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Time on the move

Optical clocks promise new standards in the measurement of time. To ensure accuracy, however, different clocks must be compared, even if they are on opposite sides of the planet.

On 1 April 2007, the source of the radio-frequency signal that has ensured that the United Kingdom has ticked to the same clock for the past 80 years was moved from central England to a new home on the northwest coast. Before railway networks spread across the country, variations in local time were made largely irrelevant by long travelling times. However, during the 1840s and 1850s, as they expanded, the train companies carried the time in London to local stations, and this was eventually adopted by public clocks. Legislation formally imposed Greenwich Mean Time (GMT) across the UK in 1880. Today's source of GMT, the MSF, a 15-kW radio signal emitting at a frequency of 60 kHz, had, until last month, been broadcast from Rugby in Warwickshire to act as a reference for the nation's clocks, maintaining the accuracy of a wide range of electronic devices to within one millisecond.

Scientists at the National Physical Laboratory (NPL) keep the timing of the MSF, or 'The Time from NPL' as it is now known, up to date using atomic clocks. Just like in a conventional clock or digital watch, atomic clocks rely on an oscillator; however, instead of a pendulum or a quartz crystal, they use an electromagnetic wave that is stabilized by reference to a resonant transition between two energy states in an atom. At present, caesium-fountain clocks set the standard with an atomic transition at microwave frequencies, remaining accurate to within one second over many millions of years. Such a precise clock might seem to be of only academic interest, but in fact it is vital for global positioning systems (GPS) and even further improvements are required in order to increase the spatial accuracy of

GPS. The stability of atomic clocks scales with oscillator frequency, and this has led researchers towards optical-frequency atomic clocks. These have seen a rapid development over recent years and now rival microwave atomic clocks in terms of accuracy, with very real potential for vast improvement, possibly to the precision of one second over a billion years.

However, just like in Britain 150 years ago, the ability to transfer this time standard to far-flung locations while maintaining the high level of stability and accuracy is of vital importance — not least to ensure that the standards in different laboratories around the world agree. On page 283 of this issue, scientists at the National Institute of Standards and Technology (NIST) in Boulder in Colorado detail how this could be achieved with photonics, and prove their idea with a 750-m-long prototype optical network. As the team points out, the requirements for such a system are rigorous: the frequency of the oscillator (approximately 2×10^{14} Hz) should vary by no more than 100 mHz over a period of one second and the timing jitter should be below one femtosecond. When it comes to transmitting the standard, optical fibres seem to have the solution: an advanced technology with a vast network already available. The difficulty is that the operation wavelengths of most optical clocks are incompatible with the transparency window of optical fibres. What is necessary is to transfer the stability to a wavelength suitable for transmission. The system constructed and tested by the NIST team consists of a number of phase-stabilized continuous-wave lasers, a 750-m closed-ring network of erbium fibre and frequency combs to shift the stability of the reference frequency to a second wavelength between 500 nm and 2 μm. The set-up is just a prototype at present, and the team admit that the principle must be extended to longer transmission distances. They suggest that distances in excess of 50 km could be possible using so-called coherent repeaters.

The usefulness of a transferable, stable, optical signal goes well beyond global positioning. Helen Margolis from NPL highlights another possible application on page 258 of this issue: answering the intriguing question of whether fundamental constants vary with time. Even the smallest variation, in the fine structure constant for example, could be detected by a discrepancy in two distant optical clock standards, as long as this difference is larger than any errors introduced while comparing them. The long-term goal, of course, is to create a newer, more precise definition of the second. For this, it is crucial that different clocks can be compared. Just as long journey times in pre-railway Britain made the synchronization of clocks pointless, the phenomenal accuracy of optical clocks is made far more useful when it can be carried around the globe. The work at NIST shows just how this could be done.