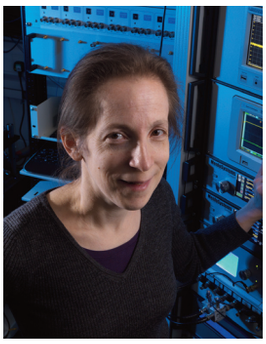
TIMEKEEPING FIT FOR THE FUTURE



Prof Helen Margolis
Head of Science (Time and Frequency), National Physical Laboratory (NPL)

Precision timing underpins the infrastructure and services we depend on in our daily lives. For example, mobile phone networks, global navigation satellite systems (GNSS) and the energy grid all require accurate atomic clocks and synchronisation technologies to operate properly. But this dependence on precise timing is not widely appreciated – time is sometimes called an "invisible utility".

Most users of accurate time and frequency signals, including operators of critical national infrastructure, currently rely on timing signals from GNSS. This is because they are free and widely available. But they are also weak. This makes them vulnerable to natural, accidental, and deliberate interference, for example by solar storms, spoofing or jamming. This vulnerability, coupled with lack of awareness of the extent to which critical national infrastructure depends on GNSS, poses a significant risk. The 2018 Blackett review "Satellite-derived time and position: a study of critical dependencies"[1] and the National Risk Register[2] both emphasise the need to increase resilience to GNSS disruption, for example by adopting suitable backup systems.

The UK already has an alternative source of time and frequency signals. At the National Physical Laboratory (NPL), we operate the national time scale UTC(NPL). This has been the UK reference for time and frequency for over 30 years, providing signals traceable to the global time scale Coordinated Universal Time (UTC). But UTC(NPL) is not as resilient as we would like, being based on atomic clocks and other timing infrastructure located on a single site. And although we operate several UTC-traceable time and frequency distribution services, it is also not as accessible as we would like.

Most users access our free services – our internet time service or the MSF radio time signal – but these only provide millisecond timing accuracy. The NPL*Time*® time-over-fibre service to users in the financial sector has far better accuracy, with a service level agreement of 1 microsecond. However its geographical reach is limited to users in the south of the UK at present.

THE UK NATIONAL TIMING CENTRE

The NPL-led National Timing Centre (NTC) programme is taking steps to reduce the over-

NPL's caesium fountain primary frequency standard

reliance of critical national infrastructure on timing signals from GNSS, and to improve user access to trusted timing signals across the UK.

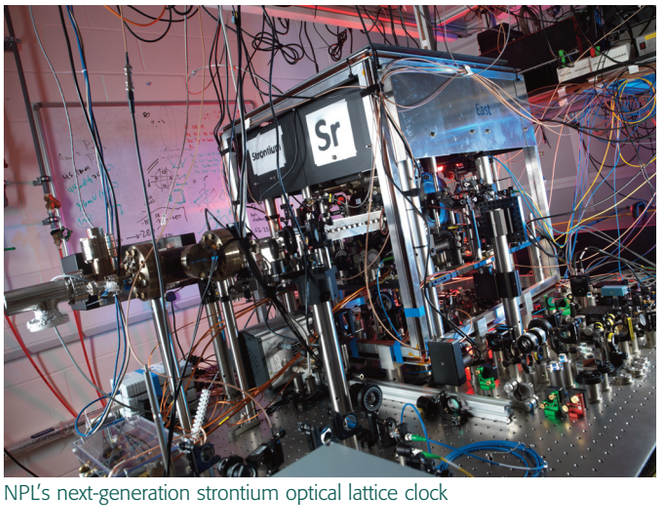
At its heart is the construction of a new, more resilient UK time scale. Our design is for a mesh of four geographically distributed, linked sites containing atomic clocks and other time scale hardware, with far more remote monitoring capabilities and automation than UTC(NPL) has today. For example, if one of the clocks in the network fails, then the switch to another will happen automatically, without human intervention. Construction of the new time scale is underway and in due course it will become the source of UTC(NPL). At that point all our existing time and frequency dissemination services will switch over to the new infrastructure.

The programme is also providing innovation opportunities for UK companies through access to time and frequency signals, expertise and funding. Three innovation nodes have been set up in partnership with the universities of Strathclyde, Surrey and Cranfield, and are being made available to successful applicants in funding calls run in partnership with Innovate UK. These innovation nodes each provide a combination of timing signals traceable to UTC(NPL) and laboratory space for industry research and development, to test new technologies and applications. The aim is to support business-led innovation, and stimulate the UK supply chain and capability, whilst developing a blueprint for future scale-up of the distribution infrastructure. To help address the known skills gap in time and frequency, two e-learning courses have also been developed[3,4].

ANTICIPATING CHANGE

The new UK time scale and the innovation nodes are based on today's time and frequency technologies, with almost all the equipment being sourced from outside the UK. We are taking steps to stimulate a UK supply chain, but in the meantime we are also anticipating the future.

The next generation of atomic clocks used for timekeeping will be based on atomic transitions at optical, rather than microwave, frequencies. The performance of these optical clocks already far surpasses that of today's caesium fountain primary frequency standards, and so a change in the definition of the unit of time (the second) is anticipated. An international roadmap towards the redefinition has been drawn up by the international metrology community, with a target date of 2030.



NPL's next-generation strontium optical lattice clock

It is critical that we anticipate this change – the redefinition will have an impact on the future clocks we need for the UK time scale and on the technologies used for distribution, as well as on end-user applications. For this reason, NPL is playing a leading role in the international work towards the redefinition.

One key goal on the roadmap is the validation of optical clock uncertainties through international comparisons. In March 2022, NPL coordinated the largest optical clock comparison ever performed, involving 11 optical clocks in 7 different countries, linked by optical fibres and via satellites. An alternative comparison approach is to use transportable optical clocks, and in March 2023 we hosted visiting optical clocks from Japan and Germany for this purpose.

Another goal is for optical clocks to contribute regularly to the global time scale UTC, to ensure that end users benefit from an improved quality of this time scale after the redefinition. UTC is derived from International Atomic Time (TAI), computed by the International Bureau of Weights and Measures (BIPM) using data from atomic clocks. In March 2023 we reached a major milestone when data from our strontium optical lattice clock provided the first UK optical steer of TAI. We are also working towards introducing optical clocks into our national time scale UTC(NPL).

Routine contributions to time scales need continuously running optical clocks and associated infrastructure, rather than research prototypes. Such systems are included in the facilities we are building in NPL's new advanced quantum metrology laboratories and will be used to generate an optically steered local time scale as well as to make regular contributions to international time scales in preparation for a redefinition of the second.

Atomic clocks are one type of technology falling within the umbrella of the UK Quantum Technologies programme, and the state-of-the-art reference frequencies in the new laboratories will be used to provide a test and evaluation facility for such technology. Companies developing quantum technology products – from laser systems to the most advanced optical atomic clocks – will be able to characterize their performance, helping them to accelerate innovation and bring new products and services to market more rapidly.

Initially this will be possible in collaborative innovation space within the new facilities. Our longer-term aim is that companies will also be able to access the time and frequency reference signals remotely via optical fibres. As a first step, an optical fibre link from NPL to the University of Birmingham is being set up as part of our contribution to the UK Quantum Technology Hub in Sensors and Timing. But our distribution hub is being set up to allow for much wider expansion of the optical fibre network in future.

FUTURE VISION

This will take us a step closer to realizing our longer-term vision: a high-accuracy time and frequency backbone running the length of the UK. Branches stemming off that backbone will provide a range of services with different performance levels, not just by fibre but also using broadcast technologies. All time and frequency signals delivered to users will be traceable to UTC(NPL), as the highest point

of reference within the UK. This distribution network will enable trusted timing signals to be made widely available to users, wherever and whenever they are needed, with the accuracy appropriate for their applications.

Our daily lives already rely on time and frequency, and as our world becomes ever more connected, the demands on timing and synchronisation will increase further. A resilient UTC(NPL), in combination with a nationwide time and frequency distribution network, will deliver assured time and frequency references to UK critical infrastructure. It will also provide the UK with a unique resource on which to build research, innovation and high-value manufacturing, stimulating the future supply chain necessary to underpin next-generation applications.

References

1 Government Office for Science, "Satellite-derived time and position: a study of critical dependencies" (2018); https://www.gov.uk/government/publications/satellite-derived-time-and-position-blackett-review

2 HM Government, National Risk Register, 2020 edition; https://www.gov.uk/government/publications/national-risk-register-2020

3 "Introduction to Time and Frequency" e-learning course; https://training.npl.co.uk/course/introduction-to-time-and-frequency-measurement/

4 "Introduction to Clock Performance" e-learning course; https://training.npl.co.uk/course/introduction-to-clock-performance/