Fri: Barnett 145-154

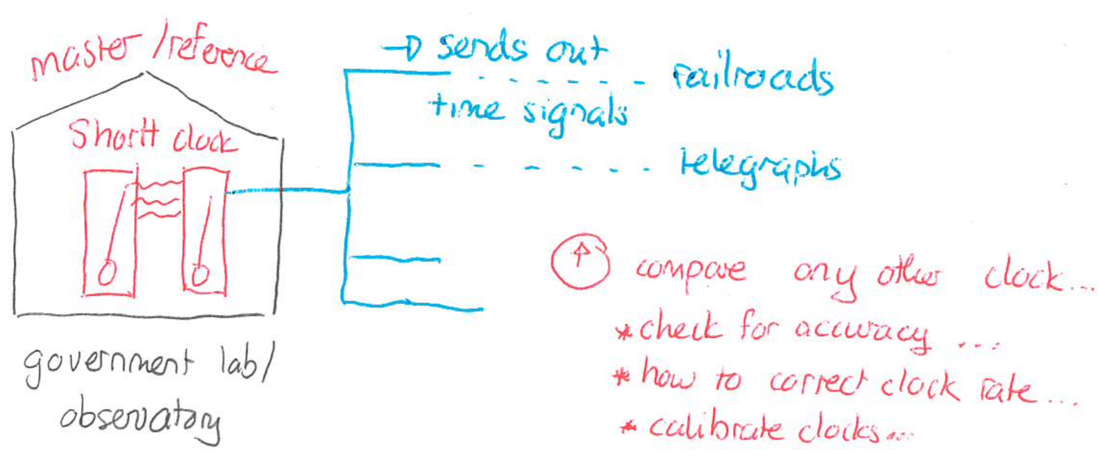
Monday after break: Draft 1.

Precision timekeeping before 1920

The best precision timekeeping before 1920 was done using sophisticated pendulum clocks. The most advanced pendulum clock at the time, the Shortt clock, lost only 0.0002s/day.

This precision was well beyond the immediate daily timekeeping needs of most people. It was even beyond some of the specialized needs that we have encountered. For example if it were used for navigation such a clock would lose 0.073s per year. This would translate into an error of 0.00030° of longitude in a year and at the equator that amounts to about 0.02mi = 30ft. Such precision was not necessary for ordinary ocean navigation at that time. Why did such a clock exist?

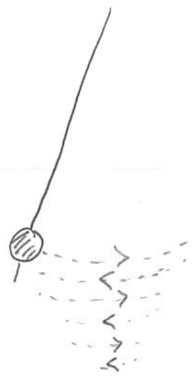
Such clocks were used as timekeeping standards, and as references against which to check other clocks. There is a structure



Limitations on pendulum clocks

Any mechanical pendulum will display damped motion and this is true of pendulums in clocks. Thus clocks and watches include mechanisms that restore the motion. Then the response of the pendulum to such a driving mechanism depends on

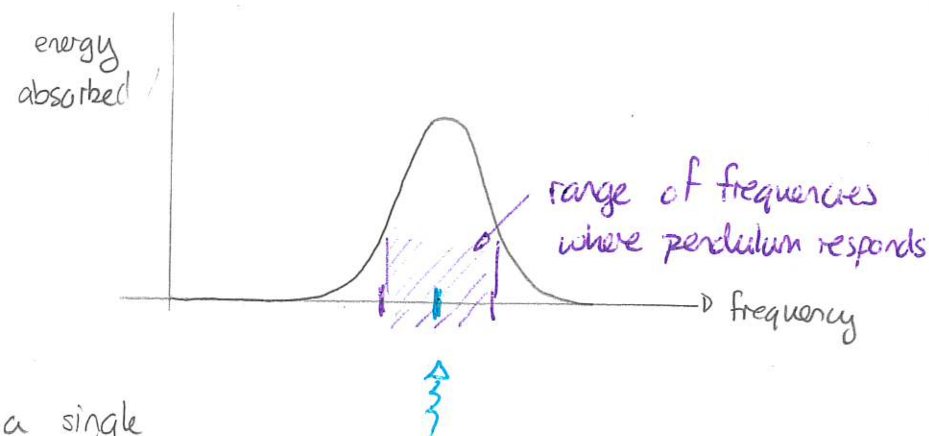
* the frequency of the driving mechanism
* the amount of friction / air drag / damping



amplitude decreases

restored

In physics these can be described via a power / energy absorbed curve.



perfect (undamped) frequency
≡ what we want

The pendulum no longer has a single perfect frequency but a range. The range increases as the damping decreases.

So for mechanical pendulums we aim to reduce this range. However, the nature of the mechanisms is such that it becomes increasingly difficult to reduce the range by the same factors.

We need physical systems where this is less of an issue.

The quartz clock uses electronics to provide an alternative.

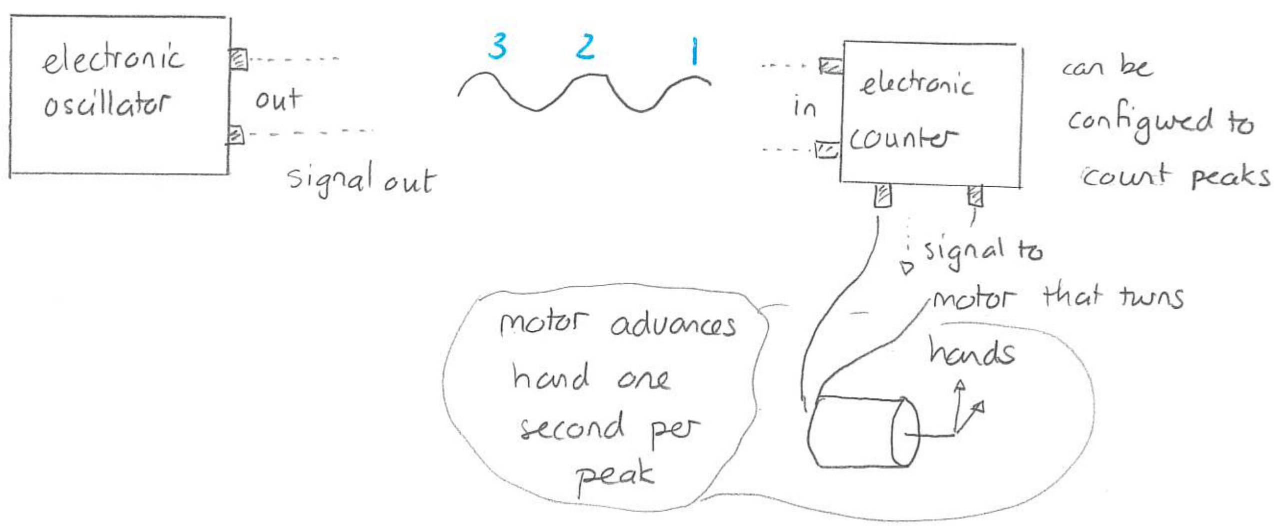
Electronic Oscillators

Electronics considers how one can move electrically charge particles, primarily electrons, through various devices in a circuit. By careful construction of such devices one can create electronic circuits where the charges oscillate.

Demo: PhET Circuit Construction Kit.

- LC circuit. - later include resistence
- Observe oscillating current.

So it is possible to construct a circuit that oscillates. We could have



Q: What issues would arise with making this work (presuming one knows about electronics)?

* the oscillations will have to be at a precise rate.
* the oscillations will die down and need to be reinforced electrically

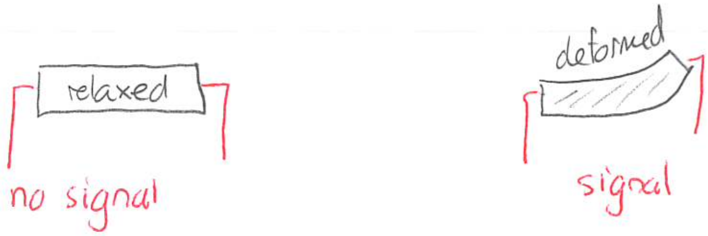
Ordinary electronic circuitry can produce reasonably stable oscillations but not with a precision that is sufficient for timekeeping needs.

Demo: PhET RLC circuit with adjustable freq. $L = 10H$ $f = 0.20Hz$.
$C = 0.06F$

Quartz Oscillators

A very good candidate for an electronic oscillator came from crystals of quartz. These have the property that they are piezoelectric:

1) if the crystal is deformed then it generates an electrical signal



Demo: Steve Mould - piezoelectricity video from about 3min -> 5min

2) if a signal is applied to the crystal it will deform.

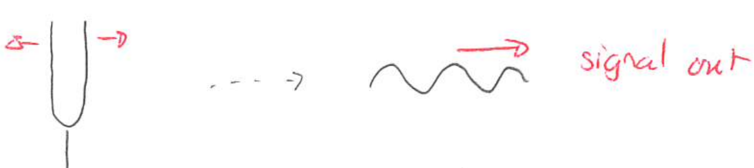
The heart of a quartz clock is a quartz crystal shaped like a tuning fork.

Demo: Tuning fork

Tuning forks oscillate with a natural frequency that depends on

1) the material from which they are made
2) the shape of the material.

A tuning fork constructed of quartz will



vibrate at a natural frequency

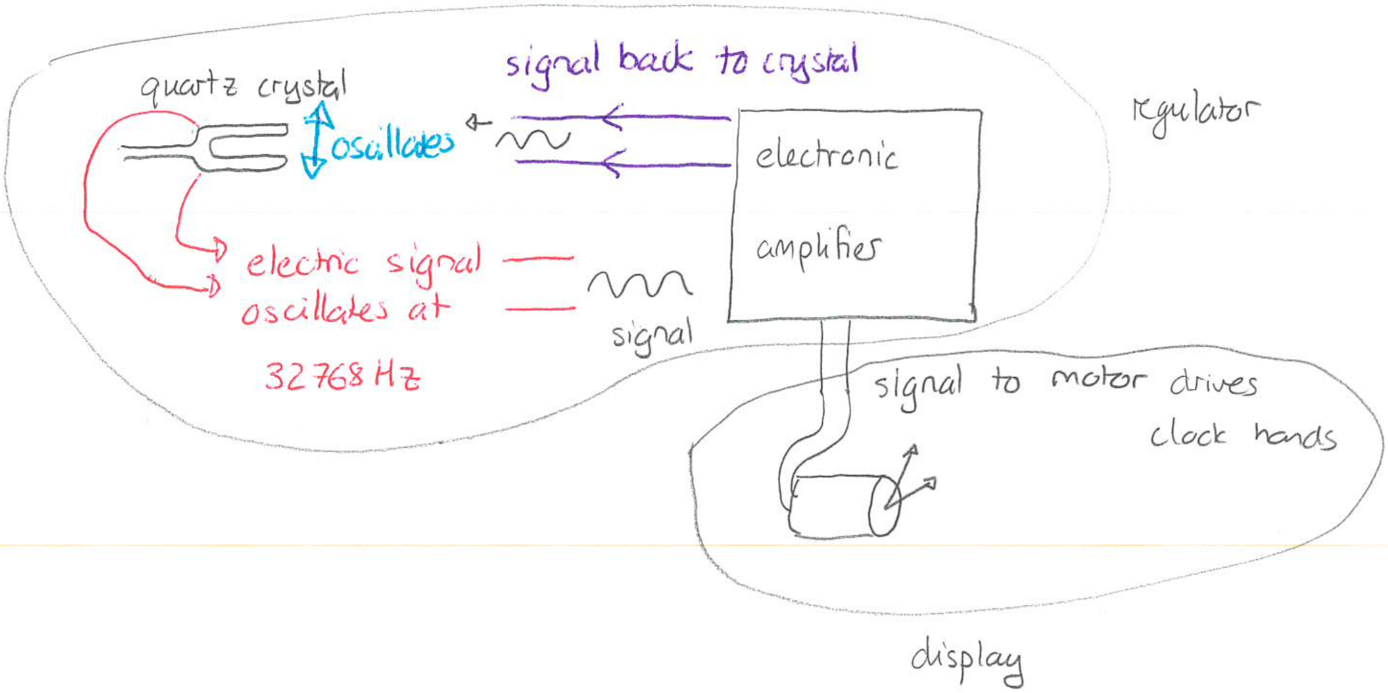
produce an electrical signal at the natural frequency

signal in

respond to a signal at the natural frequency

Demo: Steve Mould video. 5min →

Then the way that such a clock might be constructed is:



The signal from the quartz crystal in effect trains the amplifier which:

* provides a signal to drive the clock hands
* provides a signal to restore the oscillations of the quartz crystal

In practice a feedback circuit is constructed that only operates well at the frequency of the quartz crystal. So the crystal imposes its frequency on this circuit.