

National Institute of Metrology



CIPM key comparison CCEM.RF-K28.W

“RF power from 18 GHz to 26.5 GHz in rectangular waveguide”

Technical Protocol

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1. Introduction

A CIPM key comparison CCEM.RF-K28.W in “RF power from 18 GHz to 26.5 GHz in rectangular waveguide” is planned to be performed among the NMIs in 2022 to support the metrological equivalence of national measurement standards in the framework of Mutual Recognition Arrangement (MRA).

Although more and more coaxial power sensors replace waveguide power sensors, there are still many waveguide power sensors in use, including power sensors with WR-42 waveguide connectors. Many NMIs still use WR-42 waveguide microcalorimeter or calorimeter to provide power measurement traceability service in this frequency band. Therefore, it is necessary to conduct WR-42 power comparison to support CMC. A comparison of effective efficiency and calibration factor of WR-42 waveguide RF thermistor mounts is of great significance to test the existing calibration systems and reference standards, to demonstrate the precision measurement capabilities and to validate the equivalence of WR-42 waveguide thermistor mounts calibration at several National Metrology Institutes (NMIs).

2. Travelling standard

Both the effective efficiency and the calibration factor of traveling standards are to be determined at 4 frequencies between 18 GHz and 26.5 GHz (18, 21, 24, and 26.5GHz). Two WR-42 thermistor mounts will be provided as the travelling standards. It is desirable that the measurement of effective efficiency be performed in calorimeter.

2.1 Designation

Two WR-42 thermistor mounts will be provided by NIM, China as the travelling standards which have designation as follows.

Traveling standard 1 (Figure 1):

Identification name: NIM-1

Serial No: 1606

Type: K486A

Traveling standard 2 (Figure 1):

Identification name: NIM-2

Serial No: 05616

Type: K486A



Figure 1. Travelling standards.

(Note: Do not take out the filler of waveguide cavity!)

2.2 Specifications

Table 1. The specifications of Travelling Standards

Operating Frequency	18 GHz to 26.5 GHz
Connector Type	Input: WR-42(R220), UG-597/U interface Output: HP standard 6-pin connector as shown in Fig. 2
Temperature Coefficient	Negative Temperature Coefficient
Dimensions	Diameter 32.7mm Length 72.25 mm
Operating resistance	200 Ω

2.3 Output connector sketch

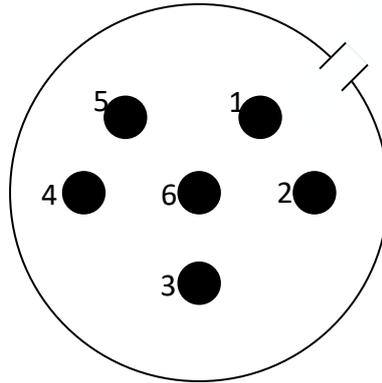


Figure 2. Pin assignment of HP standard 6-pin connector.

The RF thermistor resistance is accessible by pin 1 and pin 2, and the compensating resistance is connected by pin 3 and pin 4, as shown in the Fig. 3.

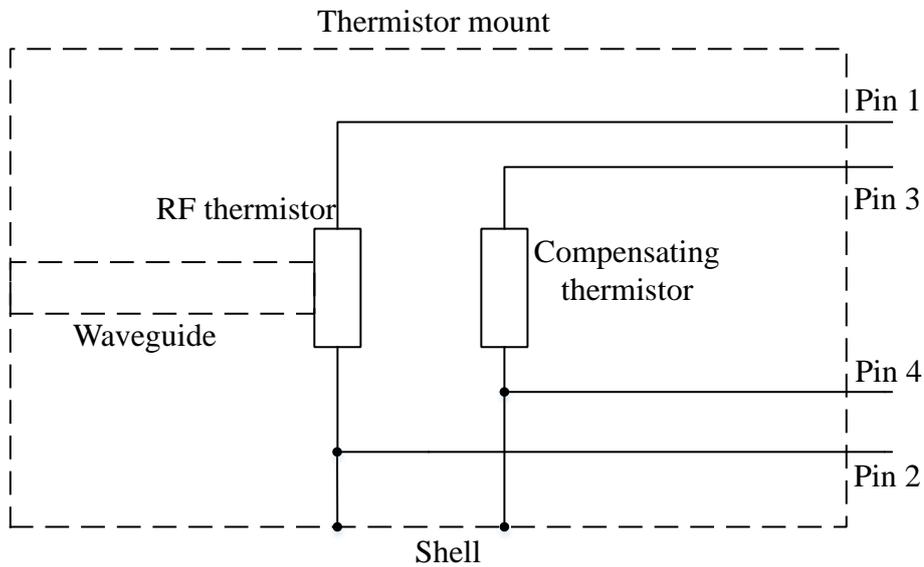


Figure 3. Schematic of the pin connections in the HP thermistor mount.

2.4 Proper Equipment

The travelling standards should only be used with measurement equipment suited for a Negative Temperature Coefficient (NTC), e.g. Type IV power meter referenced to 200 Ω or a HP/Keysight 432 power meter.

The meters operating as Positive Temperature Coefficient (PTC) power meters will result in an over-power condition and damage the device!

3. Quantities to be measured

3.1 Measuring frequencies

The measurement and evaluation frequencies are 18 GHz, 21 GHz, 24GHz and 26.5GHz respectively.

3.2 Calibration factor and effective efficiency

The calibration factor and effective efficiency of the travelling standards will be measured and evaluated at the four frequencies given under Section 3.1.

3.3 Reflection coefficient

The reflection coefficient of the travelling standards will be measured as complex quantity stated as linear magnitude and phase at the measuring frequencies. This measurement should be made whilst the thermistor mount is DC biased.

4. Organization

4.1 Participant Laboratories

The pilot laboratory for this comparison is NIM (China). The supporting group consists of PTB and NPL. The contact details of the coordinators are given below:

Pilot Laboratory: National Institute of Metrology (NIM), China

Coordinator: Dr. Cui Xiaohai

Tel: +86 010 64525201

E-mail: cuixh@nim.ac.cn

Supporting group:

Physikalisch-Technische Bundesanstalt (PTB):

Dr. Karsten Kuhlmann

E-mail: Karsten.Kuhlmann@ptb.de

National Physical Laboratory (NPL):

Mr. Murat Celep

murat.celep@npl.co.uk

Mr. Daniel Stokes

daniel.stokes@npl.co.uk

The participating institutes and contact persons with their addresses are given in Table 2.

Table2. List of participants

	Institute	Acronym	Address	Contact Persons
China	National Institute of Metrology	NIM	No. 18, Bei San Huan Dong Lu Road, Chaoyang Dist., Beijing, China 100029	Dr. Xiaohai Cui cuihx@nim.ac.cn Tel: +86 10 64525201
France	Laboratoire national de métrologie et d'essais	LNE	29 avenue Roger Hennequin 78197 Trappes Cedex FRANCE	Mr. Djamel Allal Djamel.Allal@lne.fr
U.K.	National Physical Laboratory	NPL	Hampton Road Teddington Middlesex TW11 0LW United Kingdom	Mr. Murat Celep murat.celep@npl.co.uk Mr. Daniel Stokes daniel.stokes@npl.co.uk
Germany	Physikalisch-Technische Bundesanstalt	PTB	Bundesallee 100 38116 Braunschweig Germany	Mr. Karsten Kuhlmann, Karsten.Kuhlmann@ptb.de e, +49 531 592 2220 and Mr. Jürgen Rühaak, juergen.ruehaak@ptb.de +49 531 592 2223
Turkiye	National Metrology Institute of Turkiye	TUBITAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKIYE	Dr. Erkan Danaci erkan.danaci@tubitak.gov.tr +90 262 679 50 00 / Ext.4500
Czech Republic	Czech Metrology Institute	CMI	Radiova 1136/3, Prague 10200, Czech Republic	Karel Dražil kdrazil@cmi.cz Tel: +420 266 020 173 and Jan Grajciar jgrajciar@cmi.cz
Hong Kong	Standards and Calibration Laboratory	SCL	36/F., Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong	Dr. Terry LAI Terry.lai@itc.gov.hk
Singapore	National Metrology Centre, Agency for Science, Technology and Research	NMC, A*STAR	8 CleanTech Loop, #01-20, Singapore 637145	Dr. Yusong Meng meng_yusong@nmc.a-star.edu.sg

Korea	Korea Research Institute of Standards and Science	KRISS	267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Rep. of Korea	Dr. Jae-Yong Kwon jykwon@kriss.re.kr
United States of America	National Institute of Standards and Technology	NIST	325 Broadway Mail Stop 672.01 Boulder, CO, USA	Dr. Christian J. Long christian.long@nist.gov Tel: +1-303-497-6559

4.2 Time schedule

A schematic diagram of the initial route is shown in Figure 4.

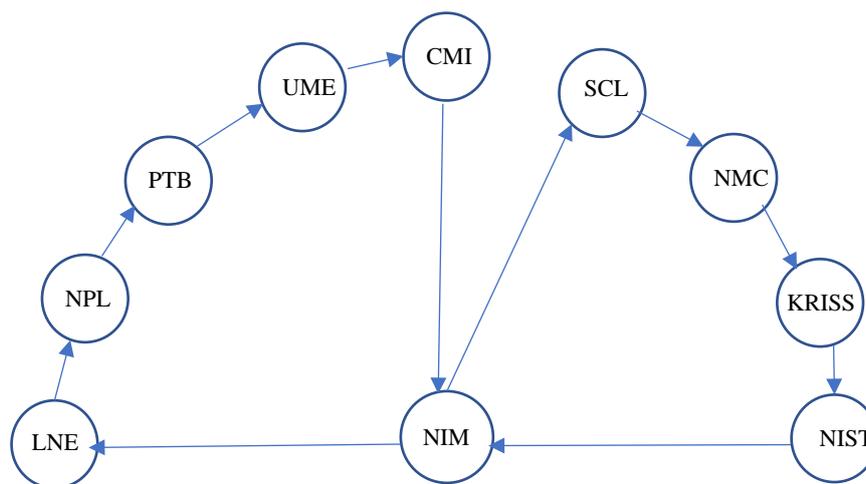


Figure 4. Schematic diagram of the initial route (planning...)

Every participant will be asked to state the time periods most convenient or unacceptable in Table 3. The date given by reply form will be taken into account in the final time schedule. The measurement will start from NIM.

The ATA carnet would be applied when NIM sent out travelling standards. The participant must ensure that the carnet is presented to customs on leaving the country, and upon its arrival in the country of destination. When the package is sent unaccompanied the carnet must be included with the other forwarding documents so that the handling agent can obtain customs clearance. In any case, the carnet must not be packed together with the device into the package. Attaching the carnet to the package is worth considering. **4-6 weeks** is scheduled for each participant, all the participants should be careful that your whole period include the total days of measurement and transportation to the next NMI.

With the agreement of the participants to the proposed circulation time schedule, the participating laboratory confirms that it is capable to perform the measurements within time period allocated in the schedule. The laboratory is requested to contact the coordinator in the pilot laboratory immediately if the measurement is delayed or the un-scheduled time should be taken. The travelling standards might be directly sent to the next laboratory without a completed measurement, according to the arrangement by pilot laboratory.

Table3. Proposed Circulation Time Schedule

NMIs	Country/Regions	Period		Duration of Calibration and Transportation	Transportation Method	Note
		Mon,	Fri,			
NIM	China(pilot)	21/11/2022	16/12/2022	4 weeks	Carnet	Microcalorimeter
LNE	France	19/12/2022	27/1/2023	6 weeks		Microcalorimeter
NPL	United Kingdom	30/1/2023	10/3/2023	6 weeks		Microcalorimeter
PTB	Germany	13/3/2023	21/4/2023	6 weeks		Microcalorimeter? After February 2023
UME	Turkiye	24/4/2023	2/6/2023	6 weeks		Microcalorimeter?
CMI	Czech Republic	5/6/2023	30/6/2023	4 weeks		Direct comparison, After June 2023
NIM	China(pilot)	3/7/2023	28/7/2023	4 weeks	Carnet	Microcalorimeter
SCL	Hong Kong	31/7/2023	25/8/2023	4 weeks		Direct comparison
NMC	Singapore	28/8/2023	22/9/2023	4 weeks		Direct comparison
KRISS	Korea	2/10/2023	10/11/2023	6 weeks		Microcalorimeter
NIST	U.S.A.	13/11/2023	22/12/2023	6 weeks		Microcalorimeter
NIM	China(pilot)	25/12/2023	2/2/2024	6 weeks	Carnet	Microcalorimeter

4.3 Transportation

Transportation is each laboratory's own responsibility and at their own expense. The travelling standards are packed in a box. The package will be accompanied by an ATA carnet to accelerate customs procedures if ATA carnet is used.

The package contains the following items:

One case (re-useable) including:

1. Two travelling standards (the value of each standard is 10000 USDs)
2. A copy of this technical protocol

After the receipt of the package, both case and standards must be inspected for any damage or contamination. The participating labs are advised to inform the pilot laboratory after arrival of the package using the confirmation note of receipt (Annex A1) by email.

The package should be sent to next laboratory immediately after completion of the measurements. Ensure that the package is complete before sending it in the original transportation case to the next participant. Please inform the pilot laboratory and the next participant about the details of dispatching the package with Annex A2 by email.

4.4 Possible failure with a travelling standard

If one of the travelling standards is damaged during the comparison, the pilot laboratory must be informed immediately. Any kind of repair must be discussed with pilot laboratory in advance. If one travelling standard cannot be repaired, all participants will discuss how to replace it.

4.5 Financial aspects,

Each participating laboratory covers the costs of the measurement, transportation, potential customs formalities, and other expense within its country. The overall costs for organizing the comparison are covered by the pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standard during transportation.

Shipping should be door to door, with the shipping laboratory responsible for ensuring that the travelling standards are delivered to the recipient's laboratory

5. Measurement instructions

5.1 Inspection and cleaning

Before measurement, the waveguide connectors and the travelling standards must be inspected if they are clean, intact, and undamaged.

It is recommended to wipe the flanges with a lint-free cleaning cloth. If a persisting sediment is still present, a cloth moisturized with pure isopropanol can be used. Please refrain from using compressed air, even at low pressure.

Never attempt to remove or move the filler from the thermistor mount flange aperture. Never blow compressed air into the thermistor mount flange aperture to clean it!

5.2 Preliminary tests before measurement

The travelling standards should be allowed to stabilize in a temperature and humidity-controlled environment for at least 1 day before commencing measurements. Also, the

electrical data of the travelling standards should be checked, according to the pin assignment shown in Fig. 2 and Fig. 3:

- 1) Unbiased RF Thermistor DC resistance at room temperature (between connector pin1 and pin2):

$$R_{\text{them}} = XX \Omega \pm XX \Omega$$

- 2) Compensating DC resistance at room temperature (between connector pin3 and pin4):

$$R_{\text{ref}} = XX \Omega \pm XX \Omega$$

The results can vary (depends on multimeter settings) but should be recorded in Annex A4.

5.3 RF measurements

- a) Power level:

The incident power level to determine the calibration factor/effective efficiency should be recorded and ideally approximately 3 mW.

- b) Frequency points:

18 GHz, 21 GHz, 24GHz and 26.5GHz.

- c) Ambient conditions:

It is suggested that the ambient conditions for the measurements should be:

Ambient temperature $23 \text{ }^\circ\text{C} \pm 1 \text{ }^\circ\text{C}$.

Relative humidity $50 \% \pm 10 \%$.

It is the responsibility of the participants themselves whether the measurement conditions meet the requirements of comparison. The above conditions are only suggestions for participants' reference.

Participants can send their preliminary results (thermistor DC resistance of the thermistor mounts, reflection coefficients without unc. budget etc.) to NIM before sending the travelling standards to the next lab. NIM will inform the lab as fast as possible, if the results are similar (same order of magnitude, completely off, ...) to the ones NIM has obtained in the past (note: these could also have a systematic offset).

5.4 Measuring methods

If the participating laboratory cannot provide RF traceability by themselves and need to trace to other NMI, they will not participate in the calculation of key comparison reference values (KCRV) of the measurement results and need to inform the pilot laboratory of their traceability status in advance.

6. Uncertainty budget

The uncertainty of measurement at all frequencies (see Annex A5) must be provided. A simplified uncertainty budget can be provided (Annex A6).

The uncertainty must be calculated according to the “ISO Guide to the Expression of Uncertainty in Measurement (GUM)” in terms of **one standard uncertainty ($k=1$)**.

7. Measurement report

The participants results should be communicated to the pilot laboratory within six weeks of completing their measurements, in accordance to the CCEM Guidelines for Planning, Organizing, Conducting, and Reporting Key, Supplementary and Pilot Comparisons. Results shall be reported to the pilot laboratory by email in pdf and MS-WORD formats. The report must contain at least;

- a) Annex A3: A detailed description of the measurement method and system used;
- b) Annex A4: A short description of the measuring setup used;
- c) Annex A5: The results of the measurement quantities, with measurement uncertainty estimated in terms of **one standard uncertainty ($k=1$)**;
- d) Annex A6: A detailed evaluation of the uncertainty of measurement for the calibration factor at 18 GHz, 21 GHz, 24 GHz, and 26.5 GHz.

The forms enclosed in the Annex (A3, A4, A5, A6) should be used instead of hand-written documentation. The signature can be added by scanning a handwritten signature into a *.jpg or .pdf document.

No information about differences of the reported results with respect to others will be communicated before the completion of the comparison, unless larger deviations of particular laboratories' results and the preliminary reference results obtained by the pilot laboratory have been observed. In this case the laboratory in question will be contacted.

8. Report of the comparison

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

The draft version of the comparison report will be issued within two months of receiving the last participants report by the pilot laboratory. The draft report will be sent to the participant laboratories for review and approval. This draft will be confidential to the participants. The participants will have four weeks to send their comments on the Draft Report. After approval and inclusion of any revisions, the Draft Report will become the Final Report.

Reference value:

Frequently, the key comparison reference value (KCRV) will be determined from the weighted mean of all reported measuring results. The uncertainty of KCRV will also be given.

Comparison results:

The measurement results of the effective efficiency and the calibration factor of the two thermistor mounts (travelling standards) will be provided by the participants for all four measuring frequencies. Comparison results will be evaluated according to the Degree of Equivalence (DoE) value.

Annex A1 Confirmation Note of Receipt

To: National Institute of Metrology (NIM)

Information and Electronics Institute

Dr. Cui Xiaohai

No. 18, Bei San Huan Dong Lu Road, Chaoyang Dist. Beijing, China, 100029

Email: cuixh@nim.ac.cn

From: (participating laboratory):

We confirm having received two thermistor mounts travelling standards of the CCEM-RF-Kxxxxxxxxx CIPM key comparison on xxxx date

After visual inspection:

No damage of the case and the travelling standards have been noticed, and the output resistance values of the two standards have been checked, and all values are okay.

The following damage(s) must be reported (if possible add a photo):

.....
.....

Date:

Signature

Annex A2 The Dispatch Note

To: National Institute of Metrology (NIM)

Information and Electronics Institute

Dr. Cui Xiaohai

No. 18, Bei San Huan Dong Lu Road, Chaoyang Dist. Beijing, China, 100029

Email: cuixh@nim.ac.cn

From: (participating laboratory):

We have informed the next participantthat we have sent two travelling standards of the CCEM-RF-Kxxxxxxx CIPM key comparison on xxxxxxxx date

We confirm the package contains the following items:

One case (re-useable) including:

1. Two travelling standards (the value of each standard is 5000 USDs).
2. A copy of this technical protocol.

Date:

Signature

Annex A3 Measurement report A

Participating laboratory: _____

A free description should be given including drawings, photos, and references, which will be part of the final report.

Date:

Signature

Annex A4 Measurement report B

Participating laboratory: _____

A tabular description of the measurement system and method(s) has to be given to be used for the final report:

1. Measuring system

Type of power standard:	
Is the power standard independent of other national measurement laboratory (NMI) ?	
Date of last calibration	

2. Measuring method

Number of repeated measurements:	

3. Measurement condition

Ambient temperature in the lab in °C	
Ambient relative humidity in the lab in %	
Thermistor DC resistance of NIM-1	
Thermistor DC resistance of NIM-2	

Date:

Signature

Annex A5 Measurement results for travelling standard NIM-

Participating laboratory: _____

1. Effective efficiency

Frequency (GHz)	Effective efficiency	Combined standard uncertainty ($k=1$)	Degree of freedom
18			
21			
24			
26.5			

2. Calibration factor

Frequency (GHz)	Calibration factor	Combined standard uncertainty ($k=1$)	Degree of freedom
18			
21			
24			
26.5			

3. Reflection coefficient

Frequency (GHz)	Reflection coefficient		Standard uncertainty ($k=1$) of	
	Lin-magnitude	Phase	Lin-magnitude	Phase
18				
21				
24				
26.5				

Annex A6 Proposed scheme for uncertainty budget for calibration factor at 18, 21, 24, 26.5GHz

Participating laboratory: _____

Measuring frequency: xx GHz

Travelling standard:

Quantity	Estimate	Standard uncertainty	Probability distribution / method of evaluation (A,B)	Sensitivity coefficient	Uncertainty contribution	Degree of freedom

Measuring frequency: xx GHz

Travelling standard:

Quantity	Estimate	Standard uncertainty	Probability distribution / method of evaluation (A,B)	Sensitivity coefficient	Uncertainty contribution	Degree of freedom

.....