EE461 Microprocessor-based Digital Design

Analog-to-Digital Conversion

Assignment 17 Solutions

1. All of the following problems concern a circuit you have based on a DIP-packaged PIC16F874 using a crystal clock source with oscillator frequency f_{OSC} = 10.00 MHz. A 4 V source is connected to pin 5 and a 1 V source is connected to pin 4.

   (a) If your program stores the value $_{0316}$ in the memory location at address $09F_{16}$, which of the possible analog input channels is (are) actually devoted to inputting analog voltages? Which pin(s) of the microprocessor correspond(s) to this channel (these channels)? What is the format of the result of an analog-to-digital conversion?

   SOLUTION

   Location 09Fh is the `ADCON1` register. The hexadecimal number 03_{16} is the same as the binary number B'0000 0011'. Now `PCFG3 :PCFG0` = `ADCON1(3 : 0)` =B'0011', devoting channels `AN4, AN2, AN1,` and `AN0` to accept analog inputs. `AN3` is devoted to accepting V_{+REF}.
   These channels and the reference input are on pins 7, 4, 3, 2, and 5 respectively.
   Because `ADCON1 (7)` = `ADFM` = 0, the result of any conversions will be 10 bits left-justified in a 16-bit field contained in the two-register combination `ADRESH : ADRESL`.

   (b) Prior to initiating an analog-to-digital conversion on Channel 4 in a PIC16F874, you must initialize the `ADCON0` register. What hexadecimal value should you place in it?

   SOLUTION

   With a 10MHz clock, `ADCS1:ADCS0` = `ADCON0(7 : 6)` must be B'10' or B'11', according to Table 11-1. (Bit `ADCS2` does not exist on the PIC16F874, only on the PIC16F874A.) With the first choice, $T_{AD} = 32T_{OSC} = 3.2$ µs.With the second choice, T_{AD} 4 µs. Not only will the first choice lead to more rapid conversions, it will also result in A/D conversions synchronized with the microprocessor clock. This may be advantageous in some cases. Furthermore, Note 2

in the table states that when the device frequency exceeds 1 MHz, the RC A/D conversion clock should only be used when sleep operations are planned. Therefore, we'll use the first choice.

Since we want to convert the data on channel 4, we should set `CHS2:CHS1:CHS0 = ADCON0(5 :3)` = 100.

Prior to initiating a conversion, we want the `GO/DONE` bit to be 0. This is `ADCON0(2) = ADCON0(GO/DONE)` = 0. The bit should not be set to 1 until after the required acquisition time has elapsed.

Lastly, we certainly want the A/D converter to be turned on, so we pick `ADON = ADCON(0) = ADCON(ADON)` = 1.

Combining all these choices, we have `ADCON0` = B'1010 0001' = H'A1'. We have set bit 1 to 0 since this bit is not implemented and always reads as a 0 anyway.

(c) Having initialized an analog-to-digital conversion and having waited for the `ADIF` bit to be asserted, you find the value $_{B316}$ in the register whose address is $_{01E16}$ and the value $_{4016}$ in the register whose address is $09E_{16}$. What nominal voltage appeared on Channel 4 to cause this result?

SOLUTION

Register $_{01E16}$ is `ADRESH` and register $_{09E16}$ is `ADRESL`. From question 1 above, we know the result is left justified so the leftmost 10 bits in the 16 bit field are the results of the conversion.

Expressing the data in binary form, we have `ADRESH:ADRESL` = $B340_{16}$ = 1011001101000000_2 and the leftmost 10 bits of this are $D = 1011001101_2 = 2CD_{16} = 717_{10}$.

This can be converted to the corresponding voltage it represents by

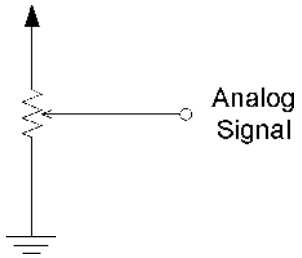
$$V_{IN,NOMINAL} = V_{-REF} + D/2^{10}(V_{+REF} - V_{-ref})$$

$$= 2.8008 \text{ V}.$$

Here we have used the fact that the high reference voltage on pin 5 is 4 V. The low reference voltage is 0 V because the 0 V internal reference was selected in question 1a above, even though a 1 V source is connected to pin 4, the V_{-REF} pin.

2. The PIC16F87XA manual suggests in equation 11-1 on page 130 that before an analog-to-digital conversion is begun, the system wait for one

acquisition time T_{ACQ} = 19.72 µs in order to make sure the sampling capacitor has enough charge accumulated to give an accurate conversion. The figure is based on two parameters that might not be applicable in a particular application: the source resistance R_S of the subsystem providing the analog voltage and the ambient temperature r. Furthermore, a conversion takes an additional time equal to twelve analog-to-digital bit-conversion periods, that is, 12 T_{AD}.



The figure above suggests a commonly used scheme for reading the position of a potentiometer using an analog-to-digital conversion. The analog voltage will be V_{DD} at one extreme and it will be 0 V at the other extreme.

(a) The PIC manual recommends that the source resistance not exceed 2.5 kΩ. Use Thévenin's theorem to find out how big the potentiometer resistance R_P can be without violating this requirement.

SOLUTION

The potentiometer can be viewed as being comprised of two resistances αR_P and $(1 - \alpha)R_P$, governed by the parameter α □ [0, 1].

From the point of view of the output terminal, these two resistances are in parallel; their Thévenin-equivalent resistance is given by

$$R_{th} = 1/\left(\left(1/\alpha R_p\right) + 1/\left((1-\alpha)R_p\right)\right) = \alpha(1-\alpha)R_p$$

By differentiating this expression with respect to , we can find its maximum possible value:

$$dR_{th}/d\alpha = (1-2\alpha)R_p$$

This can only be zero—which it must be at an extremum—when = 1/2. For this value of , $R_{TH} = R_P/4$. Since we want $R_{TH} < 2.5\ k\Omega$, we must have $R_P < 10\ k\Omega$.

(b) If the ambient temperature might be as great as 70 °C, what is the total time required to acquire and convert a sample from the potentiometer with the largest permissible value of resistance if the analog-to-digital conversion time per bit is $T_{AD} = 1.6\ \mu s$?

SOLUTION

Equation 11-1 in the data sheet gives this equation:

T_{ACQ} = Amplifier Settling Time + Hold Capacitor Charging Time + Temperature Coefficient

$$= T_{AMP} + T_C + T_{COFF}$$

$$= (2\ \mu s) + -C_{HOLD}\left(R_{IC} + R_{SS} + R_S\right) \ln \frac{1}{2047}$$

$$+ (\text{Temperature} - 25\ ^\circ C)\ (0.05\ \mu s/^\circ C)$$

where

- R_{IC} = 1 kΩ is the interconnect resistance,
- R_{SS} = 7 kΩ is the sampling switch resistance,
- $R_S = R_{MAXIMUM}$ = 2.5 kΩ is the Thévenin-equivalent source resistance of the largest permissible potentiometer,
- C_{HOLD} = 120 pF is the hold capacitance, and
- the ambient temperature is given as 70 °C.

Calculating this value yields

T_{ACQ} = 2 us -(120 pF) (1 k- + 7 k- + 2:5 k-) ln(1/2047)

+ (70°C - 25 °C) (0.05 us/°C)

= 2 us - (-9.61 us) + 2.25 us

= 13.86 us.

This yields the acquisition time. To this we must add 12 analog-todigital conversion times:

$T_{TOTAL} = T_{ACQ} + 12(T_{AD})$

= 13.86 us + 12(1.6 us)

= 33.06 us.