Team 1817:Electrical plug, connector, and receptacle temperature sensor (Hubbell)

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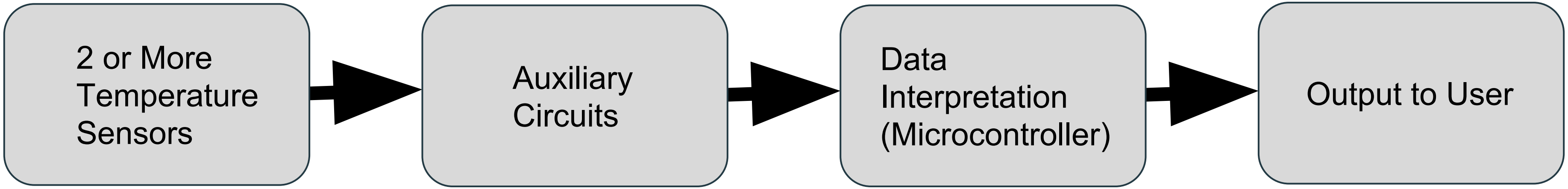
Project Statement

- The Task:
  - Research existing temperature sensing technologies
    - Accuracy
    - Temperature Range
    - Method
    - Problems
  - Look to utilize existing technology in miniaturization/optimization

Specifications/ Constraints

- Temperature sensing system:
    - Two or more sensors
    - **1 inch x 1 inch** component density
    - Temperature range: **-20°C to 80°C**
    - Minimum Accuracy: **±1°C**
    - Onboard Microcontroller for data interpretation
    - Final design cost $6-8

Setup


2 or More Temperature Sensors
Auxiliary Circuits
Data Interpretation (Microcontroller)
Output to User

Design Choices

Based on our research, the two optimal technologies are:

1. Resistance temperature detectors (RTDs)
   a. Requires minimal supplemental circuits
   b. Provides repeatability, stability, and are extremely accurate temperature sensors
2. Infrared devices (IR)
   a. Accurate, fast, and non-contact method of measurement

RTD

- Correlates resistance value to temperature value
- Close proximity/contact

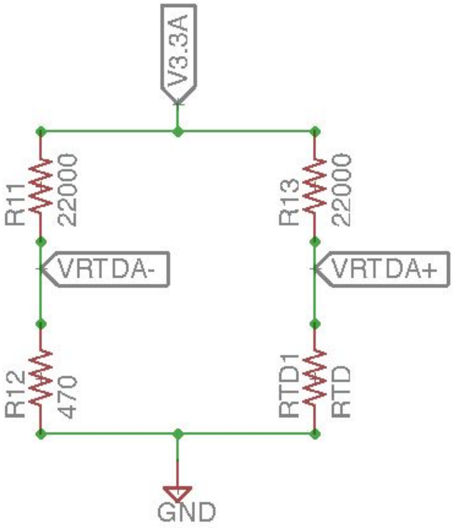


Figure 1: 2-wire RTD auxiliary circuit

Infrared

- **Non-Contact**
- IR Thermopile
  - Produces small voltage based off temperature difference
  - Requires: output voltage amplification and ambient temperature

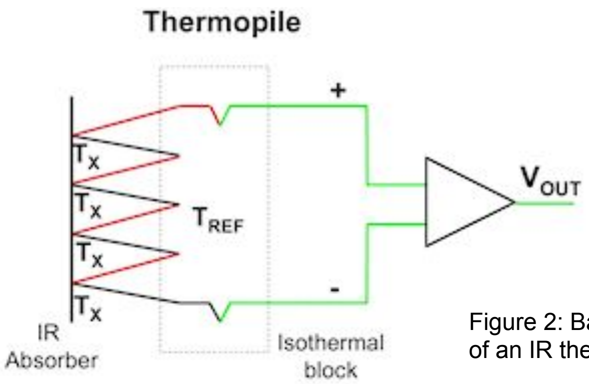
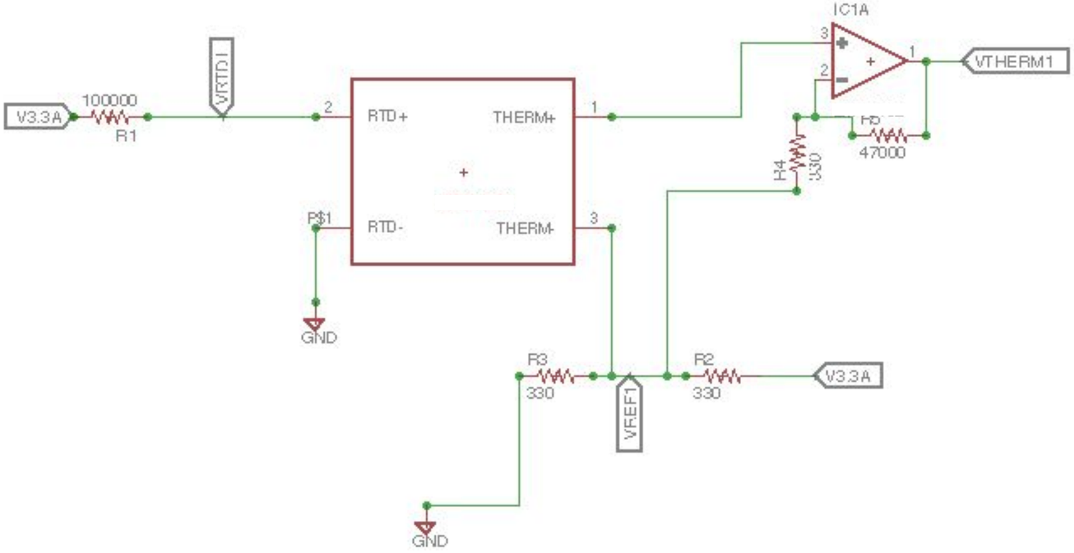


Figure 2: Basic design of an IR thermopile

Figure 2:Amphenol Advanced Sensors ZTP Thermopile Sensor

Infrared Circuit Design



- Thermopile
  - Output Voltage Range:-2mV to 11mV
- Amplifier output:

$$V_{Out} = 143.924 * V_{Therm} + V_{Bias}$$

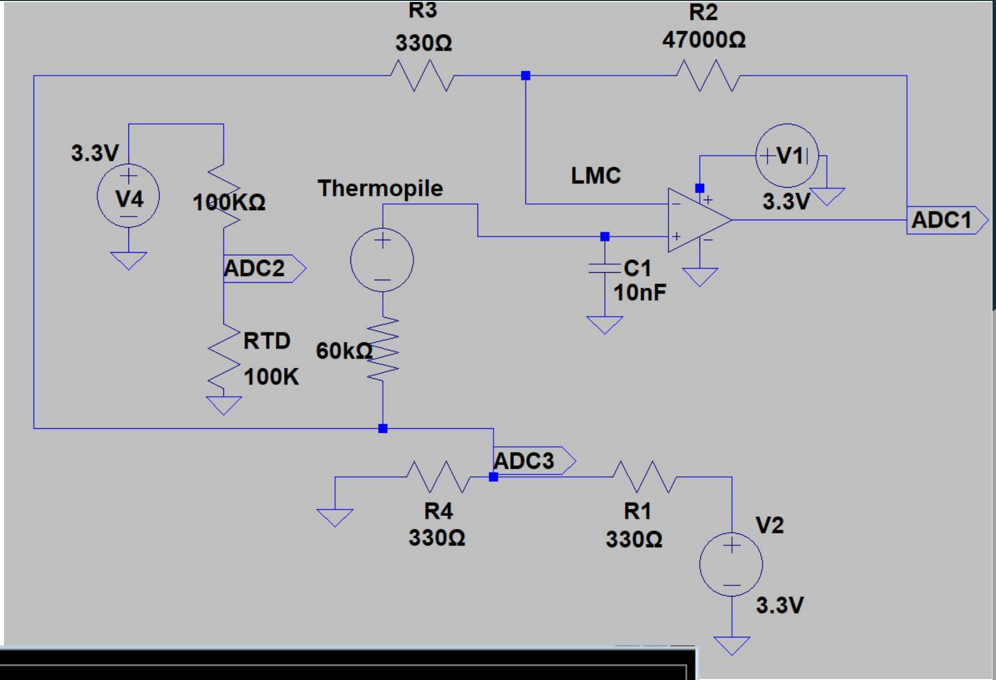
- Calculation for Temperature:

$$T_{Obj} = \sqrt[4]{\frac{V_{Therm}}{K} + T_{Ambient}^{4}}$$

Figure 3: IR thermopile test circuit

Simulation Testing

Single Amplifier Setup



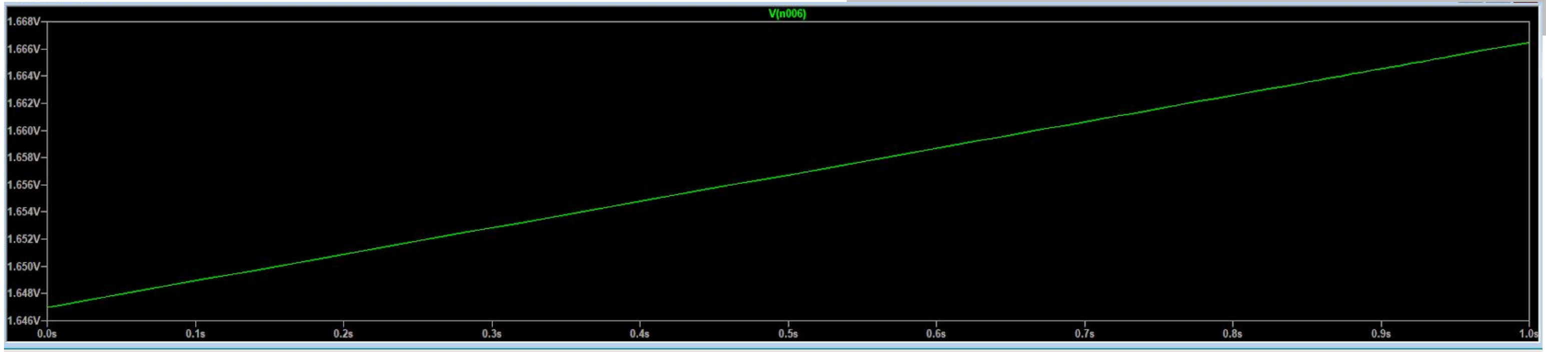


Figure 4: Thermopile node Output Voltage

Simulation Results

Single Amplifier Setup

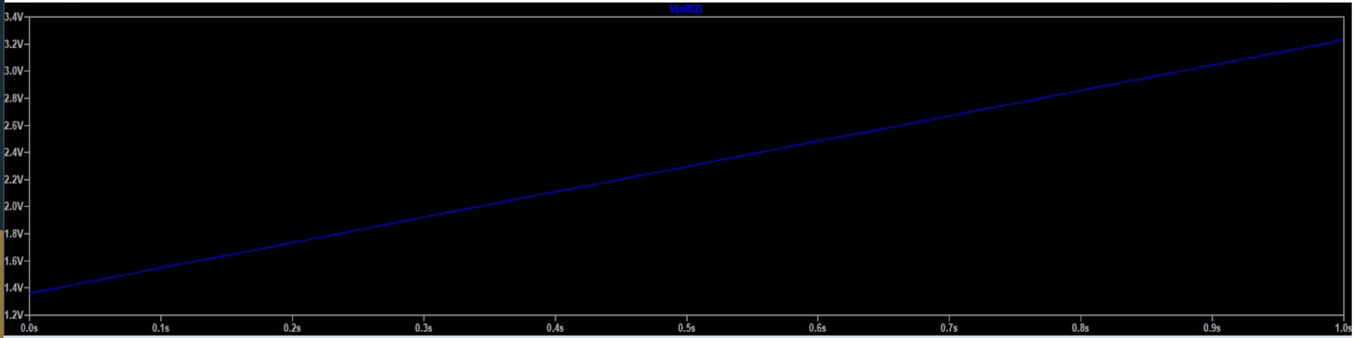


Figure 5: Overall Output Voltage

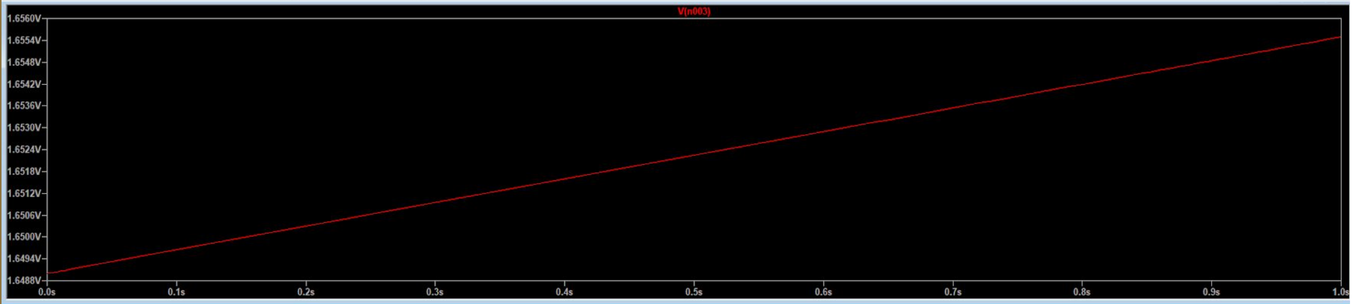


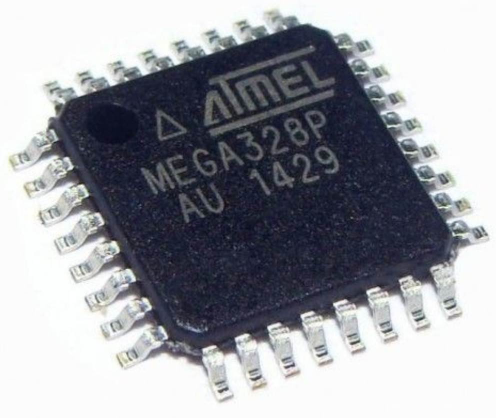
Figure 6: Reference Voltage

Microcontroller

Original Design:

- Requires multiple inputs from sensor array
- Small Size
- Atmega328P
    - **23** General purpose I/O connections
    - Offered on a development board (Testing)
    - Offered as a **standalone chip**
    - Operates within temperature sensing range
    - **Onboard 8 channel 10-bit ADC**
    - QFN package

Figure 7: Atmel Atmega328p surface mount package



Testing-Microcontroller

Original Testing: (Atmega328P)

- UART interface
  - Displays as much data as possible
    - Raw input
    - Converted temperatures
  - Multiple sensors handled at once
- Utilize ADC for measurement

Figure 8: IDE used for producing the test code.

Microcontroller

Updated Design:

- PIC16
  - Offered as QFN Package
    - Retains 28 pins
  - **11 Channels of 12 Bit ADCs**
  - 4 Comparators
  - Faster clock speed (32MHz)
  - Operation Voltages: 1.8V to 5.5V
  - Temperature Range (C) : -40 to 125

Figure 9: Microchip PIC16 surface mount package

Testing-Microcontroller

Updated Testing: (PIC16)

- Retains UART interface
- Adds: SPI
- PICkit debugging:
    - Reprogram any PIC microcontroller with a single button
    - MPLab X IDE
        - Retains C programming

Figure 10: PIC IDE

Testing

- Build auxiliary circuits on a breadboard
  - Compare components in the IR and RTD ranges
  - Different package sizes and manufacturers
  - Compare IR and RTD circuits at the same time
- Compare the temperature measurements of different materials
  - Copper, Brass, Aluminum
  - Range of temperatures from -20°C to 80°C and temperatures outside the range

Testing Circuits

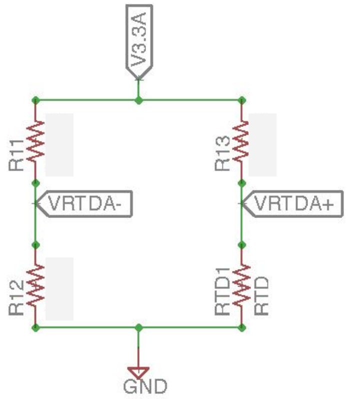


Figure 11:
RTD Circuit Implementation

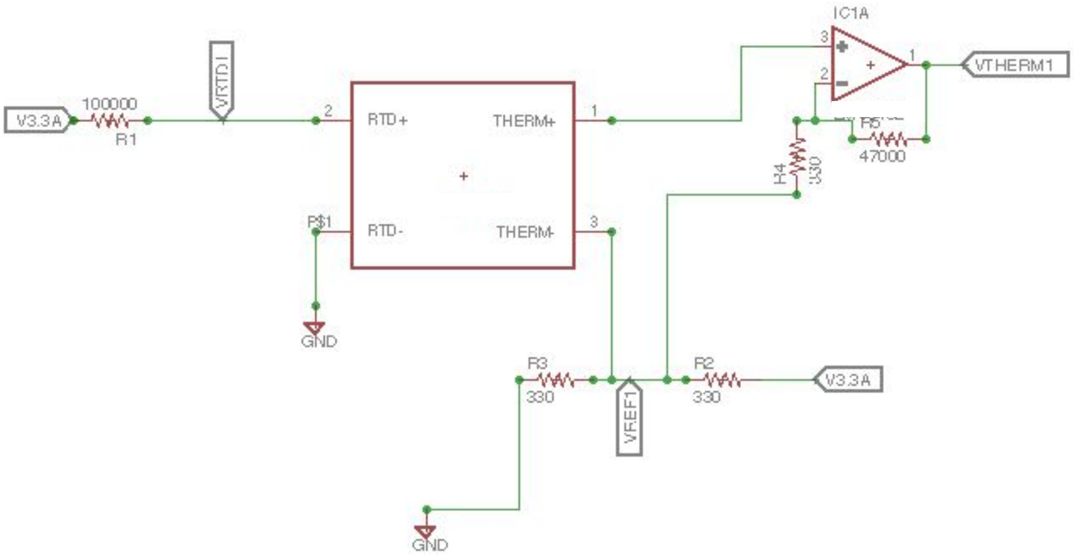


Figure 12:
IR Circuit Implementation

Testing Apparatus

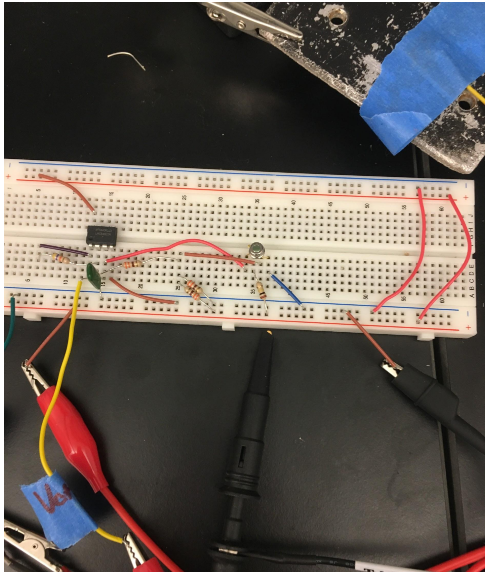


Figure 13: Thermopile testing circuit with supplementary components.

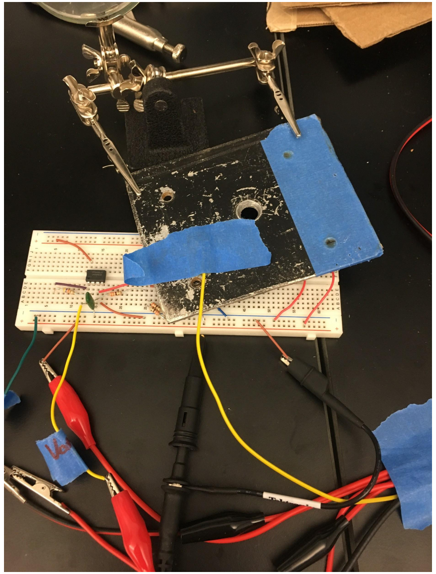


Figure 14: Thermopile testing circuit with aluminum plate as measurement target. A thermocouple is attached for reference temperature reading.

Testing Apparatus

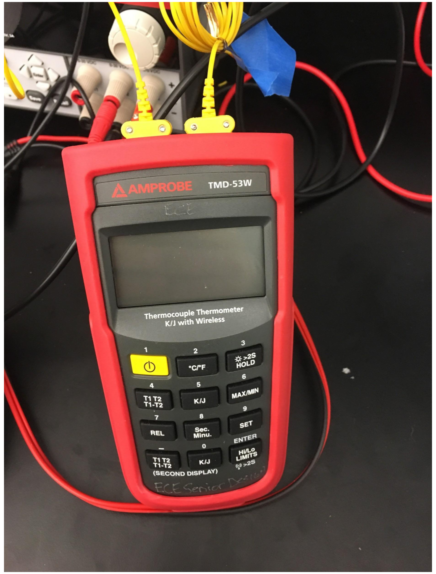


Figure 15:
Fluke with thermocouple used for reference temperature and comparison to calculated values.

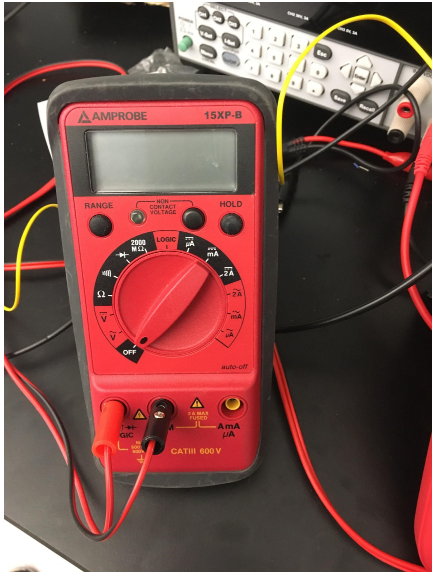
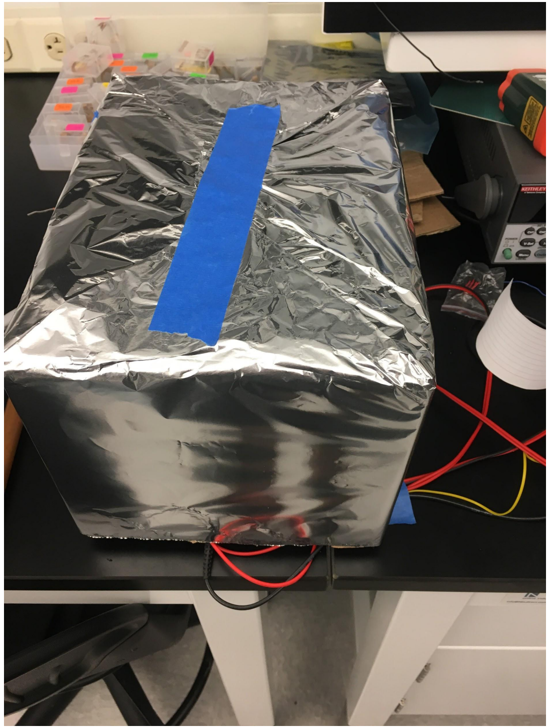


Figure 16:
Multimeter
used to take voltage readings of specific points on our circuit for verification of microcontroller measurement.

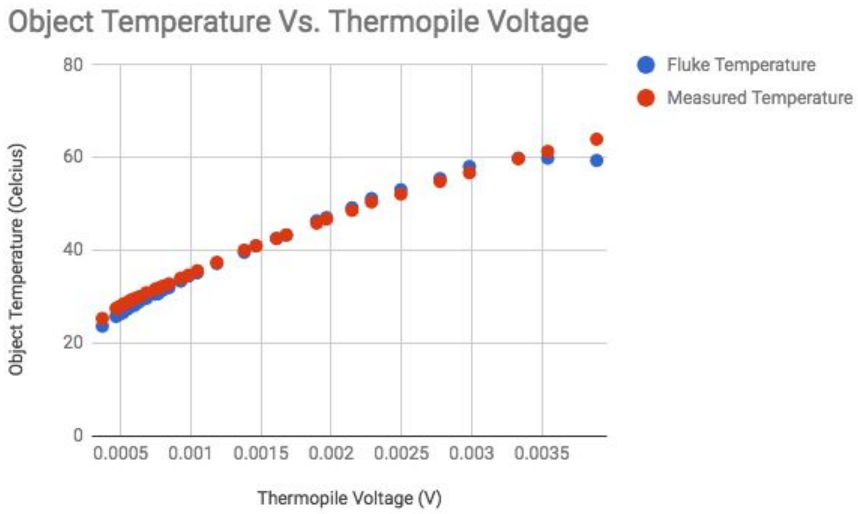
Testing Apparatus

Figure 17:
Circuit Isolation from electromagnetic interference (EMI). Utilizes cardboard to block external IR.



Experimental Findings

- Based on testing:
  - Thermopiles:
    - Fast Response
    - Accurate
    - Non-Contact
  - RTD:
    - Close proximity/contact
    - Accurate
    - Longer measurement time



PCB Considerations

- Grounding
- Error mitigation
  - Masking Color
- Part Placement
  - Single side or both sides
- Size
  - Surface mount vs. Through hole

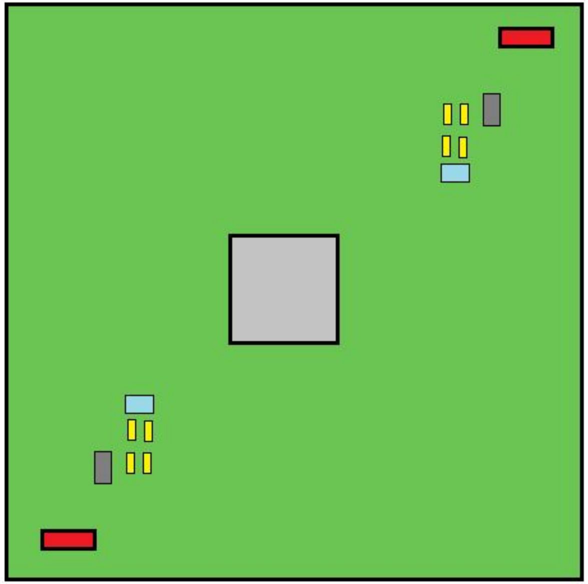
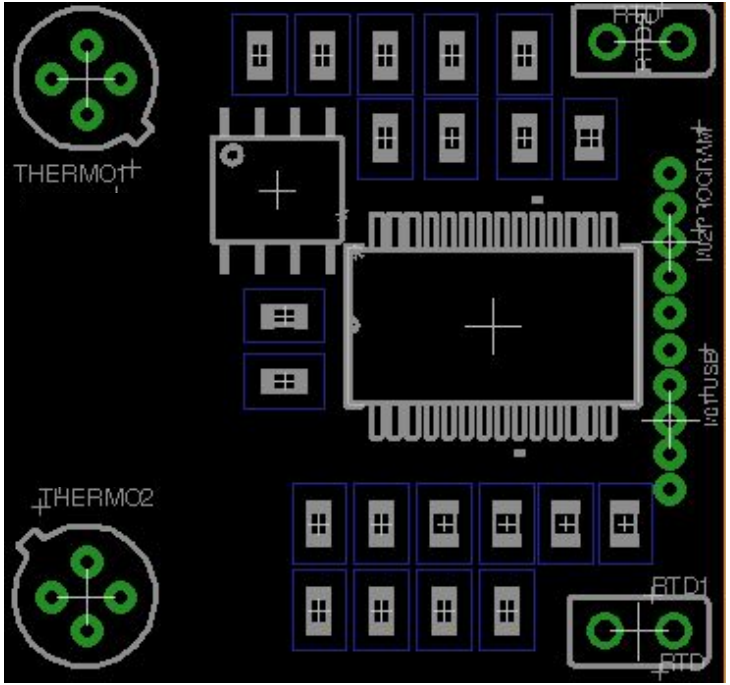


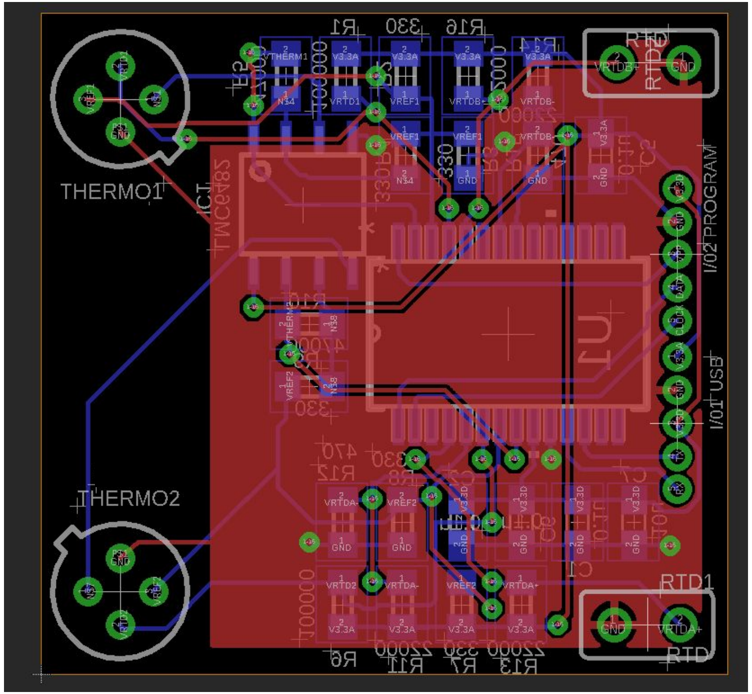
Figure 18:
General PCB layout

PCB-Prototype

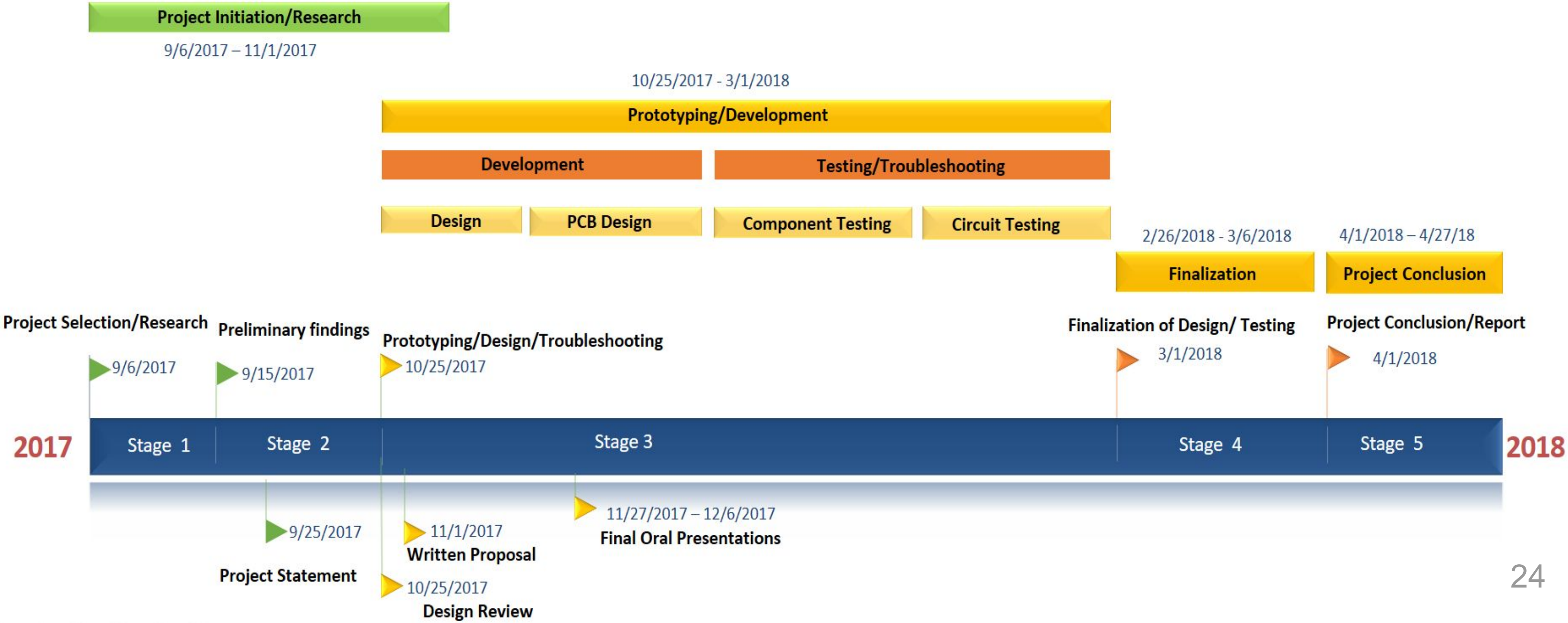
- Two RTDs and two IR thermopiles present
- Microcontroller onboard for computation
- Stay within the 1 inch by 1 inch component density
- Layout done in Eagle
- Due to size constraints 0603 surface mount passive components were used

Prototype PCB Layout





Timeline



Project Initiation/Research
9/6/2017 – 11/1/2017
10/25/2017 - 3/1/2018
Prototyping/Development
Development
Testing/Troubleshooting
Design
PCB Design
Component Testing
Circuit Testing
2/26/2018 - 3/6/2018
Finalization
4/1/2018 – 4/27/18
Project Conclusion
Project Selection/Research
9/6/2017
Preliminary findings
9/15/2017
Prototyping/Design/Troubleshooting
10/25/2017
Finalization of Design/ Testing
3/1/2018
Project Conclusion/Report
4/1/2018
2017
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
2018
9/25/2017
Project Statement
11/1/2017
Written Proposal
10/25/2017
Design Review
11/27/2017 – 12/6/2017
Final Oral Presentations

Improvements

- New design for reference voltage: Regulator
- By using only two sensors the PCB can become smaller
- Part size can be decreased by utilizing an outside company to attach components

Budgeting

Infrared only design:

	Component	Quantity Per Board	1000 Unit Price
Sensors	Thermopile	2	2.36205
Resistors	330 Ohm	6	0.04906
	47k Ohm	2	0.04906
	100k Ohm	2	0.04906
Capacitors	0.1uF	4	0.04258
	10uF	1	0.1382
OP AMP	OPAMP	1	0.74526
Microcontroller	16 Bit MicroController	1	1.69950
		Total:	$7.97

Budgeting

RTD only design:

	Component	Quantity Per Board	1000 Unit Price
Sensors	RTD	2	0.837
Resistors	470 Ohm	2	0.03346
	22k Ohm	4	0.04906
Capacitors	0.1uF	4	0.04258
	10uF	1	0.1382
Microcontroller	16 Bit MicroController	1	1.69950
		Total:	$3.95

Budgeting

Infrared & RTD combined design:

	Component	Quantity Per Board	1000 Unit Price
Sensors	RTD	2	0.837
	Thermopile	2	2.36205
Resistors	330 Ohm	6	0.04906
	470 Ohm	2	0.03346
	47k Ohm	2	0.04906
	100k Ohm	2	0.04906
	22k Ohm	4	0.04906
Capacitors	0.1uF	4	0.04258
	10uF	1	0.1382
OP AMP	OPAMP	1	0.74526
Microcontroller	16 Bit MicroController	1	1.69950
		Total:	$10.46

Questions?

Works cited

- “Figure 2”, https://www.mouser.com/new/Amphenol/ge-ztp-thermopile-ir-sensors/ Accessed: 23 October 2017
- Karaki, Habib. “Figure 3”, 27 February 2014, http://www.sensorsmag.com/components/demystifying-thermopile-ir-temp-sensors , Accessed: 23 October 2017
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- “Figure 8” http://www.atmel.com/webdoc/atmelstudio/ Accessed: 22 November 2017
- “Figure 9 http://www.microchip.com/paramchartsearch/chart.aspx?branchID=1002/ Accessed: 2 April 2017