TIME MACHINES

TIME MACHINES


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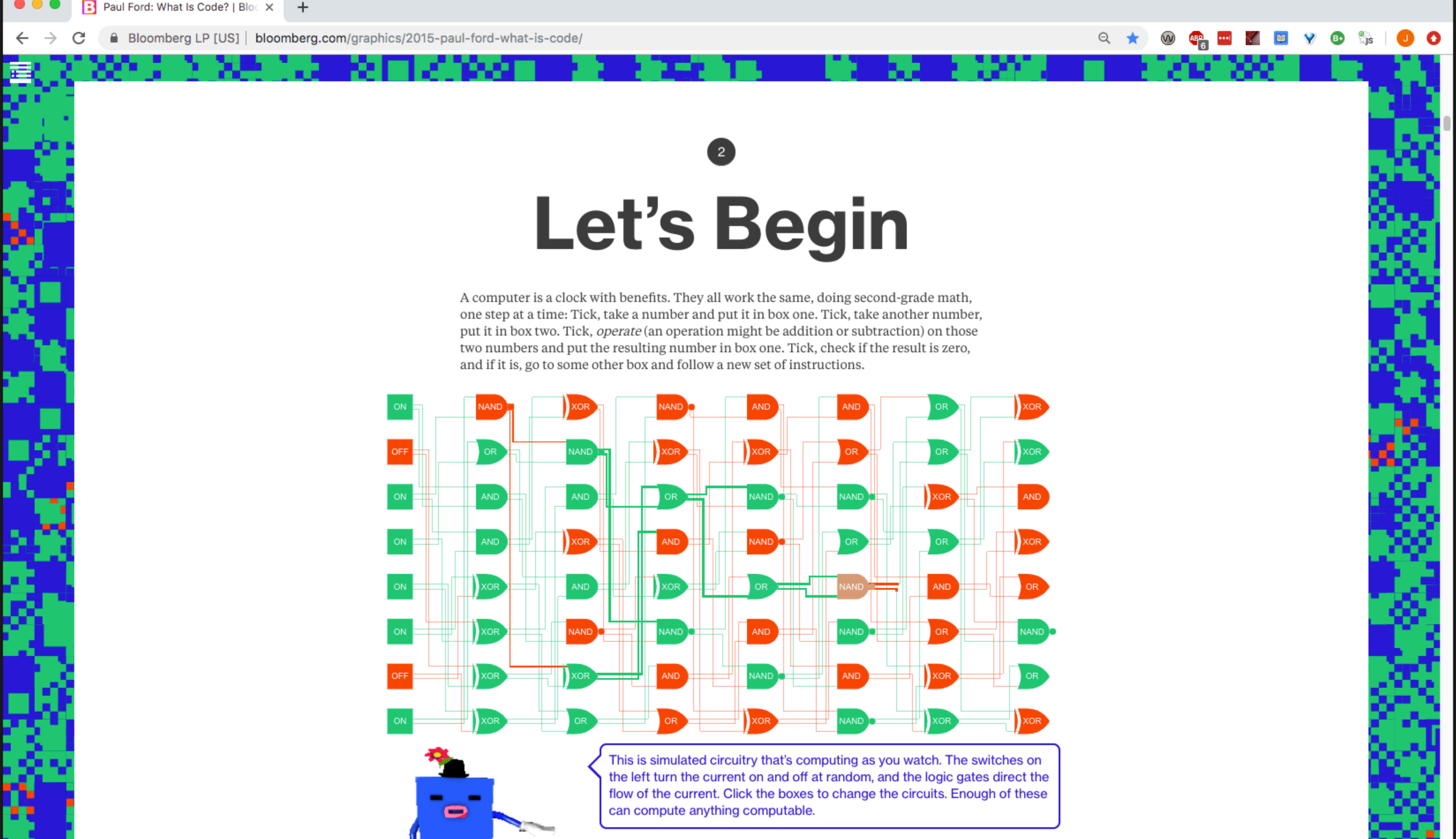
TIME MACHINE

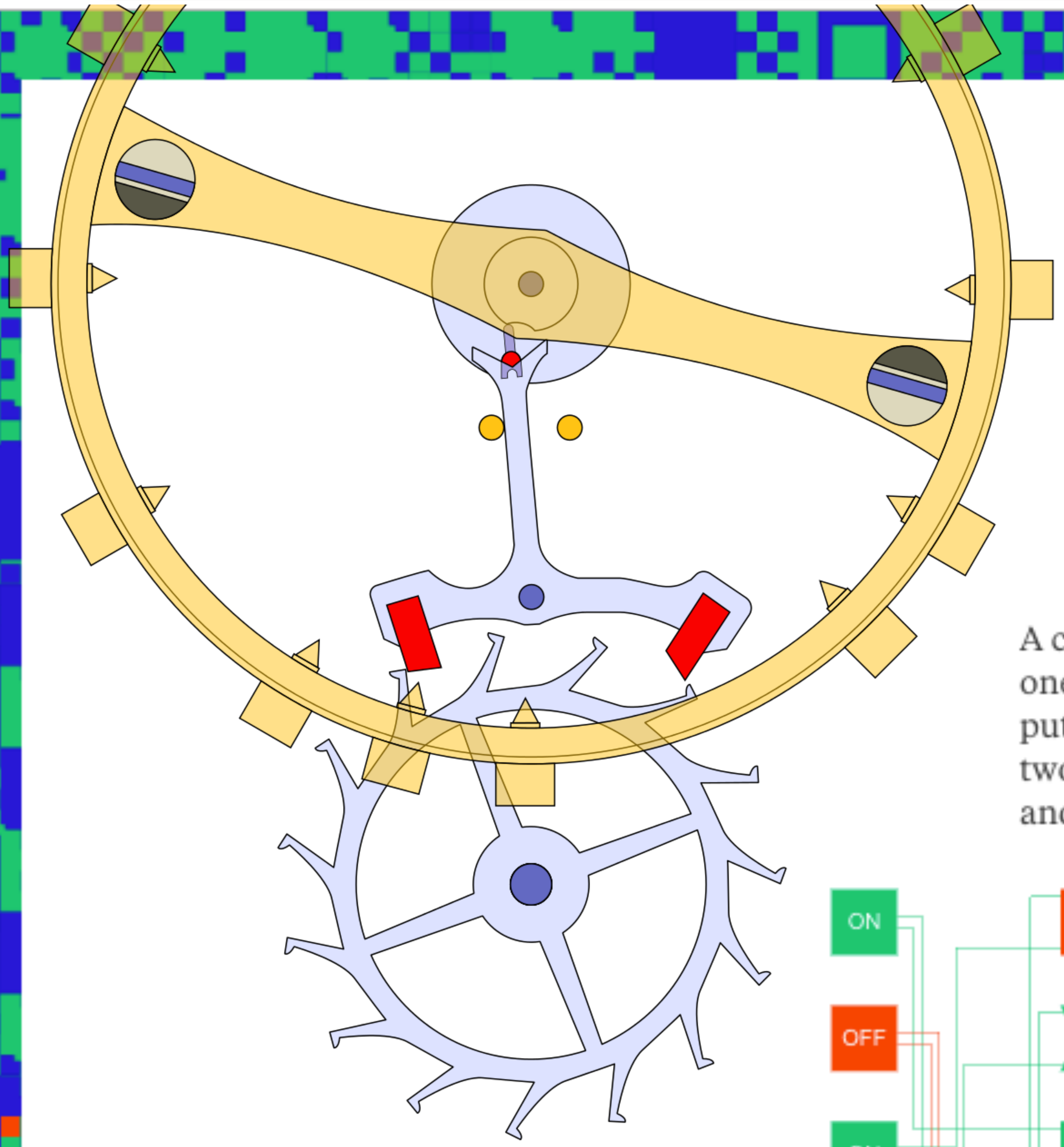


2

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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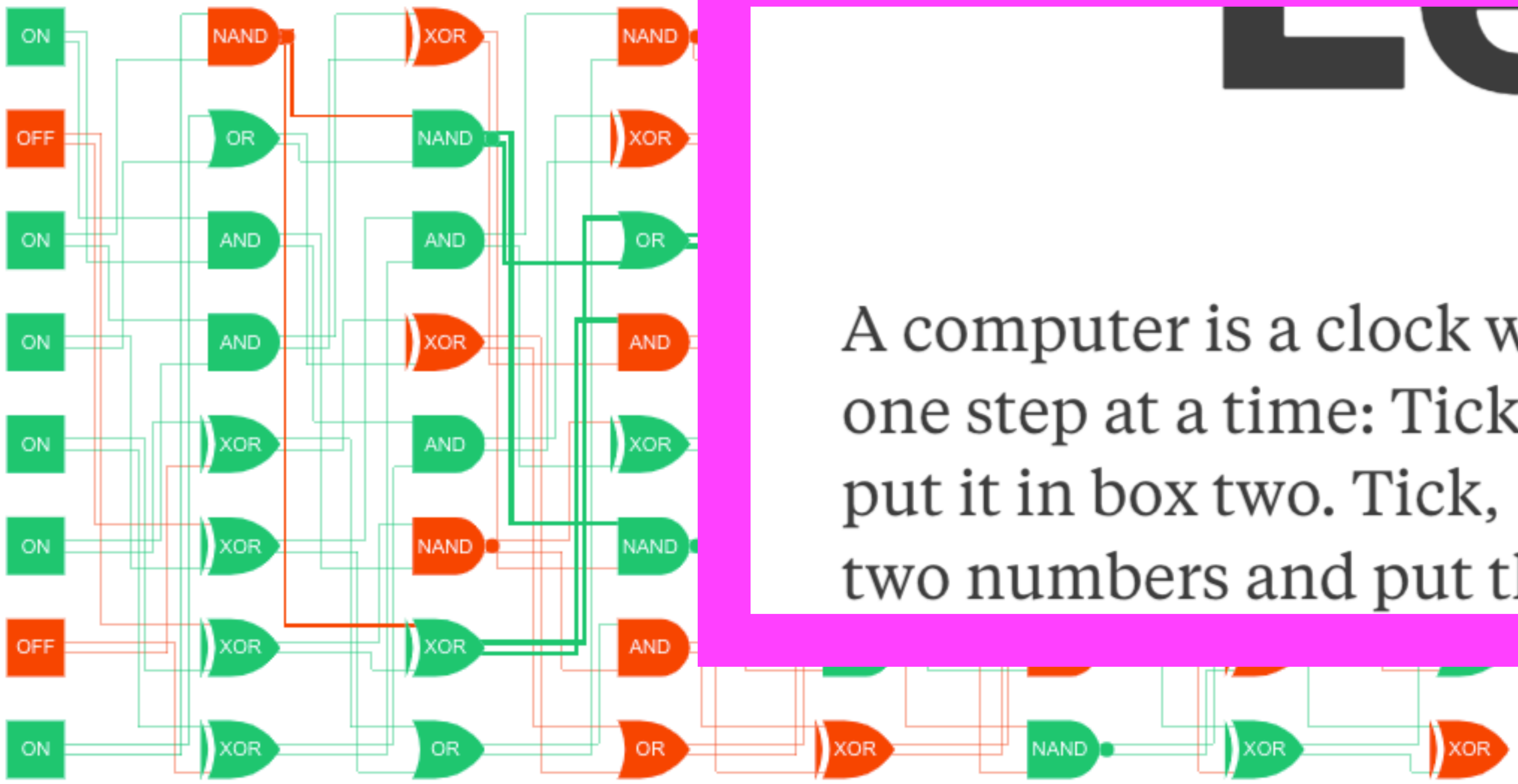

Let’s Be

A computer is a clock with benefits. They all work the
one step at a time: Tick, take a number and put it in b
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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.

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

```
void setup() {

}

void draw() {

}
```

```
function setup() {
  createCanvas(400, 400);
}

function draw() {
  background(220);
}
```

ARDUINO

PROCESSING

P5JS

"TICK"

Reference > Language > Functions > Time > Delay

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

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

```
unsigned long micros() {
    unsigned long m;
    uint8_t oldSREG = SREG, t;

    cli();
    m = timer0_overflow_count;
#if defined(TCNT0)
    t = TCNT0;
#elif defined(TCNT0L)
    t = TCNT0L;
#else
    #error TIMER 0 not defined
#endif

#ifdef 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

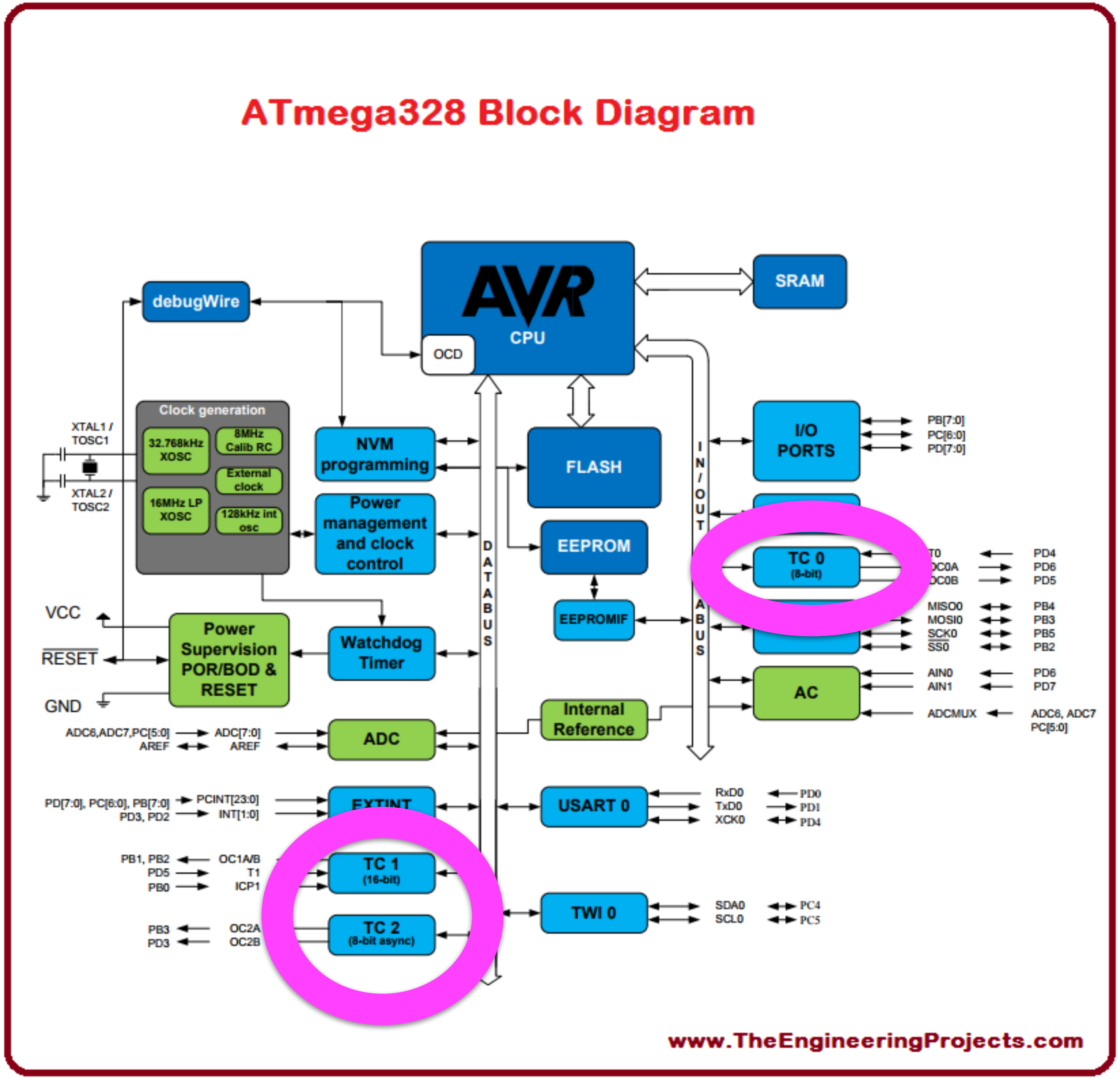
https://github.com/arduino/ArduinoCore-avr

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.



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);
. . .

#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 preceeding commands.
    // we just burned 19 (21) cycles above, remove 5, (5*4=20)
    // us is at least 8 so we can substract 5
    us -= 5; // = 2 cycles,
```

Several #elif directives covering different clock speeds

```
. . .

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

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

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

AVR Libc Reference Manual
avr-libc and assembler programs

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 TIMER0_OVF_v
TIMER0_OVF_vect:
        ldi     inttmp, 256
        out     _SFR_IO_ADDR

        in      intsav, _SFR

        sbic    _SFR_IO_ADDR
        rjmp    1f
        sbi     _SFR_IO_ADDR
        rjmp    2f
1:      cbi     _SFR_IO_ADDR
2:

        out     _SFR_IO_ADDR
        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
```

will be substituted by its value (6 in this case) before actually being passed to the assembler.

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 `TCCNT0` register, we therefore have to account for the number of clock cycles required for interrupt acknowledge and for the instructions to reload `TCCNT0` (4 clock cycles for interrupt acknowledge, 2 cycles for the jump from the interrupt vector, 2 cycles for the 2 instructions that reload `TCCNT0`). This is what the constant `fuzz` is for.

Note [5]

External functions need to be declared to be `.global`. `main` is the application entry point that will be jumped to from the ininitalization routine in `crts1200.o`.

Note [4]

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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 sevice needs to be saved,

https://www.microchip.com/webdoc/AVRLibcReferenceManual/assembler_1ass_example.html

ANALOGWRITE

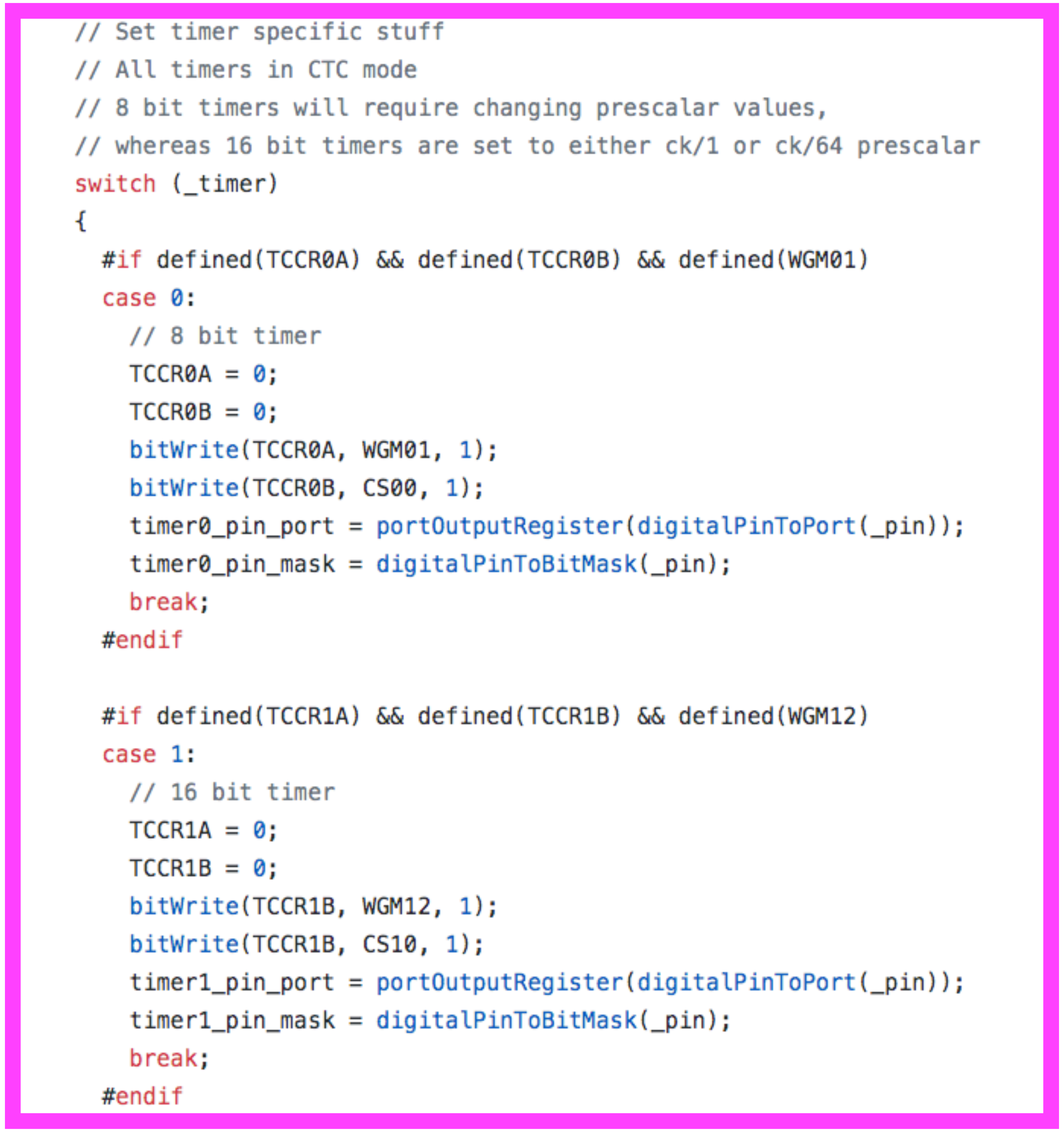
```
else
{
        switch(digitalPinToTimer(pin))
        {
                // XXX fix needed for atmega8
                #if defined(TCCR0) && defined(COM00) && !defined(__AVR_ATmega8__)
                case TIMER0A:
                        // connect pwm to pin on timer 0
                        sbi(TCCR0,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

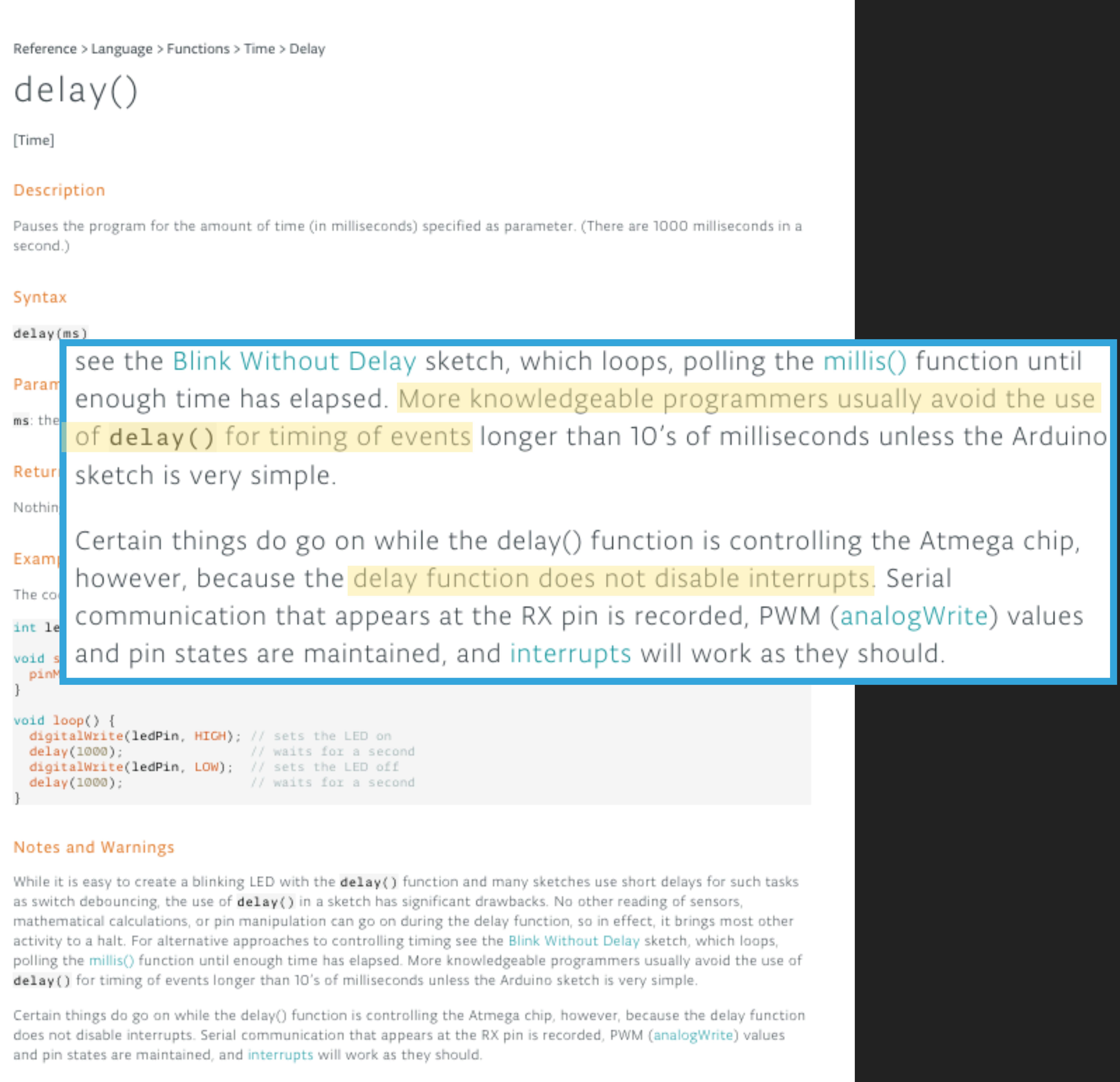
TONE



```
// 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
```

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



Reference > Language > Functions > Time > Delay

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

Retur

Nothin

Examp

The co

```
int le

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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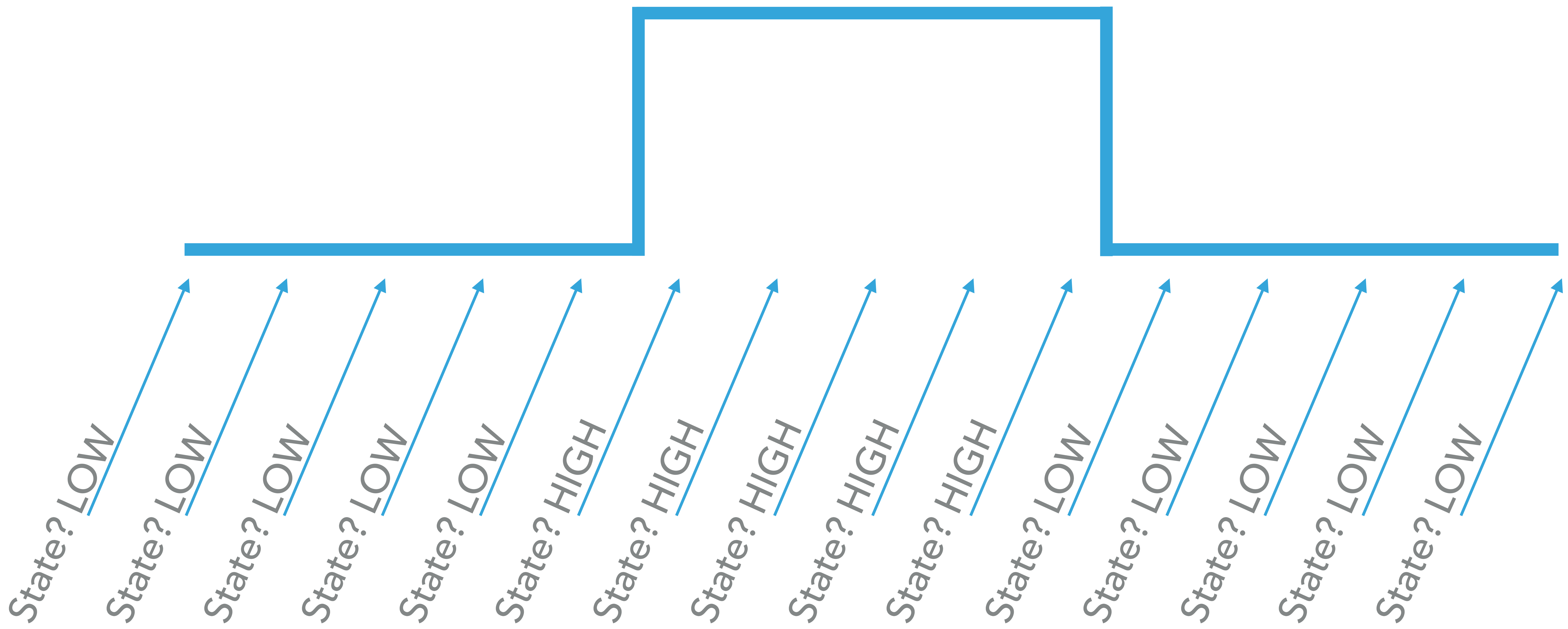
INTERRUPTS

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

Changes include:

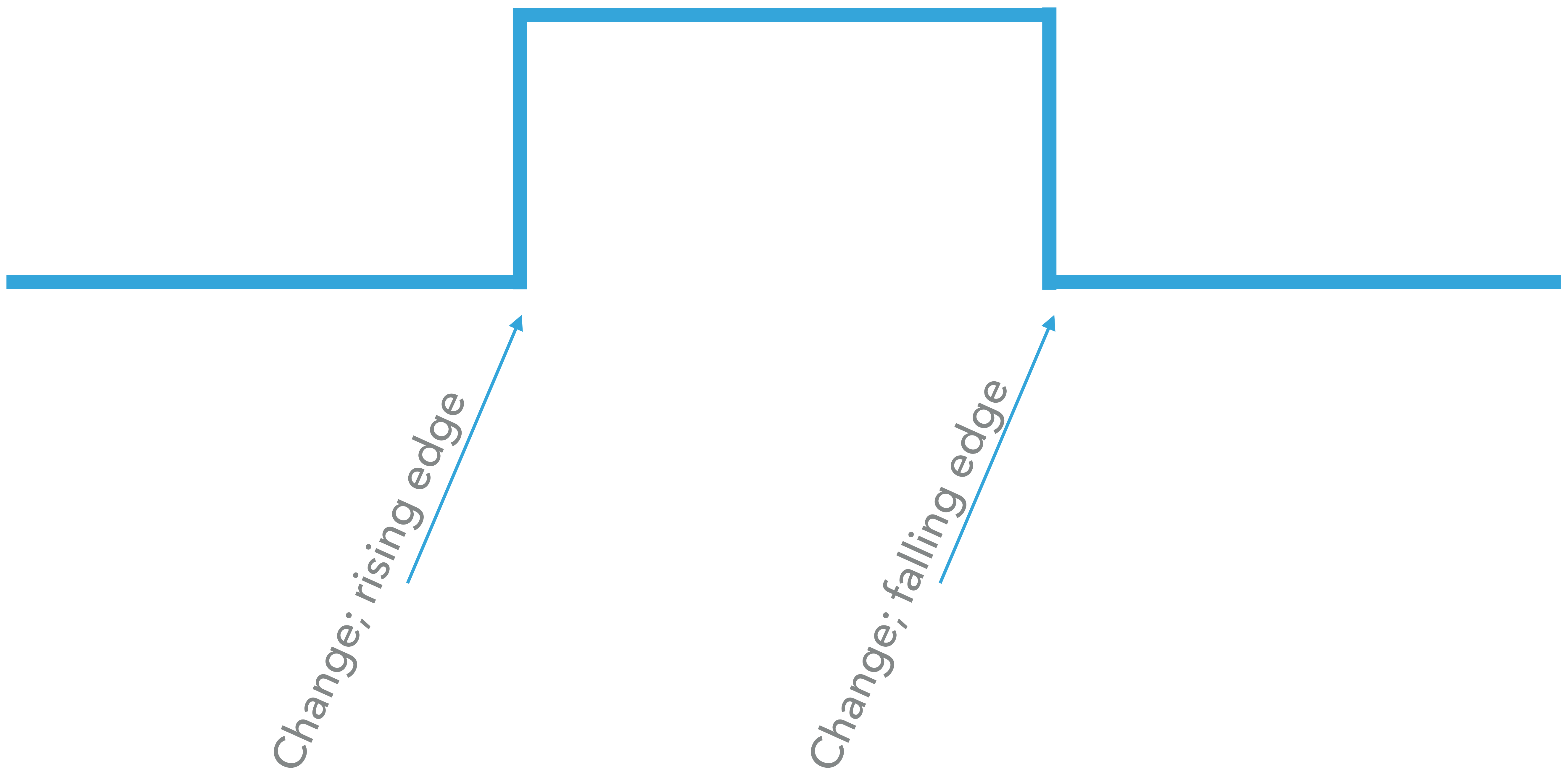
- **external,** such as voltage changes on an interrupt-enabled pin, or
- **internal**, from changes in an internal hardware **timer** (basically, a counter incrementing each clock cycle) reaching a certain value.

POLLING

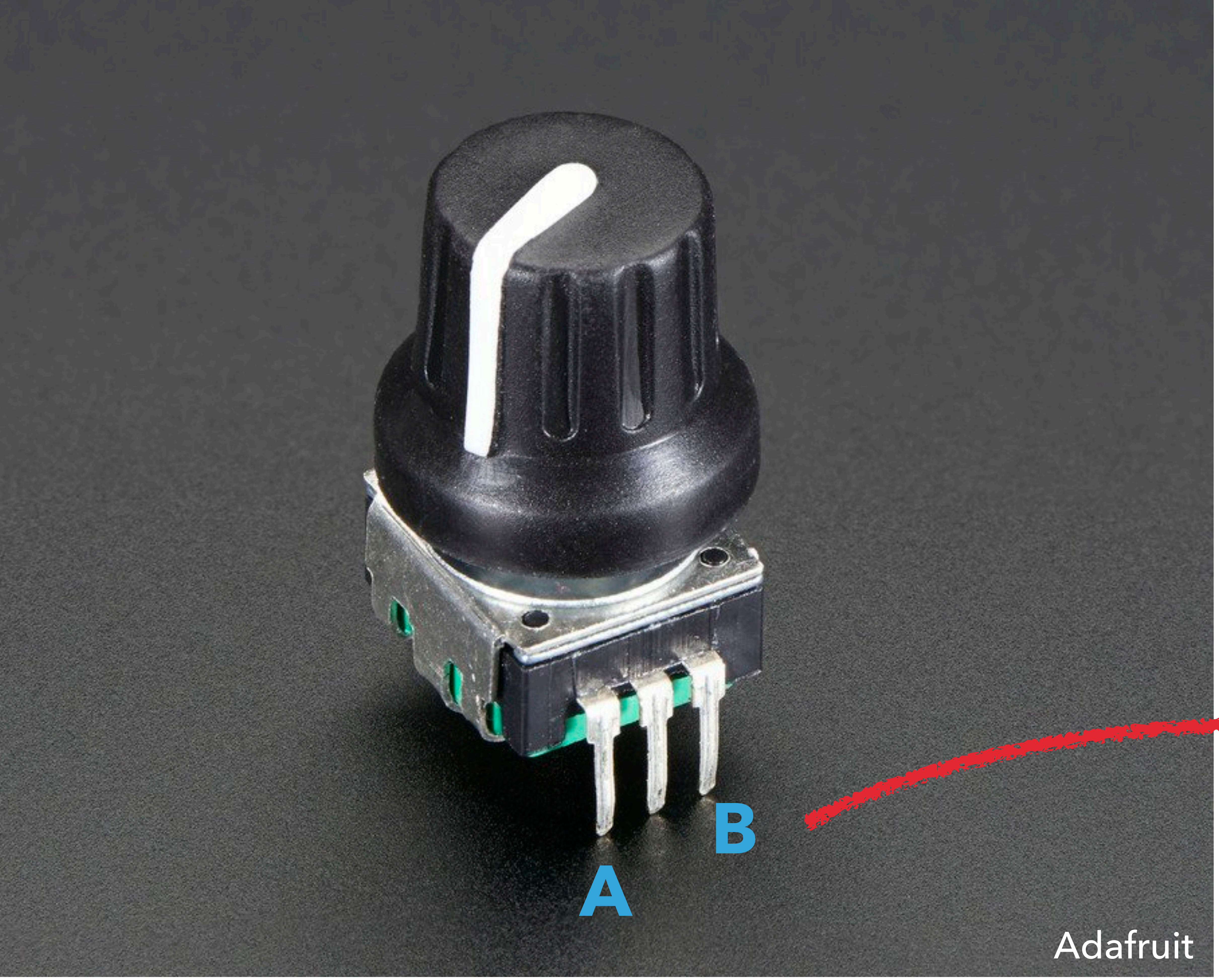


In main loop, use digital read to check the state of an input pin. Decide what to do if it is low, high, changed, etc.

INTERRUPTS

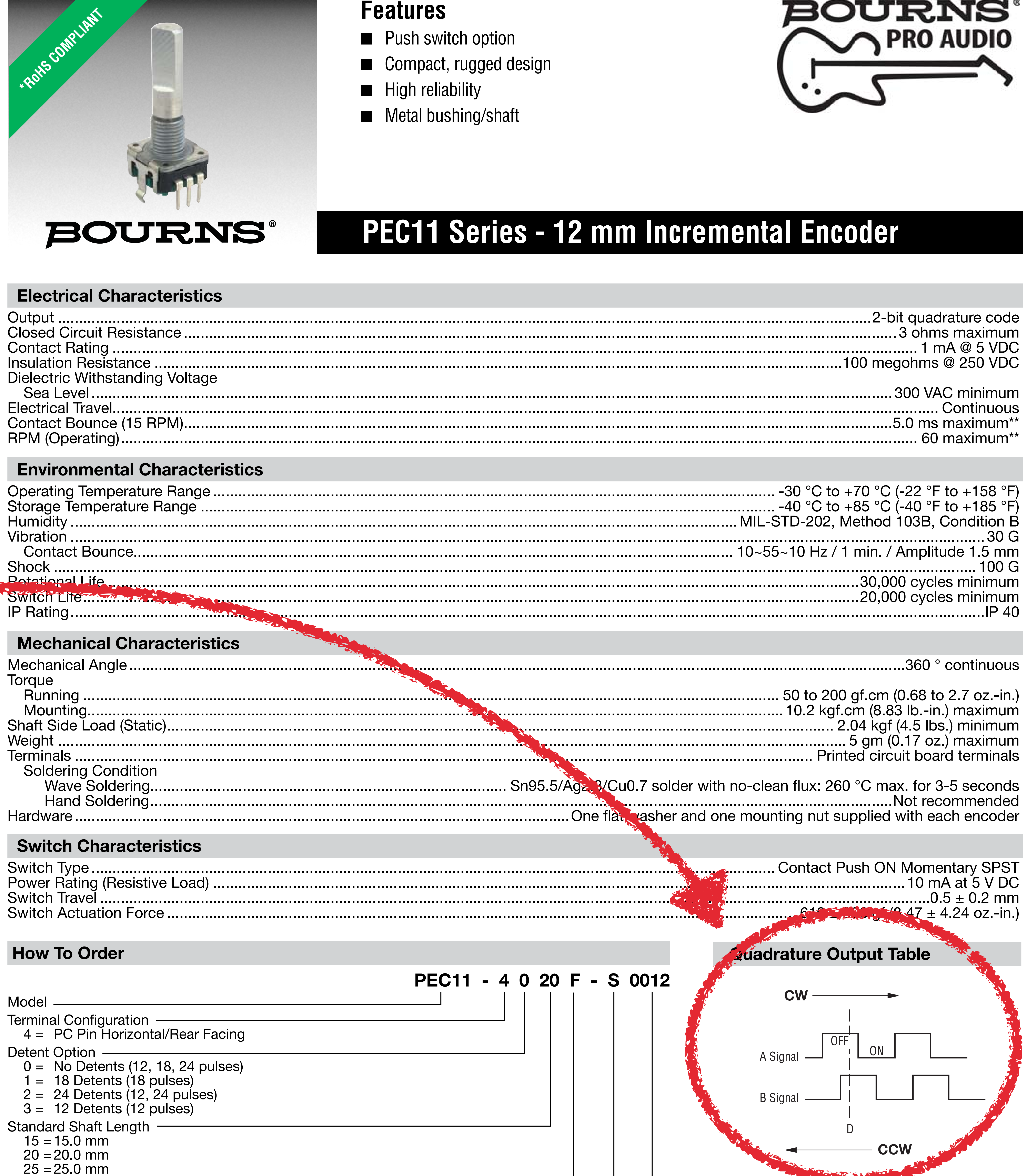


Define interrupt service routines (ISRs) for hardware changes: rising edge, falling edge, and/or change. These will be called immediately when the pin changes.



INTERRUPTS

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



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/Ag3.8/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	610 ± 305 gf.cm (8.47 ± 4.24 oz.-in.)

How To Order

PEC11 - 4 0 20 F - S 0012

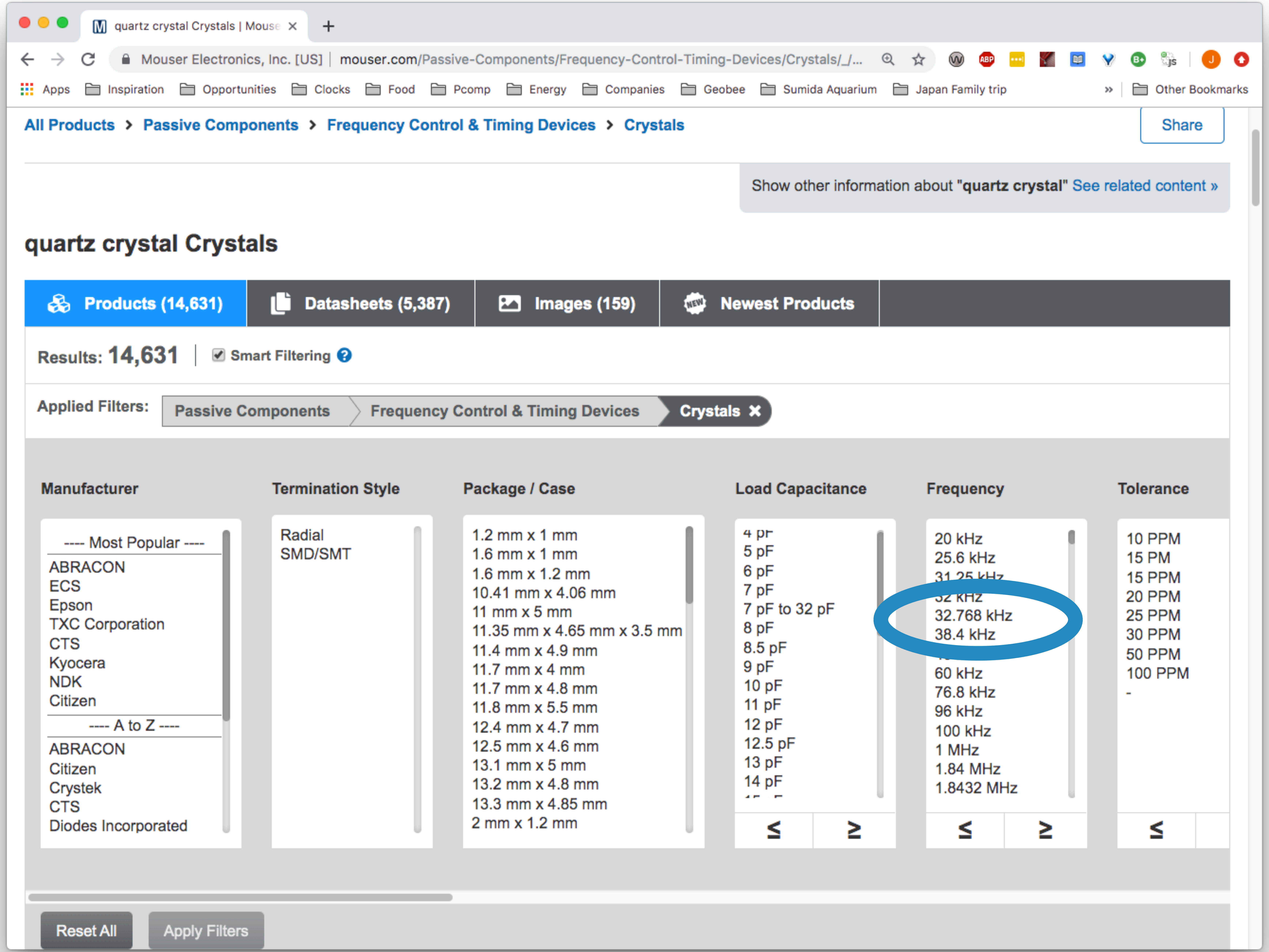
Model
Terminal Configuration
4 = PC Pin Horizontal/Rear Facing
Detent Option
0 = No Detents (12, 18, 24 pulses)
1 = 18 Detents (18 pulses)
2 = 24 Detents (12, 24 pulses)
3 = 12 Detents (12 pulses)
Standard Shaft Length
15 = 15.0 mm
20 = 20.0 mm
25 = 25.0 mm

Quadrature Output Table

Metronome

Standard quartz clock timer

32,768 = 2^15



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quartz crystal Crystals

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Applied Filters: Passive Components › Frequency Control & Timing Devices › Crystals ✖

Manufacturer

---- Most Popular ----
ABRACON
ECS
Epson
TXC Corporation
CTS
Kyocera
NDK
Citizen
---- A to Z ----
ABRACON
Citizen
Crystek
CTS
Diodes Incorporated

Termination Style

Radial
SMD/SMT

Package / Case

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

Load Capacitance

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
≤ ≥

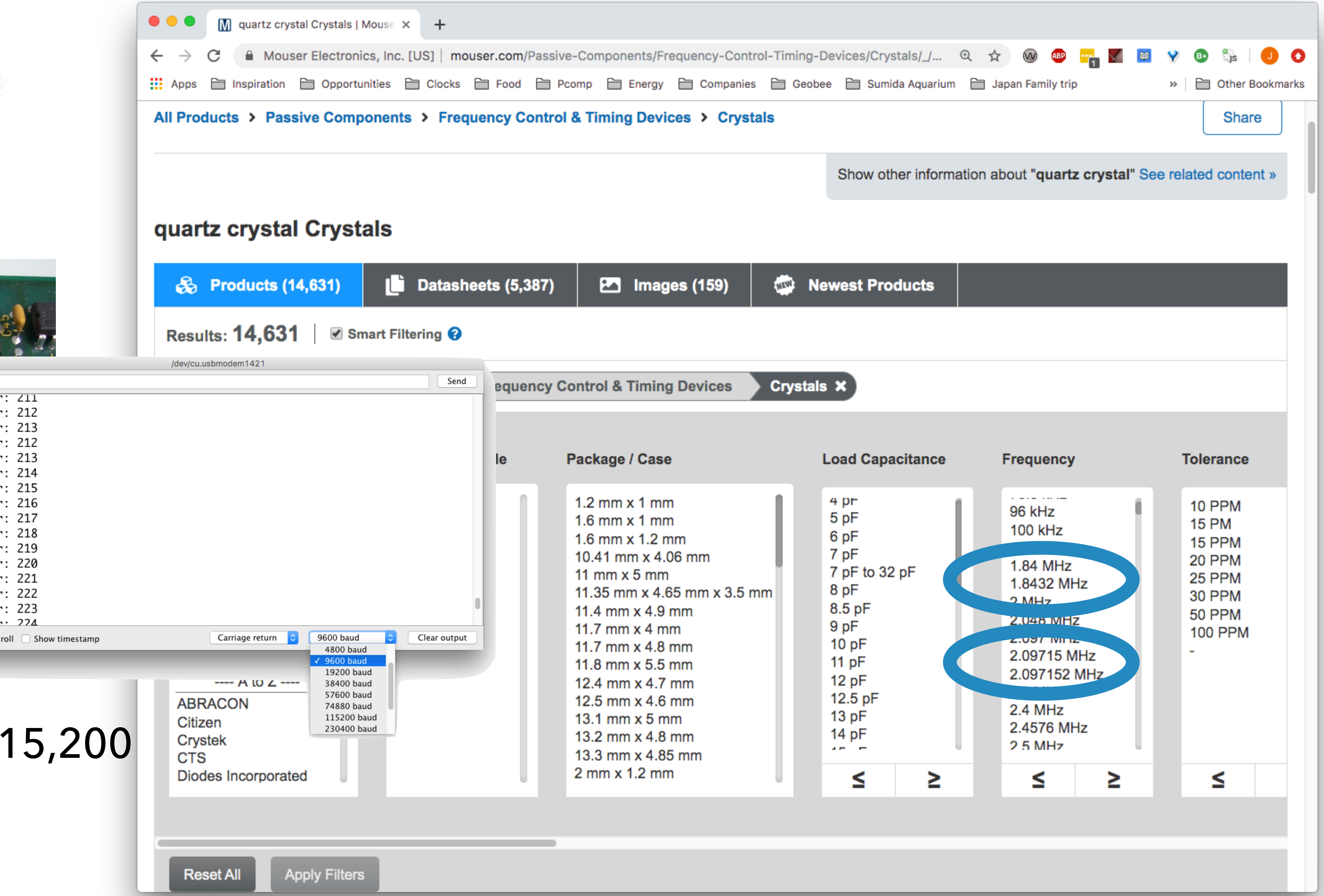
Frequency

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
≤ ≥

Tolerance

10 PPM
15 PM
15 PPM
20 PPM
25 PPM
30 PPM
50 PPM
100 PPM
-
≤

Precision timer
2,097,152 = 2^21


/dev/cu.usbmodem1421

```
Encoder: 211
Encoder: 212
Encoder: 213
Encoder: 212
Encoder: 213
Encoder: 214
Encoder: 215
Encoder: 216
Encoder: 217
Encoder: 218
Encoder: 219
Encoder: 220
Encoder: 221
Encoder: 222
Encoder: 223
Encoder: 224
```

☑ Autoscroll ☐ Show timestamp

Carriage return

9600 baud

quartz crystal Crystals | Mouse

Mouser Electronics, Inc. [US] | mouser.com/Passive-Components/Frequency-Control-Timing-Devices/Crystals/_/...

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Results: **14,631** | ☑ Smart Filtering

equency Control & Timing Devices › Crystals ✖

Package / Case

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

Load Capacitance

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

Frequency

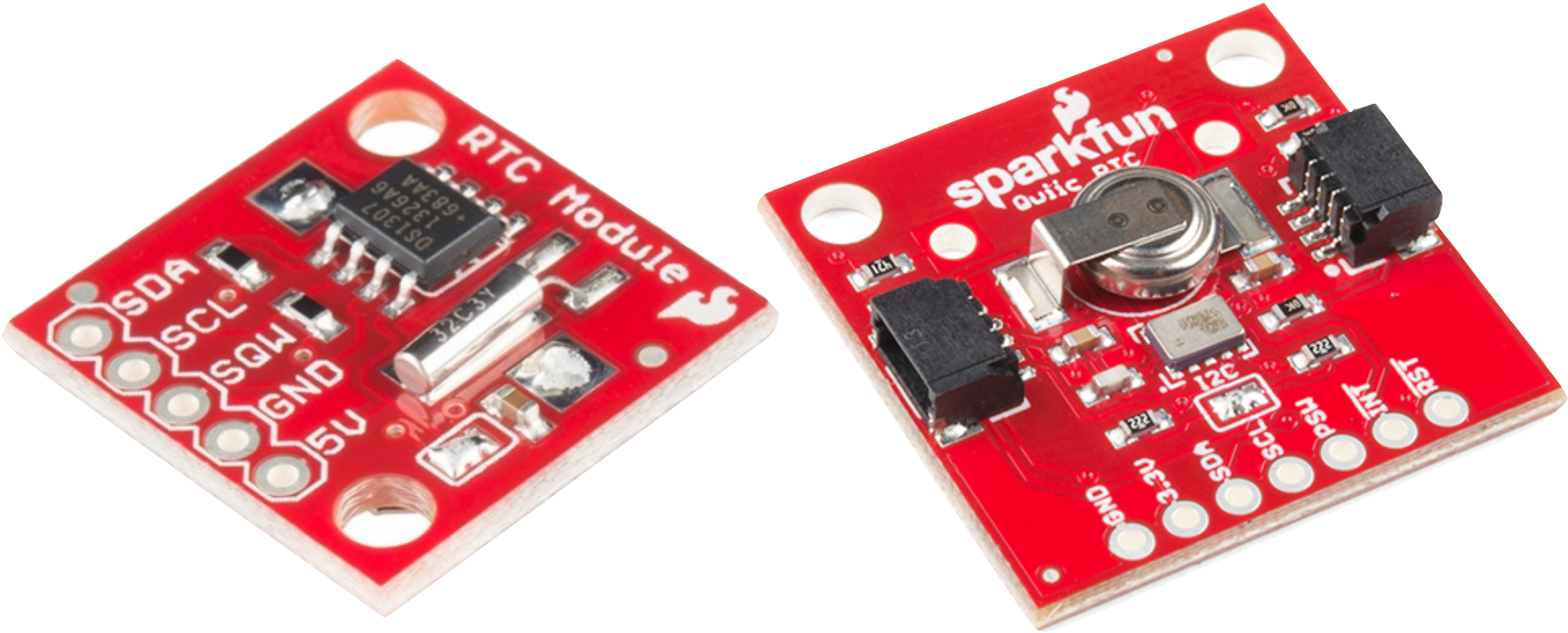
96 kHz
100 kHz
1.84 MHz
1.8432 MHz
2 MHz
2.048 MHz
2.097 MHz
2.09715 MHz
2.097152 MHz
2.4 MHz
2.4576 MHz
2.5 MHz

Tolerance

10 PPM
15 PM
15 PPM
20 PPM
25 PPM
30 PPM
50 PPM
100 PPM
-

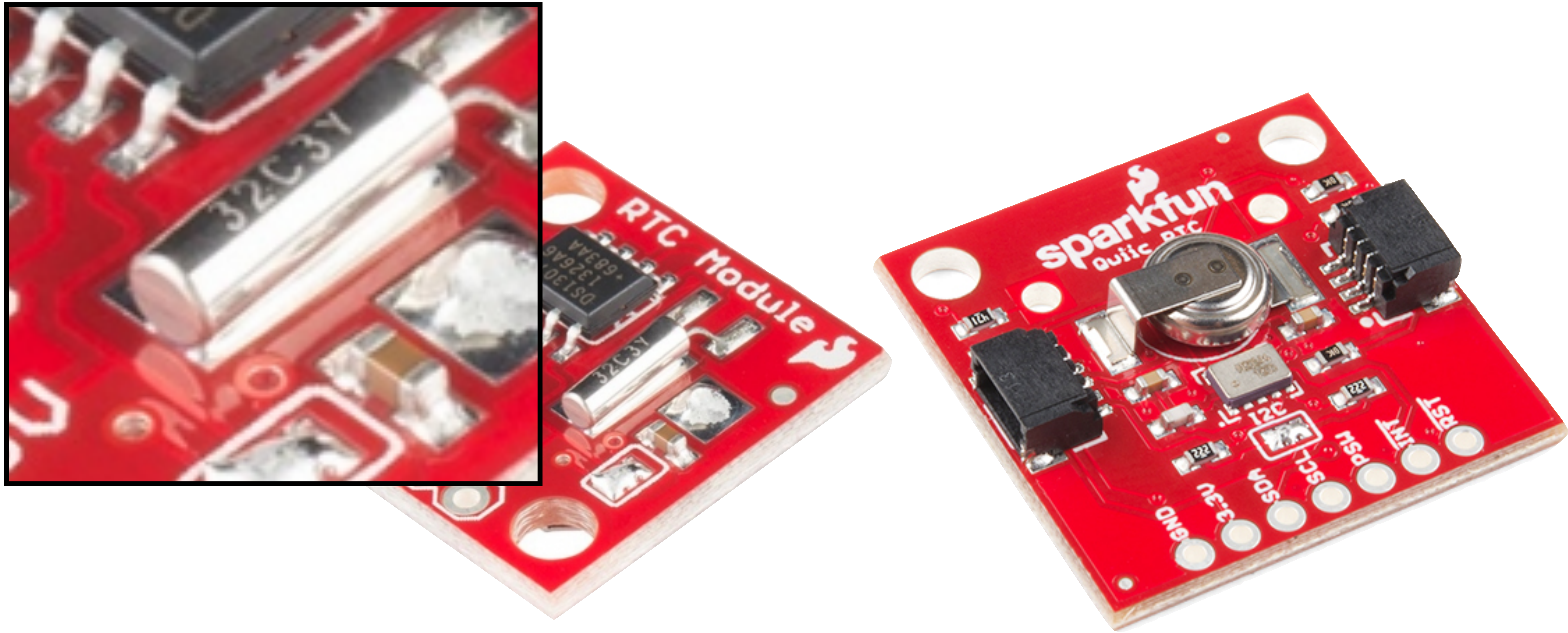
---- A to Z ----
ABRACON
Citizen
Crystek
CTS
Diodes Incorporated

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



Sparkfun RTC Breakout boards

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

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."

Sound wild? It's not an exaggeration. The electronic quartz concept is so different and important that the watch industry may never be the same again.

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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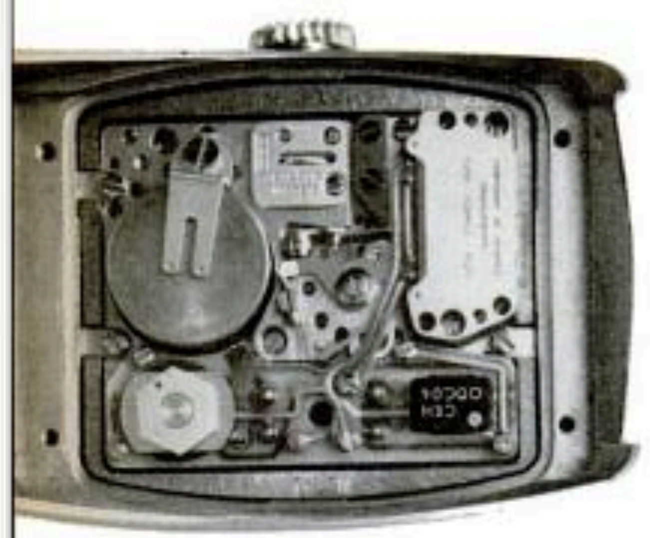

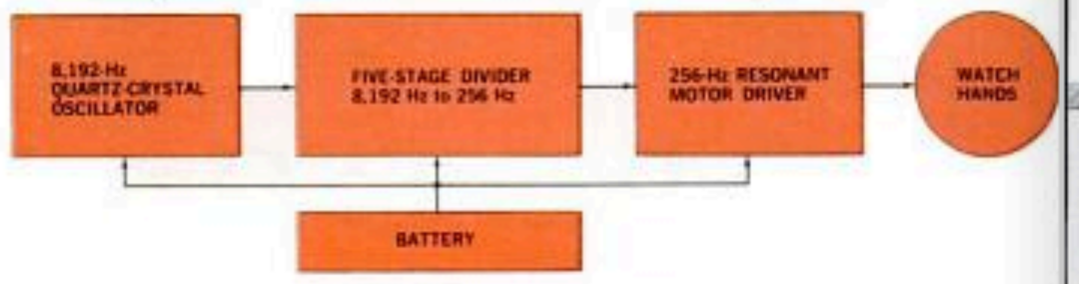

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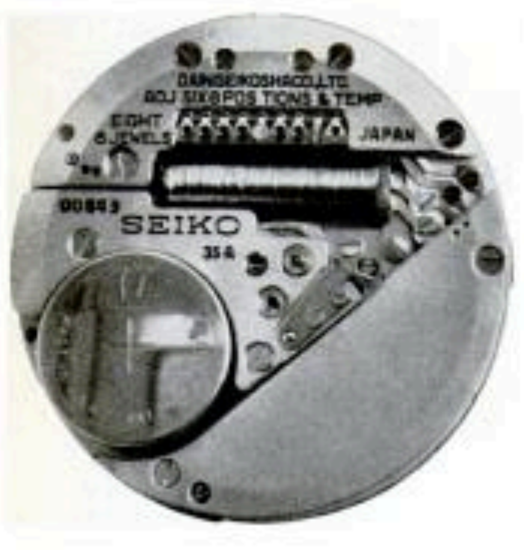

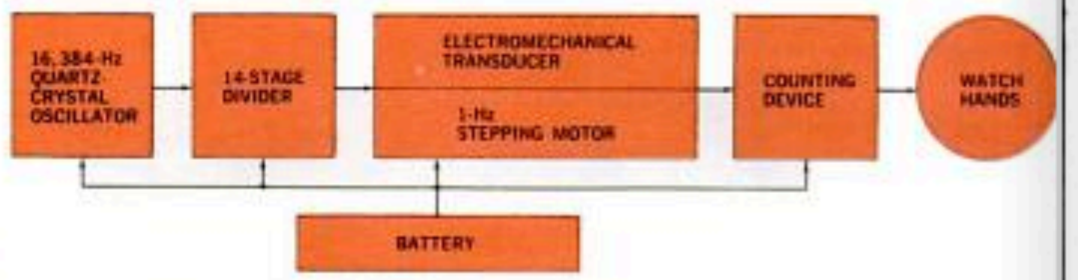

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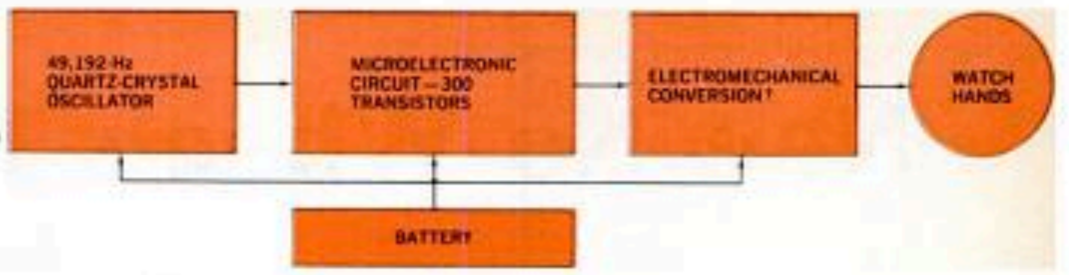

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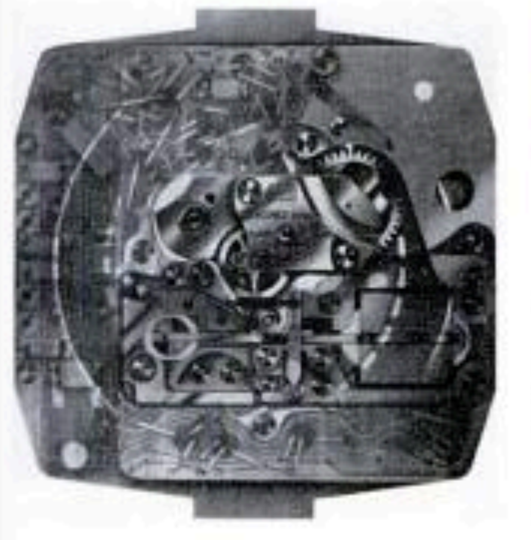

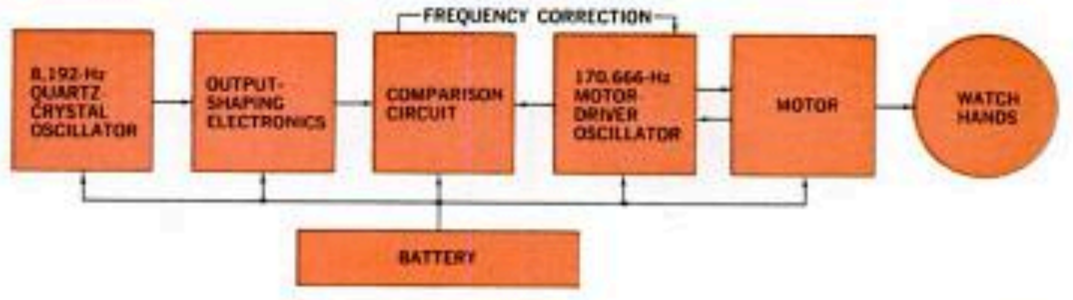

LONGINES **This one's unique:** A comparison circuit detects error in the watch's output and self-corrects. A 9,350-Hz quartz oscillator is the frequency reference—which is not divided, as in other watches. A 170-Hz servomotor, independent and operating by itself, turns the hands. Mechanical output is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

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^{13}). 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 watches a year, as we've been doing without learning a great deal abou automated mass production and methods of cost control. When it came t actually manufacturing the quart watch we already had a backlog o experience in essential fields like th design and manufacture of parts, especially miniaturized parts."

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

Despite the lack of any availabl proof, Timex has apparently figure out some way to simplify the desig and reduce the cost of building quartz-crystal watch with a super 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.

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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."

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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?

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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 limite are slightly larger and heavier than conventional wa new quartz was not available for this photo.

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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 30.5µs, 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)

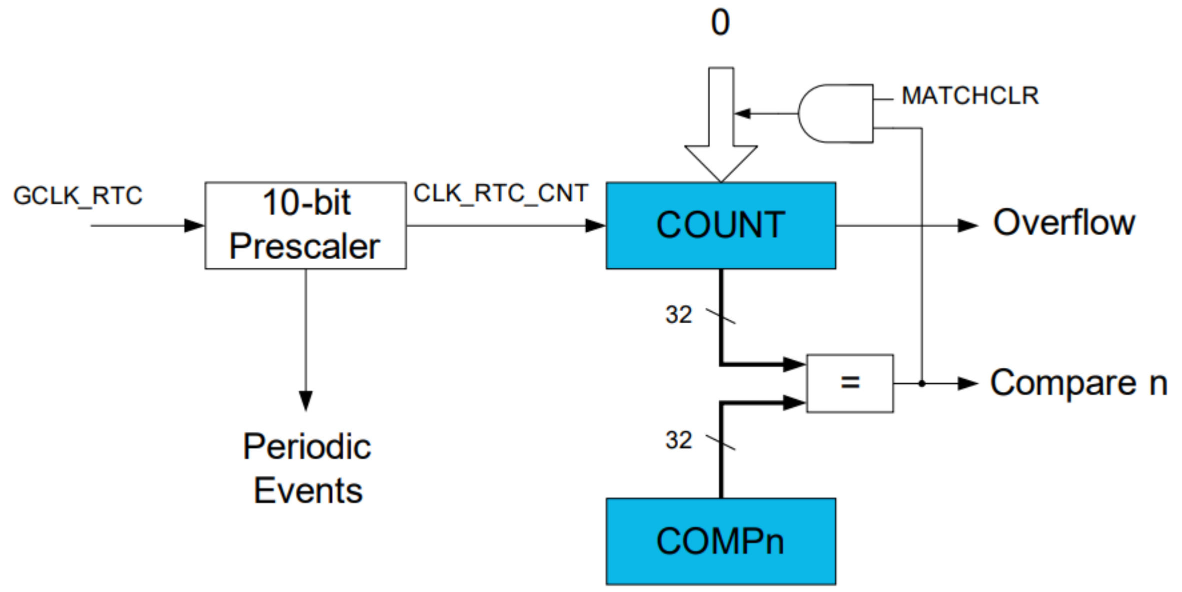


Figure 19-2. RTC Block Diagram (Mode 1 — 16-Bit Counter)

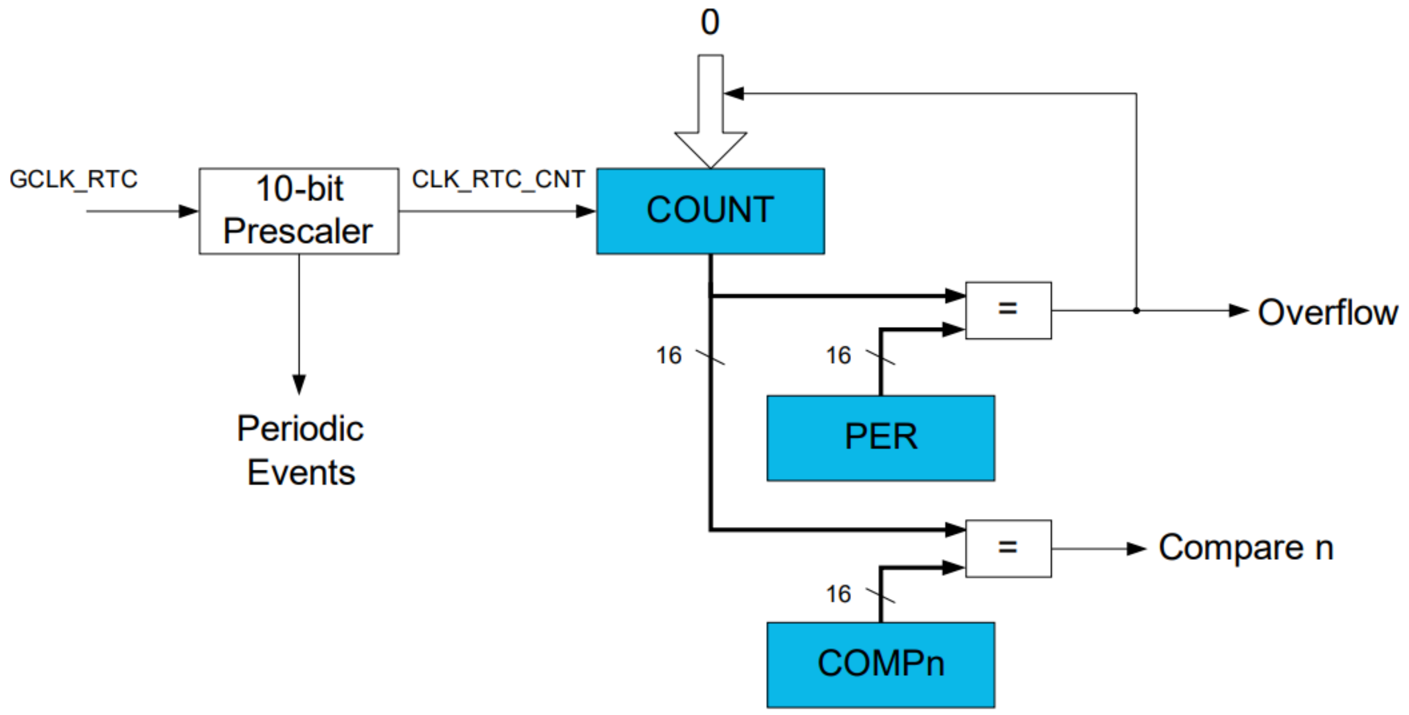
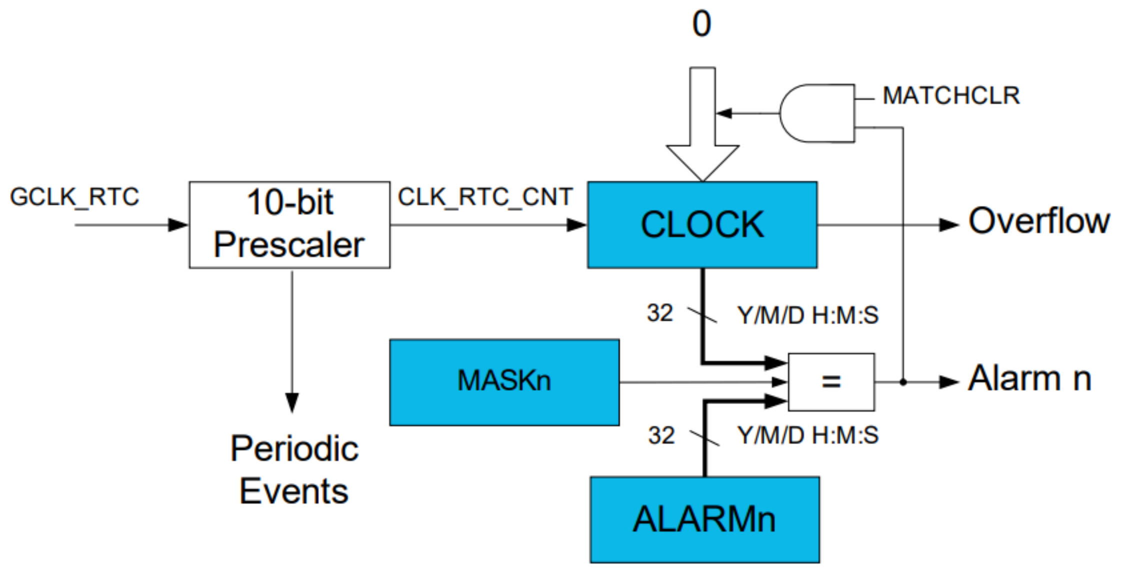


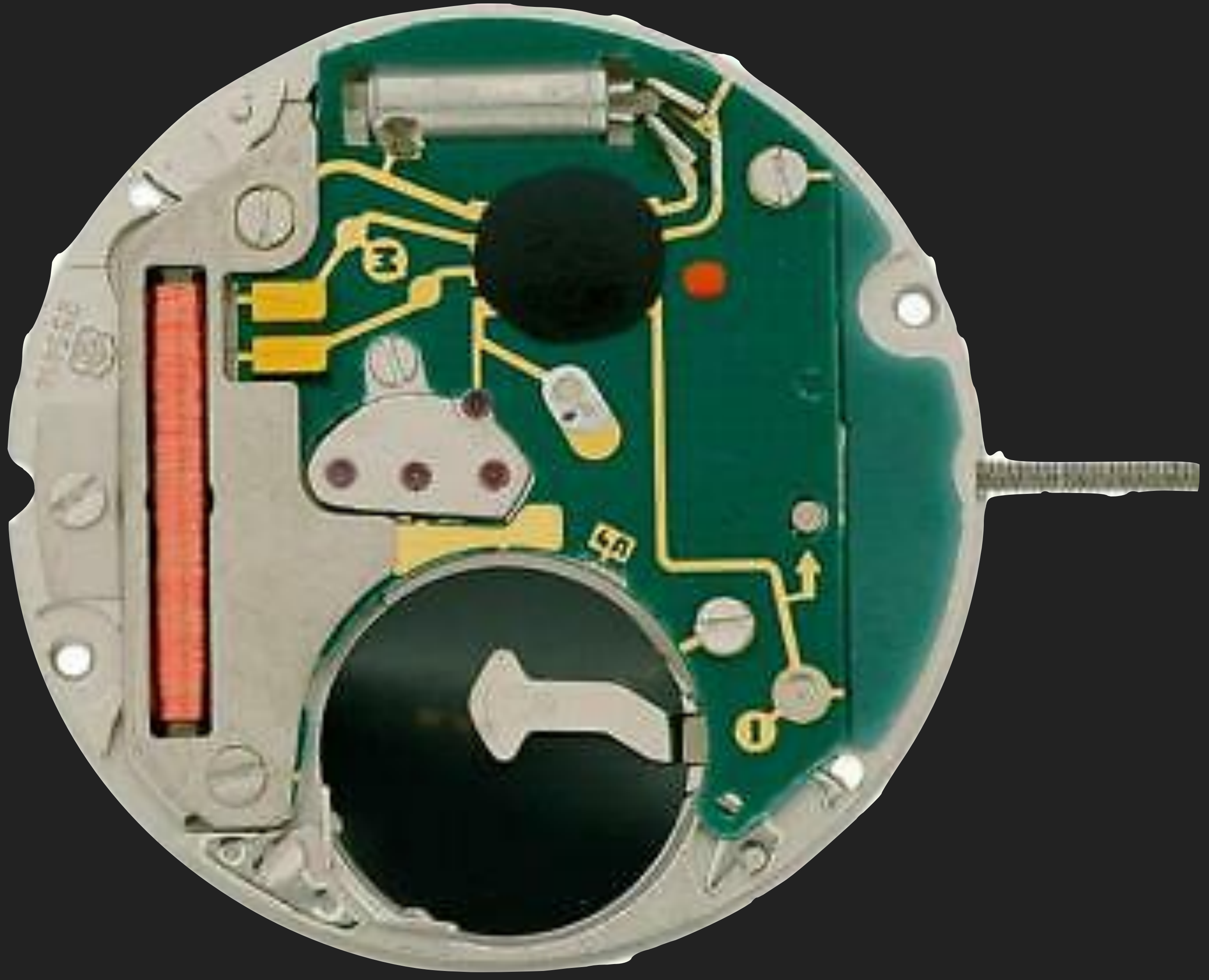
Figure 19-3. RTC Block Diagram (Mode 2 — Clock/Calendar)



OSCILLATORS

Mechanical
5–10 Hz

Electromechanical
360 Hz



Quartz
32,768 Hz

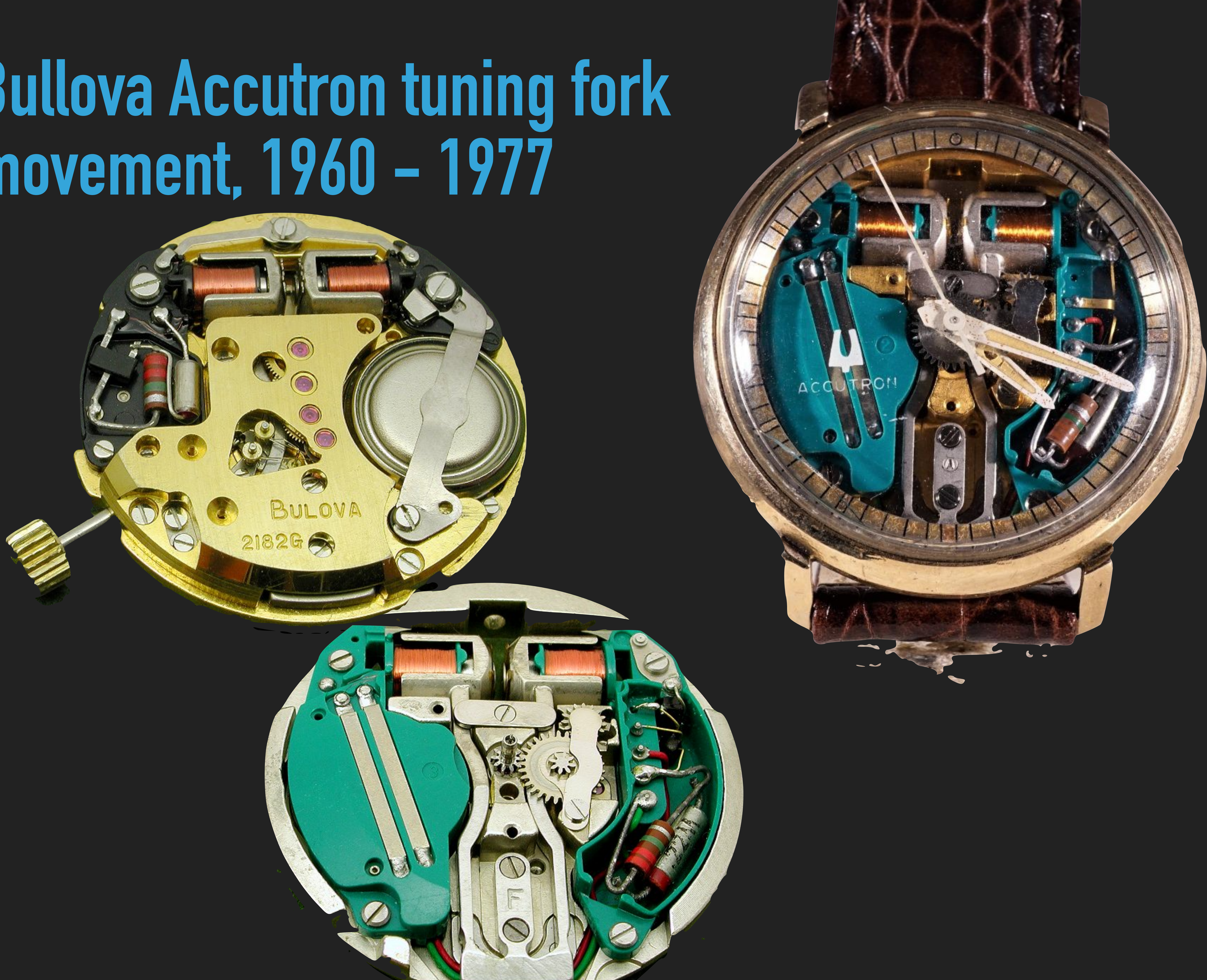
Last accurate, most expensive

(No longer made)

Most accurate, least expensive

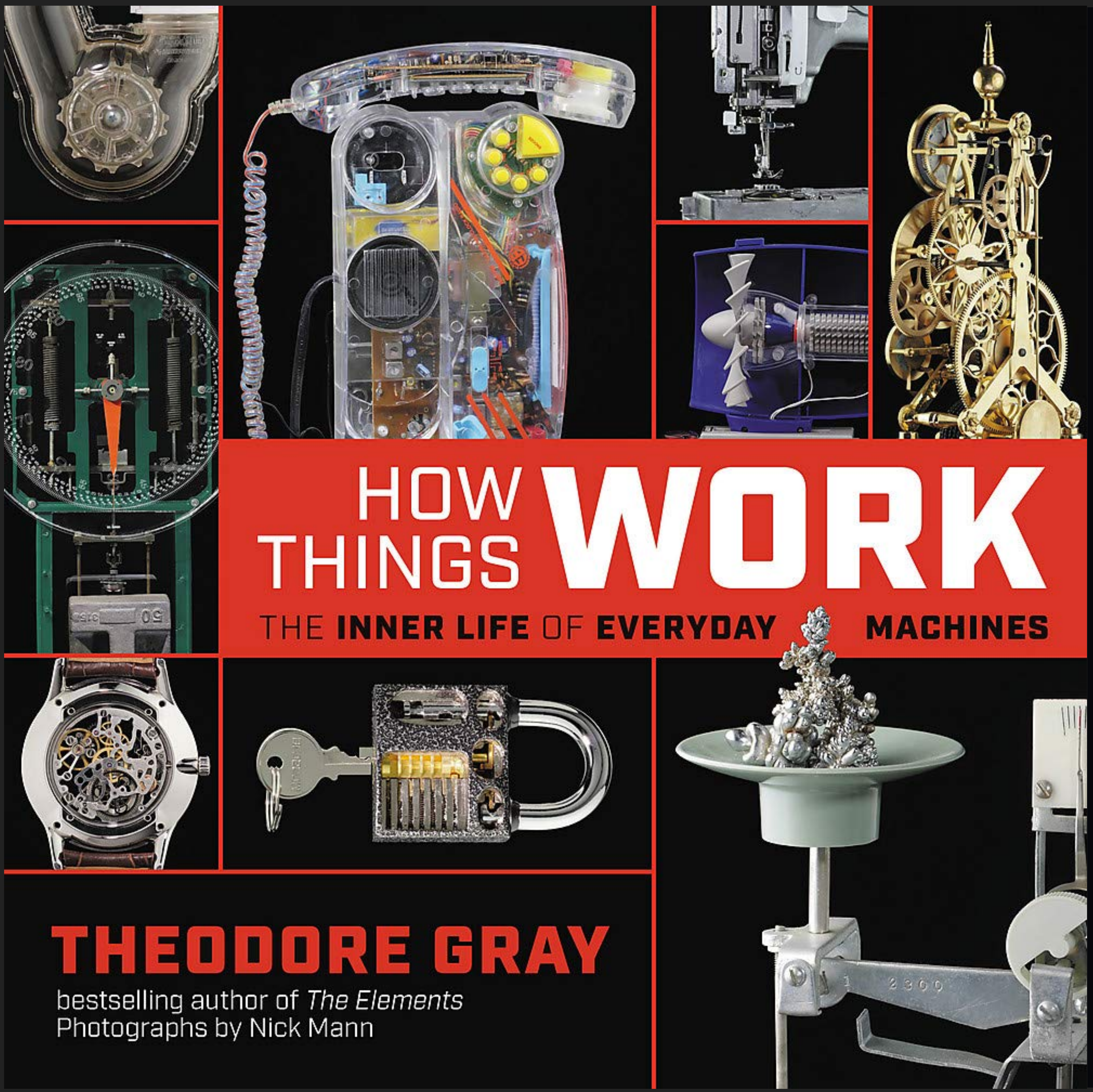
(ASIDE)

Bullova Accutron tuning fork movement, 1960 - 1977



(ASIDE)

Me ~1979



HOW THINGS WORK

THE INNER LIFE OF EVERYDAY MACHINES

THEODORE GRAY

bestselling author of *The Elements*
Photographs by Nick Mann

Pendulum Clocks

THE FIRST REALLY GOOD mechanical clocks were tick-tock-style pendulum clocks. The invention of the pendulum as a way of telling time was a *huge* advance in accuracy. Overnight, clocks went from drifting off by 15 minutes or more every day, to the best staying within 10 *seconds* per day.

This Chinese copy of an old French design shows off the very definition of "clockwork." Gears upon gears, folded in on each other, all moving together in ways that are, well, pretty confusing. To help make things understandable, I've made a spread-out model for you.

86 HOW THINGS WORK

FOR THE BENEFIT of those of you born in the present millennium, a primer on clocks of the old school. This is the universal symbol of time, the clock face. There are three "hands," which all turn around the same central point. Around the outside there are two sets of marks: one set of 60 small tick marks for seconds and minutes, and one set of 12 large tick marks for hours. This clock is showing 10:14:35 (14 minutes and 35 seconds after 10 o'clock).

The three hands on a clock are all turning around the same point, but they are turning at wildly different speeds. It takes 60 times longer for the minute hand to go around than the second hand, and the hour hand is another 12 times slower. For every complete turn of the hour hand, the second hand has to go around 720 times. This huge difference in speed is created by a mess of gears on the back of the clock.

The large tick marks with numbers (Roman numerals in this case) mark the hours.

The small tick marks, often not numbered, mark the minutes and seconds. You're just supposed to know that each hour mark corresponds to an interval of 5 minutes (for the minute hand) or 5 seconds (for the second hand). Each quarter of the circle is 15 minutes or 15 seconds, respectively.

The "hour hand" moves forward one large tick mark per hour, and takes 12 hours to go around one full turn. This hour hand is pointing about one-quarter of the way from the 10 mark to the 11 mark. That's because we are 14 minutes (and 35 seconds) past 10 o'clock.

The "minute hand" moves forward one small tick mark each minute, and takes one hour (60 minutes) to go around one full turn. This minute hand is pointing a little over halfway from the 14 minute mark to the 15 minute mark. That's because we are 35 seconds—about halfway—between those two minutes.

The "second hand" moves forward (in the "clockwise" direction) by one small tick mark each second, and takes one minute (60 seconds) to go around one full turn. This second hand is pointing at the 35 second mark.

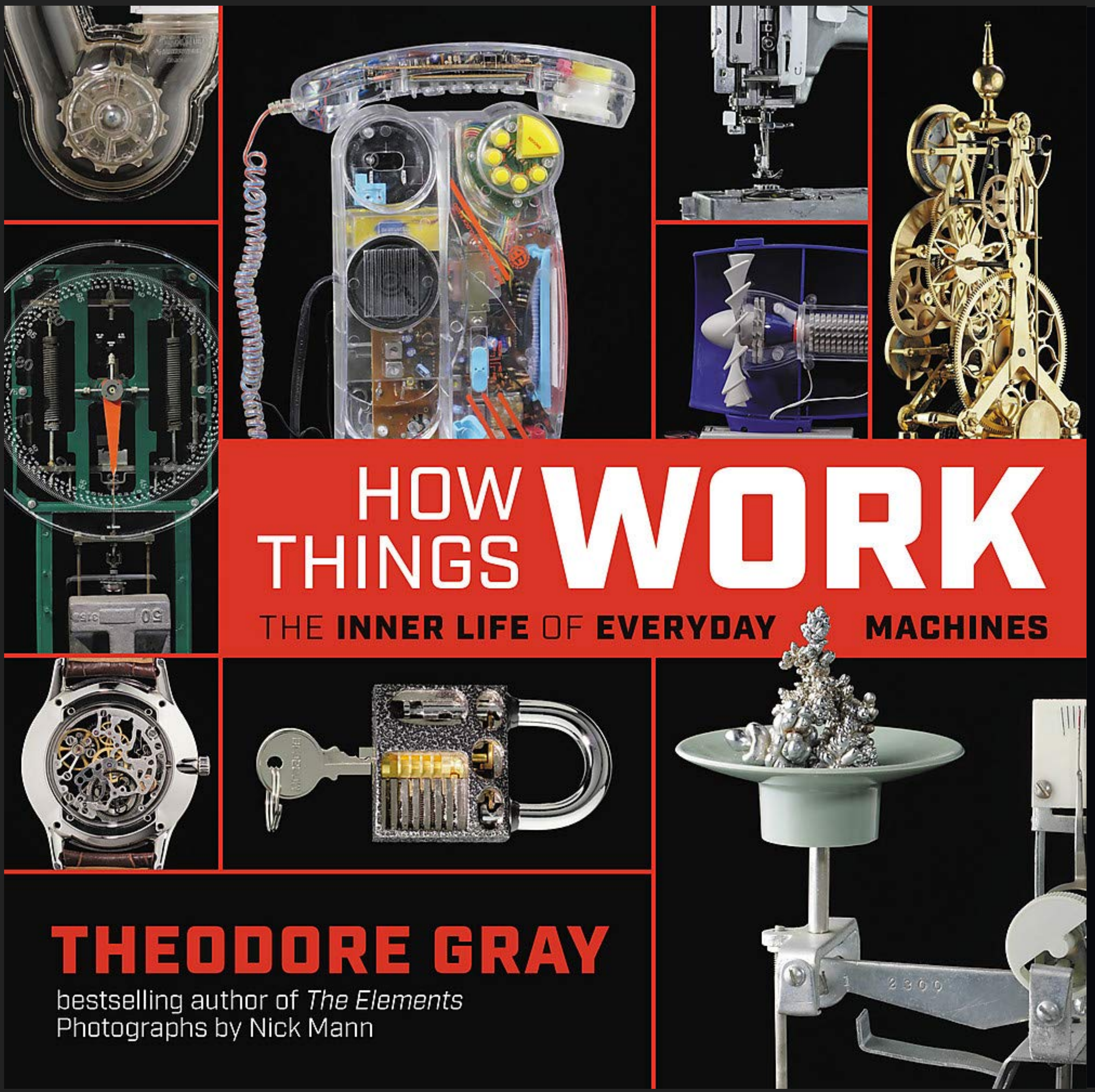
▲ There is something amusing in the fact that the telephone app on today's iPhones has an icon that looks like a phone no one has used in twenty years, and the clock app looks like a clock most people rarely see anymore. (It's also amusing that a separate telephone app is necessary on a device that is, by name, already a phone. But, the truth is, making phone calls is one of the iPhone's least commonly used functions.)

CLOCKS 87

"We've now arrived at the subject of really accurate time. Earlier I said that up until 1955 a glorified sundial was the most accurate clock in existence. Another way of saying this is that we were using the rotation of the earth as the reference standard for time, because we didn't have anything better.

Every day the time told by the world's best clocks was compared to the exact moment that a set of reference stars past directly overhead at the Greenwich Observatory in London. If there was a deviation between when the clocks said the stars should pass overhead and when they actually did, we trusted the stars over the clocks, and reset the clocks. Based on everything we knew about the earth and the clocks there was no reason to think that the clocks were a more accurate measure of time to the rotation of the earth.

Two clocks, even if one is the earth, or not enough. But if you have three clocks, and you find that two of them stay exactly in sync with the third one drifts away, now you've got some evidence that the third one is the problem. If you have 100 clocks spread all over the world, built by different people using different methods, and all but one of them agree with each other, then you can be pretty sure that the outlier is the problem, not the other 99 clocks. In 1955 the earth became that outlier – not because of anything changed about the earth but because we suddenly got much better at building clocks. What changed in 1955 with the invention of the cesium atomic clock."



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Photographs by Nick Mann

Pendulum Clocks

THE FIRST REALLY GOOD mechanical clocks were tick-tock-style pendulum clocks. The invention of the pendulum as a way of telling time was a *huge* advance in accuracy. Overnight, clocks went from drifting off by 15 minutes or more every day, to the best staying within 10 *seconds* per day.

This Chinese copy of an old French design shows off the very definition of "clockwork." Gears upon gears, folded in on each other, all moving together in ways that are, well, pretty confusing. To help make things understandable, I've made a spread-out model for you.

86 HOW THINGS WORK

FOR THE BENEFIT of those of you born in the present millennium, a primer on clocks of the old school. This is the universal symbol of time, the clock face. There are three "hands," which all turn around the same central point. Around the outside there are two sets of marks: one set of 60 small tick marks for seconds and minutes, and one set of 12 large tick marks for hours. This clock is showing 10:14:35 (14 minutes and 35 seconds after 10 o'clock).

The three hands on a clock are all turning around the same point, but they are turning at wildly different speeds. It takes 60 times longer for the minute hand to go around than the second hand, and the hour hand is another 12 times slower. For every complete turn of the hour hand, the second hand has to go around 720 times. This huge difference in speed is created by a mess of gears on the back of the clock.

The large tick marks with numbers (Roman numerals in this case) mark the hours.

The small tick marks, often not numbered, mark the minutes and seconds. You're just supposed to know that each hour mark corresponds to an interval of 5 minutes (for the minute hand) or 5 seconds (for the second hand). Each quarter of the circle is 15 minutes or 15 seconds, respectively.

The "hour hand" moves forward one large tick mark per hour, and takes 12 hours to go around one full turn. This hour hand is pointing about one-quarter of the way from the 10 mark to the 11 mark. That's because we are 14 minutes (and 35 seconds) past 10 o'clock.

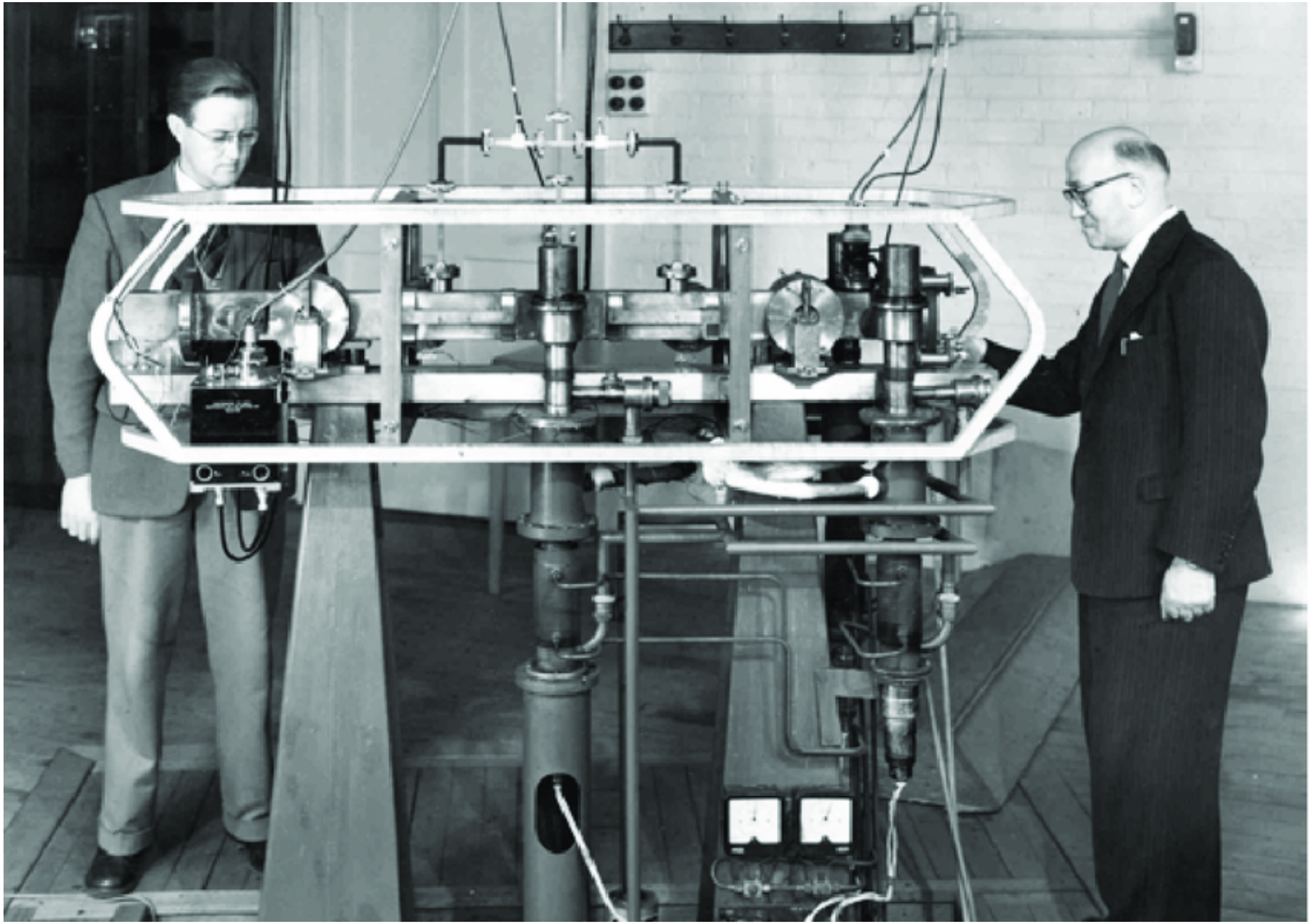
The "minute hand" moves forward one small tick mark each minute, and takes one hour (60 minutes) to go around one full turn. This minute hand is pointing a little over halfway from the 14 minute mark to the 15 minute mark. That's because we are 35 seconds—about halfway—between those two minutes.

The "second hand" moves forward (in the "clockwise" direction) by one small tick mark each second, and takes one minute (60 seconds) to go around one full turn. This second hand is pointing at the 35 second mark.

▲ There is something amusing in the fact that the telephone app on today's iPhones has an icon that looks like a phone no one has used in twenty years, and the clock app looks like a clock most people rarely see anymore. (It's also amusing that a separate telephone app is necessary on a device that is, by name, already a phone. But, the truth is, making phone calls is one of the iPhone's least commonly used functions.)

CLOCKS 87

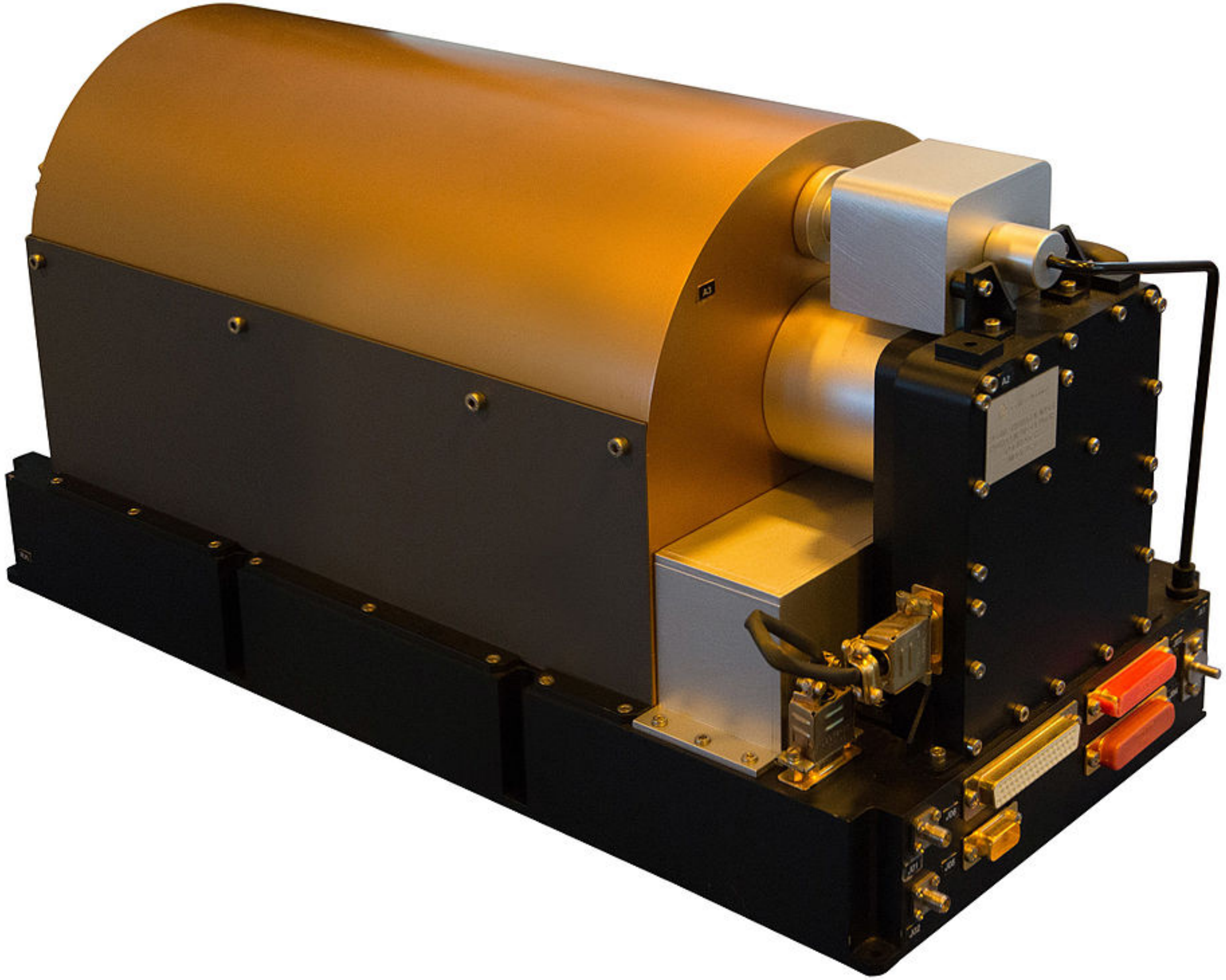
(GET THIS BOOK!)



Essen and Perry Atomic Clock, 1955

The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom.

Onsemi Chip-Scale Atomic Clock (CSAC)



Space Passive Hydrogen Maser used in Galileo satellites as a master clock for an onboard timing system
Wikipedia

GPS (US) – 01978, 31

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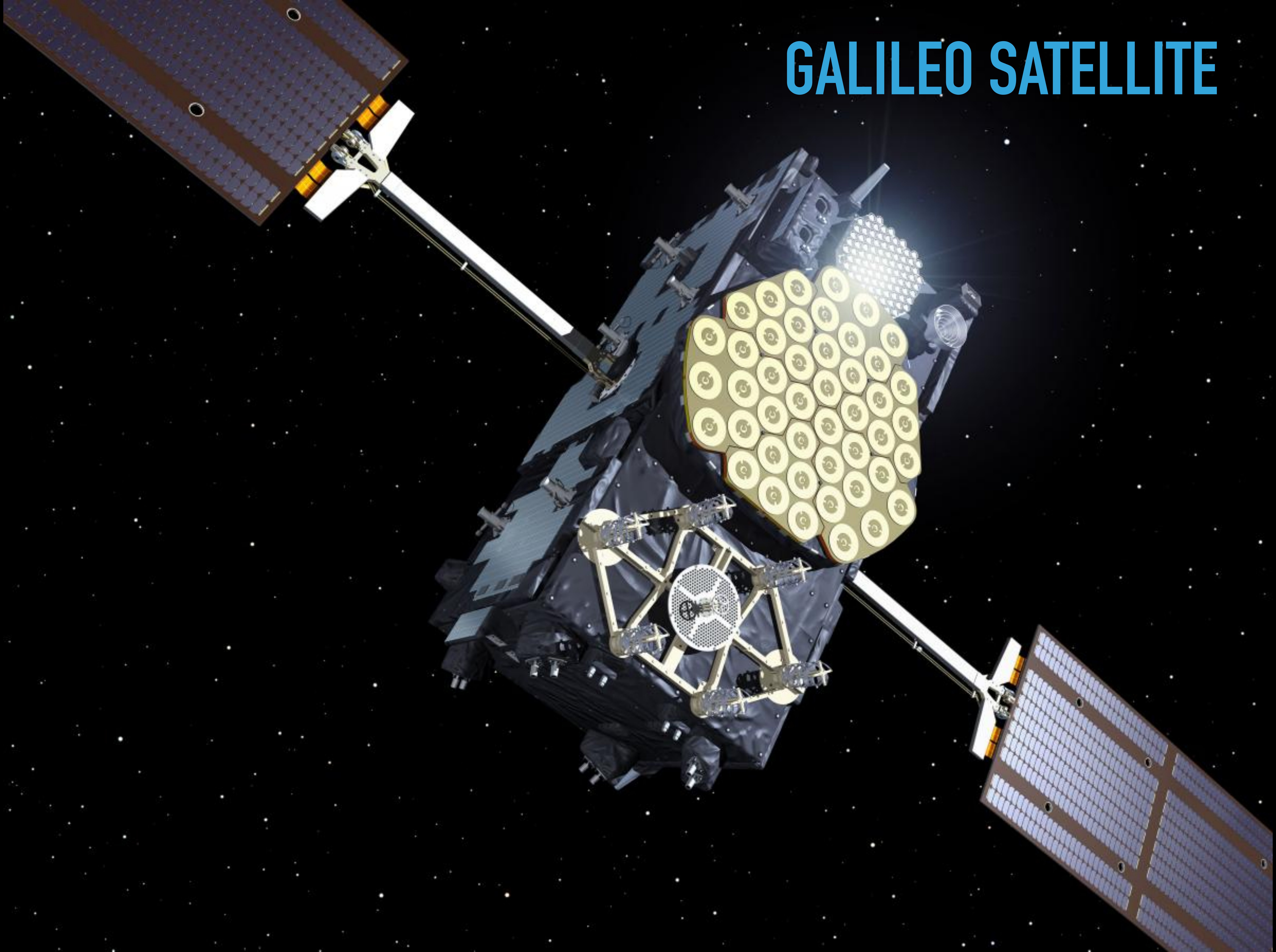
MISSION BADGES RANKED BY DESIGN

BLOCK IIF NAVSTAR GPS SPACE VEHICLE

GPS CONSTELLATION

6 orbital planes, MEO

GALILEO SATELLITE



GLONASS SATELLITE

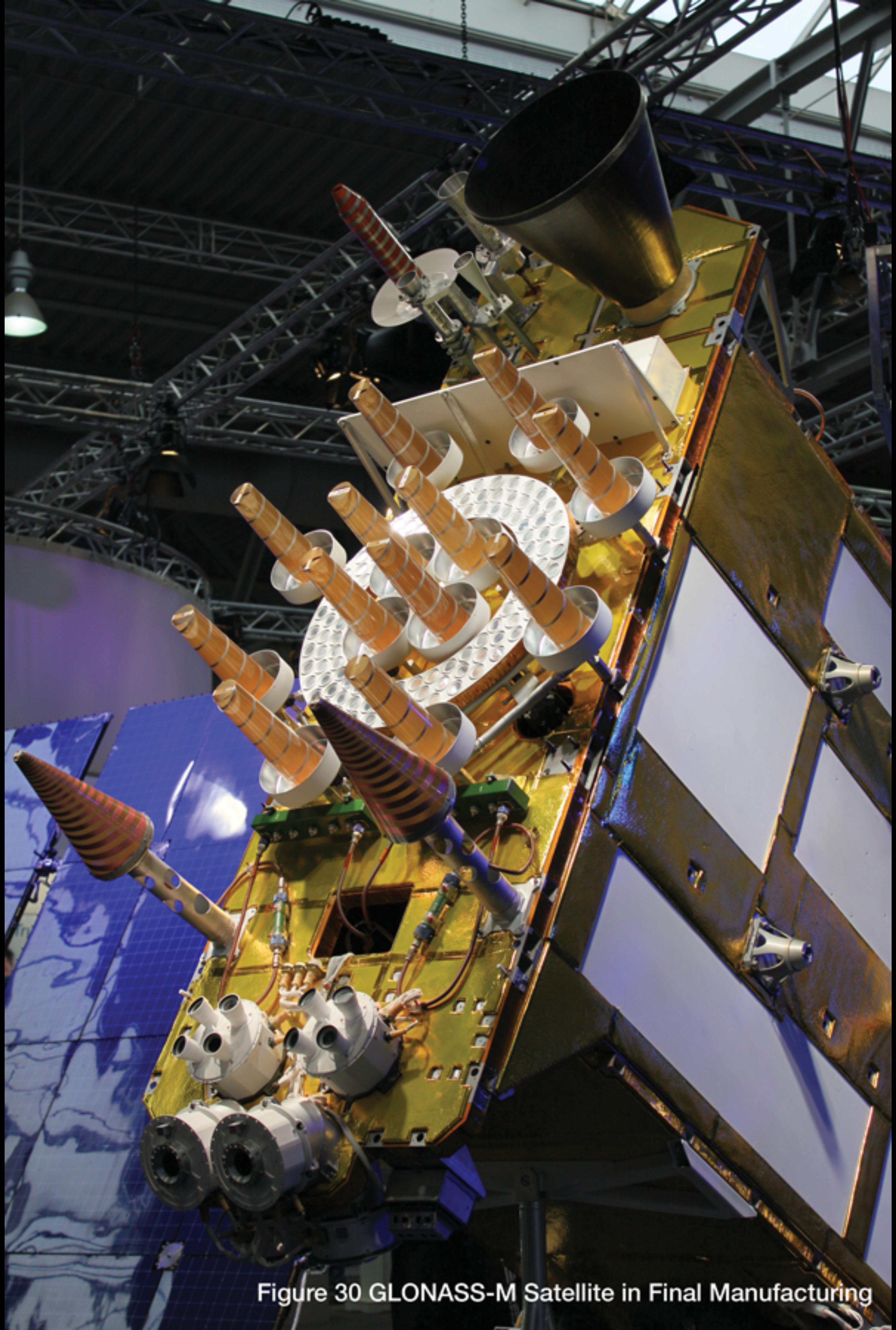


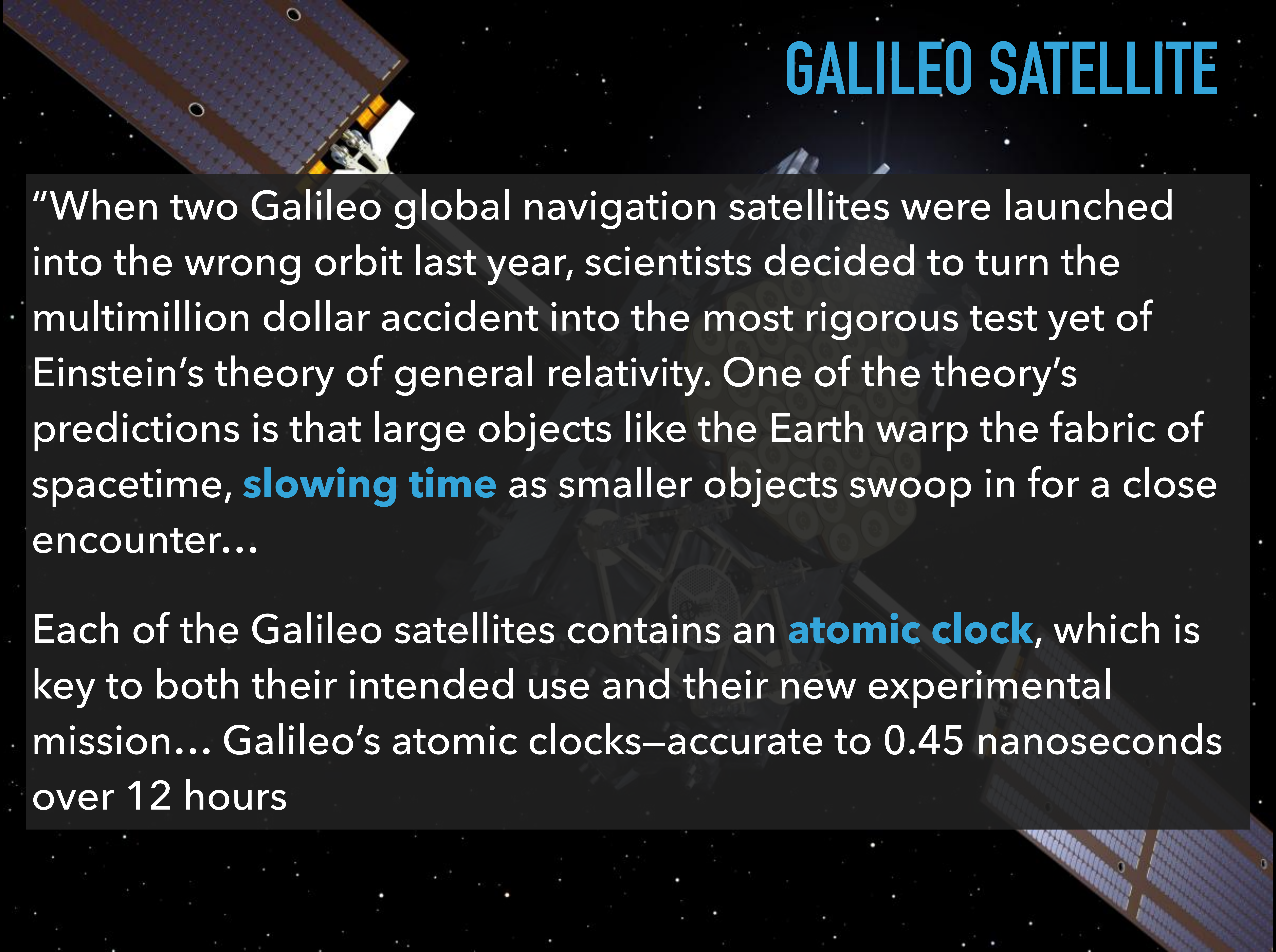
Figure 30 GLONASS-M Satellite in Final Manufacturing

novatel.com

BEIDOU SATELLITE

opengovasia.com

GALILEO SATELLITE



“When two Galileo global navigation satellites were launched into the wrong orbit last year, scientists decided to turn the multimillion dollar accident into the most rigorous test yet of Einstein’s theory of general relativity. One of the theory’s predictions is that large objects like the Earth warp the fabric of spacetime, **slowing time** as smaller objects swoop in for a close encounter…

Each of the Galileo satellites contains an **atomic clock**, which is key to both their intended use and their new experimental mission… Galileo’s atomic clocks—accurate to 0.45 nanoseconds over 12 hours

GALILEO SATELLITE