• **The MC9S12 Pulse Width Modulation System**
  o Introduction to PWM
  o Review of the Output Compare Function
  o Using Output Compare to generate a PWM signal
  o Registers used to enable the Output Capture Function
  o The MC9S12 PWM system

**Pulse Width Modulation**

• Often want to control something by adjusting the percentage of time the object is turned on

• For example,
  - A heater
  - A light
  - A DC motor

• Can use Output Compare to generate a PWM signal

• What frequency should you use for PWM?
  - A heater - ~
  - A light - ?
  - A DC motor - ?
  - A heater - period of seconds
  - A light - $> 100$ Hz
  - A DC motor
    * Big motor { 10 Hz
    * Small motor { kHz
Suppose you are controlling four motors, each at 10 kHz
- Need to handle 40,000 interrupts/second
- Each interrupt takes about 1 μs
- 4% of time spent servicing interrupts

**Close loop motor control of DC motors**

**Simplified H-Bridge diagram**
Using the MC9S12 Output Compare Function to generate a PWM signal

Want a Pulse Width Modulated signal

Want to produce pulse with width $dT$, period $T$
-Motor control

Want a Pulse Width Modulated signal

Want to produce pulse with width \( dT \), period \( T \)

Wait until \( TCNT == 0x0000 \), then bring \( PA0 \) high
Wait until \( TCNT == dT \), then bring \( PA0 \) low
Wait until \( TCNT == T \), then bring \( PA0 \) high

while (TCNT != 0x0000) ; // Wait for count of 0000
PORTA = PORTA | BIT0; // Bring PA0 high
while (TCNT != dT) ; // Wait for count of dT
PORTA = PORTA & ~BIT0; // Bring PA0 low
while (TCNT != T) ; // Wait for count of T
PORTA = PORTA | BIT0; // Bring PA0 high again
Output Compare PORT T 0–7

To use Output Compare, you must set IOSx to 1 in TIOS
How to use Output Compare Function to generate a PWM signal

1. In the main program:

   (a) Turn on timer subsystem (TSCR1 reg)
   (b) Set prescaler (TSCR2 reg)
   (c) Set up PTx as OC (TIOS reg)
   (d) Set action on compare (TCTL 1-2 regs, OMx OLx bits)
   (e) Clear Flag (TFLG1 reg)
   (f) Enable int (TIE reg)

2. In interrupt service routine

   (a) Set time for next action to occur (write TCx reg)
      • For periodic events add time to TCx register
   (b) Clear flag (TFLG1 reg)
/**
 * Program to generate PWM signal on PT2. Frequency of PWM is 1 kHz
 * (1 ms period) PWM duty cycle is 10% (high for 100 us) set prescaler to 0
 * for a 2.73 ms overflow period 1 ms is 24,000 cycles of 24 MHz clock
 */
#include <hidef.h>    /* common defines and macros */
#include "derivative.h"  /* derivative-specific definitions */
#include "vectors12.h"

#define PERIOD 24000
#define LOW 0
#define HIGH 1
#define disable() __asm(sei)
#define enable() __asm(cli)

interrupt void toc2_isr(void);
char pwm_state;      /* Tell ISR if PWM is currently low or high */
unsigned int high_time; /* Tell ISR how many cycles to keep PWM high */

void main(void )
{
    float duty_cycle;

    disable();
    TSCR1 = 0x80;   /* Turn on timer subsystem */
    TSCR2 = 0x00;   /* Set prescaler to divide by 1 */
    TIOS = TIOS | 0x04; /* Configure PT2 as Output Compare */
    TCTL2 = (TCTL2 | 0x30); /* Set up PT2 to go high on compare */
    TFLG1 = 0x04; /* Clear Channel 2 flag */
    
    * Set interrupt vector for Timer Channel 2 */
    UserTimerCh2 = (unsigned short) &toc2_isr;
    TIE = TIE | 0x04; /* Enable interrupt on Channel 2 */
pwm_state = LOW;    /* Start with PWM low */
duty_cycle = 0.10;   /* Initial duty cycle */
high_time = duty_cycle*PERIOD;    /* Cycles PWM should be high */

enable();

while (1)
{
    /* Code to adjust duty cycle to set speed to desired value */
}

interrupt void toc2_isr(void)
{
    if (pwm_state == LOW) {
        TC2 = TC2 + high_time;    /* Stay high for duty cycle */
        TCTL2 = (TCTL2 & ~0x10);    /* Set up PT2 to go low on */
        /* next compare */
        pwm_state = HIGH;
    } else {
        TC2 = TC2 + (PERIOD - high_time);    /* Stay low until */
        /* period over */
        TCTL2 = (TCTL2 | 0x30);    /* Set up PT2 to go high on */
        /* next compare */
        pwm_state = LOW;
    }
    TFLG1 = 0x04;
}

• The approach to generating a PWM signal is complicated using the Output Compare System
• A better way is to use the PWM System; just need to set up some registers and enable the system.
Pulse Width Modulation on the MC9S12

• Because PWM is used so often the MC9S12 has a built-in PWM system

• The MC9S12 PWM does not use interrupts

• The PWM system on the MC9S12 is very flexible
  - It allows you to set a wide range of PWM frequencies
  - It allows you to generate up to 8 separate PWM signals, each with a different frequency
  - It allows you to generate eight 8-bit PWM signals (with 0.5% accuracy) or four 16-bit PWM signals (with 0.002% accuracy)
  - It allows you to select high polarity or low polarity for the PWM signal
  - It allows you to use left-aligned or center-aligned PWM signals

• Because the MC9S12 PWM system is so flexible, it is fairly complicated to program

• To simplify the discussion we will only discuss 8-bit, left-aligned, high-polarity PWM signals.
Full information about the MC9S12 PWM subsystem can be found in Pulse Width Modulation Block Users Guide
Pulse Width Modulation

Need a way to set the PWM period and duty cycle

The MC9S12 sets the PWM period by counting from 0 to some maximum count with a special PWM clock

\[ \text{PWM Period} = \text{PWM Clock Period} \times \text{Max Count} \]

Once the PWM period is selected, the PWM duty cycle is set by telling the HC12 how many counts it should keep the signal high for

\[ \text{PWM Duty Cycle} = \frac{\text{Count High}}{\text{Max Count}} \]

The hard part about PWM on the MC9S12 is figuring out how to set the PWM Period
The MC9S12 Pulse Width Modulation System

• The PWM outputs are on pins 0 through 7 of Port P
  – On the Dragon12-Plus board, pins 0 through 3 of Port P control the seven-segment LEDs.
  – If you want to use the seven-segment LEDs in addition to PWM, you will need to use PWM channels 4 through 7

• There are 33 registers used by the PWM subsystem

• You don’t need to work with all 33 registers to activate PWM

• To select 8-bit mode, write a 0 to Bits 7, 6, 5 and 4 of PWMCTL register.

• To select left-aligned mode, write 0x00 to PWMCAE.

• To select high polarity mode, write a 0xFF to PWMPOL register.
• To set the period for a PWM channel you need to program bits in the following PWM registers:

  – For Channel 0 the registers are PWMCLK, PWMPRCLK, PWMSCLA and PWMPER0
  – For Channel 1 the registers are PWMCLK, PWMPRCLK, PWMSCLA and PWMPER1
  – For Channel 2 the registers are PWMCLK, PWMPRCLK, PWMSCLB and PWMPER2
  – For Channel 3 the registers are PWMCLK, PWMPRCLK, PWMSCLB and PWMPER3
  – For Channel 4 the registers are PWMCLK, PWMPRCLK, PWMSCLA and PWMPER4
  – For Channel 5 the registers are PWMCLK, PWMPRCLK, PWMSCLA and PWMPER5
  – For Channel 6 the registers are PWMCLK, PWMPRCLK, PWMSCLB and PWMPER6
  – For Channel 7 the registers are PWMCLK, PWMPRCLK, PWMSCLB and PWMPER7

• To set the duty cycle for a PWM channel you need to write to the PWDTYn register for Channel n.

• To enable the PWM output on one of the pins of Port P, write a 1 to the appropriate bit of PWME

<table>
<thead>
<tr>
<th>PWME7</th>
<th>PWME6</th>
<th>PWME5</th>
<th>PWME4</th>
<th>PWME3</th>
<th>PWME2</th>
<th>PWME1</th>
<th>PWME0</th>
<th>PWME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00A0</td>
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</table>

Set PWMEEn = 1 to enable PWM on Channel n
If PWMEEn = 0, Port P bit n can be used for general purpose I/O

<table>
<thead>
<tr>
<th>PPOL7</th>
<th>PPOL6</th>
<th>PPOL5</th>
<th>PPOL4</th>
<th>PPOL3</th>
<th>PPOL2</th>
<th>PPOL1</th>
<th>PPOL0</th>
<th>PPOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00A1</td>
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PWMPOLn – Choose polarity 1 => high polarity 0 => low polarity

We will use high polarity only. PWMPOL = 0xFF;

With high polarity, duty cycle is amount of time output is high
PWMCLKn – Choose clock source for Channel n

CH5, CH4, CH1, CH0 can use either A (0) or SA (1)

CH7, CH6, CH3, CH2 can use either B (0) or SB (1)

\[
SB = \frac{B}{2 \times PWMCLKB} \quad \text{SA} = \frac{A}{2 \times PWMCLKA}
\]

This register selects the prescale clock source for clocks A and B independently

PCKA[2−0] – Prescaler for Clock A \[A = 24 \text{ MHz} / 2^{(PCKA[2−0])}\]

PCKB[2−0] – Prescaler for Clock B \[B = 24 \text{ MHz} / 2^{(PCKB[2−0])}\]

Select center aligned outputs (1) or left aligned outputs (0)

Choose PWMCAE = 0x00 to choose left aligned mode
CONxy – Concatenate PWMx andPWMy into one 16 bit PWM

Choose PWMCTL = 0x00 to choose 8–bit mode

PWMSCLA adjusts frequency of Clock SA

PWMSCLB adjusts frequency of Clock SB

**PWMPERx sets the period of Channel n**

PWM Period = PWMPERNn x Period of PWM Clock n

**PWMDTYx sets the duty cycle of Channel n**

PWM Duty Cycle = PWMDTYn / Period x 100%
Clock Select for PWM Channel 0

You need to set PCKA, PWMSCALA, PCLK0, and PWMPER0
PWMCNT0 counts from 0 to PWMPER0 − 1

It takes PWMPER0 periods of CLK0 to make one Ch0 period

\[
\text{Ch0 Period} = \begin{cases} 
\text{PWMPER0} \times \text{CLK0 Period} & \quad (\text{PCLK0} = 0) \\
\text{PWMPER0} \times (2^{\text{PCKA}+1}) \times \text{PWMSCLA} & \quad (\text{PCLK0} = 1) 
\end{cases}
\]
How to set the Period for PWM Channel 0

• To set the period for PWM Channel 0:
  – Set the PWM Period register for Channel 0, **PWMPER0**
  – **CLK0**, the clock for Channel 0, drives a counter (**PWMCNT0**)
  – **PWMCNT0** counts from 0 to **PWMPER0** – 1
  – The period for PWM Channel 0 is **PWMPER0 × Period of CLK0**

• There are two modes for the clock for PWM Channel 0

  – You select the mode by the **PCLK0** bit:
    – If PCLK0 == 0, CLK0 is generated by dividing the 24 MHz clock by \(2^{PCKA}\), where PCKA is between 0 and 7
    – If PCLK0 == 1, CLK0 is generated by dividing the 24 MHz clock by \(2^{PCKA+1} \times PWMSCLA\), where PCKA is between 0 and 7 and PWMSCLA is between 0 and 255 (a value of 0 gives a divider of 256)

• The Period for PWM Channel 0 (in number of 41.67 ns cycles) is calculated by

\[
\text{Period} = \begin{cases} 
PWMPER0 \times 2^{PCKA} & \text{if } PCLK0 == 0 \\
PWMPER0 \times 2^{PCKA+1} \times PWMSCLA & \text{if } PCLK0 == 1 
\end{cases}
\]
• With PCLK0 == 0, the maximum possible PWM period is 1.36 ms

• With PCLK0 == 1, the maximum possible PWM period is 0.695 s

• To get a 0.5 ms PWM period, you need 12,000 cycles of the 24 MHz clock.

\[
12,000 = \begin{cases} 
PWMPER0 \times 2^{PCKA} & \text{if PCLK0 == 0} \\
PWMPER0 \times 2^{PCKA+1} \times PWMSCLA & \text{if PCLK0 == 1}
\end{cases}
\]

• You can do this in many ways

  – With PCLK0 = 0, can have

    | PCKA | PWMPER0 | Precision |
    |------|---------|-----------|
    | 6    | 187     | Approx.   |
    | 7    | 94      | Approx.   |

  – With PCLK0 = 1, can have

    | PCKA | PWMSCLA | PWMPER0 | Precision |
    |------|---------|---------|-----------|
    | 0    | 24      | 250     | Exact     |
    | 0    | 25      | 240     | Exact     |
    | 0    | 30      | 200     | Exact     |
    | 1    | 12      | 250     | Exact     |
    | 1    | 15      | 200     | Exact     |
    | 2    | 6       | 250     | Exact     |
    | 2    | 10      | 150     | Exact     |

and many other combinations
• You want PWMPER0 to be large (say, 100 or larger)
  
  – If PWMPER0 is small, you don’t have much control over the duty cycle

  – For example, if PWMPER0 = 4, you can only have 0%, 25%, 50%, 75% or 100% duty cycles

• Once you choose a way to set the PWM period, you can program the PWM registers

• For example, to get a 0.5 ms period, let’s use PCLK0 = 1, PCKA = 0, PWMSCLA = 30, and PWMPER0 = 200

• We need to do the following:

  – Write 0x00 to PWMCTL (to set up 8-bit mode)
  – Write 0xFF to PWMPOL (to select high polarity mode)
  – Write 0x00 to PWMCAE (to select left aligned mode)

  – Write 0 to Bits 2,1,0 of PWMPRCLK (to set PCKA to 0)
  – Write 1 to Bit 0 of PWMCLK (to set PCLK0 = 1)
  – Write 30 to PWMSCLA
  – Write 200 to PWMPER0
  – Write 1 to Bit 0 of PWME (to enable PWM on Channel 0)
  – Write the appropriate value to PWDTY0 to get the desired duty cycle (e.g., PWMDTY0 = 120 will give 60% duty cycle)
C code to set up PWM Channel 0 for 0.5 ms period (2 kHz frequency) PWM with 60% duty cycle

PWMCTL = 0x00; /* 8-bit Mode */
PWMPOL = 0xFF; /* High polarity mode */
PWMCAE = 0x00; /* Left-Aligned */

PWMPRCLK = PWMPRCLK & ~0x07; /* PCKA = 0 */
PWMCLK = PWMCLK | 0x01; /* PCLK0 = 1 */
PWMSCLA = 30;
PWMPER0 = 200;
PWME = PWME | 0x01; /* Enable PWM Channel 0 */
PWMDTY0 = 120; /* 60% duty cycle on Channel 0 */
Using the HCS12 PWM

1. Choose 8-bit mode (PWMCTL = 0x00)

2. Choose high polarity (PWMPOL = 0xFF)

3. Choose left-aligned (PWMCAE = 0x00)

4. Select clock mode in PWMCLK:
   - PCLKn = 0 for \(2^N\),
   - PCLKn = 1 for \(2^{(N+1)} \times M\),

5. Select N in PWMPRCLK register:
   - PCKA for channels 5, 4, 1, 0;
   - PCKB for channels 7, 6, 3, 2.

6. If PCLKn = 1, select M
   - PWMSCLA = M for channels 5, 4, 1, 0
   - PWMSCLB = M for channels 7, 6, 3, 2.

7. Select PWMPERn, normally between 100 and 255.

8. Enable desired PWM channels: PWME.
9. Select PWMDTYn, normally between 0 and PWMPERn. Then

\[
\text{Duty Cycle } n = \left( \frac{\text{PWMDTY}n}{\text{PWMPER}n} \right) \times 100\%
\]

Change duty cycle to control speed of motor or intensity of light, etc.

10. For 0% duty cycle, choose PWMDTYn = 0x00.
Program to use the MC9S12 PWM System

/*
Program to generate 15.6 kHz pulse width modulation
on Port P Bits 0 and 1

To get 15.6 kHz: 24,000,000/15,600 = 1538.5

Cannot get exactly 1538.5

Use 1536, which is 2^9 x 3

Lots of ways to set up PWM to achieve this. One way is 2^3 x 192
Set PCKA to 3, do not use PWMSCLA, set PWMPER to 192

*/

#include "hidef.h"     /* common defines and macros */
#include "derivative.h"   /* derivative-specific definitions */

void main(void)
{
    /* Choose 8-bit mode */
    PWMCTL = 0x00;

    /* Choose left-aligned */
    PWMCAE = 0x00;

    /* Choose high polarity on all channels */
    PWMPOL = 0xFF;
}
/* Select clock mode 0 for Channels 1 and 0 */
/* (no PWMSCLA) */
PWMClock = PWMClock & ~0x03;

/* Select PCKA = 3 for Channels 1 and 0 */
PWMPRCLK = (PWMPRCLK & ~0x04) | 0x03;

/* Select period of 192 for Channels 1 and 0 */
PWMPER1 = 192;
PWMPER0 = 192;

/* Enable PWM on Channels 1 and 0 */
PWME = PWME | 0x03;

/* Set duty cycle for each channel */
PWMDTY1 = 96;  /* 50% duty cycle on Channel 1 */
PWMDTY0 = 46;  /* 25% duty cycle on Channel 0 */

while (1) {
  /* Code to adjust duty cycle to meet requirements */
}
}