

Hardware Limit Timer on PIC[®] Microcontrollers

Author: Swathi Sridhar
Microchip Technology Inc.

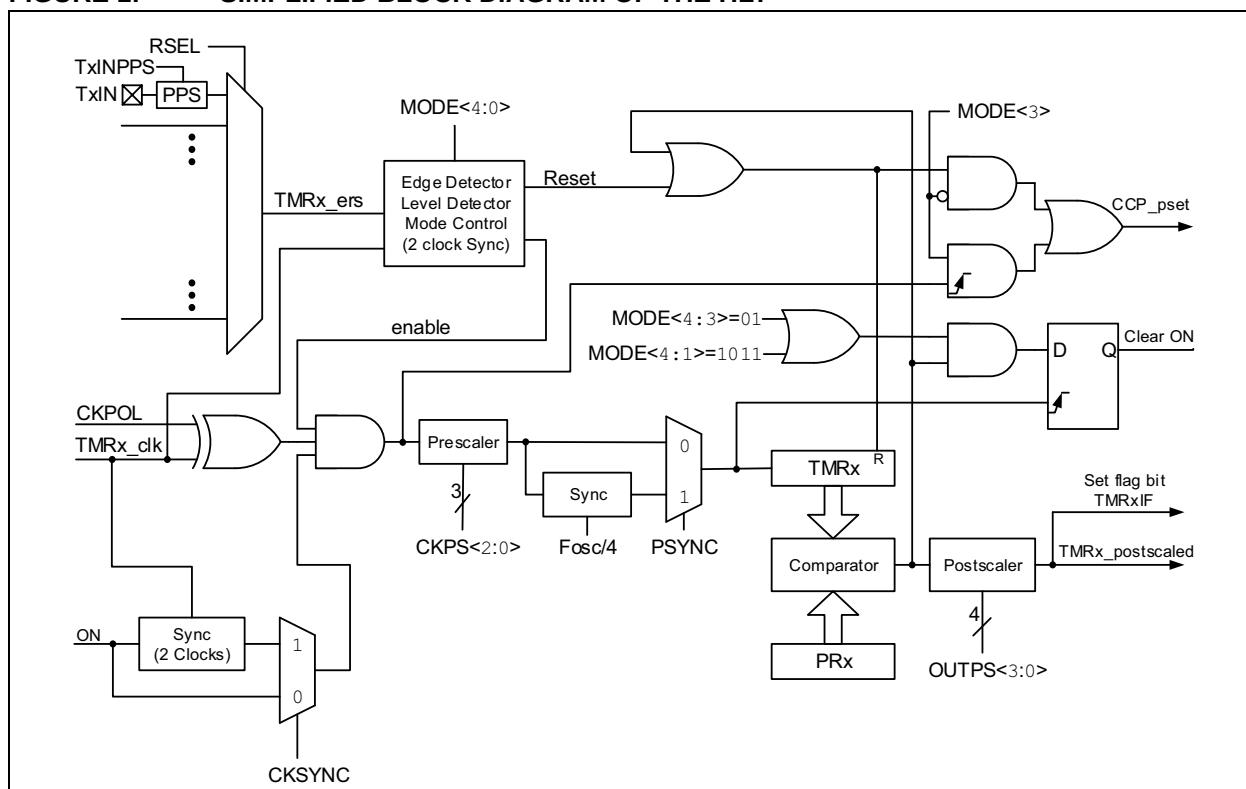
INTRODUCTION

PIC[®] microcontrollers are equipped with hardware features that are useful for implementing Fault detection in safety critical applications. The Hardware Limit Timer (HLT), which has hardware monitoring capabilities for missed periodic events, is one such feature. This on-chip peripheral helps in detecting external hardware Fault conditions like Stall and Stop conditions in a motor control application. It can also be used for any precise timing application that has a dependency on an external signal. This document aims at familiarizing the reader with the functionality of the HLT and its different modes of operation.

THE HARDWARE LIMIT TIMER

The Hardware Limit Timer is an enhanced version of Microchip's PIC microcontroller Timer2 module with the addition of an asynchronous external Reset capability and one-shot functionality. The timer can be started, stopped and reset based on an external event. This external signal can be from an external input pin or can be derived from on-chip core independent peripherals such as a comparator or the Zero-Cross Detect (ZCD). The timer can produce an interrupt signal when an expected event is missed. Using the HLT feature minimizes the CPU overhead, thereby freeing the CPU for other time-critical applications. The HLT also eliminates the need of any external components for fault handling. It has multiple modes of operation and selectable clock sources, which makes the design flexible. The simplified block diagram of Timer2 with the hardware limit feature is shown in Figure 1. The HLT is started by setting the ON bit of the TxCON register. The mode of operation is controlled by the MODE bits of the TxHLT register.

FIGURE 1: SIMPLIFIED BLOCK DIAGRAM OF THE HLT



The Hardware Limit Timer can be clocked using one of the following clock sources:

- FOSC (System Clock)
- FOSC/4 (Instruction Clock)
- LFINTOSC (Low-Frequency Internal Oscillator)
- MFINTOSC (Medium-Frequency Internal Oscillator)
- HFINTOSC (High-Frequency Internal Oscillator)
- Timer0 or Timer1 Output Pin
- Timer Input Pin

For the external source to the HLT, the following external trigger sources can be chosen:

- Complementary Waveform Generator (CWG)
- Zero-Cross Detect (ZCD)
- Capture/Compare/PWM (CCP)
- Timer4
- Timer6
- Comparator

Note: Some of these features might vary depending on the family of products. Refer to the product specific data sheet for further details.

MODES OF OPERATION

The modes in the HLT can be broadly classified into Rollover Pulse mode, One-Shot mode and Monostable mode. The Hardware Limit Timer feature for these modes allows the selected input to clear the TMRx register and restart the timing sequence. There are both edge-sensitive and level-sensitive options defined. [Table 1](#) summarizes all the modes of the timer and the working of each mode.

TABLE 1: MODES OF OPERATION OF HLT WITH START, STOP AND RESET CONDITIONS

Mode		Operation	Start	Reset	Stop
Rollover Pulse	Software Gate	Software-controlled ON bit, legacy Timer2 operation	ON = 1	Period match event	ON = 0
	Hardware Gate, Active-High	Hardware gate, active-high	Input signal = 1 and ON = 1	Period match event	Input signal = 0 or ON = 0
	Hardware Gate, Active-Low	Hardware gate, active-low	Input signal = 0 and ON = 1	Period match event	Input signal = 1 or ON = 0
	Rollover Pulse with HLT action (Edge-Triggered Hardware Limit mode and Level-Triggered Hardware Limit mode)⁽¹⁾	Input either edge Reset	ON = 1	Input edge	ON = 0
		Input rising edge Reset		Input rising edge	
		Input falling edge Reset		Input falling edge	
		Input active-low Reset		Input signal = 0	ON = 0 or held in Reset by input signal
		Input active-high Reset		Input signal = 1	

Note 1: The modes that are highlighted in the table are the HLT modes.

TABLE 1: MODES OF OPERATION OF HLT WITH START, STOP AND RESET CONDITIONS

Mode		Operation	Start	Reset	Stop
One-Shot mode	One-Shot SW Start	Software-controlled ON bit	ON = 1	Period match event	ON = 0 or next clock after period match until ON bit is set by software
	One-Shot Edge-Triggered Start	Input rising edge start	Input signal rising edge and ON = 1	Period match event	
		Input falling edge start	Input signal falling edge and ON = 1		
		Input either edge start	Input signal either edge and ON = 1		
	One-Shot Edge-Triggered Start with HLT Action (Edge-Triggered Hardware Limit One-Shot mode) ⁽¹⁾	Input rising edge start and Reset	Input signal rising edge and ON = 1	Input signal rising edge	
		Input falling edge start and Reset	Input signal falling edge and ON = 1	Input signal falling edge	
		Input rising edge start and active-low Reset	Input signal rising edge and ON = 1	Input signal = 0	
		Input falling edge start and active-high Reset	Input signal falling edge and ON = 1	Input signal = 1	
	One-Shot Level-Triggered Start with HLT Action (Level Triggered Hardware Limit One-Shot Mode)*	Input high start and active-low Reset	Input signal = 1 and ON = 1	Input signal = 0	ON = 0 or held in Reset
		Input low start and active-high Reset	Input signal = 0 and ON = 1	Input signal = 1	
Monostable	Edge-Triggered Start	Input either edge Reset	Input signal rising edge and ON = 1	Period match event	ON = 0 or next clock after period match until next input edge
		Input rising edge Reset	Input signal rising edge and ON = 1		
		Input falling edge Reset	Input signal rising edge and ON = 1		

Note 1: The modes that are highlighted in the table are the HLT modes.

The following sections will provide more details about the HLT modes of the Rollover Pulse mode and the One-Shot modes.

Rollover Pulse Mode with Hardware Limit Timer

In the Rollover Pulse mode, the ON bit allows the user to start and stop the timer. The timer increments with each clock input with the ON bit set and stops incrementing when the ON bit is cleared. If the ON bit is set again, then the timer continues to increment from where it stopped. On a period match, the timer resets on the next clock and continues counting from '0'. The Rollover Pulse modes with the hardware limit feature are:

- Edge-Triggered Hardware Limit mode
- Level-Triggered Hardware Limit mode

In Edge-Triggered Hardware Limit mode, setting the ON bit starts the timer. The external signal can reset the timer before the period match occurs.

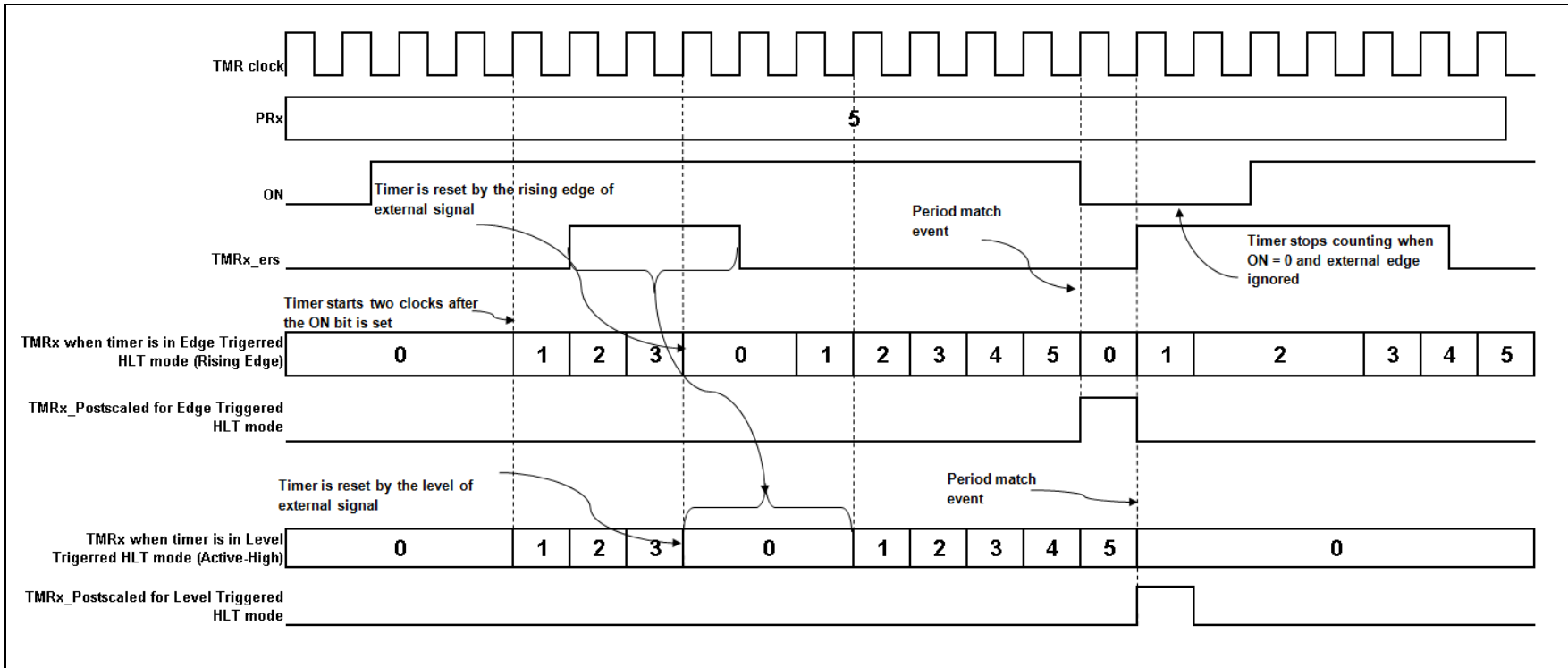
The external edges for Reset can be:

- Reset on rising edge (MODE<4:0> = 00101)
- Reset on falling edge (MODE<4:0> = 00100)
- Rising or falling either edge can reset the counter (MODE<4:0> = 00011)

The external signal level can also be used to reset the timer. This level can be a high state or a low state (MODE<4:0> = 00010 or MODE<4:0> = 00001). The operation of the Edge-Triggered Hardware Limit mode and Level-Triggered Hardware Limit mode is illustrated in [Figure 2](#).

Note 1: The setting and clearing of the ON bit is executed by the CPU. CPU execution is asynchronous to the timer clock input.

2: The timer events consume up to two clock cycles for starting and stopping.

FIGURE 2: TIMING DIAGRAM OF EDGE-TRIGGERED AND LEVEL-TRIGGERED HARDWARE LIMIT MODE

One-Shot Mode

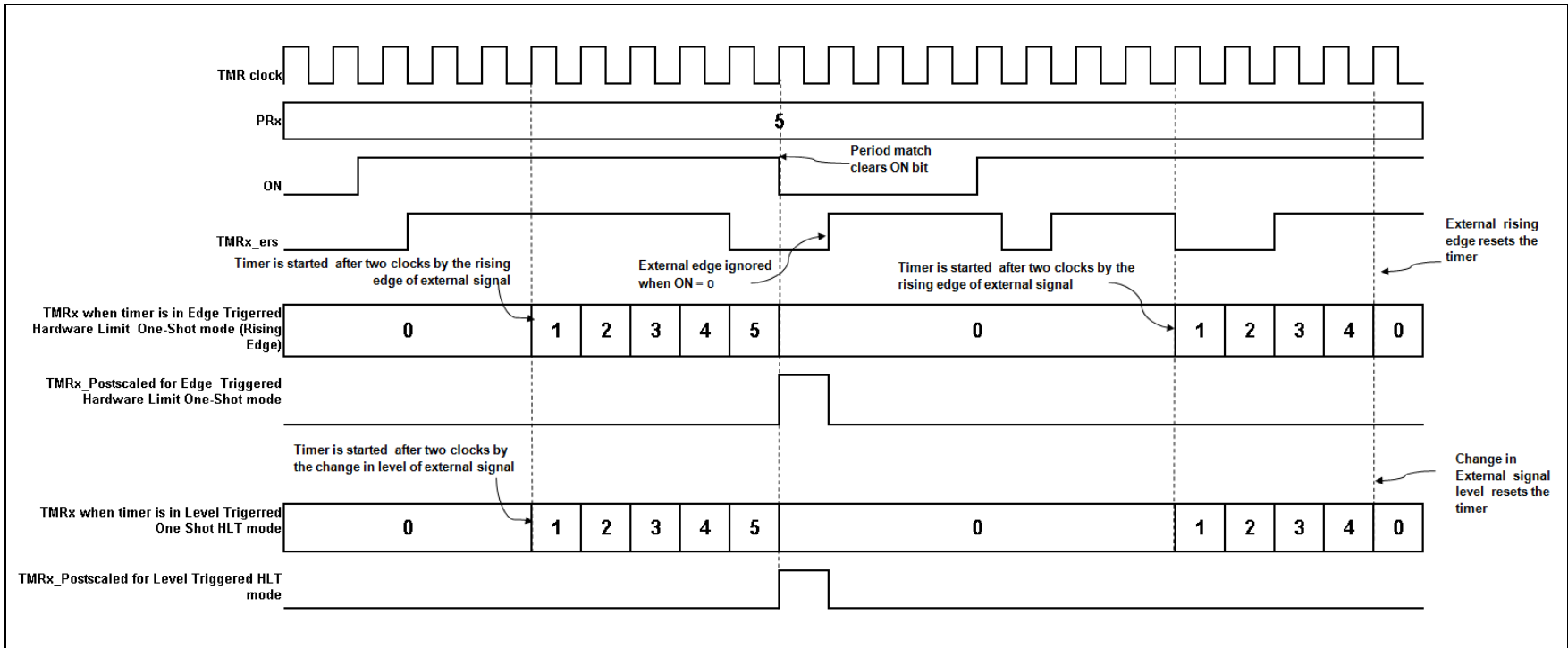
Unlike in the Rollover Pulse mode, in One-Shot mode, the ON bit is cleared in hardware when the timer rolls over. Only one timer interrupt is generated and the timer stops counting. The ON bit must be set by software to start another timer cycle. This mode is useful when the user desires to time a single event rather than a periodic event. The One-Shot modes with the hardware limit feature are:

- Edge-Triggered Hardware Limit One-Shot mode
- Level-Triggered Hardware Limit One-Shot mode

Edge-Triggered Hardware Limit One-Shot mode features not only an edge-triggered start but it also resets the timer on subsequent edges of the external signal (i.e., once the ON bit is set, the occurrence of the first edge of the external signal will start the timer). The timer runs until another edge of the external signal or until a period match occurs. The timer will automatically resume counting after the subsequent Reset edge and it will run until the period match occurs. There are two ways that this mode can be achieved:

- Rising Edge Start and Reset (MODE<4:0> = 01100)
- Falling Edge Start and Reset (MODE<4:0> = 01101)

In Level-Triggered Hardware Limit One-Shot mode, the level of the external signal starts and resets the timer. This level can be configured to either a high state or a low state (MODE<4:0> = 01110 or MODE<4:0> = 01111). The timer does not start until the ON bit is set and the external signal occurs. The timer keeps running until the external signal is at the same level. Once the level of the external signal changes its state, the timer is reset. Reset levels can either be high or low. The operation of the Edge-Triggered One-Shot Hardware Limit mode and Level-Triggered One-Shot Hardware Limit mode are illustrated in [Figure 3](#).

FIGURE 3: TIMING DIAGRAM OF EDGE-TRIGGERED HARDWARE LIMIT AND LEVEL-TRIGGERED HARDWARE LIMIT ONE-SHOT MODE

Monostable Mode

In this mode, the timer stops after a rollover but it does not clear the ON bit. An external signal edge is again required to start the timer. The timer stops either on clearing the ON bit or on the period match event. The following edges will start the timer:

- Rising Edge (MODE<4:0> = 10001)
- Falling Edge (MODE<4:0> = 10010)
- Rising or Falling Edge (MODE<4:0> = 10011)

CONFIGURATION OF TIMER2 WITH THE HARDWARE LIMIT FEATURE

Table 2 contains the summary of registers associated with the Hardware Limit Timer.

TABLE 2: REGISTERS ASSOCIATED WITH TIMER2 WITH THE HARDWARE LIMIT FEATURE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
TxCLKCON	—	—	—	—	—	TxCS<2:0>		
TxCON	ON	CKPS<2:0>			OUTPS<3:0>			
TxRST	—	—	—	—	RSEL<3:0>			
TxHLT	PSYNC	CKPOL	CKSYNC	—	MODE<3:0>			

The TxCS bits of the TxCLKCON register are used for the clock selection. The external signal source selection is done in the TxRST register. Prescaler and postscaler settings are done in the TxCON register. Example 1 shows the code snippet used to configure Timer2 registers to operate in Edge-Triggered Rollover Pulse Hardware Limit mode.

EXAMPLE 1: CODE SNIPPET FOR CONFIGURATION OF TIMER2 IN EDGE-TRIGGERED HARDWARE LIMIT MODE

```

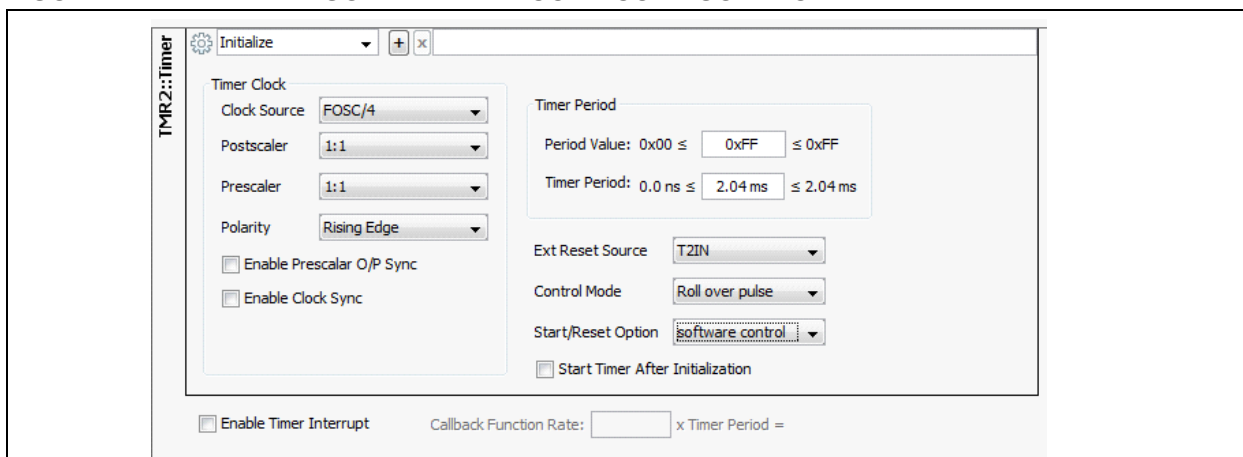
T2CLKCONbits.T2CS = 0b0000; //Clock input is Fosc/4
T2CONbits.CKPS    = 0b111;  //Prescaler setting 1:128
T2CONbits.OUTPS   = 0b1111; //Postscaler setting 1:16
T2RSTbits.RSEL    = 0b0000; //Selecting Timer2 input as external source
T2HLTbits.PSYNC   = 1;      //Prescaler synchronization bit
T2HLTbits.CKPOL   = 0;      //Rising edge of input clock clocks timer
T2HLTbits.CKSYNC  = 1;      //ON bit synchronized to input clock
T2HLTbits.MODE    = 0b01100; //Edge triggered hardware limit mode -rising edge
T2CONbits.ON      = 1;      //Timer is switched on
    
```

USING THE MPLAB® CODE CONFIGURATOR FOR CODE GENERATION OF THE HLT

The MPLAB® Code Configurator, which is a plug-in tool for MPLAB® X IDE, generates the drivers for controlling and driving the HLT based on the settings and selections made in the GUI.

The clock source selection, prescaler and postscaler settings can be done to meet the time period requirements desired by the user. External source selection and mode of operation can be picked from the drop-down selection provided by the GUI (see Figure 4). For further details refer to the “MPLAB® Code Configurator User’s Guide” (DS40001725).

FIGURE 4: TIMER2 GUI IN MPLAB® CODE CONFIGURATOR



API List for the HLT

The following API is generated by MCC for the HLT module:

- `void TMR2_Initialize(void)`: This API initializes the TxCON, TxCLKCON, TxHLT, TxRST, TxPR, TxTMR and interrupt flags, and it starts the timer.
- `void TMR2_ModeSet(TMR2_HLT_MODE mode)`: This API configures different types of HLT modes.
- `void TMR2_ExtResetSourceSet(TMR2_HLT_EXT_RESET_SOURCE reset)`: This API configures different types of HLT external Reset source.
- `void TMR2_Start(void)`: This API starts the timer by writing to the TMRxON bit.
- `void TMR2_Stop(void)`: This API stops the timer by clearing the TMRxON bit.
- `uint8_t TMR2_Counter8BitGet(void)`: This API is used to get the TxTMR register value.
- `void TMR2_Counter8BitSet(uint8_t timerVal)`: This API writes to the Timer register.
- `void TMR2_Period8BitSet(uint8_t periodVal)`: This API is used to set the Period register to a particular value.
- `void TMR2_Period8BitSet(uint8_t periodVal)`: This API is used to check if overflow has occurred, which is done by checking the TMRIF bit.

CONCLUSION

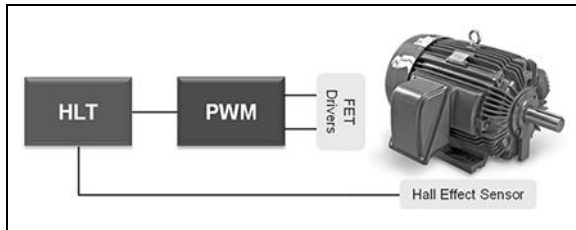
This technical brief describes how the Hardware Limit Timer module works on PIC microcontrollers. It familiarizes the reader with the hardware limit features of the Rollover Pulse modes and One-Shot modes. As explained in this technical brief, the timer in its suitable mode can be used for Fault detection in motors and in variable frequency PWM for power supply. More details can be found in each product specific data sheet.

APPENDIX A: APPLICATIONS OF THE HARDWARE LIMIT TIMER

A.1 Fault Detection in a Motor Using the HLT

The HLT in Edge-Triggered Hardware Limit Timer mode can be used in Fault detection of a cooling fan motor (Figure A-1). The RPM sensor or tachometer output of the fan is used as an external signal to the HLT. The Period register of the timer is set to a value that is sufficiently larger than the RPM count of the fan or more than the frequency of the fan tachometer output. Under normal conditions, when the fan is spinning, it gives periodic tachometer pulses. These pulses reset the timer before the period match occurs and the timer starts counting again. In the case of a Fault condition in the fan (i.e., the fan has stalled), it stops giving tachometer pulses. In this scenario, the timer continues to increment until the period match occurs. This event generates an interrupt and this interrupt can be registered to indicate that the fan is not spinning and that there is a Fault.

FIGURE A-1: FAULT DETECTION IN A MOTOR



A.2 Fixed ON Time Variable Frequency PWM Generation Using the HLT

Monostable Edge-Triggered Start mode can be used in a DC-DC converter application that is operating in Critical Conduction mode, with soft switching. By detecting the zero inductor current (used as external signal to the timer), HLT can be started for a fixed ON time. The Period register can be set to a value that is sufficiently large value, more than the maximum ON time. When HLT is used along with CCP for PWM generation, the output pulse remains active until a match of the CCP Duty register with the Timer register occurs (Figure A-2). The next pulse begins only at the next external edge, which is the ZCD event of the inductor current. This is an example of a fixed ON time variable frequency PWM generation (Figure A-3).

FIGURE A-2: INTERCONNECTION OF THE TIMER2 WITH HLT AND CCP

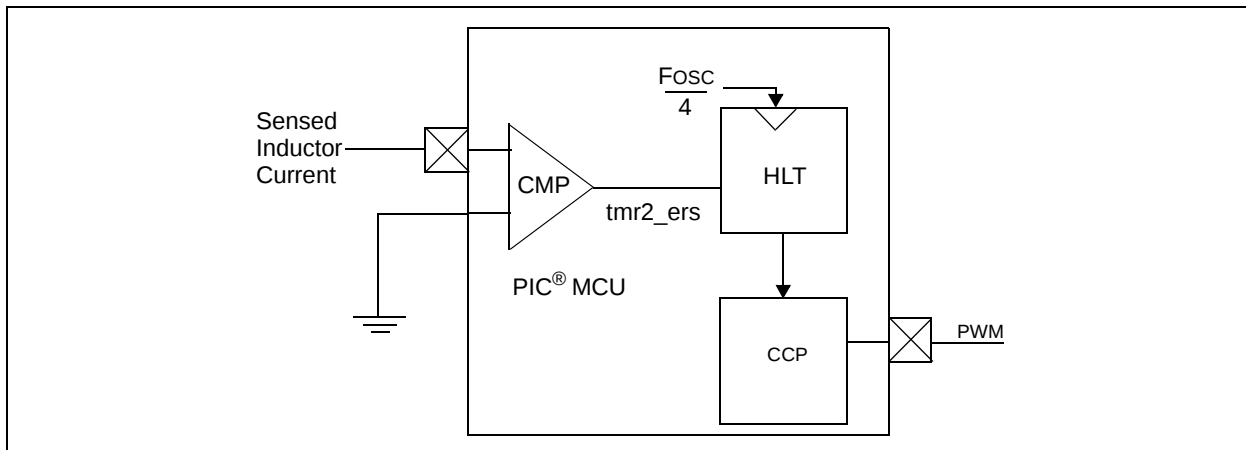
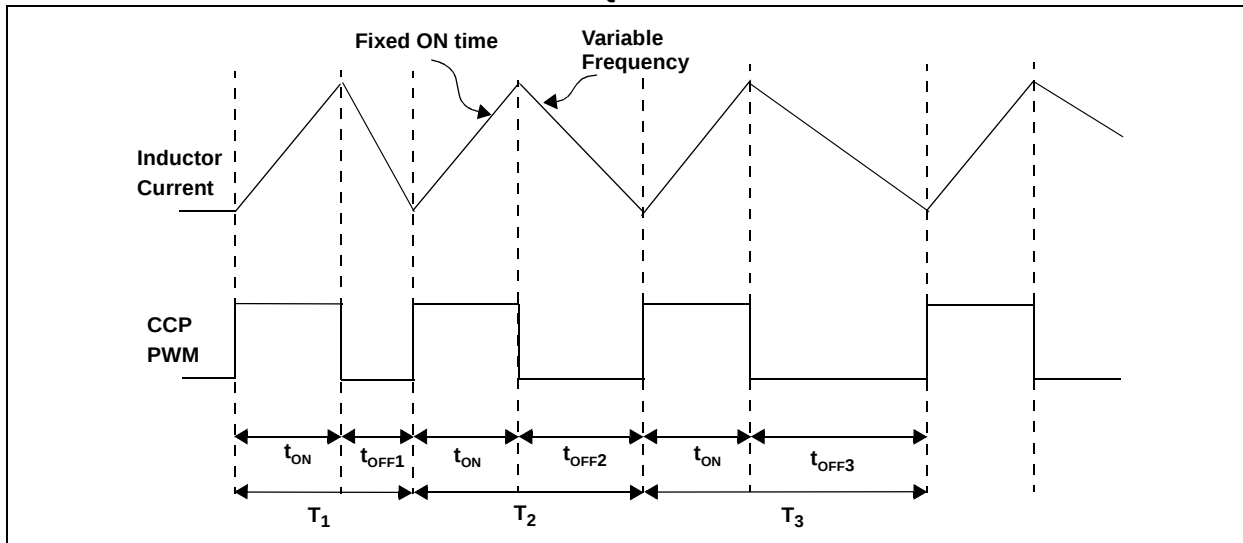


FIGURE A-3: FIXED ON TIME VARIABLE FREQUENCY PWM GENERATION



Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, flexPWR, JukeBlox, KEELOQ, KEELOQ logo, Klear, LANCheck, MediaLB, MOST, MOST logo, MPLAB, OptoLyzer, PIC, PICSTART, PIC³² logo, RightTouch, SpyNIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

The Embedded Control Solutions Company and mTouch are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Analog-for-the-Digital Age, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, ECAN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, KlearNet, KlearNet logo, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, RightTouch logo, REAL ICE, SQI, Serial Quad I/O, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademarks of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2015, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

ISBN: 978-1-63276-983-1

QUALITY MANAGEMENT SYSTEM
CERTIFIED BY DNV
= ISO/TS 16949 =

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
<http://www.microchip.com/support>
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Austin, TX
Tel: 512-257-3370

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

New York, NY
Tel: 631-435-6000

San Jose, CA
Tel: 408-735-9110

Canada - Toronto
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2943-5100
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-8792-8115
Fax: 86-571-8792-8116

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-3019-1500

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880-3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7830

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Dusseldorf
Tel: 49-2129-3766400

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Germany - Pforzheim
Tel: 49-7231-424750

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Italy - Venice
Tel: 39-049-7625286

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Poland - Warsaw
Tel: 48-22-3325737

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

Sweden - Stockholm
Tel: 46-8-5090-4654

UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820