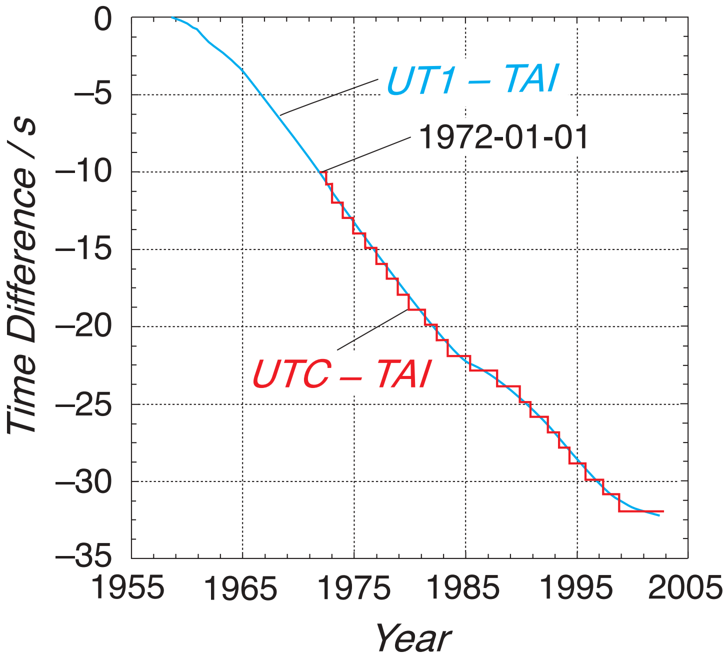
Realisation and Dissemination of Legal Time in Germany

Co-ordinated Universal Time (UTC) serves as the world-wide recognised standard for legal and public time scales which usually differ from one another by an integer number of hours according to national legislation and usage. UTC is calculated and published by the International Bureau of Weight and Measures (BIPM). On the basis of the readings of so-called primary clocks operated at PTB and other timing institutes, it has the SI second as its scale unit. But it remains co-ordinated with our natural time as derived from the angular position of the rotating Earth. Astronomers determine mean solar time (Universal Time 1, UT1) by observing star transits, and more recently, by determining the position of radio-telescopes on Earth with respect to distant reference stars, like quasars. UTC and UT1 are kept in agreement to within ±0,9 s by integrating leap seconds into UTC. The figure below illustrates how UT1, UTC and International Atomic Time (TAI) have evolved in the course of time. When TAI came into existence, it was brought into agreement with UT1. UTC has been calculated since 1972-01-01 when the difference UT1 – TAI amounted to about – 10 s. The introduction of leap seconds inserted since at irregular intervals reflects the irregularity of the rotational speed of Earth which has been known to exist since the mid thirties and finally led to the astronomical definition of the second being abandoned.



PTB is entrusted by the Time Act of 1978 with realising and disseminating the time for Germany. For this purpose, a group of atomic clocks is operated at PTB, and UTC(PTB) is realised differing from UTC by only some tens of nanoseconds. Legal time, Central European Time (CET) or Central European Summer Time (CEST), depending on the season, is derived therefrom as follows:

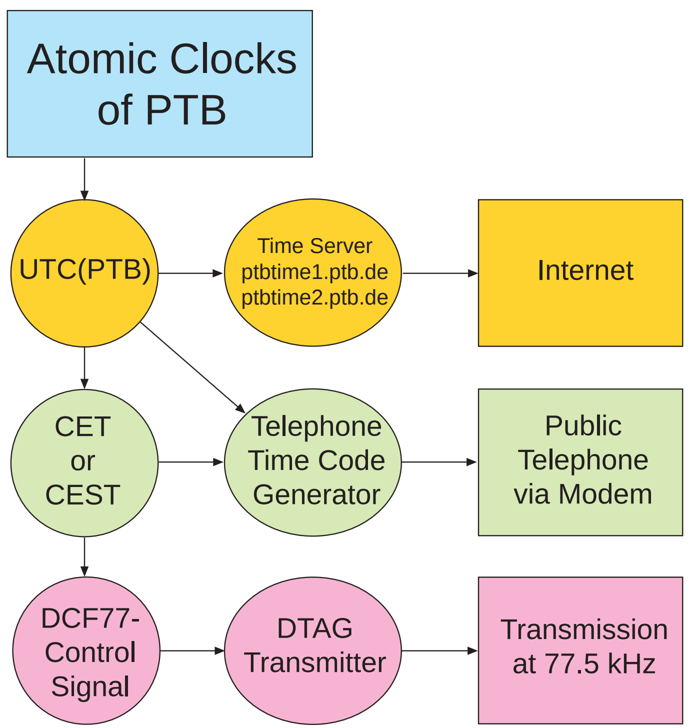
CET(D) = UTC(PTB) + 1 h

CEST(D) = UTC(PTB) + 2 h.

Daylight saving time ("summer time" according to German usage) is introduced every year under national ordinances (in Germany: BGBl. 2001, part 1, No. 35, p. 1591), currently on the basis of Decree 2000/84/EG of the European Council and Parliament, taking the different time zones into account. The current German Ordinance reads:

Section 1: CEST will be introduced each year until further notice.

Section 2: CEST begins on the last Sunday of March at 02:00 CET when clocks are advanced by one hour. It ends on the last Sunday of October at 03:00 CEST when clocks are set back by one hour. The first hour, between 02:00 and 03:00 CEST, is called 2A, the second one, between 02:00 CET and 03:00 CEST, 2B.



Schematic representation of PTB's time dissemination services

PTB offers three services to disseminate UTC and legal time. The best-known service is the dissemination of standard frequency and coded time information through DCF77. PTB also operates a telephone time service and an Internet time service. These services will be presented below, further technical documentation can be obtained on request (address on the back cover page) or under **www.ptb.de**.

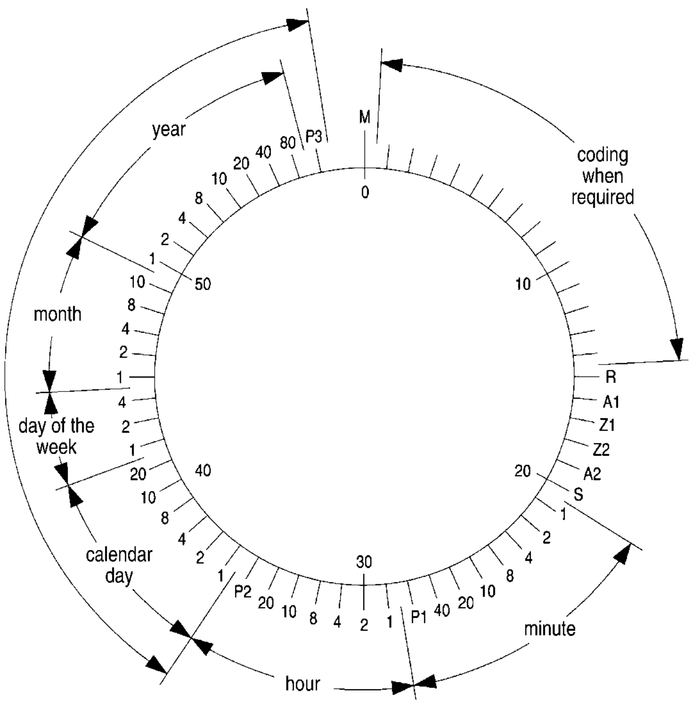
Standard Frequency and Time Dissemination through DCF77

General Information

Operating Agency	Deutsche Telekom AG
Location	Mainflingen Transmitting Station near Frankfurt/Main at 50° 01' North, 09° 00' East
Transmitter power	50 kW nominal, radiated power ≈ 30 kW
Range of Reception	up to 2000 km
Operation	continuous, 24 hours per day
Signal generation	with triply redundant equipment including atomic clocks, modulators, logic and functionality checks, monitored and remotely controlled from PTB Braunschweig
Carrier frequency	77.5 kHz, derived from PTB's atomic clocks, relative uncertainty on average over one day: $\leq 2 \cdot 10^{-12}$
Modulation	AM: Amplitude reduction to 20 % for 0.1 s (binary zero) or 0.2 s (binary one) for transmission of coded time information PM: pseudo-random modulation (PRN) of the carrier phase for the same purpose and to facilitate synchronisation of clocks with legal time to much better than 1 ms

Time Code

The scheme of coding the transmitted time information can be seen on the right. Each minute, information regarding the current minute, hour, calendar day, calendar month and calendar year (last two digits) according to the Gregorian calendar is transmitted. The time code is also transmitted via PRN by inverting the PRN sequence.



DCF77 reception range (top), scheme for coding time information (bottom): M minute marker; R request for service (internal status flag), A1: announcement of a change from CET to CEST or vice versa at the next full hour; Z1, Z2 time zone, A2 announcement of a leap second at the next full hour, S (binary 1), P1, P2 and P3: Parity check bit enabling internal checks of the quality of the received time information

PRN Modulation

To better use the available transmission frequency bandwidth and thus facilitate accurate time synchronisation for specific purposes, the carrier frequency is modulated by $\pm 13°$ with a 2^9 bit pseudo random code with a bit rate of 775 00 Hz/120. The mean value of the carrier phase remains unchanged. Receivers adapted to this service locally reproduce the PRN code and determine the time instant of reception by analysing the cross-correlation between local and received PRN signal. This allows synchronisation with legal time to well below 0.1 ms. The PRN transmission does not interfere with the use of the AM and not substantially with the use of the received carrier signal as a source of standard frequency.

Antenna support mast at the DCF77 transmitting facility in Mainflingen

PTB's Telephone Time Service

Several European institutes have reached agreement on a standard for transmitting time information over the public telephone network using modems and PCs. The phone number at PTB is (+49 531) 51 20 38. The main use is the synchronisation of PCs and LANs once daily. Making use of the delay measurement option, the signal transmission is advanced by half the measured round trip time, and a timing accuracy of 1 ms has been demonstrated. 80 ASCII characters are transmitted once per second with the last character defining the beginning of the second. The transmitted data comprise calendar date, legal time designation, day of week number, week number, day of year number, date of change CET/CEST, date of leap second introduction, if scheduled.

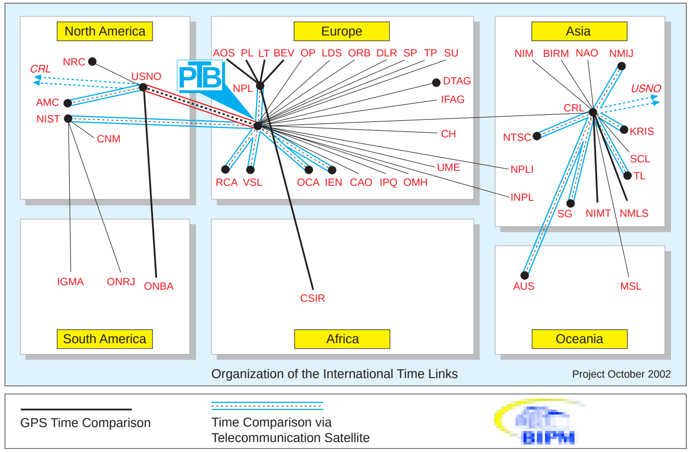
Applications of DCF77

PTB knows of abundant use of DCF77 reception all over Europe, mostly employing the AM. AM receivers can basically be kept in agreement with German legal time to 1 ms or slightly better. DCF77 signals are used to control clocks at radio and television stations, clocks on the premises of the Deutsche Bahn AG, the speaking clock of the Deutsche Telekom on public telephone, rate metering equipment in telecommunication and power networks, and traffic management systems. Time sensitive process control using DCF77 reception is rather common. The number of low-cost radio-controlled clocks for private use has reached a few ten million and is still growing. Highly accurate PM receivers are employed in the management of the power distribution grids throughout Europe and in telecommunication networks. Standard frequency generators controlled by DCF77 are used in calibration laboratories, in industry and at research centres.

Internet Time Service

Time information is provided on the Internet using the so-called Network Time Protocol. It is based on the widely used IP protocol and can be used with all operating systems. PTB currently operates two servers, but to cope with the increasing demand, the installation of a third server is envisaged. To use the service, it is necessary to install software, available and described under **www.ptb.de/eng/org/q/q4/q42/index.htm**. The adresses of PTB's servers are **ptbtime1.ptb.de** and **ptbtime2. ptb.de**. The timing accuracy is usually only moderate (fraction of a second) since the reciprocity of signal paths between client and PTB servers cannot be guaranteed due to the structure of the Internet.

Realisation of UTC by BIPM



Network of comparisons among time scales UTC(k) realised at timing institutes k (including PTB). Exchange of signals via telecommunication satellites is the state-of-the-art technique today, GPS is the standard technique employed for almost 20 years.

Universal Co-ordinated Time UTC is based on the clocks operated at the timing institutes k referred to above with their acronyms. The local time scales UTC(k) and the various clocks are compared among one another. Data analysis and calculation of UTC takes place at the International Bureau of Weight and Measures (BIPM). At first, clock data are analysed and combined to obtain a free atomic time scale. Its scale unit usually differs from the SI second as realised with primary clocks. Only after correction is the International Atomic Time TAI obtained. PTB has played an important role in this steering as the relevant information from its three primary clocks CS1, CS2, CS3, and more recently from the fountain CSF1, has been reliably available during decades. As explained above, UTC is ultimately derived from TAI and includes leap seconds.

Physikalisch-Technische Bundesanstalt
Presse- und Öffentlichkeitsarbeit
Bundesallee 100, D-38116 Braunschweig
Telephone: (05 31) 592-30 06, Telefax: (05 31) 592-30 08
E-mail: presse@ptb.de, Internet: http://www.ptb.de/

2/1203

Atomic Clocks and the SI Second

The second is one of the base units of the international system of units SI, defined in 1967 as follows:

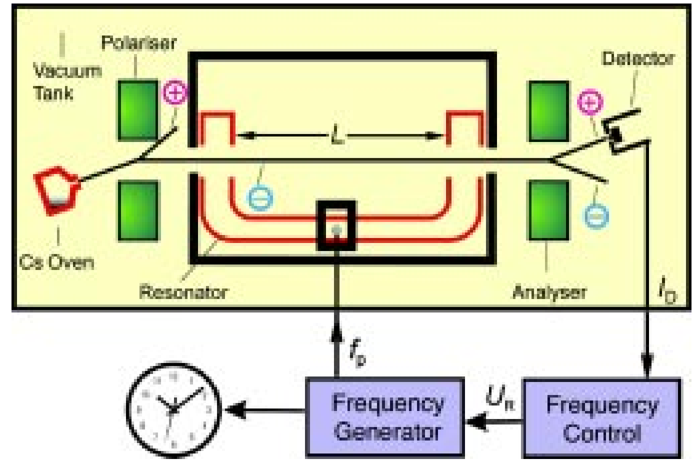
The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the caesium-133 atom.

According to this definition, the second is realised by caesium atomic clocks which are available as commercial products but are also developed and operated by metrological laboratories to obtain highest accuracy. Such so-called primary clocks are rare, only in France, Germany, Italy, Japan and the US are such clocks in operation in mid-2003.

The Basic Principle Behind Atomic Clocks

Atoms may occur in various energy states, and the transition from one state to another is accompanied by the emission or absorption of electromagnetic radiation whose frequency f_0 is determined by the energy difference ΔE between the two states as $f_0 = \Delta E/h$, where h is the Planck constant. It is commonly assumed that atomic properties such as energy differences between atomic eigenstates and thus atomic transition frequencies are natural constants and do not depend on space and time (except for relativistic effects). They are determined by fundamental constants which describe the interaction between elementary particles. An atomic frequency reference thus is significantly more stable and reproducible than the period of swing of a mechanical pendulum, the mechanical resonances of a quartz or the period of the Earth's rotation.

The Classical Caesium Atomic Clock



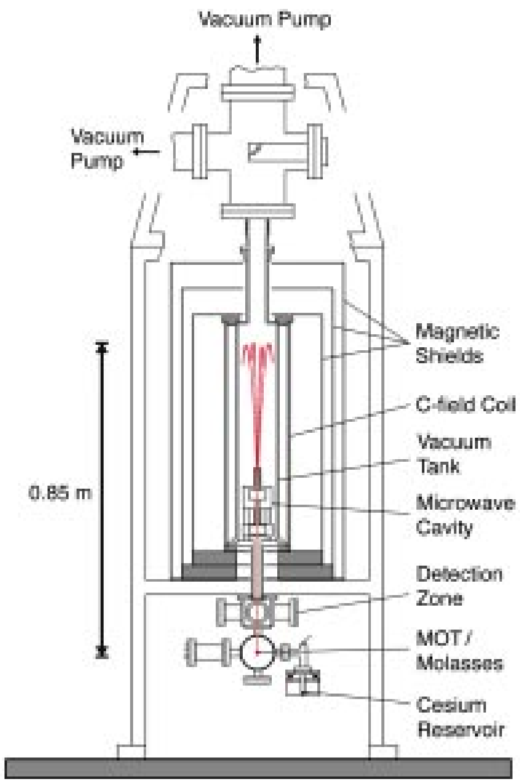
Principle of the function of a classical caesium atomic clock with a thermal atomic beam and magnetic state selection. The two eigenstates of the caesium involved are labelled (+) and (–).

There is a suitable transition in the element 133caesium at a frequency f_0 = 9 192 631 770 Hz which is basic to the functioning of a caesium atomic clock. In the vacuum chamber of such a clock an atomic beam is formed by evaporation of the caesium metal. A strong inhomogeneous magnet (polariser) deflects atoms so that only atoms in the (–) state reach the microwave resonator. By irradiation with microwave radiation at frequency f_p the atoms are with some probability transferred to the (+) state. The second magnet (analyser) deflects just those atoms that have made a transition to the (+) state to the detector which thus produces the strongest signal when f_p coincides with f_0, i. e. when the so-called resonance condition is fulfilled. Based on this signal, an electronic control circuit tunes the microwave generator so the resonance condition persists. The longer the time of flight, i. e. the distance L divided by the atomic velocity, the more sensitive the electronic control. An electronic circuit counts the periods of the microwave radiation and produces a second tick every 9 192 631 770 periods.

Primary clock CS2 of PTB which currently servis as the reference for UTC(PTB)

Caesium Fountain Clocks

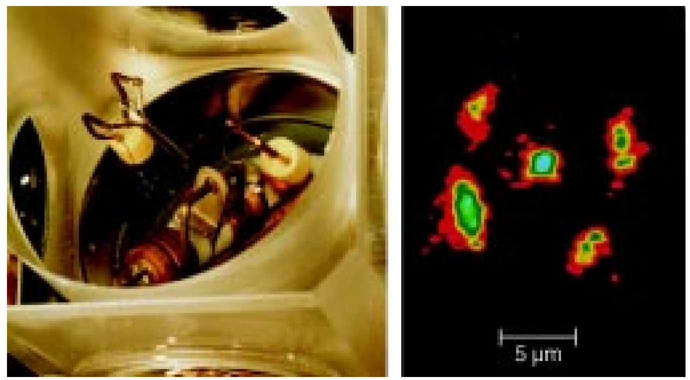
Laser radiation is employed for manipulating the atomic velocity, for state preparation and detection in the most modern variant of the caesium clock. Laser cooling in a magneto-optical trap or in an optical molasses in particular provides cold atoms with a residual thermal velocity of a few mm/s only. Such cold atoms are launched upwards and fall back under the action of gravity, like water drops in a fountain. The atoms pass the microwave resonator twice during their flight, and the time of flight above the cavity is at least 50 times longer than the corresponding value in a classical caesium clock. Several effects systematically shifting the frequency are smaller by a similar amount, and it is thus possible to realise the SI second with an uncertainty of 1 part in 10^{15} or slightly less. PTB developed such a fountain clock, CSF1, between 1997 and 2000.



Vertical section through PTB's caesium atomic fountain CSF1

What Next?

The next generation of atomic clocks is still in its infancy. The reference transition will no longer be in the microwave region (10^{10} Hz) but in the region of visible radiation ($5 \cdot 10^{14}$ Hz). One possible variant of such an optical clock studied at PTB is based on laser spectroscopy of a single charged atom (ion) kept in a tiny volume of less than 1 μm^3 in a so-called ion trap. Such a device will very likely be capable of realising a clock with an uncertainty one or two orders of magnitude smaller than that achievable with a caesium fountain.



Ion trap system developed at PTB: structure of the electrodes (middle left); detected signal of the fluorescence of five ytterbium ions trapped and forming a so-called Coulomb crystal (right)

Cover picture

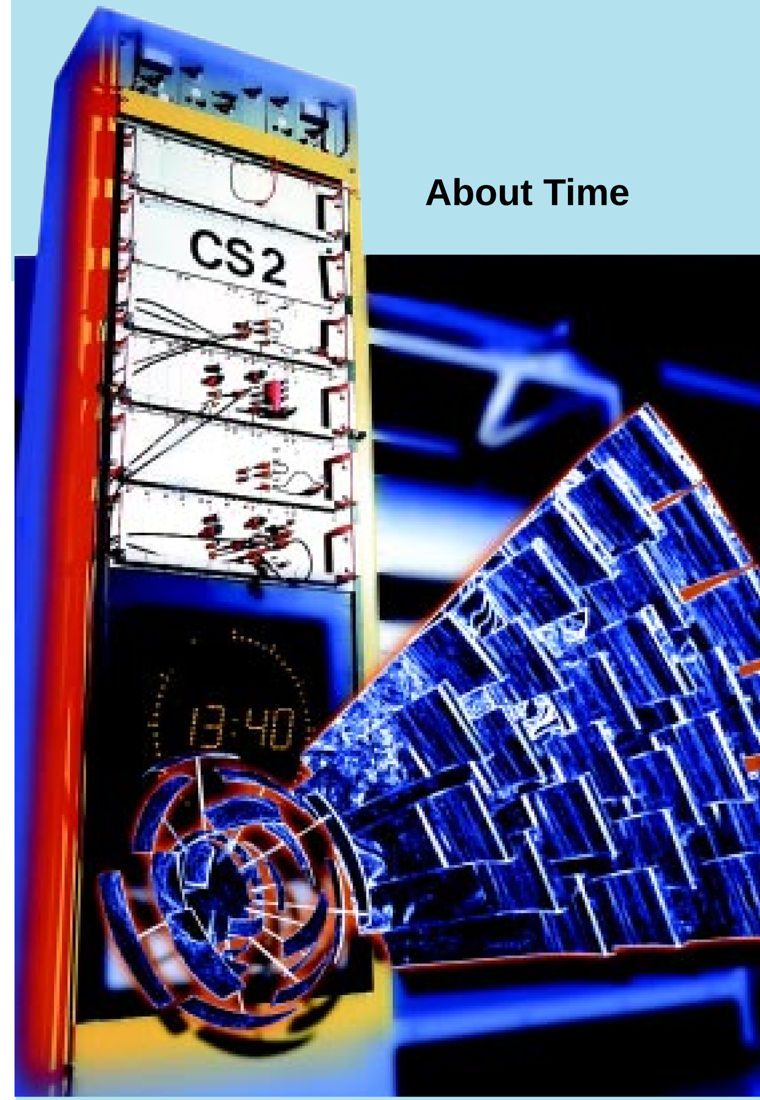
An atom emits electromagnetic radiation (waves). Metal sculpture (Bodo Kampmann, 1970) at the entrance to the building accommodating PTB clocks, the collage with primary clock CS2.

Literature

References to publications by PTB authors and a list of representative publications on time can be found under **www.ptb.de**, search "Literature Time". You may also send a request to PTB to the address given on the back page of this flyer.

Physikalisch Technische Bundesanstalt
Braunschweig and Berlin

About Time



PTB