MICROCHIP

AN546

Using the Analog-to-Digital (A/D) Converter

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INTRODUCTION

This application note is intended for PIC16C7X users with some degree of familiarity with analog system design. The various sections discuss the following topics:

- Commonly used A/D terminology
- How to configure and use the PIC16C71 A/D
- Various ways to generate external reference voltage (VREF)
- Configuring the RA3:RA0 pins

COMMONLY USED A/D TERMINOLOGY

The Ideal Transfer Function

In an A/D converter, an analog voltage is mapped into an N-bit digital value. This mapping function is defined as the transfer function. An ideal transfer is one in which there are no errors or non-linearity. It describes the "ideal" or intended behavior of the A/D. Figure 1 shows the ideal transfer function for the PIC16C7X A/D.

Note that the digital output value is 00h for the analog input voltage range of 0 to 1LSb. In some converters, the first transition point is at 0.5LSb and not at 1LSb as shown in Figure 2. Either way, by knowing the transfer function the user can appropriately interpret the data.

Transition Point

The analog input voltage at which the digital output switches from one code to the next is called the "Transition Point." The transition point is typically not a single threshold, but rather a small region of uncertainty (Figure 3). The transition point is therefore defined as the statistical average of many conversions. Stated differently, it is the voltage input at which the uncertainty of the conversion is 50%.

Code Width

The distance (voltage differential) between two transition points is called the "Code Width." Ideally the Code Width should be 1LSb (Figure 1).

FIGURE 1: PIC16C7X IDEAL TRANSFER FUNCTION

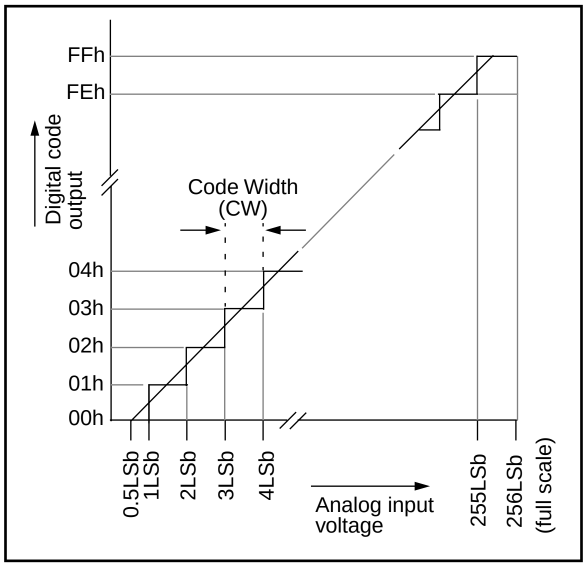
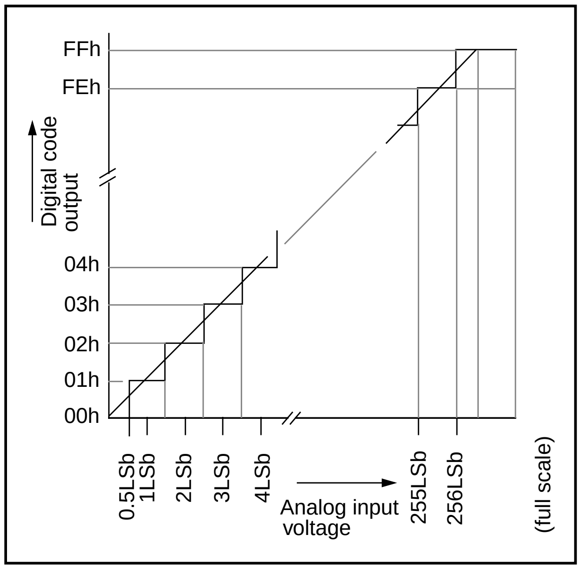


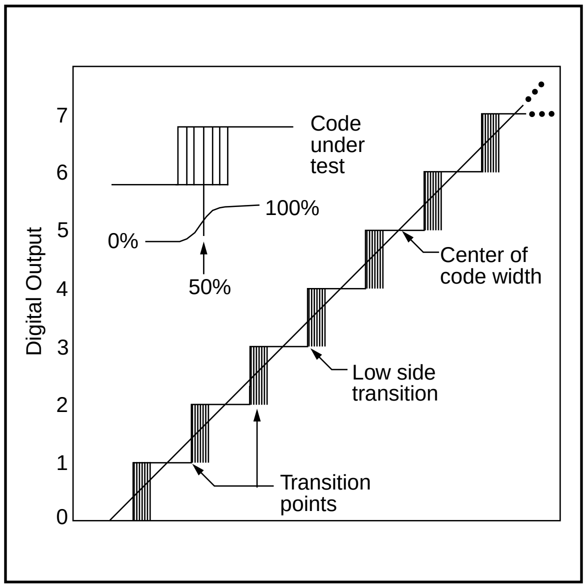
FIGURE 2: ALTERNATE TRANSFER FUNCTION



Center of Code Width

The midpoint between two transition points is called the "Center of Code Width" (Figure 3).

FIGURE 3: TRANSITION POINTS



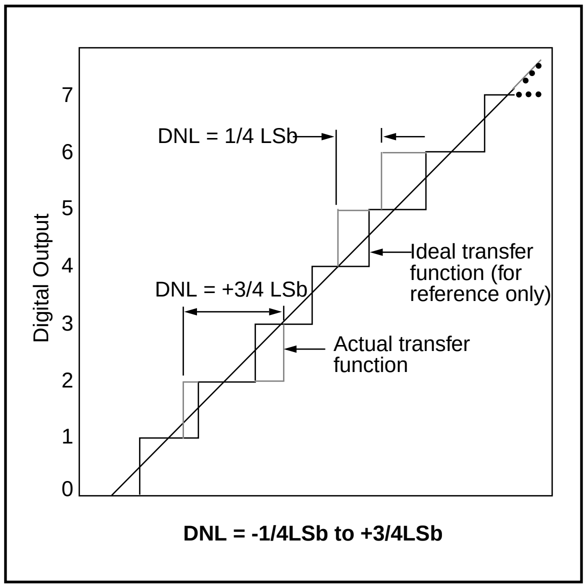
Differential Non-Linearity (DNL)

It is the deviation in code-width from 1LSb (Figure 4). The difference is calculated for each and every transition. The largest difference is reported as DNL.

It is important to note that the DNL is measured after the transfer function is normalized to match offset error and gain error.

Note that the DNL cannot be any less than -1LSb. In the other direction, DNL can be >1LSb.

FIGURE 4: DIFFERENTIAL NON-LINEARITY



Absolute Error

The maximum deviation between any transition point from the corresponding ideal transfer function is defined as the absolute error. This is how it is measured and reported in the PIC16C7X (Figure 5). The notable difference between absolute error and integral non-linearity (INL) is that the measured data is not normalized for full scale and offset errors in absolute error.

Absolute Error is probably the first parameter the user will review to evaluate an A/D. Sometimes absolute error is reported as the sum of offset, full-scale and integral non-linearity errors.

Total Unadjusted Error

Total Unadjusted Error is the same as absolute error. Again, sometimes it is reported as the sum of offset, full-scale and integral non-linearity errors.

No Missing Code

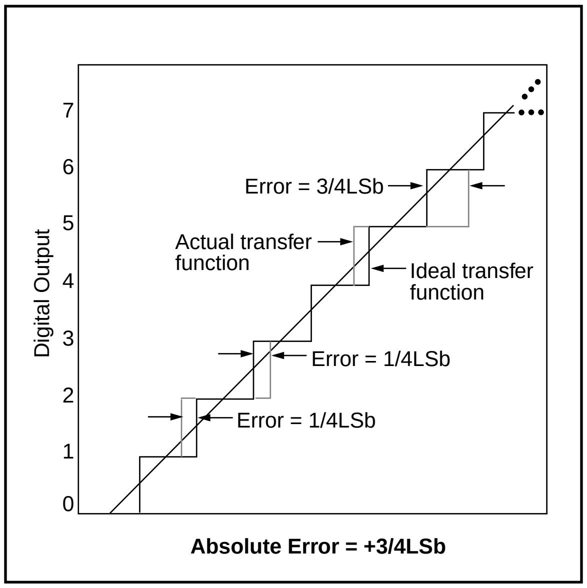
No missing code implies that as the analog input voltage is gradually increased from zero to full scale (or vice versa), all digital codes are produced. Stated otherwise, changing analog input voltage from one quantum of the analog range to the next adjacent range will not produce a change in the digital output by more than one code count.

Monotonic

Monotonicity guarantees that an increase (or decrease) in the analog input value will result in an equal or greater digital code (or less). Monotonicity does not guarantee that there are no missing codes. However, it is an important criterion for feedback control systems. Non-monotonicity may cause oscillations in such systems.

The first derivative of a monotonic function always has the same sign.

FIGURE 5: ABSOLUTE ERROR



Ratiometric Conversion

Ratiometric Conversion is the A/D conversion process in which the binary result is a ratio of the supply voltage or reference voltage, the latter being equal to full-scale value by default. The PIC16C7X is a ratiometric A/D converter where the result depends on VDD or VREF.

In some A/Ds, an absolute reference is provided resulting in "absolute conversion".

Sample and Hold

In sample and hold type A/D converters, the analog input has a switch (typically a FET switch in CMOS) which is opened for a short duration to capture the analog input voltage onto an on-chip capacitor. Conversion is typically started after the sampling switch is closed.

Track and Hold

Track and Hold is basically the same as sample and hold, except the sampling switch is typically left on. Therefore the voltage on the on-chip holding capacitor "tracks" the analog input voltage. To begin a conversion, the sampling switch is closed.

The PIC16C7X A/D falls in this category.

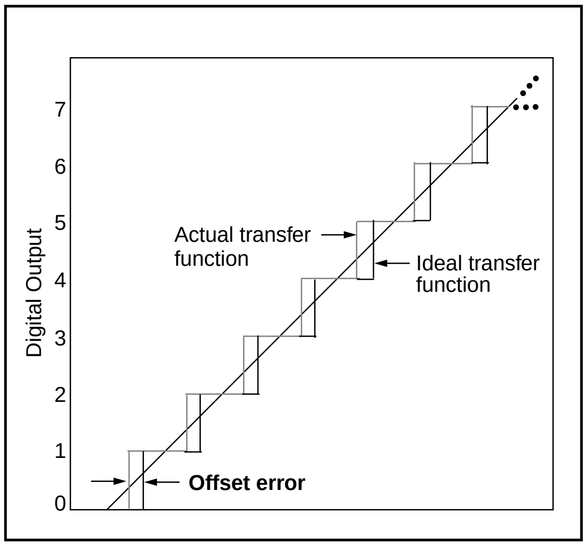
Sampling Time

Sampling Time is the time required to charge the on-chip holding capacitor to the same value as is on the analog input pin. The sampling time depends on the magnitude of the holding capacitor and the source impedance of the analog voltage input.

Offset Error (or Zero Error)

Offset Error is the difference between the first actual (measured) transition point and the first ideal transition point as shown in Figure 6. It can be corrected (by the user) by subtracting the offset error from each conversion result.

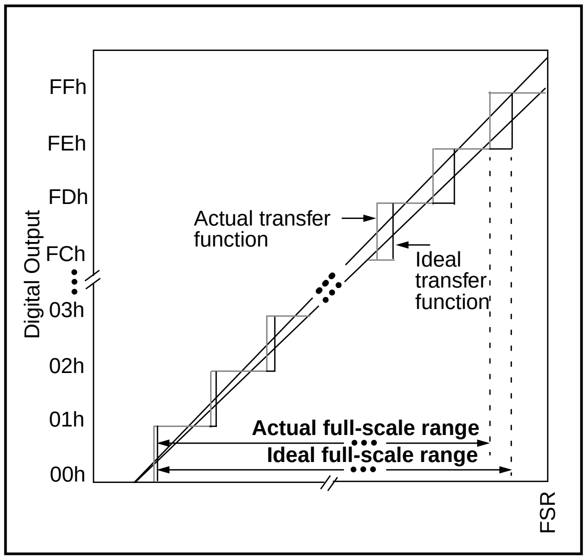
FIGURE 6: OFFSET ERROR



Full Scale Error (or Gain Error)

Full Scale Error is the difference between the ideal full scale and the actual (measured) full scale range (Figure 7). It is also called gain error, because the error changes the slope of the ideal transfer function creating a gain factor. It can be corrected (by the user) by multiplying each conversion result by the inverse of the gain.

FIGURE 7: FULL SCALE ERROR

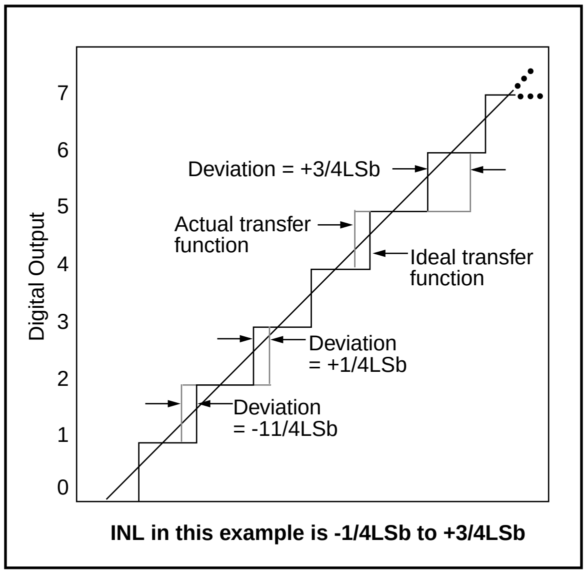


Integral Non-Linearity (INL), or Relative Error

The deviation of a transition point from its corresponding point on the ideal transfer curve is called "Integral Non-Linearity" (Figure 8). The maximum difference is reported as the INL of the converter.

It is important to note that Full Scale Error and the Offset Error are normalized to match end transition points before measuring the INL.

FIGURE 8: INTEGRAL NON-LINEARITY



HOW TO USE THE PIC16C71 A/D

The A/D in the PIC16C71 is easy to set up and use. There are a few considerations:

1. Select either VDD or VREF as reference voltage. (More on using VREF input later)

   Select A/D conversion clock (TAD): 2TOSC, 8TOSC, TOSC or TRC (internal RC clock). For the first three options, make sure that TAD ≥ 2.0 µs. If deterministic conversion time is required, select TOSC time-base. If conversion during SLEEP is required, select TRC.
2. Channel Selection: If only one A/D channel is required, program the ADCON1 register to 03h. This configures the A/D pins as digital I/O. If multiple channels are required, prior to each conversion the new channel must be selected.
3. Sampling and Conversion: After a new channel is selected, a minimum amount of sampling time must be allowed before the GO/$\overline{\text{DONE}}$ bit in ADCON0 is set to begin conversion. Once conversion begins, it is OK to select the next channel, ***but sampling does not begin until current conversion is complete***. Therefore, it is always necessary to ensure the minimum sampling time is provided for:

   i) after a conversion
   ii) after a new channel is selected
   iii) after A/D is turned on (bit ADON = 1)
4. Reading Result: Completion of a conversion can be determined by polling the GO/$\overline{\text{DONE}}$ bit (cleared), or polling flag bit ADIF (set), or waiting for an ADIF interrupt.

Additional tips:

a) Do not set bits GO/$\overline{\text{DONE}}$ and ADON in the same instruction. First, turn the A/D is on by setting bit ADON. Then allow at least 5 µs before conversion begins (setting the GO/$\overline{\text{DONE}}$ bit), longer if sampling time requirement is not met within 5 µs.

b) Aborting a conversion: A conversion can be aborted by clearing bit GO/$\overline{\text{DONE}}$. The A/D converter will stop conversion and revert back to sampling state.

c) Using the ADRES register as a normal register: The A/D only writes to the ADRES register at the end of a conversion. Therefore, it is possible to use the ADRES register as a normal file register between conversions and when A/D is off.

The following four examples provide sample code on using the A/D module.

EXAMPLE 1: HOW TO DO A SAMPLE A/D CONVERSION

```
;
;     InitializeAD, initializes and sets up the A/D hardware.
;     Always ch2, internal RC OSC.
InitializeAD
          bsf       STATUS, 5       ; select Bank1
          movlw     b'00000000'     ; select RA3-RA0
          movwf     ADCON1          ; as analog inputs
          bcf       STATUS, 5       ; select Bank0
          movlw     b'11010001'     ; select: RC osc, ch2...
          movwf     ADCON0          ; turn on A/D
Convert   call      sample-delay    ; provide necessary sampling time
;
          bsf       ADCON0, 2       ; start new A/D conversion
loop
          btfsc     ADCON0, 2       ; A/D over?
          goto      loop            ; no then loop
;
          movf      adres, w        ; yes then get A/D value
;
```

A detailed code listing is provided in Appendix A.

EXAMPLE 2: SEQUENTIAL CHANNEL CONVERSIONS

```
;
;     InitializeAD, initializes and sets up the A/D hardware.
;     Select ch0 to ch3 in a round robin fashion, internal RC OSC.
;     Load results in 4 consecutive addresses starting at ADTABLE (10h)
;
InitializeAD
          bsf       STATUS, RP0      ; select Bank1
          movlw     b'00000000'      ; select RA3-RA0
          movwf     ADCON1           ; as analog inputs
          bcf       STATUS, RP0      ; select Bank0
          movlw     b'11000001'      ; select: RC osc, ch0...
          movwf     ADCON0           ; turn on A/D
          movlw     ADTABLE          ; point fsr to top of...
          movwf     FSR              ; table
;
new_ad    call      sample_delay     ; provide necessary sampling time
          bsf       ADCON0, GO       ; start new A/D conversion
loop
          btfsc     ADCON0, GO       ; A/D over?
          goto      loop             ; no then loop
;
          movf      adres, w         ; yes then get A/D value
          movwf     0                ; load indirectly
          movlw     4                ; select next channel
          addwf     ADCON0           ;     /
          bcf       ADCON0, ADIF     ; reset interrupt flag bit.
; increment pointer to correct table offset.
          clrf      temp             ; clear temp register
          btfsc     ADCON0, CH50     ; test lsb of channel select
          bsf       temp, 0          ; set if ch1 selected
          btfsc     ADCON0, CH51     ; test msb of channel select
          bsf       temp, 1          ;     /
          movlw     ADTABLE          ; get table address
          addwf     temp, w          ; add with temp
          movwf     FSR              ; move into indirect
          goto      new_ad
;
```

A detailed code listing is provided in Appendix B.

EXAMPLE 3: SAMPLE INTERRUPT HANDLER FOR THE A/D

```
          org      0x00
          goto     start
          org      0x04
          goto     service_ad      ; interrupt vector
;
;         org      0x10
start
          movlw    b'00000000'     ;init I/O ports
          movwf    PORT_B
          tris     PORT_B
;
          call     InitializeAD
update
          bcf      flag, adover    ; reset software A/D flag
          call     SetupDelay      ; setup delay >= 10uS.
          bcf      ADCON0, adif    ; reset A/D int flag (ADIF
          bsf      ADCON0, go      ; start new A/D conversion
          bsf      INTCON, gie     ; enable global interrupt
loop
          btfsc    flag, adover    ; A/D over?
          goto     update          ; yes start new conv.
          goto     loop            ; no then keep checking
; InitializeAD, initializes and sets up the A/D hardware.
; select ch0 to ch3, RC OSC., a/d interrupt.
InitializeAD
          bsf      STATUS, RP0     ; select Bank1
          movlw    b'00000000'     ; select RA0-RA3...
          movwf    ADCON1          ; as analog inputs
          bcf      STATUS, RP0     ; select Bank0
          clrf     INTCON          ; clr all interrupts
          bsf      INTCON, ADIE    ; enable A/D int.
          movlw    b'11010001'     ; select: RC osc, ch2...
          movwf    ADCON0          ; turn on A/D
          return
;
service_ad
          btfss    ADCON0, ADIF    ; A/D interrupt?
          retfie                   ; no then ignore
          movf     ADRES, W        ; get A/D value
          return                   ; do not enable int
;
```

A detailed code listing is provided in Appendix C.

EXAMPLE 4: CONVERSIONS DURING SLEEP MODE

```
;
;     InitializeAD, initializes and sets up the A/D hardware.
;     Select ch0 to ch3, internal RC OSC.
;     While doing the conversion put unit to sleep.  This will
;     minimize digital noise interference.
;     Note that A/D's RC osc. has to be selected in this instance.
;
InitializeAD
          bsf       STATUS, RP0     ; select Bank1
          movlw     b'00000000'     ; select RA0-RA3...
          movwf     ADCON1          ; as analog inputs
          bcf       STATUS, RP0     ; select Bank0
          movlw     b'11000001'     ; select: RC osc, ch0...
          movwf     ADCON0          ; turn on A/D & ADIE
          movlw     ADTABLE         ; point fsr to top of...
          movwf     FSR             ; table
;
new_ad
          bsf       ADCON0, GO      ; start new A/D conversion
          sleep                     ; goto sleep
; when A/D is over program will continue from here
;
          movf      ADRES, w        ; get A/D value
;
```

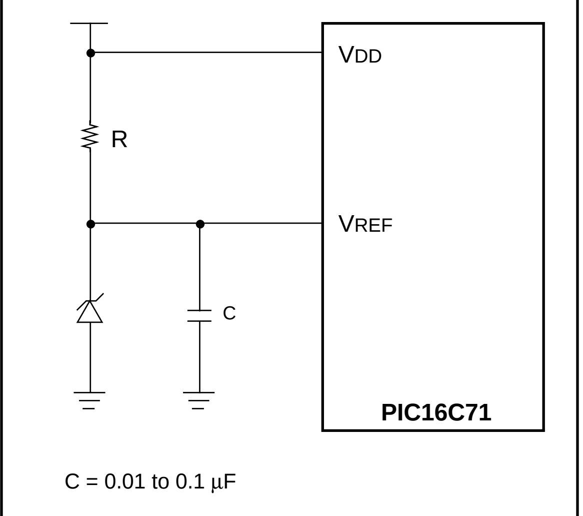
A detailed code listing is provided in Appendix D.

USING EXTERNAL REFERENCE VOLTAGE

When using the external reference voltage, keep in mind that any analog input voltage must not exceed VREF.

An inexpensive way to generate VREF is by employing a zener diode (Figure 9). Most common zener diodes offer 5% accuracy. Reverse bias current may be as low as 10 µA. However, larger currents (1 mA - 20 mA) are recommended for stability, as well as lower impedance of the VREF source.

FIGURE 9: LOW COST VOLTAGE REFERENCE



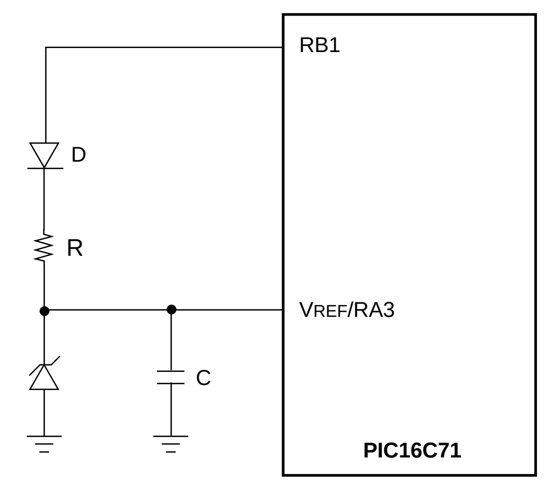
POWER MANAGEMENT IN USING VREF

In power sensitive applications, the user may turn on a VREF generator using another I/O pin (Figure 10). Drive a '1' on pin RB1, in this example, when using the A/D. Drive a '0' on pin RB1 when not using the A/D converter.

Note that this way RB1 is not floating. Even if VREF decays to some intermediate voltage, it will not cause the input buffer on RB1 to draw current.

Alternately, use RA0, RA1 or RA2 pin to supply the current instead of RB1. Configure the RA pin as analog (this will turn off its input buffer). Then use it as a digital output (Figure 11).

FIGURE 10: POWER-SENSITIVE APPLICATIONS #1



ZENERS AND REFERENCE GENERATORS

Finally, various reference voltage generator chips (typically using on-chip band-gap reference) are available. They are more accurate.

TABLE 1: ZENERS AND REFERENCE GENERATORS

Zeners	Vz	Tolerance
1N746	3.3V	±5%
1N747	3.6V	±5%
1N748	3.9V	±5%
1N749	4.3V	±5%
1N750	4.7V	±5%
1N751	5.1V	±5%
1N752	5.6V	±5%
Voltage Reference	**VREF**	**Tolerance**
AD580 (Maxim)	2.5V	±3% to ±0.4%
LM385	2.5V	±1.5%
LM1004	2.5V	±1.2%
LT1009 (LIN. Tech.)	2.5V	±0.2%
LT1019 (LIN. Tech.)	5.0V	±0.2%
LT1021 (LIN. Tech.)	5.0V	±0.05% to ±1%
LT1029 (LIN. Tech.)	5.0V	±0.2% to ±1%

VREF IMPEDANCE AND CURRENT SUPPLY REQUIREMENTS

Ideally, VREF should have as low a source impedance as possible. Referring to Figure 9, VREF source impedence ≈ R. However, smaller R increases current consumption. Since VREF is used to charge capacitor arrays inside the A/D converter and the holding capacitor, Chold ≈ 51 pF, the following guideline should be met:

$$T_{AD} = 6(1k + R)51.2pF + 1.677\mu s$$

TAD = conversion clock. For TAD = 2 µs and for CHOLD = 50 pF, VREF ≈ 50Ω.

For VREF impedance higher than this, the conversion clock (TAD) should be increased appropriately.

FIGURE 11: POWER-SENSITIVE APPLICATIONS #2

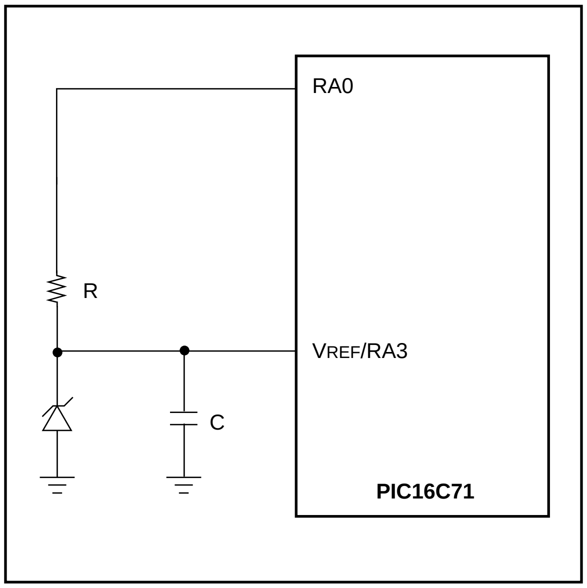


Table 2 gives examples of the maximum rate of conversion per bit, relating to the voltage reference impedance.

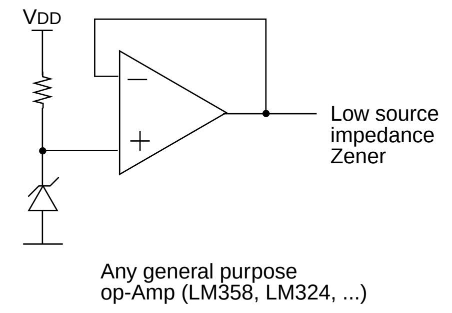
TABLE 2: MAXIMUM RATE OF CONVERSION / BIT

RVREF	TAD (Max)
1k	2.29 µs
5k	3.52 µs
10k	5.056 µs
50k	16.66 µs
100k	32.70 µs

Assumes no external capacitors

To achieve a low source impedance when using a Zener diode, a voltage follower circuit is recommended. This is shown in Figure 12.

FIGURE 12: VOLTAGE FOLLOWER CIRCUIT


VDD
Low source impedance Zener
Any general purpose op-Amp (LM358, LM324, ...)

CONFIGURING PORTA INPUTS AS ANALOG OR DIGITAL

Two bits in the ADCON1 register, PCFG1 and PCFG0, control how pins RA3:RA0 are configured.

When any of these pins are selected as analog:

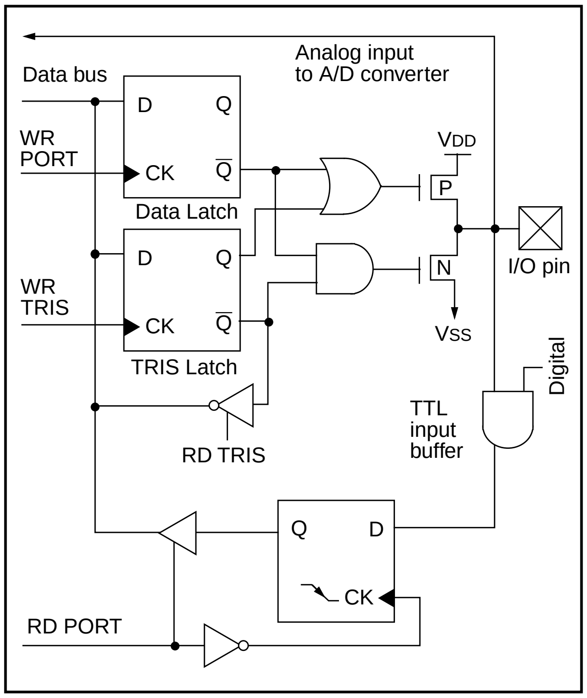
- The digital input buffer is turned off to save current (Figure 13). Reading the port will read this pin as '0'.
- The TRIS bit still controls the output buffer on this pin. So, normally the TRIS bit will be set (input).
- However, if the TRIS bit is cleared, then the pin will output whatever is in the data latch.

When any of these pins are selected as digital:

- The analog input still directly connects to the A/D and therefore the pin can be used as analog input.
- The digital input buffer is not disabled.

The user has, therefore, great flexibility in configuring these pins.

FIGURE 13: BLOCK DIAGRAM OF RA3:RA0 PINS



CURRENT CONSUMPTION THROUGH INPUT BUFFER

A CMOS input buffer will draw current when the input voltage is near its threshold (Figure 14).

In power-sensitive applications, the RA pins, when used as analog inputs, should be configured as "analog" to avoid unintended power drain.

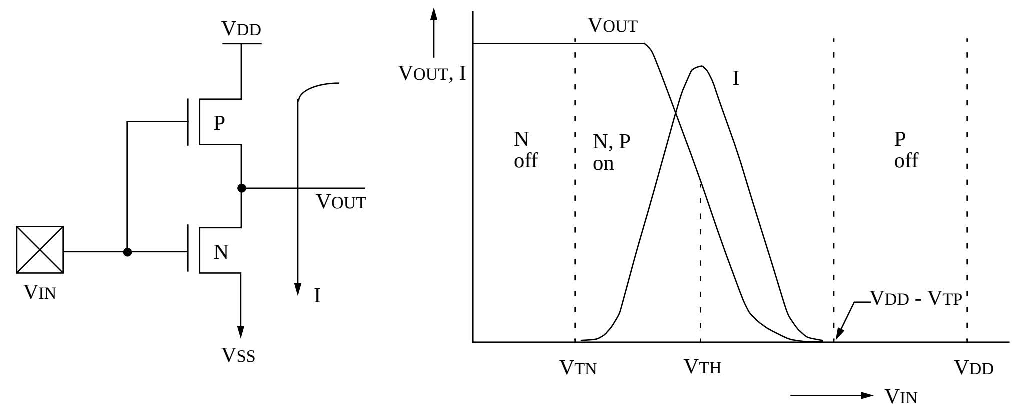
Other considerations and tips:

1. If possible, avoid any digital output next to analog inputs.
2. Avoid digital inputs that switch frequently (e.g., clocks) next to analog inputs.
3. If V_{REF} is used, then ensure that no analog pin being sampled exceeds V_{REF}.

SUMMARY

The PIC16C71 A/D converter is simple to use. It is versatile and has low power consumption.

FIGURE 14: A SIMPLE CMOS INPUT BUFFER



V_{TH} =	Threshold of the inverter
V_{TN} =	Device threshold of NMOS pull-down
$-V_{TP}$ =	Device threshold of PMOS pull-up
I =	On-current (or through current) of the inverter
I_{MAX} =	Maximum on-current occurs when $V_{IN} = V_{TH}$. Value of I_{MAX} depends on the sizes of the devices. The larger the devices, the faster the input buffer, and the larger the value of I_{MAX}. Typically, I_{MAX} is 0.2 mA – 1 mA.

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: SINGLE CHANNEL A/D (SAD)

```
MPASM 01.40 Released              SAD.ASM   1-16-1997  15:22:04         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                    00001 ;TITLE   "Single channel A/D (SAD)"
                    00002 ;This program is a simple implementation of the PIC16C71's
                    00003 ;A/D. 1 Channel is selected (CH0).
                    00004 ;The A/D is configured as follows:
                    00005 ;       Vref = +5V internal.
                    00006 ;       A/D Osc. =  internal RC
                    00007 ;       A/D Channel = CH0
                    00008 ;Hardware for this program is the PICDEM1 board.
                    00009 ;
                    00010 ;
                    00011 ;       Program:          SAD.ASM
                    00012 ;       Revision Date:
                    00013 ;                         1-14-97      Compatibility with MPASMWIN 1.40
                    00014 ;
                    00015 ;
                    00016         LIST P=16C71
                    00017         ERRORLEVEL  -302
                    00018 ;
                    00019         include "p16c71.inc"
                    00001         LIST
                    00002 ;P16C71.INC  Standard Header File, Version 1.00 Microchip Technology
                    00142         LIST
                    00020 ;
  00000010          00021 TEMP    EQU     10h
  00000001          00022 adif    equ     1
  00000002          00023 adgo    equ     2
                    00024 ;
0000                00025         ORG     0x00
                    00026 ;
                    00027 ;
0000 2810           00028         goto    start
                    00029 ;
0004                00030         org     0x04
0004 281E           00031         goto    service_int      ;interrupt vector
                    00032 ;
                    00033 ;
0010                00034         org     0x10
0010                00035 start
0010 3000           00036         movlw   B'00000000'     ;set port b as
0011 0086           00037         movwf   PORTB           ;all outputs
                    00038 ;       tris    PORTB           ;       /
0012 1683           00039         BSF     STATUS, RP0     ; Bank1
0013 0086           00040         MOVWF   TRISB           ; PortB as outputs
0014 1283           00041         BCF     STATUS, RP0     ; Bank0
                    00042 ;
0015 201F           00043         call    InitializeAD
0016                00044 update
0016 0809           00045         movf    ADRES,W         ;get a/d value
0017 0086           00046         movwf   PORTB           ;output to port b
0018 2027           00047         call    SetupDelay      ;setup time >= 10uS.
0019 1088           00048         bcf     ADCON0,adif     ;clear int flag
001A 1508           00049         bsf     ADCON0,adgo     ;start new conversion
001B                00050 loop
001B 1888           00051         btfsc   ADCON0,adif     ;a/d done?
001C 2816           00052         goto    update          ;yes then update new value.
```

```
001D 281B                  goto    loop            ;no then keep checking
                   ;
                   ;no interrupts are enabled, so if the program ever reaches here,
                   ;it should be returned with the global interrupts disabled.
001E               service_int
001E 0008                  return                  ;do not enable global.
                   ;
                   ;
                   ;
                   ;InitializeAD, initializes and sets up the A/D hardware.
                   ;Select ch0 to ch3 as analog inputs, fosc/2 and read ch3.
                   ;
001F               InitializeAD
001F 1683                  bsf     STATUS,5        ;select Bank1
0020 3000                  movlw   B'00000000'     ;select ch0-ch3...
0021 0088                  movwf   ADCON1          ;as analog inputs
0022 1283                  bcf     STATUS,5        ;select Bank0
0023 30C1                  movlw   B'11000001'     ;select:RC,ch0..
0024 0088                  movwf   ADCON0          ;turn on A/D.
0025 0189                  clrf    ADRES           ;clr result reg.
0026 0008                  return
                   ;
                   ;This routine is a software delay of 10uS for the a/d setup.
                   ;At 4Mhz clock, the loop takes 3uS, so initialize TEMp with
                   ;a value of 3 to give 9uS, plus the move etc should result in
                   ;a total time of > 10uS.
0027               SetupDelay
0027 3003                  movlw   .3
0028 0090                  movwf   TEMP
0029               SD
0029 0B90                  decfsz  TEMP, F
002A 2829                  goto    SD
002B 0008                  return


                           END

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

0000 : X---X----------- XXXXXXXXXXXXXXXX XXXXXXXXXXXX---- ----------------

All other memory blocks unused.

Program Memory Words Used:    30
Program Memory Words Free:   994


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     2 suppressed
```

APPENDIX B: SLPAD.ASM

```
MPASM 01.40 Released            SLPAD.ASM   1-16-1997  15:22:32         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                    00001
                    00002 ;TITLE   "A/D in Sleep Mode"
                    00003 ;This program is a simple implementation of the PIC16C71's
                    00004 ;A/D feature. This program demonstrates
                    00005 ;how to do a a/d in sleep mode on the PIC16C71.
                    00006 ;The A/D is configured as follows:
                    00007 ;       Vref = +5V internal.
                    00008 ;       A/D Osc. = internal RC
                    00009 ;       A/D Interrupt = OFF
                    00010 ;       A/D Channels = ch 0
                    00011 ;
                    00012 ;The ch0 A/D result is displayed as a 8 bit binary value
                    00013 ;on 8 leds connected to port b. Hardware used is that of
                    00014 ;the PICDEMO board.
                    00015 ;
                    00016 ;
                    00017 ;       Program:          SLPAD.ASM
                    00018 ;       Revision Date:
                    00019 ;                         1-14-97      Compatibility with MPASMWIN 1.40
                    00020 ;
                    00021 ;
                    00022         LIST P=16C71
                    00023         ERRORLEVEL -302
                    00024 ;
                    00025         include "p16c71.inc"
                    00001         LIST
                    00002 ;P16C71.INC  Standard Header File, Version 1.00 Microchip Technology
                    00142         LIST
                    00026 ;
  00000010          00027 TEMP    EQU     10h
  00000001          00028 adif    equ     1
  00000002          00029 adgo    equ     2
                    00030 ;
                    00031 ;
0000                00032         ORG     0x00
                    00033 ;
                    00034 ;
0000 2810           00035         goto    start
                    00036 ;
0004                00037         org     0x04
0004 281D           00038         goto    service_int      ;interrupt vector
                    00039 ;
                    00040 ;
0010                00041         org     0x10
0010                00042 start
0010 3000           00043         movlw   B'00000000'     ;make port b all
0011 0086           00044         movwf   PORTB           ;outputs.
                    00045 ;       tris    PORTB           ;       /
0012 1683           00046         BSF     STATUS, RP0     ; Bank1
0013 0086           00047         MOVWF   TRISB           ; PortB as outputs
0014 1283           00048         BCF     STATUS, RP0     ; Bank0
                    00049 ;
0015 201E           00050         call    InitializeAD
0016                00051 update
```

```
0016 0809           00052         movf    ADRES,W
0017 0086           00053         movwf   PORTB            ;save in table
0018 2027           00054         call    SetupDelay       ;
0019 1088           00055         bcf     ADCON0,adif      ;clr a/d flag
001A 1508           00056         bsf     ADCON0,adgo      ;start new a/d conversion
                    00057 ;
001B 0063           00058         sleep
001C 2816           00059         goto    update           ;wake up and update
                    00060 ;
001D                00061 service_int
001D 0008           00062         return                   ;do not enable int
                    00063 ;
                    00064 ;InitializeAD, initializes and sets up the A/D hardware.
001E                00065 InitializeAD
001E 1683           00066         bsf     STATUS,5         ;select Bank1
001F 3000           00067         movlw   B'00000000'      ;select ch0-ch3...
0020 0088           00068         movwf   ADCON1           ;as analog inputs
0021 1283           00069         bcf     STATUS,5         ;select Bank0
0022 30C1           00070         movlw   B'11000001'      ;select:internal RC, ch0.
0023 0088           00071         movwf   ADCON0           ;turn on a/d
0024 018B           00072         clrf    INTCON           ;clear all interrupts
0025 170B           00073         bsf     INTCON,ADIE      ;enable a/d
0026 0008           00074         return
                    00075 ;
                    00076 ;This routine is a software delay of 10uS for the a/d setup.
                    00077 ;At 4Mhz clock, the loop takes 3uS, so initialize TEMP with
                    00078 ;a value of 3 to give 9uS, plus the move should result in
                    00079 ;a total time of > 10uS.
0027                00080 SetupDelay
0027 3003           00081         movlw   .3
0028 0090           00082         movwf   TEMP
0029                00083 SD
0029 0B90           00084         decfsz  TEMP, F
002A 2829           00085         goto    SD
002B 0008           00086         return
                    00087
                    00088 ;
                    00089
                    00090         END


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

0000 : X---X----------- XXXXXXXXXXXXXXXX XXXXXXXXXXXX---- ----------------

All other memory blocks unused.

Program Memory Words Used:    30
Program Memory Words Free:   994


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     2 suppressed
```

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 C: INTAD.ASM

```
MPASM 01.40 Released            INTAD.ASM   1-16-1997  15:21:10         PAGE  1

LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                    00001
                    00002 ;TITLE   "Single channel A/D with interrupts"
                    00003 ;This program is a simple implementation of the PIC16C71's
                    00004 ;A/D. 1 Channel is selected (CH0). A/D interrupt is turned on,
                    00005 ;hence on completion of a/d conversion, an interrupt is generated.
                    00006 ;The A/D is configured as follows:
                    00007 ;       Vref = +5V internal.
                    00008 ;       A/D Osc. = internal RC Osc.
                    00009 ;       A/D Interrupt = On
                    00010 ;       A/D Channel = CH0
                    00011 ;
                    00012 ;The A/D result is displayed as a 8 bit value on 8 leds connected
                    00013 ;to port b. Hardware setup is the PICDEMO board.
                    00014 ;
                    00015 ;
                    00016 ;       Program:          INTAD.ASM
                    00017 ;       Revision Date:
                    00018 ;                         1-14-97      Compatibility with MPASMWIN 1.40
                    00019 ;
                    00020 ;
                    00021         LIST P=16C71
                    00022         ERRORLEVEL  -302
                    00023 ;
                    00024         include "p16c71.inc"
                    00001         LIST
                    00002 ; P16C71.INC  Standard Header File, Version 1.00  Microchip Technology
                    00142         LIST
                    00025 ;
  00000010          00026 flag    equ     10
  00000011          00027 TEMP    equ     11
  00000000          00028 adover  equ     0
  00000001          00029 adif    equ     1
  00000002          00030 adgo    equ     2
  00000006          00031 adie    equ     6
  00000007          00032 gie     equ     7
  00000005          00033 rp0     equ     5
                    00034 ;
0000                00035         ORG     0x00
                    00036 ;
                    00037 ;
0000 2810           00038         goto    start
                    00039 ;
0004                00040         org     0x04
0004 281E           00041         goto    service_ad      ;interrupt vector
                    00042 ;
                    00043 ;
0010                00044         org     0x10
0010                00045 start
0010 3000           00046         movlw   B'00000000'     ;init i/o ports
0011 0086           00047         movwf   PORTB
                    00048 ;       tris    PORTB
0012 1683           00049         BSF     STATUS, RP0     ; Bank1
0013 0086           00050         MOVWF   TRISB           ; PortB as outputs
0014 1283           00051         BCF     STATUS, RP0     ; Bank0
                    00052 ;
```

```
0015 2024                   call    InitializeAD
0016                update
0016 1010                   bcf     flag,adover     ;reset software a/d flag
0017 202D                   call    SetupDelay      ;setup delay >= 10uS.
0018 1088                   bcf     ADCON0,adif     ;reset a/d int flag (ADIF)
0019 1508                   bsf     ADCON0,adgo     ;start new a/d conversion
001A 178B                   bsf     INTCON,gie      ;enable global interrupt
001B                loop
001B 1810                   btfsc   flag,adover     ;a/d over?
001C 2816                   goto    update          ;yes start new conv.
001D 281B                   goto    loop            ;no then keep checking
                    ;
001E                service_ad
001E 1C88                   btfss   ADCON0,adif     ;ad interrupt?
001F 0009                   retfie                  ;no then ignore
0020 0809                   movf    ADRES,W         ;get a/d value
0021 0086                   movwf   PORTB           ;output to port b
0022 1410                   bsf     flag,adover     ;a/d done set
0023 0008                   return                  ;do not enable int
                    ;
                    ;
                    ;InitializeAD, initializes and sets up the A/D hardware.
                    ;select ch0 to ch3, RC OSC., a/d interrupt.
0024                InitializeAD
0024 1683                   bsf     STATUS,rp0      ;select Bank1
0025 3000                   movlw   B'00000000'     ;select ch0-ch3...
0026 0088                   movwf   ADCON1          ;as analog inputs
0027 1283                   bcf     STATUS,rp0      ;select Bank0
0028 018B                   clrf    INTCON          ;clr all interrupts
0029 170B                   bsf     INTCON,adie     ;enable a/d int.
002A 30C1                   movlw   B'11000001'     ;select:RC osc,ch0...
002B 0088                   movwf   ADCON0          ;turn on a/d
002C 0008                   return
                    ;
                    ;This routine is a software delay of 10uS for the a/d setup.
                    ;At 4Mhz clock, the loop takes 3uS, so initialize TEMP with
                    ;a value of 3 to give 9uS, plus the move should result in
                    ;a total time of > 10uS.
002D                SetupDelay
002D 3003                   movlw   .3
002E 0091                   movwf   TEMP
002F                SD
002F 0B91                   decfsz  TEMP, F
0030 282F                   goto    SD
0031 0008                   return
                    ;
                    ;
                            END

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

0000 : X---X----------- XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XX--------------

All other memory blocks unused.

Program Memory Words Used:    36
Program Memory Words Free:   988


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     2 suppressed
```

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APPENDIX D: MULTAD.ASM

```
MPASM 01.40 Released           MULTAD.ASM   1-16-1997  15:21:41         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                    00001 ;TITLE   "A/D using Multiple Channels"
                    00002 ;This program is a simple implementation of the PIC16C71's
                    00003 ;A/D feature. This program demonstrates
                    00004 ;how to select multiple channels on the PIC16C71.
                    00005 ;The A/D is configured as follows:
                    00006 ;       Vref = +5V internal.
                    00007 ;       A/D Osc. = internal RC osc.
                    00008 ;       A/D Interrupt = Off
                    00009 ;       A/D Channels = all in a "Round Robin" format.
                    00010 ;       A/D reuslts are stored in ram locations as follows:
                    00011 ;       ch0 --> ADTABLE + 0
                    00012 ;       ch1 --> ADTABLE + 1
                    00013 ;       ch2 --> ADTABLE + 2
                    00014 ;       ch3 --> ADTABLE + 3
                    00015 ;
                    00016 ;The ch0 A/D result is displayed as a 8 bit value on 8 leds
                    00017 ;connected to port b.
                    00018 ;Hardware: PICDEMO board.
                    00019 ;               Stan D'Souza 7/6/93.
                    00020 ;
                    00021 ;       Program:          MULTAD.ASM
                    00022 ;       Revision Date:
                    00023 ;                         1-14-97      Compatibility with MPASMWIN 1.40
                    00024 ;
                    00025 ;
                    00026         LIST P=16C71
                    00027         ERRORLEVEL  -302
                    00028 ;
                    00029         include "p16c71.inc"
                    00001         LIST
                    00002 ;P16C71.INC  Standard Header File, Version 1.00 Microchip Technology
                    00142         LIST
                    00030 ;
  00000010          00031 TEMP    EQU     10h
  00000001          00032 adif    equ     1
  00000002          00033 adgo    equ     2
                    00034 ;
  00000006          00035 ch2     equ     6
  00000007          00036 ch3     equ     7
  0000000C          00037 flag    equ     0C
  00000020          00038 ADTABLE equ     20
                    00039 ;
0000                00040         ORG     0x00
                    00041 ;
                    00042 ;
0000 2810           00043         goto    start
                    00044 ;
0004                00045         org     0x04
0004 2825           00046         goto    service_int      ;interrupt vector
                    00047 ;
                    00048 ;
0010                00049         org     0x10
0010                00050 start
0010 3000           00051         movlw   B'00000000'     ;make port b
```

```
0011 0086           00052         movwf   PORTB          ;as all outputs
                    00053 ;       tris    PORTB          ;       /
0012 1683           00054         BSF     STATUS, RP0     ; Bank1
0013 0086           00055         MOVWF   TRISB           ; PortB as outputs
0014 1283           00056         BCF     STATUS, RP0     ; Bank0
                    00057 ;
0015 2026           00058         call    InitializeAD
0016                00059 update
0016 0809           00060         movf    ADRES,W
0017 0080           00061         movwf   0               ;save in table
0018 3020           00062         movlw   ADTABLE         ;chk if ch0
0019 0204           00063         subwf   FSR,W           ;     /
001A 1D03           00064         btfss   STATUS,Z        ;yes then skip
001B 281E           00065         goto    NextAd          ;else do next channel
001C 0809           00066         movf    ADRES,W         ;get a/d value
001D 0086           00067         movwf   PORTB          ;output to port b
001E                00068 NextAd
001E 2030           00069         call    NextChannel     ;select next channel
001F 203C           00070         call    SetupDelay      ;set up > = 10uS
0020 1088           00071         bcf     ADCON0,adif     ;clear flag
0021 1508           00072         bsf     ADCON0,adgo     ;start new a/d conversion
0022                00073 loop
0022 1888           00074         btfsc   ADCON0,adif     ;a/d done?
0023 2816           00075         goto    update          ;yes then update
0024 2822           00076         goto    loop            ;wait till done
                    00077 ;
0025                00078 service_int
0025 0008           00079         return                  ;do not enable int
                    00080 ;
                    00081 ;
                    00082 ;InitializeAD, initializes and sets up the A/D hardware.
0026                00083 InitializeAD
0026 1683           00084         bsf     STATUS,5        ;select pg1
0027 3000           00085         movlw   B'00000000'     ;select ch0-ch3...
0028 0088           00086         movwf   ADCON1          ;as analog inputs
0029 1283           00087         bcf     STATUS,5        ;select pg0
002A 30C1           00088         movlw   B'11000001'     ;select:fosc/2, ch0.
002B 0088           00089         movwf   ADCON0          ;turn on a/d
002C 3020           00090         movlw   ADTABLE         ;get top of table address
002D 0084           00091         movwf   FSR             ;load into indirect reg
002E 0189           00092         clrf    ADRES           ;clr result reg.
002F 0008           00093         return
                    00094 ;
                    00095 ;NextChannel, selects the next channel to be sampled in a
                    00096 ;"round-robin" format.
0030                00097 NextChannel
0030 3008           00098         movlw   0x08            ;get channel offset
0031 0788           00099         addwf   ADCON0, F       ;add to conf. reg.
0032 1288           00100         bcf     ADCON0,5        ;clear any carry over
                    00101 ;increment pointer to correct a/d result register
0033 0190           00102         clrf    TEMP
0034 1988           00103         btfsc   ADCON0,3        ;test lsb of chnl select
0035 1410           00104         bsf     TEMP,0          ;set if ch1 or ch3
0036 1A08           00105         btfsc   ADCON0,4        ;test msb of chnl select
0037 1490           00106         bsf     TEMP,1          ;set if ch0 or ch2
0038 3020           00107         movlw   ADTABLE         ;get top of table
0039 0710           00108         addwf   TEMP,W          ;add with temp
003A 0084           00109         movwf   FSR             ;allocate new address
003B 0008           00110         return
                    00111 ;
                    00112 ;This routine is a software delay of 10uS for the a/d setup.
                    00113 ;At 4Mhz clock, the loop takes 3uS, so initialize TEMp with
                    00114 ;a value of 3 to give 9uS, plus the move etc should result in
                    00115 ;a total time of > 10uS.
003C                00116 SetupDelay
003C 3003           00117         movlw   .3
```

```
003D 0090           00118         movwf   TEMP
003E                00119 SD
003E 0B90           00120         decfsz  TEMP, F
003F 283E           00121         goto    SD
0040 0008           00122         return
                    00123
                    00124 ;
                    00125
                    00126         END


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

0000 : X---X----------- XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0040 : X--------------- ---------------- ---------------- ----------------

All other memory blocks unused.

Program Memory Words Used:    51
Program Memory Words Free:   973


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     2 suppressed
```

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