Timers and Event Counters

Lecture 13

In These Notes . . .

We learn the basics of the Timer/Counter peripheral

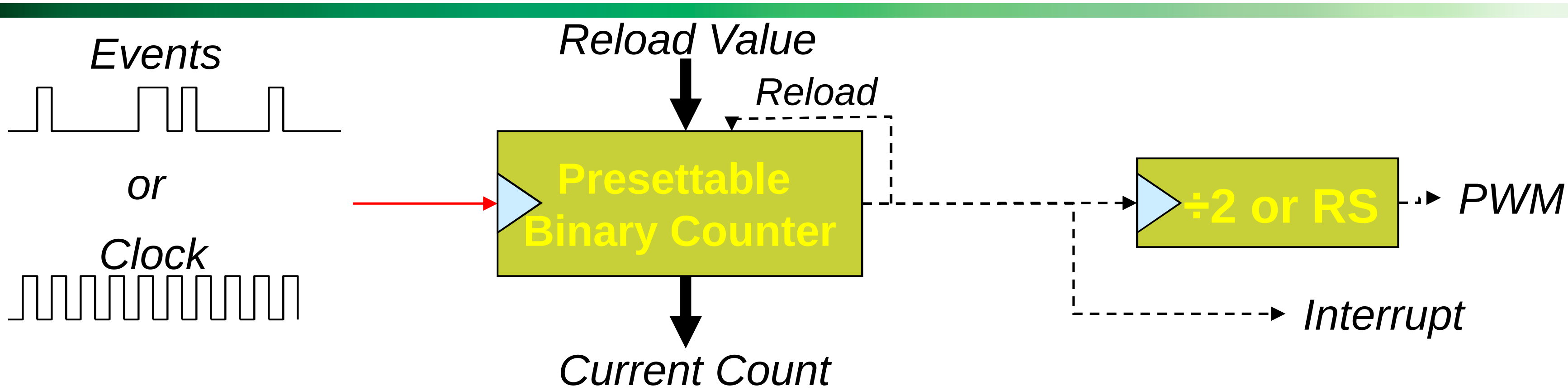
- Called *timers* by Renesas

We examine how to set up the timers for different operation:

- Timer mode
- Event counting mode
- Pulse Width Modulation (PWM) mode
- One-shot timer mode

We then examine how to use a microcontroller in these modes

Timer/Counter Introduction

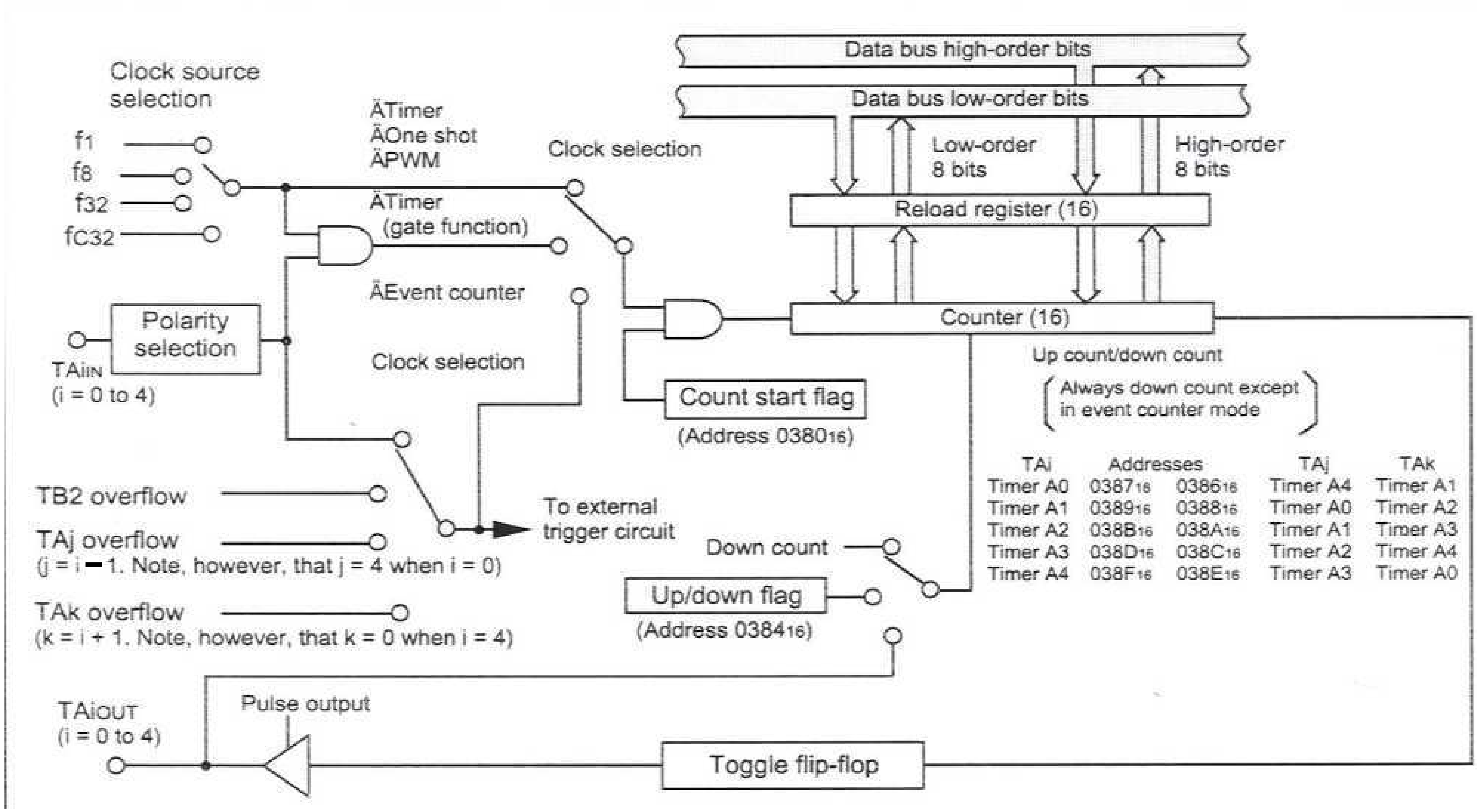


Common peripheral for microcontrollers

Based on pre-settable binary counter, enhanced with configurability

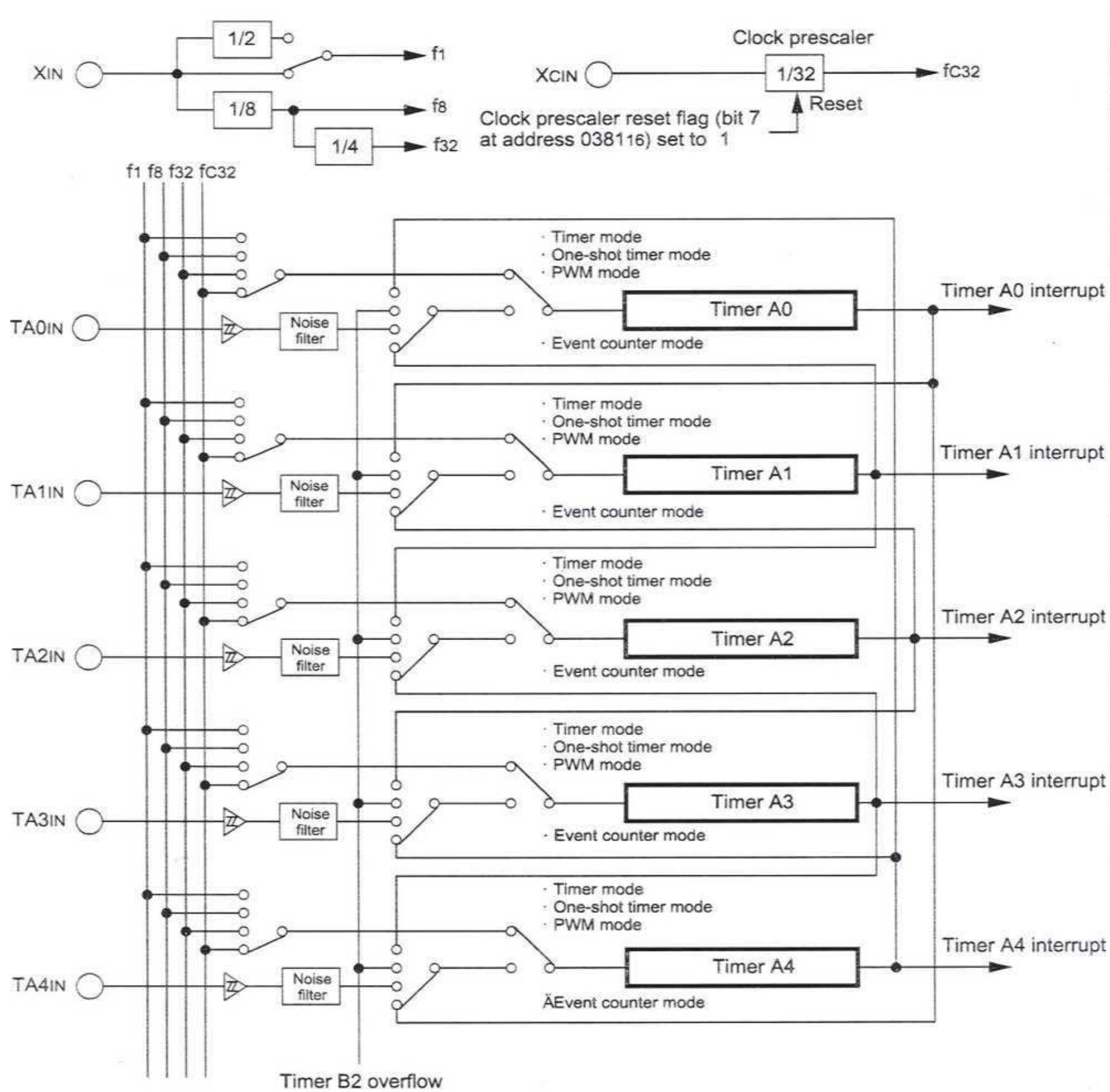
- Count value can be read and written by MCU
- Count direction can often be set to up or down
- Counter's clock source can be selected
  - **Counter mode:** count **pulses** which indicate **events** (e.g. odometer pulses)
  - **Timer mode**: clock source is periodic, so counter value is proportional to **elapsed time** (e.g. stopwatch)
- Counter's overflow/underflow action can be selected
  - Generate interrupt
  - Reload counter with special value and continue counting
  - Toggle hardware output signal
  - Stop!

Timer A Block Diagram



High-Level Timer A Block Diagram

- Timer A devices will be the most frequently used
- Flexible – can be cascaded to create larger timers (i.e. 32 bits long)



Timer A Mode Register

To use the timer, you must set up how you wish to use it (i.e. via TA0MR). After that, the mode register has different settings depending on bits 1 and 0.

Timer Ai mode register

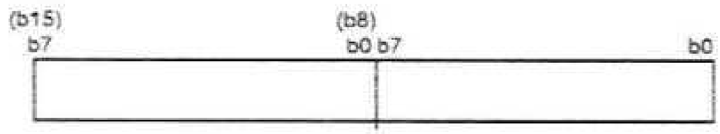
b7 b6 b5 b4 b3 b2 b1 b0

Symbol	Address	When reset
TAiMR(i=0 to 4)	0396_{16} to $039A_{16}$	00_{16}

Bit symbol	Bit name	Function	R	W
TMOD0	Operation mode select bit	b1 b0 0 0 : Timer mode 0 1 : Event counter mode 1 0 : One-shot timer mode 1 1 : Pulse width modulation (PWM) mode	O	O
TMOD1			O	O
MR0	Function varies with each operation mode		O	O
MR1			O	O
MR2			O	O
MR3			O	O
TCK0	Count source select bit (Function varies with each operation mode)		O	O
TCK1			O	O

Timer A "Data" Register

Timer Ai register (Note 1)



Symbol	Address	When reset
TA0	0387_{16},0386_{16}	Indeterminate
TA1	0389_{16},0388_{16}	Indeterminate
TA2	$038B_{16}$,$038A_{16}$	Indeterminate
TA3	$038D_{16}$,$038C_{16}$	Indeterminate
TA4	$038F_{16}$,$038E_{16}$	Indeterminate

Function	Values that can be set	R	W
· Timer mode Counts an internal count source	0000_{16} to $FFFF_{16}$	O	O
· Event counter mode Counts pulses from an external source or timer overflow	0000_{16} to $FFFF_{16}$	O	O
· One-shot timer mode Counts a one shot width	0000_{16} to $FFFF_{16}$ (Note 2,6)	×	O
· Pulse width modulation mode (16-bit PWM) Functions as a 16-bit pulse width modulator	0000_{16} to $FFFE_{16}$ (Note 3,4,6)	×	O
· Pulse width modulation mode (8-bit PWM) Timer low-order address functions as an 8-bit prescaler and high-order address functions as an 8-bit pulse width modulator	00_{16} to FE_{16} (High-order address) 00_{16} to FF_{16} (Low-order address) (Note 3,5,6)	×	O

Note 1: Read and write data in 16-bit units.
Note 2: When the timer Ai register is set to 0000_{16} , the counter does not operate and the timer Ai interrupt request is not generated. When the pulse is set to output, the pulse does not output from the TAiOUT pin.

Count Start Register

Once the timer has been loaded with a value, start it counting.

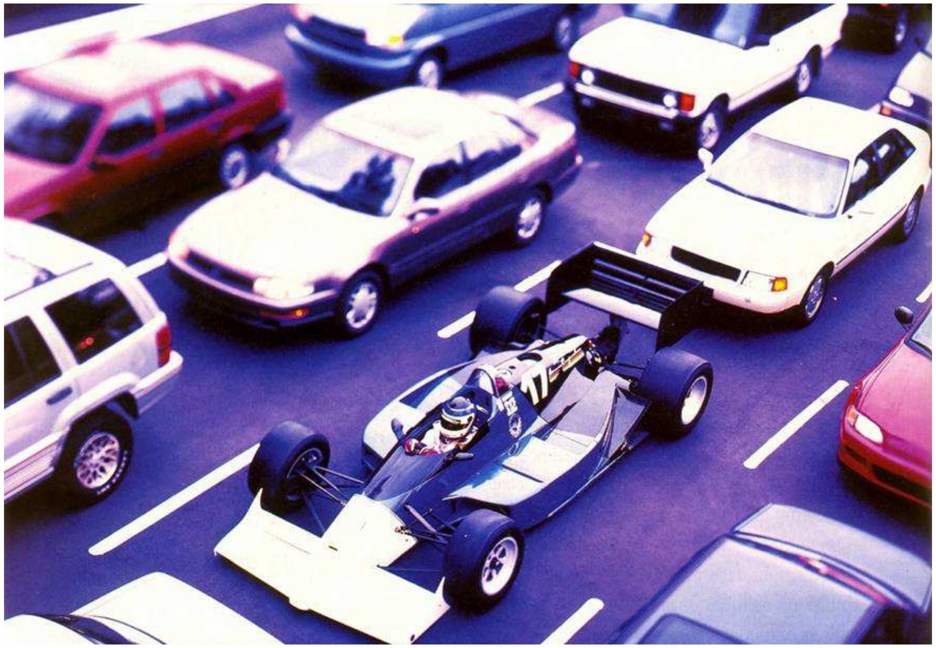
Count start flag

b7 b6 b5 b4 b3 b2 b1 b0

Symbol	Address	When reset
TABSR	0380_{16}	00_{16}

Bit symbol	Bit name	Function	R	W
TA0S	Timer A0 count start flag	0 : Stops counting 1 : Starts counting	○	○
TA1S	Timer A1 count start flag		○	○
TA2S	Timer A2 count start flag		○	○
TA3S	Timer A3 count start flag		○	○
TA4S	Timer A4 count start flag		○	○
TB0S	Timer B0 count start flag		○	○
TB1S	Timer B1 count start flag		○	○
TB2S	Timer B2 count start flag		○	○

Counter Mode



Count pulses representing events

Odometer example

- Measure total distance your car has traveled
- Events are wheel rotations, measured with magnetic sensors (dirt-proof!)
- Distance traveled = counter value * 100.53”
  - Assume 16” tire radius. Tire circumference = $2\pi r$ = 100.53”
- Will limited range of 16 bit counter be a problem?
  - 100.53” * 2^{16}-1 = 1247.78 miles
- Yes. So need to extend range in software.
  - Enable overflow interrupt for the timer
  - Create an ISR to count overflows

TAiMR in Event Counting Mode

Timer Ai mode register
(When not using two-phase pulse signal processing)

b7	b6	b5	b4	b3	b2	b1	b0
		0				0	1

Symbol	Address	When reset
TAiMR(i = 0 to 4)	0396_{16} to $039A_{16}$	00_{16}

Bit symbol	Bit name	Function	R	W
TMOD0	Operation mode select bit	b1 b0 0 1 : Event counter mode (Note 1)	O	O
TMOD1			O	O
MR0	Pulse output function select bit	0 : Pulse is not output (TAiOUT pin is a normal port pin) 1 : Pulse is output (Note 2) (TAiOUT pin is a pulse output pin)	O	O
MR1	Count polarity select bit (Note 3)	0 : Counts external signal's falling edge 1 : Counts external signal's rising edge	O	O
MR2	Up/down switching cause select bit	0 : Up/down flag's content 1 : TAiOUT pin's input signal (Note 4)	O	O
MR3	0 (Must always be 0 in event counter mode)		O	O
TCK0	Count operation type select bit	0 : Reload type 1 : Free-run type	O	O
TCK1	Invalid when not using two-phase pulse signal processing Can be 0 or 1		O	O

Up/Down Flag

The default is that the timer will count down.

Up/down flag (Note 1)

b7	b6	b5	b4	b3	b2	b1	b0

Symbol: UDF
Address: 0384_{16}
When reset: 00_{16}

Bit symbol	Bit name	Function	R	W
TA0UD	Timer A0 up/down flag	0 : Down count 1 : Up count This specification becomes valid when the up/down flag content is selected for up/down switching cause	O	O
TA1UD	Timer A1 up/down flag		O	O
TA2UD	Timer A2 up/down flag		O	O
TA3UD	Timer A3 up/down flag		O	O
TA4UD	Timer A4 up/down flag		O	O
TA2P	Timer A2 two-phase pulse signal processing select bit	0 : two-phase pulse signal processing disabled 1 : two-phase pulse signal processing enabled (Note 2) When not using the two-phase pulse signal processing function, set the select bit to 0	X	O
TA3P	Timer A3 two-phase pulse signal processing select bit		X	O
TA4P	Timer A4 two-phase pulse signal processing select bit		X	O

Trigger Select Register

You can set the trigger pulse of Timers A1 to A4

Trigger select register

b7 b6 b5 b4 b3 b2 b1 b0

Symbol	Address	When reset
TRGSR	0383_{16}	00_{16}

Bit symbol	Bit name	Function	R	W
TA1TGL	Timer A1 event/trigger select bit	b1 b0 0 0 : Input on TA1$_{IN}$ is selected (Note) 0 1 : TB2 overflow is selected 1 0 : TA0 overflow is selected 1 1 : TA2 overflow is selected	○	○
TA1TGH			○	○
TA2TGL	Timer A2 event/trigger select bit	b3 b2 0 0 : Input on TA2$_{IN}$ is selected (Note) 0 1 : TB2 overflow is selected 1 0 : TA1 overflow is selected 1 1 : TA3 overflow is selected	○	○
TA2TGH			○	○
TA3TGL	Timer A3 event/trigger select bit	b5 b4 0 0 : Input on TA3$_{IN}$ is selected (Note) 0 1 : TB2 overflow is selected 1 0 : TA2 overflow is selected 1 1 : TA4 overflow is selected	○	○
TA3TGH			○	○
TA4TGL	Timer A4 event/trigger select bit	b7 b6 0 0 : Input on TA4$_{IN}$ is selected (Note) 0 1 : TB2 overflow is selected 1 0 : TA3 overflow is selected 1 1 : TA0 overflow is selected	○	○
TA4TGH			○	○

Note: Set the corresponding port direction register to 0 .

Example – Setting-up Event Mode

```
#define  TIME_CONFIG 0x01 /* 00000001 val to load into timer mode reg
                            ||||||||_  TMOD0,TMOD1: EVENT COUNTR MODE
                            ||||||____ MR0: NO PULSE OUTPUT
                            |||||_____ MR1: COUNT FALLING EDGES
                            ||||_______MR2: USE UP/DOWN FLAG
                            |||_______ MR3: = 0 IN EVENT COUNTER MODE
                            ||________ TCK0:  RELOAD TYPE
                            |__________TCK1: BIT NOT USED   */

#define  CNTR_IPL 0x03               // TA2  priority interrupt level
#define  LED  p7_2                   // LED port on MSV1632 board
#define  LED_PORT_DIRECTION  pd7_2   // LED port dirn on MSV1632 board

void init() {
   ta2 = 100;    //e.g for an automated packaging line, 100 items per case
   // the following procedure for writing an Interrupt Priority Level follows
   // that as described in the M16C data sheets under 'Interrupts'
   _asm ("   fclr i") ;       // turn off interrupts before modifying IPL
   ta2ic |= CNTR_IPL;         // use read-modify-write instruction to write IPL
   ta2mr = TIME_CONFIG;
   _asm ("   fset i");

   ta2s = 1;  //start counting
  }
```

Example – Using Event Mode

```
#pragma INTERRUPT /B TimerA2Int
void TimerA2Int(void) {
  int delaycntr;
  delaycntr = 0;
  count++;     //e.g for an automated packaging line, cnts # of cases
  LED = 1;
  while( delaycntr <0xffff)  //software delay for flashing LED
   delaycntr++;
  LED = 0;
}

// initializes variables and LED port. Then does nothing but
//  wait for TA2 interrupts.
void main (void) {
  int temp;
  count = 0;
  LED_PORT_DIRECTION = OUTPUT;
  init();
  while (1);
}
```

Timer Mode – Measure Elapsed Time

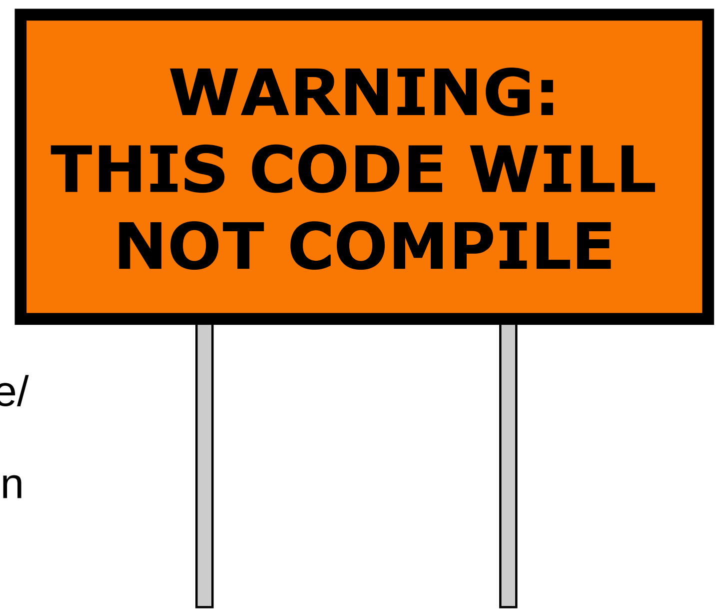
Use a fixed-frequency signal f_{base} as a time-base

To measure elapsed time – *automatically instead of measuring twiddle (debug) bits on an oscilloscope*

- Clear the timer (or read its value and subtract it out later)
- Let time go by…
- Read timer value (possibly subtract out start time)

Example

```
void Compute_Cosine(float angle){
     unsigned t_start, t_stop, t_cosine;
     t_start = timer_current_count;
     compute,
             calculate,
                     approximate,
             interpolate,
     complete.
     t_stop = timer_current_count;
     t_cosine = t_stop - t_start;
}
```



Gate function

- Can use external signal (applied to TAiIN) to enable/ disable counting
- Can select counting during either high or low portion
- Use MR1 and MR2 to configure
- *Convenient way to measure duty cycle*

TAiMR in Timer Mode

Timer Ai mode register

b7	b6	b5	b4	b3	b2	b1	b0
		0				0	0

Symbol	Address	When reset
TAiMR(i=0 to 4)	0396_{16} to $039A_{16}$	00_{16}

Bit symbol	Bit name	Function	R	W
TMOD0	Operation mode select bit	b1 b0 0 0 : Timer mode	O	O
TMOD1			O	O
MR0	Pulse output function select bit	0 : Pulse is not output (TA$_i$OUT pin is a normal port pin) 1 : Pulse is output (Note 1) (TA$_i$OUT pin is a pulse output pin)	O	O
MR1	Gate function select bit	b4 b3 0 X (Note 2): Gate function not available (TA$_i$IN pin is a normal port pin) 1 0 : Timer counts only when TA$_i$IN pin is held L (Note 3) 1 1 : Timer counts only when TA$_i$IN pin is held H (Note 3)	O	O
MR2			O	O
MR3	0 (Must always be 0 in timer mode)		O	O
TCK0	Count source select bit	b7 b6 0 0 : f1 or f2 0 1 : f8 1 0 : f32 1 1 : fc32	O	O
TCK1			O	O

Example – Setting-up Timer Mode

```
#define  TIME_CONFIG 0x40  /* 01000000 value to load into timer mode register
                              ||||||||_  TMOD0,TMOD1: TIMER MODE SELECTED
                              ||||||____ MR0:         NO PULSE OUTPUT
                              |||||_____ MR1,MR2:     GATE FUNCTION NOT SELECTED
                              |||_______ MR3:         SET TO 0 IN TIMER MODE
                              ||________ TCK0,TCK1:   F DIVIDED BY 8 SELECTED */

#define  CNTR_IPL 0x03   // TA0  priority interrupt level
#define  LED  p7_2       // LED4 is connected to p7_2 on the MSV1632/62 board

void init() {
   ta0 = 15000;  // 24meg xtal, div by 8, times 15000 counts-> 5msec interrupts.

// the following procedure for writing an Interrupt Priority Level follows
// that as described in the M16C data sheets under 'Interrupts'
// Note:  ta0ic is the interrupt control register, memory location x0055
   _asm ("   fclr i") ;      //turn off interrupts before modifying IPL
   ta0ic |= CNTR_IPL;        // use read-modify-write instruction to write IPL
   ta0mr = TIME_CONFIG;
   _asm ("   fset i");

   ta0s = 1;  //start counting
}
```

Example – Using Timer Mode

```
int time_cnt;
int count;               // Global count value, incremented every second

#pragma INTERRUPT /B TimerA0Int
void TimerA0Int(void) {
  if ((time_cnt += 5) > (1000))  {  // = 1 second
    LED ^= 1;                         // toggle LED
    count++;                          // example 1 second "clock"
    time_cnt = 0;
  }
}

// Description: initializes variables and LED port. Then does nothing but
// wait for TA0 interrupts.

void main (void) {
  time_cnt = 0;
  count = 0;
  pd7_2 = 1;
  init();
  while (1);      //LED flashing is interrupt driven
}
```

Extending Time Range in Software

Note: An n-bit counter will overflow every $2^n/f_{base}$ seconds

- 16-bit timer and 1 MHz clock ► 65.535 ms range

Need a variable to count overflows

- Using unsigned int, can count 2^{16}-1 overflows ► 2^{32}-1 ticks
- Time range: 2^{32}-1 ticks at 1 MHz ► 4,294,967.295 ms ≈ 1.193 h

```
unsigned int overflow_count=0;
```

Need an ISR which runs on overflow

```
#pragma INTERRUPT timer_isr
void timer_isr(void) {
  overflow_count++;
}
```

Configure timer to continue counting upon overflow, don't need reload with a special value

Need a function to merge overflow and timer information

```
unsigned long get_ticks(void)
  return (
(unsigned long) overflow_count << 16) +
    (unsigned long) ta3;
}
```

Warning: this code will ***intermittently*** return an incorrect tick count! Shared Data Problem

Example – Timer & Event Mode

The maximum amount of time one can count using two timers is:

- Cascade Timer A0 to Timer A1
- Use the 1/32 clock (bits 7 and 6 of TA0MR set to ’10’)
- Set both timer values to xFFFF
- Timer A1 output generates an interrupt

This would create a timer event which would interrupt the CPU every ______ seconds (almost __ hours!)

What Registers Need to be Set?

```
/*Timer A0 mode register settings
   b7 b6 b5 b4 b3 b2 b1 b0
    |  |  |  |  |  |  |  |____  TA0D0 => 0  -  00 => timer mode
    |  |  |  |  |  |  |_______  TA0D1 => 0;
    |  |  |  |  |  |__________  MR0   => 0  -  TA0out is not used
    |  |  |  |  |_____________  MR1   => 0  -  TA0in is not used
    |  |  |  |________________  MR2   => 0;
    |  |  |___________________  MR3   => 0  -  must be 0 in timer mode
    |  |______________________  TCK0  => 0;
    |_________________________  TCK1  => 1  -  TCK[10] => 00 is f1 or f2
                                                       => 01 is f8
                                                       => 10 is f32
                                                       => 11 is fc32  */
TA0MR = x80;     // Timer A0 in timer mode with f32 clock
/***************************************************************************
 - Timer A1 mode register settings
   b7 b6 b5 b4 b3 b2 b1 b0
    |  |  |  |  |  |  |  |____  TA1D0 => 1  -  01 => event counter mode
    |  |  |  |  |  |  |_______  TA1D1 => 0;
    |  |  |  |  |  |__________  MR0   => 0  -  TA1out is not used
    |  |  |  |  |_____________  MR1   => 0  -  TA1in pin not used
    |  |  |  |________________  MR2   => 0; -  Up/Down flag used
    |  |  |___________________  MR3   => 0  -  must be 0 in event counter mode
    |  |______________________  TCK0  => 0; -  reload type counter
    |_________________________  TCK1  => 0; -  Invalid for regular counting*/

TA1MR = x01;     // Timer A1 in event counter mode with reload enable
```

What Registers Need to be Set?

```
/*Value to initialize TA0 and TA1 to each time at initialization and
   each time overflow occurs

   TAi/(XTAL * fx) = Z ms      - where TAi is initialization value,
                               XTAL is the clock frequency (20MHz)
                               fx is the clock multiplier (1,1/8,1/32)
                               Z is the miliseconds between overflows

   xFFFF = 65536
   65536/(24,000,000 * 1/32) = 87.381 milliseconds

  TA0 overflows every 87.381 ms, TA1 counts the overflows up to 65536,
   then overflows every 5726.6 seconds (about 1.6 hours) */

TA0    =      xFFFF   // value loaded into TA0 data register
TA1    =      xFFFF   // value loaded into TA1 data register

/******************************************************************
  Count Start Flag -> b0 = 1 - start TA0 counting
                      b1 = 1 - start TA1 counting
                      b2-b7  - not applicable*/

TABSR  =      x03     // start Timers A0 and A1 counting
```

What Registers Need to be Set?

```
Timer Up/Down Function Register ->    b0 = 0 - TA0 counting down
                              b1 = 0 - TA1 counting down
                              b2-b7  - not applicable*/

UDF = x00;     // UDF[10] => 00 makes Timers A0 and A1 count down

/*******************************************************************
 - Timer Trigger Select Register
   b7 b6 b5 b4 b3 b2 b1 b0
                     |  |____  TA1TGL => 0  -  TA0 overflow select
                     |_______  TA1TGH => 1; */

TRGSR   =     x02;    // TA0 overflow is selected as trigger

/*********************************************************************
 Set TA1 priority level interrupt; */

TA1IC   =     x03;    // set TA1 priority level interrupt
```

Pulse-Width Modulation

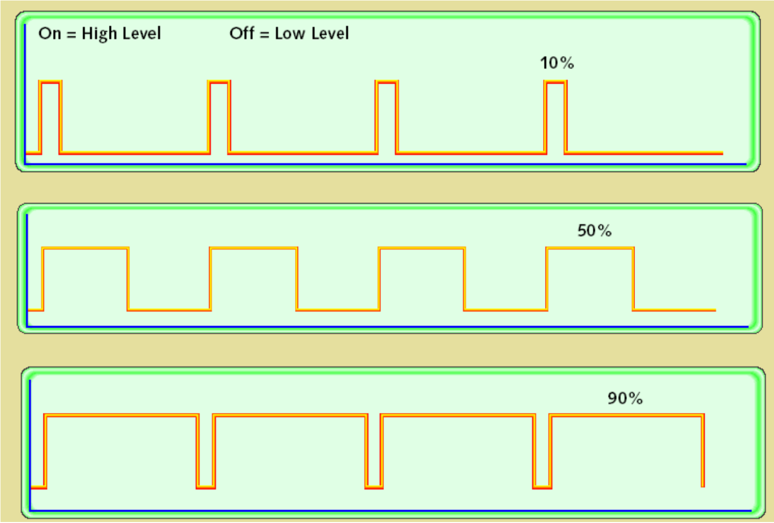
Often need to generate an analog value: motor speed, servo motor position, incandescent light dimmer, adj. switch-mode power supply

Analog circuits have some disadvantage

- Generating the voltage accurately – circuits drift with temperature and time
- Analog power amplifiers are inefficient (P = E*I)
- Analog signals are much more sensitive to noise than digital signals

PWM provides a *digital encoding* of an *analog* value

- Now circuits are digital: more efficient, less sensitive to noise, temperature, aging effects



PWM signal characteristics

- Modulation frequency – how many pulses occur per second (fixed)
- Period – 1/(modulation frequency)
- On-time – amount of time that each pulse is on (asserted)
- Duty-cycle – on-time*period
- Adjust *on-time* (hence *duty cycle*) to create encoded analog value

Pulse-Width Modulation

We rely on *low-pass filtering* to “decode” (convert) this high-frequency PWM signal to an analog DC value

- Variable speed motor control: Motor has inertia (will coast if power is turned off)
- Incandescent Lamp Dimmer: Human eye has persistence of vision (retina averages signals above 30 Hz), and filament takes time to cool down and stop emitting visible light
- Adjustable switch-mode power supply: Rely on inductor and capacitor to maintain current and voltage when not drawing current from battery

Many Timer/Counter peripherals can also generate PWM signal

- For example
  - Count up
  - ***Set*** PWM output when counter value reaches 0
  - ***Reset*** PWM output when counter value reaches n
  - When counter reaches 11.111, overflow and continue counting

Read Michael Barr’s *Embedded Systems Programming* article “Pulse Width Modulation” for more PWM information

Timer A PWM Description

Item	Specification
Count source	f_1, f_2, f_8, f_{32}, f_{C32}
Count operation	• The timer counts down (operating as an 8-bit or a 16-bit pulse width modulator) • The timer reloads a new count at a rising edge of PWM pulse and continues counting • The timer is not affected by a trigger that occurs when counting
16-bit PWM	High level width n / fi n : Set value • Cycle time$(2^{16}-1)$ / fi fixed
8-bit PWM	• High level width × n (m+1) / fi n : values set to timer Ai register's high-order address • Cycle time (2^8-1) × (m+1) / fi m : values set to timer Ai register's low-order address
Count start condition	• External trigger is input • The timer overflows • The count start flag is set (= 1)
Count stop condition	• The count start flag is reset (= 0)
Interrupt request generation timing	PWM pulse goes "L"
TA_{iIN} pin function	Programmable I/O port or trigger input
TA_{iOUT} pin function	Pulse output
Read from timer	When timer Ai register is read, it indicates an indeterminate value
Write to timer	• When counting stopped When a value is written to timer Ai register, it is written to both reload register and counter • When counting in progress When a value is written to timer Ai register, it is written to only reload register (Transferred to counter at next reload time)

Timer A Mode Register for PWM

Timer Ai mode register

b7	b6	b5	b4	b3	b2	b1	b0
					1	1	1

Symbol	Address	When reset
TAiMR(i=0 to 4)	0396_{16} to $039A_{16}$	00_{16}

Bit symbol	Bit name	Function	R	W
TMOD0	Operation mode select bit	b1 b0 1 1 : PWM mode	○	○
TMOD1			○	○
MR0	1 (Must always be 1 in PWM mode)		○	○
MR1	External trigger select bit (Note 1)	0: Falling edge of TAi_{IN} pin's input signal (Note 2) 1: Rising edge of TAi_{IN} pin's input signal (Note 2)	○	○
MR2	Trigger select bit	0: Count start flag is valid 1: Selected by event/trigger select bits	○	○
MR3	16/8-bit PWM mode select bit	0: Functions as a 16-bit pulse width modulator 1: Functions as an 8-bit pulse width modulator	○	○
TCK0	Count source select bit	b7 b6 0 0 : f_1 or f_2 0 1 : f_8 1 0 : f_{32} 1 1 : f_{C32}	○	○
TCK1			○	○

Note 1: Valid only when the TAi_{IN} pin is selected by the event/trigger select bit (addresses 0382_{16} and 0383_{16}). If timer overflow is selected, this bit can be 1 or 0 .
Note 2: Set the corresponding port direction register to 0 .

One-Shot Flag

One-shot start flag

b7	b6	b5	b4	b3	b2	b1	b0
		0					

Symbol ONSF

Address 0382_{16}

When reset 00_{16}

Bit symbol	Bit name	Function	R	W
TA0OS	Timer A0 one-shot start flag	1 : Timer start When read, the value is 0	○	○
TA1OS	Timer A1 one-shot start flag		○	○
TA2OS	Timer A2 one-shot start flag		○	○
TA3OS	Timer A3 one-shot start flag		○	○
TA4OS	Timer A4 one-shot start flag		○	○
Reserved bit		Must always be set to 0	○	○
TA0TGL	Timer A0 event/trigger select bit	b7 b6 0 0 : Input on $TA0_{IN}$ is selected (Note) 0 1 : TB2 overflow is selected 1 0 : TA4 overflow is selected 1 1 : TA1 overflow is selected	○	○
TA0TGH			○	○

Note: Set the corresponding port direction register to 0 .