EUROMET.EM.RF-K10.CL

EUROMET comparison 525 (GT-RF/99-2)

“Power in the coaxial PC 3,5 mm line system“

Final Report

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Abstract

The results and the measurement methods of the EUROMET comparison 525 are summarised in this report. The task of the comparison was to determine the calibration factor for frequencies up to 26 GHz of two identical RF power sensors with PC 3,5 mm connector in the coaxial 3,5 mm line system. Eight European national metrology institutes (NMIs) participated in this comparison, which was organised as a successor of the CCEM key comparison with the same subject. Two RF power travelling standards with male PC 3,5 mm connectors were measured at: **EIM** (Greece), **AREPA** (Denmark), **BNM-LCIE** (France), **NPL** (United Kingdom), **NMI-VSL** (Netherlands), **SP** (Sweden), **UME** (Turkey), and **PTB (**Germany**)** as the pilot laboratory.

1. Introduction

The EUROMET comparison project "RF power in the coaxial PC 3,5 mm line system" was accepted at the EUROMET RF expert meeting in December 1998. In June 1999 **at the Working Group on Radiofrequency Quantities (GT- RF) meeting**, it was decided that this project should be carried out as GT-RF Key Comparison, later called CCEM.RF-K10 CL and **entitled "**Power in 50 Ω coaxial lines, frequency: 50 MHz to 26 GHz**"** with the Physikalisch-Technische Bundesanstalt (PTB) as the pilot laboratory. The measurements of this key comparison were finished in January 2002. Most participants of the original EUROMET project successfully joined the CCEM comparison. It was however not possible to include in the CCEM Key comparison all participants of the original EUROMET comparison interested in joining it. Since later on some additional national institutes wished to join the PC 3,5 mm power comparison, the EUROMET project 525 started in April 2002 with eight participants and again PTB as the pilot laboratory. The subject of the EUROMET 525 comparison and the type of standards were the same as those of the CCEM comparison, and thus it can be considered as the regional loop of the CCEM.RF–K10 CL comparison.

As the two travelling standards had been damaged at the end of the CCEM comparison, they had to be repaired and re-measured at PTB for the EUROMET loop. Besides the type of the standards also the procedure, the quantity to be measured and the frequencies applied for the EUROMET comparison were identical to those of the CCEM key comparison. Thereby, the participants of the EUROMET comparison could directly compare their results directly with the key comparison reference value (KCRV) of the preceding CCEM key comparison. With the measurement results of two participants (NPL and PTB) - taking part in both comparisons it was possible to link the EUROMET comparison results to the KCRV results of the CCEM comparison.

2. Participants and organisation of the comparison

2.1 Organisation of the comparison and settling unexpected incidents

This EUROMET comparison was organised following the Guidelines for CIPM key comparisons.

Before the beginning of the comparison, the draft of the technical protocol had been written by the pilot laboratory and sent to all participants. After some small modifications it was approved by Dr. Giancarlo Marullo Reedtz, the EUROMET Technical Committee Chairman for Electricity and Magnetism. The final version was sent to all participants in June 2002. In this protocol, the travelling standards, the quantity to be measured, and the organisation were described and also measuring instructions and examples for the uncertainty of measurements of two typical measuring procedures were given.

In Spring 2002, a timetable for the circulation of the two travelling standards was prepared for the six participants who wished to take part in an intercomparison for RF power in the PC 3,5 mm line system but were not able to join the CCEM key comparison. The pilot laboratory (PTB) - as the seventh participant - asked NPL (UK) to join in the EUROMET comparison as well, in order that two participants should take part in both comparisons. The measurement results of these two participants would thus constitute a link between the EUROMET intercomparison and the CCEM Key comparison. The timetable was accepted at the end of April 2002 and sent to the participants.

The standards were first to be calibrated by the pilot laboratory in April 2002 and the comparison was to start on the 6th of May 2002, with the beginning of measurements by the first participant (EIM). The final measurements of the standards by the pilot laboratory were scheduled for January 27, 2003, and the end of the comparison was scheduled for February 13, 2003 (see the original timetable in Annex A).

It was planned that before the travelling standards would be forwarded to the last participant (UME, Turkey) they would have to be sent back to PTB because of customs requirements, i. e. the despatch to a country beyond the EU must be accompanied by ATA carnet.

During a check measurement at PTB in December 2002 it turned out that one of the travelling standards (PTB P1-03-2) showed significant instabilities at frequencies above 10 GHz when connecting and disconnecting the device to the measuring set up. Therefore the pilot laboratory substituted a new sensor and re-calibrated this travelling standard. The two travelling standards - the one, which was not repaired, and the repaired one - were then sent to the last participant (UME). But also after the measurements by the last participant, it was reported by UME that the repaired standards was unstable again and it was not possible to provide any reliable result with this standard. When performing later the re-measurement in the pilot laboratory the instability of this standard was confirmed. As the last participant (UME) was able to conduct a complete calibration with the non-repaired standard, it was agreed that this participant would contribute with only one set of measurement results. Since the standard became unstable again after the last measurements this standard has not been repaired any more.

2.2 List of participants

The following eight NMIs participated in this comparison:

Table 1 List of participants with name of responsible persons:

Organisation	Acronym	Country	Name of participant
Test & Kalibrering A/S	**AREPA**	Denmark	Torsten Lippert
Laboratoire Central des Industries Electriques	**BNM-LCIE**	France	Alireza Kazemipour
Hellenic Institute of Metrolgy	**EIM**	Greece	George Krikelas
Van Swinden Laboratory	**NMi-VSL**	The Netherlands	Jan de Vreede
National Physical Laboratory	**NPL**	United Kingdom	Geoff Orford
Swedish National Testing and Research Institute Measurement Technology	**SP**	Sweden	Klas Yhland
Ulusal Metroloji Enstitüsü	**UME**	Turkey	Cem Hayirli
Physikalisch-Technische Bundesanstalt	**PTB**	Germany	Dieter Janik

More details are shown in the Annex C.
Two participants were able to measure only one standard (PTB P2- 06-2) because the other standard became unstable.

2.3 Comparison schedule

For the comparison, measurements time slots of about 5 weeks for measurements including transportation were planned. In one special case (a carnet had to be used) a longer slot of 6 weeks was allocated. The finally realised timetable of the whole key comparison is given in the Annex B. In general, the participants kept very well their time slots.

Table 2: List of participants and their measuring data

Acronym	Country	Measuring period	Report submitt.	Comments
PTB	Germany	March April 2002	-----------	1. meas. at pilot lab
EIM	Greece	May 2002	July 2002	
SP	Sweden	June 2002	December 2002	
NPL	UK	July/August 2002	August 2002	
AREPA	Denmark	August/September 2002	October 2002	
NMi-VSL	Netherlands	September/October 2002	April 2003	
BNM-LNE	France	November 2002	January 2003	
PTB	Germany	Dec. 2002/Jan. 2003	--------	2. meas.at pilot lab.+ repair
UME	Turkey	February/March 2003	April 2003	
PTB	Germany	April 2003	June 2003	Final measurement

3.Travelling standards and measurement instructions

3.1 Description of the standards

For precise RF power measurements, thermal transfer standards as bolometer mounts or power-thermovoltage converters (power sensors) are used to trace back RF power to an equivalent low frequency or DC power. With these thermal transfer devices an RF power is compared with an equivalent low frequency or dc reference power both generating the same heating in an absorbing resistor in the mount matched to the characteristic line impedance.

The pilot laboratory provided two identical dc coupled power sensors for frequencies up to 26,5 GHz as travelling standards. They were of the same type as the travelling standards used for the CCEM Key Comparison CCEM.RF-K10CL (GT/RF99-2). Since different sensors were used their data will slightly differ. 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 ≈ 0,23 mV/mW.

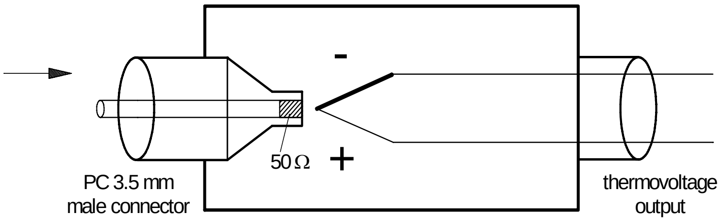

Fig.1 Block diagram of the power sensor travelling standard

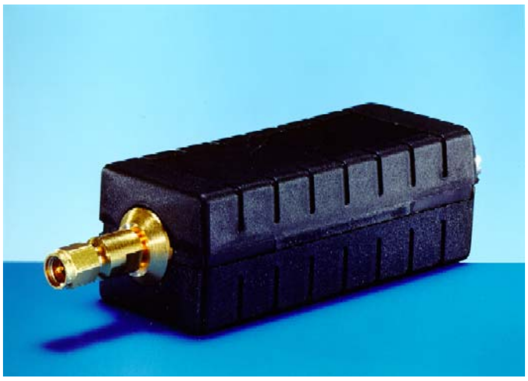

Fig. 2. Photo of the travelling standard

The sensors do not contain any electronics. They are suited for calibration calibrated either by comparing to a power standard with a stable and matched generator system or by measuring in a microcalorimeter. This type of sensor proved its suitability and long term stability over one year in a trilateral comparison [1] and also over 1 ½ year during the CCEM key comparison [draft B]. To calibrate these transfer devices no special main frame but only a commercial sensitive nV-meter is needed. It is used only to measure, with a high resolution, the coincidence of the thermal output voltage of the sensor at the measuring and the reference frequency.

Electrical data of the travelling standards:

DC input resistance R_{in} : $R_{in} = (50{,}5 \pm 1)\ \Omega$
DC output resistance R_{out} : $R_{out} = (500 \pm 60)\ \Omega$
DC resistance between the output terminals and the housing: $(2{,}2 \pm 0{,}5)\ \mathrm{k}\Omega$

The two travelling standards were designated as:

PTB-P1 Ser. No. 03-2 and PTB-P2 Ser. No. 06-2.

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 :

$$K_X(f) = P_{ref}(f_{ref}) / P_{inc}(f): \qquad (1)$$

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 power values give equal thermovoltage at the sensor output. It was decided to use a **1 kHz frequency as the reference frequency f_{ref}** for this comparison**.**

The participants where asked to measure the calibration factor $K_X(f)$ of the two travelling standards referred to 1 kHz 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 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-connector input of the two travelling standards. 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 meters is important to determine the mismatch factor between generator and power meter when making power measurements.

Together with the measurement values of the calibration factor and the reflection coefficient, the combined standard uncertainties of measurement were to be provided with the results.

The recommended ambient conditions were for the temperature: (23±1) ^{o}C and for the humidity: (50 ± 10) %. The actual data also had to be provided with the measurement results.

3.3 Measurement 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 had 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 schedule planned before the start of the comparison (Annex A), which was given in the technical protocol, had to be changed once. During the check measurements in the pilot laboratory, before forwarding the standards with an ATA carnet, it was found that one standard had become unstable. The sensor in this travelling standard was exchanged and the standard was calibrated again. Due to this not planned activity the end of the comparison was delayed by about 4 weeks.

4. Methods of measurement

Most participants used an RF power comparison system including a power splitter connected to a generator and a monitoring power meter on one side arm of the splitter indicating the measuring power. The other arm of the splitter was terminated alternately with the travelling standard (DUT) or the primary power standard of the laboratory. Since many RF power comparison systems are designed for frequencies down to 50 MHz, the calibration factor measurements between 1 kHz and 50 MHz were performed in non critical low frequency systems which are not described here. Three participants calibrated the travelling standards directly in a microcalorimeter in the coaxial 3,5 mm line system.

Because of the variety of the comparison systems and primary power standards, individual descriptions of the instruments are subsequently given:

EIM

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

SP

An automated calibration system with a power splitter and a power standard in the PC 3,5 mm line system was used. The mismatch between the splitter output and the input ports of the two compared power sensors was considered as an uncertainty contribution. The coaxial PC 3,5 mm power sensor used as the primary power standard was calibrated by NPL (UK).

AREPA

An automated calibration system with a power splitter and a reference power meter connected to one side of the splitter was used. All devices were fitted with PC 3,5 connectors. The mismatch between the splitter output and the input ports of the two compared power sensors was considered as an uncertainty contribution. The coaxial PC 3,5 mm power sensor used as the primary power standard was calibrated by SESC (UK) which is traceable to NPL.

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.

NMi-VSL

An automated calibration system with a power splitter and a reference power meter connected to one side of the splitter was used. On the other side of the splitter the travelling standard was compared with a power standard. All devices were fitted with PC 3,5 connectors. The mismatch between the splitter output and the input ports of the two compared power sensors was measured and corrected. The coaxial PC 3,5 mm power sensor used as power standard was traced back by means of adapters to NMI-VSL microcalorimeters (1. coaxial line 50 Ω N-system up to 18 GHz and 2. R220 waveguide system up to 26,5 GHz)

BNM-LNE

A symmetrical twin type microcalorimeter in the PC 3,5 mm line system as a primary RF power standard was used to determine the effective efficiency of the DUT. With the reflection coefficient measured by means of an ANA, the calibration factor was determined.

UME

The travelling standards were compared with two different power standards with adaptors for PC 3,5 mm connector by means of a stable RF generator system with PC 3,5 mm output connector. The power standard for N connector coaxial lines at 18 GHz and below was a N connector thermistor mount and for frequencies above 18 GHz it was a waveguide R 220 thermistor mount. Both power standards were calibrated in the UME microcalorimeter. The adaptors N/PC 3,5 mm and R 220/PC 3,5 mm were characterized by ANA scattering parameter measurements.

PTB

The PC 3,5 mm microcalorimeter - already used in the trilateral RF power comparison with NPL and NRC in 1998 and the CCEM Key comparison CCEM.RF-K10 CL - served as the primary power standard to calibrate the effective efficiency of the DUTs. The calibration factor was determined by means of the reflection coefficient measured with an ANA.

5. Repeated measurement, behaviour of the travelling standards

From the previous trilateral comparison [2] with the same type of travelling standard it was known that the standards would be stable over a year. Also during the CCEM Key Comparison [3] the standards were stable for more than a year during the measurements in 10 laboratories, but then they both became unstable; the reason is still unknown.

It was originally planned for the EUROMET comparison to perform two measurements in the pilot laboratory: before the start and at the end of the measurements in order to check the stability (see Annex A). During a check in the pilot laboratory and before delivering the standards with an ATA carnet and sending it to the last participant with one standard (PTB P1-03-2) no stable measurement was possible. The sensor in this travelling standard was exchanged and the standard was re-calibrated. Nevertheless, the last participant again reported that they were not able to find stable measuring results for this repaired travelling standard. This observation was proved afterwards in pilot laboratory. The other travelling standard was stable during the total comparison, the re-measurement results agreed with the first results before the start of the comparison. (s. Annex D)

6. Measurement results and reference value

6.1 Mean values of the measuring results

The participants' results were presented to the pilot laboratory as the mean value of repeated measurements for the **calibration factor** K_X and for the magnitude of the **reflection coefficient** $|\Gamma|$ together with the combined standard uncertainty for each value. Nearly all participants used the form we proposed in Annex 5 of the technical protocol to present their results. For the calibration factor at two frequencies (10 GHz and 26 GHz), all participants also sent a detailed evaluation of the uncertainty of measurements (budget) together with the resulting combined standard uncertainty (k=1). The copies of these documents for the standard of both standards are enclosed in the Annex.

To give a first impression of the measured data of the two travelling standards the comparison reference values (as calculated in 6.2) of the calibration factor are shown in Fig. 3 and for the magnitude of the reflection coefficient in Fig. 4. It is to be seen that the values of the calibration factor, as well as the values of the reflection coefficient, are significantly different for the two devices. These differences in the quantities to be measured for both standards by the same participant may cause also different deviations from the comparison reference values.

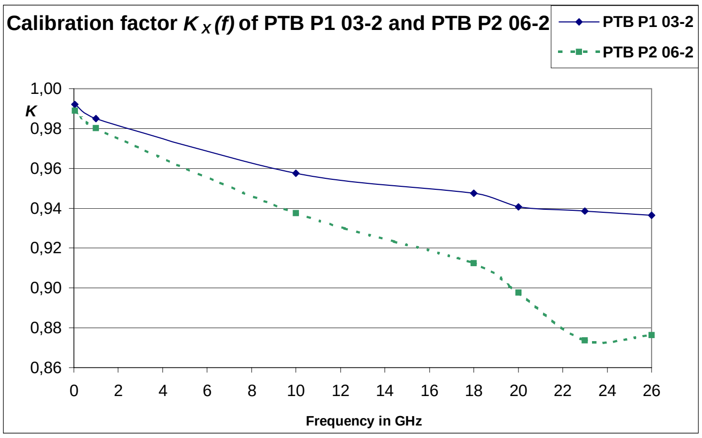

Fig.3 Reference value of the calibration factor $K_X(f)$ for both travelling standards PTB P1 03-2 and PTB P2

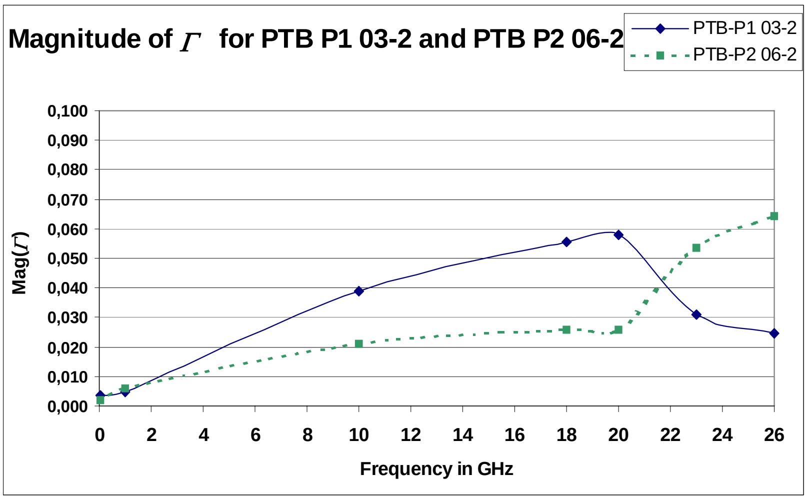

Fig. 4 Mean values of the magnitude of the reflection coefficient $|\Gamma(f)|$ for both travelling standards PTB P1 03-2 and PTB P2 06-2

6.2 Link to the CCEM Key comparison RF.K10-CL and calculation of the EUROMET Key Comparison Reference Value

In order to classify the participants' results in an intercomparison, a reference value has to be calculated, which is assumed to be the most probable mean value. It was agreed before the start of the comparison and also indicated in the Technical Protocol that the results of the EUROMET comparison should be linked to the results of the preceding CCEM Key Comparison CCEM.RF-K10.CL. Therefore two participants, NPL and PTB, took part in both comparisons and the reference value for the EUROMET loop (called *KCRVEURO)* was determined by these two measurement results considering their individual deviations from the Key Comparison Reference Value (*KCRV*) of the preceding CCEM Key comparison.

The *KCRV* of the CCEM Key Comparison was calculated following the procedure described by J. Randa in [2]. As an additional condition, only results obtained with independent primary power standards are considered for this *KCRV*, that is why only seven to eight results contributed to the *KCRV* of the CCEM key comparison [3].

To perform the link from the EUROMET to the CCEM Key comparison, in a first step the mean value of the NPL and PTB results of the key comparison was calculated for both travelling standards [*(NPL+PTB)/2*]. In a second step, for each standard the deviation of the mean values from the *KCRV*s was calculated. And finally for each measuring frequency *f* the mean deviations $\Delta KCRV(f)$ for both standards:

$$\Delta KCRV(f) = \text{Mean}[KCRV-(NPL+PTB)/2] \qquad (2)$$

were calculated (see Tables 3.1 - 3.7). This calculation proved that: $|\Delta KCRV(f)| \leq 0{,}0028$ for all frequencies: the averaged value of [(NPL+PTB)/2] deviates in the mean from the *KCRV* by less than ± 0,0028. The standard deviation of this averaging process is assumed to be the standard deviation $u(\Delta KCRV(f))$ of $\Delta KCRV(f)$. The magnitude of $u(\Delta KCRV(f)$ is less than 0,0024. These small deviations ($\Delta KCRV(f)$) and their small standard deviations prove the assumption for the EUROMET comparison that the mean of the NPL and PTB measuring values are a suitable quantity for a link to the CCEM Key Comparison. This link is justified only with the assumption that the measuring uncertainties of NPL and PTB remained unchanged during both comparisons. As NPL and PTB used the same measuring procedures in both comparisons and as both national institutes finished their measurements in both comparisons within about two years this assumption is justified.

To determine the reference value of the EUROMET comparison the mean of the NPL and PTB results (*NPLE+PTBE*)/2(*f*) has been calculated for all frequencies and each standard. The *KCR*-value of the EUROMET loop - called ***KCRVEURO*(*f*)** - was calculated by adding the deviations $\Delta KCRV(f)$, found for the CCEPM Key Comparison to the mean *(NPLE+PTBE)/2* of the EUROMET loop:

$$KCRVEURO(f) = [NPLE(f) + PTBE(f)]/2 + \Delta KCRV(f) \qquad (3)$$

The standard deviation of *KCRVEURO*(*f*) was calculated from the standard deviation of *KCRV* of the CCEM Key Comparison [3] and the standard deviation $u(\Delta KCRV(f))$. The results of $u(KCRVEURO(f))$ can be found in the Tables 3.1 to 3.7, together with all the input data of the calculations mentioned above. However, these standard uncertainties $u(KCRVEURO(f))$ are not significantly higher than the corresponding standard uncertainties of CCEM Key comparison $u(KCRV(f))$.

6.3 Normalised results of all participants

By means of the calculated reference value *KCRVEURO* an evaluation of all measurement results of the calibration factor is possible by determining the deviation of the individual measuring result Y_i from this reference value, as it is considered to be the best estimate of the most probable measurement 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 according to:

$$E_n = \frac{Y_i - KCRVEURO}{\sqrt{U^2(Y_i) + U^2(KCRVEURO)}} \qquad (4)$$

where $U(Y_i)$ is the expanded uncertainty (k=2) of the participants' measurement results and $U(KCRVEURO)$ is the standard deviation of *KCRVEURO* multiplied by the coverage factor $k = 2$ for a level of confidence of 95%. The E_n values are given in the tables 3.1-3.7.

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 reference values *KCRVEURO***. It is the deviation between the measurement value of the participant (Y_i) and the *KCRV,* in this case the *KCRVEURO*, described in 6.2.:

$$D_i = Y_i - KCRVEURO\,. \qquad (5)$$

The expanded uncertainty $U(D_i)$ of D_i is given by [2]:

$$U(D_i) = \sqrt{U^2(Y_i) + U^2(KCRVEURO)} \qquad (6)$$

From (4), (5) and (6) you get also: $U(D_\mathrm{i}) = \frac{D_\mathrm{i}}{E_\mathrm{n}}$ (7)

In Tables 3.1 – 3.7, the calibration factor *K*(*f*) of all laboratories together with the associated uncertainties of measurement (*u*(*K*) and *U*(*K*)) and the reference values *KCRVEURO* (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, the associated expanded uncertainty $U(D_\mathrm{i})$ and E_n –values, are listed in the last three columns. For the first standard PTB P1-03-2 measured by NMi-VSL however no *D*i and E_n –values were cited, because the assumption that a change of the calibration factors of this travelling standards had already happened **before** the start of measurements at NMi-VSL could not be excluded.

The deviations *D*i from the *KCRVEURO* are shown as graphs in seven figures 5.1 to 5.7. To compare the individual deviation with the stated uncertainty for each result, the expanded uncertainty bars *U*(*K*(*f*)) (k = 2) are also shown in the graphs.

Table 3.1 Results for f = 50 MHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	***f* = 50 MHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. KCRV**			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. KCRV**		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n
EIM	**0,9880**	0,0070	0,0140	-0,0041	0,0145	**-0,29**						
SP	**0,9900**	0,0029	0,0058	-0,0021	0,0069	**-0,31**	**0,9870**	0,0029	0,0058	-0,0019	0,0069	**-0,28**
NPL	**0,9912**	0,0012	0,0024	-0,0010	0,0044	**-0,21**	**0,9880**	0,0012	0,0024	-0,0009	0,0044	**-0,20**
AREPA	**0,9990**	0,0040	0,0080	0,0069	0,0088	**0,78**	**0,9940**	0,0040	0,0080	0,0051	0,0088	**0,58**
NMi-VSL	**0,9764**	0,0038	0,0076				**0,9807**	0,0038	0,0076	-0,0082	0,0085	**-0,97**
BNM-LNE							**0,9852**	0,0023	0,0046	-0,0037	0,0059	**-0,63**
UME							**0,9922**	0,0028	0,0056	0,0033	0,0067	**0,49**
PTB	**0,9917**	0,0020	0,0040	-0,0004	0,0055	**-0,08**	**0,9884**	0,0020	0,0040	-0,0005	0,0055	**-0,09**
KCRVEURO	**0,9922**	**0,0019**	**0,0037**				**0,9889**	**0,0019**	**0,0037**			
(NPLE+PTBE)/2	0,9915						0,9882					
ΔKCRV	0,0007	0,0011					0,0007	0,0011				
KCRVEURO	**0,9922**	**0,0019**					**0,9889**	**0,0019**				
KCRV		0,0015						0,0015				

Table 3.2 Results for f = 1 GHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	***f* = 1 GHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. *KCRV***			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. *KCRV***		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n
EIM	**0,9840**	0,0080	0,0160	-0,0009	0,0162	**-0,05**						
SP	**0,9830**	0,0032	0,0064	-0,0019	0,0070	**-0,26**	**0,9790**	0,0032	0,0064	-0,0011	0,0070	**-0,15**
NPL	**0,9823**	0,0030	0,0060	-0,0026	0,0066	**-0,38**	**0,9777**	0,0030	0,0060	-0,0023	0,0066	**-0,35**
AREPA	**0,9910**	0,0040	0,0080	0,0061	0,0085	**0,72**	**0,9850**	0,0040	0,0080	0,0050	0,0085	**0,58**
NMi-VSL	**0,9679**	0,0051	0,0102				**0,9708**	0,0051	0,0102	-0,0092	0,0106	**-0,87**
BNM-LNE							**0,9761**	0,0062	0,0124	-0,0040	0,0127	**-0,31**
UME							**0,9820**	0,0027	0,0054	0,0020	0,0061	**0,32**
PTB	**0,9832**	0,0025	0,0050	-0,0017	0,0057	**-0,29**	**0,9782**	0,0025	0,0050	-0,0019	0,0057	**-0,32**
KCRVEURO	**0,9849**	**0,0014**	**0,0028**				**0,9801**	**0,0014**	**0,0028**			
(NPLE+PTBE)/2	0,9828						0,9780					
ΔKCRV	0,0021	0,0002					0,0021	0,0002				
KCRVEURO	**0,9849**	**0,0014**					**0,9801**	**0,0014**				
KCRV		0,0014						0,0014				

Table 3.3 Results for f = 10 GHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	**f = 10 GHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. *KCRV***			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. *KCRV***		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	**E_n**	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	*En*
EIM	**0,9440**	0,0100	0,0200	-0,0136	0,0202	**-0,67**						
SP	**0,9560**	0,0048	0,0096	-0,0016	0,0097	**-0,16**	**0,9370**	0,0047	0,0094	-0,0003	0,0096	**-0,04**
NPL	**0,9532**	0,0044	0,0088	-0,0043	0,0091	**-0,48**	**0,9341**	0,0044	0,0088	-0,0032	0,0091	**-0,36**
AREPA	**0,9620**	0,0080	0,0160	0,0044	0,0159	**0,28**	**0,9420**	0,0070	0,0140	0,0046	0,0142	**0,33**
NMi-VSL	**0,9454**	0,0070	0,0140				**0,9314**	0,0069	0,0138	-0,0060	0,0140	**-0,43**
BNM-LNE							**0,9494**	0,0085	0,0170	0,0121	0,0171	**0,70**
UME							**0,9508**	0,0039	0,0078	0,0135	0,0081	**1,66**
PTB	**0,9601**	0,0040	0,0080	0,0025	0,0083	**0,31**	**0,9388**	0,0080	0,0160	0,0014	0,0161	**0,09**
KCRVEURO	**0,9576**	**0,0011**	**0,0022**				**0,9374**	**0,0011**	**0,0022**			
(NPLE+PTBE)/2	0,9567						0,9365					
ΔKCRV	0,0009	0,0004					0,0009	0,0004				
KCRVEURO	**0,9576**	**0,0011**					**0,9374**	**0,0011**				
KCRV		0,0010	0,0020					0,0010	0,0020			

Table 3.4 Results for 18 GHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	***f* = 18 GHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. *KCRV***			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. *KCRV***		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_\mathrm{i}(f)$	$U(D_\mathrm{i})$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_\mathrm{i}(f)$	$U(D_\mathrm{i})$	E_n
EIM	**0,9440**	0,0140	0,0280	-0,0035	0,0281	**-0,12**						
SP	**0,9400**	0,0066	0,0132	-0,0075	0,0134	**-0,56**	**0,9040**	0,0066	0,0132	-0,0084	0,0134	**-0,63**
NPL	**0,9426**	0,0053	0,0106	-0,0049	0,0109	**-0,45**	**0,9053**	0,0054	0,0108	-0,0071	0,0111	**-0,65**
AREPA	**0,9520**	0,0110	0,0220	0,0045	0,0221	**0,20**	**0,9180**	0,0110	0,0220	0,0056	0,0221	**0,25**
NMi-VSL	**0,9340**	0,0086	0,0172				**0,9091**	0,0083	0,0166	-0,0033	0,0168	**-0,20**
BNM-LNE							**0,9167**	0,0119	0,0238	0,0042	0,0239	**0,18**
UME							**0,9233**	0,0082	0,0164	0,0109	0,0166	**0,65**
PTB	**0,9484**	0,0050	0,0100	0,0009	0,0103	**0,09**	**0,9156**	0,0050	0,0100	0,0031	0,0103	**0,31**
KCRVEURO	**0,9475**	**0,0012**	**0,0024**				**0,9125**	**0,0012**	**0,0024**			
(NPLE+PTBE)/2	0,9455						0,9105					
ΔKCRV	0,0020	0,0000					0,0020	0,0000				
KCRVEURO	**0,9475**	**0,0012**					**0,9125**	**0,0012**				
KCRV		0,0012						0,0012				

Table 3.5 Results for 20 GHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	***f* = 20 GHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. *KCRV***			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. KCRV**		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n
EIM	**0,9060**	0,0130	0,0260	-0,0348	0,0267	**-1,30**						
SP	**0,9420**	0,0066	0,0132	0,0012	0,0145	**0,09**	**0,8970**	0,0066	0,0132	-0,0007	0,0145	**-0,05**
NPL	**0,9385**	0,0053	0,0106	-0,0023	0,0122	**-0,18**	**0,8944**	0,0055	0,0110	-0,0033	0,0125	**-0,26**
AREPA	**0,9540**	0,0140	0,0280	0,0132	0,0286	**0,46**	**0,9090**	0,0130	0,0260	0,0113	0,0267	**0,42**
NMi-VSL	**0,9329**	0,0086	0,0172				**0,8962**	0,0083	0,0166	-0,0015	0,0177	**-0,08**
BNM-LNE							**0,9022**	0,0128	0,0256	0,0045	0,0263	**0,17**
UME							**0,9140**	0,0083	0,0166	0,0163	0,0177	**0,92**
PTB	**0,9418**	0,0055	0,0110	0,0010	0,0060	**0,17**	**0,8998**	0,0055	0,0110	0,0021	0,0125	**0,17**
KCRVEURO	**0,9408**	**0,0030**	**0,0060**				**0,8977**	**0,0030**	**0,0060**			
(NPLE+PTBE)/2	0,9402						0,8971					
ΔKCRV	0,0006	0,0024					0,0006	0,0024				
KCRVEURO	**0,9408**	**0,0030**					**0,8977**	**0,0030**				
KCRV		0,0018						0,0018				

Table 3.6 Results for 23 GHz: Deviation D_{i} of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	f = 23 GHz											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. KCRV**			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. KCRV**		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_{\mathrm{i}}(f)$	$U(D_{\mathrm{i}})$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_{\mathrm{i}}(f)$	$U(D_{\mathrm{i}})$	E_n
EIM	**0,9310**	0,0140	0,0280	-0,0075	0,0283	**-0,27**						
SP	**0,9370**	0,0080	0,0160	-0,0015	0,0165	**-0,09**	**0,8740**	0,0080	0,0160	0,0003	0,0165	**0,02**
NPL	**0,9387**	0,0064	0,0128	0,0002	0,0134	**0,01**	**0,8748**	0,0066	0,0132	0,0011	0,0138	**0,08**
AREPA	**0,9510**	0,0170	0,0340	0,0125	0,0342	**0,36**	**0,8850**	0,0150	0,0300	0,0113	0,0303	**0,37**
NMi-VSL	**0,9271**	0,0087	0,0174				**0,8729**	0,0082	0,0164	-0,0008	0,0169	**-0,05**
BNM-LNE							**0,8918**	0,0107	0,0214	0,0181	0,0218	**0,83**
UME							**0,9002**	0,0110	0,0220	0,0265	0,0224	**1,18**
PTB	**0,9440**	0,0065	0,0130	0,0055	0,0136	**0,40**	**0,8783**	0,0065	0,0130	0,0046	0,0136	**0,33**
KCRVEURO	**0,9386**	**0,0020**	**0,0040**				**0,8738**	**0,0020**	**0,0040**			
(NPLE+PTBE)/2	0,9414						0,8766					
Δ*KCRV*	-0,0028	0,0000					-0,0028	0,0000				
KCRVEURO	**0,9386**	**0,0020**					**0,8738**	**0,0020**				
KCRV		0,0020						0,0020				

Table 3.7 Results for 26 GHz: Deviation D_i of the calibration factor $K(f)$ from the *KCRVEURO* for both travelling standards

Frequency	***f* = 26 GHz**											
Participant	**PTB P1-03-2**	**PTB P1-03-2**	**PTB P1-03-2**	**Dev. f. *KCRV***			**PTB P2-06-2**	**PTB P2-06-2**	**PTB P2-06-2**	**Dev. f. *KCRV***		
	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n	$K(f)$	$u(K(f))$	$U(K(f))$	$D_i(f)$	$U(D_i)$	E_n
EIM	**0,9140**	0,0150	0,0300	-0,0231	0,0312	**-0,74**						
SP	**0,9420**	0,0104	0,0208	0,0049	0,0225	**0,22**	**0,8820**	0,0105	0,0210	0,0050	0,0227	**0,22**
NPL	**0,9386**	0,0075	0,0150	0,0015	0,0172	**0,09**	**0,8783**	0,0077	0,0154	0,0013	0,0176	**0,07**
AREPA	**0,9440**	0,0170	0,0340	0,0069	0,0350	**0,20**	**0,8800**	0,0170	0,0340	0,0030	0,0350	**0,09**
NMi-VSL	**0,9268**	0,0097	0,0194				**0,8696**	0,0091	0,0182	-0,0074	0,0201	**-0,37**
BNM-LNE							**0,8837**	0,0101	0,0202	0,0067	0,0219	**0,31**
UME							**0,9037**	0,0181	0,0362	0,0267	0,0372	**0,72**
PTB	**0,9366**	0,0085	0,0170	-0,0005	0,0190	**-0,03**	**0,8767**	0,0085	0,0170	-0,0003	0,0190	**-0,02**
KCRVEURO	**0,9371**	**0,0043**	**0,0085**				**0,8770**	**0,0043**	**0,0085**			
(NPLE+PTBE)/2	0,9376						0,8775					
ΔKCRV	-0,0005	0,0021					-0,0005	0,0021				
KCRVEURO	**0,9371**	**0,0043**					**0,8770**	**0,0043**				
KCRV		0,0037						0,0037				

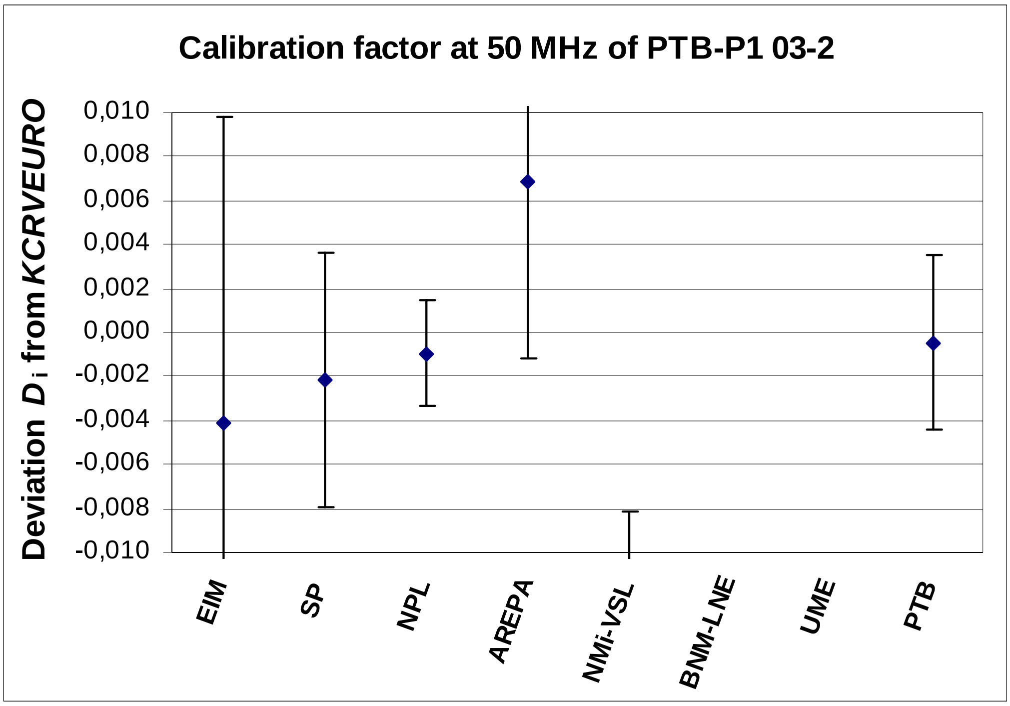

Fig. 5.1.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 50 MHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

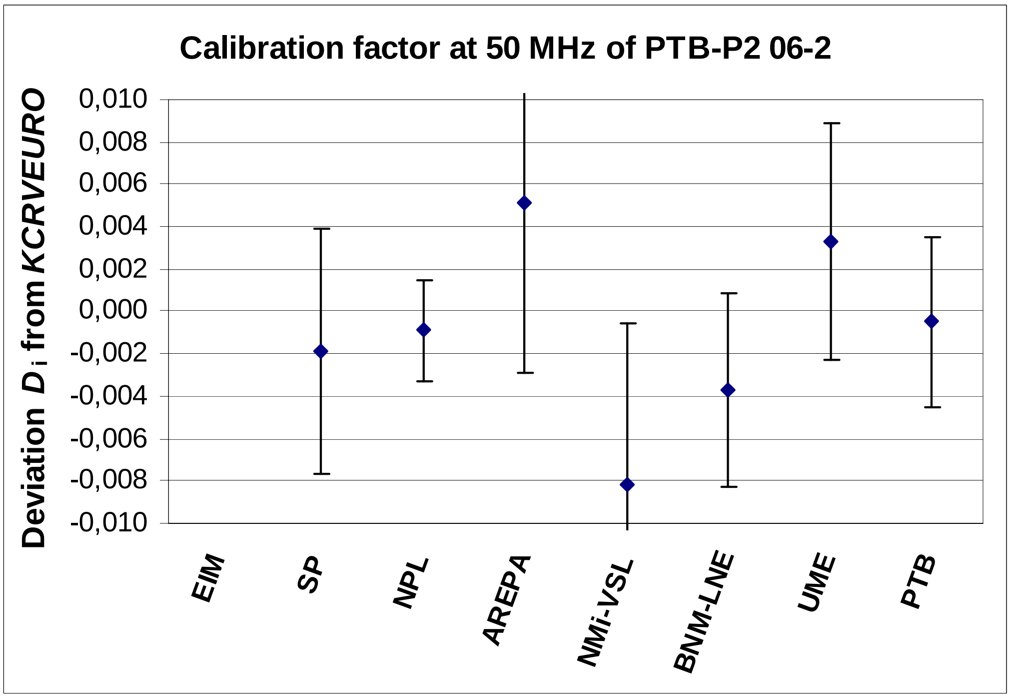

Fig. 5.1.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 50 MHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

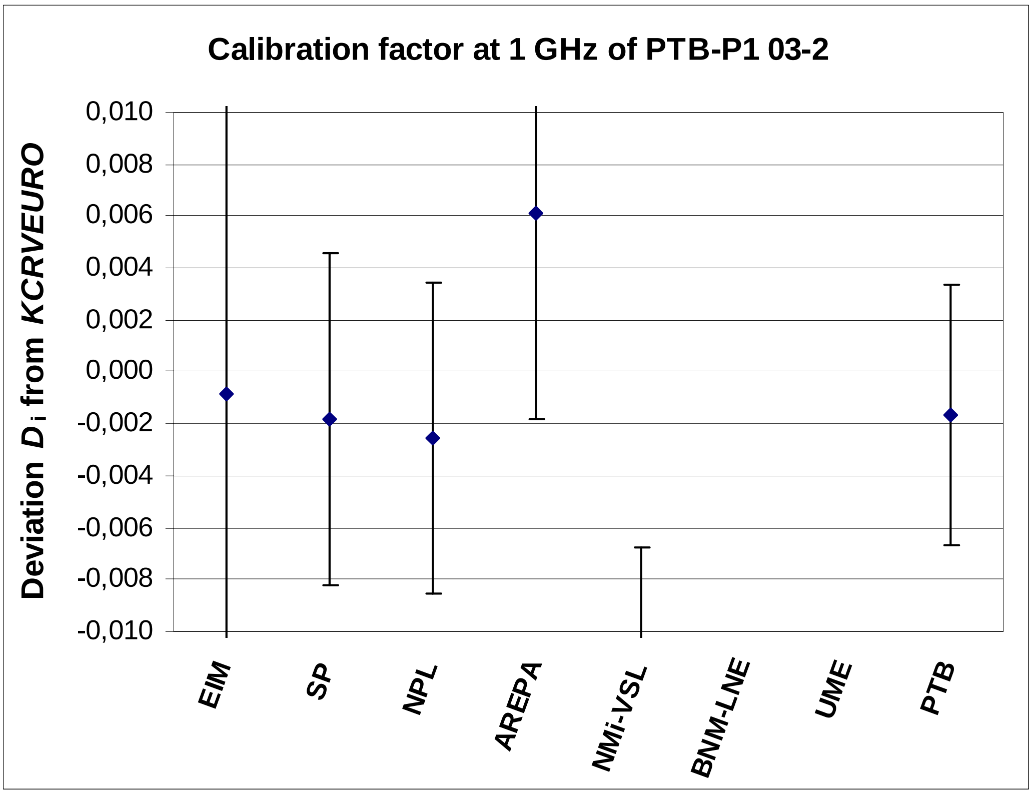

Fig. 5.2.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 1 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

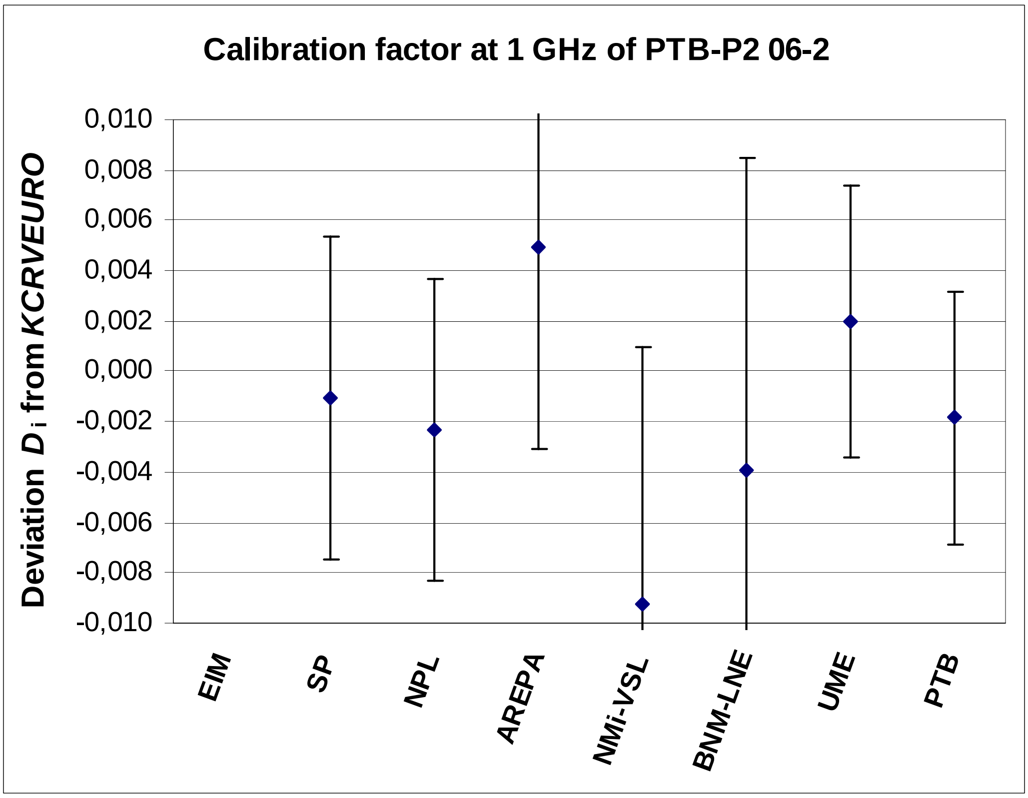

Fig. 5.2.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 1 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

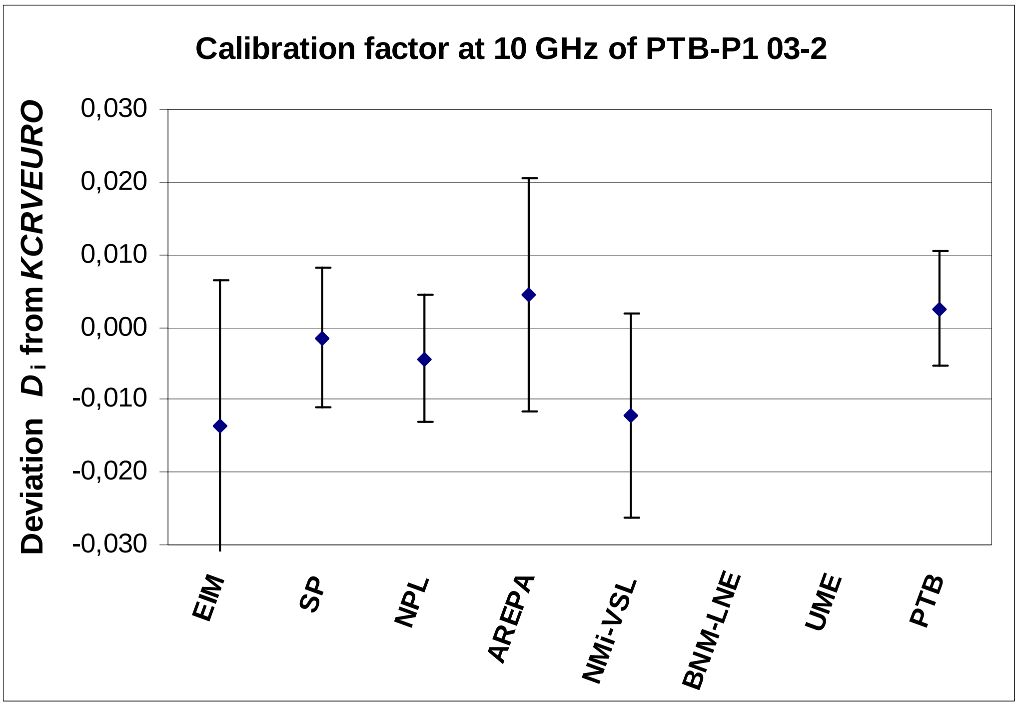

Fig. 5.3.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 10 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

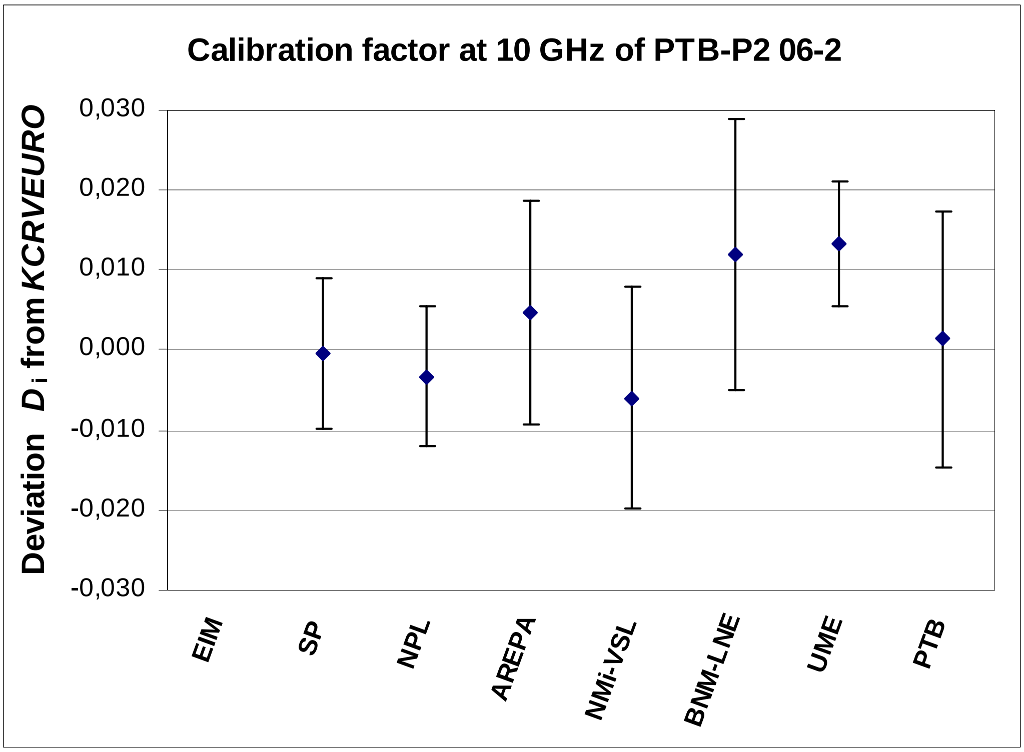

Fig. 5.3.b Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 10 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

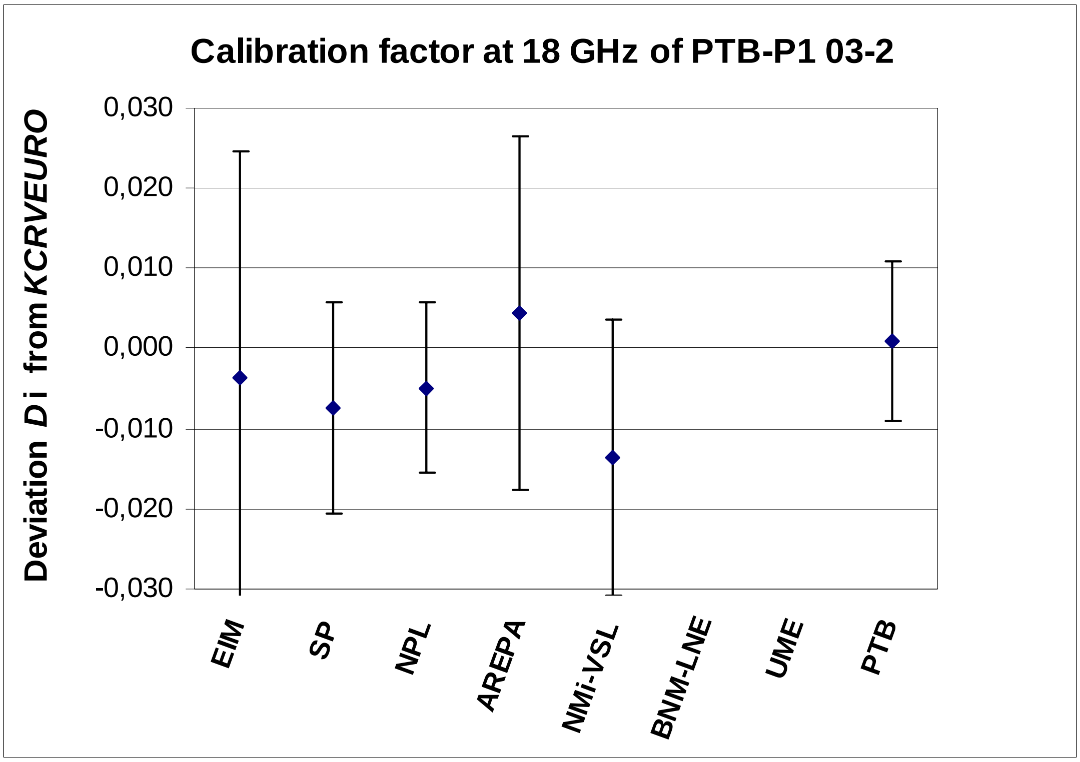

Fig. 5.4.a Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 18 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

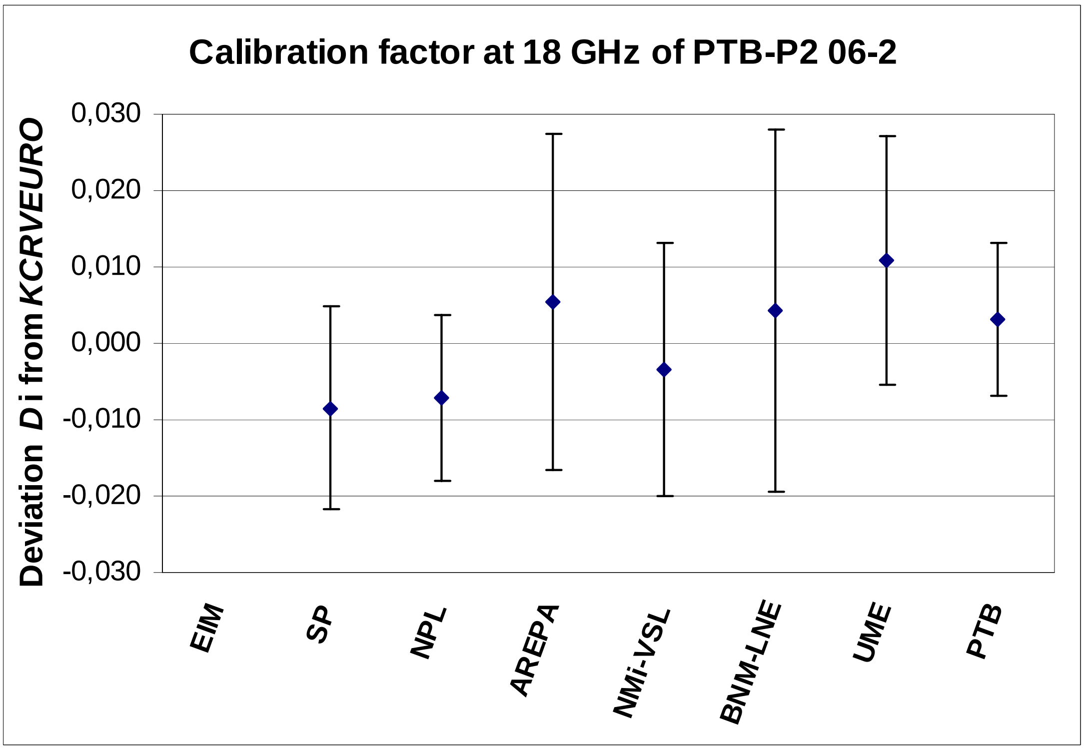

Fig. 5.4 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 18 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

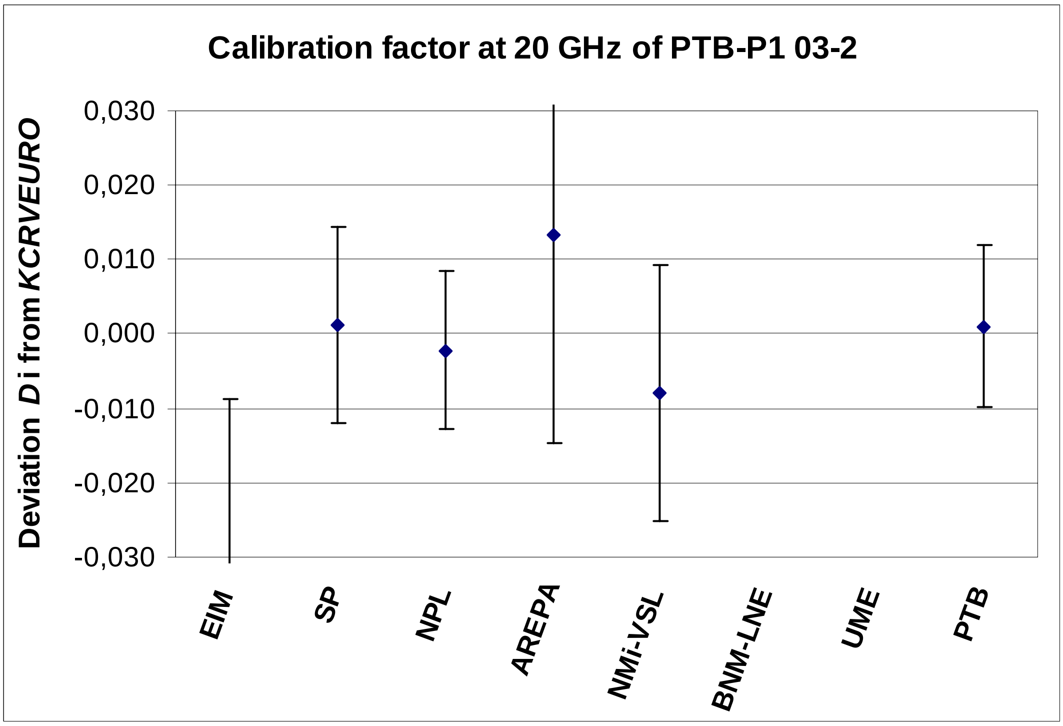

Fig. 5.5 a Deviation D_i of the measured calibration factor *K(f*) from the *KCRVEURO* at 20 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

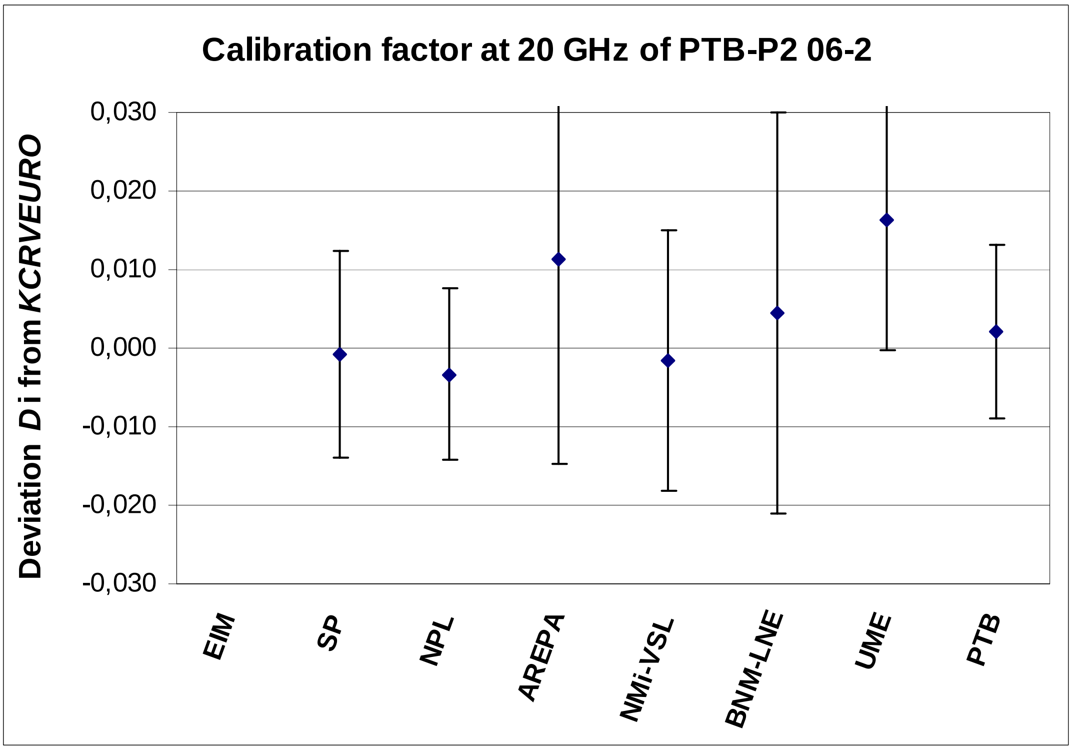

Fig. 5.5 b Deviation D_i of the measured calibration factor *K(f*) from the *KCRVEURO* at 20 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

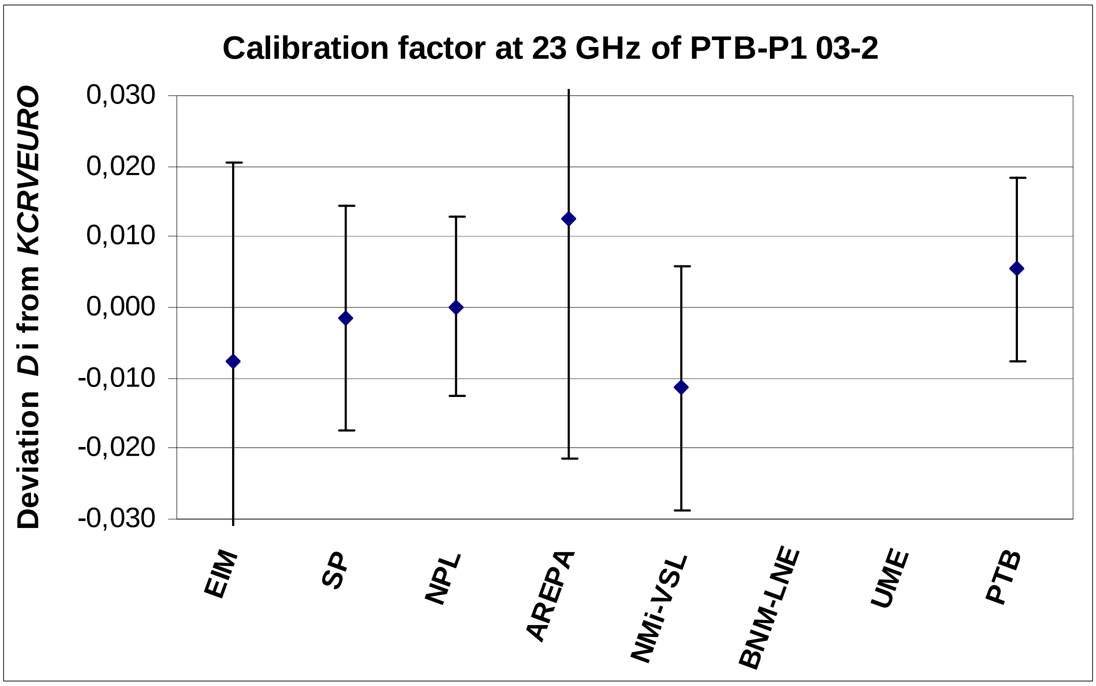

Fig. 5.6 a Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 23 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

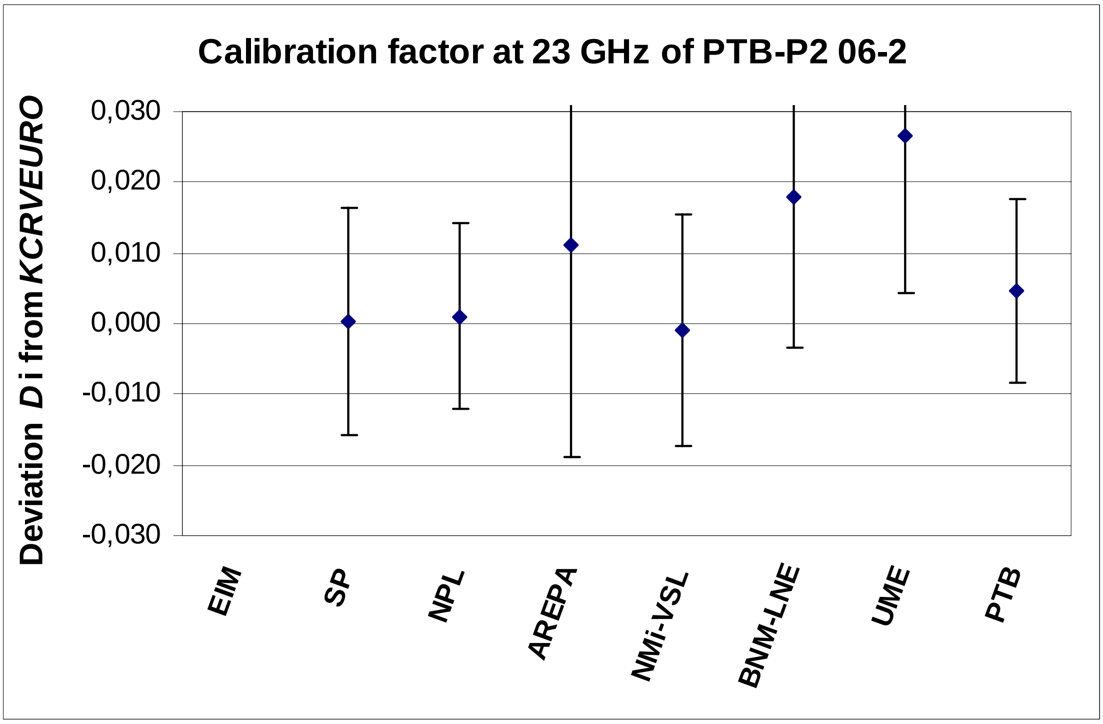

Fig. 5.6 b Deviation D_i of the measured calibration factor *K(f)* from the *KCRVEURO* at 23 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

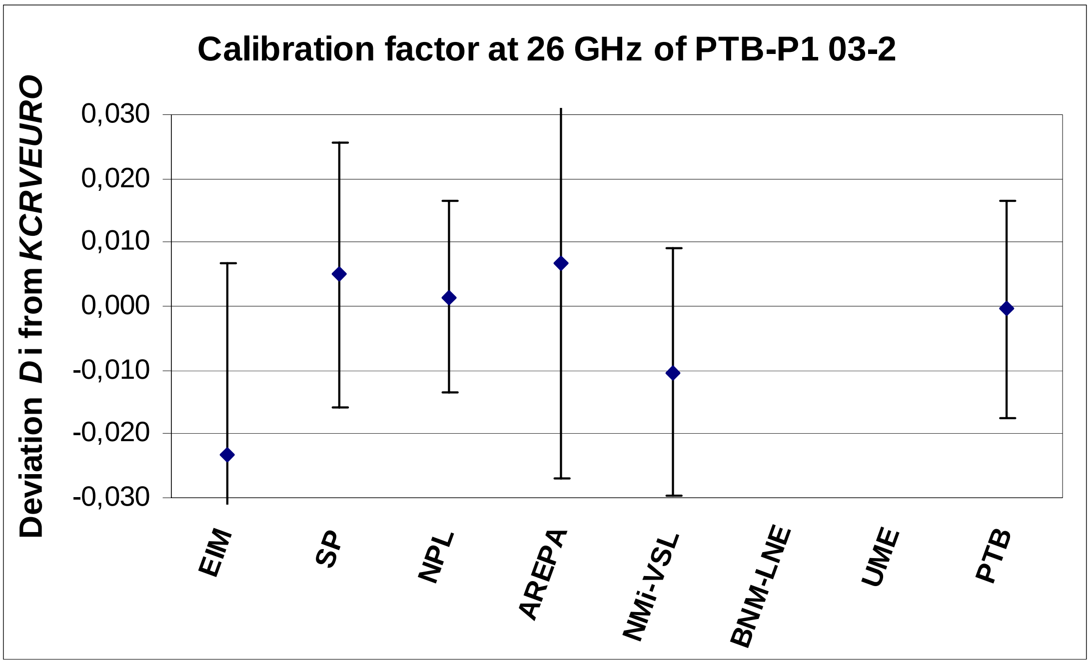

Fig. 5.7 a Deviation D_i of the measured calibration factor *K(f*) from the *KCRVEURO* at 26 GHz with expanded uncertainty bars (*k*=2) for PTB-P1 03-2

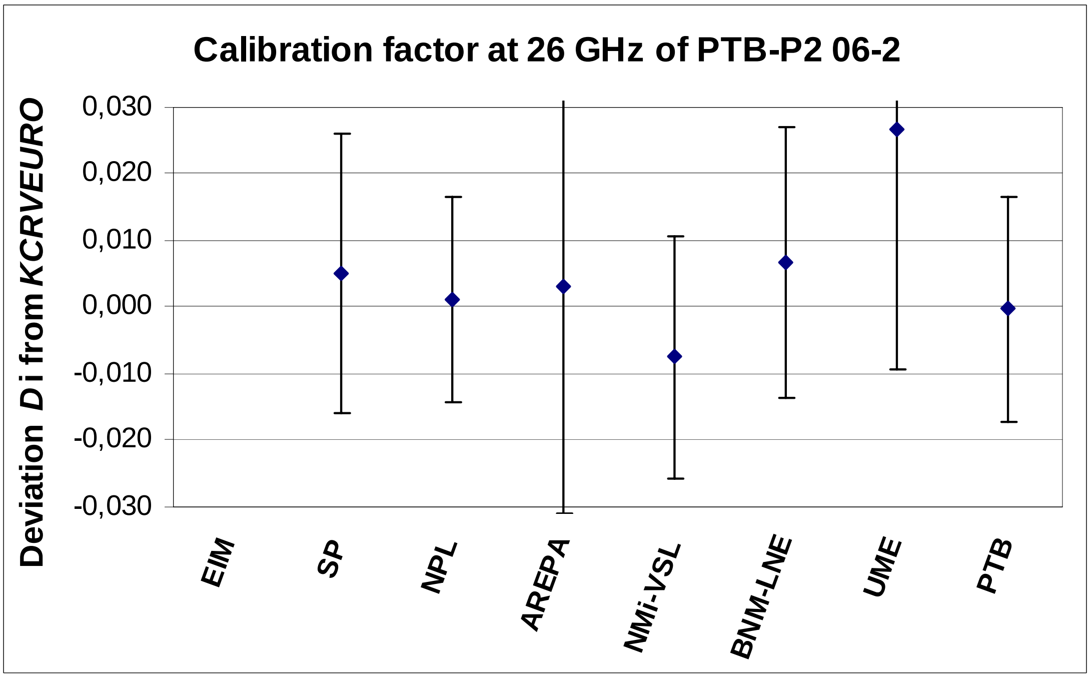

Fig. 5.7 b Deviation D_i of the measured calibration factor *K(f*) from the *KCRVEURO* at 26 GHz with expanded uncertainty bars (*k*=2) for PTB-P2 06-2

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6.3.1 Discussion of results

For an acceptable measurement result in a comparison with a known reference value, the conditions $|E_n| < 1$ or $|D_i| < U(D_i)$ should be fulfilled. The reference value of this comparison was the *KCRVEURO*, which was linked by means of the results of NPL and PTB to the CCEM Key Comparison CCEM RF.K-10 CL [3]. Two participants have not met these conditions at the following frequencies: 1) one participant at one frequency (20 GHz) and one standard and 2.) another participant at two frequencies (10 GHz and 23 GHz) for the other standard. These two participants calibrated only one standard. For a third participant no E_n and D_i value was cited for one travelling standard, because the assumption that a change of the calibration factors of this travelling standards had already happened before the start of measurements could not be excluded. But for this participant E_n and D_i values are given for the other standard.

All the other five participants however, fulfilled the conditions for all frequencies and both standards, the sixth participant for the second standard and in many cases very well, i. e. $|E_n|$ is considerably smaller than 1. Also from the diagrams it becomes obvious that for many participants the deviations from the *KCRVEURO* are considerably smaller than their stated expanded uncertainties.

Also the values for the degree of equivalence D_{ij} between each pair of laboratories were calculated. The condition for a good degree of equivalence ($|D_i| < U(D_{ij})$ was not fulfilled for 10 pairs of values of laboratories, the ratios $|D_{ij}/U(D_{ij})|$ were determined to be less than 1,7. At 10 GHz and 20 GHz these ratios (in 7 cases) are larger than 1 because the E_n-value of two of the laboratories is $|E_n| > 1$. At 50 MHz and 1 GHz the ratios (in 3 cases) were larger than one but less than 1,23 even though $|E_n| < 1$ for all laboratories but they are close to 1 for two laboratories.

6.4 Reflection coefficient results

The magnitude of the reflection coefficient was not the main quantity to be measured, e.g. no *KCRV* was calculated. The reflection coefficient is required to determine the mismatch losses making power measurements. It is also necessary to calculate the calibration factor from the effective efficiency measured in a microcalorimeter. The measurements of the reflection coefficient were therefore included in this comparison. In general, the contribution of the uncertainty of the reflection coefficient measurement to the uncertainty of the measured power is small, if the power meter is well-matched. 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. Due to this, it was found from the reflection coefficient data given by BNM-LNE that one standard (PTB-P1 03-2) had become unstable already before the measurements at BNM-LNE.

In the Annex E we present tables E-1 to E-7 showing the measured magnitude of the reflection coefficients together with the associated uncertainties and the individual deviations from the arithmetic mean value of all results. In the case of two participants, the deviations from the mean values are larger than the stated expanded uncertainty ($k = 2$) for only one standard and at two frequencies. Both participants stated very small expanded uncertainties ($k=2$) which are between 0,0020 and 0,0046. All the other participants acquired smaller deviations than the expanded uncertainties, in most cases they considerably smaller.

7. Withdrawals

After having finished his measurements, one participant mentioned, that there were significant differences between the measured calibration factors of the two travelling standards. He observed that the calibration factors of the second standard (PTB P-06-2) at higher frequencies were considerably smaller than those of the other standard. As he was not able to find the reason for these deviations he presented results for one standard only. Since the next participant sent measurement results which agreed well with the mean value of all the other participants it was assumed that the calibration factors of the standards had remained unchanged.
During check measurements in the pilot laboratory, preceding the last participant (UME), it turned out that the measurement results of the standard PTB P1 03-2 were unstable. Later on, when evaluating the final results the pilot laboratory detected that also the measurement results for the calibration factor and the reflection coefficient of the last but one participant (BNM-LNE) showed significant deviations from the mean value of all the other participants. It had to be assumed that also before or during the measurements at BNM-LNE this travelling standard was unstable. After BNM-LNE had been informed about that, it was agreed that BNM-LNE would withdraw the measurement result of this standard. As it could not be excluded that a change of the calibration factor of this travelling standard had already happened before or during the NMi-VSL measurements - the participant before BNM-LNE - no D_i, D_{ij} and E_n – values were cited for the NMi-VSL results.

8. Conclusion

Eight participants took part in the EUROMET comparison 525, two of them already achieved good agreement with the *KCRV* in the preceding CCEM key comparison. These results were used as a link between the new reference value (*KCRVEURO)* with the CCEM reference value (*KCRV*). That means only the results of the other 6 participants are new in this EUROMET comparison.

Most measurement results of the calibration factor are satisfactory (E_N <1, or $|D_i| < U(D_i)$), in many cases this condition was very well fulfilled. However, two participants have not met this condition -: in one case at one frequency, in the other case at two frequencies, out of 7 measuring frequencies in total. The estimated expanded uncertainties of the measured calibration factors increased with frequency from about 0,003 at 50 MHz to about 0,035 at 26 MHz. It can be concluded that the uncertainty contributions and finally the resulting total uncertainty were well estimated, because for most measuring frequencies the requirement for a good measuring results ($|E_n| < 1$ or $|D_i| < U(D_i)$) was fulfilled. One travelling standard remained unchanged till the end of the circulation, whereas the other standard became unstable, so that the last two participants were not able to deliver results for the second standard. However all participants delivered at least one measuring result for each of the 7 frequencies.

The EUROMET comparison and the preceding key comparison CCEM RF.K-10 CL, being linked together by two participants taking part in both of them, can be considered as one big comparison with 19 participants, which was carried out in two loops, one international and one European.

9. 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

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[3] D. Janik, T. Inoue and A. Michaud: Final report on 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 www.bipm.org – Appendix B - CCEM.RF-K10.CL

ANNEX A

Proposed schedule

EUROMET comparison 525

(April 29. 2002)

Institution	Country	Start date	Time period for measurement **and** transportation
PTB (1. Measurem.)	Germany	April 2, 2002	5 weeks
EIM	Greece	May 6, 2002	5 weeks
SP	Sweden	June 10, 2002	5 weeks
NPL	UK	July 15, 2002	5 weeks
AREPA	Denmark	August 19, 2002	5 weeks
NMi-VSL	Netherlands	September 23, 2002	5 weeks
BNM	France	October 28, 2002	5 weeks
PTB (carnet)	Germany	December 2, 2002	2 weeks
UME	Turkey	December 16, 2002	6 weeks
PTB (Final meas.)	Germany	January 27, 2003	3 weeks
End of measurement		February 17, 2003	

ANNEX B

Realised schedule

EUROMET comparison 525

Institution	Country	Start date	Time period for measurement and transportation
PTB (1. Measurement)	Germany	April 2, 2002	5 weeks
EIM	Greece	May 6, 2002	5 weeks
SP	Sweden	June 10, 2002	5 weeks
NPL	UK	July 15, 2002	5 weeks
AREPA	Denmark	August 19, 2002	5 weeks
NMi-VSL	Netherlands	September 23, 2002	5 weeks
BNM-LNE	France	October 28, 2002	5 weeks
PTB (carnet, and repair)	Germany	December 19, 2002	4 weeks
UME [1]	Turkey	January 20, 2003	6 weeks
PTB (Re-measurement)	Germany	March 3, 2003	3 weeks
End of measurement	Germany	March 21, 2003	

ANNEX C

Name	*Firstname*	**Institute**	*Street/PBox*	*Post-code*	*City*	*Land*	*Telefon, FAX*	*WWW/Email*
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List of addresses of the participants EUROMET 525

ANNEX D

The pilot laboratory's (PTB) 1., 2., 3. and mean measurement values for the calibration factor *K*(*f*)

Standard	**PTB-P1-03-2**	**PTB-P1-03-2**	**PTB-P1-03-2**	**PTB-P1-03-2**
Date	April 02	Dec. 02	March 03	PTB Mean.
Frequency in GHz	1.	2.	3.	
0,05	0,9917			**0,9917**
1	0,9832			**0,9832**
10	0,9601			**0,9601**
18	0,9484			**0,9484**
20	0,9418			**0,9418**
23	0,9440			**0,9440**
26	0,9366			**0,9366**

Standard	**PTB-P1 06-2**	**PTB-P1 06-2**	**PTB-P1 06-2**	**PTB-P1 06-2**
Date	April 02	Dec. 02	March 03	PTB Mean
Frequency in GHz	1.	2.	3.	
0,05	0,9885	0,9883	0,9884	**0,9884**
1	0,9783	0,9783	0,9780	**0,9782**
10	0,9392	0,9369	0,9403	**0,9388**
18	0,9159	0,9139	0,9170	**0,9156**
20	0,8996	0,8989	0,9010	**0,8998**
23	0,8796	0,8808	0,8745	**0,8783**
26	0,8763	0,8786	0,8753	**0,8767**

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ANNEX E-1

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

Frequency	**f = 50 MHz**							
Participant	**PTB 1-03-2** Mag(Γ)	**PTB 1-03-2** u(Mag(Γ))	**PTB 1-03-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)	**PTB 2-06-2** Mag(Γ)	**PTB 2-06-2** u(Mag(Γ))	**PTB 2-06-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)
EIM	0,0022	0,0029	0,0058	-0,0011	0,0024	0,0028	0,0056	0,0005
SP	0,0030	0,0050	0,0100	-0,0003	0,0020	0,0050	0,0100	0,0001
NPL	0,0040	0,0050	0,0100	0,0007	0,0010	0,0050	0,0100	-0,0009
AREPA	0,0040	0,0050	0,0100	0,0007	0,0020	0,0050	0,0100	0,0001
NMi-VSL	0,0027	0,0100	0,0200	-0,0006	0,0021	0,0100	0,0200	0,0002
BNM-LNE					0,0030	0,0010	0,0020	0,0011
UME					0,0011	0,0042	0,0084	-0,0008
PTB	0,0038	0,0030	0,0060	0,0005	0,0016	0,0030	0,0060	-0,0003
Mean	**0,0033**	**0,0008**	**0,0015**		**0,0019**	**0,0007**	**0,0013**	

ANNEX E-2

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

Frequency	**f = 1 GHz**							
Participant	**PTB 1-03-2** Mag(Γ)	**PTB 1-03-2** u(Mag(Γ))	**PTB 1-03-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)	**PTB 2-06-2** Mag(Γ)	**PTB 2-06-2** u(Mag(Γ))	**PTB 2-06-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)
EIM	0,0042	0,0028	0,0056	-0,0002	0,0067	0,0028	0,0056	0,0006
SP	0,0050	0,0050	0,0100	0,0006	0,0060	0,0050	0,0100	-0,0001
NPL	0,0040	0,0050	0,0100	-0,0004	0,0060	0,0050	0,0100	-0,0001
AREPA	0,0050	0,0050	0,0100	0,0006	0,0050	0,0050	0,0100	-0,0011
NMi-VSL	0,0022	0,0100	0,0200	-0,0022	0,0057	0,0100	0,0200	-0,0004
BNM-LNE					0,0060	0,0010	0,0020	-0,0001
UME					0,0073	0,0043	0,0086	0,0012
PTB	0,0060	0,0030	0,0060	0,0016	0,0062	0,0030	0,0060	0,0001
Mean	**0,0044**	**0,0013**	**0,0026**		**0,0061**	**0,0007**	**0,0014**	

ANNEX E-3

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

Frequency	**f = 10 GHz**							
Participant	**PTB 1-03-2**	**PTB 1-03-2**	**PTB 1-03-2**	**Dev. f. mean**	**PTB 2-06-2**	**PTB 2-06-2**	**PTB 2-06-2**	**Dev. f. mean**
	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)
EIM	0,0385	0,0023	0,0046	-0,0029	0,0181	0,0023	0,0046	-0,0029
SP	0,0410	0,0050	0,0100	-0,0003	0,0200	0,0050	0,0100	-0,0010
NPL	0,0420	0,0050	0,0100	0,0007	0,0210	0,0050	0,0100	0,0000
AREPA	0,0430	0,0100	0,0200	0,0017	0,0220	0,0100	0,0200	0,0010
NMi-VSL	0,0462	0,0100	0,0200	0,0049	0,0267	0,0100	0,0200	0,0057
BNM-LNE					0,0230	0,0010	0,0020	0,0020
UME					0,0183	0,0044	0,0088	-0,0027
PTB	0,0374	0,0030	0,0060	-0,0040	0,0192	0,0030	0,0060	-0,0018
Mean	**0,0414**	**0,0032**	**0,0064**		**0,0210**	**0,0029**	**0,0057**	

ANNEX E-4

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

Frequency	**f = 18 GHz**							
Participant	**PTB 1-03-2**	**PTB 1-03-2**	**PTB 1-03-2**	**Dev. f. mean**	**PTB 2-06-2**	**PTB 2-06-2**	**PTB 2-06-2**	**Dev. f. mean**
	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)
EIM	0,0560	0,0023	0,0046	0,0028	0,0200	0,0023	0,0046	-0,0058
SP	0,0530	0,0070	0,0140	-0,0002	0,0290	0,0070	0,0140	0,0032
NPL	0,0490	0,0050	0,0100	-0,0042	0,0290	0,0050	0,0100	0,0032
AREPA	0,0510	0,0150	0,0300	-0,0022	0,0210	0,0150	0,0300	-0,0048
NMi-VSL	0,0530	0,0100	0,0200	-0,0002	0,0235	0,0100	0,0200	-0,0023
BNM-LNE					0,0280	0,0010	0,0020	0,0022
UME					0,0328	0,0045	0,0090	0,0070
PTB	0,0572	0,0030	0,0060	0,0040	0,0234	0,0030	0,0060	-0,0024
Mean	**0,0532**	**0,0030**	**0,0061**		**0,0258**	**0,0045**	**0,0090**	

ANNEX E-5

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

Frequency	**f = 20 GHz**							
Participant	**PTB 1-03-2**	**PTB 1-03-2**	**PTB 1-03-2**	**Dev. f. mean**	**PTB 2-06-2**	**PTB 2-06-2**	**PTB 2-06-2**	**Dev. f. mean**
	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)
EIM	0,0620	0,0023	0,0046	0,0022	0,0323	0,0023	0,0046	0,0066
SP	0,0580	0,0080	0,0160	-0,0018	0,0240	0,0080	0,0160	-0,0017
NPL	0,0600	0,0100	0,0200	0,0002	0,0210	0,0100	0,0200	-0,0047
AREPA	0,0620	0,0200	0,0400	0,0022	0,0250	0,0200	0,0400	-0,0007
NMi-VSL	0,0567	0,0100	0,0200	-0,0031	0,0282	0,0100	0,0200	0,0025
BNM-LNE					0,0210	0,0010	0,0020	-0,0047
UME					0,0230	0,0081	0,0162	-0,0027
PTB	0,0604	0,0030	0,0060	0,0006	0,0314	0,0030	0,0060	0,0057
Mean	**0,0599**	**0,0021**	**0,0043**		**0,0257**	**0,0044**	**0,0089**	

ANNEX E-6

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

Frequency	**f = 23 GHz**							
Participant	**PTB 1-03-2**	**PTB 1-03-2**	**PTB 1-03-2**	**Dev. f. mean**	**PTB 2-06-2**	**PTB 2-06-2**	**PTB 2-06-2**	**Dev. f. mean**
	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)	Mag(Γ)	*u*(Mag(Γ))	*U*(Mag(Γ))	ΔMag(Γ)
EIM	0,0279	0,0230	0,0460	-0,0019	0,0499	0,0023	0,0046	-0,0035
SP	0,0310	0,0100	0,0200	0,0012	0,0520	0,0100	0,0200	-0,0014
NPL	0,0280	0,0100	0,0200	-0,0018	0,0540	0,0100	0,0200	0,0006
AREPA	0,0290	0,0200	0,0400	-0,0008	0,0570	0,0200	0,0400	0,0036
NMi-VSL	0,0353	0,0100	0,0200	0,0055	0,0537	0,0100	0,0200	0,0003
BNM-LNE					0,0620	0,0020	0,0040	0,0086
UME					0,0500	0,0084	0,0168	-0,0034
PTB	0,0275	0,0040	0,0080	-0,0023	0,0487	0,0040	0,0080	-0,0047
Mean	**0,0298**	**0,0030**	**0,0060**		**0,0534**	**0,0044**	**0,0088**	

ANNEX E-7

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

Frequency	**f = 26 GHz**							
Participant	**PTB 1-03-2** Mag(Γ)	**PTB 1-03-2** u(Mag(Γ))	**PTB 1-03-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)	**PTB 2-06-2** Mag(Γ)	**PTB 2-06-2** u(Mag(Γ))	**PTB 2-06-2** U(Mag(Γ))	**Dev. f. mean** ΔMag(Γ)
EIM	0,0231	0,0024	0,0048	-0,0017	0,0619	0,0024	0,0048	-0,0025
SP	0,0260	0,0110	0,0220	0,0012	0,0710	0,0110	0,0220	0,0066
NPL	0,0220	0,0100	0,0200	-0,0028	0,0680	0,0100	0,0200	0,0036
AREPA	0,0250	0,0200	0,0400	0,0002	0,0590	0,0200	0,0400	-0,0054
NMi-VSL	0,0353	0,0100	0,0200	0,0105	0,0541	0,0100	0,0200	-0,0103
BNM-LNE					0,0660	0,0020	0,0040	0,0016
UME					0,0723	0,0087	0,0174	0,0079
PTB	0,0175	0,0040	0,0080	-0,0073	0,0628	0,0040	0,0080	-0,0016
Mean	**0,0248**	**0,0059**	**0,0119**		**0,0644**	**0,0062**	**0,0123**	

ANNEX F 1

MATRIX OF EQUIVALENCE at 50 MHz
for PTB 1-03-2 and PTB 2-06-2

Standard : PTB 1-03-2
Frequency: 50 MHz

Lab j

			EIM		**SP**		**NPL**		**AREPA**		**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
EIM	-4,1	14			-2,0	15,2	-3,1	14,2	-11,0	16,1	-3,7	14,6
SP	-2,1	5,8	2,0	15,2			-1,1	6,3	-9,0	9,9	-1,7	7,0
NPL	-1,0	2,4	3,1	14,2	1,1	6,3			-7,9	8,4	-0,6	4,7
AREPA	6,9	8	11,0	16,1	9,0	9,9	7,9	8,4			7,3	8,9
PTB	-0,4	4	3,7	14,6	1,7	7,0	0,6	4,7	-7,3	8,9		

Standard : PTB 2-06-2
Frequency: 50 MHz

Lab j

			SP		**NPL**		**AREPA**		**NMi-VSL**		**BNM-LNE**		**UME**		**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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	-1,9	5,8			-1,0	6,3	-7,0	9,9	6,3	9,6	1,8	7,4	-5,2	8,1	-1,4	7,0
NPL	-0,9	2,4	1,0	6,3			-6,0	8,4	7,3	8,0	2,8	5,2	-4,2	6,1	-0,4	4,7
AREPA	5,1	8,0	7,0	9,9	6,0	8,4			*13,3*	*11,0*	8,8	9,2	1,8	9,8	5,6	8,9
NMi-VSL	-8,2	7,6	-6,3	9,6	-7,3	8,0	*-13,3*	*11,0*			-4,5	8,9	*-11,5*	*9,4*	-7,7	8,6
BNM-LNE	-3,7	4,6	-1,8	7,4	-2,8	5,2	-8,8	9,2	4,5	8,9			-7,0	7,2	-3,2	6,1
UME	3,3	5,6	5,2	8,1	4,2	6,1	-1,8	9,8	*11,5*	*9,4*	7,0	7,2			3,8	6,9
PTB	-0,5	4,0	1,4	7,0	0,4	4,7	-5,6	8,9	7,7	8,6	3,2	6,1	-3,8	6,9		

ANNEX F 2

MATRIX OF EQUIVALENCE at 1 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : PTB 1-03-2
Frequency: 1 GHz

Lab j

			EIM		SP		NPL		AREPA		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
EIM	-0,9	16,0			1,0	17,2	1,7	17,1	-7,0	17,9	0,8	16,8
SP	-1,9	6,4	-1,0	17,2			0,7	8,8	-8,0	10,2	-0,2	8,1
NPL	-2,6	6,0	-1,7	17,1	-0,7	8,8			-8,7	10,0	-0,9	7,8
AREPA	6,1	8,0	7,0	17,9	8,0	10,2	8,7	10,0			7,8	9,4
PTB	-1,7	5,0	-0,8	16,8	0,2	8,1	0,9	7,8	-7,8	9,4		

Standard : PTB 2-06-2
Frequency: 1 GHz

Lab j

			SP		NPL		AREPA		NMi-VSL		BNM-LNE		UME		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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	-1,1	6,4			1,2	8,8	-6,1	10,2	8,1	12,0	2,9	14,0	-3,1	8,4	0,8	8,1
NPL	-2,3	6,0	-1,2	8,8			-7,3	10,0	6,9	11,8	1,7	13,8	-4,3	8,1	-0,4	7,8
AREPA	5,0	8,0	6,1	10,2	7,3	10,0			***14,2***	***13,0***	9,0	14,8	3,0	9,7	6,9	9,4
NMi-VSL	-9,2	10,2	-8,1	12,0	-6,9	11,8	***-14,2***	***13,0***			-5,2	16,1	-11,2	11,5	-7,3	11,4
BNM-LNE	-4,0	12,4	-2,9	14,0	-1,7	13,8	-9,0	14,8	5,2	16,1			-6,0	13,5	-2,1	13,4
UME	2,0	5,4	3,1	8,4	4,3	8,1	-3,0	9,7	11,2	11,5	6,0	13,5			3,9	7,4
PTB	-1,9	5,0	-0,8	8,1	0,4	7,8	-6,9	9,4	7,3	11,4	2,1	13,4	-3,9	7,4		

ANNEX F 3

MATRIX OF EQUIVALENCE at 10 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : **PTB 1-03-2**
Frequency: **10 GHz**

Lab j

			EIM		SP		NPL		AREPA		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
EIM	-13,6	20,0			-12,0	22,2	-9,3	21,9	-18,0	25,6	-16,1	21,5
SP	-1,6	9,6	12,0	22,2			2,7	13,0	-6,0	18,7	-4,1	12,5
NPL	-4,3	8,8	9,3	21,9	-2,7	13,0			-8,7	18,3	-6,8	11,9
AREPA	4,4	16,0	18,0	25,6	6,0	18,7	8,7	18,3			1,9	17,9
PTB	2,5	8,0	16,1	21,5	4,1	12,5	6,8	11,9	-1,9	17,9		

Standard : **PTB 2-06-2**
Frequency: **10 GHz**

Lab j

			SP		NPL		AREPA		NMi-VSL		BNM-LNE		UME		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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	-0,3	9,4			2,9	12,9	-4,9	16,9	5,7	16,7	-12,4	19,4	***-13,8***	***12,2***	-1,7	18,6
NPL	-3,2	8,8	-2,9	12,9			-7,8	16,5	2,8	16,4	-15,3	19,1	***-16,7***	***11,8***	-4,6	18,3
AREPA	4,6	14,0	4,9	16,9	7,8	16,5			10,6	19,7	-7,5	22,0	-8,9	16,0	3,2	21,3
NMi-VSL	-6,0	13,8	-5,7	16,7	-2,8	16,4	-10,6	19,7			-18,1	21,9	***-19,5***	***15,9***	-7,4	21,1
BNM-LNE	12,1	17,0	12,4	19,4	15,3	19,1	7,5	22,0	18,1	21,9			-1,4	18,7	10,7	23,3
UME	13,5	7,8	***13,8***	***12,2***	***16,7***	***11,8***	8,9	16,0	***19,5***	***15,9***	1,4	18,7			12,1	17,8
PTB	1,4	16,0	1,7	18,6	4,6	18,3	-3,2	21,3	7,4	21,1	-10,7	23,3	-12,1	17,8		

ANNEX F 4

MATRIX OF EQUIVALENCE at 18 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : PTB 1-03-2
Frequency: 18 GHz

Lab j

			EIM		SP		NPL		AREPA		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
EIM	-3,5	28,0			4,0	31,0	1,4	29,9	-8,0	30,1	-4,4	29,7
SP	-7,5	13,2	-4,0	31,0			-2,6	16,9	-12,0	17,2	-8,4	16,6
NPL	-4,9	10,6	-1,4	29,9	2,6	16,9			-9,4	15,3	-5,8	14,6
AREPA	4,5	11,0	8,0	30,1	12,0	17,2	9,4	15,3			3,6	14,9
PTB	0,9	10,0	4,4	29,7	8,4	16,6	5,8	14,6	-3,6	14,9		

Standard : PTB 2-06-2
Frequency: 18 GHz

Lab j

			SP		NPL		AREPA		NMi-VSL		BNM-LNE		UME		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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	-8,4	13,2			-1,3	17,1	-14,0	25,7	-5,1	21,2	-12,6	27,2	-19,3	21,1	-11,5	16,6
NPL	-7,1	10,8	1,3	17,1			-12,7	24,5	-3,8	19,8	-11,3	26,1	-18,0	19,6	-10,2	14,7
AREPA	5,6	22,0	14,0	25,7	12,7	24,5			8,9	27,6	1,4	32,4	-5,3	27,4	2,5	24,2
NMi-VSL	-3,3	16,6	5,1	21,2	3,8	19,8	-8,9	27,6			-7,5	29,0	-14,2	23,3	-6,4	19,4
BNM-LNE	4,2	23,8	12,6	27,2	11,3	26,1	-1,4	32,4	7,5	29,0			-6,7	28,9	1,1	25,8
UME	10,9	16,4	19,3	21,1	18,0	19,6	5,3	27,4	14,2	23,3	6,7	28,9			7,8	19,2
PTB	3,1	10,0	11,5	16,6	10,2	14,7	-2,5	24,2	6,4	19,4	-1,1	25,8	-7,8	19,2		

ANNEX F 5

MATRIX OF EQUIVALENCE at 20 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : **PTB 1-03-2**
Frequency: **20 GHz**

Lab j

			EIM		SP		NPL		AREPA		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
EIM	-34,8	26,0			***-36,0***	***29,2***	***-32,5***	***28,1***	***-48,0***	***28,2***	***-35,8***	***28,2***
SP	1,2	13,2	***36,0***	***29,2***			3,5	16,9	-12,0	17,2	0,2	17,2
NPL	-2,3	10,6	***32,5***	***28,1***	-3,5	16,9			-15,5	15,3	-3,3	15,3
AREPA	13,2	11,0	***48,0***	***28,2***	12,0	17,2	15,5	15,3			12,2	15,6
PTB	1,0	11,0	***35,8***	***28,2***	-0,2	17,2	3,3	15,3	-12,2	15,6		

Standard : **PTB 2-06-2**
Frequency: **20 GHz**

Lab j

			SP		NPL		AREPA		NMi-VSL		BNM-LNE		UME		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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	-0,7	13,2			2,6	17,2	-12,0	29,2	0,8	21,2	-5,2	28,8	-17,0	21,2	-2,8	17,2
NPL	-3,3	11,0	-2,6	17,2			-14,6	28,2	-1,8	19,9	-7,8	27,9	-19,6	19,9	-5,4	15,6
AREPA	11,3	26,0	12,0	29,2	14,6	28,2			12,8	30,8	6,8	36,5	-5,0	30,8	9,2	28,2
NMi-VSL	-1,5	16,6	-0,8	21,2	1,8	19,9	-12,8	30,8			-6,0	30,5	-17,8	23,5	-3,6	19,9
BNM-LNE	4,5	25,6	5,2	28,8	7,8	27,9	-6,8	36,5	6,0	30,5			-11,8	30,5	2,4	27,9
UME	16,3	16,6	17,0	21,2	19,6	19,9	5,0	30,8	17,8	23,5	11,8	30,5			14,2	19,9
PTB	2,1	11,0	2,8	17,2	5,4	15,6	-9,2	28,2	3,6	19,9	-2,4	27,9	-14,2	19,9		

ANNEX F 6

MATRIX OF EQUIVALENCE at 23 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : **PTB 1-03-2**
Frequency: **23 GHz**

Lab j

			EIM		SP		NPL		AREPA		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
EIM	-7,5	28,0			-6,0	32,2	-7,7	30,8	-20,0	30,1	-13,0	30,9
SP	-1,5	16,0	6,0	32,2			-1,7	20,5	-14,0	19,4	-7,0	20,6
NPL	0,2	12,8	7,7	30,8	1,7	20,5			-12,3	16,9	-5,3	18,2
AREPA	12,5	11,0	20,0	30,1	14,0	19,4	12,3	16,9			7,0	17,0
PTB	5,5	13,0	13,0	30,9	7,0	20,6	5,3	18,2	-7,0	17,0		

Standard : **PTB 2-06-2**
Frequency: **23 GHz**

Lab j

			SP		NPL		AREPA		NMi-VSL		BNM-LNE		UME		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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	0,3	16,0			-0,8	20,7	-11,0	34,0	1,1	22,9	-17,8	26,7	-26,2	27,2	-4,3	20,6
NPL	1,1	13,2	0,8	20,7			-10,2	32,8	1,9	21,1	-17,0	25,1	-25,4	25,7	-3,5	18,5
AREPA	11,3	30,0	11,0	34,0	10,2	32,8			12,1	34,2	-6,8	36,9	-15,2	37,2	6,7	32,7
NMi-VSL	-0,8	16,4	-1,1	22,9	-1,9	21,1	-12,1	34,2			-18,9	27,0	-27,3	27,4	-5,4	20,9
BNM-LNE	18,1	21,4	17,8	26,7	17,0	25,1	6,8	36,9	18,9	27,0			-8,4	30,7	13,5	25,0
UME	26,5	22,0	26,2	27,2	25,4	25,7	15,2	37,2	27,3	27,4	8,4	30,7			21,9	25,6
PTB	4,6	13,0	4,3	20,6	3,5	18,5	-6,7	32,7	5,4	20,9	-13,5	25,0	-21,9	25,6		

ANNEX F 7

MATRIX OF EQUIVALENCE at 26 GHz for PTB 1-03-2 and PTB 2-06-2

Standard : **PTB 1-03-2**
Frequency: **26 GHz**

Lab j

Lab i	D_i /10-3	U_i /10-3	**EIM**		**SP**		**NPL**		**AREPA**		**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
EIM	-23,1	30,0			-28,0	36,5	-24,6	33,5	-30,0	45,3	-22,6	34,5
SP	4,9	20,8	28,0	36,5			3,4	25,6	-2,0	39,9	5,4	26,9
NPL	1,5	15,0	24,6	33,5	-3,4	25,6			-5,4	37,2	2,0	22,7
AREPA	6,9	34,0	30,0	45,3	2,0	39,9	5,4	37,2			7,4	38,0
PTB	-0,5	17,0	22,6	34,5	-5,4	26,9	-2,0	22,7	-7,4	38,0		

Standard : **PTB 2-06-2**
Frequency: **26 GHz**

Lab j

Lab i	D_i /10^{-3}	U_i /10^{-3}	**SP**		**NPL**		**AREPA**		**NMi-VSL**		**BNM-LNE**		**UME**		**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}	D_{ij} /10^{-3}	U_{ij} /10^{-3}
SP	5,0	21,0			3,7	26,0	2,0	40,0	12,4	27,8	-1,7	29,1	-21,7	41,9	5,3	27,0
NPL	1,3	15,4	-3,7	26,0			-1,7	37,3	8,7	23,8	-5,4	25,4	-25,4	39,3	1,6	22,9
AREPA	3,0	34,0	-2,0	40,0	1,7	37,3			10,4	38,6	-3,7	39,5	-23,7	49,7	3,3	38,0
NMi-VSL	-7,4	18,2	-12,4	27,8	-8,7	23,8	-10,4	38,6			-14,1	27,2	-34,1	40,5	-7,1	24,9
BNM-LNE	6,7	20,2	1,7	29,1	5,4	25,4	3,7	39,5	14,1	27,2			-20,0	41,5	7,0	26,4
UME	26,7	36,2	21,7	41,9	25,4	39,3	23,7	49,7	34,1	40,5	20,0	41,5			27,0	40,0
PTB	-0,3	17,0	-5,3	27,0	-1,6	22,9	-3,3	38,0	7,1	24,9	-7,0	26,4	-27,0	40,0		