

Publishable Summary for 24RPT02 MetroMag

A European Infrastructure for Low Magnetic Field Metrology

Overview

Measurements in the low magnetic field range, from around 10 μT up to 10 mT, are increasingly required by industry due to strong demand and recent developments in key areas such as the electric mobility sector (sensors embedded in electric motors, magnetic encoders, etc.), the medical sector (safety and compatibility of magnetic field-based diagnostics such as MRI and magnetoencephalography), and magnetic field sensing applied to the detection and localisation of ferromagnetic and conducting objects in safety applications and prospecting for natural mineral resources. However, only very few European NMIs have the required capabilities to perform traceable measurements in the low magnetic field range. Consequently, the adoption of novel technologies and materials is hindered by the lack of pan-European metrological expertise in this area. This project will establish standards to measure weak magnetic fields, develop a transfer standard to enable easier and faster comparisons, develop novel methods to cancel environmental magnetic fields, and establish a European infrastructure in the low magnetic field ranges to address the stakeholders' needs.

Need

Developments in sectors related to new materials, healthcare, biomedicine, environment monitoring, industrial detection, prospecting for natural resources, quantum sensing, electrical mobility, sensors for ICT and space applications are increasing requiring measurements of low magnetic fields. Primary standards of magnetic field are currently based on the nuclear magnetic resonance (NMR) technique in water samples, which ensures traceability to the frequency standard, however this capability is only available at a limited number of NMIs. In addition, this technique can only be used in DC magnetic fields and in a limited magnetic field range, with a lower limit of 10 μT . Alternative and easy to use calibration capabilities are therefore highly desired especially in new or developing calibration laboratories with limited infrastructure.

To ensure confidence in the measurements and calibrations provided by NMIs/DIs, it is necessary that the measurements are traceable, robust and comparable. Therefore, timely and reliable laboratory intercomparisons are required covering all necessary magnetic field ranges. Up to now, interlaboratory comparisons on magnetic field measurements have been very scarce, and difficult to perform due to a lack of suitable, easy to use travelling standards.

Additionally, the Earth produces its own magnetic field, typically 40-50 μT , and this is of sufficient strength to be a perturbing factor in low-intensity magnetic field measurements. Current environmental magnetic field cancellation techniques rely on shielding and compensation coils to cancel the local magnetic field in a given volume of space. However, due to constant urban development and local DC power noise, existing cancellation systems are becoming insufficient to maintain their initially designed performance, and new or improved magnetic field cancellation methods are required.

The project 21SCP02 "*Traceability Routes for Magnetic Measurements*" (TRaMM) demonstrated that the current capabilities from NMIs/DIs are not sufficient to meet the increasing demands from industry, manufacturing companies, test laboratories, research institutes and universities, and a wider network of NMIs/DIs within Europe having the capability to perform magnetic measurements and calibrations is needed.

Report Status:
PU – Public, fully open

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European Partnership



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**METROLOGY
PARTNERSHIP**



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Objectives

The overall objective of the project is to develop improved capability for measurements and calibrations of low-intensity magnetic fields and to establish a pan-European metrological infrastructure to cover the stakeholders' needs in this area.

The specific objectives are:

1. To develop optimal and effective traceable measurement standards for magnetic fields in the ranges between 10 μ T to 10 mT, where the uncertainty (at $k = 2$) ranges between 2 mT/T and 0. mT/T.
2. To develop a robust and feasible transfer standard and a cross-calibration method to provide traceability to metrological laboratories with an expected accuracy of 10^{-4} . This transfer standard will be used in an interlaboratory comparison in this project to validate the CMCs.
3. To develop new methods for magnetic field cancellation in the presence of local gradient fields, compensating for DC power noise and other sources of noise due to urban development that hinder the calibration of new, low magnetic field systems.
4. To develop a metrological infrastructure for low-intensity magnetic fields to address the main needs of the stakeholders, including via a smart specialisation approach, where different routes for traceability will be followed. Some NMIs will focus on supporting the cutting-edge research needs with relative uncertainties in the order of 10^{-7} , while others will concentrate on supporting the national standards to meet the industry, research and calibration laboratories requirements with relative uncertainties in the order of 10^{-5} .
5. To facilitate the uptake and long-term operation of capabilities, technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), standards developing organisations (ISO, IEC TC 68, CEN and CENELEC Joint Technical Committee 22), and end users (e.g. industry, regulators, manufacturers).

Progress beyond the state of the art and results

Objective 1: Development of optimal and effective traceable measurement standards for magnetic fields in the ranges between 10 μ T and 10 mT

The project will explore different approaches to realise a low range magnetic field standard with target uncertainties between 2 mT/T at 10 μ T and 0.2 mT/T at 10 mT, exploiting both more traditional and novel techniques such as free-precession nuclear magnetic resonance, optical magnetometers, fluxgates or SQUIDs (superconducting quantum interference devices). While each of these technologies is already available at a research laboratory level, the necessary studies and developments to bring them into a metrological chain to realise of the magnetic field unit are still lacking. For the first time, a comprehensive metrological assessment of their performance for the realisation of a low range magnetic field standard will be delivered.

Objective 2: Development of a robust and feasible transfer standard and a cross-calibration method to provide traceability to the metrological laboratories with an expected accuracy of 10^{-4} , plus an interlaboratory comparison

In Europe the only key comparison of the magnetic field unit was carried out more than 20 years ago, and new comparisons have been difficult to perform because they require complex calibrated travelling standards or instruments. Moreover, the existing interlaboratory comparison only covered the magnetic field range above 10 mT. The project will develop a robust travelling standard comprising small solenoids that will operate in a zero-detection mode, thus not requiring further calibration of fluxgate sensors. This will significantly ease the process of undertaking interlaboratory comparisons and will therefore both allow more frequent comparisons and promote the participation of new NMIs/DIs. An interlaboratory comparison will be undertaken and will be the basis of future worldwide key comparisons, replacing the one performed more than 20 years ago.

Objective 3: Development of new methods for magnetic field cancellation in the presence of local gradient fields

Environmental magnetic field cancellation systems rely on shielding or on passive or active compensation with triaxial coils. Shielding is generally bulky, expensive and difficult to upgrade. The project will therefore develop better feedback mechanisms to provide real-time active compensation of environmental and background magnetic fields using triaxial coils, achieving expected background field levels of a few nT. Moreover, approaches exploiting gradiometer configurations will be developed that are more effective for monitoring and compensating for the effects of field gradients and local, limited-size magnetic field sources over larger volumes.

Objective 4: Development of a metrological infrastructure for low-intensity magnetic fields to address the main needs of the stakeholders

The project will create and implement a pan-European infrastructure of European NMIs/DIs and establish new traceability paths for the measurement of low-intensity magnetic fields. The resulting European metrological infrastructure will exploit a smart specialisation concept, where different NMIs/DIs will offer competence and services at different levels with relative uncertainties between 10^{-7} and 10^{-5} to different target groups, according to their experience and regional stakeholders' needs. Furthermore, a relatively new technique based on NMR on hyperpolarised ^3He in gas samples will be tested, and its potential to form a new generation of magnetic field standards, extending the lower limit to even smaller magnetic fields, will be explored.

Outcomes and impact

Key dissemination and communication activities

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Outcomes for industrial and other user communities

The project will produce new measurement and calibrations methods and services in the participants' laboratories, enabling low range magnetic field measurements and calibrations. Industries and user communities, such as automotive, space, healthcare nuclear, and innovative materials sectors, will therefore be able to calibrate and characterise their sensors and equipment under a metrologically validated traceability chain, which has so far not been available for low magnetic field ranges. These sectors need to assess the magnetic "cleanliness" of materials and components, or to measure the exposure of humans or equipment to environment magnetic fields, or exploit new effects of magnetic materials, or for use for non-invasive or non-destructive testing, or in quantum computing and sensing. The novel and improved methods for active compensation of environment magnetic fields will enable manufacturers and end users to be able to test their probes, products and materials in conditions where the magnetic field is slowly varying in time, or where weak field gradients in space need to be monitored and compensated.

Outcomes for the metrology and scientific communities

The project will extend the number of NMIs/DIs with measurement capabilities in weak magnetic field ranges, by ameliorating the field cancellation techniques that are currently exploited to null the environmental magnetic field. The metrology developed in the project will enable traceability of low-strength magnetic field calibrations and measurements, through e.g. free precession NMR, optical or SQUID magnetometers, fluxgates, or other methods. In addition, the results obtained on hyperpolarised ^3He NMR could be used in the future to develop a new primary tesla quantum-based standard that overcomes known weaknesses of current proton NMR techniques on purified water samples. The non-calibrated transfer coil developed in the project will allow easier laboratory intercomparisons, enabling European NMIs/DIs to perform more frequent comparisons to validate measurement capabilities, thus increasing confidence. The best practice guide produced in the project will provide guidance on how to transfer low intensity magnetic field traceability from NMI primary standards to industrial laboratories, outlining traceability routes and measurement methodologies.

Outcomes for relevant standards

To disseminate the project outputs and to promote uptake of the outputs by the standardisation community and therefore maximise the outcomes and generation of impact, the consortium will present the project and its results to different standards developing bodies e.g., IEC TC 68, VDE, DKE K171, BSI ISE/108 and the IEEE Magnetic Society Standards Committee.

Longer-term economic, social and environmental impacts

Magnetic field measurements permeate modern technology and applications in areas including electrical mobility, energy transformation, environmental monitoring, healthcare and biomedicine as well as information and communication technology. Magnetic field sensors are used to determine field and background exposure, linear and angular position, torque, velocity, and acceleration to name a few, and represent a growing market in a wide range of industries that, so far, has had only limited access to a metrological infrastructure for the measurement of magnetic fields. In addition, the trend toward miniaturisation implies not only a reduction in size of the sensing elements but also the magnetic field generation devices, with a consequent decrease in the generated magnetic field strength. The possibility to calibrate sensors and to cover extended magnetic field ranges that are not addressed by current metrology services will provide the basis for European industry to increase quality, reliability and access to markets so far precluded, such as those that require validation, authorisation and traceability, e.g. health, safety, space.

Additionally, even though magnetic fields of low intensity are considered safe, the diffusion of modern technology in the form of electric and electronic devices becomes ever more pervasive in workplaces, households, and as wearable devices, thus subjecting the population to long term exposure from weak magnetic fields in environments and spaces previously considered immune to electromagnetic pollution. Low-intensity magnetic field metrology will therefore enable a new generation of sensors to quantify magnetic field exposure, in a traceable and reliable way, therefore building public confidence.

Finally, low-intensity magnetic field measurements represent a valuable opportunity for geological studies, prospecting, and pollution detection. Low-intensity magnetic field sensors will support more efficient power transformation and generation, and electrical mobility, where magnetic field measurements are becoming of the utmost importance for assessing power consumption and the efficiency of components and processes.

List of publications

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Project start date and duration:		1 July 2025, 36 months
Coordinator: Marco Coisson, INRIM E-mail: m.coisson@inrim.it		
Project website address: https://sites.google.com/inrim.it/metromag/		
Internal Beneficiaries:	External Beneficiaries:	Unfunded Beneficiaries:
1. INRIM, Italy	10. CTU, Czechia	
2. CEM, Spain	11. INNOVENT, Germany	
3. CMI, Czechia	12. NQIS, Greece	
4. DFM, Denmark	13. NSC-IM, Ukraine	
5. GUM, Poland	14. NTUA, Greece	
6. NPL, United Kingdom	15. TCD, Ireland	
7. NSAI, Ireland	16. VINS, Serbia	
8. PTB, Germany		
9. TUBITAK, Türkiye		