Basic Principles of Output Capture

- Output compare can create square waves, generate pulses, implement time delays, and execute periodic interrupts.
- Can also use with input capture to measure frequency.
- Each output capture module has:
  - An external output pin, OCn
  - A flag bit
  - A force control bit FOCn
  - Two control bits, OMn, OLn
  - An interrupt mask bit (arm)
  - A 16-bit output compare register

Basic Principles of Output Compare (cont)

- Output compare pin can control an external device.
- Output compare event occurs and sets flag when either:
  1. The 16-bit TCNT matches the 16-bit OC register
  2. The software writes a 1 to the FOC bit.
- OMn, OLn bits specify effect of event on the output pin.
- Two or three actions result from a compare event:
  1. The OCn output bit changes
  2. The output compare flag is set.
  3. An interrupt is requested if the mask is 1.
Applications of Output Compare

- Can create a fixed time delay.
  1. Read the current 16-bit TCNT
  2. Calculate TCNT+fixed
  3. Set 16-bit output compare register to TCNT+fixed
  4. Clear the output compare flag
  5. Wait for the output compare flag to be set

- Delay of steps 1 to 4 sets the minimum delay.
- Maximum delay is 65,536 cycles.

Control Bits and Flags

<table>
<thead>
<tr>
<th>OMn</th>
<th>OLn</th>
<th>Effect of when TOCn=TCNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Does not affect OCN</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Toggle OCN</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Clear OCN=0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Set OCN=1</td>
</tr>
</tbody>
</table>

Output Compare Interface on 68HC11

- Care again must be taken when clearing TFLG1.
- The following works:
  1. daa #$20
  2. staa $1023
- The following does not:
  1. ldx #$1000
  2. bset $23,X,$01
Control Bits and Flags

<table>
<thead>
<tr>
<th>OC1M</th>
<th>100C</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC1M0</td>
<td>7</td>
</tr>
<tr>
<td>OC1M1</td>
<td>6</td>
</tr>
<tr>
<td>OC1M2</td>
<td>5</td>
</tr>
<tr>
<td>OC1M3</td>
<td>4</td>
</tr>
<tr>
<td>OC1M4</td>
<td>3</td>
</tr>
<tr>
<td>OC1M5</td>
<td>2</td>
</tr>
<tr>
<td>OC1M6</td>
<td>1</td>
</tr>
<tr>
<td>OC1M7</td>
<td>0</td>
</tr>
<tr>
<td>PA7</td>
<td>0</td>
</tr>
<tr>
<td>PA6</td>
<td>0</td>
</tr>
<tr>
<td>PA5</td>
<td>0</td>
</tr>
<tr>
<td>PA4</td>
<td>0</td>
</tr>
<tr>
<td>PA3</td>
<td>0</td>
</tr>
<tr>
<td>PA2</td>
<td>0</td>
</tr>
<tr>
<td>PA1</td>
<td>0</td>
</tr>
<tr>
<td>PA0</td>
<td>0</td>
</tr>
<tr>
<td>PA7</td>
<td>0</td>
</tr>
<tr>
<td>PA6</td>
<td>0</td>
</tr>
<tr>
<td>PA5</td>
<td>0</td>
</tr>
<tr>
<td>PA4</td>
<td>0</td>
</tr>
<tr>
<td>PA3</td>
<td>0</td>
</tr>
<tr>
<td>PA2</td>
<td>0</td>
</tr>
<tr>
<td>PA1</td>
<td>0</td>
</tr>
<tr>
<td>PA0</td>
<td>0</td>
</tr>
</tbody>
</table>

Periodic Interrupt Using Output Capture

# define Rate 2000
# define OC5 0x08
unsigned int Time; // Inc every 1ms
#pragma interrupt_handler TOC5handler()
void TOC5handler(void)
TFLG1=OC5; // Ack interrupt
TOC5=TOC5+Rate; // Executed every 1 ms
Time++;
}
void ritual(void)
asm("sei"); // make atomic
TMSK1|=OC5; // Arm output compare 5
Time = 0;
TFLG1|=OC5; // Initially clear OC5F
TOC5=TCNT+Rate; // First one in 1 ms
asm(" cli");

Init for Periodic Interrupt Using Output Compare

TIME rmb 2 ;inc every 1ms
Init sei ; make atomic
ldaa TMSK1 ; Old value
oraa #$08 ; TMSK1 OC5=1
staa TMSK1 ; Arm OC5F
ldd #0
std TIME ; initialize
ldaa #$08 ; clear OC5F
staa TFLG1
ldd TCNT ; current time
add #2000 ; first in 1 ms
std TOC5
clo ; enable
rts
### ISR for Periodic Interrupt Using Output Compare

```assembly
OC5HAN 1dx  TIME [5]
iix  [3]
stx  TIME [5]
ldaa #$08 ;clear OC5F
staa  TFLG1 ;Acknowledge
1dd  TOC5
add $2000 ;next
std  TOC5
rti
org $FFE0
fdb  OC5HAN
```

### Square-Wave Generation in C

```c
unsigned int Period;  // Period in usec
#pragma interrupt_handler TOC3handler()

void TOC3handler(void){
    TOC3 = TOC3 + Period;  // calculate Next
    TFLG1 = 0x20;  // ack, OC3F=0
}

void ritual(void){
    asm("sei");  // make atomic
    TFLG1 = 0x20;  // clear OC3F
    TMSK1 = 0x20;  // arm OC3
    TCTL1 = (TCTL1 & 0xCF) | 0x10;
    TOC3 = TCNT + 50;  // first right away
    asm("cli");
}
```

### Square-Wave Generation

<table>
<thead>
<tr>
<th>Component</th>
<th>Time to process (cycles)</th>
<th>Overhead (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interrupt every (cycles)</td>
<td>14 µs</td>
<td>48</td>
</tr>
<tr>
<td>Time to process (cycles)</td>
<td>34 µs</td>
<td>0.1</td>
</tr>
<tr>
<td>Minimum period (µs)</td>
<td>24 µs</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Freq.</th>
<th>Period</th>
<th>Period cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Hz</td>
<td>100 ms</td>
<td>50.000</td>
</tr>
<tr>
<td>100 Hz</td>
<td>10 ms</td>
<td>5.000</td>
</tr>
<tr>
<td>1 kHz</td>
<td>1 µs</td>
<td>50</td>
</tr>
<tr>
<td>5 kHz</td>
<td>200 µs</td>
<td>200</td>
</tr>
<tr>
<td>1/P</td>
<td>P (µs)</td>
<td>P</td>
</tr>
</tbody>
</table>

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<td>50</td>
</tr>
<tr>
<td>5 kHz</td>
<td>200 µs</td>
<td>200</td>
</tr>
<tr>
<td>1/P</td>
<td>P (µs)</td>
<td>P</td>
</tr>
</tbody>
</table>

### Initialization for Square-Wave Generation

```assembly
Period rmb 2 ;units sec
Init   sei ;make atomic
ldaa TMSK1 ;Old value
orra #$20 ;TMSK1 OC3I=1
staa TMSK1 ;Arm OC3F
ldaa TCTL1
anda #$0F ;GM3=0
orra #$10 ;OL3=1
staa TCTL1
ldaa #$20 ;clear OC3F
staa TFLG1
1dd TCNT ;current time
add #2000 ;first in 1 ms
std TOC3
cli ;first in 1 ms
rts
```
ISR for Square-Wave Generation

OC3HAN ldaa #$20 ; clear OC3F [2]
staa TFLG1 ; Ack [4]
ldd TOC3 [6]
addd Period ; next [6]
std TOC3 [5]
rti [12]
org $FFE4
fdb OC3HAN

Pulse-Width Modulation

Component | 6811
--- | ---
Process the interrupt (cycles) | 14
Execute the handler (cycles) | 53-56
Total time T (cycles) | 67-70

Pulse-Width Modulated Square-Wave

unsigned int High; // Num of Cycles High
unsigned int Low; // Num of Cycles Low

void ritual(void){
    asm(" sei"); // make atomic
    TFLG1 = 0x20; // initially OC3F=0
    TMSK1|= 0x20; // arm OC3
    TCTL1|= 0x30; // PA5 set on next int
    TOC3 = TCNT+50; // first right away
    asm(" cli"); }

void main(void){
    High=8000; Low=2000;
    ritual();
    while(1);}

Pulse-Width Modulated Square-Wave (cont)

// Period is High+Low Cycles
#pragma interrupt_handler TOC3handler()

void TOC3handler(void){
    if(TCTL1&0x10){ // PA5 is now high
        TOC3=TOC3+High; // 1 for High cyc
        TCTL1|=0xEF; } // clear on next
    else { // PA5 is now low
        TOC3=TOC3+Low; // 0 for Low cycles
        TCTL1|=0x10; } // set on next int
    TFLG1=0x20; } // ack, clear OC3F
Init for Pulse-Width Modulated Square-Wave

High rm b 2 ; number of cycles high
Low rm b 2 ; number of cycles low
RITUAL sei ; make atomic
ldaa TMSK1 ; Old value
oraa #$20 ; TMSK1 OC3l=1
staa TMSK1 ; Arm OC3F
ldaa TCTL1
oraa #$30 ; OM3=1, OL3=1
staa TCTL1
ldaa #$20 ; clear OC3F
staa TFLG1
ldd TCNT ; current time
add #50 ; first in 25s
std TOC3
cli ; enable
rts

ISR for Pulse-Width Modulated Square-Wave (cont)

zero 1dd TOC3 [6]
addd Low ; OC is 0 [6]
std TOC3 [5]
ldaa TCTL2 [4]
oraa #$40 [2]
staa TCTL2 [4]
done rti [12]
org $FFE4
fda 0C3HAN

ISR for Pulse-Width Modulated Square-Wave

OC3HAN ldda #$20 ; clear OC3F [2]
staa TFLG1 ; Ack [4]
ldaa TCTL2 ; rise/fall? [4]
bita #$10 [2]
beq zero [3]
one 1dd TOC3 [5]
addd High ; OC3 is 1 [6]
std TOC3 [5]
ldaa TCTL2 [4]
bra done [3]

Delayed Pulse Generation

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Delayed Pulse Generation in C

```c
void Pulse(unsigned int Delay,
           unsigned int Width)
{
    asm("sei"); // make atomic
    TOC1=TCNT+Delay;
    TOC3=TOC1+Width;
    DC1M=0x20;  // connect OC1 to PA5/OC3
    DC1D=0x20;  // PA5=1 when TOC1=TCNT
    TCTL1=(TCTL1&0xCF)|0x20; // connect OC1 to PA5/OC3
    // PA5=0 when TOC3=TCNT
    TFLG1 = 0x20;  // Clear OC3F
    TMSK1|= 0x20;  // Arm OC3F
    asm(" cli");
}
```

Frequency Measurement

- Direct measurement of frequency involves counting input pulses for a fixed amount of time.
- Can use input capture to count pulses, and output capture to create a fixed time interval.
- Input Capture handler increments Counter.
- Output compare handler calculates frequency:
  \[ f = \frac{\text{Counter}}{\text{fixed time}} \]
- The frequency resolution is:
  \[ f = \frac{1}{\text{fixed time}} \]
Frequency Measurement in C

```c
#define IC1F 0x04 // connected here
#define Rate 20000 // 10 ms
#define OC5F 0x08

void ritual(void){
    asm("sei"); // make atomic
    TMSK1|=OC5F+IC1F; // Arm OC5 and IC1
    TOC5=TCNT+Rate; // First in 10 ms
    TCTL2=(TCTL2&0xCF)|0x10;
    /*IC1F set on rising edges*/
    Count=0; // Setup for first
    Done=0;
    /* Set on the subsequent measurements */
    TFLG1=OC5F+IC1F; // clear OC5F, IC1F
    asm("cli"); }
```

Conversion Between Frequency and Period

- Could measure frequency from period measurement:
  \[ f = \frac{1}{p} \]

- If range of period measurement is 36\(\mu\)s to 32ms with resolution of 500ns, frequency range is 31 to 27,778Hz.
  \[ f = \frac{1}{p} \cdot \frac{1}{500\text{ns}} = \frac{2000000}{p} \]

- Resolution relationship is not as obvious:
  \[ \Delta f = \frac{1}{(1/f) - \Delta p} - f = \frac{1}{(1/f) - 500\text{ns}} - f \]

Relationship Between Frequency and Period

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Period ((\mu)s)</th>
<th>(\Delta f) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31,250</td>
<td>32</td>
<td>500</td>
</tr>
<tr>
<td>20,000</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>10,000</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>5,000</td>
<td>200</td>
<td>13</td>
</tr>
<tr>
<td>2,000</td>
<td>500</td>
<td>2</td>
</tr>
<tr>
<td>1,000</td>
<td>1,000</td>
<td>0.5</td>
</tr>
<tr>
<td>500</td>
<td>2,000</td>
<td>0.13</td>
</tr>
<tr>
<td>200</td>
<td>5,000</td>
<td>0.02</td>
</tr>
<tr>
<td>100</td>
<td>10,000</td>
<td>0.005</td>
</tr>
<tr>
<td>50</td>
<td>20,000</td>
<td>0.001</td>
</tr>
<tr>
<td>31.25</td>
<td>32,000</td>
<td>0.0005</td>
</tr>
</tbody>
</table>
Period Measurement with $\Delta p = 1\text{ms}$

- Each rising edge generates input capture interrupt.
- Output compare is used to increment a software counter, `Time`, every 1 ms.
- Period is number of 1-ms output compare interrupts between one rising edge to the next rising edge.
- Range is 0 to 65535 determined by the 16-bit size of `Time`.

Period Measurement in C

```c
#define resolution 2000

void Ritual(void){
    asm("sei"); // make atomic
    TFLG1 = 0x24; // Clear OC3F,IC1F
    TMSK1 = 0x24; // Arm OC3 and IC1
    TCTL2 = 0x10; // rising edges
    while((TFLG1&0x04)==0);
    // wait for first rising
    TFLG1 = 0x04; // Clear IC1F
    TOC3=TCNT+resolution;
    Cnt=0; OverFlow=0; Done=0;
    asm("cli"); }
```

Frequency Measurement with $\Delta f = 0.1\text{Hz}$

- If count pulses in 10-s time interval, then number of pulses is frequency with units of 1/10s or 0.1 Hz.
- Setting output compare to interrupt every 25 ms, means that 400 interrupts creates a 10-s time delay.
- Number of input capture interrupts during this interval is the input frequency in units of 0.1 Hz.
Basic Time Involved in Frequency Measurement

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Frequency Measurement in C

#define IC1F 0x04 // connected here
#define Rate 50000 // 25 ms
#define OC5F 0x08

void ritual(void) {
    asm("sei"); // make atomic
    TMSK1|=OC5F+IC1F; // Arm OC5 and IC1
    TOC5=TCNT+Rate; // First in 25 ms
    TCTL2 = (TCTL2&0xCF)|0x10;
    /* IC1F set on rising edges */
    Count = 0; // Set up for first
    Done=0; // Set on subsequent meas
    FourHundred=0;
    TFLG1 = OC5F+IC1F; // Clear OC5F IC1F
    asm(" cli");
}

Frequency Measurement in C (cont)

#define IC1F 0x04 // connected here
#define Rate 50000 // 25 ms
#define OC5F 0x08

void ritual(void) {
    asm("sei"); // make atomic
    TMSK1|=OC5F+IC1F; // Arm OC5 and IC1
    TOC5=TCNT+Rate; // First in 25 ms
    TCTL2 = (TCTL2&0xCF)|0x10;
    /* IC1F set on rising edges */
    Count = 0; // Set up for first
    Done=0; // Set on subsequent meas
    FourHundred=0;
    TFLG1 = OC5F+IC1F; // Clear OC5F IC1F
    asm(" cli");

    #pragma interrupt_handler TIC1handler()
    void TIC1handler(void){
        Count++; // number of rising edges
        TFLG1=IC1F; // ack, clear IC1F
    }

    #pragma interrupt_handler TOC5handler()
    void TOC5handler(void){
        TFLG1= OC5F; // Acknowledge
        TOC5 = TOC5+Rate; // every 25 ms
        if (++FourHundred==400){
            Freq = Count; // 0.1 Hz units
            FourHundred=0;
            Done = 0xff;
            Count = 0;
        }
    }

    asm(" cli"); } // Setup for next