AVR205: Frequency Measurement Made Easy with Atmel tinyAVR and Atmel megaAVR

8-bit AVR® Microcontrollers

Application Note

Features

- **Frequency measurement from 10Hz to Timer_Clock_frequency/2.5**
- **Accurate measurement: Up to 99% or better, depending on the AVR® device clock source**
- **Two measurement methods: Busy wait (polled) and interrupt driven**

1 Introduction

Measuring cycles with a periodically varying signal per unit of time – frequency – is a fundamental activity in embedded electronics. This application note describes how to measure frequency of any type of waveform – sine, square, etc. – with a variable duty cycle. A basic requirement is for the signal to have an amplitude that is within the I/O pin threshold for the selected AVR device.

A second requirement for the example code presented here to work is that the selected AVR device have at least two timers, and that one of them can be used with an external clock source. One of these timers can be created by a software delay loop. The idea is to feed the signal to be measured into one timer's clock input, and then use the other timer as a time reference.

Figure 1-1. 1970s vintage frequency counter.

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2 Requirements to run the code

The code implemented as a part of this application note is based on Atmel® tinyAVR® and Atmel megaAVR® devices. For Atmel XMEGA® devices, please refer to application note AVR1617: Atmel XMEGA Uses the Event System.

As mentioned briefly above, two timers need to be available on the selected device, and one timer needs to be able to be clocked from an external source.

Figure 2-1. The AVR input clock scheme used as a synchronizer circuit.

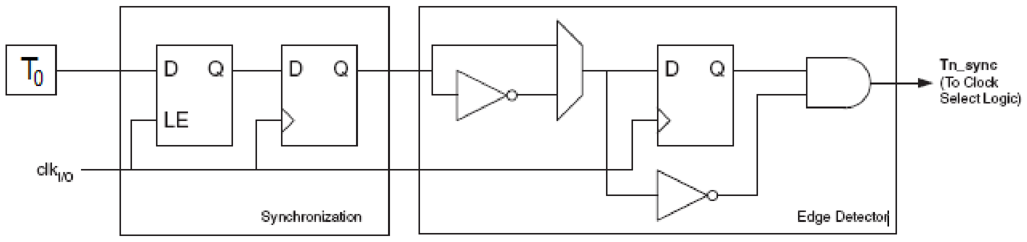


Figure 2-1 shows how the input signal is sampled. The maximum frequency of the external clock that can be detected is half the sampling frequency (Nyquist sampling theorem). However, due to variations in the system clock frequency and duty cycle caused by the selected clock source (crystal, resonator, and capacitor) tolerances, it is recommended that the maximum frequency of the external clock source be less than Timer_Clock_frequency/2.5. In this application note, the 8MHz RC oscillator frequency is fed to the timer/counter clock. Therefore, in this particular example, the recommended maximum frequency to be measured is less than 3.2MHz.

Symmetrical input signals (50% duty cycle) may be measured up to 3.2MHz, as described above. For non-symmetrical input signals, the high or low periods of the input must be greater than one timer clock pulse width, or the synchronization circuit shown above may miss an input pulse and cause inaccuracies in the frequency being measured.

For example, if an 8MHz clock is used to run the timer, the clock high and low periods add up to 125ns. Therefore, the input high or low pulse width must be greater than 125ns.

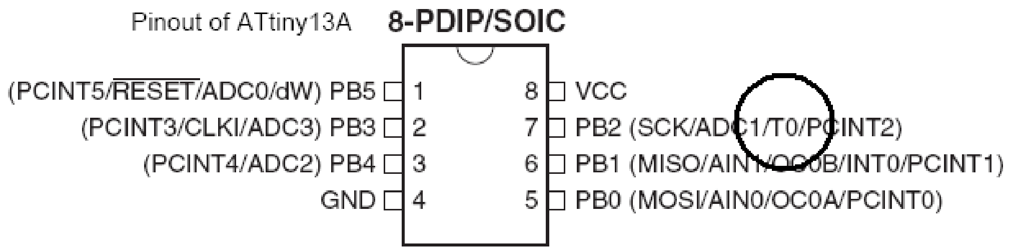
See the tinyAVR or megaAVR datasheets for more details on this sampled input technique.

2.1 List of Atmel AVR devices with external input for timer/counter clock

A simple way to determine if an external input can be used to clock a timer/counter is to observe the Atmel AVR device's pinout diagram and look for the pin designation, T0. See Figure 2-2 for an example.

A non-inclusive list of Atmel AVR devices with this feature includes: Atmel ATtiny10, ATtiny13, ATtiny20, ATtiny26, ATtiny28, ATtiny2313, ATmega48/88/168, ATmega8, ATmega16, ATmega32, ATmega8515/8535, ATmega162, ATmega164/324/644/1284, and ATmega165/325/3250/645/6450.

Figure 2-2. Atmel ATtiny13A pinout.

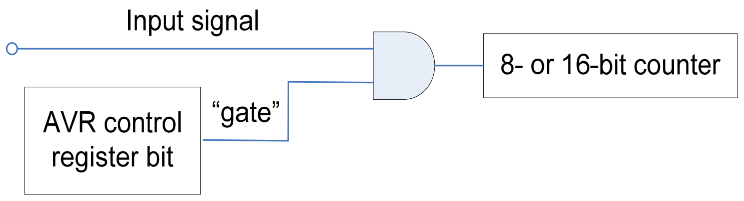

Pinout of ATtiny13A
8-PDIP/SOIC
(PCINT5/RESET/ADC0/dW) PB5 1
(PCINT3/CLKI/ADC3) PB3 2
(PCINT4/ADC2) PB4 3
GND 4
8 VCC
7 PB2 (SCK/ADC1/T0/PCINT2)
6 PB1 (MISO/AIN1/OC0B/INT0/PCINT1)
5 PB0 (MOSI/AIN0/OC0A/PCINT0)

3 Measurement principle

In this application note, the “gate-open” interval was chosen to be 0.1s, or 100ms, and so the signal to be measured will clock a counter for this time interval, and produce a frequency count result in 100ms. The resultant frequency measurement will be one-tenth the actual frequency.

This was also chosen to take advantage of the timer/counter’s 16-bit resolution; in this case, measuring frequencies from 500Hz to 5000Hz. If a frequency of 500kHz is to be measured, a gate time of 1ms would result in good use of the 16-bit timer/counter’s range.

Figure 3-1. Schematic indicating the logical gating.



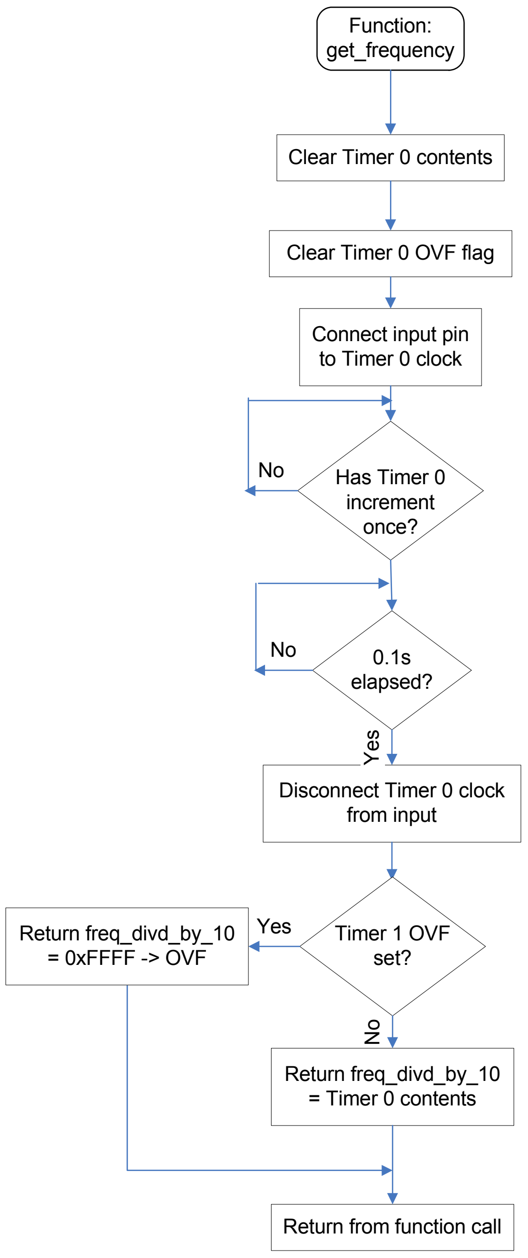
4 Two techniques: Busy wait and interrupt driven

4.1 Busy wait loop

A busy wait loop is a loop that repeatedly checks to see if an event occurs. Some applications can wait the 0.1s (100ms) for the loop to cycle, and do not require interrupts to be used.

Figure 4-1 is the flowchart for the main part of the program. Figure 4-2 is the flowchart for the C function call that actually measures the incoming signal's frequency and returns it to the main (calling) program.

Figure 4-1. Main flowchart.



Function: get_frequency
Clear Timer 0 contents
Clear Timer 0 OVF flag
Connect input pin to Timer 0 clock
No
Has Timer 0 increment once?
No
0.1s elapsed?
Yes
Disconnect Timer 0 clock from input
Return freq_divd_by_10 = 0xFFFF -> OVF
Yes
Timer 1 OVF set?
No
Return freq_divd_by_10 = Timer 0 contents
Return from function call

Power-on reset could also be an active-low signal applied to the AVR device's Reset pin.

The user's variables would also be initialized here.

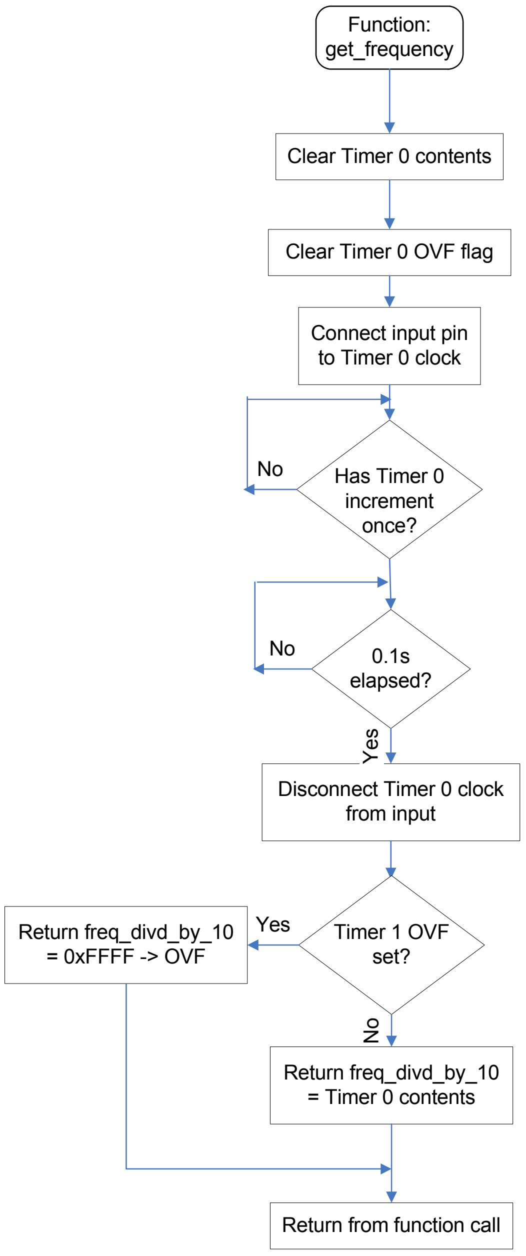
Timer contents are cleared.

User code executes at this point, and when there is a need for frequency measurement, the function call is accessed.

The function call is initiated at this point.

Results from the function call are returned via a 16-bit, non-zero number. If a 0xFFFF (65535 decimal) is returned, this indicates a timer overflow. The result is a non-valid frequency. This could occur if a too-high frequency was applied to the AVR device's input pin.

Figure 4-2. Function flowchart.



Function: get_frequency
Clear Timer 0 contents
Clear Timer 0 OVF flag
Connect input pin to Timer 0 clock
No
Has Timer 0 increment once?
No
0.1s elapsed?
Yes
Disconnect Timer 0 clock from input
Return freq_divd_by_10 = 0xFFFF -> OVF
Yes
Timer 1 OVF set?
No
Return freq_divd_by_10 = Timer 0 contents
Return from function call

The function entry point.

Clear both timers.

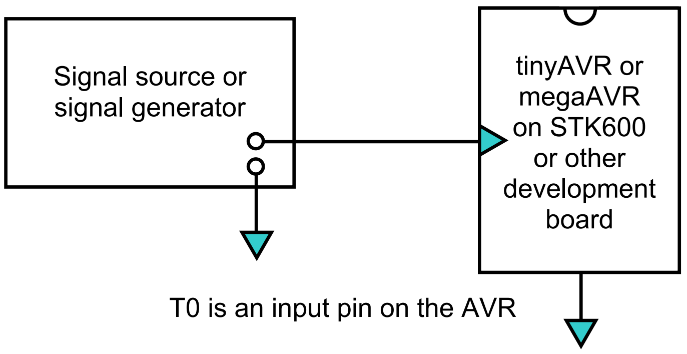
Start Timer 0 counting.

If Timer 0 has clocked once, start the 0.1s (100ms) gate counter.

When 100ms has elapsed, disconnect Timer 0 from the input signal.

Did timer overflow? If so, return a value of 0xFFFF; otherwise, return the actual 16-bit count value.

Figure 4-3. Block diagram.


Signal source or signal generator
tinyAVR or megaAVR on STK600 or other development board
T0 is an input pin on the AVR

4.1.1 How to run the project using busy wait

Atmel AVR Studio 4.18 was used to develop this code. Later versions may or may not compile the code correctly. WinAVR C compiler version 20100110 was also used. Later versions may or may not compile the code correctly. It is available from http://sourceforge.net/projects/winavr/files/.

- Refer to Figure 4-1. Connect the signal source to the AVR input pin T0
- Using AVR Studio 4, open the project, `freq_meter_busy_wait_demo.apx`
- Build the project
- Using JTAGICE mkII, start the debugging session with AVR Studio, and set a breakpoint at the C instruction `delay100ms(2);`
- Run the project, and when the breakpoint is reached, the frequency count result will be in the C variable `freq_div_by_10`
- The resulting value will be one-tenth of the actual frequency because the AVR timer counts for 100ms. If the frequency exceeds the algorithm capability, the result returned will be 0xffff, indicating overflow

4.1.2 How to build the project using busy wait

Prerequisite: knowledge of how to build, compile, and debug an AVR Studio 4 project.

- Three files will be necessary to build this project. In this example they are:
    - `avr205_frequency_meter_busy_wait_demo.c`, where the main() function is located
    - `freq_meter.c`, where the functions are located
    - `freq_meter.h`, where the specifics such as port and register names are specified, including the CPU clock speed, in this case 8,000,000Hz
- Specify which AVR, such as ATtiny861 or ATmega48

4.1.3 How to call and use these functions, using busy wait

In `freq_meter_demo.c`

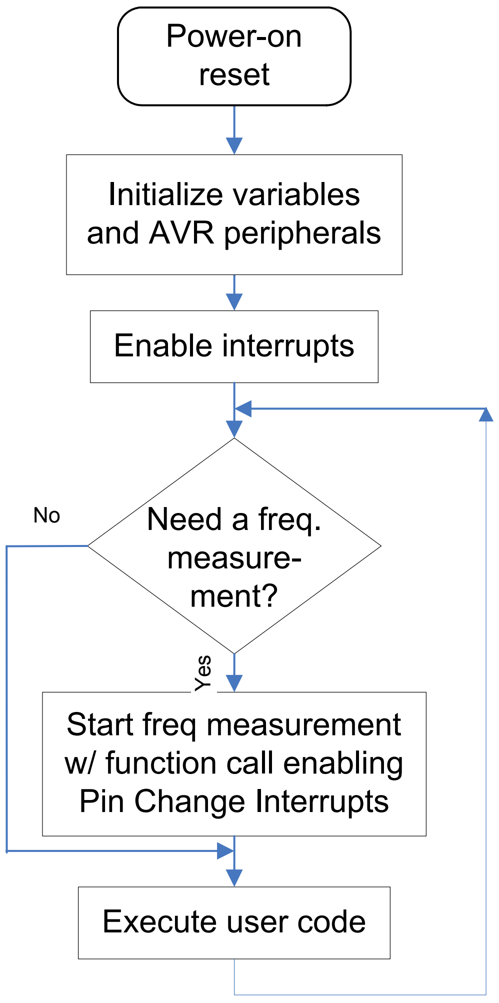
- The function `freq_meter_init();` initializes relevant registers of the AVR
- The function `user_init();` initializes user variables
- AVR interrupts are not used in this demo

- A call to `freq_cntr_get_frequency();` sets up pin change interrupts on T0 to enable frequency measurement to begin on a pin change of T0. Inside this function is the call to `delay100ms(1);`
- The busy wait technique is realized by the function call `delay100ms(1);`
- `delay100ms(2)` simulates the user's code before the function `freq_cntr_get_frequency();` is called again

4.2 Interrupt driven

When the busy wait approach is not acceptable, an implementation that uses interrupts may be used. Instead of waiting synchronously for the period timer to complete, it can simply interrupt and stop the gate counter. See the illustrations below for details.

Figure 4-4. Main loop.


Power-on reset
Initialize variables and AVR peripherals
Enable interrupts
Need a freq. measure-ment?
No
Yes
Start freq measurement w/ function call enabling Pin Change Interrupts
Execute user code

Power-on reset could also be an active-low signal applied to the AVR device's Reset pin.

The user's variables would also be initialized here.

User enables interrupts at the appropriate time in the application.

This point is only a suggestion.

Does user's code need a frequency measurement now?

If so, enable pin change interrupts.

See the following flowchart for the AVR device's response to the first pin change interrupt.

If no frequency measurement is needed at this time, continue with user's code.

4.2.1 How to run freq_meter_interrupt_demo

Atmel AVR Studio 4.18 was used to develop this code. Later versions may or may not compile the code correctly. WinAVR C compiler version 20100110 was also used. Later versions may or may not compile the code correctly. It is available separately from http://sourceforge.net/projects/winavr/files/.

- Refer to Figure 4-1. Connect the signal source to the AVR input pin T0
- Using AVR Studio 4, open the project, `frequency_meter_interrupt_demo.apx`
- Build the project
- Using JTAGICE mkII, start the debugging session with AVR Studio, and set a breakpoint at the C instruction `freq_cntr_clear_result();`
- Run the project, and when the breakpoint is reached, the frequency count result will be in the C variable `freq_cntr_result`
- The resulting value will be one-tenth of the actual frequency because the gate is 100ms. If the frequency exceeds the algorithm capability, the result returned will be 0xffff, indicating overflow

4.2.2 How to build the project using interrupts

Prerequisite: knowledge of how to build, compile and debug an AVR Studio 4 project.

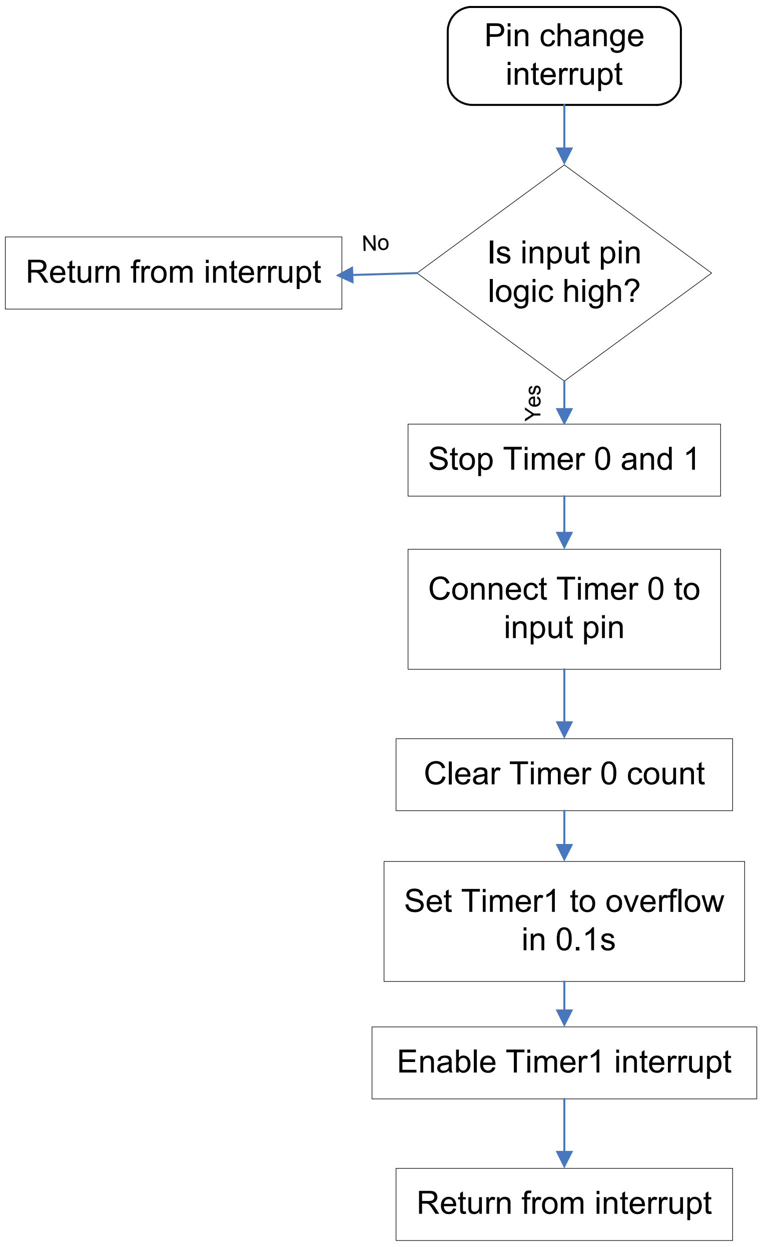
- Three files will be necessary to build this project. In this example they are:
  - `avr205_frequency meter_busy_wait.c`, where the main() function is located
  - `freq_meter.c`, where the functions are located
  - `freq_meter.h`, where the specifics such as port and register names are specified, including the CPU clock speed, in this case 8,000,000Hz
- Specify which AVR, such as ATtiny861 or ATmega48

4.2.3 How to call and use these functions, using interrupts

In `freq_meter_demo.c`

- The function `freq_meter_init();` initializes relevant registers of the AVR
- The function `user_init();` initializes user variables
- AVR interrupts are enabled by the user
- A call to `freq_cntr_start_measurement();` sets up pin change interrupts on T0 to enable frequency measurement to begin on a pin change of T0
- A call to `freq_cntr_get_result();` returns either 0x00, if the frequency measurement is not yet ready, or a hex number less than 0xffff as the resultant frequency. An error is reported via a result of 0xffff
- A call to `freq_cntr_clear_result();` clears the result returned above to prepare for the next frequency measurement

Figure 4-5. Pin change interrupt response.



This is the pin change interrupt response code.

Is the input signal pin a logic high? If not, return from the pin change interrupt.

A positive-going edge has been detected. Stop both timers.

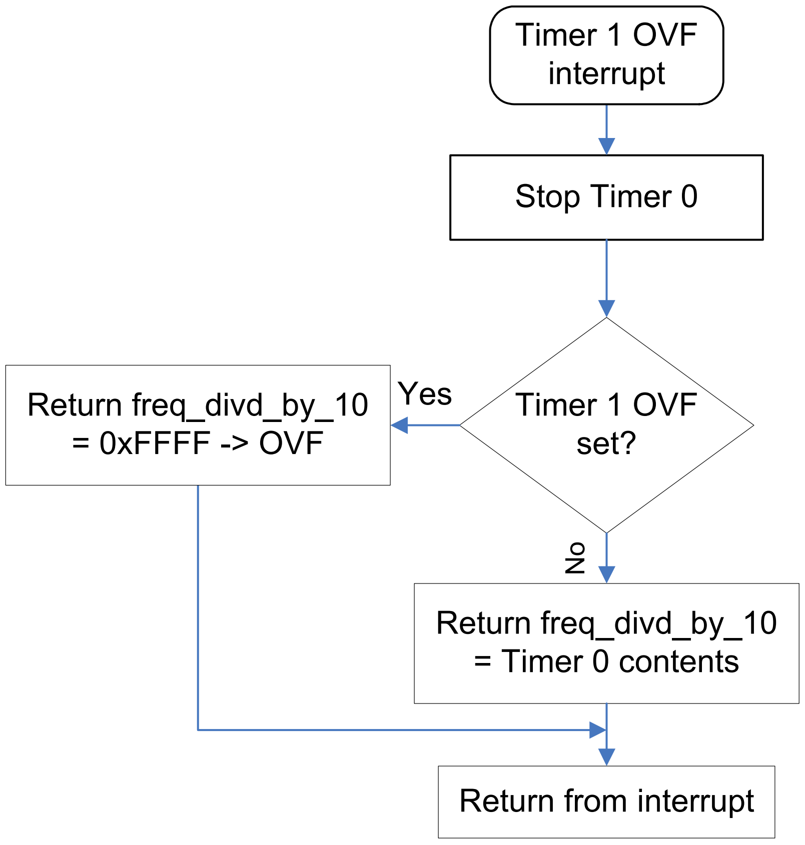
Using a register access instruction, enable the external signal to be routed to the Timer 0 clock pin.

Clearing Timer 0 assures the best possible accuracy.

Timer 1 controls the 100ms gate period and is loaded with its starting value to count up to overflow, OVF.

This allows for the code in Figure 4-5 to be entered and executed.

Figure 4-6. Timer 1 overflow interrupt code.



Timer 1 OVF interrupt
Stop Timer 0
Timer 1 OVF set?
Yes
Return freq_divd_by_10 = 0xFFFF -> OVF
No
Return freq_divd_by_10 = Timer 0 contents
Return from interrupt

Power-on reset could also be an active-low signal applied to the AVR device's Reset pin.

The user's variables would also be initialized here.

Timer contents are cleared.

User code executes at this point, and when there is a need for frequency measurement, the function call is accessed.

5 A word about input capture (not used in this application note)

Many AVR devices contain timers that offer “input capture,” which uses a set of 8-bit latches. When clocked, these latches save the instantaneous contents of the timer. Input capture is an advanced feature which is not available with simpler AVR devices, such as the Atmel ATtiny13.

Input capture registers are clocked by an input pin. But for frequency measurements, this action would need to be triggered by an output pin, and so this technique requires the use of two I/O pins, which often are not available on devices with a smaller pin count.

An Atmel XMEGA implementation of a frequency counter could use the event system to trigger an input capture.

6 Conclusion

Most Atmel tinyAVR and Atmel megaAVR devices have the capability to clock a timer/counter by an external signal. This feature allows the internal counter to be clocked as fast as 2.5MHz or higher (a function of AVR device's main clock frequency).

If a timing gate of 100ms is used as a counting period, then the counter will have the value of one-tenth the input signal frequency.

This technique can be done with or without interrupts. Both of these techniques are demonstrated here.

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