INTRODUCTION

This application note describes a temperature sensor using a PICmicro microcontroller. This temperature sensor is unique because it can work through non-ferromagnetic walls. Interfacing to a thermistor is normally a very straightforward task. Interfacing to a thermistor on the other side of a wall gets a little more complicated. Interfacing through walls can be a very valuable feature in certain applications, notably temperature sensing for refrigerators or sensing inside of a hazardous gas environment where an isolation barrier is a safety issue.

Implementation

Thermistors come in all types and values. For temperature sensing, most applications call for a NTC (negative temperature coefficient) type of thermistor where the resistance goes down with increasing temperature. Naturally, the resistance does not go down linearly, so some processing is required to translate the resistance to a temperature. This is of course a perfect job for a PICmicro microcontroller. The normal method of interfacing to a thermistor is shown below.

This method is inappropriate for a through wall temperature system because it requires a wire to connect the thermistor to the PICmicro MCU. DC currents cannot be transmitted through a wall, so this method cannot be directly converted to a through wall system.

To sense through the wall we must get current flowing through the wall. This is easily done with a pair of coils of sufficient diameter to couple through the wall. About 100 winds of wire around a 12cm disk (size of CD) will provide sufficient inductance and size to couple through ½ inch. The PICmicro MCU can source up to 25 mA so that is how the coil will be energized. See the schematic below for the new circuit.

FIGURE 1: BASIC THERMISTOR CIRCUIT

FIGURE 2: BLOCK DIAGRAM OF INDUCTIVELY COUPLED SENSOR

PIC12C674

+5V

R

Thermistor

R1

Scaling & Translation

Inductor

Thermistor

PIC12C671

Digital Output

Analog Input

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With each side of the transformer on different sides of the wall, we have created an isolation transformer. A thermistor is loading the secondary while the PICmicro MCU is driving the primary. Now the PICmicro MCU just needs a way to detect the voltage changes of the primary due to the loading on the secondary. One method is to feed a long pulse train to the coil and look at the amplitude modulation caused by the thermistor. This is effective, but it has two problems. Problem number one is, the continuous current through the thermistor will heat it and cause errors in the measurement. The second problem is, the circuitry to get a clean reading is complex and therefore not cheap.

A preferred method is to send a single pulse into the inductor and look at the transient response of the coil. We can then simplify the circuitry and eliminate the self-heating. By placing a capacitor and resistor across the primary, a RLC type circuit is formed (see Appendix B). This circuit will have a gentle peak when we energize it. See Figure 3.

FIGURE 3: RLC PULSE RESPONSE

The idea is to have the initial capacitor current dominate the first microsecond so the circuit does not look like the infinite resistance to the coil. As the capacitor charges, the coil current starts to become the dominant factor and the load becomes visible as a variation in coil peak voltage. The RC values must be adjusted to maintain a ratio of approximately 10000:1 with the inductor. With this configuration, a load on the secondary coil causes a change in the peak voltage on the primary. See Figure 4, set for the same scale as Figure 3.

The peak voltage changes with the load voltage. This is a very useful feature. To make a good measurement without an amazingly fast analog-to-digital converter we can add a sample and hold circuit. Because the voltage variation is very small (about 500 mV in this example) we need a gain of about 10 to get a 5V range. The 2.75V offset needs to be removed so a difference amplifier is used to subtract the offset and then multiply the gain. Appendix B shows the test circuit schematic.

The calibration for this circuit is simple. Adjust the pot with no load on the secondary inductor. Adjust the pot until the analog-to-digital converter (ADC) is no longer reading a full-scale voltage. Any load on the secondary will cause the voltage to drop. The gain should be set to get a good reading over the desired range.

Theory of Operation

The PICmicro MCU sends a pulse to the inductor, which induces a voltage in the secondary coil. The secondary voltage across the thermistor causes a current, which is seen as a voltage drop, on the primary. The larger the secondary current, the larger the voltage drop at the primary. The first Op Amp, U1A, implements a high speed peak hold circuit by only passing current that charges the capacitor, but not allowing the capacitor to discharge. The second Op Amp, U1B, buffers the capacitor to the difference amplifier. This prevents the capacitor voltage from dropping too fast. The third Op Amp, U1C, subtracts the offset voltage and multiplies the difference by a gain of 10. The offset voltage is provided by the fourth Op Amp, U1D. The result is read by the ADC. The capacitor (C2) is drained between reads by an output from the PICmicro MCU.
The diode prevents the PICmicro MCU from charging the capacitor. By a small change in the software, this diode could be eliminated if the PICmicro MCU pin were left as an input pin at high impedance until the capacitor needed discharging. Alternatively, the pin would not be required at all if a suitable load resistor were provided for the capacitor. This resistor would have to be large enough that the capacitor did not drain too much before the ADC sample period passed and small enough to drain the capacitor between measurements. Here is the code for a PIC12C67X that takes a measurement.

```assembly
measure ; do the measurement
  bcf INTCON,GIE ; disable irq’s
  bsf GPIO,holdcap ; arm the cap
  bsf GPIO,coil ; charge the coil
  nop ; wait a bit
  bcf GPIO,coil ; Turn off coil
  bsf ADCON0,GO ; start ADC
  btfsc ADCON0,GO ; wait for ADC
  goto $-1 ;
  bcf GPIO,holdcap ; dump the cap
  bsf INTCON,GIE ; enable irq’s
  movf ADRES,W ; result to W
  return ; all done
```

The slowest part of the measurement is waiting for the ADC to finish. In the test system, GPIO4 was used to drive an LED with a PWM signal. This PWM was generated with a Timer0 interrupt. To prevent the Timer0 interrupt from affecting the pulse timing, all interrupts are disabled during the critical section of the measurement code. The PICmicro MCU is operating from its internal RC oscillator. This leaves a few pins to accomplish other tasks.

Figure 5 illustrates the complete circuit performance using a 10k pot in place of a thermistor. The offset was adjusted until the input to the ADC was 5V without the secondary coil in place and without clipping. With the coil in place, the resistor was swept over its entire range and produces values inside the gray area. With a suitable scaling table, this output could easily be converted to a resistance or a temperature.

**Conclusion**

Using inductive coupling is common with keyless entry, low frequency RF and power supplies. This application note shows that inductive pulse coupling can also be effectively used to transfer information, like temperature sensing, through a non-ferromagnetic barrier.
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APPENDIX A: CODE LISTING

;===================================================================================================
; *
; Filename: fridge.asm *
; Date: 10/13/2000 *
; File Version: 1.0 *
; *
; Author: Joseph Julicher *
; Company: Microchip Technology *
; *
;===================================================================================================

list p=12ce674 ; list directive to define processor
#include <p12ce674.inc> ; processor specific variable definitions
errorlevel -302 ; suppress message 302 from list file

__CONFIG _CP_OFF & _WDT_OFF & _MCLRE_OFF & _PWRTE_ON & _INTRC_OSC_NOCLKOUT

;***** VARIABLE DEFINITIONS
w_temp EQU 0x70 ; variable used for context saving
status_temp EQU 0x71 ; variable used for context saving
tsr EQU 0x72 ; transmit shift register
bitcount EQU 0x73 ; transmit bit counter
led EQU 0x74 ; LED brightness
counter EQU 0x75 ; LED PWM counter
temp EQU 0x76 ; holding for PWM status

;***** CONSTANTS DEFINITIONS
speed EQU 0xDf ; PWM period constant

;***** PIN DEFINITIONS
holdcap EQU 0x02 ; GPIO pin for the hold cap
coil EQU 0x01 ; GPIO pin for the coil
pwm EQU 0x04 ; GPIO pin for the pwm (LED brightness)

;**************************************************************************
ORG 0x000 ; processor reset vector
goto main ; go to beginning of program

ORG 0x004 ; interrupt vector location
movwf w_temp ; save off current W register contents
movf STATUS,w ; move status register into W register
movwf status_temp ; save off contents of STATUS register

incf counter,w ; PWM routine
addwf led,w
btfss STATUS,C
bcf GPIO,pwm
btfsc STATUS,C
bsf GPIO,pwm
movwf counter
bcf INTCON,T0IF ; clear the TMR0 flag
bsf INTCON,T0IE ; reenable TMR0 interrupt
movlw speed
movwf TMR0
movf status_temp,w ; retrieve copy of STATUS register
movwf STATUS ; restore pre-isr STATUS register contents
movf w_temp,w ; restore W register
retfie ; return from interrupt

main
    call 0x7FF ; retrieve factory calibration value
    bsf STATUS,RP0 ; set file register bank to 1
    movwf OSCCAL ; update register with factory cal value
    bcf STATUS,RP0 ; set file register bank to 0
    clrf TMR0 ; clear the timer
    clrf counter
    clrf led

; setup GPIO
    clrf GPIO ; set all I/O’s to 0
    clrf INTCON ; clear all flags and enables
    bsf INTCON,T0IE ; enable TMR0 interrupt
    bsf INTCON,GIE ; enable all interrupts
    bsf STATUS, RP0 ; Select Page 1
    clrf OPTION_REG ; clear all options
    bsf OPTION_REG,NOT_GPPU; Turn off weak pullup
    movlw B’00001001 ; GPIO 0 is Input
    ; GPIO 1 is Output
    ; GPIO 2 is Output
    ; GPIO 3 is Input
    ; GPIO 4 is Output
    ; GPIO 5 is Output
    movwf TRISIO
    movlw B’00000110 ; GP0 is analog, VREF is Vdd
    movwf ADCON1 ; Configure A/D Inputs
    bcf PIE1,ADIE ; disable A/D Interrupts
    bcf STATUS, RP0 ; Select Page 0
    movlw B’01000001 ; 8 Tosc clock, A/D is on, Channel 0 is selected
    movwf ADCON0 ;
    bcf PI1, ADIF ; Clear A/D interrupt flag bit
repeat call measure ; make a measurement
    movwf led ; set the LED brightness
    movlw D’56 ’; wait 200 loops or 1ms
    delay nop ;
    addlw D’1 ;
    btfss STATUS,Z ;
    goto delay ;
    goto repeat ;
measure ; do the measurement
    bcf INTCON,GIE ; disable all interrupts
    bsf GPIO,holdcap ; arm the cap
    bsf GPIO,coil ; charge the coil
    nop
    bcf GPIO,coil ; Turn off coil
; wait for the inductor collapse to finish
bsf ADCON0,GO ; start ADC
btfsc ADCON0,GO ; wait for ADC to finish
goto $-1 ; go back if not finished yet
bcf GPIO,holdcap ; dump the cap
bsf INTCON,GIE ; enable all interrupts
movf ADRES,W ; move the result to W
return ; all done

END
APPENDIX B: TEST SCHEMATIC

TEST SCHEMATIC

PIC12C671

Digital Output

Analog Input

Test Point 2

ADC

Racho 5k

Digital Output

U1C

U1B

U1A

D1N4148

D1N4148

1K

VDD

V-

Digital Output

Thermistor

1k

15mH

30mH

30mH

R5 10k

R6 10k

R4 10k

R2 10k

R1 10k

R7 10k

220pf

U1 = MCP604

R7 = Offset Calibration Potentiometer

VDD

220pf

ADC

ADC

ADC

ADC

ADC
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- The PICmicro family meets the specifications contained in the Microchip Data Sheet.
- Microchip believes that its family of PICmicro microcontrollers is one of the most secure products of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the PICmicro microcontroller in a manner outside the operating specifications contained in the data sheet. The person doing so may be engaged in theft of intellectual property.
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