Final Report

CCEM.RF-K8.CL COMPARISON
CALIBRATION FACTOR OF THERMISTOR MOUNTS

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Abstract

From February 1998 to July 1999 the measurements for a Euromet project 393 were carried out. After the decision of the GT-RF (and CCEM) to extend this project into a worldwide key comparison (CCEM.RF-K8.CL with GT-RF 98-1 as its non-European part) measurements were carried out between August 1999 and December 2000.
Two travelling standards were measured by 17 national standard institutes. The results at all selected frequencies in the range from 10 MHz to 18 GHz show a good agreement between most of participants. The maximum stated uncertainty for the calibration factor ranges from 0.3 % at 50 MHz to more than 4.0 % at 18 GHz, independent of the type of connector on the DUT. Almost all results are consistent within the claimed uncertainty. The uncertainty stated for the reflection coefficient was up to 0.03 in almost all cases. Most of the results are consistent within the claimed uncertainty.
The evaluation of the Euromet project led to a new comparison (project 633) to study potential problems at several laboratories. One non-European laboratory was invited to participate as well in this project (KCDB-code EUROMET.EM.RF-K8.CL).

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1. Introduction

Among the Euromet HF experts the philosophy was put forward that for transferring the quality of the national standards to the national industry a comparison on the level of routine calibration is very useful in showing coherence of the (inter)national metrology infrastructure. Hence, during their 1997 meeting in Torino, Italy, such a comparison was initiated and registered as Euromet project 393. Its aim was to check the quality of measuring the calibration coefficient of thermistor mounts in a way similar as done for 'high level customers'. NMi Van Swinden Laboratorium (NMi-VSL) agreed to act as pilot laboratory.

In 1998 the Working group on Radio-Frequency Quantities (Groupe de Travail pour les grandeurs aux Radio-Fréquences GT-RF) of the Comité Consultatif d'Electricité et Magnetism (CCEM) decided to extend the scale of this comparison into a key comparison on a worldwide level.

This report is the technical report on the complete exercise containing both the Euromet 393 project (as regional comparison within the key comparison) and the GT-RF 98-1 comparison (as the CCEM addition to complete a worldwide exercise).

As no participant made any objection, a concept draft A report (containing results from the Euromet loop only) has been discussed during a Euromet HF experts meeting in Brussels, Belgium, in March 2000. The results have been reported during the CPEM2000 in Sydney, Australia, and have been published as well [1].

Already during the start of the project the role of comparisons as technical evidence of the performance of the national metrology institutes was indicated. Hence the pilot laboratory attempted to implement the expected requirements, e.g. a fixed measuring period, short reporting time and routine measurement conditions. It was not possible to decide on the method of calculating a reference value for the comparison and to obtain uncertainty budgets before the start of the comparison. In the CIPM guidelines [2] it is also suggested that a trial round will be held with a small group of laboratories and that they will perform an evaluation round. Although this is not done officially, the Euromet project 341 [3], in which BNM-LCIE and NMi-VSL compared their primary power facilities (microcalorimeters), can be used for this purpose. A subset of those DUTs was used in the present comparison.

In the past a number of intercomparisons [4] was organised under the umbrella of GT-RF, but these were mainly carried out using calorimetric methods.

2. Participants and schedule

During the 1997 Euromet meeting representatives of 14 laboratories expressed their interest in participating in the comparison. An offer from NMi-VSL to act as coordinator and pilot laboratory for this interlaboratory comparison was accepted. Later on, one of the laboratories withdrew, but three others joined the project. Due to internal problems one of the latter laboratories had to withdraw. In the GT-RF extension another 7 laboratories joined the official CCEM.RF comparison.

The original time schedule for the Euromet project was proposed and finalised in January 1998 and is given in Appendix F2. Some modifications were done during the comparison due to withdrawal and entering of participants. After the conversion into a CCEM.RF comparison and near the end of the Euromet project an additional time schedule was proposed to the new participants and was finalised in spring 1999 and is given in Appendix F2 as well. The final scheme for the whole project is given in Table 1. In a number of cases the official names of the laboratories changed between the start of the comparison and the writing of this report. The new names will be used throughout the report.

Finnish Telecom did carry out the measurements, but did not submit any data to the coordinator. Apparently their facilities have been closed.

Table 1. List of participants and measurement dates.

Acronym	National Metrology Institute	Country	Standard at the laboratory	Date of submission of report	Comment
NMi-VSL	NMi Van Swinden Laboratorium - Pilot	The Netherlands	January 1998		
Celsius	Celsius Metech AB	Sweden	February 1998	April 1998	
	Telecom Finland	Finland			Measurements carried out, but no report submitted
IENGF	Istituto Elettrotecnico Nazionale Galileo Ferraris	Italy	March 1998	May 1998	
INTA	Instituto Nacional de Técnica Aeroespacial	Spain	April 1998	May 1998	Measurements carried out on behalf of CEM
NMi-VSL	Pilot	The Netherlands	May 1998		
SMU	Slovak Institute of Metrology	Slovak Republic	June 1998	November 1998	
METAS (formerly OFMET)	Swiss Office of Metrology	Switzerland	July 1998	September 1998	
CMI	Czech Metrology Institute	Czech Republic	August 1998	September 1998	
OMH	National Office of Metrology	Hungary	September 1998	October 1998	
NMi-VSL	Pilot	The Netherlands	September 1998		
PTB	Physikalisch-Technische Bundesanstalt	Germany	October 1998	December 1998	
NPL	National Physical Laboratory	United Kingdom	November 1998	March 1999	
NMi-VSL	Pilot	The Netherlands	December 1998		
CSIR-NML	Council for Scientific and Industrial Research– National Metrology Laboratory	South Africa	February 1999	September 1999	
UME	Ulusal Metroloji Enstitüsü	Turkey	March 1999	April 1999	
BNM-LNE\LAMA (formerly BNM-LCIE)	Bureau National de Metrologie – Laboratoire National d'Essais \ Laboratoire André-Marie Ampère	France			Problems with the measurement set-up. The DUTs were forwarded to SIQ
SIQ	Slovenian Institute of Quality and Metrology	Slovenia	April 1999	December 1999	
BNM-LNE	Bureau National de Metrologie – Laboratoire National d'Essais	France	June 1999	February 2000	
NMi-VSL	Pilot	The Netherlands	July 1999		

Acronym	National Metrology Institute	Country	Standard at the laboratory	Date of submission of report	Comment
NIST	National Institute of Standards and Technology	United States	August 1999	November 1999	
CSIRO-NML (now National Measurement Institute, Australia)	Commonwealth Scientific and Industrial Research Organisation – National Metrology laboratory	Australia	September 1999	January 2001	Data submitted in 1999. The uncertainty budget was submitted later, due to possible remeasurement.
KRISS	Korea Research Institute of Standards and Science	Korea	November 1999	March 2000	
NMIJ/AIST (formerly ETL)	National Metrology Institute Japan (NMIJ)/ National Institute of Advanced Industrial Science and Technology (AIST)	Japan	January 2000	March 2000	
NRC	National Research Council	Canada	February 2000	March 2000	
SPRING (formerly PSB)	National Metrology Centre / Standards, Productivity and Innovation Board	Singapore			Measurements were not performed due to problems with measurement set-up
NIM	National Institute of Metrology	China	April 2000	May 2000	
NMi-VSL	Pilot	The Netherlands	August 2000		
SPRING	National Metrology Centre (SPRING Singapore)	Singapore	October 2000	December 2000	
NMi-VSL	Pilot	The Netherlands	January 2001		

The measurements are considered to be routine activity: hence only two weeks of measurements and one or two weeks for transportation were allowed. The ATA carnet was used outside the European Union: from the experience during the comparison it is no longer clear that this document is really to prefer!! Our own (NMi-VSL) experience is that a temporary import/export document within a star pattern comparison (return to the pilot laboratory after measurements at each laboratory) is to be preferred. Often this additional work will compensate the loss in time encountered now.

Concerning the time schedule of measurements a good performance is shown by almost all laboratories, despite the tight schedule of only three weeks per laboratory (including transport) within the Euromet project. But for reporting the performance of almost all laboratories is quite poor, as the guidelines ask for a report within one month after finalising the measurements.
The GT-RF 98-1 project started immediately after completion of the Euromet 393 project in July 1999 and allows for a one-month turn-around time per laboratory. Due to customs problems this time schedule turned out to be too optimistic: the transportation took often much more time.

3. Transfer Standard and required measurements

In the frequency range up to 18 GHz the two main connector types for RF power mounts are the so-called GPC7 (a sexless connector) and the so-called Type-N connector, both having a characteristic impedance of 50 ohm in a 7 mm transmission line geometry. Hence it was decided to use as transfer

standards one device for each connector type. It is assumed that external customers will at least submit thermistor mounts equipped with Type-N connectors for calibration and only sometimes thermistor mounts with PC7 connector. Therefore, in addition an adapter from PC7 to Type-N male was added to allow each laboratory to measure at least two devices.
The applied 3 DUTS used are:

- 1: Thermistor mount “TM1” with Type N - connector;
  a Hewlett Packard type 8478 B (SN: 2103 A 23274), owned by BNM-LCIE (FR)
- 2: Thermistor mount “TM2” with Type GPC 7 - connector;
  a Hewlett Packard type 8478 B Option H49 (SN: 2106 A 24460), owned by NMi-VSL (NL)
- 3: Thermistor mount “TM3”
  it is TM2 with an adapter from GPC7- to N-connector. The adapter is a part of a commercial VNA calibration kit (identifier c2-1)

The DUT power detectors are thermistor mounts that must be used in connection with a thermistor bridge which keep the thermistor resistance to a fixed value of 200 Ω. Several commercial thermistor bridges are available to determine the DC substitution power P_{DC} when rf power is applied to the thermistor mount. The mount has an available compensation scheme that allows the detection of power, even when the ambient temperature is not constant. The two signals (V_{RF} and V_{comp}) from two separated bridges inside of commercial thermistor bridges may be detected separately to determine P_{DC} . It is also possible to use the recorder output, which is proportional to P_{DC} because of an internal electronic manipulation with the V_{RF} and V_{comp} signals.

The quantity under investigation in this comparison is the calibration factor K, which is defined by:
$K = P_{DC}/P_{inc}$ with:
P_{DC} - the DC substitution power determined by the thermistor bridge of the participant and
P_{inc} - the RF power incident to the thermistor mount (DUT) at the measurement frequency.

The participants were asked to submit measurement results on each thermistor mount at 8 frequencies (10 MHz, 50 MHz, 1 GHz, 4 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz) concerning its calibration factor and also its reflection coefficient, both with an extended uncertainty (coverage factor k =2).

To substantiate the technical performance the technical protocol put emphasis on the uncertainty statements and the consistency of the measurement results. Hence, a detailed uncertainty budget, containing sources and magnitudes, was requested, as well as the traceability of the standards, in order to take into account the possibility of correlation between the results.

In principle this information is easily available, as soon as a laboratory operates effectively according to a quality assurance system based upon standards like ISO 17025.

The quantity reflection is necessary for the uncertainty calculations. In this comparison it is not the quantity under investigation.

In the guidelines no requirements are given concerning the ambient conditions.

4. Behaviour of the transfer standard

As the DUTs are a subset of the devices used in Euromet project 341, no additional checks concerning stability for transport have been performed. The normal maintenance activities within the two laboratories that owned the devices (NMi-VSL and BNM-LNE\LAMA) showed a good stability. Hence, intermediate measurements were planned after about 3 or 4 laboratories: NMi-VSL performed in total seven measurements including those at the start and at the end of the comparison.

Before processing the data obtained in the comparison an investigation is done whether a significant drift in the DUTs has occurred, based upon the 7 results obtained at VSL (see Appendix A). Within the uncertainty no significant drift has occurred over a period of 36 months. Based upon this information it is decided that no correction for drift is necessary. The pilot laboratory has decided to use one specific measurement (the measurement half-way through the comparison) as the official entry to the comparison. In Appendix A the difference between the official entry and the average of the VSL-data is indicated for information.

During the comparison some laboratories indicated a relative poor reproducibility of TM1, compared to the other DUT and results from calibrations on similar devices for customers.

5. Measurement methods

As indicated in the guidelines each laboratory should use the same measurement instrumentation as used for “high level” calibration for external customers. As PTB measures for “high level” calibrations thermistor mounts in their microcalorimeter system they used their microcalorimeter primary facility**.**
All other systems are based on a (in)direct comparison between a (working) standard and the DUT.

The majority of the laboratories used a splitter system in which one of the arms is used to monitor the output power. On the other arm the standard and the DUT were attached and for each the response in relation to the monitor signal was measured.
For each laboratory the measurement procedure (including traceability) is briefly described here. Also information about the measurement of the reflection is given.

NMi-VSL – pilot laboratory:
A substitution system is used, where the signal comes from a stable signal generator, with a 10 dB attenuator to improve the VSWR of the output port. The standard and DUT are placed alternatively on the output port of the generator, and are of similar design (thermistor mounts). The response of the thermistor mounts is obtained using the recorder output of a selfbalancing bridge, HP 432A. The recorder output has been characterised during normal maintenance using V_{RF} and V_{comp} readings.
Traceability is based on the primary VSL power facility (microcalorimeter): the working standard is calibrated in the microcalorimeter every half year.
The reflection coefficients are measured using Vector Network Analysers (HP 8753B and Wiltron 360A).

Celsius Metech:
A power splitter system is used with a feedback via the monitoring arm to keep the power into the second arm constant. The DUT and the standard are attached alternatively to this arm of the splitter. The response of the DUT is based upon the readings of the individual bridge voltages of the HP432A, V_{RF} and V_{comp}.
The laboratory’s standard (a thermo-electric sensor) is calibrated at SESC, UK, a UKAS accredited calibration laboratory (now called DERA).
The reflection coefficients are measured using Vector Network Analysers (HP 8751A and 8510C).

IENGF:
A power splitter system is used with a 6 dB attenuator attached to the test port to improve the VSWR of the system. The DUT and the standard are attached alternatively to this arm of the splitter. The ratio between the responses of the power readings on both arms is obtained as measurement value.

The standard is a thermistor mount and traceable to the IEN primary power facility (a microcalorimeter). The reflection coefficients are measured using Vector Network Analysers.

INTA:
A feedthrough system is used which is calibrated on a regular basis using thermistor mounts calibrated at NIST. The system provides a constant output due to a temperature controlled feedback loop. The response of the DUT is based upon the readings of the individual bridge voltages, V_{RF} and V_{comp}.
The reflection coefficients for the DUT with APC7 connector are measured using Vector Network Analysers. For the DUT with type-N connector two directional bridges (depending on the frequency) are used with known open and short circuit as reference.

SMU:
A feedthrough system is used which provides a calibrated output power (feedback via a directional coupler). A DVM is used for readout of the selfbalancing bridge (Weinschel PB-1C).
As standard a thermistor mount HP 8478B was used which is traceable to the SMU microcalorimeter. No measurements have been carried out at 10 MHz, 15 GHz and 18 GHz.
The reflection coefficients are measured using a SWR-bridge (Wiltron).

METAS:
A power splitter system is used with the standard (a thermistor mount) on one arm and the DUT on the other. A DVM is used for readout of the two selfbalancing bridges (Arbiter 1096).
The standard is traceable to NMi-VSL.
The reflection coefficients were measured using Vector Netwrok Analysers HP 8753D and HP 8510C. The power splitter has been evaluated using these VNAs.

CMI:
A power splitter system is used with a feedback via the monitoring arm to keep the power into the second arm constant. The standard and DUT are placed alternatively on the second arm, and are of similar design (thermistor mounts). The response of the thermistor mounts is based on a selfbalancing bridge (single read-out for Arbiter 1096, or on V_{RF} and V_{comp} in case of HP432A)
The standard is traceable to PTB, Germany.
The reflection coefficients are measured using Vector Network Analysers (HP 8510C) starting from 45 MHz. Below 45 MHz CMI used the BM553 vector voltmeter (0.1 to 1000) MHz made by former TESLA company. Measurement setup consists of the resistive power splitter and the directional transformer (optimized for lf range). The test set (vector voltmeter and generator) operates under software control and CMI used the OSL calibration method. The obtained results agree quite well with the VNA results in the frequency range (0.045 to 1) GHz.

OMH:
A feedthrough system is used for which the output level is monitored via a directional coupler. An attenuator is used to improve the VSWR of the system. The standard and DUT are placed alternatively on the test port.
The standard is a thermistor mount and traceable to the OMH primary power facility (a microcalorimeter); for 10 MHz a calorimetric device is used.
The reflection coefficients are measured using a reflectometer bridge up to 1 GHz. Above this frequency a slotted line method was used.

PTB:
The measurements are performed in the PTB primary power facility (a microcalorimeter). In this way effective efficiencies are obtained for the DUTs. After determining the reflection coefficients the calibration factors were calculated.

The reflection coefficients are measured using a Vector Network Analyser, at 10 MHz type R&S ZVR and above 10 MHz type HP 8510.

NPL:
Two different systems are used.
Up to 8 GHz: A power splitter system is used with a monitoring sensor in one arm. The ratio between the responses of the power readings on both arms is used as measurement result for the sensor under investigation (standard or DUT)
The standard is a coaxial thermistor mount (14 mm) and is traceable to the NPL primary facility (a dry twin calorimeter).
Above 8 GHz: A multistate reflectometer is used which includes a monitor for power output. The measurand is the ratio of the power readings (after normalization using the monitor signal) between the standard and the DUT which are attached alternately to the test port.
The waveguide standards are traceable to the NPL primary facilities (microcalorimeters).
In all cases the V_{RF} output of the HP432A is used as response of the DUT.
The reflection coefficients at frequencies above 10 MHz are measured using a Vector Network Analyser (HP 8510C). At 10 MHz the information from the pilot laboratory is used

CSIR-NML:
A power splitter system is used which is calibrated on a regular basis using NML standards. In this way a relation is obtained between the power reading of a monitoring sensor in one arm and the output power in the other arm.
The internal standards are traceable to the NML primary facility (a dry twin-load calorimeter).
The reflection coefficients are measured using Vector Network Analysers (HP 8753D and 8510C).

UME:
The measurement system consists of a stable signal generator system (containing an amplifier and an adapter in addition). The standard and DUT are placed alternatively on the output port of the generator, and are of similar design (thermistor mounts). The response of the thermistor mounts is based on a self-balancing bridge HP 432A, using V_{RF} and V_{comp}.
The traceability is based on the UME primary power facility (microcalorimeter) and a comparison with BNM-LCIE, both using microcalorimeter systems.
The reflection coefficients are measured using a Vector Network Analyser (HP8510C) with a 3.5 mm test set. Adapter evaluation is used to determine the reflection coefficient for the type-N and PC7 connectors. As no measurement at 10 MHz is possible with such a device, the typical value for the type 8478B was used.

SIQ:
A power splitter system is used which is calibrated on a regular basis using power sensors which are traceable to SESC, UK, a UKAS accredited calibration laboratory (now called DERA).
The standard is used as monitoring sensor. The response of the DUT is based upon the readings of the individual bridge voltages, V_{RF} and V_{comp}.
No information is received about the reflection measuring system.

BNM-LNE:
Two systems are used.
Below 1 GHz: a calibrated power splitter system is used.
At 1 GHz and higher: a calibrated single six-port system is used.
The standards are traceable to the LCIE primary power facility (a microcalorimeter).
The reflection coefficients were measured using a heterodyne network analyser (10 MHz and 50 MHz) and a single six-port system (1 GHz and above).

NIST:

Two systems are used:

Up to 1 GHz: A six-port system is used to determine source and load reflection coefficients and to transfer the calibration factor from the standard to the device(s) under test.

Above 1 GHz: a power splitter system is used for transfer of the calibration factor from the standard to the device(s) under test.

The standards are traceable to the NIST primary power facility (a microcalorimeter).

All relevant reflection coefficients are determined using a commercial Vector Network Analyser.

CSIRO-NML:

Two different measuring set-ups were used.

At 10 and 50 MHz a direct comparison set-up was used with a tuned directional coupler. Above 50 MHz a six-port system was used.

The laboratory standard is calibrated using the NML microcalorimeter.

The reflection coefficients are determined using a HP8510C and an Advantest R3762A network analyser.

KRISS:

A power splitter system is used with a feedback stabilised output power. The output voltages of the laboratory's standard and the device(s) under test are obtained using a Type IV bridge and are measured using a long scale DVM. The standards are calibrated using the laboratory's microcalorimeters.

The reflection coefficients are measured using vector network analysers.

NMIJ/AIST:

A broadband power meter calibration system is used, using a twin-type calorimeter (isothermal controlled) as the standard (home-built). All power measuring components are isolated from the surroundings. A power splitter is used in transferring the calibration factor of the standard to the device(s) under test. The power splitter ratio of the power splitter, and, if necessary, the influence of adapter(s) used on the standard are determined separately.

The reflection coefficients are determined using VNAs (HP 8753E and Wiltron 360B).

NRC:

Two different measuring set-ups were used.

At 10 and 50 MHz the travelling standards were compared directly to the reference standard twin load coaxial calorimeter using a 50 ohm power divider. The two different positions of the power divider were used to cancel the small asymmetry of the divider.

In the frequency range from 1 to 18 GHz a six-port reflectometer using thermistor mounts as detectors was calibrated against the calorimeter and then used to measure the thermistor mounts under test.

The power reference standard is a calorimeter (equipped with PC7 connectors) developed at NRC. The reflection measurements are based upon an in-house procedure using a series of airlines, short circuit and match load.

NIM:

The standard is a power splitter system with a feedback stabilised output power. The signal from the DUT is detected using a home-built power meter.

The reflection coefficients were measured using a VNA (HP8722ES) and an impedance analyser (HP4191A).

SPRING:

The calibration factors were obtained using the method of DC substitution power comparing the device under test against a power transfer standard traceable to the national reference standard maintained at SPRING. This was calibrated by NIST. The reflection coefficients were measured using Vector Network Analysers (HP 8510C and HP8751A).

6. Technical protocol

In the protocol ("guidelines for the comparison", see Appendix F1) participants were asked to present their measurement results in the format of the mean of the calibration factor and the magnitude of the reflection coefficient at the 8 frequencies, including a statement of uncertainty with a coverage factor of k = 2. In addition they were requested to give a detailed uncertainty budget that would allow the pilot laboratory to determine whether important contributions might have been overlooked and to allow for drafting a common agreed basis for uncertainty calculation in this field. A copy of an example from the EA document on uncertainty (EAL-R2-S1, now EA-04/02-S1) was included, giving guidance for providing such an uncertainty budget. Also the traceability for the standards used should be provided to ascertain that correlation between measurement results would not be overlooked.
In addition the participants were asked to provide the results on a calibration certificate in a way similar to the request of a customer. In this way it is possible to see which aspects are considered to be important in reporting to a customer.

The comparison started before the official guidelines [2] were available. However, draft versions were available, and along with informal discussions they were used to define the technical protocol. Aside from the EA document no common scheme to report the uncertainty budgets was given to the participants. At the end of the comparison information about 4 sources of uncertainty was asked for. Of course the global uncertainties given in the measurement reports were not modified. The uncertainty budgets are reported in Appendix D. If no electronic version was available, the paper information was scanned in.

A number of the laboratories did not provide a *detailed* uncertainty budget immediately and were asked later to provide this information in order to harmonise the information and to follow the new guidelines for the key comparisons.
In some cases reporting took a very long time (see Table 1).

7. Measurement results

7.1. General results

The participants were asked to submit measurement results on each thermistor mount at 8 frequencies (10 MHz, 50 MHz, 1 GHz, 4 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz) concerning its calibration factor and also its reflection coefficient, both with an extended uncertainty (coverage factor k =2).
After receiving the measurement data (including uncertainty statement) the coordinator has compiled these results in an Excel spreadsheet for further analysis. Each laboratory has received the relevant part of this spreadsheet for checking the correctness of these data.

Figure 1 gives a first impression of the overall result of the comparison. The averages of the results (calibration factor and reflection coefficient) from all participants are given for each of the three DUTs, including the average of the stated uncertainties (k=2) as given by the participants. For the determination of the Key Comparison Reference Value (KCRV) only the results from those participants may be used that are both member of the GT-RF and have an independent realisation of the SI unit. In general this means that they have a microcalorimeter for a primary determination of RF power. In Table 2 a list of those laboratories is given. The mean of the results obtained by those laboratories is given as well in figure 1, together with the average value of the stated uncertainties (k=2) of the relevant laboratories. The fourth measurement of NMi-VSL is its official entry.

As the calibration factors are strongly dependant on frequency the participants in the Euromet loop decided to present the results referenced either to the average value obtained from the results of all participants or to the KCRV.
In Figure 2 the results of the individual laboratories are given for the three DUTs as deviation of the individually measured value from the average value obtained from *all* participants. The uncertainty bars are the k=2 values as given by each of the laboratories.

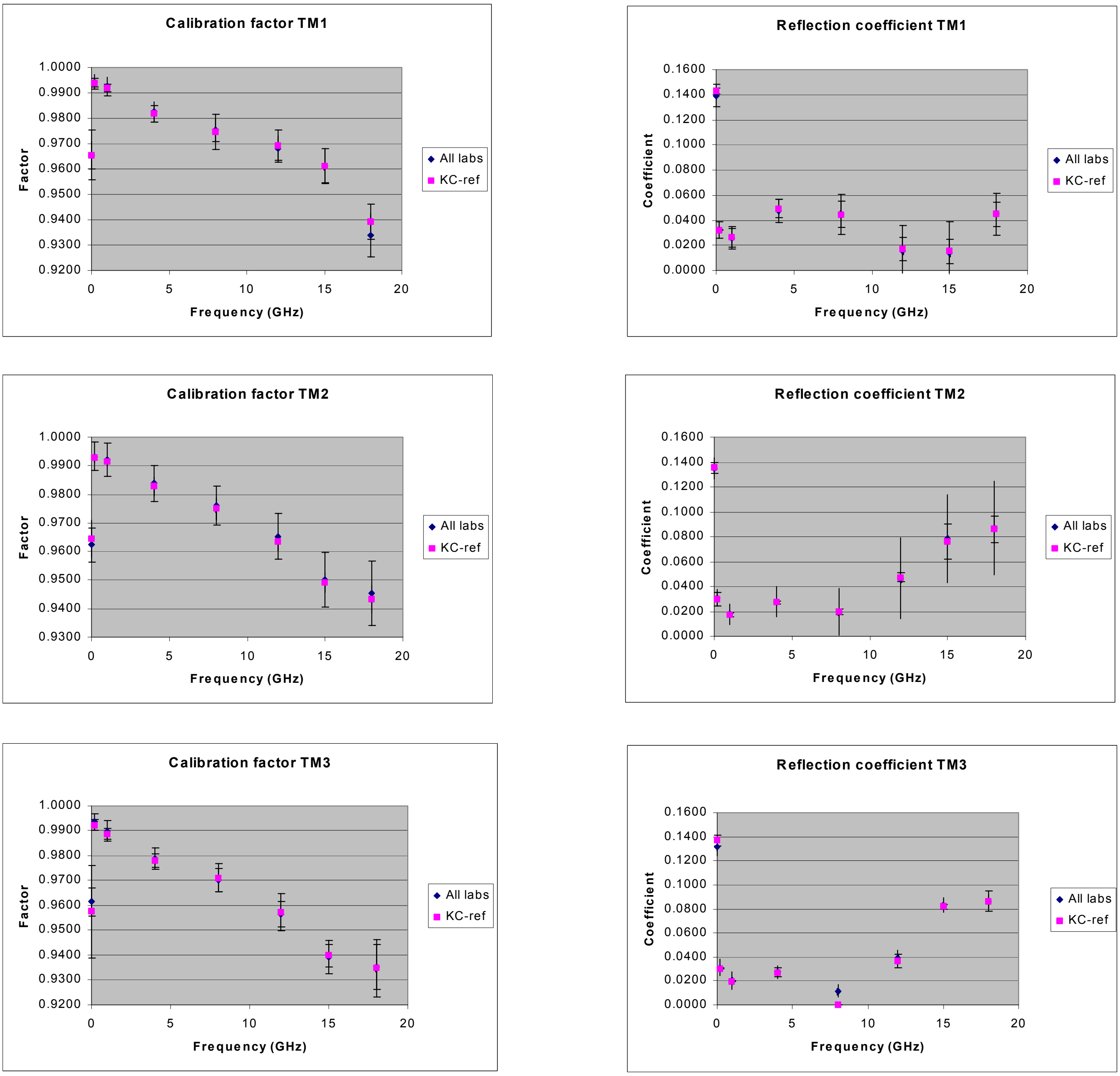
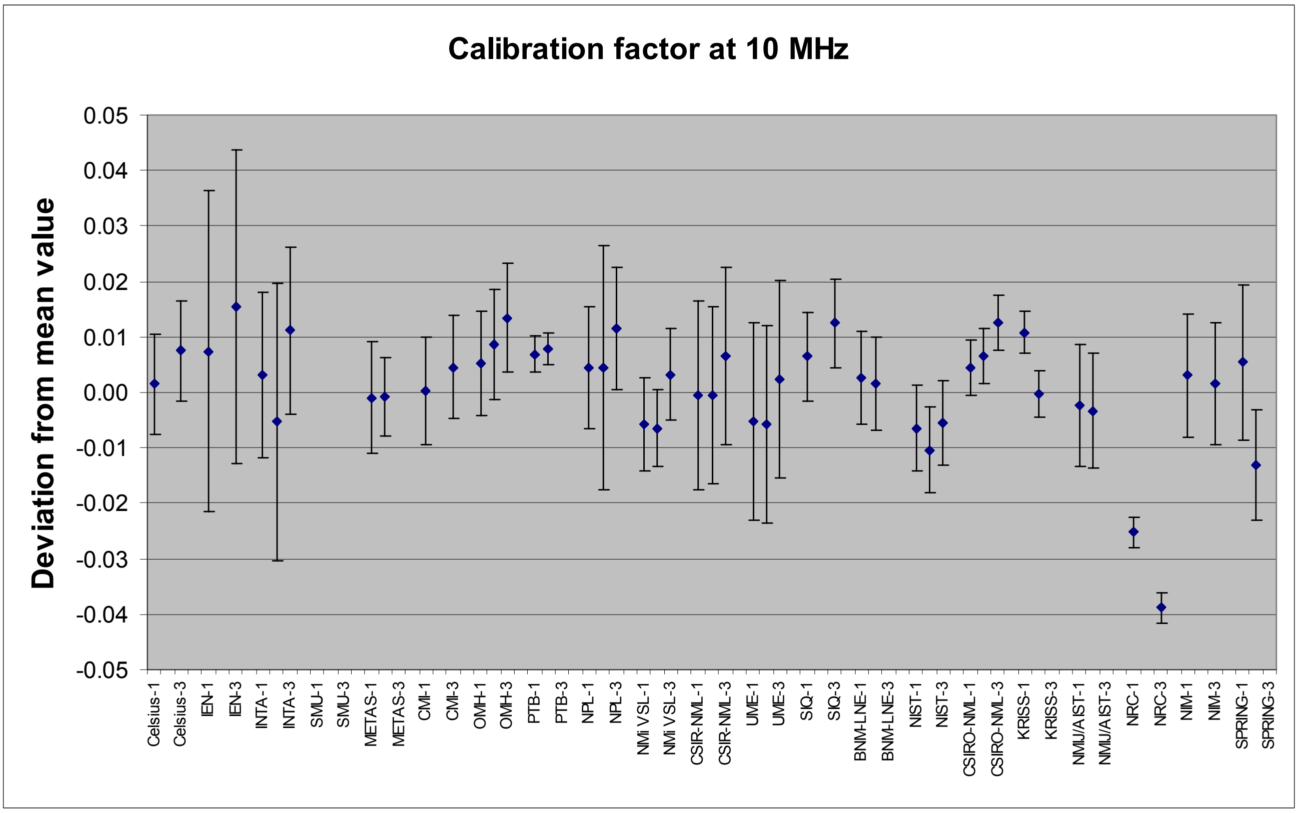


Figure 1: Global result obtained in the comparison for the three DUTs. The left column presents the average calibration factor and the right column the average reflection coefficient. The uncertainty bars refer to the average of the stated uncertainties (k=2) as given by the participants. KC-ref indicates the result when only those laboratories are included which have an independent realisation of the power standard and are member of the GT-RF.



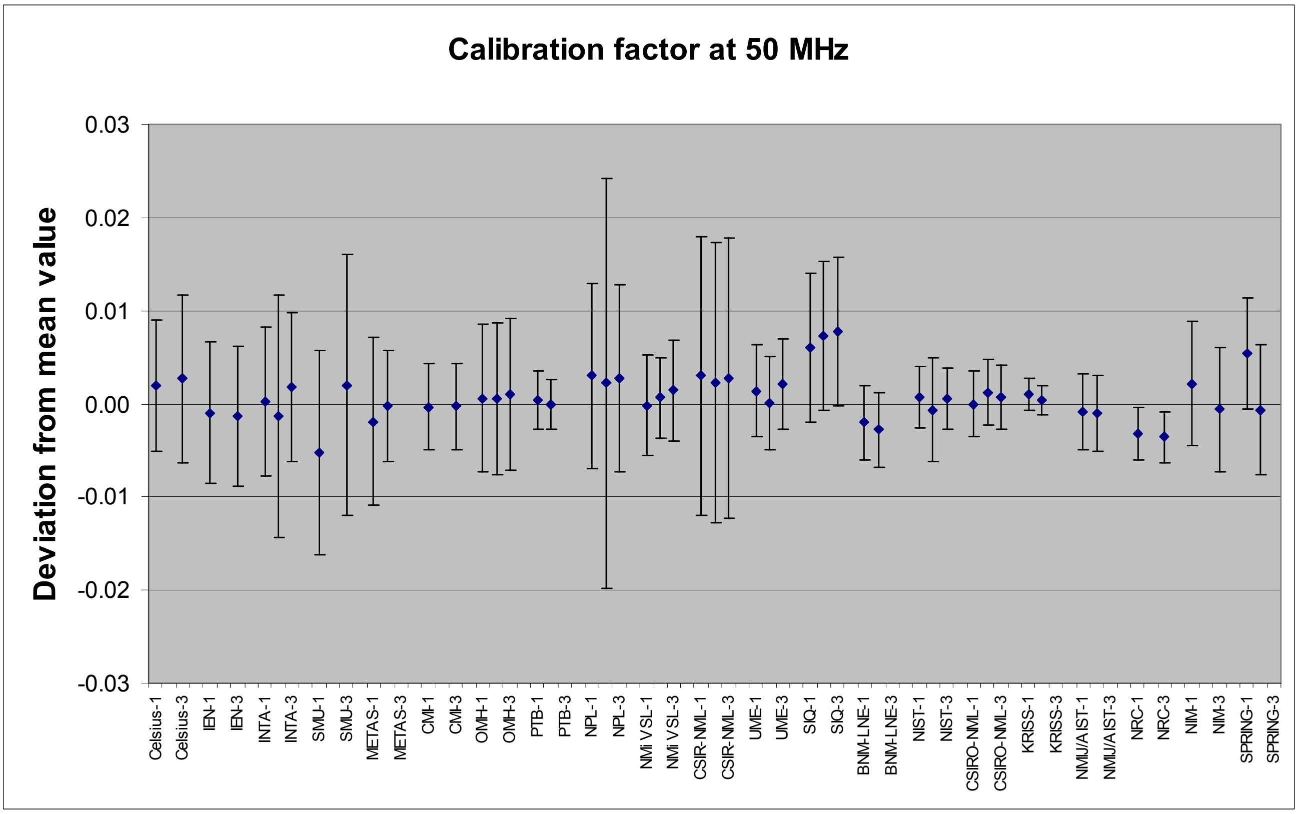
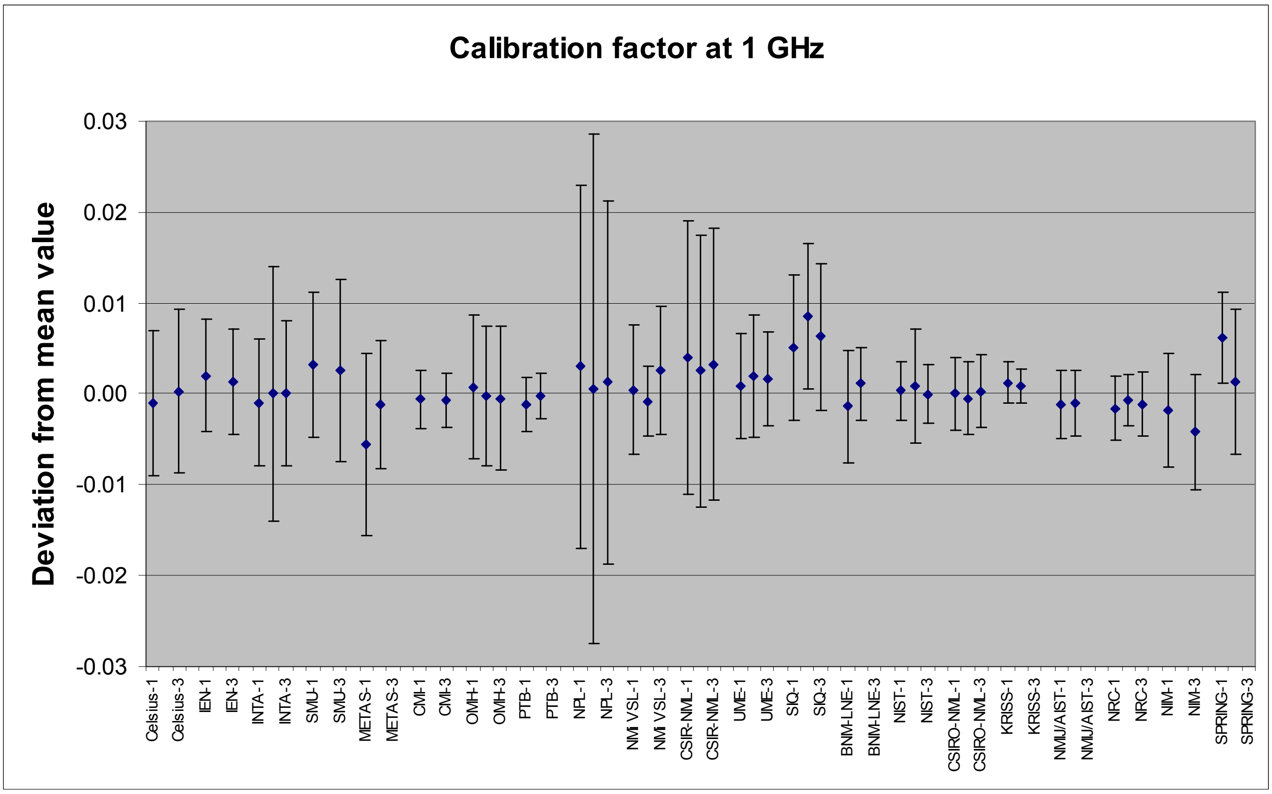


Figure 2.1: Measurements at 10 MHz (top) and 50 MHz (bottom). The measurements are identified by the laboratory's name and the DUT identifier (1 – blank – 3). For each DUT the zero line refers to the mean value of the calibration factor as measured by all laboratories. The error bars refer to the k=2 uncertainty as given by the participants.



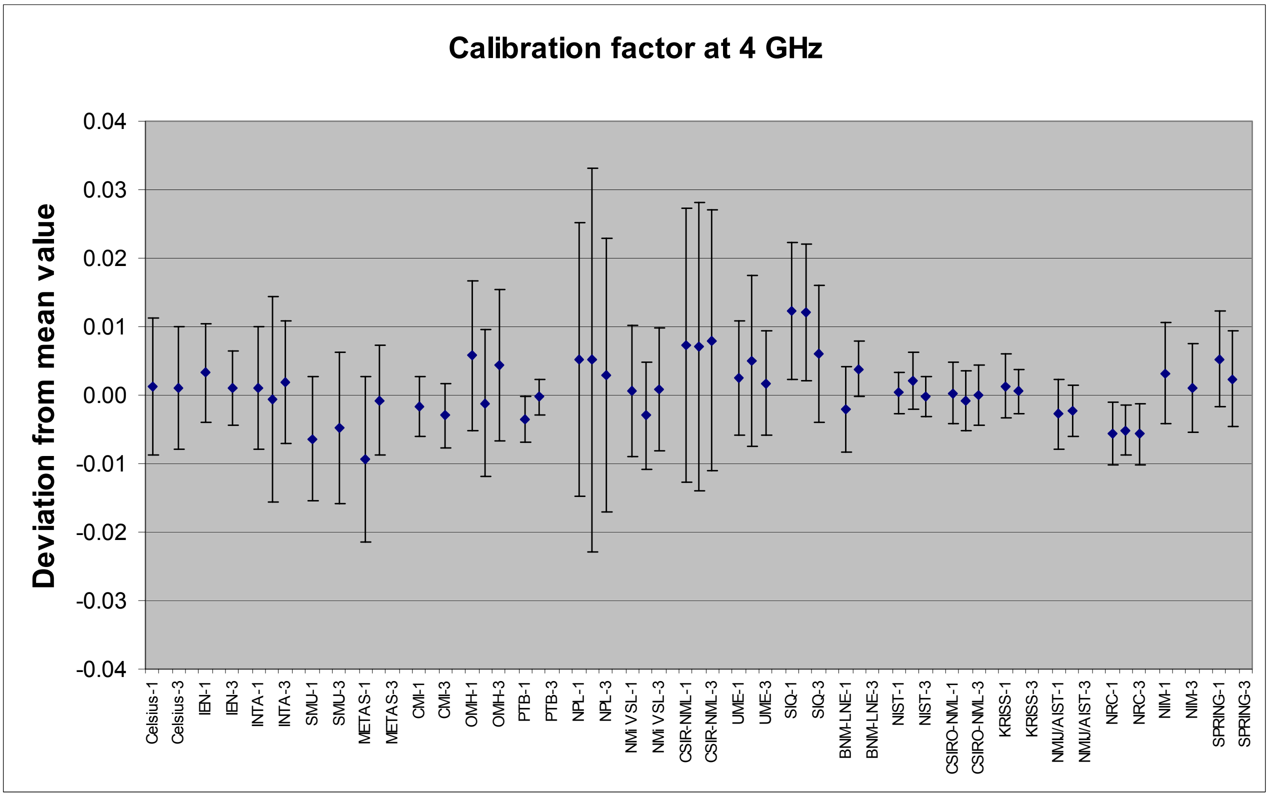
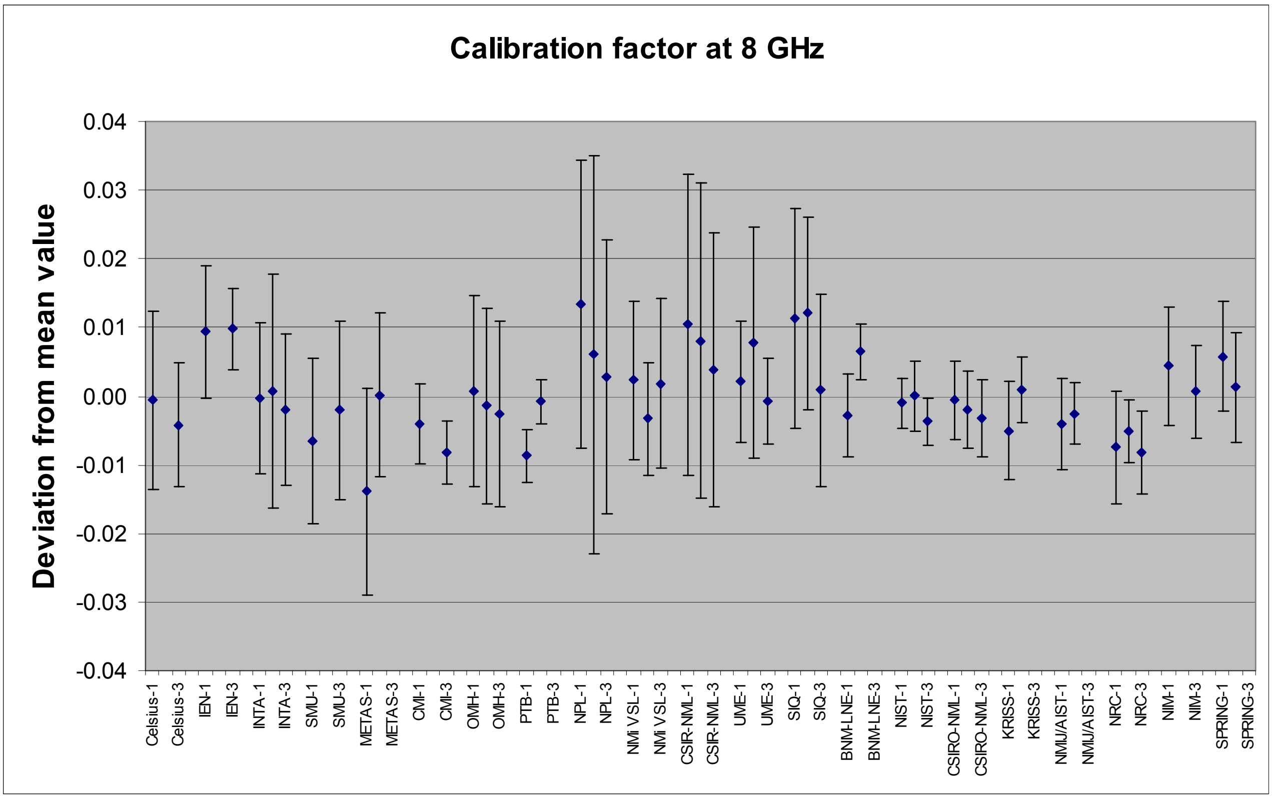


Figure 2.2: Measurements at 1 GHz (top) and 4 GHz (bottom). The measurements are identified by the laboratory’s name and the DUT identifier (1 – blank – 3). For each DUT the zero line refers to the mean value of the calibration factor as measured by all laboratories. The error bars refer to the k=2 uncertainty as given by the participants.



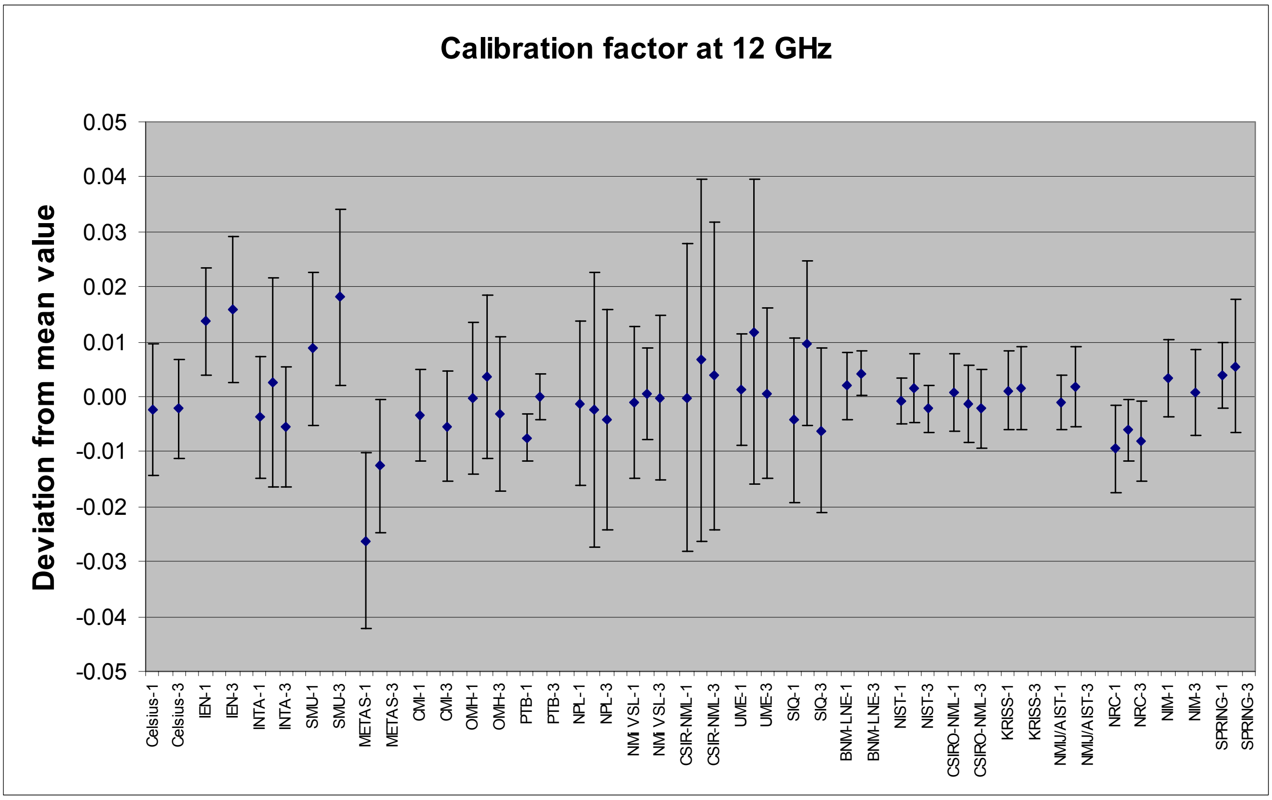
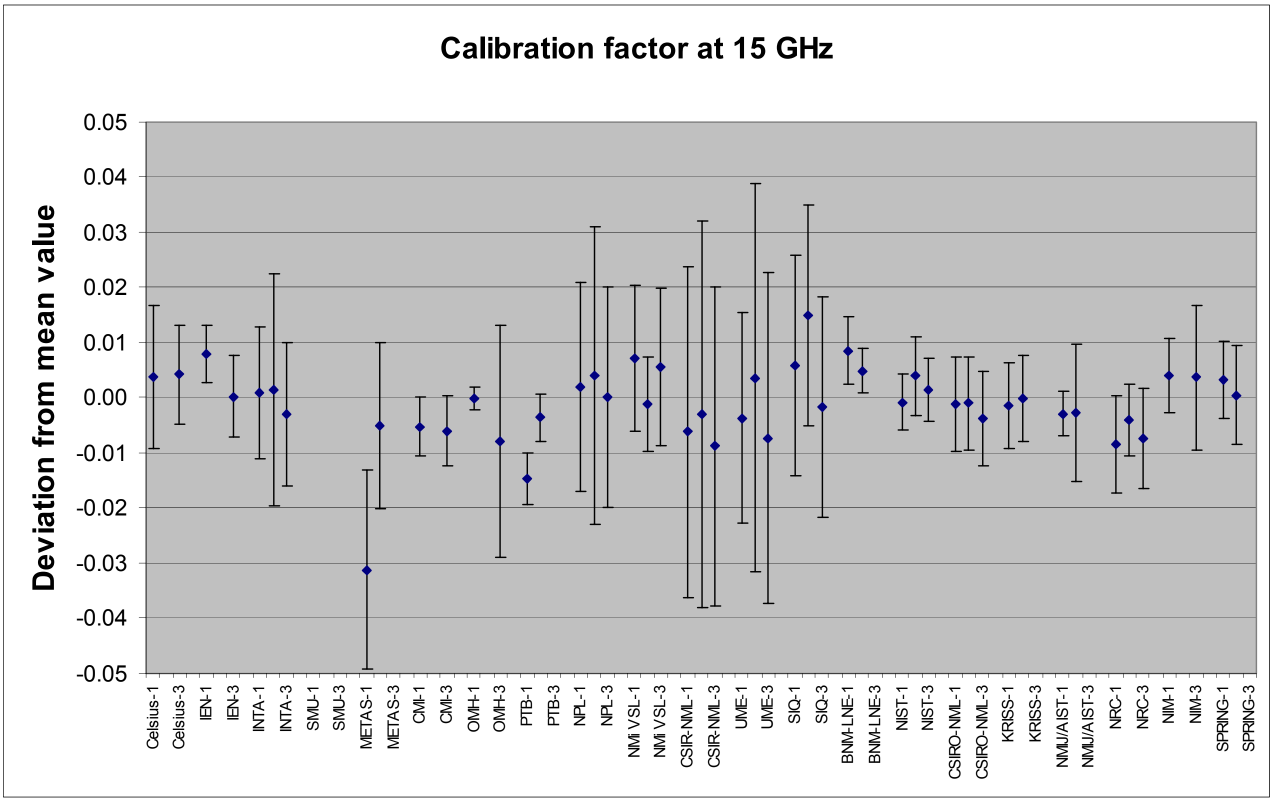


Figure 2.3: Measurements at 8 GHz (top) and 12 GHz (bottom). The measurements are identified by the laboratory's name and the DUT identifier (1 – blank – 3). For each DUT the zero line refers to the mean value of the calibration factor as measured by all laboratories. The error bars refer to the k=2 uncertainty as given by the participants.



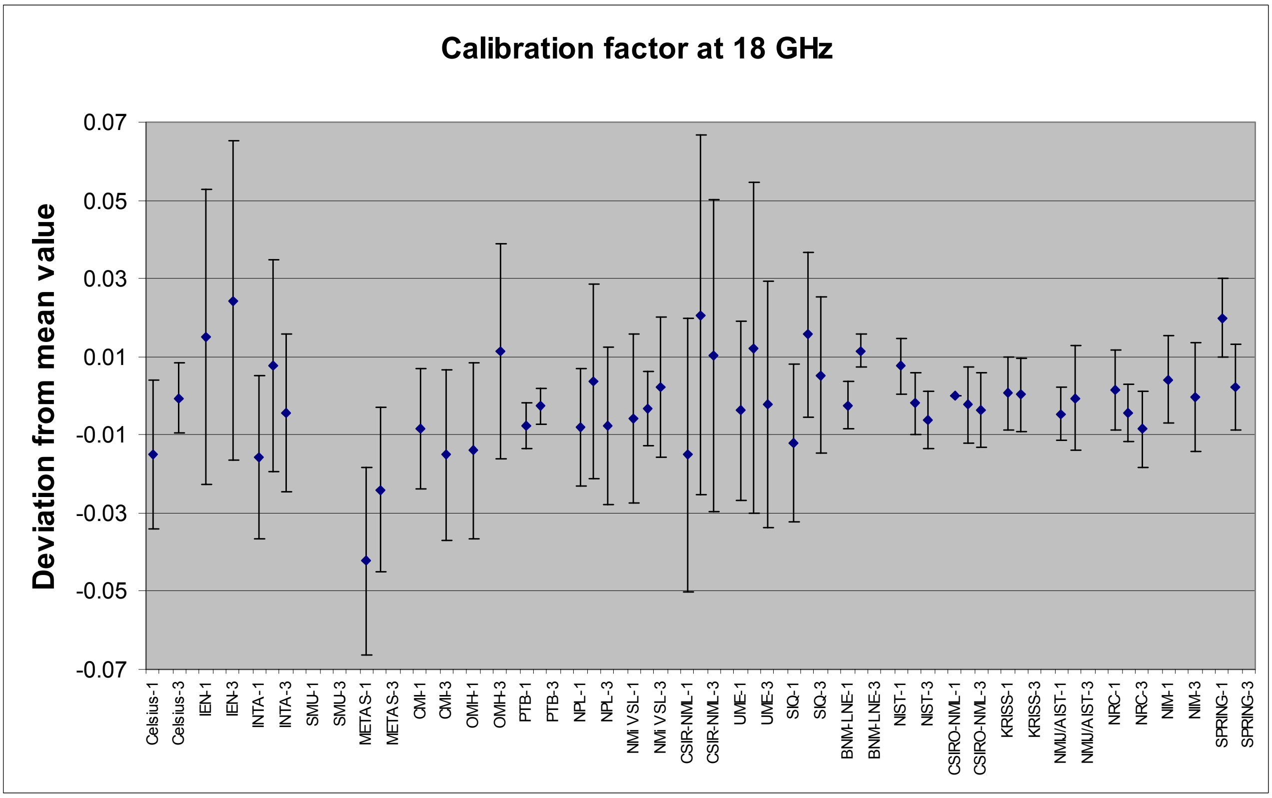


Figure 2.4: Measurements at 15 GHz (top) and 18 GHz (bottom). The measurements are identified by the laboratory's name and the DUT identifier (1 – blank – 3). For each DUT the zero line refers to the mean value of the calibration factor as measured by all laboratories. The error bars refer to the k=2 uncertainty as given by the participants.

7.2. Determining the KCRV

Following the BIPM guidelines only the results from the members of the GT-RF which have an independent realisation of the quantity are taken into account for the determination of the KCRV. This is done using the procedure given by J. Randa [5]. Here the median and its associated MAD are used to determine whether results should be considered to be outlier. These values are then excluded from the calculation of the KCRV. Following the discussions between the participants the pilot has calculated the KCRV as an unweighted mean of the selected values.
In Table 2 the result of this process is indicated for each frequency and each DUT.

Table 2: List of laboratories that are members of GT-RF and have an independent realisation of the quantity power. Outliers are indicated by "X".

Laboratory	Frequency																							
(Member GT-RF having an independent realisation)	10 MHz			50 MHz			1 GHz			4 GHz			8 GHz			12 GHz			15 GHz			18 GHz		
DUT (TM1, TM2 or TM3)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
IENGF																X		X						X
PTB																								
NPL														X										
NMi-VSL																								
BNM-LNE														X										
NIST																								
CSIRO-NML																								
KRISS																								
NMIJ/AIST																								
NRC	X		X									X												
NIM									X															

After this elimination process the actual KCRV is determined as the unweighted mean of the results of the contributors and its associated standard deviation.
In Table 3 three overall results are given, viz. the mean for all participants (with the associated spread), the mean for the potential contributors to the KCRV (with its associated spread) and the KCRV itself (after elimination of the outliers) with the uncertainty in its value. In the last column the change due to elimination of the outliers is given.

With this information we are now able to calculate the degrees of equivalence for each of the participants.

Table 3: Summary of characterisation of the three DUTs as result of this comparison

DUT	TM1				
Frequency	Overall mean	Mean GT-RF	KCRV	Uncertainty in KCRV	Change due to outliers
10 MHz	0.9663 ± 0.0060	0.9655 ± 0.0100	0.9681	0.0018	+0.0025
50 MHz	0.9945 ± 0.0032	0.9940 ± 0.0018	0.9940	0.0005	0.0000
1 GHz	0.9925 ± 0.0042	0.9920 ± 0.0016	0.9920	0.0005	0.0000
4 GHz	0.9826 ± 0.0046	0.9818 ± 0.0033	0.9818	0.0010	0.0000
8 GHz	0.9748 ± 0.0051	0.9746 ± 0.0069	0.9746	0.0021	0.0000
12 GHz	0.9680 ± 0.0055	0.9692 ± 0.0060	0.9679	0.0013	-0.0014
15 GHz	0.9595 ± 0.0072	0.9611 ± 0.0071	0.9611	0.0021	0.0000
18 GHz	0.9338 ± 0.0093	0.9391 ± 0.0070	0.9391	0.0021	0.0000

DUT	TM2				
Frequency	Overall mean	Mean GT-RF	KCRV	Uncertainty in KCRV	Change due to outliers
10 MHz	0.9633 ± 0.0067	0.9645 ± 0.0064	0.9645	0.0023	0.0000
50 MHz	0.9933 ± 0.0055	0.9928 ± 0.0015	0.9928	0.0005	0.0000
1 GHz	0.9923 ± 0.0066	0.9915 ± 0.0008	0.9915	0.0003	0.0000
4 GHz	0.9844 ± 0.0071	0.9829 ± 0.0033	0.9829	0.0011	0.0000
8 GHz	0.9767 ± 0.0076	0.9749 ± 0.0040	0.9731	0.0008	-0.0018
12 GHz	0.9650 ± 0.0089	0.9633 ± 0.0030	0.9633	0.0010	0.0000
15 GHz	0.9498 ± 0.0106	0.9490 ± 0.0035	0.9490	0.0012	0.0000
18 GHz	0.9456 ± 0.0131	0.9434 ± 0.0049	0.9434	0.0017	0.0000

DUT	TM3				
Frequency	Overall mean	Mean GT-RF	KCRV	Uncertainty in KCRV	Change due to outliers
10 MHz	0.9617 ± 0.0063	0.9575 ± 0.0186	0.9640	0.0030	0.0065
50 MHz	0.9936 ± 0.0036	0.9923 ± 0.0021	0.9923	0.0007	0.0000
1 GHz	0.9896 ± 0.0046	0.9887 ± 0.0022	0.9894	0.0005	0.0007
4 GHz	0.9790 ± 0.0050	0.9780 ± 0.0027	0.9790	0.0004	0.0010
8 GHz	0.9702 ± 0.0054	0.9712 ± 0.0058	0.9712	0.0020	0.0000
12 GHz	0.9572 ± 0.0059	0.9572 ± 0.0075	0.9545	0.0012	-0.0026
15 GHz	0.9376 ± 0.0079	0.9398 ± 0.0044	0.9398	0.0016	0.0000
18 GHz	0.9350 ± 0.0106	0.9347 ± 0.0114	0.9307	0.0016	-0.0040

7.3 **Values and uncertainties**

The participants have measured a total of up to three DUTs. For N and PC7 systems they can have different standards and, if relevant, they use for one connector system an adapter introducing additional uncertainties as compared to the other connector. However, for most laboratories its measurement principle is the same for all DUTs: the uncertainty budget will be very similar for all devices, except for the relevant laboratory reference standard. Hence, the data are presented as if they are derived from three almost identical devices.

For each result in the comparison the deviation between the laboratory's result and the KCRV is determined along with its associated uncertainty following the procedure outlined in [5]. This procedure takes into account the fact whether a laboratory result has contributed to the determination of the KCRV or not.

For each frequency and each laboratory an overview is given concerning the three DUTs individually, viz. TM1, TM2 and TM3 (see Table 4.x and figure 3.x).

Table 4.1: Results at 10 MHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	-0.0011	0.0097	--	--	0.0010	0.0108
IEN	0.0049	0.0262	--	--	0.0090	0.0247
INTA	0.0006	0.0154	-0.0053	0.0254	0.0047	0.0162
SMU	--	--	--	--	--	--
METAS	-0.0035	0.0106	-0.0008	0.0083	--	--
CMI	-0.0023	0.0104	--	--	-0.0020	0.0111
OMH	0.0026	0.0101	0.0086	0.0110	0.0070	0.0116
PTB	0.0043	0.0047	0.0077	0.0052	--	--
NPL	0.0019	0.0105	0.0045	0.0196	0.0050	0.0111
NMi-VSL	-0.0082	0.0083	-0.0064	0.0075	-0.0032	0.0093
CSIR-NML	-0.0031	0.0174	-0.0005	0.0166	0.0000	0.0171
UME	-0.0077	0.0182	-0.0059	0.0184	-0.0040	0.0188
SIQ	0.0039	0.0088	--	--	0.0060	0.0100
BNM-LNE	0.0000	0.0083	0.0015	0.0086	--	--
NIST	-0.0090	0.0078	-0.0104	0.0081	-0.0120	0.0088
CSIRO-NML	0.0019	0.0057	0.0065	0.0063	0.0060	0.0074
KRISS	0.0083	0.0049	-0.0003	0.0059	--	--
NMIJ/AIST	-0.0049	0.0104	-0.0034	0.0105	--	--
NRC	-0.0278	0.0046	--	--	-0.0453	0.0067
NIM	0.0005	0.0106	--	--	-0.0048	0.0111
SPRING	0.0029	0.0145	-0.0132	0.0110	--	--

Table 4.2: Results at 50 MHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	0.0020	0.0071	--	--	0.0027	0.0071
IEN	-0.0010	0.0070	--	--	-0.0013	0.0067
INTA	0.0003	0.0081	-0.0013	0.0130	0.0018	0.0081
SMU	-0.0052	0.0111	--	--	0.0020	0.0141
METAS	-0.0019	0.0091	-0.0003	0.0061	--	--
CMI	-0.0003	0.0047	--	--	-0.0003	0.0048
OMH	0.0006	0.0080	0.0005	0.0082	0.0010	0.0083
PTB	0.0004	0.0030	-0.0001	0.0025	--	--
NPL	0.0030	0.0091	0.0022	0.0191	0.0027	0.0088
NMi-VSL	-0.0002	0.0050	0.0006	0.0039	0.0015	0.0049
CSIR-NML	0.0030	0.0150	0.0022	0.0150	0.0027	0.0151
UME	0.0014	0.0050	0.0001	0.0051	0.0021	0.0050
SIQ	0.0060	0.0081	0.0072	0.0081	0.0077	0.0081
BNM-LNE	-0.0020	0.0038	-0.0028	0.0036	--	--
NIST	0.0007	0.0032	-0.0007	0.0050	0.0006	0.0032
CSIRO-NML	0.0000	0.0033	0.0012	0.0032	0.0007	0.0034
KRISS	0.0010	0.0019	0.0004	0.0018	--	--
NMIJ/AIST	-0.0008	0.0099	-0.0011	0.0095	--	--
NRC	-0.0032	0.0027	--	--	-0.0036	0.0028
NIM	0.0022	0.0062	--	--	-0.0006	0.0060
SPRING	0.0054	0.0061	-0.0007	0.0071	--	--

Table 4.3: Results at 1 GHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	-0.0010	0.0081	--	--	-0.0004	0.0081
IEN	0.0020	0.0057	--	--	0.0006	0.0050
INTA	-0.0010	0.0071	0.0000	0.0140	-0.0006	0.0081
SMU	0.0032	0.0081	--	--	0.0019	0.0100
METAS	-0.0056	0.0100	-0.0012	0.0070	--	--
CMI	-0.0006	0.0033	--	--	-0.0014	0.0032
OMH	0.0007	0.0080	-0.0003	0.0077	-0.0012	0.0080
PTB	-0.0012	0.0029	-0.0003	0.0023	--	--
NPL	0.0030	0.0181	0.0005	0.0247	0.0006	0.0169
NMi-VSL	0.0005	0.0065	-0.0008	0.0034	0.0018	0.0060
CSIR-NML	0.0040	0.0150	0.0025	0.0150	0.0026	0.0150
UME	0.0008	0.0059	0.0019	0.0067	0.0010	0.0053
SIQ	0.0050	0.0081	0.0085	0.0080	0.0056	0.0081
BNM-LNE	-0.0014	0.0057	0.0011	0.0036	--	--
NIST	0.0003	0.0030	0.0008	0.0056	-0.0007	0.0029
CSIRO-NML	0.0000	0.0037	-0.0005	0.0036	-0.0004	0.0035
KRISS	0.0012	0.0023	0.0008	0.0018	--	--
NMIJ/AIST	-0.0012	0.0099	-0.0011	0.0096	--	--
NRC	-0.0016	0.0033	-0.0007	0.0025	-0.0018	0.0031
NIM	-0.0018	0.0058	--	--	-0.0049	0.0064
SPRING	0.0062	0.0051	0.0013	0.0080	--	--

Table 4.4: Results at 4 GHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	0.0012	0.0102	--	--	0.0000	0.0100
IEN	0.0032	0.0067	--	--	0.0000	0.0046
INTA	0.0010	0.0092	-0.0006	0.0152	0.0009	0.0090
SMU	-0.0064	0.0092	--	--	-0.0058	0.0110
METAS	-0.0094	0.0122	-0.0008	0.0083	--	--
CMI	-0.0017	0.0048	--	--	-0.0040	0.0048
OMH	0.0057	0.0111	-0.0012	0.0110	0.0034	0.0111
PTB	-0.0036	0.0037	-0.0003	0.0032	--	--
NPL	0.0052	0.0182	0.0051	0.0248	0.0020	0.0169
NMi-VSL	0.0006	0.0089	-0.0030	0.0072	0.0000	0.0076
CSIR-NML	0.0072	0.0201	0.0071	0.0211	0.0070	0.0190
UME	0.0025	0.0085	0.0050	0.0127	0.0007	0.0076
SIQ	0.0122	0.0102	0.0121	0.0102	0.0050	0.0100
BNM-LNE	-0.0021	0.0059	0.0038	0.0042	--	--
NIST	0.0003	0.0034	0.0020	0.0043	-0.0012	0.0026
CSIRO-NML	0.0002	0.0045	-0.0009	0.0045	-0.0010	0.0038
KRISS	0.0013	0.0047	0.0005	0.0036	--	--
NMIJ/AIST	-0.0028	0.0101	-0.0023	0.0099	--	--
NRC	-0.0057	0.0046	-0.0052	0.0039	-0.0067	0.0046
NIM	0.0031	0.0070	--	--	0.0001	0.0056
SPRING	0.0052	0.0073	0.0023	0.0073	--	--

Table 4.5: Results at 8 GHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	-0.0006	0.0136	--	--	-0.0042	0.0136
IEN	0.0094	0.0097	--	--	0.0098	0.0065
INTA	-0.0003	0.0118	0.0026	0.0171	-0.0020	0.0117
SMU	-0.0065	0.0127	--	--	-0.0021	0.0136
METAS	-0.0139	0.0156	0.0020	0.0121	--	--
CMI	-0.0041	0.0071	--	--	-0.0082	0.0062
OMH	0.0007	0.0145	0.0004	0.0143	-0.0026	0.0141
PTB	-0.0087	0.0054	0.0010	0.0032	--	--
NPL	0.0134	0.0194	0.0079	0.0290	0.0028	0.0178
NMi-VSL	0.0023	0.0112	-0.0015	0.0071	0.0018	0.0115
CSIR-NML	0.0104	0.0224	0.0099	0.0231	0.0038	0.0204
UME	0.0021	0.0098	0.0096	0.0170	-0.0007	0.0074
SIQ	0.0114	0.0165	0.0139	0.0141	0.0008	0.0146
BNM-LNE	-0.0028	0.0068	0.0083	0.0043	--	--
NIST	-0.0010	0.0053	0.0019	0.0046	-0.0037	0.0050
CSIRO-NML	-0.0006	0.0066	-0.0001	0.0050	-0.0032	0.0063
KRISS	-0.0050	0.0076	0.0028	0.0043	--	--
NMIJ/AIST	-0.0040	0.0107	-0.0007	0.0093	--	--
NRC	-0.0074	0.0085	-0.0032	0.0042	-0.0083	0.0066
NIM	0.0044	0.0088	--	--	0.0006	0.0071
SPRING	0.0058	0.0090	0.0031	0.0081	--	--

Table 4.6: Results at 12 GHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	-0.0009	0.0123	--	--	0.0005	0.0122
IEN	0.0151	0.0101	--	--	0.0185	0.0135
INTA	-0.0024	0.0113	0.0027	0.0191	-0.0028	0.0113
SMU	0.0101	0.0142	--	--	0.0208	0.0162
METAS	-0.0249	0.0162	-0.0126	0.0122	--	--
CMI	-0.0021	0.0087	--	--	-0.0027	0.0103
OMH	0.0012	0.0140	0.0036	0.0149	-0.0005	0.0142
PTB	-0.0061	0.0046	0.0000	0.0041	--	--
NPL	0.0001	0.0137	-0.0023	0.0221	-0.0015	0.0171
NMi-VSL	0.0003	0.0125	0.0005	0.0076	0.0025	0.0129
CSIR-NML	0.0011	0.0281	0.0067	0.0331	0.0065	0.0281
UME	0.0027	0.0104	0.0118	0.0278	0.0032	0.0157
SIQ	-0.0029	0.0152	0.0097	0.0151	-0.0035	0.0152
BNM-LNE	0.0033	0.0059	0.0043	0.0041	--	--
NIST	0.0005	0.0045	0.0016	0.0058	0.0005	0.0043
CSIRO-NML	0.0021	0.0068	-0.0013	0.0066	0.0005	0.0064
KRISS	0.0025	0.0069	0.0015	0.0070	--	--
NMIJ/AIST	0.0003	0.0101	0.0019	0.0098	--	--
NRC	-0.0081	0.0075	-0.0061	0.0054	-0.0053	0.0066
NIM	0.0048	0.0068	--	--	0.0034	0.0070
SPRING	0.0052	0.0065	0.0056	0.0122	--	--

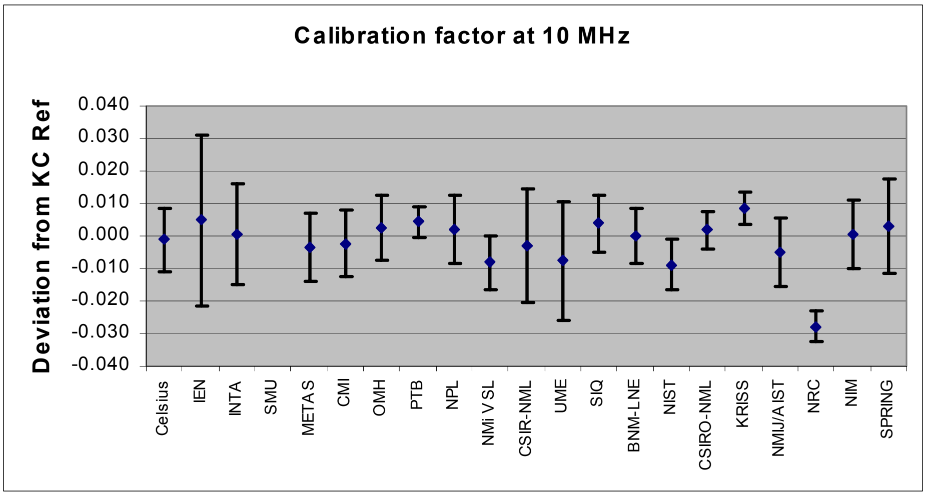
Table 4.7: Results at 15 GHz: deviation of calibration factor from the KCRV for the three DUTs

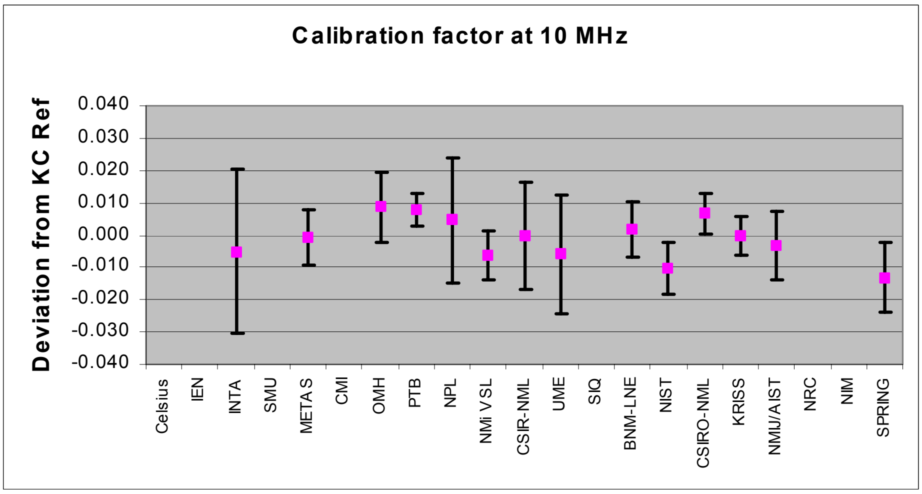
Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	0.0039	0.0137	--	--	0.0042	0.0143
IEN	0.0079	0.0064	--	--	0.0002	0.0071
INTA	0.0009	0.0127	0.0015	0.0211	-0.0030	0.0134
SMU	--	--	--	--	--	--
METAS	-0.0312	0.0185	-0.0051	0.0152		
CMI	-0.0052	0.0069	--	--	-0.0060	0.0071
OMH	-0.0001	0.0047	--	--	-0.0079	0.0212
PTB	-0.0146	0.0060	-0.0036	0.0044	--	--
NPL	0.0019	0.0177	0.0040	0.0239	0.0002	0.0176
NMi-VSL	0.0072	0.0127	-0.0012	0.0079	0.0057	0.0128
CSIR-NML	-0.0061	0.0303	-0.0030	0.0351	-0.0088	0.0292
UME	-0.0037	0.0196	0.0036	0.0353	-0.0073	0.0302
SIQ	0.0059	0.0205	0.0150	0.0201	-0.0018	0.0202
BNM-LNE	0.0086	0.0071	0.0049	0.0042	--	--
NIST	-0.0008	0.0062	0.0039	0.0067	0.0015	0.0058
CSIRO-NML	-0.0011	0.0088	-0.0010	0.0078	-0.0038	0.0080
KRISS	-0.0014	0.0083	-0.0002	0.0073	--	--
NMIJ/AIST	-0.0029	0.0107	-0.0028	0.0099	--	--
NRC	-0.0084	0.0090	-0.0041	0.0062	-0.0074	0.0084
NIM	0.0040	0.0075	--	--	0.0037	0.0118
SPRING	0.0033	0.0082	0.0005	0.0093	--	--

Table 4.8: Results at 18 GHz: deviation of calibration factor from the KCRV for the three DUTs

Laboratory	TM1		TM2		TM3	
	Value	Unc.	Value	Unc.	Value	Unc.
Celsius	-0.0151	0.0195	--	--	0.0033	0.0153
IEN	0.0149	0.0344	--	--	0.0283	0.0409
INTA	-0.0158	0.0214	0.0076	0.0272	-0.0004	0.0203
SMU	--	--	--	--	--	--
METAS	-0.0423	0.0244	-0.0241	0.0213		
CMI	-0.0084	0.0159	--	--	-0.0112	0.0220
OMH	-0.0140	0.0230	--	--	0.0153	0.0276
PTB	-0.0078	0.0067	-0.0027	0.0053	--	--
NPL	-0.0081	0.0142	0.0036	0.0219	-0.0037	0.0172
NMi-VSL	-0.0057	0.0200	-0.0034	0.0090	0.0063	0.0154
CSIR-NML	-0.0151	0.0353	0.0206	0.0461	0.0143	0.0401
UME	-0.0038	0.0233	0.0121	0.0424	0.0017	0.0317
SIQ	-0.0121	0.0204	0.0156	0.0213	0.0093	0.0203
BNM-LNE	-0.0024	0.0070	0.0114	0.0054		
NIST	0.0076	0.0078	-0.0019	0.0077	-0.0022	0.0070
CSIRO-NML	-0.0001	0.0042	-0.0024	0.0091	0.0003	0.0087
KRISS	0.0006	0.0094	0.0002	0.0090	--	--
NMIJ/AIST	-0.0047	0.0107	-0.0007	0.0101	--	--
NRC	0.0015	0.0101	-0.0044	0.0071	-0.0045	0.0088
NIM	0.0042	0.0110	--	--	0.0036	0.0121
SPRING	0.0199	0.0108	0.0020	0.0115	--	--

On the next pages a graphical representation of the results is given.





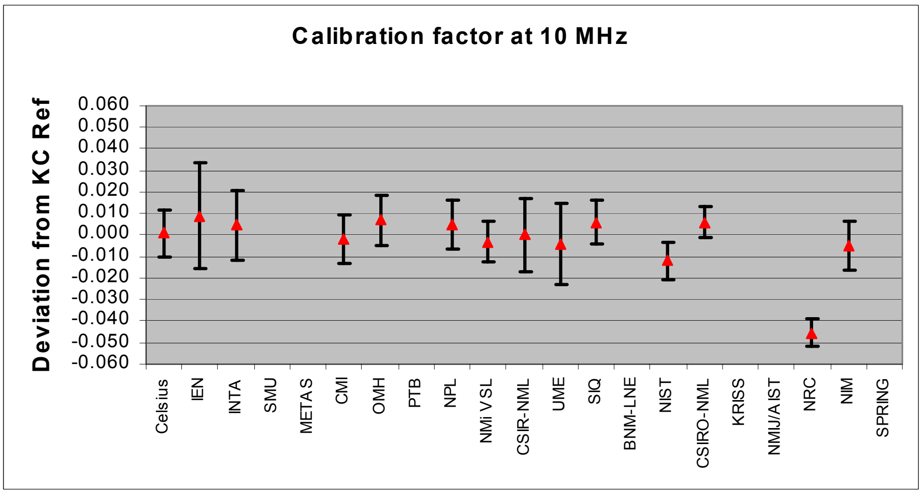
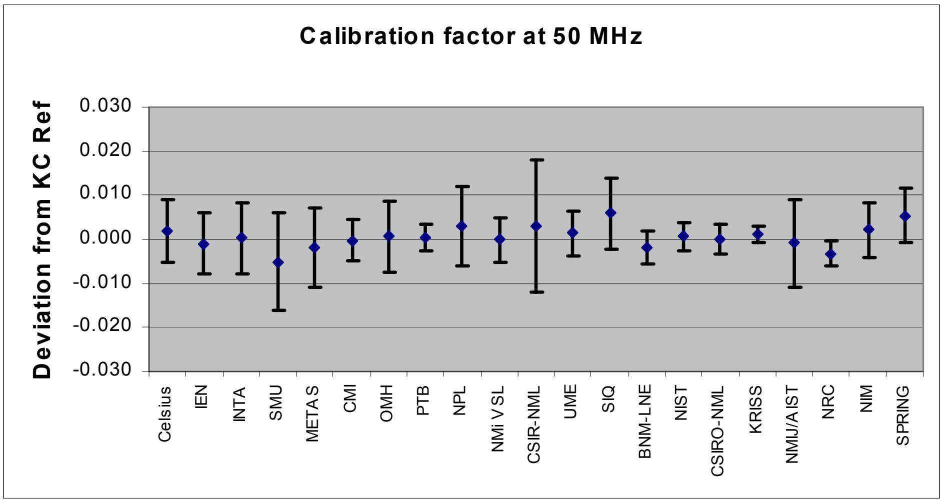
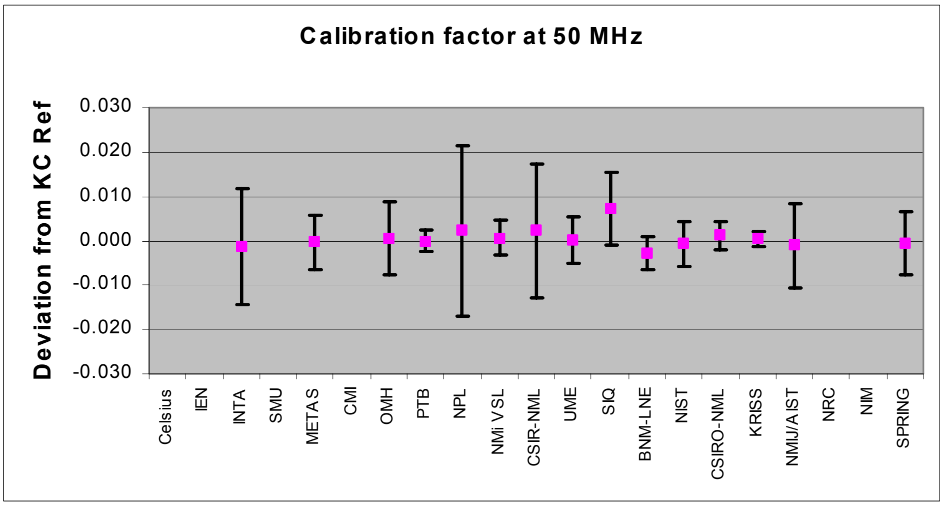


Figure 3.1: Final result of the measurements at 10 MHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.





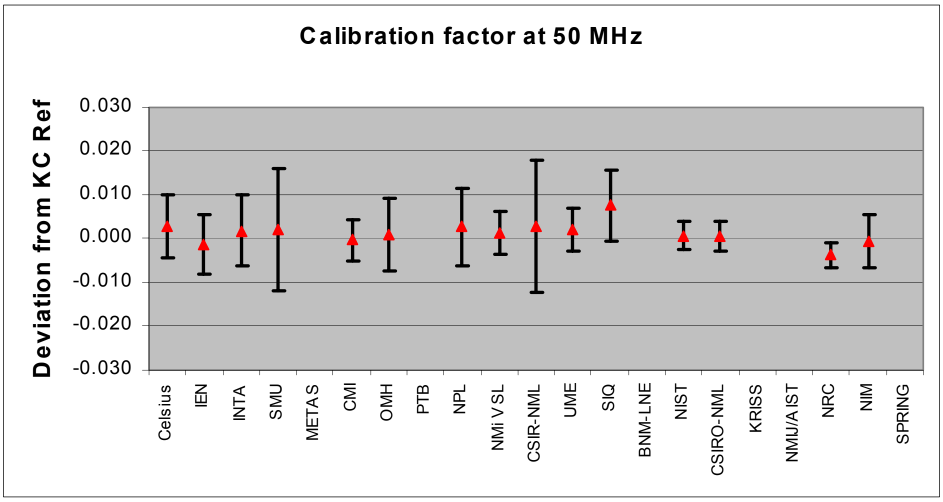
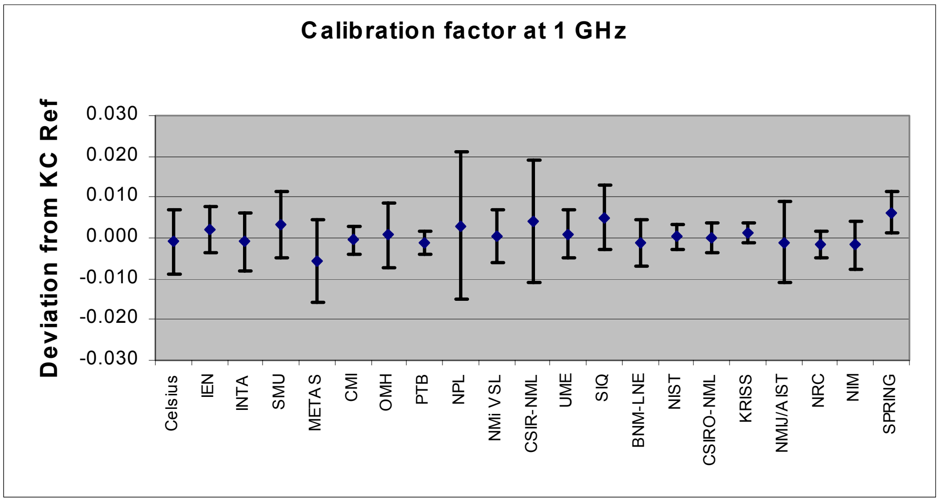
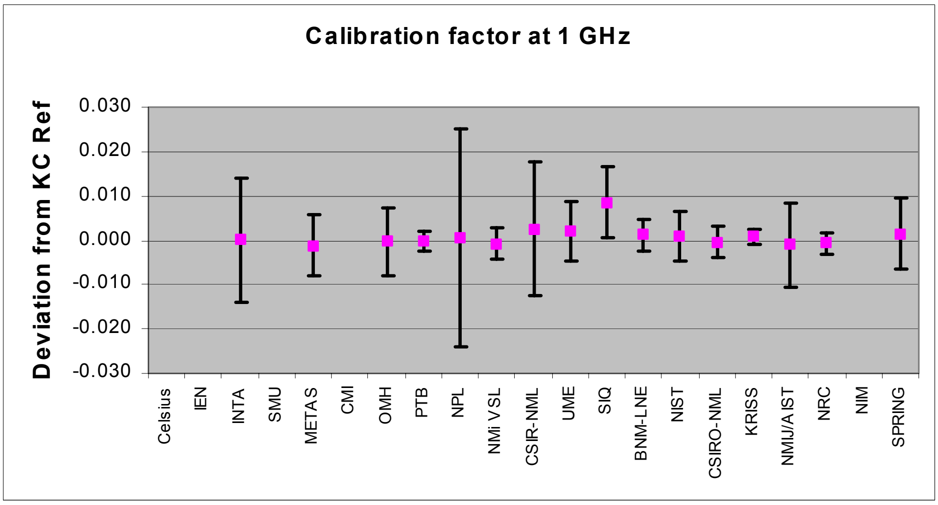


Figure 3.2: Final result of the measurements at 50 MHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.





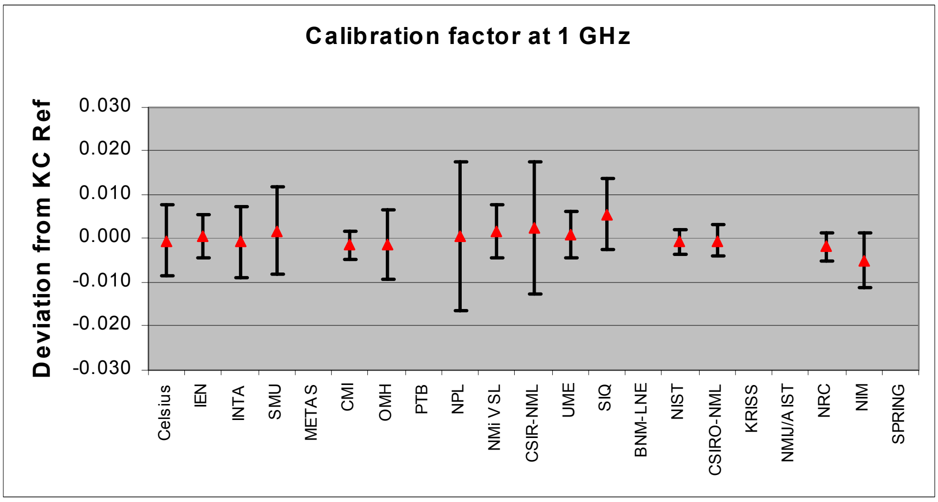
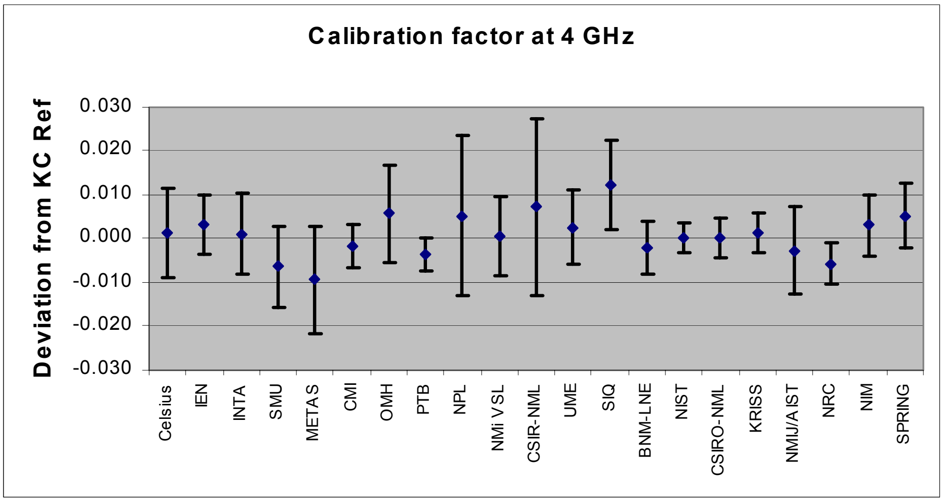
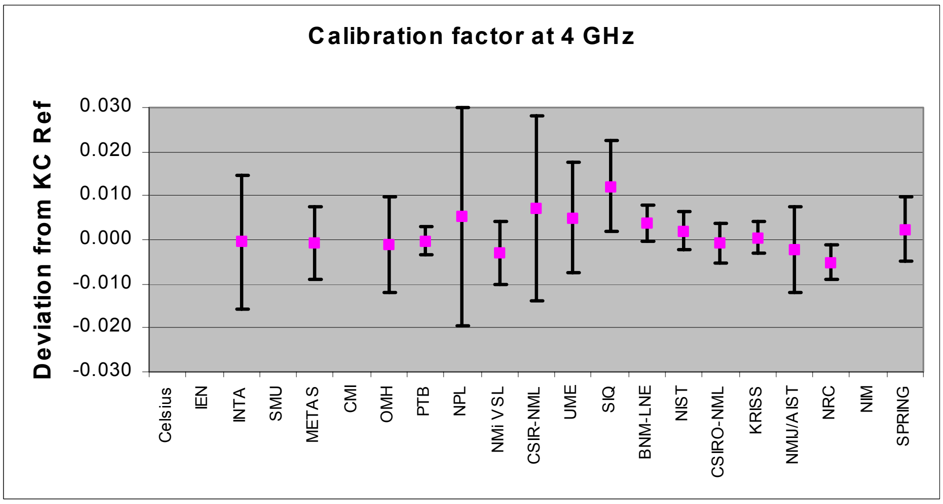


Figure 3.3: Final result of the measurements at 1 GHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.





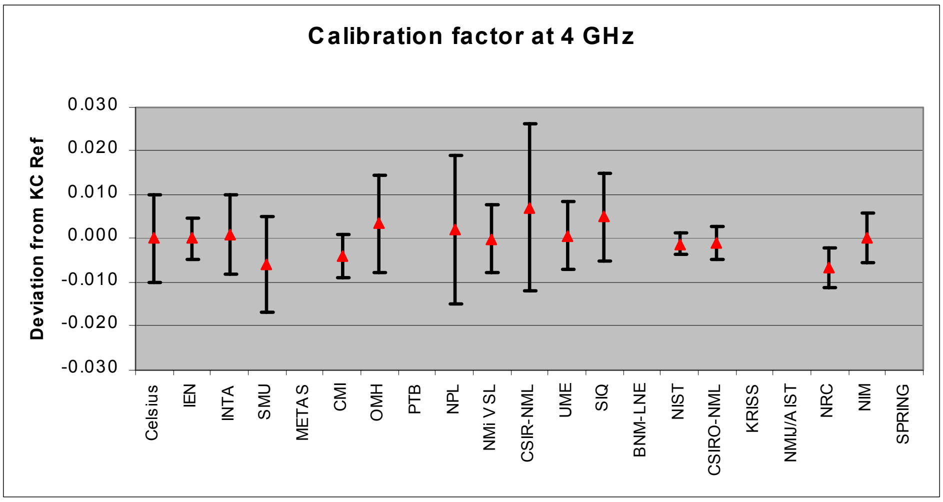


Figure 3.4: Final result of the measurements at 4 GMHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.

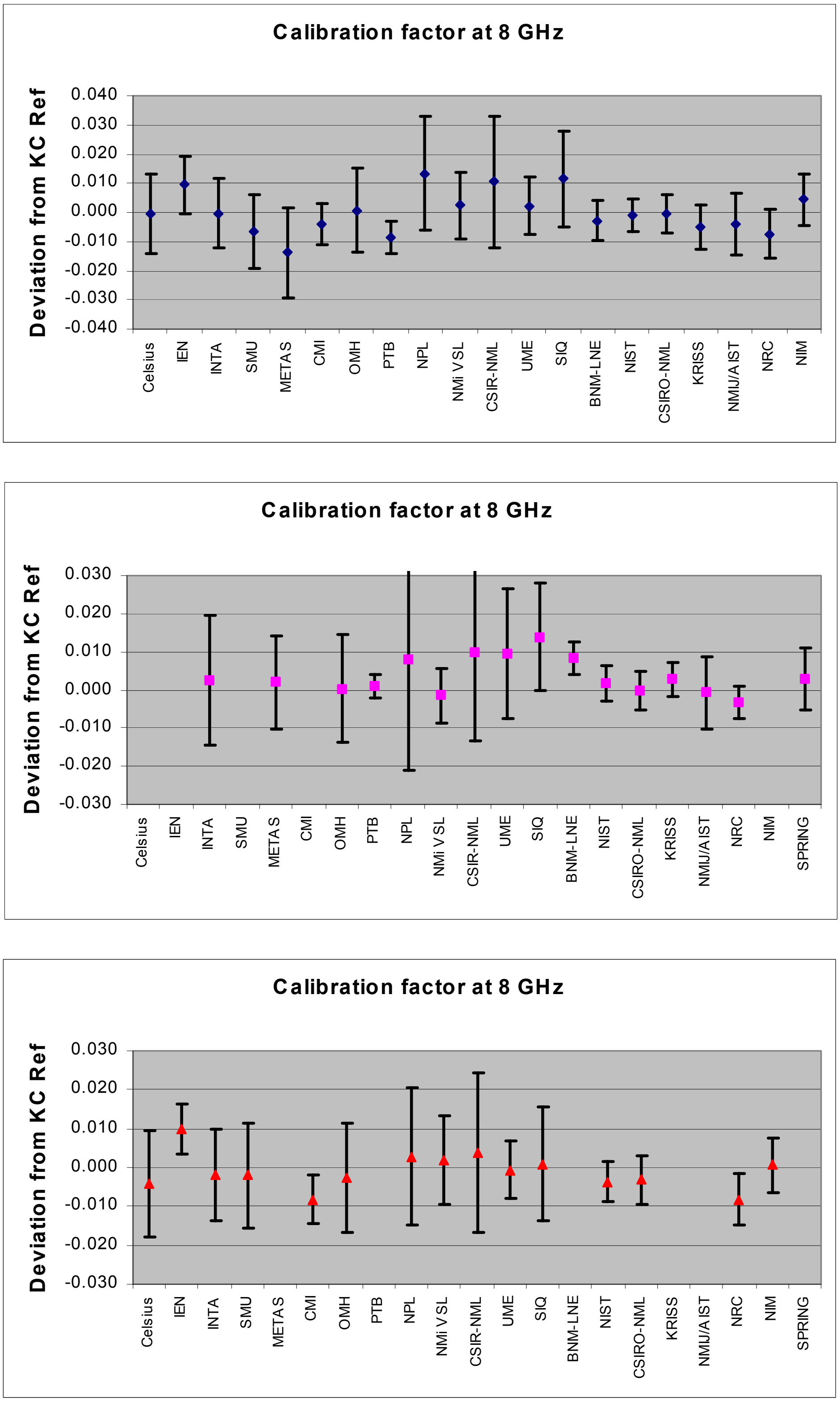


Figure 3.5: Final result of the measurements at 8 GMHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.

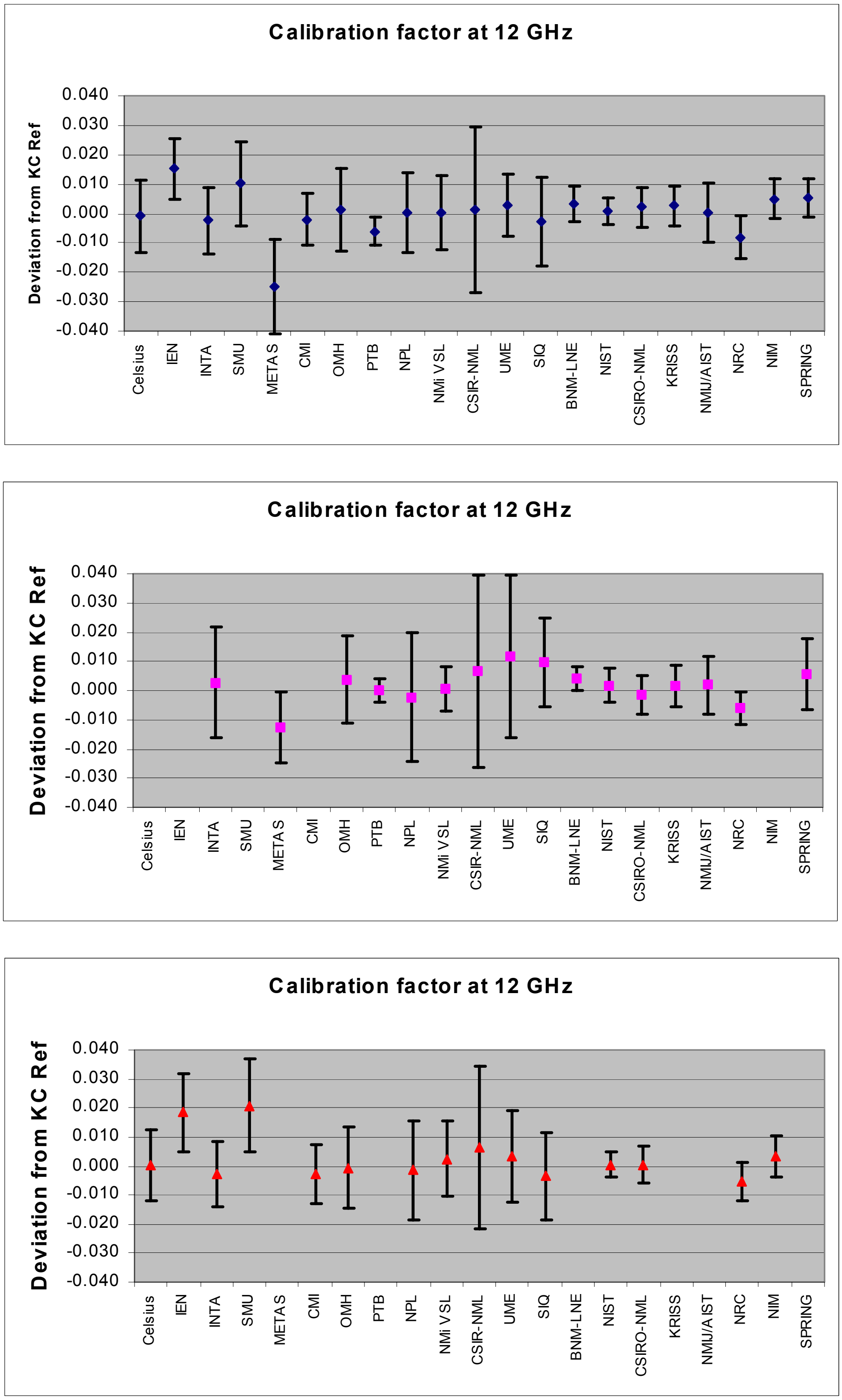
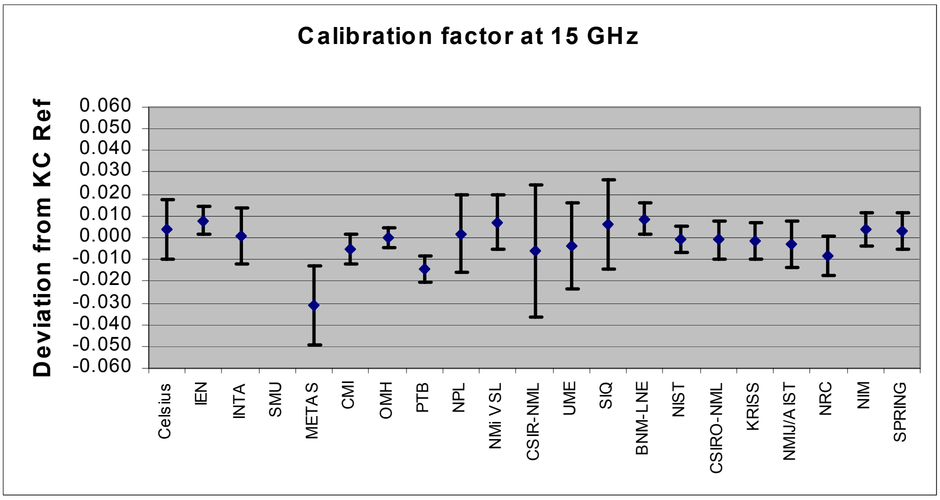
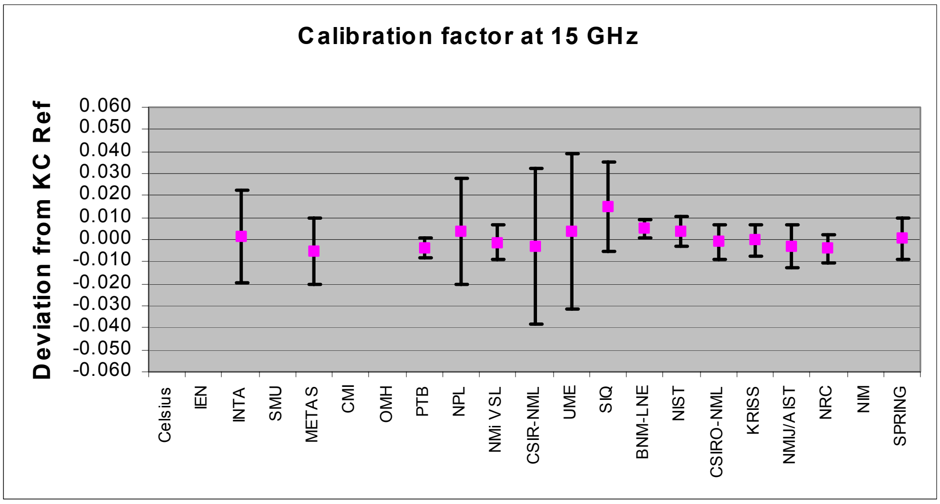


Figure 3.6: Final result of the measurements at 12 GMHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.





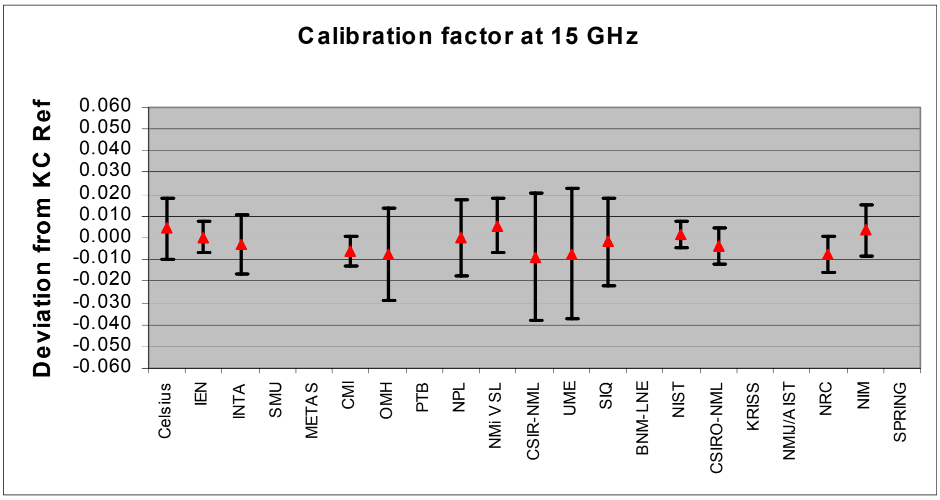
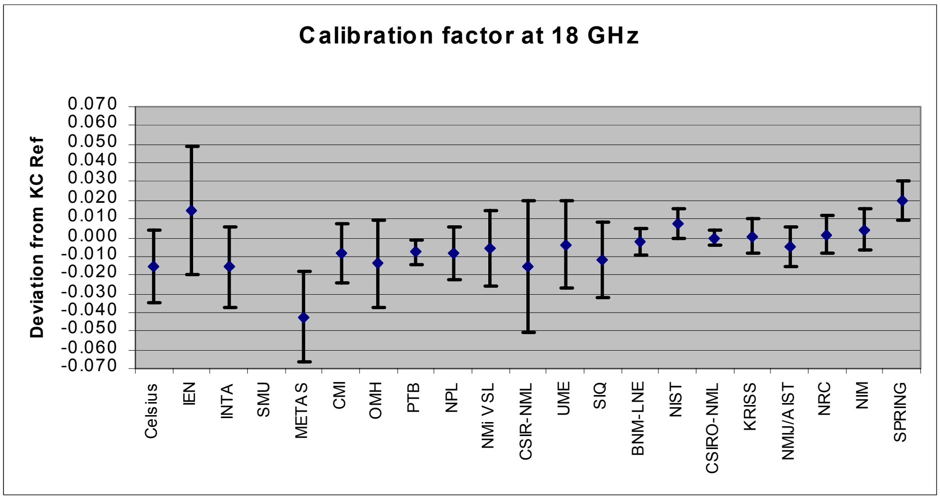
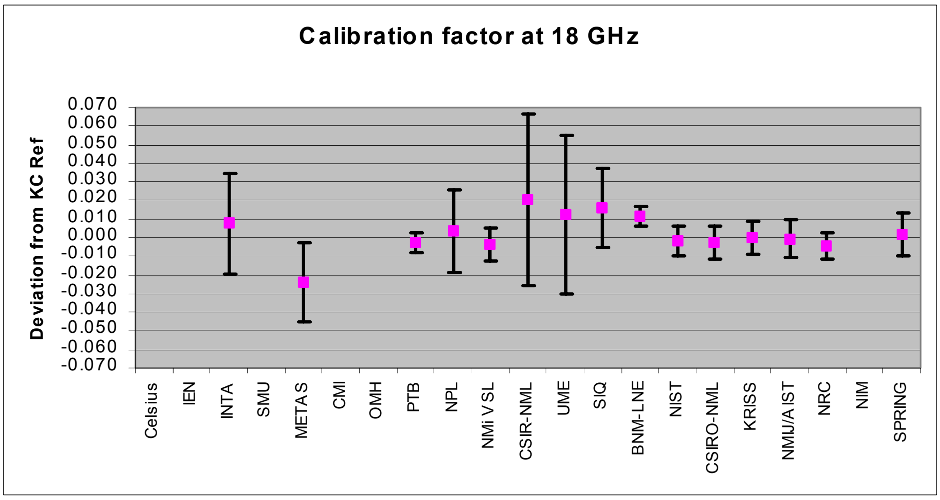


Figure 3.7: Final result of the measurements at 15 GHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.





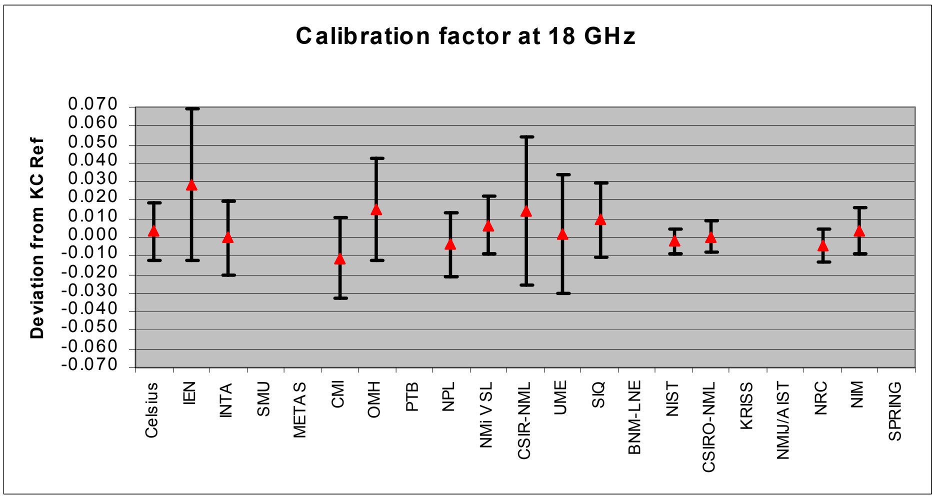


Figure 3.8: Final result of the measurements at 18 GHz for TM1 (top), TM2 (middle) and TM3 (bottom). The zero line is the reference value (KCRV) as determined following the BIPM guidelines using the Randa method. The uncertainty (k=2) is calculated using the same method.

A visual inspection of the graphs indicates potential problems for NRC at 10 MHz and for METAS at frequencies above 12 GHz for TM1 (with Type-N connector).
An examination of Table 4.x learns that there might be problems at other laboratories as well:

- IENGF at 8 GHz and 12 GHz;
- SMU at 12 GHz;
- METAS at 12 GHz, 15 GHz and 18 GHz; a trend deviating from others towards higher frequencies
- BNM-LNE at 15 GHz.
- PTB at 10 MHz and 15 GHz: the traceability chain is at least one step shorter, as PTB is using their primary facility, thus resulting in smaller uncertainties than other laboratories. See also section 9.2
- NIST at 10 MHz;
- NRC at 10 MHz, 50 MHz, 4 GHz and 12 GHz.

In addition the reported uncertainties are larger than might be expected from some National Measurement Institutes. This is possible due to the use of secondary standards for the calibration of customer devices.

This comparison makes it evident that:
If a small group of participants use measuring methods giving small uncertainties while most participants use other methods with much larger uncertainties, the mean value of a comparison is mainly influenced by the larger group with larger uncertainties. Therefore it does not imply that the measuring result achieved by a participant of the smaller group is wrong being outside the range defined by the larger group.
Note: at present no analysis on the reflection data is done. It is considered to be an auxiliary parameter, mainly needed to determine the mismatch uncertainty. The results as presented in figure B.1-8 of Appendix B indicate no large errors in the measurements.

The pilot laboratory asked the participants for submission of the results on a certificate as if the measurements done were performed on request of a normal external customer. In Appendix E information is given about the submitted certificates. In general the uncertainty is given with reference to a coverage factor k (often converted into a confidence interval); k=2 and and a level of 95%. In most cases the reflection coefficient is given as well, often with an uncertainty statement.

7.4 Uncertainty budgets

As usual in international comparisons the amount of information is quite dependent upon the specific laboratory. The detailed uncertainty budgets for two frequencies (10 MHz and 18 GHz) and one connector type (TM1) are presented in Appendix D. As far as possible an exact copy of the submitted uncertainty budget is given.

In the budgets most laboratories indicate the following 4 main contributions:

- Uncertainty in reference standard
- Mismatch signal source - reference standard
- Mismatch signal source - DUT
- Reproducibility (spread in the measurement data)

Of course, variations are present in the budget, e.g. due to the specific measurement set-up.
It seems to be useful to look to the relative contribution of each of these terms to the overall stated uncertainty. Usually the laboratory reference standard contributed more than 50% to the uncertainty in

the value of the calibration factor. This means that for a final analysis submission of a detailed uncertainty budget of the laboratory's reference standard would be necessary.
For national metrology institutes usually this value is obtained either directly from a measurement in a primary facility or indirectly using a transfer standard.

7.5. Reflection coefficient

For this quantity also discrepancies are observed. In the present framework the influence on the calibration factor due to such discrepancies is rather small (of the order of 0.1%). However, in a comparison dedicated to impedance one should advice further investigation into the uncertainty budgets.
More information about the reflection measurements is given in Appendix B.

8. Conclusions

The maximum stated uncertainty for the calibration factor ranges from 0.3 % at 50 MHz to more than 4.0 % at 18 GHz, independent of the type of connector on the DUT. Almost all results are consistent within the claimed uncertainty.

The uncertainty stated for the reflection coefficient was up to 0.03 in almost all cases. Most of the results are consistent within the claimed uncertainty.

Taking these facts into account, the results show a satisfactory agreement for both the calibration factor and the reflection coefficient.

In short, the results support the equivalence of national standards laboratories for the measurement of the calibration factor of thermistor mounts using methods routinely used in calibrations for external customers.

9. Follow-up

9.1 New Euromet project

Based upon the information made available in the 2000 Euromet meeting a follow-up project was suggested to investigate the problems found in the Euromet loop. For METAS it was impossible to investigate the problems due to a relocation of the facilities and a change in methods. IEN suspected that there might be problems with their reference standard(s) and NPL wanted to measure again using standards which had a smaller uncertainty than those used in the present exercise. This proposal was forwarded to the Euromet Technical Chairman and later approved as a Euromet key comparison as project 633, partly as two other NMIs wanted to participate to evaluate their present capabilities in a direct link to other laboratories. The pilot laboratory suggested to NRC to participate in this project, as there were some problems with the results and information about the measurement set-up used was poor due to a change in personnel. NRC decided to participate in this comparison.

9.2 Individual actions

A remeasurement with TM 1 was made at **PTB**, now both in the microcalorimeter and by comparison with a power splitter to a thermistor mount as a standard which had formerly been calibrated in the microcalorimeter. PTB obtained two different results: 1. in the microcalorimeter the value was reproduced as was given in the report and 2. in the power splitter comparison a value was obtained which was very close to the KCRV mean value.
Based upon their experience both **NIST** and **PTB** indicated that it is likely that at 10 MHz the thermistor mount shows some leakage out of its output connector (this happens sometimes with HP thermistor mounts at low frequencies). This fact can cause different results when measuring inside a calorimeter or by applying other methods. This may also be the reason for the much larger spread of the participants results at 10 MHz compared to 50 MHz.

At **METAS** a complete new built-up was realised and information is obtained from more recent comparisons. Hence, the following information is provided by METAS (Juerg Furrer). Some bugs in the uncertainty calculation, concerning the power splitter asymmetry were found: the given value (by P. Morard) was clearly too optimistic. The given Type A contribution (u_A = 0.000075 at 18 GHz) is very low. This low value gives now the impression, that in 1999 the connector repeatability was not taken into account. Now, normally Type A contribution for good connectors is of the order of u_A = 0.0003 (at 18 GHz). This indicates, that probably all measurements were taken with the same connector position and therefore a problem with the repeatability was not detected. This could be the reason for the low values of the CalFactor (METAS) at the higher frequencies.

As personnel has left **NRC** a recent investigation of the documentation led to a few possible explanations for the discrepancies: - the wrong Tee identifier might been inputted in the software for the measurements at 10 MHz; - the apparent systematic shift might be due to an inaccurate value of the DC resistance of the calorimeter (incorrect input in the software); - an unsuspected bias due to a noisy feedback amplifier (noisy readings): at present this has been replaced by a more quiet one.

At the time of the comparison NRC intended to use the six-port system for customer calibrations. As soon as it became clear that there was a problem the decision was made not to use it as such.

After this and follow up exercises, at **IEN** it became clear that the discrepancies in the IEN results were due to the excess of wear of the instrumentation connectors. These were responsible of the high reflection coefficients, then of the high mismatch error at some frequency. As corrective action IEN decided to refurbish all the critical components of its instrument set-up, that is, power splitter and thermistor mounts used as transfer standards.

10. References

[1] J.P.M. de Vreede et al., “International comparison for RF power in the frequency range up to 18 GHz”, IEEE Trans. Instr. & Meas. Vol. 50 (2001) No 2, p. 409-413

[2] Guidelines for CIPM key comparisons (Appendix F of MRA), 1 March 1999, text available on the BIPM-website (www.bipm.fr)

[3] “Calibration of thermistor mounts (Euromet project 341)”, Metrologia 34,1997), pp.443-444

[4] e.g., “Power in coaxial lines at 12, 14 and 17 GHz (GT-RF 75-A11)”, IEEE Trans. Instrum. Meas. I&M 43 (1995) pp.3-6

[5] J. Randa, "Proposal for KCRV & Degree of Equivalence for GTRF Key Comparisons", Document of the Working Group on radio frequency quantities of the CCEM, GT-RF/2000-12, September 2000.

[6] Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Metrology Institutes, endorsed by the International Committee on Weight and Measures, text available on the BIPM web site (www.bipm.fr).

[7] “Guide to the Expression of Uncertainty in Measurement”, ISO/TAG 4, published by ISO, 1993, corrected and reprinted 1995.

[8] “Expression of the Uncertainty in Measurement in Calibration” document EA-04/02, December 1999, available on the EA-website (www.european-accreditation.org)

APPENDIX A

Measurements of the pilot laboratory

Several measurements were planned to check the stability of the DUTs during the Euromet 393 comparison. Due to the extension of this project with the GT-RF 98-1, the CCEM.RF-K8.CL comparison contains in total seven measurements at the pilot laboratory.
In this Appendix the details concerning the results of these measurements are described.

Each time the DUTs are measured several times against some of the working standards. Below the results are presented in terms of one result per measuring period. As the reflection coefficient is needed as support for the uncertainty calculation, the reflection coeffcient has not been measured always.

In figures A1 and A2 the results per frequency are given for each device.

A least square fit is made to all series of measurements. As is shown in the following tables the differences indicate no significant change in the calibration factor and reflection coefficients for all DUTs at each frequency.
Hence it is concluded that a correction for a change in the behaviour of the DUTs does not have to be applied.

The measurement dates are as follows:

15-Jan-98
15-May-98
15-Sep-98
15-Dec-98
15-Jul-99
15-Jul-00
15-Jan-01

Based upon these results the pilot laboratory decided to use the midterm data (December 1998) as the official input data for this comparison. In table A1 the official data are compared with the average values of the seven measurement series.

Table A1: Difference between results obtained in December 1998 and the average results from all NMi-VSL data

	Thermistor TM1		Thermistor TM2		Thermistor TM3	
Frequency (GHz)	Cal.fact.	Refl.	Cal.fact.	Refl.	Cal.fact.	Refl.
0.01	0.0007	0.0010	0.0011	0.0010	-0.0002	0.0007
0.05	-0.0001	0.0000	-0.0001	0.0001	-0.0003	0.0000
1	-0.0002	0.0002	0.0006	-0.0001	-0.0004	0.0002
4	-0.0002	-0.0007	0.0019	-0.0007	-0.0006	-0.0008
8	-0.0003	-0.0013	0.0019	-0.0001	-0.0020	-0.0013
12	-0.0006	-0.0010	0.0019	-0.0021	-0.0022	-0.0013
15	-0.0008	-0.0013	0.0026	-0.0010	-0.0015	-0.0003
18	-0.0001	0.0006	0.0033	0.0012	-0.0003	-0.0006

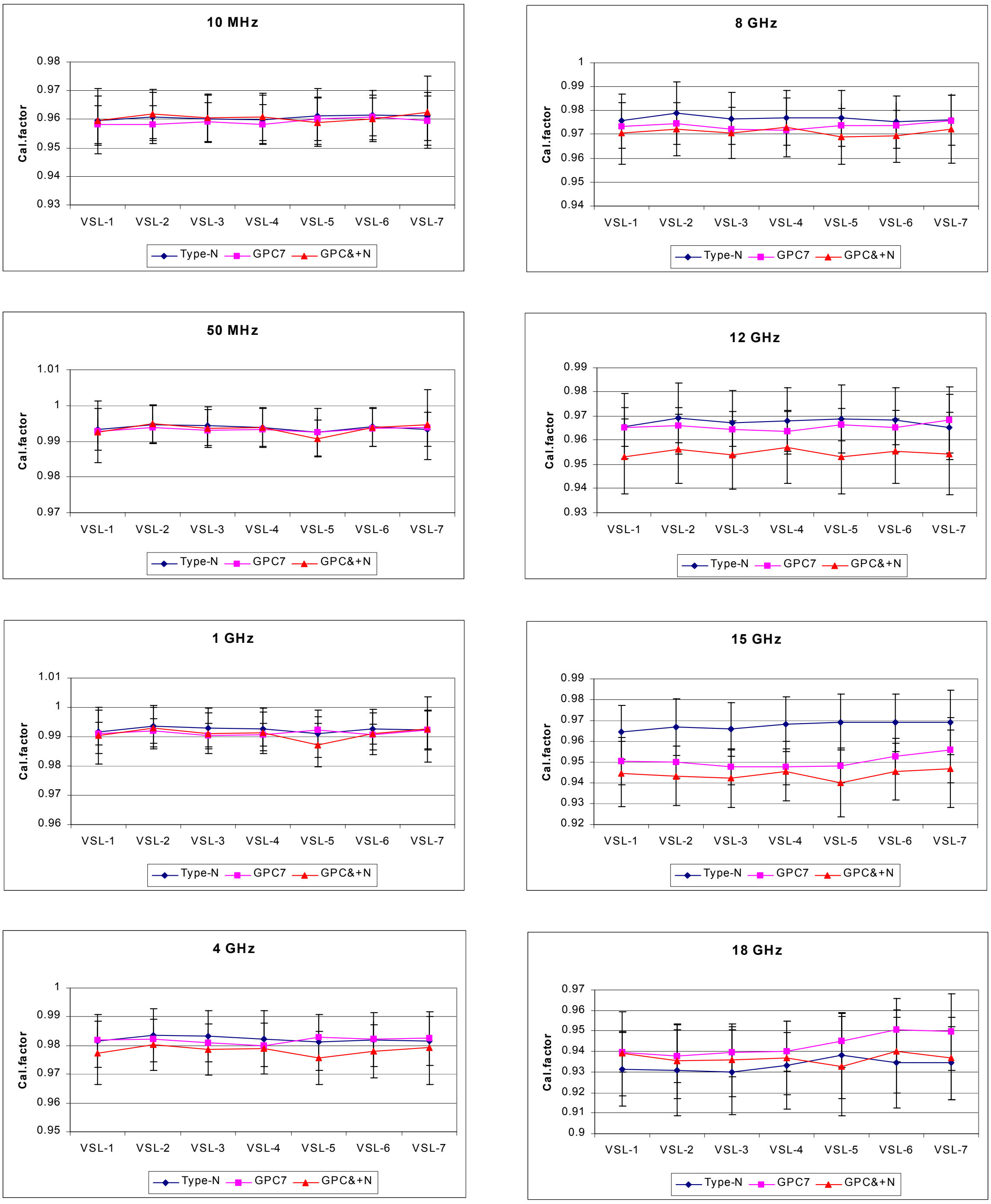


Figure A1: Overview of the individual results on the calibration factor obtained by NMi-VSL during the intercomparison. The lines connecting the measurement points are meant to give a clearer view of the changes between the individual measurements

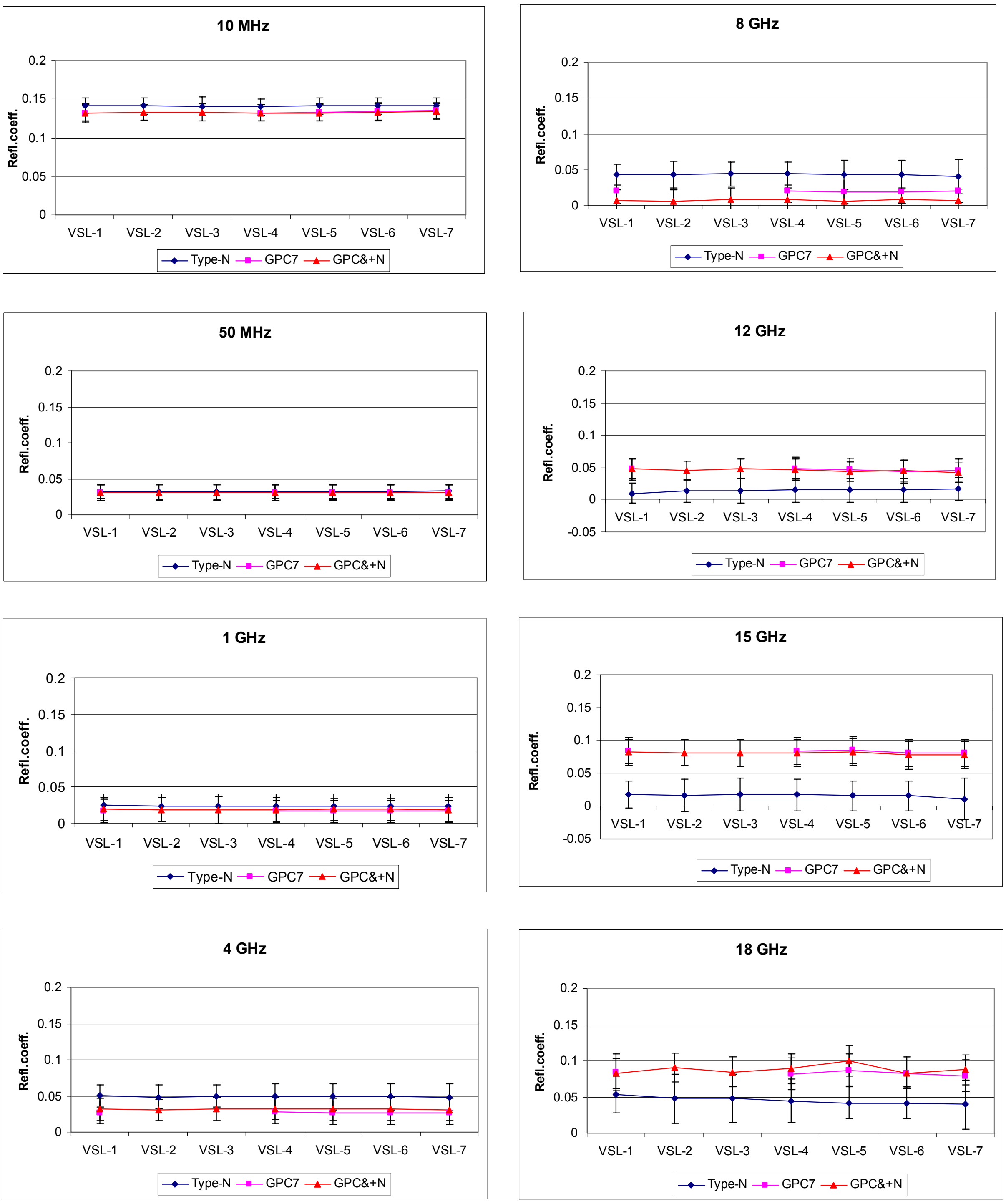
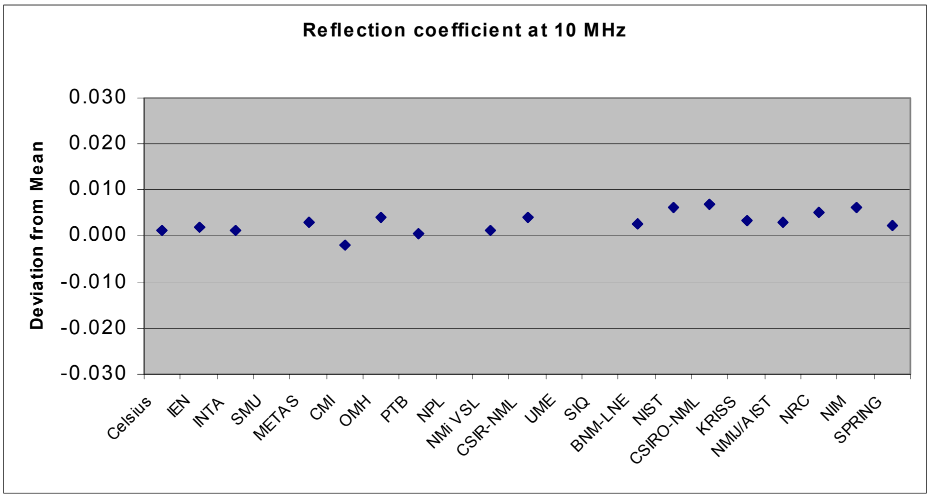
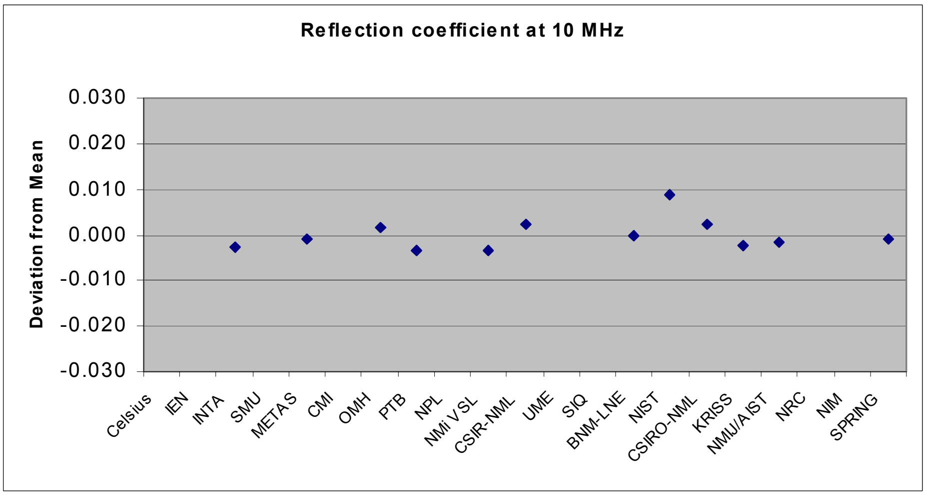


Figure A.2: Overview of the individual results of the reflection coefficient obtained by NMi-VSL during the intercomparison. The lines connecting the measurement points are meant to give a clearer view of the changes between the individual measurements

APPENDIX B
Reflection measurements





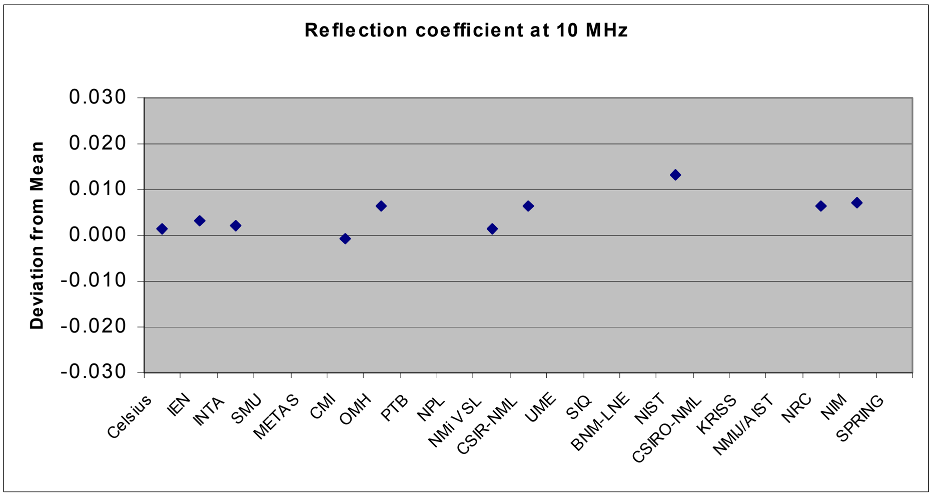
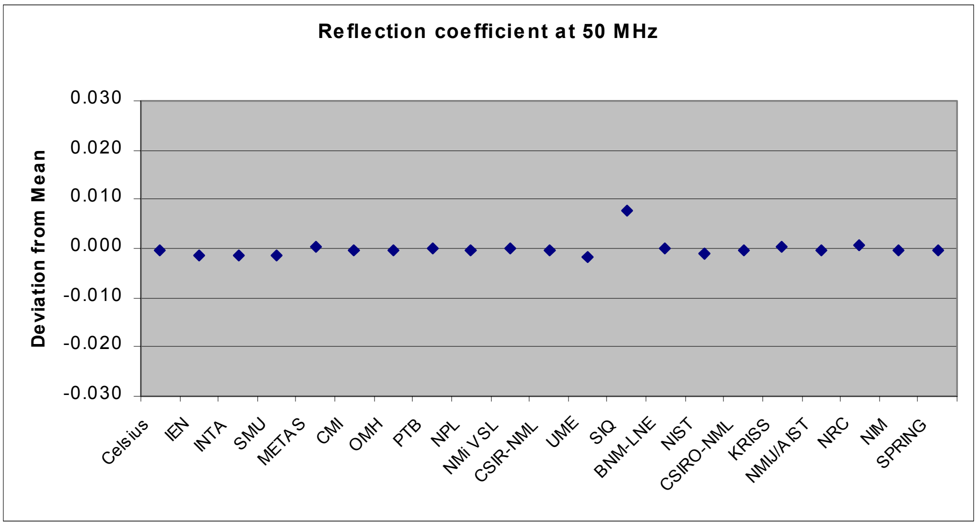
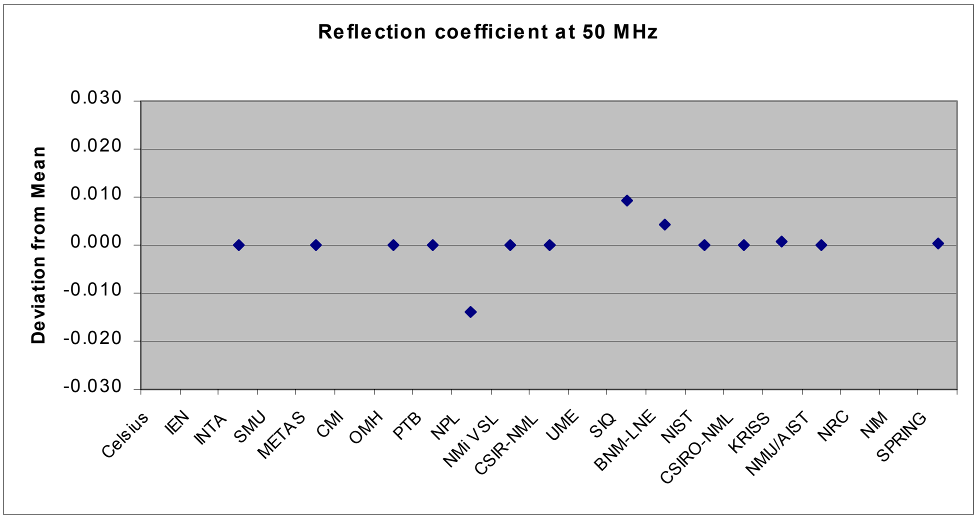


Figure B.1: Reflection coefficient measured at 10 MHz: Deviation from the mean value as obtained from the KCRV-contribuants





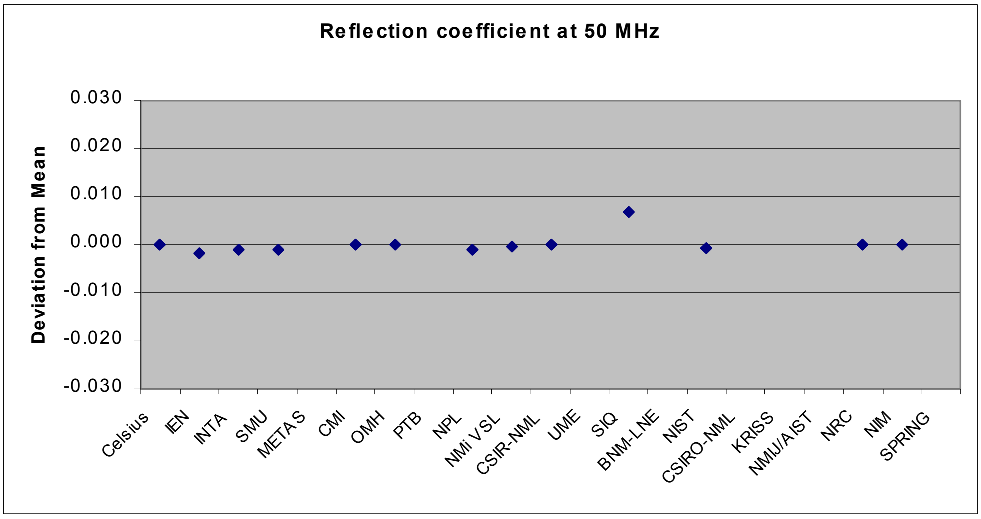
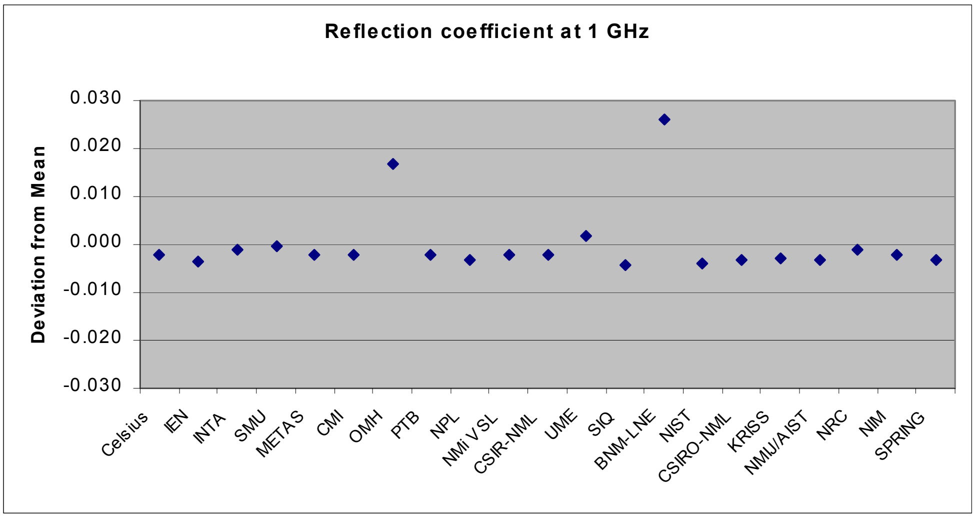
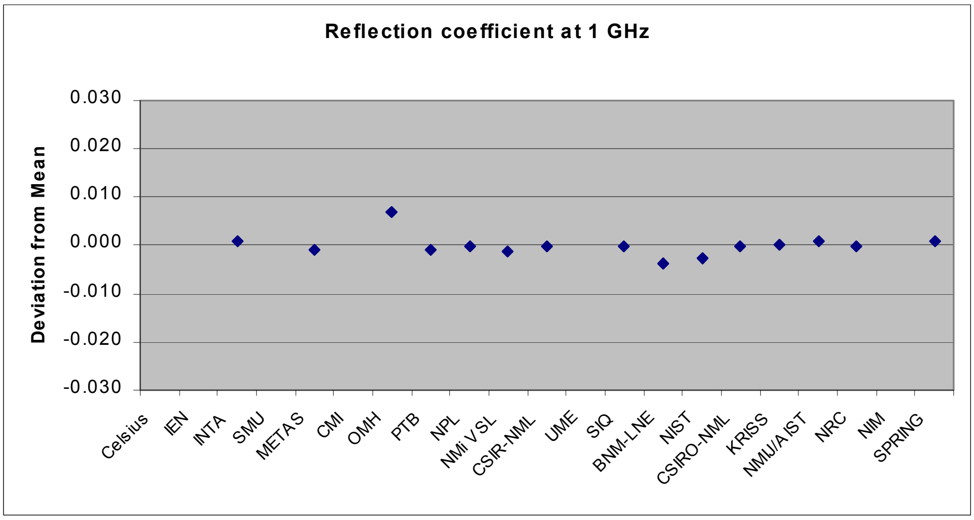


Figure B.2: Reflection coefficient measured at 50 MHz: Deviation from the mean value as obtained from the KCRV-contribuants





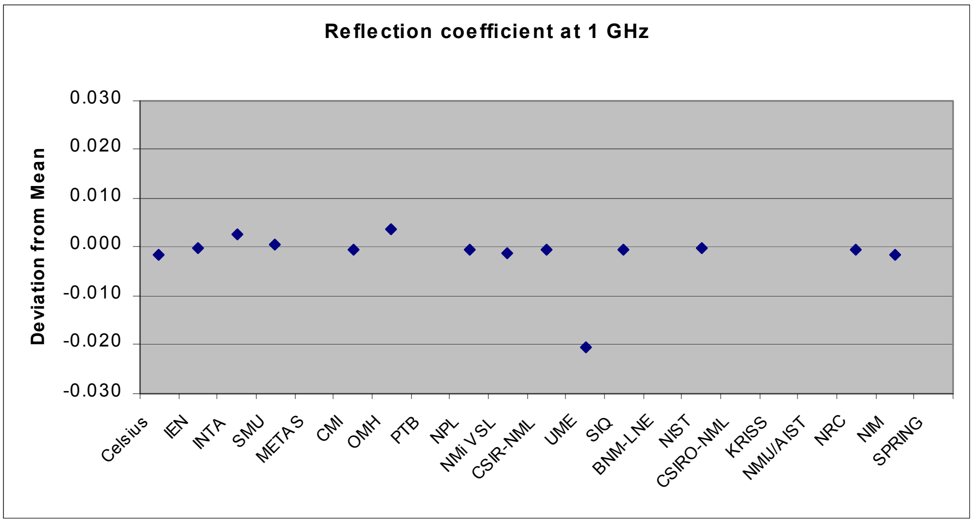
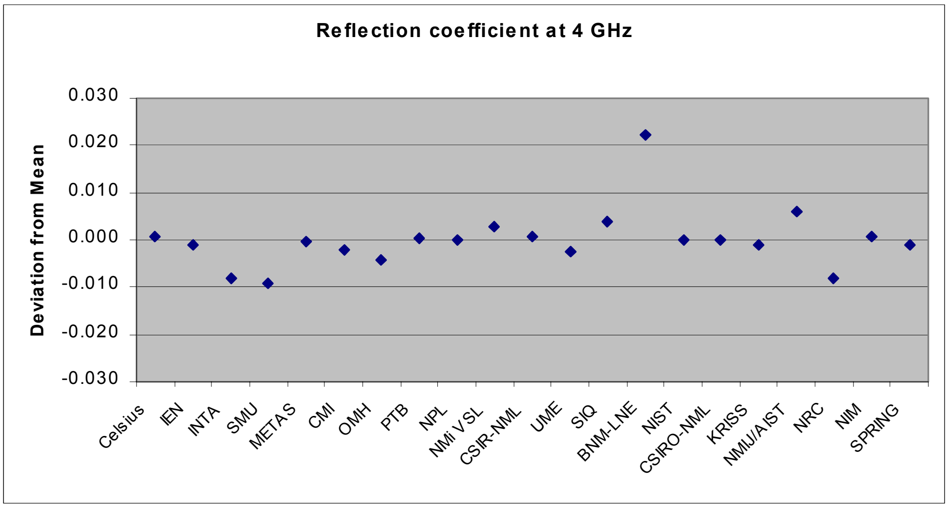
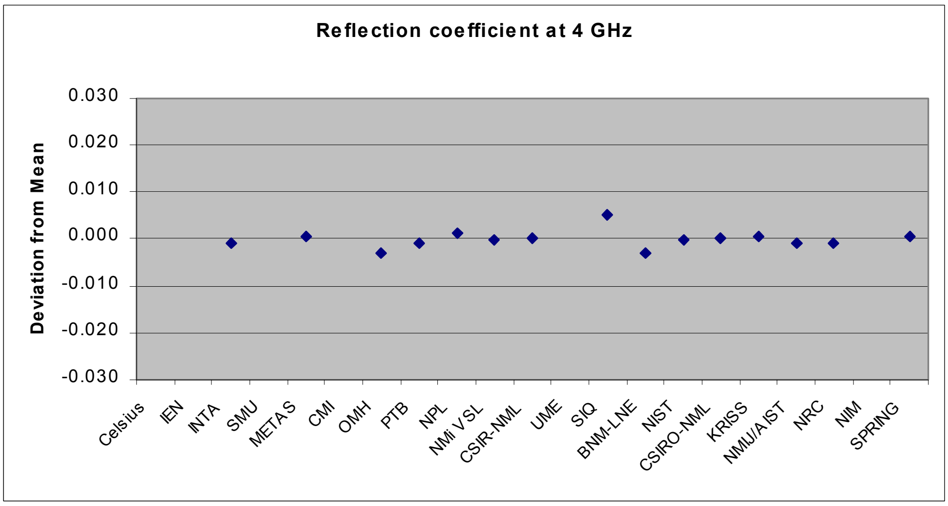


Figure B.3: Reflection coefficient measured at 1 GMHz: Deviation from the mean value as obtained from the KCRV-contribuants





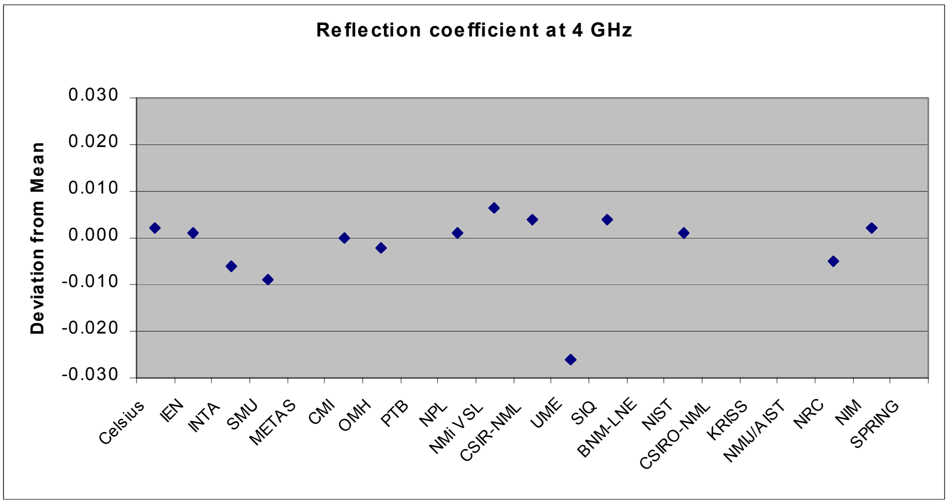
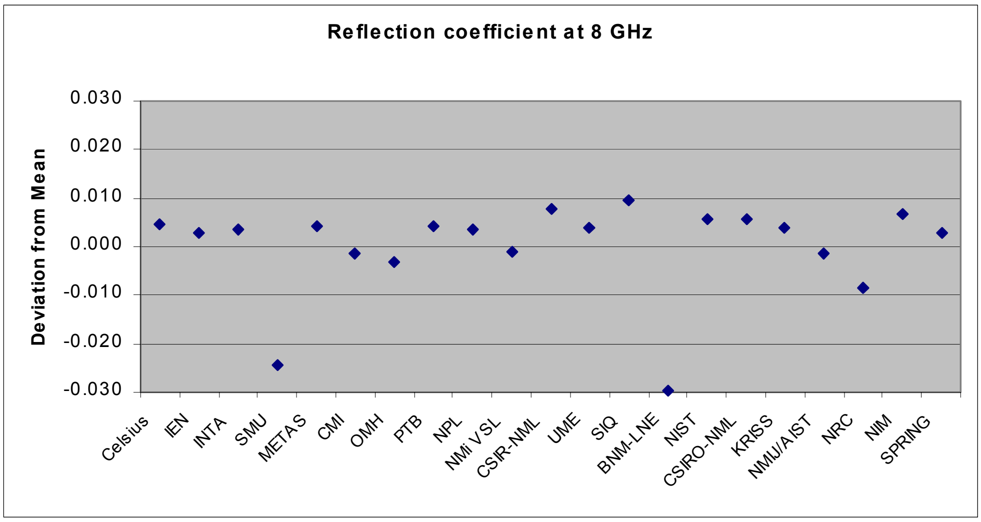
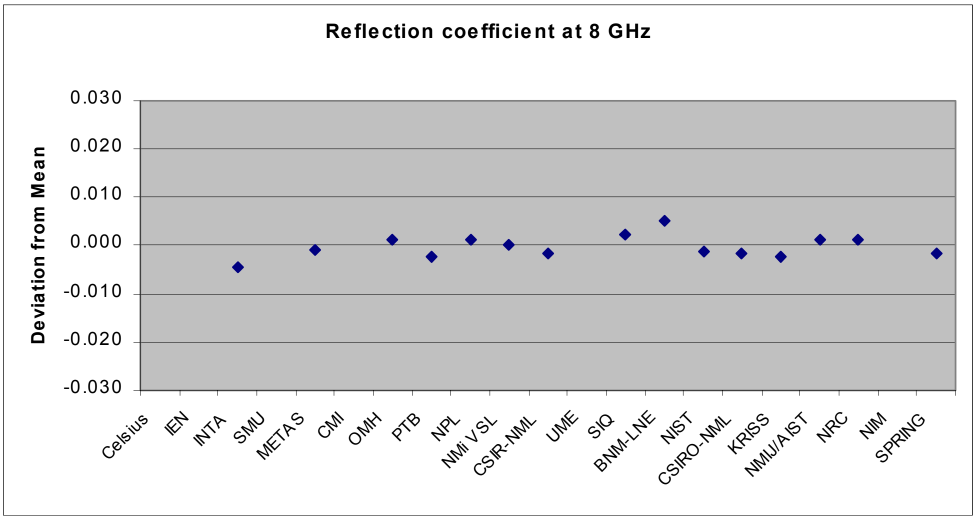


Figure B.4: Reflection coefficient measured at 4 GHz: Deviation from the mean value as obtained from the KCRV-contribuants





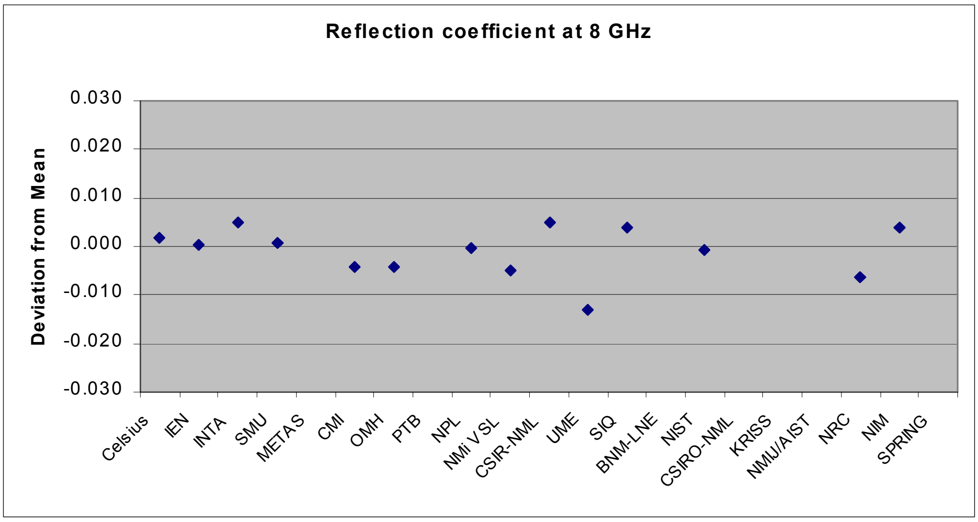
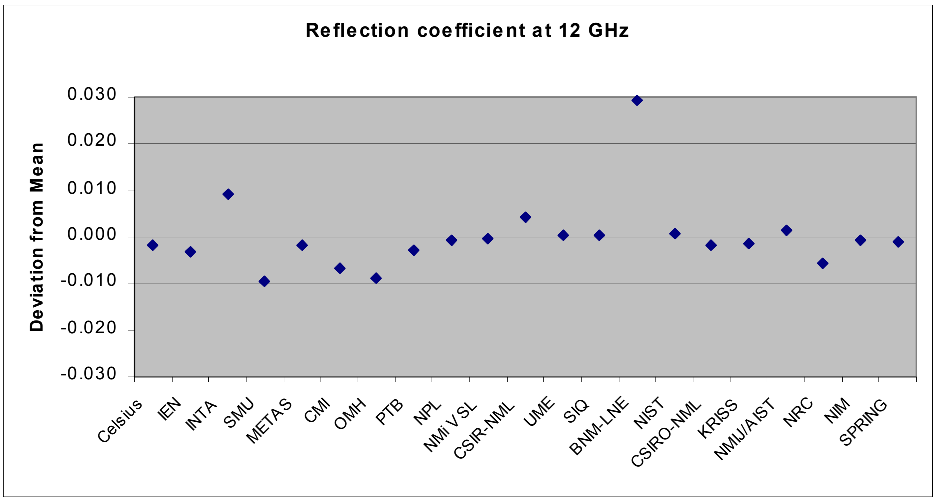
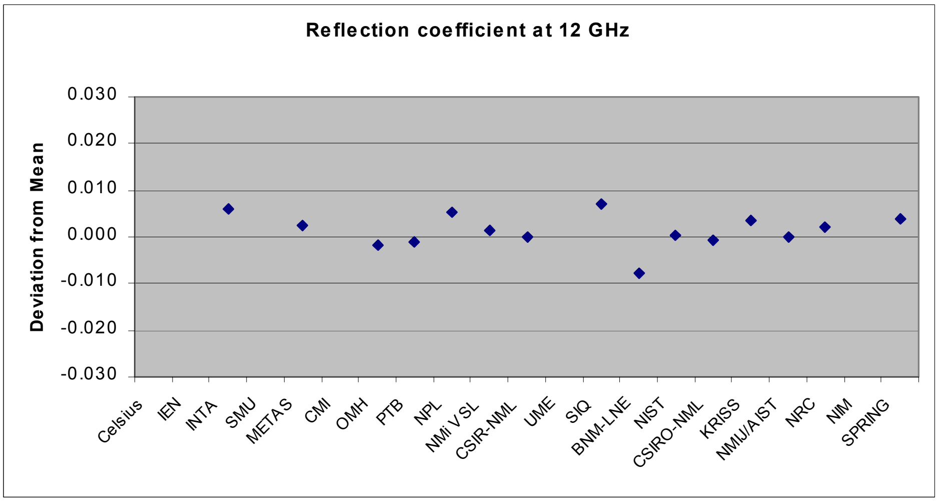


Figure B.5: Reflection coefficient measured at 8 GHz: Deviation from the mean value as obtained from the KCRV-contribuants





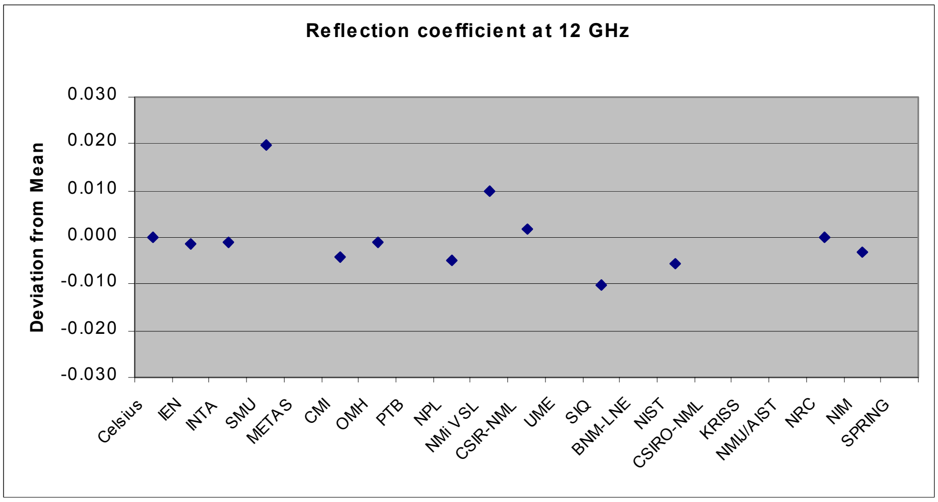
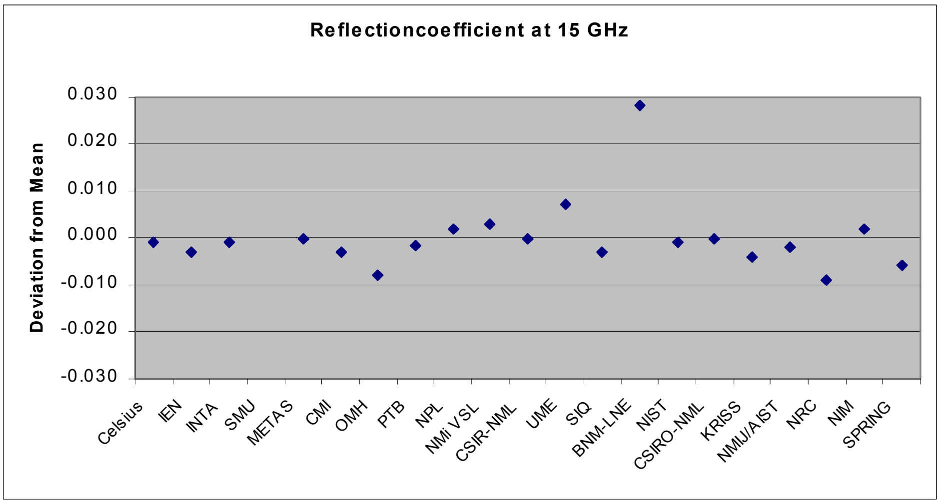
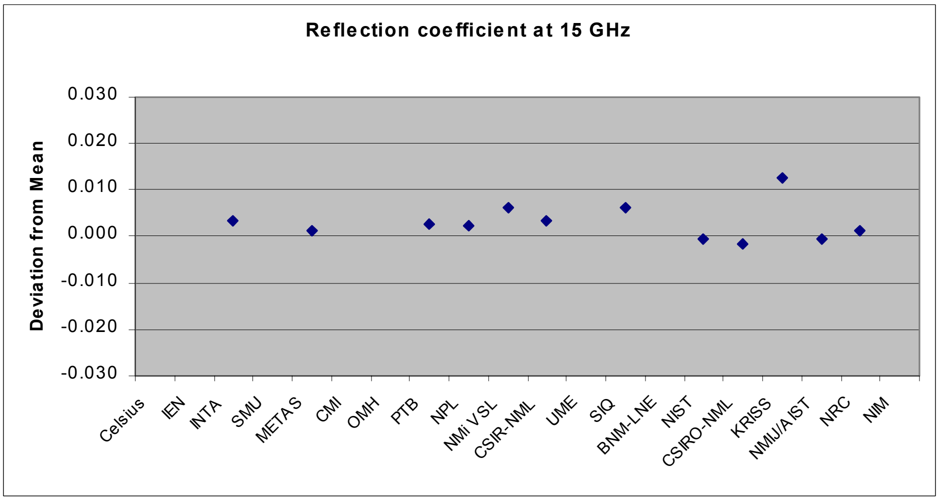


Figure B.6: Reflection coefficient measured at 12 GHz: Deviation from the mean value as obtained from the KCRV-contribuants





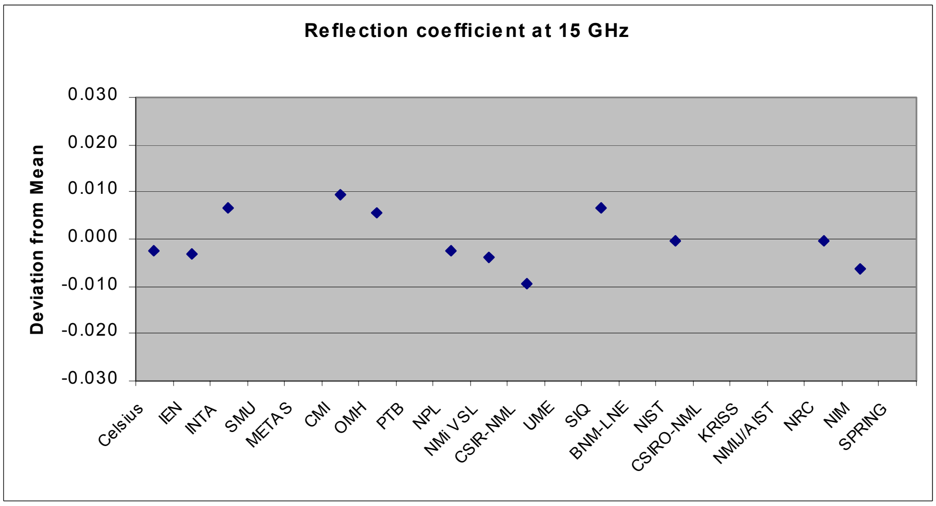
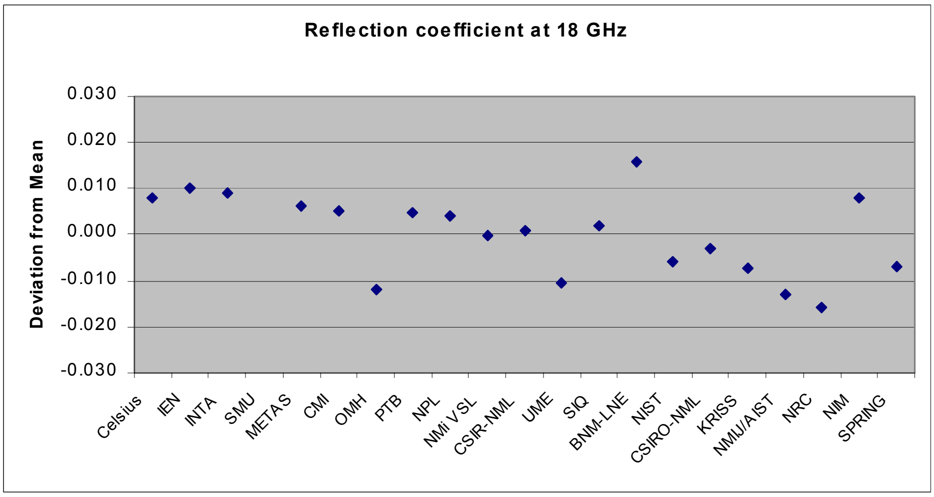
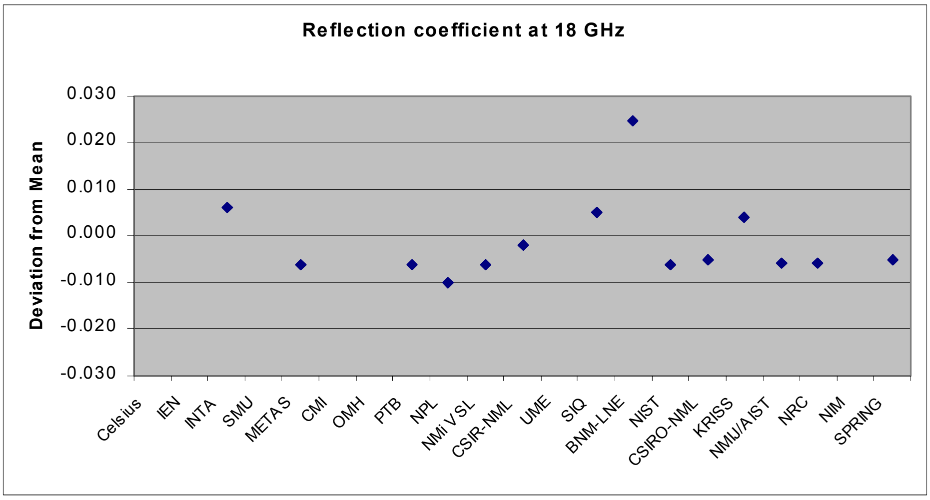


Figure B.7: Reflection coefficient measured at 15 GHz: Deviation from the mean value as obtained from the KCRV-contribuants





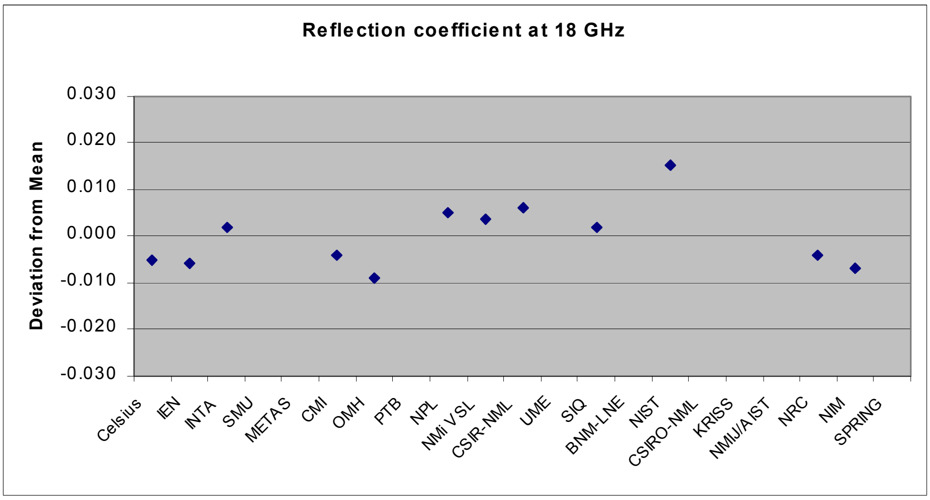


Figure B.8: Reflection coefficient measured at 18 GHz: Deviation from the mean value as obtained from the KCRV-contribuants

APPENDIX C

Degrees of equivalence for calibration factor at 10 MHz and at 18 GHz

Key comparison CCEM.RF-K8.CL

Measurand: calibration factor in coaxial 7 mm transmission line Nominal value:1.00
Pilot laboratory: NMi-VSL Travelling standards: three thermistor mounts identified as TM1, TM2 and TM3; TM1 and TM3 have a male type N 50 ohm connector and TM2 has a GPC7-connector (for more details, see the Final Report)

For the degrees of equivalence only the results at 10 MHz and 18 GHz are given. For the results at the other 6 frequencies see the Final Report on the comparison.
As the actual calibration factors of the DUTs are not relevant for the quality of the measurement results, for each DUT the results are given as the difference between the laboratory result and the relevant KCRV. The nominal value of the calibration factor for each DUT is therefore zero for each frequency.
D_i = the difference from the KCRV (the unweighted mean of selected laboratories) for laboratory i
U_i = the uncertainty of $D_{,i}$ taken into account the uncertainty of the KCRV.

Measurement frequency: 10 MHz

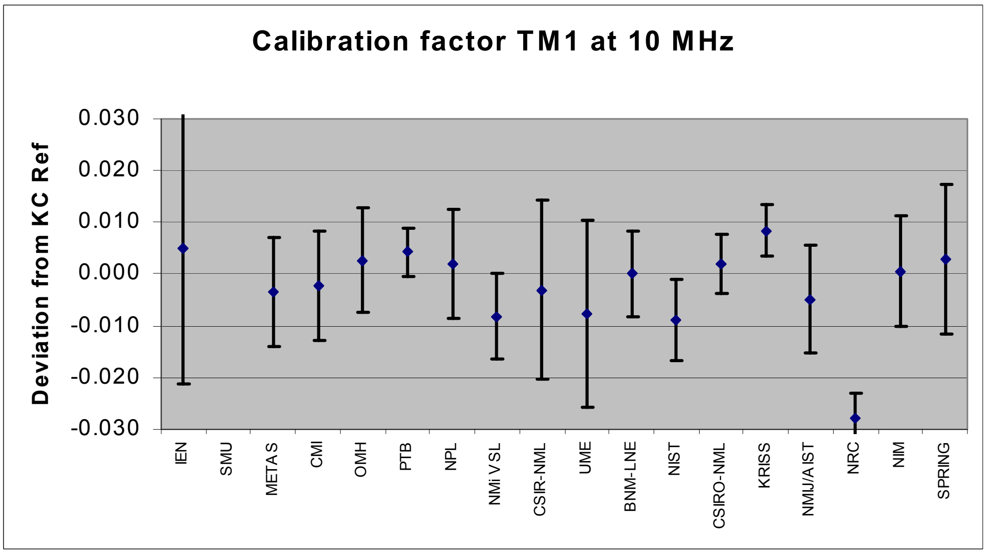
Laboratory	TM1		TM2		TM3	
	D_i	U_i	D_i	U_i	D_i	U_i
IEN	0.0049	0.0262	N/A		0.0090	0.0247
SMU	--	--	N/A		--	--
METAS	-0.0035	0.0106	-0.0008	0.0082	N/A	
CMI	-0.0023	0.0104	N/A		-0.0020	0.0111
OMH	0.0026	0.0101	0.0086	0.0109	0.0070	0.0116
PTB	0.0043	0.0047	0.0077	0.0050	N/A	
NPL	0.0019	0.0105	0.0045	0.0199	0.0050	0.0111
NMi-VSL	-0.0082	0.0083	-0.0064	0.0075	-0.0032	0.0093
CSIR-NML	-0.0031	0.0174	-0.0005	0.0166	0.0000	0.0171
UME	-0.0077	0.0182	-0.0059	0.0183	-0.0040	0.0188
BNM-LNE	0.0000	0.0083	0.0015	0.0085	N/A	
NIST	-0.0090	0.0078	-0.0104	0.0081	-0.0120	0.0088
CSIRO-NML	0.0019	0.0057	0.0065	0.0061	0.0060	0.0074
KRISS	0.0083	0.0049	-0.0003	0.0057	N/A	
NMIJ/AIST	-0.0049	0.0104	-0.0034	0.0105	N/A	
NRC	-0.0278	0.0046	--	--	-0.0453	0.0067
NIM	0.0005	0.0106	N/A		-0.0048	0.0111
SPRING	0.0029	0.0145	-0.0132	0.0109	N/A	

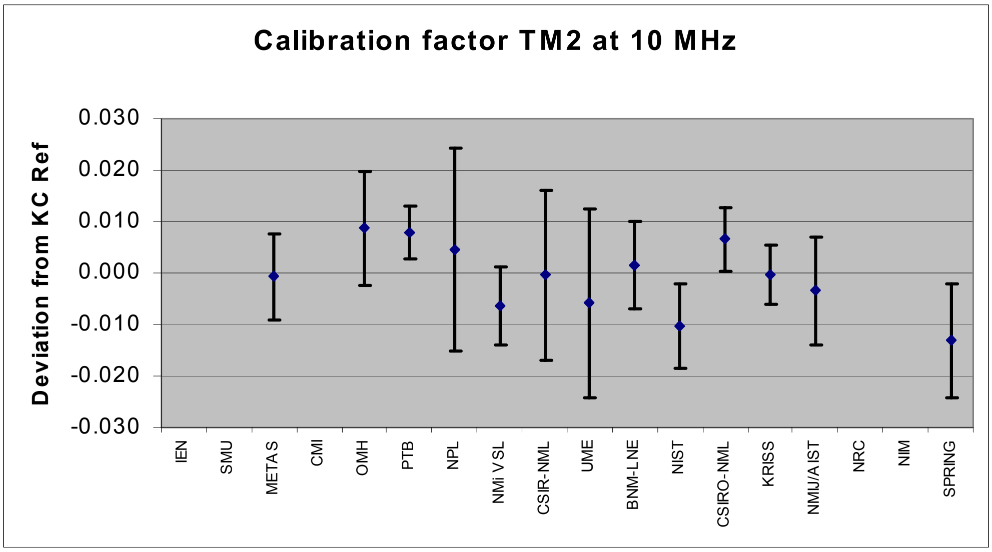
Measurement frequency: 18 GHz

Laboratory	TM1		TM2		TM3	
	D_i	U_i	D_i	U_i	D_i	U_i
IEN	0.0149	0.0344	N/A		0.0283	0.0409
SMU	--	--	N/A		--	--
METAS	-0.0423	0.0244	-0.0241	0.0212	N/A	
CMI	-0.0084	0.0159	N/A		-0.0112	0.0220
OMH	-0.0140	0.0230	--	--	0.0153	0.0276
PTB	-0.0078	0.0067	-0.0027	0.0051	N/A	
NPL	-0.0081	0.0142	0.0036	0.0226	-0.0037	0.0172
NMi-VSL	-0.0057	0.0200	-0.0034	0.0091	0.0063	0.0154
CSIR-NML	-0.0151	0.0353	0.0206	0.0461	0.0143	0.0401
UME	-0.0038	0.0233	0.0121	0.0424	0.0017	0.0317
BNM-LNE	-0.0024	0.0070	0.0114	0.0049	N/A	
NIST	0.0076	0.0078	-0.0019	0.0077	-0.0022	0.0070
CSIRO-NML	-0.0001	0.0042	-0.0024	0.0091	0.0003	0.0087
KRISS	0.0006	0.0094	0.0002	0.0090	N/A	
NMIJ/AIST	-0.0047	0.0107	-0.0007	0.0102	N/A	
NRC	0.0015	0.0101	-0.0044	0.0071	-0.0045	0.0088
NIM	0.0042	0.0110	N/A		0.0036	0.0121
SPRING	0.0199	0.0108	0.0020	0.0114	N/A	

Laboratories in green have participated in the definition of the KCRV

--	indicates no measurements on the specified device at this frequency.
N/A	= no measurement on this device


Calibration factor TM1 at 10 MHz
Deviation from KC Ref
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING


Calibration factor TM2 at 10 MHz
Deviation from KC Ref
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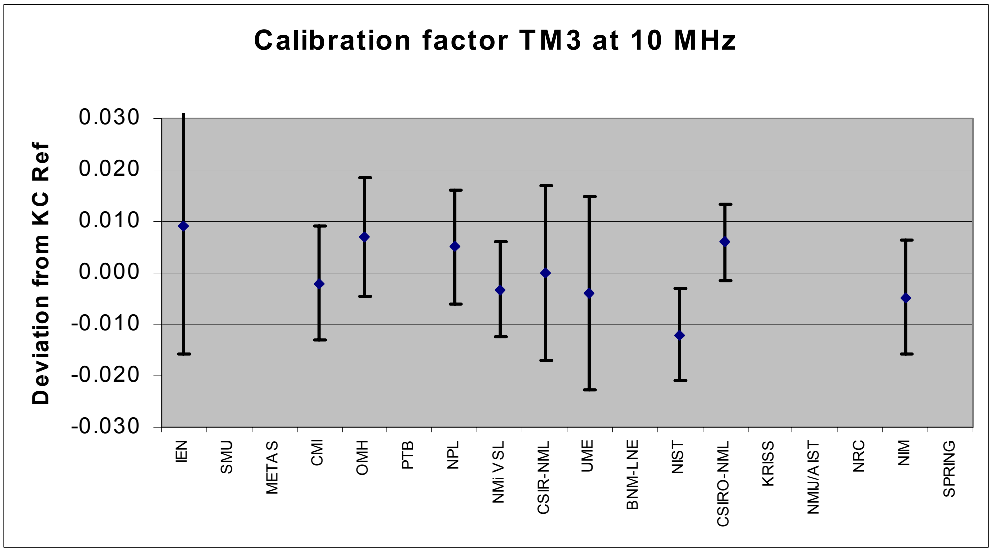
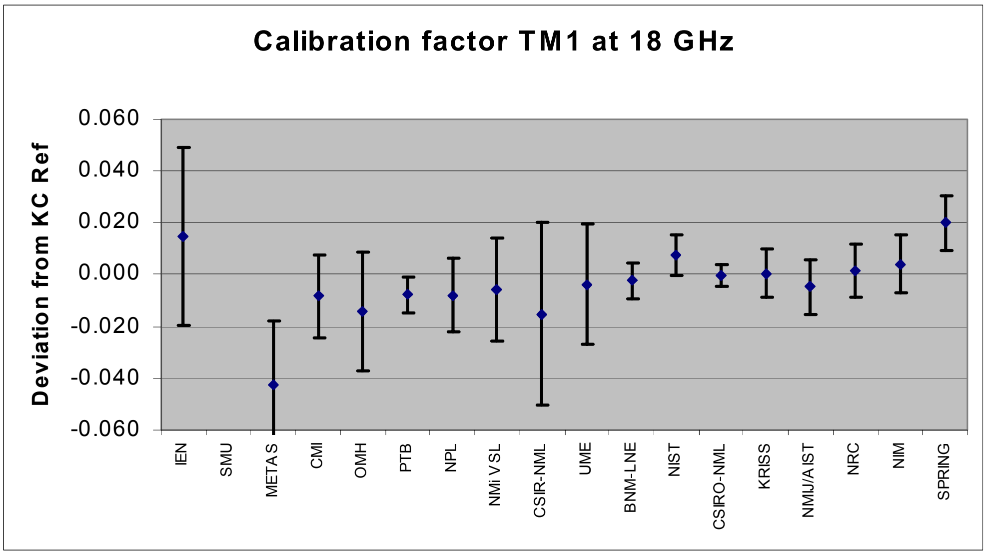
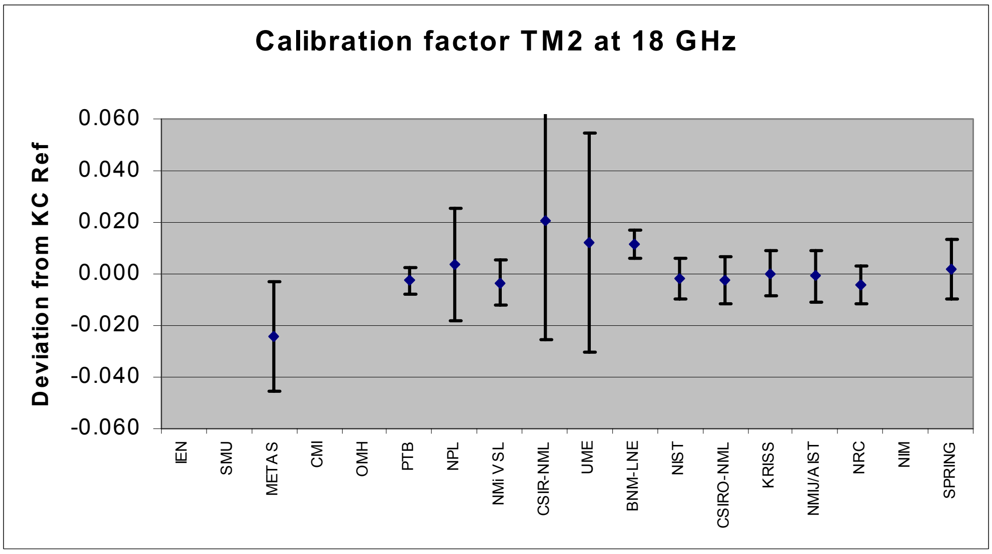
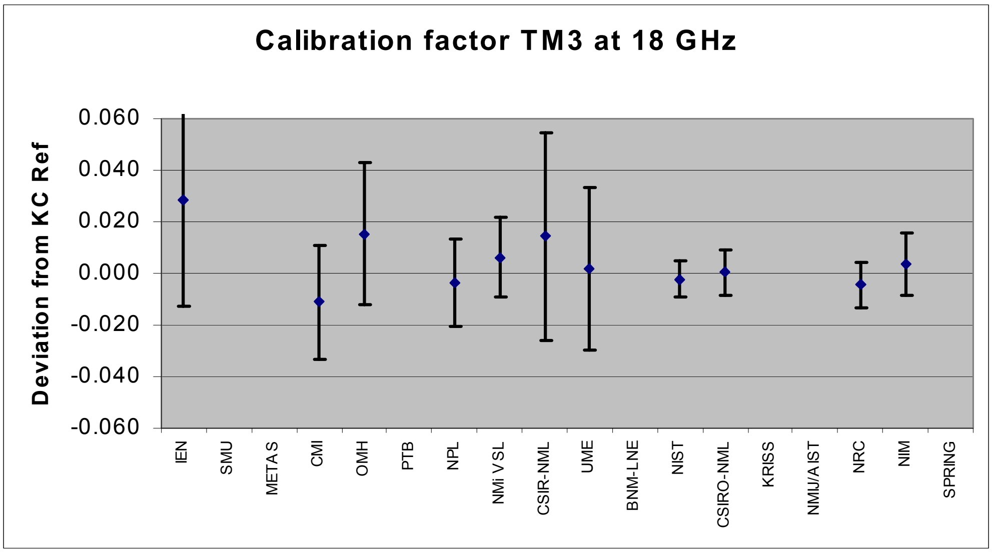
0.020
0.010
0.000
-0.010
-0.020
-0.030
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING


Calibration factor TM3 at 10 MHz
Deviation from KC Ref
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING


Calibration factor TM1 at 18 GHz
Deviation from KC Ref
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING


Calibration factor TM2 at 18 GHz
Deviation from KC Ref
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING


Calibration factor TM3 at 18 GHz
Deviation from KC Ref
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0.040
0.020
0.000
-0.020
-0.040
-0.060
IEN
SMU
METAS
CMI
OMH
PTB
NPL
NMi VSL
CSIR-NML
UME
BNM-LNE
NIST
CSIRO-NML
KRISS
NMIJ/AIST
NRC
NIM
SPRING

Appendix D
Participant uncertainty budget for thermistor mount TM1
Frequencies 10 MHz and 18 GHz

Pilot laboratory: NMi-VSL

Frequncy 10 MHz

REF: VSL-H48.4 Type-N connector
Data from: [HF\Beheer97\Sensor2]H48_4

VSWR source: Users_HF\Euromet\periode4\onz_p4

DUT Users_HF\euromet\periode4\vna
Data from 1998

		Value	Uncertainty	Distribution	factor	St.dev	sens.factor	Contr.to Unc	Square
Ks	Calibration factor REF at 10 MHz	0.9619	0.0034	Normal	1	0.0034	1.004124	0.003414	1.17E-05
dKd	uncertainty due drift	0	0.001	rectangula	1.732051	0.000577	1.004124	0.00058	3.36E-07
Msr	mismatch REF 50 MHz	1	0.0004	U	1.414214	0.000283	0.965867	0.000273	7.46E-08
Msc	mismatch REF 10 MHz	1	0.002	U	1.414214	0.001414	0.965867	0.001366	1.87E-06
Mxr	mismatch DUT 50 MHz	1	0.0005	U	1.414214	0.000354	0.965867	0.000341	1.17E-07
Mxc	mismatch DUT 10 MHz	1	0.0021	U	1.414214	0.001485	0.965867	0.001434	2.06E-06
pcr	nonlinearity etc at 50 MHz	1	0.0012	normal	2	0.0006	0.965867	0.00058	3.36E-07
pcc	nonlinearity etc at 10 MHz	1	0.0012	normal	2	0.0006	0.965867	0.00058	3.36E-07
p	ratio in response tov 50 MHz	0.9983	0.0004	normal	1	0.0004	0.967512	0.000387	1.5E-07
Kx=		0.960		0.004114	(k=1)			0.004114	1.69E-05
				0.008	(k=2)				

Frequency 18 GHz

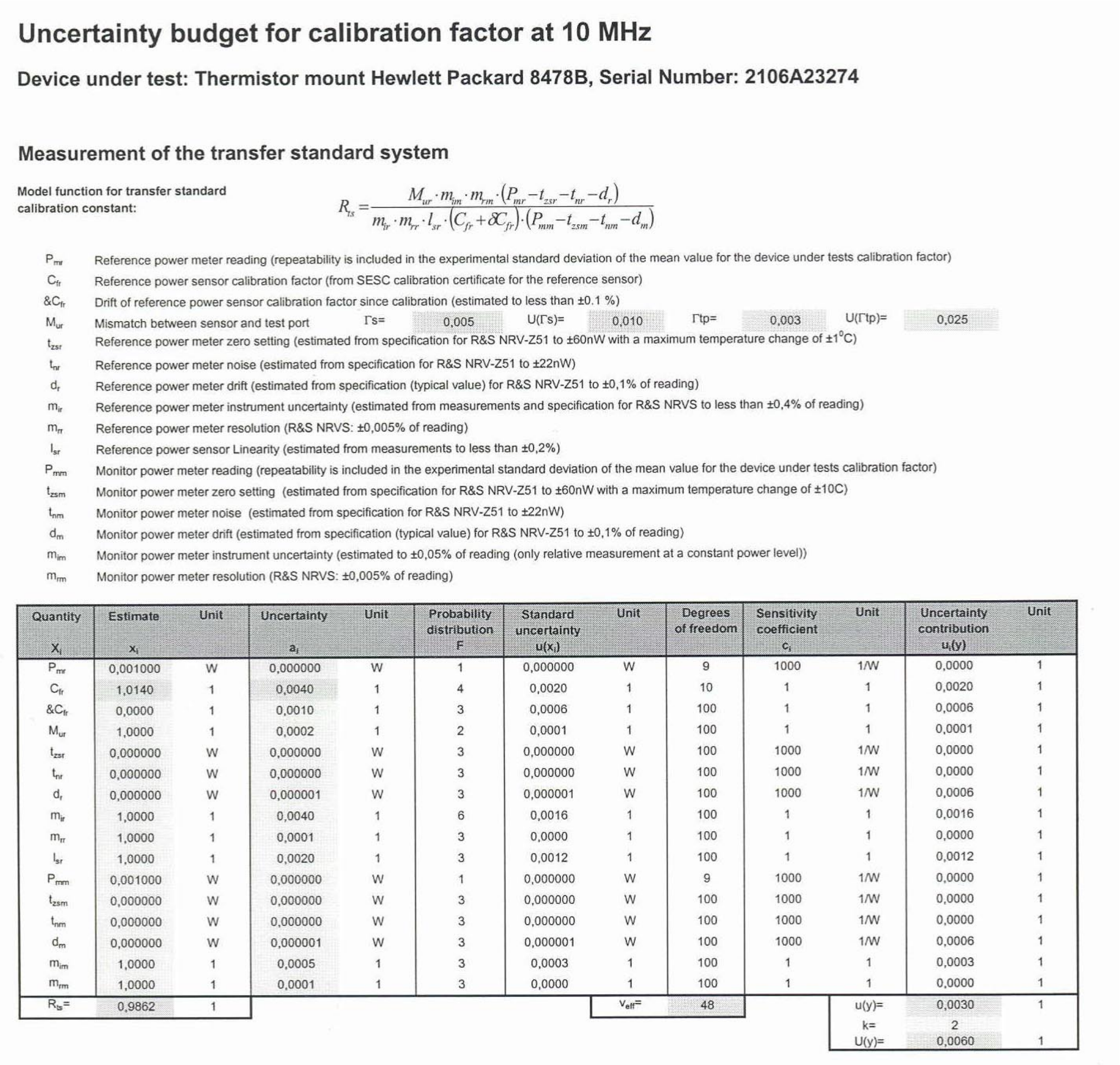
REF: VSL-H48.4 Type-N connector
Data from: [HF\Beheer97\Sensor2]H48_4

VSWR source: Users_HF\Euromet\periode4\onz_p4

DUT Users_HF\euromet\periode4\vna
Data from 1998

		Value	Uncertainty	Distribution	factor	St.dev	sens.factor	Contr.to Unc	Square
Ks	Kalibratiefactor REF at 18 GHz	0.9363	0.0082	normal	1	0.0082	1.031578	0.008459	7.16E-05
dKd	uncertainty due drift	0	0.001	rechthoek	1.732051	0.000577	1.031578	0.000596	3.55E-07
Msr	mismatch REF 50 MHz	1	0.0004	U	1.414214	0.000283	0.965867	0.000273	7.46E-08
Msc	mismatch REF 18 GHz	1	0.0051	U	1.414214	0.003606	0.965867	0.003483	1.21E-05
Mxr	mismatch DUT 50 MHz	1	0.0005	U	1.414214	0.000354	0.965867	0.000341	1.17E-07
Mxc	mismatch DUT 18 GHz	1	0.0025	U	1.414214	0.001768	0.965867	0.001707	2.92E-06
pcr	nonlinearity etc at 50 MHz	1	0.0012	normaal	2	0.0006	0.965867	0.00058	3.36E-07
pcc	nonlinearity etc at 18 GHz	1	0.0012	normaal	2	0.0006	0.965867	0.00058	3.36E-07
p	ratio in response tov 50 MHz	0.9973	0.0067	normaal	1	0.0067	0.968482	0.006489	4.21E-05
Kx=		0.934		0.011398	(k=1)			0.011398	0.00013
				0.023	(k=2)				

Celsius Metech



Uncertainty budget for calibration factor at 10 MHz

Device under test: Thermistor mount Hewlett Packard 8478B, Serial Number: 2106A23274

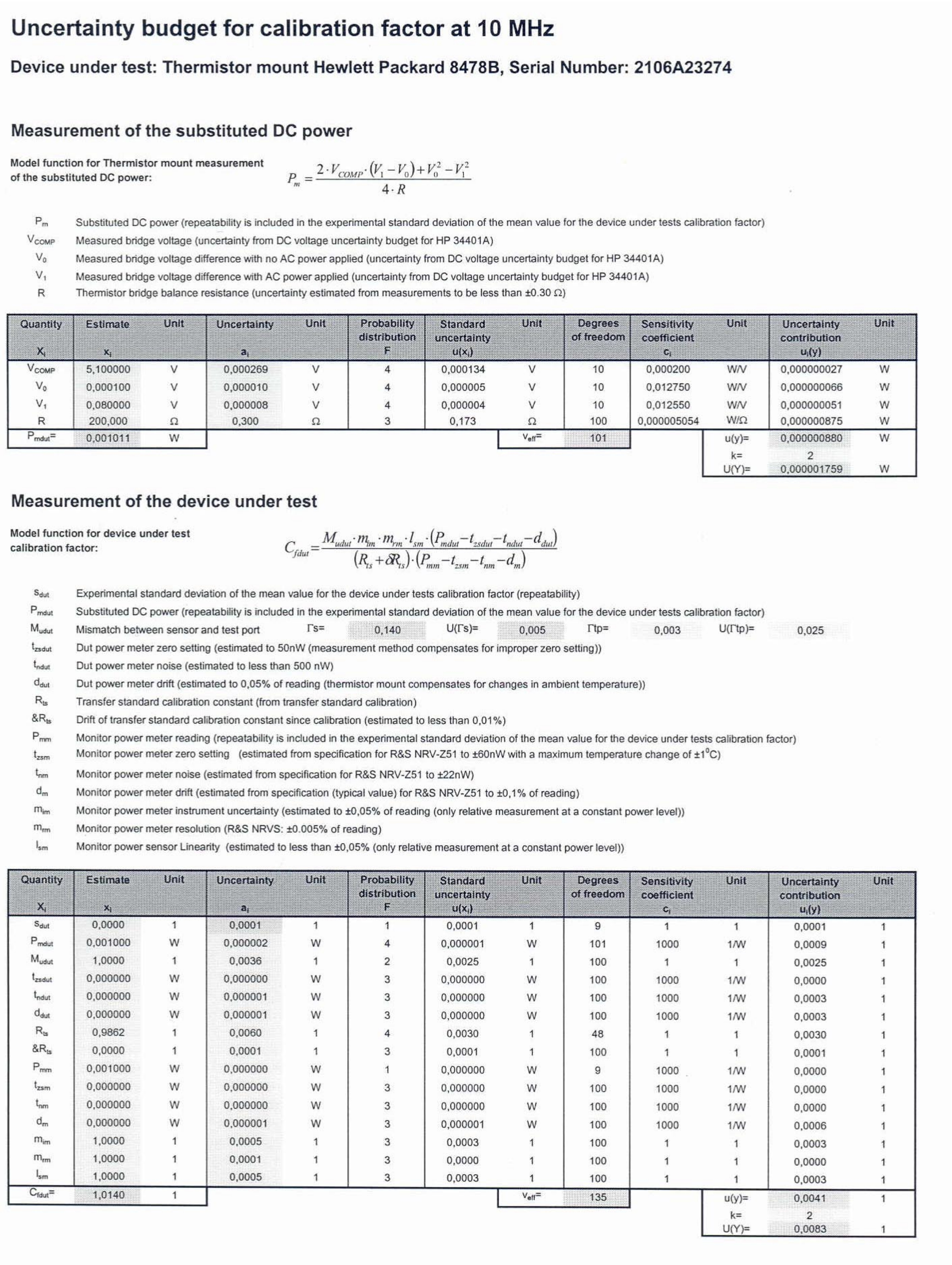
Measurement of the transfer standard system

Model function for transfer standard calibration constant:

$$R_{ts}=\frac{M_{ur}\cdot m_{im}\cdot m_{rm}\cdot\left(P_{mr}-t_{zsr}-t_{nr}-d_{r}\right)}{m_{ir}\cdot m_{rr}\cdot l_{sr}\cdot\left(C_{fr}+\delta C_{fr}\right)\cdot\left(P_{mm}-t_{zsm}-t_{nm}-d_{m}\right)}$$

P_{mr}	Reference power meter reading (repeatability is included in the experimental standard deviation of the mean value for the device under tests calibration factor)
C_{fr}	Reference power sensor calibration factor (from SESC calibration certificate for the reference sensor)
&C_{fr}	Drift of reference power sensor calibration factor since calibration (estimated to less than ±0.1 %)
M_{ur}	Mismatch between sensor and test port Γs= 0,005 U(Γs)= 0,010 Γtp= 0,003 U(Γtp)= 0,025
t_{zsr}	Reference power meter zero setting (estimated from specification for R&S NRV-Z51 to ±60nW with a maximum temperature change of ±1^{0}C)
t_{nr}	Reference power meter noise (estimated from specification for R&S NRV-Z51 to ±22nW)
d_r	Reference power meter drift (estimated from specification (typical value) for R&S NRV-Z51 to ±0,1% of reading)
m_{ir}	Reference power meter instrument uncertainty (estimated from measurements and specification for R&S NRVS to less than ±0,4% of reading)
m_{rr}	Reference power meter resolution (R&S NRVS: ±0,005% of reading)
l_{sr}	Reference power sensor Linearity (estimated from measurements to less than ±0,2%)
P_{mm}	Monitor power meter reading (repeatability is included in the experimental standard deviation of the mean value for the device under tests calibration factor)
t_{zsm}	Monitor power meter zero setting (estimated from specification for R&S NRV-Z51 to ±60nW with a maximum temperature change of ±10C)
t_{nm}	Monitor power meter noise (estimated from specification for R&S NRV-Z51 to ±22nW)
d_m	Monitor power meter drift (estimated from specification (typical value) for R&S NRV-Z51 to ±0,1% of reading)
m_{im}	Monitor power meter instrument uncertainty (estimated to ±0,05% of reading (only relative measurement at a constant power level))
m_{rm}	Monitor power meter resolution (R&S NRVS: ±0,005% of reading)

Quantity X_i	Estimate x_i	Unit	Uncertainty a_i	Unit	Probability distribution F	Standard uncertainty $u(x_i)$	Unit	Degrees of freedom	Sensitivity coefficient c_i	Unit	Uncertainty contribution $u_i(y)$	Unit
P_{mr}	0,001000	W	0,000000	W	1	0,000000	W	9	1000	1/W	0,0000	1
C_{fr}	1,0140	1	0,0040	1	4	0,0020	1	10	1	1	0,0020	1
&C_{fr}	0,0000	1	0,0010	1	3	0,0006	1	100	1	1	0,0006	1
M_{ur}	1,0000	1	0,0002	1	2	0,0001	1	100	1	1	0,0001	1
t_{zsr}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
t_{nr}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
d_r	0,000000	W	0,000001	W	3	0,000001	W	100	1000	1/W	0,0006	1
m_{ir}	1,0000	1	0,0040	1	6	0,0016	1	100	1	1	0,0016	1
m_{rr}	1,0000	1	0,0001	1	3	0,0000	1	100	1	1	0,0000	1
l_{sr}	1,0000	1	0,0020	1	3	0,0012	1	100	1	1	0,0012	1
P_{mm}	0,001000	W	0,000000	W	1	0,000000	W	9	1000	1/W	0,0000	1
t_{zsm}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
t_{nm}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
d_m	0,000000	W	0,000001	W	3	0,000001	W	100	1000	1/W	0,0006	1
m_{im}	1,0000	1	0,0005	1	3	0,0003	1	100	1	1	0,0003	1
m_{rm}	1,0000	1	0,0001	1	3	0,0000	1	100	1	1	0,0000	1
R_{ts}=	0,9862	1					v_{eff}=	48		u(y)=	0,0030	1
										k=	2	
										U(y)=	0,0060	1



Uncertainty budget for calibration factor at 10 MHz

Device under test: Thermistor mount Hewlett Packard 8478B, Serial Number: 2106A23274

Measurement of the substituted DC power

Model function for Thermistor mount measurement of the substituted DC power:

$$P_m = \frac{2 \cdot V_{COMP} \cdot (V_1 - V_0) + V_0^2 - V_1^2}{4 \cdot R}$$

P_m	Substituted DC power (repeatability is included in the experimental standard deviation of the mean value for the device under tests calibration factor)
V_{COMP}	Measured bridge voltage (uncertainty from DC voltage uncertainty budget for HP 34401A)
V_0	Measured bridge voltage difference with no AC power applied (uncertainty from DC voltage uncertainty budget for HP 34401A)
V_1	Measured bridge voltage difference with AC power applied (uncertainty from DC voltage uncertainty budget for HP 34401A)
R	Thermistor bridge balance resistance (uncertainty estimated from measurements to be less than ±0.30 Ω)

Quantity X_i	Estimate x_i	Unit	Uncertainty a_i	Unit	Probability distribution F	Standard uncertainty $u(x_i)$	Unit	Degrees of freedom	Sensitivity coefficient c_i	Unit	Uncertainty contribution $u_i(y)$	Unit
V_{COMP}	5,100000	V	0,000269	V	4	0,000134	V	10	0,000200	W/V	0,000000027	W
V_0	0,000100	V	0,000010	V	4	0,000005	V	10	0,012750	W/V	0,000000066	W
V_1	0,080000	V	0,000008	V	4	0,000004	V	10	0,012550	W/V	0,000000051	W
R	200,000	Ω	0,300	Ω	3	0,173	Ω	100	0,000005054	W/Ω	0,000000875	W
P_{mdut}=	0,001011	W					v_{eff}=	101		u(y)=	0,000000880	W
										k=	2	
										U(Y)=	0,000001759	W

Measurement of the device under test

Model function for device under test calibration factor:

$$C_{fdut} = \frac{M_{udut} \cdot m_{im} \cdot m_{rm} \cdot l_{sm} \cdot (P_{mdut} - t_{zsdut} - t_{ndut} - d_{dut})}{(R_{ts} + \delta R_{ts}) \cdot (P_{mm} - t_{zsm} - t_{nm} - d_m)}$$

s_{dut}	Experimental standard deviation of the mean value for the device under tests calibration factor (repeatability)
P_{mdut}	Substituted DC power (repeatability is included in the experimental standard deviation of the mean value for the device under tests calibration factor)
M_{udut}	Mismatch between sensor and test port Γs= 0,140 U(Γs)= 0,005 Γtp= 0,003 U(Γtp)= 0,025
t_{zsdut}	Dut power meter zero setting (estimated to 50nW (measurement method compensates for improper zero setting))
t_{ndut}	Dut power meter noise (estimated to less than 500 nW)
d_{dut}	Dut power meter drift (estimated to 0,05% of reading (thermistor mount compensates for changes in ambient temperature))
R_{ts}	Transfer standard calibration constant (from transfer standard calibration)
&R_{ts}	Drift of transfer standard calibration constant since calibration (estimated to less than 0,01%)
P_{mm}	Monitor power meter reading (repeatability is included in the experimental standard deviation of the mean value for the device under tests calibration factor)
t_{zsm}	Monitor power meter zero setting (estimated from specification for R&S NRV-Z51 to ±60nW with a maximum temperature change of ±1°C)
t_{nm}	Monitor power meter noise (estimated from specification for R&S NRV-Z51 to ±22nW)
d_m	Monitor power meter drift (estimated from specification (typical value) for R&S NRV-Z51 to ±0,1% of reading)
m_{im}	Monitor power meter instrument uncertainty (estimated to ±0,05% of reading (only relative measurement at a constant power level))
m_{rm}	Monitor power meter resolution (R&S NRVS: ±0.005% of reading)
l_{sm}	Monitor power sensor Linearity (estimated to less than ±0,05% (only relative measurement at a constant power level))

Quantity X_i	Estimate x_i	Unit	Uncertainty a_i	Unit	Probability distribution F	Standard uncertainty $u(x_i)$	Unit	Degrees of freedom	Sensitivity coefficient c_i	Unit	Uncertainty contribution $u_i(y)$	Unit
s_{dut}	0,0000	1	0,0001	1	1	0,0001	1	9	1	1	0,0001	1
P_{mdut}	0,001000	W	0,000002	W	4	0,000001	W	101	1000	1/W	0,0009	1
M_{udut}	1,0000	1	0,0036	1	2	0,0025	1	100	1	1	0,0025	1
t_{zsdut}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
t_{ndut}	0,000000	W	0,000001	W	3	0,000000	W	100	1000	1/W	0,0003	1
d_{dut}	0,000000	W	0,000001	W	3	0,000000	W	100	1000	1/W	0,0003	1
R_{ts}	0,9862	1	0,0060	1	4	0,0030	1	48	1	1	0,0030	1
&R_{ts}	0,0000	1	0,0001	1	3	0,0001	1	100	1	1	0,0001	1
P_{mm}	0,001000	W	0,000000	W	1	0,000000	W	9	1000	1/W	0,0000	1
t_{zsm}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
t_{nm}	0,000000	W	0,000000	W	3	0,000000	W	100	1000	1/W	0,0000	1
d_m	0,000000	W	0,000001	W	3	0,000001	W	100	1000	1/W	0,0006	1
m_{im}	1,0000	1	0,0005	1	3	0,0003	1	100	1	1	0,0003	1
m_{rm}	1,0000	1	0,0001	1	3	0,0000	1	100	1	1	0,0000	1
l_{sm}	1,0000	1	0,0005	1	3	0,0003	1	100	1	1	0,0003	1
C_{fdut}=	1,0140	1					v_{eff}=	135		u(y)=	0,0041	1
										k=	2	
										U(Y)=	0,0083	1

IENGF

Data Analysis and Accuracy Assessment.

No filtering process has been applied to the original measured power ratios *p*. Concerning the accuracy assessment, the procedure suggested in EA-4/02 Document have been used. The scheme of the uncertainty budget is reported in the Table I below for the power sensor H8478B sn 2106A23274 at the frequency of 18GHz .

Quantity	estimate	standard uncertainty	Probability distribution	sensitivity coefficient	uncertainty contribution
X_i	x_i	$u(x_i)$		c_i	$u_i(y)$
K_S	0.9269	0.0019	normal	1.0291	0.0029
M_S	1	0.0169	U-shaped	-0.9539	-0.0191
M_X	1	0.0072	U-shaped	0.9539	0.0120
$p=P_U/P_S$	1.0291	0.0014	normal	0.9948	0.0030
$y=K_U$	0.9539			K=1	0.0184

Table I: Uncertainty budged for the travelling standard H48.2 at the frequency of 18GHz .

Error propagation has been calculated on the basis of the formula:

$$K_U = K_S \frac{P_U}{P_S} p \qquad (1)$$

in which the quantities K_S, P_S, P_U are assumed having a gaussian distribution, while M_S, M_U having a U-shaped probability distribution.

The uncertainty related to Calibration Factor K_S of the IENGF standard is basically the uncertainty claimed by IENGF for its primary power standard in the frequency range 10 MHz-18 GHz.

The uncertainty related to the mismatch factors M_S and M_U, whose values are assumed equal 1, has been calculated by means the formula

$$u(M_x) = \frac{2\left|\Gamma_{eq}\right|\left|\Gamma_x\right|}{\sqrt{2}} \quad ; x=S,\ U \qquad (2)$$

using the reflection coefficients of equivalent generator (power splitter output ports), of the standard and unknown $\Gamma_{eq}, \Gamma_S, \Gamma_U$.

It must be pointed out, the uncertainties related to K_S, M_S, M_U are type B terms only. At the quantity *p* instead, both a type A and a type B uncertainty term is associated.

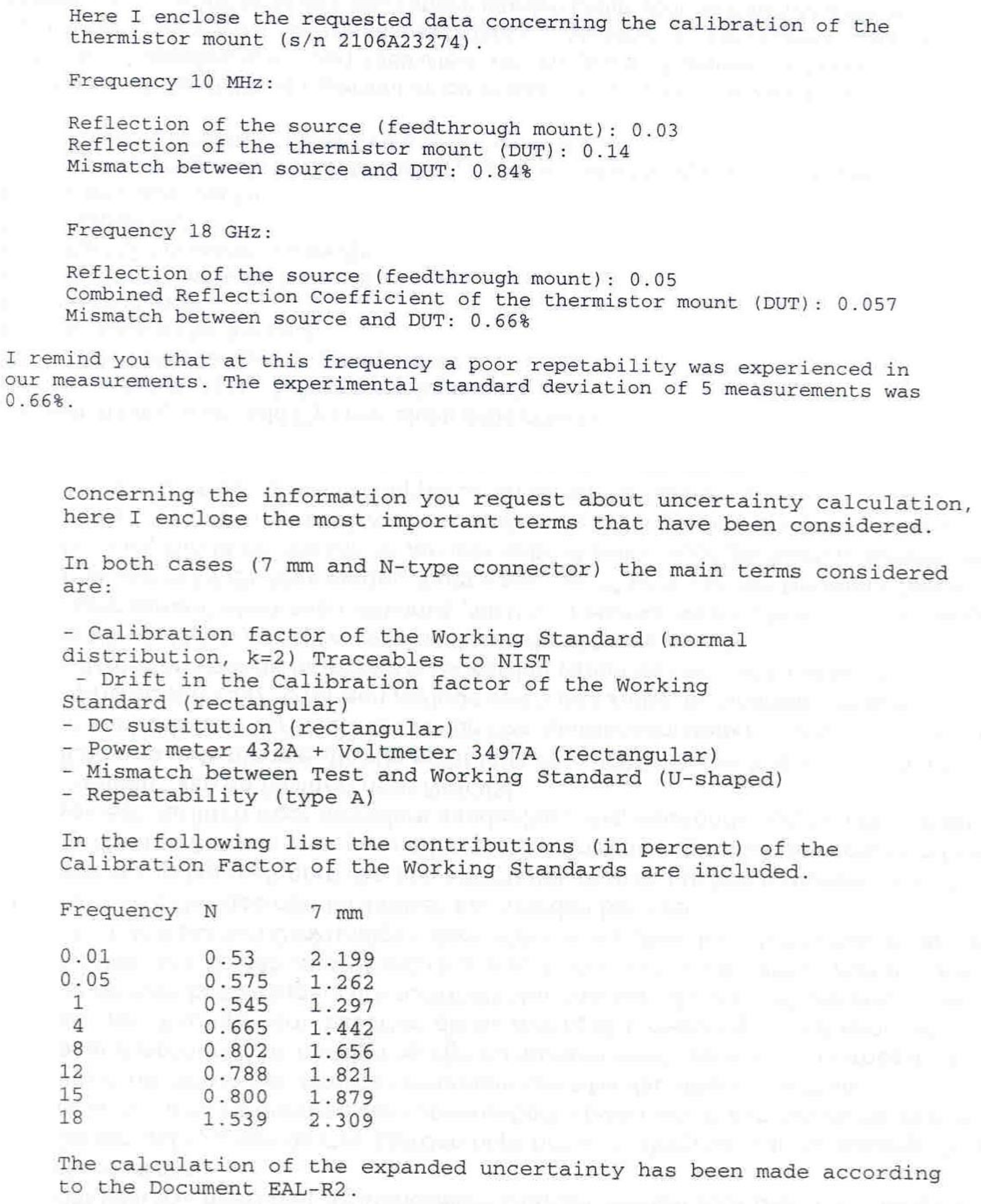
Indeed, the power levels P_S , P_U are quantities measured by means of the dc-substitution method through the following formula:

$$P = R_T\left(\frac{V_{1dc}}{2R}\right)^2 - R_T\left(\frac{V_{2dc}}{2R}\right)^2 \qquad (3)$$

where R_T is the dynamic resistance of the thermistor, while $\frac{V_{1dc}}{2R}$ and $\frac{V_{2dc}}{2R}$ are the dc-bias supplied by the self-balancing bridge to the thermistor mount without and with HF-power respectively. All the quantities involved in formula (3) are known or measured with great accuracy, therefore their contribution to the type B uncertainty is very small and could be neglected. In other words, the quantity *p* could be considered affected by an uncertainty term of type A only, that is the standard deviation resulting from the measurements. Anyway, the supplied Official Data has been calculated including all the uncertainty terms.

Error budget does not include the direct contribution of the power splitter asymmetry on *p*. This error term is considered negligible and compensated by the sensor exchange on the output ports.

INTA



Here I enclose the requested data concerning the calibration of the thermistor mount (s/n 2106A23274).

Frequency 10 MHz:

Reflection of the source (feedthrough mount): 0.03
Reflection of the thermistor mount (DUT): 0.14
Mismatch between source and DUT: 0.84%

Frequency 18 GHz:

Reflection of the source (feedthrough mount): 0.05
Combined Reflection Coefficient of the thermistor mount (DUT): 0.057
Mismatch between source and DUT: 0.66%

I remind you that at this frequency a poor repetability was experienced in our measurements. The experimental standard deviation of 5 measurements was 0.66%.

Concerning the information you request about uncertainty calculation, here I enclose the most important terms that have been considered.

In both cases (7 mm and N-type connector) the main terms considered are:

- Calibration factor of the Working Standard (normal distribution, k=2) Traceables to NIST
- Drift in the Calibration factor of the Working Standard (rectangular)
- DC sustitution (rectangular)
- Power meter 432A + Voltmeter 3497A (rectangular)
- Mismatch between Test and Working Standard (U-shaped)
- Repeatability (type A)

In the following list the contributions (in percent) of the Calibration Factor of the Working Standards are included.

Frequency	N	7 mm
0.01	0.53	2.199
0.05	0.575	1.262
1	0.545	1.297
4	0.665	1.442
8	0.802	1.656
12	0.788	1.821
15	0.800	1.879
18	1.539	2.309

The calculation of the expanded uncertainty has been made according to the Document EAL-R2.

SMU

f [GHz]	Source	SMÚ Standard	DUT N-connector	DUT APC 7 with adapter	SMÚ Standard u_C [%]	u_A [%]
	$\|\Gamma_s\|$ min $\|\Gamma_s\|$ max	$\|\Gamma\|_{STAND}$	$\|\Gamma\|_{DUT}$	$\|\Gamma\|_{DUT}$	(k = 1)	
0,05	0,0186 0,0186	0,035	0,031	0,030	0,6	≤ 0,02
12	0,245 0,375	0,034	0,006	0,057	0,5	≤ 0,027

1. Measurement method used for calibration factor measurement is the method of replace of DUT by SMÚ thermistor mount standard on calibrated reference power output. (see Fig. 1).

   As SMÚ standard was used the primary standard of RF power. It's tracebility is based on own microcalorimeter or on previous intercomparison results.
2. Reflection coefficient was measured by means of SWR bridge (Wiltron).
3. The measuring procedure included 5 measurements at each position of thermistor mount input (rotation at 120°). To uncertainty calculation included :
   - uncertainty of calibration factor of SMÚ thermistor mount standard (0,35 ÷ 0,6 % k=1)
   - uncertainty of reflection coefficient (0,01 ÷ 0,015)
   - uncertainty of mismatch
   - uncertainty of power measurements with precision power bridge (< 0,1 %)
   - repeatibility (u_a) 0,02 ÷ 0,03 %

METAS

INFORMATION ON THE MEASUREMENTS CONCERNING THE THERMISTOR N (SN 2106A23274)

① **UNCERTAINTY OF THE STANDARD**
(Ustd)

at 10 MHz:	0.005	**(expanded uncertainty k=2)**
at 18 GHz:	0.020	

② **UNCERTAINTY BETWEEN THE EFFECTIVE SOURCE AND THE STANDARD**
(Um1)

at 10 MHz:	0.000283
at 18 GHz:	0.000885

③ **MISMATCH BETWEEN THE EFFECTIVE SOURCE AND THE DUT**
(Um2)

at 10 MHz:	0.000284
at 18 GHz:	0.000614

④ **TYPE A UNCERTAINTY**
(UA)

at 10 MHz:	0.000011
at 18 GHz:	0.000075

⑤ **MEASUREMENT UNCERTAINTY (k=1 values)**

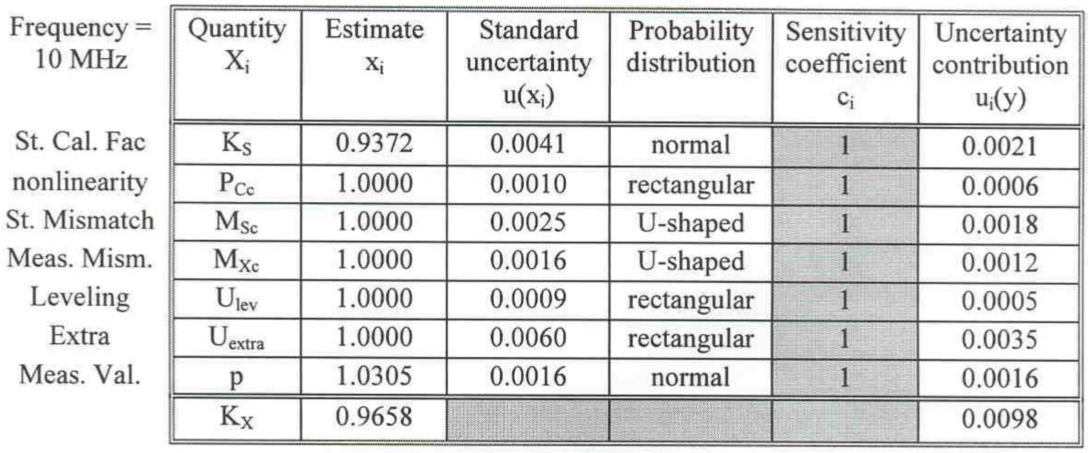
⇨ including splitter (US), adapter (Uad) and power meter (Upm) uncertainty.

at 10 MHz:	**0.0049**
at 18 GHz:	**0.0119**

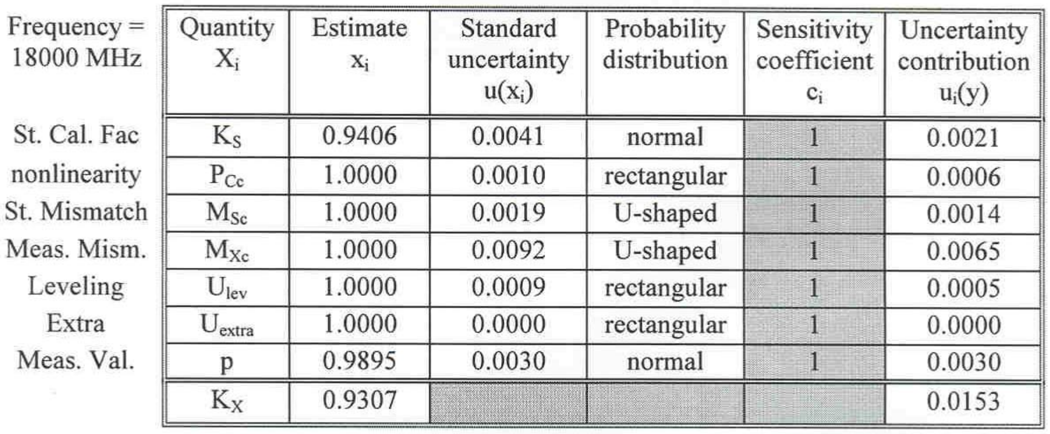
$$U = k\sqrt{\frac{U_{Std}^2}{4}+\frac{U_{m1}^2}{2}+\frac{U_{m2}^2}{2}+\frac{U_S^2}{4}+\frac{U_{ad}^2}{4}+\frac{U_{pm}^2}{2}+U_A^2}$$

CMI

s/n **2106A23274**		10 MHz	18 GHz
item	Description	Contribution	Contribution
1	standard	0.0041	0.0022
2	Mism - working	0.0018	0.0014
3	Mism - DUT	0.0012	0.0065
4	Type A	0.0016	0.0030
5	Total (k=1)	0.0049	0.0076



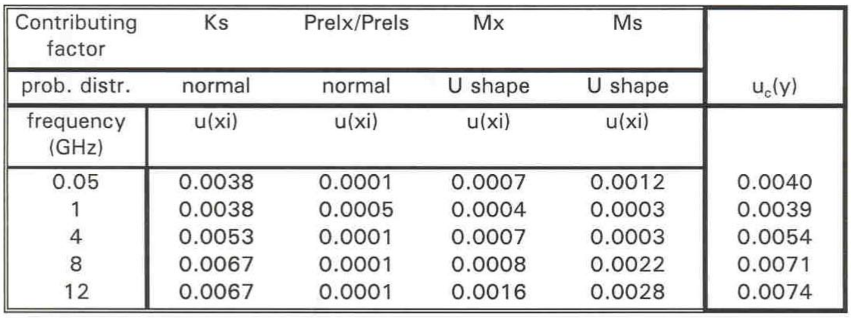
Frequency = 10 MHz	Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$
St. Cal. Fac	K_S	0.9372	0.0041	normal	1	0.0021
nonlinearity	P_{Cc}	1.0000	0.0010	rectangular	1	0.0006
St. Mismatch	M_{Sc}	1.0000	0.0025	U-shaped	1	0.0018
Meas. Mism.	M_{Xc}	1.0000	0.0016	U-shaped	1	0.0012
Leveling	U_{lev}	1.0000	0.0009	rectangular	1	0.0005
Extra	U_{extra}	1.0000	0.0060	rectangular	1	0.0035
Meas. Val.	p	1.0305	0.0016	normal	1	0.0016
	K_X	0.9658				0.0098



Frequency = 18000 MHz	Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$
St. Cal. Fac	K_S	0.9406	0.0041	normal	1	0.0021
nonlinearity	P_{Cc}	1.0000	0.0010	rectangular	1	0.0006
St. Mismatch	M_{Sc}	1.0000	0.0019	U-shaped	1	0.0014
Meas. Mism.	M_{Xc}	1.0000	0.0092	U-shaped	1	0.0065
Leveling	U_{lev}	1.0000	0.0009	rectangular	1	0.0005
Extra	U_{extra}	1.0000	0.0000	rectangular	1	0.0000
Meas. Val.	p	0.9895	0.0030	normal	1	0.0030
	K_X	0.9307				0.0153

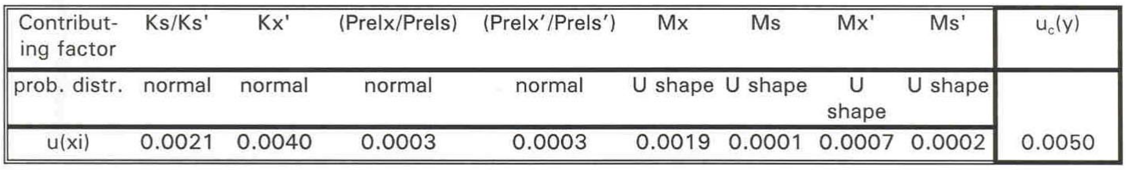
OMH

Uncertainty budget for the evaluations (except 10 MHz):



Contributing factor	Ks	Prelx/Prels	Mx	Ms	$u_c(y)$
prob. distr.	normal	normal	U shape	U shape	
frequency (GHz)	u(xi)	u(xi)	u(xi)	u(xi)	
0.05	0.0038	0.0001	0.0007	0.0012	0.0040
1	0.0038	0.0005	0.0004	0.0003	0.0039
4	0.0053	0.0001	0.0007	0.0003	0.0054
8	0.0067	0.0001	0.0008	0.0022	0.0071
12	0.0067	0.0001	0.0016	0.0028	0.0074

Uncertainty budget for 10 MHz evaluation:



Contributing factor	Ks/Ks'	Kx'	(Prelx/Prels)	(Prelx'/Prels')	Mx	Ms	Mx'	Ms'	$u_c(y)$
prob. distr.	normal	normal	normal	normal	U shape	U shape	U shape	U shape	
u(xi)	0.0021	0.0040	0.0003	0.0003	0.0019	0.0001	0.0007	0.0002	0.0050

Evaluation of the measurement results

The results of the calibration factor comparison above 10MHz were evaluated according to the form:

$$Kx=Ks*(Prelx/Prels)*Mx/Ms \tag{1}$$

where

	Prlelx;Prels	relativ indication (power ratio with respect to reference power meter) while measuring at the test port of Fig 1
with		the unknown and standard thermistor mount
	Mx;Ms	mismatch factors while measuring Prelx and Prels
	Ks	calibration factor of the standard power meter

The results of the calibration factor comparison at 10MHz were evaluted according the form:

$$Kx/Kx'=(Ks/Ks')*(Prelx/Prels)/(Prelx'/Prels')*Mx*Ms'/Mx'/Ms \tag{2}$$

that means the values in (1) become relative values with respect to the same quantites, denoted with the sign(‘), of a reference frequency (50MHz) measurement in the same measuring arrangement.

PTB

Uncertainty (k=2) budget for η_{cal} at 10 MHz, HP 8478 B, SerNo. 2106 A 23274

quantity X_i	**estimate** x_i	**probability distribution**	**standard uncertainty** $u(x_i)$	**effective degrees of freedom** $\nu_{eff,i}$	**sensitivity coefficient** c_i	**contribution to the standard uncertainty** $u_i(y)$
V	0,90456	gauss.	0,00011	8	-0,088	-0,00001
δV	0	rect.	0,00009	50	-0,088	-0,000008
e	1,00167	gauss.	0,00013	8	-5,296	-0,00069
δe	0	rect.	0,00021	50	-5,296	-0,00111
g	1,00076	rect.	0,00069	50	0,9716	0,00067
Γ	0,1396	gauss.	0,00265	50	-0,2769	0,000734
η_{cal}	0,9724		0,00164	106		

$U(\eta_{cal}) = k * u(\eta_{cal}) = 2 * 0{,}00164 = 0{,}00328$

The calibration factor at 10 MHz is : η_{cal} = 0,9724 ± 0,0033

Uncertainty (k=2) budget for η_{cal} at 18 GHz, HP 8478 B, SerNo. 2106 A 23274

quantity X_i	**estimate** x_i	**probability distribution**	**standard uncertainty** $u(x_i)$	**effective degrees of freedom** $\nu_{eff,i}$	**sensitivity coefficient** c_i	**contribution to the standard uncertainty** $u_i(y)$
V	0,90407	gauss.	0,00015	8	-0,62750	-0,0000941
δV	0	rect.	0,00012	50	-0,62750	-0,0000753
e	1,01334	gauss.	0,00020	8	-4,74303	-0,000950
δe	0	rect.	0,00035	50	-4,74303	-0,00166
g	1,001745	rect.	0,00225	50	0,92962	0,00209
Γ	0,0498	gauss.	0,00395	50	-0,09298	-0,000370
η_{cal}	0,9313		0,00286	102		

$U(\eta_{cal}) = k * u(\eta_{cal}) = 2 * 0{,}00286 = 0{,}00572$

The calibration factor at 18 GHz is : η_{cal} = 0,9313 ± 0,0058

NPL

The calibration factor of the standard sensor can be transferred to that of the unknown sensor using the following :

$$CF_U = CF_S D_S \frac{R_U}{R_S} M$$

where :

$$M = \left(1 \pm 2\left|\Gamma_G\right|\left|\Gamma_S\right|\right)\left(1 \pm 2\left|\Gamma_G\right|\left|\Gamma_U\right|\right)$$

and :

CF_U is the calibration factor of the unknown sensor

CF_S is the calibration factor of the secondary standard sensor

D_S is a factor to allow for drift in the value of the effective efficiency of the secondary standard sensor since the last calibration

R_U is the power ratio between the unknown sensor and the reference sensor

R_S is the power ratio between the secondary standard sensor and the reference sensor

Γ_S, Γ_U and Γ_G are the Voltage Reflection Coefficients of the secondary standard sensor, unknown sensor and the system respectively.

In order to assess a level of repeatability the unknown sensor was measured eight times.

The following example of the uncertainty calculations relates to the calibration of the Type N Mount at a frequency of 10 MHz on the 14mm system

Secondary Standard Sensor: The secondary standard sensor was calibrated one month prior to these measurements. The value of the calibration factor, given in the calibration certificate, is 99.8% ±1,0% (coverage factor $k = 2$).

Drift in standard: The drift factor of the effective efficiency of the secondary standard is estimated from annual calibrations to be 1.000 per year with deviations within ±0,05%. The probability distribution is assumed to be rectangular

Power ratios: The expanded uncertainty ±0,08% (coverage factor $k = 2$) is assigned to the power ratio readings for R_S and R_U due to non-linearity and uncertainty in the measurement of DC voltages.

Mismatch: As the transfer standard system is not perfectly matched and the phase of the reflection coefficients of the transfer standard, the unknown and standard power sensor are not known, there will be an uncertainty due to mismatch for each sensor. The corresponding limits of deviation have to be calculated for the standard sensor and the unknown sensor from the relationship:

$$M_{S,U} = 1 \pm 2\left|\Gamma_G\right|\left|\Gamma_{S,U}\right|$$

The measured magnitude of the reflection coefficients of the transfer standard, the reference sensor and the sensor to be calibrated at a frequency of 10 MHz are:

$|\Gamma_G|$ = 0.0014
$|\Gamma_S|$ = 0.0021
$|\Gamma_U|$ = 0.14

However, each of the above measurements of reflection coefficient has an uncertainty which is taken into account by adding this in quadrature to the measured value. The uncertainty in the measurement of reflection coefficient is ±0.01 in all cases therefore the mismatch uncertainty is calculated from the following values of reflection coefficient:

$\lvert\Gamma_{Gu}\rvert$	=	0.01			
$\lvert\Gamma_{Su}\rvert$	=	0.01	M_S	=	0.02 %
$\lvert\Gamma_{Uu}\rvert$	=	0.14	M_U	=	0.28 %

The probability distribution of the individual contributions to mismatch is U-shaped.

Correlation: None of the input quantities are considered to be correlated to any significant extent.

Measurements: Eight separate measurements were made which involved disconnection and reconnection of both the unknown and the standard sensor on the power transfer system.

Uncertainty budget for 10 MHz:

Quantity X_i	Estimate x_i	standard uncertainty $u(x_i)\%$	Probability Distribution	sensitivity coefficient c_i	Uncertainty Contribution $u_i(y)\%$
CF_s	99.8	0,5	Normal	1,0	1,0
D_S	1.000	0,06	Rectangular	1,0	0,06
R_S	0,92329	0,04	Normal	1,0	0,04
R_U	0,89709	0,04	Normal	1,0	0,04
M_S	1.000	0,01	U-shaped	1,0	0,01
M_U	1.000	0,20	U-shaped	1,0	0,20
r	0,97163	0,02	Normal	1,0	0,02
CF_u	96.97				0,55

Expanded uncertainty:

$$U = ku(CF_U) = 2 \cdot 0{,}55\% \approx 1{,}1\%$$

Uncertainty budget: (for standard 13136)

Quantity X_i	Estimate x_i	standard uncertainty $u(x_i)\%$	Probability Distribution	sensitivity coefficient c_i	Uncertainty Contribution $u_i(y)\%$
η_S	96,5	0,25	Normal	1,0	0,25
D_S	1.000	0,02	Rectangular	1,0	0,02
CC_S	9,2051	0,05	Normal	1,0	0,05
CC_U	8,5839	0,05	Normal	1,0	0,05
A_{EFF}	0,9663	0,61	U-shaped	1,0	0,61
M_U	0,9976	0,20	U-shaped	1,0	0,20
r	89,987	0,30	Normal	1,0	0,30
CF_u	92.90				0,75

Expanded uncertainty:

$$U = ku(CF_U) = 2 \cdot 0{,}75\% \approx 1{,}5\%$$

Reported result:

The calibration factor of the thermistor mount at 18 GHz is 93,1%±1,5%

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95%.

CSIR-NML

UNCERTAINTY BUDGET for (K=2) UBM or Certificate N **Euromet 393**

References: ISO/TAG4 Guide to the Expression of Uncertainty in Measurement 1993 (BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML), EAL R2, NLA TG-3001

Description **Calibration of thermistor** power sensors (50 Ohm) **Type:** HP 8478B type N **Range:** 50 MHz and 1GHz **Metrologist** E Dressler

Symbol	Source of Uncertainty	Relative Value U(Xi) +/-	Unit		Absolute Value U(Xi) +/-	Unit	Probability Distribution (N, R, T, U)	Divisor Factor	Sensitivity Coefficien Ci	Relative Uncertainty Unit	Contribution Ui (y)	Absolute Unit	Reliability %	Degrees of Freedom vi	Remarks	
Std	Calibration of Ksys (transfer std.)	1.10E+00	%	+			N	2.00	1	5.50E-01			100	infinite	Value from cal against standard	
	Max deviations due to drift (Ksys	2.00E-01	%	+			R	1.73	1	1.15E-01			90	50.00	Estimation-historical data lacking	
	Pwr. meter instrumentation	7.00E-01	%	+			R	1.73	1	4.04E-01			90	50.00	RSS of 2 instr. Uncertainties	
				+			U		1							
				+			U		1							
				+			U		1							
				+			U		1							
	DUT mismatch unc. (worst case)	1.25E-01	%	+			U	1.41	1	8.84E-02			90	50.00	200*0.025*0.025 %	
	Max deviations due to drift (monit	2.00E-01	%	+			R	1.73	1	1.15E-01			90	50.00	estimated from historical data	
	drift of 50 MHz source	2.00E-01	%	+			R	1.73	1	1.15E-01			90	50.00	estimated from historical data	
				+												
				+												
				+												
UUT	Repeatability (Type "A")	2.00E-01	%	+			Normal	1.00	1	2.00E-01				2	Number of Readings	**3**
				+												
				+												
				+												
				+												
				+												
				+												
				+												
				+												
				+												
	Combined Uncertainty	**BMC (k=1)**			**+**			**Total**	**Normal**	0.74	+		**Veff**	217.56	Checked and Approved By	
	Expanded Uncertainty	45% (k=2)			+			**Normal (k=2)**		**1.49**	+		St'd (t)	2.00	Signature	

UME

UME results for type N travelling thermistor mount, HP8478B-S/N:2106A23274

1 Frequency (GHz): 0.01

S/N	Uncertainty Component X_i	Value of X_i	Probability Distribution	Coverage Factor (k)	Uncertainty Contribution
	$u(\bar{s})$	0.000578	normal	1	0.000578
	$u(\bar{d})$	0.000081	normal	1	0.000081
1	$\sqrt{u^2(\bar{s})+u^2(\bar{d})}$				**0.000584**
2	M_{STD}	**0.008436**	**U-shape**	**√(2)**	**0.005965**
3	M_{DUT1}	**0.008436**	**U-shape**	**√(2)**	**0.005965**
4	C_s	**0.005**	**normal**	**2**	**0.0025**
	P_c	0,00144	rectangular	√(3)	0.000833
	V_1	0.000026	rectangular	√(3)	0.000015
	V_2	0,000312	rectangular	√(3)	0.000181
	V_3	0.000044	rectangular	√(3)	0.000025
5	**Total Un.**		**normal**	**1**	**0.008898**
	Expanded uncer.		normal	2	0.017796

2 Frequency(GHz): 18

S/N	Uncertainty Component X_i	Value of X_i	Probability Distribution	Coverage Factor k	Uncertainty Contribution
	$u(\bar{s})$	0,000133	normal	1	0.000133
	$u(\bar{d})$	0,000086	normal	1	0.000086
1	$\sqrt{u^2(\bar{s})+u^2(\bar{d})}$				**0.000158**
2	M_{STD}	**0.011371**	**U-shape**	**√(2)**	**0.008041**
3	M_{DUT1}	**0.004264**	**U-shape**	**√(2)**	**0.003015**
4	C_s	**0,015**	**normal**	**2**	**0.0075**
	P_c	0,00144	rectangular	√(3)	0.000833
	V_1	0.000026	rectangular	√(3)	0.000015
	V_2	0,000312	rectangular	√(3)	0.000181
	V_3	0.000044	rectangular	√(3)	0.000025
5	**Total Un.**		**normal**	**1**	**0.011467**
	Expanded uncer.		normal	2	0.022934

SIQ

Breakdown of the uncertainty budget

Uncertainty budget is covered in detail in the RF and MW Power Calibration Procedure MN611000C, Chapter 5. Since the measurements were made with thermistor mounts, the uncertainty due to thermistor mount power meter would enter uncertainty budget. Note that the uncertainty of 0,0006 W/W (k = 1) due to this power meter is insignificant for total uncertainty.

Relevant statistical information

The following data include all relevant information on the individual calibration factor measurement results, where

u1	uncertainty of power sensor - splitter combination calibration constant,
u2	short term stability of power sensor - splitter combination calibration constant,
u3	uncertainty due to mismatch between measured thermistor mount and splitter arm,
u4	uncertainty due to thermistor mount power meter,
u_typeA	standard deviation of measured results
u_typeB	combined uncertainties u1, u2 and u3
u calc	calculated total uncertainty
u	reported uncertainty of the measurement

1.) HP 8478B s.n. 2106A24406 - N

f [MHz]	*CF*	*u*	*u calc*	*u_typeA*	*u_typeB*	*u1*	*u2*	*u3*	*u4*
10	0,972	0,8%	0,64%	0,01%	0,32%	0,54%	0,05%	0,24%	0,06%
50	1,000	0,8%	0,58%	0,01%	0,29%	0,54%	0,05%	0,12%	0,06%
1000	0,997	0,8%	0,64%	0,01%	0,32%	0,62%	0,05%	0,08%	0,06%
4000	0,994	1,0%	1,00%	0,07%	0,50%	0,91%	0,05%	0,27%	0,06%
8000	0,986	1,6%	1,63%	0,15%	0,80%	1,34%	0,05%	0,61%	0,06%
12000	0,965	1,5%	1,18%	0,04%	0,59%	1,12%	0,05%	0,24%	0,06%
15000	0,967	2,0%	1,16%	0,04%	0,58%	1,12%	0,05%	0,18%	0,06%
18000	0,927	2,0%	1,47%	0,03%	0,73%	1,12%	0,05%	0,66%	0,06%

BNM-LNE

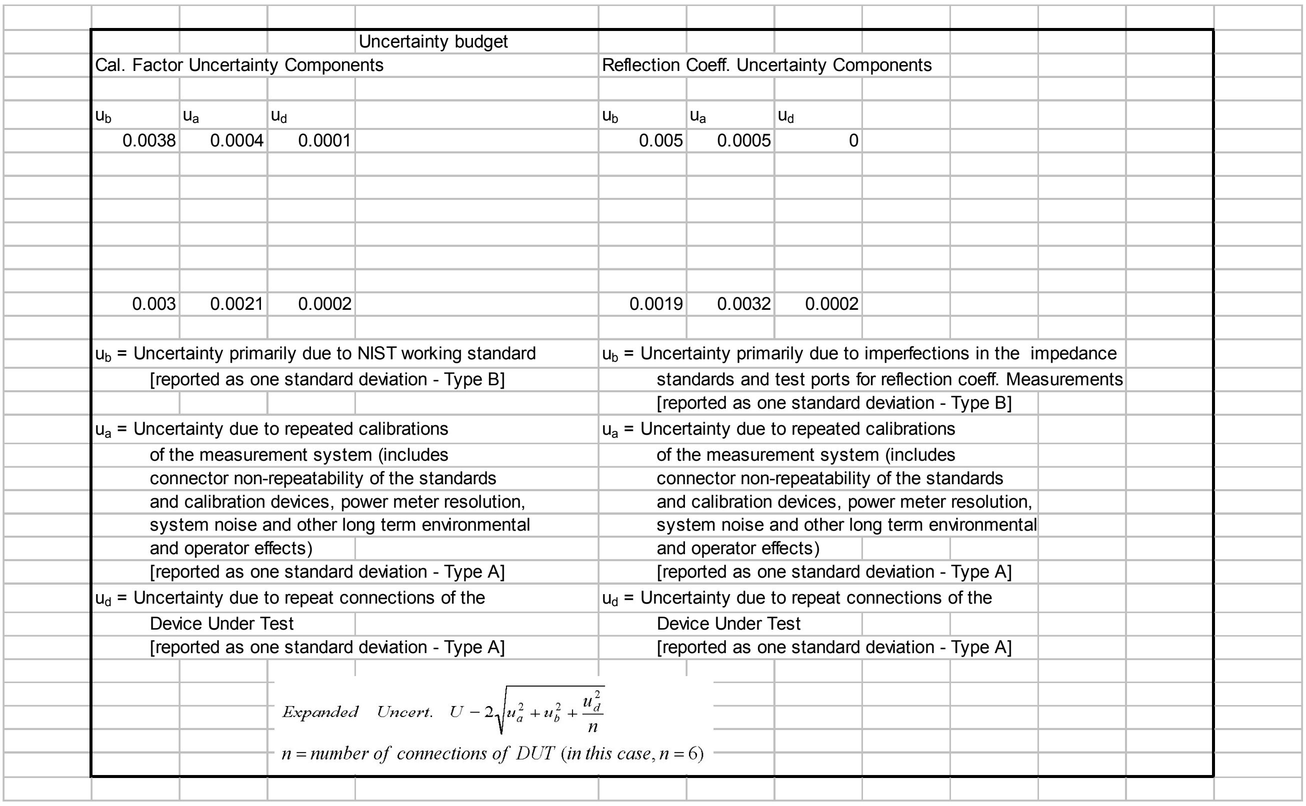
- The main uncertainty components in measuring thermistor mount in type-N male are listed below:

Typical example at 10 MHz	
- reference standard	$1.50\ 10^{-3}$
- mismatch	$3.90\ 10^{-3}$
- linearity and resolution	$3.70\ 10^{-4}$
- measurement repeatability (type A)	$3.00\ 10^{-4}$
Total standard type uncertainty (k=1)	**$4.20\ 10^{-3}$**

Typical example at 12 GHz	
- reference standard	$1.20\ 10^{-3}$
- standard mount mismatch contribution	$1.06\ 10^{-3}$
- unknown mount mismatch contribution	$1.12\ 10^{-3}$
- six-port calibration constant	$5.10\ 10^{-5}$
- contribution of the adapter (reflection)	$3.40\ 10^{-4}$
- contribution of the adapter (attenuation)	$2.11\ 10^{-3}$
- measurement repeatability (type A)	$7.00\ 10^{-4}$
Total standard type uncertainty (k=1)	**$3.00\ 10^{-3}$**

Typical example at 18 GHz	
- reference standard	$1.16\ 10^{-3}$
- standard mount mismatch contribution	$1.20\ 10^{-3}$
- unknown mount mismatch contribution	$1.20\ 10^{-3}$
- six-port calibration constant	$1.00\ 10^{-4}$
- contribution of the adapter (reflection)	$4.70\ 10^{-4}$
- contribution of the adapter (attenuation)	$2.06\ 10^{-3}$
- measurement repeatability (type A)	$9.00\ 10^{-4}$
Total standard type uncertainty (k=1)	**$3.10\ 10^{-3}$**

NIST



			Uncertainty budget			
Cal. Factor Uncertainty Components				Reflection Coeff. Uncertainty Components		
u_b	u_a	u_d		u_b	u_a	u_d
0.0038	0.0004	0.0001		0.005	0.0005	0
0.003	0.0021	0.0002		0.0019	0.0032	0.0002

u_b = Uncertainty primarily due to NIST working standard [reported as one standard deviation - Type B]	u_b = Uncertainty primarily due to imperfections in the impedance standards and test ports for reflection coeff. Measurements [reported as one standard deviation - Type B]
u_a = Uncertainty due to repeated calibrations of the measurement system (includes connector non-repeatability of the standards and calibration devices, power meter resolution, system noise and other long term environmental and operator effects) [reported as one standard deviation - Type A]	u_a = Uncertainty due to repeated calibrations of the measurement system (includes connector non-repeatability of the standards and calibration devices, power meter resolution, system noise and other long term environmental and operator effects) [reported as one standard deviation - Type A]
u_d = Uncertainty due to repeat connections of the Device Under Test [reported as one standard deviation - Type A]	u_d = Uncertainty due to repeat connections of the Device Under Test [reported as one standard deviation - Type A]

$$Expanded \quad Uncert. \quad U - 2\sqrt{u_a^2 + u_b^2 + \frac{u_d^2}{n}}$$

$$n = number\ of\ connections\ of\ DUT\ (in\ this\ case, n = 6)$$

CSIRO-NML

Uncertainty Calculations:			CSIRO-NML			
	Themistor N:		2106 A 23274			
10 MHz						
At directional coupler 3 test port		Distribution	Factor	Std Deviation		
Type A	0.0004	Normal	1	0.0004		
Type B						
Mismatch	0.00071	U-shape	0.707	0.0005		
Instrumentation, etc	0.0007	Normal	1	0.0007		
Uncertainty of Working	0.00188	Normal	1	0.0019		
Calibration of DUT						
Type A	0.0006	Normal	1	0.0006		
Type B						
Mismatch	0.00121	U-shape	0.707	0.0009		
Instrumentation, etc	0.0007	Normal	1	0.0007		
Total Uncertainty (k=2)					0.0049	
18 GHz						
Calibration of Six-Port		Distribution	Factor	Std Deviation		
Type A	0.0009	Normal	1	0.0009		
Type B						
Mismatch	0.001	U-shape	0.707	0.0007		
Instrumentation, etc	0.0007	Normal	1	0.0007		
Uncertainty of Working	0.00434	Normal	1	0.0043		
Calibration of DUT						
Type A	0.0009	Normal	1	0.0009		
Type B						
Mismatch	0.00142	U-shape	0.707	0.0010		
Instrumentation, etc	0.0007	Normal	1	0.0007		
Total Uncertainty (k=2)					0.0096	

KRISS

		Uncertainty budget of the GT/RF 98-1 comparison					
Measurement result			KRISS				
	Thermister N:		2106 A 23274				
	Freq:		10 MHz				
	Quantity	estimate	standard	probabili	sensitivi	Uncertainty	
			uncertair	distribut	coefficie	Contribution	
	X_i	x_i	$u(x_i)$		C_i NOTE	$u_i(y)$	
	η_{S1}	0.9816	0.0011	Normal	0.9966	0.0011	
	η_{S2}	0.9871	0.001	Normal	0.9873	0.001	
	R_{S1}	1.0086	0.0005	Normal	0.9698	0.0005	
	R_{S2}	0.9809	0.0002	Normal	0.9935	0.0002	
	R_D	0.9778	0.0003	Normal	1.0005	0.0003	
	M_1	0.9661	0.0015	Normal	1.0125	0.0015	
	?$_{S1}$?	0.1838	0.0039	Normal	-0.3683	-0.0014	
	?$_{D}$?	0.1422	0.0037	Normal	0.0004	0	
	?$_{GE}$?	0.004	0.0035	Normal	-0.0217	-0.0001	
	Φ_{GS1}	1.6732	1.8139	Normal	-0.0014	-0.0025	
	Φ_{GD}	1.6241	1.814	Normal	0.0011	0.002	
	M_2	0.9842	0.001	Normal	0.9902	0.001	
	?$_{S2}$?	0.1257	0.0037	Normal	0.9935	0.0037	
	?$_{D}$?	0.1422	0.0037	Normal	0.9967	0.0037	
	?$_{GE}$?	0.004	0.0035	Normal	0.0001	0	
	Φ_{GS2}	1.6307	1.814	Normal	-0.001	-0.0018	
	Φ_{GD}	1.6241	1.814	Normal	0.0011	0.002	
	K_D	0.9764				0.0019	

		Uncertainty budget of the GT/RF 98-1 comparison					
Measurement result			KRISS				
	Thermister N:		2106 A 23274				
	Freq:		18 GHz				
	Quantity	estimate	standard	probabili	sensitivi	Uncertainty	
			uncertair	distribut	coefficie	Contribution	
	X_i	x_i	$u(x_i)$		C_i NOTE	$u_i(y)$	
	η_{S1}	0.9458	0.0046	Normal	0.9994	0.0046	
	η_{S2}	0.9341	0.0049	Normal	1.0096	0.0049	
	R_{S1}	0.9466	0.0008	Normal	0.9985	0.0008	
	R_{S2}	0.9597	0.0011	Normal	0.9827	0.0011	
	R_D	0.9528	0.0002	Normal	0.992	0.0002	
	M_1	1.0059	0.0028	Normal	0.9396	0.0026	
	M_2	1.0024	0.0034	Normal	0.9408	0.0032	
	K_D	0.9436				0.0047	

NMIJ/AIST

???????????(10mW, 18 GHz)
?????? : 2000/1/26
?? : 8478B
???? : 23274
?? : Thermistor Mount
???? : HP

"C1"?????????
?????????????????
????????????????

基本式

$$K = \frac{1}{Cd} * \frac{Pu}{Pmu} * \frac{1}{\eta_a} * \frac{1}{\left|1 - \Gamma g \Gamma u\right|^2}$$

#8478B 2106A 23274 | 18 GHz | Table 4-1 Uncertainty budget of the calibration facor

Input quantity	Input estimate Xi	Unit	Source of uncertainty		Type	Distribution	Sunsitivity Ci	Standard uncertainty u(Xi)	|Ci|u(Xi) =ui(Ku)	???
Power splitting ratio (Cd)	1.0617	none	Cd measurement? ? (1σ)	0.0021	B	Normal	-0.8801	0.00210	1.85E-03	***
RF power (Pu)	10	mW	Resolution (±δXi)	0.001	B	Uniform	0.0934	0.00029	2.70E-05	4
Monitor power (Pmu)	10	mW	Resolution (±δXi)	0.001	B	Uniform	-0.0934	0.00029	2.70E-05	4
Efficiency of adaptor (η_a)	0.987	none	Approximation (1σ)	0.0007	A	t	-0.9464	0.00070	6.62E-04	51
			Resolution (±δXi)	0.0001	B	Uniform	-0.9464	0.00003	2.73E-05	4
Measured K	0.9344	none	Measurement (σn-1)	0.0003	A	t	1	0.00020	1.98E-04	11
Source mimatch			Γg	0.058	B	?	0.9344	0.00265	2.48E-03	4
			Γu	0.032						
Measurement equation			$K = \frac{1}{Cd} * \frac{Pu}{Pmu} * \frac{1}{\eta_a} * \frac{1}{\left\|1 - \Gamma g \Gamma u\right\|^2}$				Combined standard uncertainty $\sqrt{\sum u_i^2}$		0.0034	
							Uncertainty 2 $\sqrt{\sum u_i^2}$		0.0068	
????? ???? (K)	0.9344	??	???	95%					???? ????	????? νeff
			????? ????	2.16					0.0034	13
			???? ???? : k =	2						
			?????? U(Ku)=k*uc(Ku)	0.0068	0.72%					

NRC

Traveling standard HP 8478B Ser. No. 23274

Frequency GHz	Calibration factor K	Type A uncertainty	Type B uncertainty	Total uncertainty	Reflection coefficient magnitude	Uncertainty
0.01	0.9403	0.0001	0.0028	0.0028	0.144	0.004
0.05	0.9908	0.0002	0.0028	0.0028	0.033	0.004
1.00	0.9904	0.0004	0.0034	0.0035	0.025	0.004
4.00	0.9761	0.0010	0.0045	0.0046	0.039	0.005
8.00	0.9672	0.0058	0.0059	0.0082	0.037	0.008
12.00	0.9598	0.0028	0.0073	0.0079	0.010	0.008
15.00	0.9527	0.0030	0.0083	0.0088	0.005	0.008
18.00	0.9406	0.0040	0.0094	0.0102	0.029	0.009

NIM

Frequency Relative Standard Uncertainty

10(MHz)	No.	Source of Uncertainty	Type	Symbol	CoverageFactor(ki)	Value
	1	Calibration Factor Kc ofthe Power Transfer Standard	B	u_1	$\sqrt{3}$	0.0045
	2	DC Substitution Power Pcu of the Power Transfer Standard	B	u_2	$\sqrt{3}$	0.0006
	3	DC Substitution Power Pbu ofthe Travelling Standard	B	u_3	$\sqrt{3}$	0.0006
	4	Mismatch Error ( )	B	u_4		0.0031
	5	Dispersion of The Results	A	$u_5 = s$	3	0.001
	6	Relative Combined Standard Uncertainty	B	u_c	$U_{95} = k_c u_c$ $(k_c = 2)$	0.0056

18000(MHz)	No.	Source of Uncertainty	Type	Symbol	CoverageFactor(ki)	Value
	1	Calibration Factor Kc ofthe Power Transfer Standard	B	u_1	$\sqrt{3}$	0.004
	2	DC Substitution Power Pcu of the Power Transfer Standard	B	u_2	$\sqrt{3}$	0.0006
	3	DC Substitution Power Pbu ofthe Travelling Standard	B	u_3	$\sqrt{3}$	0.0006
	4	Mismatch Error ( )	B	u_4		0.0037
	5	Dispersion of The Results	A	$u_5 = s$	3	0.0006
	6	Relative Combined Standard Uncertainty	B	u_c	$U_{95} = k_c u_c$ $(k_c = 2)$	0.0056

SPRING

GTRF HP8478B THERMISTOR MOUNT - TYPE N (S/N 2106A23274)

Cal Factor Result:

Frequency (MHz)	**Cal Factor**	**Std Dev**	**Reflection Coefficient F1109**	**Reflection Coefficient DUT(hp8478B)**
10	0.9710	0.0004	0.0291	0.14107

Uncertainty Calculation for the Measurement:

Uncertainty Budget for Cal Factor (10MHz)

Type	**Source of unc. $u_i(x)$**	**Val of $u_i(x)$ (%)**	**Probability Distribution**	**k**	**Std Unc (%)**	**DOF**
B	DC Substitution, $u_1(x)$	0.15	Rectangular	1.7320508	0.0866025	Infinity
B	Cal factor of Transfer Std, $u_2(x)$	0.6	Normal	2	0.3	Infinity
B	Stability of Transfer Std, $u_3(x)$	0.2	Rectangular	1.7320508	0.1154701	Infinity
B	Type IV Bridge, $u_4(x)$	0.05	Rectangular	1.7320508	0.0288675	Infinity
B	Digital Multimeter, $u_5(x)$	0.0128	Rectangular	1.7320508	0.0073901	Infinity
B	Mismatch, $u_6(x)$	0.8210274	U-shape	1.4142136	0.580554	Infinity
A	Repeatibility, $u_7(x)$	0.016329932	t	1	0.0163299	5
	Combined Uncertainty, $u_c(x)$	-	t	-	0.6700977	14177024
	Expanded uncertainty, U	**1.340195422**	t	2	**-**	14177024

Mismatch, M = 2 * Rho_{std} * Rho_x

Effective degree of freedom, v_{eff} = $[u_c(x)^4] / [u_7(x)^4 / (n-1)]$

Combined unc., $u_c(x)$ = SQRT $[u_1(x)^2 + u_2(x)^2 + u_3(x)^2 + u_4(x)^2 + u_5(x)^2 + u_6(x)^2 + u_7(x)^2]$

GTRF HP8478B THERMISTOR MOUNT - TYPE N (S/N 2106A23274)

Cal Factor Result:

Frequency (MHz)	Cal Factor	Std Dev	Reflection Coefficient F1109	Reflection Coefficient DUT(hp8478B)
18000	0.9590	0.0006	0.0476	0.03803

Uncertainty Calculation for the Measurement:

Uncertainty Budget for Cal Factor (18GHz)

Type	Source of unc. $u_i(x)$	Val of $u_i(x)$ (%)	Probability Distribution	k	Std Unc (%)	DOF
B	DC Substitution, $u_1(x)$	0.15	Rectangular	1.7320508	0.0866025	Infinity
B	Cal factor of Transfer Std, $u_2(x)$	0.8	Normal	2	0.4	Infinity
B	Stability of Transfer Std, $u_3(x)$	0.2	Rectangular	1.7320508	0.1154701	Infinity
B	Type IV Bridge, $u_4(x)$	0.05	Rectangular	1.7320508	0.0288675	Infinity
B	Digital Multimeter, $u_5(x)$	0.0128	Rectangular	1.7320508	0.0073901	Infinity
B	Mismatch, $u_6(x)$	0.3620456	U-shape	1.4142136	0.2560049	Infinity
A	Repeatibility, $u_7(x)$	0.024494897	t	1	0.0244949	5
	Combined Uncertainty, $u_c(x)$	-	t	-	0.4978552	853256.59
	Expanded uncertainty, U	**0.995710376**	t	2	-	853256.59

Mismatch, M = 2 * Rho_{std} * Rho_x

Effective degree of freedom, v_{eff} = $[u_c(x)^4] / [u_7(x)^4 / (n-1)]$

Combined unc., $u_c(x)$ = SQRT $[u_1(x)^2 + u_2(x)^2 + u_3(x)^2 + u_4(x)^2 + u_5(x)^2 + u_6(x)^2 + u_7(x)^2]$

Appendix E
Information on issued certificates

Most of the participants have provided a certificate either for each of the DUTs or one certificate covering all measurements (* means: no certificate is sent to the pilot laboratory).

The following points are checked by the pilot laboratory:
- uncertainty statement (whether it refers to k=2 or to 95% confidence level)
- ambient conditions
- explicit mentioning of reflection coefficient on certificate.

Participant	Uncertainty statement			Ambient conditions		Reflection coefficient	
	k=2	←or →	95%	Temperature (°C)	R.H. %	Value	Uncertainty
NMi-VSL	X			23 ± 0.5	45 ± 5	Y	Y
Celsius	X	→	X	23 ± 1	45 ± 5	Y	Y
IENGF	X			23 ± 0.3	50	N	
INTA	X	←	X	23 ± 1	< 70	Y	Y
SMU	X			25 ± 1	50 ± 10	Y	Y
METAS			X	23 ± 0.5	45 ± 5	Y	
CMI	X					Y	Y
OMH	X			*25 ± 1*	*40 ± 10*	Y	
PTB	X	→	X	23 ± 0.5	50 ± 10	N	
NPL	X	→	X	23 ± 1		Y	Y
CSIR-NML	X	→	X	23 ± 2	50 ± 15	Y	Y
UME	X	→	X	23 ± 1	45 ± 10	Y	Y
SIQ	X	→	X	23 ± 2	50 ± 20	Y	Y
BNM-LNE *	X						
NIST	X			23	40	Y	Y
CSIRO-NML			X	21.5 ± 0.5	52 ± 5	Y	Y
KRISS *							
NMIJ/AIST *				23 ± 1	50 ± 10		
NRC *				23 ± 0.5	35		
NIM				23 ± 3 (±1)	55 ± 25	Y	Y
SPRING	X	→	X	23 ± 1	55 ± 5	Y	Y

If ambient conditions are given in italic, this information was not mentioned on the certificate.

Note: if the arrow points to the right, the uncertainty statement is based upon a k=2 statement and afterwards “converted” into a confidence level statement. The process is reversed if the arrow points to the left.

APPENDIX F

Comparison protocol and schedule

F1) Technical Protocol

F2) Original Schedule

F3) Contact Persons

F1) Technical Protocol

The Euromet protocol is used throughout the whole CCEM.RF-K8.CL comparison.

Guidelines for Euromet project 393

***Scope**:*
This project is an international comparison of one of the high frequency key quantities. It should be considered to be a first attempt to implement the draft procedures of CIPM key comparisons in the field of high frequency electrical quantities. Emphasis lies on maintaining an approved tight measuring schedule using available state of the art measuring techniques.

***Measuring quantity**:*
Power sensors are usually calibrated in terms of calibration factor. In most cases a reference frequency of 50 MHz is used to obtain the frequency dependence of a power sensor.
Thermistor mounts are considered to be the most fundamental power measuring device for traceability to the fundamental SI units. Therefore they are used as primary standards in most of the national standards laboratories. Also high level calibration laboratories use these devices as their highest internal standard.
The purpose of the excercise is to determine the level of consistency of calibration results as given by different national standards laboratories.
The main measuring quantity therefore is the calibration factor as determined at a number of prescribed frequencies, together with the appropiate uncertainty statement. Also the value of the reflection coefficient has to be determined, as it is, at least, necessary for the uncertainty calculation.

Travelling standards
A set of two thermistor mounts is used, one with an APC7 connector and the other with a type-N male connector. It is expected that both mounts will be measured.
In case no facilities and/or traceability for APC7 connectors is available, an APC7-N adapter should be used to 'convert' the device under test. For this purpose such an adapter and an suitable torque wrench is supplied as well.

Measurement procedure
As already indicated, the normal laboratory procedure for high level calibration of power sensors should be used. Hence, no attempt should be made to improve facilities just for this comparison.
Usually customers expect to be served within a couple of weeks.This is also the main reason for allowing a relative short turn-around time for the measurements.
The two travelling standards are to be calibrated, in the appropiate connector type. If necessary the adapter should be used. However, it would be good for the statistics if all participants will measure the combination as well.
If it is possible, please determine the breaking torque of the wrench and report it as well.

Submission of results
Each laboratory is expected to submit its report to the coordinator within one month after the end of its measuring period. It would be nice to include in the report a normal calibration certificate as the official result of the calibration.
Anyway, the pilot laboratory needs sufficient information to make a first evaluation of the results before a general discussion can take place concerning the procedural and technical aspects of the comparison.

A breakdown of the uncertainty budget is an essential part of evaluating measurement results. According to the CIPM guidelines the ISO Guide on the Calculation of Uncertainties in Measurements (GUM) should be followed. A practical implementation of this document within the European accreditation bodies is the EAL-R2 (1997) document. To serve as a guideline for presenting your uncertainty budget, a copy of the example for the calibration of power sensors is attached to this guideline.
The report should therefore contain at least a short description of the measurement set-up, preferably with some schematic drawing, the relevant statistical information on the individual measurement results and traceability chain.
An example of presenting a summary of the basic results is given in the table below.

Results of Euromet project 393				
Laboratory:				
Frequency [GHz]	*Calibration factor*	*Uncertainty (k=2)*	*Reflection coefficient*	*Uncertainty in refl. coefficient (k=2)*
0.01				
0.05				
1.00				
4.00				
8.00				
12.00				
15.00				
18.00				

Discussion of results
It is expected that an open discussion will take place at a future Euromet meeting for HF quantities, shortly after distributing a draft report containing a compilation of the results and a first attempt of interpretation. Afterwards the final result can be published in Metrologia and, hopefully at CPEM2000 and the related IEEE I&M issue.

Problems during the exercise*:*
If technical and/or other problems arise, it is of the utmost importance to contact immediately the coordinator to discuss the matter and to inform the laboratory next in line about this fact. If the problem can not be solved within the allowed time frame, it will be necessary to adapt the schedule by shifting a few laboratories to a latter time slot.
It is assumed that the participating laboratory takes care of insurance of the package during the stay at the laboratory and the transportation to the next participant.

Transport and customs
The travelling standards can be sent using regular package mail. The devices and the accessories are stored in a plastic container, which is provided by the coordinator. Additional packaging as protection is suggested.
Inside the European Union no customs papers are necessary, but a pro-forma invoice is provided in case of questioning. For all participants outside the Union, an ATA-carnet will be provided, if applicable.

Circulation time schedule
At present the revised schedule as distributed in Febraury 1998 is valid. Updates of the schedule will be sent when and where necessary. A turn-around time between laboratories of 3 weeks is used. The exercise is divided in 4 loops with intermediate measurements at the pilot laboratory. It is the responsibility of each participating laboratory to inform the next participant in advance to arrange the transportation of the standards, and to inform the coordinator about the date of transportation.

Coordinator
The pilot laboratory for this comparison is NMi Van Swinden Laboratorium (VSL). The coordinator for this comparison is:
Dr. Jan P.M. de Vreede
NMi Van Swinden Laboratorium
Schoemakerstraat 97
P.O. Box 654, 2600 AR Delft
The Netherlands
Telephone: +31 - 15 269 1500
Fax: +31 - 15 261 2971
E-mail: JdeVreede@nmi.nl

F2) Original Schedule

Period	Laboratory	Country
February **1998**	**Celsius**	**Sweden**
March	**Finnish Telecom**	**Finland**
April	**IENGF**	**Italy**
May	**INTA**	**Spain**
May	**Pilot**	**The Netherlands**
June	**SMU**	**Slovak Republic**
July	**METAS**	**Switzerland**
August	**CMI**	**Czech republic**
September	**OMH**	**Hungary**
September	**Pilot**	**The Netherlands**
October	**PTB**	**Germany**
November	**NPL**	**UK**
December	**Pilot**	**The Netherlands**
January **1999**	**CSIR-NML**	**South-Africa**
February	**UME**	**Turkey**
March	**BNM-LNE\LAMA**	**France**
April	**SIQ**	**Slovenia**
May	**Pilot**	**The Netherlands**
July	**Pilot**	**The Netherlands**
August	**NIST**	**USA**
September	**CSIRO-NML**	**Australia**
October	**KRISS**	**Republic of Korea**
November	**NMIJ/AIST**	**Japan**
December	**NRC**	**Canada**
January **2000**	**SPRING**	**Singapore**
February	**NIM**	**People's Republic of China**
March	**Pilot**	**The Netherlands**

Table F1: The top part refers to the original Euromet 393 project and the bottom part to the international loop (GT-RF 98-1)

F3) Contact Persons

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** **Contact person (responsible for measurements during the comparison) is no longer responsible for this activities.**

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