

# TIME MACHINES

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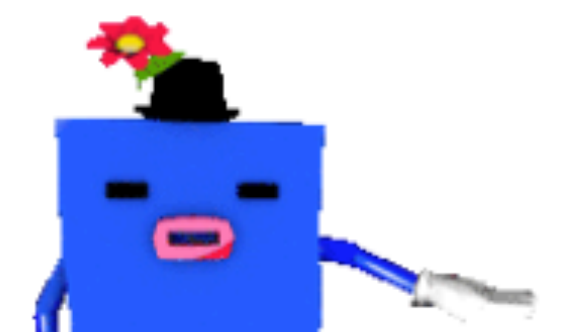
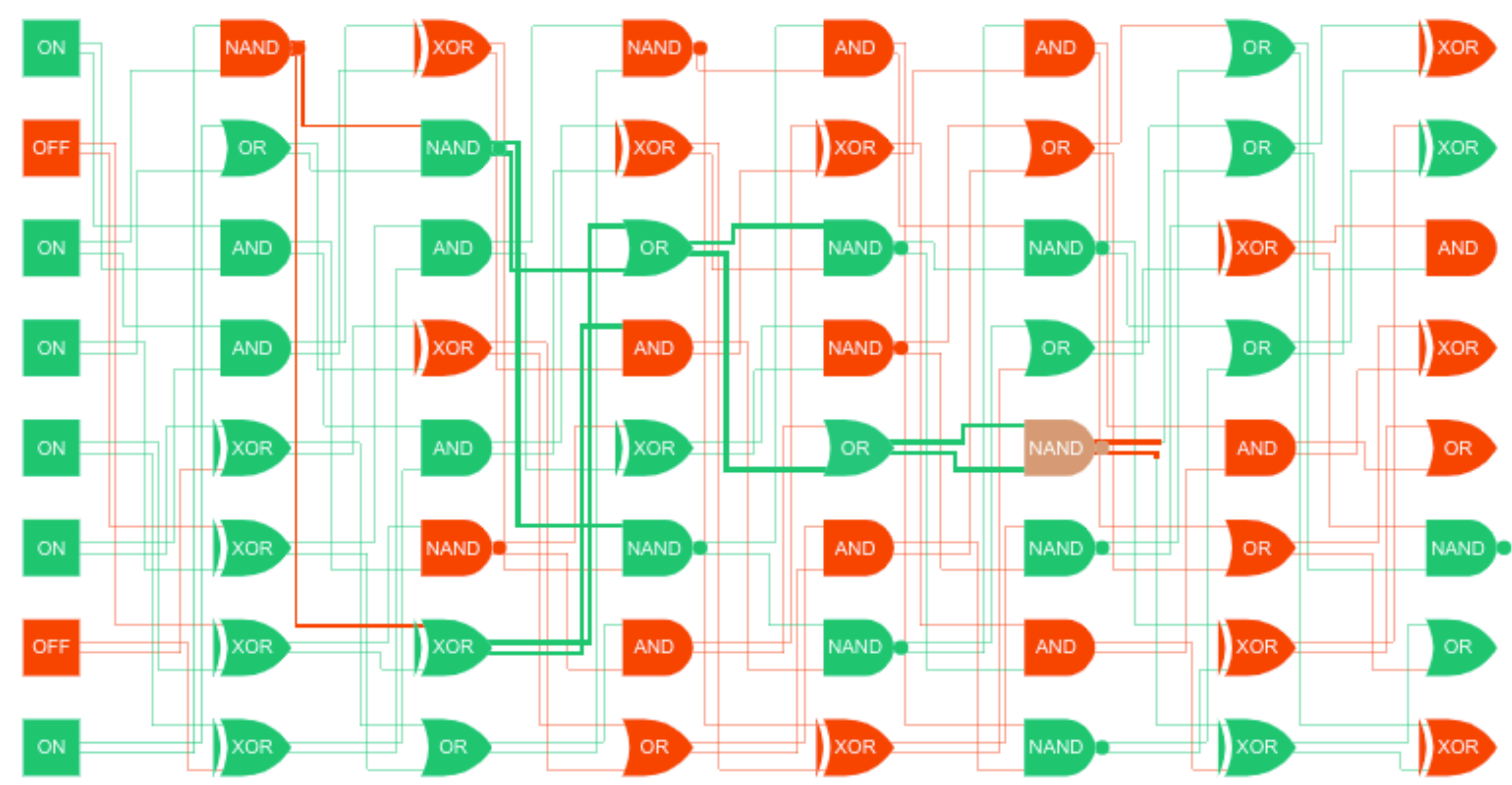
**HOT TUB  
TIME MACHINE**

# TIM

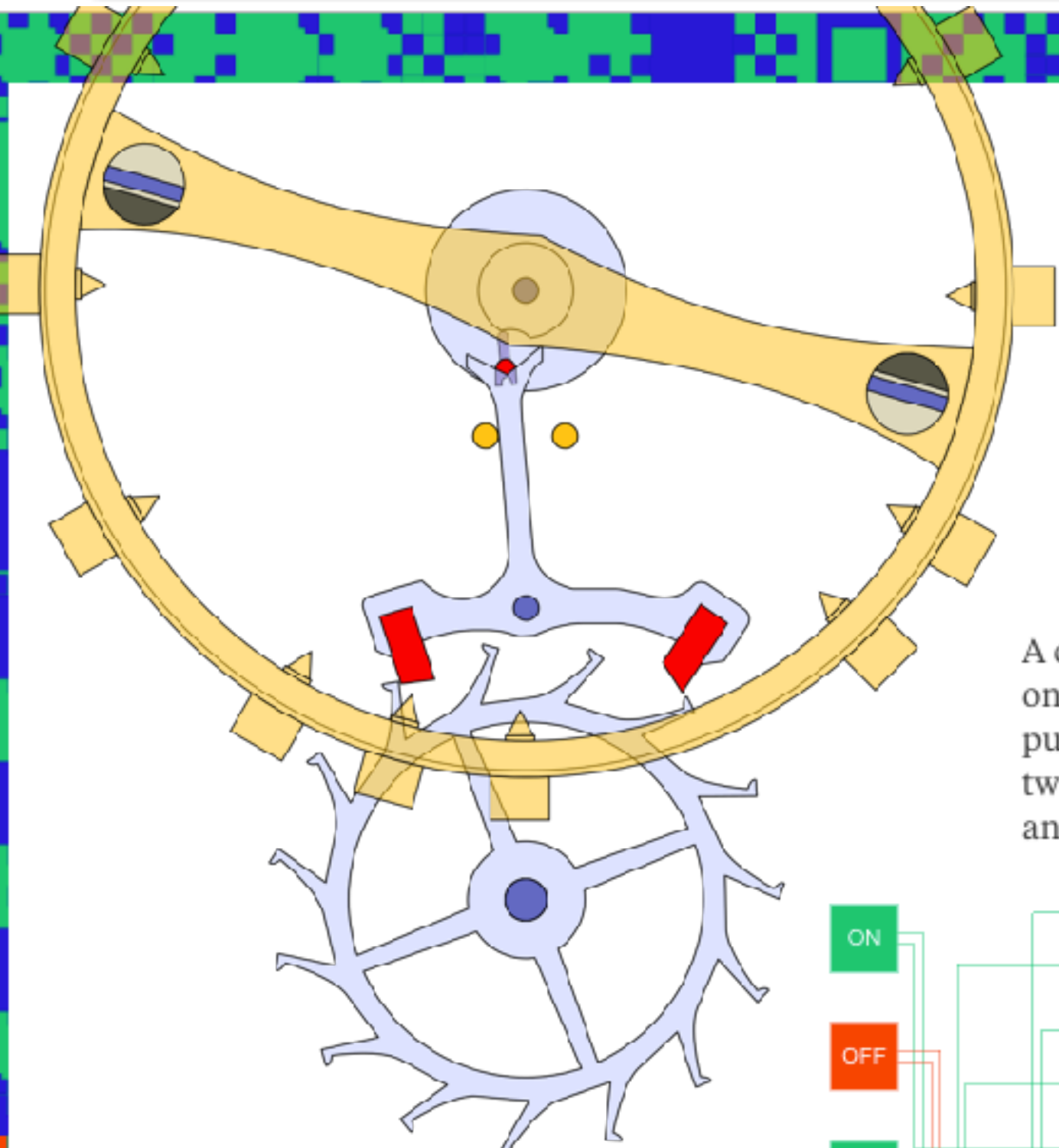


# Let's Begin

A computer is a clock with benefits. They all work the same, doing second-grade math, one step at a time: Tick, take a number and put it in box one. Tick, take another number, put it in box two. Tick, *operate* (an operation might be addition or subtraction) on those two numbers and put the resulting number in box one. Tick, check if the result is zero, and if it is, go to some other box and follow a new set of instructions.



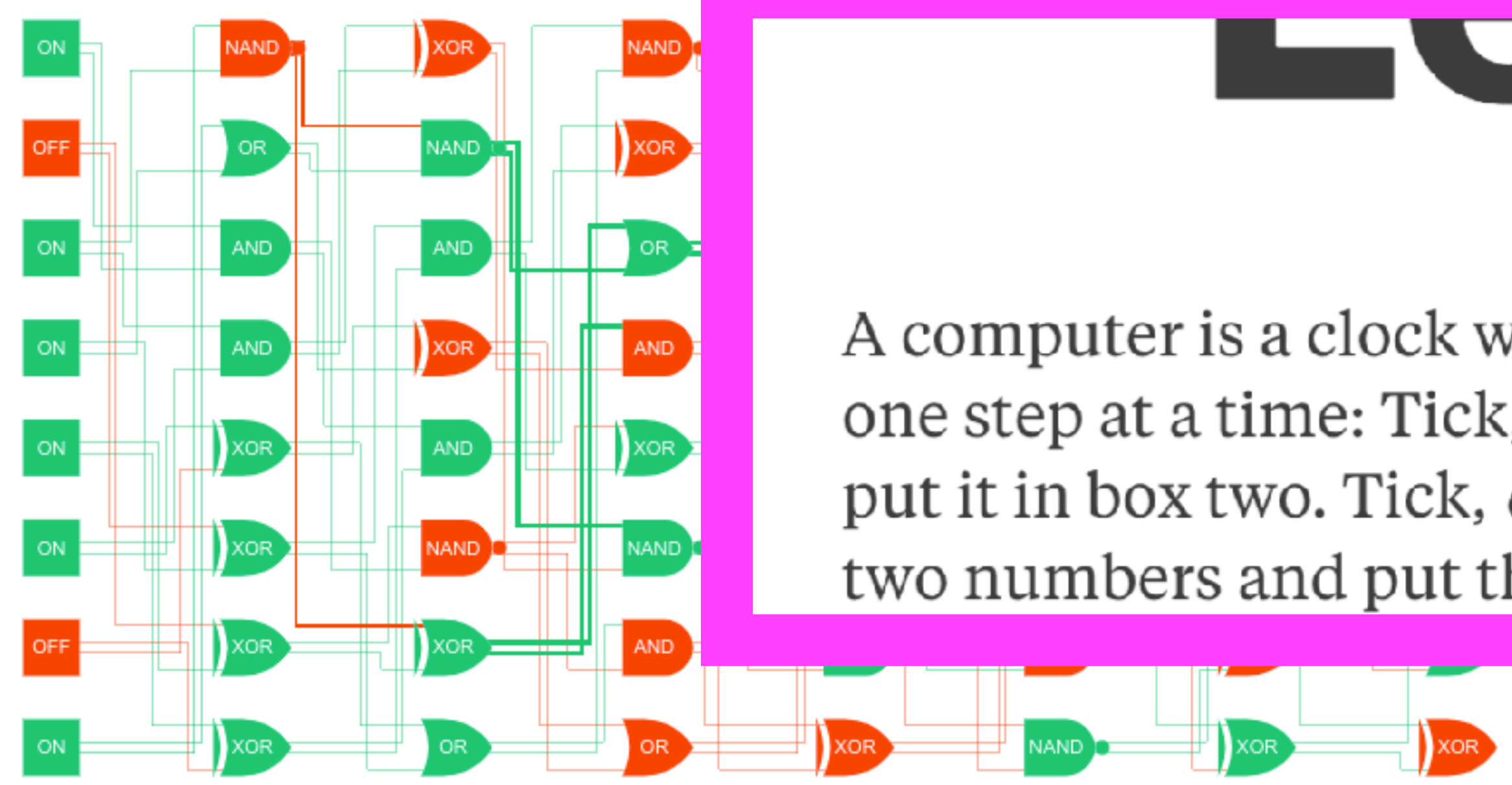
This is simulated circuitry that's computing as you watch. The switches on the left turn the current on and off at random, and the logic gates direct the flow of the current. Click the boxes to change the circuits. Enough of these can compute anything computable.



2

# Let's Begin

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```
sketch_sep29a | Arduino 1.8.13
sketch_sep29a
1 void setup() {
2   // put your setup code here, to run once:
3
4 }
5
6 void loop() {
7   // put your main code here, to run repeatedly:
8
9 }
```

ARDUINO

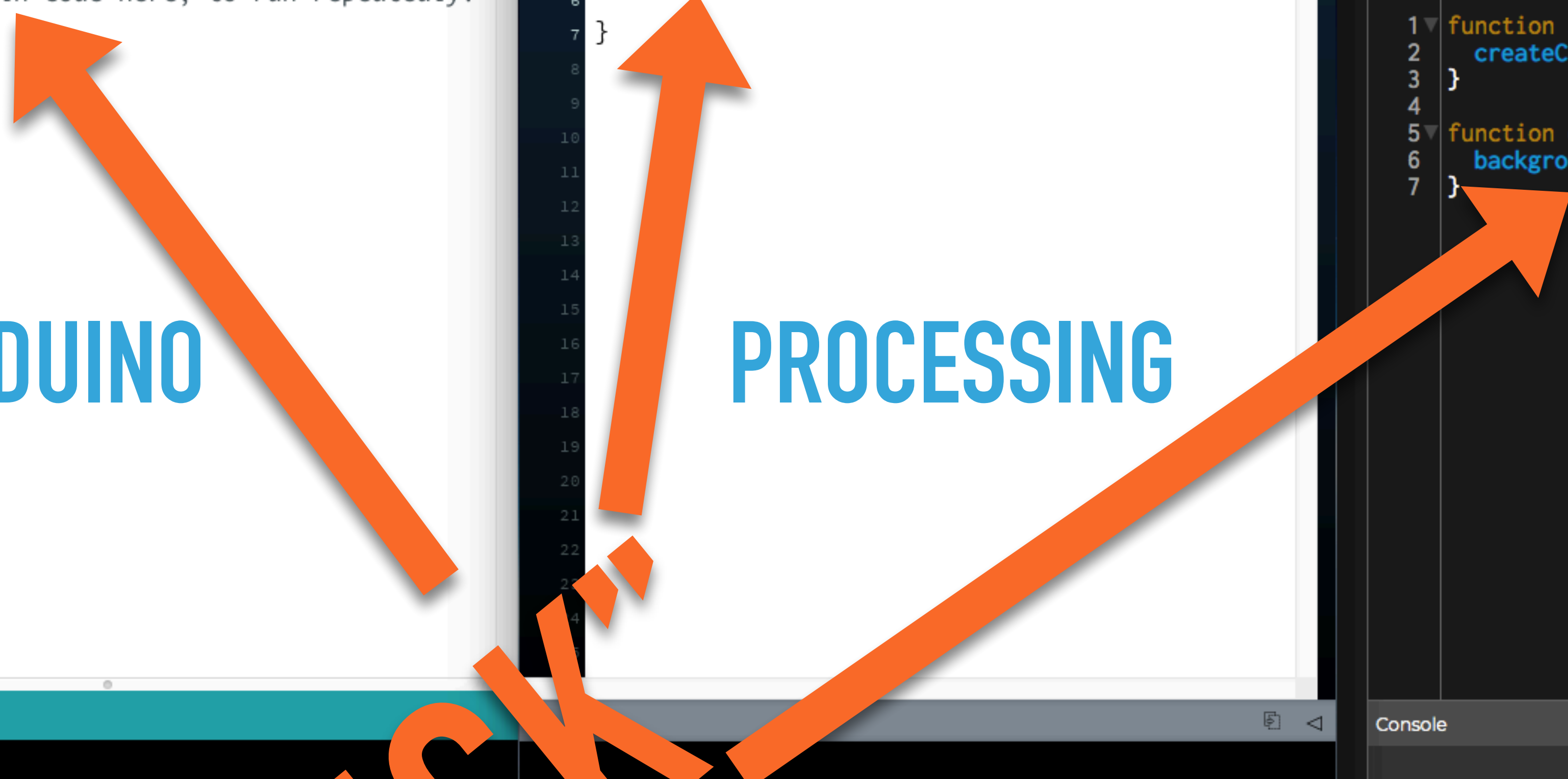
```
sketch_200929a | Processing 3.5.3
sketch_200929a
1 void setup() {
2
3 }
4
5 void draw() {
6
7 }
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
```

PROCESSING

```
p5.js Web Editor
editor.p5js.org
File Edit Sketch Help English Hello, jfeddersen!
p5+ Auto-refresh Nettle cardboard
sketch.js Preview
1 function setup() {
2   createCanvas(400, 400);
3 }
4
5 function draw() {
6   background(220);
7 }
```

P5JS

TICK



# delay()

[Time]

## Description

Pauses the program for the amount of time (in milliseconds) specified as parameter. (There are 1000 milliseconds in a second.)

## Syntax

```
delay(ms)
```

## Parameters

**ms**: the number of milliseconds to pause. Allowed data types: `unsigned long`.

## Returns

Nothing

## Example Code

The code pauses the program for one second before toggling the output pin.

```
int ledPin = 13;           // LED connected to digital pin 13

void setup() {
  pinMode(ledPin, OUTPUT); // sets the digital pin as output
}

void loop() {
  digitalWrite(ledPin, HIGH); // sets the LED on
  delay(1000);                // waits for a second
  digitalWrite(ledPin, LOW);  // sets the LED off
  delay(1000);                // waits for a second
}
```

## Notes and Warnings

While it is easy to create a blinking LED with the `delay()` function and many sketches use short delays for such tasks as switch debouncing, the use of `delay()` in a sketch has significant drawbacks. No other reading of sensors, mathematical calculations, or pin manipulation can go on during the delay function, so in effect, it brings most other activity to a halt. For alternative approaches to controlling timing see the [Blink Without Delay](#) sketch, which loops, polling the `millis()` function until enough time has elapsed. More knowledgeable programmers usually avoid the use of `delay()` for timing of events longer than 10's of milliseconds unless the Arduino sketch is very simple.

Certain things do go on while the `delay()` function is controlling the Atmega chip, however, because the delay function does not disable interrupts. Serial communication that appears at the RX pin is recorded, PWM (`analogWrite`) values and pin states are maintained, and `interrupts` will work as they should.

```
void delay(unsigned long ms) {  
    uint32_t start = micros();  
  
    while (ms > 0) {  
        yield();  
        while ( ms > 0 && (micros() - start) >= 1000) {  
            ms--;  
            start += 1000;  
        }  
    }  
}
```

← micros() function on next slide



```
unsigned long micros() {
```

```
    unsigned long m;  
    uint8_t oldSREG = SREG, t;
```

```
    cli();  
    m = timer0_overflow_count;
```

```
#if defined(TCNT0) ← 8-Bit Timer/Counter  
    t = TCNT0;
```

```
#elif defined(TCNT0L)  
    t = TCNT0L;
```

```
#else  
    #error TIMER 0 not defined  
#endif
```

```
#ifndef TIFR0  
    if ((TIFR0 & _BV(TOV0)) && (t < 255))  
        m++;
```

```
#else  
    if ((TIFR & _BV(TOV0)) && (t < 255))  
        m++;
```

```
#endif
```

```
    SREG = oldSREG;
```

```
    return ((m << 8) + t) * (64 / clockCyclesPerMicrosecond());
```

```
}
```

8-Bit Timer/Counter

Do some math to internal timer register to return run time in microseconds

<https://github.com/arduino/ArduinoCore-avr>

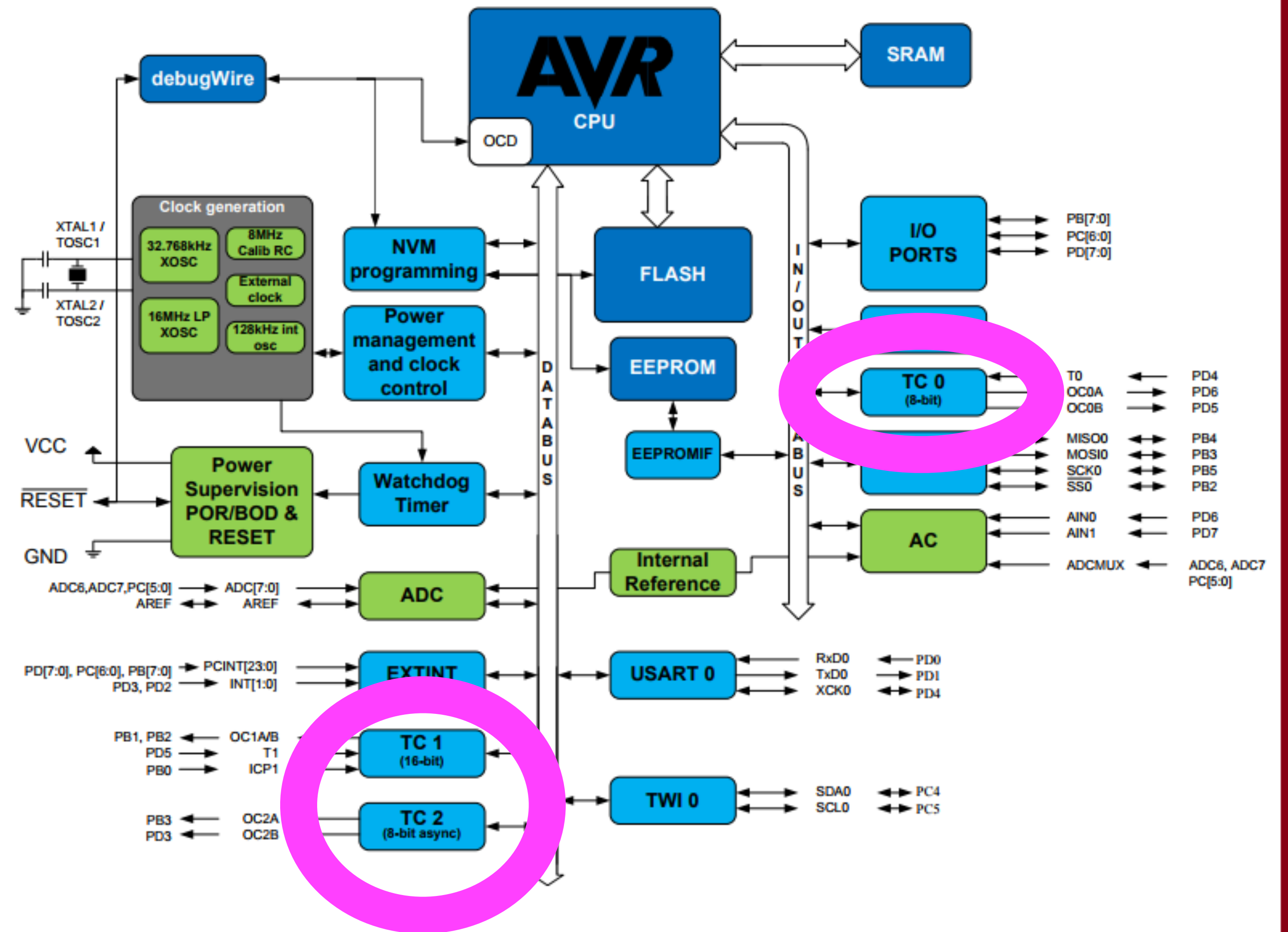
<https://web.engr.oregonstate.edu/~traylor/ece473/lectures/tcnt0.pdf>

# TIMER/COUNTERS ARE PRIMARY BUILDING BLOCKS OF MICROCONTROLLERS

Timing-based functions (analogWrite, tone, servo, etc.) make use of internal timers. These timers can trigger time-based interrupts, triggering functions.

However, accessing these timers typically involves architecture-specific registers and these change from chip to chip.

## ATmega328 Block Diagram



## Note - does not use micros()

```
/* Delay for the given number of microseconds. Assumes a 1, 8, 12, 16, 20 or 24 MHz clock. */
void delayMicroseconds(unsigned int us) {
    // call = 4 cycles + 2 to 4 cycles to init us(2 for constant delay, 4 for variable)
    // calling avrlib's delay_us() function with low values (e.g. 1 or
    // 2 microseconds) gives delays longer than desired.
    //delay_us(us);
    . . .

#ifdef F_CPU
    #elif F_CPU >= 16000000L
        // for the 16 MHz clock on most Arduino boards
        // for a one-microsecond delay, simply return. the overhead
        // of the function call takes 14 (16) cycles, which is 1us
        if (us <= 1) return; // = 3 cycles, (4 when true)

        // the following loop takes 1/4 of a microsecond (4 cycles)
        // per iteration, so execute it four times for each microsecond of
        // delay requested.
        us <<= 2; // x4 us, = 4 cycles

        // account for the time taken in the preceding commands.
        // we just burned 19 (21) cycles above, remove 5, (5*4=20)
        // us is at least 8 so we can subtract 5
        us -= 5; // = 2 cycles,
        . . .

        // busy wait
        __asm__ __volatile__ (
            "1: sbiw %0,1" "\n\t" // 2 cycles
            "brne 1b" : "=w" (us) : "0" (us) // 2 cycles
        );
        // return = 4 cycles
    }
}

```

Several #elif directives  
covering different clock  
speeds

Countdown in Assembly:  
SBIW - Subtract Immediate from Word  
BRNE - Branch if Not Equal

Example program -- AVR Libc

microchip.com/webdoc/AVRLibcReferenceManual/assembler\_1ass

MICROCHIP AVR Libc Reference Manual avr-libc and assembler programs

CONTENTS SEARCH

TIMER Go

Results for: timer

- : Watchdog timer handling
- Why do some 16-bit timer registers sometimes get trashed?
- : Interrupts
- The Source Code
- Combining C and assembly source files
- Allowing specific system-wide interrupts
- asmdemo.c
- Examining the Object File
- isrs.S
- The Project
- Example program
- How do I perform a software reset of the AVR?
- Part 5: main()
- Macro wdt\_reset
- : Basic busy-wait delay loops
- What is all this \_BV() stuff about?

### Example program

The following annotated example features a simple 100 kHz square wave generator using an AT90S1200 clocked with a 10.7 MHz crystal. Pin PD6 will be used for the square wave output.

```

#include <avr/io.h>           : Note [1]

work = 16                    : Note [2]
tmp  = 17

inttmp = 19
intsav = 0
SQUARE = PD6                 ; Note [3]

tmconst= 10700000 / 200000
fuzz= 8

.section .text
.global main
main:
rcall ioinit
1:
rjmp 1b

.global TIMERO_OVF_vect
TIMERO_OVF_vect:
ldi inttmp, 256
out  _SFR_IO_ADDR(TIMSK), inttmp

in  intsav, _SFR_IO_ADDR(TIMSK)

sbic _SFR_IO_ADDR(TIMSK), 1f
rjmp 1f
sbi  _SFR_IO_ADDR(TIMSK), 1f
rjmp 2f
1:
cbi  _SFR_IO_ADDR(TIMSK), 1f
2:

out  _SFR_IO_ADDR(TCCR0), work
reti

ioinit:
sbi  _SFR_IO_ADDR(DDRD), SQUARE

ldi  work, _BV(TOIE0)
out  _SFR_IO_ADDR(TIMSK), work

ldi  work, _BV(CS00)          : tmr0: CK/1
out  _SFR_IO_ADDR(TCCR0), work

ldi  work, 256 - tmconst

```

Example program -- AVR Libc

microchip.com/webdoc/AVRLibcReferenceManual/assembler\_1ass

MICROCHIP AVR Libc Reference Manual avr-libc and assembler programs

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here only since actually, all the following instructions would not modify SREG either, but that's not commonly the case.) Also, it must be made sure that registers used inside the interrupt routine do not conflict with those used outside. In the case of a RAM-less device like the AT90S1200, this can only be done by agreeing on a set of registers to be used exclusively inside the interrupt routine; there would not be any other chance to "save" a register anywhere. If the interrupt routine is to be linked together with C modules, care must be taken to follow the [register usage guidelines](#) imposed by the C compiler. Also, any register modified inside the interrupt service needs to be saved, usually on the stack.

**Note [4]**

The assembler uses integer operations in the host-defined integer size (32 bits or longer) when evaluating expressions. This is in contrast to the C compiler that uses the C type `int` by default in order to calculate constant integer expressions. In order to get a 100 kHz output, we need to toggle the PD6 line 200000 times per second. Since we use `timer 0` without any prescaling options in order to get the desired frequency and accuracy, we already run into serious timing considerations: while accepting and processing the `timer` overflow interrupt, the `timer` already continues to count. When pre-loading the `TCCR0` register, we therefore have to account for the number of clock cycles required for interrupt acknowledge and for the instructions to reload `TCCR0` (4 clock cycles for interrupt acknowledge, 2 cycles for the jump from the interrupt vector, 2 cycles for the 2 instructions that reload `TCCR0`). This is what the constant `fuzz` is for.

# ANALOGWRITE

```
else
{
    switch(digitalPinToTimer(pin))
    {
        // XXX fix needed for atmega8
        #if defined(TCCR0) && defined(COM00) && !defined(__AVR_ATmega8__)
        case TIMER0A:
            // connect pwm to pin on timer 0
            sbi(TCCR0, COM00);
            OCR0 = val; // set pwm duty
            break;
        #endif

        #if defined(TCCR0A) && defined(COM0A1)
        case TIMER0A:
            // connect pwm to pin on timer 0, channel A
            sbi(TCCR0A, COM0A1);
            OCR0A = val; // set pwm duty
            break;
        #endif

        #if defined(TCCR0A) && defined(COM0B1)
        case TIMER0B:
            // connect pwm to pin on timer 0, channel B
            sbi(TCCR0A, COM0B1);
            OCR0B = val; // set pwm duty
            break;
        #endif

        #if defined(TCCR1A) && defined(COM1A1)
        case TIMER1A:
            // connect pwm to pin on timer 1, channel A
            sbi(TCCR1A, COM1A1);
            OCR1A = val; // set pwm duty

```

# TONE

```
// Set timer specific stuff
// All timers in CTC mode
// 8 bit timers will require changing prescalar values,
// whereas 16 bit timers are set to either ck/1 or ck/64 prescalar
switch (_timer)
{
    #if defined(TCCR0A) && defined(TCCR0B) && defined(WGM01)
    case 0:
        // 8 bit timer
        TCCR0A = 0;
        TCCR0B = 0;
        bitWrite(TCCR0A, WGM01, 1);
        bitWrite(TCCR0B, CS00, 1);
        timer0_pin_port = portOutputRegister(digitalPinToPort(_pin));
        timer0_pin_mask = digitalPinToBitMask(_pin);
        break;
    #endif

    #if defined(TCCR1A) && defined(TCCR1B) && defined(WGM12)
    case 1:
        // 16 bit timer
        TCCR1A = 0;
        TCCR1B = 0;
        bitWrite(TCCR1B, WGM12, 1);
        bitWrite(TCCR1B, CS10, 1);
        timer1_pin_port = portOutputRegister(digitalPinToPort(_pin));
        timer1_pin_mask = digitalPinToBitMask(_pin);
        break;
    #endif

```

# delay()

[Time]

## Description

Pauses the program for the amount of time (in milliseconds) specified as parameter. (There are 1000 milliseconds in a second.)

## Syntax

`delay(ms)`

## Param

ms: the

## Return

Nothing

## Exampl

The co

```
int led
```

```
void s
```

```
pinM
```

```
}
```

```
void loop() {
```

```
  digitalWrite(ledPin, HIGH); // sets the LED on
```

```
  delay(1000); // waits for a second
```

```
  digitalWrite(ledPin, LOW); // sets the LED off
```

```
  delay(1000); // waits for a second
```

```
}
```

## Notes and Warnings

While it is easy to create a blinking LED with the `delay()` function and many sketches use short delays for such tasks as switch debouncing, the use of `delay()` in a sketch has significant drawbacks. No other reading of sensors, mathematical calculations, or pin manipulation can go on during the delay function, so in effect, it brings most other activity to a halt. For alternative approaches to controlling timing see the [Blink Without Delay](#) sketch, which loops, polling the `millis()` function until enough time has elapsed. More knowledgeable programmers usually avoid the use of `delay()` for timing of events longer than 10's of milliseconds unless the Arduino sketch is very simple.

Certain things do go on while the `delay()` function is controlling the Atmega chip, however, because the delay function does not disable interrupts. Serial communication that appears at the RX pin is recorded, PWM (`analogWrite`) values and pin states are maintained, and `interrupts` will work as they should.

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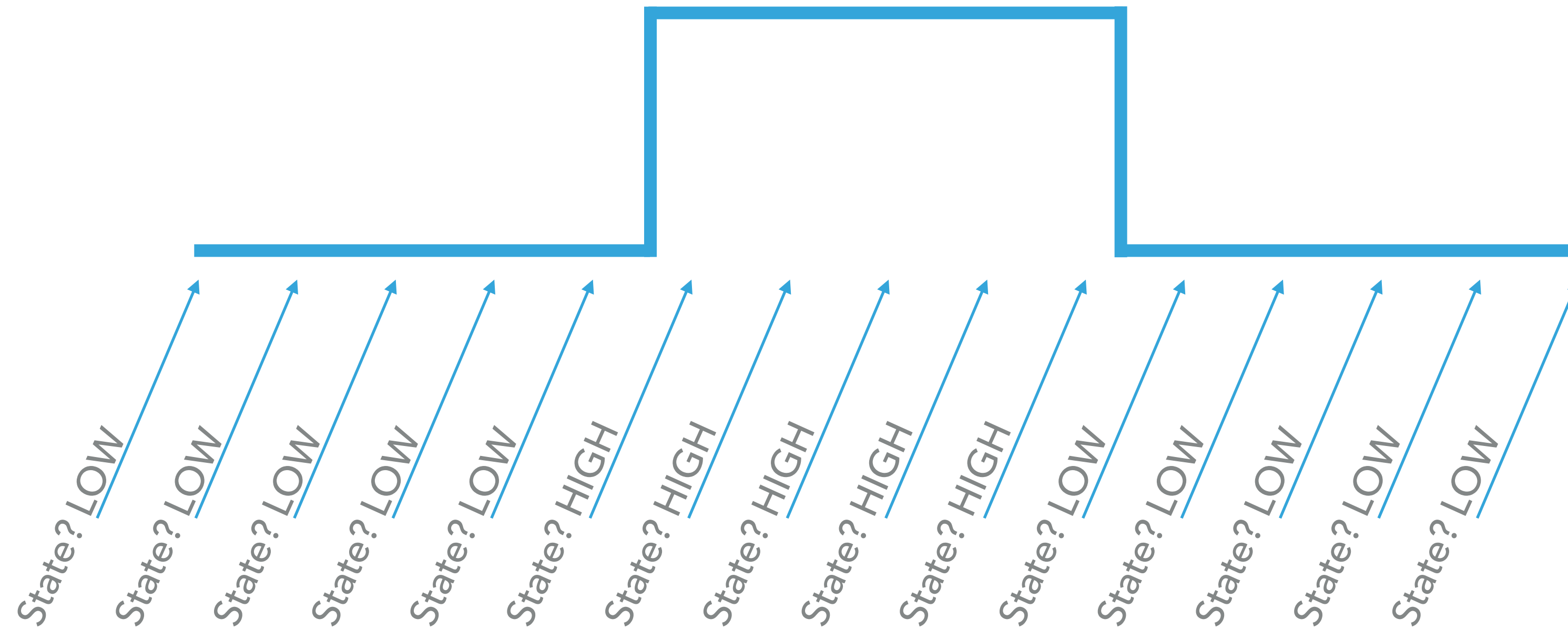
# INTERRUPTS

Microcontrollers can process **interrupts**: functions called automatically by hardware changes.

Changes include:

- ▶ **external**, such as voltage changes on an interrupt-enabled pin, or
- ▶ **internal**, from changes in an internal hardware **timer** (basically, a counter incrementing each clock cycle) reaching a certain value.

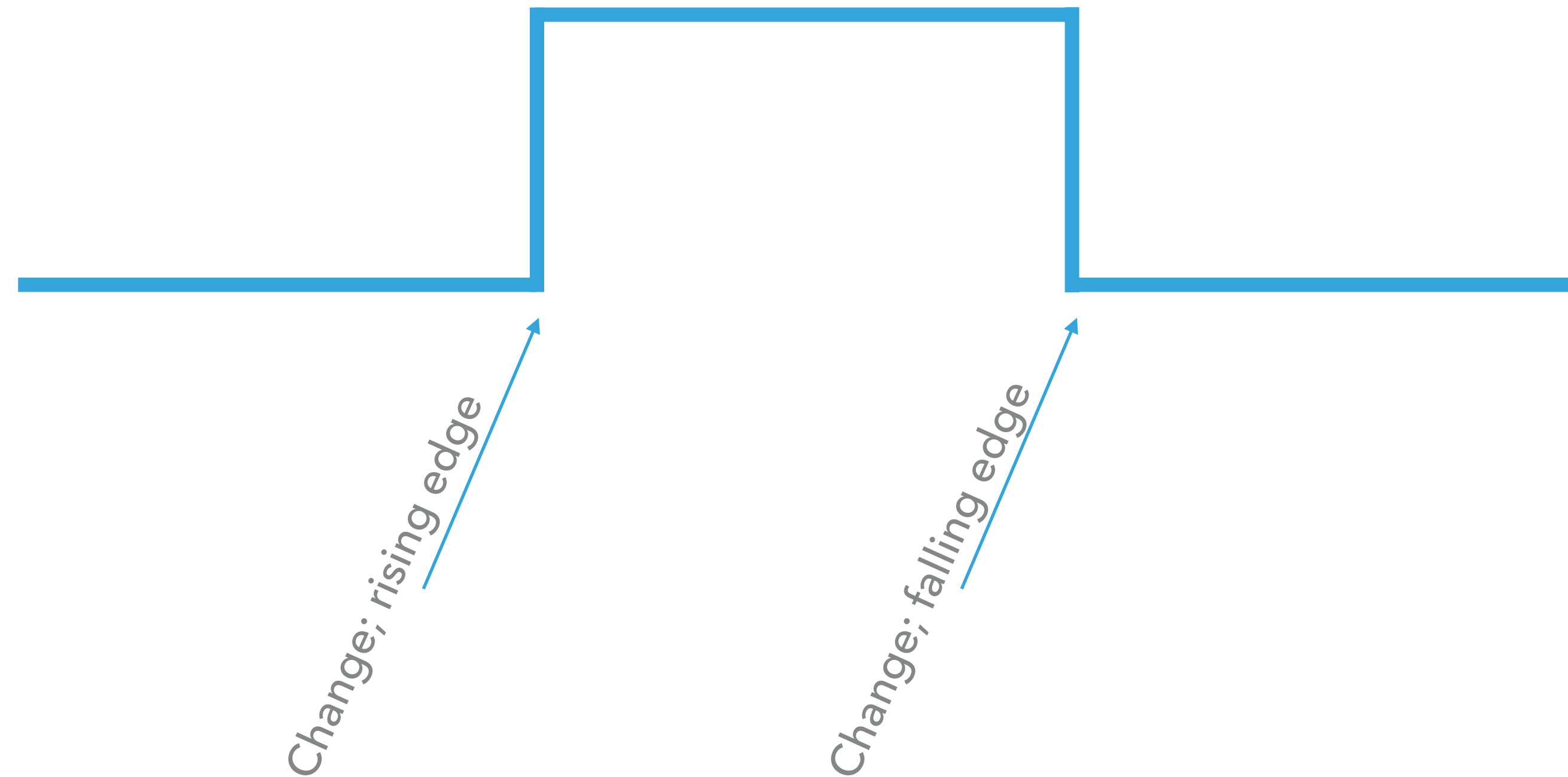
# POLLING



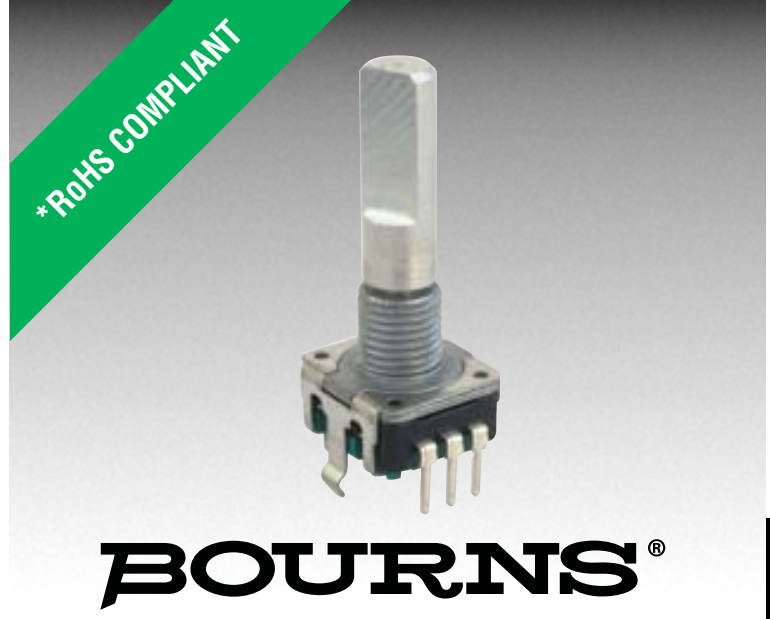
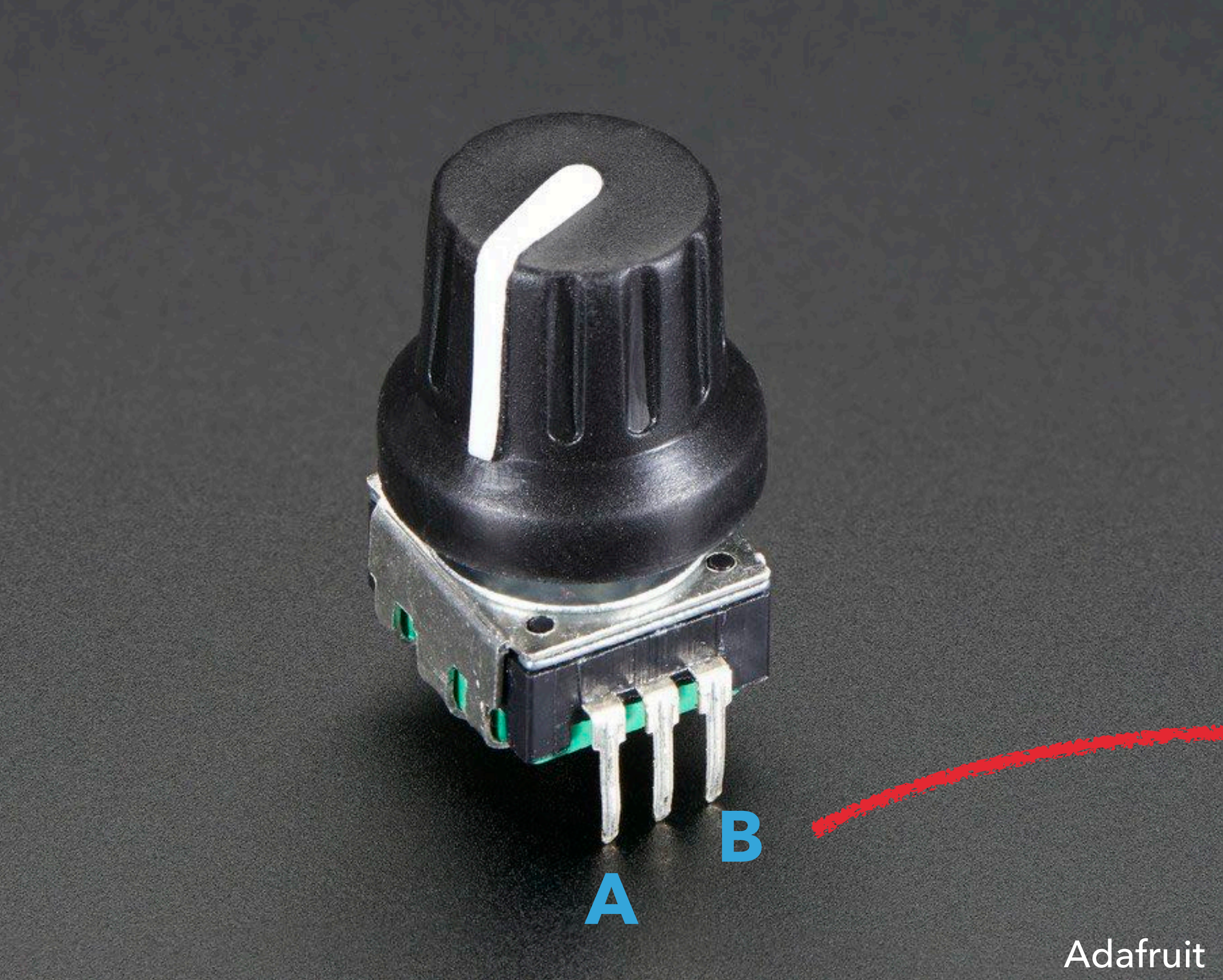
In main loop, use digital read to check the state of an input pin. Decide what to do if it is low, high, changed, etc.



# INTERRUPTS



Define interrupt service routines (ISRs) for hardware changes: rising edge, falling edge, and/or change. These will be called immediately when the pin changes.



- Features**
- Push switch option
  - Compact, rugged design
  - High reliability
  - Metal bushing/shaft



**PEC11 Series - 12 mm Incremental Encoder**

**Electrical Characteristics**

Output .....	2-bit quadrature code
Closed Circuit Resistance .....	3 ohms maximum
Contact Rating .....	1 mA @ 5 VDC
Insulation Resistance .....	100 megohms @ 250 VDC
Dielectric Withstanding Voltage	
Sea Level .....	300 VAC minimum
Electrical Travel.....	Continuous
Contact Bounce (15 RPM).....	5.0 ms maximum**
RPM (Operating).....	60 maximum**

**Environmental Characteristics**

Operating Temperature Range .....	-30 °C to +70 °C (-22 °F to +158 °F)
Storage Temperature Range .....	-40 °C to +85 °C (-40 °F to +185 °F)
Humidity .....	MIL-STD-202, Method 103B, Condition B
Vibration .....	30 G
Contact Bounce.....	10~55~10 Hz / 1 min. / Amplitude 1.5 mm
Shock .....	100 G
Rotational Life .....	30,000 cycles minimum
Switch Life.....	20,000 cycles minimum
IP Rating .....	IP 40

**Mechanical Characteristics**

Mechanical Angle .....	360 ° continuous
Torque	
Running .....	50 to 200 gf.cm (0.68 to 2.7 oz.-in.)
Mounting.....	10.2 kgf.cm (8.83 lb.-in.) maximum
Shaft Side Load (Static).....	2.04 kgf (4.5 lbs.) minimum
Weight .....	5 gm (0.17 oz.) maximum
Terminals .....	Printed circuit board terminals
Soldering Condition	
Wave Soldering.....	Sn95.5/Ag2.3/Cu0.7 solder with no-clean flux: 260 °C max. for 3-5 seconds
Hand Soldering.....	Not recommended
Hardware .....	One flat washer and one mounting nut supplied with each encoder

**Switch Characteristics**

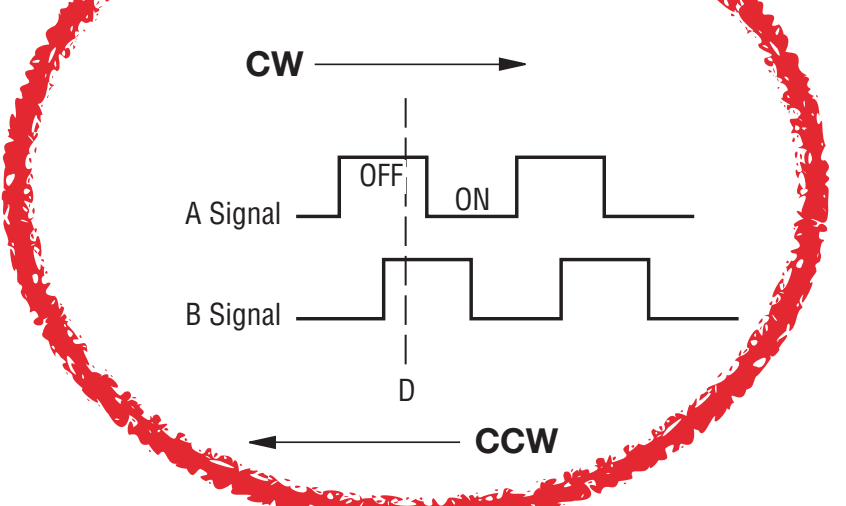
Switch Type .....	Contact Push ON Momentary SPST
Power Rating (Resistive Load) .....	10 mA at 5 V DC
Switch Travel .....	0.5 ± 0.2 mm
Switch Actuation Force .....	61 ± 3 gf (0.47 ± 4.24 oz.-in.)

**How To Order**

**PEC11 - 4 0 20 F - S 0012**

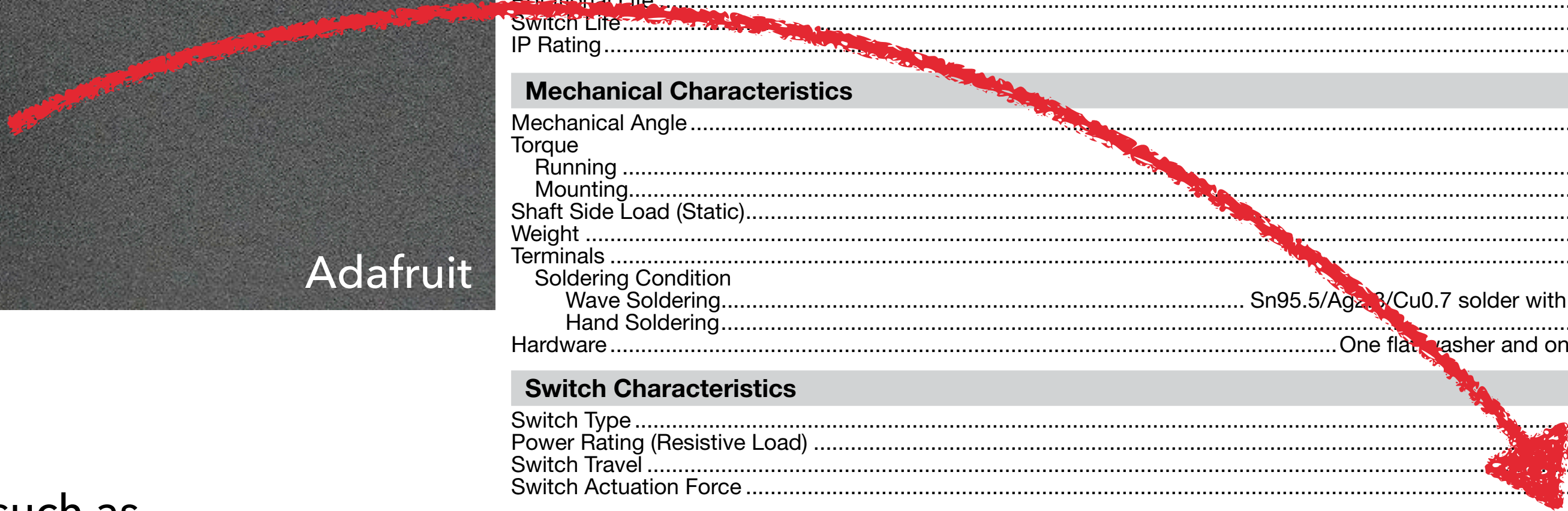
Model .....	PEC11
Terminal Configuration .....	4 = PC Pin Horizontal/Rear Facing
Detent Option .....	0 = No Detents (12, 18, 24 pulses) 1 = 18 Detents (18 pulses) 2 = 24 Detents (12, 24 pulses) 3 = 12 Detents (12 pulses)
Standard Shaft Length .....	15 = 15.0 mm 20 = 20.0 mm 25 = 25.0 mm

**Quadrature Output Table**



# INTERRUPTS

Excellent for resolving fast-changing inputs such as the signals from rotary encoders.



Metronome



Standard quartz clock timer  
 $32,768 = 2^{15}$

The screenshot shows the Mouser Electronics website with search results for "quartz crystal Crystals". The page displays various filters and a list of product options. The "Frequency" filter is set to 32.768 kHz, which is circled in blue. The "Applied Filters" section shows "Passive Components", "Frequency Control & Timing Devices", and "Crystals".

**quartz crystal Crystals**

Products (14,631) | Datasheets (5,387) | Images (159) | Newest Products

Results: 14,631 | Smart Filtering

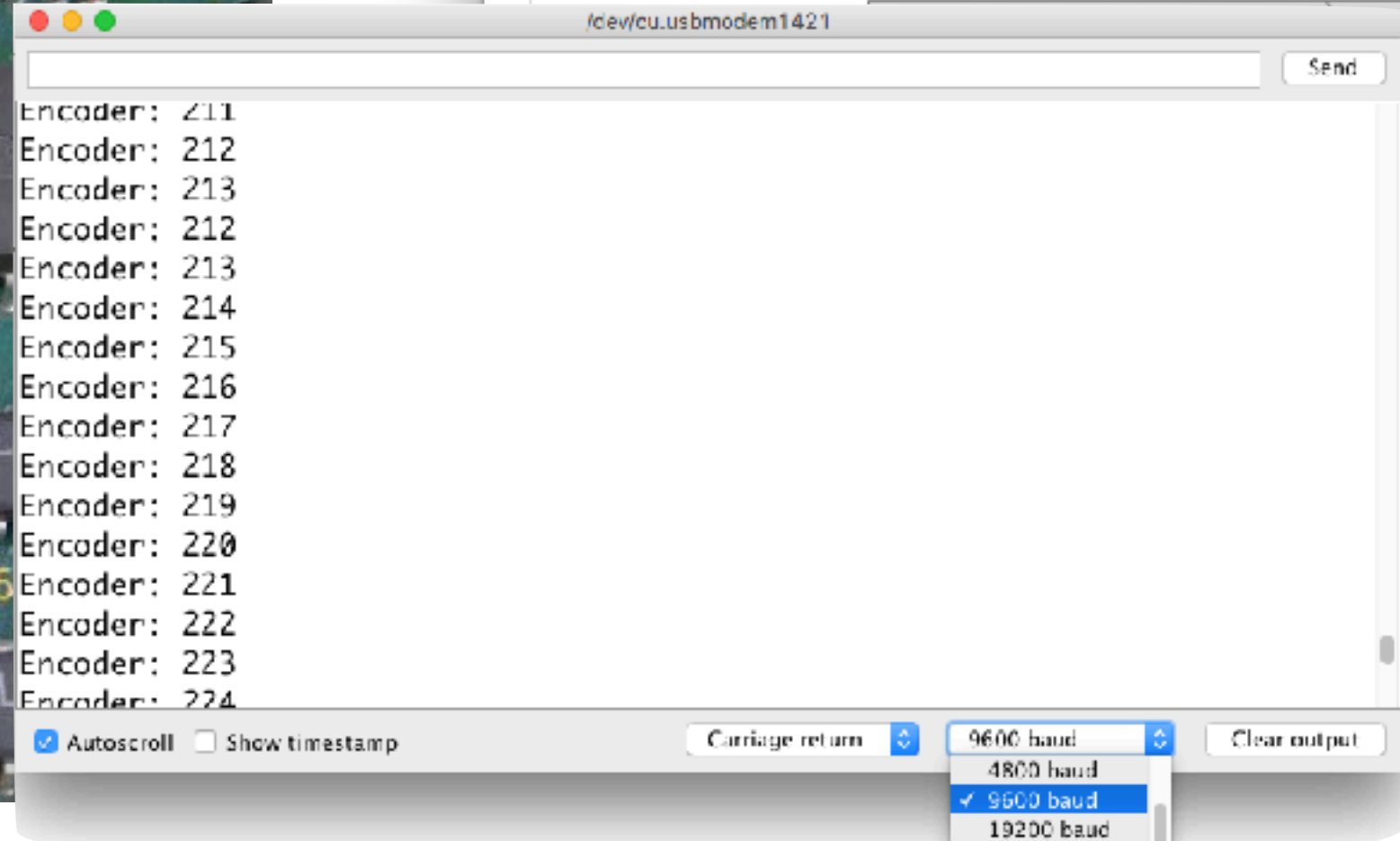
Applied Filters: Passive Components > Frequency Control & Timing Devices > Crystals

Manufacturer	Termination Style	Package / Case	Load Capacitance	Frequency	Tolerance
--- Most Popular --- ABRACON ECS Epson TXC Corporation CTS Kyocera NDK Citizen --- A to Z --- ABRACON Citizen Crystek CTS Diodes Incorporated	Radial SMD/SMT	1.2 mm x 1 mm 1.6 mm x 1 mm 1.6 mm x 1.2 mm 10.41 mm x 4.06 mm 11 mm x 5 mm 11.35 mm x 4.65 mm x 3.5 mm 11.4 mm x 4.9 mm 11.7 mm x 4 mm 11.7 mm x 4.8 mm 11.8 mm x 5.5 mm 12.4 mm x 4.7 mm 12.5 mm x 4.6 mm 13.1 mm x 5 mm 13.2 mm x 4.8 mm 13.3 mm x 4.85 mm 2 mm x 1.2 mm	4 pF 5 pF 6 pF 7 pF 7 pF to 32 pF 8 pF 8.5 pF 9 pF 10 pF 11 pF 12 pF 12.5 pF 13 pF 14 pF	20 kHz 25.6 kHz 31.25 kHz 32 kHz 32.768 kHz 38.4 kHz 60 kHz 76.8 kHz 96 kHz 100 kHz 1 MHz 1.84 MHz 1.8432 MHz	10 PPM 15 PM 15 PPM 20 PPM 25 PPM 30 PPM 50 PPM 100 PPM -

Reset All | Apply Filters



Precision timer  
 $2,097,152 = 2^{21}$



$$1,843,200 / 16 = 115,200$$
$$/32 = 57,600$$
$$/192 = 9600$$

quartz crystal Crystals

Products (14,631) | Datasheets (5,387) | Images (159) | Newest Products

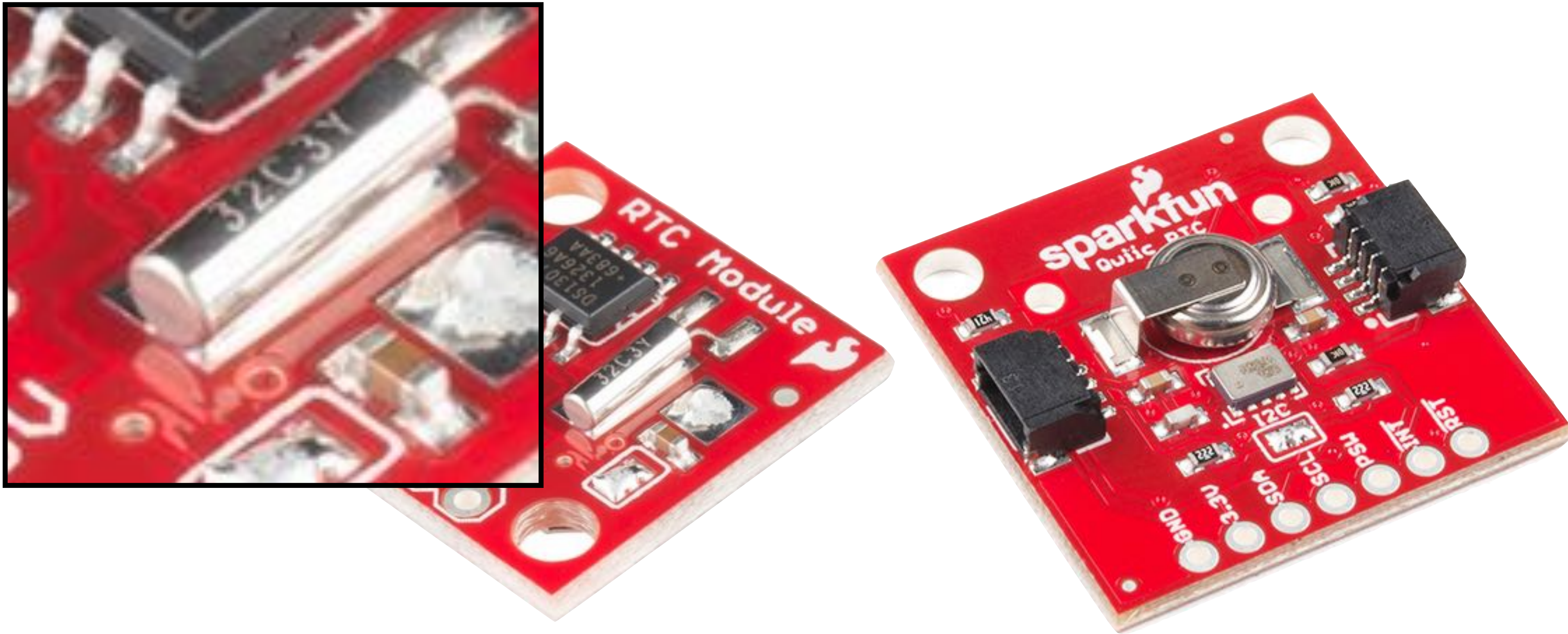
Results: 14,631 | Smart Filtering

Package / Case	Load Capacitance	Frequency	Tolerance
1.2 mm x 1 mm	4 pF	96 kHz	10 PPM
1.6 mm x 1 mm	5 pF	100 kHz	15 PM
1.6 mm x 1.2 mm	6 pF	15 PPM	20 PPM
10.41 mm x 4.06 mm	7 pF	1.84 MHz	25 PPM
11 mm x 5 mm	7 pF to 32 pF	1.8432 MHz	30 PPM
11.35 mm x 4.65 mm x 3.5 mm	8 pF	2 MHz	50 PPM
11.4 mm x 4.9 mm	8.5 pF	2.048 MHz	100 PPM
11.7 mm x 4 mm	9 pF	2.097 MHz	-
11.7 mm x 4.8 mm	10 pF	2.09715 MHz	-
11.8 mm x 5.5 mm	11 pF	2.097152 MHz	-
12.4 mm x 4.7 mm	12 pF	2.4 MHz	-
12.5 mm x 4.6 mm	12.5 pF	2.4576 MHz	-
13.1 mm x 5 mm	13 pF	2.5 MHz	-
13.2 mm x 4.8 mm	14 pF	-	-
13.3 mm x 4.85 mm	-	-	-
2 mm x 1.2 mm	-	-	-



Sparkfun RTC Breakout boards

[https://github.com/ITPNYU/clock-club/tree/master/RTC\\_Clock\\_Examples](https://github.com/ITPNYU/clock-club/tree/master/RTC_Clock_Examples)



Sparkfun RTC Breakout boards

[https://github.com/ITPNYU/clock-club/tree/master/RTC\\_Clock\\_Examples](https://github.com/ITPNYU/clock-club/tree/master/RTC_Clock_Examples)

# Super-Accurate Thousand-Dollar Quartz Watches... Now There's One Under \$200!

Here's the ultimate in timekeeping: Watches below are among the first models to appear in the U.S. Produced in limited quantity, all are slightly larger and heavier than conventional watches. Timex' new quartz was not available for this photo.



**They hum like amplifiers, and their vibrating crystals insure accuracy of seconds a month**

By OSCAR SCHISGALL

The most accurate timepiece ever devised by man. That's how watch makers describe the newest thing in timekeeping: the electronic quartz watch. Some also call it "the most important new way of measuring time developed in more than 200 years."

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Big problem with quartz watches until now: They're terribly expensive.

The first models coming out of Switzerland and Japan start at \$595 in stainless steel, go up to \$2,200 in gold. That's why they've been manufactured in limited quantities and only a few have been sold. Now Timex has announced a new model scheduled to go on sale late next month. The price, as of this writing, is estimated at somewhere between \$150 and \$185.

What's an electronic quartz watch? How does it differ from others? How good is it? Let's take these questions one at a time.

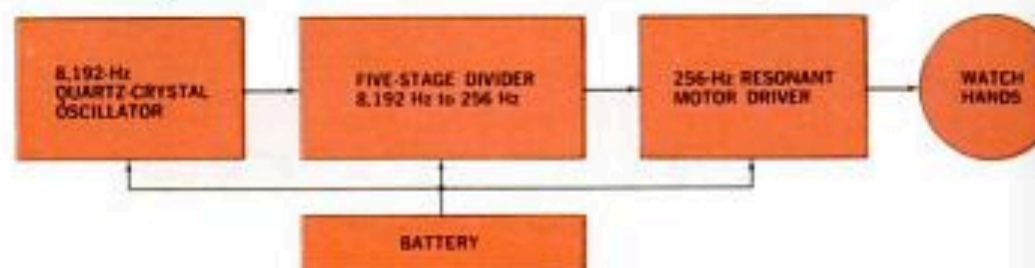
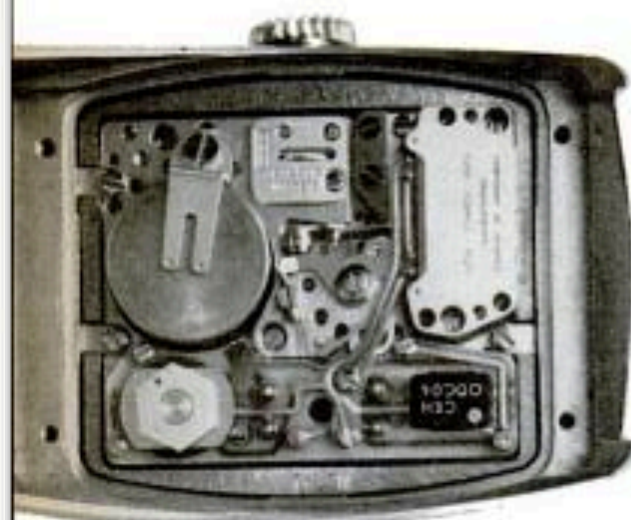
The quartz watch is based on a principle entirely different from those of all other watches. Most watches rely on the familiar balance wheel. A carefully balanced spring-driven wheel rocks back and forth at a rate (usually five times a second) determined by its size and weight. The accuracy with

which it maintains that base rate largely determines the watch's accuracy. A top-quality balance-wheel movement keeps accurate time to within perhaps four minutes a month. The tuning-fork concept is more sophisticated. The tuning fork, much like the one the piano tuner uses, vibrates or oscillates 360 times per second; and it results in a watch that's accurate to within a minute a month.

The quartz watch completely abandons the mechanical time-regulating device—balance wheel or tuning fork. Instead, it uses an electronic oscillator much like the one that controls the frequency of a broadcast station. The frequency of this oscillator—exactly as in a radio station—is determined by a bar-shaped sliver of quartz. Most quartz watches use quartz oscillators

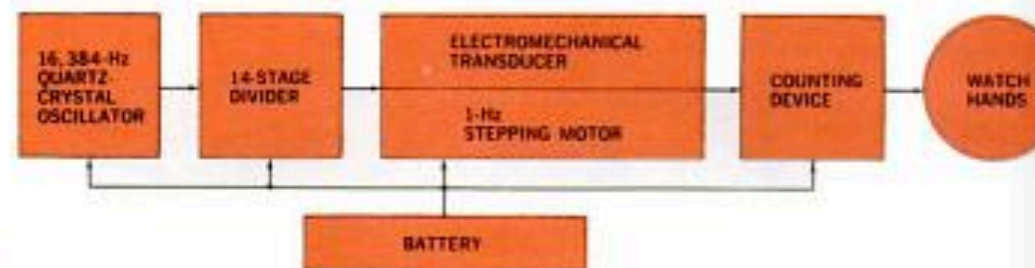
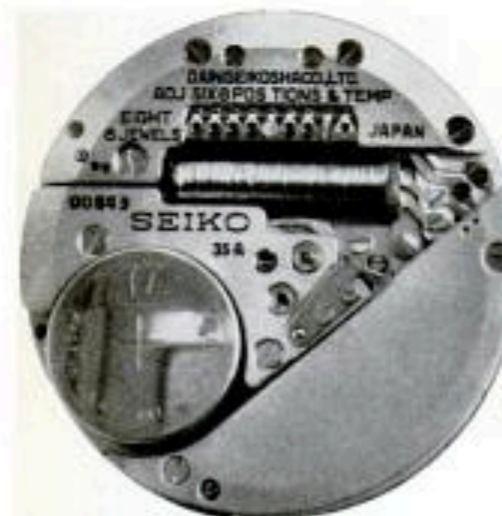
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There are at least two reasons why the Timex is so much cheaper — advanced



**SWISS-CEH** The Swiss Center of Electronic Horology developed this quartz watch for its member companies, among them Bulova and Omega. The 8,192-Hz quartz oscillator goes through a five-stage divider in a micro-electronic integrated circuit. The resulting output is 256 Hz. This frequency goes to an

electromagnetic motor which further divides the pulse into one-second intervals. Using this pulse, the wheel train turns the hands. Omega's integrated circuit contains 21 transistors and 61 other electronic elements. Member companies in the CEH or organization may alter the basic movement slightly to fit an individual watch case.



**SEIKO** This quartz has five major components: 16,384-Hz quartz-crystal oscillator circuit, integrated circuit with an electromechanical transducer, and silver-oxide battery. The divider circuit halves the 16,384-Hz frequency 14 times (8,192; 4,096; etc.—down to a single pulse).

The electromechanical transducer convert the one-pulse signal into mechanical motion, to turn the six-pole stepping motor in 60-degree increments. Finally, the counting device moves the second hand at exact one-second intervals. Pulling out the crown stop the second hand, for precise control. Battery life is claimed to be one year.

with 8,192 Hz—vibrations per second. If you listen to a quartz watch, it hums like a tuning fork—but it's far more accurate.

Quartz, the familiar transparent crystalline mineral, is a remarkable substance. It has piezoelectric characteristics. If a voltage is applied across a slab of quartz, it bends slightly. Put the quartz in an oscillator circuit and it will vibrate at its natural frequency, which is determined by its size and shape.

This natural oscillation frequency is so precise that quartz watches are accurate to within seconds per month. Most quartz-watch makers guarantee accuracy to within five seconds a month; the Timex people conservatively claim an accuracy of 15 seconds a month.

How they work. Most quartz watches operate on the same general principle. (Longines work differently; Timex, we can't say.) First, you have a quartz-crystal oscillator circuit. Next, a small mercury or silver oxide battery to provide voltage so the quartz can oscillate. But the quartz crystal's natural vibrating frequency is too high; more manageable speeds

are needed to move around the hands.

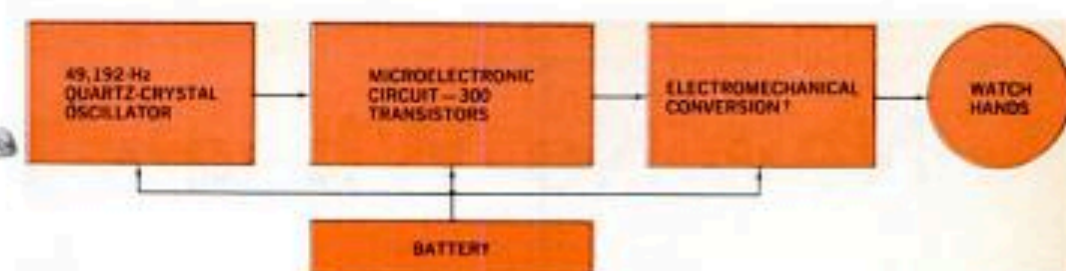
Micro-electronic integrated circuits come in here. "Dividers" in these circuits "step down" the frequency by halving it several times (8,192 frequency is the 13th power of 2—2<sup>13</sup>). The number of dividers in the circuit depends on the quartz-crystal frequency and other circuitry a particular company uses.

Whether the pulse is divided down to one pulse or a slightly higher frequency (256 in the Swiss movements), an electro-mechanical motor receives the pulse and converts electrical energy to mechanical energy. This drives the wheel train that eventually turns the hands. Of course, each company's watch works a little differently. (See explanations above.)

Still, the big mystery is why the Timex is so much cheaper—between a third and a quarter of the price of its nearest competitor. Undoubtedly, there are at least two reasons.

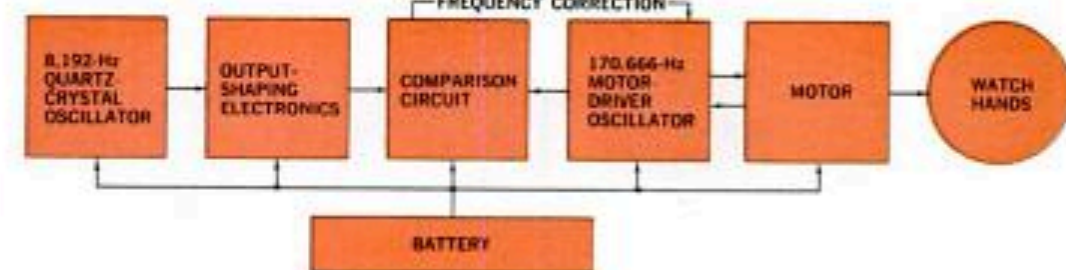
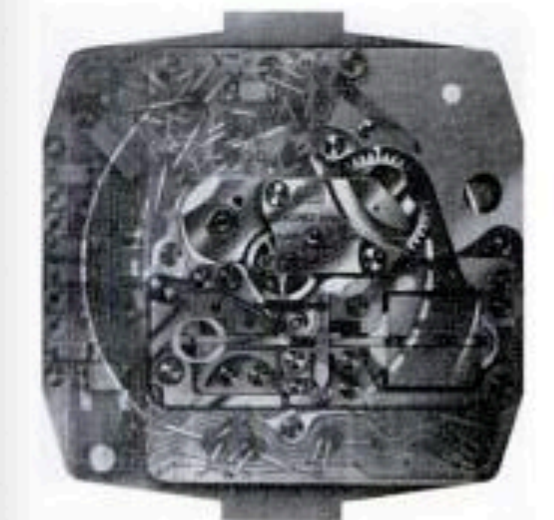
First, a technology geared to enormous production. "We have developed mass-production techniques unmatched outside the United States," says Joakim Lehmkuhl, president of Timex. "You can't produce 19 million

mass-production technology and a circuit that's still top secret



**TIMEX** What's inside? We don't know yet. At press time the technical information was still "top secret." We do know that the Timex movement uses a crystal oscillator with a 49,192-Hz frequency—far higher than any other quartz on the market. This frequency is not a power of two as in the others—which makes it even

more mysterious. It has a micro-electronic circuit—about one centimeter square—containing 300 transistors. It also uses a silver-oxide battery good for a year. It could have several things in it—including some kind of comparison circuit, or a digital or analog means of controlling the watch's speed. It's accurate to 15 seconds a month.



**LONGINES** This one's unique: A comparison circuit detects error in the watch's output and self-corrects. A 9,350-Hz quartz oscillator is the frequency reference—which is not divided, as in other watches. A 170-Hz servomotor, independent and operating by itself, turns the hands. Mechanical output is compared

with the quartz signal. If there's an error signal in the comparison circuit, a correction is applied to the motor. If motor frequency and crystal frequency are in step, the error signal is zero. The circuit has 14 transistors, 19 resistors, and seven capacitors. Insurance against loss or theft for one year comes with the watch.

high frequency. The company has apparently made an important breakthrough in quartz-watch technology—one that gives it a tremendous advantage—and company engineers and executives are understandably reluctant to reveal their secret.

Although the Timex people showed me various versions of their watch, they refused permission to photograph it—face or movement. Nevertheless, Timex executive vice-president Robert Mohr did give POPULAR SCIENCE some exclusive technical information, emphasizing that "our watch, as far as I know, is entirely different from any other quartz watch." This, along with our speculation of what's inside it, is above.

How about watch performance? Reliability? "Since there are virtually no moving parts," says Lehmkuhl, "very little can go wrong. We have put the watch through every conceivable test of temperature, altitude, and humidity. We have made every test for position error—dial up, dial down, three o'clock up, six o'clock up, nine o'clock up. Where we found bugs we corrected them."

And shock and water resistance?

"Water resistant, yes. As for being shock resistant..." Lehmkuhl smiled. "It is sturdy, but we don't recommend that you hurl it against walls as we did in torture tests with our conventional watches. We wouldn't recommend such treatment for any item that costs over \$100."

In any event, Timex seems destined to be the first to market the new watch in quantity, and Seiko threatens to be a close second. Why aren't the Swiss (such as Bulova, Omega, Longines, and others) marketing quartz watches in large numbers?

Tuning-fork watches. Bulova has had a lot of success with its Accutron tuning-fork watch. Now other Swiss companies have been licensed by Bulova to make tuning-fork watches. As one Swiss manufacturer said, "We want to make the most of our tuning-fork watch, which represents a heavy investment. Time enough for the quartz watch when the tuning-fork has passed the peak of popularity."

Another predicted differently. "Timex and its advertising campaign for the quartz watch may well be the catalyst that will compel all of us to jump in and compete."

I asked Joakim Lehmkuhl of Timex how far away he thought the era of the quartz watch might be.

"We don't expect a hundred million Americans to throw away their watches tomorrow morning in order to buy a quartz watch. We are dealing not only with watches, but with human nature. We expect, as new watches are bought, that purchasers will want the latest and most accurate type. Simply because the quartz watch is unquestionably the newest and most accurate example of horology man has so far achieved, we are confident that it will be, if not the dominant watch of tomorrow, surely that of the day after tomorrow."

And what can we expect, the day after that? Nuclear timekeeping. Some day you may be able to buy a watch containing a milligram of an alpha-particle-emitting radioactive isotope as a power source. It may be accurate to within a few seconds a year—almost as accurate as the movement of the Earth itself! Although Bulova's engineers are already exploring nuclear timekeeping, they believe it's a long way off. Name? What else but the atomic watch? □



# Super-Accurate Thousand-Dollar Quartz Watches...

## Now There's One Under \$200!

Here's the ultimate in timekeeping: Watches below are among the first models to appear in the U.S. Produced in limited quantities, they are slightly larger and heavier than conventional watches. New quartz was not available for this photo.

\$1,325



They hum like amplifiers, and their vibrating crystals insure accuracy of seconds a month

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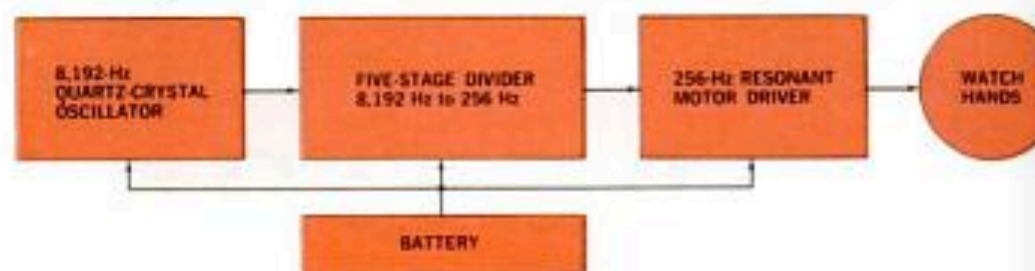
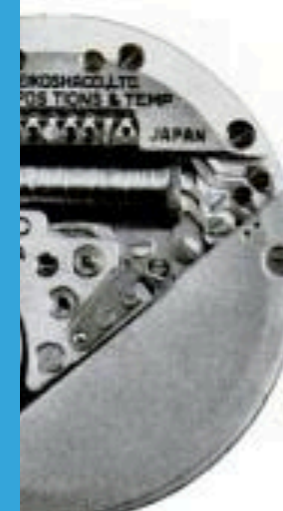
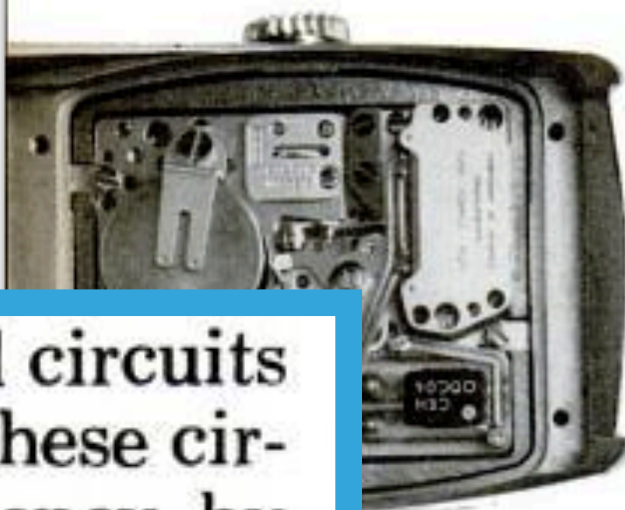
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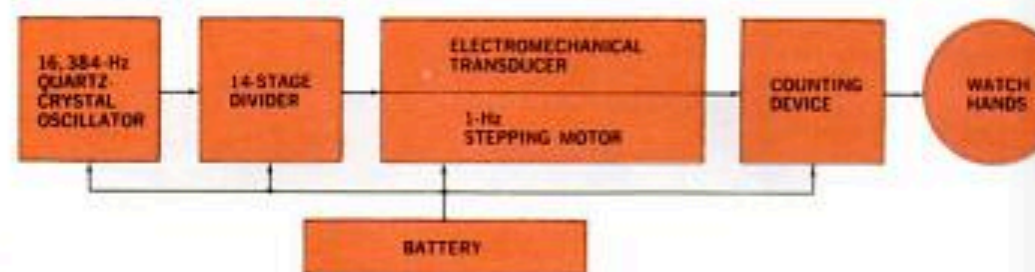
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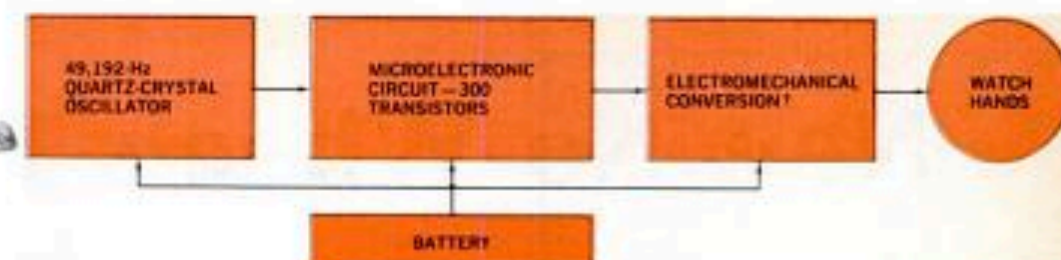
watches a year, as we've been doing without learning a great deal about automated mass production and methods of cost control. When it came to actually manufacturing the quartz watch we already had a backlog of experience in essential fields like the design and manufacture of parts, especially miniaturized parts."

Timex produces all the parts in its watches—except the quartz-crystal oscillator and the circuit. At Waterbury, Conn., I watched skilled workers assemble the watches.

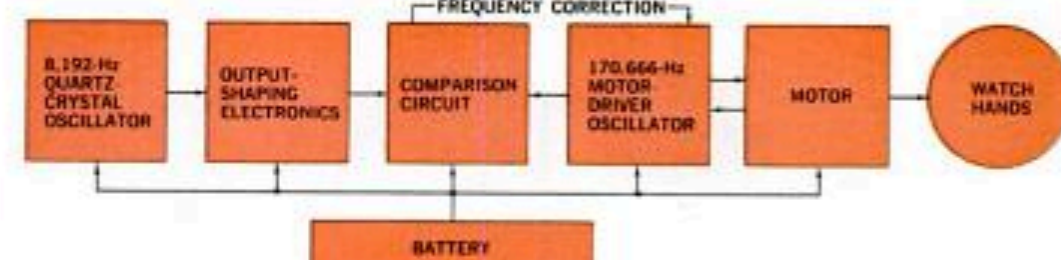
My guide, an engineer, pointed out that in the field of conventional watches, Timex has been manufacturing pin-lever movements, which are less expensive to produce than the Swiss and Japanese jeweled movements. But he, like the others I talked to at Timex, would not agree that their quartz-crystal watch used a basically less-advanced mechanism than its competition. This leads directly to the second reason for lower cost.

Despite the lack of any available proof, Timex has apparently figured out some way to simplify the design and reduce the cost of building a quartz-crystal watch with a super

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## 19. RTC – Real-Time Counter

### 19.1 Overview

The Real-Time Counter (RTC) is a 32-bit counter with a 10-bit programmable prescaler that typically runs continuously to keep track of time. The RTC can wake up the device from sleep modes using the alarm/compare wake up, periodic wake up, or overflow wake up mechanisms

The RTC is typically clocked by the 1.024kHz output from the 32.768kHz High-Accuracy Internal Crystal Oscillator(OSC32K) and this is the configuration optimized for the lowest power consumption. The faster 32.768kHz output can be selected if the RTC needs a resolution higher than 1ms. The RTC can also be clocked from other sources, selectable through the Generic Clock module (GCLK).

The RTC can generate periodic peripheral events from outputs of the prescaler, as well as alarm/compare interrupts and peripheral events, which can trigger at any counter value. Additionally, the timer can trigger an overflow interrupt and peripheral event, and can be reset on the occurrence of an alarm/compare match. This allows periodic interrupts and peripheral events at very long and accurate intervals.

The 10-bit programmable prescaler can scale down the clock source. By this, a wide range of resolutions and time-out periods can be configured. With a 32.768kHz clock source, the minimum counter tick interval is 30.5 $\mu$ s, and time-out periods can range up to 36 hours. For a counter tick interval of 1s, the maximum time-out period is more than 136 years.

### 19.2 Features

- 32-bit counter with 10-bit prescaler
- Multiple clock sources
- 32-bit or 16-bit Counter mode
  - One 32-bit or two 16-bit compare values
- Clock/Calendar mode
  - Time in seconds, minutes and hours (12/24)
  - Date in day of month, month and year
  - Leap year correction
- Digital prescaler correction/tuning for increased accuracy
- Overflow, alarm/compare match and prescaler interrupts and events
  - Optional clear on alarm/compare match



### 19.3 Block Diagram

Figure 19-1. RTC Block Diagram (Mode 0 — 32-Bit Counter)

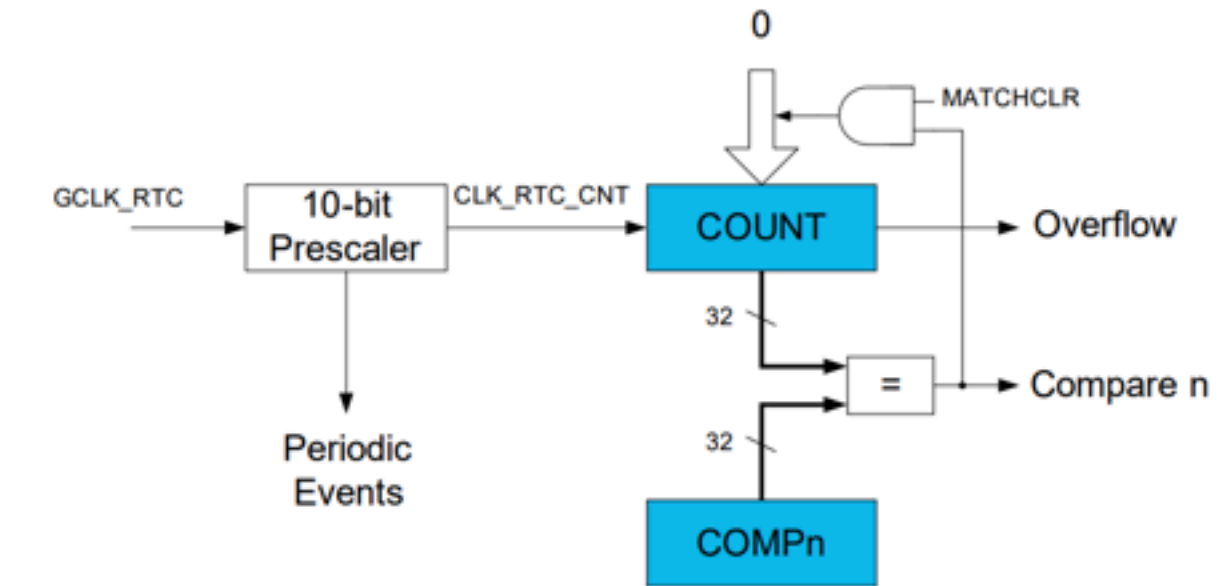


Figure 19-2. RTC Block Diagram (Mode 1 — 16-Bit Counter)

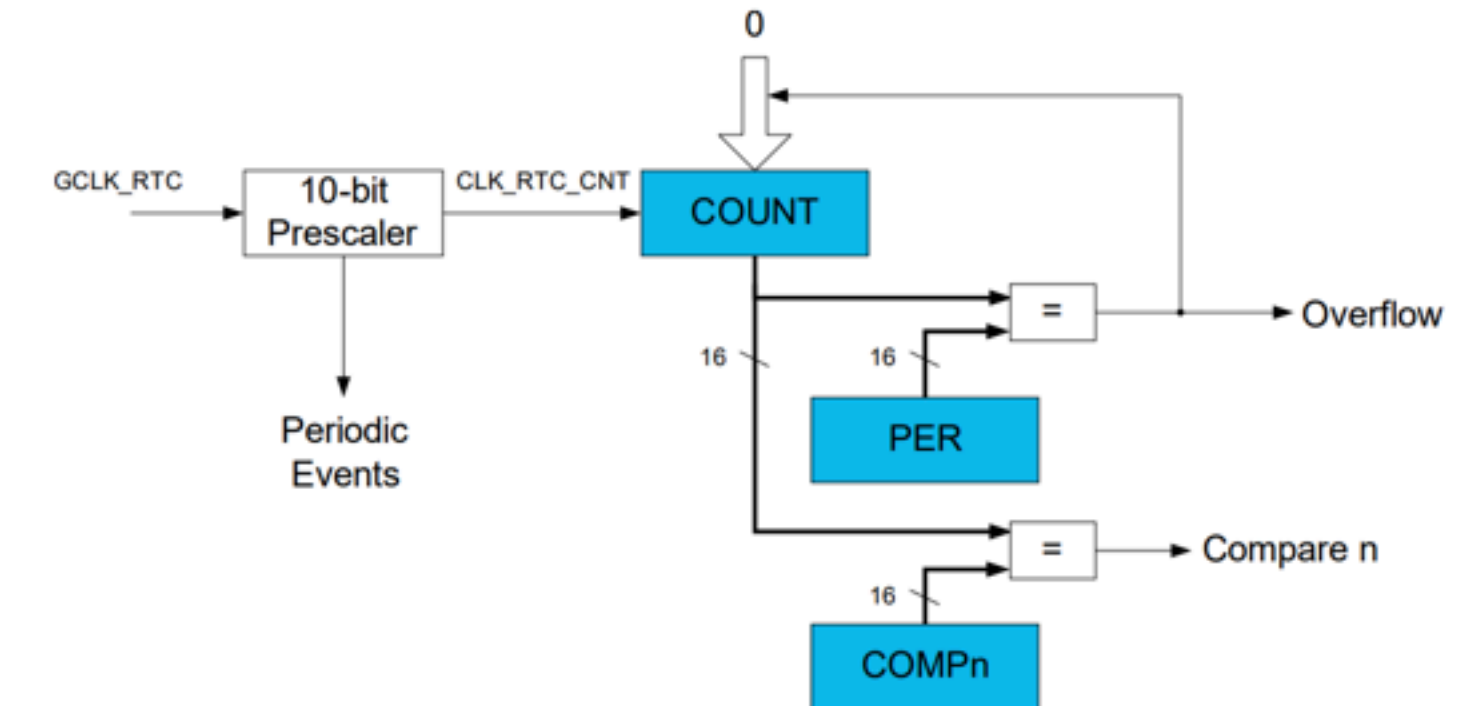


Figure 19-3. RTC Block Diagram (Mode 2 — Clock/Calendar)

