AN606

Low Power Design Using PICmicro™ Microcontrollers

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INTRODUCTION

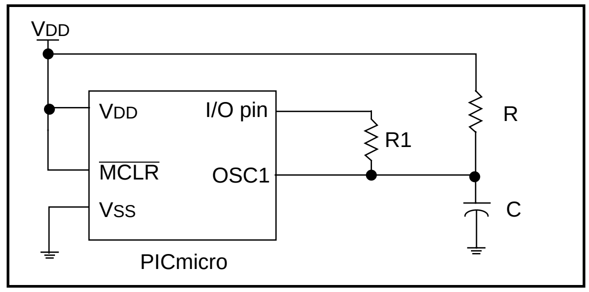
Power consumption is an important element in designing a system, particularly in today's battery powered world. The PICmicro family of devices has been designed to give the user a low-cost, low-power, and high-performance solution to this problem. For the application to operate at the lowest possible power, the designer must ensure that the PICmicro devices are properly configured. This application note describes some design techniques to lower current consumption, some battery design considerations, and suggestions to assist the designer in resolving power consumption problems.

DESIGN TECHNIQUES

Many techniques are used to reduce power consumption in the PICmicro devices. The most commonly used methods are SLEEP Mode and external events. These modes are the best way to reduce I_{PD} in a system. The PICmicro device can periodically wake-up from Sleep using the Watchdog Timer or external interrupt, execute code and then go back into SLEEP Mode. In SLEEP Mode the oscillator is shut off, which causes the PICmicro device to consume very little current. Typical I_{PD} current in most PICmicro devices is on the order of a few microamps.

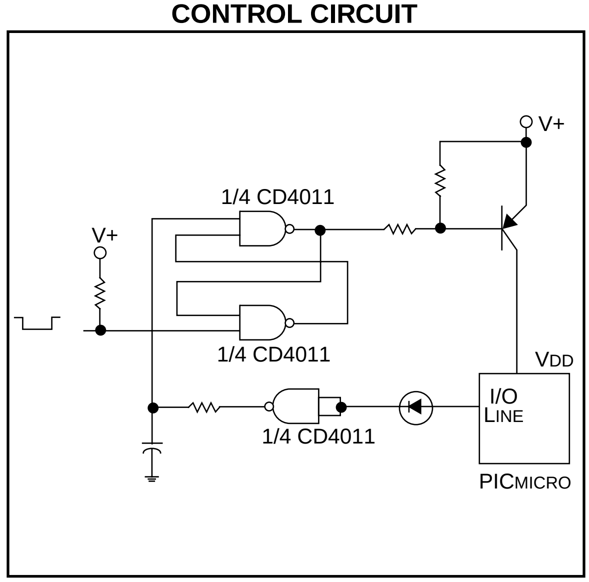
In cases where the PICmicro uses an RC oscillator but cannot use SLEEP Mode, another technique is used to lower power consumption. An I/O pin can remove a parallel resistance from the oscillator resistor while waiting for an event to occur. This would slow down the internal clock frequency, by increasing the resistance, and thus reduce Ipd. Once an event occurs the resistor can be switched in and the PICmicro device can process the event at full speed. Figure 1 shows how to implement this technique. The resistor **R1** would be used to increase the clock frequency by making the I/O pin an output and setting it to V_{DD}.

FIGURE 1: USING AN EXTERNAL RESISTOR TO LOWER POWER IN RC MODE



External events can be used to control the power to PICmicro devices. For these cases, the Watchdog Timer can be disabled to further reduce current consumption. Figure 2 shows an example circuit that uses an external event to latch power on for the PICmicro device. Once the device has finished executing code, it disables power by resetting the latch. The latching circuit uses a low-power 4000 series CMOS quad chip which consumes a typical of 10 µA of current. The measured value of current consumption for the complete circuit with the PICmicro powered-down was 1 nA. Current consumption for a PICmicro in SLEEP Mode is typically 1 µA.

FIGURE 2: EXTERNAL EVENT POWER CONTROL CIRCUIT



Power consumption is dependent on the oscillator frequency of the system. The device must operate fast enough to interface with external circuitry, yet slow enough to conserve power. The designer must account for oscillator start-up time, external circuitry initialization, and code execution time when calculating device power consumption. Table 1 shows various frequency oscillators, oscillator modes and the average current consumption of each mode. A PIC16C54 was used to collect data for Table 1 and the code is shown in Example 1. A current profile for a PIC16C54 in RC oscillator mode running at 261 kHz is shown in Figure 3. Figure 4 shows a current profile for a PIC16C54 in XT mode running at 1 MHz. The current profile includes three regions: power-up, active, and sleep. The power-up region is defined as the time the PICmicro device is in Power-on Reset and/or Oscillator Start-up Time. The active region is the time that the PICmicro device is executing code and the sleep region is the time the device is in SLEEP Mode. When using a 32.768 kHz crystal in LP oscillator mode, the designer must check that the oscillator has stabilized during the Power-on Reset. Otherwise, the device may not come out of reset properly.

TABLE 1: OSCILLATOR MODES

Osc. Type	Frequency	Osc. Mode	Power-up Region Current, Time	Active Region Current, Time	Sleep Region Current, Time	
Resistor / Capacitor	261 kHz	RC	51.2 µA, 17.5 ms	396 µA , 12.8 ms	0.32 µA,	140 ms
Resistor / Capacitor	1.13 MHz	RC	61.4 µA, 17.5 ms	810 µA, 2.5 ms	0.3 µA,	140 ms
Crystal	32.768 kHz	LP	51.2 µA, 19 ms	23.5 µA, 93 ms	0.3 µA,	140 ms
Crystal	50 kHz	LP	61.4 µA, 16 ms	39.4 µA, 48.5 ms	0.28 µA,	140 ms
Crystal	1 MHz	XT	92 µA, 17.5 ms	443 µA, 3 ms	0.35 µA,	140 ms
Crystal	8 MHz	HS	123 µA, 18 ms	2.11 mA, 250 µs	0.3 µA,	140 ms
Resonator	455 kHz	XT	38.4 µA, 17.3 ms	421 µA, 7 ms	0.34 µA,	140 ms
Resonator	8 MHz	HS	143 µA, 18 ms	2.5 mA, 250 µs	0.29 µA,	140 ms

EXAMPLE 1: CURRENT PROFILE CODE

```
    TITLE "Current Profiling Program"
    LIST P=16C54, F=INHX8M
    INCLUDE "C:\PICMASTR\P16C5X.INC"
;***************************************************************************
;***************************************************************************
;;       This program initializes the PIC16C54, delays for 256 counts, then goes
;       to sleep. The WDT wakes up the PIC16C54.
;;*************************************************************************
;***************************************************************************
;Define General Purpose register locations
       LSB            EQU 0x10   ;delay control register
       Reset Vector
       ORG 0
START
       MOVLW          0x0B       ;WDT Prescaler of 1:8
       OPTION
       CLRF           PORTA      ;clear PORTA
       CLRF           PORTB      ;clear PORTB
       CLRW                      ;make PORTA and PORTB pins outputs
       TRIS           PORTA
       TRIS           PORTB
       CLRF           LSB
LOOP   DECFSZ         LSB,1
       GOTO           LOOP
       SLEEP                     ;go to sleep
       END
```

FIGURE 3: CURRENT PROFILE (261 kHz RC MODE)

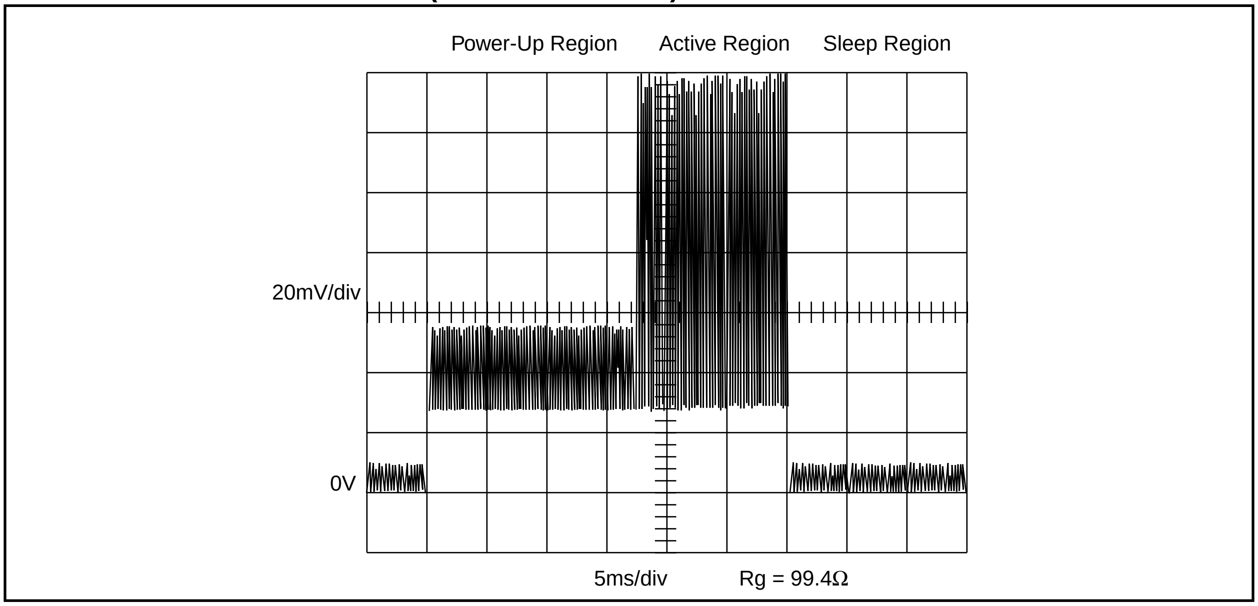
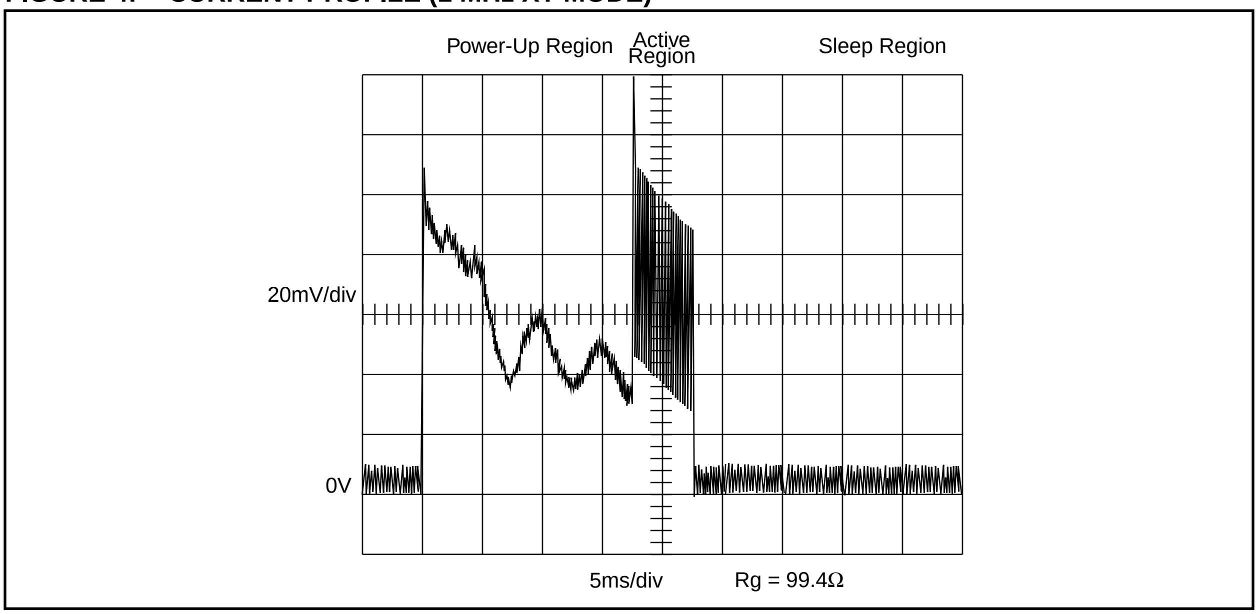


FIGURE 4: CURRENT PROFILE (1 MHz XT MODE)



Designing a system for lower supply voltages, typically 3V, is another method to reduce I_{PD}. This type of design is best utilized in a battery powered system where current consumption is very low. A wide range of devices from op-amps and Analog-to-Digital (A/D) converters to CMOS logic products are being manufactured for low voltage operation. This gives the designer the flexibility to design a low voltage system with the same type of components that are available for a 5V design. Refer to the PICmicro device data sheets for I_{PD} vs. V_{DD} data.

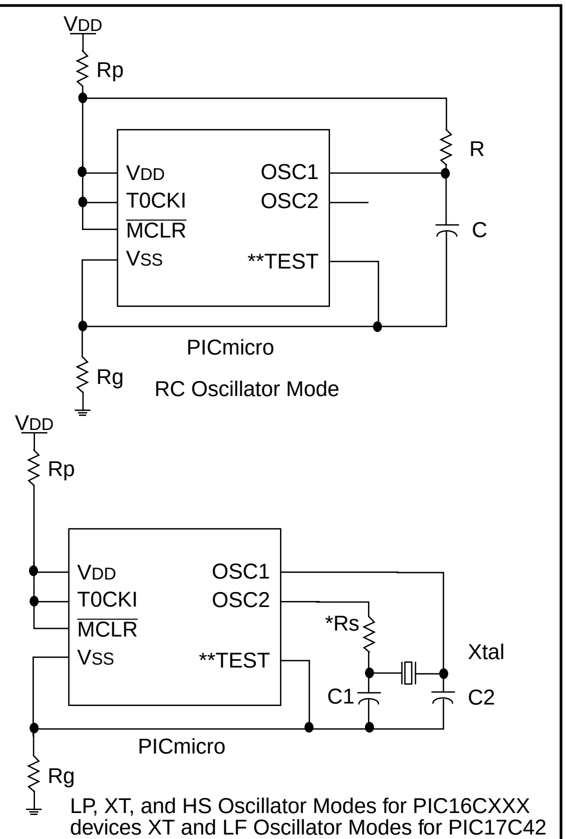
Since any I/O pin can source or sink up to 20 mA, the PICmicro devices can provide power to other components. Simply connect the V_{DD} pin of an external component to an I/O pin. Currently, most of the op-amps, A/D converters, and other devices manufactured today are low-power and can be powered by this technique. This provides the ability to turn off power to sections of the system during periods of inactivity.

Temperature will effect the current consumption of the PICmicro devices in different ways. Typically devices will consume more current at extreme temperatures and batteries will have less available current at those same temperatures. PICmicro devices will exhibit higher I_{PD} currents at high temperatures. Refer to the PICmicro device data sheets for I_{PD} vs. Temperature data.

TROUBLESHOOTING IPD

The first step in troubleshooting IPD problems is to measure the IPD that the circuit is consuming. Circuits to measure IPD for all oscillator modes are shown in Figure 5 for PICmicro devices. The resistor Rp is used to measure the amount of current entering the VDD pin when resistor Rg is shorted. The resistor Rg is used to measure the amount of current leaving the VSS pin when resistor Rp is shorted. The value of Rp and Rg should be approximately 100Ω for all oscillator modes. The two values of current should be approximately the same when the PICmicro is operating at the lowest possible power. If you find that the values of IPD measured from both configurations are not equivalent or are higher than the specifications, the following suggestions should help to find the source of extra current.

FIGURE 5: CIRCUITS TO MEASURE IPD FOR PICMICRO DEVICES



*Rs for HS and XT modes on PIC16CXXX devices XT mode on PIC17CXXX devices

**PIC17C42 only

Basically, if Ip is not equal to Ig, then an I/O pin is either sourcing (IP>IG) current or sinking (IP<IG) current.

- Is the $\overline{\text{MCLR}}$ pin tied to VDD? Is the rate of rise of VDD slower than 0.05 V/ms? Does VDD start at VSS then rise? These conditions will not guarantee that the chip will come out of reset and function properly. Some of the circuits on PICmicro devices will start operating at lower voltage levels than other circuits. See Application Note AN522 "Power-Up Considerations" in the Microchip *Embedded Control Handbook*.
- Are all inputs being driven to VSS or VDD? If any input is not driven to either VSS or VDD, it will cause switching currents in the digital (i.e., flashing) input buffers. The exceptions are the oscillator pins and any pin configured as an analog input. During Power-on Reset or Oscillator Start-up time, pins that are floating may cause increased current consumption.
- All unused I/O pins should be configured as outputs and set high or low. This ensures that switching currents will not occur due to a floating input.
- Is the TMR0 (T0CKI) pin pulled to VSS or VDD? The TMR0 pin of PIC16C5X devices should be tied to VSS or VDD for the lowest possible current consumption.
- If an analog voltage is present at a pin, is that pin configured as an analog input? If an analog voltage is present at a pin configured as a digital input, the digital input buffers devices will consume more current due to switching currents.
- Are all on-chip peripherals turned off? Any on-chip peripheral that can operate with an external clock source, such as the A/D converter or asynchronous timers, will consume extra current.
- Are you using the PORTB internal pull-up resistors? If so and if any PORTB I/O pin is driving or receiving a zero, the additional current from these resistors must be considered in the overall current consumption.
- Is the Power-Up Timer being used? This will add additional current drain during power-up.
- If the currents measured at the Rp and Rg resistors are not the same, then current is being sourced or sunk by an I/O pin. Make sure that all I/O pins that are driving external circuitry are switched to a low power state. For instance, an I/O pin that is driving an LED should be switched to a state where the LED is off.
- Is the window of a JW package device covered? Light will affect the current consumption of a JW package device with the window left uncovered.

I_{PD} Analysis Using A Random Sample

The Microchip *1994 Microchip Data Book* specifies the typical I_{PD} current for a PIC16C5X part at 4 µA and the maximum I_{PD} current at 12 µA. These values are valid at a V_{DD} voltage of 3V and a temperature range of 0°C to 70°C with the Watchdog Timer enabled. A control group of fifty PIC16C54's were randomly selected with pre-production and production samples. I_{PD} tests were run on the group for a voltage range of 2.5V to 6.5V and for a temperature range of 0°C to 70°C. Table 2 compares the median and maximum values obtained by the I_{PD} tests to the typical and maximum values in the data book. The I_{PD} test data and the data book values are based on V_{DD} = 3.0V, Watchdog Timer Enabled, and a temperature range of 0°C to 70°C.

The values in the data book are obtained from devices in which the manufacturing process has been skewed to various extremes. This should produce devices which function close to the minimum and maximum operating ranges for each parameter shown in the data book. The typical values obtained in the data book are actually the mean value of characterization data at a temperature of 25°C. The minimum and maximum values shown in the data book are the mean value of the characterization data at the worst case temperature, plus or minus three times the standard deviation. Statistically this means that 99.5% of all devices will operate at or below the typical value and much less than the maximum value.

TABLE 2: I_{PD} COMPARISON OF CONTROL GROUP vs. DATA BOOK VALUES

Source	Typical or Median I_{PD}	Maximum
Control Group	2.349 µA	3.048 µA
1994 Microchip Data Book	4 µA	12 µA

BATTERY DESIGN

When designing a system to use batteries, the designer must consider the maximum current consumption, operating voltage range, size and weight constraints, operating temperature range, and the frequency of operation. Once the system design is finished, the designer must again ask some questions that will define what type of battery to use. What is the operating voltage range? What is the current drain rate? What are the size constraints? How long will the system be used? What type of battery costs can be tolerated? What range of temperatures will the system be operated?

It is difficult to state a rule of thumb for selecting batteries because there are many variables to consider. For example, operating voltages vary from one battery type to another. Lithium cells typically provide 3.0V while Nickel-Cadmium cells provide 1.2V. On the other hand, Lithium cells can withstand minimal discharge rates while Nickel-Cadmium can provide up to 30A of current. A designer must consider all characteristics of each battery type when making a selection. Appendix B contains a simple explanation of batteries, a characteristic table for some common battery types, and discharge curves for the common batteries.

It is very important when doing a low power design to correctly estimate the required capacity of the power source. At this point, the designer should be able to estimate the operating voltage, current drain rates and how long the system is supposed to operate. To explain how to estimate the required capacity of a system, we will use the first entry from Table 1 using an RC oscillator set at 261 kHz. Figure 3 shows the current profile for this entry. It can be seen that the profile has a period of 170.3 ms with a 17.5 ms power-up region, a 12.8 ms active region, and a 140 ms sleep region. Assuming that the system will be required to operate for six months, we can now calculate the capacity required to power this system. Example 2 will illustrate the procedure. If a system does not have a periodic current profile, then the percentages obtained in step 1 of Example 2 will have to be estimated.

EXAMPLE 2: CAPACITY CALCULATION

1. Calculate the percentage of time spent in power-up, active, and sleep regions.

   power-up
   (17.5 ms / 170.3 ms) x 100 = 10.3%

   active
   (12.8 ms / 170.3 ms) x 100 = 7.5%

   sleep
   (140 ms / 170.3 ms) x 100 = 82.2%

2. Calculate the number of hours in 6 months.

   6 months
   x (30 days / month)
   x (24 hours / day) = 4320 hours

3. Using the number of hours, percentages, and currents calculate the capacity for each period of time

   power-up
   4320 hours x 10.3% x 51.2 µA = 22.8 mAh

   active
   4320 hours x 7.5% x 396 µA = 128.3 mAh

   sleep
   4320 hours x 82.2% x 0.32 µA = 1.14 mAh

4. Sum the capacities of each period

   22.8 mAh + 128.3 mAh + 1.14 mAh = 152.2 mAh

The capacity required to operate the circuit for six months is 152.2 mAh. Example 2 does not take into consideration temperature effects or leakage currents that are associated with batteries. The load resistance of a battery is affected by temperature which in turn changes the available voltage and current; however, the self discharge rate is higher.

EXAMPLE DESIGN

A PIC16C54 with an LP oscillator of 32.768 kHz is used in this design. A Linear Technology low-power 12-bit A/D converter samples a temperature sensor. This data is transmitted via an LED at 300 baud to a receiver. The A/D converter, op-amp, and temperature sensor are powered from an I/O pin on the PIC16C54. The Watchdog Timer is enabled to periodically wake the system up from Sleep and take a sample. Figure 6 shows the schematic for the example design and Appendix A contains the source code.

This circuit has two operating modes, active and sleep. There was not a distinct power-up region in this design. In the circuit with the peripheral chips powered directly from the battery, the example design consumed 8 mA of current in the active mode and 6.5 mA in SLEEP Mode. With the peripheral chips powered from an I/O pin of the PIC16C54, the example design consumed 4 mA of current in the active mode and 0.5 µA in SLEEP Mode. The advantage of using an I/O pin to provide power to peripherals can be seen in a calculation of the capacity required to operate the circuit for one month. Example 3 details the two capacity calculations.

EXAMPLE 3: CAPACITY CALCULATION FOR THE EXAMPLE DESIGN

1. Calculate the percentage of time spent in the active and SLEEP Modes.

   active - battery power
   (210 ms / 2.61 s) x 100 = 8%

   sleep - battery power
   (2.4 s / 2.61 s) x 100 = 92%

   active - I/O power
   (188 ms / 2.638 s) x 100 = 7.1%

   sleep - I/O power
   (2.45 s / 2.638 s) x 100 = 92.9%

2. Calculate the number of hours in 1 month.

   1 month
   x (30 days / month)
   x (24 hours / day)
   = 720 hours

3. Using the number of hours, percentages and currents calculate the capacity for each period of time.

   active - battery power
   720 hours x 8% x 8 mA = 461 mAh

   sleep - battery power
   720 hours x 92% x 6.5 mA = 4306 mAh

   active - I/O power
   720 hours x 7.1% x 4 mA = 205 mAh

   sleep - I/O power
   720 hours x 92.9% x 0.5 µA = 0.4 mAh

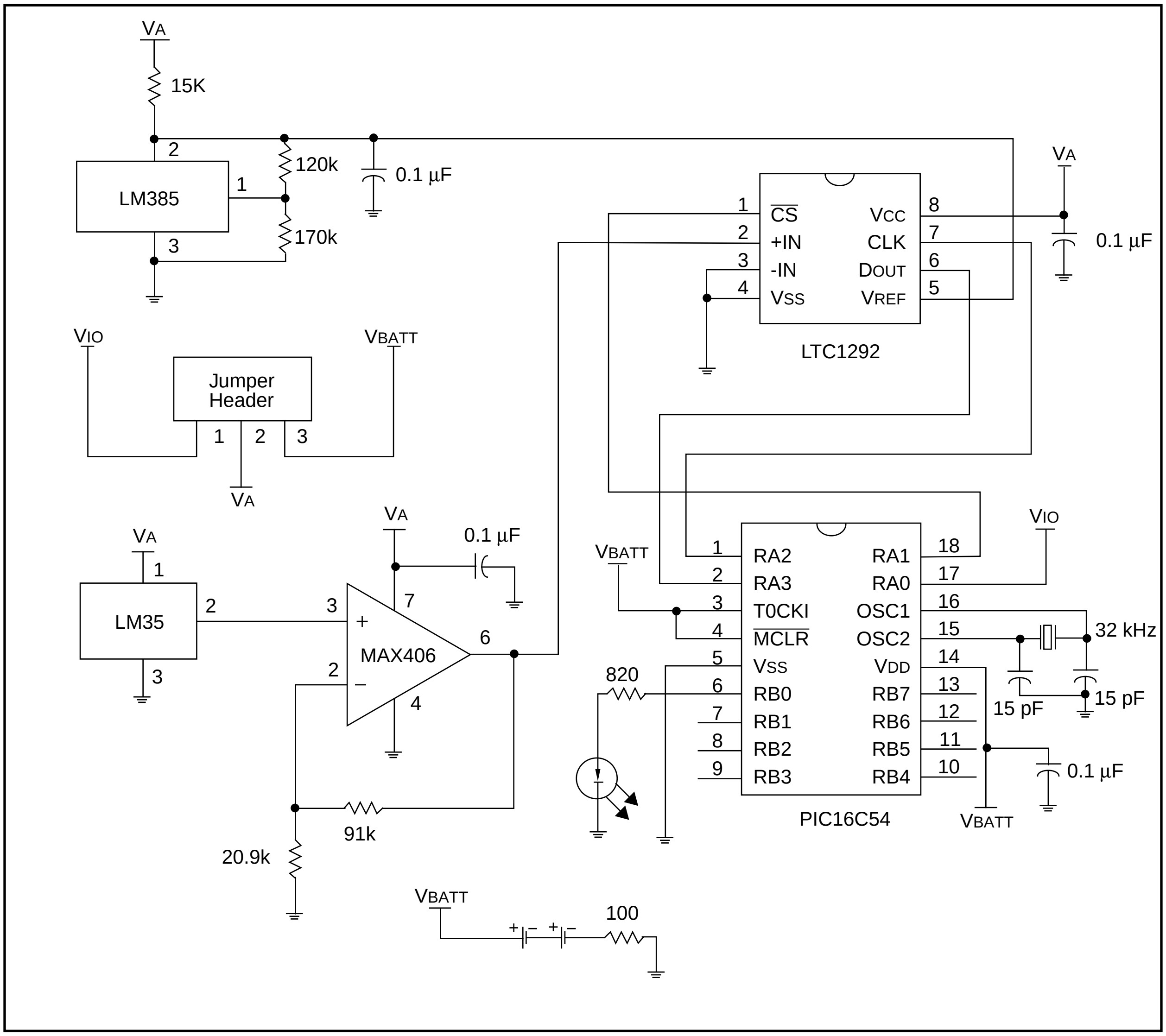
4. Sum the capacities of each period.

   battery power
   461 mAh + 4306 mAh = 4767 mAh

   I/O power
   205 mAh + 0.4 mAh = 206 mAh

The capacity required to operate this circuit for one month can be reduced by a factor of twenty just by powering the peripheral components from an I/O pin. The example design will use two Panasonic® BR2325 Lithium batteries in series to provide power to the circuit. This results in a Vbatt of 6V and a capacity of 165 mAh. Using the estimation process, the circuit should function for approximately 24 days. The actual time of operation was 24.2 days with the system running in an ambient temperature of 22°C.

FIGURE 6: EXAMPLE DESIGN SCHEMATIC



SUMMARY

This application note has described some of the methods used to lower IPD and reduce overall system current consumption. Some obvious methods such as SLEEP Mode and low voltage design were given. Techniques such as powering components from I/O pins and oscillator mode and frequency selection can also be important in reducing IPD and overall system current. Some suggestions for troubleshooting IPD problems were presented. Finally, some considerations for designing a battery powered system were offered.

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: EXAMPLE DESIGN CODE

```
MPASM 01.02.05 Released    LOWPWR.ASM   1-9-1995  13:2:42                 PAGE  1
Ipd/Battery Apnote Example Design
LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                     0001         TITLE "Ipd/Battery Apnote Example Design"
                     0002         LIST P=16C54, F=INHX8M
                     0003
                     0004         INCLUDE "P16C5X.INC"
                     0002 ;P16C5X.INC  Standard Header File, Ver. 0.1 Microchip Technology, Inc.
                     0004
                     0005
                     0006 ;*******************************************************************
                     0007 ;******************************************************************
                     0008 ;
                     0009 ;       Filename:       lowpwr.asm
                     0010 ;       REVISION:       9 Jan 95
                     0011 ;
                     0012 ;*******************************************************************
                     0013 ;
                     0014 ;  This program initializes the PIC, takes a sample, and outputs the
                     0015 ;  value to PORTB pin 0 (the LED), and then goes to Sleep.  The
                     0016 ;  Watchdog Timer wakes the device up from Sleep.  PORTA pin 0 is used
                     0017 ;  to control power to peripherals.
                     0018 ;
                     0019 ;*******************************************************************
                     0020 ;*******************************************************************
                     0021
                     0022 ;       Define variable registers
  0010               0023         MSB             EQU     0x10
  0011               0024         LSB             EQU     0x11
  0012               0025         DELAY_CNT       EQU     0x12
  0013               0026         SHIFT           EQU     0x13
  0014               0027         COUNT           EQU     0x14
                     0028
                     0029 ;       Reset Vector
                     0030         ORG     0x1FF
  01FF 0A00          0031         GOTO    START
                     0032
                     0033 ;       Start of main code
                     0034         ORG     0
                     0035
                     0036 ;********************************************************************
                     0037 ;       Main routine which initializes the device, and has main loop.
                     0038 ;********************************************************************
0000                 0039 START
0000 0C2F            0040         MOVLW   0x2F            ;1:128 WDT PRESCALAR
0001 0002            0041         OPTION
0002 0C02            0042         MOVLW   0x02            ;RA1 SET HIGH
0003 0025            0043         MOVWF   PORTA
0004 0066            0044         CLRF    PORTB           ;ALL PINS SET TO Vss
0005 0C08            0045         MOVLW   0x08            ;RA3-DATA INPUT
0006 0005            0046         TRIS    PORTA           ;RA0-POWER,RA1-CS,RA2-CLOCK OUTPUTS
0007 0040            0047         CLRW                    ;PORTB ALL OUTPUTS, RBO-LED OUTPUT
0008 0006            0048         TRIS    PORTB
0009 0071            0049         CLRF    LSB             ;CLEAR A/D RESULT REGISTERS
000A 0070            0050         CLRF    MSB
                     0051
000B 0004            0052         CLRWDT
```



```
000C 0911                CALL    SAMPLE          ;GET SAMPLE FROM A/D
000D 0004                CLRWDT
000E 0948                CALL    OUTPUT          ;OUTPUT SAMPLE TO LED AT 300 BAUD
000F 0004                CLRWDT
0010 0003                SLEEP


                 ;*********************************************************************
                 ;       Main routine for retrieving a sample from the A/D.
                 ;*********************************************************************
0011             SAMPLE
0011 0505                BSF     PORTA,0         ;TURN POWER ON TO PERIPHERALS
0012 0943                CALL    DELAY           ;WAIT FOR PERIPHERALS TO STABILIZE
0013 0C0B                MOVLW   0x0B            ;DATA COUNTER, 12 BIT A/D
0014 0034                MOVWF   COUNT
0015 0C08                MOVLW   0x08            ;SET SHIFT REGISTER
0016 0033                MOVWF   SHIFT
0017 0000                NOP
0018 0425                BCF     PORTA,1         ;ENABLE A/D
0019 0000                NOP
001A 0545                BSF     PORTA,2         ;1ST CLOCK RISE
001B 0000                NOP
001C 0445                BCF     PORTA,2         ;1ST CLOCK FALL
001D 0000                NOP
001E 0545                BSF     PORTA,2         ;NULL BIT CLOCK RISE
001F 0000                NOP
0020 0445                BCF     PORTA,2         ;NULL BIT CLOCK FALL
0021 0000                NOP

0022 0933        LOOP    CALL    READ            ;READ DATA BIT
0023 0000                NOP
0024 0545                BSF     PORTA,2         ;BIT CLOCK RISE
0025 0000                NOP
0026 0445                BCF     PORTA,2         ;BIT CLOCK FALL
0027 0000                NOP
0028 02F4                DECFSZ  COUNT,F         ;CHECK LOOP COUNTER
0029 0A22                GOTO    LOOP
002A 0933                CALL    READ            ;READ LAST BIT
002B 0000                NOP
002C 0545                BSF     PORTA,2         ;SET CLOCK
002D 0000                NOP
002E 0525                BSF     PORTA,1         ;SET CS
002F 0000                NOP
0030 0445                BCF     PORTA,2         ;CLEAR CLOCK
0031 0405                BCF     PORTA,0         ;POWER DOWN PERIPHERALS
0032 0800                RETURN

                 ;*********************************************************************
                 ;       Reads a bit from PORTA, data line from the A/D.
                 ;*********************************************************************
0033             READ
0033 0004                CLRWDT
0034 0774                BTFSS   COUNT,3         ;CHECK IF AT BIT 8 - 11
0035 0A3B                GOTO    RLOW            ;GOTO BITS 0 - 7
0036 0765                BTFSS   PORTA,3         ;CHECK IF DATA IS CLEAR
0037 0A3F                GOTO    REND            ;GOTO EXIT
0038 0213                MOVF    SHIFT,W         ;ADD A ONE TO MSB IN THE CORRECT
0039 01F0                ADDWF   MSB,F           ;BIT POSITION
003A 0A3F                GOTO    REND
003B 0765        RLOW    BTFSS   PORTA,3
003C 0A3F                GOTO    REND
003D 0213                MOVF    SHIFT,W         ;ADD A ONE TO LSB IN THE CORRECT
003E 01F1                ADDWF   LSB,F           ;BIT POSITION
003F 0333        REND    RRF     SHIFT,F         ;SHIFT
0040 0603                BTFSC   STATUS,C        ;IF ONE IS IN THE CARRY
0041 0333                RRF     SHIFT,F         ;SHIFT AGAIN
```

```
0042 0800                      RETURN
                        ;*********************************************************************
                        ;       Simple delay loop for 772 clock cycles.
                        ;*********************************************************************
0043                    DELAY
0043 0004                      CLRWDT                          ;RESET WATCHDOG TIMER
0044 0072                      CLRF    DELAY_CNT
0045 02F2               DLOOPL DECFSZ  DELAY_CNT,F
0046 0A45                      GOTO    DLOOPL
0047 0800                      RETURN
                        ;*********************************************************************
                        ;       Output sample to LED at 300 baud.
                        ;*********************************************************************
0048                    OUTPUT
0048 0C08                      MOVLW   0x08                    ;SHIFT 8 MSB BITS OUT
0049 0034                      MOVWF   COUNT
004A 0370               MSBOUT RLF     MSB,F                   ;SHIFT LSB INTO CARRY
004B 0703                      BTFSS   STATUS,C                ;IF CARRY IS SET
004C 0A50                      GOTO    MSBCLR
004D 0506                      BSF     PORTB,0                 ;SET PORTB,0
004E 0968                      CALL    BAUD
004F 0A54                      GOTO    MSBCHK                  ;CHECK FOR ALL 8 BITS TO BE SENT
0050 0406               MSBCLR BCF     PORTB,0                 ;OTHERWISE CLEAR PORTB,0
0051 0000                      NOP                             ;WAIT TO SET BAUD RATE 600
0052 0000                      NOP
0053 0968                      CALL    BAUD
0054 02F4               MSBCHK DECFSZ  COUNT                   ;CHECK FOR ALL 8 BITS TO BE SENT
0055 0A4A                      GOTO    MSBOUT
0056 0C08                      MOVLW   0x08                    ;SHIFT 8 LSB BITS OUT
0057 0034                      MOVWF   COUNT
0058 0371               LSBOUT RLF     LSB,F                   ;SHIFT LSB INTO CARRY
0059 0703                      BTFSS   STATUS,C                ;IF CARRY IS SET
005A 0A5E                      GOTO    LSBCLR
005B 0506                      BSF     PORTB,0                 ;SET PORTB,0
005C 0968                      CALL    BAUD
005D 0A62                      GOTO    LSBCHK                  ;CHECK FOR 8 BITS TO BE SENT
005E 0406               LSBCLR BCF     PORTB,0                 ;OTHERWISE CLEAR PORTB,0
005F 0000                      NOP                             ;WAIT TO SET BAUD RATE 600
0060 0000                      NOP
0061 0968                      CALL    BAUD
0062 02F4               LSBCHK DECFSZ  COUNT                   ;CHECK FOR 8 BITS TO BE SENT
0063 0A58                      GOTO    LSBOUT
0064 0406                      BCF     PORTB,0                 ;CLEAR PORTB,0
0065 0071                      CLRF    LSB                     ;CLEAR LSB
0066 0070                      CLRF    MSB                     ;CLEAR MSB
0067 0800                      RETURN
                        ;*********************************************************************
                        ;       Delay loop for sending data to the LED at 300 baud.
                        ;*********************************************************************
0068                    BAUD
0068 0000                      NOP
0069 0000                      NOP
006A 0000                      NOP
006B 0000                      NOP
006C 0000                      NOP
006D 0000                      NOP
006E 0000                      NOP
006F 0000                      NOP
0070 0000                      NOP
```

```
0071 0000            0185          NOP
0072 0000            0186          NOP
0073 0000            0187          NOP
0074 0000            0188          NOP
0075 0800            0189          RETURN
                     0190
                     0191          END
                     0192
                     0193

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

0000 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0040 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXX----------

0180 : ---------------- ---------------- ---------------- ----------------
01C0 : ---------------- ---------------- ---------------- ---------------X

All other memory blocks unused.


Errors   :     0
Warnings :     0
Messages :     0
```

APPENDIX B: BATTERY DESCRIPTIONS

Presently there are two types of batteries that are manufactured, primary and secondary. Primary batteries are those that must be thrown away once their energy has been expended. Low current drain, short duty cycles, and remote operation favor primary batteries such as Carbon Zinc and Alkaline. Secondary batteries can be recharged once they have exhausted their energy. High current drain or extended usage favors secondary batteries especially when the cost of replacement of disposable batteries is not feasible. Secondary batteries include Nickel-Cadmium and Nickel Metal Hydride.

A battery may be discharged by different means depending on the type of load. The type of load will have a significant effect on the life of the battery. The typical modes of discharge are constant resistance, constant current, and constant power. Constant resistance is when the load maintains a constant resistance throughout the discharge cycle. Constant current is the mode where the load draws the same current during discharge. Finally, constant power is defined as the current during a discharge increases as the battery voltage decreases.

The constant resistance mode results in the capacity of the battery being drained at a rapid and excessive rate, resulting in a short life. This is caused by the current during discharge following the drop in battery voltage. As a result, the levels of current and power during discharge are in excess of the minimum required.

The constant current mode has lower current and power throughout the discharge cycle than the constant resistance mode. The average current drain on the battery is lower and the discharge time to the end-voltage is longer.

The constant power discharge mode has the lowest average current drain and therefore has the longest life. During discharge, the current is lowest at the beginning of the cycle and increases as the battery voltage drops. Under this mode the battery can be discharged below its end voltage, because the current is increased as the voltage drops. The constant power mode provides the most uniform performance throughout the life of the battery and has the most efficient use of the energy in the battery.

The nominal voltage is the no-load voltage of the battery, the operating voltage is the battery voltage with a load, and the end-of-life voltage is the voltage when the battery has expended its energy. Energy Density is used to describe the amount of energy per unit of volume or mass (Wh/kg or Wh/l). Generally, energy density decreases with decreasing battery size within a particular type of battery. Most batteries are rated by an amp-hour (Ah) or milliamp-hour (mAh) rating. This rating is based on a unit of charge, not energy. A 1-amp current corresponds to the movement of 1 coulomb (C) of charge past a given point in 1 second (s). Table B-1 lists some typical characteristics of the most common types of batteries.

TABLE B-1: TYPICAL BATTERY CHARACTERISTICS

	Carbon Zinc	Alkaline	Nickel Cadmium	Lithium	Nickel Metal Hydride	Zinc Air	Silver Oxide
Cell Voltage							
Nominal	1.5	1.5	1.2	3.0	1.2	1.4	1.6
Operating	1.25-1.15	1.25-1.15	1.25-1.00	2.5-3.0	1.25-1.0	1.35-1.1	1.5
End of life	0.8	0.9	0.9	1.75	0.9	0.9	0.9
Operating Temperature	-5°C to 45°C	-20°C to 55°C	-40°C to 70°C	-30°C to 70°C	-20°C to 50°C	0°C to 45°C	-20°C to 50°C
Energy Density (Wh/kg)	70	85	30	300	55	300	100
Capacity	60mAh to 18Ah	30mAh to 45Ah	150mAh to 4Ah	35mAh to 4Ah	500mAh to 5Ah	50mAh to 520mAh	15mAh to 210mAh
Advantages		High capacity, good low temp	good low temp, good high rate discharge	good low and high temp, good high rate discharge, long shelf life	better capacity than Nicad for same size	high energy density, good shelf life	good low temp, good shelf life
Limitations	Low energy density, poor low temp, poor high rate discharge		poor low rate discharge, disposal hazards	Violent reaction to water		Cannot stop reaction once started	poor high rate discharge
Relative Cost	low	low	medium	high	high	high	high
Type	**Primary**	**Primary**	**Secondary**	**Primary**	**Secondary**	**Primary**	**Primary**

Typical discharge curves for alkaline, carbon zinc, lithium, nickel cadmium, nickel metal hydride, silver oxide, and zinc air are shown in Figure B-1 through Figure B-7. These curves are only typical representations of each battery type and are not specific to any battery manufacturer. Also the load and current drain are different for each type of battery.

FIGURE B-1: ALKALINE DISCHARGE CURVE (16 mA LOAD)

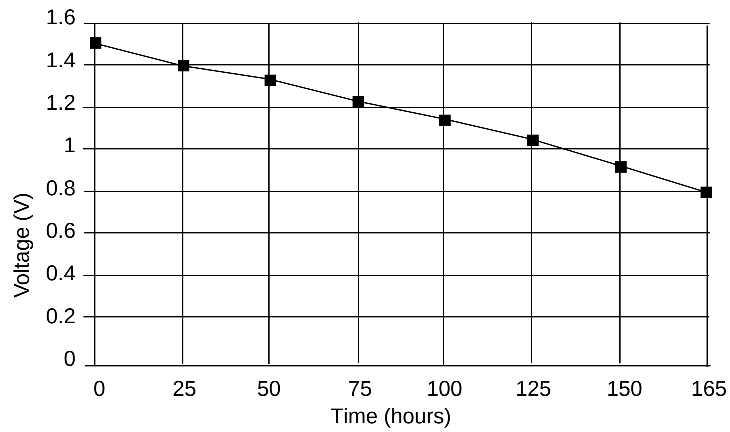


FIGURE B-2: CARBON ZINC DISCHARGE CURVE (16 mA LOAD)

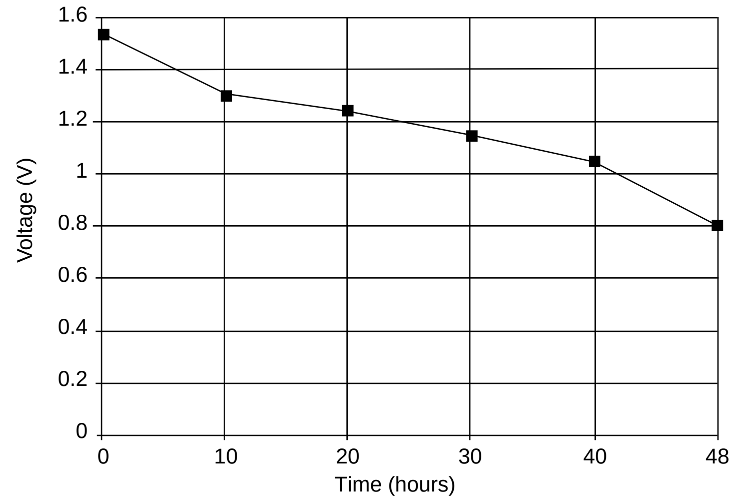


FIGURE B-3: LITHIUM DISCHARGE CURVE (2.8 mA LOAD)

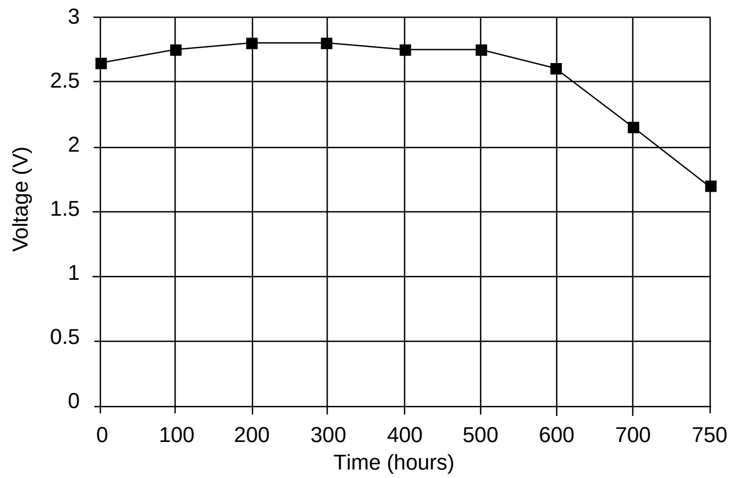


FIGURE B-4: NICKEL CADMIUM DISCHARGE CURVE (500 mA LOAD)

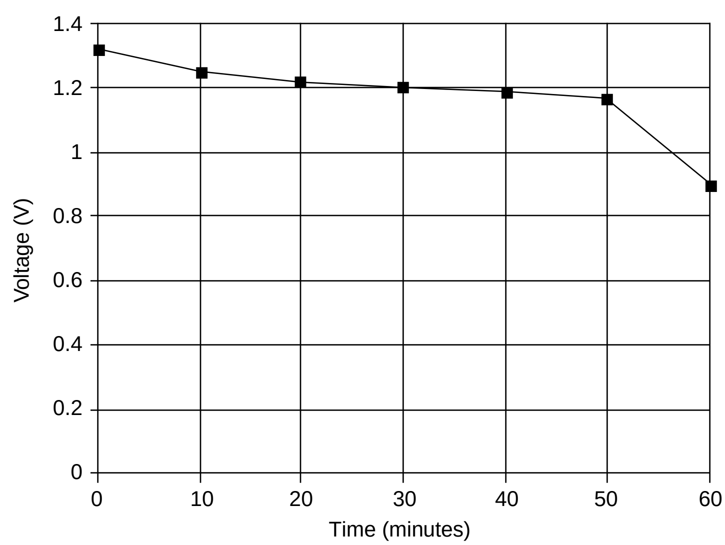


FIGURE B-5: NICKEL METAL HYDRIDE DISCHARGE CURVE (1500 mA LOAD)

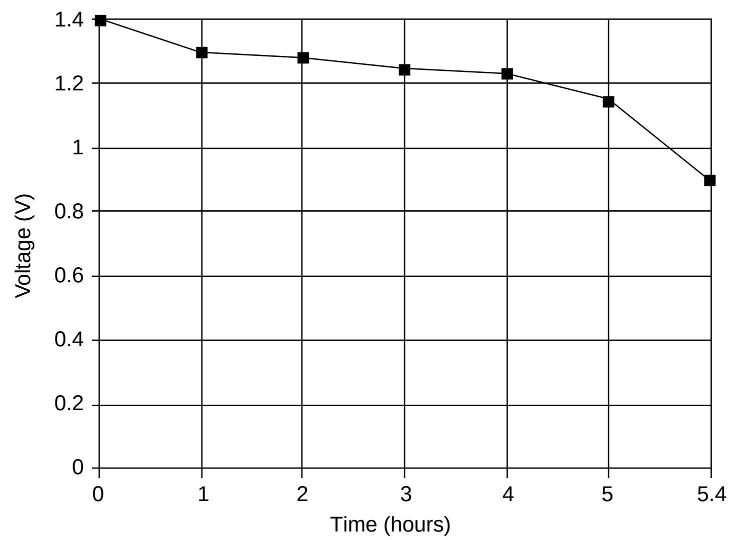


FIGURE B-6: SILVER OXIDE DISCHARGE CURVE (1 mA LOAD)

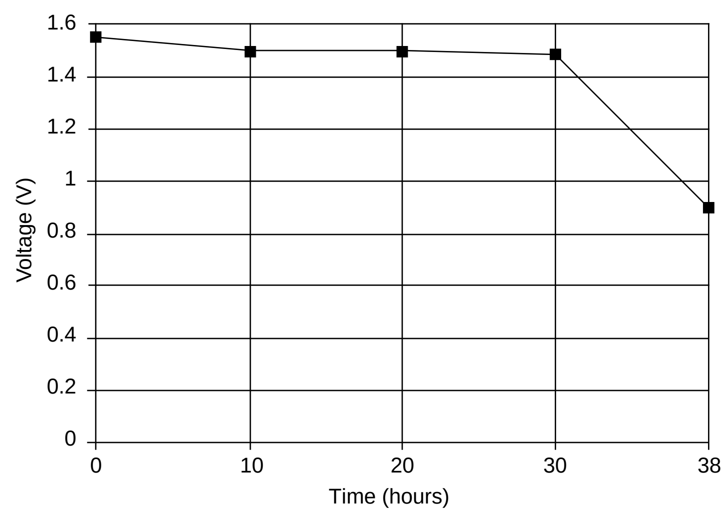
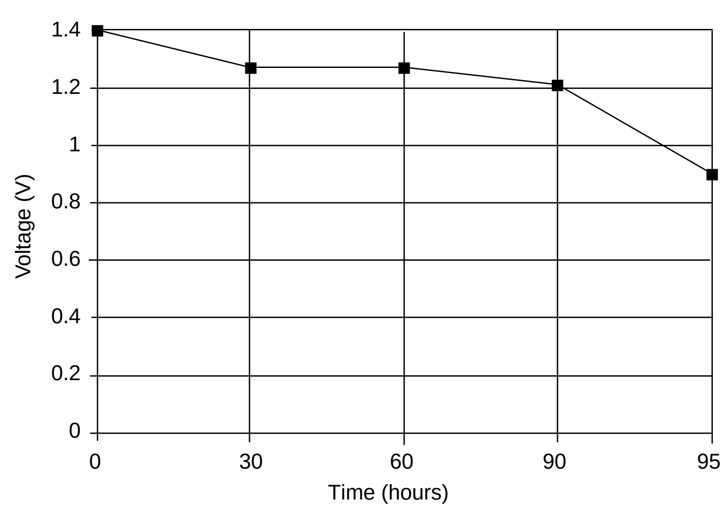


FIGURE B-7: ZINC AIR DISCHARGE CURVE (1.3 mA LOAD)



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