Milestone 2- Closed Loop Systems

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1 Design Overview

A closed loop system involves using the feedback of a system to control it. In this closed loop system design, the MSP430G2553 is used as a temperature controlling device. Using a voltage regulator to heat up a proportional to absolute temperature (PTAT) device and a fan to cool it down, the MSP430G2553 code uses pulse width modulation control and analog to digital conversion to achieve desired temperatures. The main goal of this design is to achieve a steady state temperature within 3°C/1.5°C of the desired temperature.

1.1 Design Features

This design features many key embedded system elements such as:

- Temperature control to specific temperatures
- Specification of temperatures communicated to micro-controller through UART
- Analog to digital converter for turning analog temperature values into digital values that can be read by the micro-controller
- Control over the speed of the fan using pulse width modulation

1.2 Featured Applications

This design can be used for heating and cooling regulation. Some of these applications are:

- Room/house temperature control
- Hardware cooling (laptops, phones, PC)

- Thermostat
- Household items (Refrigerator, stove)

1.3 Design Resources

The code for this project can be found in the following GitHub Repository:
https://github.com/Intro-To-Embedded-Systems-RU09342/milestone-2-alpha-team

1.4 Block Diagram

The figure below shows a simple diagram of this closed loop system, highlighting how each of the devices used connect to each other and transfer data.

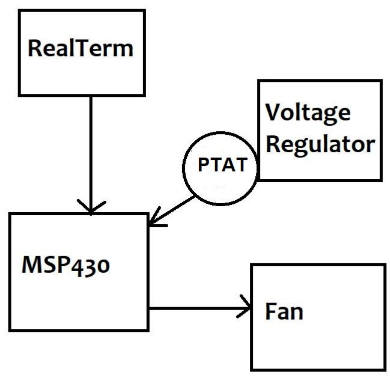

Figure 1: System Block Diagram

1.5 Board Image

The images below show how the system was set up and tested in practice.

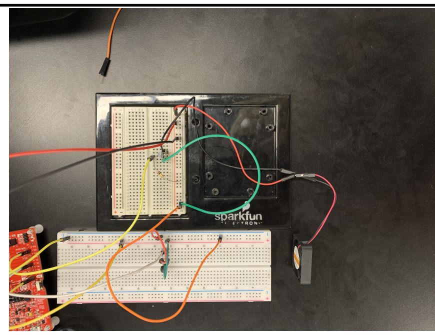

Figure 2: Board Image

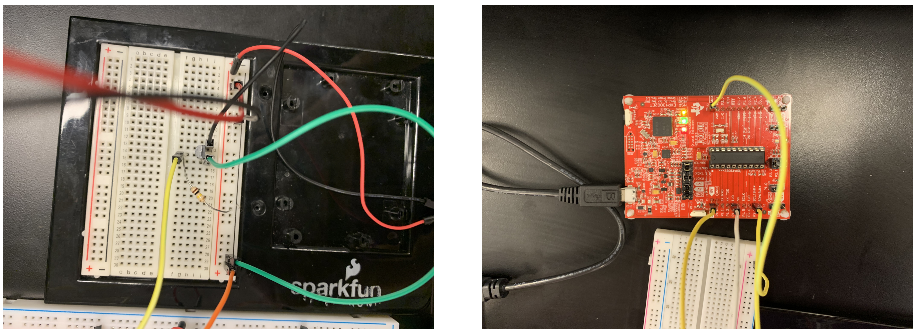

Figure 3: Low Side Switch and G2 Close Up

2 Key System Specifications

In this section, the voltage parameters of each of the devices used in this design are specified. As seen in the table below, both the MSP430 and the Fan are powered off of 5V. The voltage regulator takes in 12V and regulates it to 5V. The PTAT can be powered between 2.7V and 5V. The temperature limits for the PTAT are also stated, as well as the temperature range for testing this closed loop system.

PARAMETER	SPECIFICATIONS	DETAILS
MSP430 Voltage	5V	
Fan Voltage	5V	
Regulator Voltage	12V to 5V	Takes 12V input and dissipates 7V as heat
PTAT Voltgae	2.7V-5V	Can be powered anywhere within this voltage range
PTAT Temp Range	-40°C - 150°C	Temperatures that the PTAT can detect
Temperature Limits	15°C- 100°C	Range of temperatures for this system

3 System Description

This closed loop system is a simple way to read and control temperature using a few easy to work with devices. The design has four main components; the heating system, cooling system, temperature read, and temperature value communication. First, a desired temperature is set using UART communication in hexadecimal values. This is communicated to the micro-controller, which then activates the heating and cooling systems to reach the desired temperature.

The heating system consists of a 5V voltage regulator, which takes in 12V and decreases it to 5V, dissipating the rest of the voltage as heat. This dissipated voltage heats up the attached PTAT temperature sensor. The PTAT then communicates this temperature value to the micro-controller using an analog to digital converter. The MSP430 micro-controller takes this temperature and decides if it is close to the specified value.

If the temperature is hotter than the desired value, a small fan will be activated, which is the cooling system. The fan's speed is controlled using a pulse width modulation system, which cools off the PTAT until the desired temperature is reached.

3.1 Detailed Block Diagram

The following figure shows a detailed version of the block diagram above, highlighting the specific connections as well as micro-controller pins and power sources.

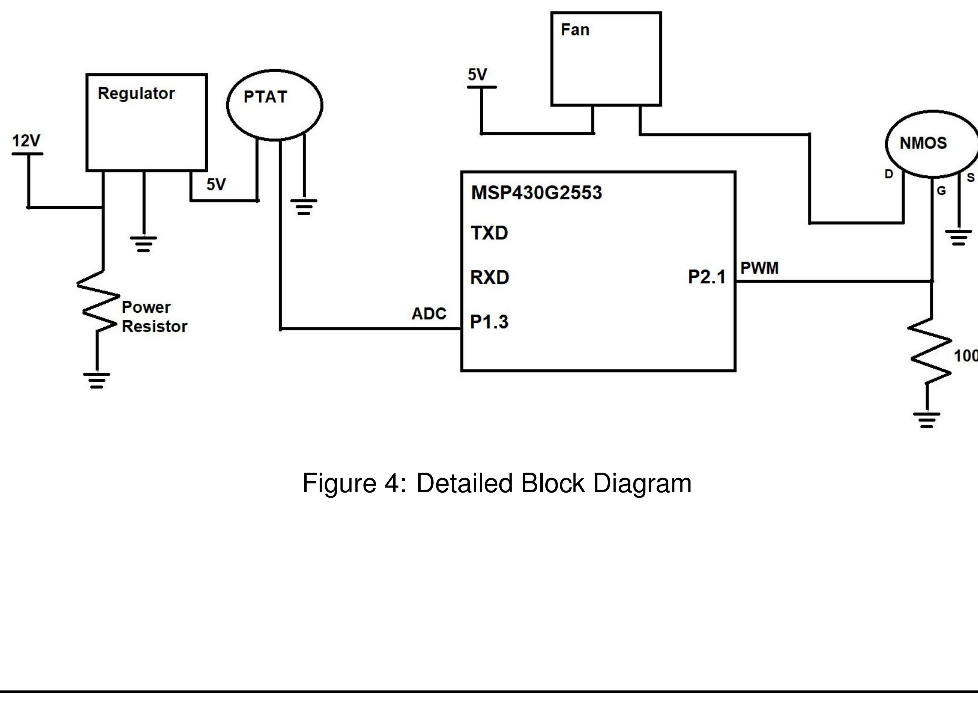

Figure 4: Detailed Block Diagram

3.2 Highlighted Devices

- MSP430G2553: This is the micro-controller that is the heart of this closed loop system. It runs the code needed for the system to work successfully.
- PTAT: This is a temperature sensing device that is reading temperature values and sending them to the micro-controller.
- Voltage regulator: This is the device that is used to heat the PTAT to its desired temperature.
- Fan Model EDL3007S05: This fan is used to cool the PTAT to its desired temperature.

3.3 MSP430G2553

The MSP430G2553 was chosen for this project due to its easily compatible systems and easy to work with design, which includes multiple 16-bit timers, 24 accessible pins, ultra-low power, and UART communication capability. This device used C code to control the speed of the fan, the reading of temperature, and the communication through UART. For the speed of the fan, Timer A1 on the G2 board was utilized, as well as its capture and compare registers, to specify the speed of the fan at different times. The on board analog to digital converter was utilized, and set up to take the temperature readings from the PTAT. This board also has built in UART communication capability, which was the method used to communicate with the system.

3.4 PTAT and Voltage Regulator

The PTAT is set up so that it is directly attached to the voltage regulator. The voltage regulator circuit requires a power resistor to be set up in order to speed up the heating process. In this process, the regulator takes in a 12V input and regulates it to 5V. Since the PTAT is attached, the heat that is dissipated from the regulation process heats it up. This temperature is then read by the micro-controller. The pinout for the PTAT and the Voltage regulator can be seen in Figures 5 and 6.

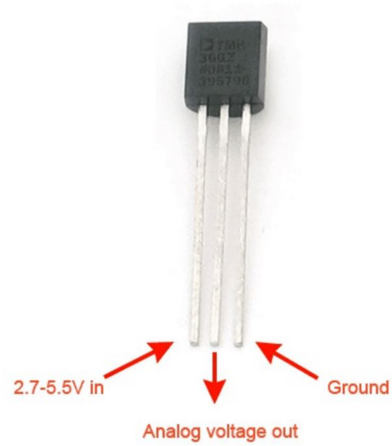

Figure 5: PTAT Pin Functionality

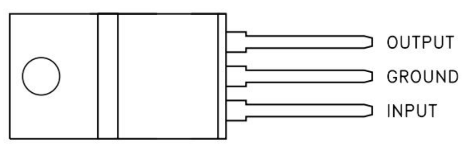

Figure 6: Voltage Regulator Pin Functionality

3.5 Fan

The fan used is powered off of 5V, and requires a convert-o-box in order to regulate its current and voltage levels. More details on this convert-o-box are discussed in the design requirements section. This fan was chosen due to its small size, its low cost, and simplicity of setup. The fan pins can be seen in Figure 7 below.

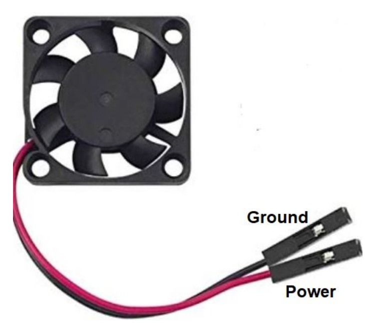

Figure 7: Fan Pin Functionality

4 SYSTEM DESIGN THEORY

This system contains two major design pieces. These are the driving code using the MSP430G2553 board, and the supporting hardware circuit. The code needs to be able to allow UART communication, control the speed of the fan using PWM, and convert analog temperature values into digital, readable values. The supporting circuit needs to be able to provide power to the hardware safely, as well as work properly in order to control the temperature. The following sections explain in detail the theory and functionality of each component of this closed loop system.

4.1 Pin Setup

The output pins on the micro-controller exist to communicate with the off board circuits. The code is set up so that each of the functionalities can be outputted to its respective circuit. The code consists of three main parts; the UART communication, the Analog to Digital Converter, and the Pulse Width Modulation system. The UART communication can be done through USB, so it does not require anything to output or input to the transmit and receive pins. The ADC is sent to pin P1.3, so the PTAT's analog pin is directly connected to this ADC pin. The PWM is sent to pin P2.1, which then connects to the fan in order to change its speed.

Each of the pins on the G2 board come with preset functionalities. Many pins correspond to different timers, some are connected to clocks, and some are able to work with multiple different types of outputs. Pin P1.3 is preset to the on board analog to digital converter, which is why it was used for that purpose. The PWM system utilized Timer A1's capture and compare register 1, so pin P2.1 was used. The figure below shows each of the pins that were utilized in this system.

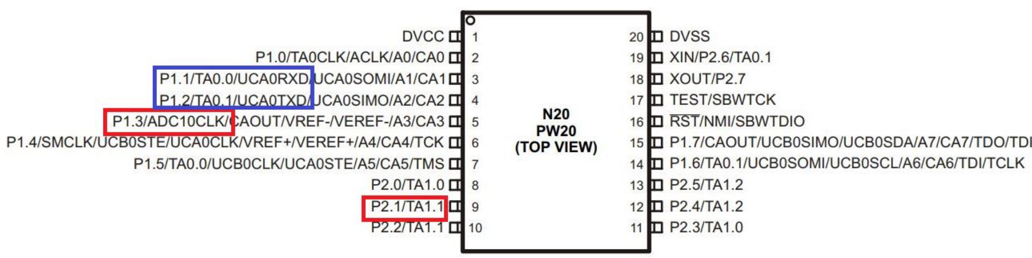

Figure 8: MSP430G2553 Pins Utilized in this Design

4.2 Analog to Digital Converter

The analog to digital converter is coded into the MSP430 board using the built in ADC parameters. The ADC is first set up using Channel 3. It is then set to sample and hold for 64 clock cycles, and the interrupt is enabled. This means that the ADC will take in a new temperature value every 64 clock cycles.

4.3 Pulse Width Modulation System

The Pulse Width Modulation system exists to control the spinning speed of the fan using its duty cycle. The lower the fan's duty cycle, the slower it will spin. Once the temperature is received by the ADC, the PWM function uses this temperature to determine how much hotter the PTAT is than the desired temperature. Using this information, the fan switches on at a speed that will modify the temperature to get as close as possible to the value specified through UART. This function then continues to read the temperature values and adjust the duty cycle as needed. Figure 9 shows the duty cycle and how it works with the fan.

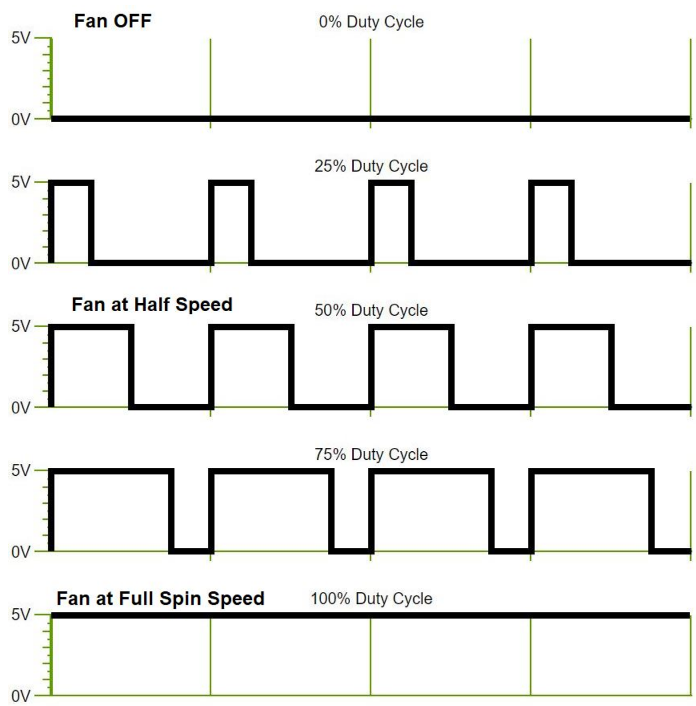

Figure 9: Fan Duty Cycle

The code utilizes Timer A1's capture and compare register 1, which is connected to P2.1 on the G2 board. The PWM portion of the code takes in the desired temperature and the temperature received from the ADC and initializes an if statement. The if statement says, if the temperature received is greater than the desired temperature, set the value of TA1CCR1 (Timer A1 capture and compare register 1) to slightly less than 100% duty cycle. If the temperature received is less than or equal to the desired temperature, the TA1CCR1 value is set to zero. It then continues to do this until the desired temperature is reached. The on board LEDs are also utilized in the code. The red LED located at P1.6 is directly connected to the PWM, and blinks every time the duty cycle changes.

4.4 UART Communication

The G2 micro-controller comes with Universal Asynchronous Receiver/Transmitter (UART) communication capability. Using a software called RealTerm, temperature values are able to be sent to the board from a laptop or PC device. The board will receive and process these values and decide what needs to happen.

The UART communication is set up using P1.1 as the receiving output and P1.2 as the transmitting output. The baudrate is then set to 9600, which means it is capable of transmitting 9600 bits per second. Temperature values are sent through UART using hexadecimal byte format.

4.5 Fan Convert-o-Box: Low Side Switch

In order for the fan to be controlled safely and properly, a low side switch is put into place. A low side switch is a device that regulates the current by using a MOSFET as a switch. The low side switch is constructed using an NPN MOSFET, with the source to ground, drain to load, and gate to supply. The MOSFET used was a 2N7000, with the pinouts shown in Figure 10.

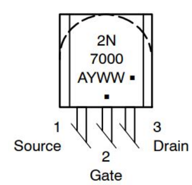

Figure 10: MOSFET Pin Functionality

The low side switch is constructed by grounding the source pin, then attaching the gate pin to the PWM pin of the MSP430 board. The drain is then connected to the ground pin of the fan. The power pin of the fan is connected to 5V power on the breadboard. The low side switch setup is shown in Figure 11.

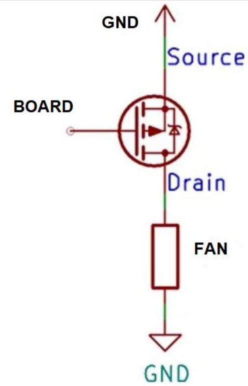

Figure 11: Low Side Switch Setup

4.6 Voltage Regulator Circuit

Besides the Low Side Switch, a simple circuit needs to be built for the voltage regulator. For the voltage regulator, there needed to be a 12V power rail as well as a 5V power rail to connect to the voltage regulator pins. A power resistor needed to be added in order to control the dissipation across the regulator.

The PTAT was put up against the regulator, with the analog voltage pin connected to the analog to digital converter pin on the MSP430, the input pin connected to the 5V output pin of the regulator, and the final pin connected to ground. With this configuration, the voltage that is dissipated will heat up the PTAT, sending the temperature values back to the board.

5 Getting Started- Hardware Setup

The device can be set up by constructing the circuits for the voltage regulator and fan on a breadboard or a printed circuit board. The board needs to have two power rails, one for 12V supply, and one for 5V supply, with a common ground between the two. If using multiple breadboards, they also must be connected together through a common ground. The voltage regulator and PTAT circuit is shown below. In the Figure 12, the resistor represents a power resistor, which allows for the device to dissipate power more quickly. The regulator is powered at 12V and 5V, and connected to the PTAT through its output, which is 5V.

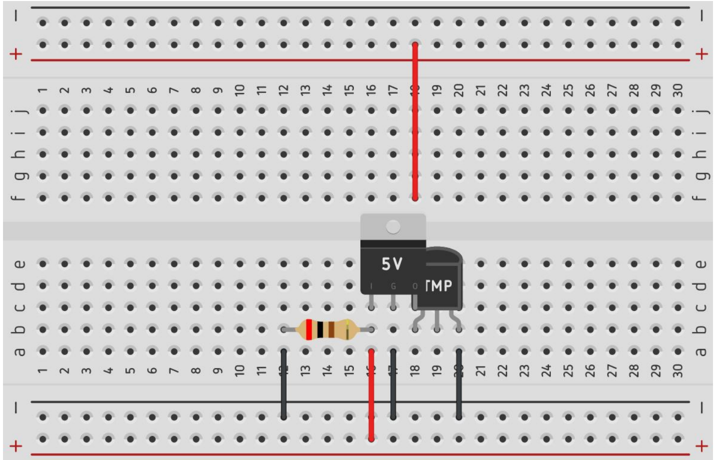

Figure 12: Voltage Regulator Breadboard Circuit

The next circuit is the low side switch circuit, which will connect to the fan. It connects the source to ground, and the gate will go to the PWM output of the board. The drain will be connected to the fan. This is shown in Figure 13.

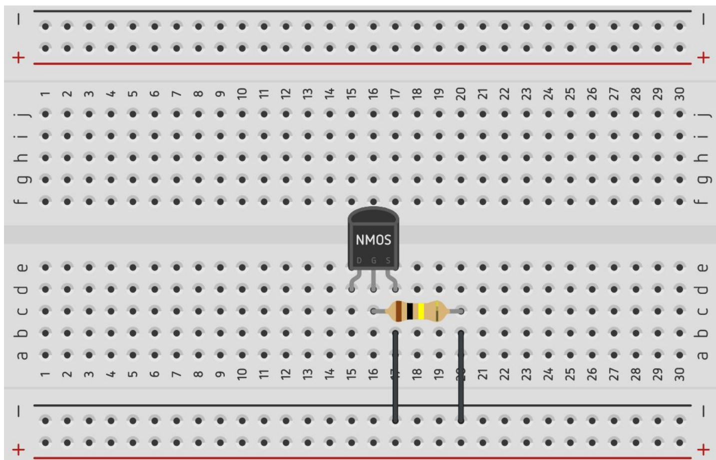

Figure 13: Low Side Switch Breadboard Circuit

6 Getting Started- Software Setup

The two softwares used for this design are Code Composer studio and RealTerm. Code Composer can be downloaded and opened on a laptop or PC, with the code for this project open. Selecting the "flash" option with the MSP430 plugged in will flash the code onto the micro-controller. Flashing the code allows for it to work without being directly run from Code Composer. Once this is done, it is ready for use.

The other main software needed is RealTerm, which is used to send the data through UART. Once RealTerm is downloaded and opened and the board is flashed, the device is ready for data to be sent. The specifics for setting up RealTerm are discussed in the following section.

7 Test Setup

After the circuits are built and the software is downloaded, everything needs to be connected together. A jumper wire is run from the voltage regulator circuit's Vout to the ADC pin out, pin P1.3. The ground of the NPN MOSFET and the power rail of the breadboard are connected to the ground and Vin wires of the fan. Then the fan is connected to the board by running a jumper wire to pin P2.1. The common grounds are connected between the breadboard and the micro-controller. The breadboard is given power from a power supply, and then the device is ready to use. Figure 14 below details these connections.

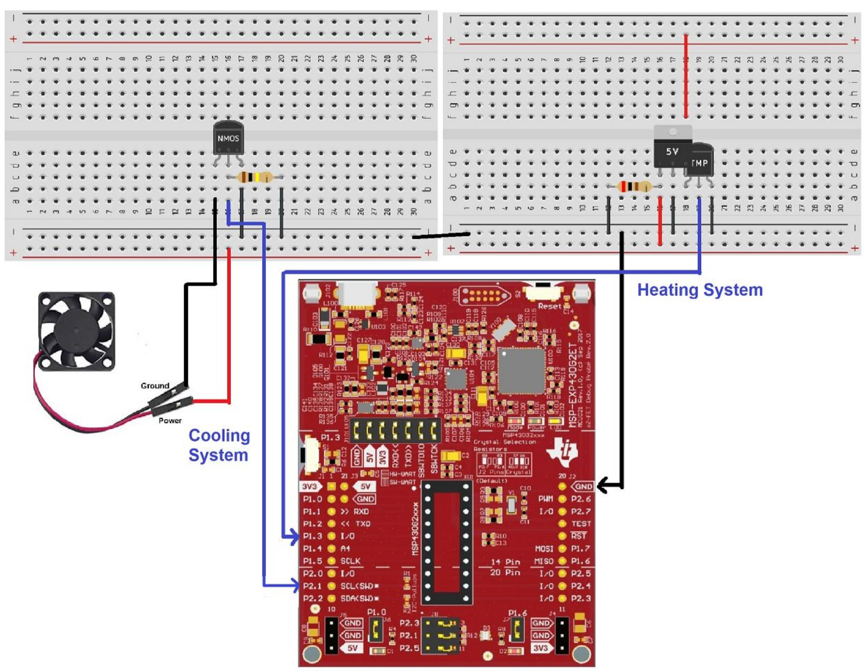

Figure 14: Connections Between Breadboard Circuits and MSP430 Micro Controller

The next step is to open RealTerm and set up the proper ports. the default tab upon opening RealTerm is the display tab. In this tab, the Display As section should have Hex [space] selected, and Half-Duplex checked to the right of it. Pressing the Change button will save these settings. Figure 15 shows the display tab with its correct settings.

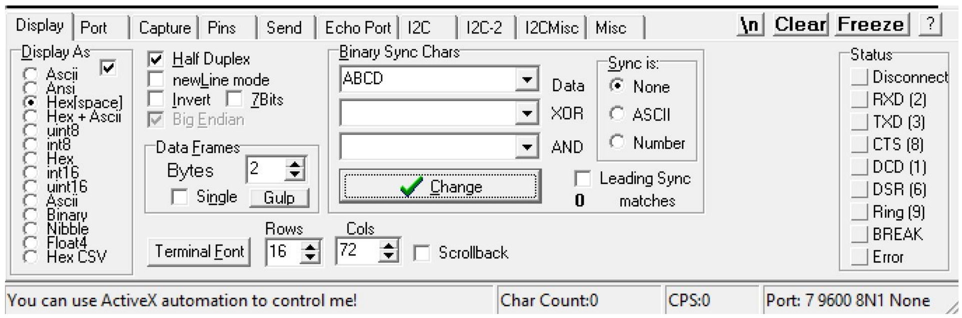

Figure 15: Real Term Display Tab Setup

In the Port tab, the correct COM port must be selected. To find the COM port for UART, navigate to Device Manager and expand under the Ports tab. The correct COM port will say UART next to it. Then, the baudrate should be set to 9600. Pushing the change button will save these settings. Figure 16 shows the port tab.

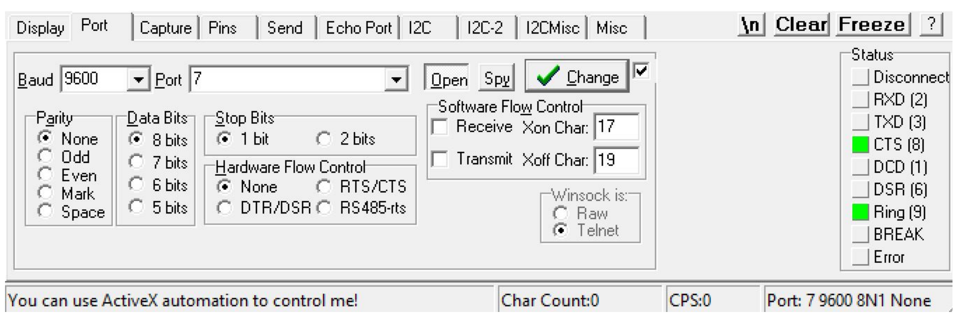

Figure 16: Real Term Port Tab Setup

After the RealTerm setup is complete, data can be sent through its Send tab in hexadecimal format.

7.1 Test Data

In practice, the values of the desired temperature were sent through UART in RealTerm's send tab. The values were sent in hexadecimal, which converted to Celsius values and set the desired temperature to that hexadecimal value. The circuits were built as shown in section 5 and connected to the board as shown in section 7. In order for the PTAT to cool off as much as possible, two fans were connected instead of one. The fans were not very powerful, which made it difficult to keep the temperature low. Figure 17 shows the data that was sent through UART from RealTerm. This figure shows the desired temperature in green, which is the user input, and the UART returned the current temperature in yellow. The voltage regulator was powered at 12V. In one test, the temperature was set to an extremely low value to find the lowest possible temperature the device can reach when the voltage regulator is on. This was found to be 2E (46°C), which was determined to be the oscillation point of the device. This means that setting the desired temperature to 2E will turn the fan on and off repeatedly. When the voltage regulator power was lowered from 12V to 8V, the temperature was able to reach as low as 23 (35°C).

When the voltage regulator was powered at 12V, the device could reach extremely high temperatures of 3B (59°C). Lowering the voltage to 8V caused the highest possible temperature to decrease to 35 (53°C).

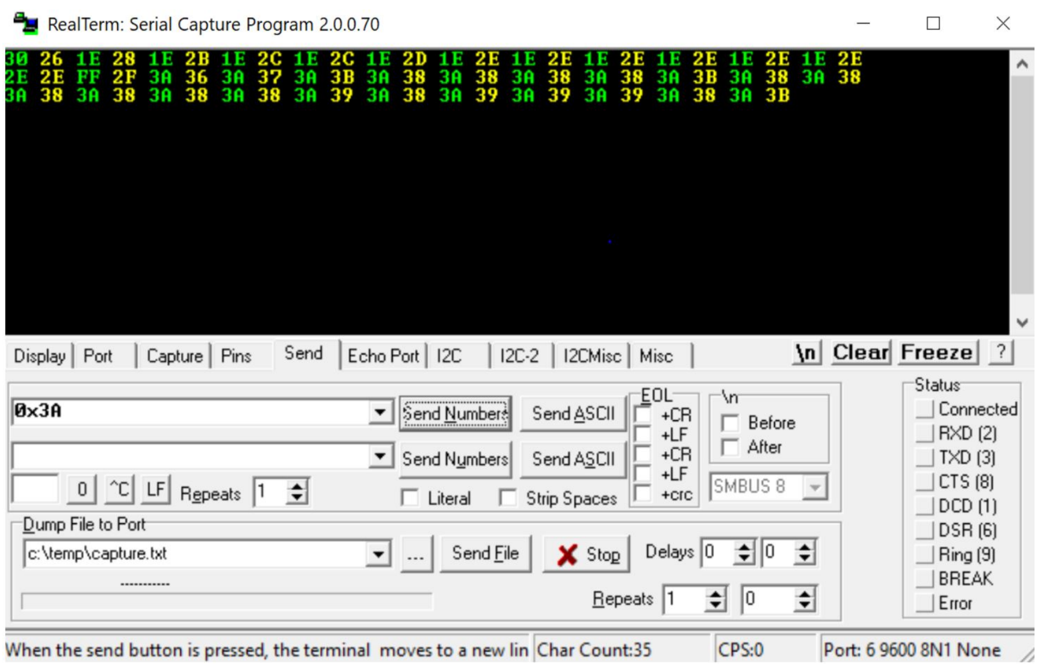

Figure 17: Test Data from RealTerm

7.2 Bill of Materials

- MSP430G2553 microcontroller
- EasyCargo Pi-Fan Model: EDL3007S05

- TMP36 Proportional to Absolute Temperature device
- 100kΩ resistor
- NPN MOSFET
- Power resistor
- 5V Voltage regulator
- various jumper wires and connecting wires
- Power supply
- Breadboard

7.3 Data Sheets

- MOSFET: https://www.onsemi.com/pub/Collateral/2N7000-D.PDF
- Fan: https://www.amazon.com/Easycargo-Raspberry-30x30x7mm-Brushless-30mmx30mmx7m
- PTAT: http://www.ti.com/lit/ds/symlink/lm35.pdf
- Voltage Regulator: https://datasheet.octopart.com/L7805CV-STMicroelectronics-datasheet-7264666.pdf
- Thermistor: https://www.vishay.com/docs/29049/ntcle100.pdf