A Comparator Based Slope ADC

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INTRODUCTION

Comparators are used for many things, but many people want to build analog-to-digital converters using a comparator. Comparators are one basic building block of all ADC architectures. A PICmicro® microcontroller with internal comparators can become an ADC with the application of some software and a minimum of external hardware. In this application note you will be shown how to build a Slope ADC. This ADC has been used with the digital pins on PICmicro microcontrollers for many years. The addition of a comparator to the circuit improves the results and reduces the power consumption.

A characteristic to measure with a Slope ADC is resistance. By using a thermistor, temperature can be directly converted to a resistance. Measuring a thermistor is a good way to demonstrate the functions of a Slope ADC. Temperature measurement, or control, is one of the more common applications of microprocessor systems. One of the first signs of an illness in a person is a fever. Overheating fuels cause disasters. Food that has not been stored at the proper temperature spoils. Nearly every system or process requires an accurate understanding of the temperature. This application note describes another way to measure the temperature, and a way to build an analog-to-digital converter.

An example of some of the PICmicro microcontrollers that have comparators are:

- PIC12F629
- PIC12F675
- PIC16C620
- PIC16C621
- PIC16C22
- PIC16CE623

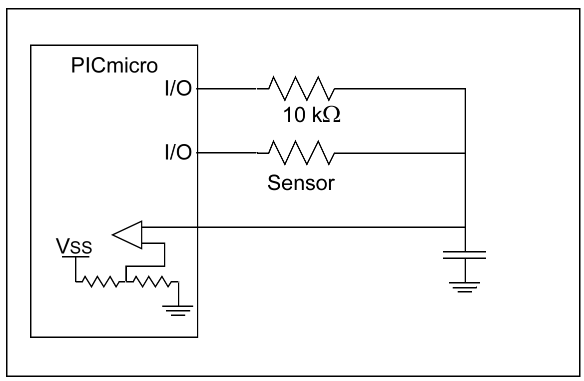
Thermistors

Thermistors are devices that change in resistance with changes in temperature. Thermistors are more properly called RTDs (Resistive Temperature Detectors). An RTD can be made from a variety of substances depending on the desired operation temperature range, the desired operation environment, the required accuracy and the cost. Platinum RTDs can achieve an accuracy of much less than 1°C. Other low cost RTDs achieve an accuracy of just a few degrees.

Slope ADC

Analog-to-digital converters can be created in a variety of ways. For this application note, we will build a slope converter. The slope converter works by timing the rate that a capacitor charges to a specified voltage. This is done twice, once with a reference source and once with a sensor. By performing the operation twice, variations in capacitor values or timing accuracy can be minimized. The reference source for this application note was simply a 10 kΩ resistor. The sensor was a 10 kΩ thermistor. See Figure 1.

FIGURE 1: SENSOR SCHEMATIC



To make a measurement, the following steps are taken:

1. Activate the comparator & voltage reference.
2. Clear the timer.
3. Activate the thermistor.
4. Wait for the comparator to trip.
5. Multiply the timer value by the value of the reference resistor.
6. Discharge the timing capacitor.
7. Clear the timer.
8. Activate the reference.
9. Wait for the comparator to trip.
10. Divide the result of step 5 by the new timer value.
11. Shutdown the comparator and voltage reference.
12. Return with the result of step 10 stored as the thermistor resistance.

Scaling the Data

One advantage of using RTD is that the response is nearly linear. Most RTDs are specified with an R25/R50 value. This is the ratio of the 25°C, with the 25°C value. The ratio is a linear relationship that can be coded to convert the ADC values to temperature. The Multiple and Divide code is located in Appendix C.

Using the Data

How an application will use the data from a sensor will depend on the function. For this application note, the data is simply displayed on a 3-digit, 7-segment LED display. The segments are driven by PORTB on an 18-pin PICMicro microcontroller. The digits are selected by a second 8-pin PICmicro microcontroller (See Figure 2). The digit selection was performed by the second PICmicro microcontroller to demonstrate a simple I/O expander.

The software for the PIC12F629 is located in Appendix B. The master sends the pulse train to select the correct digit while driving the segment lines. See Figure 4 for a scope capture of the pulse train.

FIGURE 2: DISPLAY SCHEMATIC

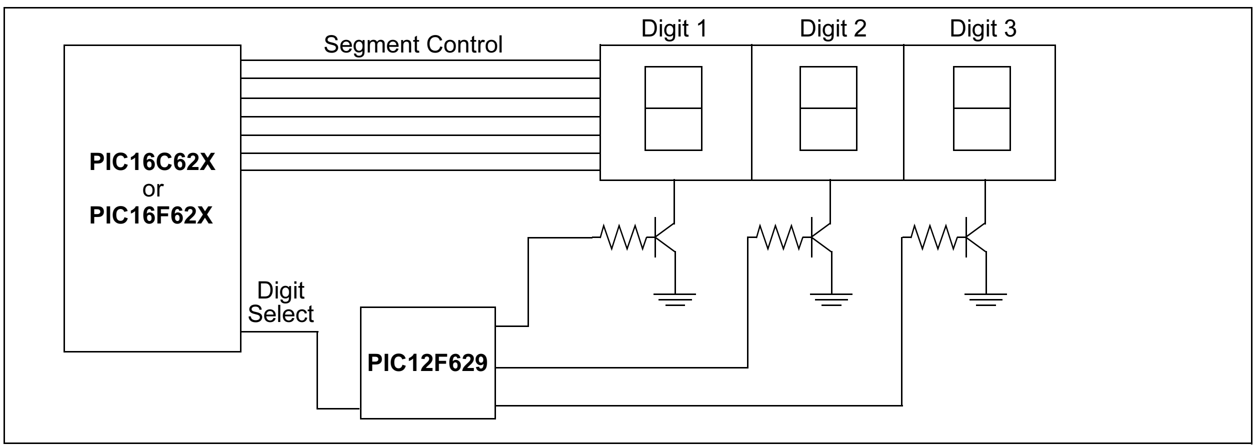


FIGURE 3: CAPACITOR CHARGE GRAPH

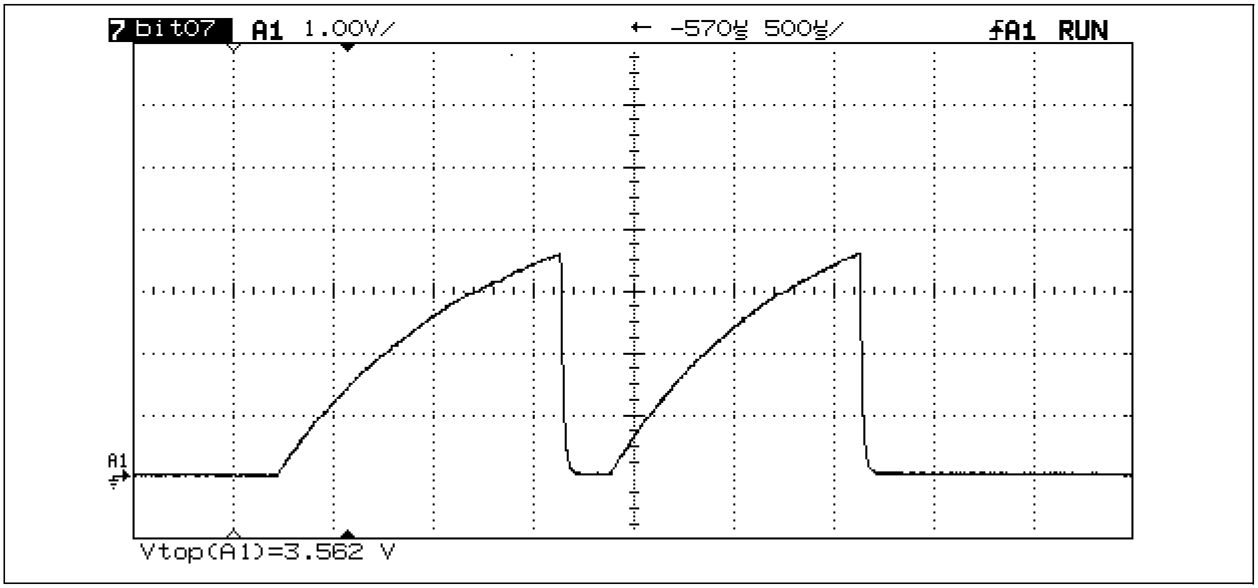
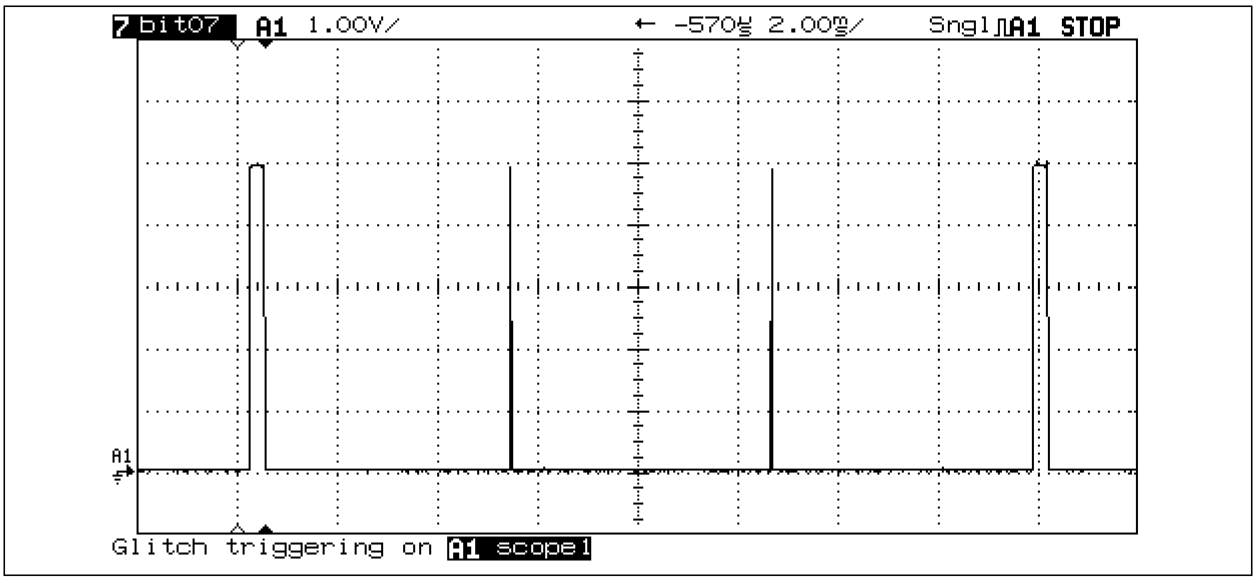


FIGURE 4: DIGIT SELECT SIGNAL TO PIC12F629



Conclusion

Using a comparator to read analog's voltage is a straight-forward process combining a small amount of discrete circuitry with a small piece of firmware. Other ADCs can also be built in this manner. See AN700 for directions on how to build a delta sigma ADC using comparators and a few inexpensive discrete components.

APPENDIX A: SLOPE CODE

```
;**************************************************************
; Perform Slope Conversion
; Uses a0,a1,b0,b1
; result is the unknown resistance in Ohms stored at c0,c1,c2,c3
;**************************************************************
reference_value     equ                 .10000  ; reference resistance
Measure_Resistance

       banksel TRISA
       movlw        0x27                ;          76543210
       movwf        TRISA               ; PortA is OOIOOIII
       banksel      PORTA
       movf         CMCON,W

       bsf          PORTA,3             ; start current through the reference
       call         T0Timing

       movwf        a0
       movf         T0_HIGH,W
       movwf        a1                  ; store timer value

       clrf         PORTA

       ; clearing the Capacitor
       banksel TRISA
       movlw        0x2D                ;          76543210
       movwf        TRISA               ; PortA is OOIOIIOI

       banksel      b0
       movlw        high reference_value
       movwf        b1
       movlw        low reference_value
       movwf        b0

       call         multiply

       banksel      TRISA
       movlw        0x2E                ;          76543210
       movwf        TRISA               ; PortA is OOIOIIIO
       banksel      CMCON
       movf         CMCON,W

       bsf          PORTA,0             ; start current through the sensor
       call         T0Timing

       movwf        a0
       movf         T0_HIGH,W
       movwf        a1
       clrf         PORTA
```

```
banksel     TRISA
movlw       0x2D                ;           76543210
movwf       TRISA               ; PortA is OOIOIIOI
banksel     PORTA

call        divide

return
```

APPENDIX B: DIGIT MULTIPLEXING CODE

```
main
          call        0x3FF               ; 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

          ; time the input
          movlw      reset_time
time_loop
          addlw      0xFF
          btfss      STATUS,Z                 ; countdown the reset time
          goto       time_loop

          btfsc      GPIO,3
          goto       reset_return

          incf       state,w
          andlw      0x03
          addwf      PCL,F
          goto       state0
          goto       state1
          goto       state2
          goto       state3
state0
state1
          movlw .1
          movwf      state
          movlw      .4
          goto       update
state2
          movlw      .2
          movwf      state
          movlw      .2
          goto       update
state3
          movlw      .3
          movwf      state
          movlw      .1
update
          movwf      GPIO

          goto       normal_return
```


APPENDIX C: MULTIPLE AND DIVIDE ROUTINES

```
;**************************************************************
; Unsigned Divide Routine 32/16=32
; c3:c2:c1:c0 / a1:a0 = c3:c2c1:c0
;**************************************************************

divide
      ; Test for zero division
      movf          a0,W
      iorwf         a1,W
      btfsc         STATUS,Z
      retlw         0x00

      ; prepare used variables
      clrf          tmp
      clrf          tmp1

      clrf          tmp2

      movlw         D'32'                ; initialize bit counter
      movwf         bcnt

DIVIDE_LOOP_32by16
      rlf           c0,F
      rlf           c1,F
      rlf           c2,F
      rlf           c3,F
      ; shift in highest bit from dividend through carry in temp
      rlf           tmp1,F
      rlf           tmp,F

      rlf           tmp2,F

      movf          a0,W                  ; get LSB of divisor
      btfsc         tmp2,7
      goto          Div32by16_add

      ; subtract 16 bit divisor from 16 bit temp
      subwf         tmp1,F               ; subtract

      movf          a1,W                 ; get top byte
      btfss         STATUS,C             ;  if overflow ( from prev. subtraction )
      incfsz        a1,W                 ; increase source
      subwf         tmp,F                ; and subtract from dest.

      movlw         1
      btfss         STATUS,C
      subwf         tmp2,F
      goto          DIVIDE_SKIP_32by16   ; carry was set, subtraction ok, continue with next bit
```

```
Div32by16_add
                                        ; result of subtraction was negative restore temp
     addwf          tmp1,F              ; add it to the lsb of temp

     movf           a1,W                ; MSB byte
     btfsc          STATUS,C            ; check carry for overflow from previous addition
     incfsz         a1,W
     addwf          tmp,F               ; handle overflow

     movlw          1
     btfsc          STATUS,C
     addwf          tmp2,F

DIVIDE_SKIP_32by16
         decfsz         bcnt,F              ; decrement loop counter
         goto           DIVIDE_LOOP_32by16  ; another run
         ; finally shift in the last carry
         rlf            c0,F
         rlf            c1,F
         rlf            c2,F
         rlf            c3,F
         retlw          0x01                ; done



;***************************************************************
; Unsigned Multiply 16x16
; a1:a0 * b1:b0 = c3:c2:c1:c0
;***************************************************************
multiply
         clrf           c3
         clrf           c2
         clrf           c1
         clrf           c0
         bsf            c1, 7
multiply_lp1
         rrf            a1, f
         rrf            a0, f
         btfss          STATUS,C
         goto           multiply_lp2
         movf           b0, w
         addwf          c2, f
         movf           b1, w
         btfsc          STATUS,C
         incfsz         b1, w
         addwf          c3, f
multiply_lp2
         rrf            c3, f
         rrf            c2, f
         rrf            c1, f
         rrf            c0, f
         btfss          STATUS,C
         goto           multiply_lp1
         return
```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