Milestone 2: Temperature Regulator

Jordan Alberico & Tim Duong
Rowan University

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1 Design Overview

The goal of the lab is to create a closed loop system. The system involves a thermistor which changes resistance based on the temperature. The thermistor is constantly being heated by a voltage regulator. Using an analog to digital converter on a msp430, the voltage drop across the thermistor is converted to a digital signal. Based on this digital signal and the set point temperature, the microprocessor will determine to increase or decrease the PWM of a fan using modified bang-bang. This system contantly receives feedback from the thermistor to determine a course of action endlessly.

1.1 Design Features

Design features:

- Microprocessor: MSP430F5529
- Voltage Regulator
- Thermistor Voltage Divider Circuit
- Fan with low-side switch

1.2 Featured Applications

- UART Temperature Readings over RealTerm
- MSP430F5529 setting the set point temperature

1.3 Design Resources

Datasheets:

- Thermistor: `http://www.vishay.com/docs/29049/ntcle100.pdf`
- MOSFET: `https://www.onsemi.com/pub/Collateral/2N7000-D.PDF`
- Diode: `https://www.diodes.com/assets/Datasheets/ds23001.pdf`
- Voltage Regulator: `https://www.mouser.com/datasheet/2/389/l78-974043.pdf`

Github URL: `https://bit.ly/2DKAtqQ`

1.4 Block Diagram

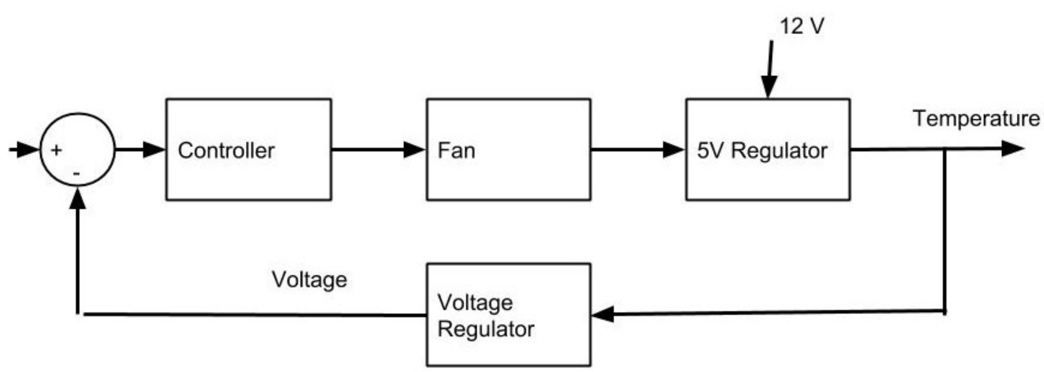
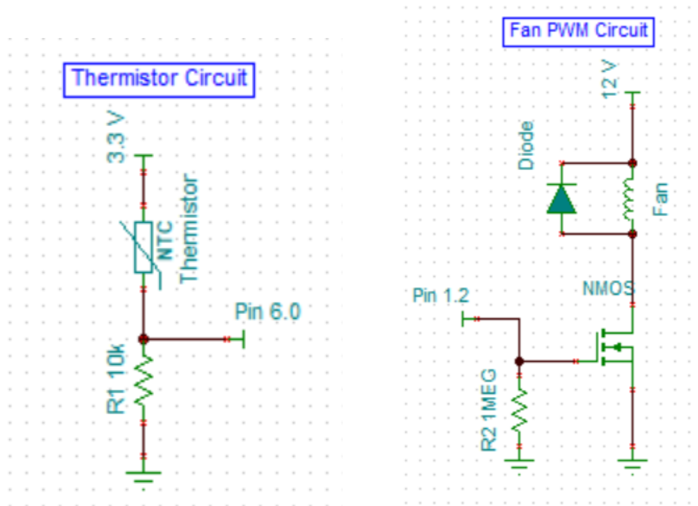


Figure 1: Temperature Control Block Diagram

1.5 Board Schematic

2 Key System Specifications

The main specifications the system is capable of performing can be found in the table below. To add more detail to the chart, the BAUD rate is determined by modulation and divisions. This is used to determine the rate of bits the processor can handle in a second. The ADC12 converts analog to digital by using a 3.3 reference voltage. This is used to calculate the temperature of the thermistor. The PWM is controlled by the timer peripheral and is used to control the fan.



(a) Thermistor Circuit (b) Fan PWM Circuit

Figure 2: Thermistor and Fan PWM Circuits

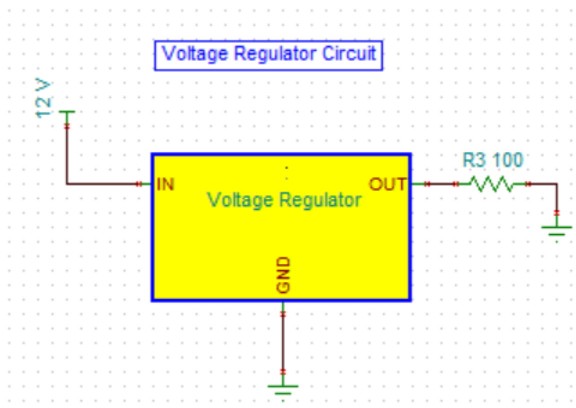


Figure 3: Voltage Regulator Circuit

3 System Description

The objective of this project was to create a temperature regulating system. A voltage regulator will be operated to act as the device that needs temperature regulation. As the regulator heats up, a thermistor will monitor the temperature. When the regulator gets too hot, the fan circuit will activate cooling down the regulator. The fan is operated through a PWM circuit to control the speed of the fan. The control system for the fan will be modified bang bang control to prevent oscillation of the regulator's

PARAMETER	SPECIFICATIONS	DETAILS
BAUD Rate	9600	Use USB to interface. Determines Bit rate
ADC12	12-bit ADC	Use P6.0 3.3V reference Used to determine temp.
PWM	Reset/Set	Use P1.2 to control Fan PWM.
UART	P4.4 is Transmit P4.5 is Receive	Used to display calculated temp.
TimerA	TA0CCR0,TA0CCR1 TA1CCR0	TA0 is used to set PWM TA1 is used for polling rate

temperature.

3.1 Detailed Block Diagram

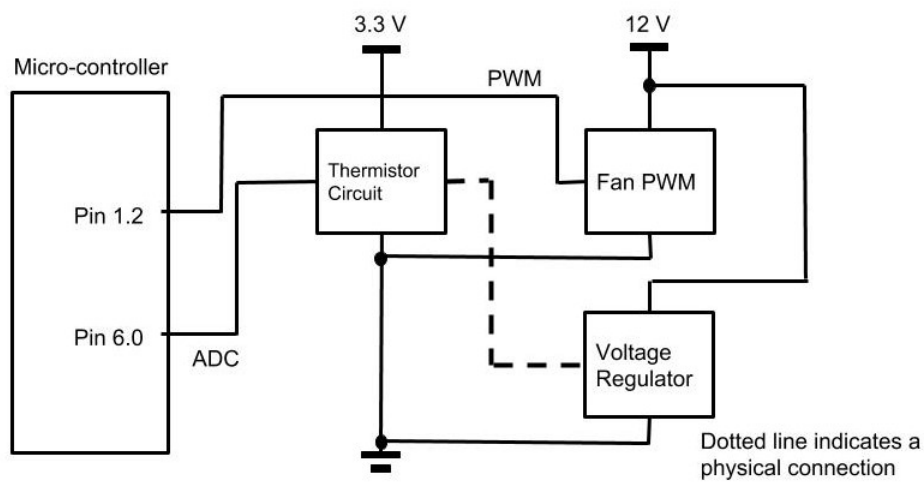


Figure 4: Temperature Control Detailed Block Diagram

3.2 Highlighted Devices

- MSP430F5529LP - Microcontroller responsible for the control system.
- VISHAY NTCLE100E3 Thermistor - Detect temperature of voltage regulator.
- 10,000 ohm Resistor - Thermistor circuit.
- L7809CV Voltage Regulator - To simulate a device that heats up quickly.

- 100 Ohm resistor - Voltage regulator circuit.
- MB AMBEYOND 12V DC Fan - To cool the regulator.
- 2N7000 Small Signal MOSFET - Fan PWM Circuit.
- 1N5817 Diode - Fan PWM Circuit.
- 1 Mega-Ohm Resistor - Fan PWM Circuit.

3.3 Device/IC 1

The chosen microprocessor is the MSP430F5529. There are three peripherals used in the microprocessor: the timer peripheral, the ADC12 peripheral, and UART peripheral. The timer peripheral is used on P1.2 to control the PWM of the fan using output mode 7. The ADC12 peripheral is used on P6.0 to read in the voltage of the thermistor. The microprocessor uses the Steinhart-hart equation with the calculated voltage from P6.0 to find the temperature of the thermistor. The UART peripheral is used to display the calculated temperature from the microprocessor to the computer display using realTerm.

3.4 Device/IC 2

There are three main circuits that make up the temperature control system. The first is the thermistor circuit which is essentially a voltage divider circuit. The voltage across the thermistor changes as the temperature of the thermistor changes. The microprocessor is able to convert this analog voltage signal into a digital signal and calculate the temperature. The second circuit is the voltage regulator circuit. The voltage regulator uses a 12v power supply and eight 8k ohm resisors in parallel to heat up the thermistor. The parallel resistor provides a net resistance of 1k ohm but increases the power to the voltage regulator allowing the temperature to increase faster. The third circuit is the low side switch to power the fan. Because the fan runs on 12V, the microprocessor cannot provide a sufficient voltage and current to run the fan. Therefore, a low-side switch using an NMOS is used to power the fan.

4 SYSTEM DESIGN THEORY

4.1 Temperature Control

The system is responsible for accurately sensing the temperature of the voltage regulator. This is done by using a thermistor. Since the resistance of the thermistor changes with temperature, it is a satisfactory device to use for this purpose. The thermistor is set up in series with a 10,000 ohm resistor therefore creating a voltage divider circuit. Pin 6.0 is configured for ADC and connected to the voltage divider. The ADC used for this system is 12-bit with a sampling timer. This means the resolution for the conversion is 0.806 mV since the thermistor circuit is operating at 3.3 V.

This is used to sample the voltage from the thermistor circuit. The ADC samples the voltage every 1000 cycles of the clock. The program uses equations to calculate the resistance of the thermistor based on the voltage determined by the ADC converter. Since the thermistor used in the circuit has negative temperature coefficient (NTC), the Steinhart Hart equation can be used to determine the temperature the thermistor is measuring. The values of the coefficients of the Steinhart Hart equation are found on the datasheet of the thermistor. Once the temperature is accurately measured, it can be used in the control system to pulse the fan accordingly.

4.2 Fan PWM

The fan PWM system is responsible for cooling down the voltage regulator when the temperature is above the set point. TimerA0 is responsible for the PWM of the fan. The timer is configured with SMClk, in up mode with an outmode of reset/set. This allows for hardware PWM which is more efficient than software PWM. TA0CCR1 is modified by the control system of the timer responsible for sampling the temperature: TimerA1.

4.3 Control System

The control system used to set the PWM is a modified bang bang control. Every 1.5 seconds, TimerA1's interrupt is triggered. TimerA1 is configured as AClk in up mode. Inside the interrupt, If the temperature measured is higher than the set point, the fan's PWM determined by TA0CCR1 is increased by 20%. If the temperature measured is lower than the set point and the fan is on, then the PWM of the fan will decrease by 20%. This system is more efficient than the bang bang control system since the fan can operate at a lower speed. this prevents the temperature of the voltage regulator from oscillating.

5 Getting Started/How to use the device

The first step is to build and flash the code on to a MSP430F5529 microprocessor. Build a voltage divider circuit with a 10k thermistor and a 10k ohm resistor with a voltage of 3.3v. Ensure the 10k thermistor is connected to ground and the 10k ohm resistor is connected to high voltage. Build the low-side switch circuit for the fan using an NMOS. The NMOS source is connected to ground, the drain connected to the negative terminal of the fan, and the gate to P1.2. Ensure there is a large resistor on the gate like 1M ohm to dissipate floating charge. Also ensure there is a feedback diode in parallel with the fan as this protects against high voltage cause by an inductor and switch. Reference figure 2 to see how to design the fan PWM circuit and thermistor circuit. Next, design the voltage regulator circuit according to figure 3, and make sure the voltage regulator and the thermistor make physical contact. Connect P6.0 of the microprocessor to the positive side of the thermistor. Ensure all grounds are shared across the circuits. The system is constructed and should be operational when the power supply is turned on. Note the fan will only turn on if the temperature reading is higher than the set point temperature in the code of the microprocessor.

6 Getting Started Software/Firmware

6.1 Communicating with the Device

The only input from the user to the system is the set point temperature. The user has to open code composer and manually change the set point temperature, build the project, and flash the project on to the microprocessor. The MSP430 does send information out to the user and the system. The user can receive live temperature readings from the MSP430 by opening RealTerm and the right port and setting the BAUD rate to 9600. The readings are sent in 8 bits so the user needs to change the format of the UART to unsigned 8-bit integer in order to get live temperature readings.

6.2 Device Specific Information

7 Test Setup

There are three testing scenarios. The system must operate when the thermistor is heated from room temperature to 65 degrees Celsius. The system must maintain 65 degrees within a bounds of 3 degrees which is about 100 mV on the oscilloscope. The system then needs to cool the thermistor from 65 degrees to 35 degrees within the same bounds. Lastly, the system must maintain a temperature of 45 degrees from 35 degrees. The temperatures can be changed by changing the set point temperature inside the code of the microprocessor.