AVR134: Real Time Clock (RTC) using the Asynchronous Timer

8-bit AVR® Microcontroller

Application Note

Features

- **Real Time Clock with Very Low Power Consumption (4 µA @ 3.3V)**
- **Very Low Cost Solution**
- **Adjustable Prescaler to Adjust Precision**
- **Counts Time, Date, Month, and Year with Auto Leap Year Configuration**
- **Year 2000 Compliant Date Format**
- **Can be Used on all AVR Controllers with RTC Module**
- **"C"-Code for ATMega103 Inculded**

Introduction

This application note describes how to implement a Real Time Clock (RTC) on AVR microcontrollers that features the RTC module. The implementation requires only one discrete component – a 32.768 kHz watch crystal. The application has very low power consumption because the microcontroller operates in Power-save mode most of the time. In Power-save mode the AVR controller is sleeping with only a Timer running. The Timer is clocked by the external crystal. On every Timer overflow the time, date, month, and year are counted. This RTC implementation is written for the ATmega103, and can easily be ported to other AVRs with RTC Module. The advantages of implementing a RTC in software compared to an external hardware RTC are obvious:

- Lower cost
- Few external components
- Lower power
- Greater flexibility

Theory of Operation

The implementation of a RTC utilizes the asynchronous operation of the RTC module. In this mode, Timer/Counter0 runs independently from the CPU clock.

Figure 1 shows that the AVR controller operates from the 4 MHz main clock source in normal operation. When low power operation is desired the AVR operates in Power-down mode, with only the asynchronous timer running from an external 32.768 kHz crystal.

The software Real Time Clock (RTC) is is implemented using a 8-bit Timer/Counter with Overflow Interrupt. The software controls the Overflow Interrupt to count clock and calendar variables. The Timer Overflow Interrupt is used to update the software variables "second", "minute", "hour", "date", "month" and "year" at the correct intervals.

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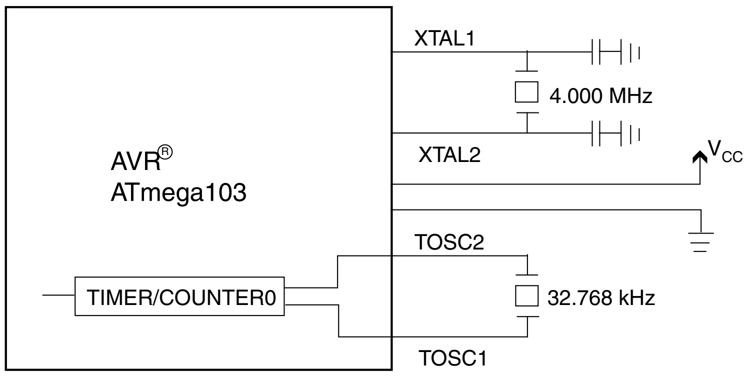
Figure 1. Oscillator Connection for Real Time Clock



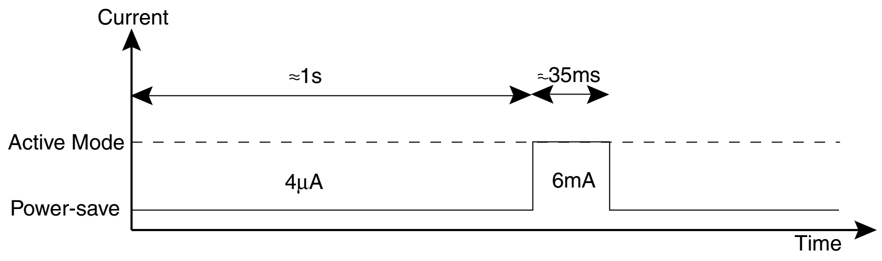
Because of the amount time for the Timer/Counter to complete one overflow is always the same, each of these timer variables will be incremented by a fixed number with every Timer Overflow. The Timer Overflow Interrupt routine is used to perform this task.

To reduce power consumption, AVR enters Power-save mode, in which all On-chip modules are disabled except for the RTC. As shown in Table 1, the MCU typically consumes less than 4 µA in this mode. The device will wake-up on the Timer Overflow Interrupt. The updates of the timer variables are performed during the active period.

Then the AVR re-enters the Power-save mode until the next Timer Overflow occurs. Figure 2 and Figure 3 shows the time the AVR controller operates in Power-save mode versus that Active mode.

To calculate the total power consumption, the power consumption in Power-save mode must be added to the power consumption in Active mode. The time it takes to update the timer variables in the interrupt routine is less than 100 cycles, with a 4 MHz main clock this is 25 µs. The power consumption for this period is neglectable. More important is the wake-up period for the controller. The wake-up time can be programmed to 35 ms for use with external crystal, or 1 ms for use with ceramic resonator. An example of a circuit that wake up once every second to update the RTC will show the power consumption for the two types of clock source:

Figure 2. Current Figures for Crystal Oscillator, 35 ms Startup Time

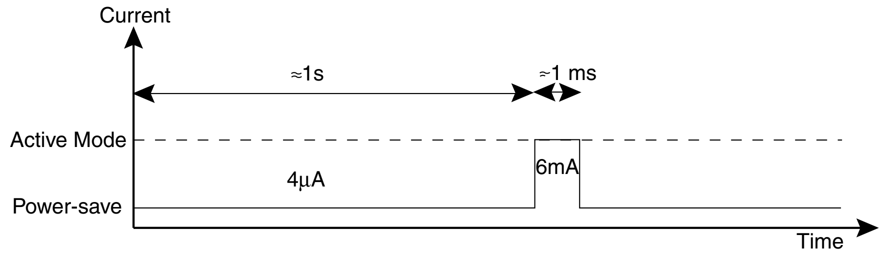


Total current consumption per second:

= (1 sec * 4 µA) + (35 ms * 6 mA) = 4 µAs + 210 µAs = 214 µAs

This shows that the dominating part of the current consumption is in Active mode.

Figure 3. Current Figures for Ceramic Resonator, 0.5 ms Startup Time



Total current consumption per second:

= (1 sec * 4 μA) + (1 ms * 6 mA) = 4 μAs + 6 μAs = 10 μAs

This shows that by reducing the startup time the current consumption is reduced from 100 μAs to 7 μAs.

Table 1. Current Consumption by the AVR Controller in Each Mode

Mode	Typical	Max
Active 4 MHz, 3.3 V_{CC}	4 mA	6.0 mA
Idle 4 MHz, 3.3 V_{CC}	1.8 mA	2.0 mA
Power-down 4 MHz, 3.3 V_{CC}	< 1.0 μA	2.0 μA
Power-save 4 MHz, 3.3 V_{CC}	< 4.0 μA	6.0 μA

Calculation

Given the frequency of the watch crystal, the user can determine the time for each tick in the Timer/Counter by selecting the desired prescale factor. As shown in Table 2, CS02, CS01, and CS00 in the TCCR0 (Timer/Counter0 Control Register) define the prescaling source of the Timer/Counter, where CK is the frequency of the watch crystal. For example, if CK equals 32.768 kHz, the Timer/Counter will tick at a frequency of 256 Hz with a prescaler of CK/128.

Table 2. Timer/Counter0 Prescale Select

CS02	CS01	CS00	Description(1)	Overflow Period
0	0	0	Timer/Counter0 is stopped	–
0	0	1	CK	1/64s
0	1	0	CK/8	1/8s
0	1	1	CK/32	1/4s
1	0	0	CK/64	1/2s
1	0	1	CK/128	1s
1	1	0	CK/256	2s
1	1	1	CK/1024	8s

Note: 1. CK = 32.768 kHz

Configuration Example

As shown in Figure 1, the crystal should be connected directly between pins TOSC1 and TOSC2. No external capacitance is needed. The Oscillator is optimized for use with a 32.768 kHz watch crystal, or an external clock signal in the interval of 0 Hz - 256 kHz. In this example, the eight LEDs in port B are used to display the RTC. The LED on Port B pin 0 will change state every second. The next six LEDs represents the minute in binary, and the LED on pin 7 stays on for one hour and off for the next.

Considerations should be taken when clocking the Timer/Counter from an asynchronous clock source. A 32.768 kHz crystal have a stabilization time up to one second after Power-up. The controller must therefore not enter Power-save mode less than a second after Power-up. Care must be taken when changing to asynchronous operation. See the data sheet for detailed instructions. When updating the Timer Register the data is transferred to a temporary register and latched after two external clock cycles. The Asynchronous Status Register (ASSR) contains status flags that can be checked to control that the written register is updated.

Implementation

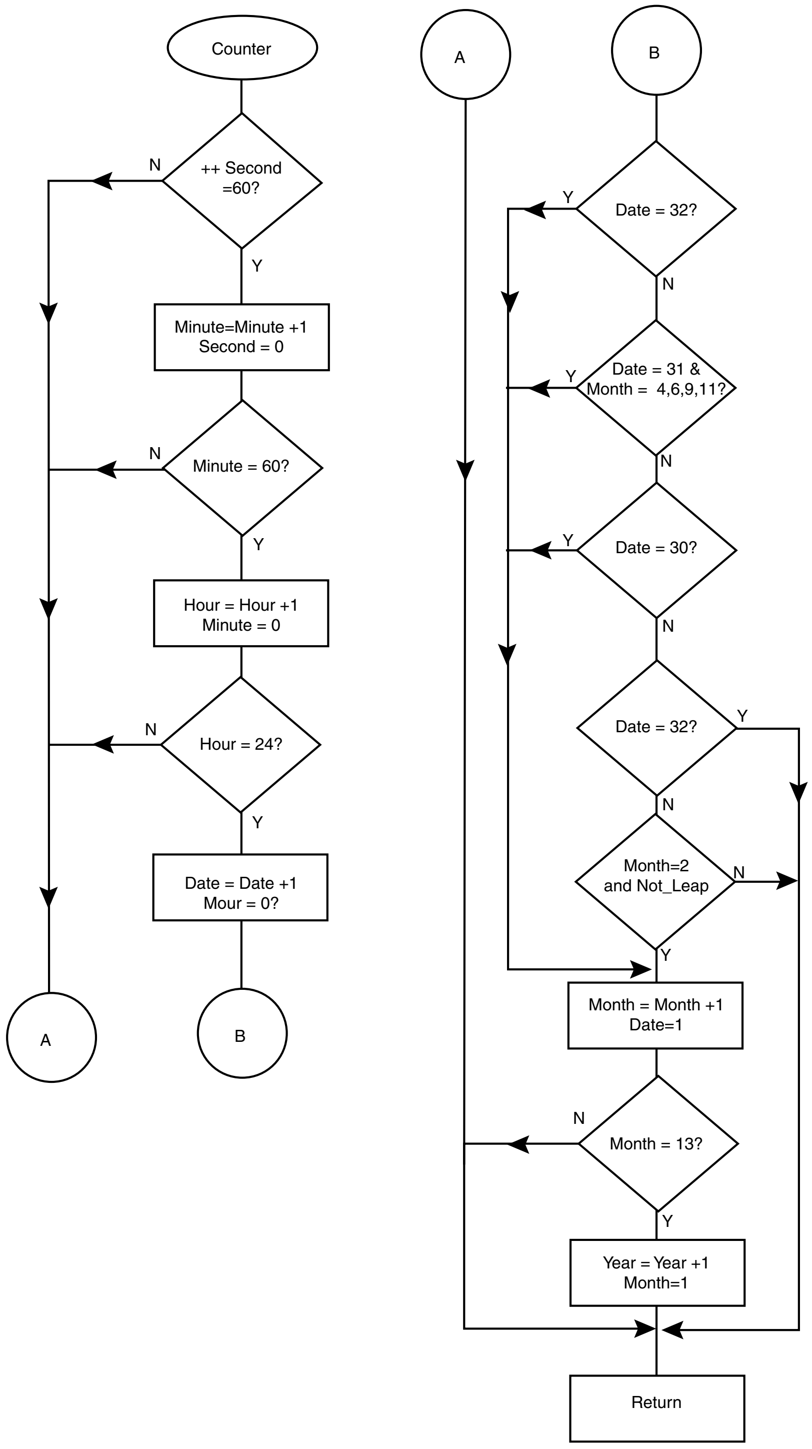
The software consists of two subroutines. “counter” is the Timer/Counter Overflow service routine, which updates all the timer variables whenever a Timer Overflow occurs. The other one, “not_leap”, corrects the date for leap years. The main program sets up all the necessary I/O Registers to enable the RTC module and controls the Power-down sequence.

The AS0 bit in the ASSR (Asynchronous Status Register) is set to configure Timer/Counter0 to be clocked from an external clock source. Only this timer can perform asynchronous operations. The start value for the Timer is Reset and the desired prescaler value is selected. To synchronize with the external clock signal the program wait for the ASSR Register to be updated. TOIE0 bit in the TIMSK (Timer/Counter Interrupt Mask Register) is then set to enable Timer/Counter0 Overflow Interrupt. The Global Interrupt Enable bit in SREG (Status Register) also has to be set to enable all interrupts. SM1 and SM0 bit in MCUCR (MCU Control Register) are set to select Power-save mode. The SLEEP instruction will then place the controller. in sleep mode. A loop in the main program executes the SLEEP instruction.

"counter" Overflow Interrupt Routine

The interrupt routine is executed every time a Timer Overflow occurs. It wakes up the MCU to update the timer variables. An interrupt procedure cannot return or accept any variables. A global structure with timer variables are declared to keep track of time: "second", "minute", "hour", "date", "month" and "year". Since the time required to complete one Timer Overflow is known, "second" will be incremented by a fixed number every time. Once it reaches 60, "minute" is incremented by "1" and "second" is set to "0".

Figure 4. Flow Chart, CounterInterrupt Routine



“not_leap” Subroutine

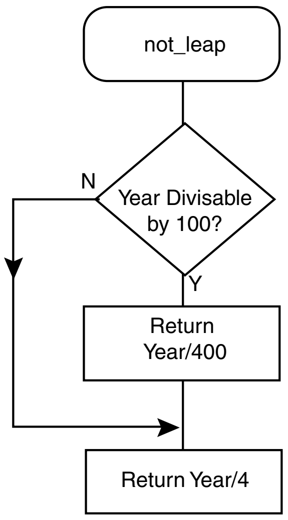
This routine checks whether or not it is a leap year. It returns true if the year is not leap and false for leap. It is considered a leap year if both of the following conditions are satisfied:

1. The year is divisible by 4, and
2. If the year is divisible by 100, it also has to be divisible by 400.

Accuracy

The RTC on the AVR controller maintains high accuracy as long as the watch crystal is accurate. Asynchronous operation allows the Timer to run without any delays even when the CPU is under heavy computation. However, a small neglible discrepancy does occur because the timer variables are not updated in parallel. By the time they are finished updating, they deviate from the Timer/Counter very slightly. The largest discrepancy occurs when all the timer variables are overflowed. At this moment, “second” is 59, “minute” is 59, “hour” is 23, and so on. It takes 94 cycles for the MCU to complete the update. At a 4 MHz CPU clock, the error between the RTC and the watch crystal will not exceed 23.5 µs found by $94/(4 * 10^6)$. A typical error should be 6 µs since 24 cycles are needed to update “second”. This error does not accumulate since the Timer is always synchronous with the watch crystal.

Figure 5. Flow Chart



Resources

Table 3. CPU and Memory Usage

Function	Code Size (Bytes)	Cycles	Example Register	Interrupt	Description
main	104	–	R16	Timer0 Overflow	Sets the necessary configuration
counter	356	–	R16, R17, R30, R31	–	Updates the variables
not_leap	48	10 (typical)	R16, R17, R20, R21	–	Checks for leap year
Total	508	–		–	

Table 4. Peripheral Usage

Peripheral	Description	Interrupts Enabled
TOSC1, TOSC2	connected to external crystal	–
Timer/counter0	real-time clock	Timer/counter0 overflow
8 I/O pins on port B	flashing LEDs (example only)	–

Code

```
/**** A V R  A P P L I C A T I O N  NOTE 1 3 4 **************************
*
* Title:      Real-Time Clock
* Version:    1.01
* Last Updated:    12.10.98
* Target:     ATmega103 (All AVR Devices with secondary external oscillator)
* Support E-mail: avr@atmel.com
*
* Description
* This application note shows how to implement a Real-Time Clock utilizing a
* secondary external oscilator. Included a test program that performs this
* function, which keeps track of time, date, month, and year with auto
* leap-year configuration. 8 LEDs are used to display the RTC. The 1st LED
* flashes every second, the next six represents the minute, and the 8th LED
* represents the hour.
*

****************************************************************************
**************/

#include <iom103.h>
#include <ina90.h>

char        not_leap(void);

type        def struct{
unsigned    char second;          //enter the current time, date, month, and
                                  //year
unsigned    char minute;
unsigned    char hour;
unsigned    char date;
unsigned    char month;
unsigned    int year;
             }time;

 time t;

void C_task main(void)            //C_task means "main" is never called from
                                  //another function
{
    int     temp0,temp1;

    for(temp0=0;temp0<0x0040;temp0++) // Wait for external clock crystal to
                                      //stabilize
    {
        for(temp1=0;temp1<0xFFFF;temp1++);
    }
    DDRB=0xFF;
    TIMSK &=~((1<<TOIE0)|(1<<OCIE0));//Disable TC0 interrupt
    ASSR |= (1<<AS0);             //set Timer/Counter0 to be asynchronous
                                  //from the CPU clock with a second external
                                  //clock(32,768kHz)driving it.
    TCNT0 = 0x00;
    TCCR0 = 0x05;                 //prescale the timer to be clock source /
128 to make it exactly 1 second for every overflow to occur
    while(ASSR&0x07);             //Wait until TC0 is updated
    TIMSK |= (1<<TOIE0);          //set 8-bit Timer/Counter0 Overflow
                                  //Interrupt Enable
    _SEI();                       //set the Global Interrupt Enable Bit

    while(1)
    {
        MCUCR = 0x38;             //entering sleeping mode: power save mode
        _SLEEP();                 //will wake up from time overflow interrupt
        _NOP();
        TCCR0=0x05;               // Write dummy value to Control register
        while(ASSR&0x07);         //Wait until TC0 is updated
    }
}

interrupt [TIMER0_OVF_vect] void counter(void)//Overflow interrupt vector
{

    if (++t.second==60)           //keep track of time, date, month, and year
    {
        t.second=0;
        if (++t.minute==60)
        {
            t.minute=0;
            if (++t.hour==24)
            {
                t.hour=0;
                if (++t.date==32)
                {
                    t.month++;
                    t.date=1;
                }
                else if (t.date==31)
                {
                    if ((t.month==4) || (t.month==6) || (t.month==9) ||
(t.month==11))
                    {
                        t.month++;
                        t.date=1;
                    }
                }
                else if (t.date==30)
                {
                    if(t.month==2)
                    {
                       t.month++;
                       t.date=1;
                    }
                }
                else if (t.date==29)
                {
                    if((t.month==2) && (not_leap()))
                    {
                        t.month++;
                        t.date=1;
                    }
                }
                if (t.month==13)
                {
                    t.month=1;
                    t.year++;
                }
            }
        }
    }
    PORTB=~(((t.second&0x01)|t.minute<<1)|t.hour<<7);


}

char not_leap(void)                 //check for leap year
{
    if (!(t.year%100))
        return (char)(t.year%400);
    else
        return (char)(t.year%4);
}
```

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