



TECHNICAL PROTOCOL

Comparison of Magnetic Field Strength Measurements for Frequencies up to 30 MHz

**EURAMET.EM.RF-S46
(EURAMET Project No: 1538)**

TÜBİTAK UME
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Contents

1.	Introduction	3
2.	Travelling Standards	3
3.	Participant Institutes	4
4.	Time Schedule	5
5.	Transport Case	6
6.	Transportation of Travelling Standards.....	6
6.1.	Failure of Travelling Standards	7
6.2.	Financial aspects.....	7
7.	Measurement Quantities and Frequency Points.....	8
8.	Method of Computation of the Reference Value	9
9.	Measurement Instructions	9
9.1.	Environmental Conditions.....	9
9.2.	Before Measurements	9
9.3.	Powering of the standard during the measurements.....	9
9.4.	Method of Measurement.....	9
10.	Measurement Uncertainty	11
11.	Reporting of Results.....	11
12.	Final Report of the Comparison.....	11
13.	References	12
	ANNEX A.....	13

1. Introduction

Magnetic field probes are widely utilized in the measurement of non-ionizing radiation magnetic fields emanating from high voltage lines, high voltage power transformers, welding or induction heating equipment [1] and in electromagnetic compatibility (EMC) testing (IEC 62233 [2] and IEC 62311 [3]) and other applications in the frequency range of 5 Hz – 1 GHz. Therefore, the calibration of magnetic field probes is of fundamental importance for the traceability of the magnetic field measurements. They must be calibrated by National Metrology Institutes (NMIs) or accredited calibration laboratories in accordance with international standards such as IEEE 1309 [4] and IEEE 1308 [5]. The existing NMIs or emerging NMIs should participate in international comparison measurements in order to assure the quality of their measurement results or support their CMCs in the CIPM KCDB.

It has been discussed to organize a comparison on Magnetic Field Strength Measurements during the EURAMET TCEM SC RFMW including EMC meeting organized as a virtual (online) meeting on 20-21 April 2021.

The comparison will be carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [6].

TÜBİTAK UME will act as the pilot institute. The travelling standards will be provided by TÜBİTAK UME. TÜBİTAK UME will be responsible for monitoring the performance of the travelling standards during the circulation and also for the evaluation & reporting of the comparison results.

2. Travelling Standards

The travelling standards will be supplied by TÜBİTAK UME. These standards were chosen for their high accuracy and stability over time. The photos and the general specifications of the travelling standards are presented in Figure1 and Table 1 respectively.



Figure 1. The photo of the travelling standards, a) ELT 400, b) HF3061 with NBM-550

Table 1. The general specifications of the travelling standard

Name	Manufacturer / Model Number	Serial Number	General Specifications
Magnetic Field Probe (Low frequency)	Narda Safety Test Solutions / ELT Probe 100 cm ²	M-1859	<ul style="list-style-type: none"> ✓ Frequency Range: 10 Hz – 400 kHz ✓ Measurement Range: 0.5 μT – 160 mT ✓ Noise Level: 0,24 μT (320 μT – HIGH range)
Low Frequency Field Meter	ELT – 400	O-0450	<ul style="list-style-type: none"> ✓ Power Supply: 9 V/2000 mA
Magnetic Field Probe (High frequency)	Narda Safety Test Solutions / HF3061	D-0934	<ul style="list-style-type: none"> ✓ Frequency Range: 300 kHz – 30 MHz ✓ Measurement Range: 0,012 A/m – 16 A/m ✓ Noise Level: 0,01 A/m
High Frequency Field Meter	NBM 550	B-1002	<ul style="list-style-type: none"> ✓ Power Supply: 9 V/1.5 A

3. Participant Institutes

The pilot laboratory for this comparison is TÜBİTAK UME (Turkey). The participating laboratories and contact persons with their addresses are presented in Table 2.

Table 2. The information of the participant institutes

Acronym of Institute	Country	Contact Person	Shipping Address
TÜBİTAK UME	Turkey	Osman Şen osman.sen@tubitak.gov.tr Tel: +90 262 679 50 00	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, Turkey
CMI	Czech Republic	Tomáš Pavlíček tpavlicek@cmi.cz Tel: +420 266 020 185	Český metrologický institut Radiová 1136/3 CZ-10200 Praha, Czech Republic
PTB	Germany	Franziska Weickert Franziska.weickert@ptb.de Tel: +47 592 2510	Physikalisch-Technische Bundesanstalt 2.51 Magnetische Messtechnik Bundesallee 100 38116 Braunschweig, Germany
INRIM	Italy	Gabriella Crotti g.crotti@inrim.it Tel: +39 011 3919826	Istituto Nazionale di Ricerca Metrologica Strada delle Cacce, 91 10135 Torino, Italy
GUM	Poland	Arkadiusz Podgórn arkadiusz.podgorni@gum.gov.pl Tel : +48 22 581 9452	Central Office of Measures (GUM), Microwaves, Electromagnetic Field and Electromagnetic Compatibility Section Electricity and Magnetism Laboratory, 00- 139 Warszawa, Poland

Acronym of Institute	Country	Contact Person	Shipping Address
SASO NMCC	Saudi Arabia	Saleh Almojaewel s.mojaewel@saso.gov.sa Tel: +966 11 252 97 30	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 Kingdom of Saudi Arabia
RISE	Sweden	Mats Cedheim mats.cedheim@ri.se Tel : +46 10 516 60 86	Research Institutes of SWEDEN (RISE) Mats Cedheim/Hus 15 Brinellgatan 4, 504 62 Borås Sweden
METAS	Switzerland	Frédéric Pythoud frederic.pythoud@metas.ch Tel: +41 58 387 03 35	Federal Institute of Metrology (METAS), Laboratory EMC, Lindenweg 50 3003 Bern-Wabern, Switzerland
NPL	United Kingdom	Stuart Harmon Stuart.harmon@npl.co.uk Tel: +44 20 8943 6908	National Physical Laboratory (NPL) Hampton Road, Teddington, Middlesex, TW11 0LW, UK

4. Time Schedule

The time schedule for the comparison measurement is given in Table 3. The circulation of the travelling standards will be organized by the pilot laboratory to allow the participants to perform the measurements. Each institute will have two weeks to carry out the measurements and three weeks to send the travelling standards to the next participant. Any deviation in the agreed plan should be approved by the pilot laboratory.

Table 3. The time schedule for the comparison measurements

Participant	Country	Measurement Dates
TÜBİTAK UME (first measurement)	Turkey	03 January 2022 – 14 January 2022
CMI	Czech Republic	07 February 2022 – 18 February 2022
METAS	Switzerland	14 March 2022 – 25 March 2022
TÜBİTAK UME	Turkey	18 April 2022 – 29 April 2022
PTB	Germany	23 May 2022 – 03 June 2022
NPL	United Kingdom	27 June 2022– 08 July 2022
TÜBİTAK UME	Turkey	01 August 2022 – 12 August 2022

Participant	Country	Measurement Dates
GUM	Poland	05 September 2022 – 16 September 2022
RISE	Sweden	10 October 2022 – 21 October 2022
TÜBİTAK UME	Turkey	14 November 2022 – 25 November 2022
SASO NMCC	Saudi Arabia	19 December 2022 – 30 December 2022
INRIM	Italy	23 January 2023 – 03 February 2023
TÜBİTAK UME (last measurement)	Turkey	20 February 2023 – 03 March 2023

5. Transport Case

The travelling standard will be packed in a strong carrying case, which must be used while the comparison is in progress. The overall dimensions of the case are approximately 70 cm x 46 cm x 30 cm and the case has a total weight of 12 kg. There will be the following items in the carrying case.

- Magnetic Field Probes (ELT 400 with probe, HF3061 probe with NBM-550 monitor)
- Technical Protocol of Magnetic Field Strength Comparison up to 30 MHz

After the receipt of the carrying case, each participant must check it against any damage to the items inside the box. If the travelling standards have any damage due to the transportation, this situation must be reported to the pilot laboratory by using the form presented in Table 4 before reinitiating or resuming the comparison.

When the participated laboratory finishes the measurement, the next laboratory and the pilot laboratory shall be informed about the shipment by using the form given in Table 5. If there are not any foreseen problems with the shipment, all the items shall be checked and re-packed into the carrying case and it shall be dispatched to the next laboratory.

6. Transportation of Travelling Standards

The participants will be responsible for arranging transportation to the next participant.

The participants shall inform the pilot laboratory by filling and emailing the following form when the travelling standards arrive.

Table 4. Sample form for the information of arrival of the travelling standard

Confirmation Note For Receipt		
Date of Arrival		
NMI		
Name of Responsible Person		
Travelling standard	<input type="checkbox"/> Damaged	<input type="checkbox"/> Not Damaged
Additional Notes:		

The participants shall also inform the next participant and the pilot institute by e-mail about the shipment of the travelling standards by filling the following form.

Table 5. Sample form for the information of dispatch of the travelling standard

Confirmation Note For Dispatch	
Date of Shipment	
NMI	
Name of Responsible Person	
Shipment Information (company name etc.)	
Additional Notes:	

6.1. Failure of Travelling Standards

In case of any damage or malfunction of the travelling standards, the comparison will be reinitiated after the travelling standards are repaired.

6.2. Financial aspects

The participants will be responsible for the costs of the shipment to the next recipient (transportation and customs formalities) as well as any damage that may occur within their countries.

Each participant is also responsible for the insurance of the standard from the arrival in their institute until the arrival in the subsequent institute. The value for insurance purposes can be assumed to be approximately 15000 Euros.

7. Measurement Quantities and Frequency Points

The correction factor defined below is determined for each frequency given in Table 6. The correction factors are obtained using the following equation;

$$\text{Correction Factor (dB)} = 20 * \log_{10} \left(\frac{\text{Actual Field } (\mu\text{T or A/m})}{\text{Indicated Field } (\mu\text{T or A/m})} \right)$$

Table 6. Measurement frequencies & levels for magnetic field probes

Measurement Frequency	Level for Magnetic Field Measurements	Measurement Range for ELT – 400	Relevant Travelling Standard
53 Hz	10 μT	320 μT – Low	ELT Probe 100 cm^2
	100 μT	320 μT – High	
	300 μT	320 μT – High	
	1000 μT	80 mT – Low	
	2000 μT	80 mT – Low	
400 Hz	10 μT	320 μT – Low	
10 kHz	10 μT	320 μT – Low	
100 kHz	10 μT	320 μT – Low	
300 kHz	3 μT	320 μT – Low	
500 kHz	0,15 A/m	-	
5 MHz	0,15 A/m	-	
10 MHz	0,15 A/m	-	
20 MHz	0,15 A/m	-	
30 MHz	0,15 A/m	-	

During the comparison measurements, the participating laboratories are responsible for performing measurements, taking necessary precautions, and taking into account the magnetic field limit values given in the EU directive [7] or other national directives on worker safety. If required, the calibration levels above the safety limits may be removed from the comparison by the related participating laboratories and they become exempt from the comparison and analysis of these high magnetic field levels.

8. Method of Computation of the Reference Value

The comparison reference value (CRV) for each measurement point will be calculated using the results of all the participant institutes. The method used will be the arithmetic mean of the participants not considered as outliers. The determination of outliers will be based on the 2.5·MAD criterion, which makes use of the median of all participants and of the calculated ‘median of absolute deviations’ (MAD). The participants whose difference with respect to the median is demonstrated to be more than 2.5 times the median of absolute deviations will be considered as outliers, and as such will not be taken into account in the determination of the CRV [8].

9. Measurement Instructions

9.1. Environmental Conditions

- The ambient temperature and humidity must be measured. No corrections will be applied for temperature and humidity effects.
- Preferably, the measurements should be carried out at the ambient conditions given below;
 - Temperature : $(22 \pm 2) ^\circ\text{C}$
 - Relative humidity : $(45 \pm 10) \text{ %rh}$

9.2. Before Measurements

- The travelling standards should be allowed to stabilize in a temperature and humidity controlled environment for at least 24 hours without operating before starting the measurements.
- The travelling standards should be allowed to warm up for 10 minutes minimum before starting the measurements
- Before the measurements, the batteries of the travelling standards should be fully charged.

9.3. Powering of the standard during the measurements

- During the calibration process, the travelling standards shall not be connected to the charging unit.

9.4. Method of Measurement

- Each participant institute may use their own measurement method.
- The magnetic field measurements shall be performed in a fixed position and shall not be rotated. During the measurements, the display of the ELT-400 or NBM-550 field analyzer/meter shall point to the ceiling as shown Figure 2.



Figure 2. The position of magnetic field probe during comparison measurements

- The measurement parameters of the field analyser (ELT-400, See Fig. 3) and field meter (NBM-550) are given in Table 7 and Table 8 respectively.

Table 7. ELT-400 Measurement Parameters

Range	Low Cut	Detector	Max Hold
320 μ T-High	10 Hz	RMS	OFF

Table 8. NBM-550 Measurement Parameters

Result Type	Apply Correction Frequency	Unit
Actual	OFF	A/m



a) 320 μ T – Low Range*



b) 320 μ T – High Range



c) 80 mT – Low Range*

Figure 3. Measurement settings of the ELT-400 during measurements

* When the low measuring range is selected, the low measuring range indicator does not appear on the ELT – 400 screen.

10. Measurement Uncertainty

The measurement uncertainty shall be calculated according to the JCGM 100 “Guide to the Expression of Uncertainty in Measurement” [7] for the coverage probability of approximately 95%.

The detailed measurement uncertainty budget shall be provided for each of the following frequencies:

53 Hz, 400 Hz, 10 kHz, 100 kHz, 300 kHz, 500 kHz, 5 MHz, 10 MHz, 20 MHz and 30 MHz.

The example uncertainty budget shown below for the magnetic field probe measurement may be used by the participant laboratories. In the event that other uncertainty sources occur, the participant laboratories may apply them in the uncertainty table given below.

Uncertainty budget @ the frequency of Hz						
Source of uncertainty	Type	Value	Probability distribution	k-factor	Sensitivity coefficient	Standard Uncertainty (dB)
Standard resistor uncertainty						
Multimeter uncertainty						
The probe position						
Non-uniformity of field						
.....						
.....						
Total Uncertainty (k=2)						

11. Reporting of Results

For the measurement results of the participants, the measurement report format given in Annex A will be used and the measurement report containing the measurement results of the participants will be sent to the pilot laboratory by e-mail within three weeks after the completion of the measurements.

12. Final Report of the Comparison

The pilot laboratory is responsible for the preparation of a final comparison report.

The Draft A version of the comparison report will be issued by the pilot institute within two months after the receipt of the participant reports. The Draft A report will be sent to the participants for discussion and approval. The participants will have two weeks to send their comments on the Draft A Report.

After the approval, the Draft A report will become the Draft B report. The Draft B report will be approved by all the participants before being released to the appropriate technical committee and EURAMET Secretary for their approval.

13. References

- [1] IEC 61786-1:2013 Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings - Part 1: Requirements for measuring instruments
- [2] IEC 62233:2005, Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure
- [3] IEC 62311:2019, Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure, 2005 Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz),
- [4] IEEE Std. 1309:2013, "IEEE Standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz".
- [5] IEEE Std. 1308:1994, "Magnetic Flux Density and Electric Field Strength Meters -10 Hz to 3 kHz"
- [6] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, Ver. 2.1, 2017 (available on the BIPM website: https://www.bipm.org/utis/common/pdf/CC/CCEM/ccem_guidelines.pdf).
- [7] EMF Directive (2013/35/EU), 26 June 2013
- [8] W. Bich, M. Cox, T. Estler, L. Nielsen, W. Woeger, "Proposed guidelines for the evaluation of key comparison data", April 2002. Available at: <http://www.bipm.org/cc/CCAUV/Allowed/3/CCAUV0236.pdf>.
- [9] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utis/common/documents/jcgm/JCGM_100_2008_E.pdf)

ANNEX A

**Measurement Report for EURAMET XXXXX
Supplementary Comparison**

1. Participant Information

Institute Name	
Contact Person	
Telephone No	
Fax No	
E-mail	
Address	

2. Measurement Date

Measurement Dates -
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3. Environmental Condition

Temperature (°C)	
Relative Humidity (%rh)	

4. References Used In Measurement

Name of Equipment	Manufacturer	Type / Model	Serial No



5. Measurement Procedure

6. Measurement Results

Frequency	Level for Magnetic Field Measurements	Correction Factor (dB)	Measurement Uncertainty (dB) (k=2)
53 Hz	10 μ T		
	100 μ T		
	300 μ T		
	1000 μ T		
	2000 μ T		
400 Hz	10 μ T		
10 kHz	10 μ T		
100 kHz	10 μ T		
300 kHz	3 μ T		
500 kHz	0,15 A/m		
5 MHz	0,15 A/m		
10 MHz	0,15 A/m		
20 MHz	0,15 A/m		
30 MHz	0,15 A/m		

7. Detailed Uncertainty Budget

Uncertainty budget @ the frequency of Hz						
Source of uncertainty	Type	Value	Probability distribution	k-factor	Sensitivity coefficient	Standard Uncertainty (dB)
Total Uncertainty (k=2)						