ECE/CS 5780/6780: Embedded System Design

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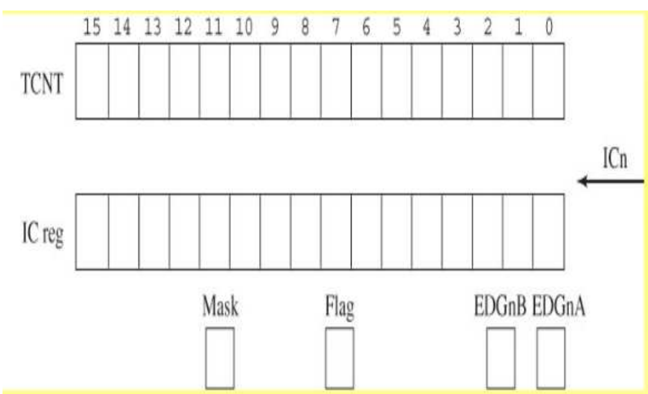
Lecture 12: Input Capture

Basic Principles of Input Capture

- Triggers interrupts on rising or falling transitions of external signals.
- Can also measure the period or pulse width of TTL-level signals.
- Each input capture module has:
  - An external input pin, ICn
  - A flag bit
  - Two edge control bits, EDGnB and EDGnA
  - An interrupt mask bit (arm)
  - A 16-bit input capture register

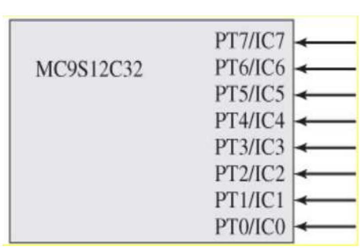
Basic Components of Input Capture



Basic Principles of Input Capture (cont)

- Two or three actions result from a capture event:
  1. Current TCNT copied into input capture register.
  2. The input capture flag is set.
  3. An interrupt is requested if the mask is 1.
- The input capture mechanism has many uses:
  1. Arm the flag bit so that an interrupt is requested on the active edge of an external signal.
  2. Perform two rising edge captures and subtract to obtain the period.
  3. Perform a rising edge capture, then a falling edge capture, and subtract to obtain the pulse width.

Input Capture Interface on the 6812



Control Bits and Flags

- Input captures are on port T (i.e., **PTT**).
- Set pin to input capture mode by setting bit to 0 in **TIOS**.
- Input capture registers are **TC0**, . . . , **TC7**.
- Arm interrupts using **TIE**.
- Flags are found in **TFLG1**.
- Set edge to trigger on using **TCTL3** and **TCTL4**.

EDGnB	EDGnA	Active edge
0	0	None
0	1	Capture on rising
1	0	Capture on falling
1	1	Capture on both rising and falling

TCNT Control Bits

PR2	PR1	PR0	Divide by	TCNT Period (4 MHz E Clk)	TCNT Period (24 MHz E Clk)
0	0	0	1	250 ns	41.7 ns
0	0	1	2	500 ns	83.3 ns
0	1	0	4	1 μs	166.7 ns
0	1	1	8	2 μs	333.3 ns
1	0	0	16	4 ns	666.7 ns
1	0	1	32	8 μs	1.333 μs
1	1	0	64	16 μs	2.667 μs
1	1	1	128	32 μs	5.333 μs

Setting the TFLG1 Register

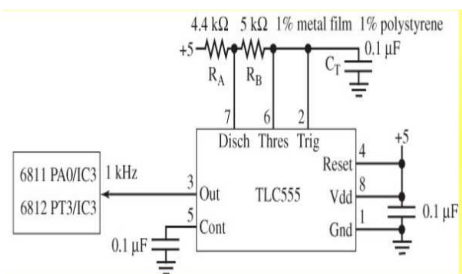
- Care must be taken when clearing the TFLG1 register.
- The following works:

```
TFLG1 = 0x01;     ldy  #$1000
                  ldaa #$01
                  staa $23,Y
```

- The following does not:

```
TFLG1 |= 0x01;    ldx  #$1000
                  bset $23,X,$01
```


Real Time Interrupt Using an Input Capture



Component	6812
Longest instruction (cycles, μs)	13=3.25μs
Process the interrupt (cycles, μs)	9=2.25μs
Execute the handler (cycles, μs)	11=2.75μs
Max latency (μs)	8.25μs

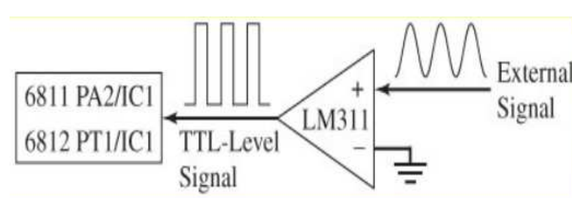
Periodic Interrupt Using Input Capture

```
unsigned short Time;          // incremented
void Init(void){
  asm sei                     // make atomic
  TIOS &=~0x08;               // PT3 input capture
  DDRT &=~0x08;               // PT3 is input
  TSCR1 = 0x80;               // enable TCNT
  TSCR2 = 0x01;               // 500ns clock
  TCTL4 = (TCTL4&0x3F)|0x40;
  TIE |= 0x08;                // Arm IC3, rising
  TFLG1 = 0x08;               // initially clear
  Time = 0;
  asm cli }
void interrupt 11 IC3Han(void){
  TFLG1 = 0x08;               // acknowledge
  Time++; }
```

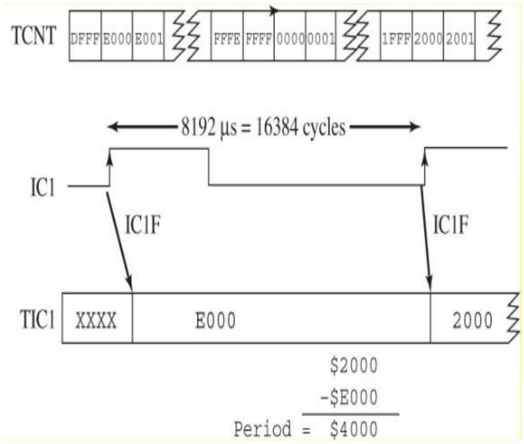

Period Measurement

- *Resolution* of a period measurement is the smallest change in period that can be detected.
  - Resolution of TCNT is from 250ns to 32μs (4 MHz E Clock).
- Resolution is also the units of measurement.
- *Precision* is the number of separate and distinguishable measurements.
  - Precision of TCNT is 65,536 different periods (16-bit).
- *Range* is min and max values that can be measured.
- Good measurement systems should detect under and overflows, and when there is no period.

Period Measurement



Period Measurement Example



Period Measurement Resolution

Component	6812
Process the interrupt (cycles,μs)	9=2.25μs
Execute the entire handler (cycles,μs)	31=7.75μs
Minimum period (cycles,μs)	40=10μs

Period (μs)	Cycles/interrupt	Time in handler (%)
10	40	100
20	40	50
100	40	10
P	40	1000/P

Initialization for Period Measurement

```
unsigned short Period;       // 500 ns units
unsigned short First;        // TCNT first edge
unsigned char Done;          // Set each rising
void Init(void){
  asm sei                    // make atomic
  TIOS &=~0x02;              // PT1 input capture
  DDRT &=~0x02;              // PT1 is input
  TSCR1 = 0x80;              // enable TCNT
  TSCR2 = 0x01;              // 500ns clock
  TCTL4 = (TCTL4&0xF3)|0x04; // rising
  First = TCNT;              // first will be wrong
  Done = 0;                  // set on subsequent
  TFLG1 = 0x02;              // Clear C1F
  TIE |= 0x02;               // Arm IC1
  asm cli }
```

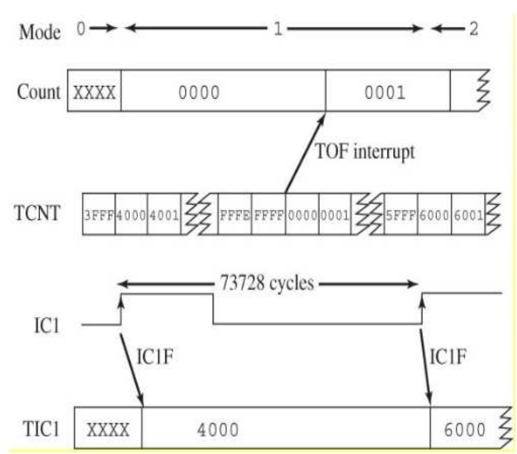

ISR for Period Measurement

```
void interrupt 9 TC1handler(void){
  Period = TC1-First; // 500ns resolution
  First = TC1;        // Setup for next
  TFLG1 = 0x02;       // ack by clearing C1F
  Done = 0xFF;
}
```

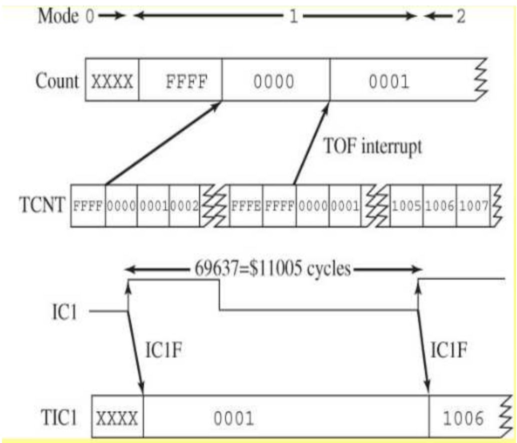

32-bit Period Measurement

- Every time TCNT register overflows from $FFFF to 0, the TOF flag is set.
- Can increase precision to 32-bits by counting the number of TOF flag setting events during one period (`Count`).
- To do this, arm both input capture and timer overflow interrupts.
- For each timing measurement, high 16-bits are value of `Count`, and low 16-bits are value in input capture register.

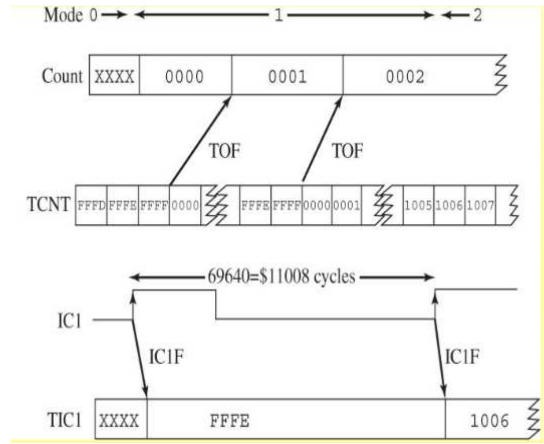
Simple Illustration of 32-bit Period Measurement



TOF Set Just Before IC1F Flag



TOF Set Just After IC1F Flag



Initialization for 32-Bit Period Measurement

```
unsigned short MsPeriod,LsPeriod;
unsigned short First;
unsigned short Count;
unsigned char Mode;
void Init(void){
  asm sei                       // make atomic
  TIOS &=~0x02;                 // PT1 input capture
  DDRT &=~0x02;                 // PT1 is input
  TSCR2 = 0x81 ;                // Arm, TOF 30.517Hz
  TSCR1 = 0x80;                 // enable counter
  TFLG1 = 0x02;                 // Clear C1F
  TIE |= 0x02;                  // Arm IC1, C1I=1
  TCTL4 = (TCTL4&0xF3)|0x04; // rising
  TFLG2 = 0x80;                 // Clear TOF
  Mode = 0;                     // searching for first
  asm cli }
```

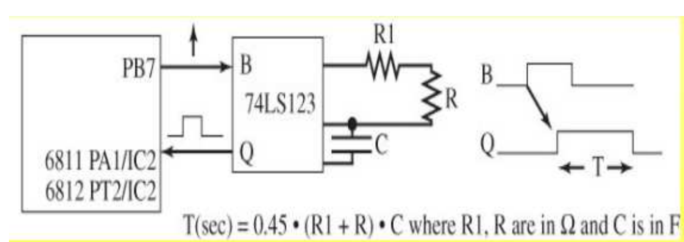

Input Capture ISR for Period Measurement

```
void interrupt 9 TIC1handler(void){
  if(Mode==0){             // first edge
    First = TC1; Count=0;
    Mode=1;
    if(((TC1&0x8000)==0)&&(TFLG2&0x80)) Count--;
  } else {                 // second edge
    if(((TC1&0x8000)==0)&&(TFLG2&0x80)) Count++;
    Mode = 2;              // measurement done
    MsPeriod = Count;
    LsPeriod = TC1-First;
    if(TC1<First){
      MsPeriod--;          // borrow
    }
    TIE=0x00; TSCR2=0x00; } // Disarm
  }
  TFLG1 = 0x02; }          // ack, clear C1F
```


Timer Overflow ISR for 32-Bit Period Measurement

```
void interrupt 16 TOhandler(void){
  TFLG2 = 0x80;  // ack
  Count++;
  if(Count==65535){        // 35 minutes
    MsPeriod=LsPeriod=65535;
    TIE=0x00; TSCR2=0x00;  // Disarm
    Mode = 2;              // done
  }
}
```


Measure Resistance Using Pulse Width



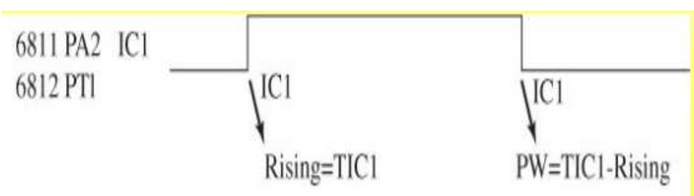
Gadfly Pulse-Width Measurement

```
void Init(void){
  DDRB |= 0x80;  // PB7 is output
  TIOS &=~0x04;  // clear bit 2
  DDRT &=~0x04;  // PT2 is input capture
  TSCR1 =0x80;   // enable
  TSCR2 =0x01;   // 500 ns clock
  TIE = 0x00;}   // no interrupts
```


Gadfly Pulse-Width Measurement (cont)

```
unsigned short Measure(void) {
unsigned short Rising;
  TCTL4 = (TCTL4&0xCF)|0x10; // Rising
  TFLG1 = 0x04;              // clear C2F
  PORTB&=~0x80;
  PORTB|= 0x80;              // rising edge on PB7
  while(TFLG1&0x04==0){};    // wait for rise
  Rising = TC2;              // TCNT at rising edge
  TFLG1 = 0x04;              // clear C2F
  TCTL4 = (TCTL4&0xCF)|0x20; // Falling
  while(TFLG1&0x04==0){};    // wait for fall
  return(TC2-Rising-1000); }
```


Interrupt-Driven Pulse-Width Measurement



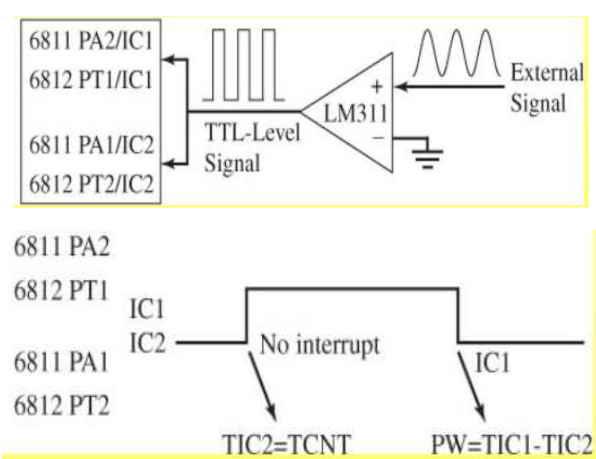
Pulse-Width Measurement Using Interrupts

```
unsigned short PW;     // units of 500 ns
unsigned short Rising; // TCNT at rising
unsigned char Done;    // Set each falling
void Init(void) {
  asm sei              // make atomic
  TIOS &=~0x02;        // clear bit 1
  DDRT &=~0x02;        // PT1 is input capture
  TSCR1 =0x80;         // enable
  TSCR2 =0x01;         // 500 ns clock
  TCTL4|=0x0C;         // Both edges IC1
  TIE |= 0x02;         // arm IC1
  TFLG1 = 0x02;        // clear C1F
  Done = 0;
  asm cli
}
```


Pulse-Width Measurement Using Interrupts

```
void interrupt 9 TC1handler(void){
  if(PTT&0x02){      // PT1=1 if rising
    Rising = TC1;    // Setup for next
  } else{
    PW = TC1-Rising; // measurement
    Done = 0xFF;
  }
  TFLG1 = 0x02;      // ack, clear C1F
}
```


Pulse-Width Measurement Using Two Channels



Pulse-Width Measurement Using Two Channels

```
unsigned short PW;          // units of 500 ns
unsigned char Done;         // Set each falling
void Init(void) {
  asm sei                   // make atomic
  TIOS &=~0x06;             // clear bits 2,1
  DDRT &=~0x06;             // PT2,PT1 input captures
  TSCR1 = 0x80;             // enable
  TSCR2 = 0x01;             // 500 ns clock
  TCTL4 =(TCTL4&0xCF)|0x10; // IC2 Rise
  TCTL4 =(TCTL4&0xF3)|0x08; // IC1 Fall
  Done = 0;                 // set on the falling edge
  TIE |= 0x02;              // arm IC1, not IC2
  TFLG1 = 0x02;             // clear C1F
  asm cli
}
```


Pulse-Width Measurement Using Two Channels

```
void interrupt 9 TIC1handler(void){
  TFLG1 = 0x02;  // ack C1F
  PW = TC1-TC2;  // from rise to fall
  Done = 0xFF;
}
```