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New definition of second ticks closer after international optical-clock comparison

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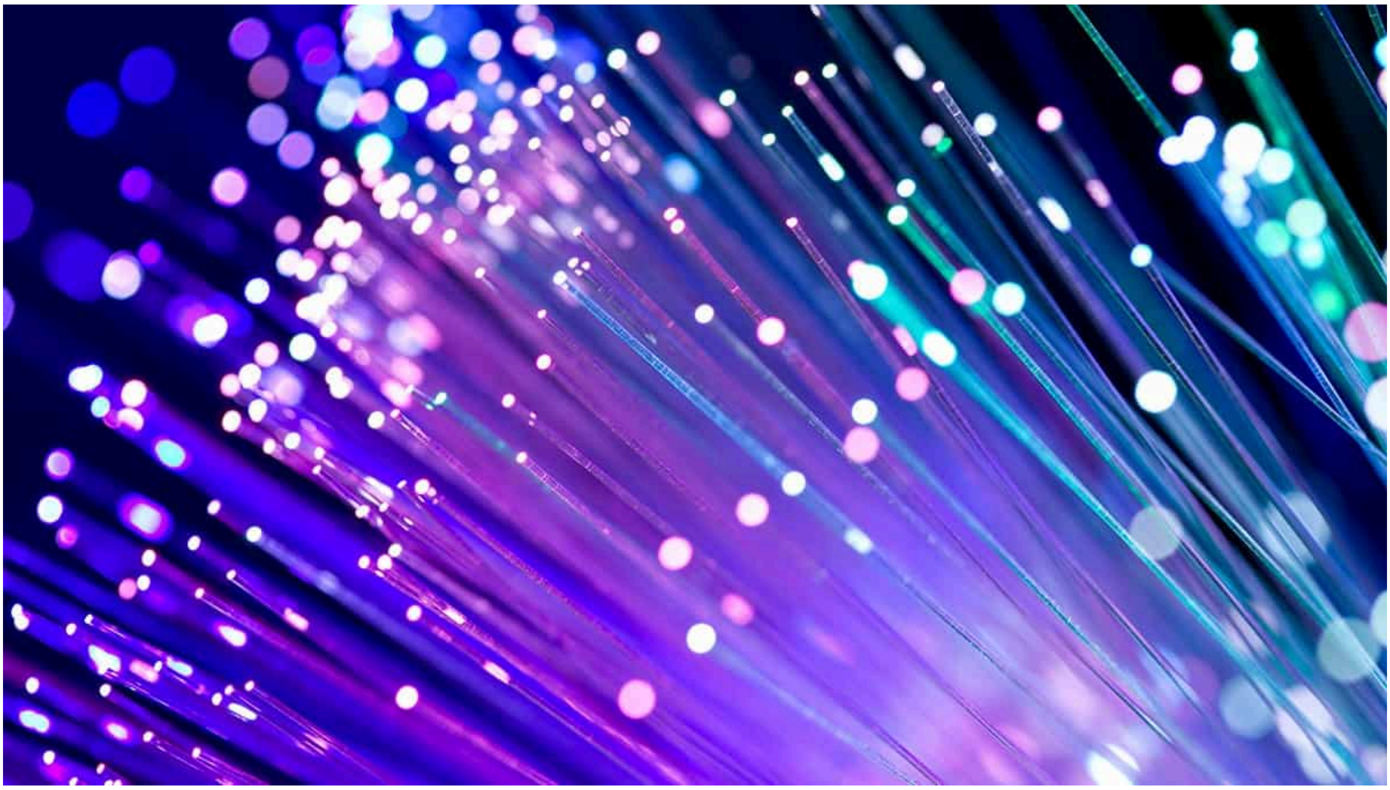

Bright idea Optical fibres are playing a crucial role in the comparison of optical clocks. (Courtesy: istock/morepixels)

Atomic clocks are crucial to many modern technologies including satellite navigation and telecoms networks, and are also used in fundamental research. The most commonly used clock is based on caesium-133. It uses microwave radiation to excite an electron between two specific hyperfine energy levels in the atom's ground state. This radiation has a very precise frequency, which is currently used to define the second as the SI unit of time.

Atomic clocks are currently being supplanted by the optical clocks, which use light rather than microwaves to excite atoms. Because optical clocks operate at higher frequencies, they are much more accurate than microwave-based timekeepers.

Despite the potential of optical atomic clocks, the international community has yet to use one to define the second. Before this can happen, metrologists must be able to compare the timekeeping of different types of optical clocks across long distances to verify that they are performing as expected. Now, as part of an EU-funded project, researchers have made a highly coordinated comparison of optical clocks across six countries in two continents: the UK, France, Germany, Italy, Finland and Japan.

Time flies

The study consisted of 38 comparisons (frequency ratios) performed simultaneously with ten different optical clocks. These were an indium ion clock at LUH in Germany; ytterbium ion clocks of two different types at PTB in Germany; a ytterbium ion clock at NPL in the UK; ytterbium atom clocks at INRIM in Italy and NMIJ in Japan; a strontium ion clock at VTT in Finland; and strontium atom clocks at LTE in France and at NPL and PTB.

To compare the clocks, the researchers linked the frequency outputs from the different systems using two methods: radio signals from satellites and laser light travelling through optical fibres. The satellite method used GPS satellite navigation signals, which were available to all the clocks in the study. The team also used customized fibre links, which allowed measurements with 100 times greater precision than the satellite technique. However, fibres could only be used for international connections between clocks in France, Germany and Italy. Short fibre links were used to connect clocks within institutes located in the UK and Germany.

A major challenge was to coordinate the simultaneous operation of all the clocks and links. Another challenge arose at the analysis stage because the results did not always confirm the expected values and there were some inconsistencies in the measurements. However, the benefit of comparing so many clocks at once and using more than one link technique is that it was often possible to identify the source of problems.

Wait a second

The measurements provided a significant addition to the body of data for international clock comparisons. The uncertainties and consistency of such data will influence the choice of which optical transition(s) to use in the new definition of the second. However, before the redefinition, even lower uncertainties will be required in the comparisons. There are also several other very different criteria that need to be met as well, such as demonstrating that optical clocks can make regular contributions to the international atomic time scale.

Rachel Godun at NPL, who coordinated the clock comparison campaign, says that repeated measurements will be needed to build confidence that the optical clocks and links can be operated reliably and always achieve the expected performance. She also says that the community must push towards lower measurement uncertainties to reach less than 5 parts in 10^{18} – which is the target ahead of the redefinition of the second. “More comparisons via optical fibre links are therefore needed because these have lower uncertainties than comparisons via satellite techniques”, she tells *Physics World*.

Pierre Dubé of Canada’s National Research Council says that the unprecedented number of clocks involved in the measurement campaign yielded an extensive data set of frequency ratios that were used to verify the consistency of the results and detect anomalies. Dubé, who was not involved in the study, adds that it significantly improves our knowledge of several optical frequency ratios and our confidence in the measurement methods, which are especially significant for the redefinition of the SI second using optical clocks.

“The optical clock community is strongly motivated to obtain the best possible set of measurements before the SI second is redefined using an optical transition (or a set of optical transitions, depending on the redefinition option chosen)”, Dubé concludes.

The research is described in *Optica*.

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‹ Back to Metrology