TB3237

Getting Started with HLVD (High/Low-Voltage Detect)

Introduction

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Many PIC® microcontrollers have a High/Low-Voltage Detect (HLVD) module that can be used to monitor the device voltage (V_{DD}) and inform the user through an interrupt signal when the supply voltage drops below the specified threshold (i.e., trip point) or exceeds the trip point. This is a programmable circuit that allows the user to set the device voltage trip point and the direction of change from the trip point: positive going (exceeding the trip point), negative going (falling below the trip point) or both. This feature is useful in battery monitoring applications.

This technical brief describes the HLVD peripheral in detail. It also covers the following use cases:

- Monitoring battery discharge
- Detection of USB-power attach or detach

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1. Relevant Devices

The following PIC® microcontroller families are equipped with the HLVD module:

- PIC18-Q10
- PIC18-K40
- PIC18-K42
- PIC18-K83

2. General Overview

The HLVD is a necessary power supply monitoring feature in numerous battery-powered applications, where the supply voltage of a microcontroller may fall below the specified threshold level and require battery replacement or recharging for the uninterrupted operation of the microcontroller. The HLVD feature is capable of monitoring the supply voltage of a microcontroller which is directly powered by a battery power source. The HLVD-based voltage monitoring circuitry has several advantages over an ADC-based voltage monitoring circuit, as listed below:

1. The microcontroller PORT pins are not required to implement the supply voltage monitor.
2. This module does not require external components, and hence no excess power consumption by the external circuitry.
3. The HLVD module uses an internal bandgap reference and draws a typical of 22 μA when enabled. It can be disabled except when needed to reduce even this tiny current draw.
4. It can generate an interrupt when V_{DD} is below or above the selected trip point (depending on how it is configured).

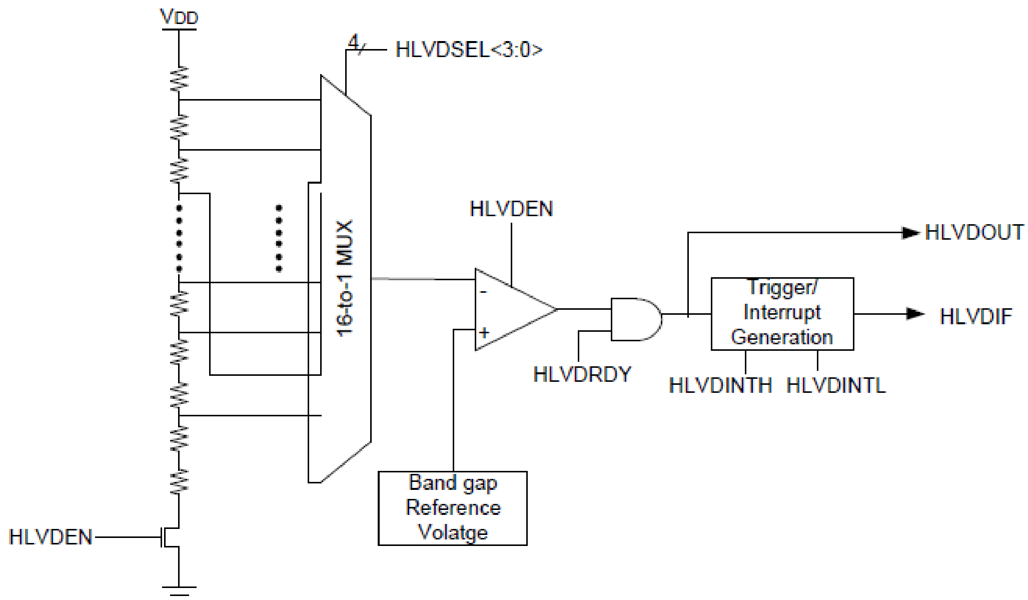
   Note:

   1. The HLVD can only be used to measure the supply voltage of the microcontroller (i.e., V_{DD}), so it cannot be used to monitor a battery supplying power through a voltage regulator.
   2. There are 16 steps over the measurement range with manufacturing tolerances on the bandgap reference and internal resistive voltage divider. The trip point settings shown below in Table 4-1 are available for a PIC18-Q10 family of devices. The trip point settings depend on the device used. Refer to the device data sheet for more details.

3. Block Diagram

The HLVD module's block diagram is shown in the figure below.

Figure 3-1. HLVD Block Diagram



The HLVD can be software-enabled through the HLVDEN bit. Each time the HLVD module is enabled, the HLVDRDY bit can be used to detect when the module is stable and ready to use. The HLVDINTH and HLVDINTL bits of the HLVDCON0 register determine the overall operation of the module. When INTH is set, the module monitors for rise in V_{DD} above the trip point set by the SEL bits. When INTL is set, the module monitors for drop in V_{DD} below the trip point set by the SEL bits. When both the INTH and INTL bits are set, any changes above or below the trip point set by the SEL bits can be monitored. The OUT bit can be read to determine if the voltage is greater than or less than the selected trip point. If the supply voltage is below the set point, then the HLVDOUT bit will be set and, if the supply voltage is above the set point, the OUT bit will be cleared.

4. Detailed Operation

When the HLVD module is enabled, a comparator inside the HLVD module uses an internally generated voltage reference as the set point. The set point is compared with the trip point, where each node in the resistor divider represents a trip point voltage. The trip point voltage is the voltage level at which the device detects a high or low voltage event, depending on the configuration of the module. When the supply voltage is equal to the trip point, the voltage tapped from the resistor array is equal to the internal reference voltage generated by the voltage reference module. The comparator then generates an interrupt signal by setting the HLVDIF bit. The trip point voltage is software programmable to any of the 16 values. The trip point is selected by programming the SEL bits.

Table 4-1. HLVD Trip Point Settings

Sr. No.	HLVDSEL	Trip Point Voltage (V)		
		Min.	Typ.	Max.
1	HLVDSEL=`b'0000'`	1.81	1.90	1.90
2	HLVDSEL=`b'0001'`	2.00	2.10	2.12
3	HLVDSEL=`b'0010'`	2.20	2.25	2.33
4	HLVDSEL=`b'0011'`	2.40	2.50	2.54
5	HLVDSEL=`b'0100'`	2.50	2.60	2.65
6	HLVDSEL=`b'0101'`	2.70	2.75	2.86
7	HLVDSEL=`b'0110'`	2.80	2.90	2.97
8	HLVDSEL=`b'0111'`	3.00	3.15	3.18
9	HLVDSEL=`b'1000'`	3.30	3.35	3.50
10	HLVDSEL=`b'1001'`	3.50	3.60	3.71
11	HLVDSEL=`b'1010'`	3.60	3.75	3.82
12	HLVDSEL=`b'1011'`	3.80	4.00	4.03
13	HLVDSEL=`b'1100'`	4.00	4.20	4.24
14	HLVDSEL=`b'1101'`	4.20	4.35	4.45
15	HLVDSEL=`b'1110'`	4.50	4.65	4.77

Note: Refer to the device data sheet for the typical Trip Point Voltage (V) settings and to the MPLAB® Code Configurator (MCC) configuration GUI of the HLVD peripheral for minimum and maximum Trip Point Voltage (V) settings.

4.1 Operation with Various Supply Voltages

The allowable operating voltage of the microcontroller should be considered in determining the low-level threshold that needs to be set. For instance, the PIC18-Q10 microcontrollers can operate up to 1.8V so all the voltage thresholds mentioned in Table 4-1 can be used. Some 8-bit PIC microcontrollers can operate up to 2.3V while others can operate up to 2V.

Note: The maximum allowed clock speed is a function of the supply voltage. The LF versions of the PIC microcontrollers can operate down to 2V at a maximum clock speed of 4 MHz.

Refer to the device data sheet to confirm the operating voltage range and maximum clock speed with respect to the operating voltage.

4.2 Operation of the Module in Various Sleep Modes

If enabled, the HLVD module can operate during various Power-Down modes such as Idle, Doze and Sleep mode. If the device voltage crosses the trip point, the HLVDIF bit will be set and the device will wake up from the Power-Down mode (i.e., Doze/Idle/Sleep). The device execution will continue from the interrupt vector address if interrupts have been globally enabled.

4.3 Current Consumption

When enabled, the HLVD module draws a typical current of 22 μA in the PIC18-Q10 devices. Refer to the Electrical Specifications section of the device data sheet for details on the current consumption.

4.4 HLVD Start-up Time

If the HLVD module is disabled to lower the device current consumption, the reference voltage used by the HLVD circuit will require time to become stable before a low or high-voltage condition can be reliably detected. This FVR start-up time (TFVRST), is typically 25 μs for the PIC18-Q10 devices. The HLVD interrupt flag is not enabled until TFVRST has expired and a stable reference voltage has been reached.

Note: The FVR start-up time (TFVRST), may vary with the PIC microcontroller family. Refer to the device data sheet to confirm the start-up time.

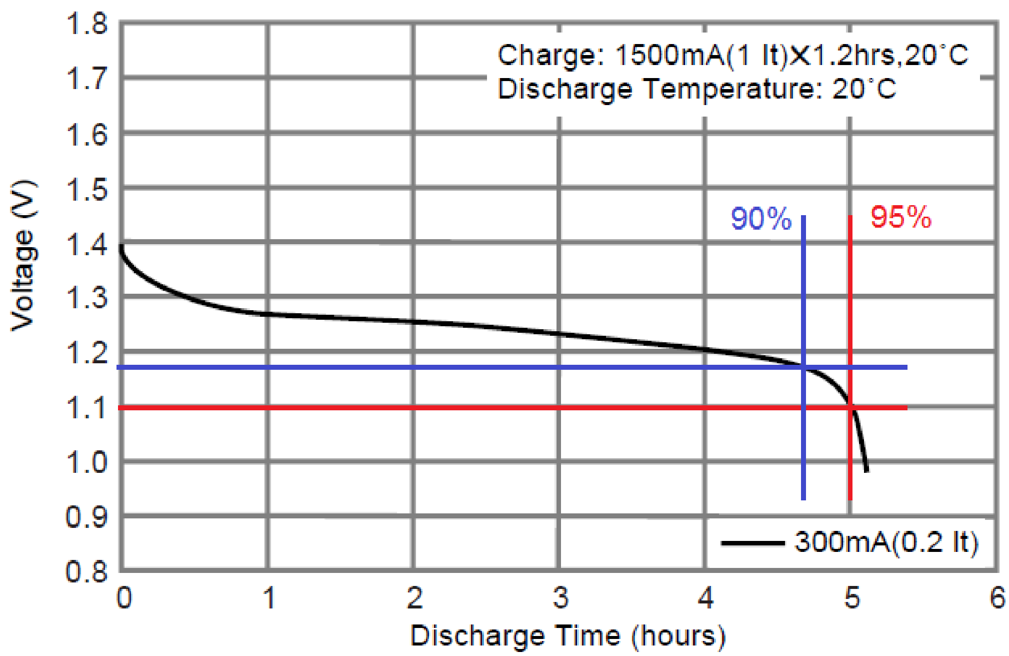
5. Applications

5.1 Battery Monitoring

Monitoring the battery voltage is very important in case of battery-powered applications for safe and steady operation of the system and for protecting the battery from operating outside its safe operating area. The below section discusses how to monitor battery discharging cycles when the HLVD peripheral is used.

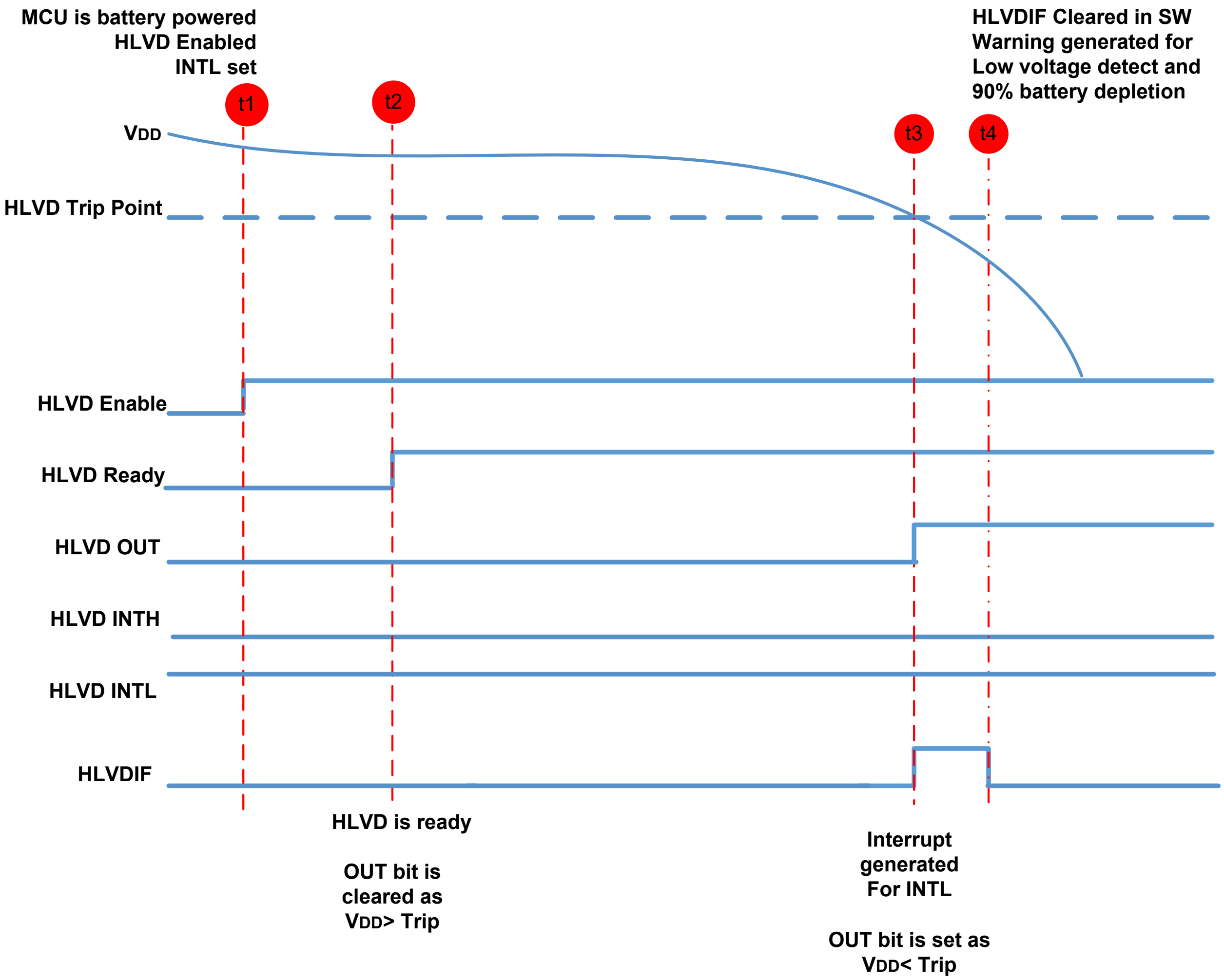
- **Monitoring Battery Discharge:** Determining the threshold for 'low battery' depends on the battery chemistry and the load drawn by the circuit. A typical discharge curve of a 1.2V battery is shown in Figure 2. The voltage decreases slowly in the operating range of the battery but starts to fall rapidly when the battery depletes. The challenge is to get the maximum life from the battery but still provide a warning in time to allow any action which is necessary before the battery is dead. The blue lines show that 90% of the battery capacity has been used and the cell voltage at this point is about 1.19V. The red line shows that 95% of the battery capacity has been used and that the cell voltage is about 1.1V. The cell voltage is dropping rapidly at this point. A three-cell pack would provide 4.2V with new and unused batteries. The 90% point would be 3.57V, and the 95% point would be 3.3V. This need to fit with the HLVD thresholds of the device. HLVDSEL=`b'1001'` provides a trip point of 3.6V and the next setting HLVDSEL=`b'1000'` provides a trip point of 3.35V. Thus, in order to provide a warning at 90% battery depletion, the HLVDSEL=`b'1001'` can be used.

Figure 5-1. Battery Discharge Curve



The timing diagram is shown in Figure 5-2:

Figure 5-2. Timing Diagram Low-Voltage Detect

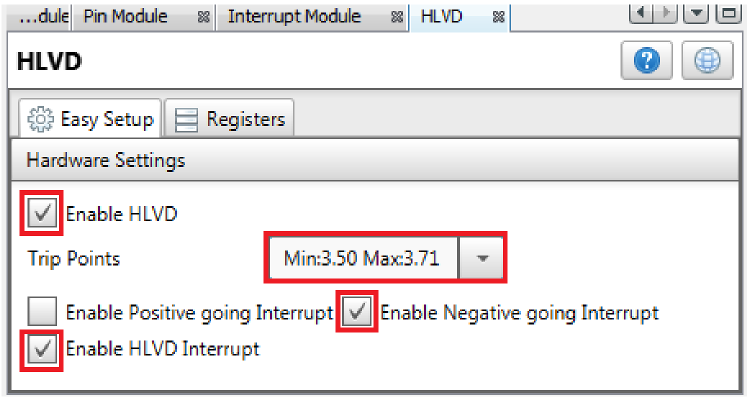


- Set the trip point voltage for HLVD. Set the INTL bit and enable the HLVD module. (event t1 in the figure above).
- The HLVD module will be ready after the HLVD start-up time, typically 25 uS in the PIC18-Q10 devices (t2).
- When the supply voltage goes below the trip point, the OUT bit will be set and the HLVD module will generate an interrupt for INTL (t3).
- The HLVDIF flag can be cleared in Interrupt Service Routine (ISR) and a warning can be generated for the low-voltage detect (t4) event.

The MPLAB® Code Configurator (MCC) is a free, graphical programming environment that generates seamless, easy-to-understand C code to be inserted into the project. Using an intuitive interface, it enables and configures a rich set of peripherals and functions specific to the application. The HLVD configuration in MCC for detecting low-voltage events is explained below:

1. Select the HLVD module from the **Device Resources** tab in the MCC Configuration window.
2. Select the desired HLVD trip point from the drop-down options. This will alter the values in the HLVDSEL bits of the HLVDCON1 register. The value selected here is ‘Min:3.50’ and ‘Max:3.71’.
3. To detect the low-voltage drops, set the check box for enabling negative going interrupt which will set the INTL bit.
4. Enable the HLVD module by checking the ‘**Enable HLVD**’ check box .
5. If interrupts are desired, enable the HLVD interrupt by setting the ‘**Enable HLVD Interrupt**’ check box .

Figure 5-3. HLVD Configuration for Low-Voltage Detect



In the Interrupt Service Routine (ISR), add relevant application code to take appropriate action.

MCC generates ready to use APIs for easy usage of the HLVD module. The following APIs are generated by MCC.

1. The `HLVD_Initialize()` API can be used for initialization of the HLVD module.

```
void HLVD_Initialize(void)
{
    // set the HLVD_Initialize module to the options selected in the User Interface
     // SEL Min:3.00 Max:3.18;
    HLVDCON1 = 0x07;
     // HLVDINTL enabled; HLVDINTH disabled; HLVDEN enabled;
    HLVDCON0 = 0x81;

    PIR2bits.HLVDIF = 0;
    // Enable HLVD interrupt.
    PIE2bits.HLVDIE = 1;
}
```

2. The `HLVD_OutputStatusGet()` API can be used to determine the status of the HLVDOUT bit.

```
bool HLVD_OutputStatusGet(void)
{
    //return HLVD voltage status
    return(HLVDCON0bits.HLVDOUT);
```

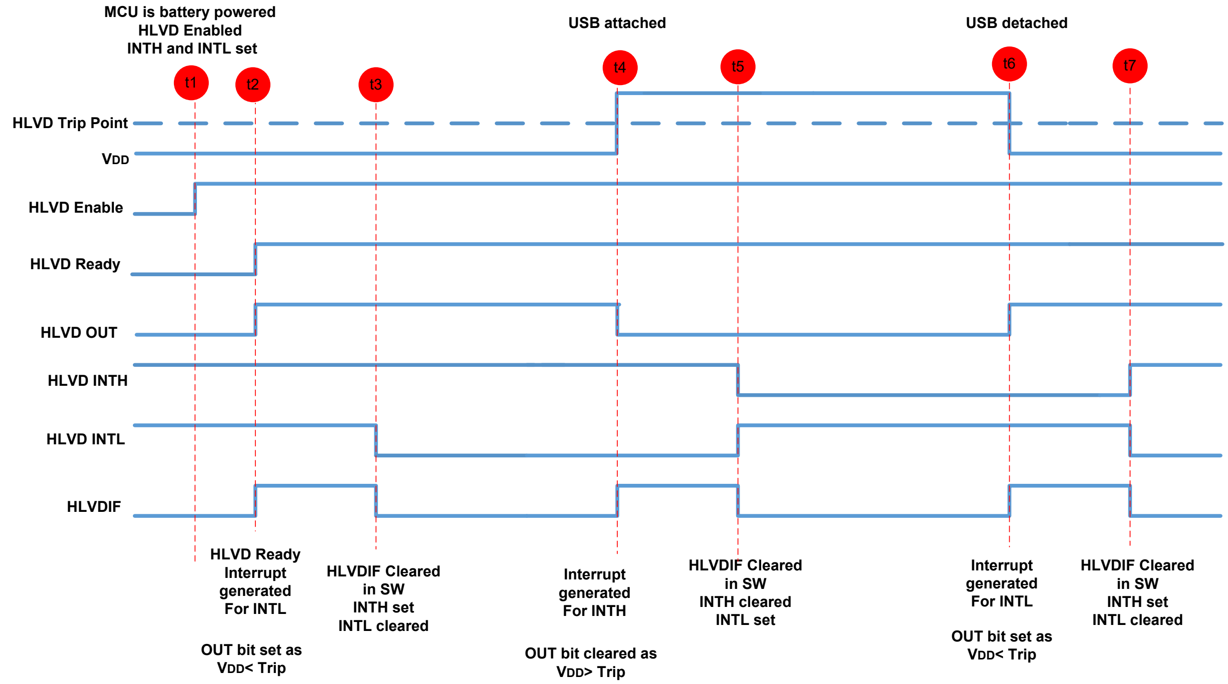
3. If the HLVD trip point has to be changed, then the `HLVD_TripPointSetup(bool Negative_Trip,bool Positive_Trip, HLVD_TRIP_POINTS trip_points)` API can be used.

```
void HLVD_TripPointSetup(bool Negative_Trip,bool Positive_Trip,
        HLVD_TRIP_POINTS trip_points)
{
   //set Negative trip
   HLVDCON0bits.HLVDINTL = Negative_Trip;
 //set Positive trip
   HLVDCON0bits.HLVDINTH = Positive_Trip;
   // Set trip points
   HLVDCON1 = trip_points;
}
```

5.2 Detection of Universal Serial Bus (USB) Attach or Detach

If the device can be powered either using the Universal Serial Bus (USB) or battery having lower voltage than USB, the HLVD module could be periodically enabled to detect USB attach or detach. An attach would indicate a high-voltage detect from 3.3V (battery voltage) to 5V (the voltage on USB) and vice versa for a detach. This feature could save few extra components for a design and an attach signal (input pin). HLVDSEL=`b'1011'` provides a trip point of 4V. Thus, to detect if USB is attached, the INTH bit can be set while to detect the USB detach, INTL bit will be set. The timing diagram is shown in Figure 5-4:

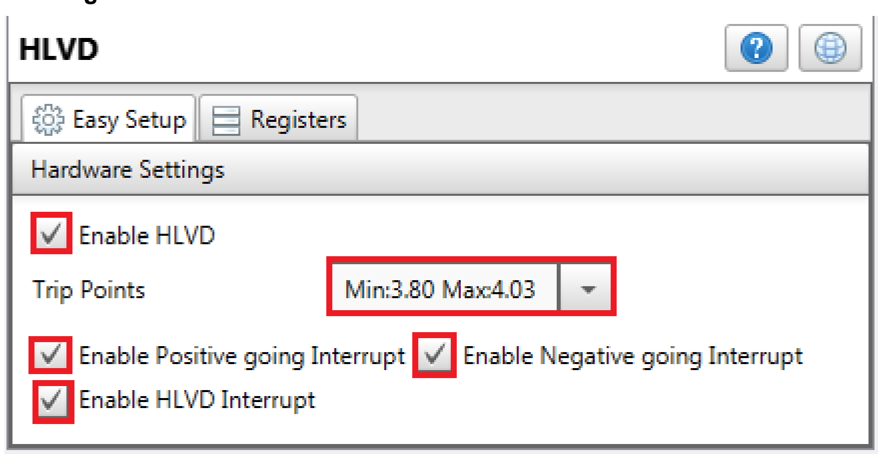
Figure 5-4. Timing Diagram USB Attach Detach



- After the device is powered up for the very first time, set both INTH and INTL bits. Also, enable the HLVD module. (event t1 in the timing diagram above).
- After the HLVD module is ready, it will generate an interrupt (t2). In the ISR, monitor the OUT bit status to determine whether the microcontroller is powered with USB or battery. If the microcontroller is powered with a 3.3V battery, then the supply voltage is below the trip point (i.e., 4V) so the OUT bit would have been set.
- The INTH bit should be kept set to detect USB attach and the INTL bit should be cleared (t3).
- When the USB is attached, the supply voltage (5V) is above the trip point (e.g., 4V) so the OUT bit will be cleared and the HLVD module will generate an interrupt for INTH (t4).
- In the ISR, the INTL bit should be set and INTH should be cleared to detect the USB detach (t5).
- When USB is detached (t6), the supply voltage (3.3V) is below the trip point (i.e., 4V) so the OUT bit will be set and the HLVD module will generate an interrupt for INTL (t6).
- In the ISR, the INTH bit should be set to detect the next USB attach (t7) event.

The HLVD configuration in MCC for the detection of USB attach detach is shown in Figure 5-5:

Figure 5-5. HLVD Configuration in MCC for USB Attach or Detach Detection



After the first power-on and first HLVD interrupt, check the status of the HLVD OUT bit using MCC generated API `HLVD_OutputStatusGet ()`. If the OUT bit is set, the USB is detached, and the device is powered using the battery. Clear the INTL bit and keep the INTH bit set using `HLVD_TripPointSetup` API (`bool Negative_Trip`, `bool Positive_Trip`, `HLVD_TRIP_POINTS trip_points`). Use the same `HLVD_TripPointSetup` API for setting either the INTH or INTL bits to detect USB attach and detach events, subsequently.

Note: The code example for the usage of the HLVD module can be found at the following page: https://mplabxpress.microchip.com/mplabcloud/example.

6. Conclusion

The HLVD module of the 8-bit PIC microcontrollers is a valuable feature for monitoring the supply voltage of a microcontroller that is directly battery-powered. The usage of the HLVD module does not require any extra PORT pin and components for supply voltage monitoring. The HLVD module can be configured seamlessly using MCC GUI. MCC also generates ready to use APIs for using and configuring the HLVD module.

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ISBN: 978-1-5224-5378-9

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