[[Image:Atomic clocks.jpg|thumb|250px|NIST-F1[[銫]]噴泉原子鐘，是[[美國]]時間和[[頻率標準]]，其[[不確定性]]為5.10<sup>-16</sup>（2005年）。]]

'''原子鐘'''是一種[[鐘]]，它以[[原子]]共振[[頻率標準]]來計算及保持時間的準確。原子鐘是世界上已知最準確的時間測量和頻率標準，也是國際[[時間和頻率轉換]]的[[基準]]，用來控制[[電視]]廣播和[[全球定位系統]]衛星的訊號。

原子鐘並不使用[[放射性]]計時，而是使用[[電子]]轉變[[能級]]時釋放的精確[[微波]]訊號。早期的原子鐘為附上工具的[[激微波]]。今天最好的原子鐘是以[[原子噴泉]]中冷原子的[[吸收光譜法]]作爲基礎的。

==歷史==

世界上第一座原子鐘建于1949年，位于美國的[[國家度量衡標準實驗室]]。第一座準確的原子鐘於1955年建造，位于[[英國國家物理實驗室]]，其計時根據[[銫]]-133原子的一種特定躍遷。從此國際上便公認了基於原子時的一[[秒]]的定義。

Since the beginning of development in the 1950s, atomic clocks have been made based on the hyperfine (microwave) transitions in [[hydrogen]]-1, caesium-133, and [[rubidium]]-87.

For decades, scientific-instrument companies such as [[Hewlett-Packard]] have been making caesium-beam clocks and [[hydrogen maser]]s for entities like [[NIST]] and [[USNO]].

In August 2004, [[National Institute of Standards and Technology|NIST]] scientists demonstrated a chip-scaled atomic clock.<ref name="Chip-Scale">{{Cite web|url=http://tf.nist.gov/timefreq/ofm/smallclock/index.htm|title=Chip-Scale Atomic Devices at NIST|accessdate=2008-01-17|publisher=NIST|month=May | year=2007}}</ref> According to the researchers, the clock was believed to be one-hundredth the size of any other. It was also claimed that it requires just 75&nbsp;[[milliwatt|mW]], making it suitable for battery-driven applications. This device could conceivably become a consumer product. It will presumably be much smaller, consume less power, and be much cheaper to produce than the traditional caesium-fountain clocks used by [[NIST]] and [[USNO]] as reference clocks.

In February 2008, physicists at [[JILA]], a joint institute of the National Institute of Standards and Technology (NIST) and the [[University of Colorado at Boulder]], demonstrated a new clock based on [[strontium]] atoms trapped in a [[laser]] grid. The new clock is more than twice as accurate as the best clock up to now, the [[NIST-F1]], and has an inaccuracy of less than one second in 200 million years (compared to 1 second per 80 million years for the F1).<ref>[http://www.nist.gov/public\_affairs/clock/clock.html Collaboration Helps Make JILA Strontium Atomic Clock ‘Best in Class’<!-- Bot generated title -->]</ref>

==How they work==

Since 1967, the International System of Units ([[SI]]) has defined the second as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two energy levels of the ground state of the caesium-133 atom.

This definition makes the caesium oscillator (often called an atomic clock) the primary standard for time and frequency measurements (see [[caesium standard]]). Other physical quantities, like the [[volt]] and [[metre]], rely on the definition of the second as part of their own definitions.<ref name="Franklin">{{Cite web|url=http://www.franklinclock.com/faq.htm|title=FAQs|accessdate=2008-01-17|publisher=Franklin Instrument Company |year=2007}}</ref>

The core of the atomic clock is a [[tunable microwave cavity]] containing the gas. In a hydrogen maser clock the gas emits [[microwaves]] (''[[maser|mases]]'')<!-- "mases" is the present tense of "to mase", from maser.--> on a [[hyperfine transition]], the field in the cavity oscillates, and the cavity is tuned for maximum microwave amplitude. Alternatively, in a caesium or rubidium clock, the beam or gas absorbs microwaves and the cavity contains an electronic amplifier to make it oscillate. For both types the atoms in the gas are prepared in one electronic state prior to filling them into the cavity. For the second type the number of atoms which change electronic state is detected and the cavity is tuned for a maximum of detected state changes.

This adjustment process is where most of the work and complexity of the clock lies. The adjustment tries to correct for unwanted side-effects, such as frequencies from other electron transitions, temperature changes, and the "spreading" in frequencies caused by ensemble effects. One way of doing this is to sweep the microwave oscillator's frequency across a narrow range to generate a modulated signal at the detector. The detector's signal can then be [[lock-in amplifier|demodulated]] to apply feedback to control long-term drift in the radio frequency. In this way, the quantum-mechanical properties of the atomic transition frequency of the caesium can be used to tune the microwave oscillator to the same frequency, except for a small amount of experimental error. When a clock is first turned on, it takes a while for the oscillator to stabilize.

In practice, the feedback and monitoring mechanism is much more complex than described above.

[[Image:Clock accurcy.jpg|thumb|right|250px|Historical accuracy of atomic clocks from [[NIST]].]]

A number of other atomic clock schemes are in use for other purposes. [[Rubidium standard]] clocks are prized for their low cost, small size (commercial standards are as small as 400 cm³) and short-term stability. They are used in many commercial, portable and aerospace applications. Hydrogen masers (often manufactured in Russia) have superior short-term stability compared to other standards, but lower long-term accuracy.

Often, one standard is used to fix another. For example, some commercial applications use a Rubidium standard periodically corrected by a [[Global Positioning System|GPS]] receiver. This achieves excellent short-term accuracy, with long-term accuracy equal to (and traceable to) the U.S. national time standards.

The lifetime of a standard is an important practical issue. Modern rubidium standard tubes last more than ten years, and can cost as little as US$50. Caesium reference tubes suitable for national standards currently last about seven years and cost about US$35,000. The long-term stability of hydrogen maser standards decreases because of changes in the cavity's properties over time.

Modern clocks use [[magneto-optical trap]]s to cool the atoms for improved precision.

==Application==

Atomic clocks are used to generate standard frequencies.{{Fact|date=January 2008}} They are installed at sites of [[time signal]]s, [[LORAN-C]], and [[Alpha (radio navigation)|Alpha]] navigation transmitters.{{Fact|date=January 2008}} They are also installed at some longwave and mediumwave broadcasting stations to deliver a very precise carrier frequency, which can also function as standard frequency.{{Fact|date=January 2008}}

Further, atomic clocks are used for long-baseline [[interferometry]] in [[radioastronomy]].{{Fact|date=January 2008}}

Atomic clocks are the basis of the [[GPS]] navigation system. The GPS master clock is a weighted average of atomic clocks at the ground stations and on-board the GPS satellites, each of which has several atomic clocks.

==Power consumption==

{{Expand-section|date=June 2008}}

Power consumption varies enormously, but there is a crude scaling with size.{{Fact|date=January 2008}} Chip scale atomic clocks can use power on the order of 100 [[Watt|mW]];{{Fact|date=January 2008}} NIST-F1 uses power orders of magnitude greater.{{Fact|date=January 2008}}

==Research==

[[Image:ChipScaleClock2 HR.jpg|thumb|250px|Chip-scale atomic clock unveiled by [[NIST]]]]

Most research focuses on ways to make the clocks smaller, cheaper, more accurate, and more reliable. These goals often conflict.

New technologies, such as femtosecond frequency combs, optical lattices and quantum information, have enabled prototypes of next generation atomic clocks. These clocks are based on optical rather than microwave transitions. A major obstacle to developing an optical clock is the difficulty of directly measuring optical frequencies. This problem has been solved with the development of self-referenced mode-locked lasers, commonly referred to as femtosecond [[frequency comb]]s. Before the demonstration of the frequency comb in 2000, [[terahertz]] techniques were needed to bridge the gap between radio and optical frequencies, and the systems for doing so were cumbersome and complicated. With the refinement of the frequency comb these measurements have become much more accessible and numerous optical clock systems are now being developed around the world.

Like in the radio range absorption spectroscopy is used to stabilize an oscillator — in this case a laser. When the optical frequency is divided down into a countable radio frequency using a [[femtosecond comb]], the [[bandwidth (signal processing)|bandwidth]] of the phase noise is also divided by that factor. Although the bandwidth of laser phase noise is generally greater than stable microwave sources, after division it is less.

The two primary systems under consideration for use in optical frequency standards are single ions isolated in an ion trap and neutral atoms trapped in an optical lattice.<ref name=saoc>{{cite journal | first = WH | last = Oskay | coauthors = Diddams SA, Donley EA, Fortier TM, Heavner TP, Hollberg L, Itano WM, Jefferts SR, Delaney MJ, Kim K, Levi F, Parker TE, Bergquist JC | year = 2006 | month = July 14 | title =Single-atom optical clock with high accuracy | journal = Physical Review Letters | volume = 97 | issue = 2 | pages = 020801 | pmid = 16907426 | url =http://www.boulder.nist.gov/timefreq/general/pdf/2096.pdf | accessdate = 2007-03-25 | doi =10.1103/PhysRevLett.97.020801|format=PDF}}</ref> These two techniques allow the atoms or ions to be highly isolated from external perturbations, thus producing an extremely stable frequency reference.

Optical clocks have already achieved better stability and lower systematic uncertainty than the best microwave clocks.<ref name=saoc/> This puts them in a position to replace the current standard for time, the caesium fountain clock.

Atomic systems under consideration include but are not limited to [[Aluminium|Al]]+, [[Mercury (element)|Hg]]+,<ref name=saoc/> [[Mercury (element)|Hg]], [[Strontium|Sr]], [[Strontium|Sr]]+, [[Indium|In]]+, [[Calcium|Ca]]+, [[Calcium|Ca]], [[Ytterbium|Yb]]+ and [[Ytterbium|Yb]].

==Radio clocks==

{{main|Radio clock}}

Modern radio clocks can be referenced to atomic clocks, and provide a way of getting high-quality atomic-derived time over a wide area using inexpensive equipment. However, radio clocks are not appropriate for high-precision scientific work. Many retailers market radio clocks as "atomic clocks"; though the radio signals they receive usually come from true atomic clocks, they are ''not'' atomic clocks themselves.

There are a number of longwave radio transmitters around the world, in particular [[DCF77]] (Germany), [[HBG Prangins|HBG]] (Switzerland), [[JJY]] (Japan), [[Time from NPL|NPL]] or [[Time from NPL|MSF]] (United Kingdom), [[Télé Distribution Française|TDF]] (France) and [[WWVB]] (United States). Many other countries can receive these signals (JJY can sometimes be received even in Western Australia and Tasmania at night), but it depends on time of day and atmospheric conditions. There is also a transit delay of approximately 1 [[millisecond|ms]] for every 300 kilometers (186&nbsp;mi) the receiver is from the transmitter. When operating properly and when correctly synchronized, better brands of radio clocks are normally accurate to the second.

Typical radio "atomic clocks" require placement in a location with a relatively unobstructed atmospheric path to the transmitter, perform synchronization once a day during the night-time, and need fair to good atmospheric conditions to successfully update the time. The device that keeps track of the time between, or without, updates is usually a cheap and relatively inaccurate [[quartz-crystal clock]], since it is thought that an expensive precise time keeper is not necessary with automatic atomic clock updates. The clock may include an indicator to alert users to possible inaccuracy when synchronization has not been successful within the last 24 to 48 hours.

==See also==

{{portal|Time|MontreGousset001.jpg}}

{{portalpar|Electronics|Nuvola\_apps\_ksim.png}}

\* [[Network Time Protocol]]

\* [[NIST-F1]]

\* [[Radio clock]]

\* [[Télé Distribution Française]]

\* [[GPS]]

\* [[Frequency comb#optical clockwork|Optical Clockwork]]

\* [[Primary Atomic Reference Clock in Space]]

\* [[Magneto-optical trap]]

\* [[International Atomic Time]]

==References==

{{reflist}}

==External links==

\* [http://inms-ienm.nrc-cnrc.gc.ca/faq\_time\_e.html#Q10 ''What is a Cesium atom clock?'']

\* [http://inms-ienm.nrc-cnrc.gc.ca/research/optical\_frequency\_projects\_e.html#optical National Research Council of Canada: ''Optical frequency standard based on a single trapped ion'']

\* [http://tycho.usno.navy.mil/ United States Naval Observatory Time Service Department]

\* [http://www.ptb.de PTB Braunschweig, Germany - with link in English language]

\* [http://www.npl.co.uk/time/ National Physical Laboratory (UK) time website]

\* [http://www.boulder.nist.gov/timefreq/service/its.htm NIST Internet Time Service (ITS): Set Your Computer Clock Via the Internet]

\* [http://www.nist.gov/public\_affairs/releases/miniclock.htm NIST press release about chip-scaled atomic clock]

\* [http://nist.time.gov/ NIST website]

\* [http://www.sciencemuseum.org.uk/onlinestuff/stories/atomic\_clocks.aspx?keywords=atomic Web pages on atomic clocks] by [[Science Museum (London)|The Science Museum (London)]]

\* [http://news.bbc.co.uk/2/hi/science/nature/4023777.stm Optical Atomic Clock] BBC, 2005

\* [http://jpsj.ipap.jp/link?JPSJ/75/104302/ Optical lattice clock]; [[Journal of the Physical Society of Japan]]

\* [http://www.npl.co.uk/server.php?show=ConWebDoc.971 The atomic fountain]

{{Time Topics}}

{{Time measurement and standards}}

[[Category:Clocks]]

[[Category:Horology]]

[[Category:Nuclear technology]]

[[Category:Electronic test equipment]]

[[bg:Атомен часовник]]

[[ca:Rellotge atòmic]]

[[cs:Atomové hodiny]]

[[da:Atomur]]

[[de:Atomuhr]]

[[et:Aatomkell]]

[[es:Reloj atómico]]

[[fr:Horloge atomique]]

[[id:Jam atom]]

[[it:Orologio atomico]]

[[he:שעון אטומי]]

[[kn:ಪರಮಾಣು ಗಡಿಯಾರ]]

[[lt:Atominis laikrodis]]

[[lv:Atompulkstenis]]

[[hu:Atomóra]]

[[nl:Atoomklok]]

[[ja:原子時計]]

[[no:Atomur]]

[[pl:Zegar atomowy]]

[[pt:Relógio atômico]]

[[ru:Атомные часы]]

[[sq:Ora atomike]]

[[sk:Atómové hodiny]]

[[sr:Атомски часовник]]

[[fi:Atomikello]]

[[sv:Atomur]]

[[th:นาฬิกาอะตอม]]

[[vi:Đồng hồ nguyên tử]]

[[uk:Атомний годинник]]

[[vec:Orołojo atòmico]]