NPL National Physical Laboratory

The World Time System

Introduction
The importance of a single time scale being accepted and used world-wide cannot be over-emphasised. Applications from global communications to satellite navigation, surveying and transport systems are underpinned by precise timing, and the same stable and accurate time scale must be in use everywhere for such systems to operate correctly. This article gives a brief overview of the definition and generation of the international time scale, known as Coordinated Universal Time (UTC).

The definition of UTC
UTC is an atomic time scale, based on the outputs from a large number of atomic clocks around the world. It is an integrated time scale, meaning that it is a simple count of the basic unit of time duration, the second. UTC time is conventionally counted in the universally-understood units of minutes, hours and days.

The definition of the second in the International System of Units (SI) was changed in 1967 from one based on astronomical measurements to one based on the frequency of the transition between two particular energy levels in caesium atoms. The definition is formally given as: '*The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom'*, with the additional qualification in 1997 that, '*This definition refers to a caesium atom at rest at a temperature of 0 K'*.

When a time scale is calculated by combining results from atomic clocks in widely dispersed locations, the gravitational differences between the locations give rise to relativistic effects that must be taken into account. For example, a 1000 m difference in altitude between two timing institutes would cause their clocks to differ in frequency by roughly a part in 10^{13}. The solution is to remove this frequency shift by correcting for each clock's offset from a surface of constant gravitational potential roughly coincident with the Earth's surface known as the geoid.

The generation of UTC
Since 1988, the generation of UTC has been the responsibility of the Bureau International des Poids et Mesures (BIPM), located near Paris. The BIPM collects clock comparison and time transfer results from around 55 National Measurement Institutes (NMIs) around the world, allowing more than 200 atomic clocks to contribute to UTC.

Each calendar month, the BIPM processes the clock measurements from the preceding month to produce a smooth and highly stable time scale known as Echelle Atomique Libre (EAL). The duration of the scale interval is then corrected using results from primary frequency standards to bring it as close as possible to the SI definition of the second, the result being a time scale known as International Atomic Time or TAI.

One of the most important applications of precise timekeeping for many years has been celestial navigation, which requires accurate knowledge of the Earth's rotation angle or, equivalently, mean solar time. TAI has the disadvantage that it slowly diverges from time scales based on the Earth's rotation, and UTC was developed as a time scale for practical use that combined the stability of atomic time with a close linkage to mean solar time. Since 1972, this link has been achieved by inserting (or removing) one-second steps known as leap seconds into (or from) UTC to ensure that it remains within 0.9 seconds of an astronomical time scale based on the mean solar day known as UT1.

A leap second can be applied to UTC at the end of December or June, or exceptionally March or September. The decision is taken by the International Earth Rotation and Reference Systems Service, based on analysis of results from several different methods for monitoring changes in the Earth's rotation, and announced around 5 months in advance. The difference between TAI and UTC was set to exactly 10 s on 1 January 1972, and following the leap second at the end of 31 December 2008 the offset has been TAI-UTC = 34 s.

The outcome of this process is the international time scale, UTC, which the BIPM publishes in its Circular T each month in the form of the offset between each contributing local time scale and UTC at 5-day intervals. The stages involved in forming UTC are shown schematically in figure 1. Both EAL and TAI are regarded as intermediate stages in the calculation of UTC, which today forms the basis of all precise time measurement.

Figure 1: Schematic diagram of the international time system.