AN513

Analog to Digital Conversion

INTRODUCTION

This application note describes a method for implementing analog to digital conversion on the PIC16C5X series of microcontrollers. The converter requires only five external components and is software and hardware configurable for conversion resolutions from 6 bits up to 10 bits and conversion times of 250µs or longer. The method is useable for both voltage and current conversion and uses a software calibration technique that compensates for time and temperature drift as well as component errors. The PIC16C5X microcontrollers are ideal for simple analog applications because:

* Very low cost.
* Few external components required.
* Fully programmable. PIC16C5X microcontrollers are offered as One-Time-Programmable (OTP) EPROM devices.
* Available off the shelf from distributors.
* Calibration in software for improved measurement accuracy.
* Power savings using PIC16C5X's Sleep mode.
* PIC16C5X's output pins have large, current source/sink capability to drive LED's directly.

THEORY OF OPERATION

The application uses a capacitive charging circuit (see Figure 1) to convert the input voltage to time, which can be easily measured using a microcontroller. First, the reference voltage is applied to the input voltage to current converter (U1). The equivalent circuit is shown in Figure 2. This circuit provides a linearly variable current as a function of input voltage. The logarithmic characteristic that would occur if the input voltage was applied directly to an RC is not present. The capacitor C is charged up until the threshold on the chip input trips. This generates a software calibration value that is used to calibrate out most circuit errors, including inaccuracies in the resistor and capacitor, changes in the input threshold voltage and temperature variations. After the software calibration value is measured, the capacitor is discharged (see Figure 3) and the input voltage is connected to V_{IN}. The time to trip the threshold is measured for the input voltage and compared to the calibration value to determine the actual input voltage.

FIGURE 1 - VOLTMETER A TO D CONVERTER

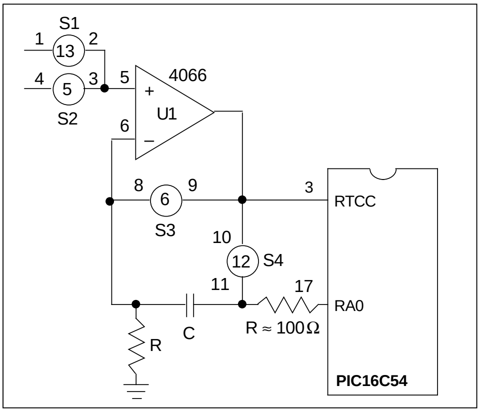


FIGURE 2 - VOLTMETER MEASUREMENT CYCLE

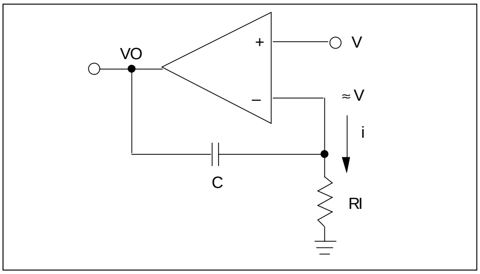
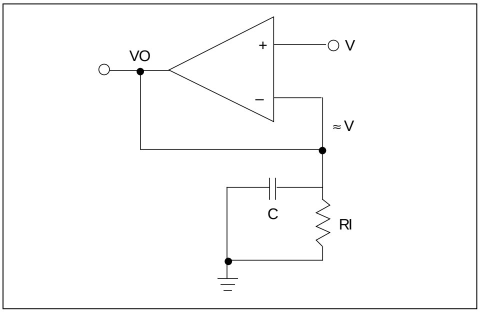


FIGURE 3 - VOLTMETER DISCHARGE CYCLE



CIRCUIT CONFIGURATION

The values of R and C are selected based upon the number of bits of resolution required.

$RC = (Vi * T)/Vt$

Where:

Vi = Lowest voltage to be measured (at least ten lsb's)

T = Time to do the number of bits of resolution desired

Vt = Threshold voltage of the PIC16C5X input being used

Actual value for RC should be slightly smaller than calculated to ensure that the PIC16C5X does not overcount during the measurement.

For example use a 3 volt input and 8 bits resolution with a 8 MHz clock and 6 instruction cycles per count:

Vi = 100 mV

T = 256 *1/8 MHz * 4 clocks/cycle * 6 cycles = 768µS

Vt = 3.0V (est)

For input voltages greater than 3 volts a resistor divider network should be used to keep the maximum voltage on V_{IN} to less than 3 Volts. For best performance the reference voltage should be between 2 and 3 volts.

The circuit can also be used as a current mode A to D converter. In this case the input voltage to current converter is not needed and the reference current and input current are both routed via analog switches directly into the capacitor.

CIRCUIT PERFORMANCE

The calibration cycle removes all first order errors (offset, gain, R and C inaccuracy, power supply voltage and temperature) except the reference voltage drift. Any change in the reference voltage, including noise, between the calibration cycle and the measurement cycle may result in measurement errors. Other error sources are analog switch leakage, resistor and capacitor nonlinearities, input threshold uncertainty and time measurement uncertainty (+/- one instruction cycle time). Measured performance shows the converter to be accurate within +/- 1% of full scale.

Example

Assembly code implementing the circuit of Figure 1 is listed in Appendix A: This code measures the time up to 16 bits and calculates the results using 16-bit multiply and divide subroutines. In actual applications, if measurement accuracy permits, it may be advantageous to use 8 bits. The math code can be substantially reduced and the measure time is reduced by the simpler code and shorter count.

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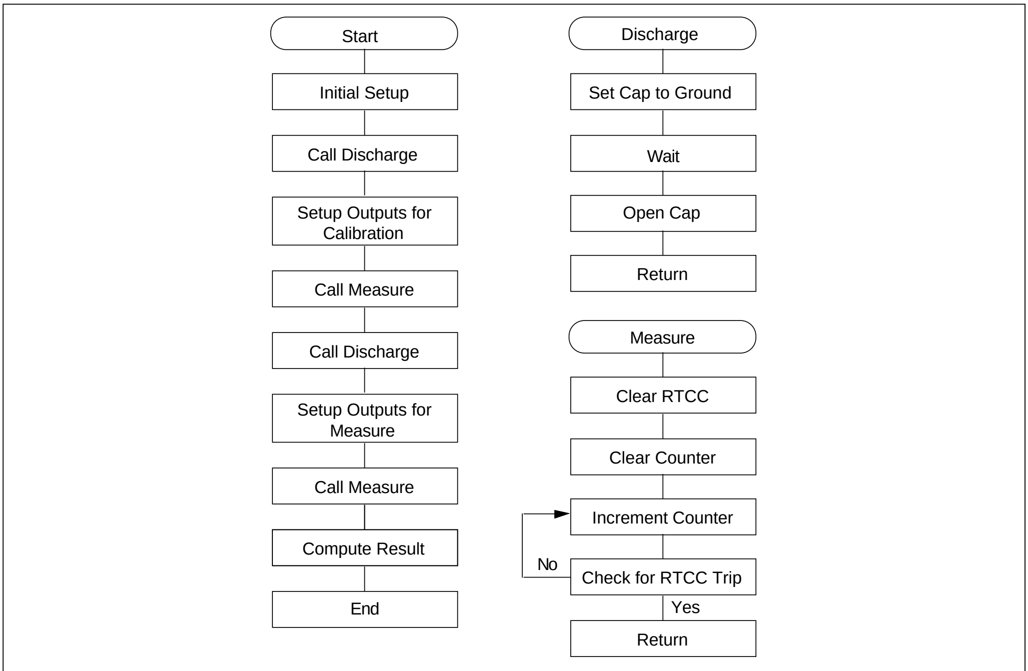
FIGURE 4 - TRANSMISSION FLOW CHART



APPENDIX A:

```
MPASM B0.54                                                        PAGE  1
VOLTMETER/AD CONVERTER PROGRAM REV 3-29-90


                             TITLE  'VOLTMETER/AD CONVERTER PROGRAM REV 3-29-90'
                             LIST   P=16C54,F=inhx16,n=0

0008                 ACCA     EQU     8
000A                 ACCB     EQU     0A
000C                 ACCC     EQU     0C
000E                 ACCD     EQU     0E
0010                 ACCE     EQU     10
0012                 TMEAS    EQU     12
0014                 TEMP     EQU     14

0060                 VCALMS   EQU     60              ;VCAL MSB VALUE IN HEX
00A4                 VCALLS   EQU     0A4             ;VCAL LSB VALUE IN HEX

                              ORG 1FF
01FF 0A58                     GOTO    VOLTS           ;PROGRAM CODE
                              ORG     0               ;SUBROUTINES

0000 0209            MADD     MOVF    ACCA+1,W
0001 01EB                     ADDWF   ACCB+1          ;ADD LSB
0002 0603                     BTFSC   3,0             ;ADD IN CARRY
0003 02AA                     INCF    ACCB
0004 0208                     MOVF    ACCA,W
0005 01EA                     ADDWF   ACCB            ;ADD MSB
0006 0800                     RETLW   0
0007 0000                     NOP

0008 0915            MPY      CALL    SETUP           ;RESULTS IN B(16 MSB'S) AND C(16 LSB'S)
0009 032E            MLOOP    RRF     ACCD            ;ROTATE D RIGHT
000A 032F                     RRF     ACCD+1
000B 0603                     SKPNC                   ;NEED TO ADD?
000C 0900                     CALL    MADD
000D 032A                     RRF     ACCB
000E 032B                     RRF     ACCB+1
000F 032C                     RRF     ACCC
0010 032D                     RRF     ACCC+1
0011 02F4                     DECFSZ  TEMP            ;LOOP UNTIL ALL BITS CHECKED
0012 0A09                     GOTO    MLOOP
0013 0800                     RETLW   0

0014 0000                     NOP
0015 0C10            SETUP    MOVLW   10
0016 0034                     MOVWF   TEMP
0017 020A                     MOVF    ACCB,W          ;MOVE B TO D
0018 002E                     MOVWF   ACCD
0019 020B                     MOVF    ACCB+1,W
001A 002F                     MOVWF   ACCD+1
001B 020C                     MOVF    ACCC,W
001C 0030                     MOVWF   ACCE
001D 020D                     MOVF    ACCC+1,W
001E 0031                     MOVWF   ACCE+1
001F 006A                     CLRF    ACCB
0020 006B                     CLRF    ACCB+1
0021 0800                     RETLW   0

0022 0000                     NOP
0023 0915            DIV      CALL    SETUP
0024 0C20                     MOVLW   20
0025 0034                     MOVWF   TEMP
0026 006C                     CLRF    ACCC
0027 006D                     CLRF    ACCC+1
```

```
0028 0403            DLOOP    CLRC
0029 0371                     RLF     ACCE+1
002A 0370                     RLF     ACCE
002B 036F                     RLF     ACCD+1
002C 036E                     RLF     ACCD
002D 036D                     RLF     ACCC+1
002E 036C                     RLF     ACCC
002F 0208                     MOVF    ACCA,W
0030 008C                     SUBWF   ACCC,W          ;CHECK IF A>C
0031 0743                     SKPZ
0032 0A35                     GOTO    NOCHK
0033 0209                     MOVF    ACCA+1,W
0034 008D                     SUBWF   ACCC+1,W        ;IF MSB EQUAL THEN CHECK LSB
0035 0703            NOCHK    SKPC                    ;CARRY SET IF C>A
0036 0A3E                     GOTO    NOGO
0037 0209                     MOVF    ACCA+1,W        ;C-A INTO C
0038 00AD                     SUBWF   ACCC+1
0039 0703                     BTFSS   3,0
003A 00EC                     DECF    ACCC
003B 0208                     MOVF    ACCA,W
003C 00AC                     SUBWF   ACCC
003D 0503                     SETC                    ;SHIFT A 1 INTO B (RESULT)
003E 036B            NOGO     RLF     ACCB+1
003F 036A                     RLF     ACCB
0040 02F4                     DECFSZ  TEMP            ;LOOP UNTILL ALL BITS CHECKED
0041 0A28                     GOTO    DLOOP
0042 0800                     RETLW   0

0043 0C0E            DSCHRG   MOVLW   B’00001110'     ;DISCHARGE C (RA0 ON)
0044 0005                     TRIS    5
0045 0CFF                     MOVLW   0FF
0046 0034                     MOVWF   TEMP
0047 02F4            LOOP     DECFSZ  TEMP            ;WAIT
0048 0A47                     GOTO    LOOP
0049 0C0F                     MOVLW   B’00001111'     ;ALL RA HIGH Z
004A 0005                     TRIS    5
004B 0800                     RETLW   0

004C 0061            M_TIME   CLRF    1               ;CLEAR RTCC REGISTER
004D 0069                     CLRF    ACCA+1          ;CLEAR 16 BIT COUNTER
004E 0068                     CLRF    ACCA
004F 03E9            TLOOP    INCFSZ  ACCA+1
0050 0A54                     GOTO    ENDCHK
0051 03E8                     INCFSZ  ACCA
0052 0A54                     GOTO    ENDCHK
0053 0A56                     GOTO    END_M
0054 0701            ENDCHK   BTFSS   1,0             ;CHECK FOR RTCC TRIP
0055 0A4F                     GOTO    TLOOP
0056 0201            END_M    MOVF    1,W
0057 0800                     RETLW   0

0058 0C06            VOLTS    MOVLW   B’00000110'     ;SET S2 AND S3 HIGH(ON WHEN ACTIVATED)
0059 0026                     MOVWF   6
005A 0CF0                     MOVLW   B’11110000'     ;ACTIVATE SWITCHES S1-S4
005B 0006                     TRIS    6
005C 0C28                     MOVLW   B’00101000'     ;SELECT POSITIVE EDGE FOR RTCC
005D 0002                     OPTION
005E 0C00                     MOVLW   B’00000000'
005F 0025                     MOVWF   5               ;SET RA0 LOW (ON WHEN ACTIVATED)

0060 0943            MEAS     CALL    DSCHRG          ;CHARGE CAPACITOR TO VIN
0061 0C0A                     MOVLW   B’00001010'     ;S2 AND S4 ON
0062 0026                     MOVWF   6
0063 094C                     CALL    M_TIME          ;MEASURE TIME
0064 0209                     MOVF    ACCA+1,W
0065 0033                     MOVWF   TMEAS+1         ;STORE LSB
0066 0208                     MOVF    ACCA,W
0067 0032                     MOVWF   TMEAS           ;STORE MSB
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```
0068 0C05          CAL      MOVLW   B'00000101'     ;S1 AND S3 ON
0069 0026                   MOVWF   6
006A 0943                   CALL    DSCHRG          ;CHARGE CAPACITOR TO VREF
006B 0C09                   MOVLW   B'00001001'     ;S1 AND S4 ON
006C 0026                   MOVWF   6
006D 094C                   CALL    M_TIME          ;MEASURE TIME

006E 0CA4                   MOVLW   VCALLS
006F 002B                   MOVWF   ACCB+1
0070 0C60                   MOVLW   VCALMS
0071 002A                   MOVWF   ACCB

0072 0908                   CALL    MPY             ;MULTIPLY ACCA(TCAL) * ACCB(VREF)
0073 0213                   MOVF    TMEAS+1,W
0074 0029                   MOVWF   ACCA+1
0075 0212                   MOVF    TMEAS,W
0076 0028                   MOVWF   ACCA

0077 0923                   CALL    DIV             ;DIVIDE ACCB(TCAL * V) BY ACCA(TMEAS)

0078 0A58                   GOTO VOLTS

                            END

Errors   :    0
Warnings :    0
```

NOTES:

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