hopf Elektronik GmbH

Whitepaper

WHAT IS TIME

DEFINITION AND MEASUREMENT METHODS OF TIME

TIME REFERENCE SYSTEMS

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DOCUMENT:	HOPF_WHITEPAPER_WHAT-IS-TIME_V0100_EN
VERSION:	01.00
DATE:	03/22/2021
CUSTOMER:	external

RELEASE NOTES:

Reviewed on:	03/22/2021	Released:	03/22/2021
Reviewed by:	S. Hofbauer	Released by:	E. Ruprecht

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Atomic clocks

Nowadays time is measured by means of atomic clocks. Atomic clocks with their Caesium-133 atoms are primary clocks which means they are the most accurate chronometers we know.

Therefore atomic clocks provide a very valuable time reference base for other clocks, e.g. clock systems of ***hopf*** Elektronik GmbH.

But how does an atomic clock actually work?

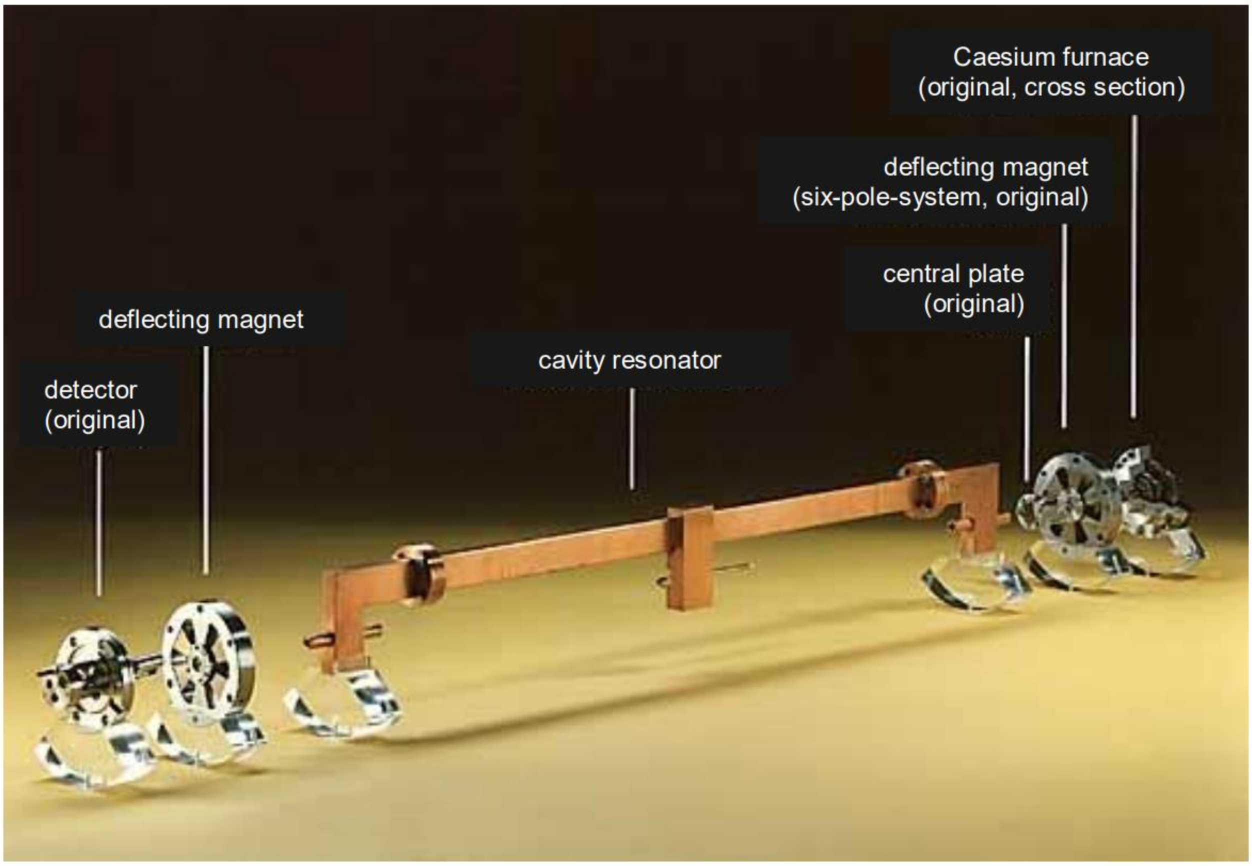

Illustration: components of an atomic clock

(source: Physikalisch Technische Bundesanstalt Braunschweig, PTB)

In principle an atomic clock – like any other clock – consists of:

1. a pulse generator as well as
2. a counting mechanism

The pulse generator in a conventional clock is a pendulum or a balance wheel – Caesium atoms which show a characteristic effect when being irradiated with microwaves are the pulse generator of an atomic clock.

A small quantity of Caesium is heated in a furnace at approximately 100°C which leads to the fact that Caesium evaporates. A ray of Caesium atoms emerges through an orifice. As parts of the atomic clock are arranged in a vacuum the Caesium atoms are able to fly freely.

After evaporating the Caesium atoms are disposable in two different energy levels – they occur in one of the two lowest energetic levels which Caesium atoms can have. As only atoms with one specific energetic level are suitable for measuring highly-precise time, atoms occurring in an unsuitable energetic level are deflected by a magnet. Atoms with suitable energetic level reach the so-called cavity resonator where they are irradiated with microwaves.

When these microwaves have a specific frequency, the Caesium atoms change their energy level and are subsequently trapped in a particular section. The largest number of Caesium atoms trapped in the section can be reached if this specific frequency (= resonance frequency of the Caesium-133 atom set in vibration) reaches exactly 9,192,631,770 periods.

After 9,192,631,770 periods a so-called atomic second has passed (definition SIunit of a second).

The counting mechanism is responsible for reckoning and displaying the number of Caesium atoms which have changed their energy level due to being irradiated with microwaves.

Therefore atomic clocks are the most precise chronometers – over 3 million years they diverge approximately 1 second.

The Bureau International des Poids in Paris collects and evaluates data of approximately 260 atomic clocks worldwide to set up the International Atomic Time (TAI) by averaging the data of all clocks. The International Atomic Time is therefore based on an atomic time normal, the so-called SI-second. However, for everyday life time scales based on earth rotation and the position of the sun are more interesting for us.

International Atomic time vs. Universal Time Coordinated vs. Central European Time

Time used in everyday's life aims at being oriented towards the solar zenith angle on the one hand and utilizing a constant and monotonical time format (TAI) for complex technical conditions on the other hand. As a compromise between these two crucial factors the Universal Time Coordinated (UTC) was introduced.

Illustration: International Atomic Time / Universal Time Coordinated / Central European Summer Time

(source: Physikalisch Technische Bundesanstalt Braunschweig, PTB)

Due to the deceleration of the earth rotation the Universal Time Coordinated (UTC) is slower than the International Atomic Time (TAI). To compensate this difference a leap second is inserted occasionally, based on instructions of the International Earth Rotation and Reference Systems Service IERS (www.iers.org). The last time a leap second was inserted was on December 31, 2016, 23:59:60 UTC.

Our present time zones are basically linked to UTC. The differences between UTC and the time zones are constant, usually integer hours. The combination of UTC and the individual time zones results in the Standard Time which – combined with switching to Summer / Winter Time – results in the Local Time in turn. The time base UTC is made accessible to the public via diverse transmission methods.

DCF77 signal

In Germany the Physikalisch Technische Bundesanstalt (PTB) in Braunschweig is responsible for distributing the valid legal time. The time signal is transmitted to a long-wave radio station in Mainflingen at Frankfurt which provides the validated and statutory German time to clock systems in Western Europe via the internationally valid call sign DCF77 on frequency 77,5 kHz.

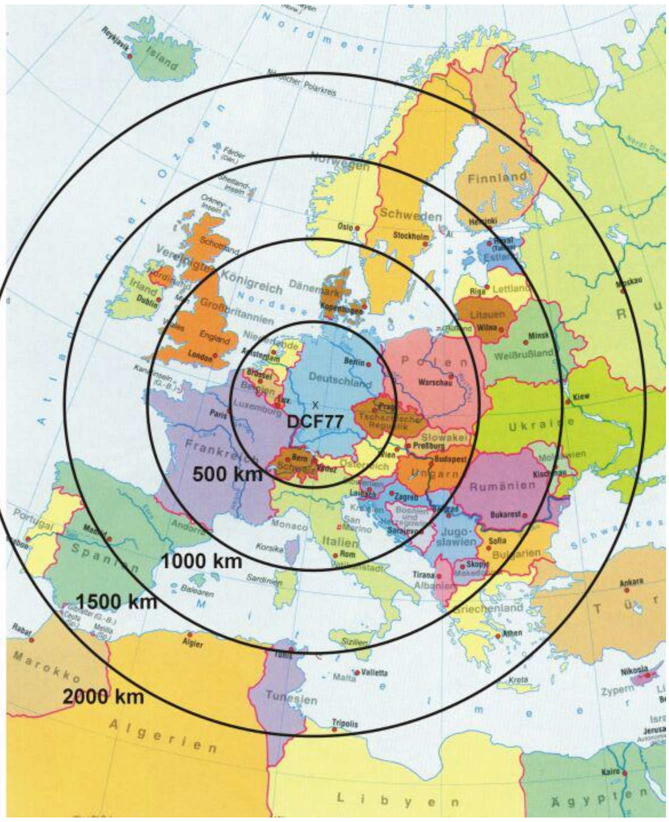

Illustration: geographical scope of the call sign DCF77

(source: Physikalisch Technische Bundesanstalt Braunschweig, PTB)

The DCF77 signal may be received up to a distance of approximately 2,000 km (depending on the time of day and year). There are several institutes responsible for transmitting highly-precise time worldwide:

- Great Britain: National Physical Laboratory
- USA: National Institute for Standards and Technology (NIST)
- Japan: Communications Research Laboratory (CRL)
- China: National Time Service Center

How is time transmitted by GPS to a clock system of hopf Elektronik GmbH?

At a height of about 20,000 km satellites circle around the earth on six different orbits twice a day. The space segment consists of at least 24 satellites. Every satellite operates at least two atomic clocks with an accuracy of at least 1 x 10-12. The time signal together with the orbit data is transmitted continuously at the frequency of 1,57542 GHz. The satellite data is transmitted at the speed of light (approximately 300,000 kilometres per second or approximately one billion kilometres per hour - exact value: 1,079,252,848.8 km/h).

A GPS antenna receives the transmitted data from all satellites which are in the visual range of the antenna. Data sent from the satellites is analysed by a multi-channel GPS receiver. The GPS receiver compares the time of the emitted GPS signal with the time when the signal was received. Based on that analysis the distance of the individual satellite can be calculated. By analysing the data of four or more satellites the GPS receiver is able to determine its absolute position (latitude and longitude) as well as its height above the surface of the earth.

If the correct position is calculated, the duration of the time signals sent by the satellites can be determined. Thus, the time reference can be determined with an accuracy of a few nanoseconds, depending on the accuracy of the position calculation.

By adding or subtracting the leap seconds from GPS-UTC the Universal Time Coordinated is calculated. Leap seconds – as already mentioned above – offer the possibility to compensate the inaccuracy due to the earth rotation. Compensation may be done automatically as the offset information is provided by the time signal emitted from the GPS satellites. Based on UTC it is at least possible to precisely determine the Standard Time or the Local Time (considering switching from Summer to Winter Time or vice versa) by applying the correct time zone information.

You are interested in our time synchronization solutions?

We are looking forward to seeing you on www.timeserver.eu/products

Sources:

- Physikalisch Technische Bundesanstalt Braunschweig, www.ptb.de
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), www.dlr.de
- http://www.kowoma.de/gps