Timers and PWM

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Overview of PWM, Timers, Serial Intf.

- Timers
- Pulse Width Modulator -- PWM

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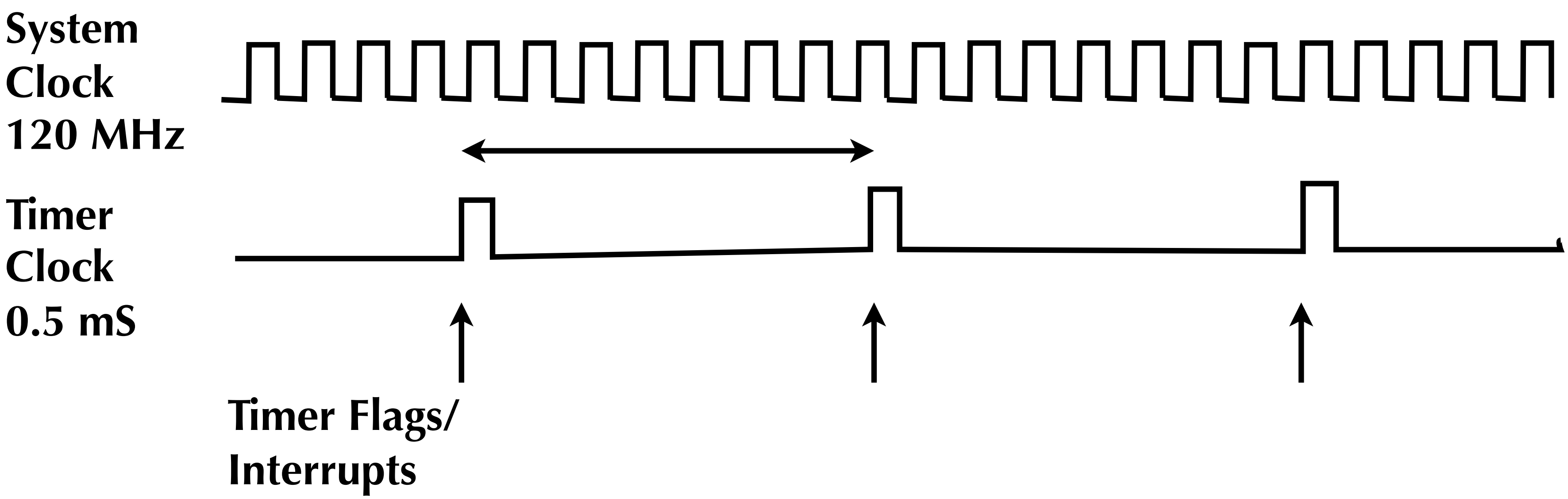
Timers

- Periodic time tick, similar to SysTick
- Count external events
- Measure time of external events
- The TM4C1294 has eight General Purpose Timer Modules (GPTM)

Periodic Time Tick



Not to scale

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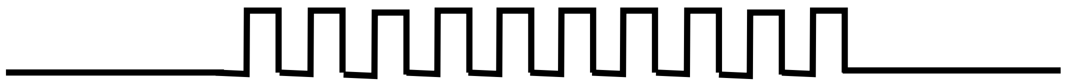
Count Events

External Events



10 Events
-- Measure motion of motor
-- Measure position of sensor
-- Sensor measurement

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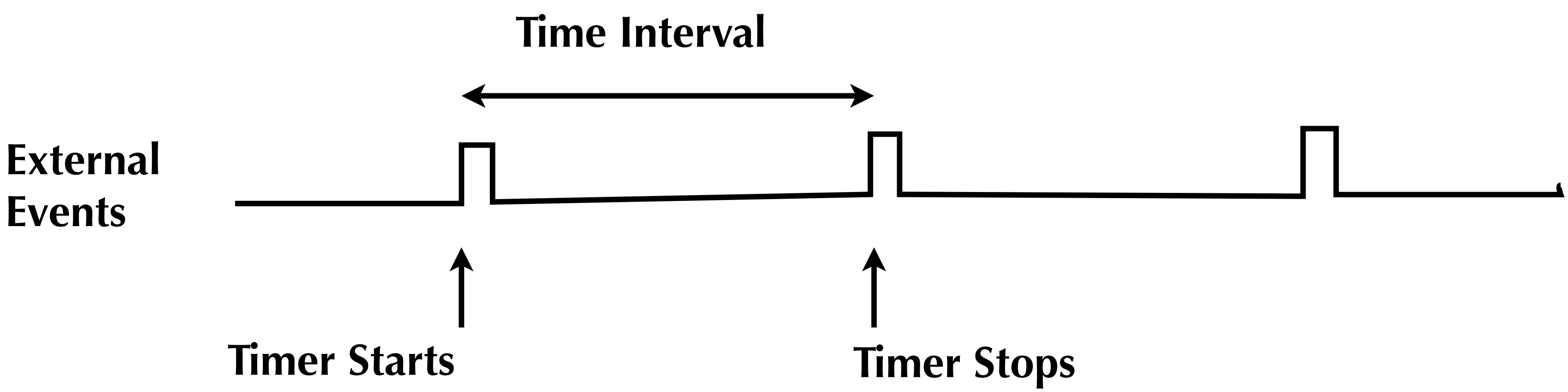
Measure Time Interval



-- Measure Motor Speed
-- E.g. at 3,000 RPM; shaft rotates 50 times per second; 20 mS Time Interval

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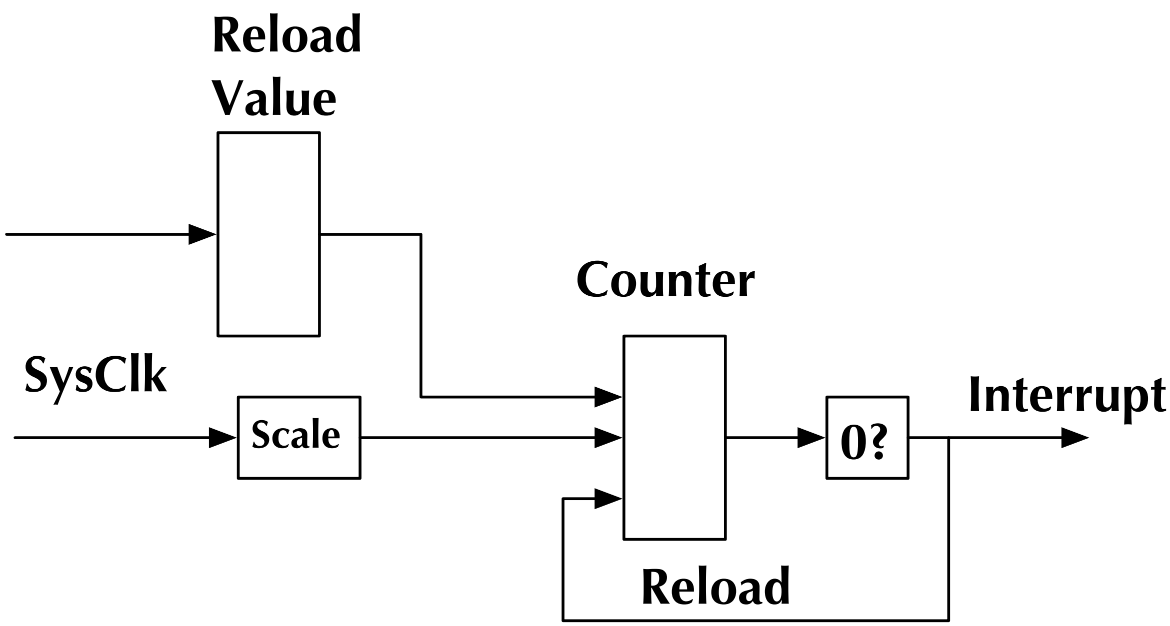
Timer Features

- Eight General-Purpose Timer Modules (GPTM), each of which provides two 16-bit timers/counters.
    - As a single 32-bit timer
    - As one 32-bit Real-Time Clock (RTC) to event capture
    - For Pulse Width Modulation (PWM)
    - To trigger analog-to-digital conversions
- 32-bit Timer modes
    - Programmable one-shot timer
    - Programmable periodic timer
    - Real-Time Clock when using an external 32.768-KHz clock as the input
    - User-enabled stalling when the controller asserts CPU Halt flag during debug
    - ADC event trigger

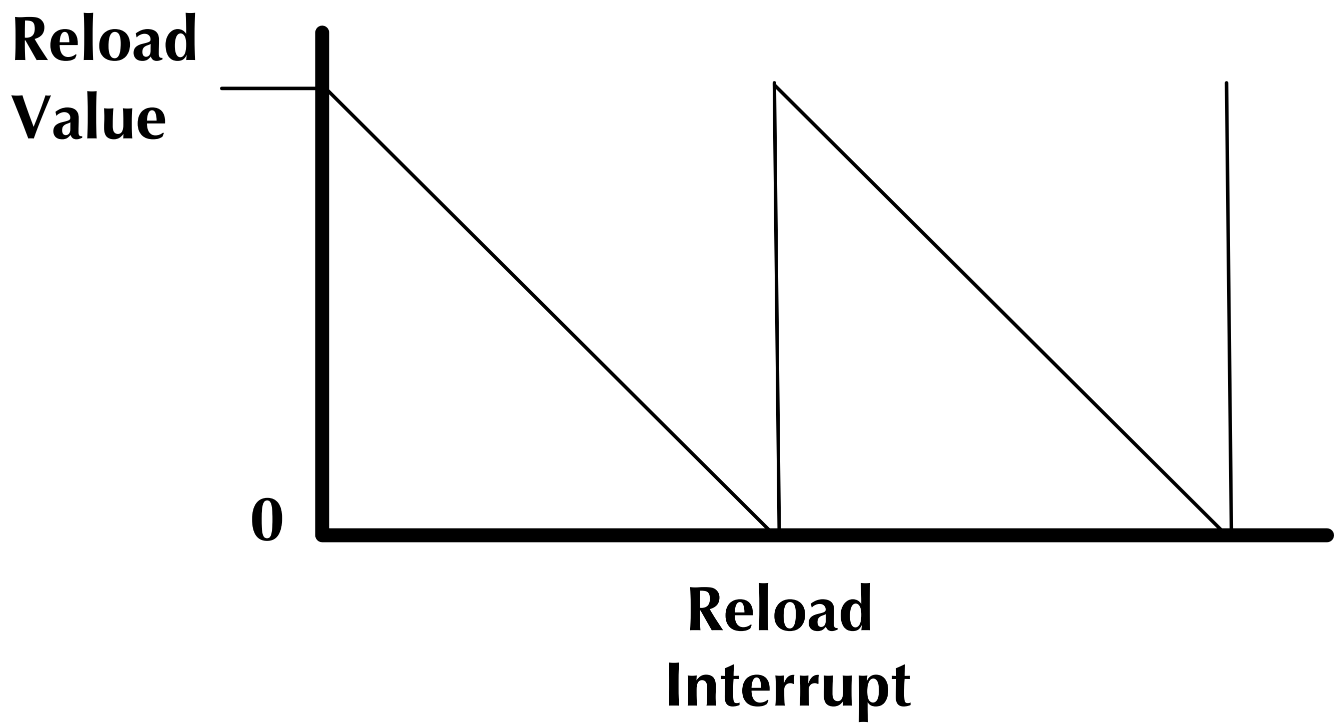
Timer Features

- 16-bit Timer modes
  - General-purpose timer function with an 8-bit pre-scaler (for one-shot and periodic modes only)
  - Programmable one-shot timer
  - Programmable periodic timer
  - User-enabled stalling when the controller asserts CPU Halt flag during debug
  - ADC event trigger
- 16-bit Input Capture modes
  - Input edge count capture
  - Input edge time capture
- 16-bit PWM mode
  - Simple PWM mode with software-programmable output inversion of the PWM signal

Timer Conceptual Diagram



Timer Counter Values



Timer Clock Generation

- At nominal 120 MHz
  - 16-bit counter -- 0.548 mS
- Divided System Clock by Pre-Scale Value
  - Pre-Scale Values of 1-256
  - With a Pre-Scale Value of 256, 16-bit counter -- 140.35 mS

Parameter Calculation

System clock is 120*10^6 (120 MHz), a period of 8.33 ns

T_T = 8.33 ns * M, where M is the Reload Value and 0 < M < 2^16 (65,536)

Suppose T_T = 20 ms, then M = 20*10^-3 / 8.33*10^-9 = 2.4*10^6
2.4*10^6 > 2^16

We must reduce M to M < 2^16. We scale the system clock by K
T_T = (8.33 ns * K) * M, where M is the Reload Value, 0 < M < 2^16, and
K is the scale value, 1 <= K <= 256; many possibilities for K and M.

Let's pick M = 60,000; then we have 60,000 = 20^10-3 / (8.33^10-9 * K);
Solving for K we get K = 20^10-3 / (60,000 * 8.33*10^-9); K = 40.02, but must be an integer, K >= 40

So, M = 60,000 and K = 40, T_T = 19.99 ms.

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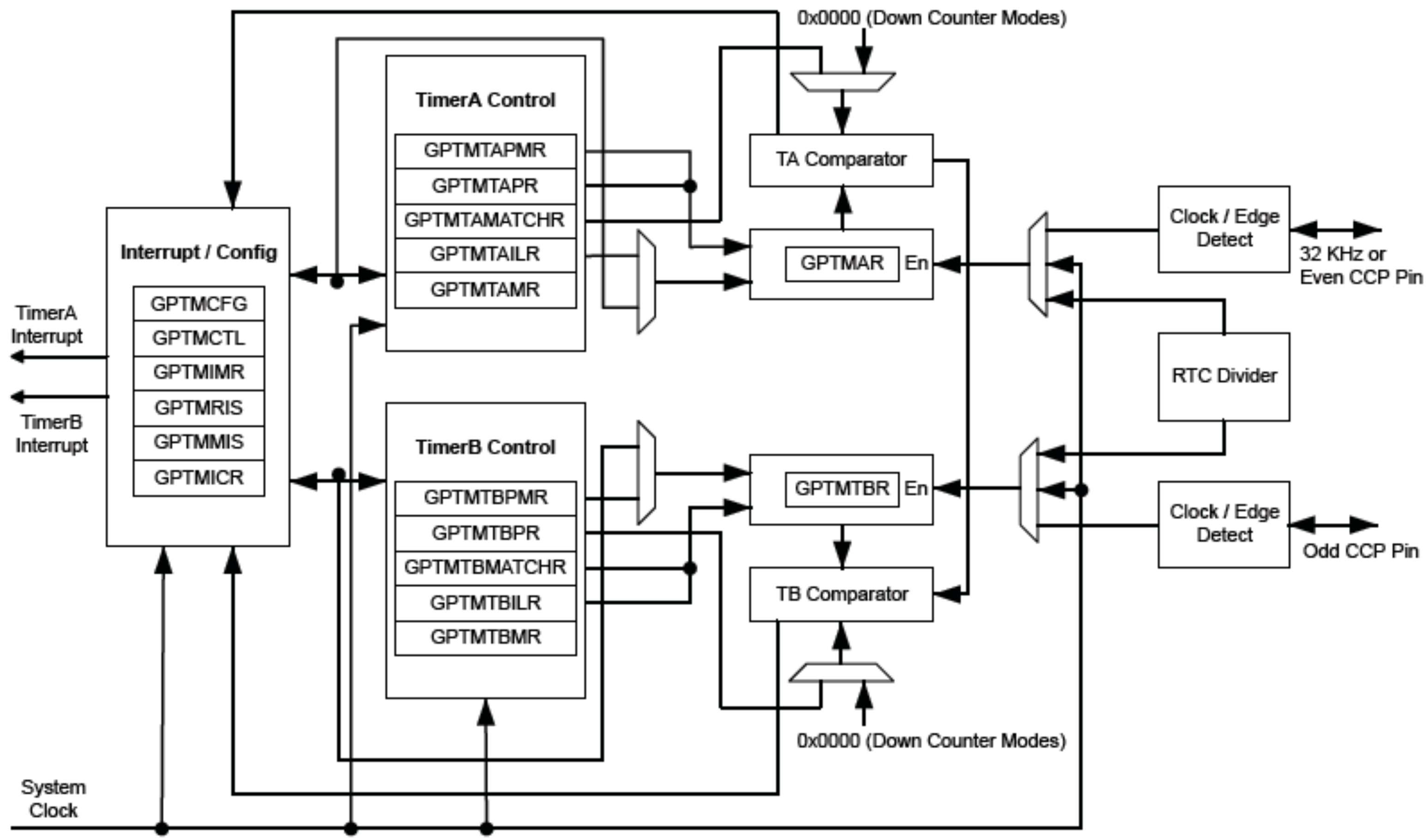
GPTM Block Diagram

Figure 9-1. GPTM Module Block Diagram



Programming Example -- FreeRTOS

```
//
*****************************************************************************
//
// Set up timer for 10 mS interval and handle with interrupts
//
//      Author:        Gary J. Minden
//      Organization:  KU/EECS/EECS 388
//      Date:          2014-04-21
//      Version:       1.0
//
//      Purpose:       Set up timer for 10 mS interval and handle
//                       with interrupts
//
//      Notes:
//
//***************************************************************************
//
```

Programming Example -- FreeRTOS

```
#include "inc/hw_ints.h"
#include "inc/hw_memmap.h"
#include "inc/hw_sysctl.h"
#include "inc/hw_types.h"

#include "driverlib/sysctl.h"
#include "driverlib/interrupt.h"
#include "driverlib/timer.h"
#include "Drivers/rit128x96x4.h"
#include "drivers/uartstdio.h"

#include "FreeRTOS.h"
#include "task.h"
#include "semphr.h"

#include "stdio.h"
```

Programming Example -- FreeRTOS

```
//
// Gloabal subroutines and variables
//

extern void Task_TimerInterrupt( void *pvParameters );
extern void Timer_0_A_ISR();

unsigned long int TimeCount = 0;

xSemaphoreHandle Timer_0_A_Semaphore;
```

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Programming Example -- FreeRTOS

```
//**************************************************************************
//
// Task initialization

void Task_TimerInterrupt( void *pvParameters ) {

   //**********************************************************************
   //
   // Constants and Variables
   unsigned long int Hours, Minutes, Seconds, CentiSeconds;
   char DisplayString[24];

   //
   // Initialize Timer_0_A_Semaphore
   //
   vSemaphoreCreateBinary( Timer_0_A_Semaphore );
```

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Programming Example -- FreeRTOS

```
//
// Adapted from TI Stellaris Timer Example
//
SysCtlPeripheralEnable( SYSCTL_PERIPH_TIMER0 );
 IntRegister( INT_TIMER0A, Timer_0_A_ISR );
TimerConfigure( TIMER0_BASE,
                TIMER_CFG_SPLIT_PAIR | TIMER_CFG_A_PERIODIC );
TimerPrescaleSet( TIMER0_BASE, TIMER_A, 9 );  // Set K (actual – 1)
TimerLoadSet( TIMER0_BASE, TIMER_A, 50000 );  // Set M
// Enable Timer_0_A interrupt
TimerIntEnable( TIMER0_BASE, TIMER_TIMA_TIMEOUT );
// Enable Timer_0_A interrupt in NVIC
IntEnable( INT_TIMER0A );
// Enable (Start) Timer
TimerEnable( TIMER0_BASE, TIMER_A );
```

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Programming Example -- FreeRTOS

```
//
//  Initialize time of day to 00:00:00.00
//
Hours = 0;
Minutes = 0;
Seconds = 0;
CentiSeconds = 0;
```

Programming Example -- FreeRTOS

```
while( 1 ) {
xSemaphoreTake( Timer_0_A_Semaphore, portMAX_DELAY );
CentiSeconds++;
if ( CentiSeconds >= 100 ) {
    CentiSeconds = 0;
    Seconds++;
    // If Seconds is a mutiple of 10, print the TOD
    // at the end of the outer most if-statement
    if ( (Seconds % 10) == 0 ) {
        bPrintTimeOfDay = true;
    } else {
        bPrintTimeOfDay = false;
    }
    if ( Seconds >= 60 ) {
        Seconds = 0;
        Minutes++;
        if ( Minutes >= 60 ) {
            Minutes = 0;
            Hours++;
            if ( Hours >= 24 ) {
                Hours = 0;
            }
        }
    }
}
```

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Programming Example -- FreeRTOS

```
        if ( bPrintTimeOfDay ) {
          UARTprintf( "Time: %02d:%02d:%02d:%02d\n",
                         Hours, Minutes, Seconds, CentiSeconds );
          bPrintTimeOfDay = false;
        }

    }

}
```

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Programming Example -- FreeRTOS

```
//*************************************************************************
//
//  Define an interrupt service routine for Timer_0_A
//  We'll try the TI ARM Compiler pragma
//

void Timer_0_A_ISR() {

   portBASE_TYPE xHigherPriorityTaskWoken = pdFALSE;

   //
   //  Clear interrupt and increment count
   //
   TimerIntClear( TIMER0_BASE, TIMER_TIMA_TIMEOUT );
   TimeCount++;

   //
   //  "Give" the Timer_0_A_Semaphore
   //
   xSemaphoreGiveFromISR( Timer_0_A_Semaphore,
                          &xHigherPriorityTaskWoken );
```

Programming Example -- FreeRTOS

```
//
// If xHigherPriorityTaskWoken was set to true,
//   we should yield.  The actual macro used here is
//   port specific.
//
portYIELD_FROM_ISR( xHigherPriorityTaskWoken );
```

Timer Exercise

Compute K and M for T_T = 30 ms

Timer Exercise

Compute K and M for T_T = 17 ms

Timer Exercise

Compute K and M for T_T = 45 ms

Timer Exercise

Compute K and M for T_T = 3 ms

Timer Exercise

Compute K and M for T_T = 23 ms

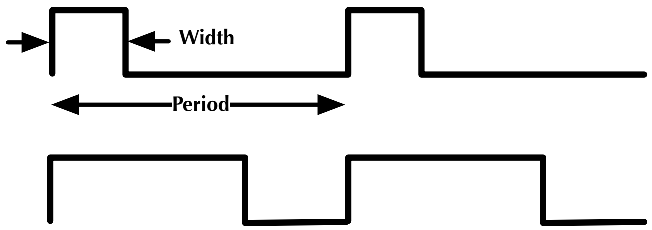
Timer Exercise

Compute K and M for T_T = 77 ms

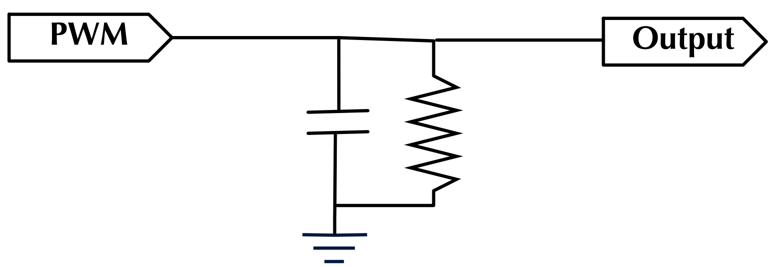
Pulse Width Modulator

PWM

- Generate a repeating pulse with variable width



- Useful for controlling various devices, including motors, servos, and electronics
- Use a low-pass filter to get DC output. DC voltage varies as pulse width. Longer pulse, higher voltage



PWM Features

- Four PWM generator blocks, each with one 16-bit counter, two PWM comparators, a PWM signal generator, a dead-band generator, and an interrupt/ADC-trigger selector
- One fault input in hardware to promote low-latency shutdown
- One 16-bit counter
- Two PWM comparators
- PWM generator
- Dead-band generator
- Optional output inversion of each PWM signal (polarity control)
- Optional fault handling for each PWM signal
- Can initiate an ADC sample sequence

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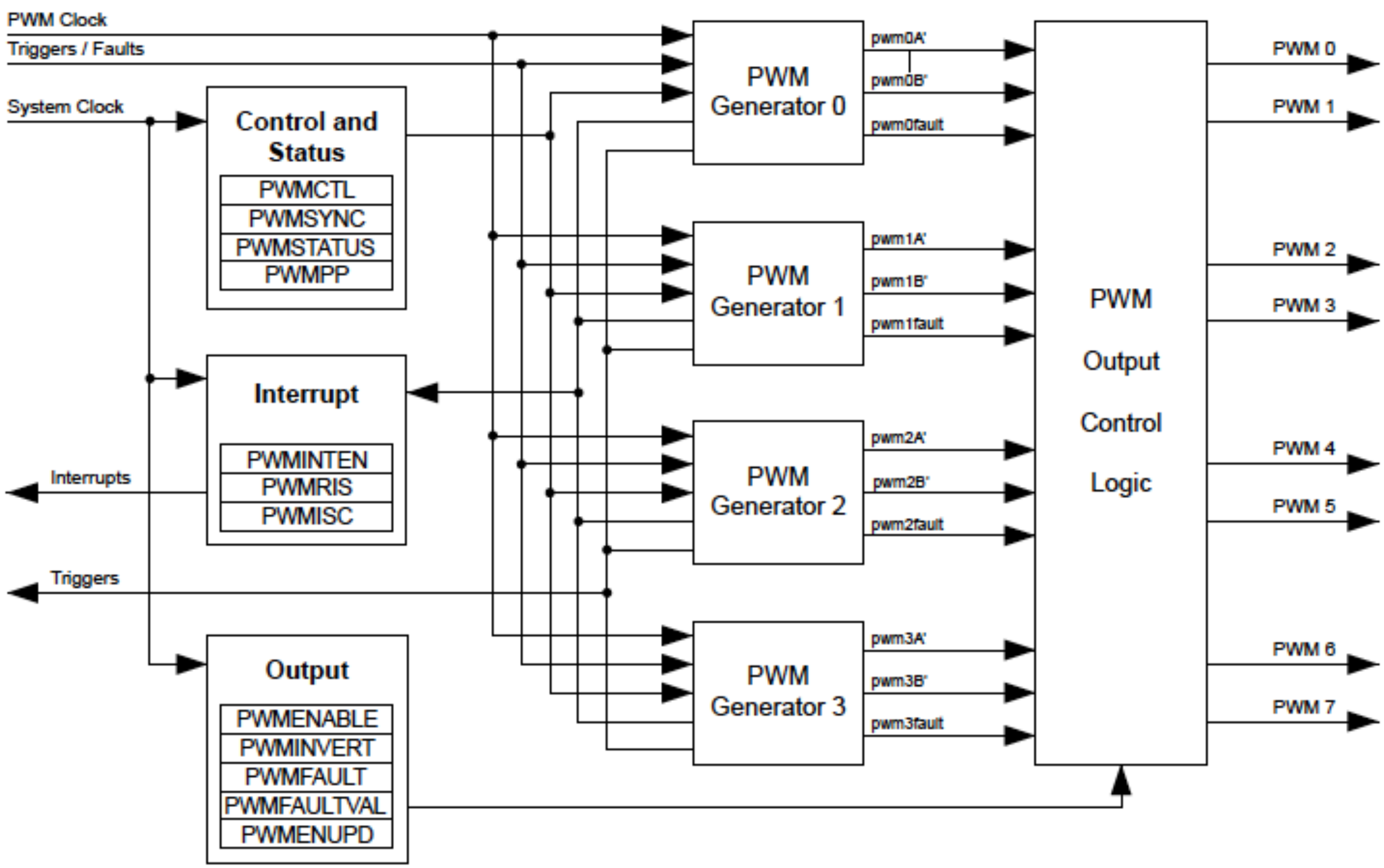
PWM Block Diagram

Figure 23-1. PWM Module Diagram



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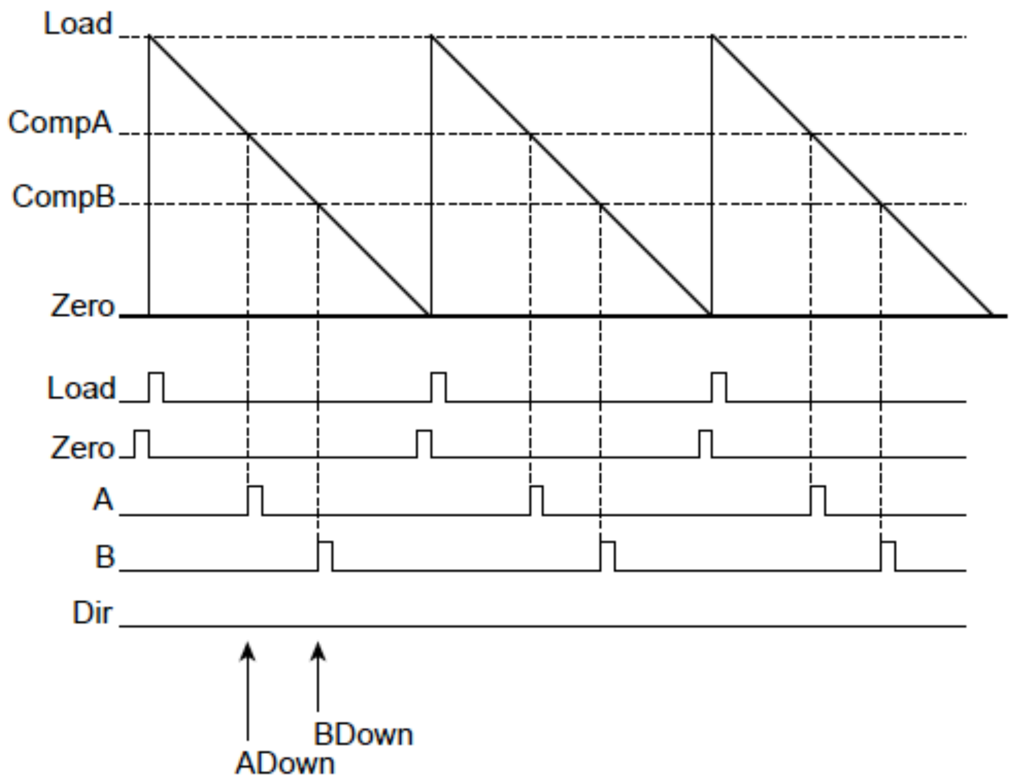
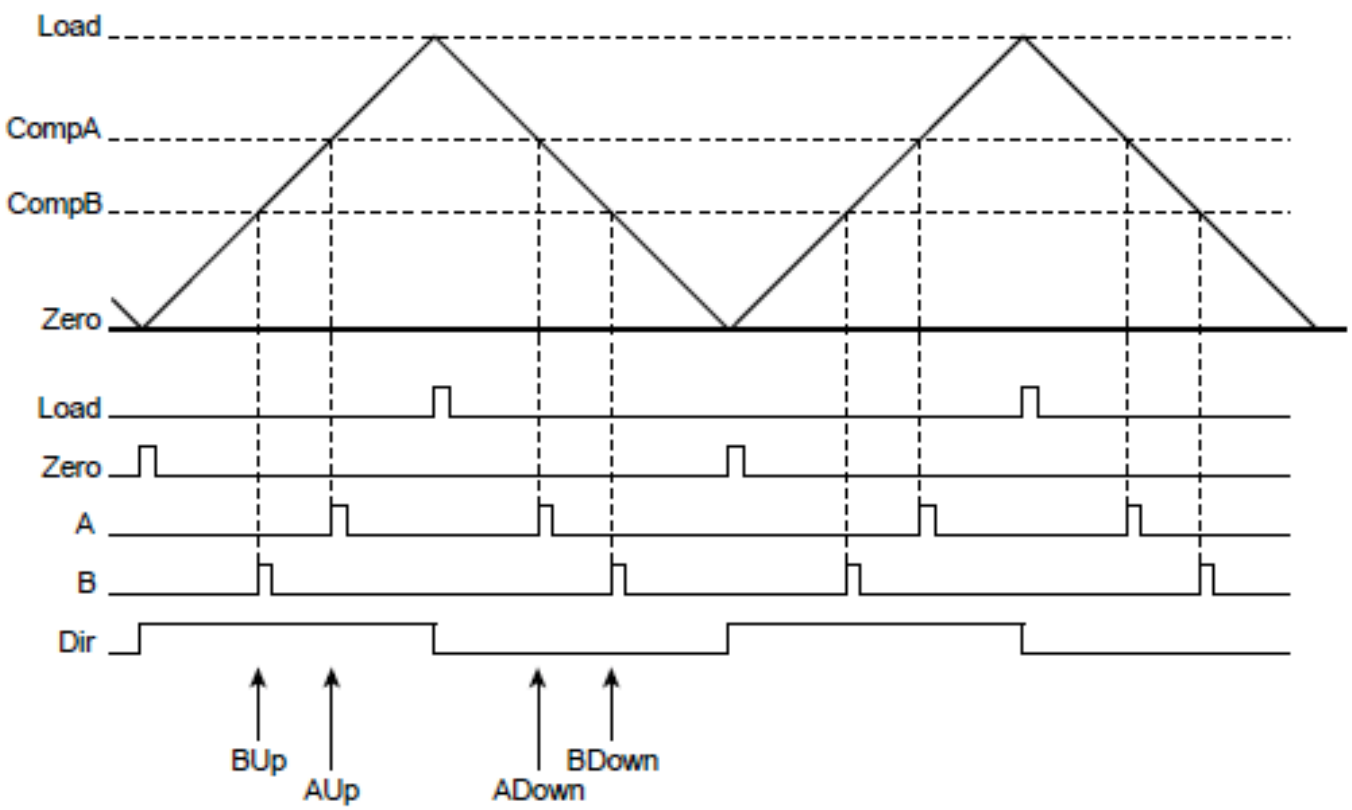
PWM General Operation

Figure 16-3. PWM Count-Down Mode



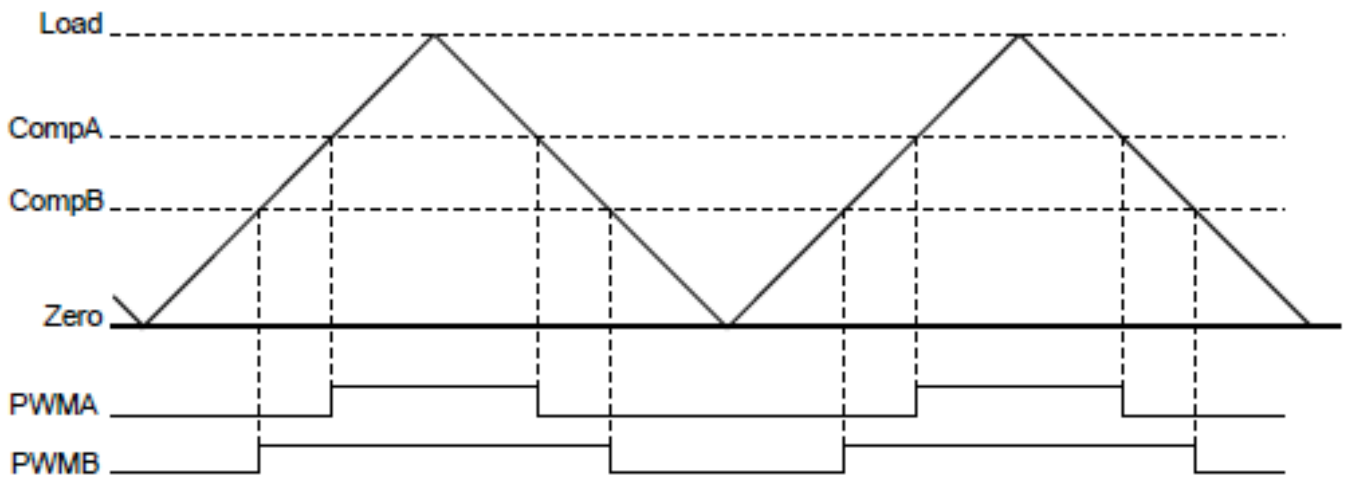
PWM Up/Down Mode

Figure 16-4. PWM Count-Up/Down Mode



PWM Example

Figure 16-5. PWM Generation Example In Count-Up/Down Mode



PWM Example Program

```
//*****************************************************************************
//—Task_Motor_PWM_0_4
//
//        Author:       Gary J. Minden
//        Organization:KU/EECS/EECS 388
//        Date:         2017—11—03 (B71103)
//        Platform:     TI Tiva TM4C1294 evaluation board
//        Version:      1.0
//
//        Purpose:      This task implements several PWM control motor
//                      tests. The tests include:
//                      (1) Alternating CW, pause, CCW motion
//
//                      APIs are defined for:
//                      (1) Enable/Disable the motor for all tasks.
//                      (2) Set the motor speed and direction based on
//                          percentage of PWM period.
//                      (3) Set the motor speed and direction based on
//                          RPM and direction.
//
//                      Set up PWM 0 output 4 (PWM_0_4) for 20 mS period
//                      to control a servo. We will use PWM_0 output
//                      4 connected through PortG<0>.
//                      We will not use interrupts.
//
//*****************************************************************************
```

PWM Example Program

```
#include "inc/hw_ints.h"
#include "inc/hw_memmap.h"
#include "inc/hw_sysctl.h"
#include "inc/hw_types.h"

#include <stddef.h>
#include <stdbool.h>
#include <stdint.h>
#include <stdarg.h>

#include "driverlib/sysctl.h"
#include "driverlib/pin_map.h"
#include "driverlib/gpio.h"
#include "driverlib/pwm.h"
#include "Drivers/uartstdio.h"

#include "Drivers/Processor_Initialization.h"
#include "Tasks/Task_ReportData.h"

#include "stdio.h"

#include "FreeRTOS.h"
#include "task.h"
```

PWM Example Program

```
//
//     Defines
//
//
//     Define a scale for specifying the pulse width.
//     The scale is 1000 / 20 ms. A value of 100
//     represents ( 75 / 1000 ) ms = 1.5 ms. This
//     is the neutral position.
//
#define    PWM_Period          1000
#define    PWM_State_Low       50
#define    PWM_State_High      100
#define    PWM_State_Neutral   75
```

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PWM Example Program

```
//
//    PWM Parameters
//
//       Example to be presented in lecture
//
#define    PWM_0_4_Period         XXX
#define    PWM_0_4_Low_Count      ((PWM_0_4_Period * PWM_State_Low) / PWM_Period)
#define    PWM_0_4_High_Count     ((PWM_0_4_Period * PWM_State_High) / PWM_Period)
#define    PWM_0_4_Neutral_Count  ((PWM_0_4_Period * PWM_State_Neutral) / PWM_Period)
```

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PWM Example Program

```
//    Define PWM duty cycle states. We alternate between a 1.0 mS
//       pulse and a 2.0 mS pulse. The full period (1000) is 20.0 mS.
//       1.0 mS is 1/20 (50/1000) and 2.0 mS is 2/20 (100/1000).
//
typedef      enum   { PWM_CCW_100, PWM_Stop, PWM_CW_100 }  PWM_States;
PWM_States   PWM_CurrentState = PWM_Stop;
```

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PWM Example Program

```
//
//    Task initialization
//
extern void Task_Motor_PWM_0_4( void *pvParameters ) {

      //*****************************************************************************
      //
      // Constants and Variables
      //
      // Time interval between changes in duty cycle, 0.5 Seconds
      //
      uint32_t     DutyCycleDelta = pdMS_TO_TICKS( 1000 );

      //
      // Configure PWM_0_0 for XX mS period.
      //
      SysCtlPeripheralEnable( SYSCTL_PERIPH_GPIOG );
      SysCtlPeripheralEnable( SYSCTL_PERIPH_PWM0 );
```

PWM Example Program

```
//
// Configure the GPIO pin muxing to select PWM_0_4 functions for these pins.
// This step selects which alternate function is available for these pins.
// This is necessary if your part supports GPIO pin function muxing.
// Consult the data sheet to see which functions are allocated per pin.
// Set GPIO PortG<0> as PWM pins to output the PWM_0_4 signal.
//  PWM signals were taken from Table 10–2 of the TM4C1294 datasheet.
//
GPIOPinConfigure( GPIO_PG0_M0PWM4 );
GPIOPinTypePWM( GPIO_PORTG_BASE, GPIO_PIN_0 );

//
// Configure PWM0 to count down without synchronization.
//
PWMClockSet( PWM0_BASE, PWM_SYSCLK_DIV_64 );
PWMGenConfigure( PWM0_BASE, PWM_GEN_2, PWM_GEN_MODE_DOWN |
                   PWM_GEN_MODE_NO_SYNC );
PWMGenPeriodSet( PWM0_BASE, PWM_GEN_2, PWM_0_4_Period );

//
// Set PWM_0_4 to a duty cycle of PWM_0_4_Neutral_Count
//
PWMPulseWidthSet( PWM0_BASE, PWM_OUT_4, PWM_0_4_Neutral_Count );
```

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PWM Example Program

```
//
// Enable the PWM_0_4 output signals.
//
PWMOutputState( PWM0_BASE, PWM_OUT_4_BIT, true );

//
// Enable the PWM generators.
//
PWMGenEnable( PWM0_BASE, PWM_GEN_2 )
```

PWM Example Program

```
    //
    // Main task.
    //
    while ( 1 ) {

        //
        // ********Your code here********
        //

        //
        // Task delay.
        //
        vTaskDelay( DutyCycleDelta );

    }
}
```

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PWM Parameters

- We need two time durations: the period and the pulse width
- The system clock frequency is 120 MHz which has a period of 8.33 ns
- The basic time duration function is:

$$T_p = (8.33 \text{ ns} * K) * M$$

where T_p is the time duration, e.g. period, K is the scaling factor, and M is the re-load value.

  - K and M must be integers
  - K = 1, 2, 4, …, 64 and M < 2^16
  - Determining K and M is an iterative process

PWM Parameters

- Suppose we want T_p = 33 ms

  33 ms = (8.33 ns * K) * M

  Pick M = 50,000, then

  K = 33 ms / (8.33 ns * 50,000) = 79.23

  Maximum K is 64, so set K = 64, then

  M = 33 ms / (8.33 ns * 64) = 61,900

  M must be an integer less than 65,536

PWM Parameters

- K is common for period and pulse width
- Pulse duration is less than period, do M_w is less than M_p
- Compute M_p as above