Milestone 2 Application Note

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1 Design Overview

For this milestone project, the ultimate objective was to develop a system capable of maintaining different desired temperature values as entered by the user. The system consists of a 12 V (Volt) fan to be powered on at varying speeds depending on the temperature value that must be reached to satisfy the user's request. The system itself is comprised of interfacing an MSP430G2553 micro-controller with a circuit, constructed to both capture and read the current temperature value of a linear, 5 V voltage regulator by utilizing a PTAT (Proportional to Absolute Temperature) sensor. In addition to incorporating a voltage regulator and PTAT, the circuit also includes a small, functional 12 V cooling fan salvaged from an ancient computer, and an IRL520 NMOS (N-Channel MOSFET) transistor utilized to act as a buffer between the 12 V fan and MSP430G2553 micro-controller. The IRL520 NMOS is responsible for enabling the micro-controller to properly monitor the PWM (Pulse Width Modulation) of the fan being powered by 12 volts, as connecting the micro-controller directly to the cooling fan may increase the potential risk of damaging it due to its 3.6 V intake limitation. Code, written in C, would also be implemented for the MSP430G2553 micro-controller for the purposes of allowing UART (Universal Asynchronous Receiver/Transmitter) to successfully transmit and receive temperature values to the user. Through the utilization of Realterm, a software program used by engineers to transmit and receive streams of data, a desired temperature value would be transmitted to the micro-controller as entered by the user. The code implemented for this system would also hold the capability of altering the duty cycle (speed) of the fan through the incorporation of different PWM signals. An ADC (Analog-to-Digital Converter) was also implemented in C as it was designed to convert the output voltage of the PTAT from an analog to a digital value. The digital value obtained would then be converted to a temperature value (in Celsius) based on a conversion factor such that 3.3 V being outputted from the PTAT is equivalent to the digital value of 1024. Several trials would be performed to ensure the accuracy and validity of the results obtained.

1.1 Design Features

- Hardware PWM
- UART Communication
- Heat Sinks
- Speed Control for Fan

1.2 Featured Applications

- Temperature Control
- Temperature Measurement
- ADC Conversion
- Effective Cooling of a Heat Source

1.3 Design Resources

- GitHub Team Repository Link:
  https://github.com/Intro-To-Embedded-Systems-RU09342/milestone-2-goon_squad
- TMP36GZ (PTAT) Datasheet:
  https://www.analog.com/media/en/technical-documentation/data-sheets/TMP35_36_37.pdf
- IRL520 (NMOS) Power Mosfet Datasheet:
  https://www.vishay.com/docs/91017/91017.pdf
- LM340T57805 5V Regulator Datasheet:
  http://www.ti.com/lit/ds/symlink/lm340.pdf
- MSP430x2xx Family User Guide:
  https://www.ti.com/lit/ug/slau144j/slau144j.pdf

1.4 Block Diagram

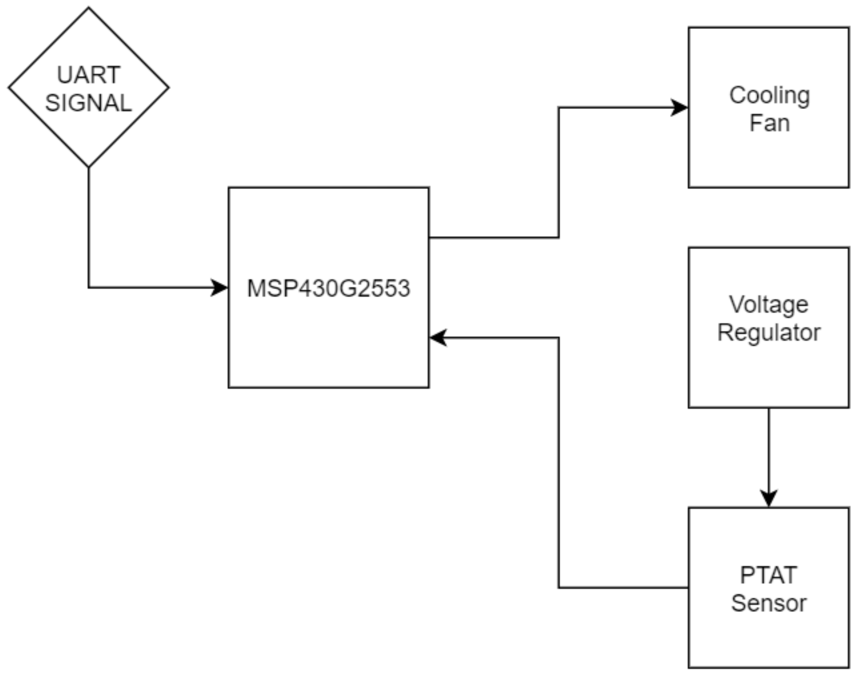


Figure 1: Block Diagram of System

1.5 Board Image

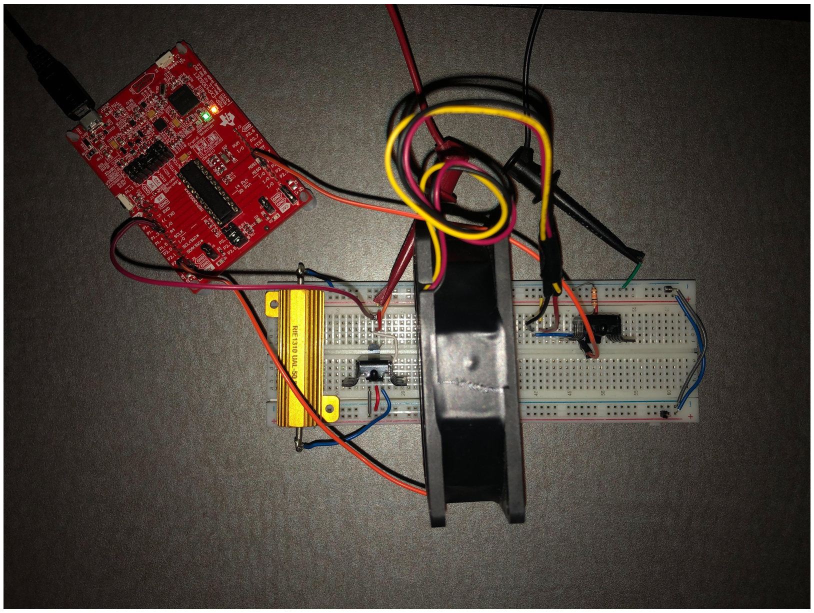


Figure 2: Image of Breadboard and Micro-Controller Setup

2 Key System Specifications

Parameter	Specification	Details
12 V Cooling Fan	Must monitor speed of the fan when powered on.	Hardware PWM will be utilized to alter the speed of the fan depending on the temperature value entered by user
Temperature Control	Must hold temperature of Voltage Regulator to desired temperature value entered by user	The current temperature value of the Voltage Regulator will be compared with the desired value entered by the user via Realterm and the fan speed will be adjusted to meet this desired temperature.
PTAT Sensor Measurement	Creates a voltage based on the current temperature value of the Voltage Regulator.	The output voltage of the PTAT will be converted to a digital value through the utilization of an ADC. The resulting digital value from the ADC will then be converted to a temperature value. Digital value is converted to temperature value based on conversion factor derived from testing.
UART Communication	Must transmit data from User Computer to MSP430G2553.	The desired temperature value of the Voltage Regulator, as entered by user via Realterm, will be received.

3 System Description

The system is built to power a cooling fan on and off in addition to monitoring the speed of the fan depending on the state of the system. The problem that requires solving is to determine an efficient and safe method for preventing a 5 V Voltage Regulator from overheating. To prevent this from occurring, a fan will be utilized to power on when it appears the Voltage Regulator is reaching a stage where overheating is imminent. The system will determine the speed the fan is running at in order to cool the voltage regulator to a desired temperature. This desired temperature that the voltage regulator would reach, as a result of the cooling fan, would be entered by the user beforehand via Realterm. To put this into simpler terms, the temperature value entered by the user via Realterm will be the desired temperature value the fan will aim to keep the voltage regulator at. For visual purposes, the system should be able to read the current temperature value of the regulator and display it on Realterm so the user is able to identify the accuracy of this value and verify the fan is cooling the voltage regulator to its desired temperature.

3.1 Detailed Block Diagram

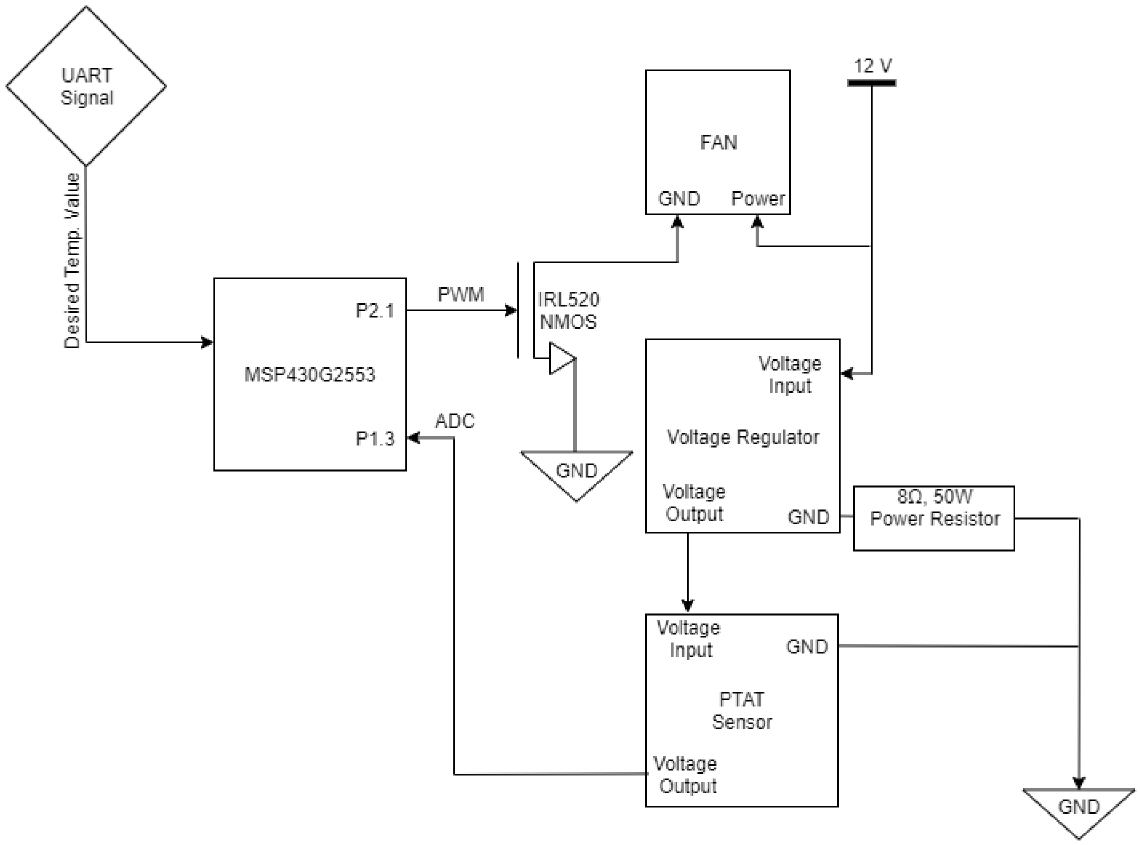


Figure 3: Detailed Block Diagram of System

3.2 Highlighted Devices

- MSP430G2553 - Micro-Controller containing both on-board timer peripherals for PWM purposes and ADC peripheral for reading voltage values from PTAT.
- TMP36GZ (PTAT) - Utilized as temperature sensor for 5 V Voltage Regulator
- IRL520 NMOS (N-Channel MOSFET) - Buffer to enable MSP430G2553 to monitor PWM of 12V Cooling Fan without having 12V going into the micro-controller and potentially damaging it.
- PVA080G12Q (Fan) - 12 V DC brushless fan utilized to monitor the temperature of the Voltage Regulator to desired value.

- LM340T57805 (5V Voltage Regulator) - Linear 5 V Voltage Regulator which would have 12 V supplied to it in order to overheat the regulator and enable the fan to perform its specific job.

3.3 Device/IC 1

The MSP430G2553 micro-controller (Figure 4) would be utilized for the system and is primarily responsible for executing the implemented code, written in C, to allow the system to function accordingly. All implemented code for this system is programmed on the MSP430G2553, allowing it to control the status of the system. To incorporate Hardware PWM, the on-board TXD (Transmit Data) and RXD (Receive Data) jumpers are required to be extracted from its default vertical position and be reconnected at its initial on-board position, but horizontally as shown in Figure 9. The code for this system would include an ADC function to read the output voltage value of the PTAT and convert the given analog value to a digital value. Once this digital value has been obtained, this specific value would then be converted to a temperature value in Celsius. The code itself would also consist of a UART function to allow Realterm, a software program used by engineers to transmit and receive streams of data, to be utilized when the code is programmed on the micro-controller. When the user is on Realterm, they will be prompted to enter a desired temperature value of their choice. Once the value has been entered via Realterm, the code programmed on the MSP430G2553 will allow the system to read the user's request and change the current temperature value to the desired value inputted and maintain it.

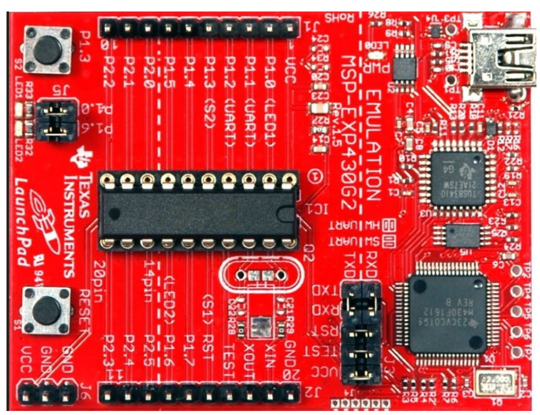


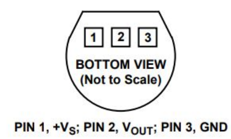
Figure 4: The MSP430G2553 Microcontroller

3.4 Device/IC 2

The TMP36GZ PTAT (Figure 5a) would be utilized as a temperature sensor for the 5V Voltage Regulator, such that it will read the current temperature value of the regulator and output a certain voltage depending on the temperature of the regulator.

To elaborate on how the voltage of the PTAT changes with respect to temperature, there is an existing linear relationship between the output voltage across the PTAT and temperature expressed in Celsius. According to the TMP36GZ datasheet (Refer to Design Resources for more information), the TMP36GZ PTAT is rated to output 10 mV/°C. In addition, the TMP36GZ has an offset of 0.5 V meaning at 0 °C, the output voltage of the PTAT is 0.5 V, followed by increasing at a rate of 10 mV per 1 °C. Note, the TMP36GZ has a typical accuracy of 1°C at 25°C and 2°C over the temperature range of 40°C to 125°C. The voltage outputting from the PTAT is transmitted to the MPS430G2553 and is then converted from an analog value to a digital value, using the ADC functionality of the micro-controller. The digital value is then converted to its temperature value in Celsius.

(a) TMP36GZ



(b) Bottom View

Figure 5: The TMP36GZ Temperature Sensor

3.5 Device/IC 3

The IRL520 NMOS, an N-Channel Power MOSFET, would be utilized as a buffer in the designed circuitry between the MSP430G2553 and PVA80G12Q Fan. The IRL520 NMOS would be primarily responsible for allowing the MSP430G2553 to monitor the PWM of the 12V PVA80G12Q Fan without having 12 V go directly to the MSP430G2553 from the fan. Hence, the IRL520 would be connected between the MSP430G2553 and PVA80G12Q Fan, to prevent a direct path of 12 V from the fan to the MSP430G2553. If the MSP430G2553 is subject to having 12 V being supplied to it, the micro-controller would most likely become permanently damaged because of its 3.6 V intake limitation. The IRL520 NMOS is rated at a maximum of 16 V and 9 A (amperes of current), an essential factor as the fan utilized in this system needs a minimum of 0.65 A to function at a maximum duty cycle of 100%. As shown in Figure 6, the IRL520 NMOS contains three terminals, these are represented as gate, drain and source (from left to right). To optimize the performance of the IRL520, the PWM signal will be transmitted from the MSP430G2553 to the gate terminal of the IRL520 NMOS, while the drain terminal connects to the ground terminal of the PVA80G12Q Fan and the source terminal connects strictly to ground.

(a) IRL520 (b) N-Channel

Figure 6: The IRL520 N-Channel Power Mosfet

3.6 Device/IC 4

The 12V, 0.65 A DC (Direct Current) PVA080G12Q Fan (Figure 7), salvaged from an ancient computer, would be utilized primarily to monitor the temperature of the 5 V Voltage Regulator and prevent it from reaching a state of overheating, as a result of 12 V being supplied to the regulator. When the user enters a desired temperature value for the Voltage Regulator via Realterm, the PWM of the PVA080G12Q will change to reach the desired temperature value for the regulator. Although there is no official datasheet for the PVA080G12Q, it consisted of two pins (colored as red and black) used strictly for a power source and ground respectively. The power source pin of the fan would be connected to a power supply providing 12 V and 0.65 A to turn the fan on completely. Since the fan would not be able to remain stationary when powered on at a 100% duty cycle or maximum speed, the PVA080G12Q would be taped to prevent it from moving erratically during testing.

Figure 7: The PVA080G12Q Fan

3.7 Device/IC 5

The LM340T57805 (Figure 8) is the linear, 5 V Voltage Regulator utilized for the system. In order for every component to perform their desired task, 12 V would be supplied to the LM340T57805 to increase the probability of having it overheat, as it is rated at only 5 V, and the need for the PVA080G12Q Fan to cool it down, to prevent the regulator from officially overheating. The Voltage Regulator would also be supplied with a heat sink to effectively control and cool the temperature of it.

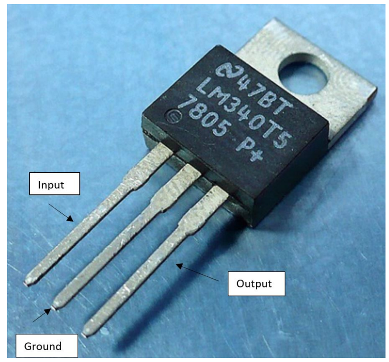


Figure 8: The LM340T57805 Voltage Regulator

4 SYSTEM DESIGN THEORY

4.1 Design Requirement 1

In order to have a system capable of controlling and monitoring the temperature of the voltage regulator at any instant, it is essential to understand how to achieve it. Therefore, the first design requirement for this system is being able to accurately and precisely capture the temperature of the voltage regulator. In order to achieve this simple task, a PTAT needs to be incorporated to correctly read the temperature of the voltage regulator. To maximize the accuracy of the temperature being read, the PTAT and voltage regulator in the circuitry would need be close enough to the point where both components are physically touching throughout the entire duration of testing. The PTAT does serve to be useful as it has a linear relationship between the voltage it is outputting and the temperature it is reading. To specify, the TMP36GZ, the specific PTAT chosen for this sytem is rated to output at 10 mV/°C and has an offset of 0.5 V at 0 °C. In other words, the PTAT will output at an incremental rate of 10 mV for every 1 °C increase from the voltage regulator. Using a digital multi-meter, the output voltage across the PTAT would be measured to determine the current temperature of the voltage regulator. The Vout (output voltage) pin of the TMP36GZ (Refer to Design Resources for more information) would be connected to Pin 1.3 on the MSP430G2553 to be read and converted to a digital value. Pin 1.3 would be utilized specifically for the MSP430G2553 because it is the only input pin to enable accessibility to the ADC (Analog to Digital) features of the micro-controller. After running the code to test the functionality of the ADC, the program would be built to store the converted digital value of the PTAT output voltage into ADC register ADC10MEM (ADC memory). Once the digital value would accurately be obtained, through numerous trials of experimentation, a conversion factor would be derived to determine an accurate value for the temperature of the voltage regulator in Celsius. When testing the functionality of the ADC features on the MSP430G2553, it was learned that at 3.3 V, the converted digital stored in ADC10MEM would be equivalent to 1024 bits, the maximum digital value that could possibly be obtained.Once this was learned, the output voltage of the PTAT would able to be accurately converted into a digital value, followed by being converted to a temperature value in Celsius, to determine the current temperature of the regulator.

4.2 Design Requirement 2

The second key design requirement for this system is enabling the MSP430G2553 to monitor the speed of the cooling fan. To allow the micro-controller to change the speed of the fan, the on-board Hardware PWM functionality on the MSP430G2553 has to be enabled. To achieve this, the on-board TXD and RXD jumpers are required to be extracted from its default vertical position and be reconnected at its initial on-board position, but horizontally, as shown in Figure 9. Once this step is complete, code (implemented in C) would be written to alternate the duty cycle (speed) the fan is being powered on at, and will be programmed to the MSP430G2553 micro-controller. To specify on the code written to change the duty cycle of the fan, the TA0CCR0 (Timer A Capture/Compare Register 0) on the MSP430G2553 would be instantiated to count up to a maximum numerical value of 1024. Once the TA0CCR0 reaches this max value, an interrupt would be engaged to change the output mode of the timer to a set/reset state to utilize the PWM signal. An additional follow-up interrupt for the timer would be engaged when the user enters a value for their desired temperature value via Realterm. Depending on the value the user inputted for their desired temperature, the interrupt will manage the duty cycle of the fan at a rate that will allow the desired temperature value to be achieved for the regulator. Pin 2.1 on the MSP430G2553 would be utilized as the output pin to transmit PWM signals. Although a PWM signal would need to be transmitted from the MSP430G2553 to the fan to control its duty cycle, another issue occurred determining the best method for sending PWM signals from the MSP430G2553 to the 12 V fan without becoming subject to 12 V, as it will serve to permanently damage the micro-controller. To resolve this issue, an IRL520 NMOS would be utilized to act as a buffer between the micro-controller and 12 V fan. The IRL520 NMOS would be primarily responsible for isolating the MSP430G2553 and the 12 V fan to allow both of these components to perform their job at an efficient manner, as well as negating the probability of damaging the micro-controller from a voltage supply of 12 V. From a circuity point of view, it is essential to understand how to properly interface the IRL520 NMOS in this design with the MSP430G2553 and fan. After reading the datasheet for the IRL520 NMOS (Refer to Design Resources for more information), it was learned this MOSFET contained three pins resembling gate, drain and source (front view of MOSFET from left to right). To optimize the performance of the IRL520 NMOS, the drain terminal would connect to the ground pin of the fan, the source terminal would connect directly to ground, and Pin 2.1 would connect to the gate terminal to allow the MSP430G2553 to safely and effectively transmit PWM signals to the fan to alternate its duty cycle with respect to the desired temperature value entered by the user.

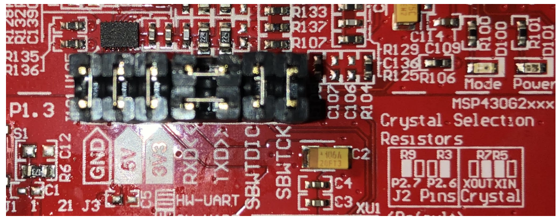


Figure 9: TXD and RXD Jumper Placement on Micro-Controller

4.3 Design Requirement 3

The third key design requirement for this system is UART communication, to enable the user to communicate with the system by entering a desired temperature value of their choice via Realterm. The value entered by the user is the desired temperature they choose to set the voltage regulator at. Once the user has entered a value for desired temperature. The MSP430G2553 micro-controller would be utilized to incorporate its UART functionality and Realterm would be accessed to transmit data from the system involving the temperature value of the voltage regulator. To enable the UART functionality of the MSP430G2553, a UART function would be instantiated and in code to achieve this. For the purposes of having the MSP430G2553 be able to communicate properly and function alongside Realterm, the baud rate is required to be set to 9600 (9.6 kHz). When writing the code, an interrupt would also be implemented to occur when the user enters a value for desired temperature value on Realterm.

4.4 Design Requirement 4

The fourth and final key design requirement for this system is properly changing and managing the temperature of the voltage regulator accordingly with the user's request. To incorporate this correctly, all the previous key design requirements would need to be utilized. To begin, the code written to optimize the performance of the system will be programmed on to the MSP430G2553 micro-controller. The user is then able to access Realterm and enter a value for the desired temperature of their choice to set the voltage regulator at. Once a value has been inputted on Realterm and transmitted to the micro-controller, the MSP430G2553 would then adjust the duty cycle of the fan at a certain rate to obtain the desired temperature value of the regulator, as it is programmed to. Once the desired temperature of the voltage regulator has been met, it will maintain the regulator at this specific temperature until the user enters a new temperature value on Realterm for the regulator to be set at. In order for the regulator to be set to specific temperatures as a result of the duty cycle the fan is running at, several trials of experimentation would be conducted to determine the resulting temperatures of the voltage regulator at varying duty cycles. Once consistent values were obtained over several trials, representing the change in temperature ranges for the regulator at varying duty cycles, the code written for the system would be changed accordingly to instruct the MSP430G2553 to adjust the duty cycle based on the temperature range the desired temperature value entered by the user is in.

4.5 PI Control

A crude PI (Proportional Integral) Controller was utilized to manage the temperature of the voltage regulator. The PI Control was incorporated such that the duty cycle of the fan would change subject to the numerical difference between the current temperature and desired temperature. The duty cycle would become larger as a result of the difference between the current and desired temperature becoming much larger and vice versa. To specify, if the difference between the current and desired temperature values is less than 0, a 20 % duty cycle would result. If the difference is greater than 3, a maximum duty cycle of 100 % would result. If the difference is greater than 1, a duty cycle of 80 % would result. If the current temperature and desired temperature were equivalent, the duty cycle would result to 60 %.

Temperature Difference	Duty Cycle
>3	100%
>1	80%
= 0	60%
<0	20%

5 Getting Started/How to use the device

- Connect MSP430G2553 to Computer
- Set up Realterm on Computer
- Enter value for desired temperature (in °C) via Realterm
- Watch the fan operate at specific duty cycle to cool the voltage regulator to the desired temperature entered by the user

6 Getting Started Software/Firmware

6.1 Hierarchy Chart

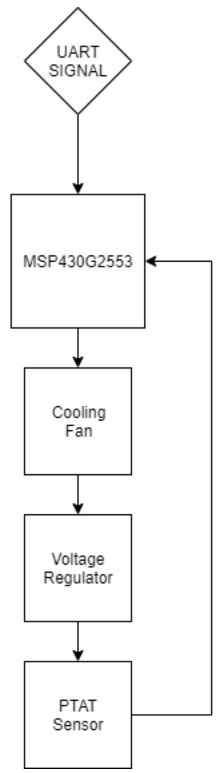


Figure 10: Hierarchy Chart Showing Flow of Communication Between Devices

6.2 Communicating with the Device

Communicating with the first device, MSP430G2553, is accomplished by using a UART software program on your PC, Realterm. Setting up Realterm to function properly with the MSP430G2553 is relatively simple. First, open up Realterm on your PC followed by selecting ”Hex[space]” under the Display tab, then check the ”Half Duplex” box. Next, click the Port tab and select 9600 for the baud rate, as the MSP430G2553 operates at this specific baud rate. Once this is complete, you will then be prompted to choose the correct device port connect from the PC to the MSP430G2553 in order for Realterm to be compatible and function accordingly with it. Lastly, click the send tab to transmit a value for the desired temperature you like the voltage regulator to be set at, in Celsius, over to the MSP430G2553 micro-controller. The desired temperature value the user is inputting on Realterm must be expressed in hexadecimal.

7 Test Setup

In order to properly recreate and test this system, these following steps must be completed in order to set up the circuit:

- Connect the Voltage Regulator
  - Using Figure 8 as a reference, the voltage regulator contains 3 pins. Beginning with the input voltage pin, this will connect directly to the 12 V supply. The following pin is used for grounding purposes only. The final pin is represented as the output voltage pin and is connected to the voltage input pin of the PTAT.
  - A heat sink can also be added to the voltage regulator at this point
- Connect the PTAT
  - The PTAT is the temperature sensor. This component must be touching the voltage regulator or its heat sink in order to have an accurate reading.
  - Using Figure 5b as reference, pin 1 of the PTAT connects to the 5 V output pin from voltage regulator.
  - Connect pin 3 to ground
  - Connect pin 2 to P1.3 of the micro-controller
- Connect the Power Resistor
  - The power resistor will be connected to the ground pin of the voltage regulator and to ground.
- Connect MOSFET
  - Using Figure 6a as reference, the gate pin of the MOSFET must connect to P2.1 of the micro-controller, the source pin connected to ground and drain pin left unconnected.
- Connect Fan
  - Connect the red wire to the 12 V power source and the black wire to the ground.
  - Make sure to also direct the fan close to the 5V voltage regulator while placed securely in a stationary position so as to be able to effectively cool the fan.
- Set up and connect the MSP430G2553
  - In order to use the MSP430G2553 UART features, make sure the RXD and TXD jumpers are connected horizontally.
  - Connect the ground pin of the MSP430G2553 to ground of the breadboard. The ground pins of all the components should be connected to the same ground line.

– Connect the MSP430G2553 micro-controller to a laptop with the code for the system. Communicate with the micro-controller to setup the temperature you desire. (See 6.2 in Getting Started Software/Firmware)

8 Design Files

8.1 Schematics

Figure 11: Complete Circuit Diagram of System

8.2 Bill of Materials

Item #	Description	Quantity
1	MSP430G2553 Micro-Controller	1
2	PVA080G12Q 12 V Fan	1
3	LM340T5 7805 Voltage Regulator	1
4	TMP36GZ PTAT	1
5	IRL520 NMOS Transistor	1
6	$8\,\Omega$ 50 W Power Resistor	1
7	Heatsink	2