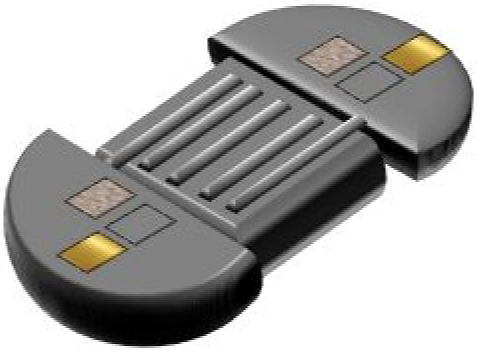
Oven-Control Circuit for TPoS MEMS Oscillator

Senior Design I Initial Project Document
September 13, 2018



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Project Sponsor:
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1. Nomenclature

MEMS: Microelectromechanical systems
PPB: Parts per billion
TCF: Temperature coefficient of frequency
TPoS: Thin-film piezoelectric-on-substrate
UCF: University of Central Florida
VCCS: Voltage-controlled current source

2. Project Description

2.1 Background

Microelectromechanical resonators (microsystems that resonate after being stimulated electrically) have a number of sensing, filtering, and timing applications. The particular resonator to be used for this project is an oscillator. [1]

Oscillators are devices used to produce periodic, oscillating electric currents or voltages through changes in energy. The electronic signals generated by these devices are often a product of the circuit design and the values of the components; however, they generally assume sine or square waveforms. Oscillators can convert direct current (DC) from a given power supply to an alternating current (AC) signal. They are often distinguished by their output signal frequency and output signal type, and this lends to different applications. For example, oscillators can generate clock signals exercised in computers and broadcast signals utilized in transmitters.

The output signal frequency of a quartz oscillator is affected by the temperature of the quartz crystal, which can impact its resonance frequency. An oven-controlled crystal oscillator (OCXO) is a specific type of oscillator that controls the temperature of an oscillator circuit using an oven. This type of oscillator is often used to provide improved temperature stability and frequency accuracy with respect to a standard crystal oscillator. The drawback to using an oven-controlled crystal oscillator is that it often consumes a lot of power, which can be expensive.

A resonator is a device that naturally oscillates at its resonant frequencies with a greater amplitude than at other frequencies. The oscillations can be generated either mechanically or electromagnetically which allows the resonator to generate specific frequencies or detect specific frequencies. Resonators with mechanically generated oscillations have applications such as stringed and percussion instruments, where specific frequencies are generated utilizing acoustic cavity resonators, guitar resonators, etc. Resonators with electromagnetically generated oscillations have applications such as lasers or particle accelerators, which generate certain frequencies by transferring energy using resonator cavities.

The temperature coefficient of frequency (TCF) is used to determine the thermal stability of a resonator. Thermal stability is important to consider because temperature change affects the resonant frequencies of the system. The TCF is found by placing a test sample within a cavity on a low loss, low dielectric constant, and low thermal expansion material. The cavity is then placed within a temperature chamber, and the resonant frequency is measured at each temperature over the desired range of temperatures. The TCF can then be calculated and expressed in parts-per-million-per-degree Celsius (ppm/ºC). [2]

Thin-film piezoelectric-on-substrate (TPoS) resonators have been the subject of Dr. Abdolvand's research for over a decade. These resonators are a type of lateral bulk acoustic resonators (which vibrate via expansion and contraction due to electric signal converted into a force) specifically shown to have high Q-factors in the MHz range. [3] TPoS resonators involve creating piezoelectric components (which will translate electrical energy into mechanical energy) as a part of the silicon bulk. [1]

The oscillator to be used here is a microelectromechanical system (MEMS) TPoS resonator. The resonator in this application acts as a filter for the frequencies and attenuates all but the resonance frequency and a number of the surrounding frequencies. This number largely depends on the Q-factor of the resonator. A higher Q-factor results in a narrow attenuation band and, thus, has a better performance by reducing the noise of unwanted frequencies also being fed back to the resonator.

2.2 Motivation

This project focuses on designing an oven-control circuit for a TPoS MEMS oscillator to keep it at a constant resonance frequency. While circuits of this type have been designed before, this one will be unique because of the specific type of resonator used. The TPoS resonator to be used has been designed by researchers at the University of Central Florida (UCF) in the Dynamic Microsystems Lab under the direction of Dr. Reza Abdolvand.

MEMS resonators have been shown to have applications as a smaller, more easily fabricated, and sometimes less expensive oscillator compared to the current crystal oscillators that dominate the market. The challenge with MEMS oscillators currently centers around their performance, especially since they have a distinct TCF. The TCF details the changes in resonance frequency with respect to temperature and is minimized at the resonance frequency.

Because resonator performance is affected by temperature, having a method of stabilizing the temperature to the value corresponding to the resonance frequency should help optimize and stabilize the resonator performance, minimizing changes in the frequency by keeping the resonator operating at a temperature where the TCF is stable. Because cooling the resonator would require a more elaborate setup, this project would seek to heat the resonator to a stable temperature above the standard industrial limit of $85\,^{\circ}$C. The finished product should standardize the elevated temperature of the resonator within a distinct range.

The temperature could be controlled via the current passed through the resonator. Prior research will be used to ascertain the relationship between resonator temperature and current passed through it. A control loop could be used in conjunction with a microcontroller to ensure that the temperature remains stable.

2.3 Design Constraints and Requirement Specifications

2.3.1 Design Constraints

- Design should resonate at around 70MHz and should not deviate more than +/- a few Hz
- Design will need to operate at above $85\,^{\circ}$C
- Design should incorporate a display to measure and display operational frequency and temperature
- Design should incorporate a stand-by mode when control loop is not active (to save power)
- Parts per billion (ppb) accuracy; must change no more than 0.07Hz per degree of temperature change

2.3.2 Design Requirement Specifications

Table 1: Design Requirement Specifications

Description	**Value**	**Related Standards/Purpose**
Project Cost Ceiling	$500	No Related Standards. Low cost without limiting project material quality. Designated by sponsor.
Time	31 Weeks (Total)	No Related Standards. Time limitation of Senior Design 1 and 2 courses to create, design, and build a working prototype of project.
Accuracy	Less than 0.07Hz per 1°C of temperature change	No Related Standards. Required to ensure Parts Per Billion (ppb) accuracy which is a requirement set by sponsor.
Operating Temperatures	Room temperature (approximately 23 °C) to greater than 85 °C (approximately 90 °C)	Standard Industrial Limit is 85 °C (per MIL-STD-810G). "Ensure the range of temperatures and rate of change of the test item's skin temperature is adequate to achieve the test profile. A typical range is -40°C to +85°C; " Necessary to go above this standard value to test the effects of temperature on resonance frequency.[4]
Resonant Frequency	70MHz with minimal deviation (+/ a few Hz)	No Related Standards. Specific to resonator used within project which is set by sponsor.

2.4 Deliverable Requirements

Hardware Deliverables:

1. Low power
2. Parts per billion (ppb) frequency stability
3. Communication (must be able to relay temperature and frequency to user)

Software Deliverables:

1. Controls within ppb accuracy (most likely 0.1-0.2 °C accuracy)
2. Speed of sensitivity
3. Efficient code

Project responsibilities are as follows:

Michaela Pain (software engineer):

- Choose and program microcontroller
- Add additional features for interface

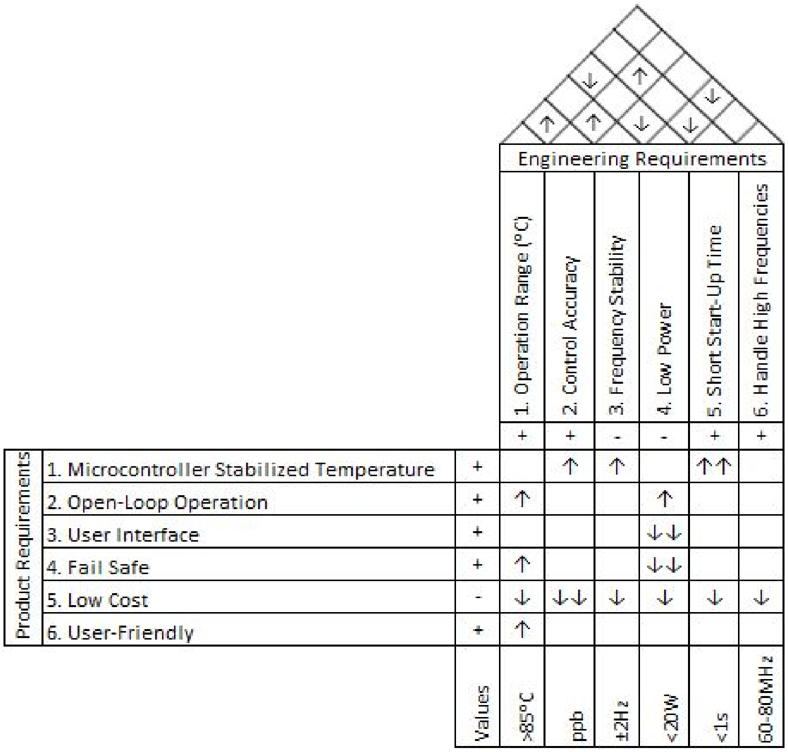
Megan Driggers (electrical engineer):

- Design PCB
- Oversee power and voltage requirements

Heather Hofstee (electrical engineer):

- Lead team and coordinate with Dr. Abdolvand
- Design hardware schematic

2.5 House of Quality



Product Requirements		1. Operation Range (°C)	2. Control Accuracy	3. Frequency Stability	4. Low Power	5. Short Start-Up Time	6. Handle High Frequencies
		+	+	-	-	+	+
1. Microcontroller Stabilized Temperature	+		↑	↑		↑↑	
2. Open-Loop Operation	+	↑			↑		
3. User Interface	+				↓↓		
4. Fail Safe	+	↑			↓↓		
5. Low Cost	-	↓	↓↓	↓	↓	↓	↓
6. User-Friendly	+	↑					
	Values	>85°C	ppb	±2Hz	<20W	<1s	60-80MHz

Strong Positive Correlation	↑↑
Strong Negative Correlation	↓↓
Positive Correlation	↑
Negative Correlation	↓
Maximize Element	+
Minimize Element	-

Figure 1: House of Quality

2.6 Block Diagrams

2.6.1 PCB design process flowchart - Megan Driggers

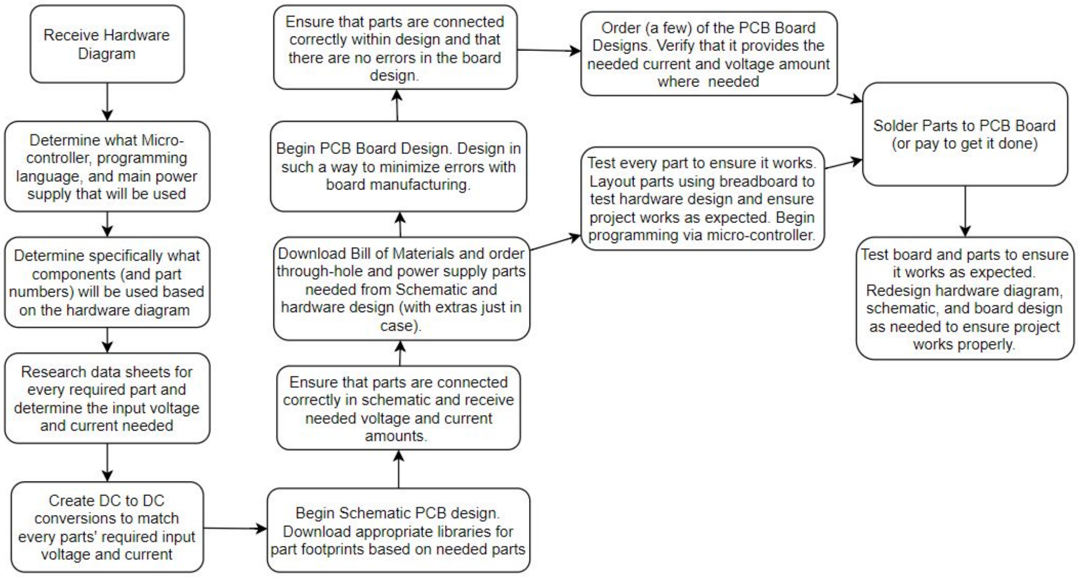


Figure 2: PCB Design Process Flowchart (Megan Driggers)

2.6.2 Hardware Diagram - Heather Hofstee

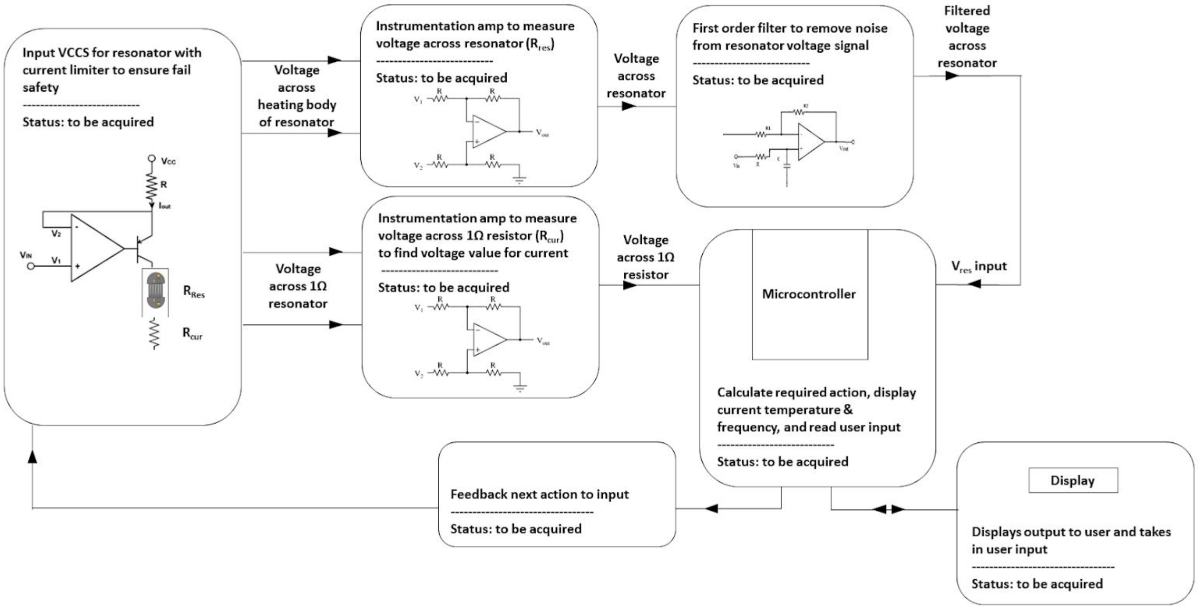


Figure 3: Hardware Diagram (Heather Hofstee)

2.6.3 Software Flow Diagram - Michaela Pain

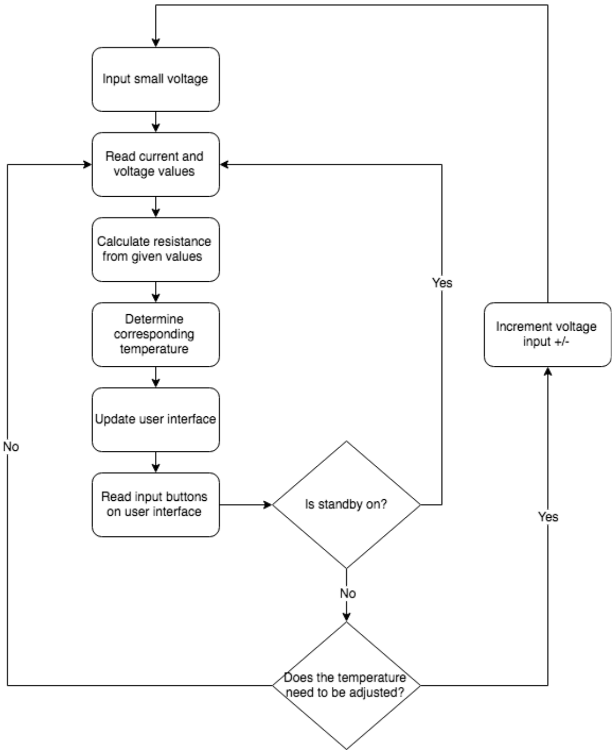


Figure 4: Software Flow Diagram (Michaela Pain)

2.7 Financing

Project Budget: $500

Financing will be provided by project sponsor, Dr. Reza Abdolvand.

Table 2: Project Finances

Part	Manufacturer	Part Number	Price (estimates)	Number Needed	Actual Cost
Microcontroller	TBD	TBD	Less than $10	1	TBD
PCB Boards	Element 14	N/A	Less than $40	3	TBD
Display	TBD	TBD	Less than $30	1	TBD
Miscellaneous parts for resonator	TBD	TBD	TBD	TBD	TBD
Miscellaneous parts for DC to DC conversions and power supply	TBD	TBD	Less than $25	TBD	TBD
Miscellaneous Parts for measuring voltage	TBD	TBD	TBD	TBD	TBD
Shipping Costs			Less than $50		TBD
					Total:

2.8 Project Schedule

Descriptive project goals for both semesters

2.8.1 Fall 2018/ Senior Design 1 Project Schedule

Table 3: Fall 2018 Project Schedule

Week	Dates	Task(s)	Status	Member(s)
1	8/20-8/26	Register as group, begin team discussion	Complete	All
2	8/27-9/2	Attend boot camp, start working on initial summary, schedule meeting with Dr. Abdolvand	Complete	All, Heather
3	9/3-9/9	Meet with Dr. Abdolvand; over half completion of initial summary	Complete	All
4	9/10-9/16	Complete 10 page Initial Project Summary	Complete	All
5	9/17-9/23	Meet to discuss details of Initial Project Summary	Upcoming	All
6	9/24-9/30	Update Initial Project Summary and resubmit	Upcoming	All
7	10/1-10/7	Complete 15 out of 45 pages for design document	Upcoming	All
8	10/8-10/14	Complete 20 out of 45 pages for design document	Upcoming	All
9	10/15-10/21	Complete 30 out of 45 pages for design document	Upcoming	All
10	10/22-10/28	Refine design document and begin selecting components	Upcoming	All
11	10/29-11/5	45 page design document due, begin order components	Upcoming	All
12	11/6-11/11	Complete 60 out of 75 pages	Upcoming	All
13	11/12-11/18	75 page design document due	Upcoming	All
14	11/19-11/25	Complete 80 out of 90 pages for design document	Upcoming	All
15	11/26-12/3	Order PCB, finish 90 out of 90 pages for design document	Upcoming	All
16	12/3-12/9	Final exams; Final 90 page design document due	Not started	All

2.8.2 Spring 2019/ Senior Design 2 Project Schedule

Table 4: Spring 2019 Project Schedule

Week	Dates	Task(s)	Status	Member(s)
1	1/7-1/13	Reconvene group, plan prototyping, schedule meeting with Dr. Abdolvand	Upcoming	All
2	1/14-1/20	Meeting with Dr. Abdolvand, begin to order parts	Upcoming	All, Heather
3	1/21-1/27	Begin prototyping	Upcoming	All
4	1/28-2/3	Assemble prototype, begin testing	Upcoming	All
5	2/4-2/10	Continue testing, consider redesign	Upcoming	All
6	2/11-2/17	Redesign if necessary and reorder parts, schedule meeting with Dr. Abdolvand	Upcoming	All
7	2/18-2/24	Meeting with Dr. Abdolvand, reassemble prototype, begin testing	Upcoming	All, Heather
8	2/25-3/3	Continue testing, hone working prototype	Upcoming	All
9	3/4-3/10	Continue testing, hone working prototype	Upcoming	All
10	3/11-3/17	Finalize working prototype, assign roles regarding final document	Upcoming	All
11	3/18-3/25	Work on Final Documentation	Upcoming	All
12	4/1-4/7	Complete Final Documentation	Upcoming	All
13	4/8-4/14	Prepare for Final Presentation, Peer Reviews	Upcoming	All
14	4/15-4/21	Final Presentation (Exact Date TBD)	Upcoming	All
15	4/22-4/28	Final Exams	Not started	All

3. References

[1]. R. Abdolvand, B. Bahreyni, J. Lee and F. Nabki, “Micromachined Resonators: A Review,” in *Micromachines*, vol. 7, no. 160, September 2016.
[2] “Temperature Coefficient of Resonant Frequency.” *Basics of Laboratory Safety and Equipment*, www.students.tut.fi/~khamousk/TCF.htm.
[3] J. Charmet, R. Daly, P. Thiruvenkatanathan, J. Woodhouse, and A. A. Seshia1, "Observations of modal interaction in lateral bulk acoustic resonators," in *Applied Physics Letters*, 105, 013502, pp. 1-4, 2014.
[4] Military Specification (MIL)-STD-810G, Environmental Engineering Considerations and Laboratory Tests, revision G (DOD, 31 October 2008).