Ultralow Power Thermostat

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ABSTRACT

This application note describes how to implement an ultralow power battery-based thermostat using the MSP430F41x microcontroller. A thermistor is read using the slope A/D technique. The circuit constantly displays the temperature, on an LCD driven directly by the MSP430, even while the microcontroller spends most of its time in ultralow power standby mode. The user can input a temperature set point, which the software automatically stores in the MSP430's flash memory so it is not lost if the batteries are changed. All bytes of the flash information memory segment are filled with set point entries before it is erased and reused. This maximizes the flash memory lifetime. A real time clock is also maintained and can be displayed.

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1 Introduction

Most battery-powered applications can benefit from having all key features integrated into one integrated circuit. This reduces component count and board size, and speeds development time, all of which save money. A one-chip solution also simplifies the development process, since most of the effort can be directed to the single chip that provides the solution. In this application the MSP430F41x provides just such a solution. The onboard comparator measures the slope A/D conversions of a thermistor to determine the ambient temperature. The MSP430 directly drives an external LCD to display the temperature and other information. The flash memory of the microcontroller is used to automatically store a temperature set point, input by the user, in case there is a loss of power. The MSP430 also has a very versatile clocking and interrupt scheme that allows this application to highly utilize low-power standby modes, to maximize battery life, while still maintaining a real-time clock.

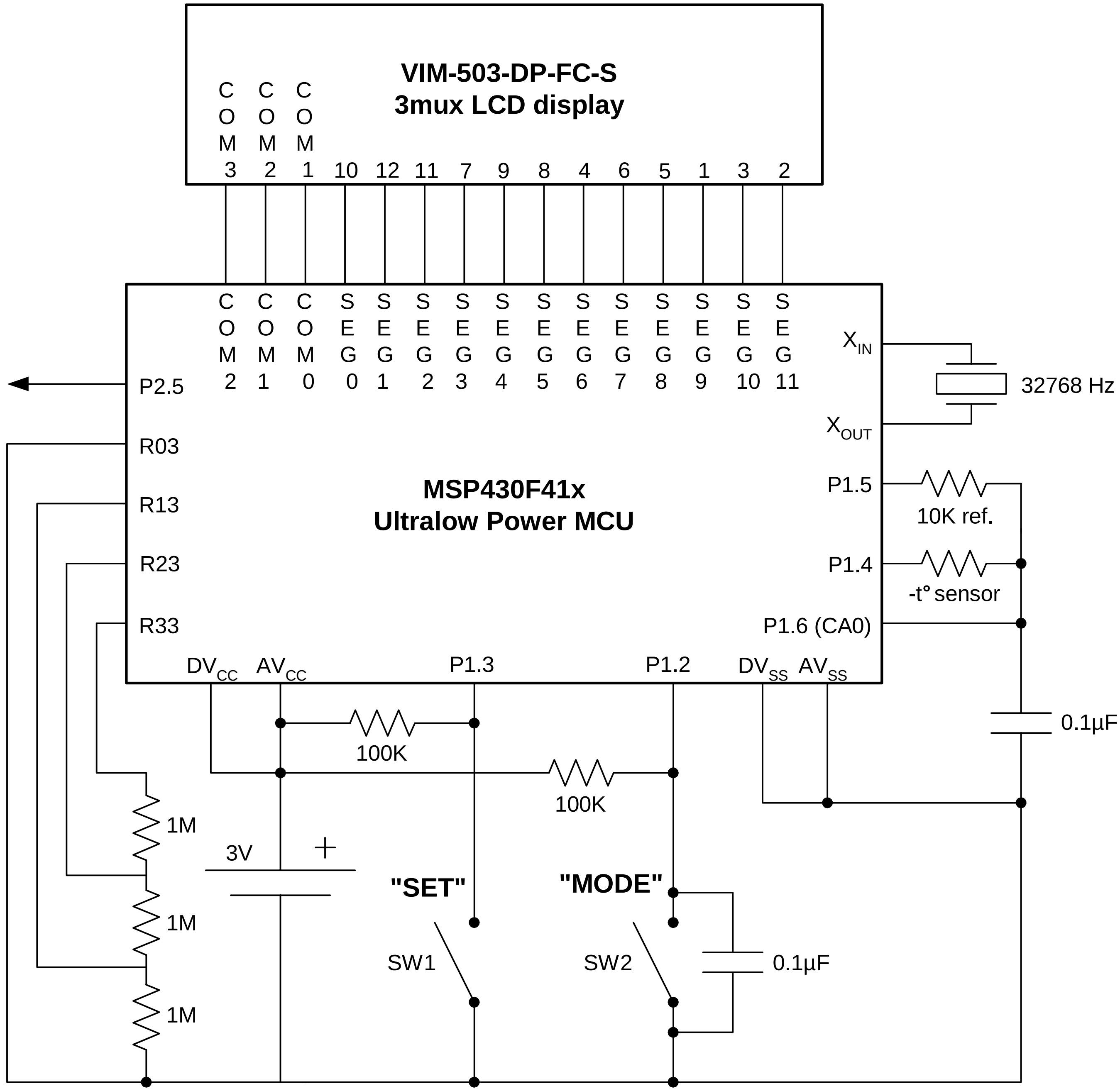

Figure 1. MSP430F41x Based Thermostat Circuit

2 Theory of Operation

The circuit can operate in one of four modes determined by pressing the mode switch. The modes are thermostat, set point, time, and seconds. While in the set point and time modes, the user can change the set point or time using the set switch.

The software is interrupt driven, by a recurring one-second interrupt. Between interrupts the circuit stays in low power mode three (LPM3) and only draws an average of 7µA of current. The user is not aware the circuit is in low-power mode since the LCD module, and therefore the LCD (Varitronix # VIM-503-DP-FC-S), remain active. The one-second interrupt is generated by one of the counters in the Basic Timer module, which continues to count even while the part is in LPM3. The other counter in the module supplies the framing frequency for the LCD, allowing it to also remain active.

The Basic Timer is clocked by a 32kHz crystal that is active in LPM3 as well. When the one-second interrupt occurs, the onboard frequency locked loop (FLL+) starts so that code is executed at a preset high frequency. The real-time clock is then updated, even if the software is not in time mode. Next the low-power mode bits are cleared from the stack so that the part returns to the main loop in active mode, at the end of the interrupt routine. Once in the main loop the current operating mode is determined and the software branches to the associated routines. Once the routines are completed, the software returns to the main loop where it is immediately put into LPM3 to await the next one-second interrupt.

The MSP430 will support static, two, three, and four multiplex rate LCDs. The LCD used in this case is a three and one-half digit, three multiplex rate display. While the software to drive a three multiplex LCD is somewhat more involved then the other possible multiplex rates, the three mux rate displays do give better contrast over a wider temperature range than four mux rate displays. They also do not require as many segment pins as static or two multiplex rate displays. Segment pins that are not required to drive the LCD can be switched to function as I/O pins. See the MSP430x4xx User's Guide for specific details on the mux rates and segment pins.

While in thermostat mode the circuit reads the resistance of the thermistor (Murata #NTH4G1S33B103F01, Radio Shack #270-110A), which changes as the temperature changes, by performing a slope conversion. The slope conversion is accomplished by charging a 0.1µf capacitor to a voltage level near V_{CC} using the reference resistor that is connected to an I/O pin. The capacitor is then discharged through the known reference resistor or the unknown resistance of the thermistor. At the same time the Timer A module counts the time required to discharge it. As the capacitor is being discharged, the voltage level is monitored by the onboard comparator module of the MSP430. The voltage level is compared against an internal reference voltage and an interrupt occurs when the voltage on the capacitor drops to a level below that of the reference. The interrupt causes the timer to stop and the time to discharge the capacitor is captured. The process is then repeated for the other resistive path, either the reference resistor or the thermistor. Once the two discharge times are known the value of the thermistor can be determined by taking the ratio of the clock cycles needed to discharge using the thermistor, versus the cycles needed to discharge using the reference resistor, then multiplying it by the known value of the reference resistor. Software routines then equate the resistance reading to a temperature. The temperature is compared to a set point input by the user via the set switch. If the temperature is at or above the set point the LCD flashes the reading and pin 5 of port 2 goes high and remains high as long as the reading is greater than or equal to the set point. The flashing LCD provides user feedback and the I/O pin could be used to control a heating/cooling system. Since the temperature in most rooms does not normally change quickly it is not necessary to measure the temperature every second. The software counts the number of seconds the circuit has been in thermostat mode and only measures the temperature after a predetermined number, which is set to four in the associated example software. This further conserves battery power since the slope A/D conversion is only performed every few seconds.

While the circuit is in set point mode the letters SP are displayed on the LCD followed by the two-digit temperature set point. The user is able to change the set point by pressing or holding the set switch. Doing so will increment the set point one degree at a time through the range of the thermostat. If the maximum is exceeded, it will roll over to the lowest set point and increment from there. When the set point mode is exited, by pressing the mode switch, the software compares the new set point to the current one. If it did not change nothing is done. If it did change, a routine unlocks the flash to allow a write or segment erase. The software then checks to see if all of the flash information memory segment has been filled. If it is not full a flash memory pointer is incremented to the next flash memory location and the new value is written to the information memory. If the information memory segment is full the segment is first erased, the pointer is set back to the beginning of the segment, and the new set point is written. After a write or erase the flash memory is locked. By using all of the 256 bytes of the information memory segment, before the erasing the segment, the operating life of the application is extended. At the time of this writing the flash memory locations could be written and erased 10,000 times each at 25 degree C. This means that the set point could potentially be changed 2.56 million times before any flash memory errors occur.

The circuit also maintains a real-time clock. The current hours and minutes are displayed when the circuit is in time mode. The clock can be adjusted by pressing or holding the set switch while in time mode. The time mode will automatically revert back to thermostat mode after ten seconds since that is the main purpose of the circuit. There is also a seconds mode that simply counts seconds and displays them on the LCD.

3 Conclusion

The MSP430F41x can provide a single chip solution in many applications due to its integration of many features and modules. In this case of a thermostat application, the ‘F41x is able to read the external sensor, update and store a set point in permanent memory, maintain a real-time clock, determine if any action is required based on the temperature, and display all the information on an LCD. All of these functions are accomplished while the MSP430F41x maintains ultralow power performance. This software could be expanded to include upper and lower set points and different set points for different times of the day or from day to day. The MSP430F41x could also datalog temperature readings and/or set points for later use or analysis.

References

1. MSP430F41x data sheet, 2001, SLAS340
2. *MSP430x4xx User’s Guide*, 2001, SLAU056
3. *MSP430 Applications Report Book*, 2000, SLAA024

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