CCEM KEY COMPARISON CCEM.RF-K10.CL (GT-RF / 99-2)

“Power in 50 Ω coaxial lines, frequency: 50 MHz to 26 GHz“

Measurement Techniques and Results

Final Report

Dieter Janik
Working Group „High frequency measuring techniques“
Physikalisch-Technische Bundesanstalt Braunschweig
Bundesallee 100, 38116 Braunschweig
GERMANY
e-mail: dieter.janik@ptb.de

in cooperation with :

T. Inoue (NMIJ, JAPAN) and A. Michaud (NRC, CANADA)

Coordinator: L. Brunetti (IEN, ITALY)

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Abstract

This report summarises the results and the measuring methods of an international key comparison between twelve national metrology institutes (NMIs) and is concerning the calibration factor of RF power sensors in the coaxial 3,5 mm line for frequencies up to 26 GHz. Two RF power travelling standards fitted with male PC 3,5 mm connectors were measured at seven frequencies. The following NMIs participated**:** **NMIJ** (Japan), **NRC** (Canada), **NIST** (USA), **METAS** (Switzerland), **CSIR-NML** (South Africa), **NMIA** (Australia), **NPL** (UK), **SiQ** (Slovenia), **IEN** (Italy), **VNIIFTRI** (Russian Fed.), **SPRING**, (Singapore), and **PTB** (Germany), as the pilot laboratory.

1. Introduction

The key comparison for RF power in the 3,5 mm coaxial line system described in this report is the first key comparison for RF power covering the large bandwidth from 50 MHz to 26 GHz. Twelve NMIs participated in this comparison.
This comparison had originally been agreed at the meeting of the EUROMET RF expert group on the 3rd of December 1998, as the EUROMET comparison 525 including 6 participants. On the 20th of June 1999, at the Working Group on Radiofrequency Quantities (GT-RF) meeting in Sèvres (France), it was decided that this comparison should become an international CIPM key comparison CCEM.RF-K10CL (GT-RF/99-2) entitled "Power in 50 Ω coaxial lines, frequency: 50 MHz to 26 GHz". The Physikalisch-Technische Bundesanstalt (PTB) served as the pilot laboratory and all participants of the former EUROMET comparison joined the key comparison.

This key comparison was needed because of the growing importance of the coaxial 3,5 mm line system for broadband (DC to 26,5 GHz) RF measurements. Before this exercise, only a trilateral international comparison has been performed [1] to examine the new measuring systems for RF power in 3,5 mm coaxial line. It was informal and did not follow the formal rules of a key comparisons. In the Mutual Recognition Arrangement (MRA) it is stated, that the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organised by the Consultative Committees of the CIPM working closely together with the Regional Metrology Organisations (RMO's).

2. Participants and organisation of the comparison

2.1 Organisation of the comparison

At the GT-RF working group meeting in 1999, fifteen national metrology institutes expressed their interest to participate in this key comparison. After a participants inquiry made by the pilot laboratory the timetable of the comparison was arranged. The standards were first to be calibrated by the pilot laboratory and the comparison was to start on the 1st of July 2000, with the measurements to be carried out by NMIJ as the first participant. The re-measurements of the standards by the pilot laboratory were scheduled for April 2001, and the end of the comparison was scheduled for March 2002 (see the original timetable in Annex A) .

One participant who was not a member of the Meter Convention had to withdraw because this membership is a requirement for the participation in CCEM key comparisons. During the running of the comparison three other European NMIs asked to join it. Therefore, it was decided that the CCEM comparison should be followed by a subsequent comparison, EUROMET 525, including these four participants, with the same subject ,and also the same pilot laboratory.

After eleven successful measurements (including those of the pilot laboratory) both travelling standards became unstable and had to be repaired and calibrated by the pilot laboratory. After a final check measurement of the repaired standards performed by the 12th participant, their nominal 50 Ω input impedance changed to about 1 Ω. Since the 12th participant was able to deliver a complete set of measurement results for the two (renewed) travelling standards, it was arranged with the remaining two participants to terminate the key comparison. The measurement results of the 12th participant were however included. The two remaining NMIs later joined the subsequent EUROMET 525 comparison. In conclusion, 12 participants on the 15 scheduled at the beginning of the comparison, have measured the travelling standards.

Before the beginning of the comparison, a technical protocol of 15 pages was written by the pilot laboratory in co-operation with two helping laboratories which were represented by Dr. Takeumi Inoue of NMIJ (Japan) and Dr. Alain Michaud of NRC (Canada). This protocol described the travelling standards, the quantity to be measured, and the measurement procedures. The protocol also gave examples for the uncertainty of measurements of two typical measurement scenarios. The protocol was distributed to all participants before the start of the measurements.

2.2 List of participants

The following 12 NMIs participated in this comparison:

Table 1 List of participants with name of responsible persons:

Organisation	Acronym	Country	Name of participant
Council for Scientific and Industrial Research-National Metrology Laboratory	**CSIR-NML**	South Africa	Erik Dressler
National Measurement Institute	**NMIA**	Australia	Tieren Zhang
Istituto Ellettrotecnico Nazionale “Galileo Ferraris“	**IEN**	Italy	Luciano Brunetti
Metrology and Accreditation Switzerland	**METAS**	Switzerland	Jürg Furrer
National Metrology Institute Japan	**NMIJ**	Japan	Takeumi Inoue
National Institute of Standards and Technology	**NIST**	U.S.A	John Juroshek
National Physical Laboratory	**NPL**	UK	Geoff Orford
National Research Council	**NRC**	Canada	Alain Michaud
Physikalisch-Technische Bundesanstalt	**PTB**	Germany	Dieter Janik
Slovenian Institute of Quality and Metrology	**SiQ**	Slovenia	Rado Lapuh
National Metrology Centre (SPRING Singapore)	**SPRING**	Singapore	Li Hua
All-Russian Scientific and Research Institute	**VNIIFTRI**	Russia Fed.	V. G. Chuicko

More details are shown in the Annex C.
All participants measured the two travelling standards. However one participant withdrew the results for one standard afterwards.

2.3 Comparison schedule

For the comparison measurements, time slots were planned of about 6 weeks for transportation and measurement outside Europe and 5 weeks inside Europe. The time slots were allocated to the individual participants according to the preferences given in the response to the inquiry performed by the pilot laboratory before the start of the comparison. In some instances (Christmas holidays, special customs clearance) longer slots were allocated. When planning the schedule in detail it was attempted to group together the participants of the countries which needed an ATA carnet, and in a second following group, the European countries which did not need special customs documents. The final time table of the whole key comparison is given in the Annex B. In general the participants kept their time slots very well.

Table 2: List of participants and their measuring data

Acronym	Country	Measuring period	Report submitted	Comments
PTB	Germany	May/June 2000	Jan. 2002	1. meas. at pilot lab
NMIJ	Japan	July/Aug. 2000	Nov. 2000	
NRC	Canada	Aug./Sept. 2000	July 2001	
NIST	USA	Oct./Nov. 2000	Feb. 2001	
METAS	Swiss	Nov./Dec. 2000	June 2001	
CSIR-NML	South Africa	Dec.2000/Jan.2001	March 2001	
PTB	Germany	Feb. 2001	May 2001	2. meas. at pilot lab.
NMIA	Australia	March/April 2001	May 2001	
NPL	UK	April/May 2001	June 2001	
SiQ	Slovenia	May/June 2001	Oct. 2001	
IEN	Italy	June/July 2001	Oct. 2001	
PTB	Germany	August 2001	Jan. 2002	Check at pilot lab.
VNIIFTRI	Russia Fed.	Sept./Oct. 2001	Jan. 2002	
PTB	Germany	November 2001		Check at pilot lab. **Meas. new standards**
SPRING	Singapore	Dec. 2001/Jan. 2002	March 2002	**New standards damaged**

2.4 Unexpected incidents

During the comparison it turned out that one participant was not a member of the Meter Convention and therefore was not allowed to take part in this key comparison. This participant later joined the subsequent EUROMET 525 comparison. The sequence of the measurements had to be changed in two cases because two participants asked, after the start of the measurements, to shift their measuring periods. No time was however lost because other participants agreed to take the measurements earlier. After the measurements of 11 participants, it was detected that both standards became unstable and had to be repaired. The travelling standards were supplied with new sensor elements and had to be re-calibrated in the pilot laboratory because of changed measurement values. These new standards failed again after a complete measurement was conducted by the 12th participant. As a problem with the travelling standards occurred a second time the comparison was terminated at this stage and the two remaining participants joined the following EUROMET 525 comparison. Comparing the originally planned schedule and the realised one (Annex A and B), it follows that the total duration of the comparison was reduced by 3 months (from 21 months to about 19 months), though the number of participants was reduced from 15 to 12.

3. Travelling standards and measurement instructions

3.1 Description of the standards

The pilot laboratory provided as the travelling standards two identical dc coupled power sensors working from dc up to 26,5 GHz. These travelling standards, as shown in Fig.1 and Fig. 2, are modified commercial power-thermovoltage converters (power sensors) fitted with PC 3,5 male input connectors. The nominal input impedance of the sensor is 50 Ω and the responsivity R – the ratio of the output thermovoltage and the RF input power – is
$R \approx 0{,}23$ mV/mW.

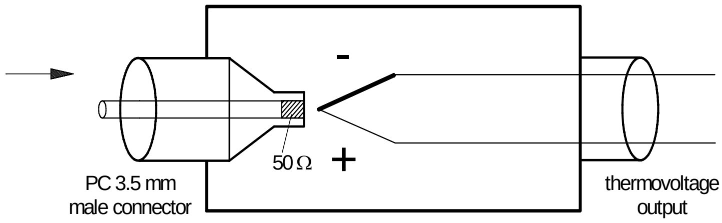

Fig.1 Block diagram of the power sensor travelling standard

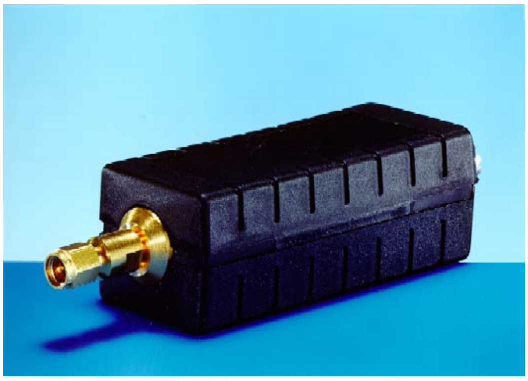

Fig. 2. Photo of the travelling standard

The sensors contain no electronics. They are suited to be calibrated either by comparing to a power standard with a stable and matched generator system or directly in a microcalorimeter. This type of sensor proved its suitability and long term stability over one year in a trilateral comparison [1]. To calibrate these transfer devices only a sensitive commercial nV-meter is needed. It is used only to measure, with a high resolution, the output voltage of the sensor.

Electrical data of the two travelling standards:

dc input resistance R_{in} : R_{in} = (50,5 ± 1) Ω,
dc output resistance R_{out} : R_{out} = (430 ± 10) Ω,
dc resistance between the output terminals and the housing: 1,5 kΩ to 6 kΩ.

The two travelling standards were designated as:

PTB-P 1 Ser. No. 3 and PTB-P 2 Ser. No. 6.

3.2 Quantities to be measured and condition of measurement

The RF performance of an RF power sensor is described by its **calibration factor K_X(f)** which is defined as :

$$K_X(f) = P_{ref}(f_{ref}) / P_{inc}(f):$$

where $P_{ref}(f_{ref})$ is the reference power at the low frequency reference frequency f_{ref} and $P_{inc}(f)$ is the incident power at the measuring frequency f under the condition that both powers give equal thermovoltage at the sensor output. It was decided to use for this comparison a **1 kHz frequency as the reference frequency f_{ref}.**

The participants were asked to measure the calibration factor $K_X(f)$ of the two travelling standards at **7 frequencies: 50 MHz, 1 GHz, 10 GHz, 18 GHz, 20 GHz, 23 GHz and 26 GHz.** The measurements at 50 MHz, 1 GHz and 10 GHz were optional. The suggested power level for this measurement was (3 ± 1) mW.

Additionally the participants were asked to measure at the same frequencies the **magnitude of the voltage reflection coefficient** $|\Gamma(f)|$ at the PC 3,5 mm input connector of each travelling standard at the same frequencies. The reflection coefficient is not the main quantity to be measured in this comparison. The knowledge of the input reflection coefficient of a RF power meter is important to determine the mismatch factor between generator and power sensor when making power measurements.

Together with the measurement values of the calibration factor and the reflection coefficient, the combined standard uncertainty of measurements was to be provided with the results.

The recommended environment conditions were (23 ± 1)°C for the temperature and (50 ± 10)% for the humidity. The actual temperature and humidity were also to be provided with the measurement results.

3.3 Measuring instructions

The participants were asked to check the typical electrical data as mentioned in the technical protocol before the measurements. Also the value of the input connector pin depth was to be checked, in order to test the nominal specifications of the input connector. The participant was free to choose his own measuring method, but the actual measuring method had to be described in a short report attached to the measuring results.

3.4 Deviation from the protocol

The planned schedule of the comparison (Annex A), which was given in the technical protocol, had to be changed two times. One participating laboratory had to withdraw because its home country is not a member of the Meter Convention, and two participants asked for another period of measurements (see 2.4). As the two standards failed after the measurements of the 11th and the 12th participant, it was decided in agreement with the remaining two participants that this key comparison should be terminated after the 12th participant. The remaining two participants joined the subsequent EUROMET 525 comparison with the same subject.

4 Methods of measurement

Most participants used an RF power comparison system including a resistive power splitter or a directional coupler connected to a generator and a monitor power meter on one coupler arm indicating the measuring power. The other arm of the splitter or coupler was terminated alternately with the travelling standard (DUT) or the primary power standard of the laboratory. As many RF power comparison systems are not designed for frequencies below 50 MHz, the calibration factor measurements between 1 kHz and 50 MHz have been performed in non-critical low frequency systems which are not described here. Only two participants calibrated the travelling standards directly in a microcalorimeter for power sensors in coaxial 3,5 mm line.
Because of the great variety of the comparison systems and primary power standards used, individual descriptions of the instrumentation are given:

NMIJ

A broadband power comparison system in 2,9 mm coaxial line with integrated power splitter and a bolometric power standard for frequencies up to 40 GHz at the side arm was used. As the PC 2,9 mm K-connector at the test port of the system is mechanically and electrically compatible with PC 3,5 mm-connector a direct connection of the DUT was possible.

NRC

The basic component of the comparison system at 1 GHz and 10 GHz was a 3 dB-coupler. A twin dry-load-calorimeter with PC 7 connectors was used as the primary power standard. A similar system but with a 3 dB-waveguide coupler (R 220) and waveguide thermistor mount, calibrated against the NRC-R 220-waveguide microcalorimeter as the primary power standard, was used at higher frequencies. The adaptors to the PC 3,5 mm-connector of the DUT were characterized by the measurement of their scattering parameters.

NIST

The calibration was performed in a direct comparison system including a power splitter for the very broadband 2,4 mm coaxial line system up to 50 GHz. The reference power standard was a 2,4 mm special bolometric film detector which was calibrated as a power standard in the coaxial NIST-2,4 mm microcalorimeter. The PC 3,5 mm DUT was connected to the comparison system by a 2,4 mm /3,5 mm adaptor, which was characterised by scattering parameter measurements using a network analyser (ANA). The mismatch between the test port and the input of the DUT or power standard was determined and corrected.

METAS

A calibration system with power splitter and a power standard in the coaxial 2,4 mm system was used. The coaxial adaptor 2,4 mm/3,5 mm to connect the DUT to the system was characterized by means of ANA scattering parameter measurements. The coaxial 2,4 mm primary power standard was calibrated by NPL (UK).

CSIR-NML

A comparison system with power splitter in the coaxial 3,5 mm line was used, but without a monitor power meter. The DUT and the power standard were connected directly to the two ports of the splitter. Two measurements with both devices exchanged at the splitter ports were averaged to eliminate the asymmetry of the splitter. The power standard with PC 3,5 mm connector was calibrated at Agilent (UK) and thereby traced back to NPL (UK).

NMIA

Two different RF power comparison systems with directional couplers and Six-Port Networks were used. The power standards in the coaxial line at 18 GHz and below, were the N connector thermistor mounts calibrated in the NMIA microcalorimeter. The R 220 waveguide thermistor power standards used at frequencies above 18 GHz were calibrated at NIST (USA). The adaptors N/PC 3,5 mm and the waveguide R 220/PC 3,5 mm were characterized by ANA scattering parameter measurements.

NPL

A power comparison system in the 3,5 mm line system was used. By means of a 6 dB attenuator with known reflection coefficients at the PC 3,5 mm-power splitter test port, the mismatch between test port and the input of the DUT or power standard was determined and corrected. The primary power standard was the PC 3,5 mm NPL dry calorimeter.

SiQ

A comparison system in the coaxial 3,5 mm line system with a 3,5 mm monitor power meter was used. The power standard in the 3,5 mm line system with PC 3,5 mm connector was calibrated by DERA (UK), an accredited calibration laboratory which is traced back to NPL (UK).

IEN

A new designed microcalorimeter for the 3,5 mm line system as a primary RF power standard was used to determine directly the effective efficiency of the DUTs. With the reflection coefficient measured by means of an ANA, the calibration factor was determined.

PTB

The microcalorimeter - already used in the trilateral RF power comparison with NPL and NRC in 1998 - served as a primary power standard to calibrate directly the effective efficiency of the DUT for this comparison. The calibration factor was then determined using the reflection coefficient measured with an ANA.

VNIIFTRI

For 1 GHz and 10 GHz a comparison system in the 7 mm coaxial line system with N-connector was used, whereas for 18 GHz, 20 GHz, 23 GHz and 26 GHz a waveguide system was employed. The primary two power standards were equipped with the same connector types. By means of adaptors to the PC 3,5 mm-connector, the DUTs were compared with these standards. The adaptors were characterised by ANA scattering parameter measurements.

SPRING

A comparison system in coaxial 3,5 mm line system was used with power splitter and a monitoring power meter. As the primary power standard a PC 3,5 mm temperature stabilised thermistor mount was applied which was calibrated by NIST (USA).The mismatch at the test port was determined and corrected by measuring the complex reflection coefficients by an ANA at the test port, at the input of the DUTs and of the primary power standard.

5 Repeated measurement, behaviour of the travelling standards

From the previous trilateral comparison with the same type of travelling standard it was known that the standards would be stable over a year. It was originally planned to conduct three measurements in the pilot laboratory to check the stability (see Annex A): one before the start of the measurements, one re-measurement in the middle of the comparison and one at the end of all measurements. For the measurements by VNIIFTRI, the standards were dispatched directly from the pilot laboratory and sent back to it because of customs requirements, therefore a check of the electrical data was planned in the pilot laboratory.

During this check, following the measurements by VNIIFTRI, it came out that for frequencies above 10 GHz no stable calibration factor measurements were possible. The reason for this failure was not found, because the electrical data of both standards were unchanged. Due to this anomalous behaviour, a stability check was possible only by the re-measurement in the middle of the comparison and not with a final measurement. Comparing the re-measurement results for the two calibration factors with the first measurement results the deviations remained within the typical repeatability of the measurements (see table in Annex D).

In order to proceed with the comparison, the pilot laboratory exchanged the two power detector elements in both travelling standards. As the measuring values were subject to change due to the repair, the designations of the standards were changed to: **PTB 1 Ser. No. 3-1** and **PTB 2 Ser. No. 6-1.** The two renewed travelling standards were calibrated in the pilot laboratory and sent to the next participant the SPRING (Singapore). After a complete set of measurements of both standards at SPRING, the standards failed when starting a second measurement cycle. The input impedances of both standards changed from 50 Ω to about 1 Ω.

Later, in the pilot laboratory it was discovered that the output of the sensor elements is sensitive to strong discharge pulses when they are directly coupled to the output leads of the sensor mount. The sensitive sensor elements are built for commercial power mounts, where the output is connected to a low-resistance electronic circuit, thereby these elements are protected in this case.

After the second damage of the standards the comparison was finished in consulting with the remaining two participants. They agreed to join the subsequent EUROMET (525) comparison with the same subject.

6 Measurement results and reference value

6. 1 Mean values of the measuring results

The measurement results were presented to the pilot laboratory as the mean of repeated measurements both for the **calibration factor** and for the modulus of the **reflection coefficient,** together with their combined standard uncertainties. Nearly all participants used the form we proposed in the Annex 5 of the technical protocol to present their results. For the calibration factors at two frequencies (10 GHz and 26 GHz), also a detailed uncertainty budget together with the resulting combined standard uncertainty was sent from all participants. The copies of these documents for the standard PTB 1 - 3 are enclosed in the Annex H.

From the results concerning the two travelling standards and coming from all the participants the **unweighted mean values** for the **calibration factor** and the **magnitude of the reflection factor** were calculated and used to obtain a first trend of the circulation.

As stated in the technical protocol, the mean value for the calibration factor must be calculated only from the measuring results obtained by laboratories using **independent** primary power standards. Therefore a second mean value using only results of independent standards (called mean-ind.) was calculated.

As Key Comparison Reference Value (***KCRV***) a third mean was calculated according to [2] from the results achieved using **independent** standards and **without considering outliers** (see ch. 6.2).

Since both travelling standards had to be repaired after the measurement of the 11th participant, the values for the standards PTB 1-3 and PTB 2-6 are the mean values of 11 participants (without SPRING).

Table 3: Different mean values with associated standard deviations of the calibration factor of PTB 1-3

Travelling standard: PTB 1-3 calibration factor						
Frequency in GHz	**Mean of all**	**Std. dev. of mean**	**Mean of ind. standards**	**Std. dev. of mean**	***KCRV***	**Std. dev of *KCRV***
0,05	**0,9868**	0,0011	**0,9866**	0,0010	**0,9866**	0,0010
1	**0,9757**	0,0009	**0,9760**	0,0012	**0,9760**	0,0012
10	**0,9427**	0,0020	**0,9431**	0,0028	**0,9416**	0,0007
18	**0,9296**	0,0023	**0,9291**	0,0029	**0,9317**	0,0014
20	**0,9269**	0,0022	**0,9248**	0,0033	**0,9276**	0,0020
23	**0,9250**	0,0017	**0,9232**	0,0025	**0,9252**	0,0019
26	**0,9172**	0,0029	**0,9166**	0,0043	**0,9228**	0,0022

Table 4: Different mean values with associated standard deviations of the calibration factor of PTB 2-6

Travelling standard: PTB 2-6 calibration factor						
Frequency in GHz	**Mean of all**	**Std. dev. of mean**	**Mean of ind. standards**	**Std. dev. of mean**	***KCRV***	**Std. dev of *KCRV***
0,05	**0,9895**	0,0012	**0,9895**	0,0015	**0,9895**	0,0019
1	**0,9801**	0,0010	**0,9804**	0,0014	**0,9804**	0,0015
10	**0,9400**	0,0024	**0,9410**	0,0032	**0,9380**	0,0012
18	**0,9068**	0,0028	**0,9068**	0,0043	**0,9079**	0,0010
20	**0,8954**	0,0029	**0,8918**	0,0044	**0,8960**	0,0016
23	**0,8815**	0,0025	**0,8816**	0,0043	**0,8776**	0,0021
26	**0,8827**	0,0034	**0,8857**	0,0051	**0,8857**	0,0051

The repaired standards, PTB 1 3-1 and PTB 2 6-1, were measured only by SPRING and PTB (pilot laboratory), therefore only the mean of both values is given without a standard deviations. The *KCRV-1* values of these repaired standards were determined by means of the PTB (pilot) values (see 6.2).

Table 5: Mean values of the calibration factors of PTB 1-3-1 and PTB 2-6-1

Calibration factor						
Travelling	**standard:**	**PTB 1-3-1**		**Travelling**	**standard:**	**PTB 2-6-1**
Frequency In GHz	**Mean of all**	***KCRV-1***		**Frequency In GHz**	**Mean of all**	***KCRV-1***
0,05	**0,9917**	**0,9895**		0,05	**0,9888**	**0,9881**
1	**0,9821**	**0,9841**		1	**0,9778**	**0,9800**
10	**0,9427**	**0,9358**		10	**0,9403**	**0,9398**
18	**0,8958**	**0,9004**		18	**0,9088**	**0,9126**
20	**0,8827**	**0,8849**		20	**0,9060**	**0,9110**
23	**0,8584**	**0,8582**		23	**0,8861**	**0,8861**
26	**0,8581**	**0,8601**		26	**0,8925**	**0,8926**

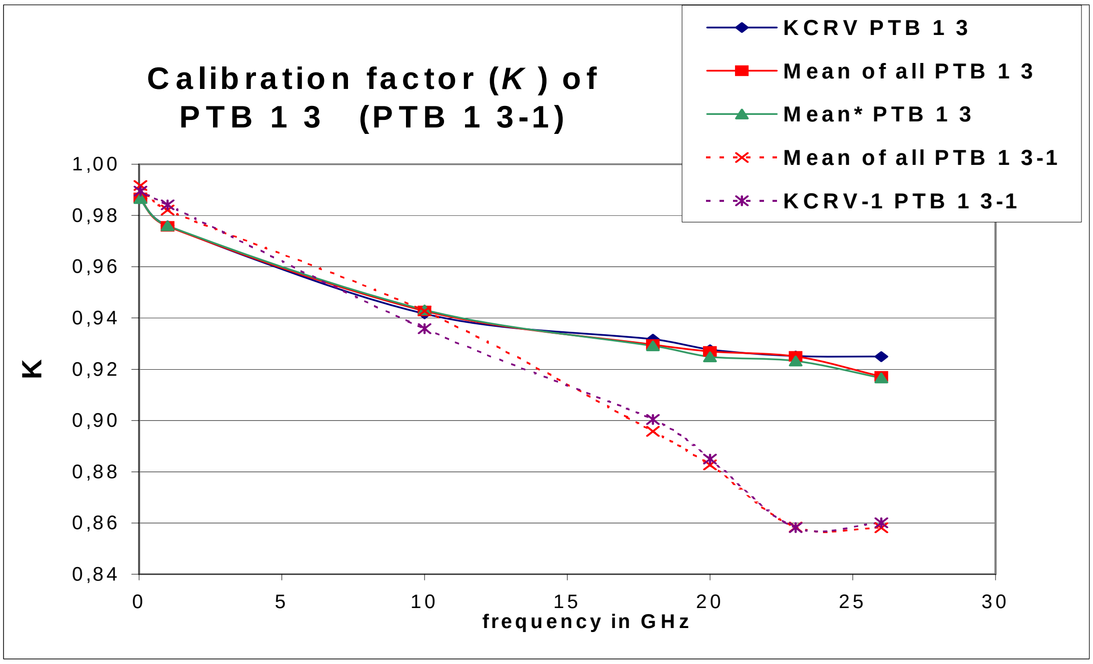

Fig. 3: Different mean values of the calibration factor for travelling standard PTB 1-3 (PTB1-3-1, dashed)

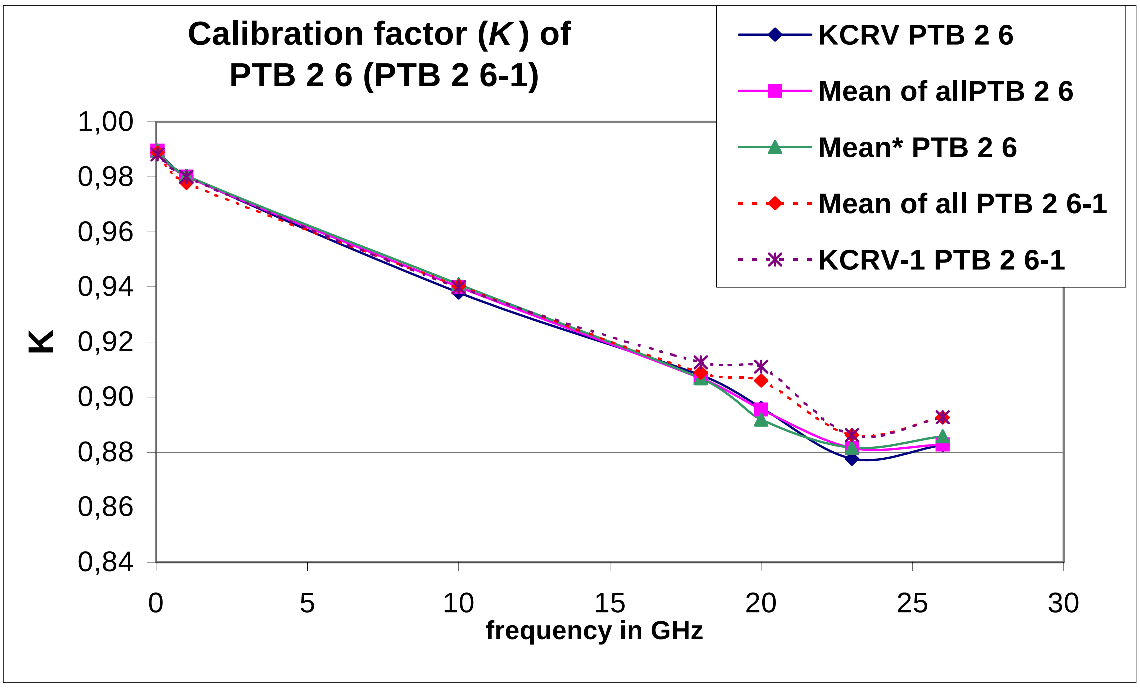

Fig. 4: Different mean values of the calibration factor for travelling standard PTB 2-6 (PTB 2-6-1, dashed)

Since for the reflection measurements no special knowledge has been acquired about the standards and methods, only an arithmetic mean of all unweighted results has been determined.

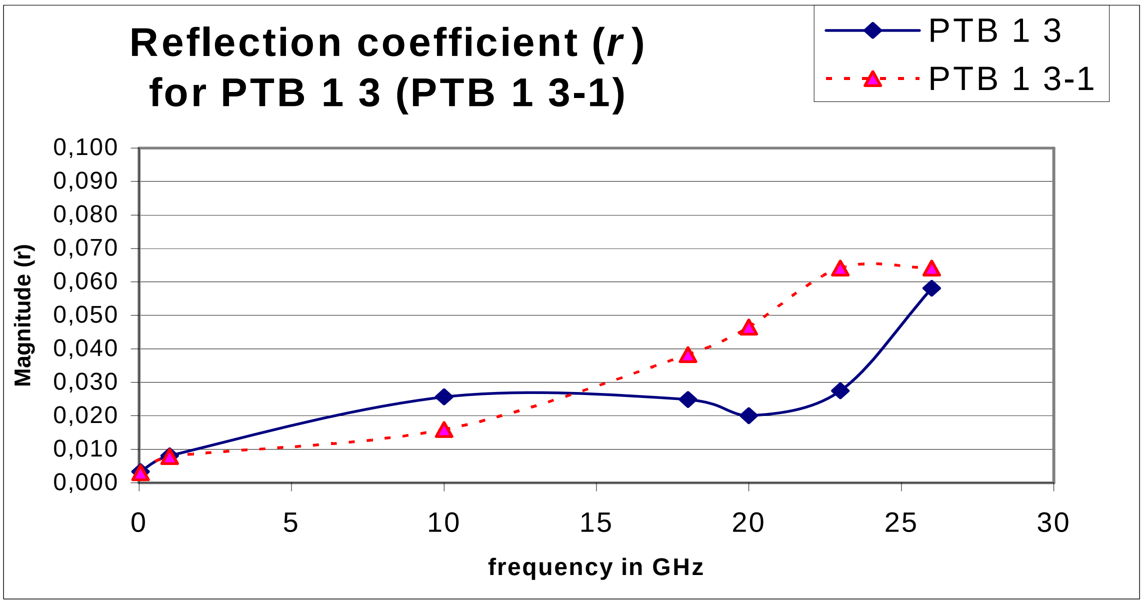

Fig. 5: Mean values of the magnitude of the reflection coefficient for travelling standard PTB 1-3 (PTB1-3-1, dashed)

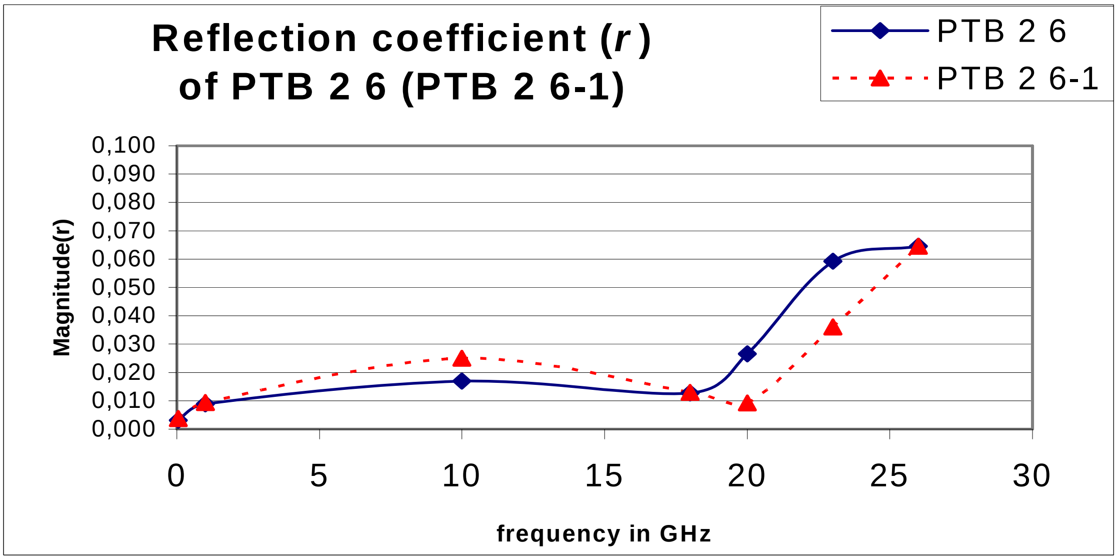

Fig. 6: Mean values of the magnitude of the reflection coefficient for travelling standard PTB 2-6 (PTB 2-6-1, dashed)

As it can be seen in Figs. 3 to 6 representing the measurement results of the travelling standards PTB 1 and PTB 2 before (solid line) and after the repair (dashed lines), both the calibration factors and the reflection coefficients changed significantly due to the repair. Therefore the measurement values achieved before and after the repair cannot be compared.

The standard deviations of all three mean values of the calibration factor increase with frequency from about $1{\cdot}10^{-3}$ at low frequencies to about $5{\cdot}10^{-3}$ at 26 GHz (Tables 3 to 4). For frequencies above 1 MHz in most cases the *KCRV* standard deviations are smaller than the standard deviations assigned to the other two mean values, an effect of the elimination of outliers [2] with the determination of the *KCRV*. At all frequencies the deviations between the corresponding mean value of all participants and the mean value of independent standards are less than $4{\cdot}10^{-3}$. Also, the corresponding *KCRV* values are in close coincidence with these two mean values in most cases. Only for PTB 1-3 at 26 GHz and PTB 2-6 at 23 GHz are the deviations a little larger, ($6{\cdot}10^{-3}$ and about $4{\cdot}10^{-3}$ respectively).

6.2 Calculation of the Key Comparison Reference Value (*KCRV*) and its associated uncertainty

In order to compare the results of the participants a reference value has to be calculated, which is assumed to be the most probable mean value. For this report the procedure described by J. Randa in [2] will be used to determine the Key Comparison Reference Value (KCRV). As an additional condition only results obtained with independent primary power standards are considered for this *KCRV*. As the primary power standards are considered to be independent from each other no covariances between the individual results had to be considered.

Following the procedure [2], first the median value Y_{med} for a sample of measurement results for each frequency and standard is calculated. In a second step, for each individual result Y_j the absolute deviation $|Y_j - Y_{\mathrm{med}}|$ from the median Y_{med} is determined. A new estimator *S*(MAD) for the variability of the results is calculated from the median of the individual absolute deviations (MAD). A result Y_j for which the relation $|Y_j - Y_{\mathrm{med}}| > 2{,}5{\cdot}S(\mathrm{MAD})$ holds is considered as an outlier and this result is not used to calculate the *KCRV*. Applying this procedure to the results of this comparison data resulted in only a few values that were outliers. In Table 6 the participants are listed which used independent power standards and therefore were allowed to contribute to the *KCRV* with the exception of individual outlier values which are marked in the list.

Table 6: List of participants which are considered to contribute to the *KCRV*, (outliers which are excluded from the contribution are marked by X)

Frequency :	50 MHz		1 GHz		10 GHz		18 GHz		20 GHz		23 GHz		26 GHz	
Trav. Std :	1-3	2-6	1-3	2-6	1-3	2-6	1-3	2-6	1-3	2-6	1-3	2-6	1-3	2-6
Participant														
NMIJ													X	
NRC														
NIST														
PTB														
NMIA#														
NPL														
IEN					X			X			X	X	X	
VNIIFTRI					X	X	X	X	X	X				

only up to 18 GHz

From all Y_i which have not proven to be outliers **an unweighted arithmetic mean was calculated as the *KCRV* with its associated standard deviation** *u*(*KCRV*) according to [2] for each frequency and each standard according to:

$$KCRV = \frac{1}{N}\cdot\sum_{j=1}^{N} Y_j \qquad \text{and} \qquad u(KCRV) = \sqrt{\frac{1}{N(N-1)}\cdot\sum_{j=1}^{N}(Y_j - KCRV)^2}\ .$$

N is the number of participants from Table 6 excluding marked outliers.

The results of this procedure are given in Table 3 and Table 4 (see ch. 6.1) together with other mean values.

When the travelling standards had been repaired, only one participant (SPRING) and the pilot laboratory (PTB) measured the repaired standards PTB 1-3 -1 and PTB 2-6-1. Since PTB participated in both measuring loops before and after the repair, the measurement data of SPRING had a link to the first loop through the PTB measurement results. In this case PTB results were the reference values. With the first loop (11 participants), for each frequency, the two deviations (of the two standards) of the PTB results from the *KCRV* were averaged. With these mean deviations and the results coming from the second loop (SPRING and PTB), the *KCRV*s (named *KCRV-1*) of the repaired standards were calculated. These *KCRV-1* values were compared with the mean values of the two participants (SPRING and PTB) in Table 5 and shown in Fig. 3 and Fig. 4 (see 6.1). The standard deviations of *KCRV* and *KCRV-1* are assumed to be equal.

6.3 Normalised results of all participants (E_n- and DoE-values)

With the calculated *KCRV* (see ch. 6.2), an evaluation of all calibration factor measurement results is possible by determining the deviation of the individual measuring result Y_i from the *KCRV*. The *KCRV* is considered to be the best estimate of the result of the comparison. As a figure of merit for the individual measurement value Y_i, the **E_n-value for each participant** and each standard was calculated. According to the EAL-P7-Document, E_n was calculated by means of the following formula:

$$E_n = \frac{Y_i - KCRV}{\sqrt{U^2(Y_i) + U^2(KCRV)}}$$

where $U(Y_i)$ is the expanded uncertainty (k = 2) of the participants' measurement result and $U(KCRV)$ denotes the expanded standard deviation (k = 2) of *KCRV* [2] multiplied by the coverage factor k = 2 for a level of confidence of 95%. For the evaluation of the SPRING measurement results the *KCRV-1* value (see ch. 6.2) is used as the most probable reference mean value. Thereby the results of SPRING can be compared directly with the results of the other 11 participants.

According to the CCEM guidelines, another figure of merit was also determined: the **degree of equivalence (DoE) of each national standard with respect to the *KCRV*** (or *KCRV-1*). It is the deviation between the measurement value of the participant (Y_i) and the *KCRV* (or *KCRV-1*) defined by [3]:

$$D_i = Y_i - KCRV\,.$$

In tables 7.1 –7.7 the calibration factor K of all laboratories together with the associated uncertainties of measurement ($u(K)$ and $U(K)$) and the calculated *KCRV* (or *KCRV*-1) (see ch. 6.2) are given for each of the seven frequencies and for each travelling standard. As a figure of merit of the individual results, the D_i - and E_n –values, are listed in the last two columns. For VNIIFTRI however E_n –values were not cited, because the supposition that a change of the calibration factors of both travelling standards had already happened **before** the start of measurements at VNIIFTRI could not be rebutted.

The deviations D_i from the *KCRV* (or *KCRV*-1) are shown as graphs in seven figures 7.1 to 7.7. To compare the individual deviation with the stated uncertainty for each result, the expanded uncertainty (k = 2) $U(K(f))$ bars are also shown in the graph.

Table 7.1 Results for 50 MHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards
For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 50 MHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-3 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f**. *KCRV*** *D*i	*E*n
NMIJ	**0,9828**	0,0014	0,0028	-0,0038	-1,1	**0,9845**	0,0014	0,0028	-0,0050	-1,1
NRC	**0,9837**	0,0040	0,0080	-0,0029	-0,4					
NIST	**0,9887**	0,0086	0,0172	0,0021	0,1	**0,9910**	0,0086	0,0172	0,0015	0,1
METAS	**0,9810**	0,0060	0,0120	-0,0056	-0,5	**0,9850**	0,0060	0,0120	-0,0045	-0,4
CSIR-NML	**0,9920**	0,0070	0,0140	0,0054	0,4	**0,9930**	0,0070	0,0140	0,0035	0,2
PTB	**0,9877**	0,0020	0,0040	0,0011	0,2	**0,9889**	0,0020	0,0040	-0,0006	-0,1
NMIA	**0,9880**	0,0020	0,0040	0,0014	0,3	**0,9900**	0,0020	0,0040	0,0005	0,1
NPL	**0,9857**	0,0015	0,0030	-0,0009	-0,2	**0,9872**	0,0017	0,0034	-0,0023	-0,5
SiQ	**0,9890**	0,0030	0,0060	0,0024	0,4	**0,9910**	0,0030	0,0060	0,0015	0,2
IEN	**0,9895**	0,0052	0,0104	0,0029	0,3	**0,9951**	0,0058	0,0116	0,0056	0,5
VNIIFTRI										
KCRV	**0,9866**	0,0010	0,0020			**0,9895**	0,0019	0,0038		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,9897**	0,0020	0,0040	0,0002	0,0	**0,9883**	0,0020	0,0040	0,0002	0,0
Spring	**0,9936**	0,0067	0,0134	0,0041	0,3	**0,9892**	0,0067	0,0134	0,0011	0,1
***KCRV*-1**	**0,9895**	0,0023	0,0020			**0,9881**	0,0028	0,0038		

Table 7.2 Results for 1 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 1 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-3 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9720**	0,0017	0,0034	-0,0040	-1,0	**0,9764**	0,0017	0,0034	-0,0040	-0,9
NRC	**0,9763**	0,0040	0,0080	0,0003	0,0					
NIST	**0,9741**	0,0087	0,0174	-0,0019	-0,1	**0,9784**	0,0087	0,0174	-0,0020	-0,1
METAS	**0,9720**	0,0070	0,0140	-0,0040	-0,3	**0,9770**	0,0070	0,0140	-0,0034	-0,2
CSIR-NML	**0,9780**	0,0080	0,0160	0,0020	0,1	**0,9820**	0,0080	0,0160	0,0016	0,1
PTB	**0,9741**	0,0025	0,0050	-0,0019	-0,3	**0,9784**	0,0025	0,0050	-0,0020	-0,3
NMIA	**0,9760**	0,0025	0,0050	0,0000	0,0	**0,9810**	0,0025	0,0050	0,0006	0,1
NPL	**0,9740**	0,0030	0,0060	-0,0020	-0,3	**0,9780**	0,0032	0,0064	-0,0024	-0,3
SiQ	**0,9750**	0,0030	0,0060	-0,0010	-0,2	**0,9790**	0,0030	0,0060	-0,0014	-0,2
IEN	**0,9817**	0,0063	0,0126	0,0057	0,4	**0,9857**	0,0058	0,0116	0,0053	0,4
VNIIFTRI	**0,9800**	0,0030	0,0060	0,0040		**0,9850**	0,0060	0,0120	0,0046	
KCRV	**0,9760**	0,0012	0,0024			**0,9804**	0,0015	0,0030		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,9821**	0,0025	0,0050	-0,0020	-0,4	**0,9780**	0,0025	0,0050	-0,0020	-0,3
Spring	**0,9821**	0,0067	0,0134	-0,0020	-0,1	**0,9775**	0,0067	0,0134	-0,0025	-0,2
***KCRV*-1**	**0,9841**	0,0027	0,0024			**0,9800**	0,0032	0,0030		

Table 7.3 Results for 10 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards
For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 10 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-3 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9438**	0,0020	0,0040	0,0022	0,5	**0,9402**	0,0019	0,0038	0,0022	0,5
NRC	**0,9404**	0,0040	0,0080	-0,0012	-0,1					
NIST	**0,9417**	0,0088	0,0176	0,0001	0,0	**0,9406**	0,0088	0,0176	0,0026	0,1
METAS	**0,9410**	0,0100	0,0200	-0,0006	0,0	**0,9390**	0,0100	0,0200	0,0010	0,0
CSIR-NML	**0,9460**	0,0110	0,0220	0,0044	0,2	**0,9430**	0,0110	0,0220	0,0050	0,2
PTB	**0,9428**	0,0040	0,0080	0,0012	0,1	**0,9376**	0,0040	0,0080	-0,0004	0,0
NMIA	**0,9420**	0,0047	0,0094	0,0004	0,0	**0,9400**	0,0047	0,0094	0,0020	0,2
NPL	**0,9390**	0,0044	0,0088	-0,0026	-0,3	**0,9360**	0,0045	0,0090	-0,0020	-0,2
SiQ	**0,9380**	0,0070	0,0140	-0,0036	-0,3	**0,9310**	0,0070	0,0140	-0,0070	-0,5
IEN	**0,9344**	0,0135	0,0270	-0,0072	-0,3	**0,9335**	0,0153	0,0306	-0,0045	-0,1
VNIIFTRI	**0,9610**	0,0060	0,0120	0,0194		**0,9590**	0,0100	0,0200	0,0210	
KCRV	**0,9416**	0,0007	0,0014			**0,9380**	0,0012	0,0024		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,9362**	0,0040	0,0080	0,0004	0,0	0,9402	0,0040	0,0080	0,0004	0,0
Spring	**0,9384**	0,0074	0,0148	0,0026	0,2	0,9404	0,0071	0,0142	0,0006	0,0
***KCRV*-1**	**0,9358**	0,0014	0,0014			**0,9398**	0,0025	0,0024		

Table 7.4 Results for 18 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 18 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-3 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9352**	0,0058	0,0116	0,0035	0,3	**0,9092**	0,0038	0,0076	0,0013	0,2
NRC	**0,9378**	0,0048	0,0096	0,0061	0,6					
NIST	**0,9290**	0,0088	0,0176	-0,0027	-0,2	**0,9074**	0,0088	0,0176	-0,0005	0,0
METAS	**0,9280**	0,0100	0,0200	-0,0037	-0,2	**0,9060**	0,0100	0,0200	-0,0019	-0,1
CSIR-NML	**0,9280**	0,0130	0,0260	-0,0037	-0,1	**0,9030**	0,0130	0,0260	-0,0049	-0,2
PTB	**0,9304**	0,0050	0,0100	-0,0013	-0,1	**0,9048**	0,0050	0,0100	-0,0031	-0,3
NMIA	**0,9330**	0,0063	0,0126	0,0013	0,1	**0,9110**	0,0063	0,0126	0,0031	0,2
NPL	**0,9290**	0,0055	0,0110	-0,0027	-0,2	**0,9070**	0,0055	0,0110	-0,0009	-0,1
SiQ	**0,9370**	0,0080	0,0160	0,0053	0,3	**0,9110**	0,0080	0,0160	0,0031	0,2
IEN	**0,9273**	0,0138	0,0276	-0,0044	-0,2	**0,9231**	0,0146	0,0292	0,0152	0,5
VNIIFTRI	**0,9110**	0,0070	0,0140	-0,0207		**0,8850**	0,0120	0,0240	-0,0229	
KCRV	**0,9317**	0,0014	0,0028			**0,9079**	0,0010	0,0020		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,8982**	0,0050	0,0100	-0,0022	-0,2	**0,9104**	0,0050	0,0100	-0,0022	-0,2
Spring	**0,8933**	0,0098	0,0196	-0,0071	-0,4	**0,9071**	0,0100	0,0200	-0,0055	-0,3
***KCRV*-1**	**0,9004**	0,0034	0,0028			**0,9126**	0,0020	0,0020		

Table 7.5 Results for 20 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 20 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-3 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9328**	0,0039	0,0078	0,0052	0,6	**0,8973**	0,0047	0,0094	0,0013	0,1
NRC	**0,9301**	0,0048	0,0096	0,0025	0,2					
NIST	**0,9259**	0,0090	0,0180	-0,0017	-0,1	**0,8952**	0,0090	0,0180	-0,0008	0,0
METAS	**0,9290**	0,0110	0,0220	0,0014	0,1	**0,9000**	0,0110	0,0220	0,0040	0,2
CSIR-NML	**0,9320**	0,0150	0,0300	0,0044	0,1	**0,9010**	0,0150	0,0300	0,0050	0,2
PTB	**0,9263**	0,0055	0,0110	-0,0013	-0,1	**0,8904**	0,0055	0,0110	-0,0056	-0,5
NMIA	**0,9320**	0,0093	0,0186	0,0044	0,2	**0,9000**	0,0093	0,0186	0,0040	0,2
NPL	**0,9310**	0,0055	0,0110	0,0034	0,3	**0,8970**	0,0056	0,0112	0,0010	0,1
SiQ	**0,9300**	0,0080	0,0160	0,0024	0,1	**0,9020**	0,0080	0,0160	0,0060	0,4
IEN	**0,9192**	0,0131	0,0262	-0,0084	-0,3	**0,9000**	0,0145	0,0290	0,0040	0,1
VNIIFTRI	**0,9080**	0,0110	0,0220	-0,0196		**0,8710**	0,0220	0,0440	-0,0250	
KCRV	**0,9276**	0,0020	0,0040	0,0000		**0,8960**	0,0016	0,0032		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,8814**	0,0055	0,0110	-0,0035	-0,3	**0,9075**	0,0055	0,0110	-0,0035	-0,3
Spring	**0,8840**	0,0099	0,0198	-0,0009	0,0	**0,9044**	0,0103	0,0206	-0,0066	-0,3
***KCRV*-1**	**0,8849**	0,0041	0,0040			**0,9110**	0,0028	0,0032		

Table 7.6 Results for 23 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards
For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 23 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-4 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9262**	0,0044	0,0088	0,0010	0,1	**0,8784**	0,0044	0,0088	0,0008	0,1
NRC	**0,9284**	0,0048	0,0096	0,0032	0,3					
NIST	**0,9225**	0,0092	0,0184	-0,0027	-0,1	**0,8779**	0,0092	0,0184	0,0003	0,0
METAS	**0,9280**	0,0110	0,0220	0,0028	0,1	**0,8820**	0,0100	0,0200	0,0044	0,2
CSIR-NML	**0,9310**	0,0160	0,0320	0,0058	0,2	**0,8820**	0,0160	0,0320	0,0044	0,1
PTB	**0,9251**	0,0065	0,0130	-0,0001	0,0	**0,8769**	0,0065	0,0130	-0,0007	-0,1
NMIA	**0,9270**	0,0092	0,0184	0,0018	0,1	**0,8810**	0,0092	0,0184	0,0034	0,2
NPL	**0,9310**	0,0066	0,0132	0,0058	0,4	**0,8840**	0,0067	0,0134	0,0064	0,5
SiQ	**0,9260**	0,0080	0,0160	0,0008	0,0	**0,8800**	0,0080	0,0160	0,0024	0,1
IEN	**0,9115**	0,0190	0,0380	-0,0137	-0,4	**0,9013**	0,0207	0,0414	0,0237	0,6
VNIIFTRI	**0,9180**	0,0120	0,0240	-0,0072		**0,8710**	0,0290	0,0580	-0,0066	
KCRV	**0,9252**	0,0019	0,0038			**0,8776**	0,0021	0,0042		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,8578**	0,0065	0,0130	-0,0004	0,0	**0,8857**	0,0065	0,0130	-0,0004	0,0
Spring	**0,8590**	0,0130	0,0260	0,0008	0,0	**0,8866**	0,0134	0,0268	0,0005	0,0
***KCRV*-1**	**0,8582**	0,0037	0,0038			**0,8861**	0,0033	0,0042		0,0

Table 7.7 Results for 26 GHz: Deviation D_i of the calibration factor *K*(*f*) from the *KCRV* for both travelling standards For the repaired standards : PTB 1-3-1 and PTB 2-6-1 deviation from *KCRV-1*

Frequency	***f* = 26 GHz**									
Participant	PTB 1-3 *K*(*f*)	PTB 1-3 *u*(*K*(*f*))	PTB 1-4 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n	PTB 2-6 *K*(*f*)	PTB 2-6 *u*(*K*(*f*))	PTB 2-6 *U*(*K*(*f*))	Dev. f. *KCRV* *D*i	*E*n
NMIJ	**0,9020**	0,0069	0,0138	-0,0208	-1,4	**0,8686**	0,0075	0,0150	-0,0171	-0,9
NRC	**0,9258**	0,0048	0,0096	0,0030	0,3					
NIST	**0,9145**	0,0094	0,0188	-0,0083	-0,4	**0,8778**	0,0095	0,0190	-0,0079	-0,4
METAS	**0,9090**	0,0120	0,0240	-0,0138	-0,6	**0,8700**	0,0120	0,0240	-0,0157	-0,6
CSIR-NML	**0,9250**	0,0190	0,0380	0,0022	0,1	**0,8810**	0,0190	0,0380	-0,0047	-0,1
PTB	**0,9227**	0,0085	0,0170	-0,0001	0,0	**0,8805**	0,0085	0,0170	-0,0052	-0,3
NMIA	**0,9200**	0,0091	0,0182	-0,0028	-0,1	**0,8830**	0,0093	0,0186	-0,0027	-0,1
NPL	**0,9270**	0,0077	0,0154	0,0042	0,3	**0,8890**	0,0077	0,0154	0,0033	0,2
SiQ	**0,9190**	0,0080	0,0160	-0,0038	-0,2	**0,8790**	0,0080	0,0160	-0,0067	-0,4
IEN	**0,9003**	0,0187	0,0374	-0,0225	-0,6	**0,9032**	0,0206	0,0412	0,0175	0,4
VNIIFTRI	**0,9240**	0,0140	0,0280	0,0012		**0,8950**	0,0150	0,0300	0,0093	
KCRV	**0,9228**	0,0022	0,0044			**0,8857**	0,0051	0,0102		
	PTB 1-3-1	PTB 1-3-1	PTB 1-3-1			PTB 2-6-1	PTB 2-6-1	PTB 2-6-1		
PTB*	**0,8580**	0,0085	0,0170	-0,0027	-0,2	**0,8905**	0,0085	0,0170	-0,0027	-0,1
Spring	**0,8583**	0,0084	0,0168	-0,0024	-0,1	**0,8945**	0,0088	0,0176	0,0013	0,1
***KCRV*-1**	**0,8607**	0,0037	0,0044			**0,8932**	0,0110	0,0102		

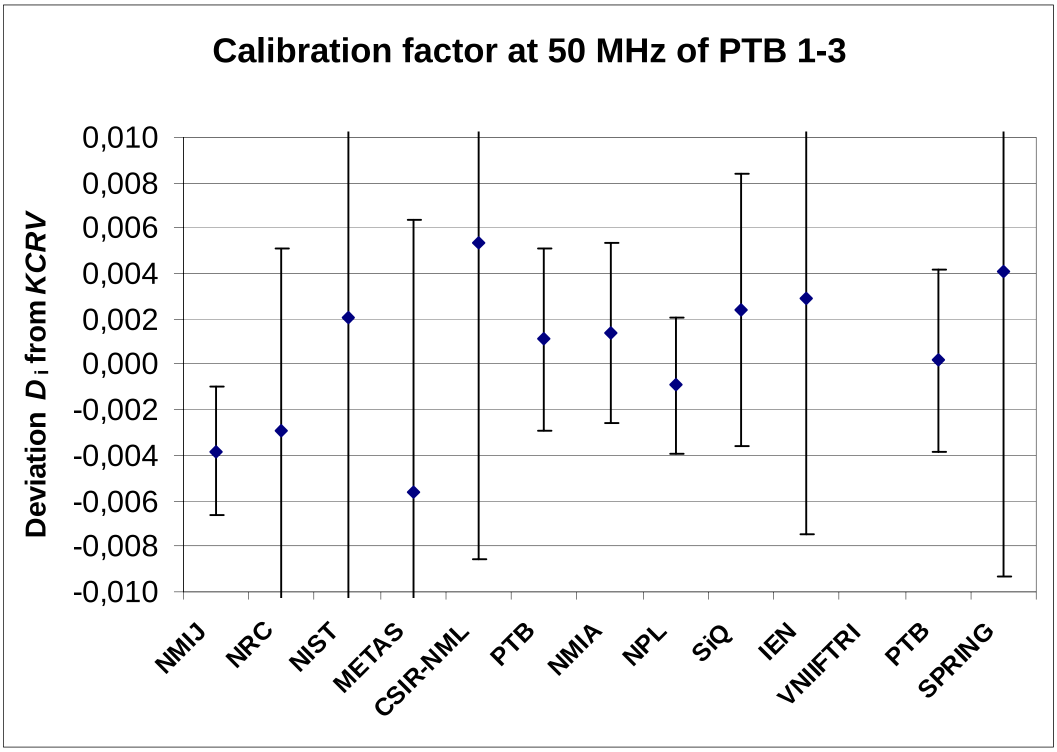

Fig. 7.1.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 50 MHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1)

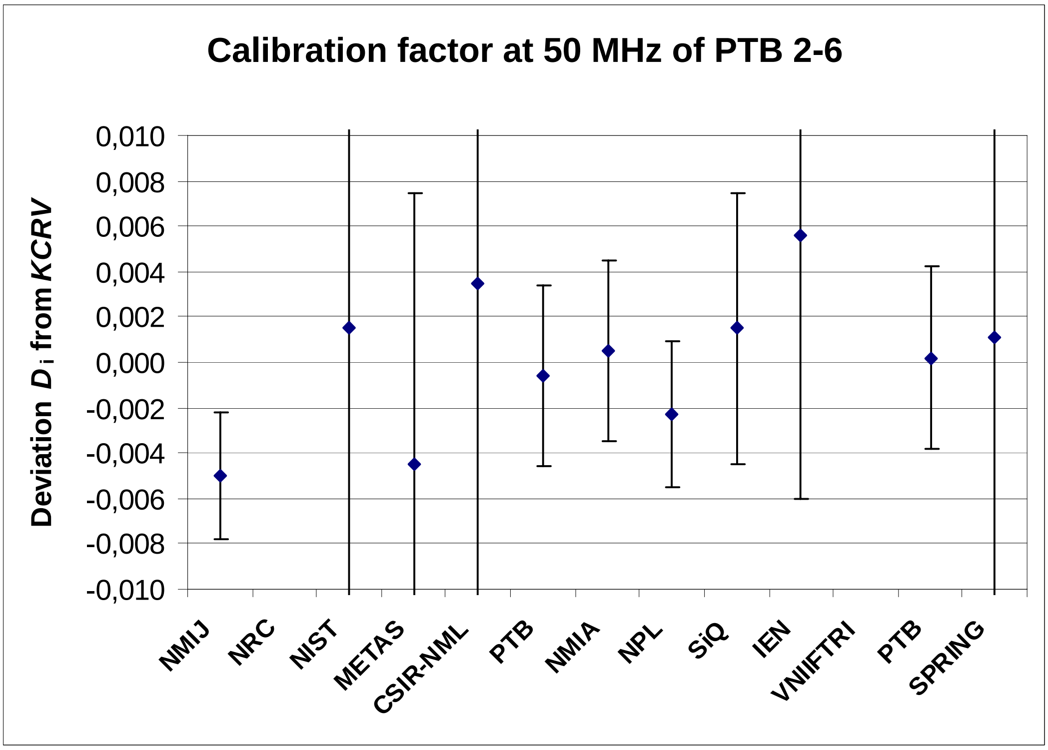

Fig. 7.1.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 50 MHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

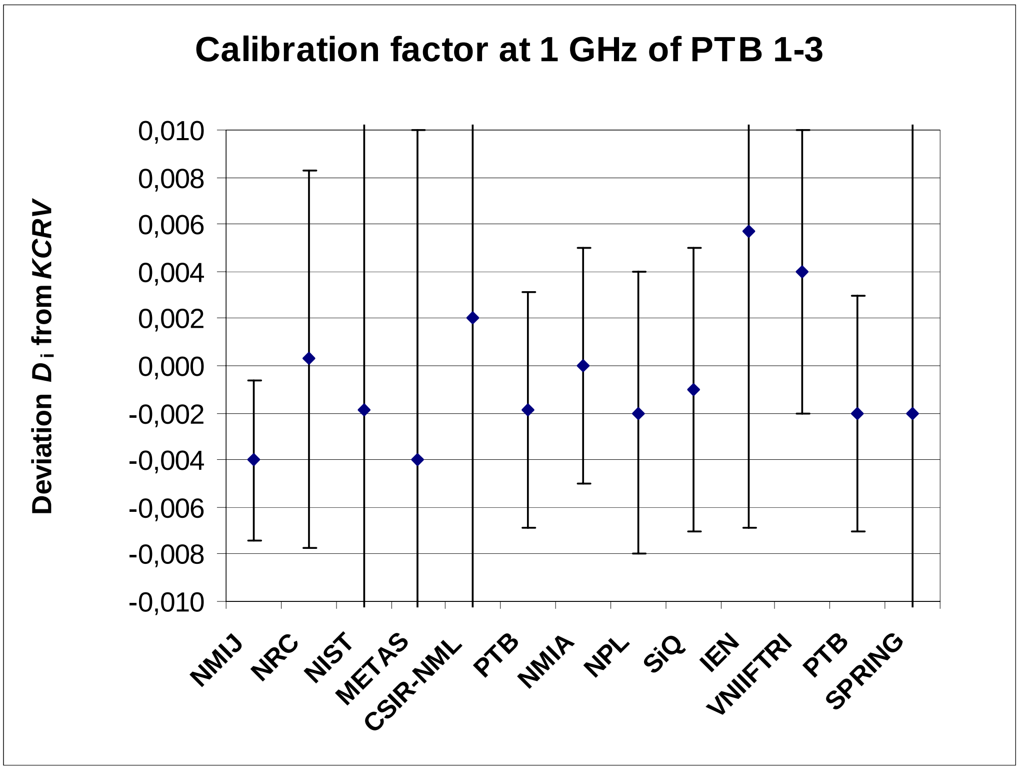

Fig. 7.2.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 1 GHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1

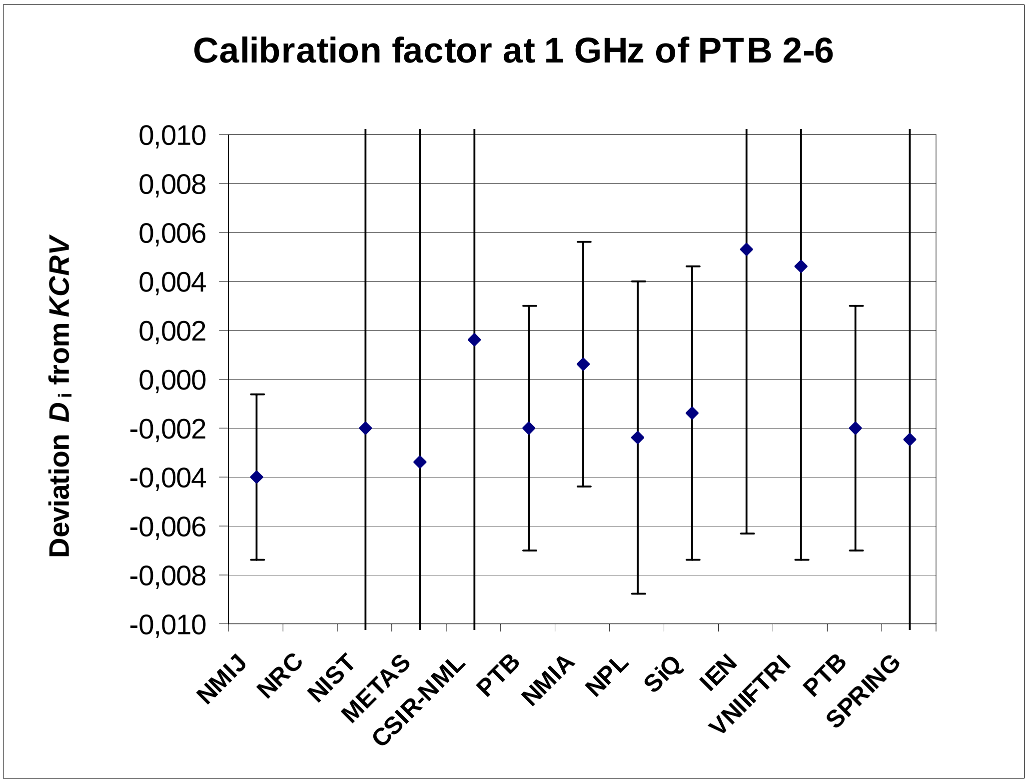

Fig. 7.2.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 1 GHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

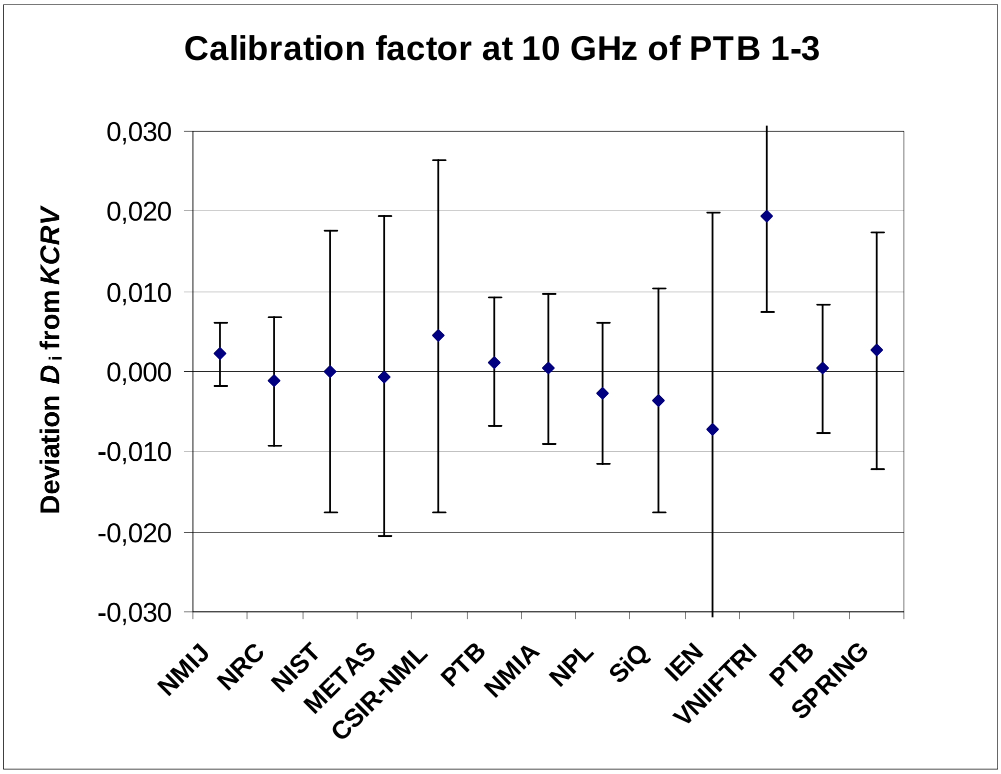

Fig. 7.3.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 10 GHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1)

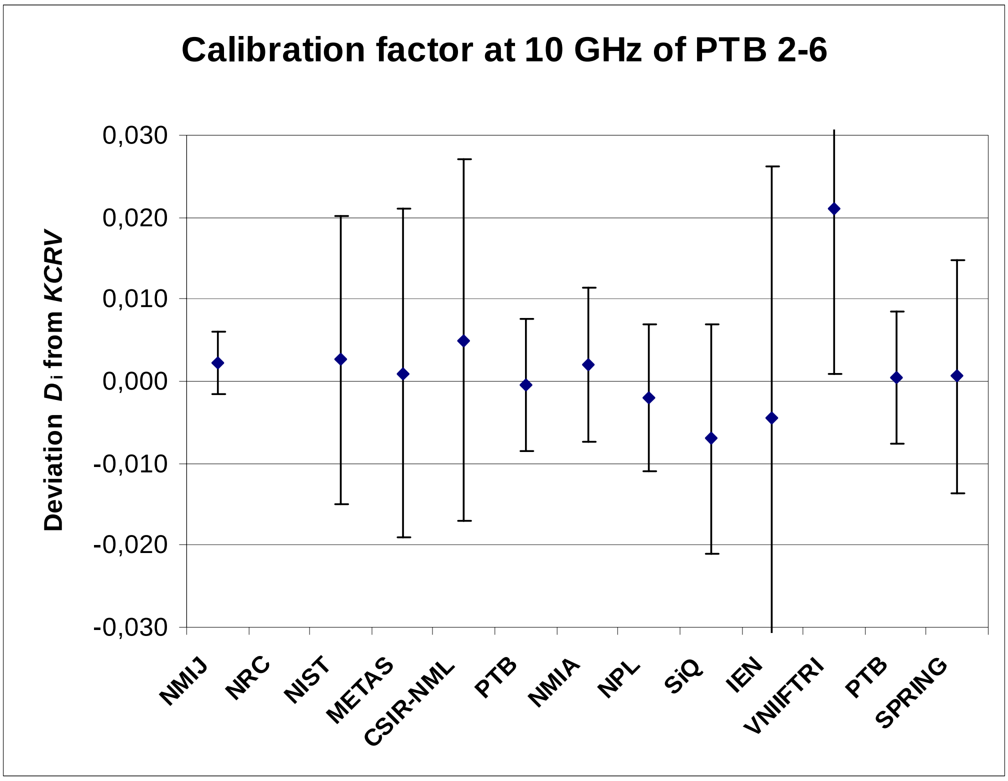

Fig. 7.3.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 10 GHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

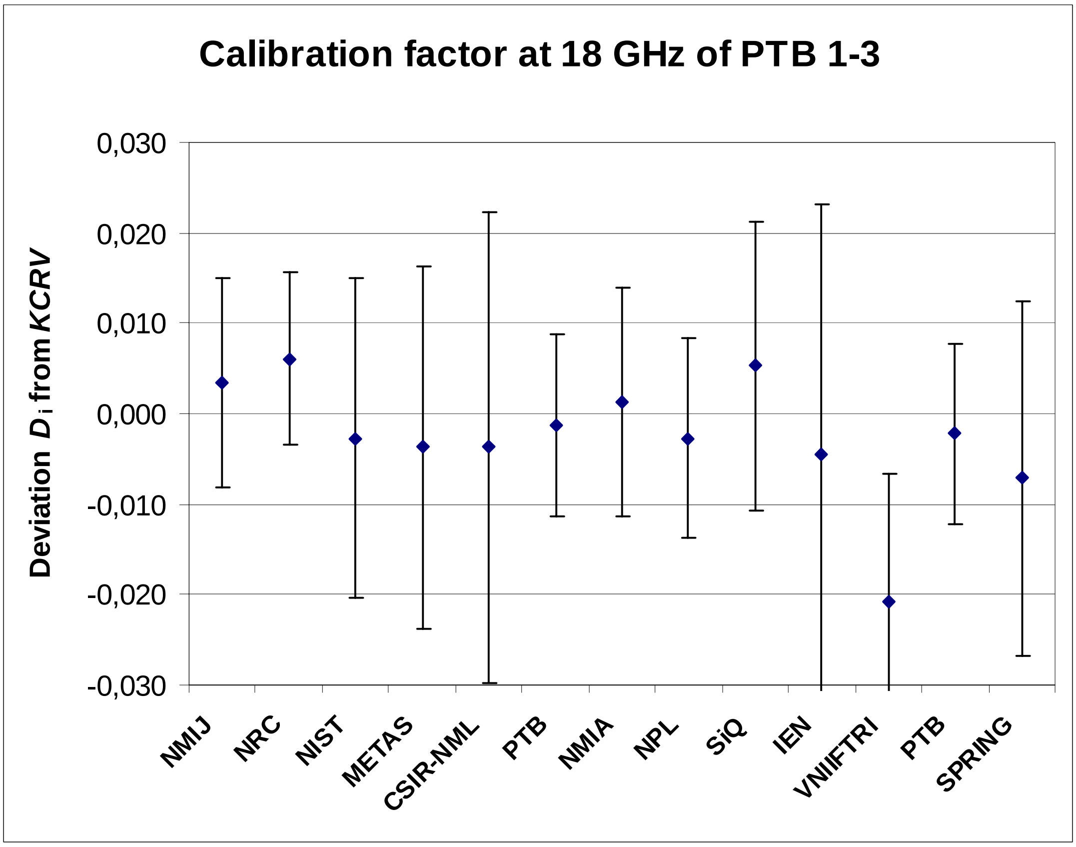

Fig. 7.4 a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 18 GHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1)

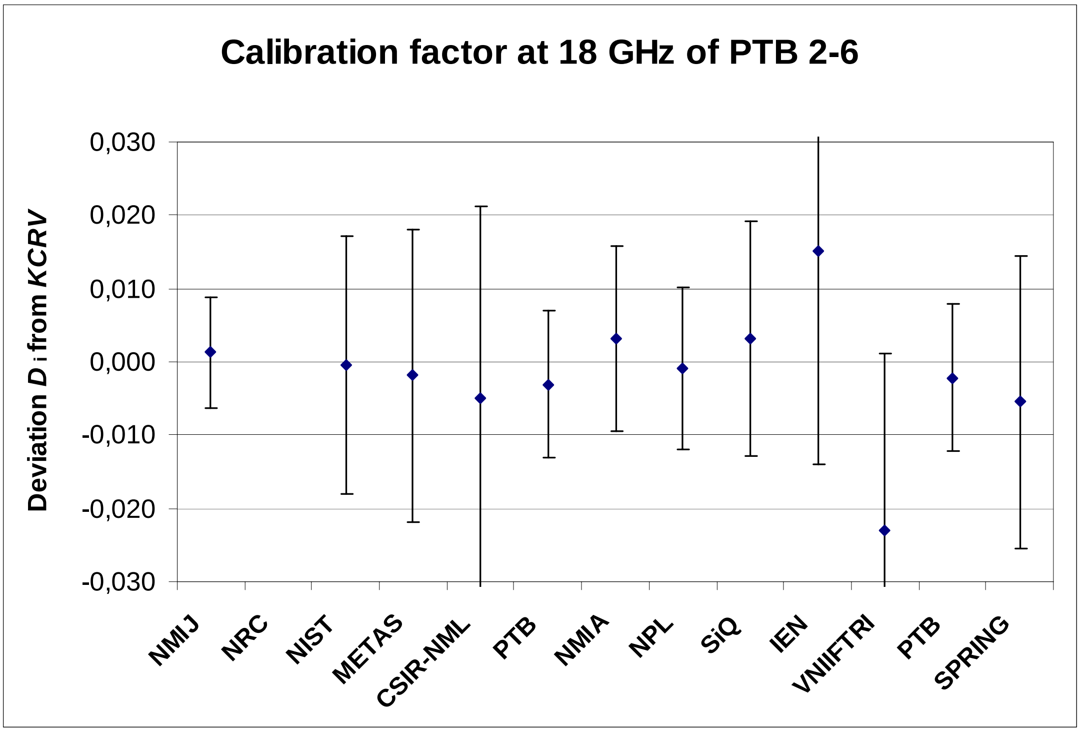

Fig. 7.4 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 18 GHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

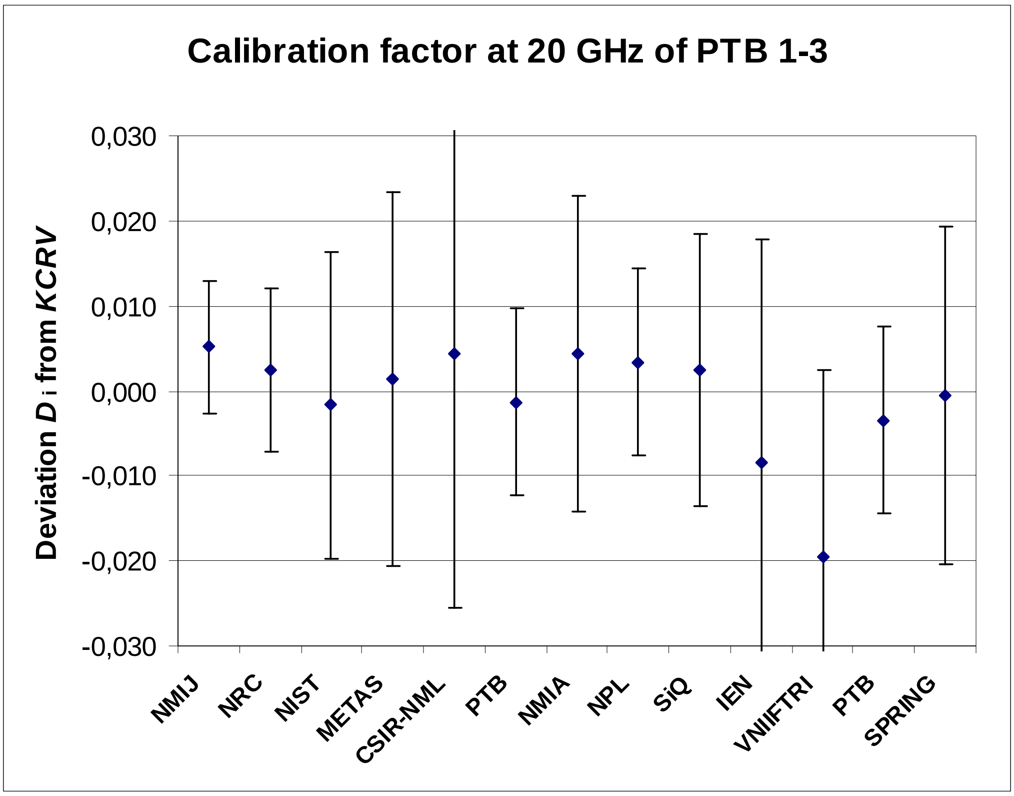

Fig. 7.5 a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 20 GHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1)

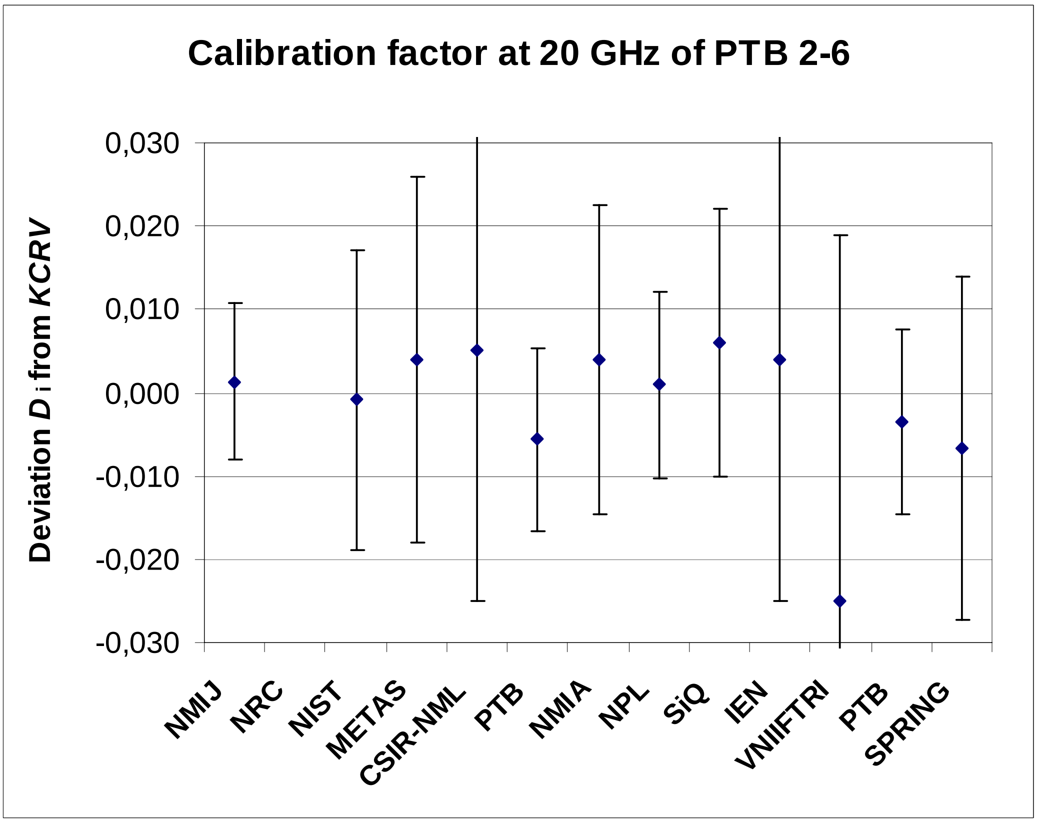

Fig. 7.5 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 20 GHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

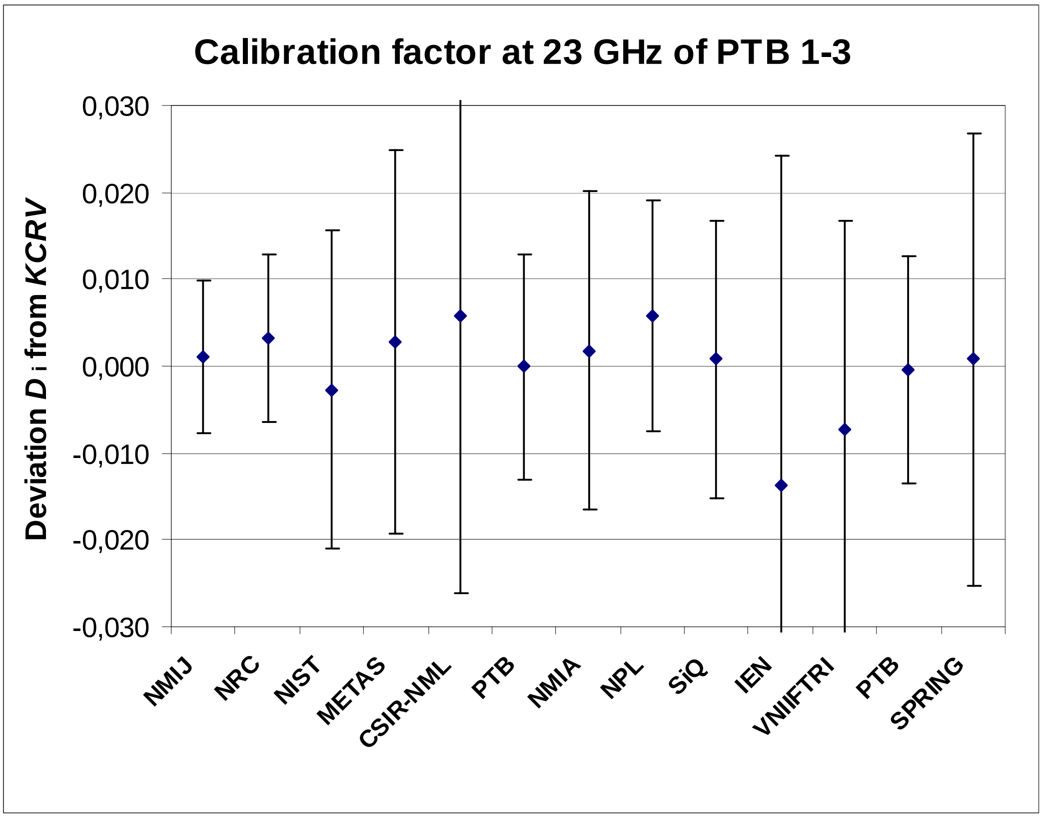

Fig. 7.6 a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 23 GHz with expanded uncertainty (*k*=2) for PTB 1-3 (PTB 1-3-1)

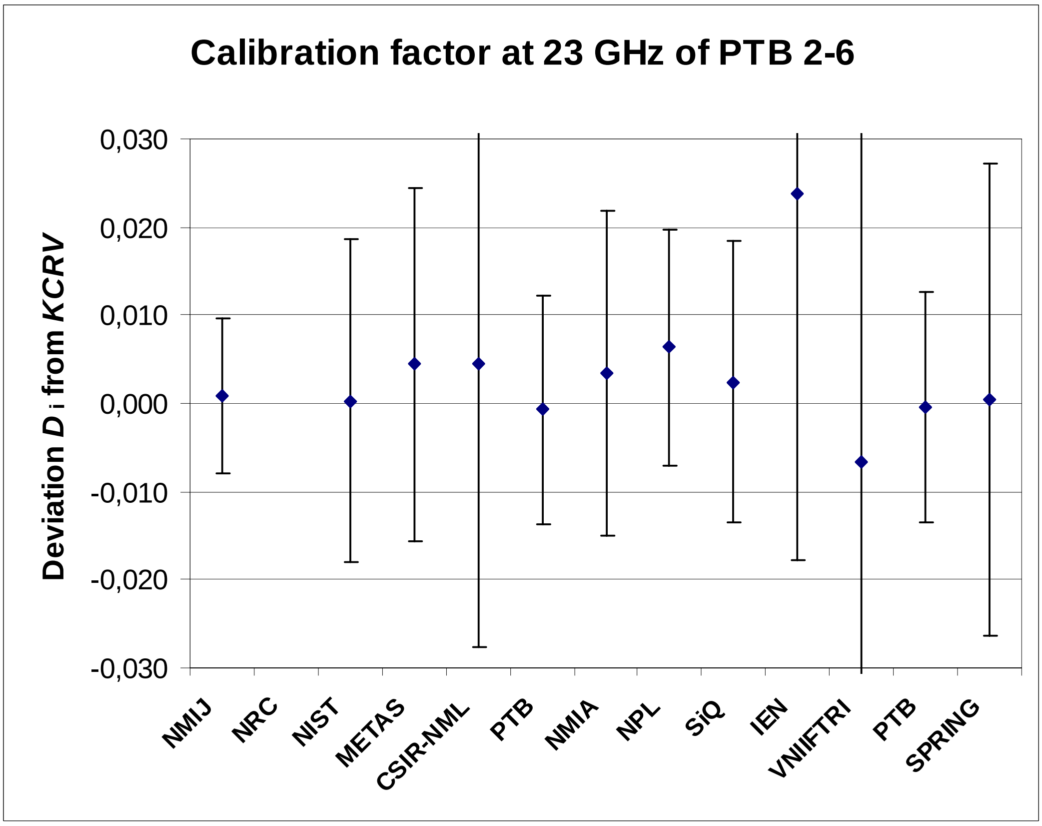

Fig. 7.6 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 23 GHz with expanded uncertainty (*k*=2) for PTB 2-6 (PTB 2-6-1)

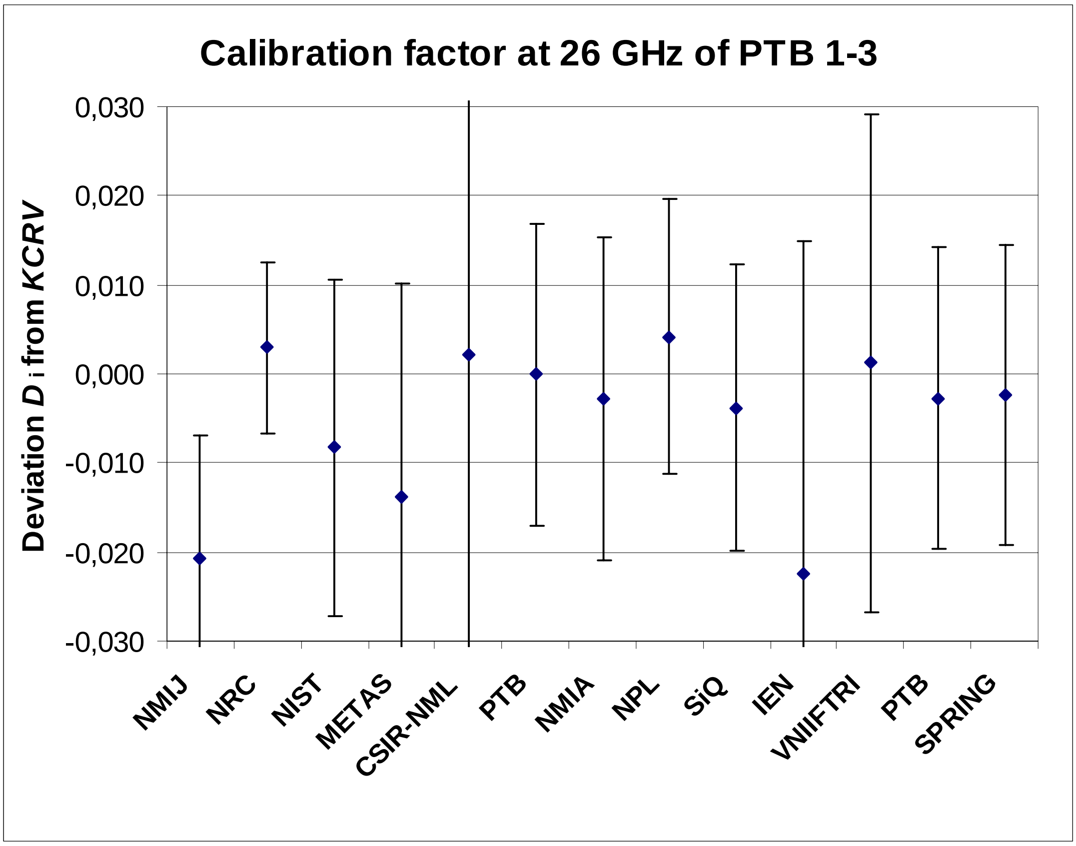

Fig. 7.7 a Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 26 GHz with expanded uncertainty bars (*k*=2) for PTB 1-3 (PTB 1-3-1)

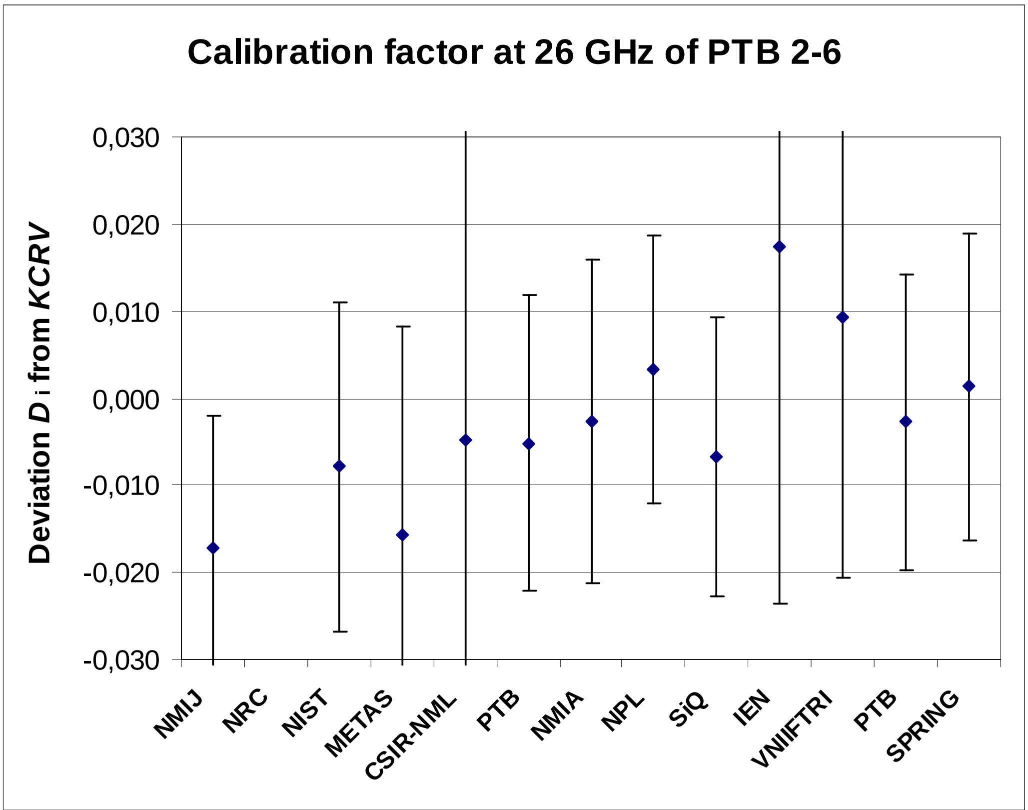

Fig. 7.7 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRV* at 26 GHz with expanded uncertainty bars (*k*=2) for PTB 2-6 (PTB 2-6-1)

6.3.1 Degree of equivalence between each pair of participating laboratories

For CCEM key comparisons it is also mandatory to calculate the degree of equivalence between each pair of participating laboratories. This degree of equivalence D_{ij} between the two laboratories *i* and *j* is defined by [3]:

$$D_{ij} = Y_i - Y_j$$

with its expanded uncertainty (k = 2)

$$U_{ij} = \sqrt{(2 \cdot u_i)^2 + (2 \cdot u_j)^2}\,.$$

As Y_i and Y_j are the measurement results K_i and K_j of the laboratories *i* and *j*, D_{ij} can be calculated by:

$$D_{ij} = K_i - K_j\,.$$

With the deviations $D_i = Y_i - KCRV$ and $D_j = Y_j - KCRV$ (see ch.6.3) together with K in tables 7.1 to 7.7, D_{ij} can be calculated also by:

$$D_{ij} = D_i - D_j\,.$$

The results of these degrees of equivalence, D_{ij} for each pair of laboratories together with their associated expanded uncertainties U_{ij} are listed in 7 tables in Annex F for standard PTB 1-3 and in another 7 tables in Annex G for standard PTB 2-6 respectively. For an acceptable measurement result, the condition $|D_{ij}| < U_{ij}$ should be fulfilled. For $|D_{ij}| \geq U_{ij}$ the pair of data is marked by italic numbers in the tables of Annex F and Annex G.

6.3.2 Discussion of results

For an acceptable measurement result in a comparison with a known reference value, the conditions $|E_n| < 1$, and for the degree of equivalence, $|D_{ij}| < U_{ij}$ should be fulfilled. The condition for $|E_n|$ was slightly exceeded by one participant at three frequencies for one standard and for one frequency of the other standard, but in all cases the value of E_n was $|E_n| \leq 1{,}4$. It seems that only the uncertainty estimation is too optimistic. All the other participants, however, fulfil the condition at all frequencies and for both standards. In most cases the mentioned condition was satisfied very well, i.e. $|E_n|$ is much smaller than 1. Also from the diagrams, it becomes obvious that for some participants the deviations from the *KCRV* is much smaller than the stated expanded uncertainties. For one participant, no E_n-value was cited, because the assumption that a change of calibration factor of both standards had happened before the start of the measurements could not be rebutted.

The values for the degree of equivalence were calculated for all participants. The condition for a good degree of equivalence ($|D_{ij}| < U_{ij}$) was not fulfilled for 22 pairs of values of participants, but the ratios $|D_{ij}|/U_{ij}$ stayed well below 1,5. In 18 of these 22 cases one laboratory is involved for which a change of the calibration factors of both standards before the measurements cannot be excluded. In relation to the high number of the pairs of values (826), because of 12 participants, 2 standards and 7 frequencies, the few exceeding indicate a good agreement between the participants of this comparison.

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6.4 Reflection coefficient results

The magnitude of the reflection coefficient was not the main quantity to be measured, so no *KCRV* should be calculated. The reflection coefficient is however required to determine the mismatch losses when making power measurements. It is also needed to calculate the calibration factor from the effective efficiency measured in a microcalorimeter. Therefore the measurements of the reflection coefficient were included in this comparison. Another reason for including the reflection coefficient measurements in this comparison was the possibility of detecting a hidden failure of the standards by monitoring their reflection during the comparison.

In the Annex E we present tables where the measured reflection coefficients together with the associated uncertainties and the individual deviations from the arithmetic mean value of all results are listed. For only one participant the deviation from the mean value is larger than the stated expanded uncertainty (k = 2), which holds for one standard at two frequencies. For all the other participants the deviations are smaller than the expanded uncertainties, in most cases they are very small.

7. Withdrawals

By providing his results, one participant mentioned significant differences between the measured calibration factors of the two travelling standards, i.e. the calibration factors of PTB 2-6 were much smaller than those of PTB 1-3. He was not able to find the reason for this deviation in his measuring set-up. Later it turned out from the results of the remaining participants that the calibration factors of the two standards were similar. When this information was given to the participant he withdrew his measuring results of the second standard.

8. Follow-up comparison

The EUROMET 525 comparison started on April 2nd 2002 with the same subject as the CCEM.RF-K10.CL, again with PTB serving as the pilot laboratory. Besides the three participants which were not able to participate in the CCEM key comparison, five other participants joined the EUROMET 525 comparison including NPL (UK) which was invited by the pilot laboratory. As PTB and NPL took part in both comparisons, their measurement results allow to realise a link between the EUROMET 525 results and the KCRV value of the CCEM.RF-K10.CL key comparison. In total, the EUROMET 525 comparison included nine participants.

9. Conclusion

The key comparison CCEM.RF-K10.CL was completed with very satisfying final results**:** for 10 of the 12 participants the deviation from the *KCRV* was well within their claimed expanded uncertainty (k = 2). Only for one of the participants the $|E_n|$ values were greater that 1 for 4 measurement values. For one participant $|E_n|$ values were not calculated. The limit given by the degree of equivalence ($|D_{ij}| < U_{ij}$) was exceeded by a few pairs of laboratories only. The values for the degree of equivalence were calculated for all participants. In relation to the high number of measurement results (12 participants and 7 frequencies) the few exceeding indicate a good agreement between all participants

The expanded uncertainties of the measured calibration factors increased with frequency, ranging from about 0,003 at 50 MHz to about 0,04 at 26 GHz. It can be concluded that nearly all uncertainty contributions and the final resulting total uncertainty were well estimated. As many $|E_n|$ values are much smaller than one and in most cases $|D_{ij}| << U_{ij}$, many estimations seem to be conservative. The resulting *KCRV* confirms great confidence since 8 independent primary power standards of many very different designs were used (e.g. coaxial symmetric and twin type microcalorimeters for the PC 3,5 mm, PC 2,9 mm, and PC 2,4 mm coaxial systems, waveguide microcalorimeters, and also dry calorimeters). A good agreement between results obtained with the various primary power standards for the PC 3,5 mm coaxial line system of nearly all participating NMIs was stated.

10. References.

[1] D. Janik, J.T.Ascroft, and R.F. Clark, ”Measurement techniques and results of an intercomparison for RF power in a 3,5 mm coaxial line up to 26 GHz,” IEEE Trans. Instrum. Meas. vol. IM-48, pp 166-168 April 1999

[2] J. Randa, ”Proposal for KCRV & Degree of Equivalence for GTRF Key Comparisons, ”Document of the CCEM Working Group on Radiofrequency Quantities, GT-RF/2000-12, September 2000

[3] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Attached, Supplementary and Pilot Comparisons. March 29. 2004

ANNEX A

Proposed time schedule
International Key Comparison CCEM.RF K 10 CL
(June 30, 2000) (Start)

Institution	Country	Start date	Time for measurement and transportation
NMIJ	Japan	July 1, 2000	6 weeks
NRC	Canada	August 14, 2000	6 weeks
NIST	U.S.A	September 25, 2000	6 weeks
CSIR-NML	South Africa	November 6, 2000	6 weeks
NMIA	Australia	December 18, 2000	7 weeks
METAS	Switzerland	February 5, 2001	6 weeks
SiQ	Slovenia	March 19, 2001	6 weeks
PTB (Remeas.)	Germany	April 30, 2001	4 weeks
NPL	UK	May 28, 2001	5 weeks
NMI-VSL	Netherlands	July 2, 2001	5 weeks
BNM-LCIE	France	August 6, 2001	5 weeks
IEN	Italy	September 10, 2001	5 weeks
EIM	Greece	October 15, 2001	5 weeks
PTB (no meas.)	Germany	November 19, 2001	2 weeks
VNIIFTRI	Russia Fed.	December 3, 2001	7 weeks
SPRING	Singapore	January 21, 2002	6 weeks
PTB (Final meas.)	Germany	March 4, 2002	3 weeks
End of meas.	Germany	March 22, 2002	

ANNEX B

Actual time schedule
International Key Comparison CCEM.RF-K10.CL
(Feb. 4, 2002)

Institution	Country	Start date	Time for measurement and transportation
NMIJ	Japan	July 1, 2000	6 weeks
NRC	Canada	August 14, 2000	6 weeks
NIST	U.S.A	September 25, 2000	6 weeks
METAS	Switzerland	November 6, 2000	6 weeks
CSIR-NML	South Africa	December 18, 2000	7 weeks
PTB (1.Remeas.)	Germany	February 5, 2001	4 weeks
NMIA	Australia	March 5, 2001	6 weeks
NPL	UK	April 16, 2001	5 weeks
SiQ	Slovenia	May 21, 2001	5 weeks
IEN	Italy	June 25, 2001	5 weeks
PTB (check)	Germany	July 30, 2001	4 weeks
VNIIFTRI	Russia Fed.	August 27, 2001	8 weeks
PTB (Standards repaired and remeasured)	Germany	November 13, 2001	4 weeks
SPRING	Singapore	December 17, 2001	6 weeks
PTB (Standards back)	Germany	January 30, 2002	

ANNEX C: Addresses of the participants of CCEM.RF-K 10 CL

Name	*First name*	**Institute**	*Street/Pbox*	*Postcode*	*City*	*Land*	*Telefon, FAX*	*WWW/Email*
Mr. Chuicko,	V. G.	**VNIIFTRI** All-Russian Scientific and Research Institute for Physical-Technical and Radiotechnical Measurements	Mendeleevo	141570	Moscow Region	Russian Federation	+7 (0) 95 535 9253, + 7 (0)95 535 9245	lab201@vniiftri.org
Dr. Zhang	Tieren	**NMIA** National Measurement Institute,	PO Box 218 Bradfield Rd.	NSW 2071	Lindfield	Australia	+61 2 8467 3560, +61 2 8467 3610	tieren.zhang@measurement.gov.au
Dr. Shan	Yueyan	**SPRING** National Metrolgy Centre	I Science Park Drive	118221	Singapore	Singapore	+65 6279 1929, +65 6279 1995	shan_yueyan@spring.gov.sg
Dr. Brunetti	Luciano	**IEN** Istituto Elettrotecnico Nazionale "Galileo Ferraris"	Strada delle Cacce 91	I-10135	Torino	Italy	+ 39 011 391 9230, + 39 011 391 9259	brunetti@ien.it
Mr. Orford	Geoff	**NPL** National Physical Laboratory	Queens Road	TW11 0LW	Middlesex, Teddington	United Kingdom	+ 44 (0) 20 8943 6555, + 44 (0) 20 8943 6037	geoff.orford@npl.co.uk
Dr. Inoue	Takeumi	**NMIJ** Metrology Institute Japan	1-1-4 Umezono	305-8568	Tsukuba-shi, Ibaraki	Japan	+ 81 298 61 5631, + 81 298 61 5640	t.inoue@aist.go.jp
Mr. Juroshek	John R.	**NIST** National Institute of Standards and Technology Metrology	Broadway 325	CO 80303	Boulder	United States	+ 1 303 497 5362, + 1 303 497 3970	juroshek@boulder.nist.gov
Dr. Janik	Dieter	**PTB** Physikalisch-Technische Bundesanstalt	Bundesallee 100	D-38116	Braunschweig	Germany	+ 49 531 592 2222, + 49 531 592 2228	dieter.janik@ptb.de
Dr. Michaud	Alain	**NRC-CNRC** National Research Council	Montreal Road	K1A 0R6	Ottawa, Ontario	Canada	+1 613 998 6925, +1 613 952 1394	alain.michaud@nrc.ca
Mr. Furrer	Jürg	**METAS** Metrology and Accreditation Switzerland	Lindenweg 50	CH - 3003	Bern-Wabern	Switzerland	+ 41 31 323 3494, + 41 31 323 3210	juerg.furrer@metas.ch
Mr. Dressler	Erik	**CSIR/NML** *National Metrology Laboratory*	P.O. Box 395	1	Pretoria	South Africa	+ 27 12 841 4342, + 27 12 841 2131	redressl@csir.co.za
Dr. Lapuh	Rado	**SiQ** Slovenian Institute of Quality and Metrology	Trzaska cesta 2	1000	Ljubljana	Slovenia	+386 1 477 8320, +386 1 477 8303	rado.lapuh@siq.si

ANNEX D

The pilot laboratory's (PTB) 1. , 2. and mean measurement values for the calibration factor *K*(*f*)

Standard	**PTB 1-3**		
Date	June 00	February 01	
Frequency	PTB 1.	PTB 2.	**PTB Mean**
in GHz	*K*(*f*)	*K*(*f*)	*K*(*f*)
0,05	0,9875	0,9879	**0,9877**
1	0,9740	0,9742	**0,9741**
10	0,9425	0,9431	**0,9428**
18	0,9297	0,9310	**0,9304**
20	0,9272	0,9253	**0,9263**
23	0,9243	0,9259	**0,9251**
26	0,9224	0,9230	**0,9227**

Standard	**PTB 2-6**		
Date	June 00	February 01	
Frequency	PTB 1.	PTB 2.	**PTB Mean**
in GHz	*K*(*f*)	*K*(*f*)	*K*(*f*)
0,05	0,9891	0,9887	**0,9889**
1	0,9785	0,9782	**0,9784**
10	0,9372	0,9379	**0,9376**
18	0,9047	0,9049	**0,9048**
20	0,8913	0,8894	**0,8904**
23	0,8759	0,8778	**0,8769**
26	0,8802	0,8808	**0,8805**

ANNEX E-1

Table A.1 Results for 50 MHz: Deviation of the magnitude of the reflection coefficient **Mag. (*Γ*)** from the arithmetic mean value

Frequency	***f* = 50 MHz**							
Participant	**PTB 1-3 Mag(*Γ*)**	**PTB 1-3 *u*(Mag(*Γ*))**	**PTB 1-3 *U*(Mag(*Γ*))**	**Dev. f. mean**	**PTB 2-6 Mag(*Γ*)**	**PTB 2-6 *u*(Mag(*Γ*))**	**PTB 2-6 *U*(Mag(*Γ*))**	**Dev. f. mean**
NMIJ	0,0050	0,0090	0,0180	0,0018	0,0030	0,0090	0,0180	-0,0001
NRC	0,0040	0,0050	0,0100	0,0008	0,0050	0,0050	0,0100	0,0019
NIST	0,0025	0,0040	0,0080	-0,0008	0,0028	0,0040	0,0080	-0,0003
METAS	0,0030	0,0040	0,0080	-0,0003	0,0020	0,0040	0,0080	-0,0011
CSIR-NML	0,0020	0,0030	0,0060	-0,0013	0,0040	0,0030	0,0060	0,0009
PTB	0,0027	0,0030	0,0060	-0,0006	0,0027	0,0030	0,0060	-0,0004
NMIA	0,0024	0,0015	0,0030	-0,0009	0,0029	0,0015	0,0030	-0,0002
NPL	0,0020	0,0100	0,0200	-0,0013	0,0020	0,0100	0,0200	-0,0011
SiQ	0,0060	0,0070	0,0140	0,0028	0,0040	0,0070	0,0140	0,0009
IEN	0,0029	0,0045	0,0090	-0,0004	0,0026	0,0045	0,0090	-0,0005
VNIIFTRI								
Mean	**0,0033**	**0,0013**	**0,0027**		**0,0031**	**0,0010**	**0,0019**	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0027	0,0060	0,0120	-0,0003	0,0032	0,0060	0,0120	-0,0005
SPRING	0,0033	0,0024	0,0048	0,0003	0,0041	0,0024	0,0048	0,0005
Mean-1	**0,0030**	**0,0004**	**0,0008**		**0,0037**	**0,0006**	**0,0013**	

ANNEX E-2

Table A.2 Results for 1 GHz: Deviation of the magnitude of the reflection coefficient **Mag. (Γ)** from the arithmetic mean value

Frequency	***f* = 1 GHz**							
Participant	**PTB 1-3** Mag(Γ)	**PTB 1-3** *u*(Mag(Γ))	**PTB 1-3** *U*(Mag(Γ))	**Dev. f. mean**	**PTB 2-6** Mag(Γ)	**PTB 2-6** *u*(Mag(Γ))	**PTB 2-6** *U*(Mag(Γ))	**Dev. f. mean**
NMIJ	0,0040	0,0090	0,0180	-0,0041	0,0030	0,0090	0,0180	-0,0059
NRC	0,0060	0,0050	0,0100	-0,0021	0,0060	0,0050	0,0100	-0,0029
NIST	0,0074	0,0035	0,0070	-0,0007	0,0087	0,0035	0,0070	-0,0002
METAS	0,0080	0,0040	0,0080	-0,0001	0,0080	0,0040	0,0080	-0,0009
CSIR-NML	0,0070	0,0030	0,0060	-0,0011	0,0090	0,0030	0,0060	0,0001
PTB	0,0066	0,0030	0,0060	-0,0015	0,0081	0,0030	0,0060	-0,0008
NMIA	0,0074	0,0017	0,0034	-0,0007	0,0087	0,0017	0,0034	-0,0002
NPL	0,0160	0,0100	0,0200	0,0079	0,0130	0,0100	0,0200	0,0041
SiQ	0,0090	0,0070	0,0140	0,0009	0,0100	0,0070	0,0140	0,0011
IEN	0,0072	0,0045	0,0090	-0,0009	0,0083	0,0045	0,0090	-0,0006
VNIIFTRI	0,0100	0,0060	0,0120	0,0019	0,0150	0,0060	0,0120	0,0061
Mean	**0,0081**	**0,0031**	**0,0061**		**0,0089**	**0,0032**	**0,0063**	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0080	0,0060	0,0120	0,0002	0,0092	0,0060	0,0120	-0,0002
SPRING	0,0077	0,0024	0,0048	-0,0001	0,0096	0,0024	0,0048	0,0002
Mean-1	**0,0079**	**0,0002**	**0,0004**		**0,0094**	**0,0003**	**0,0006**	

ANNEX E-3

Table A.3 Results for 10 GHz: Deviation of the magnitude of the reflection coefficient **Mag. (*Γ*)** from the arithmetic mean value

Frequency	***f* = 10 GHz**							
Participant	**PTB 1-3** Mag(*Γ*)	**PTB 1-3** *u*(Mag(*Γ*))	**PTB 1-3** *U*(Mag(*Γ*))	**Dev. f. mean**	**PTB 2-6** Mag(*Γ*)	**PTB 2-6** *u*(Mag(*Γ*))	**PTB 2-6** *U*(Mag(*Γ*))	**Dev. f. mean**
NMIJ	0,0260	0,0100	0,0200	0,0003	0,0150	0,0100	0,0200	-0,0020
NRC	0,0270	0,0050	0,0100	0,0013	0,0190	0,0050	0,0100	0,0020
NIST	0,0281	0,0038	0,0076	0,0024	0,0183	0,0038	0,0076	0,0013
METAS	0,0280	0,0060	0,0120	0,0023	0,0190	0,0060	0,0120	0,0020
CSIR-NML	0,0260	0,0030	0,0060	0,0003	0,0180	0,0030	0,0060	0,0010
PTB	0,0260	0,0030	0,0060	0,0003	0,0181	0,0030	0,0060	0,0011
NMIA	0,0269	0,0025	0,0050	0,0012	0,0185	0,0025	0,0050	0,0015
NPL	0,0260	0,0100	0,0200	0,0003	0,0180	0,0100	0,0200	0,0010
SiQ	0,0270	0,0070	0,0140	0,0013	0,0180	0,0070	0,0140	0,0010
IEN	0,0262	0,0066	0,0132	0,0005	0,0171	0,0066	0,0132	0,0001
VNIIFTRI	0,0150	0,0080	0,0160	-0,0107	0,0080	0,0080	0,0160	-0,0090
Mean	**0,0257**	**0,0036**	0,0072		**0,0170**	**0,0032**	0,0064	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0165	0,0060	0,0120	0,0007	0,0060	0,0060	0,0120	-0,0090
SPRING	0,0152	0,0024	0,0048	-0,0007	0,0240	0,0024	0,0048	0,0090
Mean-1	**0,0159**	**0,0009**	0,0018		**0,0150**	**0,0127**	0,0255	

ANNEX E-4

Table A.4 Results for 18 GHz: Deviation of the magnitude of the reflection coefficient **Mag. (*Γ*)** from the arithmetic mean value

Frequency	***f* = 18 GHz**							
Participant	**PTB 1-3** Mag(*Γ*)	**PTB 1-3** *u*(Mag(*Γ*))	**PTB 1-3** *U*(Mag(*Γ*))	**Dev. f. mean**	**PTB 2-6** Mag(*Γ*)	**PTB 2-6** *u*(Mag(*Γ*))	**PTB 2-6** *U*(Mag(*Γ*))	**Dev. f. mean**
NMIJ	0,0300	0,0100	0,0200	0,0051	0,0050	0,0100	0,0200	-0,0078
NRC	0,0240	0,0050	0,0100	-0,0009	0,0110	0,0050	0,0100	-0,0018
NIST	0,0180	0,0043	0,0086	-0,0069	0,0135	0,0043	0,0086	0,0007
METAS	0,0220	0,0060	0,0120	-0,0029	0,0130	0,0060	0,0120	0,0002
CSIR-NML	0,0240	0,0030	0,0060	-0,0009	0,0130	0,0030	0,0060	0,0002
PTB	0,0210	0,0030	0,0060	-0,0039	0,0129	0,0030	0,0060	0,0001
NMIA	0,0199	0,0031	0,0062	-0,0050	0,0128	0,0031	0,0062	0,0000
NPL	0,0220	0,0100	0,0200	-0,0029	0,0120	0,0100	0,0200	-0,0008
SiQ	0,0210	0,0070	0,0140	-0,0039	0,0140	0,0070	0,0140	0,0012
IEN	0,0241	0,0066	0,0132	-0,0008	0,0101	0,0066	0,0132	-0,0027
VNIIFTRI	0,0480	0,0090	0,0180	0,0231	0,0240	0,0090	0,0180	0,0112
Mean	**0,0249**	**0,0083**	**0,0165**		**0,0128**	**0,0045**	**0,0089**	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0380	0,0060	0,0120	-0,0003	0,0120	0,0060	0,0120	-0,0010
SPRING	0,0385	0,0024	0,0048	0,0003	0,0140	0,0024	0,0048	0,0010
Mean-1	**0,0383**	**0,0004**	**0,0007**	0,0000	**0,0130**	**0,0014**	**0,0028**	0,0000

ANNEX E-5

Table A.5 Results for 20 GHz**:** Deviation of the magnitude of the reflection coefficient **Mag. (*Γ*)** from the arithmetic mean value

Frequency	***f* = 20 GHz**							
Participant	**PTB 1-3** Mag(*Γ*)	**PTB 1-3** *u*(Mag(*Γ*))	**PTB 1-3** *U*(Mag(*Γ*))	**Dev. f. mean**	**PTB 2-6** Mag(*Γ*)	**PTB 1-3** *u*(Mag(*Γ*))	**PTB 1-3** *U*(Mag(*Γ*))	**Dev. f. mean**
NMIJ	0,0160	0,0150	0,0300	-0,0040	0,0270	0,0150	0,0300	0,0004
NRC	0,0170	0,0050	0,0100	-0,0030	0,0250	0,0050	0,0100	-0,0016
NIST	0,0182	0,0044	0,0088	-0,0018	0,0257	0,0044	0,0088	-0,0009
METAS	0,0170	0,0060	0,0120	-0,0030	0,0250	0,0060	0,0120	-0,0016
CSIR-NML	0,0160	0,0030	0,0060	-0,0040	0,0260	0,0030	0,0060	-0,0006
PTB	0,0188	0,0030	0,0060	-0,0012	0,0244	0,0030	0,0060	-0,0022
NMIA	0,0169	0,0033	0,0066	-0,0031	0,0257	0,0033	0,0066	-0,0009
NPL	0,0170	0,0100	0,0200	-0,0030	0,0300	0,0200	0,0400	0,0034
SiQ	0,0230	0,0070	0,0140	0,0030	0,0220	0,0070	0,0140	-0,0046
IEN	0,0167	0,0066	0,0132	-0,0033	0,0280	0,0066	0,0132	0,0014
VNIIFTRI	0,0430	0,0100	0,0200	0,0230	0,0340	0,0100	0,0200	0,0074
Mean	**0,0200**	**0,0079**	**0,0158**		**0,0266**	**0,0032**	0,0064	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0460	0,0060	**0,0120**	-0,0004	0,0100	0,0060	**0,0120**	0,0007
SPRING	0,0469	0,0024	**0,0048**	0,0004	0,0085	0,0024	**0,0048**	-0,0008
Mean-1	**0,0465**	**0,0006**	0,0013		**0,0093**	**0,0011**	0,0021	

ANNEX E-6

Table A.6 Results for 23 GHz: Deviation of the magnitude of the reflection coefficient **Mag. (Γ)** from the arithmetic mean value

Frequency	**f = 23 GHz**							
Participant	**PTB 1-3** Mag(Γ)	**PTB 1-3** u(Mag(Γ))	**PTB 1-3** U(Mag(Γ))	**Dev. f. mean**	**PTB 2-6** Mag(Γ)	**PTB 1-3** u(Mag(Γ))	**PTB 1-3** U(Mag(Γ))	**Dev. f. mean**
NMIJ	0,0300	0,0180	0,0360	0,0025	0,0610	0,0180	0,0360	0,0017
NRC	0,0300	0,0050	0,0100	0,0025	0,0600	0,0050	0,0100	0,0007
NIST	0,0261	0,0047	0,0094	-0,0014	0,0589	0,0047	0,0094	-0,0004
METAS	0,0280	0,0060	0,0120	0,0005	0,0590	0,0060	0,0120	-0,0003
CSIR-NML	0,0250	0,0030	0,0060	-0,0025	0,0580	0,0030	0,0060	-0,0013
PTB	0,0261	0,0030	0,0060	-0,0014	0,0595	0,0030	0,0060	0,0002
NMIA	0,0242	0,0036	0,0072	-0,0033	0,0590	0,0036	0,0072	-0,0003
NPL	0,0200	0,0200	0,0400	-0,0075	0,0600	0,0200	0,0400	0,0007
SiQ	0,0330	0,0070	0,0140	0,0055	0,0620	0,0080	0,0160	0,0027
IEN	0,0266	0,0067	0,0134	-0,0009	0,0581	0,0067	0,0134	-0,0012
VNIIFTRI	0,0340	0,0110	0,0220	0,0065	0,0570	0,0120	0,0240	-0,0023
Mean	**0,0275**	**0,0040**	**0,0081**		**0,0593**	**0,0014**	0,0028	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0640	0,0060	0,0120	-0,0001	0,0380	0,0060	0,0120	0,0019
SPRING	0,0642	0,0024	0,0048	0,0001	0,0342	0,0024	0,0048	-0,0019
Mean-1	**0,0641**	**0,0001**	0,0003		**0,0361**	**0,0027**	0,0054	

ANNEX E-7

Table A.7 Results for 26 GHz: Deviation of the magnitude of the reflection coefficient **Mag. (Γ)** from the arithmetic mean value

Frequency	***f* = 26 GHz**							
Participant	**PTB 1-3** Mag(Γ)	**PTB 1-3** *u*(Mag(Γ))	**PTB 1-3** *U*(Mag(Γ))	**Dev. f. mean**	**PTB 2-6** Mag(Γ)	**PTB 2-6** *u*(Mag(Γ))	**PTB 2-6** *U*(Mag(Γ))	**Dev. f. mean**
NMIJ	0,0380	0,0180	0,0360	-0,0201	0,0430	0,0180	0,0360	-0,0215
NRC	0,0550	0,0050	0,0100	-0,0031	0,0680	0,0050	0,0100	0,0035
NIST	0,0617	0,0051	0,0102	0,0036	0,0690	0,0051	0,0102	0,0045
METAS	0,0570	0,0060	0,0120	-0,0011	0,0690	0,0060	0,0120	0,0045
CSIR-NML	0,0570	0,0030	0,0060	-0,0011	0,0690	0,0030	0,0060	0,0045
PTB	0,0579	0,0030	0,0060	-0,0002	0,0683	0,0030	0,0060	0,0038
NMIA	0,0565	0,0038	0,0076	-0,0016	0,0685	0,0038	0,0076	0,0040
NPL	0,0600	0,0200	0,0400	0,0019				
SiQ	0,0640	0,0080	0,0160	0,0059	0,0740	0,0080	0,0160	0,0095
IEN	0,0543	0,0067	0,0134	-0,0038	0,0641	0,0067	0,0134	-0,0004
VNIIFTRI	0,0780	0,0120	0,0240	0,0199	0,0520	0,0120	0,0240	-0,0125
Mean	**0,0581**	**0,0094**	**0,0188**		**0,0645**	**0,0095**	**0,0190**	
	PTB 1-3-1	**PTB 1-3-1**	**PTB 1-3-1**		**PTB 2-6-1**	**PTB 2-6-1**	**PTB 2-6-1**	
PTB	0,0660	0,0060	0,0120	0,0019	0,0650	0,0060	0,0120	0,0005
SPRING	0,0623	0,0025	0,0050	-0,0019	0,0640	0,0024	0,0048	-0,0005
Mean-1	**0,0642**	**0,0026**	0,0052		**0,0645**	**0,0007**	0,0014	

ANNEX F-1 Matrix of equivalence for standard PTB 1–3 at 50 MHz

Standard : **PTB 1 - 3**

Frequency: **50 MHz**

Lab *j* →

			NMIJ		**NRC**		**NIST**		**METAS**		**CSIR-NML**		**PTB**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-3,8	2,8			-0,9	8,5	-5,9	17,4	1,8	12,3	-9,2	14,3	***-4,9***	***4,9***
NRC	-2,9	8,0	0,9	8,5			-5,0	19,0	2,7	14,4	-8,3	16,1	-4,0	8,9
NIST	2,1	17,2	5,9	17,4	5,0	19,0			7,7	21,0	-3,3	22,2	1,0	17,7
METAS	-5,6	12,0	-1,8	12,3	-2,7	14,4	-7,7	21,0			-11,0	18,4	-6,7	12,6
CSIR-NML	5,4	14,0	9,2	14,3	8,3	16,1	3,3	22,2	11,0	18,4			4,3	14,6
PTB	1,1	4,0	***4,9***	***4,9***	4,0	8,9	-1,0	17,7	6,7	12,6	-4,3	14,6		
NMIA	1,4	4,0	***5,2***	***4,9***	4,3	8,9	-0,7	17,7	7,0	12,6	-4,0	14,6	0,3	5,7
NPL	-0,9	3,0	2,9	4,1	2,0	8,5	-3,0	17,5	4,7	12,4	-6,3	14,3	-2,0	5,0
SiQ	2,4	6,0	6,2	6,6	5,3	10,0	0,3	18,2	8,0	13,4	-3,0	15,2	1,3	7,2
IEN	2,9	10,4	6,7	10,8	5,8	13,1	0,8	20,1	8,5	15,9	-2,5	17,4	1,8	11,1
SPRING	4,1	13,4	7,9	13,7	7,0	15,6	2,0	21,8	9,7	18,0	-1,3	19,4	3,0	14,0

			NMIA		**NPL**		**SiQ**		**IEN**		**SPRING**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-3,8	2,8	***-5,2***	***4,9***	-2,9	4,1	-6,2	6,6	-6,7	10,8	-7,9	13,7
NRC	-2,9	8,0	-4,3	8,9	-2,0	8,5	-5,3	10,0	-5,8	13,1	-7,0	15,6
NIST	2,1	17,2	0,7	17,7	3,0	17,5	-0,3	18,2	-0,8	20,1	-2,0	21,8
METAS	-5,6	12,0	-7,0	12,6	-4,7	12,4	-8,0	13,4	-8,5	15,9	-9,7	18,0
CSIR-NML	5,4	14,0	4,0	14,6	6,3	14,3	3,0	15,2	2,5	17,4	1,3	19,4
PTB	1,1	4,0	-0,3	5,7	2,0	5,0	-1,3	7,2	-1,8	11,1	-3,0	14,0
NMIA	1,4	4,0			2,3	5,0	-1,0	7,2	-1,5	11,1	-2,7	14,0
NPL	-0,9	3,0	-2,3	5,0			-3,3	6,7	-3,8	10,8	-5,0	13,7
SiQ	2,4	6,0	1,0	7,2	3,3	6,7			-0,5	12,0	-1,7	14,7
IEN	2,9	10,4	1,5	11,1	3,8	10,8	0,5	12,0			-1,2	17,0
SPRING	4,1	13,4	2,7	14,0	5,0	13,7	1,7	14,7	1,2	17,0		

ANNEX F-2 Matrix of equivalence for standard PTB 1–3 at 1 GHz

Standard : **PTB 1 - 3**

Frequency: **1 GHz**

Lab *j* →

			NMIJ		**NRC**		**NIST**		**METAS**		**CSIR-NML**		**PTB**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-4,0	3,4			-4,3	8,7	-2,1	17,7	0,0	14,4	-6,0	16,4	-2,1	6,0
NRC	0,3	8,0	4,3	8,7			2,2	19,2	4,3	16,1	-1,7	17,9	2,2	9,4
NIST	-1,9	17,4	2,1	17,7	-2,2	19,2			2,1	22,3	-3,9	23,6	0,0	18,1
METAS	-4,0	14,0	0,0	14,4	-4,3	16,1	-2,1	22,3			-6,0	21,3	-2,1	14,9
CSIR-NML	2,0	16,0	6,0	16,4	1,7	17,9	3,9	23,6	6,0	21,3			3,9	16,8
PTB	-1,9	5,0	2,1	6,0	-2,2	9,4	0,0	18,1	2,1	14,9	-3,9	16,8		
NMIA	0,0	5,0	4,0	6,0	-0,3	9,4	1,9	18,1	4,0	14,9	-2,0	16,8	1,9	7,1
NPL	-2,0	6,0	2,0	6,9	-2,3	10,0	-0,1	18,4	2,0	15,2	-4,0	17,1	-0,1	7,8
SiQ	-1,0	6,0	3,0	6,9	-1,3	10,0	0,9	18,4	3,0	15,2	-3,0	17,1	0,9	7,8
IEN	5,7	12,6	9,7	13,1	5,4	14,9	7,6	21,5	9,7	18,8	3,7	20,4	7,6	13,6
VNIIFTRI	4,0	6,0	***8,0***	***6,9***	3,7	10,0	5,9	18,4	8,0	15,2	2,0	17,1	5,9	7,8
SPRING	-2,0	13,4	2,0	13,8	-2,3	15,6	-0,1	22,0	2,0	19,4	-4,0	20,9	-0,1	14,3

			NMIA		**NPL**		**SiQ**		**IEN**		**VNIIFTRI**		**SPRING**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-4,0	3,4	-4,0	6,0	-2,0	6,9	-3,0	6,9	-9,7	13,1	***-8,0***	***6,9***	-2,0	13,8
NRC	0,3	8,0	0,3	9,4	2,3	10,0	1,3	10,0	-5,4	14,9	-3,7	10,0	2,3	15,6
NIST	-1,9	17,4	-1,9	18,1	0,1	18,4	-0,9	18,4	-7,6	21,5	-5,9	18,4	0,1	22,0
METAS	-4,0	14,0	-4,0	14,9	-2,0	15,2	-3,0	15,2	-9,7	18,8	-8,0	15,2	-2,0	19,4
CSIR-NML	2,0	16,0	2,0	16,8	4,0	17,1	3,0	17,1	-3,7	20,4	-2,0	17,1	4,0	20,9
PTB	-1,9	5,0	-1,9	7,1	0,1	7,8	-0,9	7,8	-7,6	13,6	-5,9	7,8	0,1	14,3
NMIA	0,0	5,0			2,0	7,8	1,0	7,8	-5,7	13,6	-4,0	7,8	2,0	14,3
NPL	-2,0	6,0	-2,0	7,8			-1,0	8,5	-7,7	14,0	-6,0	8,5	0,0	14,7
SiQ	-1,0	6,0	-1,0	7,8	1,0	8,5			-6,7	14,0	-5,0	8,5	1,0	14,7
IEN	5,7	12,6	5,7	13,6	7,7	14,0	6,7	14,0			1,7	14,0	7,7	18,4
VNIIFTRI	4,0	6,0	4,0	7,8	6,0	8,5	5,0	8,5	-1,7	14,0			6,0	14,7
SPRING	-2,0	13,4	-2,0	14,3	0,0	14,7	-1,0	14,7	-7,7	18,4	-6,0	14,7		

ANNEX F-3 Matrix of equivalence for standard PTB 1-3 at 10 GHz

Standard : **PTB 1 - 3**

Frequency: **10 GHz**

Lab *j* →

Lab i			NMIJ		NRC		NIST		METAS		CSIR-NML		PTB	
	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	2,2	4,0			3,4	8,9	2,1	18,0	2,8	20,4	-2,2	22,4	1,0	8,9
NRC	-1,2	8,0	-3,4	8,9			-1,3	19,3	-0,6	21,5	-5,6	23,4	-2,4	11,3
NIST	0,1	17,6	-2,1	18,0	1,3	19,3			0,7	26,6	-4,3	28,2	-1,1	19,3
METAS	-0,6	20,0	-2,8	20,4	0,6	21,5	-0,7	26,6			-5,0	29,7	-1,8	21,5
CSIR-NML	4,4	22,0	2,2	22,4	5,6	23,4	4,3	28,2	5,0	29,7			3,2	23,4
PTB	1,2	8,0	-1,0	8,9	2,4	11,3	1,1	19,3	1,8	21,5	-3,2	23,4		
NMIA	0,4	9,4	-1,8	10,2	1,6	12,3	0,3	20,0	1,0	22,1	-4,0	23,9	-0,8	12,3
NPL	-2,6	8,8	-4,8	9,7	-1,4	11,9	-2,7	19,7	-2,0	21,9	-7,0	23,7	-3,8	11,9
SiQ	-3,6	14,0	-5,8	14,6	-2,4	16,1	-3,7	22,5	-3,0	24,4	-8,0	26,1	-4,8	16,1
IEN	-7,2	27,0	-9,4	27,3	-6,0	28,2	-7,3	32,2	-6,6	33,6	-11,6	34,8	-8,4	28,2
VNIIFTRI	19,4	12,0	***17,2***	***12,6***	***20,6***	***14,4***	19,3	21,3	20,0	23,3	15,0	25,1	***18,2***	***14,4***
SPRING	2,6	14,8	0,4	15,3	3,8	16,8	2,5	23,0	3,2	24,9	-1,8	26,5	1,4	16,8

Lab *i*			NMIA		NPL		SiQ		IEN		VNIIFTRI		SPRING	
	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	2,2	4,0	*1,8*	*10,2*	4,8	9,7	5,8	14,6	9,4	27,3	***-17,2***	***12,6***	-0,4	15,3
NRC	-1,2	8,0	-1,6	12,3	1,4	11,9	2,4	16,1	6,0	28,2	***-20,6***	***14,4***	-3,8	16,8
NIST	0,1	17,6	-0,3	20,0	2,7	19,7	3,7	22,5	7,3	32,2	-19,3	21,3	-2,5	23,0
METAS	-0,6	20,0	-1,0	22,1	2,0	21,9	3,0	24,4	6,6	33,6	-20,0	23,3	-3,2	24,9
CSIR-NML	4,4	22,0	4,0	23,9	7,0	23,7	8,0	26,1	11,6	34,8	-15,0	25,1	1,8	26,5
PTB	1,2	8,0	0,8	12,3	3,8	11,9	4,8	16,1	8,4	28,2	***-18,2***	***14,4***	-1,4	16,8
NMIA	0,4	9,4			3,0	12,9	4,0	16,9	7,6	28,6	***-19,0***	***15,2***	-2,2	17,5
NPL	-2,6	8,8	-3,0	12,9			1,0	16,5	4,6	28,4	***-22,0***	***14,9***	-5,2	17,2
SiQ	-3,6	14,0	-4,0	16,9	-1,0	16,5			3,6	30,4	***-23,0***	***18,4***	-6,2	20,4
IEN	-7,2	27,0	-7,6	28,6	-4,6	28,4	-3,6	30,4			-26,6	29,5	-9,8	30,8
VNIIFTRI	19,4	12,0	***19,0***	***15,2***	***22,0***	***14,9***	***23,0***	***18,4***	26,6	29,5			16,8	19,1
SPRING	2,6	14,8	2,2	17,5	5,2	17,2	6,2	20,4	9,8	30,8	-16,8	19,1		

ANNEX F-4 Matrix of equivalence for standard PTB 1-3 at 18 GHz

Standard : **PTB 1 - 3**

Frequency: **18 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIJ**		**NRC**		**NIST**		**METAS**		**CSIR-NML**		**PTB**	
			D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	3,5	11,6			-2,6	15,1	6,2	21,1	7,2	23,1	7,2	28,5	4,8	15,3
NRC	6,1	9,6	2,6	15,1			8,8	20,0	9,8	22,2	9,8	27,7	7,4	13,9
NIST	-2,7	17,6	-6,2	21,1	-8,8	20,0			1,0	26,6	1,0	31,4	-1,4	20,2
METAS	-3,7	20,0	-7,2	23,1	-9,8	22,2	-1,0	26,6			0,0	32,8	-2,4	22,4
CSIR-NML	-3,7	26,0	-7,2	28,5	-9,8	27,7	-1,0	31,4	0,0	32,8			-2,4	27,9
PTB	-1,3	10,0	-4,8	15,3	-7,4	13,9	1,4	20,2	2,4	22,4	2,4	27,9		
NMIA	1,3	12,6	-2,2	17,1	-4,8	15,8	4,0	21,6	5,0	23,6	5,0	28,9	2,6	16,1
NPL	-2,7	11,0	-6,2	16,0	-8,8	14,6	0,0	20,8	1,0	22,8	1,0	28,2	-1,4	14,9
SiQ	5,3	16,0	1,8	19,8	-0,8	18,7	8,0	23,8	9,0	25,6	9,0	30,5	6,6	18,9
IEN	-4,4	27,6	-7,9	29,9	-10,5	29,2	-1,7	32,7	-0,7	34,1	-0,7	37,9	-3,1	29,4
VNIIFTRI	-20,7	14,0	***-24,2***	***18,2***	***-26,8***	***17,0***	-18,0	22,5	-17,0	24,4	-17,0	29,5	***-19,4***	***17,2***
SPRING	-7,1	19,6	-10,6	22,8	-13,2	21,8	-4,4	26,3	-3,4	28,0	-3,4	32,6	-5,8	22,0

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIA**		**NPL**		**SiQ**		**IEN**		**VNIIFTRI**		**SPRING**	
			D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	3,5	11,6	*2,2*	*17,1*	6,2	16,0	-1,8	19,8	7,9	29,9	***24,2***	***18,2***	10,6	22,8
NRC	6,1	9,6	4,8	15,8	8,8	14,6	0,8	18,7	10,5	29,2	***26,8***	***17,0***	13,2	21,8
NIST	-2,7	17,6	-4,0	21,6	0,0	20,8	-8,0	23,8	1,7	32,7	18,0	22,5	4,4	26,3
METAS	-3,7	20,0	-5,0	23,6	-1,0	22,8	-9,0	25,6	0,7	34,1	17,0	24,4	3,4	28,0
CSIR-NML	-3,7	26,0	-5,0	28,9	-1,0	28,2	-9,0	30,5	0,7	37,9	17,0	29,5	3,4	32,6
PTB	-1,3	10,0	-2,6	16,1	1,4	14,9	-6,6	18,9	3,1	29,4	***19,4***	***17,2***	5,8	22,0
NMIA	1,3	12,6			4,0	16,7	-4,0	20,4	5,7	30,3	***22,0***	***18,8***	8,4	23,3
NPL	-2,7	11,0	-4,0	16,7			-8,0	19,4	1,7	29,7	***18,0***	***17,8***	4,4	22,5
SiQ	5,3	16,0	4,0	20,4	8,0	19,4			9,7	31,9	***26,0***	***21,3***	12,4	25,3
IEN	-4,4	27,6	-5,7	30,3	-1,7	29,7	-9,7	31,9			16,3	30,9	2,7	33,9
VNIIFTRI	-20,7	14,0	***-22,0***	***18,8***	***-18,0***	***17,8***	***-26,0***	***21,3***	-16,3	30,9			-13,6	24,1
SPRING	-7,1	19,6	-8,4	23,3	-4,4	22,5	-12,4	25,3	-2,7	33,9	13,6	24,1		

ANNEX F-5 Matrix of equivalence for standard PTB 1-3 at 20 GHz

Standard : **PTB 1 - 3**

Frequency: **20 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIJ D_{ij} /10^{-3}	NMIJ U_{ij} /10^{-3}	NRC D_{ij} /10^{-3}	NRC U_{ij} /10^{-3}	NIST D_{ij} /10^{-3}	NIST U_{ij} /10^{-3}	METAS D_{ij} /10^{-3}	METAS U_{ij} /10^{-3}	CSIR-NML D_{ij} /10^{-3}	CSIR-NML U_{ij} /10^{-3}	PTB D_{ij} /10^{-3}	PTB U_{ij} /10^{-3}
NMIJ	5,2	7,8			2,7	12,4	6,9	19,6	3,8	23,3	0,8	31,0	6,5	13,5
NRC	2,5	9,6	-2,7	12,4			4,2	20,4	1,1	24,0	-1,9	31,5	3,8	14,6
NIST	-1,7	18,0	-6,9	19,6	-4,2	20,4			-3,1	28,4	-6,1	35,0	-0,4	21,1
METAS	1,4	22,0	-3,8	23,3	-1,1	24,0	3,1	28,4			-3,0	37,2	2,7	24,6
CSIR-NML	4,4	30,0	-0,8	31,0	1,9	31,5	6,1	35,0	3,0	37,2			5,7	32,0
PTB	-1,3	11,0	-6,5	13,5	-3,8	14,6	0,4	21,1	-2,7	24,6	-5,7	32,0		
NMIA	4,4	18,6	-0,8	20,2	1,9	20,9	6,1	25,9	3,0	28,8	0,0	35,3	5,7	21,6
NPL	3,4	11,0	-1,8	13,5	0,9	14,6	5,1	21,1	2,0	24,6	-1,0	32,0	4,7	15,6
SiQ	2,4	16,0	-2,8	17,8	-0,1	18,7	4,1	24,1	1,0	27,2	-2,0	34,0	3,7	19,4
IEN	-8,4	26,2	-13,6	27,3	-10,9	27,9	-6,7	31,8	-9,8	34,2	-12,8	39,8	-7,1	28,4
VNIIFTRI	-19,6	22,0	***-24,8***	***23,3***	-22,1	24,0	-17,9	28,4	-21,0	31,1	-24,0	37,2	-18,3	24,6
SPRING	-0,5	19,8	-5,7	21,3	-3,0	22,0	1,2	26,8	-1,9	29,6	-4,9	35,9	0,8	22,7

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIA D_{ij} /10^{-3}	NMIA U_{ij} /10^{-3}	NPL D_{ij} /10^{-3}	NPL U_{ij} /10^{-3}	SiQ D_{ij} /10^{-3}	SiQ U_{ij} /10^{-3}	IEN D_{ij} /10^{-3}	IEN U_{ij} /10^{-3}	VNIIFTRI D_{ij} /10^{-3}	VNIIFTRI U_{ij} /10^{-3}	SPRING D_{ij} /10^{-3}	SPRING U_{ij} /10^{-3}
NMIJ	5,2	7,8	*0,8*	*20,2*	1,8	13,5	2,8	17,8	13,6	27,3	***24,8***	***23,3***	5,7	21,3
NRC	2,5	9,6	-1,9	20,9	-0,9	14,6	0,1	18,7	10,9	27,9	22,1	24,0	3,0	22,0
NIST	-1,7	18,0	-6,1	25,9	-5,1	21,1	-4,1	24,1	6,7	31,8	17,9	28,4	-1,2	26,8
METAS	1,4	22,0	-3,0	28,8	-2,0	24,6	-1,0	27,2	9,8	34,2	21,0	31,1	1,9	29,6
CSIR-NML	4,4	30,0	0,0	35,3	1,0	32,0	2,0	34,0	12,8	39,8	24,0	37,2	4,9	35,9
PTB	-1,3	11,0	-5,7	21,6	-4,7	15,6	-3,7	19,4	7,1	28,4	18,3	24,6	-0,8	22,7
NMIA	4,4	18,6			1,0	21,6	2,0	24,5	12,8	32,1	24,0	28,8	4,9	27,2
NPL	3,4	11,0	-1,0	21,6			1,0	19,4	11,8	28,4	23,0	24,6	3,9	22,7
SiQ	2,4	16,0	-2,0	24,5	-1,0	19,4			10,8	30,7	22,0	27,2	2,9	25,5
IEN	-8,4	26,2	-12,8	32,1	-11,8	28,4	-10,8	30,7			11,2	34,2	-7,9	32,8
VNIIFTRI	-19,6	22,0	-24,0	28,8	-23,0	24,6	-22,0	27,2	-11,2	34,2			-19,1	29,6
SPRING	-0,5	19,8	-4,9	27,2	-3,9	22,7	-2,9	25,5	7,9	32,8	19,1	29,6		

ANNEX F-6 Matrix of equivalence for standard PTB 1-3 at 23 GHz

Standard : **PTB 1 - 3**

Frequency: **23 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIJ D_{ij} /10^{-3}	NMIJ U_{ij} /10^{-3}	NRC D_{ij} /10^{-3}	NRC U_{ij} /10^{-3}	NIST D_{ij} /10^{-3}	NIST U_{ij} /10^{-3}	METAS D_{ij} /10^{-3}	METAS U_{ij} /10^{-3}	CSIR-NML D_{ij} /10^{-3}	CSIR-NML U_{ij} /10^{-3}	PTB D_{ij} /10^{-3}	PTB U_{ij} /10^{-3}
NMIJ	1,0	8,8			-2,2	13,0	3,7	20,4	-1,8	23,7	-4,8	33,2	1,1	15,7
NRC	3,2	9,6	2,2	13,0			5,9	20,8	0,4	24,0	-2,6	33,4	3,3	16,2
NIST	-2,7	18,4	-3,7	20,4	-5,9	20,8			-5,5	28,7	-8,5	36,9	-2,6	22,5
METAS	2,8	22,0	1,8	23,7	-0,4	24,0	5,5	28,7			-3,0	38,8	2,9	25,6
CSIR-NML	5,8	32,0	4,8	33,2	2,6	33,4	8,5	36,9	3,0	38,8			5,9	34,5
PTB	-0,1	13,0	-1,1	15,7	-3,3	16,2	2,6	22,5	-2,9	25,6	-5,9	34,5		
NMIA	1,8	18,4	0,8	20,4	-1,4	20,8	4,5	26,0	-1,0	28,7	-4,0	36,9	1,9	22,5
NPL	5,8	13,2	4,8	15,9	2,6	16,3	8,5	22,6	3,0	25,7	0,0	34,6	5,9	18,5
SiQ	0,8	16,0	-0,2	18,3	-2,4	18,7	3,5	24,4	-2,0	27,2	-5,0	35,8	0,9	20,6
IEN	-13,7	38,0	-14,7	39,0	-16,9	39,2	-11,0	42,2	-16,5	43,9	-19,5	49,7	-13,6	40,2
VNIIFTRI	-7,2	24,0	-8,2	25,6	-10,4	25,8	-4,5	30,2	-10,0	32,6	-13,0	40,0	-7,1	27,3
SPRING	0,8	26,0	-0,2	27,4	-2,4	27,7	3,5	31,9	-2,0	34,1	-5,0	41,2	0,9	29,1

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIA D_{ij} /10^{-3}	NMIA U_{ij} /10^{-3}	NPL D_{ij} /10^{-3}	NPL U_{ij} /10^{-3}	SiQ D_{ij} /10^{-3}	SiQ U_{ij} /10^{-3}	IEN D_{ij} /10^{-3}	IEN U_{ij} /10^{-3}	VNIIFTRI D_{ij} /10^{-3}	VNIIFTRI U_{ij} /10^{-3}	SPRING D_{ij} /10^{-3}	SPRING U_{ij} /10^{-3}
NMIJ	1,0	8,8	*-0,8*	*20,4*	-4,8	15,9	0,2	18,3	14,7	39,0	8,2	25,6	0,2	27,4
NRC	3,2	9,6	1,4	20,8	-2,6	16,3	2,4	18,7	16,9	39,2	10,4	25,8	2,4	27,7
NIST	-2,7	18,4	-4,5	26,0	-8,5	22,6	-3,5	24,4	11,0	42,2	4,5	30,2	-3,5	31,9
METAS	2,8	22,0	1,0	28,7	-3,0	25,7	2,0	27,2	16,5	43,9	10,0	32,6	2,0	34,1
CSIR-NML	5,8	32,0	4,0	36,9	0,0	34,6	5,0	35,8	19,5	49,7	13,0	40,0	5,0	41,2
PTB	-0,1	13,0	-1,9	22,5	-5,9	18,5	-0,9	20,6	13,6	40,2	7,1	27,3	-0,9	29,1
NMIA	1,8	18,4			-4,0	22,6	1,0	24,4	15,5	42,2	9,0	30,2	1,0	31,9
NPL	5,8	13,2	4,0	22,6			5,0	20,7	19,5	40,2	13,0	27,4	5,0	29,2
SiQ	0,8	16,0	-1,0	24,4	-5,0	20,7			14,5	41,2	8,0	28,8	0,0	30,5
IEN	-13,7	38,0	-15,5	42,2	-19,5	40,2	-14,5	41,2			-6,5	44,9	-14,5	46,0
VNIIFTRI	-7,2	24,0	-9,0	30,2	-13,0	27,4	-8,0	28,8	6,5	44,9			-8,0	35,4
SPRING	0,8	26,0	-1,0	31,9	-5,0	29,2	0,0	30,5	14,5	46,0	8,0	35,4		

ANNEX F-7 Matrix of equivalence for standard PTB 1-3 at 26 GHz

Standard : **PTB 1 - 3**

Frequency: **26 GHz**

Lab *j* →

			NMIJ		**NRC**		**NIST**		**METAS**		**CSIR-NML**		**PTB**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-20,8	13,8			***-23,8***	***16,8***	-12,5	23,3	-7,0	27,7	-23,0	40,4	-20,7	21,9
NRC	3,0	9,6	***23,8***	***16,8***			11,3	21,1	16,8	25,8	0,8	39,2	3,1	19,5
NIST	-8,3	18,8	12,5	23,3	-11,3	21,1			5,5	30,5	-10,5	42,4	-8,2	25,3
METAS	-13,8	24,0	7,0	27,7	-16,8	25,8	-5,5	30,5			-16,0	44,9	-13,7	29,4
CSIR-NML	2,2	38,0	23,0	40,4	-0,8	39,2	10,5	42,4	16,0	44,9			2,3	41,6
PTB	-0,1	17,0	20,7	21,9	-3,1	19,5	8,2	25,3	13,7	29,4	-2,3	41,6		
NMIA	-2,8	18,2	18,0	22,8	-5,8	20,6	5,5	26,2	11,0	30,1	-5,0	42,1	-2,7	24,9
NPL	4,2	15,4	25,0	20,7	1,2	18,1	12,5	24,3	18,0	28,5	2,0	41,0	4,3	22,9
SiQ	-3,8	16,0	17,0	21,1	-6,8	18,7	4,5	24,7	10,0	28,8	-6,0	41,2	-3,7	23,3
IEN	-22,5	37,4	-1,7	39,9	-25,5	38,6	-14,2	41,9	-8,7	44,4	-24,7	53,3	-22,4	41,1
VNIIFTRI	1,2	28,0	22,0	31,2	-1,8	29,6	9,5	33,7	15,0	36,9	-1,0	47,2	1,3	32,8
SPRING	-2,4	16,8	18,4	21,7	-5,4	19,3	5,9	25,2	11,4	29,3	-4,6	41,5	-2,3	23,9

			NMIA		**NPL**		**SiQ**		**IEN**		**VNIIFTRI**		**SPRING**	
Lab *i*	D_i /10^{-3}	U_i /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
NMIJ	-20,8	13,8	*-18,0*	*22,8*	-25,0	20,7	-17,0	21,1	1,7	39,9	-22,0	31,2	-18,4	21,7
NRC	3,0	9,6	5,8	20,6	-1,2	18,1	6,8	18,7	25,5	38,6	1,8	29,6	5,4	19,3
NIST	-8,3	18,8	-5,5	26,2	-12,5	24,3	-4,5	24,7	14,2	41,9	-9,5	33,7	-5,9	25,2
METAS	-13,8	24,0	-11,0	30,1	-18,0	28,5	-10,0	28,8	8,7	44,4	-15,0	36,9	-11,4	29,3
CSIR-NML	2,2	38,0	5,0	42,1	-2,0	41,0	6,0	41,2	24,7	53,3	1,0	47,2	4,6	41,5
PTB	-0,1	17,0	2,7	24,9	-4,3	22,9	3,7	23,3	22,4	41,1	-1,3	32,8	2,3	23,9
NMIA	-2,8	18,2			-7,0	23,8	1,0	24,2	19,7	41,6	-4,0	33,4	-0,4	24,8
NPL	4,2	15,4	7,0	23,8			8,0	22,2	26,7	40,4	3,0	32,0	6,6	22,8
SiQ	-3,8	16,0	-1,0	24,2	-8,0	22,2			18,7	40,7	-5,0	32,2	-1,4	23,2
IEN	-22,5	37,4	-19,7	41,6	-26,7	40,4	-18,7	40,7			-23,7	46,7	-20,1	41,0
VNIIFTRI	1,2	28,0	4,0	33,4	-3,0	32,0	5,0	32,2	23,7	46,7			3,6	32,7
SPRING	-2,4	16,8	0,4	24,8	-6,6	22,8	1,4	23,2	20,1	41,0	-3,6	32,7		

ANNEX G-1 Matrix of equivalence for standard PTB 2-6 at 50 MHz

Standard : **PTB 2 - 6**
Frequency: **50 MHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIJ** D_{ij} /10^{-3}	**NMIJ** U_{ij} /10^{-3}	**NIST** D_{ij} /10^{-3}	**NIST** U_{ij} /10^{-3}	**METAS** D_{ij} /10^{-3}	**METAS** U_{ij} /10^{-3}	**CSIR-NML** D_{ij} /10^{-3}	**CSIR-NML** U_{ij} /10^{-3}	**PTB** D_{ij} /10^{-3}	**PTB** U_{ij} /10^{-3}
NMIJ	-5,0	2,8			-6,5	17,4	-0,5	12,3	-8,5	14,3	-4,4	4,9
NIST	1,5	17,2	6,5	17,4			6,0	21,0	-2,0	22,2	2,1	17,7
METAS	-4,5	12,0	0,5	12,3	-6,0	21,0			-8,0	18,4	-3,9	12,6
CSIR-NML	3,5	14,0	8,5	14,3	2,0	22,2	8,0	18,4			4,1	14,6
PTB	-0,6	4,0	4,4	4,9	-2,1	17,7	3,9	12,6	-4,1	14,6		
NMIA	0,5	4,0	***5,5***	***4,9***	-1,0	17,7	5,0	12,6	-3,0	14,6	1,1	5,7
NPL	-2,3	3,2	2,7	4,3	-3,8	17,5	2,2	12,4	-5,8	14,4	-1,7	5,1
SiQ	1,5	6,0	6,5	6,6	0,0	18,2	6,0	13,4	-2,0	15,2	2,1	7,2
IEN	5,6	11,6	10,6	11,9	4,1	20,7	10,1	16,7	2,1	18,2	6,2	12,3
SPRING	1,1	13,4	6,1	13,7	-0,4	21,8	5,6	18,0	-2,4	19,4	1,7	14,0

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIA** D_{ij} /10^{-3}	**NMIA** U_{ij} /10^{-3}	**NPL** D_{ij} /10^{-3}	**NPL** U_{ij} /10^{-3}	**SiQ** D_{ij} /10^{-3}	**SiQ** U_{ij} /10^{-3}	**IEN** D_{ij} /10^{-3}	**IEN** U_{ij} /10^{-3}	**SPRING** D_{ij} /10^{-3}	**SPRING** U_{ij} /10^{-3}
NMIJ	-5,0	2,8	***-5,5***	***4,9***	-2,7	4,3	-6,5	6,6	-10,6	11,9	-6,1	13,7
NIST	1,5	17,2	1,0	17,7	3,8	17,5	0,0	18,2	-4,1	20,7	0,4	21,8
METAS	-4,5	12,0	-5,0	12,6	-2,2	12,4	-6,0	13,4	-10,1	16,7	-5,6	18,0
CSIR-NML	3,5	14,0	3,0	14,6	5,8	14,4	2,0	15,2	-2,1	18,2	2,4	19,4
PTB	-0,6	4,0	-1,1	5,7	1,7	5,1	-2,1	7,2	-6,2	12,3	-1,7	14,0
NMIA	0,5	4,0			2,8	5,1	-1,0	7,2	-5,1	12,3	-0,6	14,0
NPL	-2,3	3,2	-2,8	5,1			-3,8	6,8	-7,9	12,0	-3,4	13,8
SiQ	1,5	6,0	1,0	7,2	3,8	6,8			-4,1	13,1	0,4	14,7
IEN	5,6	11,6	5,1	12,3	7,9	12,0	4,1	13,1			4,5	17,7
SPRING	1,1	13,4	0,6	14,0	3,4	13,8	-0,4	14,7	-4,5	17,7		

ANNEX G-2 Matrix of equivalence for standard PTB 2-6 at 1 GHz

Standard : **PTB 2 - 6**

Frequency: **1 GHz**

Lab *j* →

Lab *i*	D_i /10^-3	U_i /10^-3	NMIJ		NIST		METAS		CSIR-NML		PTB	
			D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3
NMIJ	-4,0	3,4			-2,0	17,7	-0,6	14,4	-5,6	16,4	-2,0	6,0
NIST	-2,0	17,4	2,0	17,7			1,4	22,3	-3,6	23,6	0,0	18,1
METAS	-3,4	14,0	0,6	14,4	-1,4	22,3			-5,0	21,3	-1,4	14,9
CSIR-NML	1,6	16,0	5,6	16,4	3,6	23,6	5,0	21,3			3,6	16,8
PTB	-2,0	5,0	2,0	6,0	0,0	18,1	1,4	14,9	-3,6	16,8		
NMIA	0,6	5,0	4,6	6,0	2,6	18,1	4,0	14,9	-1,0	16,8	2,6	7,1
NPL	-2,4	6,4	1,6	7,2	-0,4	18,5	1,0	15,4	-4,0	17,2	-0,4	8,1
SiQ	-1,4	6,0	2,6	6,9	0,6	18,4	2,0	15,2	-3,0	17,1	0,6	7,8
IEN	5,3	11,6	9,3	12,1	7,3	20,9	8,7	18,2	3,7	19,8	7,3	12,6
VNIIFTRI	4,6	12,0	8,6	12,5	6,6	21,1	8,0	18,4	3,0	20,0	6,6	13,0
SPRING	-2,5	13,4	1,5	13,8	-0,5	22,0	0,9	19,4	-4,1	20,9	-0,5	14,3

Lab *i*	D_i /10^-3	U_i /10^-3	NMIA		NPL		SiQ		IEN		VNIIFTRI		SPRING	
			D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3	D_{ij} /10^-3	U_{ij} /10^-3
NMIJ	-4,0	3,4	-4,6	6,0	-1,6	7,2	-2,6	6,9	-9,3	12,1	-8,6	12,5	-1,5	13,8
NIST	-2,0	17,4	-2,6	18,1	0,4	18,5	-0,6	18,4	-7,3	20,9	-6,6	21,1	0,5	22,0
METAS	-3,4	14,0	-4,0	14,9	-1,0	15,4	-2,0	15,2	-8,7	18,2	-8,0	18,4	-0,9	19,4
CSIR-NML	1,6	16,0	1,0	16,8	4,0	17,2	3,0	17,1	-3,7	19,8	-3,0	20,0	4,1	20,9
PTB	-2,0	5,0	-2,6	7,1	0,4	8,1	-0,6	7,8	-7,3	12,6	-6,6	13,0	0,5	14,3
NMIA	0,6	5,0			3,0	8,1	2,0	7,8	-4,7	12,6	-4,0	13,0	3,1	14,3
NPL	-2,4	6,4	-3,0	8,1			-1,0	8,8	-7,7	13,2	-7,0	13,6	0,1	14,8
SiQ	-1,4	6,0	-2,0	7,8	1,0	8,8			-6,7	13,1	-6,0	13,4	1,1	14,7
IEN	5,3	11,6	4,7	12,6	7,7	13,2	6,7	13,1			0,7	16,7	7,8	17,7
VNIIFTRI	4,6	12,0	4,0	13,0	7,0	13,6	6,0	13,4	-0,7	16,7			7,1	18,0
SPRING	-2,5	13,4	-3,1	14,3	-0,1	14,8	-1,1	14,7	-7,8	17,7	-7,1	18,0		

ANNEX G-3 Matrix of equivalence for standard PTB 2-6 at 10 GHz

Standard : **PTB 2 - 6**
Frequency: **10 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIJ** D_{ij} /10^{-3}	**NMIJ** U_{ij} /10^{-3}	**NIST** D_{ij} /10^{-3}	**NIST** U_{ij} /10^{-3}	**METAS** D_{ij} /10^{-3}	**METAS** U_{ij} /10^{-3}	**CSIR-NML** D_{ij} /10^{-3}	**CSIR-NML** U_{ij} /10^{-3}	**PTB** D_{ij} /10^{-3}	**PTB** U_{ij} /10^{-3}
NMIJ	2,2	3,8			-0,4	18,0	1,2	20,4	-2,8	22,3	2,6	8,9
NIST	2,6	17,6	0,4	18,0			1,6	26,6	-2,4	28,2	3,0	19,3
METAS	1,0	20,0	-1,2	20,4	-1,6	26,6			-4,0	29,7	1,4	21,5
CSIR-NML	5,0	22,0	2,8	22,3	2,4	28,2	4,0	29,7			5,4	23,4
PTB	-0,4	8,0	-2,6	8,9	-3,0	19,3	-1,4	21,5	-5,4	23,4		
NMIA	2,0	9,4	-0,2	10,1	-0,6	20,0	1,0	22,1	-3,0	23,9	2,4	12,3
NPL	-2,0	9,0	-4,2	9,8	-4,6	19,8	-3,0	21,9	-7,0	23,8	-1,6	12,0
SiQ	-7,0	14,0	-9,2	14,5	-9,6	22,5	-8,0	24,4	-12,0	26,1	-6,6	16,1
IEN	-4,5	30,6	-6,7	30,8	-7,1	35,3	-5,5	36,6	-9,5	37,7	-4,1	31,6
VNIIFTRI	21,0	20,0	18,8	20,4	18,4	26,6	20,0	28,3	16,0	29,7	21,4	21,5
SPRING	0,6	14,2	-1,6	14,7	-2,0	22,6	-0,4	24,5	-4,4	26,2	1,0	16,3

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	**NMIA** D_{ij} /10^{-3}	**NMIA** U_{ij} /10^{-3}	**NPL** D_{ij} /10^{-3}	**NPL** U_{ij} /10^{-3}	**SiQ** D_{ij} /10^{-3}	**SiQ** U_{ij} /10^{-3}	**IEN** D_{ij} /10^{-3}	**IEN** U_{ij} /10^{-3}	**VNIIFTRI** D_{ij} /10^{-3}	**VNIIFTRI** U_{ij} /10^{-3}	**SPRING** D_{ij} /10^{-3}	**SPRING** U_{ij} /10^{-3}
NMIJ	2,2	3,8	0,2	10,1	4,2	9,8	9,2	14,5	6,7	30,8	-18,8	20,4	1,6	14,7
NIST	2,6	17,6	0,6	20,0	4,6	19,8	9,6	22,5	7,1	35,3	-18,4	26,6	2,0	22,6
METAS	1,0	20,0	-1,0	22,1	3,0	21,9	8,0	24,4	5,5	36,6	-20,0	28,3	0,4	24,5
CSIR-NML	5,0	22,0	3,0	23,9	7,0	23,8	12,0	26,1	9,5	37,7	-16,0	29,7	4,4	26,2
PTB	-0,4	8,0	-2,4	12,3	1,6	12,0	6,6	16,1	4,1	31,6	-21,4	21,5	-1,0	16,3
NMIA	2,0	9,4			4,0	13,0	9,0	16,9	6,5	32,0	-19,0	22,1	1,4	17,0
NPL	-2,0	9,0	-4,0	13,0			5,0	16,6	2,5	31,9	***-23,0***	***21,9***	-2,6	16,8
SiQ	-7,0	14,0	-9,0	16,9	-5,0	16,6			-2,5	33,7	***-28,0***	***24,4***	-7,6	19,9
IEN	-4,5	30,6	-6,5	32,0	-2,5	31,9	2,5	33,7			-25,5	36,6	-5,1	33,7
VNIIFTRI	21,0	20,0	19,0	22,1	***23,0***	***21,9***	***28,0***	***24,4***	25,5	36,6			20,4	24,5
SPRING	0,6	14,2	-1,4	17,0	2,6	16,8	7,6	19,9	5,1	33,7	-20,4	24,5		

ANNEX G-4 Matrix of equivalence for standard PTB 2-6 at 18 GHz

Standard : **PTB 2 - 6**

Frequency: **18 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIJ D_{ij} /10^{-3}	NMIJ U_{ij} /10^{-3}	NIST D_{ij} /10^{-3}	NIST U_{ij} /10^{-3}	METAS D_{ij} /10^{-3}	METAS U_{ij} /10^{-3}	CSIR-NML D_{ij} /10^{-3}	CSIR-NML U_{ij} /10^{-3}	PTB D_{ij} /10^{-3}	PTB U_{ij} /10^{-3}
NMIJ	1,3	7,6			1,8	19,2	3,2	21,4	6,2	27,1	4,4	12,6
NIST	-0,5	17,6	-1,8	19,2			1,4	26,6	4,4	31,4	2,6	20,2
METAS	-1,9	20,0	-3,2	21,4	-1,4	26,6			3,0	32,8	1,2	22,4
CSIR-NML	-4,9	26,0	-6,2	27,1	-4,4	31,4	-3,0	32,8			-1,8	27,9
PTB	-3,1	10,0	-4,4	12,6	-2,6	20,2	-1,2	22,4	1,8	27,9		
NMIA	3,1	12,6	1,8	14,7	3,6	21,6	5,0	23,6	8,0	28,9	6,2	16,1
NPL	-0,9	11,0	-2,2	13,4	-0,4	20,8	1,0	22,8	4,0	28,2	2,2	14,9
SiQ	3,1	16,0	1,8	17,7	3,6	23,8	5,0	25,6	8,0	30,5	6,2	18,9
IEN	15,2	29,2	13,9	30,2	15,7	34,1	17,1	35,4	20,1	39,1	18,3	30,9
VNIIFTRI	-22,9	24,0	-24,2	25,2	-22,4	29,8	-21,0	31,2	-18,0	35,4	-19,8	26,0
SPRING	-5,5	20,0	-6,8	21,4	-5,0	26,6	-3,6	28,3	-0,6	32,8	-2,4	22,4

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIA D_{ij} /10^{-3}	NMIA U_{ij} /10^{-3}	NPL D_{ij} /10^{-3}	NPL U_{ij} /10^{-3}	SiQ D_{ij} /10^{-3}	SiQ U_{ij} /10^{-3}	IEN D_{ij} /10^{-3}	IEN U_{ij} /10^{-3}	VNIIFTRI D_{ij} /10^{-3}	VNIIFTRI U_{ij} /10^{-3}	SPRING D_{ij} /10^{-3}	SPRING U_{ij} /10^{-3}
NMIJ	1,3	7,6	-1,8	14,7	2,2	13,4	-1,8	17,7	-13,9	30,2	24,2	25,2	6,8	21,4
NIST	-0,5	17,6	-3,6	21,6	0,4	20,8	-3,6	23,8	-15,7	34,1	22,4	29,8	5,0	26,6
METAS	-1,9	20,0	-5,0	23,6	-1,0	22,8	-5,0	25,6	-17,1	35,4	21,0	31,2	3,6	28,3
CSIR-NML	-4,9	26,0	-8,0	28,9	-4,0	28,2	-8,0	30,5	-20,1	39,1	18,0	35,4	0,6	32,8
PTB	-3,1	10,0	-6,2	16,1	-2,2	14,9	-6,2	18,9	-18,3	30,9	19,8	26,0	2,4	22,4
NMIA	3,1	12,6			4,0	16,7	0,0	20,4	-12,1	31,8	26,0	27,1	8,6	23,6
NPL	-0,9	11,0	-4,0	16,7			-4,0	19,4	-16,1	31,2	22,0	26,4	4,6	22,8
SiQ	3,1	16,0	0,0	20,4	4,0	19,4			-12,1	33,3	26,0	28,8	8,6	25,6
IEN	15,2	29,2	12,1	31,8	16,1	31,2	12,1	33,3			***38,1***	***37,8***	20,7	35,4
VNIIFTRI	-22,9	24,0	-26,0	27,1	-22,0	26,4	-26,0	28,8	***-38,1***	***37,8***			-17,4	31,2
SPRING	-5,5	20,0	-8,6	23,6	-4,6	22,8	-8,6	25,6	-20,7	35,4	17,4	31,2		

ANNEX G-5 Matrix of equivalence for standard PTB 2-6 at 20 GHz

Standard : **PTB 2 - 6**

Frequency: **20 GHz**

Lab j →

Lab i	D_i /10^{-3}	U_i /10^{-3}	**NMIJ** D_{ij} /10^{-3}	**NMIJ** U_{ij} /10^{-3}	**NIST** D_{ij} /10^{-3}	**NIST** U_{ij} /10^{-3}	**METAS** D_{ij} /10^{-3}	**METAS** U_{ij} /10^{-3}	**CSIR-NML** D_{ij} /10^{-3}	**CSIR-NML** U_{ij} /10^{-3}	**PTB** D_{ij} /10^{-3}	**PTB** U_{ij} /10^{-3}
NMIJ	1,3	9,4			2,1	20,3	-2,7	23,9	-3,7	31,4	6,9	14,5
NIST	-0,8	18,0	-2,1	20,3			-4,8	28,4	-5,8	35,0	4,8	21,1
METAS	4,0	22,0	2,7	23,9	4,8	28,4			-1,0	37,2	9,6	24,6
CSIR-NML	5,0	30,0	3,7	31,4	5,8	35,0	1,0	37,2			10,6	32,0
PTB	-5,6	11,0	-6,9	14,5	-4,8	21,1	-9,6	24,6	-10,6	32,0		
NMIA	4,0	18,6	2,7	20,8	4,8	25,9	0,0	28,8	-1,0	35,3	9,6	21,6
NPL	1,0	11,2	-0,3	14,6	1,8	21,2	-3,0	24,7	-4,0	32,0	6,6	15,7
SiQ	6,0	16,0	4,7	18,6	6,8	24,1	2,0	27,2	1,0	34,0	11,6	19,4
IEN	4,0	29,0	2,7	30,5	4,8	34,1	0,0	36,4	-1,0	41,7	9,6	31,0
VNIIFTRI	-25,0	44,0	-26,3	45,0	-24,2	47,5	-29,0	49,2	-30,0	53,3	-19,4	45,4
SPRING	-6,6	20,6	-7,9	22,6	-5,8	27,4	-10,6	30,1	-11,6	36,4	-1,0	23,4

Lab i	D_i /10^{-3}	U_i /10^{-3}	**NMIA** D_{ij} /10^{-3}	**NMIA** U_{ij} /10^{-3}	**NPL** D_{ij} /10^{-3}	**NPL** U_{ij} /10^{-3}	**SiQ** D_{ij} /10^{-3}	**SiQ** U_{ij} /10^{-3}	**IEN** D_{ij} /10^{-3}	**IEN** U_{ij} /10^{-3}	**VNIIFTRI** D_{ij} /10^{-3}	**VNIIFTRI** U_{ij} /10^{-3}	**SPRING** D_{ij} /10^{-3}	**SPRING** U_{ij} /10^{-3}
NMIJ	1,3	9,4	-2,7	20,8	0,3	14,6	-4,7	18,6	-2,7	30,5	26,3	45,0	7,9	22,6
NIST	-0,8	18,0	-4,8	25,9	-1,8	21,2	-6,8	24,1	-4,8	34,1	24,2	47,5	5,8	27,4
METAS	4,0	22,0	0,0	28,8	3,0	24,7	-2,0	27,2	0,0	36,4	29,0	49,2	10,6	30,1
CSIR-NML	5,0	30,0	1,0	35,3	4,0	32,0	-1,0	34,0	1,0	41,7	30,0	53,3	11,6	36,4
PTB	-5,6	11,0	-9,6	21,6	-6,6	15,7	-11,6	19,4	-9,6	31,0	19,4	45,4	1,0	23,4
NMIA	4,0	18,6			3,0	21,7	-2,0	24,5	0,0	34,5	29,0	47,8	10,6	27,8
NPL	1,0	11,2	-3,0	21,7			-5,0	19,5	-3,0	31,1	26,0	45,4	7,6	23,4
SiQ	6,0	16,0	2,0	24,5	5,0	19,5			2,0	33,1	31,0	46,8	12,6	26,1
IEN	4,0	29,0	0,0	34,5	3,0	31,1	-2,0	33,1			29,0	52,7	10,6	35,6
VNIIFTRI	-25,0	44,0	-29,0	47,8	-26,0	45,4	-31,0	46,8	-29,0	52,7			-18,4	48,6
SPRING	-6,6	20,6	-10,6	27,8	-7,6	23,4	-12,6	26,1	-10,6	35,6	18,4	48,6		

ANNEX G-6 Matrix of equivalence for standard PTB 2-6 at 23 GHz

Standard : **PTB 2 - 6**
Frequency: **23 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIJ D_{ij} /10^{-3}	NMIJ U_{ij} /10^{-3}	NIST D_{ij} /10^{-3}	NIST U_{ij} /10^{-3}	METAS D_{ij} /10^{-3}	METAS U_{ij} /10^{-3}	CSIR-NML D_{ij} /10^{-3}	CSIR-NML U_{ij} /10^{-3}	PTB D_{ij} /10^{-3}	PTB U_{ij} /10^{-3}
NMIJ	0,8	8,8			0,5	20,4	-3,6	21,9	-3,6	33,2	1,5	15,7
NIST	0,3	18,4	-0,5	20,4			-4,1	27,2	-4,1	36,9	1,0	22,5
METAS	4,4	20,0	3,6	21,9	4,1	27,2			0,0	37,7	5,1	23,9
CSIR-NML	4,4	32,0	3,6	33,2	4,1	36,9	0,0	37,7			5,1	34,5
PTB	-0,7	13,0	-1,5	15,7	-1,0	22,5	-5,1	23,9	-5,1	34,5		
NMIA	3,4	18,4	2,6	20,4	3,1	26,0	-1,0	27,2	-1,0	36,9	4,1	22,5
NPL	6,4	13,4	5,6	16,0	6,1	22,8	2,0	24,1	2,0	34,7	7,1	18,7
SiQ	2,4	16,0	1,6	18,3	2,1	24,4	-2,0	25,6	-2,0	35,8	3,1	20,6
IEN	23,7	41,4	22,9	42,3	23,4	45,3	19,3	46,0	19,3	52,3	24,4	43,4
VNIIFTRI	-6,6	58,0	-7,4	58,7	-6,9	60,8	-11,0	61,4	-11,0	66,2	-5,9	59,4
SPRING	0,5	26,8	-0,3	28,2	0,2	32,5	-3,9	33,4	-3,9	41,7	1,2	29,8

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIA D_{ij} /10^{-3}	NMIA U_{ij} /10^{-3}	NPL D_{ij} /10^{-3}	NPL U_{ij} /10^{-3}	SiQ D_{ij} /10^{-3}	SiQ U_{ij} /10^{-3}	IEN D_{ij} /10^{-3}	IEN U_{ij} /10^{-3}	VNIIFTRI D_{ij} /10^{-3}	VNIIFTRI U_{ij} /10^{-3}	SPRING D_{ij} /10^{-3}	SPRING U_{ij} /10^{-3}
NMIJ	0,8	8,8	-2,6	20,4	-5,6	16,0	-1,6	18,3	-22,9	42,3	7,4	58,7	0,3	28,2
NIST	0,3	18,4	-3,1	26,0	-6,1	22,8	-2,1	24,4	-23,4	45,3	6,9	60,8	-0,2	32,5
METAS	4,4	20,0	1,0	27,2	-2,0	24,1	2,0	25,6	-19,3	46,0	11,0	61,4	3,9	33,4
CSIR-NML	4,4	32,0	1,0	36,9	-2,0	34,7	2,0	35,8	-19,3	52,3	11,0	66,2	3,9	41,7
PTB	-0,7	13,0	-4,1	22,5	-7,1	18,7	-3,1	20,6	-24,4	43,4	5,9	59,4	-1,2	29,8
NMIA	3,4	18,4			-3,0	22,8	1,0	24,4	-20,3	45,3	10,0	60,8	2,9	32,5
NPL	6,4	13,4	3,0	22,8			4,0	20,9	-17,3	43,5	13,0	59,5	5,9	30,0
SiQ	2,4	16,0	-1,0	24,4	-4,0	20,9			-21,3	44,4	9,0	60,2	1,9	31,2
IEN	23,7	41,4	20,3	45,3	17,3	43,5	21,3	44,4			30,3	71,3	23,2	49,3
VNIIFTRI	-6,6	58,0	-10,0	60,8	-13,0	59,5	-9,0	60,2	-30,3	71,3			-7,1	63,9
SPRING	0,5	26,8	-2,9	32,5	-5,9	30,0	-1,9	31,2	-23,2	49,3	7,1	63,9		

ANNEX G-7 Matrix of equivalence for standard PTB 2-6 at 26 GHz

Standard : **PTB 2 - 6**

Frequency: **26 GHz**

Lab *j* →

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIJ D_{ij} /10^{-3}	NMIJ U_{ij} /10^{-3}	NIST D_{ij} /10^{-3}	NIST U_{ij} /10^{-3}	METAS D_{ij} /10^{-3}	METAS U_{ij} /10^{-3}	CSIR-NML D_{ij} /10^{-3}	CSIR-NML U_{ij} /10^{-3}	PTB D_{ij} /10^{-3}	PTB U_{ij} /10^{-3}
NMIJ	-17,1	15,0			-9,2	24,2	-1,4	28,3	-12,4	40,9	-11,9	22,7
NIST	-7,9	19,0	9,2	24,2			7,8	30,6	-3,2	42,5	-2,7	25,5
METAS	-15,7	24,0	1,4	28,3	-7,8	30,6			-11,0	44,9	-10,5	29,4
CSIR-NML	-4,7	38,0	12,4	40,9	3,2	42,5	11,0	44,9			0,5	41,6
PTB	-5,2	17,0	11,9	22,7	2,7	25,5	10,5	29,4	-0,5	41,6		
NMIA	-2,7	18,6	14,4	23,9	5,2	26,6	13,0	30,4	2,0	42,3	2,5	25,2
NPL	3,3	15,4	20,4	21,5	11,2	24,5	19,0	28,5	8,0	41,0	8,5	22,9
SiQ	-6,7	16,0	10,4	21,9	1,2	24,8	9,0	28,8	-2,0	41,2	-1,5	23,3
IEN	17,5	41,2	34,6	43,8	25,4	45,4	33,2	47,7	22,2	56,0	22,7	44,6
VNIIFTRI	9,3	30,0	26,4	33,5	17,2	35,5	25,0	38,4	14,0	48,4	14,5	34,5
SPRING	1,3	17,6	18,4	23,1	9,2	25,9	17,0	29,8	6,0	41,9	6,5	24,5

Lab *i*	D_i /10^{-3}	U_i /10^{-3}	NMIA D_{ij} /10^{-3}	NMIA U_{ij} /10^{-3}	NPL D_{ij} /10^{-3}	NPL U_{ij} /10^{-3}	SiQ D_{ij} /10^{-3}	SiQ U_{ij} /10^{-3}	IEN D_{ij} /10^{-3}	IEN U_{ij} /10^{-3}	VNIIFTRI D_{ij} /10^{-3}	VNIIFTRI U_{ij} /10^{-3}	SPRING D_{ij} /10^{-3}	SPRING U_{ij} /10^{-3}
NMIJ	-17,1	15,0	-14,4	23,9	-20,4	21,5	-10,4	21,9	-34,6	43,8	-26,4	33,5	-18,4	23,1
NIST	-7,9	19,0	-5,2	26,6	-11,2	24,5	-1,2	24,8	-25,4	45,4	-17,2	35,5	-9,2	25,9
METAS	-15,7	24,0	-13,0	30,4	-19,0	28,5	-9,0	28,8	-33,2	47,7	-25,0	38,4	-17,0	29,8
CSIR-NML	-4,7	38,0	-2,0	42,3	-8,0	41,0	2,0	41,2	-22,2	56,0	-14,0	48,4	-6,0	41,9
PTB	-5,2	17,0	-2,5	25,2	-8,5	22,9	1,5	23,3	-22,7	44,6	-14,5	34,5	-6,5	24,5
NMIA	-2,7	18,6			-6,0	24,1	4,0	24,5	-20,2	45,2	-12,0	35,3	-4,0	25,6
NPL	3,3	15,4	6,0	24,1			10,0	22,2	-14,2	44,0	-6,0	33,7	2,0	23,4
SiQ	-6,7	16,0	-4,0	24,5	-10,0	22,2			-24,2	44,2	-16,0	34,0	-8,0	23,8
IEN	17,5	41,2	20,2	45,2	14,2	44,0	24,2	44,2			8,2	51,0	16,2	44,8
VNIIFTRI	9,3	30,0	12,0	35,3	6,0	33,7	16,0	34,0	-8,2	51,0			8,0	34,8
SPRING	1,3	17,6	4,0	25,6	-2,0	23,4	8,0	23,8	-16,2	44,8	-8,0	34,8		

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ANNEX H Uncertainty budgets of the participants for 10 GHz and 26 GHz

NPL

Scheme for the uncertainty budget for K_X

The mathematical model: $$K_X = K_{DUT50} \times CC_{TS} \times \Delta CC_{TS} \times \frac{R_{RF}}{R_{50}} \times \frac{MF_{DUT50}}{MF_{DUTRF}} \times \Delta_{DUT}$$

Where

K_{DUT50}: Calibration Factor of the DUT at 50 MHz with respect to 1 kHz
CC_{TS}: Calibration Constant of the 3,5 mm Transfer Standard with respect to 50 MHz
ΔCC_{TS}: Factor to account of any change in CC_{TS} since the last calibration
R_{RF}: Ratio of DUT output to Transfer Standard at the Calibration Frequency
R_{50}: Ratio of DUT output to Transfer Standard at 50 MHz
MF_{DUTRF}: Mismatch Factor for the DUT at the Calibration Frequency
MF_{DUT50}: Mismatch Factor for the DUT at 50 MHz
Δ_{DUT}: Factor to account for variations in the measurement of the DUT due to random effects (connector)

CC_{TS} and Δ_{DUT} have expectations of 1.00 all other quantities are obtained from either measurement or calculation

Measuring frequency: 10 GHz **travelling standard: PTB 1-3**

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$ %	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$ %	Degree of freedom ν_i
K_{DUT50}	0.9858	0.12	Normal / B	1	0.12	600
CC_{TS}	1.01194	0.41	Normal / B	1	0.41	500
ΔCC_{TS}	1.00	0.10	Rect /B	1	0.058	50
R_{RF}	54.921	0.05	Rect /B	1	0.03	50
R_{50}	58.341	0,05	Rect /B	1	0.03	50
MF_{DUT50}	0.99994	0.02	Normal / B	1	0.02	50
MF_{DUTRF}	1.0003	0.05	Normal / B	1	0.05	50
Δ_{DUT}	1.000	0.01	Normal / A	1	0.01	4
K_X	0,9388	0.44				ν_{eff} 622

Measuring frequency: 26 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$ %	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$ %	Degree of freedom ν_i
K_{DUT50}	0.9858	0.12	Normal / B	1	0.12	600
CC_{TS}	0.9820	0.74	Normal / B	1	0.74	500
ΔCC_{TS}	1.00	0.10	Rect /B	1	0.058	50
R_{RF}	56.236	0.05	Rect /B	1	0.03	50
R_{50}	58.341	0,05	Rect /B	1	0.03	50
MF_{DUT50}	0.99994	0.01	Normal / B	1	0.01	50
MF_{DUTRF}	1.0066	0.13	Normal / B	1	0.13	50
Δ_{DUT}	1.000	0.01	Normal / A	1	0.01	4
K_X	0,9269	0.77				ν_{eff} 559

NIST Model: **Scheme for the uncertainty budget for C_{DUT}**

The calibration factor of the DUT is given by : $$C_{DUT} = C_S \frac{P_{3,S}}{P_{3,DUT}} \frac{P_{DUT}}{P_S} \frac{|1-\Gamma_{DUT}\Gamma_G|^2}{|1-\Gamma_S\Gamma_G|^2},$$

where $P_{3,S}$ is the power measured by the port 3 monitor detector when the NIST standard detector is connected and $P_{3,DUT}$ is the power measured by the port 3 monitor detector when the DUT is connected. P_{DUT} and P_S are the powers measured by the DUT and standard detectors respectively that are connected to port 2 of the splitter. C_S is the calibration factor of the NIST standard, which is determined by measurements of the detector in the NIST microcalorimeter [2].

NIST Uncertainty estimates for travelling standard PTB 1-3 at 10.0 GHz.

Source of Uncertainty	Method of Evaluation	Probability Distribution	Eff. Degrees of Freedom	Contribution to Std. Unc.
Direct Comparison Mismatch Correction	Type B	Gaussian	50	0.0015
Microcalorimeter 2.4 mm Standard	Type B	Gaussian	50	0.0046
Calibration of Direct Comparison	Type A	Gaussian	2	0.0013
Connector Repeatability	Type A	Rectangular	9	0.0010
dc Reference Measurement	Type B	Gaussian	50	0.0063
2.4 mm/3.5 mm Adapter Correction	Type B	Gaussian	50	0.0036
Combined Standard Uncertainty		Gaussian	129	0.0088

NIST Uncertainty estimates for travelling standard PTB 1-3 at 26.0 GHz.

Source of Uncertainty	Method of Evaluation	Probability Distribution	Eff. Degrees of Freedom	Contribution to Std. Unc.
Direct Comparison Mismatch Correction	Type B	Gaussian	50	0.0018
Microcalorimeter 2.4 mm Standard	Type B	Gaussian	50	0.0051
Calibration of Direct Comparison	Type A	Gaussian	2	0.0007
Connector Repeatability	Type A	Rectangular	9	0.0024
dc Reference Measurement	Type B	Gaussian	50	0.0063
2.4 mm/3.5 mm Adapter Correction	Type B	Gaussian	50	0.0041
Combined Standard Uncertainty		Gaussian	137	0.0093

CSIR-NML

Scheme for the uncertainty budget for K_X

Measuring frequency: 10 GHz **travelling standard: PTB 1 -3**

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
K_S	0,970	0,015	N / B	1	0,0075	200
δK_S	0,000	0,002	R / B	1	0,0012	50
$M_{sr,50\ MHz}$	1,000	0,0010	U / B	1	0,00071	50
$M_{sc\ ,port\ 2}$	1,000	0,0013	U / B	1	0,00092	50
$M_{sc\ ,port\ 3}$	1,000	0,0011	U / B	1	0,00078	50
$M_{xc\ ,port\ 2}$	1,000	0,0025	R / B	1	0,0018	50
$M_{xc\ ,port\ 3}$	1,000	0,0022	U / B	1	0,0016	50
$P_{cr,50MHz}$	1,003	0,0080	N / B	1	0,004	200
$P_{cr,1kHz}$	1,000	0,0010	N / B	1	0,0005	200
P_{CC}	1,000	0,003	N / B	1	0,0015	200
Power meter	1,000	0,007	R / B	1	0,0040	50
P	0,972	0,003	N / A	1	0,0015	3
K_X	**0,946**	**0,011**				ν_{eff} 426

Measuring frequency: 26 GHz **travelling standard: PTB 1 -3**

Quantity X_i	estimate x_i	Standard Uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
K_S	0,943	0,0250	N / B	1	0,0125	200
δK_S	0,000	0,011	R / B	1	0,00635	50
$M_{sr,50\ MHz}$	1,000	0,0010	U / B	1	0,00071	50
$M_{sc\ ,port\ 2}$	1,000	0,0070	U / B	1	0,00495	200
$M_{sc\ ,port\ 3}$	1,000	0,0076	U / B	1	0,00537	200
$M_{xc\ ,port\ 2}$	1,000	0,0059	R / B	1	0,00417	200
$M_{xc\ ,port\ 3}$	1,000	0,0064	U / B	1	0,00453	200
$P_{cr,50MHz}$	1,003	0,0080	N / B	1	0,0040	200
$P_{cr,1kHz}$	1,000	0,0010	N / B	1	0,00058	200
P_{CC}	1,000	0,003	N / B	1	0,0015	200
Power meter	1,000	0,007	R / B	1	0,0040	50
P	0,978	0,003	N / A	1	0,0030	3
K_X	**0,925**	**0,019**				ν_{eff} 527

NMIJ **Scheme for the uncertainty budget for K_X**

The mathematical model: $$K_X(f)=\frac{P(1\text{kHz})}{P_{\text{inc}}(f)}\cdot\frac{U_{\text{Th}}(f)}{U_{\text{Th}}(1\text{kHz})}=C_{\text{d}}\cdot\frac{R_{\text{rf}}}{R_{\text{ac}}}\cdot M_{\text{u}}$$

With

$$C_{\text{d}}=\frac{P_{\text{inc}}(f)}{P_{\text{mu}}}\cdot M_{\text{u}}\qquad R_{rf}=\frac{U_{Th}(f)}{P_{mu}}\qquad R_{ac}=\frac{U_{Th}(1kHz)}{P(1kHz)}\qquad M_u=\left|1-\Gamma_{\text{g}}\cdot\Gamma_{\text{u}}\right|$$

C_d : power splitting ratio
P_{mu}: monitor power
U_{Th}: thermal voltage
(see: T. Inoue and K. Yamamura: "A broadband power meter calibration system in the frequency range from 10 MHz to 40 GHz using coaxial calorimeter " in IEEE Trans. IM Vol. 45 No.1 Feb. 1996)

Measuring frequency: 10 GHz **travelling standard: PTB 1- 3**

Quantity X_i	estimate x_i	Source of uncertainty	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
C_d	1.00	Calorimeter	$1.60 \cdot 10^{-3}$	Normal / B	-1.00	$1.60 \cdot 10^{-3}$	12
R_{rf}	0.23 V/W	Ratio of U_{Th} to monitor	$3.58 \cdot 10^{-5}$	Normal / B	4.35	$1.56 \cdot 10^{-4}$	10
		Std. dev of meas value	$1.10 \cdot 10^{-4}$	Normal / A	4.35	$4.78 \cdot 10^{-4}$	5
R_{ac}	0.23 V/W	Ratio of U_{Th} to 1 kHz	$7.39 \cdot 10^{-5}$	Normal / B	-4.35	$3.21 \cdot 10^{-4}$	9
		Std. dev of meas value	$1.0 \cdot 10^{-5}$	Normal / A	-4.35	$4.35 \cdot 10^{-5}$	*5*
M_u	1.00	Mismatch	$1,04 \cdot 10^{-3}$	U / B	1.00	$1.04 \cdot 10^{-3}$	4
K_X	**0.9438**		**$2.00 \cdot 10^{-3}$**				ν_{eff} 18

Measuring frequency: 26 GHz **travelling standard: PTB 1- 3**

Quantity X_i	estimate x_i	Source of uncertainty	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
C_d	1.00	Calorimeter	$3.40 \cdot 10^{-3}$	Normal / B	-1.00	$3.40 \cdot 10^{-3}$	9
R_{rf}	0.23 V/W	Ratio of U_{Th} to monitor	$3.58 \cdot 10^{-5}$	Normal / B	4.35	$1.56 \cdot 10^{-4}$	10
		Std. dev of meas value	$1.10 \cdot 10^{-4}$	Normal / A	4.35	$4.78 \cdot 10^{-4}$	5
R_{ac}	0,23 V/W	Ratio of U_{Th} to 1 kHz	$7.39 \cdot 10^{-5}$	Normal / B	-4.35	$3.21 \cdot 10^{-4}$	9
		Std. dev of meas value	$1.00 \cdot 10^{-5}$	Normal / A	-4.35	$4.35 \cdot 10^{-5}$	5
M_u	1.00	Mismatch	$5.87 \cdot 10^{-3}$	U / B	1.00	$5.87 \cdot 10^{-3}$	4
K_X	**0.9020**		**$6.90 \cdot 10^{-3}$**				ν_{eff} 6

NMIA

Scheme for the uncertainty budget for K_X

Measuring frequency: 18 GHz **travelling standard: PTB 1-3**

Uncertainty component	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
Calibration of Six-port	0.0009	Normal / A	1	0.0009	15
Mismatch	0.0010	U / B	1	0.0010	20
Instrumentation etc.	0.0007	Normal / A	1	0.0007	20
Uncertainty of Working standard	0.0043	Normal / B	1	0.0043	30
Adaptor	0.0044	Normal / B	1	0.0044	15
K_X = 0.9330	**0.0063**				ν_{eff} 44

Measuring frequency: 23 GHz **travelling standard: PTB 1-3**

Uncertainty component	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
Calibration of Six-port	0.0030	Normal / A	1	0.0030	15
Mismatch	0.0010	U / B	1	0.0010	20
Instrumentation etc.	0.0015	Normal / A	1	0.0015	20
Uncertainty of Working standard	0.0055	Normal / B	1	0.0055	30
Adaptor	0.0064	Normal / B	1	0.0064	15
K_X = 0.9270	**0.0092**				ν_{eff} 47

SiQ **Scheme for the uncertainty budget for K_X**

Measuring frequency: 10 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
K_S	0,9921	0,0065	Normal / B	0,946	0,0061	1000000
δK_S	0,000	0,0020	Rect. / B	0,542	0,0011	1000000
M_S	1,000	0,0024	U / B	0,663	0,0016	1000000
M_X	1,000	0,0031	U / B	0,663	0,0020	1000000
p_{Cr}	1,000	0,0010	Normal / B	0,938	0,0009	1000000
p_{Cc}	1,000	0,0010	Normal / B	0,938	0,0009	1000000
p	0,9456	0,0009	Normal / A	0,992	0,0009	5
K_X	**0,938**	**0,007**				ν_{eff} 16 000

Measuring frequency: 26 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
K_S	0,9891	0,0080	Normal / B	0,929	0,0074	1000000
δK_S	0,000	0,0020	Rect. / B	0,531	0,0011	1000000
M_S	1,000	0,0009	U / B	0,650	0,0006	1000000
M_X	1,000	0,0042	U / B	0,650	0,0027	1000000
p_{Cr}	1,000	0,0010	Normal / B	0,919	0,0009	1000000
p_{Cc}	1,000	0,0010	Normal / B	0,919	0,0009	1000000
p	0,9293	0,0002	Normal / A	0,989	0,0002	5
K_X	**0,919**	**0,008**				ν_{eff} 13 0000

IEN

The mathematical model: $K_X = (1-|\Gamma|^2)\cdot\eta_{eff}$ and $\eta_{eff} = g(e+\delta e_{th}+\delta e_U)$

With.

η_{eff}: effective efficiency of the DUT

g: microcalorimeter efficiency

$e = e_{1kHz}/e_f$ ratio of microcalorimeter output thermovoltage e at 1 kHz to that at the measuring frequency f

δe_{th}: correction factor for the thermal voltage drift of the system

δe_U: correction factor for not perfect 1 kHz – f power substitution

Scheme for the uncertainty budget for K_X

Measuring frequency: 10 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_X)$	Degree of freedom ν_i
Γ	0.0262	0.0066	U /B	-0.049	-0.000033	100
g	1.1559	0.0166	Normal / B	0.808	0.0135	26
e	0.8089	0.0006	Normal / A	1.151	0.00068	11
δe_{th}	0.00	0.0011	Rect. / B	1.151	0.0013	100
δe_U	-0.0003	0.0004	Rect. / B	0.895	0.00032	100
K_X	**0.9344**	**0.0135**				ν_{eff} 26

Measuring frequency: 26 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_X)$	Degree of freedom ν_i
Γ	0.0543	0.0067	U /B	-0.098	-0.00066	100
g	1.3191	0.0230	Normal / B	0.808	0.0186	27
e	0.6845	0.0007	Normal / B	1.314	0.00086	11
δe_{th}	0.00	0.0008	Rect. / B	1.314	0.0011	100
δe_U	0.00033	0.0004	Rect. / B	0.895	0.00038	100
K_X	**0.9003**	**0.0187**				ν_{eff} 27

VNIIFTRI

Scheme for the uncertainty budget for K_X

Measuring frequency: 10 GHz **travelling standard: PTB 2-6**

Quantity X_i	Rel. std uncertainty $u(x_i)$ in 10^{-3}	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
K_c	1,7	Rect. / B	1	1,63	∞
P_{et}	0,6	Rect. / A	1	0,57	∞
N_X	1,2	Norm / A	1	1,15	7
N_{cal}	0,3	Rect. / A	1	0,29	∞
P_{cal}	0,2	Rect. / B	1	0,189	∞
P_{ref}	0,3	Rect. / A	1	0,29	∞
M_{et}	2,1	U / B	1	2,10	∞
M_X	32,1	U / B	1	2,01	∞
η	3,2	Rect. / B	1	3,07	3
					ν_{eff} 16,2

K_C= 0,959 ± 0,010 **$u(K_C)$ = 0,00469**

Measuring frequency: 26 GHz **travelling standard: PTB 1- 3**

Quantity X_i	Rel. std uncertainty $u(x_i)$ in 10^{-3}	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
K_c	1,7	Rect. / B	1	1,16	∞
P_{et}	0,6	Rect. / A	1	0,55	∞
N_X	2,1	Norm / A	1	1,94	7
N_{cal}	0,3	Rect. / A	1	0,28	∞
P_{cal}	0,2	Rect. / B	1	0,18	∞
P_{ref}	0,3	Rect. / A	1	0,28	∞
M_{et}	1,6	U / B	1	1,48	∞
M_X	13,4	U / B	1	12,38	∞
η	5,7	Rect. / B	1	5,27	3
					ν_{eff} 139

K_C= 0,924 ± 0,028 **$u(K_C)$ = 0,0138**

SPRING

Scheme for the uncertainty budget for K_X

Measuring frequency: 10 GHz **travelling standard: PTB 1 - 3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability Distribut. / method of eval. (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
K_S	0.877 4	0.006 3	Normal / B	1.06	0.006 7	Infinity
DC power in W	$3.00 \cdot 10^{-3}$	$0.000\ 5 \cdot 10^{-3}$	Rect / B	311.4	0.000 16	Infinity
P_S(c) in W	$2.76 \cdot 10^{-3}$	$0.002\ 7 \cdot 10^{-3}$	Rect / B	-338.0	-0.000 91	Infinity
U_X (r) in V	$649 \cdot 10^{-6}$	$0.19 \cdot 10^{-6}$	Rect / B	-1 438.5	-0.000 27	Infinity
U_X (c) in V	$637 \cdot 10^{-6}$	$0.19 \cdot 10^{-6}$	Rect / B	1 465.1	0.000 28	Infinity
U_{MS} (c) in V	0.387 66	$0.015 \cdot 10^{-3}$	Rect / B	4.8	0.000 07	Infinity
U_{MX}(c) in V	0,387 61	$0.015 \cdot 10^{-3}$	Rect / B	-0.73	-0.000 01	Infinity
$\lvert \Gamma_S \rvert$	0.021	0.002 4	Rect / B	0.053	0.000 12	Infinity
Phase (Γ_S), rad	2.49	0.50	Rect / B	-0.001 9	-0.000 97	Infinity
$\lvert \Gamma_{dut} \rvert$	0.015	0.002 4	Rect / B	-0.092	-0.000 21	Infinity
Phase (Γ_{dut}),rad	1.74	1.8	Rect / B	-0.001 4	-0.002 5	Infinity
$\lvert \Gamma_g \rvert$	0.049	0.002 4	Rect / B	0.011	0.000 02	Infinity
Phase (Γ_g),rad	-0.89	0.050	Rect / B	0.000 52	0.000 03	Infinity
Type A	0.002 3	0.000 73	Normal /A	1	0.000 73	9
K_X	**0.9384**	**0.007 4**				ν_{eff} 94 706

Measuring frequency: 26 GHz **travelling standard: PTB 1 - 3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability Distribut. / method of eval. (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Kx)$	Degree of freedom ν_i
K_S	0.751 7	0.007 1	Normal / B	1.14	0.008 0	Infinity
DC power in W	$3.00 \cdot 10^{-3}$	$0.000\ 5 \cdot 10^{-3}$	Rect / B	284.6	0.000 14	Infinity
P_S(c) in W	$2.38 \cdot 10^{-3}$	$0.002\ 7 \cdot 10^{-3}$	Rect / B	-359.0	-0.000 98	Infinity
U_X (r) in V	$649 \cdot 34^{-6}$	$0.19 \cdot 10^{-6}$	Rect / B	-1 314.7	-0.000 25	Infinity
U_X (c) in V	596.07^{-6}	$0.19 \cdot 10^{-6}$	Rect / B	1 432.2	0.000 27	Infinity
U_{MS} (c) in V	0.387 47	$0.015 \cdot 10^{-3}$	Rect / B	4.4	0.000 07	Infinity
U_{MX}(c) in V	0,387 39	$0.015 \cdot 10^{-3}$	Rect / B	-0.66	-0.000 01	Infinity
$\lvert \Gamma_S \rvert$	0.1336	0.002 9	Rect / B	-0.11	0.000 31	Infinity
Phase (Γ_S), rad	-2.72	0.033	Rect / B	-0.01 7	-0.000 56	Infinity
$\lvert \Gamma_{dut} \rvert$	0.0623	0.002 5	Rect / B	-0.13	-0.000 32	Infinity
Phase (Γ_{dut}),rad	2.98	0.055	Rect / B	-0.007 8	-0.000 43	Infinity
$\lvert \Gamma_g \rvert$	0.074 4	0.003 4	Rect / B	0.012	0.000 41	Infinity
Phase (Γ_g),rad	0.62	0.051	Rect / B	0.009 0	0.000 46	Infinity
Type A	0.005 7	0.001 8	Normal /A	1	0.001 8	9
K_X	**0.8583**	**0.008 4**				ν_{eff} 4 148

NRC-INMS

Measuring frequency: 10 GHz **travelling standard: PTB 1-3**

Uncertainty component	Standard uncertainty $u(x_i)$ in 10^{-3}	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y_i)$ in 10^{-3}	Degree of freedom ν_i
Responsitivity	2,52	Normal / B	1	2,52	8,2
Att.of calorimeter Input lines	2,00	Normal / B	1	2,00	8,0
RF-DC current distr. In calorimeter	0,15	Normal / B	1	0,15	8,0
Calorimeter reflection	0,016	Normal / B	1	0,016	8,0
Transfer standard	1,50	Normal / B	1	1,50	8,0
Adapter Transm.	1,74	U/B	1	1,74	8,0
Data statistics	0,10	Normal /A	1	0,10	9,0
Connector repetability	0,50	Normal /A	1	0,50	9,0
Temperature depend..	0,000 3	U/B	2000	0,58	2,0
					ν_{eff} 30,2

The calibration factor K_X at 10 GHz : K_X = 0,9404 ± 0,008 2 (k = 2)

Measuring frequency: 26 GHz **travelling standard: PTB 1-3**

Uncertainty component	Standard uncertainty $u(x_i)$ in 10^{-3}	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y_i)$ in 10^{-3}	Degree of freedom ν_i
Responsitivity	2,52	Normal / B	1	2,52	8,2
Calorimeter	2,00	Normal / B	1	2,00	8,0
Transfer standard	2,00	Normal / B	1	2,00	8,0
Adapter Transm.	2,15	U / B	1	2,15	8,0
Mismatch	2,00	Normal / B	1	2,00	8,0
Data statistics	0,32	Normal /A	1	0,32	9,0
Connector repetability	0,13	Normal /A	1	0,13	24,0
Temperature depend.	0,000 3	U/B	2000	0,58	2,0
					ν_{eff} 40,3

The calibration factor K_X at 26 GHz : K_X = 0,925 8 ± 0,009 8 (k = 2)

METAS Uncertainty budget for K_X (CCEM RF-K10CL)

Uncertainty contributions

*X*1: Reference power sensor calibration factor uncertainty
*X*2: Uncertainty due to drift of reference sensor calibration since the last calibration.
*X*3: Uncertainty of power meter calibrator (50 MHz) output power
*X*4: Uncertainty due to imped. mismatch between power splitter output 2 and DUT
*X*5: Unc. due to imped. Mism. betw. power splitter (Port 2) and input of 3.5mm adapter
*X*6: Unc. due to imped. Mism. betw. 2.4-mm-adapter-output and reference sensor
*X*7: Repeatability of 6 measurements
*X*8: Unc. due to power meter display resolution during internal adjustment (50 MHz)
*X*9: Unc. due to mism. betw. power meter calibrator output and reference sensor at 50 MHz
*X*10: System temperature coefficient
*X*14: Adapter attenuation uncertainty
*X*15: Unc. due to imped. mismatch between power splitter (Port 2) and reference sensor

Measuring frequency: 10 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
*X*1	0.983	0.013	Normal / B	1	0.0065	
*X*2	1	0.001	Rect / B	1	0.00058	
*X*3		0.006	Normal / B	1	0.003	
*X*4	1	0.0013	U / B	1	0.0009	
*X*5	1	0.00043	U / B	1	0.0003	
*X*6	1	0.00015	U / B	1	0.00011	
*X*7		0.0004	Normal / A	1	0.0004	
*X*8	1	0.001	Rect / B	1	0.00058	
*X*9	1	0.00139	U / B	1	0.00099	
*X*10	1	0.001	Rect / B	1	0.00058	
*X*14		0.0139	Normal / B	1	0.0069	
*X*15	1	0.0007	U / B	1	0.0005	
K_X	**0.941**	**0.010**				ν_{eff}

METAS

Measuring frequency: 26 GHz **travelling standard: PTB 1-3**

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(K_x)$	Degree of freedom ν_i
$X1$	0.959	0.015	Normal / B	1	0.0075	
$X2$	1	0.001	Rect / B	1	0.00058	
$X3$		0.006	Normal / B	1	0.003	
$X4$	1	0.0035	U / B	1	0.0025	
$X5$	1	0.00149	U / B	1	0.0011	
$X6$	1	0.00252	U / B	1	0.0018	
$X7$		0.0004	Normal / A	1	0.0004	
$X8$	1	0.001	Rect / B	1	0.00058	
$X9$	1	0.00139	U / B	1	0.00099	
$X10$	1	0.001	Rect / B	1	0.00058	
$X14$		0.0186	Normal / B	1	0.0093	
$X15$	1	0.0037	U / B	1	0.0026	
$\boldsymbol{K_X}$	0.909	0.012				ν_{eff}

PTB

Scheme for the uncertainty budget for K_X

Model:
$$K_X(f) = \left(1 - \left|\Gamma_{in}(f)\right|^2\right) \cdot \eta_{\mathrm{eff}}(f)$$

with:
$$\eta_{eff}(f) = c_r \cdot \left(e_{\mathrm{th}} + \delta e_{\mathrm{th}}\right) \cdot \left(1 + \delta V\right)$$

Γ_{in}: input reflection coefficient of the sensor
V: ratio $V_{RF}/V_{ref} \cong 1$ of sensor output voltages V_{RF} at the measuring frequency f and V_{ref} at the reference frequency f_{ref}
δV: deviation of V from 1 because of unbalance between output voltage at RF and reference frequency
e_{th}: microcalorimeter thermal voltage ratio e_{fref}/e_f,
δe_{th}: correction of thermal voltage ratio e_{fref}/e_f, because of thermal drift
c_r : microcalorimeter equivalence correction factor*
f: measuring frequency
f_{ref}: reference frequency 1 kHz

* Uncertainty of c_r includes the nonlinearity of the thermopile voltage, losses in the isolation section and non equivalence of RF and DC**-power**

PTB

Uncertainty of measurement budget for $K_X(f)$ at 10 GHz for PTB 1 - 3

Measurement June 2000

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / type	Sensitivity coefficient c_i	Contribution to the std. unc. $u_i(y)$	Degrees of freedom $\nu_{eff\ i}$
Γ_{in}	0,026 0	0,003 0	Normal / **B**	0,049	0,000 2	500
δV	0	0,000 2	Normal / **B**	1,010	0,000 1	50
e	0,932 9	0,000 6	Normal / **A**	1,010	0,000 6	6
δe	0,000 7	0,000 8	Rect / **B**	1,010	0,000 5	50
c_r	1,011 0	0,004 2	Normal / **B**	0,933	0,003 9	500
K_X	0,9425	0,004 0				$\nu_{eff\ I}$: 515

The calibration factor K_X at 10 GHz : K_X = 0,942 5 ± 0,008 0 (k = 2)

Uncertainty of measurement budget for $K_X(f)$ at 26 GHz for PTB 1 - 3

Measurement June 2000

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distributio n / type**	**Sensitivity coefficient** c_i	**Contribution to the std. unc.** $u_i(y)$	**Degrees of freedom** $\nu_{eff\ i}$
Γ_{in}	0,057 9	0,003 0	Normal / **B**	0,107	0,000 3	500
δV	0	0,000 2	Normal / **B**	1,015	0,000 1	50
e	0,9091	0,000 6	Normal / **A**	1,015	0,000 6	7
δe	0,000 7	0,001 5	Rect / **B**	1,015	0,000 9	50
c_r	1,018 0	0,009 2	Normal / **B**	0,906	0,008 3	500
$\boldsymbol{K_X}$	**0,9224**	**0,008 4**				$\nu_{eff\ I}$: 518

The calibration factor K_X at 26 GHz : K_X = 0,922 4 ± 0,017 0 (k = 2)