AN513

Analog to Digital Conversion Using a PIC16C54

Author: *Doug Cox*
Microchip Technology Inc.

INTRODUCTION

This application note describes a method for implementing analog to digital (A/D) 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 250 µs or longer. The method is usable for both voltage and current conversion and uses a software calibration technique that compensates for time and temperature drift as well as component errors. 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 Sleep mode
- Output pins have large, current source/sink capability to drive LED's directly

THEORY OF OPERATION

The application uses a capacitive charging circuit (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 the 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 (Figure 3), and the input voltage is connected to VIN. The time to the trip threshold is measured for the input voltage and compared to the calibration value to determine the actual input voltage.

FIGURE 1: VOLTMETER A/D CONVERTER

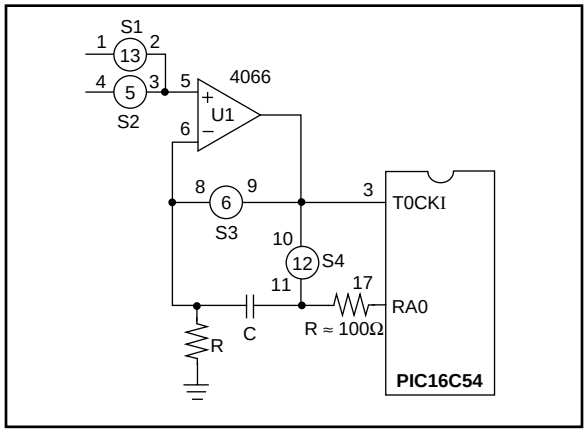


FIGURE 2: VOLTMETER MEASUREMENT CYCLE

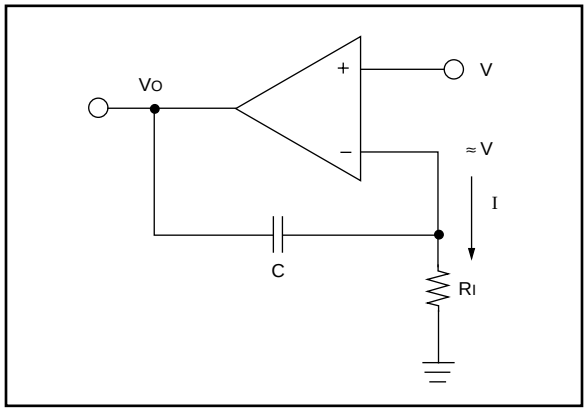
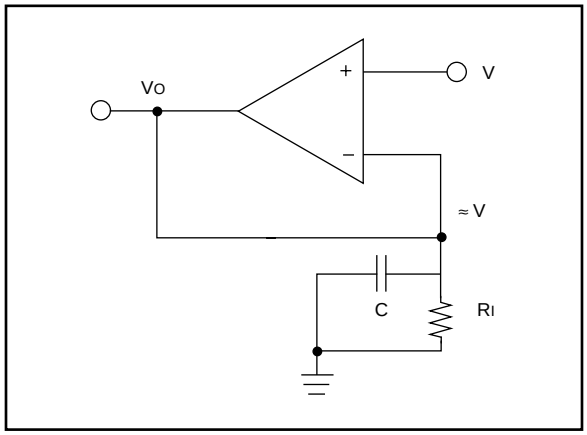


FIGURE 3: VOLTMETER DISCHARGE CYCLE



CIRCUIT CONFIGURATION

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

$$RC = (V_I \bullet T)/V_T$$

Where:

V_I = Lowest voltage to be measured (at least ten LSb's)

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

V_T = 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 3V input and 8-bit resolution with a 8 MHz clock and 6 instruction cycles per count:

$V_I = 100$ mV
$T = 256 \bullet 1/8$ MHz $\bullet$ 4 clocks/cycle $\bullet$ 6 cycles = 768 µs
$V_T = 3.0$V (est)

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

The circuit can also be used as a current mode A/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.

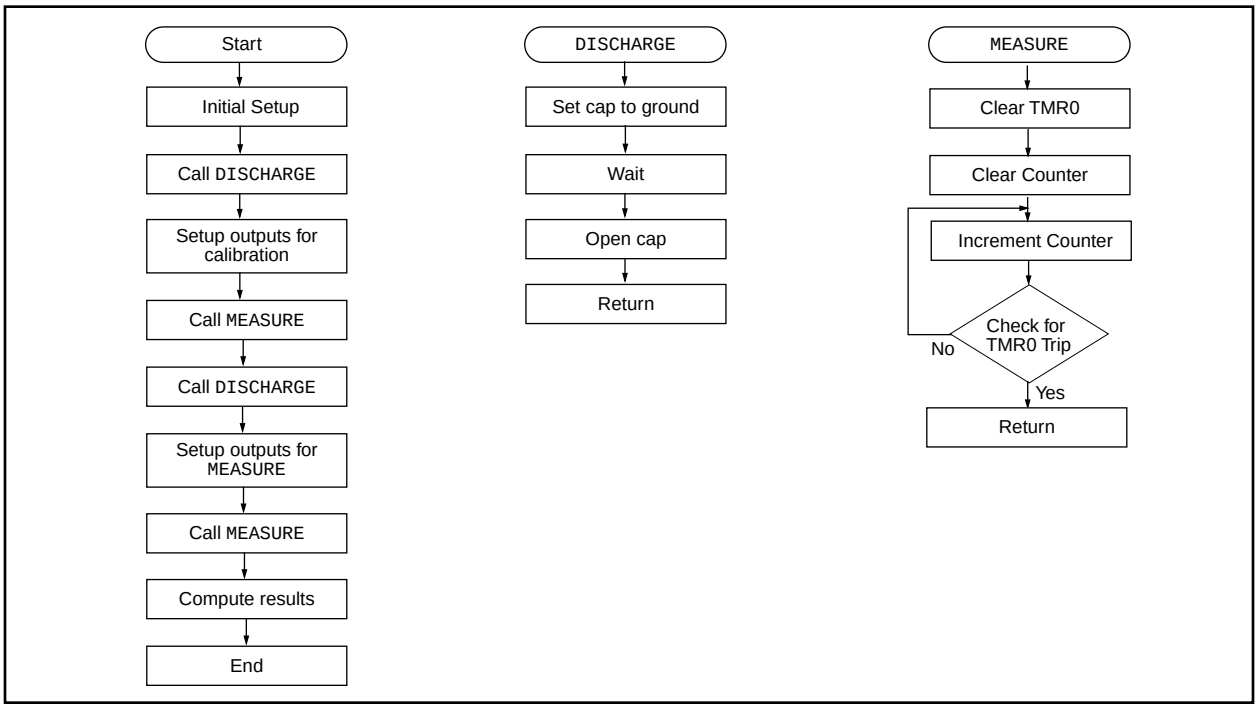
CIRCUIT PERFORMANCE

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 may be analog switch leakage, resistor and capacitor non-linearities, 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.

FIGURE 4: TRANSMISSION FLOWCHART



Please check the Microchip BBS for the latest version of the source code. Microchip's Worldwide Web Address: www.microchip.com; Bulletin Board Support: MCHIPBBS using CompuServe® (CompuServe membership not required).

APPENDIX A: VOLTMETER/AD CONVERTER PROGRAM

```
MPASM 01.40 Released         VOLTMETR.ASM   1-16-1997  12:35:25         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                     00001         TITLE  'VOLTMETER/AD CONVERTER PROGRAM REV 3-29-90'
                     00002         LIST   P=16C54
                     00003 ;
                     00004 ;*****************************************************************
                     00005 ;
                     00006 ;       Program:          VOLTMETR.ASM
                     00007 ;       Revision Date:
                     00008 ;                       1-13-97      Compatibility with MPASMWIN 1.40
                     00009 ;
                     00010 ;*****************************************************************
                     00011 ;
  00000008           00012 ACCA     EQU     8
  0000000A           00013 ACCB     EQU     0A
  0000000C           00014 ACCC     EQU     0C
  0000000E           00015 ACCD     EQU     0E
  00000010           00016 ACCE     EQU     10
  00000012           00017 TMEAS    EQU     12
  00000014           00018 TEMP     EQU     14
                     00019 ;
  00000001           00020 F        EQU     1
                     00021 ;
  00000060           00022 VCALMS   EQU     60           ;VCAL MSB VALUE IN HEX
  000000A4           00023 VCALLS   EQU     0A4          ;VCAL LSB VALUE IN HEX
                     00024
01FF                 00025         ORG 1FF
01FF 0A58            00026         GOTO    VOLTS        ;PROGRAM CODE
0000                 00027         ORG     0            ;SUBROUTINES
                     00028
0000 0209            00029 MADD     MOVF    ACCA+1,W
0001 01EB            00030          ADDWF   ACCB+1, F    ;ADD LSB
0002 0603            00031          BTFSC   3,0          ;ADD IN CARRY
0003 02AA            00032          INCF    ACCB, F
0004 0208            00033          MOVF    ACCA,W
0005 01EA            00034          ADDWF   ACCB, F      ;ADD MSB
0006 0800            00035          RETLW   0
0007 0000            00036          NOP
                     00037
0008 0915            00038 MPY      CALL    SETUP        ;RESULTS IN B(16 MSB'S) AND C(16 LSB'S)
0009 032E            00039 MLOOP    RRF     ACCD, F      ;ROTATE D RIGHT
000A 032F            00040          RRF     ACCD+1, F
000B 0603            00041          SKPNC                ;NEED TO ADD?
000C 0900            00042          CALL    MADD
000D 032A            00043          RRF     ACCB, F
000E 032B            00044          RRF     ACCB+1, F
000F 032C            00045          RRF     ACCC, F
0010 032D            00046          RRF     ACCC+1, F
0011 02F4            00047          DECFSZ  TEMP, F      ;LOOP UNTIL ALL BITS CHECKED
0012 0A09            00048          GOTO    MLOOP
0013 0800            00049          RETLW   0
                     00050
0014 0000            00051          NOP
0015 0C10            00052 SETUP    MOVLW   10
0016 0034            00053          MOVWF   TEMP
0017 020A            00054          MOVF    ACCB,W       ;MOVE B TO D
```



```
0018 002E          00055          MOVWF   ACCD
0019 020B          00056          MOVF    ACCB+1,W
001A 002F          00057          MOVWF   ACCD+1
001B 020C          00058          MOVF    ACCC,W
001C 0030          00059          MOVWF   ACCE
001D 020D          00060          MOVF    ACCC+1,W
001E 0031          00061          MOVWF   ACCE+1
001F 006A          00062          CLRF    ACCB
0020 006B          00063          CLRF    ACCB+1
0021 0800          00064          RETLW   0
                   00065
0022 0000          00066          NOP
0023 0915          00067 DIV      CALL    SETUP
0024 0C20          00068          MOVLW   20
0025 0034          00069          MOVWF   TEMP
0026 006C          00070          CLRF    ACCC
0027 006D          00071          CLRF    ACCC+1
0028 0403          00072 DLOOP    CLRC
0029 0371          00073          RLF     ACCE+1, F
002A 0370          00074          RLF     ACCE, F
002B 036F          00075          RLF     ACCD+1, F
002C 036E          00076          RLF     ACCD, F
002D 036D          00077          RLF     ACCC+1, F
002E 036C          00078          RLF     ACCC, F
002F 0208          00079          MOVF    ACCA,W
0030 008C          00080          SUBWF   ACCC,W       ;CHECK IF A>C
0031 0743          00081          SKPZ
0032 0A35          00082          GOTO    NOCHK
0033 0209          00083          MOVF    ACCA+1,W
0034 008D          00084          SUBWF   ACCC+1,W     ;IF MSB EQUAL THEN CHECK LSB
0035 0703          00085 NOCHK    SKPC                 ;CARRY SET IF C>A
0036 0A3E          00086          GOTO    NOGO
0037 0209          00087          MOVF    ACCA+1,W     ;C-A INTO C
0038 00AD          00088          SUBWF   ACCC+1, F
0039 0703          00089          BTFSS   3,0
003A 00EC          00090          DECF    ACCC, F
003B 0208          00091          MOVF    ACCA,W
003C 00AC          00092          SUBWF   ACCC, F
003D 0503          00093          SETC                 ;SHIFT A 1 INTO B (RESULT)
003E 036B          00094 NOGO     RLF     ACCB+1, F
003F 036A          00095          RLF     ACCB, F
0040 02F4          00096          DECFSZ  TEMP, F      ;LOOP UNTILL ALL BITS CHECKED
0041 0A28          00097          GOTO    DLOOP
0042 0800          00098          RETLW   0
                   00099
0043 0C0E          00100 DSCHRG   MOVLW   B'00001110'  ;DISCHARGE C (RA0 ON)
0044 0005          00101          TRIS    5
0045 0CFF          00102          MOVLW   0FF
0046 0034          00103          MOVWF   TEMP
0047 02F4          00104 LOOP     DECFSZ  TEMP, F      ;WAIT
0048 0A47          00105          GOTO    LOOP
0049 0C0F          00106          MOVLW   B'00001111'  ;ALL RA HIGH Z
004A 0005          00107          TRIS    5
004B 0800          00108          RETLW   0
                   00109
004C 0061          00110 M_TIME   CLRF    1            ;CLEAR TMR0 REGISTER
004D 0069          00111          CLRF    ACCA+1       ;CLEAR 16 BIT COUNTER
004E 0068          00112          CLRF    ACCA
004F 03E9          00113 TLOOP    INCFSZ  ACCA+1, F
0050 0A54          00114          GOTO    ENDCHK
0051 03E8          00115          INCFSZ  ACCA, F
0052 0A54          00116          GOTO    ENDCHK
0053 0A56          00117          GOTO    END_M
0054 0701          00118 ENDCHK   BTFSS   1,0          ;CHECK FOR TMR0 TRIP
0055 0A4F          00119          GOTO    TLOOP
0056 0201          00120 END_M    MOVF    1,W
```

```
0057 0800           00121          RETLW   0
                    00122
0058 0C06           00123 VOLTS    MOVLW   B'00000110'  ;SET S2 AND S3 HIGH(ON WHEN ACTIVATED)
0059 0026           00124          MOVWF   6
005A 0CF0           00125          MOVLW   B'11110000'  ;ACTIVATE SWITCHES S1-S4
005B 0006           00126          TRIS    6
005C 0C28           00127          MOVLW   B'00101000'  ;SELECT POSITIVE EDGE FOR TMR0
005D 0002           00128          OPTION
005E 0C00           00129          MOVLW   B'00000000'
005F 0025           00130          MOVWF   5            ;SET RA0 LOW (ON WHEN ACTIVATED)
                    00131
0060 0943           00132 MEAS     CALL    DSCHRG       ;CHARGE CAPACITOR TO VIN
0061 0C0A           00133          MOVLW   B'00001010'  ;S2 AND S4 ON
0062 0026           00134          MOVWF   6
0063 094C           00135          CALL    M_TIME       ;MEASURE TIME
0064 0209           00136          MOVF    ACCA+1,W
0065 0033           00137          MOVWF   TMEAS+1      ;STORE LSB
0066 0208           00138          MOVF    ACCA,W
0067 0032           00139          MOVWF   TMEAS        ;STORE MSB
                    00140
0068 0C05           00141 CAL      MOVLW   B'00000101'  ;S1 AND S3 ON
0069 0026           00142          MOVWF   6
006A 0943           00143          CALL    DSCHRG       ;CHARGE CAPACITOR TO VREF
006B 0C09           00144          MOVLW   B'00001001'  ;S1 AND S4 ON
006C 0026           00145          MOVWF   6
006D 094C           00146          CALL    M_TIME       ;MEASURE TIME
                    00147
006E 0CA4           00148          MOVLW   VCALLS
006F 002B           00149          MOVWF   ACCB+1
0070 0C60           00150          MOVLW   VCALMS
0071 002A           00151          MOVWF   ACCB
                    00152
0072 0908           00153          CALL    MPY          ;MULTIPLY ACCA(TCAL) * ACCB(VREF)
0073 0213           00154          MOVF    TMEAS+1,W
0074 0029           00155          MOVWF   ACCA+1
0075 0212           00156          MOVF    TMEAS,W
0076 0028           00157          MOVWF   ACCA
                    00158
0077 0923           00159          CALL    DIV          ;DIVIDE ACCB(TCAL * V) BY ACCA(TMEAS)
                    00160
0078 0A58           00161          GOTO VOLTS
                    00162
                    00163          END

MEMORY USAGE MAP ('X' = Used,  '-' = Unused)

0000 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0040 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXX-------
01C0 : ---------------- ---------------- ---------------- ---------------X

All other memory blocks unused.

Program Memory Words Used:   122
Program Memory Words Free:   390


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     0 suppressed
```

Note the following details of the code protection feature on PICmicro® MCUs.

- 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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New York
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Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

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Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401, 24th Floor,
Ming Xing Financial Tower
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Chengdu 610016, China
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No. 71 Wusi Road
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Room 701, Bldg. B
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Shenzhen 518001, China
Tel: 86-755-2350361 Fax: 86-755-2366086

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Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

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Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
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200 Middle Road
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Germany
Microchip Technology GmbH
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D-81739 Munich, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom
Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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