Questions?

Timing of Events

Suppose that we want produce a pulse on a digital line that was exactly 500 ms in length?

- What would the code look like?

Timing of Events

```
// Assume it is pin 0 of port B

PORTB = PORTB | 1;
delay_ms(500);
PORTB = PORTB & ~1;
```

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Timing of Events

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`delay_ms()` is implemented by using a for() loop

- The microcontroller can't do anything else while it is looping
- Have to loop a precise number of times (not always easy to do)

Timing of Events: Another Example

Suppose we would want to measure the width of a pulse. How would we implement this?

Timing of Events: Another Example

How would we implement this?

```
// Wait for pin to go high
while(PINB & 0x1 == 0){};

// Now count until it goes low
for(counter = 0; PINB & 0x1; ++counter)
{
  delay_ms(1);
}
// Now: counter is the width of
//   of the pulse in ms
```

Timing of Events: Another Example

Again: the program cannot be doing anything else while it is waiting

Counter/Timers in the Mega2560

The mega2560 includes six counter/timer devices in hardware.

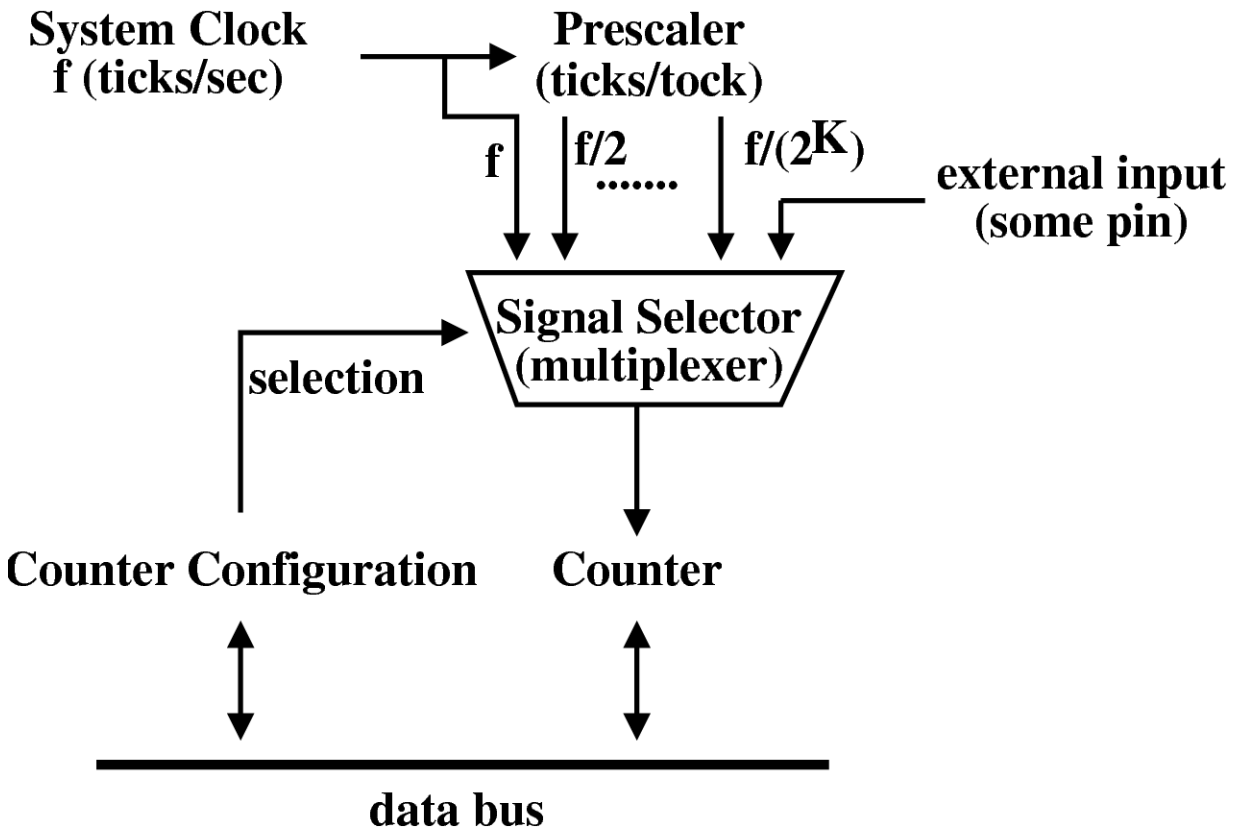
These can:

- Be used to count the number of events that have occurred (either external or internal)
- Act as a clock

Timer 0

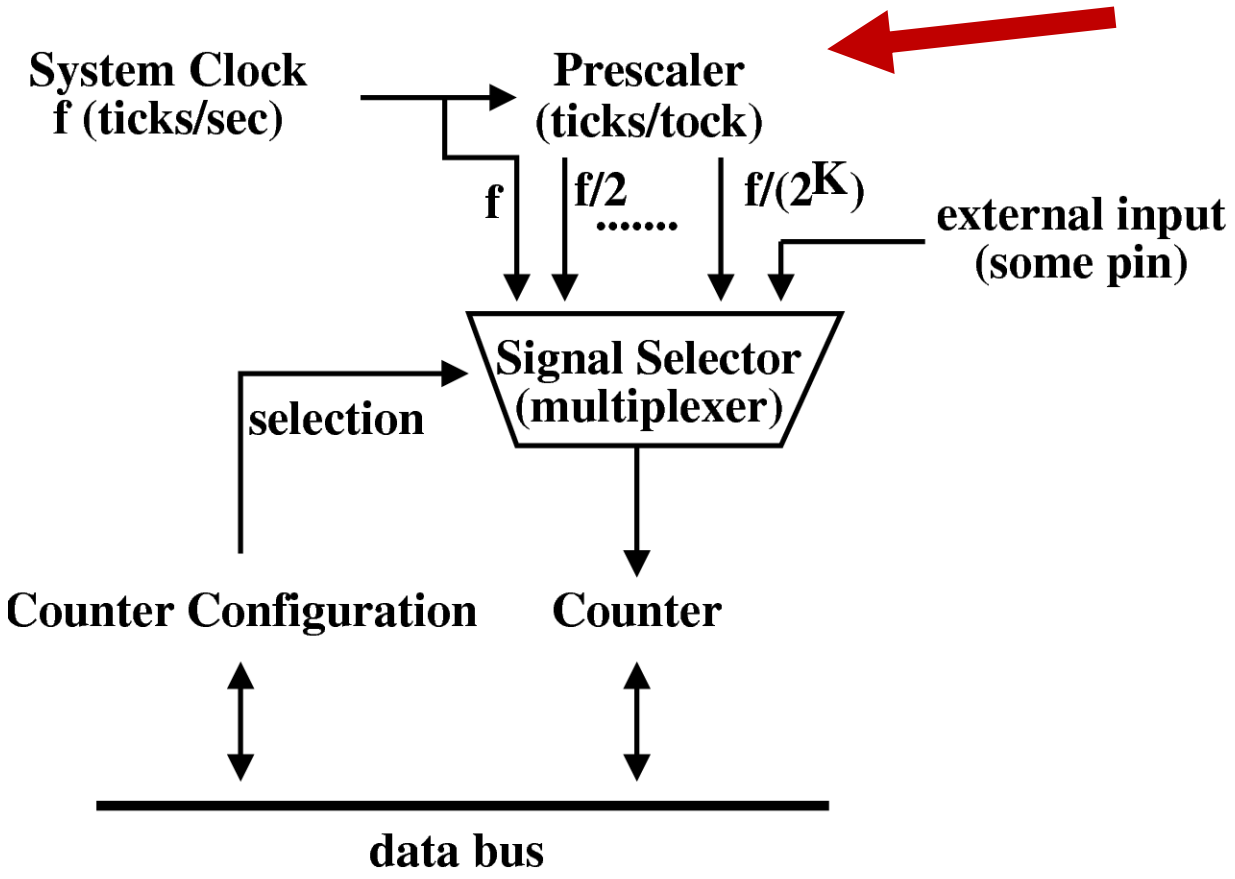
- Two possible input sources:
  - Pin T0 (PD4)
  - System clock
    - Potentially divided by a “prescaler”
- 8-bit counter
- When the counter turns over from 0xFF to 0x0, an interrupt (an event) can be generated (more on this later)

Generic Timer Implementation



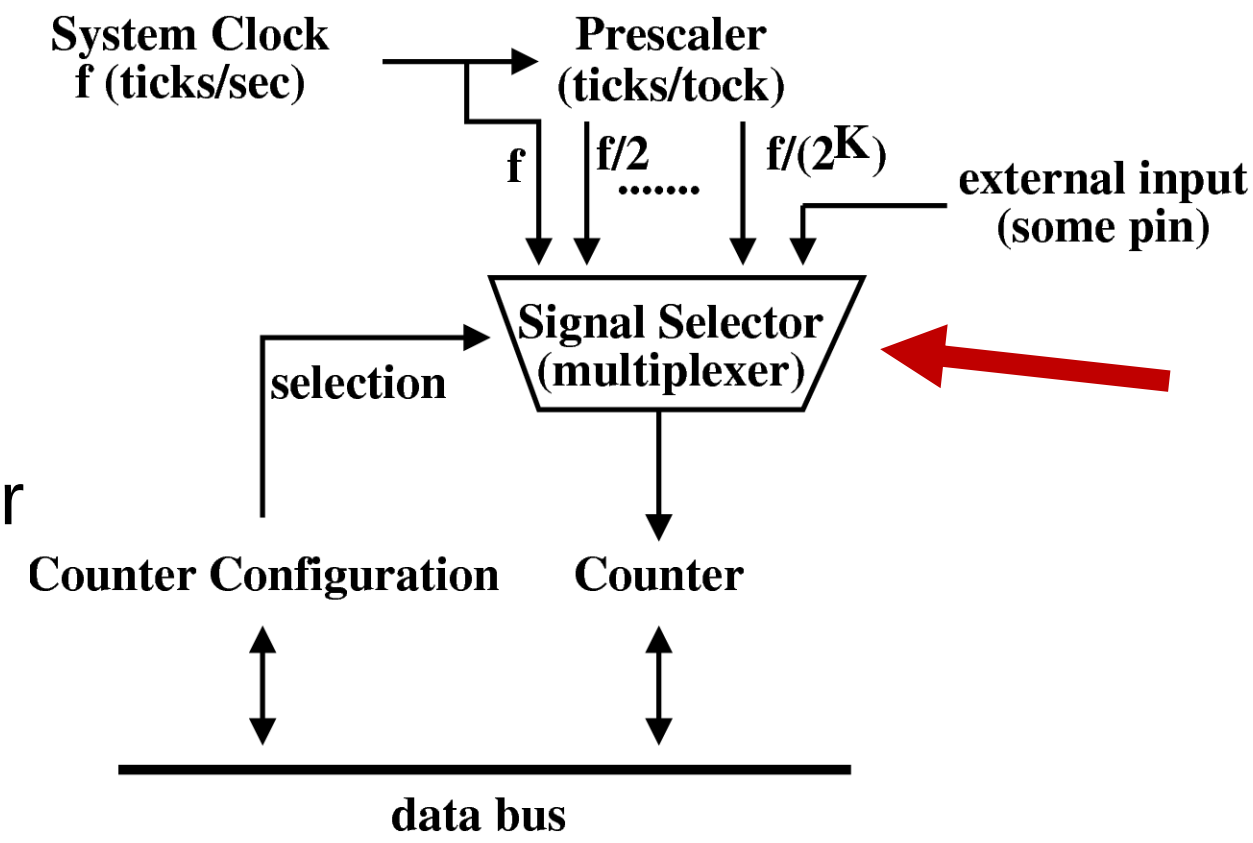
Generic Timer Implementation

- **Prescaler**: divides clock frequency



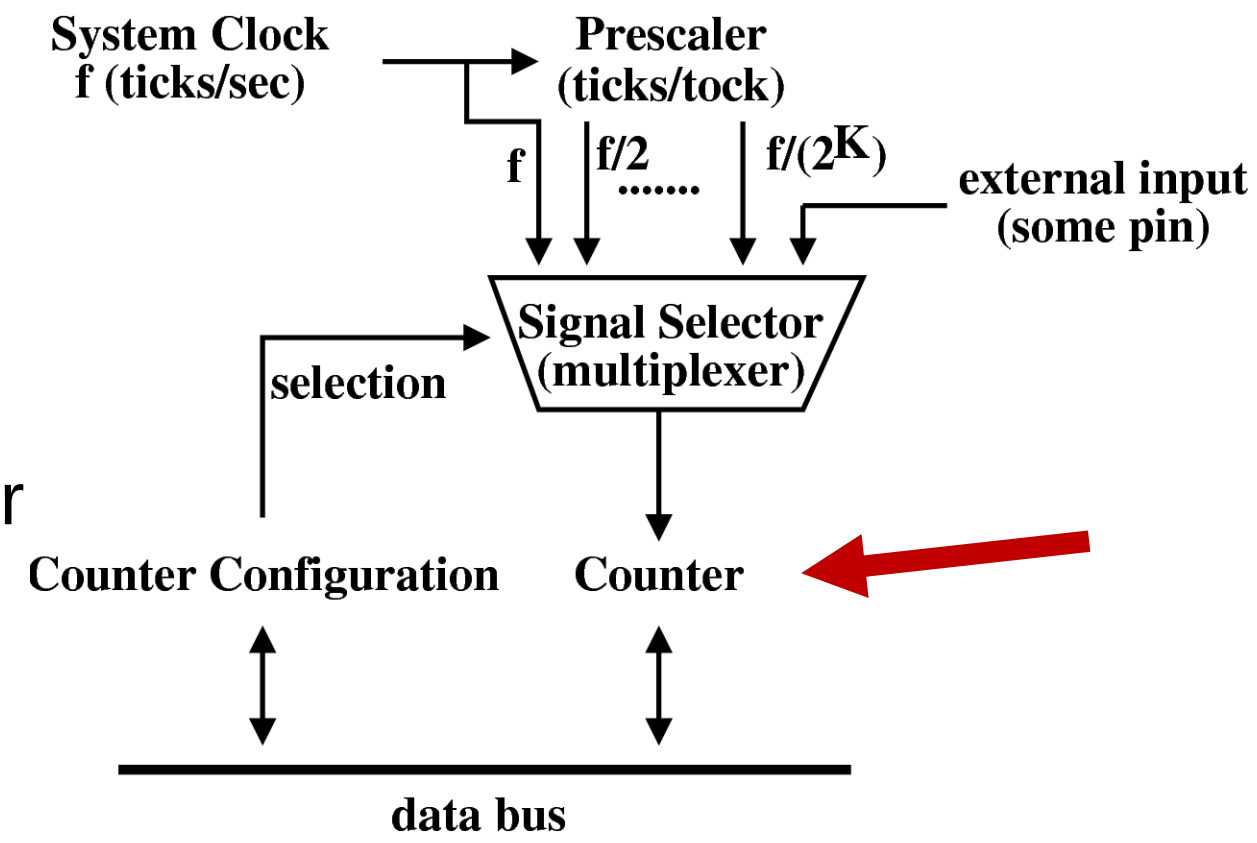
Generic Timer Implementation

- **Prescaler**: divides clock frequency
- **Multiplexer**: selects one of the inputs to drive the counter



Generic Timer Implementation

- **Prescaler**: divides clock frequency
- **Multiplexer**: selects one of the inputs to drive the counter
- **Counter**: increment on low-to-high transition of its input



Timer 0 (and Timer 1)

Possible prescalers:

- 8
- 64
- 256
- 1024

Timing Example

Suppose:

- f=16MHz clock
- Prescaler of 1024
- We wait for the timer to count from 0 to 156

How long does this take?

Timer 0 Example

$$delay = \frac{1024 * 156}{16,000,000} = 9948 \ \mu s \approx 10 \ ms$$

Timer 0 Code Example

```
timer0_config(TIMER0_PRE_1024);   // Init: Prescale by 1024

timer0_set(0);       // Set the counter to 0

<Do something else for a while>
while(timer0_read() < 156) {
    <Do something while waiting>
};

// Break out of while loop after ~10 ms
```

See Atmel HOWTO for example code (timer_demo2.c)

Timer 0 Example

Advantage over delay_ms():

- Can do other things while waiting
- Timing is much more precise
  - We no longer rely on a specific number of instructions to be executed

Timer 0 Example

One caution:

- “something else” cannot take very much time

(we have a solution for this – coming soon!)

Next Example

How do we time a delay of 100 usecs?

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$$counts * prescale = .0001 * clock\_freq$$

$$= .0001 * 16000000$$

$$= 1600$$

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$$counts * prescale = .0001 * clock\_freq$$

$$= .0001 * 16000000$$

$$= 1600$$

$$200 * 8 = 1600$$

OR

$$25 * 64 = 1600$$

Timer 0 Code Example

```
timer0_config(TIMER0_PRE_8);   // Init: Prescale by 8

timer0_set(0);       // Set the timer to 0

<Do something else for a while>
while(timer0_read() < 200) {
    <Do something while waiting>
};

// Break out of while loop after ~100 us
```

:

Now we come to ticks and tocks, sir.
Try to say this Mr. Knox, sir....

Clocks on fox tick.
Clocks on Knox tock.
Six sick bricks tick.
Six sick chicks tock.

Please, sir. I don't like this trick, sir.
My tongue isn't quick or slick, sir.
I get all those ticks and clocks, sir,
mixed up with the chicks and tocks, sir.
I can't do it, Mr. Fox, sir.

:

Dr. Seuss

Example 3: Timing the Width of a Pulse

- Input: port B, pin 1
- How long is the pin high?

Timing a Pulse Width: Our Original Implementation

```
// Wait for pin to go high
while(PINB & 0x1 == 0){};

// Now count until it goes low
for(counter = 0; PINB & 0x1; ++counter)
{
  delay_ms(1);
}
// Now: counter is the width of
//   of the pulse in ms
```

Example: Timing a Pulse Width

```
// Init: Prescale by 1024
timer0_config(TIMER0_PRE_1024);

// Wait for pin to go high
while(PINB & 0x1 == 0){
   <Do something while waiting>
};
timer0_set(0);        // Set the timer to 0

while((PINB & 0x1) != 0) {
   <Do something while waiting>
};
pulse_width = timer0_read();
```

Example: Timing a Pulse Width

What is the “resolution” of pulse_width?

Example: Timing a Pulse Width

What is the “resolution” of pulse_width?

- Each “tock” is:

$$delay = \frac{1024}{16,000,000} = 64 \ \mu s$$

Example: Timing a Pulse Width

So, with pulse_width tocks:

$$delay = \frac{1024 * pulse\_width}{16,000,000} = 64 * pulse\_width \ \mu s$$

Example: Timing a Pulse Width

```
// Init: Prescale by 1024
timer0_config(TIMER0_PRE_1024);

// Wait for pin to go high
while(PINB & 0x2 == 0){
   <Do something while waiting>
};
timer0_set(0);          // Set the timer to 0

while((PINB & 0x2) != 0) {
   <Do something while waiting>
};
pulse_width = read_timer0();
```

Note: the longer "something" takes, the larger the possible error in timing

Other Timers Besides Timer 0

Timers 1, 3, 4, 5:

- 16 bit counter
- Prescalers: 1, 8, 64, 256, 1024

Timer 2:

- 8 bit counter
- Prescalers: 1, 8, 32, 64, 128, 256, 1024

Note

See oulib documentation for the list of possible prescalers for the timers

Pulse-Width Modulation in Hardware

- The Atmel Mega processors will perform a wide-range of timing functions in hardware
- This includes the generation of pulse-width modulated signals
- Once configured, your main program need only to set the duty cycle of the PWM signal

Pulse-Width Modulation in Hardware

- Configuration includes:
  - Signal frequency (through the prescalers)
  - Signal polarity (high then low or vice-versa)
  - Resolution for specifying the duty cycle
- Once configured:
  - You need only specify changes to the duty cycle

PWM on the Atmel Mega2560s

Timers 1, 3, 4, 5: each have 3 PWM output channels associated with them (known as A, B, and C)

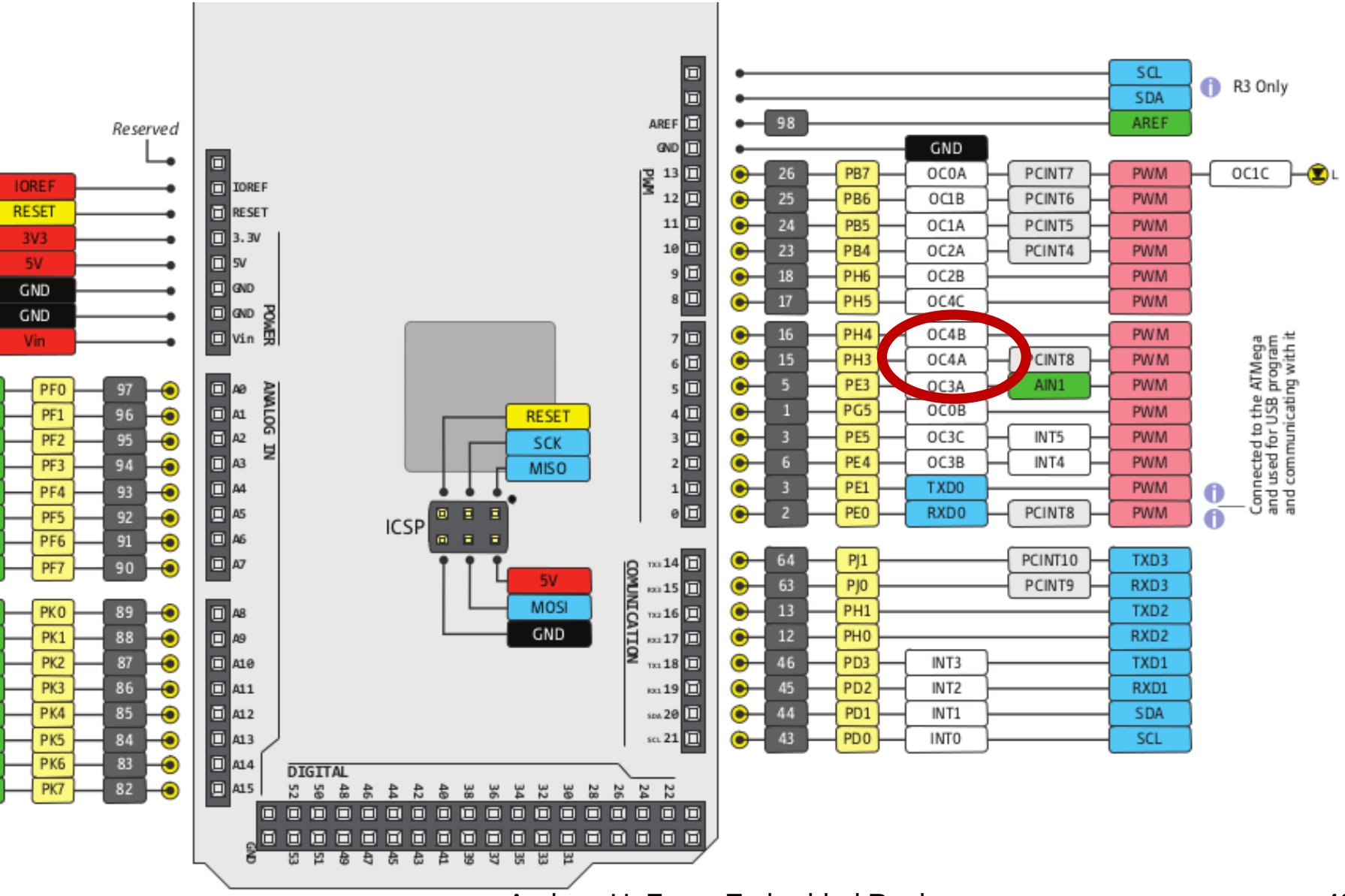
For our example here:

- Use 10 bits of the 16 available with the counter
- Counter counts from 0 to 1023, and then back to 0
- Output goes high at 0
- Output goes low at specified count
  - Specified by the “output compare” register

Example

For our example, we will use:

- Timer 4, channel A
  - I/O Port H, pin 3
- 10-bit resolution
- Prescaler of 8


Reserved
IOREF
RESET
3V3
5V
GND
GND
Vin
PF0 97
PF1 96
PF2 95
PF3 94
PF4 93
PF5 92
PF6 91
PF7 90
PK0 89
PK1 88
PK2 87
PK3 86
PK4 85
PK5 84
PK6 83
PK7 82
POWER
ANALOG IN
A0 A1 A2 A3 A4 A5 A6 A7
A8 A9 A10 A11 A12 A13 A14 A15
ICSP
RESET
SCK
MISO
5V
MOSI
GND
PWM
AREF
GND
13 12 11 10 9 8
7 6 5 4 3 2 1 0
COMUNICATION
TX3 14
RX3 15
TX2 16
RX2 17
TX1 18
RX1 19
SDA 20
SCL 21
DIGITAL
52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22
GND
53 51 49 47 45 43 41 39 37 35 33 31
SCL
SDA
AREF
R3 Only
98
GND
26 PB7 OC0A PCINT7 PWM
25 PB6 OC1B PCINT6 PWM
24 PB5 OC1A PCINT5 PWM
23 PB4 OC2A PCINT4 PWM
18 PH6 OC2B PWM
17 PH5 OC4C PWM
OC1C
L
16 PH4 OC4B PWM
15 PH3 OC4A PCINT8 PWM
5 PE3 OC3A AIN1 PWM
1 PG5 OC0B PWM
3 PE5 OC3C INT5 PWM
6 PE4 OC3B INT4 PWM
3 PE1 TXD0 PWM
2 PE0 RXD0 PCINT8 PWM
Connected to the ATMega and used for USB program and communicating with it
64 PJ1 PCINT10 TXD3
63 PJ0 PCINT9 RXD3
13 PH1 TXD2
12 PH0 RXD2
46 PD3 INT3 TXD1
45 PD2 INT2 RXD1
44 PD1 INT1 SDA
43 PD0 INT0 SCL

Initialization Example (Timer 4)

```
int main(void){
   // The timer 4 channel A pin is labeled “OC4A” on the Arduino
   //   circuit diagram
   DDRH = 0x8;

   // tocks/sec = 2,000,000/sec (with a 16,000,000 ticks/sec clock)
   timer4_config(TIMER4_PRE_8);

   // Configure for 10-bit PWM
   timer4_output_compare_config(TIMER4_OUTPUT_COMPARE_CONFIG_PWM_F_10);

   // Configure timer 4, channel A for PWM: high then low
   timer4_compare_output_A_mode_set(TIMER16B_COMPARE_OUTPUT_MODE_CLEAR);
   :
   :
```

Use Example

```
:
:
int16_t i;

 // Loop forever
while(1) {

     // Slowly increase the duty cycle on channel A
     for(i=0; i < 1024; ++i) {
            timer4_output_compare_A_set(i);
            delay_ms(1);
     };

     // Slowly bring the duty cycle back to zero
     for(i=1023; i > 0; --i) {
            timer4_output_compare_A_set(i);
            delay_ms(1);
     };
};
```

See examples_2560/pwm for more details (Atmel HOWTO)

More on timers soon (with interrupts!)