SIM.EM-K5.2026

SIM Key Comparison of 50 Hz/60 Hz Power

TECHNICAL PROTOCOL

August 03, 2026

Pilot laboratory:
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1. INTRODUCTION

Committed to underpin the Mutual Recognition Arrangement as proposed by the Comité International des Poids et Mesures (CIPM), a regional key comparison of 50 Hz/60 Hz power (SIM.EM-K5.2026) is being currently planned under the auspices of the SIM Electricity and Magnetism Metrology Working Group (SIM MWG-1).

The last comparison (SIM.EM-K5.2012) was realized from 2010 to 2012, the Centro Nacional de Metrología (CENAM) being the pilot laboratory. Eleven national metrology institutes (NMI) from the Inter-American System of Metrology (SIM) then participated and the final report was published in 2015 [1].

The Consultative Committee on Electricity and Magnetism (CCEM) organized from 2018 to 2020 the last CCEM-K5.2017 key comparison of 50 Hz/60 Hz power, VSL Netherlands being the pilot laboratory. Eleven NMIs from different regional metrology organizations then participated including three NMIs from SIM. The participation of those three SIM NMIs in this new SIM.EM-K5.2026 will provide the link to CCEM-K5.2017 whose final report was published in January 2026 [3].

NMIs participating in this new SIM.EM-K5.2026 will be responsible for conducting the tests in their respective laboratories and submitting their measurement results to the pilot laboratory. The goal is to compare their national standards of 50 Hz/60 Hz power measurement. The SIM MWG-1 assigned the Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro) to serve as the pilot laboratory for this comparison, to provide the metrological characterization of the reference standard, and to issue the comparison report.

The new SIM.EM-K5.2026 has benefitted from the test protocol and data analysis method adopted in the last CCEM-K5.2017 [2][3]. The present protocol has been prepared by following the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [4].

2. TRAVELING STANDARD

2.1 General requirements

Two RADIAN RD-22-432 standards will be used as traveling standards in this new SIM.EM-K5.2026 (see Figures 1 and 2). The traveling standards are provided by Inmetro.

Figure 1: Traveling standard: RD-22-432, serial number: 202068

Figure 2: Traveling standard: RD-22-432, serial number: 200669

Due to Radian innovations in the areas of active transformer design and advanced signal processing, accuracy and precision are intrinsic characteristics of the RD-22-432 Dytronic Single-Phase Transfer Standard.

The RD-22-432 utilizes enhanced measurement technology consisting of an Integrating Analog to Digital Signal Converter based upon a high-speed, charge-balance conversion principle. In addition, the RD-22-22-432 uses an electronically compensated autoranging external concentric core current comparator transformer along with an electronically compensated voltage input transformer and a hermetically sealed reference set to provide the highest degree of accuracy, stability and versatility offered in a primary transfer standard.

The concentric core current comparator is located externally from the RD-22-432 but both are mounted on the same platform. The current comparator consists of a multi-level electronically compensated transformer whose interior core is thoroughly shielded from the outside world and containing zero flux. The signal detector is highly insensitive to the location of the conductor within making it easy to accurately characterize the current comparator.

The RD-22-432 provides a repeatability of 0.00001% (100 parts per billion) for a 15-minute test and of ± 0.0001% (one part per million) for a 15-second test.

Measurement results of power may be read on a digital backlit LCD display. The standard is provided with an 8-pin RJ-45 jack for RS-232 serial communication. The standard may be connected to any simple PC and measurement results may be recorded on the computer as a data sheet with a software package that will be provided to participating laboratories. Users may record instantaneous measurements of RMS voltage and current, power factor, phase angle, active power and frequency.

The long-term stability of the traveling standards will be assessed by Inmetro by means of a series of scheduled calibrations with its national standard of electric power measurement.

The traveling standards should be powered with a 24 V DC power supply (Auxiliary Power Input Converter) delivered with the standards. **MAKE SURE that the voltage input selector of the 24 V DC power supply (auxiliary power converter) is set to the correct value – 120 V or 240 V – before connecting the power supply to the AC mains.**

2.2 Description

RD-22-432 physical description:

Serial numbers: 202068 and 200669.

Size: 215.9 mm (height); 165.0 mm (wide); 431.8 mm (deep)
Container size (placed horizontally): 80 cm (length) x 59 cm (width) x 48 cm (height)
Weight (Platform, RD-22-432 and current comparator) = 6.1 kg; auxiliary power converter = 5.0 kg; mains cable, auxiliary power converter cable, data loggers (two), batteries, and fuses = 0.15 kg; transport container = 18.45 kg (each container); Gross (total) weight: 29.7 kg
Potential inputs: 4 mm banana jacks
Current input: a single turn through concentric core current comparator (CCCC)
Auxiliary input: 4 mm banana jacks
Time reference input: port 1, BNC connector
Output pulse: port 2; BNC connector, to be used for energy measurements only
Three-phase SYNC or analog sense: port 3; BNC connector
RS-232 serial communication: 8-pin RJ-45 jack

RD-22-432 normal operating conditions
Input voltage: 40 V to 600 V (Autoranging)
Input current: 0.2 to 200 A (Autoranging)
Frequency: 45 Hz to 65 Hz
Auxiliary power converter: 120 V or 240 V ± 10%
Auxiliary power DC input: 24 V nominal
Phase angle: 0° to 360° or -180° to +180°
Power factor: -1 to +1
Operating temperature: 23 °C ± 2 °C
Humidity: 0% to 95% non-condensing

2.3 Measurand

The measurand is the calibration error of the traveling standard when measuring active power; the calibration error will be expressed in µW/VA.

The participating laboratory should report a single measurement result (the measured value and uncertainty associated with that value) for each test point given in Table 1.

Table 1. SIM.EM-K5.2026 testing points.

Parameter	Value
RMS voltages	120 V 240 V
RMS current	5 A
Power factor	1.0 0.5 lead 0.5 lag 0.0 lead 0.0 lag
Frequency	50 Hz, 53 Hz, and 60 Hz
Total amount of test points	30 (10 for each frequency)

Notes:

1. The term 'lead' means that the current phase angle is greater than the voltage phase angle, and the term 'lag' means that the current phase angle is smaller than the voltage phase angle.

2. The measured value of the calibration error of the traveling standard should be reported. The calibration error is here defined as the difference between the active power (in watts) indicated by the traveling standard and the active power (in watts) applied to it, this difference being divided by the nominal apparent power (in VA).

3. Both the measured value and the (expanded) uncertainty associated with that value should be expressed in µW/VA.

4. The expanded uncertainty quoted in the report shall consider the uncertainty components of the corresponding reference standard of 50 Hz/60 Hz power measurement of the participating laboratory. The expanded uncertainty should be evaluated for a level of confidence of 95.45 % by taking into account both Type A and Type B methods.

5. The testing frequency of 53 Hz should provide a link to CCEM-K5.2017. However, the participating laboratories proposed to include testing frequencies of 50 Hz and 60 Hz in SIM.EM-K5.2026.

2.4 Relevant parameters

The values of RMS voltage, RMS current, power factor, and frequency, are relevant parameters to the key comparison of 50 Hz/60 Hz power. As indicated in Annex A4 *Layout of the Measurement Report*, participating laboratories must record the mean value of RMS voltage, RMS current, power factor, and frequency, for each of the test points in Table 1. As shown in Annex A3 *Typical scheme of an uncertainty budget*, the participating laboratory must identify all uncertainty components pertinent to the measurement of active power.

2.5 Software for data logging the power readings from the traveling standard

The traveling standard comes with a software package for data logging the power readings (see the memory stick in the container). The software package RR-PCSuite Version 5.30.00 Installer, which runs on both Windows 10 and Windows 7, is available. The pilot will provide a download link by email when requested by a participant.

2.6 Key comparison reference value and degrees of equivalence

This test protocol has been prepared by following the CCEM guidelines in [4]. The principles of the method of computation of the reference value are as follows:

i. The key comparison reference value $KCRV_{\mathrm{SIM.EM\text{-}K5}}$ and the degrees of equivalence (DOE) among the participating laboratories shall be determined according to the procedure agreed upon for CCEM-K5.2017 [2][3].

ii. The mean of the measured values reported by the participating laboratories weighted by the expanded uncertainties associated with those values will be used for the calculation of the $KCRV_{\mathrm{SIM.EM\text{-}K5}}$.

iii. The degree of equivalence (DOE) of each participating laboratory shall be expressed quantitatively by two terms:
   - The deviation between the measured value reported by the participating laboratory and the $KCRV_{\mathrm{SIM.EM\text{-}K5}}$.
   - The expanded uncertainty associated with this deviation for 95.45 % level of confidence (k =2 for a normal distribution).

iv. In order to compare the results of the different participating laboratories, each laboratory should report a single measurement result (the measured value and the expanded uncertainty associated with that value) for each of the test points shown in Table 1.

v. As requested by CCEM, bilateral degrees of equivalence will not be explicitly shown, but the formula for obtaining them will be included, thus allowing any participating laboratory to calculate its bilateral degree of equivalence from the degrees of equivalence of the participating laboratories.

2.7 Link between the CCEM-K5.2017 and SIM.EM-K5.2026

The results of the SIM.EM-K5.2026 key comparison 50/60 Hz power should be linked with the results of the last key comparison organized by the CIPM, the CCEM-K5.2017 in the same key quantity.

The link procedure is based on [6]. It consists of an additive correction applied to the results of SIM.EM-K5.2026 so that the corrected results can be directly compared with the results of CCEM.K5.2017. The additive correction is determined from a weighted mean of the differences with respect to the KCRV obtained by the linking laboratories in the two comparisons. This criterion is applicable since the SIM.EM-K5.2026 covers all measuring points of CCEM-K5.2017. The degrees of equivalence (DOE) of SIM.EM-K5.2026 will be calculated from this link. This procedure does not change the CCEM-K5.2017 key comparison reference value and associated uncertainty.

The linking laboratories accepted that their measurement results be used to link the SIM.EM-K5.2026 results to those of CCEM-K5.2017.

The linking procedure is described below. It is basically the same adopted in SIM.EM-K5.2012 [8].

i. The key comparison reference value $KCRV_{\text{CCEM-K5}}$, with associated expanded uncertainty ($U_{\text{CCEM-K5}}$), derived from the CCEM-K5.2017 [2] is used as the reference value for linking the SIM.EM-K5.2026. Values are expressed in µW/VA.

ii. Obtain from [2] the i-th difference $D_{i,\text{CCEM-K5}}$ with respect to $KCRV_{\text{CCEM-K5}}$ and the associated standard uncertainty $u_{i,\text{CCEM-K5}}$ of the i-th linking laboratory, $i = 1, 2, \cdots, N$, that participated in both CCEM-K5.2017 and SIM.EM-K5.2026.

iii. Obtain the SIM.EM-K5.2026 key comparison reference value $KCRV_{\text{SIM.EM-K5}}$ and the associated expanded uncertainty $U_{\text{SIM.EM-K5}}$. Values are expressed in µW/VA.

iv. Obtain the i-th difference $D_{i,\text{SIM.EM-K5}}$ with respect to $KCRV_{\text{SIM.EM-K5}}$ and the associated standard uncertainty $u_{i,\text{SIM.EM-K5}}$ of the i-th linking laboratory, $i = 1, 2, \cdots, N$, that participated in both CCEM-K5.2017 and SIM.EM-K5.2026.

v. Let $D_{j,\text{SIM.EM-K5}}$ denote the j-th difference with respect to $KCRV_{\text{SIM.EM-K5}}$ of the j-th laboratory, $j = 1, 2, \cdots, M$, participating *only* in the SIM.EM-K5.2026 comparison. The present linking method aims at providing an estimate $\widehat{D}_{j,\text{SIM.EM-K5}}$ of $D_{j,\text{SIM.EM-K5}}$, as if such laboratory had participated in CCEM-K5.2017:

$$\widehat{D}_{j,\text{SIM.EM-K5}} = D_{j,\text{SIM.EM-K5}} + d, \quad (j = 1, 2, \cdots, M) \tag{1}$$

where d is a correction which is estimated by a weighted mean of the differences D_i between the result of each i-th linking laboratory, $i = 1, 2, \cdots, N$, in CCEM-K5.2017 and the corresponding result in SIM.EM-K5.2026:

$$d = \sum_{i=1}^{N} w_i D_i, \qquad (i = 1, 2, \cdots, N) \tag{2}$$

where the weight w_i is determined by the overall standard uncertainty u_i of the i-th linking laboratory:

$$w_i = \frac{\frac{1}{u_i^2}}{\sum_{i=1}^{N}\frac{1}{u_i^2}}, \qquad (i = 1, 2, \cdots, N) \tag{3}$$

and

$$D_i = D_{i,\text{CCEM-K5}} - D_{i,\text{SIM.EM-K}}\ , \qquad (i = 1, 2, \cdots, N) \tag{4}$$

vi. In the above rationale the following assumptions may apply:

(a) there is a possibility that a unknown bias exist in the measurement results of the linking laboratories, which may remain constant within an uncertainty interval over the time between the CCEM-K5.2017 and the SIM.EM-K5.2026;

(b) the bias, and its associated uncertainty, may be referred to as the reproducibility of the measurement results from the linking laboratories.

vii. The overall standard uncertainty u_i of the i-th linking laboratory associated with the weighted mean in (2) is calculated as

$$u_i^2 = u_{i,\mathrm{CCEM}}^2 + u_{i,\mathrm{SIM.EM-K5}}^2 + 2r_i^2, \quad (i = 1, 2, \cdots, N) \tag{5}$$

where $2r_i^2$ is the uncertainty of the imperfect reproducibility of results of a linking laboratory in the time period, which spans its measurements at the CCEM-K5.2017 and at the SIM.EM-K5.2026, whence the factor of 2.

viii. It is important to ensure the consistency of the link between the SIM.EM-K5.2026 and the CCEM-K5.2017. The main concern is the criterion of "reproducibility" of the measurement results over the time span between the two comparisons. Delahaye [6] used the proposal of B. N. Taylor [7], based on the Birge ratio [7], between an internal and an external consistency.

ix. The internal consistency is related to the uncertainty associated with the weighted mean of the differences D_i. It is expressed in terms of the variance of the correction d, that is

$$V_{\mathrm{int}}(d) = \frac{1}{\sum_{i=1}^{N} \frac{1}{u_i^2}} . \quad (i = 1, 2, \cdots, N) \tag{6}$$

x. The external consistency is related to the standard deviation of the weighted mean of the differences between each D_i and d. It is expressed as:

$$V_{\mathrm{ext}}(d) = \frac{\sum_{i=1}^{N} w_i\,(D_i - d)^2}{(N-1)} . \quad (i = 1, 2, \cdots, N) \tag{7}$$

xi. The Birge ratio is defined as $BR = \sqrt{\frac{V_{\mathrm{ext}}(d)}{V_{\mathrm{int}}(d)}}$, and the criterion of consistency is:

(a) $BR = 1$: there is consistency in the link between CCEM-K5.2017 and SIM.EM-K5.2026.

(b) $BR > 1$: some of the uncertainty values of the linking laboratories are underestimated, thus, there is no consistency in the link between CCEM-K5.2017 and SIM.EM-K5.2026.

(c) $BR < 1$: some of the uncertainty values of the linking laboratories may be overestimated. It is possible that the reproducibility factor r_C be overestimated. The link between CCEM-K5.2017 and SIM.EM-K5.2026 is consistent.

2.8 Preparation of Drafts A and B for this key comparison

As stated in the CCEM Guidelines [4], the following information shall be considered when preparing the Drafts A and B containing the comparison results:

- individual values for each institute together with their declared uncertainties;
- the key comparison reference value with its associated uncertainty;
- for each institute, the deviation from the key comparison reference value and the uncertainty in that deviation (at a 95.45 % level of confidence), that is its degree of equivalence;

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3. ORGANIZATION

3.1 Coordinators and members of the support group

Coordinators of the pilot laboratory (please send messages to both):
Rodrigo Simões Ribeiro (Inmetro) rsribeiro@inmetro.gov.br
Gregory Kyriazis (Inmetro) gakyriazis@inmetro.gov.br
Organization: Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro)
Diretoria de Metrologia Científica e Tecnologia (Dimci)
Divisão de Metrologia Elétrica (Diele)
Address: Av. Nossa Senhora das Graças, 50 – 25250-020 – Duque de Caxias – RJ – Brasil
Phone: +55 21 2679 9074 or +55 21 2679 9704 (secretary)

Members of the support group:

Name	Organization	Address	Email
Marco Antonio Rodriguez Guerrero	CENAM		mrodrigu@cenam.mx

3.2 Participating laboratories (see also Annex A1 *Detailed list of participating laboratories*)

Table 2. List of participating laboratories

	Participating laboratory	**Contact person**	**Email**	**Link to CCEM-K5.2017**
1	CENAM (Mexico)	Marco Antonio Rodriguez Guerrero Benjamín Noyola Maldonado	mrodrigu@cenam.mx bnoyola@cenam.mx	Yes
2	CENAMEP AIP (Panama)	Carlos Espinosa B. Julio González V.	cespinosa@cenamep.org.pa jgonzalez@cenamep.org.pa	No
3	CIM (El Salvador)	José Rigoberto Osegueda Miranda	jose.osegueda@cim.gob.sv	No
4	IBMETRO (Bolivia)	Juan Jose Mendoza Aguirre	jjmendoza@ibmetro.gob.bo	No
5	INACAL (Peru)	Lady D. Pereira Billy Quispe	lpereira@inacal.gob.pe bquispe@inacal.gob.pe	No
6	INEN (Ecuador)	William D. Paucar Quinteros Diego A. Trávez Tacuri Edison M. Condor Laica	wpaucar@normalizacion.gob.ec dtravez@normalizacion.gob.ec econdor@normalizacion.gob.ec	No
7	INM (Colombia)	Nestor Eduardo Polanía Vargas Jorge Cristancho	nepolania@inm.gov.co jacristancho@inm.gov.co	No
8	Inmetro (Brazil)	Rodrigo S. Ribeiro Gregory Kyriazis	rsribeiro@inmetro.gov.br gakyriazis@inmetro.gov.br	Yes
9	INTI (Argentina)	Lucas Di Lillo	ldilillo@inti.gob.ar	No
10	INTN (Paraguay)	Jorge Parra Hilda Villa	jparra@intn.gov.py hvilla@intn.gov.py	No
11	LMVE-ICE (Costa Rica)	Rodolfo Durán Isabel Castro	rdurang@ice.go.cr bcastro@ice.go.cr	No
12	NIST (USA)	Thomas Nelson	thomas.nelson@nist.gov	Yes
13	NRC (Canada)	Harold Parks Branislav Djokic	harold.parks@nrc-cnrc.gc.ca branislav.djokic@nrc-cnrc.gc.ca	No
14	UdeC (Chile)	Rodrigo Ramos Daniel Cárcamo	roramos@udec.cl dacarcam@udec.cl	No
15	UTE (Uruguay)	Gonzalo Aristoy Leonardo Trigo	garistoy@ute.com.uy ltrigo@ute.com.uy	No

3.3 Time schedule (see also Annex A2 *Time schedule*)

Tables 3 and 4 show the time schedule of the comparison. The final schedule with precise information of allocated times to each laboratory will be delivered later by Inmetro and included in Annex A2 of this protocol. If a delay occurs affecting the overall time schedule, the schedule will be revised and all the participating laboratories will be informed by Inmetro of any change.

It may be noticed on Tables 3 and 4 that the comparison is planned to start in August 2026 in order to complete a period of 6 (six) months required by the pilot laboratory for characterization of the traveling standards.

1. The RD-22-432, serial number: 202068, will be used to ensure the link between the SIM.EM-K5.2026 and the CCEM-K5.2017. Thus, this standard will be sent to either those NMIs who did take part in the CCEM-K5.2017 or to those NMIs whose declared Calibration and Measurement Capabilities (CMC), reported at the Key Comparison Database (KCDB), show measurement uncertainties below ±50 µW/VA (k = 2) for the calibration services of electric power meters.

Table 3. Circulation schedule for RD-22-432 – S/N 202068

RD-22-432 – S/N 202068			
Laboratory		Allocated time	
		receiving day	sending day
1	NRC, H. Parks, B. Djokic (Canada)		
2	CENAM, M. Rodriguez, B. Noyola (Mexico)		
3	NIST, T. Nelson (USA)		
4	Inmetro, R. Simões, G. Kyriazis (Brasil)		
5	UTE, G. Aristoy, L. Trigo (Uruguay)		
6	INTI, Lucas Di Lillo (Argentina)		
7	Inmetro, R. Simões, G. Kyriazis (Brasil)		

Note: It is recommended that the measurement interval at each participating laboratory should not be more than two weeks in order to comply with the planned schedule.

2. The laboratories that do not attend the criteria for receiving the RD-22-432 - S/N 202068 standard will receive the RD-22-432 – S/N 200669 standard.

Table 4. Circulation schedule for RD-22-432 – S/N 200669

RD-22-432 – S/N 200669			
Laboratory		Allocated time	
		receiving day	sending day
1	LMVE-ICE, R. Durán, I. Castro (Costa Rica)		
2	CIM, J. Osegueda (El Salvador)		
3	CENAMEP AIP, C. Espinosa, J. González (Panama)		

4	Inmetro, R. Simões, G. Kyriazis (Brasil)		
5	UdeC, R. Ramos, D. Cárcamo (Chile)		
6	INM, N. Polanía, J. Cristancho (Colombia)		
7	INTN, J. Parra, H. Villa (Paraguay)		
8	IBMETRO, J. Mendoza (Bolivia)		
9	INACAL, L. Pereira, B. Quispe (Peru)		
10	INEN, W. Paucar, D. Trávez, E. Condor (Ecuador)		
11	Inmetro, R. Simões, G. Kyriazis (Brasil)		

Note: It is recommended that the measurement interval at each participating laboratory should not be more than two weeks in order to comply with the planned schedule.

3.4 Delivery scheme

To reduce delays at customs, the traveling standard shall be sent directly to the address of the subsequent laboratory according to the schedule program in Tables 3 and 4. Make sure that the address of the subsequent laboratory is as given in Annex A1.

The traveling standard will be provided with an individual rugged plastic container, suitable for shipping the standard on airplane. The standard, the 24-V DC power supply, and accompanying small items, like the environmental data loggers, spare batteries and line fuses, are to be transported inside the rugged plastic container.

The traveling standard is packaged along with environmental data loggers. During measurements at the participating laboratory, make sure that the data loggers remains close to the traveling standard, in order to take measurements of ambient temperature. There is no need for the participating laboratory to try accessing the loggers. Their contents will be downloaded at Inmetro in order to keep track of the changes of temperature, humidity and shock which may have occurred during transportation or while staying at the participating laboratory. Spare batteries are included in the container in case replacement is needed.

IMPORTANT: In order to establish the final comparison schedule, all participants should inform Inmetro whether they agree to ship the traveling standard under a DDP (Delivered Duty Paid) or DAP (Delivered at Place) arrangement. This information is critical for organizing the logistics in each NMI. It may be preferable to use a DAP arrangement, under which the receiving NMI would clear customs, as a business identification number is required for customs clearance in many countries.

In a DAP arrangement, costs involved with sending the traveling standard either to Inmetro or to the subsequent NMI are paid by the shipping NMI and costs related to customs clearance of the traveling standard entering a country are paid by the receiving NMI. Nowadays, a business identification number is required in the countries where the traveling standard arrive, and it would take too long for the shipping NMI to apply for a business identification number. That is why we suggest that the receiving NMI should clear customs.

The contact person of the participating laboratory must inform Inmetro of all pertinent information when shipping the traveling standard.

3.5 Unpacking, handling and packing

Unpacking:

1. Upon arrival, the participating laboratory must carefully inspect the traveling standard before it is removed from the rugged plastic container. In case of damage to the traveling standard and/or container, please take a photo and send it to the pilot laboratory.
2. For removing the traveling standard from the container, please refer below to the handling instructions.
3. Fill in the *Confirmation note of receipt* (Annex A5) and send it to the pilot laboratory.

Handling:

Extreme care should be taken to remove the traveling standard from the rugged plastic container. For removing the RD-22-432 from the container, the metal handlers located at both sides of its platform must be used. The RD-22-432 should **NEVER** be lifted from the Concentric Current Comparator.

Packing:

1. When packing the traveling standard, make sure that it is comfortably located inside the container. Please refer to the above handling instructions.
2. **All accompanying items should be placed in the container.** Make sure that the **24-V DC power supply, environmental data loggers, the spare batteries, line fuses, and memory stick (software)** are also placed in the container.
3. Inform the pilot laboratory of pertinent details regarding the clearance of customs, shipping and flights. If the traveling standard should be sent to another participating laboratory, make sure that both the recipient laboratory and the pilot laboratory are informed about traveling details.
4. Fill in the *Confirmation note of shipment* (Annex A6) and send it to the pilot laboratory.

3.6 Failure of the reference standard.

In case of failure:

1. Unplug the traveling standard.
2. Write immediately to the pilot laboratory describing the behavior of the traveling standard. Send along any message displayed on the backlit LCD. Take photos of the measuring system and of the connecting cables to the traveling standard.
3. Wait for instructions from the pilot laboratory on the way to proceed.

3.7 Financial aspects, insurance, customs

In every case, the participating laboratory should ensure that its organization covers insurance for any defect of the traveling standard while it is in its premises.

All the participating laboratories will be responsible for expenses related to sending the traveling standard either to the subsequent participating laboratory or to the pilot laboratory. All the participating laboratories will be responsible for expenses related to customs clearance of the traveling standard in their countries.

For customs purposes, the traveling standard is accompanied by a copy of its invoice. Participants should know that the price of the traveling standards as stands for in their invoice amounts up to 40 % of the total price of the standard. This price is merely for customs purposes.

4. MEASUREMENT INSTRUCTIONS

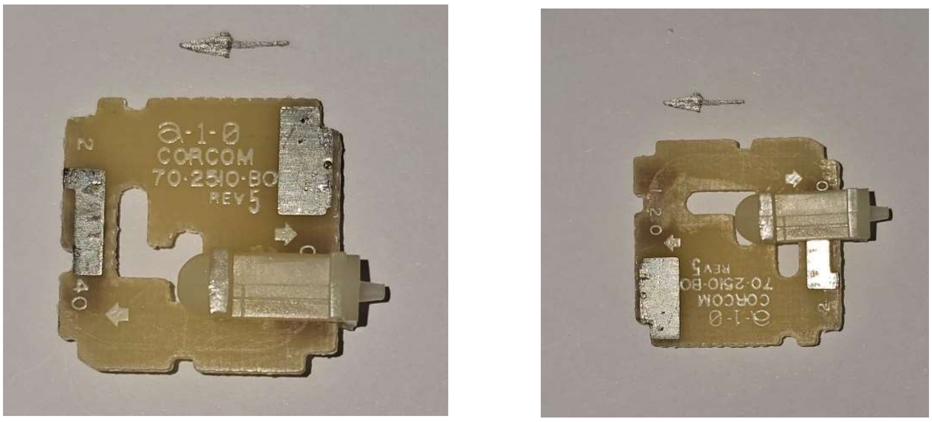
4.1 General instructions.

No tests need to be performed on the RD-22-432 before measurements at the participating laboratory.

CAUTION: ***Make sure that the line voltage selector at the Auxiliary Power Input Converter rear panel is set correctly. There are two options for line voltage range: (a) 120 V and (b) 240 V. Select the most appropriate to the nominal line voltage of your laboratory. Use of incorrect line voltage range will result in damage to the instrument.***

The Auxiliary Power Input Converter can be operated from an AC power source of 120 V ± 10 % or 240 V ± 10 %, 45 – 65 Hz. The Power Entry Module, located on the rear panel, provides a dual voltage selector that is integrated with the fuse holder.

To change the selected voltage, first ***disconnect the power cord*** to the instrument. Open the fuse cover using a small blade screwdriver or similar tool. Pull up the fuse holder/voltage selector panel. Remove the small printed circuit and reverse vertically its position (see Figure 3). Insert the small printed circuit in the correct position. Close the fuse holder/voltage selector panel.



(a) (b)

Figure 3: Small printed circuit: (a) position for 240 V and (b) position for 120 V.

One line fuse is rated at 1.5 A and two others are rated at 800 mA (all 250 V fuses).

Spare line fuses are included in the container in case replacement is needed.

4.2 Particular requirements for energizing and connecting the traveling standard

4.2.1 Energizing the traveling standards at 24 V DC

The traveling standards are provided with a 24 V DC power supply, which shall be connected to the mains at either 120 V or 240 V, 45 Hz to 65 Hz.

Before connecting the 24 V DC power supply to the mains:

1. **MAKE SURE that the voltage input selector of the 24 V DC power supply is set to the correct value: either 120 V or 240 V**.
2. Make sure that this 24 V DC supply is properly connected to the Auxiliary Power input port of the traveling standard as shown in Figure 4.
3. Then, plug the 24 V DC power supply to the mains power.

The auxiliary power to the traveling standard should be applied at least 4 hours before starting the tests.

IMPORTANT: In order to achieve the best measurement capability of the traveling standard, allow it to warm up at least 4 hours at room temperature.

4.2.2 Connecting the traveling standard

Make sure that the testing voltage and current sources are properly connected to the traveling standard. Refer to Figures 4 and 5 for details.

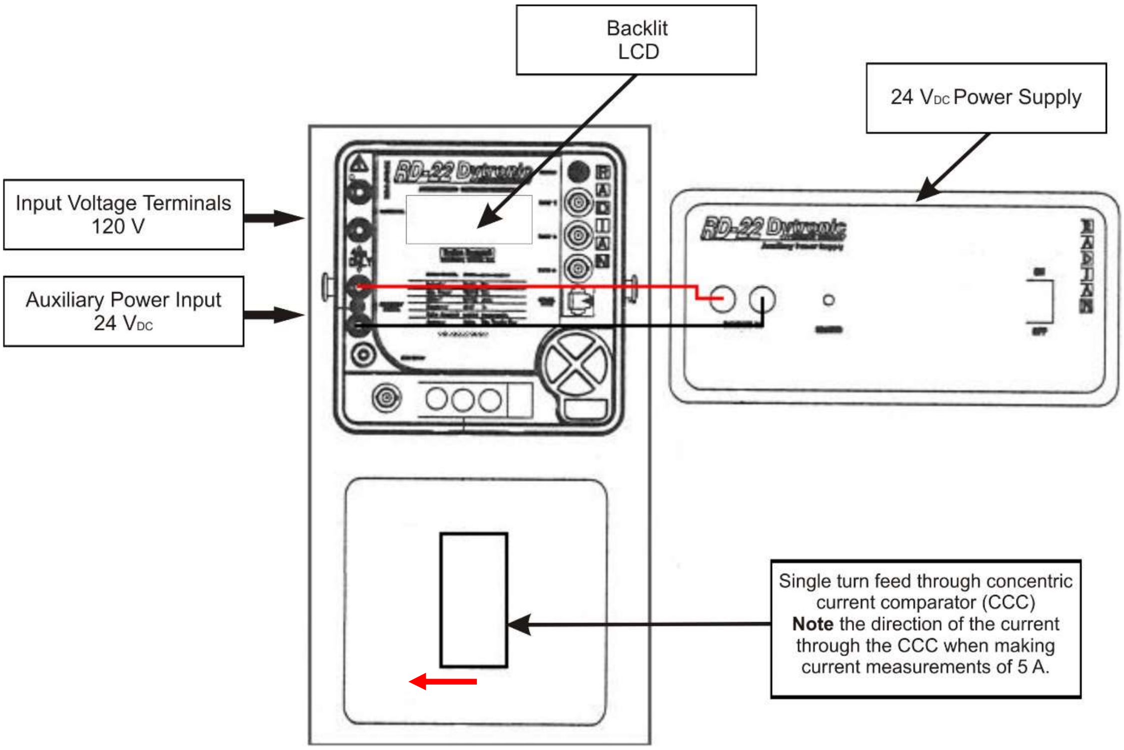


Figure 4. Connecting the RD-22-432.

Using the Concentric Current Comparator (CCC) of the RD-22-432

In order to achieve the best current measurements when using the RD-22-432, please, take into account the following instructions:

1. **Current flow**: Make sure that the testing current flows through the CCC as shown in Figure 5, where the current cables are connected to the current source. Note that the cable (with a red tape) penetrating the CCC is connected to the positive polarity (HI) output terminal of the current source so that the current flows as described by the arrow printed on the RD-22-432 panel.
2. **Highly accurate current measurements**: We recommend that you install the current cables at the top of the CCC core, as shown in Figure 5. Measurement errors are minimized by this procedure.

rsribeiro@inmetro.gov.br and gakyriazis@inmetro.gov.br
www.inmetro.gov.br

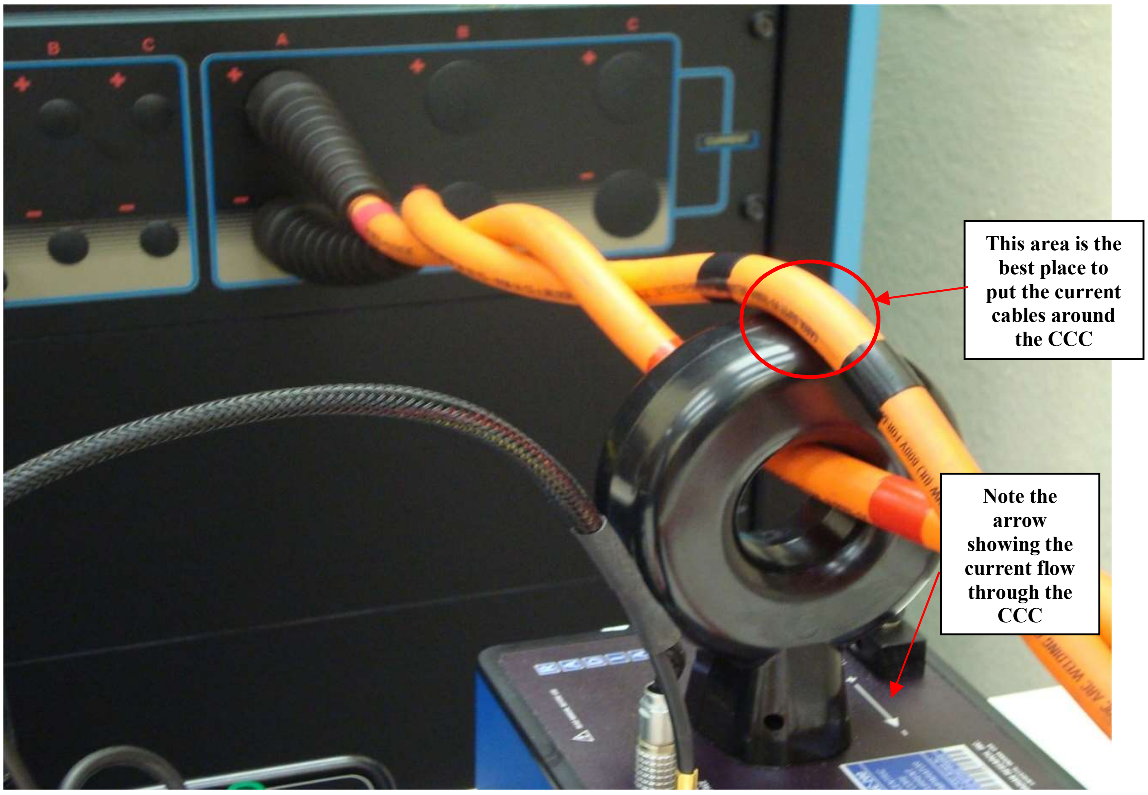


Figure 5. Current cables around the Concentric Current Comparator of the RD-22-432.

4.3 Method of measurement of active power

The measurement method is that used by the participating laboratory for the provision of a calibration. Make sure that the testing voltage and current are within at least 0.2% of the values shown in Table 1.

1. Upon arrival, allow the traveling standard to warm up at least 4 hours after powering it with the 24 V DC power supply.
2. For the voltage and current sources, make sure that their frequency is set at 50 Hz, 53 Hz, or 60 Hz, according to the testing points shown in Table 1.
3. At every power factor shown in Table 1, make as many independent measurements as stated on the calibration procedures of your laboratory.
4. Record the readings of active power, voltage, current, power factor and frequency using the software for data logging the power readings from the traveling standard.
5. Calculate the calibration error of the traveling standard at the testing points shown in Table 1. The calibration error is here defined as the difference between the active power (in watts) indicated by the traveling standard and the active power (in watts) applied to it, this difference being divided by the nominal apparent power (in VA). The calibration error should be expressed in µW/VA. The error is positive if the indication of the traveling standard is more positive than the applied active power.
6. The average of at least five sets of measurements should be reported.
7. The expanded uncertainty quoted in the laboratory's report should encompass the Type A and Type B uncertainties of the corresponding NMI calibration service. The expanded uncertainty should be estimated for a level of confidence of 95.45 %.
8. Report the ambient temperature and relative humidity of the laboratory.
9. The measurement report of the participant may be completed according to Annex A4 *Layout of the measurement report*.

5. MEASUREMENT UNCERTAINTY (See Annex A3 *Typical scheme of uncertainty budget*)

The measurement uncertainty must be evaluated by following the *Guide for the Expression of Uncertainty in Measurement* [5].

Participating laboratories are requested to report the main uncertainty components of their measurement systems and their contributions to the expanded uncertainty.

In order to have a comparable uncertainty evaluation, each laboratory should report the following information in the form of an uncertainty budget:

i. The result of the type A method of uncertainty evaluation which yields the standard deviation of the mean of the distribution of readings recorded by the participating laboratory in order to calculate its final measured value reported.
ii. The result of the type B method of uncertainty evaluation.
iii. The expanded uncertainty for 95.45 % level of confidence.
iv. The degrees of freedom for the evaluation of the expanded uncertainty at 95.45 % level of confidence.

6. MEASUREMENT REPORT (See Annex A4 *Layout of the measurement report*)

The participating laboratory should report the following information within 2 (two) months from the end of measurement at its premises:

1. Measured value (mean value) of the calibration error of the traveling standard at the test points shown in Table 1, expressed in µW/VA.
2. Expanded uncertainty associated with the measured value for 95.45 % level of confidence expressed in µW/VA (and the corresponding degrees of freedom).
3. The uncertainty components resulting from the Type A and Type B methods of uncertainty evaluation of the calibration error of the traveling standard.
4. Mean value and expanded uncertainty of relevant parameters measured by the traveling standard: RMS voltage, RMS current, power factor / phase angle, and frequency. The expanded uncertainty of the relevant parameters should be determined for a 95.45 % level of confidence ($k = 2$ for a normal distribution).
5. The final measurement results for all the 30 test points must also be reported using the Excel template file associated with the comparison.
6. Evaluation of measurement uncertainty shall comply with the *Guide to the Expression of Uncertainty in Measurement* [5].
7. A complete uncertainty budget and any additional information must be reported as shown in Annex A3.

All participants must report the results of the comparison to Inmetro as soon as possible, in every case, not later than 2 (two) months after the measurements are completed at each of their premises.

7. REFERENCES

1. SIM.EM-K5 Final Report and Linkage to CCEM-K5, 2014, 52 pages, *Metrologia*, 2015, **52**, *Tech. Suppl.*, 01002.
2. CCEM-K5.2017 Key Comparison of 50/60 Hz Power – Technical Protocol – December 2017.
3. G. Kok, G. Rietveld, R. Carranza, and M. Schmidt, CCEM-K5.2017 Key Comparison of 50/60 Hz Power – Final Report – 08 January 2026.
4. CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons. CCEM, 21 March 2007.

5. JCGM 100:2008 – *Evaluation of Measurement Data* - *Guide to the Expression of Uncertainty in Measurement*.
6. F. Delahaye and T. J. Witt, “Linking the Results of Key Comparison CCEM-K4 with the 10 pF Results of EUROMET Project 345”, *Metrologia* 39 (Tech. Suppl.) 01005, 2002.
7. B. N. Taylor, W. H. Parker and D. N. Langenberg, “Determination of *e*/*h*, using macroscopic quantum phase coherence in superconductors: implications for quantum electrodynamics and the fundamental physical constants”, *Rev. Mod. Phys.*, Vol. 41, pp. 373-496, Jul. 1969.
8. CENAM, Mexico, “ADDENDUM: Link between the CCEM-K5:2002 and SIM.EM-K5:2012”, Nov. 2014.

A1. *Detailed list of participating laboratories*

	Participating laboratory	Contact person	NMI address (shipping address)	Email	Phone
1	CENAM	Marco Antonio Rodriguez Guerrero Benjamín Noyola Maldonado	CENAM Centro Nacional de Metrología Carretera a Los Cués, km 4.5, El Marqués, Querétaro, México Zip Code: 76246	mrodrigu@cenam.mx bnoyola@cenam.mx	CENAM (+52) 4422110500; ext 3455 Personal mobile - Marco Rodriguez (+52) 4426157163
2	CENAMEP AIP	Carlos Espinosa B. Julio González V.	CENAMEP AIP Centro Nacional de Metrología de Panamá Edificio 206, Ciudad del Saber, Clayton, Ciudad de Panamá, Panamá Zip Code: 0643-01353	cespinosa@cenamep.org.pa jgonzalez@cenamep.org.pa	(507) 517-3160 (507) 517-3150 Personal mobile – Julio González (507) 65067747
3	CIM	José Rigoberto Osegueda Miranda	CIM Centro de Investigaciones de Metrología Ciudad Universitaria, Facultad de Ingeniería y Arquitectura, Final 25 Av. Norte, San Salvador, El Salvador C. A. Zip code: 01101	jose.osegueda@cim.gob.sv	(503) 7844-1095 (503) 2590-5362
4	IBMETRO	Juan Jose Mendoza Aguirre	IBMETRO Instituto Boliviano de Metrología Municipio de Achocalla, Avenida Illimani, Zona Valle Hermoso, La Paz – Bolivia	jjmendoza@ibmetro.gob.bo	(+591) 77775448, (+591 2) 2890101 int. 303
5	INACAL	Lady D. Pereira Billy Quispe	INACAL Instituto Nacional de Calidad Calle La Prosa 150, San Borja, Lima 15034, Perú	lpereira@inacal.gob.pe bquispe@inacal.gob.pe	(511)6408820 Anx 1514 Personal mobile – Lady Pereira (+51) 992044773 (511)6408820 Anx 1506
6	INEN	William D. Paucar Quinteros Diego A. Trávez Tacuri Edison M. Condor Laica	INEN Servicio Ecuatoriano de Normalización Av. General Rumiñahui, Puente Nro. 5, Calle Gonzalo Endara Crow – Sector Conocoto, Quito - Ecuador Código postal: 170809	wpaucar@normalizacion.gob.ec dtravez@normalizacion.gob.ec econdor@normalizacion.gob.ec	+593-2-3825960, ext: 2018, 2072 Personal Mobile: (+593) 998783060 (+593) 987187533 (+593) 984873161
7	INM	Nestor Eduardo Polanía Vargas Jorge Cristancho	INM Instituto Nacional de Metrología de Colombia Av. Carrera 50 No 26 – 55 Interior. 2. Bogotá, D.C. – Colombia Zip code: 111321	nepolania@inm.gov.co jacristancho@inm.gov.co	+57-254222 Extensión 1632 Mobile: +573213417668
8	Inmetro	Rodrigo Simões. Ribeiro Gregory Kyriazis	Inmetro Instituto Nacional de Metrologia, Qualidade e Tecnologia Av. Nossa Senhora das Graças, 50, Prédio 2 25250-020 - Duque de Caxias - RJ – Brasil	rsribeiro@inmetro.gov.br gakyriazis@inmetro.gov.br	xx55(21)26799074 xx55(21)26799704 +5521995439219
9	INTI	Lucas Di Lillo	INTI Instituto Nacional de Tecnología Industrial Av. Gral Paz 5445, CP1650, San Martin, Buenos Aires, Argentina	ldilillo@inti.gob.ar	+541147246200 extension 6673 +5491121643656

10	INTN	Jorge Parra Hilda Villa	INTN Instituto Nacional de Tecnología, Normalización y Metrología Avda. Artigas 3973 y Gral Roa, Asunción – Paraguay 001519	jparra@intn.gov.py hvilla@intn.gov.py	(+59) 521 288 6000 +595 981 219 154
11	LMVE-ICE	Rodolfo Durán Isabel Castro	LMVE-ICE Laboratorio Metrológico, Contiguo a la Antigua Planta de Generación Plantel ICE Colima, Tibas, San Jose. Costa Rica San José 1000	rdurang@ice.go.cr bcastro@ice.go.cr	(506) 20002805 (506) 20012374 (506) 87109125
12	NIST	Thomas Nelson	NIST National Institute of Standards and Technology 100 Bureau Dr. Bldg. 220, Room B162 Gaithersburg, MD 20899 USA	thomas.nelson@nist.gov	+13019752986
13	NRC	Harold Parks Branislav Djokic	National Research Council (NRC) Canada Building M-50 1200 Montreal Road Ottawa, Ontario K1A 0R6 Canada	harold.parks@nrc-cnrc.gc.ca branislav.djokic@nrc-cnrc.gc.ca	Mobile phone #s: H.P.: (613) 618-5757 B.D.: (613) 807-7591
14	UdeC	Rodrigo Ramos Daniel Cárcamo	Universidad de Concepción (UdeC) Edmundo Larenas 270, interior, Concepción, Chile. CP 4030000	roramos@udec.cl dacarcam@udec.cl	56 (41) 2661088 56 9 88660205
15	UTE	Gonzalo Aristoy Leonardo Trigo	Laboratorio UTE Calle Paraguay número 2385, Ciudad Montevideo, Uruguay. CP11800	garistoy@ute.com.uy ltrigo@ute.com.uy	(+598) 15524400 (+598) 99508079

A2. *Time schedule*

RD-22-432 – S/N 202068			
Laboratory		Allocated time	
		receiving day	sending day
1	NRC, H. Parks, B. Djokic (Canada)		
2	CENAM, M. Rodriguez, B. Noyola (Mexico)		
3	NIST, T. Nelson (USA)		
4	Inmetro, R. Simões, G. Kyriazis (Brasil)		
5	UTE, G. Aristoy, L. Trigo (Uruguay)		
6	INTI, Lucas Di Lillo (Argentina)		
7	Inmetro, R. Simões, G. Kyriazis (Brasil)		

RD-22-432 – S/N 200669			
Laboratory		Allocated time	
		receiving day	sending day
1	LMVE-ICE, R. Durán, I. Castro (Costa Rica)		
2	CIM, J. Osegueda (El Salvador)		
3	CENAMEP AIP, C. Espinosa, J. González (Panama)		
4	Inmetro, R. Simões, G. Kyriazis (Brasil)		
5	UdeC, R. Ramos, D. Cárcamo (Chile)		
6	INM, N. Polanía, J. Cristancho (Colombia)		
7	INTN, J. Parra, H. Villa (Paraguay)		
8	IBMETRO, J. Mendoza (Bolivia)		
9	INACAL, L. Pereira, B. Quispe (Peru)		
10	INEN, W. Paucar, D. Trávez, E. Condor (Ecuador)		
11	Inmetro, R. Simões, G. Kyriazis (Brasil)		

A3. *Typical scheme of an uncertainty budget*

The measurement uncertainty must be determined by following the *Guide to the Expression of Uncertainty in Measurement* [5]. Information on the uncertainty in measurement should be provided using the form shown below.

Participating laboratories are requested to report the main uncertainty components of their measurement systems and their contribution to the expanded uncertainty.

In order to have a comparable uncertainty evaluation, we request each participating laboratory to report the following information in the form of an uncertainty budget:

i. The result of the type A method of uncertainty evaluation which yields the standard deviation of the mean of the distribution of readings recorded by the participating laboratory in order to calculate its final measured value reported.
ii. The result of the type B method of uncertainty evaluation.
iii. The expanded uncertainty at 95.45 % level of confidence.
iv. The degrees of freedom for the evaluation of the expanded uncertainty at 95.45 % level of confidence.

Main uncertainty components y_i	Standard uncertainty $u(y_i)$	Type A or Type B evaluation method /probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degrees of freedom n_i
1) Standard deviation of the mean of distribution of readings		Type A pdf: Normal			
2) uncertainty components of the standard of the participating laboratory					
3) Ambient conditions					
3.1) temperature					
Root square sum of Type A standard uncertainties and effective degrees of freedom					
Root square sum of Type B standard uncertainties and effective degrees of freedom					
Combined standard uncertainty and effective degrees of freedom					
Expanded uncertainty (95.45 % coverage factor)					

A4. *Layout of the measurement report*

1. Identification of the traveling standard: RD-22-432 (also inform the serial number)
2. Identification of the participating laboratory and its representative
3. Measurement set-up and traceability scheme
4. Measurement procedure
5. Measurement results:
   a. Measured value (mean value) of the calibration error expressed in µW/VA at the test points shown in Table 1.
   b. Expanded uncertainty associated with the measured value for 95.45 % level of confidence expressed in µW/VA (and the corresponding degrees of freedom).
   c. Mean value of relevant parameters measured by the traveling standard: RMS voltage, RMS current, power factor/phase angle, and frequency.
   d. Mean date of measurement.
   e. Ambient conditions: mean value and spread of temperature and humidity measurements.

   The above measurement results must (also) be reported using the Excel template file that comes with this protocol.
6. Detailed uncertainty budget as in Annex A3.
7. Signature and title of laboratory representative.

A5. *Confirmation note of receipt*

To: Rodrigo Simões Ribeiro, rsribeiro@inmetro.gov.br and
Gregory Kyriazis, gakyriazis@inmetro.gov.br
Inmetro, Brasil

CC: …………
(previous participating laboratory)

From: ………
(participating laboratory)

Re: SIM.EM-K5.2026 Receipt of traveling standard (identification of the traveling standard: RD-22-432 – also inform the serial number)

We confirm having received the traveling standard of the SIM.EM-K5.2026 key comparison of 50 Hz/60 Hz power on (date)….

After visual inspection:

No damage of the transport package and the traveling standard has been noticed.

or

The following damage(s) is (are) reported. In such a case, please add pictures of damages.

Date: …………….

A6. *Confirmation note of shipment*

To: Rodrigo Simões Ribeiro, rsribeiro@inmetro.gov.br and
Gregory Kyriazis, gakyriazis@inmetro.gov.br
Inmetro, Brasil

CC: …………
(subsequent participating laboratory)

From: ………
(participating laboratory)

Re: SIM.EM-K5.2026 Dispatch of traveling standard (identification of the traveling standard: RD-22-432 – also inform the serial number)

We confirm having shipped the traveling standard of the SIM.EM-K5.2026 key comparison of 50 Hz/60 Hz power on (date)…. to the following address**:**

a) if the traveling standard will be sent to the pilot laboratory:

Inmetro
Diretoria de Metrologia Científica, Industrial e Tecnologia (Dimci)
Divisão de Metrologia Elétrica (Diele) – Prédio 2
Av. Nossa Senhora das Graças, 50
25250-020 - Duque de Caxias - RJ
Brasil
A/C Rodrigo Simões Ribeiro

b) if the traveling standard will be sent to another participating laboratory**:**

Shipping address of the subsequent participating laboratory (see Annex A1)

We confirm that we have included in the shipping container, the following items:

☐ RD-22-432
☐ 24-V DC power supply
☐ Data loggers
☐ Batteries
☐ Fuses
☐ Memory stick (software)

In any case, add the following information:

• flight number,
• airline,
• estimated time of arrival,
• air bill number and
• any other pertinent information about the shipment

Date: …………….