European Metrology
Programme for
Innovation and Research

EURAMET

# SI Broader Scope - Projects

An overview of the funded projects from the Targeted Programme SI Broader Scope.

The aim of these projects is to underpin the development of the SI system of measurement units.

The projects focus on preparations for the implementation of the redefinition of the SI base units, the development of practical realisations of the redefined units and traceability of measurement results.

EURAMET e.V. - the European Association of National Metrology Institutes

# Precision surface measurements for innovative optics

## Measurement to support innovation in optical aspheres and freeform surfaces

Aspheres and freeform surfaces are components used in a variety of optical systems, from medical imaging to astronomy. They deliver better image quality compared to traditional spherical elements and as a result their use is growing rapidly. However, the ability to develop higher-performance aspheres and freeform surfaces is limited by the precision with which the shape of their surface can be measured. Although modern optical polishing techniques can remove material at the nanometre level, measurement techniques are unable to measure with the same degree of precision. This project will build on the work of the previous EMRP project IND10 Form, which achieved measurements below 100 nanometres, by developing new measurement capabilities within European National Measurement Institutes to routinely measure below 30 nanometres. The capabilities developed will strengthen Europe's position in global optics, and will be used by industry to develop a new level in optical device performance.

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| **Project 15SIB01** |
| Reference algorithms and metrology on aspherical and freeform lenses |
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# Paving the way for the new kelvin

## New methods to determine a comprehensive and low-uncertainty temperature dataset

In 2018, the kelvin – the SI base unit of temperature – will be redefined in terms of the fundamental Boltzmann constant, as part of the international effort to make a logical, coherent and complete system of units for the foreseeable future. To guarantee a successful transition, the redefinition must be founded on robust primary thermometry methods and results. In particular, a robust dataset is required that details deviations between temperatures founded on the current rather than the new kelvin definition. This project will build upon the achievements of the preceding EMRP project SIB01 InK by extending the capabilities developed into areas previously unexplored, such as ultralow temperatures in the range of 0.0009 K to 1 K. The new methods and data developed will complete the remaining gaps in knowledge required to establish a comprehensive low-uncertainty dataset, ensuring the definition is achieved and disseminated effectively.

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| **Project 15SIB02** |
| Implementing the new kelvin 2 |
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# Unlocking the potential of next-generation clocks

## High-accuracy time measurement for optical atomic clocks

Accurate global timekeeping is based on the use of a worldwide standard definition of the second, the SI base unit of time. The second is currently best realised using caesium fountain atomic clocks, but optical atomic clocks can measure time with even greater accuracy. However, many previous demonstrations of optical atomic clock performance have been based on estimates, not experimental verification. This project will build on the achievements of EMRP projects SIB04 Ion Clock and SIB55 ITOC and help to unlock the potential of these clocks by developing measurement techniques that can verify accuracy to one billionth of a billionth of a second, one hundred times more accurately than caesium clocks. The ability to measure time to such a degree of accuracy will support the use of optical atomic clocks in the definition and proposed redefinition of the second, and will find application in a broad range of scientific and commercial arenas, from aiding in the search for dark matter to improving the service from global navigation satellite systems.

| **Project 15SIB03** |
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| Optical clocks with 1E-18 uncertainty |
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# Bringing traceability to AC measurements

## Developing AC voltage measurement systems for industrial end-users

The volt is the SI unit of electrical potential energy and refers to the energy that could be released if a current were allowed to flow. The value of the volt has been precisely defined, to ensure it is measured with universal consistency, and every voltage measurement made is traceable back to this SI definition. Although voltage measurements made from direct currents (DC) can be traced back reliably to the standard volt, measurements made from alternating currents (AC) cannot, particularly in high-end applications, due to sources of uncertainty in the traceability chain. This project will develop reliable and easy to use AC voltage measurement systems that can be traced to the standard SI volt. These measurement systems will allow a range of industrial end-users to develop previously unachievable processes and products that rely on fast analogue-to-digital conversion, such as power quality monitors, which provide support to the smart grids of the future.

| **Project 15SIB04** |
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| Waveform metrology based on spectrally pure Josephson voltages |
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# Comparing next-generation clocks through optical fibres

## Building a European optical fibre network for comparing optical atomic clocks

Caesium atomic clocks are used to accurately define the second, the SI base unit of time. But optical atomic clocks are more accurate and more stable than caesium clocks, and are the most promising candidates for use in the proposed re-definition of the second. Clocks in different locations need to be regularly compared to reveal and reduce uncertainty, but the current satellite-based techniques used to compare caesium clocks are not precise enough. This project will build on the achievements of EMRP project SIB02 NEAT-FT and help to unlock the full accuracy potential of optical atomic clocks, by developing comparison techniques for optical clocks based on optical fibres, including installing and upgrading fibre optic links between European National Measurement Institutes. This network will allow optical clocks to be compared at new levels of accuracy and will pave the way for future improvements in the precision of time measurement in fields such as transport, communications and finance.

| **Project 15SIB05** |
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| Optical frequency transfer - a European network |
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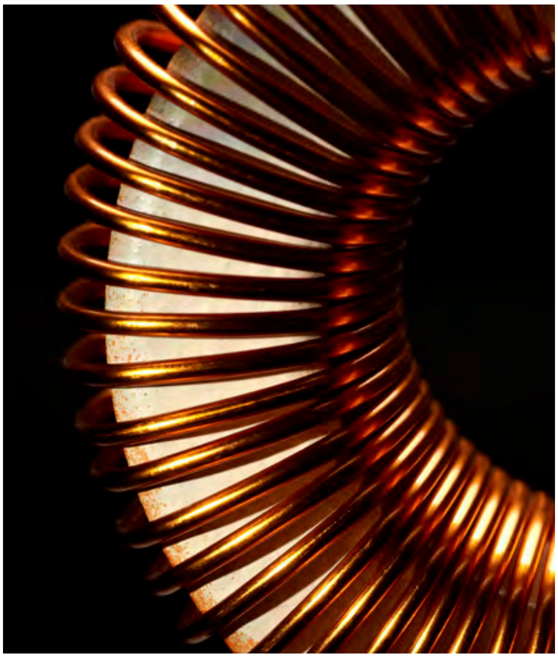
# Measuring magnetic fields at the nanoscale

## Accurate and traceable measurement capabilities for micro and nanoscale magnetic field measurement

The development of smaller, higher-performance electronic devices demands the measurement of magnetic fields on ever smaller scales. Although magnetic fields at the macro level can be measured accurately and reliably traced back to magnetic reference standards, measurements at the micro and nano level cannot – this is hindering high-tech industries' ability to conduct the quantitative analysis and quality control needed to develop innovative products. This project will develop European metrology capabilities that build on the achievements of EMRP project EXL04 SpinCal to extend the accurate and traceable measurement of magnetic fields to micrometre and nanometre scales. This will contribute to the international harmonisation of high-resolution magnetic field measurement, and allow European industry to measure and manipulate fields with previously unattainable levels of precision. Industrial users in fields including computing, magnetic sensing and biomedicine will be able to develop new standards in quality control and product performance.



| **Project 15SIB06** |
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| Nano-scale traceable magnetic field measurements |
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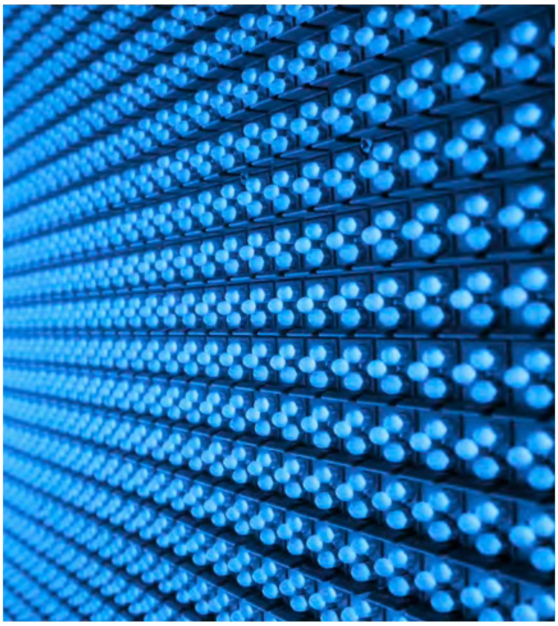
# Increasing confidence in energy efficient lighting

## Developing LED-based standard lamps for solid-state light calibration

Solid-state lighting, which uses light-emitting diodes (LEDs), is globally replacing traditional incandescent lighting, due to lower power consumption and greater durability. Photometers are used to measure the performance of lights, and are calibrated using standard lamps to ensure the accuracy and consistency of measurements. However, the standard lamps used for calibration are currently based on incandescent lights, not LEDs. This project will develop new standard lamps based on LEDs and new measurement techniques for defining the properties of solid-state lights. The results will be used by National Measurement Institutes and test laboratories to accurately calibrate solid-state light photometers and will give European industry an advantage in the development of new commercial standard lamps. These outputs will result in a more reliable classification of the energy efficiency of solid-state lighting, increasing consumer confidence in this new greener technology.



| Project 15SIB07 |
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| Future photometry based on solid-state lighting products |
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# Precision control of single electrons

## Using single-electron sources to realise the new ampere

The ampere is the SI base unit of electric current. In the proposed redefinition for 2018, the ampere will be based on the value of the elementary charge, a fundamental physical constant that is the magnitude of the charge on an electron. To ensure that the new ampere can be directly realised, methods are needed that can accurately and reliably generate an electric current by controlling the flow of individual electrons. One practical method for achieving this is to use single-electron sources that generate currents by introducing just one electron at a time into a circuit. This project, built on the achievements of EMRP project SIB07 Qu-Ampere will develop capabilities for the fabrication, testing and validation of single-electron sources. These capabilities will be used to support the ampere redefinition, and will be available for industrial users to calibrate their small-current measurement devices and instruments to ensure consistency in traceable current measurements.

| Project 15SIB08 |
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| Quantum realisation of the SI ampere |
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# 3D measurements for advanced nanotechnology

## Metrology for accurate and traceable nanoscale 3D measurement

The demand for smaller and higher-performance electronic devices in our everyday lives requires the development of increasingly smaller and more sophisticated nanoscale components. Yet current techniques to measure the dimensions of nano-objects are inadequate for emerging needs, as the uncertainties involved are too great to meet the requirements of industry and scientific research. Conventional 3D metrology, using coordinate measuring machines, is accurate to almost one nanometre, but an emerging class of scanning probe microscopes (SPM) have the potential to exceed this level of accuracy beyond the nanometre level. However, standardised SPM techniques, traceable to reference measures, have not yet been devised. This project will build on the achievements of EMRP project NEW01 Trend by developing SPM-based approaches to measure objects in three dimensions, which can be traced reliably to reference measures. More accurate nano-measurement will support the development of new and higher-performance devices in fields as diverse as medicine, energy capture and storage, and space exploration, offering the potential for broad technological and societal impact.

**Project 15SIB09**

Traceable three-dimensional nanometrology

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# Understanding beta radiation from radionuclides

## Metrology for the accurate measurement of radionuclide beta spectra

Radionuclides are unstable atoms that decay, releasing radiation. Radionuclides that release beta radiation (electrons) are used in a range of applications, but techniques to measure the precise energy levels (spectra) of beta radiation are not sufficiently accurate. For example, radionuclides are used in medical diagnosis, and a precise knowledge of the energy of beta emissions is important to ensure correct dosage. Yet the spectra of these nuclides often have large uncertainties. This project will develop theoretical and experimental approaches to measure the spectra of beta radiation to an unprecedented level of accuracy, including modelling the shape of spectra for the first time, and the development of novel beta radiation detection techniques. These methods will allow the energy of beta radiation to be measured with greater precision, supporting the more effective use of radionuclides in a broad range of applications, including medical diagnosis, nuclear power management, environmental protection and even the detection of neutrinos in astrophysics.

**Project 15SIB10**

Radionuclide beta spectra metrology

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# Europe's National Measurement Institutes working together

**The majority of European countries have a National Metrology Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to the changing demands of the world. It makes sense for these NMIs to collaborate with one another, and the European Association of National Metrology Institutes (EURAMET) is the body that coordinates collaborative activities in Europe.**

The European Metrology Programme for Innovation and Research (EMPIR) follows on from the successful European Metrology Research Programme (EMRP), both implemented by EURAMET. The programmes are jointly funded by the participating countries and the European Union and have a joint budget of over 1000 M€ for calls between 2009 and 2020. The programmes facilitate the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities. This accelerates innovation in areas where shared resources and decision-making processes are desirable because of economic factors and the distribution of expertise across countries or industrial sectors.

EURAMET wants to involve European industry and universities at all stages of the programme, from proposing Potential Research Topics to hosting researchers funded by grants to accelerate the adoption of the outputs of the projects.

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