and embedded processors
  - Contains a multitude of tools for development and debugging embedded applications
  - Compatible with our microcontroller
  - Previous software experience

Tool	Description	Operating System	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 IDE	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

Resistance Control Algorithm

- A proportional integral derivative (PI) controller was used to implement control system to stabilize the resistance
    - Takes action based on past, present and prediction of future control errors
    - Delivers control output at desired levels

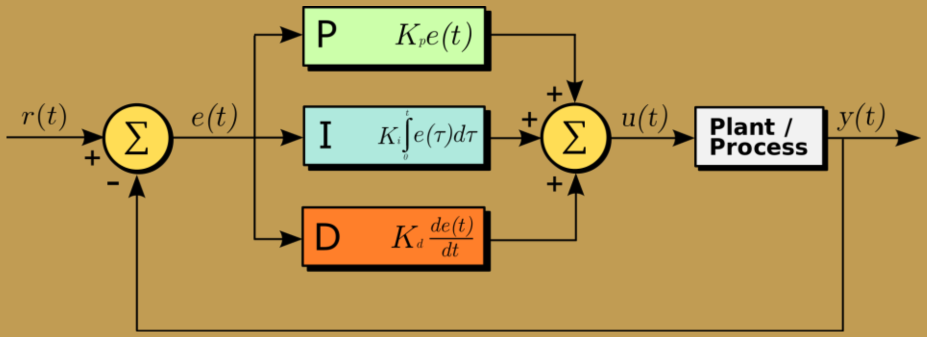


Figure 17: PID Control System

Source: https://www.elprocus.com/the-working-of-a-pid-controller/

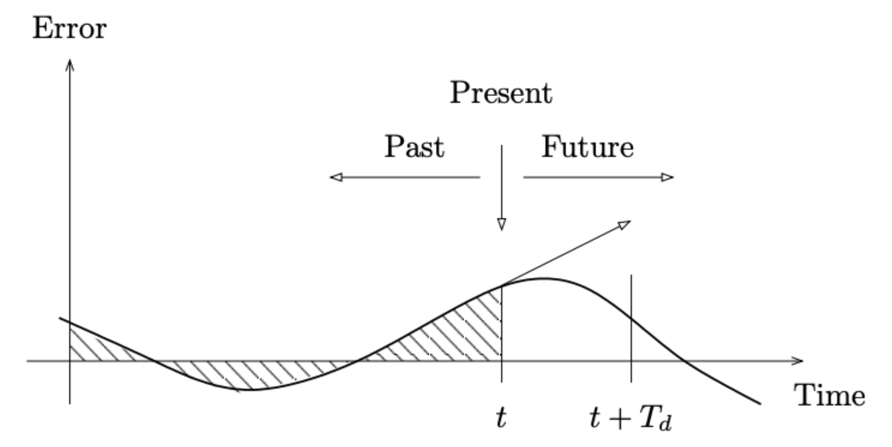


Figure 18: Graphical Representation of Controller

Source: Analysis and Design of Feedback Systems by Astrom and Murray

Resistance Control Algorithm

- Our PI controller algorithm works as follows:
  - Continuously calculates the error
  - Calculates a correction based on proportional and integral terms
    - The P-term is proportional to the current error
    - The I-term is proportional to the integral of the error
  - Applies the correction to modify the current output
    - Which in turn affects the voltage and resistance
- Loop tuning was used to produce the optimal control function

Initial Control System Testing

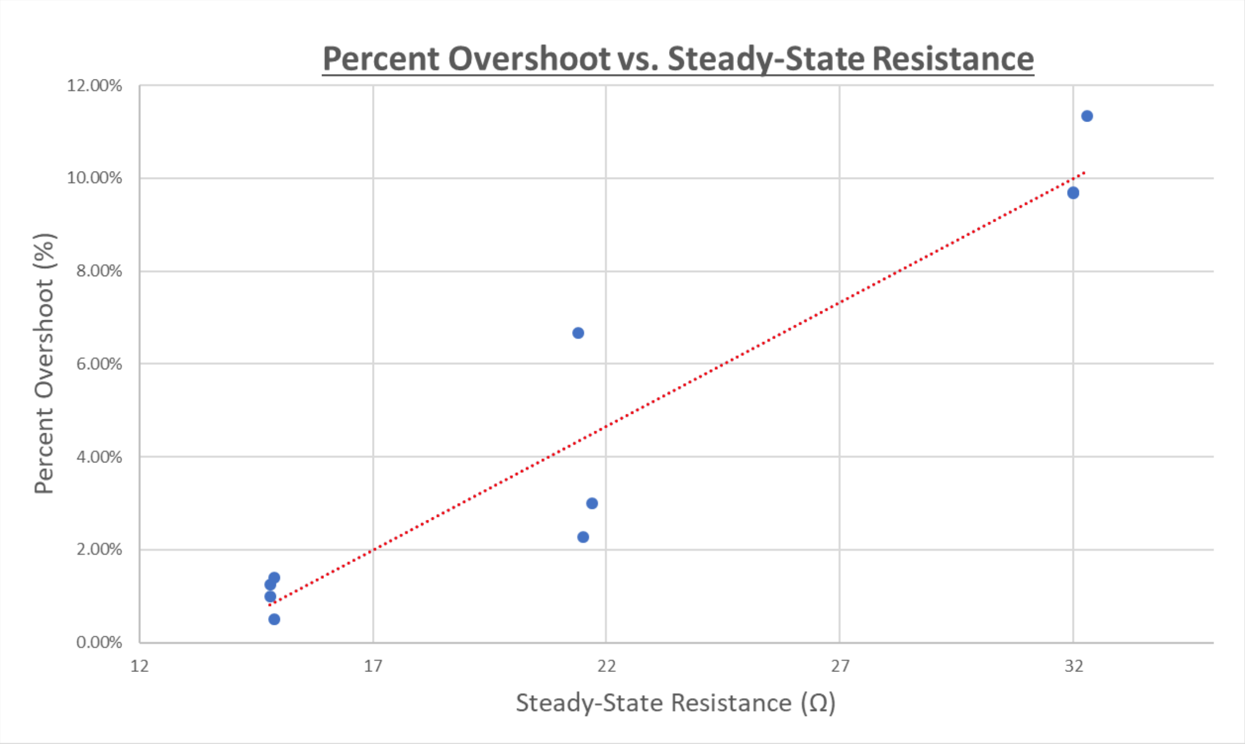


Figure 19: Initial control system testing (constant K_p and K_i)

- Error = $E(t)$ = Resistance-Desired Resistance
  - (For negative TCR)
- Controller = $K_p + \frac{K_i}{s}$

- When the resonator's transfer function is approximated to a first order system of form:

$$\frac{b}{s+a} \rightarrow b * e^{-at} * u(t)$$

- $K_p = \frac{2\zeta\omega_0 - a}{b}, \quad K_i = \frac{{\omega_0}^2}{b}$
- The 'b' for each system is dependent on its resistance and is different for each system.
- The data shows that for constant K_p and K_i values, the overshoot changes linearly with the system's resistance.
- Therefore, K_p and K_i are both inversely proportional to the resistance.

Resistance Control System Results

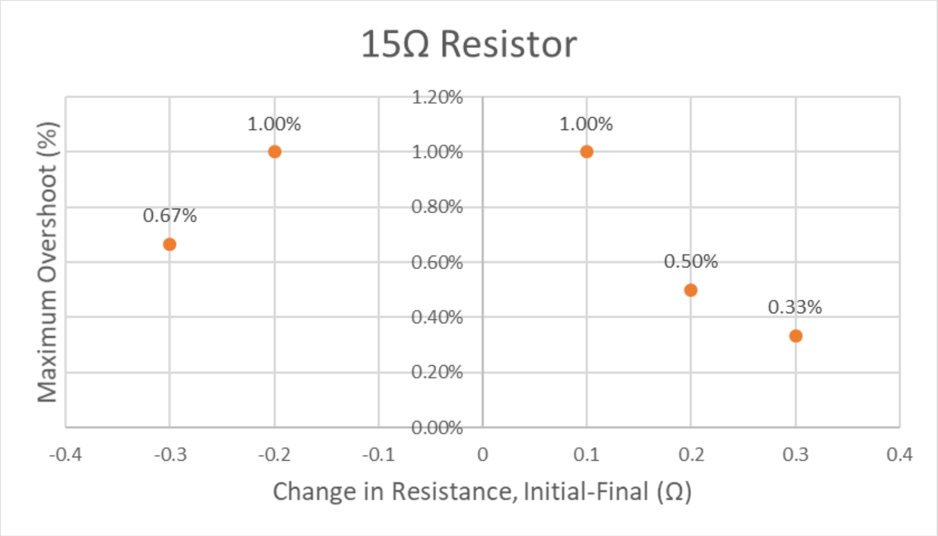


Figure 20: 15Ω Resistor overshoot analysis

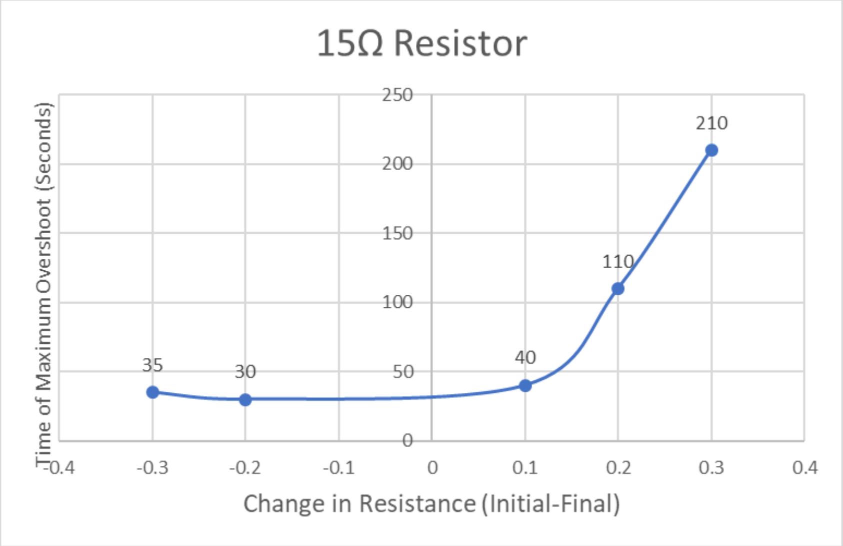


Figure 21: 15Ω Resistor time analysis

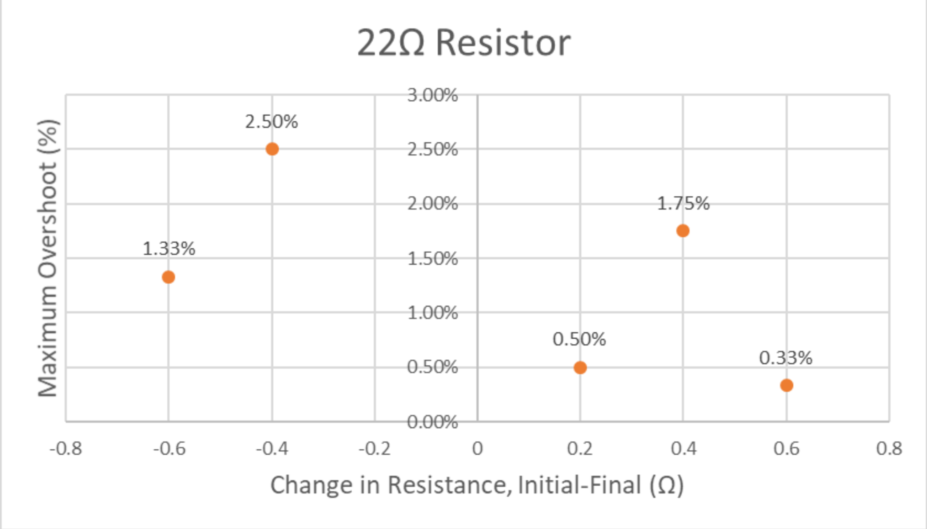


Figure 22: 22Ω Resistor overshoot analysis

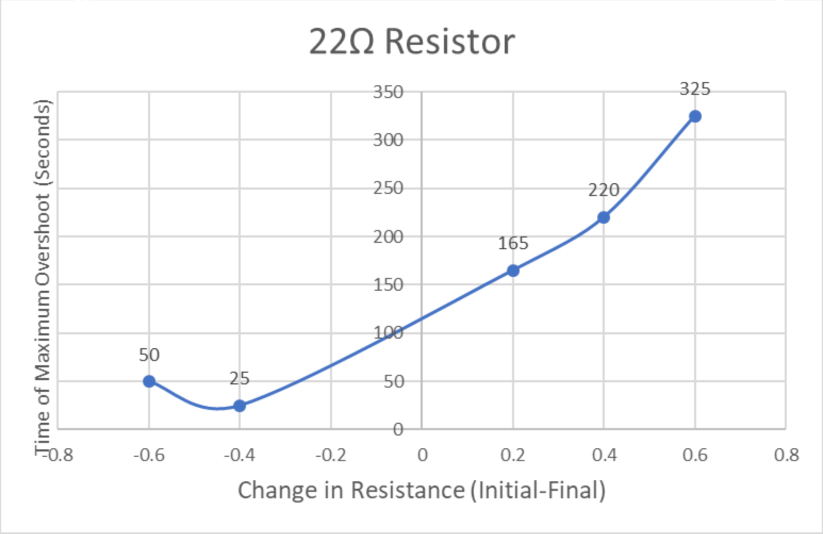
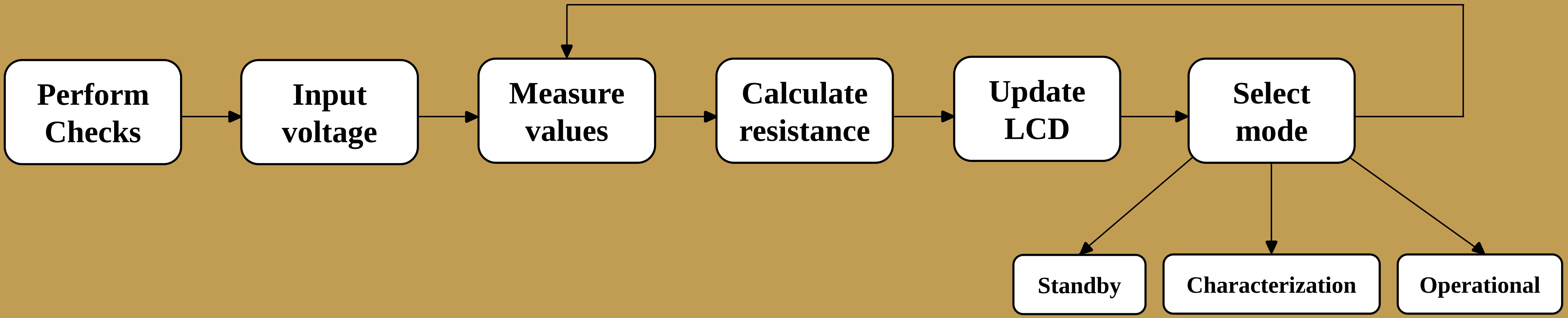


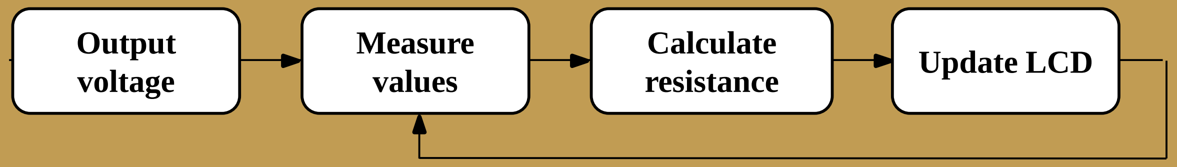
Figure 23: 22Ω Resistor time analysis

Program Flow



Program Flow

Standby

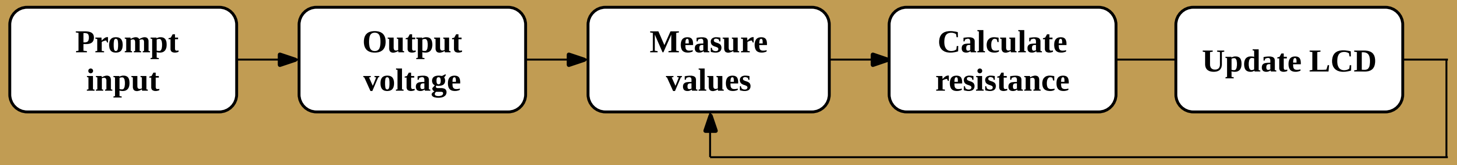


Output voltage → Measure values → Calculate resistance → Update LCD

Exiting loop:

Mode : select mode

Characterization



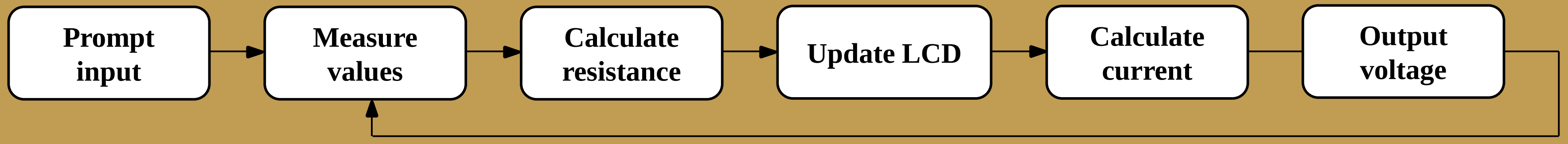
Prompt input → Output voltage → Measure values → Calculate resistance → Update LCD

Exiting loop:

Mode : select mode

Up : re-input current

Operational

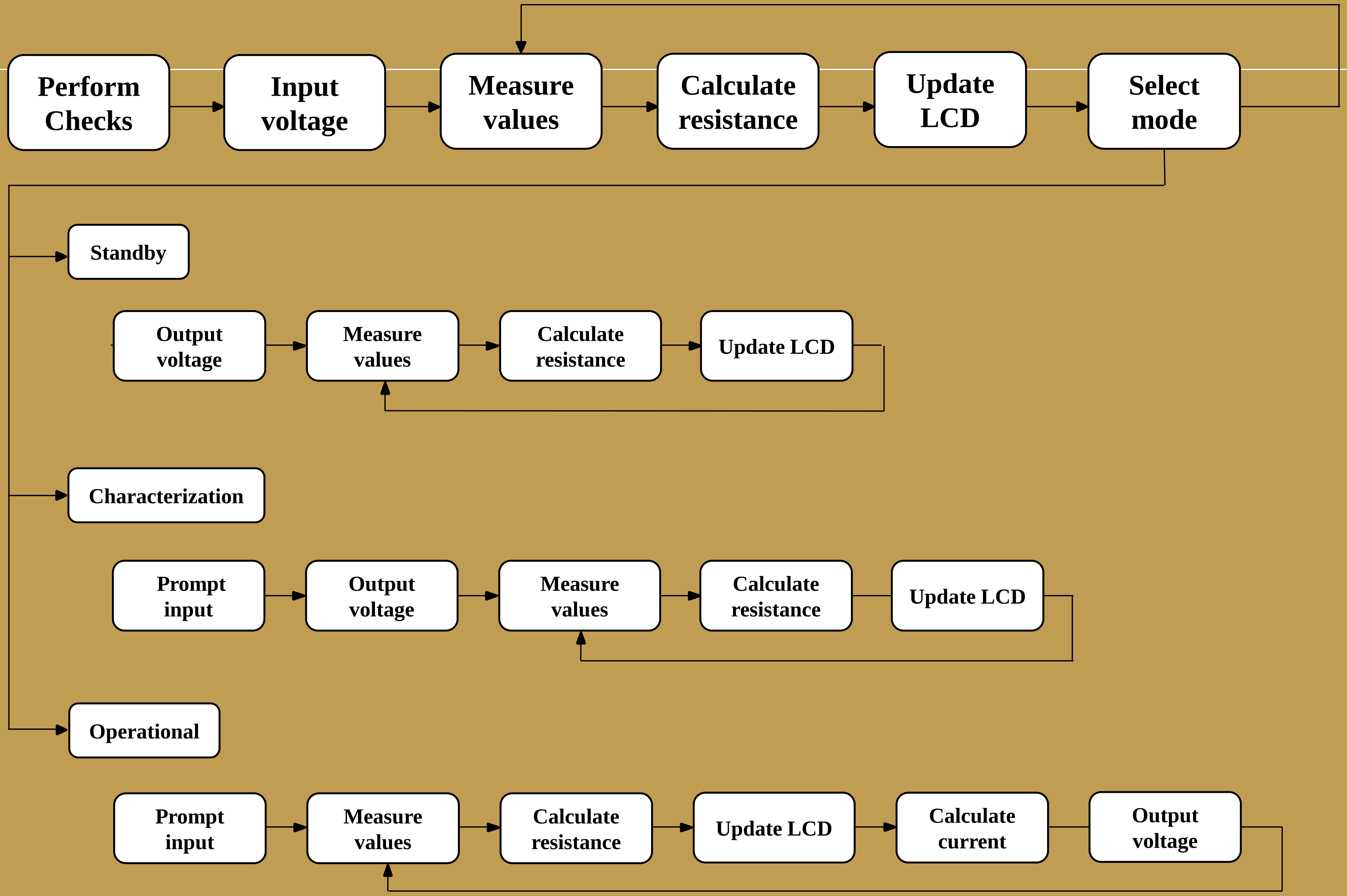


Prompt input → Measure values → Calculate resistance → Update LCD → Calculate current → Output voltage

Exiting loop:

Mode : select mode

Up : re-input resistance



Perform Checks
Input voltage
Measure values
Calculate resistance
Update LCD
Select mode

Standby

Output voltage
Measure values
Calculate resistance
Update LCD

Characterization

Prompt input
Output voltage
Measure values
Calculate resistance
Update LCD

Operational

Prompt input
Measure values
Calculate resistance
Update LCD
Calculate current
Output voltage

LCD Testing

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

ADMINISTRATIVE

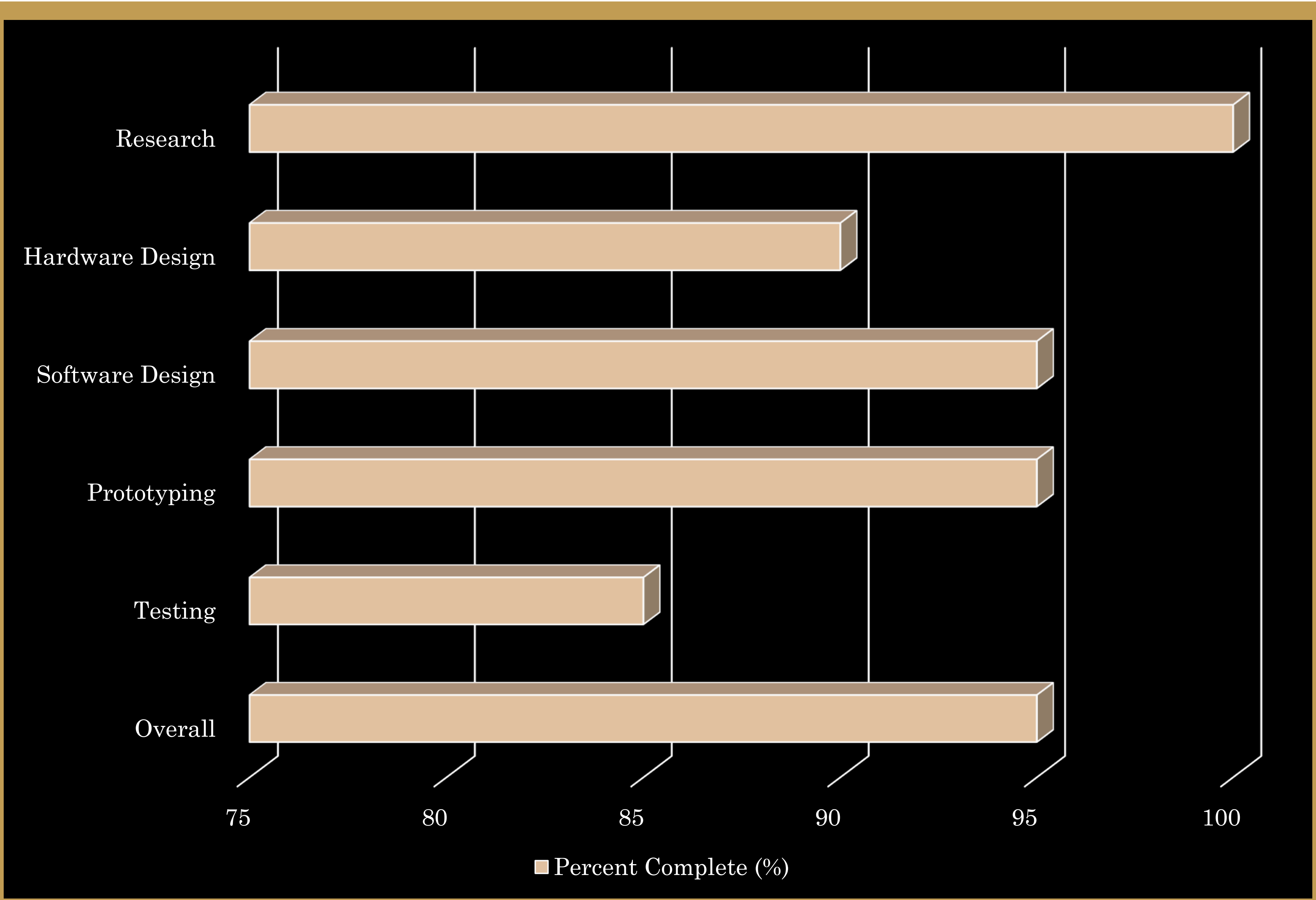
Work Distribution

	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	
PCB Assembly/ Soldering	P	P	
Power Supplies	P		
Control System Design	P	S	S
Display and User Input		S	P
Microcontroller Programming			P
Component Selection	P	P	P
Key: P=Primary, S=Secondary			

Budget

	Vendor	Expense	Cost
1st Board Iteration	Advanced Circuits	PCB (Quantity: 2)	$89.77
	Digikey	Parts	$43.77
	Mouser	Parts	$89.64
2nd Board Iteration	Advanced Circuits	PCB (Quantity: 1)	$122.61
	Mouser	Parts	$86.08
3rd Board Iteration	PCBWay	PCB (Quantity: 5)	$74.00
	Mouser	Parts	$85.39
Other	eBay	MSP430 Programming FET	$27.95
		Total budget remaining: $380.79	**Total spent: $619.21**

Current Progress



Challenges and Takeaways

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

Final Thoughts

- Acknowledgements
- Optimize current range
- Control loop for positive TCR device
- Write up user instructions

Questions?