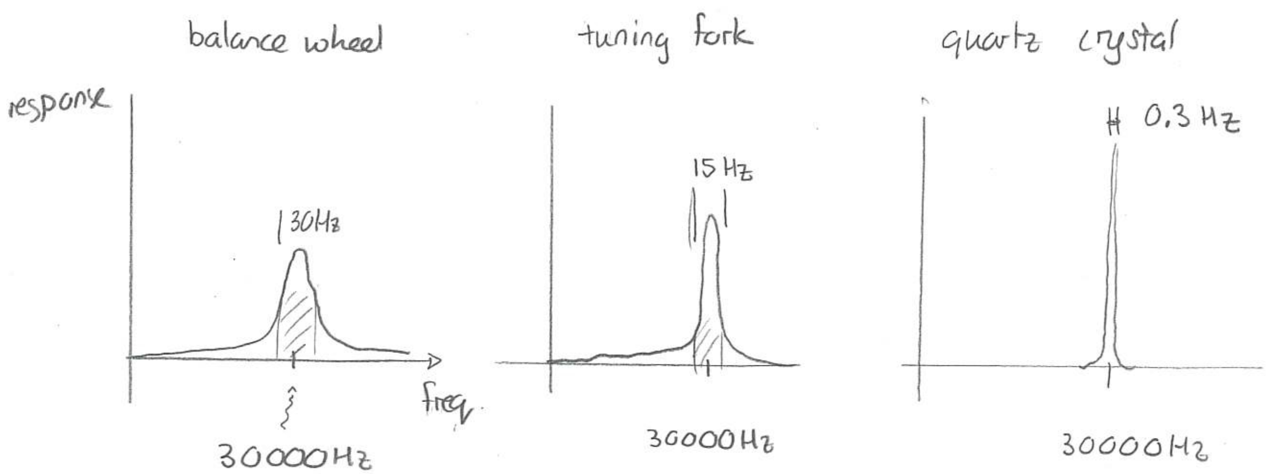
Mon: Nov 29 - term paper first draft

Read

Quart clock performance

A quartz clock uses a tuning fork created as a quartz crystal as a regulator to supply an electrical signal to the clock at a very precise frequency. Why is this inherently better than a pendulum or balance spring? The reason is that for typical oscillating devices, the range of frequencies where the quartz crystal responds well is much narrower than other devices:



Generally for a quartz crystal the range of frequencies in which it operates is $\frac{1}{100000}$ to $\frac{1}{1000000}$ of its true natural frequency. This is considerably less than for most mechanical oscillators. Therefore it will be inherently superior in maintaining a precise frequency.

Demo: Marty Jospin video

1 Crystal oscillator

A crystal can be constructed to oscillate with a (natural) frequency of 40000 Hz. This is intended to be used to regulate a clock that counts time in increments of one second. This means that it is constructed so that it advances the time that the clock displays by exactly one second after every 40000 oscillations.

This crystal oscillator can be made to oscillate appreciably anywhere in the range of frequencies 39999.80 Hz to 40000.20 Hz. The electronics still counts off the number of oscillations and advances the second hand after the same number of oscillations that it would for 40000 Hz. This will cause errors in the timekeeping. We want to see how much error.

a) Suppose that the oscillator is actually oscillating at 39999.80 Hz. How long does it take to do one oscillation? How much time actually passes when the clock display advances by exactly one second (i.e. while the electronics counts of exactly 40000 oscillations)? How much time does this clock gain or lose every second? How much time will it gain or lose per day (86400 s)?

one oscillation period $= \frac{1}{\text{freq}} = \frac{1}{39999.80} = 2.5000125 \times 10^{-5}$ s

There will be 40000 of these in the time to advance display by 1s.

So

$40000 \times 2.5000125\text{s} = 1.000005\text{s}$

The clock loses 0.000005s per second

per day $\times 86400 \approx 0.43$ s per day

The same size error occurs if the oscillator is actually oscillating at 40000.20 *Hz.*

b) How long would it take the oscillator that oscillates at 39999.80 Hz to lose 0.001 s?

every second it loses 0.000005s. So it takes

$$\frac{0.001\text{s}}{0.000005\text{s}} = 200\text{s} = 3 \text{ min } 20\text{s}.$$

to lose 0.001 s

c) What sorts of tasks that you have done require timing that is this precise? What sorts of tasks that you might do require timing that is this precise?

It's conceivable that a scientific experiment done in a freshman class might require this accuracy.

Very few such tasks.

d) Why do we have or need quartz clocks?

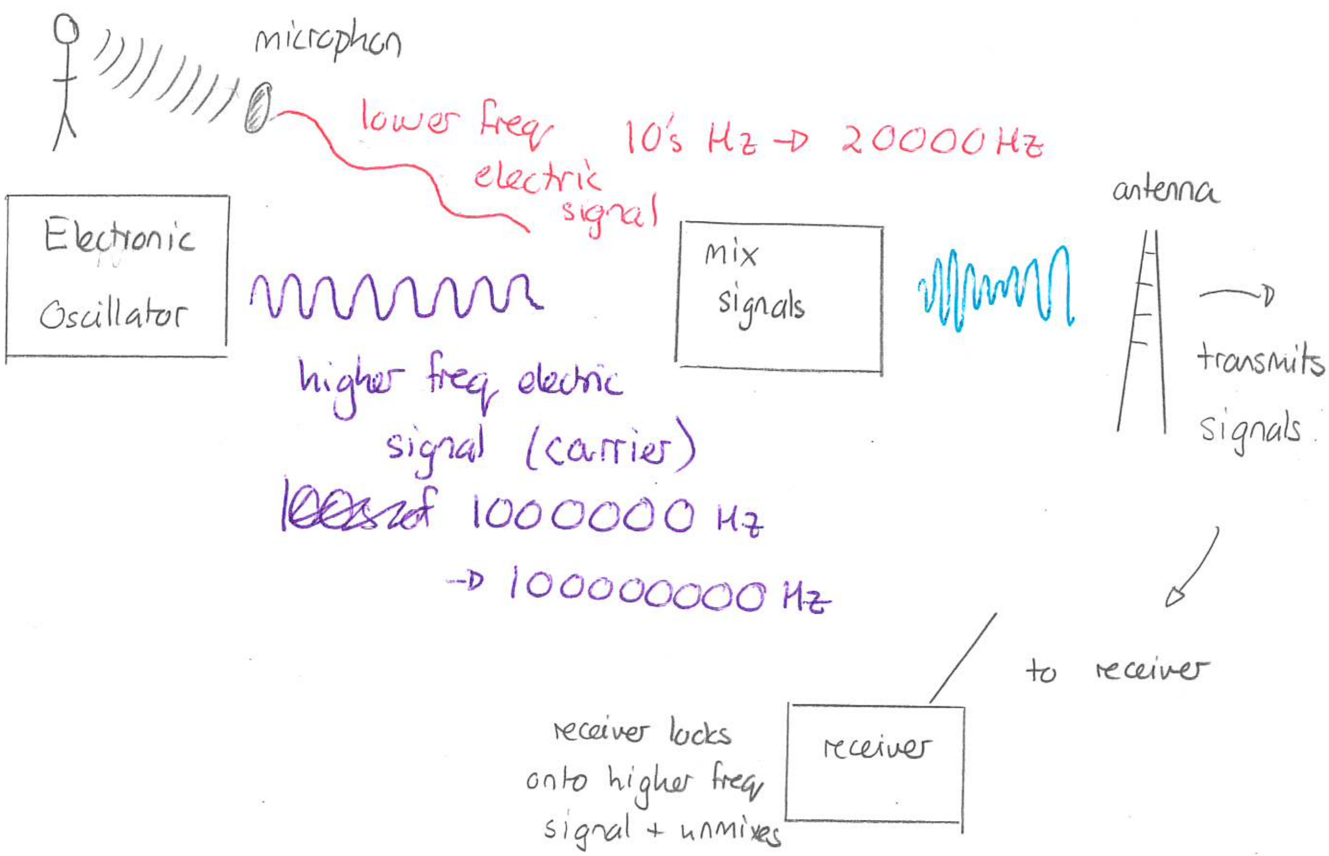
Quartz clock development and production

Quartz clocks have an accuracy that is not essential for ordinary daily activities. The primary impetus for the development of quartz clocks comes from

1) radio communication
2) telephone communication

Katzir J. Mod Hist 89, p 119 (2017)
Katzir Am. Sci 73 p 1-39 (2016)
Lombardi IEEE Inst Meas. Oct 2011 p41

Radio communication was initially developed in the early 20th century. The idea is to use a radio wave to carry a signal



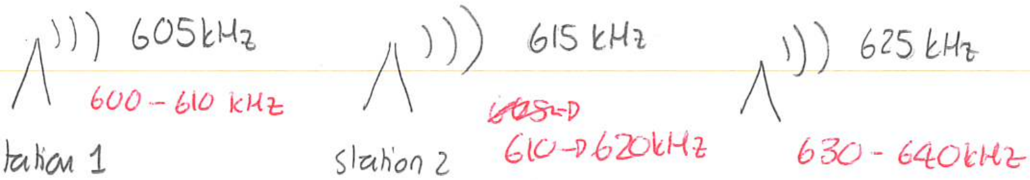
Q: (Without ~~knowing~~ knowing electronics) What would practical issues with this type of communication be?

A similar process occurs with landline telephone communication. Many signals need to be fed through the same physical line. This was called multiplexing.

To illustrate the issues with this, consider radio transmission of the AM type. In this case:

* carrier wave is in the range 600 kHz → 1600 kHz
* each station gets a band of about 10 kHz.

We would have a barely overlapping situation:



In this situation, we could only have 100 radio stations. Furthermore any slight variation in carrier frequency would result in interference. The radio stations could not afford to let their carrier frequency differ by even 1 kHz. So they require

↳ actually required to be 0.5 kHz (1927) and 0.05 kHz (1932) [Lombardi]

1) measure frequencies with an accuracy of 99.9%

2) generate " " " " " 99.9%

In the 1920s the problem of frequency measurement and frequency standards led to the development of electronic quartz oscillators

Q Who would have used/wanted these?

Efforts to develop this were spearheaded in two places:

1) National Physical Laboratory (UK)

* government laboratory
* regulated radio transmission in England
* naval uses

2) AT+T (US)

* wanted frequency standards for telephone + radio communication
* frequency accuracy to 1 part per million.
* constructed first quartz clock in 1927 as an offshoot.

The US National Bureau of Standards adopted a quartz freq. standard to manage its system of time signals in 1927. The first quartz clock was developed by Marrison at Bell Labs in 1927.

Initially such quartz clocks were intended for specialized operations

NIST image

Lombardi

By the late 1930s portable versions of this such as the Rohde+ Schwarz clock would lose 0.004s at most per day. This surpassed most pendulum clocks. By the 1950s the accuracy of these had improved to the level of about 0.000001s per day.

Quartz watches first appeared in the late 1960s in prototype form. The first commercial quartz watch was produced by Seiko (Astron) in 1969.

Current quartz watchs lose about 0.5s per day, meaning it would take about 120 days to lose one minute