MSP430 Timers In-Depth

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Agenda

• Introduction
• Basic Timer
• RTC
• Watchdog Timer (WDT/WDT+)
• Timer_A
• Timer_B
• Summary and Applications
Introduction

• Timers: Essential to almost any embedded application
  ▪ Generate fixed-period events
  ▪ Periodic wakeup
  ▪ Count edges
  ▪ Replacing delay loops with timer calls allows CPU to sleep, consuming much less power

• Five types of MSP430 timer modules

• Different tasks call for different timers. But which one?

• We will:
  ▪ Discuss all five timer modules
  ▪ Extract the unique characteristics of each, compare/contrast them
  ▪ Spend majority of time on Timer_A/B
  ▪ Look at real-world application examples
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Basic Timer: Overview

- Found only on ‘4xx
- Primary characteristics
  - Clock for LCD module
  - Good choice for RTC implementation
  - Basic interval timer
  - Simple interrupt capability
- Wide range of intervals – up to two seconds

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void main(void)
{
    WDTCTL = WDTPW + WDTHOLD; // Stop watchdog timer
    FLL_CTL0 |= XCAP14PF;   // Set load caps
    setTime(0x12,0,0,0);    // Init
    BTCTL = BT_ADLY_1000;   // Set interval
    IE2 |= BTIE;            // Enable BT int
    __BIS_SR(LPM3_bits + GIE); // Sleep, enable ints
}

#pragma vector=BASICTIMER_VECTOR
__interrupt void BT_ISR(void)
{
    incrementSeconds();
    if(sec==60) {sec = 0; incrementMinutes();}
    if(min==60) {min = 0; incrementHours();}
    if(hours>12) hours=1;
}
void main(void)
{
    int i;
    WDTCTL = WDTPW + WDTHOLD;
    FLL_CTL0 |= XCAP14PF;
    LCDCTL = LCDP2 + LCD4MUX + LCDON;
    BTCTL = BTFRFQ1; // LCD freq=ACLK/128
    P5SEL = 0xFC; // Set LCD pins
    for (;;)
    {
        for (i=0; i<7; ++i) // Display #
        {
            LCDMEM[i] = digit[i];
        }
    }
}
Basic Timer: Thermostat Example

```c
void main(void)
{
    << Code to initialize WDT/caps/LCD/IOs >>
    BTCTL = BT_ADLY_2000;     // Two seconds
    BTCTL |= BT_fLCD_DIV256;   // LCD=ACLK/256
    IE2 = BTIE;               // Enable ints

    while(1)
        checkTempAndUpdateDisplay();
}
#pragma vector=BASICTIMER_VECTOR
__interrupt void basic_timer(void)
{
    if(count&0x01)             // Every other time
        __BIC_SR_IRQ(LPM3_bits); // Exit after return

    count++;
}
```
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Real-Time Clock Module: Overview

- First introduced on ‘FG4619 (new module)
- Extension of the Basic Timer
- Two modes
  - Counter: BT is unaltered, and there’s now an additional 32-bit counter
  - Calendar: BT becomes part of RTC module, all of which drives an RTC
- BT and RTC share interrupt vectors
RTC: Calendar Mode

- Clock functions handled automatically
- Registers for:
  - Year
  - Month
  - Date
  - Day of week
  - Hour
  - Minute
  - Second
- Either BCD or hex format
- No generic BT functionality
- Handles leap year calculation
- RTC interrupt
  - Can be enabled/disabled
  - Triggered on turnover of min/hr/midnight/noon
- Intervals from every minute to once a day; one-second intervals no longer required to implement RTC
- No “alarm clock” (exact time) interrupt – easily implemented in code
void main(void) {  
    WDTCTL = WDTPW+WDTHOLD; // Stop the dog  
    RTCCTL = RTCBCD+RTCHOLD+RTCMODE_3+RTCTEV_0+RTCIE;  
        // Enable, BCD, int every minute  
    RTCSEC = 0x00; // Set Seconds  
    RTCMIN = 0x00; // Set Minutes  
    RTCHOUR = 0x08; // Set Hours  
    RTCDOW = 0x02; // Set DOW  
    RTCDAY = 0x23; // Set Day  
    RTCMON = 0x08; // Set Month  
    RTCYEAR = 0x2005; // Set Year  
    RTCCTL &= ~RTCHOLD; // Enable RTC  
    __BIS_SR(LPM3_bits+GIE); // Enter LPM3 w/ interrupt 
}  

#pragma vector=BASICTIMER_VECTOR  
__interrupt void basic_timer(void) {  
    P5OUT ^= 0x02; // Toggle P5.1 every minute 
}
RTC: Counter Mode

- BT remains “intact”
- RTC provides an additional 32-bit counter
- BT/RTC counters share one interrupt vector
- In effect, the 32-bit counter replaces the 16-bit one
- RTCIE bit selects whether interrupt generated by RTC or BT counters
- If set, interrupt generated by overflow of RTC counter (selectable 8/16/24/32-bit)
- Interrupt vector is shared with BT
RTC: BT/RTC Interval Timer Example

• Setting RTCIE in interval mode causes interrupt to be generated from 32-bit RTC interval counter

```c
void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;
    FLL_CTL0 |= XCAP18PF;
    P5DIR |= 0x02;
    BTCTL = BTSSEL + BT_fCLK2_DIV256; // 1MHz/256 = ~244us Interval
    RTCCTL = RTCMODE_1 + RTCTEV_0 + RTCIE; // 1MHz/(128*256) = 32 Hz
    IE2 |= BTIE;
    __BIS_SR(LPM0_bits + GIE);
}

#pragma vector=BASICTIMER_VECTOR
__interrupt void basic_timer_ISR(void)
{
    P5OUT ^= 0x02; // Toggle P5.1
}
```
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Watchdog (WDT+/+) Module: Overview

- Found on all MSP430 devices
- Two flavors: WDT & WDT+
- Two modes
  - Watchdog
  - Interval timer
- Access password protected
- Separate interrupt vectors for POR and interval timer
- Sourced by ACLK or SMCLK
- Controls RST/NMI pin mode
- WDT+ adds failsafe/protected clock
WDT: Watchdog Function

- Controlled start if s/w problem occurs
- Code must “pet” the “dog” before interval expires, otherwise PUC
- Selectable intervals
- Powers up active as watchdog w/ ~32ms reset – YOUR CODE MUST INITIALIZE THE WDT
- In addition to PUC, WDTIFG sources reset vector interrupt
- Code can use WDTIFG to determine whether dog caused interrupt
WDT: Common Design Issues

- Program keeps resetting itself!
- Program acting wacky – how did execution get to that place?
  - Try setting interrupt near beginning of main() to see if code is re-starting
- CPU seems to freeze before even getting to first instruction
  - Is this a C program with a lot of initialized memory?
  - Generally can occur only with very large-memory versions of the device
  - Solution: Use __low_level_init() function, stop watchdog there

```c
void main(void) {
    WDTCTL = WDTPW+WDTHOLD; // Stop the dog
    .
    .
}
```
WDT: Interval Timer Function

• No PUC issued when interval is reached

• If WDTIE and GIE set when interval is reached, a WDT interval interrupt generated instead of reset interrupt

• Selectable intervals
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Timer_A Module: Overview

• The most versatile
• Async 16-bit timer/counter
• Four input clocks, including externally-sourced
• Selectable count mode
• Extensive interrupt capability
• Up to three capture/compare registers (CCR) generate events when value reached
• “Capture” or “Compare” mode
• Output not only interrupts, but also “output signals”
• Extensive connections to other modules
Timer A: Capture Mode

- Measure time before a signal event occurs
- Why not just use a CPU interrupt and have CPU fetch timer value?
  - Extra cycles expire
  - Dependent on ints being enabled
- Input signal from:
  - External pin
  - Internal signal (i.e., Comp_A)
  - Vcc/GND
- Edge direction – programmable
- Applications:
  - Analog signal rising to Comp_A threshold
  - Slope ADC
  - Frequency measurement
  - Vcc threshold detect (via voltage divider)
Timer A: Compare Mode

- Cause an event after a defined period (exact opposite of capture mode)

- What kind of event?
  - CPU interrupt
  - Modules tied internally to timer output (DMA, start ADC/DAC conversion)
  - External components

- Applications:
  - PWM generation
  - RTC
  - Thermostat
  - Timer_A UART

![Diagram showing Timer and CCRx connections with EQUx values]

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Timer A: Count Modes

• Determines pattern of counter direction
  - What will it do when it rolls over?
  - Does it always count up? Maybe down?
  - What is the maximum value?

• Typically used in compare mode to generate cyclical events

• Can apply to capture mode in measuring cyclical events

• The modes:
  - Continuous: Up to FFFF, rolls over to 0000, back up to FFFF, etc.
  - Up: Up to value specified by CCR0, rolls over to 0000, back up to CCR0 value, etc.
  - Up/down: Up to value specified by CCR0, count down to 0000, back up to CCR0 value, etc.
Timer A: Count Modes

Up

- 0xFFFFh
- TACCR0
- Up to FFFF, rolls over to 0000, back up to FFFF, etc.

Up/Down

- 0xFFFFh
- TACCR0
- Up to value in CCR0, count down to 0000, back up to value in CCR0, etc.

Continuous

- 0xFFFFh
- Up to value specified by CCR0, rolls over to 0000, back up to CCR0 value, etc.
Timer A: CCR Output Mode

- Each CCR generates an output signal, available externally.
- This is a separate and different type of output compared to interrupts.
- Operate continuously while CPU sleeps.
- Output modes determine how the timer pattern translates to output signal.
- Note that CCR0 plays a role in CCR1-2 output signals.
- For different combinations of count modes, output modes, and CCR values, a multitude of outputs and behaviors possible.
Timer A: Count Modes

- Output Mode 1: Set
- Output Mode 2: Toggle/Reset
- Output Mode 3: Set/Reset
- Output Mode 4: Toggle
- Output Mode 5: Reset
- Output Mode 6: Toggle/Set
- Output Mode 7: Reset/Set

Interrupt Events
Timer A: Interrupt Overview

- **Two vectors:**
  - $TACCR0$ for CCR0 CCIFG (higher priority)
  - $TAIV$ for all CCIFG except CCR0, plus TAIFG

- **In compare mode:**
  - Corresponding CCIFG set when TAR reaches TACCRx

- **In capture mode:**
  - Corresponding CCIFG set when event occurs and new value placed in TACCRx

- Also TAIFG bit – set whenever timer reaches zero
Timer A: TAIV Interrupt Handling

- TAIV interrupt handler uses switch mechanism to identify correct sub-vector to handle

<table>
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<tr>
<th>ISR</th>
<th>Instruction 1</th>
<th>Instruction 2</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCRX_ISR</td>
<td>add &amp;TAIV,PC</td>
<td>; Offset to Jump table</td>
<td>; No source</td>
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<td></td>
<td>reti</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>jmp CCR1_ISR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>jmp CCR2_ISR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>reti</td>
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</tr>
<tr>
<td></td>
<td>reti</td>
<td>; No source</td>
<td></td>
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<tr>
<td>TIMOVH</td>
<td>xor.b #08h, &amp;P1OUT</td>
<td></td>
<td>; No source</td>
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<tr>
<td></td>
<td>reti</td>
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<td></td>
</tr>
<tr>
<td>CCR1_ISR</td>
<td>xor.b #02h, &amp;P1OUT</td>
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<td>; No source</td>
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<tr>
<td></td>
<td>reti</td>
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<td></td>
</tr>
<tr>
<td>CCR2_ISR</td>
<td>xor.b #04h, &amp;P1OUT</td>
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<td>; No source</td>
</tr>
<tr>
<td></td>
<td>reti</td>
<td></td>
<td></td>
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</tbody>
</table>
Timer_A: Internal Connections

- Timer_A/B have several internal connections to other modules
  - Comp_A
  - DMA
  - DAC12
  - External inputs/outputs

- Avoids CPU wakeup – saves power
- Faster response – no cycles wasted while ISR loads/executes
Timer_A: Internal Connections

Why are they important? Example:

→ Automatic SOC trigger eliminates phase error
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Timer_B Module: Overview

- Same as Timer_A, except:
  - Some implementations have 7 CCRs
  - Bit-length of timer is programmable as 8-, 10-, 12-, or 16-bit
  - No SCCI bit function
  - Double-buffered CCR registers
  - CCR registers can be grouped
Timer B: Double-Buffered CCR Registers

- New register TBCLx with TBCCRx
- TBCLx takes on role of TACCRx in determining interrupts
- TBCL0 takes on role of TACCR0 in count modes
- Can’t access TBCLx directly; write to TBCCRx, then at the load event, moves to TBCLx
- Load event timing is programmable:
  - Immediately
  - When TBR counts to zero
  - When TBR counts to old TBCLx value

- Load events can be grouped – multiple TBCCRx loaded into TBCL together
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Timer Modules: Unique Features

- **Basic Timer / RTC**
  - RTC-specific functionality
  - LCD functions
  - Interrupt intervals up to two seconds

- **WDT / WDT+**
  - Can reset device automatically
  - Interrupt intervals up to one second

- **Timer_A/B**
  - Widest interrupt interval range: 1/MCLK to 32 seconds
  - Control count direction
  - Set count max w/o software intervention
  - Has outputs with configurable duty cycle
  - Internal connection to other peripherals
  - Capture capability
**Timer Modules: Interval Ranges**

Assuming either clock source can be used to source the timer, what are the interval ranges for interrupts?

<table>
<thead>
<tr>
<th></th>
<th>Minimum Period</th>
<th>Maximum Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Watchdog</strong></td>
<td>61us / 16.4kHz</td>
<td>1sec / 1Hz</td>
</tr>
<tr>
<td><strong>Basic / RTC</strong></td>
<td>1.9us / 524kHz</td>
<td>2sec / 0.5Hz</td>
</tr>
<tr>
<td><strong>Timer_A/B</strong></td>
<td>0.95us / 1.048MHz</td>
<td>32sec / .031Hz</td>
</tr>
</tbody>
</table>

**Example 2: MCLK = SMCLK = 16MHz and ACLK = VLOCLK = 12kHz**

<table>
<thead>
<tr>
<th></th>
<th>Minimum Period</th>
<th>Maximum Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Watchdog</strong></td>
<td>4us / 250kHz</td>
<td>2.7sec / 0.37Hz</td>
</tr>
<tr>
<td><strong>Basic / RTC</strong></td>
<td>125ns / 8MHz</td>
<td>5.5sec / 0.18Hz</td>
</tr>
<tr>
<td><strong>Timer_A/B</strong></td>
<td>62.5ns / 16MHz</td>
<td>87.4sec / .011Hz</td>
</tr>
</tbody>
</table>

Values are approximate
void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;
    P1DIR |= 0x04;           // Output
    P1SEL |= 0x04;           // TA1 option
    P2DIR |= 0x01;           // Output
    P2SEL |= 0x01;           // TA2 option
    CCR0 = 512-1;            // PWM Period
    CCTL1 = OUTMOD_7;        // Reset/set
    CCR1 = 384;              // Duty cycle
    CCTL2 = OUTMOD_7;        // Reset/set
    CCR2 = 128;              // Duty cycle
    TACTL = TASSEL_2 + MC_1; // SMCLK, up mode
    __BIS_SR(LPM0_bits);
}
Timer Applications: Voice Recorder

Which timer to use?
Summary

• There are a variety of MSP430 timers available
• Timers allow more time in sleep mode, saving power
• Use the Basic Timer and Watchdog Interval timer for simple interval situations
• Use Timer_A/B for PWM, capture, and more-complex counting situations
• A wealth of information is available: check the User’s Guides, code examples, and application reports
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