TB3316

Using the PIC16F180xx Charge Pump

Introduction

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Microcontrollers require a constant voltage to run many programmed analog operations. When that voltage starts to degrade (like a battery loosing charge), these programmed analog operations might not perform as they should. A charge pump can be used to ensure that the voltage used by analog peripherals will stay constant, even if the operating voltage of the microcontroller drops. This technical brief highlights the use of the charge pump and its key settings.

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1. Charge Pump

The primary use of the charge pump is to supply a constant voltage to the gates of transistor devices contained in analog peripherals, signal and reference circuitry, and to prevent degradation of transistor performance at low operating voltages. By using the charge pump for any of the mentioned applications, it will result in consuming additional current. Ultimately, it is up the reader to decide when to use the charge pump. This section describes how to configure and use the charge pump.

1.1 Configuring the Charge Pump

The charge pump uses one register (CPCON) to control the entire module . There are two different settings that can be set and three indicator bits within the register, each of which will be explained in this section.

1.1.1 Disabled

The charge pump is disabled by default (CPCON = `00`, as shown in Example 1-1). Clearing the Charge Pump Enable (CPON) bits will disable the charge pump.

Example 1-1. Disabled

```
CPCONbits.CPON = 0b00; //Default state
```

1.1.2 Manually Enabled

The charge pump can be manually enabled via the CPON bits. When the CPON bits are configured as '`11`', the charge pump is enabled (see Example 1-2). In this case, the charge pump provides additional voltage to all analog systems, regardless of V_{DD} levels, but also consumes additional current.

Example 1-2. Manually Enabled

```
CPCONbits.CPON = 0b11;
```

1.1.3 Automatically Enabled

The charge pump can also be enabled automatically. This feature allows the application to determine when to enable the charge pump. If the charge pump is enabled while V_{DD} levels are above a sufficient threshold, the charge pump does not improve analog performance, but also consumes additional current. Allowing hardware to monitor V_{DD} and determine when to enable the charge pump prevents unnecessary current consumption.

When the CPON bits are configured as '`10`' (as shown in Example 1-3), the charge pump hardware monitors V_{DD} and compares the V_{DD} levels to a reference voltage threshold (V_{AUTO}), which is fixed at 4.6V and is not configurable. When hardware detects a V_{DD} level lower than the threshold, the charge pump is automatically enabled. If V_{DD} returns to a level above the threshold, the hardware automatically disables the charge pump.

Example 1-3. Automatically Enabled - without Analog Peripheral

```
CPCONbits.CPON = 0b10;
```

When the CPON bits are configured as '`01`' (as shown in Example 1-4), the charge pump hardware waits for an analog peripheral, such as the Analog-to-Digital Converter (ADC), to be enabled before monitoring V_{DD}. In this case, the charge pump hardware monitors all analog peripherals, and once an analog peripheral is enabled, the hardware begins to compare V_{DD} to V_{AUTO}. When the hardware detects a V_{DD} level lower than the threshold, the hardware will enable the charge pump. If V_{DD} returns to a level above the threshold, or if the analog peripheral is disabled, the charge pump is automatically disabled.

Example 1-4. Automatically Enabled - with Analog Peripheral

```
CPCONbits.CPON = 0b01;
```

1.1.4 Charge Pump Oscillator

The Charge Pump Oscillator Selection (CPOS) bit selects the charge pump oscillator source. The CPOS bit allows the user to select between the charge pump's internal oscillator or the oscillator driving the ADC.

When the CPOS is set (CPOS = 1), the charge pump utilizes its internal oscillator. The charge pump's internal oscillator provides a very steady output voltage, but at a higher operating current. Example 1-5 shows how to set the CPOS bit to utilize the internal oscillator of the charge pump.

Example 1-5. Charge Pump Oscillator - Internal Oscillator

```
CPCONbits.CPOS = 1;
```

When CPOS is clear (CPOS = 0), and the ADGO bit is clear (GO = 0), the charge pump is clocked by the ADCRC. When ADGO is set (GO = 1), the charge pump is clocked by a derivative of the F_{osc} (as determined by the ADCLK register). This allows the charge pump to operate at a lower current when the ADC is not converting, while offering higher performance when the ADC is converting.

Example 1-6 shows how to set the CPOS bit and the ADCON0 GO bit to utilize the ADC clock.

Example 1-6. Charge Pump Oscillator - ADC Oscillator

```
CPCONbits.CPOS = 0;
ADCON0bits.GO = 0;
```

Example 1-7 shows how to set the CPOS bit and the ADCON0 Go bit to utilize the F_{osc} Clock.

Example 1-7. Charge Pump Oscillator - F_{osc} Clock

```
CPCONbits.CPOS = 0;
ADCON0bits.GO = 1;
```

Note: Example 1-6 and Example 1-7 were not used within the examples in 1.2. Examples using the Charge Pump.

1.1.5 Charge Pump Request

The Charge Pump Request (CPREQ) bit indicates whether the charge pump has or has not been requested by an analog peripheral. If the charge pump has been requested by an analog peripheral, the CPREQ bit will be set (CPREQ = 1). If the charge pump has not been requested by an analog peripheral (default state), the CPREQ bit remains cleared (CPREQ = 0).

1.1.6 Charge Pump Threshold

The Charge Pump Threshold (CPT) bit indicates whether or not V_{DD} is at an acceptable operating level. Charge pump hardware compares V_{DD} to the threshold voltage (V_{AUTO}), which is fixed at 4.6V and is not configurable. If V_{DD} is above V_{AUTO}, the CPT bit is set (CPT = 1). If V_{DD} is below V_{AUTO}, CPT is clear (CPT = 0).

1.1.7 Charge Pump Ready

The Charge Pump Ready Status (CPRDY) bit indicates whether the charge pump is ready for use. When CPRDY is set (CPRDY = 1), the charge pump has reached a steady-state operation and is ready for use. When CPRDY is clear (CPRDY = 0), the charge pump is either in the OFF state or has not reached a steady-state operation.

1.1.8 Indicator Code

To be able to see the information that is stored in the CPREQ, CPT, and CPRDY bits, an indicator code was developed. Example 1-8 shows that code which converts the information in the CPREQ, CPT, and CPRDY bits to I/O pin states that can be monitored.

Example 1-8. Basic Indicator Code

```
void displayBits(){
        //***** CPT, CPRDY, and CPREQ Bits turning on LEDs *****//
        if(CPCONbits.CPT == 1){
            LATAbits.LATA4 = 1;
        } else {
            LATAbits.LATA4 = 0;;
        }

        if(CPCONbits.CPRDY == 1){
            LATAbits.LATA5 = 1;
        } else {
            LATAbits.LATA5 = 0;
        }

        if(CPCONbits.CPREQ == 1){
            LATAbits.LATA6 = 1;
         } else {
            LATAbits.LATA6 = 0;
        }
}
```

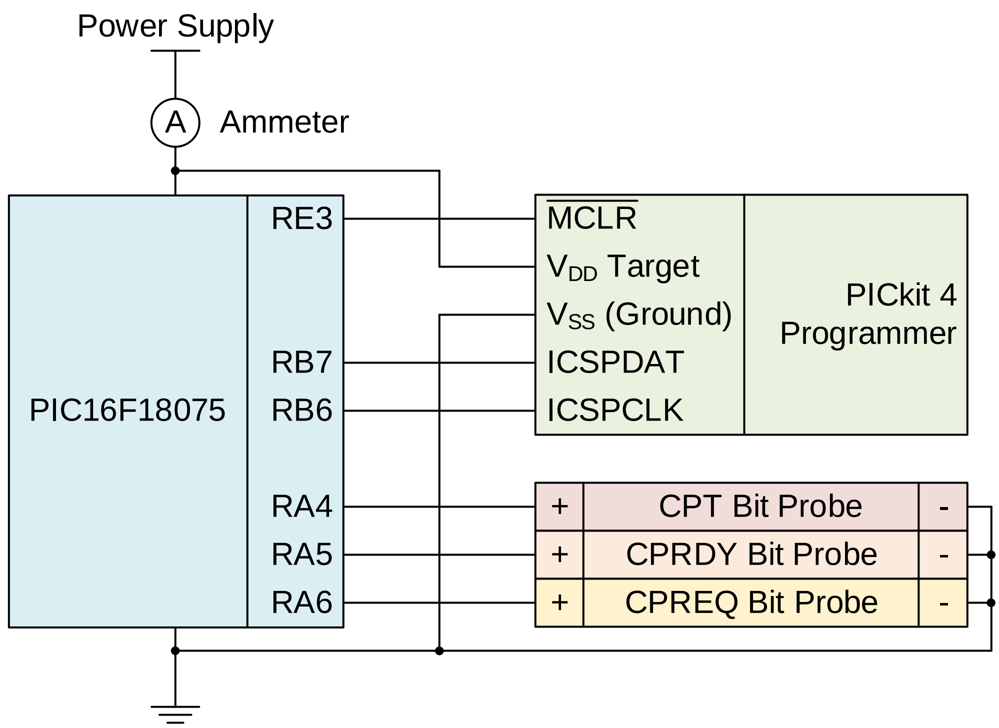
1.2 Examples using the Charge Pump

By using a power supply on the V_{DD} of the PIC® microcontroller, the input voltage can be changed to show how the current reacts to setting and voltage changes. Explanations of each example follow. The graph in section 1.2.3. Results shows how each of the voltage levels and settings selected affect the microcontroller's current consumption.

1.2.1 Circuit Setup

The basic setup for these examples start with having the power supply attached through an ammeter to the V_{DD} and V_{SS} pins of the PIC microcontroller. In addition, the five pins that connect to the MPLAB® PICkit™ 4 In-Circuit Debugger were also connected. To monitor the behavior of the CPREQ, CPT, and CPRDY bits, Example 1-8 was included in the code and probes were used to determine when each of the bits went high or low. Figure 1-1 shows the hardware setup.

Figure 1-1. Circuit Diagram/Setup



1.2.2 Code Setup

The code is written so that there are five steps, four of which are within an endless `while` loop. The steps use the code mentioned in Example 1-1 through Example 1-8.

The steps involve:

1. Enabling the Digital-to-Analog Converter (DAC).
2. Enabling the charge pump internal oscillator.
3. Setting the level of the DAC.
4. Displaying the charge pump indicator bits to pins.

Each of the remaining steps set the correct CPON bits for the setting that is being examined, then a 5-second delay occurs, and then the indicator bits are displayed by turning on or off the pins associated with them. The operating code can be seen in Example 1-9. The function “`displayBits()`” is the same code shown in Example 1-8 above.

Example 1-9. Charge Pump Operating Code

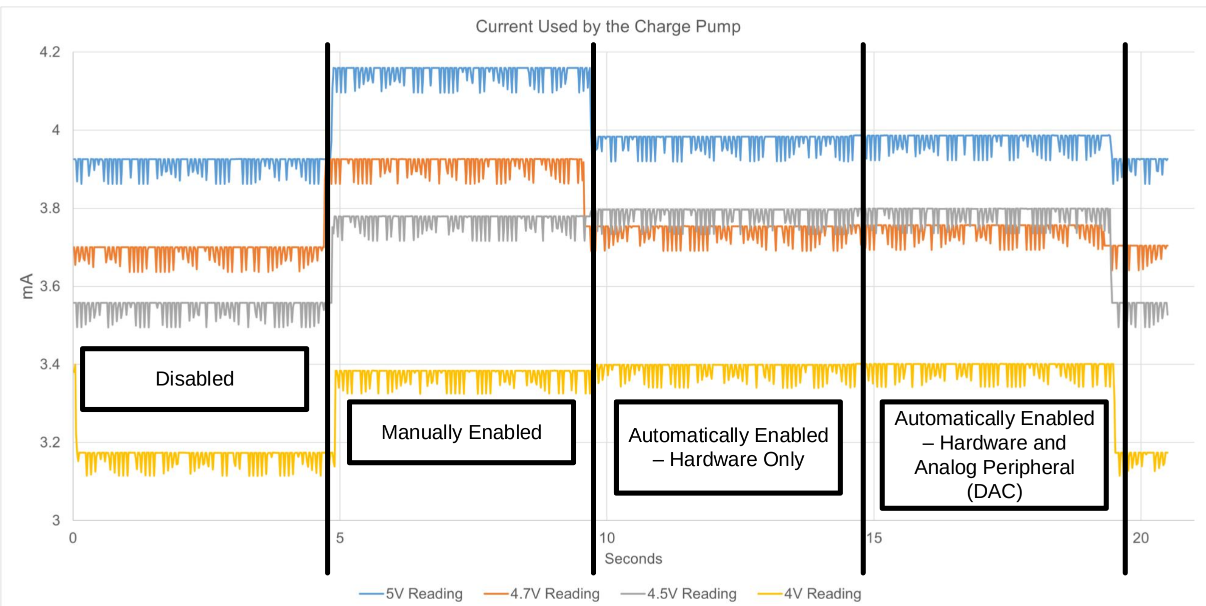
```
int main(void)
{
    SYSTEM_Initialize();
    DAC1CONbits.EN = 1;      //enable the DAC
    CPCONbits.CPOS = 0b1;    //set Charge Pump Oscillator to the
                             //internal oscillator
    DAC1DATL = 0xE6;         //set DAC to output 90% of Vdd
    displayBits();           //show CPT, CPRDY, and CPREQ bits on pins
                             //RA4, RA5, and RA6

    while(1)
    {
        //Disabled
        CPCONbits.CPON = 0b00;   //Default state
        __delay_ms(5000);        //wait 5 seconds
        displayBits();
```

```
        //Manually Enabled
        CPCONbits.CPON = 0b11;
         __delay_ms(5000);      //wait 5 seconds
        displayBits();

        //Automatically Enabled - Hardware only
        CPCONbits.CPON = 0b10;
        __delay_ms(5000);       //wait 5 seconds
        displayBits();

        //Automatically Enabled - Hardware and DAC
        CPCONbits.CPON = 0b01;
        __delay_ms(5000);       //wait 5 seconds
        displayBits();
    }
}
```

1.2.3 Results

When combining the circuit shown in Figure 1-1 and the code in Example 1-9, data can be collected to show how much current the PIC microcontroller uses with different settings and voltages for the charge pump. Figure 1-2 shows the different current used by the PIC at the different settings and input voltages.

Figure 1-2. Current Used by the Charge Pump



There are four regions within the graph, separated from each other with vertical lines and labeled with the step of the code that it represents. For example, the region at the left side correlates to the Disabled setting being active. Moving to the right, this is followed by Manually Enabled, Automatically Enabled – Hardware Only, and finally the Automatically Enabled – Hardware and Analog Peripheral (DAC).

At the 5V reading (the highest line), there is a clear distinction in current used between the Disabled and Manually Enabled sections. Both Automatically Enabled sections are slightly higher than the Disabled section but are still low when compared to the Manually Enabled section. The Automatically Enabled sections are slightly higher than the Disabled level while also being distinctly lower than the Manually Enabled level; therefore, it takes some current to run the Automatically Enabled feature but not the same amount of current that is needed to run the entire charge pump.

The 4.7V reading (the second highest line) is very similar to the 5V line. The only difference is that it uses less voltage, which affects the current that is being used. The reason why the Automatically Enabled sections are slightly above the Disabled section is also the same as the 5V line.

The 4.5V reading (the second lowest line) is where the charge pump really shines. The Disabled and Manually Enabled sections are similar to the previous readings, they just shifted down to 4.5V. Around 4.6V, the charge pump gets automatically triggered. Both Automatically Enabled sections are now at a current level like the Manually Enabled section and not the Disabled section, like it was previously. This increase in current is caused by the charge pump turning on.

The 4V reading (the bottom line) is nearly identical to the 4.5V line, just with a shift down because there is less voltage available, so the current used will be less.

2. Conclusion

The charge pump can be used to help work with basic analog circuits to ensure that there is a constant voltage. The different settings of the charge pump (CPCON) register allow the enabled status and clock to be selected and the indicator bits to be used to inform the development process. When the charge pump is enabled, either manually or automatically, it will have the effect of consuming more current, while also keeping the voltage constant.

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