• **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 - the higher the percentage, the more heat output
  - A light - the higher the percentage, the brighter the light
  - A DC motor -- the higher the percentage, the faster the motor goes

• 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
Closed Loop Motor Control
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

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
The MC9S12 Output Compare Function

- The MC9S12 allows you to force an event to happen on any of the eight PORTT pins
- An external event is a rising edge, a falling edge, or a toggle
- To use the Output Compare Function:
  - Enable the timer subsystem (set TEN bit of TSCR1)
  - Set the prescaler
  - Tell the MC9S12 that you want to use Bit x of PTT for output compare
  - Tell the MC9S12 what you want to do on Bit x of PTT (generate rising edge, falling edge, or toggle)
  - Tell the MC9S12 what time you want the event to occur
  - Tell the MC9S12 if you want an interrupt to be generated when the event is forced to occur
Using Output Compare on the MC9S12

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)

<table>
<thead>
<tr>
<th>OMx</th>
<th>OLx</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Disconnected</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Toggle</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Clear</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Set</td>
</tr>
</tbody>
</table>

   (d) 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;
}

• Question: What are restrictions on minimum and maximum duty cycles?
• Can you have 0% duty cycle?
• Can you have 100% duty cycle?
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 systems 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

**PWM Period = PWM Clock Period x 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

**PWM Duty Cycle = Count High/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

Set PWME\text{En} = 1 to enable PWM on Channel n
If PWME\text{En} = 0, Port P bit n can be used for general purpose I/O

PWMPOLn \text{– Choose polarity} 1 \Rightarrow \text{high polarity} 0 \Rightarrow \text{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)

\[
SB = \frac{B}{2 \times \text{PWMCLK}} \quad \text{SA} = \frac{A}{2 \times \text{PWMCLA}}
\]

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

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

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

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

Choose PWMCAE = 0x00 to choose left aligned mode
CONxy – Concatenate PWMx and PWMy 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

\textbf{PWMPERx sets the period of Channel } n

\[ \text{PWM Period} = \text{PWMPER}_n \times \text{Period of PWM Clock } n \]

\textbf{PWMDTYx sets the duty cycle of Channel } n

\[ \text{PWM Duty Cycle} = \frac{\text{PWMDTY}_n}{\text{Period}} \times 100\% \]
Clock Select for PWM Channel 0

You need to set PCKA, PWSCALA, PCLK0, and PWPER0
PWMCNT0 counts from 0 to PWMPER0 − 1

It takes PWMPER0 periods of CLK0 to make one Ch0 period

\[ \text{Ch0 Period} = \text{PWMPER0} \times \text{CLK0 Period} \]

\[ = \begin{cases} 
\text{PWMPER0} \times (2^{PCKA}) & (\text{PCLK0} = 0) \\
\text{PWMPER0} \times (2^{PCKA+1}) \times \text{PWMSCLA} & (\text{PCLK0} = 1) 
\end{cases} \]
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 (PWCNT0)
  – PWCNT0 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 $2^{PCKA+1} \times PWSCLA$, where PCKA is between 0 and 7 and PWSCALA 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

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

<table>
<thead>
<tr>
<th>PCKA</th>
<th>PWMPER0</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>187</td>
<td>Approx.</td>
</tr>
<tr>
<td>7</td>
<td>94</td>
<td>Approx.</td>
</tr>
</tbody>
</table>

  – With PCLK0 = 1, can have

<table>
<thead>
<tr>
<th>PCKA</th>
<th>PWMSCLA</th>
<th>PWMPER0</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24</td>
<td>250</td>
<td>Exact</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>240</td>
<td>Exact</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>200</td>
<td>Exact</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>250</td>
<td>Exact</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>200</td>
<td>Exact</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>250</td>
<td>Exact</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>150</td>
<td>Exact</td>
</tr>
</tbody>
</table>

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 */
Interdependence of clocks for Channels 0, 1, 4 and 5

• The clocks for Channels 0, 1, 4 and 5 are interdependent

• They all use PCKA and PWMSCLA

• To set the clock for Channel n, you need to set PCKA, PCKn, PWMSCLA (if PCLKn == 1) and PWMPERn where n = 0, 1, 4 or 5
**PWM Channels 2, 3, 6 and 7**

- PWM channels 2, 3, 6 and 7 are similar to PWM channels 0, 1, 4 and 5

- To set the clock for Channel n, you need to set PCKB, PCLKn, PWMSCLB (if PCLKn == 1) and PWMPERn where n = 2, 3, 6 or 7
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 PWMPER$n$, 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 */
    PWMCTCL = 0x00;

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

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