FINAL REPORT

CCEM.RF-K4.CL COMPARISON

RF-Voltage measurements up to 1 GHz*

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(Completed by James Randa[2])

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This comparison was initiated and led by Jan de Vreede, who sadly passed away during preparation of the final report. His friends and colleagues in the comparison dedicate this report to his memory.

Abstract**:** We report the results of an international comparison of measurements of radio frequency voltage in the frequency range 1 MHz to 1 GHz. This comparison was performed as a "Key Comparison" under the auspices of the Consultative Committee for Electricity and Magnetism (CCEM) of the International Committee for Weights and Measures (CIPM). Participating laboratories were the designated National Metrology Institutes (NMIs) for their respective countries.
Keywords**:** CCEM, GT-RF, international measurement comparison, radio frequency voltage

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1 Introduction

During the nineteen eighties modern equipment in the field of ac-dc transfer and of ac-voltage came on the market operating up to tens of megahertz. Progress in microcircuits also led to the development of tools measuring voltages in the ranges up to 1 gigahertz. In 1992 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 start a comparison to investigate the quality of voltage measurements up to high frequencies of at least 300 MHz, with an optional frequency extension to 1 GHz. This comparison (GT-RF 92-6) is an extension of a similar proposal made in the 1992 CCEM meeting for a comparison on ac-dc transfer devices up to 50 MHz [1]. In order to avoid confusion it was decided to delay the start of the GT-RF comparison to such a time that the low-frequency CCEM comparison would almost be finished. After the introduction of the Mutual Recognition Arrangement (MRA) [2], the GT-RF comparison was assigned the number CCEM.RF-K4.CL. This report is the technical report on the complete exercise, including all the problems that occurred during the comparison.

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 [3] 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. This trial round was carried out in 1997 between PTB (Germany), NRC (Canada) and the pilot laboratory VSL (the Netherlands), whose name was NMi-VSL when the comparison started. The full names of all participating national metrology institutes (NMIs) can be found in Table 1. In the past a similar intercomparison was organised under the umbrella of the GT-RF; viz. GT-RF 75-A5 [4] with PTB (Germany) as pilot.

Due to the length of time it has taken to complete this comparison, and because of the disruption caused by Jan de Vreede's untimely death and the consequent transfer of piloting responsibilities, the participants (with the approval of the CCEM) decided to complete the report under the old (pre-MRA) rules, which were in effect when the comparison began. Thus the final key comparison reference values (KCRVs) and degrees of equivalence (DOEs) were not computed and submitted to the Key Comparison Database (KCDB), and the comparison will be submitted for approval for provisional equivalence rather than full equivalence. However, since some work had been completed in computing KCRVs, we include those results in this report, calling them "reference values." These results are reported in Section 7.

Mention of trade names or specific products in this report does not indicate approval or disapproval of them by participants of the comparison. Specific companies and products are named only in order to provide adequate technical detail regarding the measurements.

2 Participants and schedule

During 1996 invitations were sent out to participate in the comparison. Based upon the received information a time schedule and a transport scheme were determined. The comparison was split into 4 loops, two within the European Community and two outside it. In this way an equal worldwide distribution was obtained, while still maintaining a relatively simple procedure for customs handling. However, almost immediately after the start of the first loop, damage to the equipment occurred. This led effectively to a restart of the comparison. The original time schedule is given in **Appendix A**, and the contact persons for the participating NMIs are listed in **Appendix B**. During the remainder of the comparison similar problems often occurred, which led to significant delays. Hence the pilot laboratory decided to make only short-term plans. The final time schedule is given in Table 1.

Since RF-dc measurements are time consuming, due to their nature of measuring temperature differences and/or temperature stabilisation, each laboratory was allowed 5 weeks of measurements and one or two weeks of transport to the next participant. The ATA carnet was used outside the European Community (now European Union). Given VSL's experience during this comparison, we now believe that a temporary import/export document within a star pattern comparison (return to the pilot laboratory after measurements at each laboratory) is preferred. The star pattern requires more work, but it has fewer long delays.

Table 1. List of participants and measurement dates.

Acronym	National Metrology Institute	Country	Standard at the laboratory	Date of submission of report	Comment
VSL	Van Swinden Laboratorium	The Netherlands	January 1997		Pilot Lab
NRC	National Research Council Canada	Canada	March 1997	April 1998	Trial round
PTB	Physikalisch-Technische Bundesanstalt	Germany	April 1997	June 1997	Trial round
VSL					
METAS		Switzerland		--	Breakdown / ATA
VSL			January 1998		
SMU	Slovak Insitute of Metrology	Slovak Republic	March 1998	June 1998	
CMI	Czech Metrological Institute	Czech Republic	May 1998	June 1998	Withdrew before Draft A was finished
METAS		Switzerland		--	Problems with set-up; no measurements
VSL			July 1998		
Arepa	AREPA Test & Calibration	Denmark	September 1998	February 1999	
CEM	Centro Espanol de Metrologia	Spain	October 1998	November 1998	
INRIM (formerly IEN)		Italy	December 1998	February 1999	Breakdown of Ballantine; replaced. Withdrew before Draft A was finished
BNM-LCIE	Bureau National de Métrologie	France	February 1999	--	Breakdown of Ballantine and R&S
VSL			May 1999		Check measurement / Replacement of R&S sensor

Acronym	National Metrology Institute	Country	Standard at the laboratory	Date of submission of report	Comment
SIQ	Slovenian Institute for Quality	Slovenia	July / August 1999	February 2000	
PTB	Physikalisch-Technische Bundesanstalt	Germany	August 1999		Intermediate check
NIST	National Institute of Standards and Technology	United States of America	October 1999	December 1999	
VSL			December 1999		Check measurement
NMIA		Australia	April 2000		No results submitted due to withdrawal after measurements
KRISS	Korean Research Institute of Standards and Standardisation	Republic of Korea	July 2000	March 2003	Breakdown of R&S / Repaired in KRISS
VSL			December 2000		Check measurement
VNIIM		Russian Federation	January 2002	?	
VSL			February 2002		Check measurement
NIM		People's Republic of China	March 2002	?	
VSL			April 2002		Check measurement
PTB	Physikalisch-Technische Bundesanstalt	Germany	May 2002	September 2003	Intermediate check
METAS		Switzerland	July 2002	September 2003	
NMC (formerly SPRING)		Singapore		--	Breakdown of R&S
VSL			August 2002		Check measurement / Replacement of R&S sensor
LNE (formerly BNM-LNE)	Laboratoire National de Métrologie et d'Essais	France	October 2002	March 2004	New report submitted after discussion about reference plane
VSL			November 2002		
NMC		Singapore	December 2002	March 2003	
VSL			February 2003		

3 Transfer standards and required measurements

In order to evaluate the laboratory's performance for RF voltage measurements in the frequency range up to 1 GHz the working group (GT-RF) decided to use both a device especially designed for RF-dc transfer difference and a normal power sensor, because either one of these instruments could be used to obtain traceability to the relevant SI unit, either via the low-frequency chain of ac-dc techniques or via a RF-power and RF-impedance chain. The two devices in the comparison were:

- a Ballantine model 1396A RF-dc transfer with the following characteristics:
  - Input voltage: 1,3 V
  - Output voltage: 7 mV (at nominal input voltage)
  - Input resistance: 200 Ω (nominal)
  - Output resistance: 7 Ω (nominal)
- a Rohde und Schwarz power sensor NRV-Z51 with the following characteristics:
  - Impedance: 50 ohms
  - Input power: -20 dBm to +20 dBm (0,01 mW to 100 mW)
  - Equivalent voltage: 22 mV to 2,2 V (visible by changing display parameter)

The Rohde und Schwarz sensor will be referred to as R&S. As ac-dc transfer devices (and therefore also RF-dc devices) are renowned for breaking down during interlaboratory comparisons, a check measurement was propose, which would exclude as much as possible the influence of the individual laboratory. The easiest check is a measurement of the two devices against each other, as all components are present in the package. Another check is either a DC voltage measurement or a 50 MHz measurement. The latter was not always carried out, and therefore no results are reported here.

The participants were asked to submit measurement results on each device at 9 frequencies (six required frequencies: 1.0 MHz, 10 MHz, 50 MHz, 100 MHz, 200 MHz, and 300 MHz; and three optional frequencies: 500 MHz, 700 MHz, and 1 GHz) concerning its RF-dc transfer difference calibration factor together with an uncertainty (coverage factor k = 1).

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 from different laboratories. In principle this information is readily available, provided a laboratory operates effectively according to a quality assurance system based upon standards like ISO 17025.

4 Behaviour of the transfer standards

Both types of transfer standards showed problems, but one broke down several times during the exercise. Therefore an identification scheme was defined to distinguish the different configurations during the exercise. In Table 2 an overview is given with the round identification. The rounds are groups of measurements on the same devices within a relatively short period. An asterisk in the table means that a suspicion of defect was indicated, but that the same device was used further on as no clear change could be detected. The main link between the results of the different laboratories is the continuous monitoring of the

DUTs during their stay at VSL. Two identical devices were kept at VSL especially for this purpose. These were characterised at the same time as the travelling standards in the normal traceability chain leading to the primary standards. After a breakdown of a travelling standard one of the monitoring devices was used to replace a damaged/repaired device. Different R&S sensors have been used, each of which broke down at least once. One sensor is identified by Z25, Z26 and Z27, and the other sensor by Z40 and Z41: after each breakdown the identifying code was modified. In the case of the Ballantine device 621, questions arose in measurements from December 1998 through February 1999, as indicated in Tables 1 and 2. Device 621 was temporarily replaced by device 239 at that time. However, it was established that 621 was operating properly, and 621 was used throughout the remainder of the comparison. The measurements on 239 were not used; the two participants who measured 239 either withdrew from the comparison or performed measurements on 621 at a later date. Thus the same Ballantine device was used throughout the comparison.

Table 2: Devices used during the comparison.

Round	Start	Finish	Ballantine device	R&S device
1	End 1996	August 1997	621	Z40
2	September 1997	June 1998	621	Z25
3	September 1998	November 1998	621	Z25 *
3a	December 1998	February 1999	239	Z25
4	July 1999	March 2000	621*	Z25
5	August 2000	March 2001	621	Z26
6+7	July 2001	May 2002	621	Z41
8	August 2002	February 2003	621	Z27

5 Measurement methods

The majority of the laboratories used a normal ac-dc system, often modified to allow measurements at high frequencies. There are some differences, especially concerning the connection of the Ballantine device to the measuring system. Already in the guidelines, it was mentioned that a potential problem for interpreting the data would be the choice of the measurement plane (or reference plane) to which the data are referred. Hence laboratories were asked to state their choice explicitly. For each laboratory the measurement procedure (including traceability) is briefly described here.

<u>VSL – pilot laboratory:</u>
At lower frequency (up to 100 MHz), the traceability is based on the calculable ac-dc transfer standard developed at VSL [5]. Above 1 MHz, the traceability is based on the RF-power traceability using thermistor mounts measured in the VSL microcalorimeter system and the reflection coefficients measured using a Vector Network Analyser (hp 8753E with test set hp 85044). During the comparison the results in the overlapping frequency range were used to obtain a smooth frequency response from low frequency to high frequency.

NRC:
No measurements were done on the Ballantine system. The R&S sensor was measured against a working standard using an external Tee. The reference is the midplane of the Tee, a model UG-107B/U. During the measurements the same number of measurements were carried out for each of the two positions of the Tee.

PTB:
The RF voltage standard at PTB is a dry calorimeter. Its power traceability is based on the comparison with a thermistor mount calibrated in the PTB microcalorimeter, and its impedance traceability is based on ANA measurements referred to precision 7 mm air lines. Below 100 MHz the frequency-dependent power and impedance responses of this dry calorimeter were determined by extrapolation of the response at higher frequencies down to dc by modelling of the dry calorimeter. The dry calorimeter voltage standard has a type N-female connector and was connected directly to the Ballantine converter. For the R&S sensor the dry calorimeter connector was changed to a N-male connector and both devices were compared by means of a N-Tee. For the power sensor, the reference plane is the midpoint of a model UG-107B/U Tee. For the Ballantine converter, the reference plane is the midpoint of the built-in Tee of the converter.

SMU:
An ac-dc transfer system is used with a Fluke A55 (up to 50 MHz) and a thermistor mount hp 8478b as working standards. The thermistor mount was calibrated against the SMU thermistor voltage standard. As external Tee (for the R&S sensor) a General Radio 874-TL is used at lower frequencies and an Amphenol-Tuchel UG-107B/U at higher frequencies. The latter was of poor quality.

CMI:
A power splitter method is used with a resistive Tee and a levelling monitor in one arm. The working standard is an hp 8478b calibrated at PTB, Germany. The DC measurements are done separately. During the measurements the impedance of the R&S sensor changed. *The results refer to the situation after the change.*

Arepa:
An ac-dc transfer method is used with direct read-out. For the R&S sensor an external Tee is used. A Fluke 5800A is used at DC and 1 MHz. All other measurements are done using 1 MHz as intermediate reference.

CEM:
An ac-dc transfer system is used. Three different working standards have been used, viz. PTB Multijunction Thermal Converter (from 10 Hz to 1 MHz), a VSL Calculable HF device (1 MHz to 100 MHz) and a Ballantine 1396A thermal converter calibrated at NIST. Different lay-outs were used to connect the DUTs to the relevant working standards.

INRIM:
A basic RF-dc transfer system is used since the INRIM standard is a Ballantine 1396A, which is calibrated in-house against the INRIM primary standard, a power system. For the Ballantine, an external Tee is used to connect the two converters. In all other cases, the internal Tee of a Ballantine is used (either INRIM's or the travelling standard).

SIQ:
An ac-dc transfer system is used up to 20 MHz. For higher frequencies a two step approach is used by adding a RF-RF transfer to the lower frequency measurement.

NIST:
An RF-dc transfer system is used. For TVCs like the Ballantine 1396, the switch is connected to the internal Tee of the DUT. The other side of the Tee is connected via an airline and an attenuator to a thermistor mount. In the case of a device like the R&S sensor, an external Tee is used. The power readings are converted into voltage taking into account the relevant reflection coefficients.

KRISS:
An RF-dc transfer system is used with an NRV-Z51 sensor as voltage standard. The DUT's are compared with the standard using a type N Tee or the built-in Tee with a type N f-f adapter. The RF-dc difference of the standard was determined from dc resistance, effective efficiency, and equivalent parallel conductance at the reference plane. The effective efficiency was measured using a direct comparison method against the standard thermistor mount, whose effective efficiency was measured with a Type-N microcalorimeter system. The admittance was measured with a precision LCR meter at 1 MHz, and with network analyzers at the other frequencies. The measured admittance was corrected for the ANA imperfections using standard air lines as the impedance standard.

VNIIM:
A direct comparison method is used, using a diode compensation voltmeter with diode measuring transducer, which was calibrated by the National AC Voltage Standard. A special T-joined (tee) type N-Tee connector was used to connect to the travelling standard.

NIM:
R&S NRV-Z51: In the frequency range (10 – 1000) MHz the output of the R&S sensor is kept constant by varying the output voltage of a generator, which output level is measured using the NIM primary voltage standard GDY69. The reference planes are about 3.2 mm apart. The dc value is measured parallel to the R&S read-out with a precision voltmeter 7081. At 1 MHz an ac-dc transfer method is used for comparing the R&S sensor with the NIM coaxial thermal voltage converter TRZ8202. Its built-in Tee is used as reference plane.
Ballantine 1396A: The same ac-dc transfer method is used, but now the built-in Tee of the travelling standard is used.
Check of DUTs: The Ballantine is used as reference: its voltage output is kept constant. The reference plane is the midplane of the built-in Tee.

METAS:
As laboratory standards, a TVC code HF6 (traceable to VSL) is used up to 50 MHz; up to 1000 MHz a R&S NRV-Z51 power sensor is used, which is characterised using a thermistor mount traceable to NPL. The measurement process is done in two steps using 1 kHz as intermediate between dc and the requested frequency. A Tee was always used to connect the DUT and reference to the generator. The midplane of the Tee used (external in case of the R&S sensor, internal in the other case(s)) is the reference plane for the results obtained. Afterwards a correction was applied for the VSWR of the devices. The VSWR was measured using a hp 8753D vector network analyser.

BNM-LNE:
The normal ac-dc transfer method of BNM-LNE is used with some modifications for use at these higher frequencies (no measurements are carried out above 100 MHz). As a working standard, a Ballantine 1394 TVC is used. It was calibrated with a GR874-N adapter against a HF TVC constructed and calibrated at NMi-VSL. The same Tee as used in this calibration was used to obtain the measurement results. No direct measurements were done on the R&S sensor, only the requested check measurements.

NMC:
An ac-dc transfer system is used for the Ballantine 1396. A working standard is used as reference, calibrated at frequencies below 100 MHz to voltage standards (traceable to VSL) and above 100 MHz to power standards (microcalorimeter and thermistor mount), which are all maintained within NMC. For the R&S sensor the same method is used below 100 MHz, but at higher frequencies the DUT is measured against the working standard using a resistive splitter and a monitoring sensor at the other arm.

6 Technical protocol

In the technical protocol (see **Appendix C**), participants were asked to present their measurement results in the format of the mean, including a statement of uncertainty with a coverage factor of k = 1 using a template sent together with the DUTs. 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. Also the traceability for the standards used should be provided to insure that correlation between measurement results would not be overlooked. The problem of the reference plane was mentioned only in the main text. For the check measurement (measuring the two DUTs against each other) the definition of DUT and reference was explicitly asked. The protocol did not include any requirements concerning the ambient conditions.

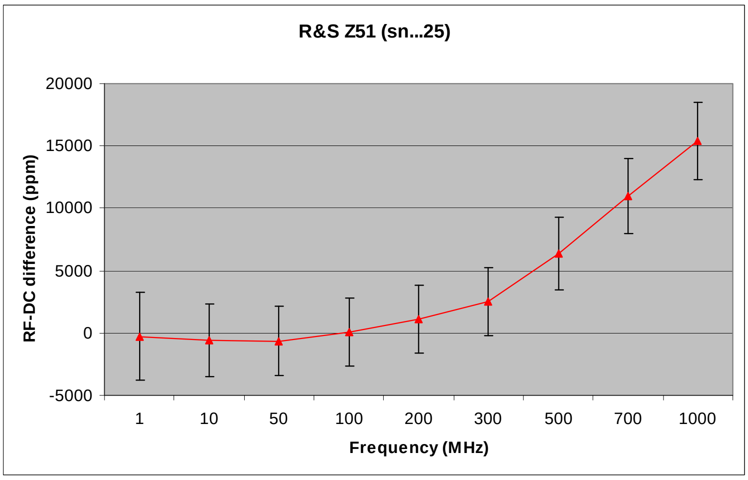
The comparison started before the official guidelines [3] were available. However, draft versions were available, and along with informal discussions they were used to define the technical protocol. Of course the global uncertainties given in the measurement reports were not modified.

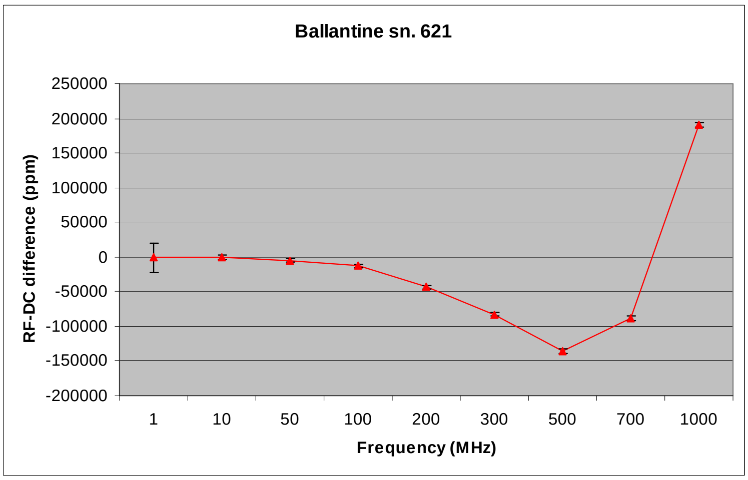
7 Measurement results

7.1 General results

The participants were asked to submit measurement results on each device at 9 frequencies (6 required frequencies: 1.0 MHz, 10 MHz, 50 MHz, 100 MHz, 200 MHz and 300 MHz; 3 optional frequencies: 500 MHz, 700 MHz and 1000 MHz) concerning its RF-dc transfer difference calibration factor together with an extended uncertainty (coverage factor k =1). After receiving the measurement data (including uncertainty statement), the coordinator compiled these results in an Excel spreadsheet for further analysis. Each laboratory received the relevant part of this spreadsheet for checking the correctness of these data.

Figure 1 gives a general impression of the frequency response for the three measurands: the power sensor, the thermal converter, and the check measurement using the two devices against each other. One series of the pilot laboratory measurements is shown here as example. Especially for the thermal converter (Ballantine), large frequency deviations take





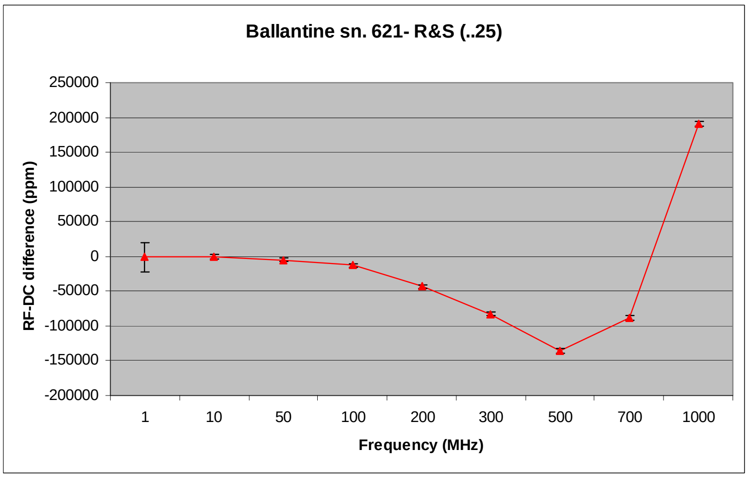
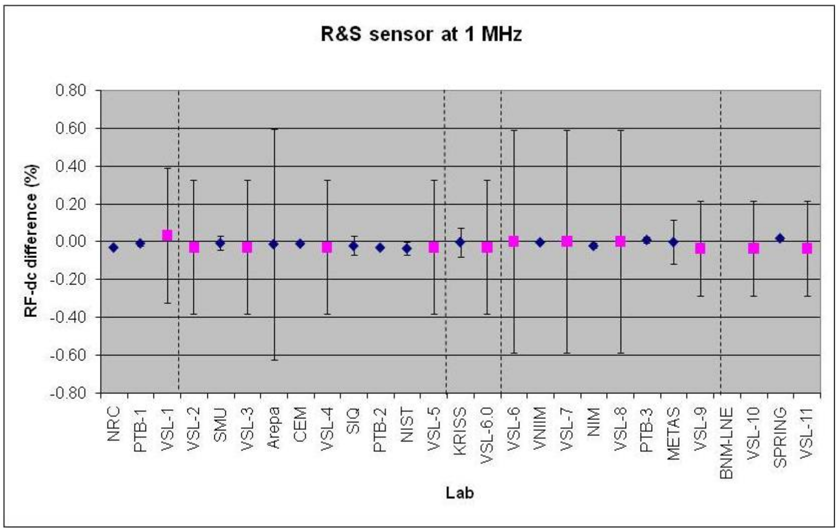
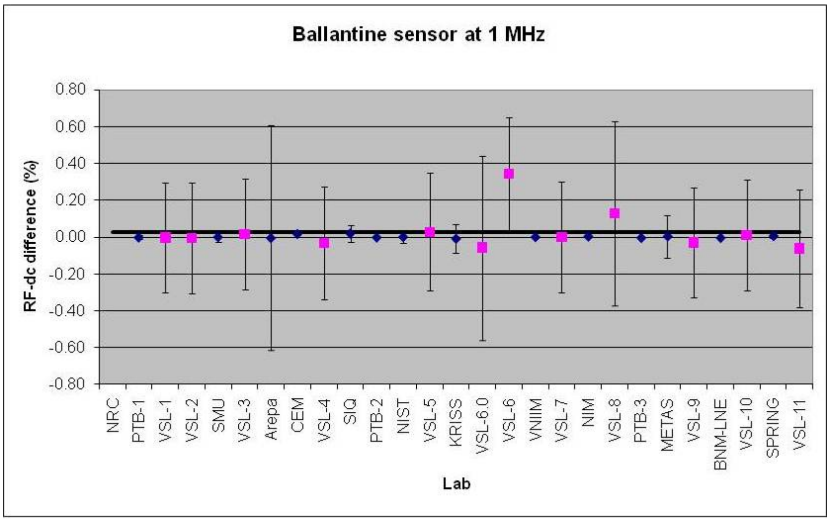


Figure 1: Frequency response of the two devices and a check against each other (measurements performed at the pilot laboratory).

place, much larger than usually encountered on low frequency devices and high frequency power sensors. Figures 2 through 10 contain the results of the participants and the individual pilot measurements. The uncertainty bars refer to the (k=1) uncertainties as stated by the participants. The data submitted are summarized in **Appendix D**, and the uncertainty budgets of the participants are reported in **Appendix E**. During the analysis it became clear that indeed there was some confusion about the definition of the quantity to be reported: the largest differences between the results appeared to be due to opposite signs. The pilot has decided that its "own" sign convention is the correct one. Where relevant, the sign has been changed.

As the thermal converter (Ballantine) was the only DUT that survived the entire exercise, a reference line representing an average of the pilot results is drawn in the figures for the Ballantine results to give an idea about the reproducibility or stability of the pilot measurements. For the power sensor (R&S) a total of 5 different devices have been used. The most obvious solution would be to look to the differences between the results obtained on the same device by a participant and the pilot. However, that would introduce the rather large pilot-lab uncertainties into all the power-sensor results. This point will be treated below, in Section 7.2.2. The check measurement (Ballantine directly against the R&S power sensor) should give consistent results, as one would only expect a statistical spread and no dependence on the traceability of the standards. Slight differences will occur because the same combination could not always be used.





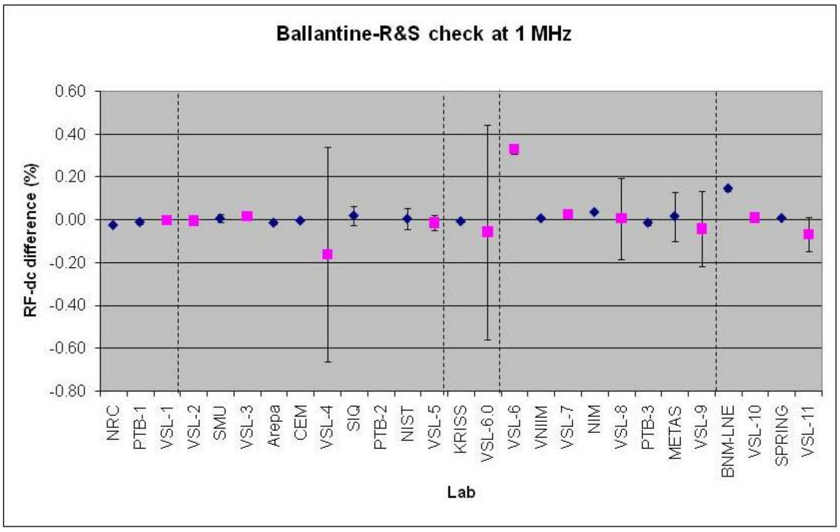
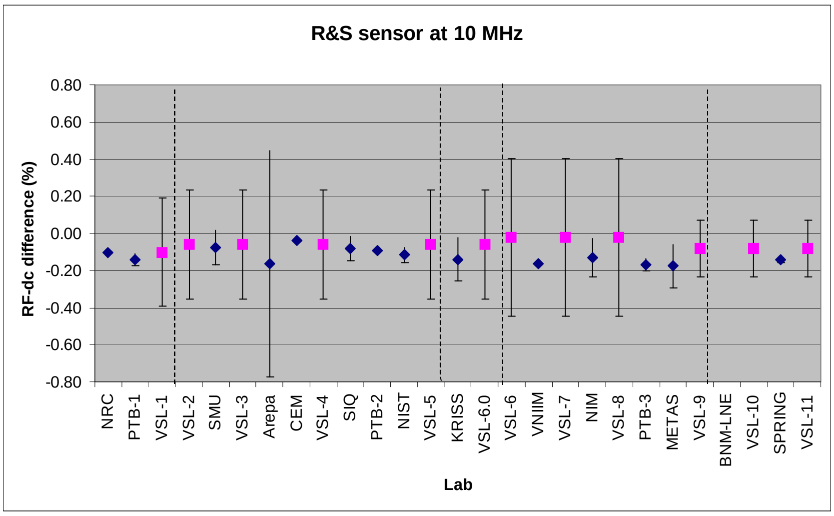
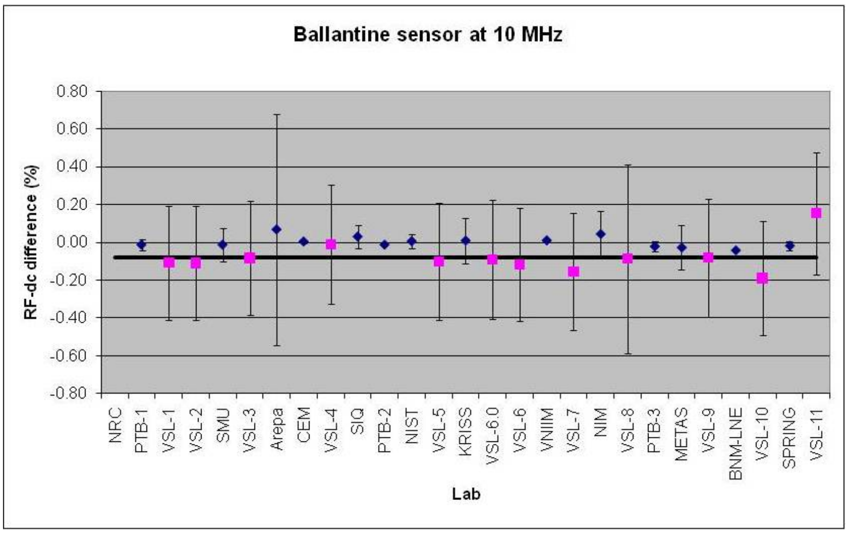


Figure 2: The results obtained at 1 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place. The solid line in the Ballantine sensor graph is the average of the VSL results.





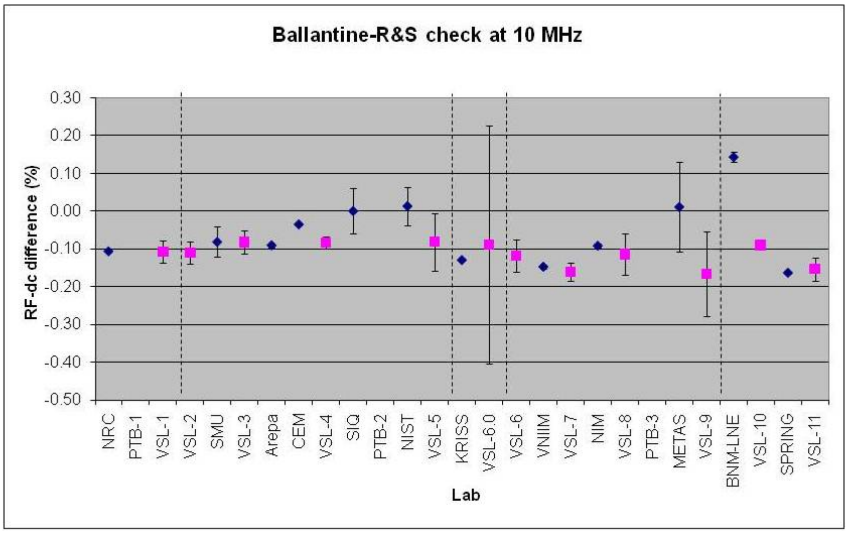
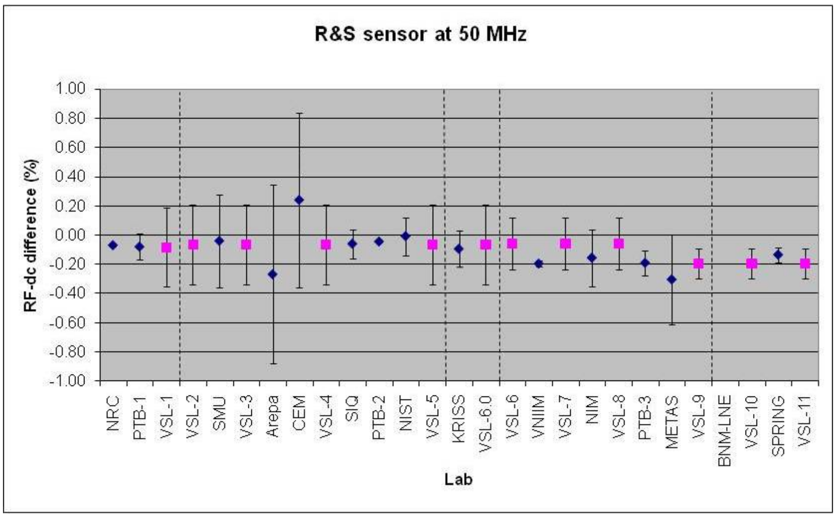
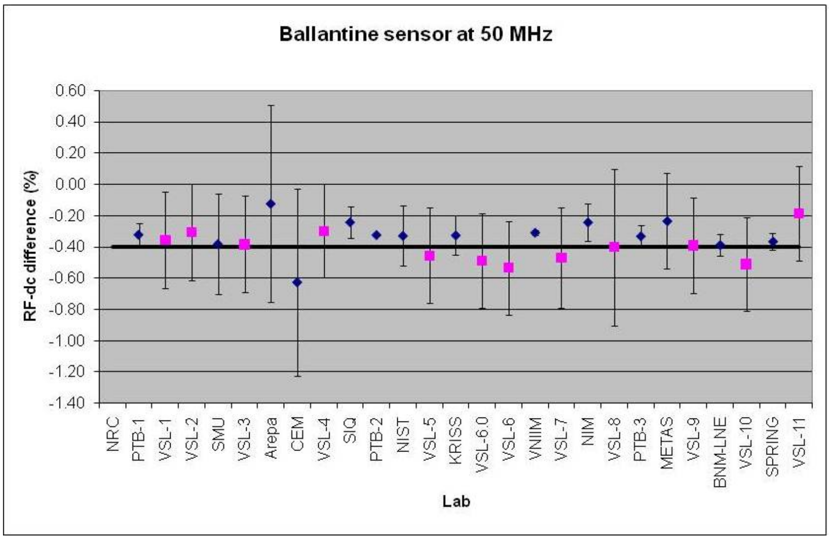


Figure 3: The results obtained at 10 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





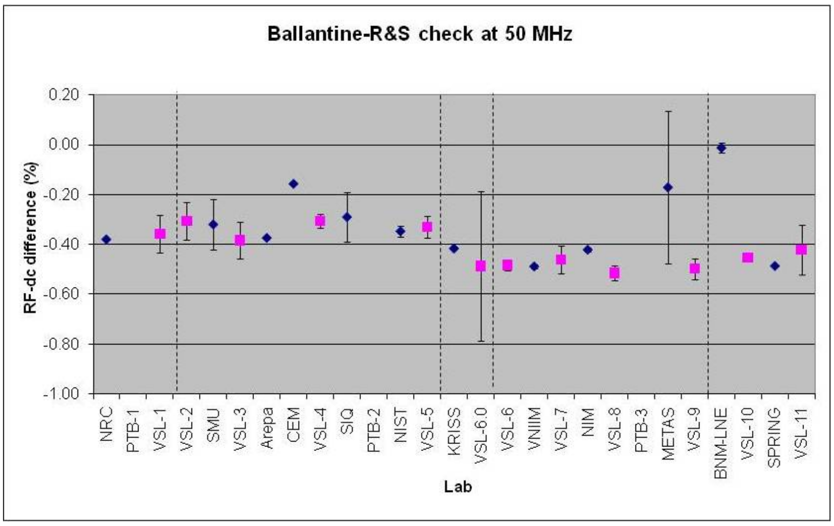


Figure 4: The results obtained at 50 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.

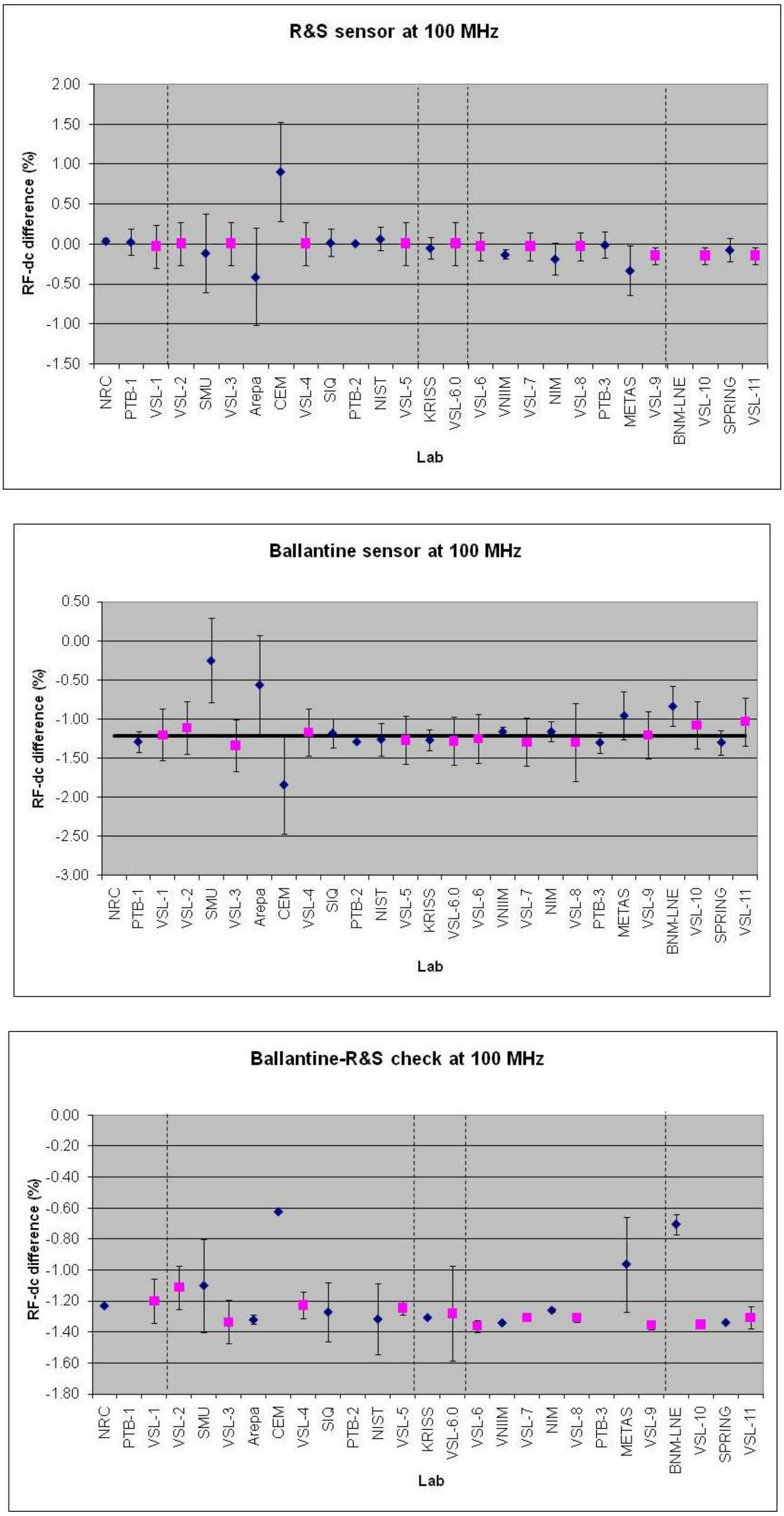
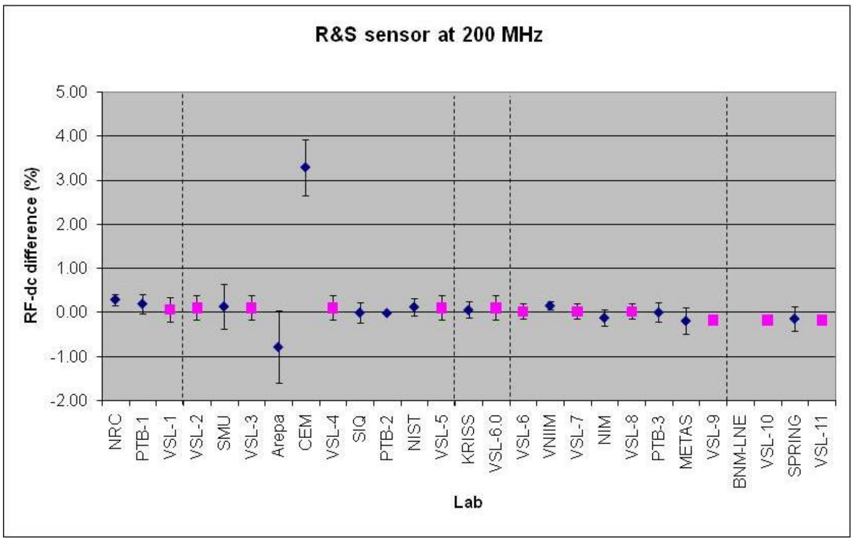
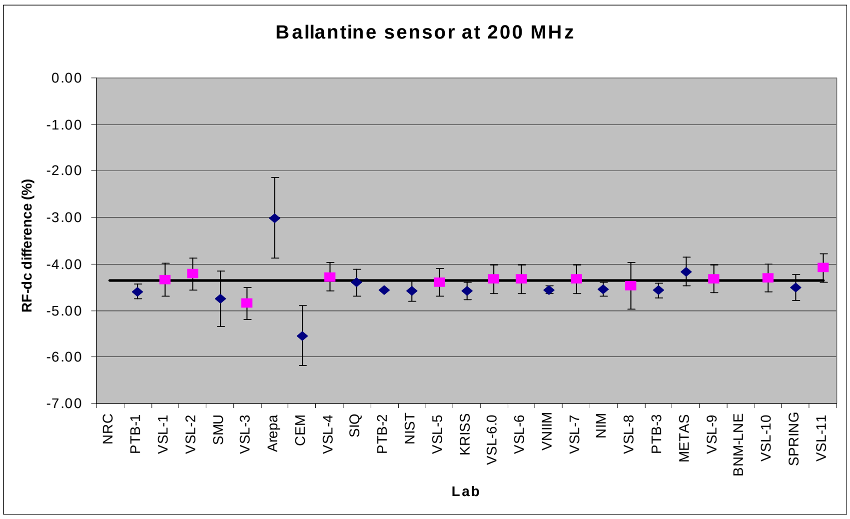


Figure 5: The results obtained at 100 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





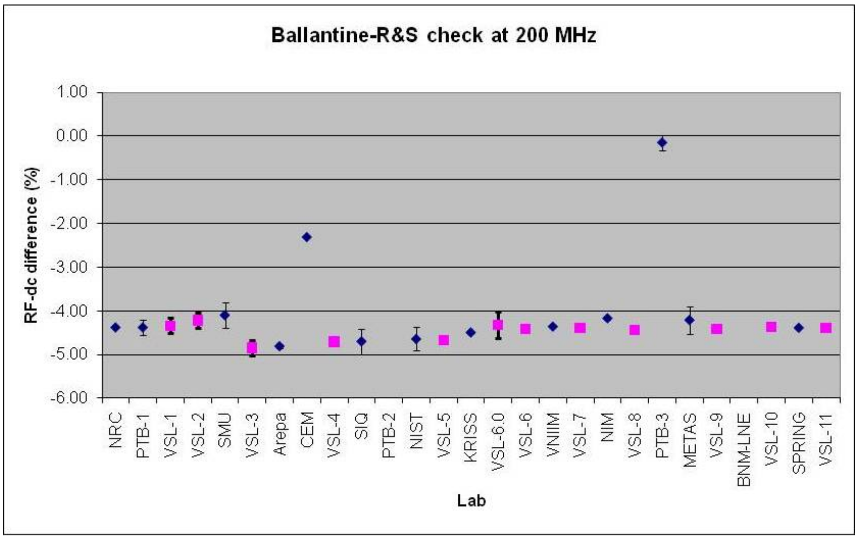
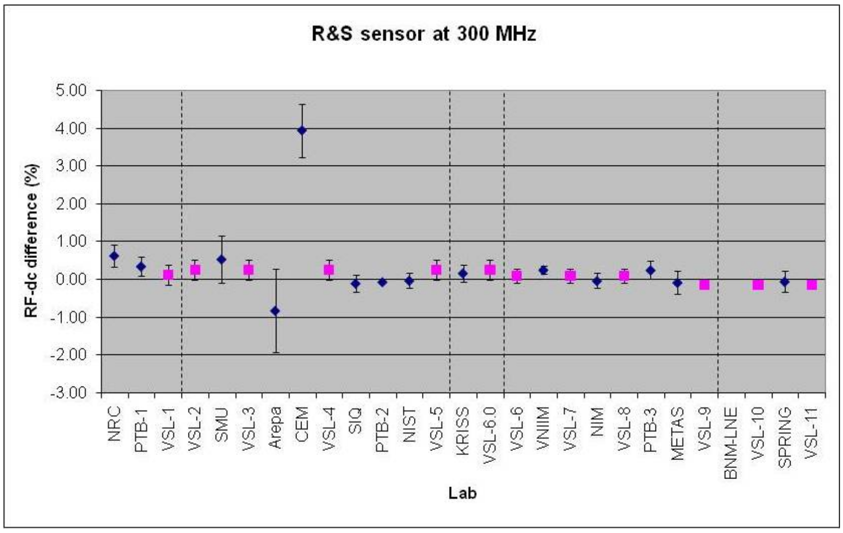
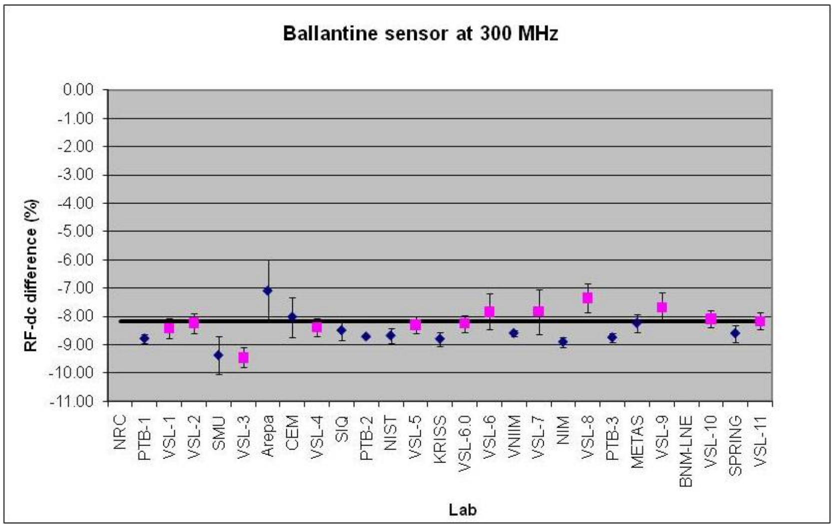


Figure 6: The results obtained at 200 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





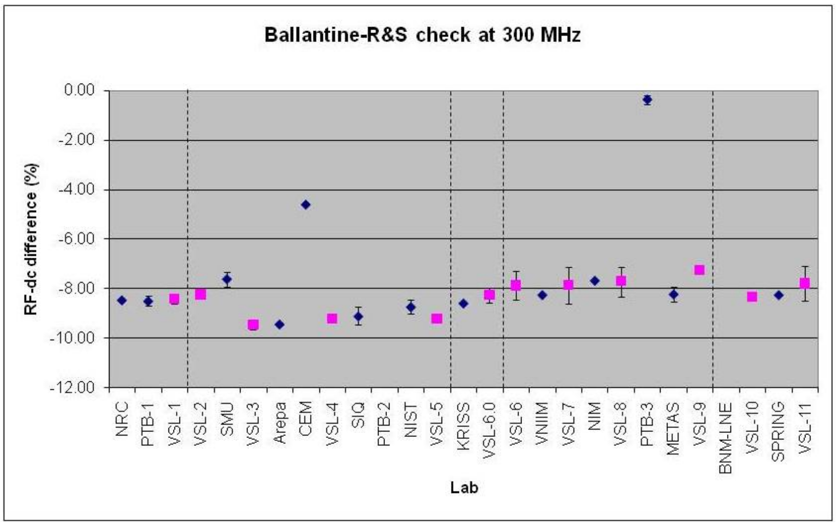
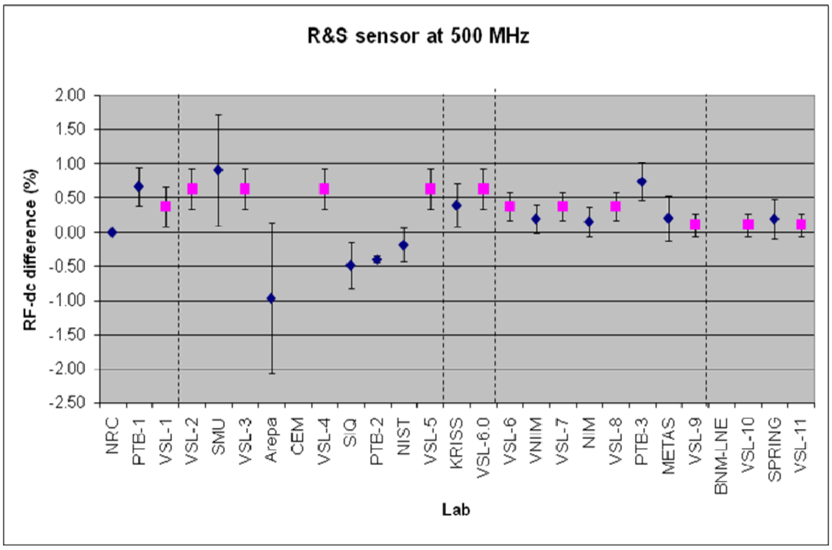
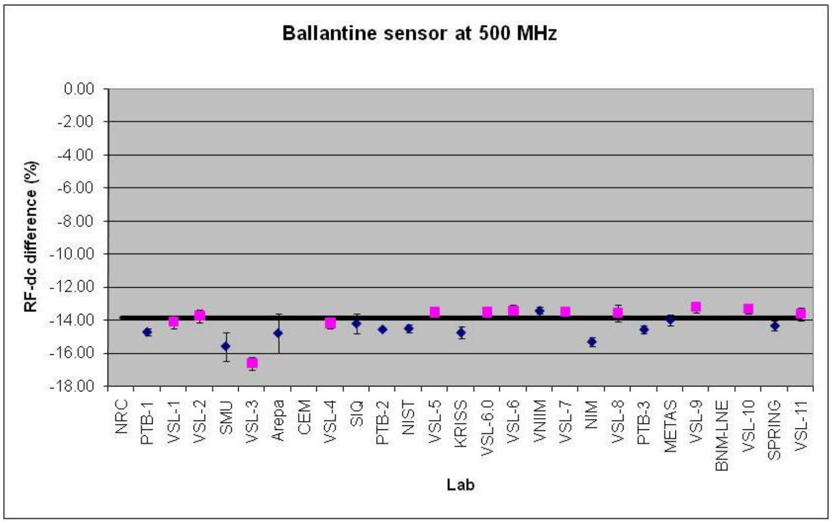


Figure 7: The results obtained at 300 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





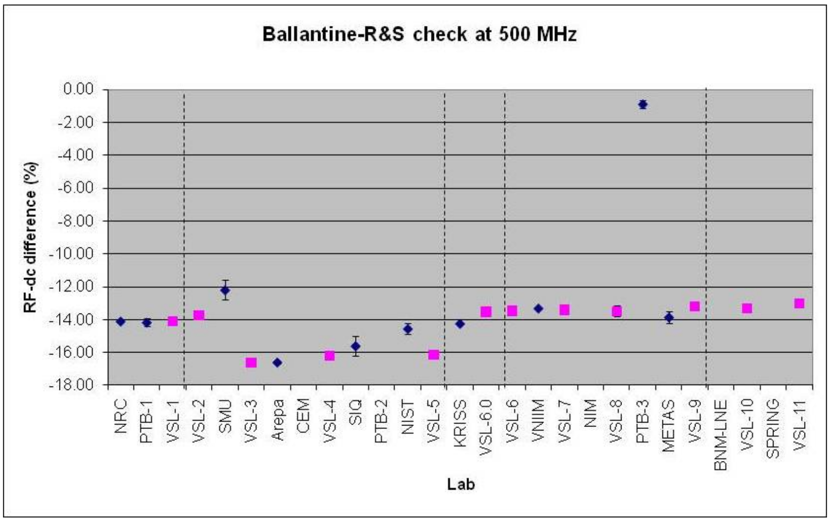
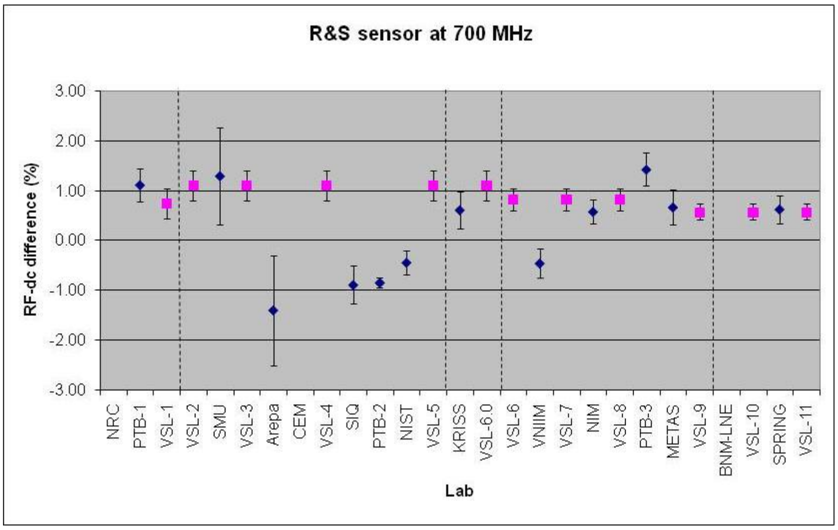
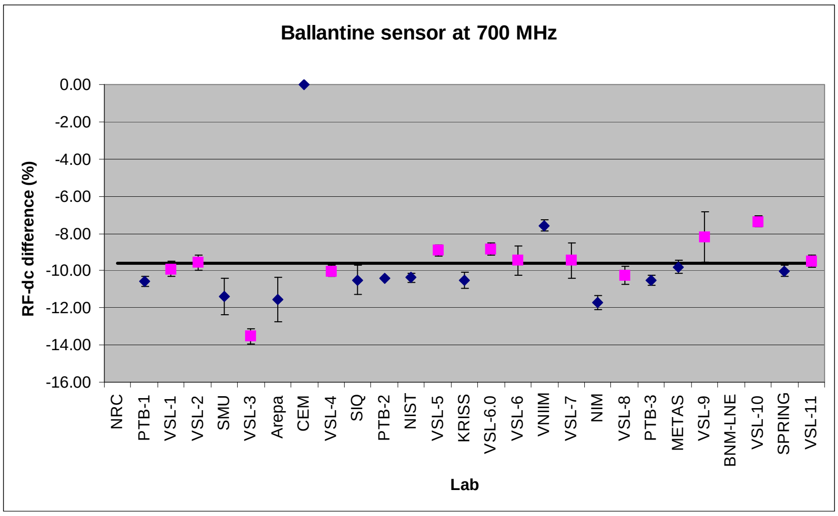


Figure 8: The results obtained at 500 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





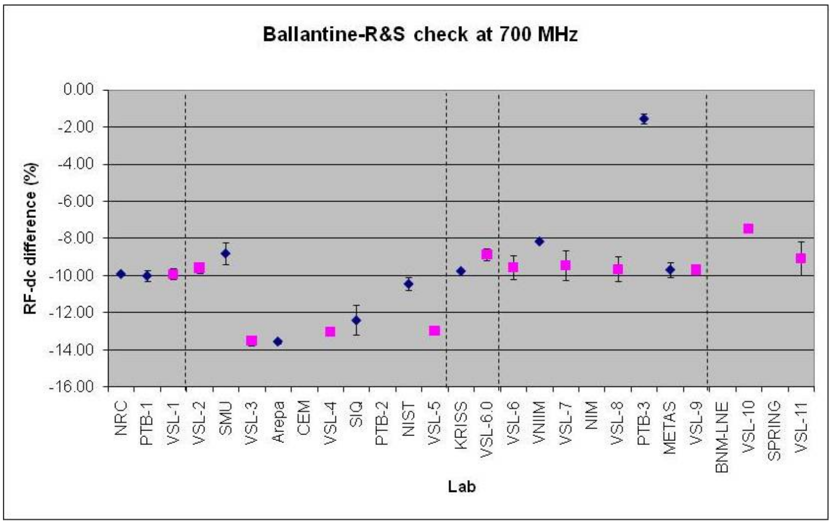
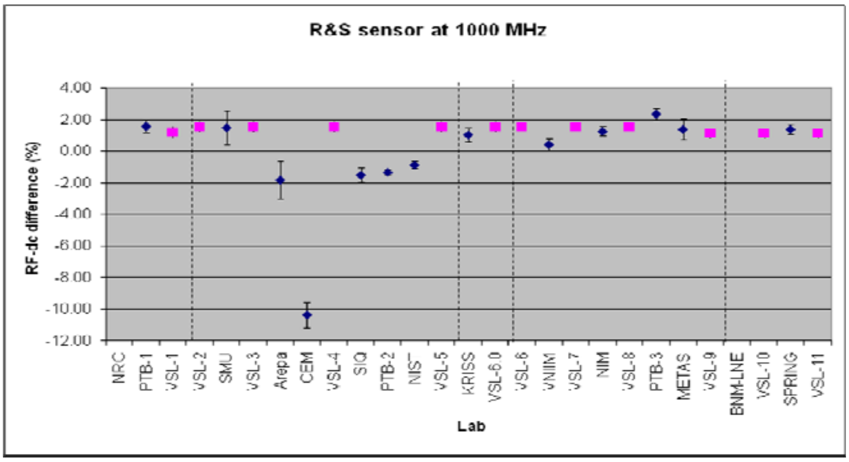
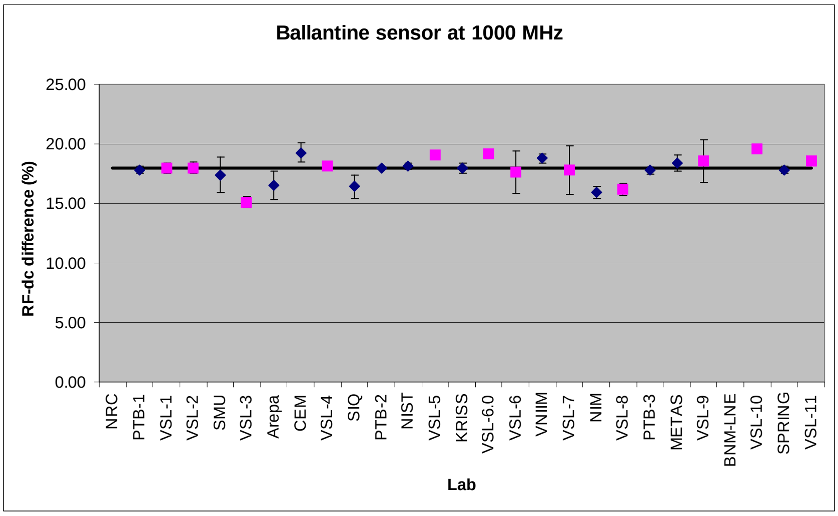


Figure 9: The results obtained at 700 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.





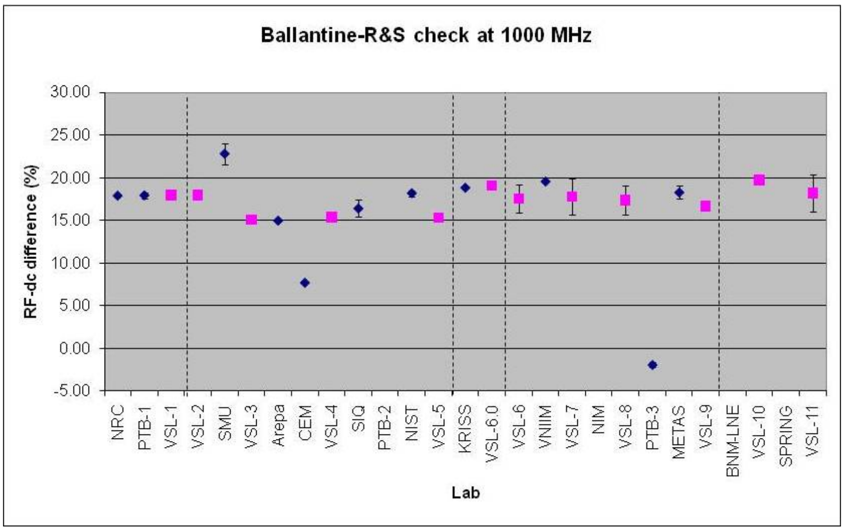


Figure 10: The results obtained at 1000 MHz by the participants for the three measurands. The results from the pilot laboratory are given as squares. The dotted lines indicate where a change in power sensor took place.

7.2 Determining reference values

Because this comparison was begun under the “old rules,” before Key Comparison Reference Values (KCRVs) and Degrees of Equivalence (DOEs) were introduced and required, and because of problems arising from the transition to a new pilot laboratory, the participants and the CCEM agreed to complete the report under the old rules and to seek only provisional equivalence rather than full equivalence. Nevertheless, considerable work was done on computing reference values, and we therefore present those results.

7.2.1 Thermal converter Ballantine

In this case, it would be possible to use the method of [6]. However, there was no provision in the protocol for identifying and excluding outliers. Therefore we use a simple mean of all measuremements as the reference value. The multiple results from the pilot are combined into one value and one uncertainty, and the same is done for the two official PTB results (PTB-1 and PTB-3). This is implemented in section 7.3.

7.2.2 Power sensor R&S

There is a basic problem in treating the power-sensor results, due to the fact that the sensor had to be repaired and replaced several times during the course of the comparison, and therefore we must contend with the possibility that the different participants may have been measuring sensors with different characteristics. We are able to deal with this situation because the pilot lab (VSL) measured the sensor before and after each repair or replacement.

One possible strategy would be to compute the differences between the results obtained on the same device by a participant and the pilot lab, thereby referencing all the results to the pilot lab’s measurements. There is, however, a significant problem with this procedure. The uncertainty in the difference between a participant’s result and the appropriate VSL result is the root sum of squares of the two individual uncertainties. But the uncertainties in many of the VSL results are quite large (cf. Figs. 2 – 10), and so in these cases the uncertainty in the difference will be dominated by the VSL uncertainty, and it will be so large as to obscure all but the most extreme disagreements.

We therefore adopt a different strategy for dealing with potential changes in the power sensor. We observe that, although different sensors may in principle have different characteristics, in practice the RF-dc difference does *not* differ or change. This is seen by comparing the VSL measurements before and after each change in Figures 2 – 10. The RF-dc difference is very nearly the same before and after every change or repair at every frequency. Any small differences are comparable to the differences observed for the thermal converter (Ballantine) sensor, which was the same throughout the comparison. Therefore, since there is evidence that the different power sensors are very nearly the same (and no evidence of any significant difference), and since the alternative (subtracting the appropriate VSL measurement) washes out too much information, we choose to treat the power-sensor results as if all the power sensors are the same. The reference values are then computed in the usual manner, by taking the mean of the results from all the participants.

7.2.3 Check measurements

In principle this measurement is not part of the comparison, but should give confidence in the stability of the devices and the individual measurement set-up. The results are summarized in Table 3 and Figure 11. In Table 3, the “Unc” (%) column is the larger of the average fractional uncertainty and the standard deviation of the fractional uncertainties, and the Max column is the larger of the two preceding columns.

Table 3: Results of the check measurements divided in two groups (pilot and other participants)

Frequency		Average (%)	StDev (%)	"Unc" (%)	Max (%)
1	Others	0.01	0.04	0.03	0.04
	VSL	0.00	0.12	0.23	0.23
10	Others	-0.07	0.07	0.03	0.07
	VSL	-0.11	0.03	0.08	0.08
50	Others	-0.33	0.11	0.09	0.11
	VSL	-0.42	0.08	0.08	0.08
100	Others	-1.14	0.27	0.12	0.27
	VSL	-1.28	0.07	0.09	0.09
200	Others	-4.07	0.86	0.13	0.86
	VSL	-4.46	0.18	0.10	0.18
300	Others	-7.77	1.61	0.14	1.61
	VSL	-8.30	0.68	0.31	0.68
500	Others	-13.55	2.58	0.25	2.58
	VSL	-14.18	1.31	0.18	1.31
700	Others	-9.83	2.27	0.29	2.27
	VSL	-10.22	1.90	0.36	1.90
1000	Others	16.27	4.86	0.43	4.86
	VSL	17.35	1.47	0.87	1.47

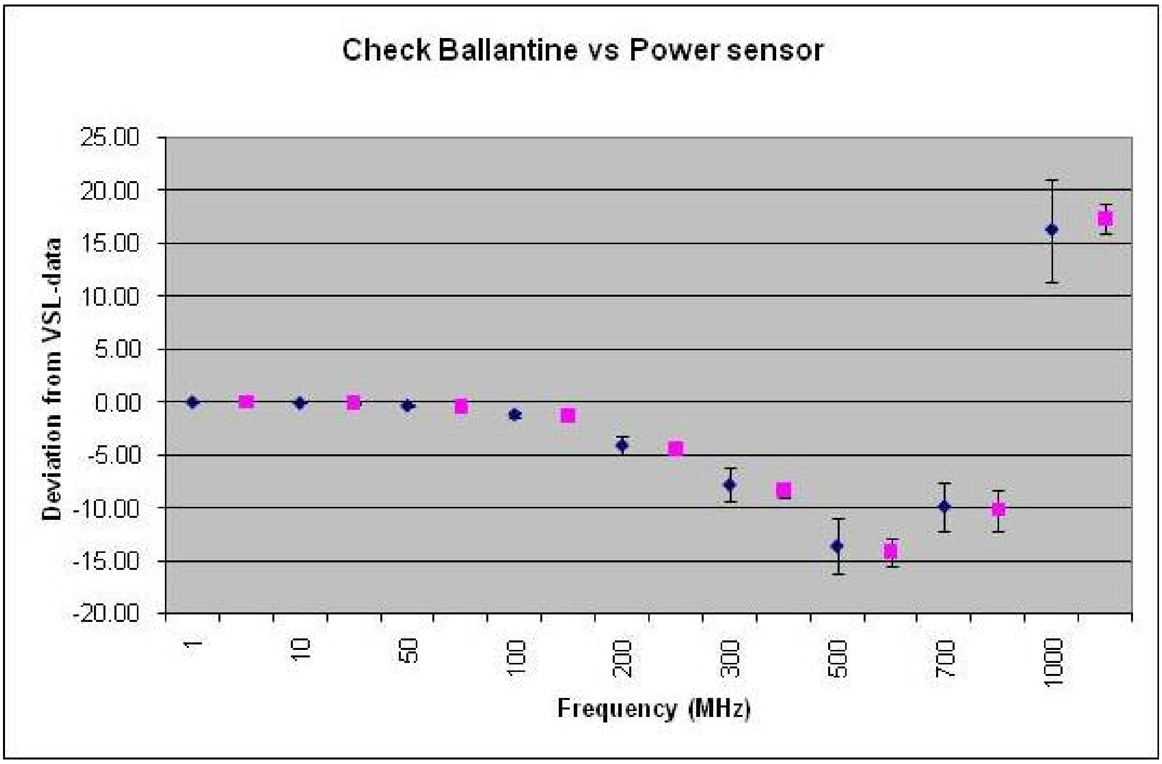


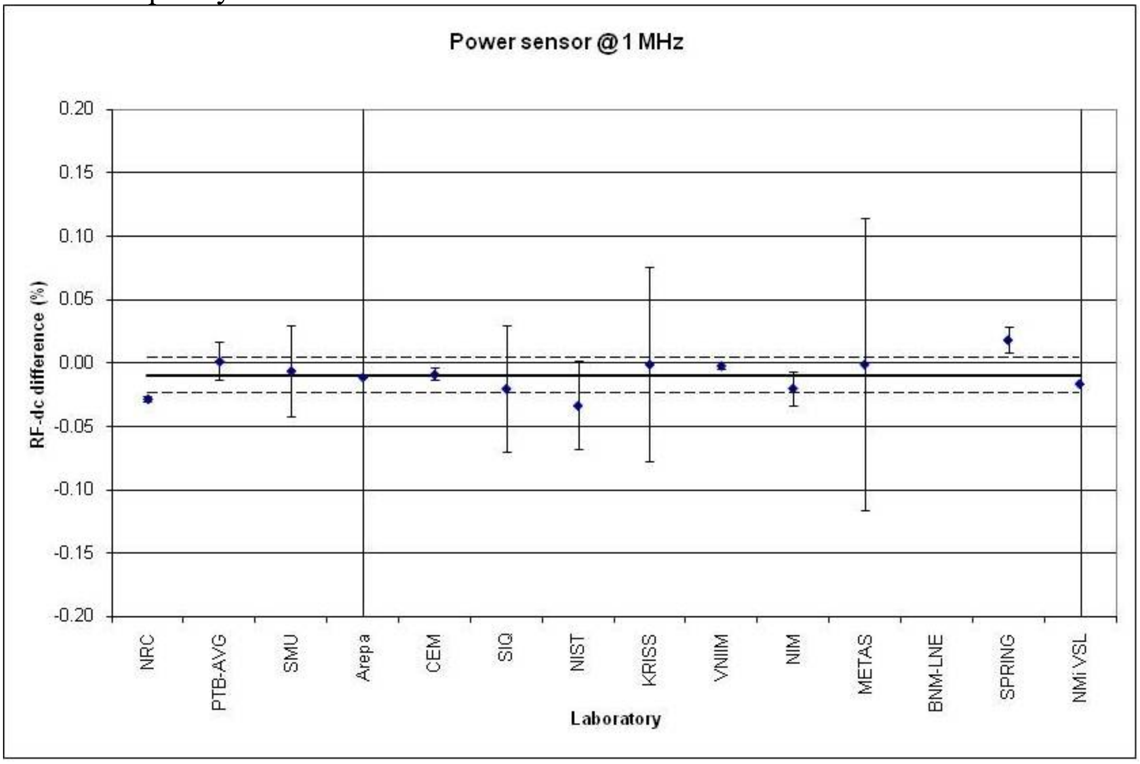
Figure 11: A summary of the check measurements in which the response of the thermal converter is measured against the response of the power sensor. Data are given in Table 3. The pink squares refer to VSL data. The diamonds refer to the average results from the other participants. The VSL data are offset in frequency, one bin to the right of the average results.

7.3 Values and uncertainties

From the information on the RF-dc differences for the two DUTs, a reference value for each DUT is computed along the lines suggested above. There was no attempt to identify and exclude outliers. The reference value is based on the unweighted mean of all measurements and the associated standard uncertainty. These are indicated in the graphs of Figs. 12 – 20 as a bold line and two dashed lines (+ and – “limits”). The graphs and the accompanying tables (Tables 4 – 12) contain the measured values and uncertainties reported by the participants. The result of the pilot laboratory is an averaged value and is given as last of the list (all others are in chronological order). PTB acted a few times as an intermediate check, on request from the pilot laboratory, and therefore there are multiple PTB measurements. One of these measurements (PTB-2) was an informal check performed at the request of the pilot laboratory, and it is not included in the reference-value computation. The other two measurements (PTB-1 and PTB-3) were full measurements, and we have combined them into a single PTB result for inclusion in the reference-value computation.

For each frequency an overview of the results is given by means of two figures and one table containing the data of the two DUTs. The data are presented in terms of percentage instead of using parts per million or just the unit. This choice leads to a reasonable presentation without too much change in the graphs and without too many insignificant digits.

7.3.1 Frequency: 1 MHz



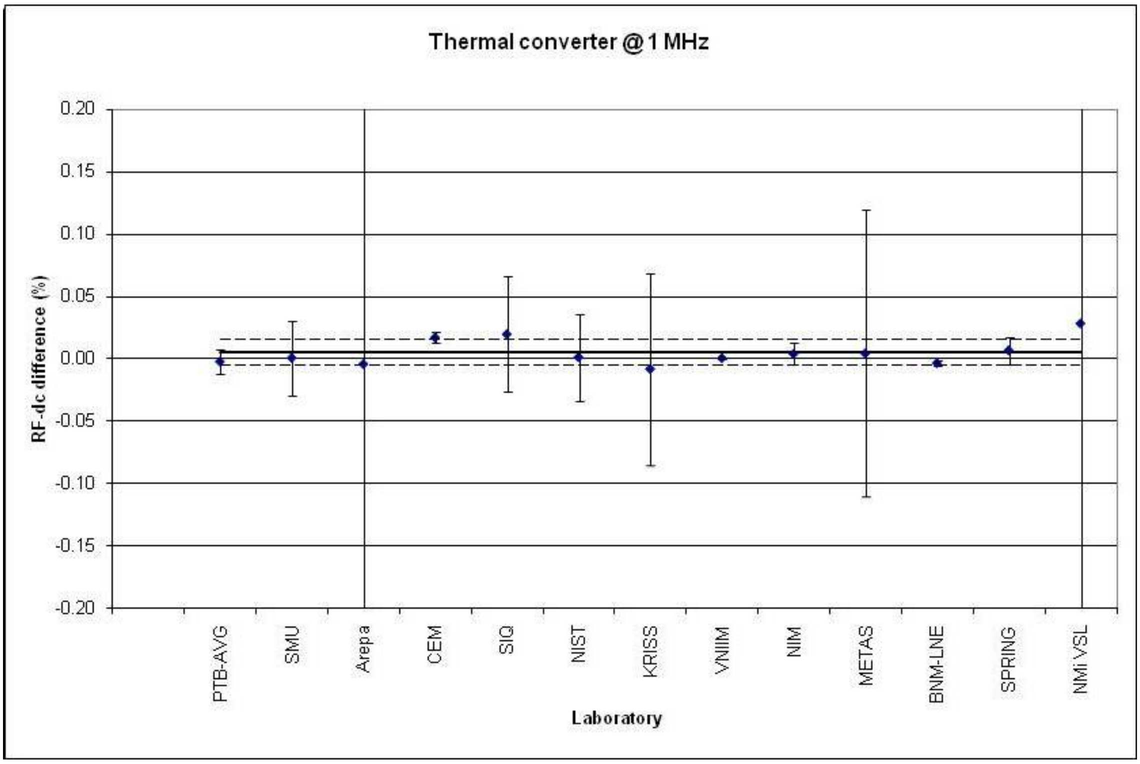


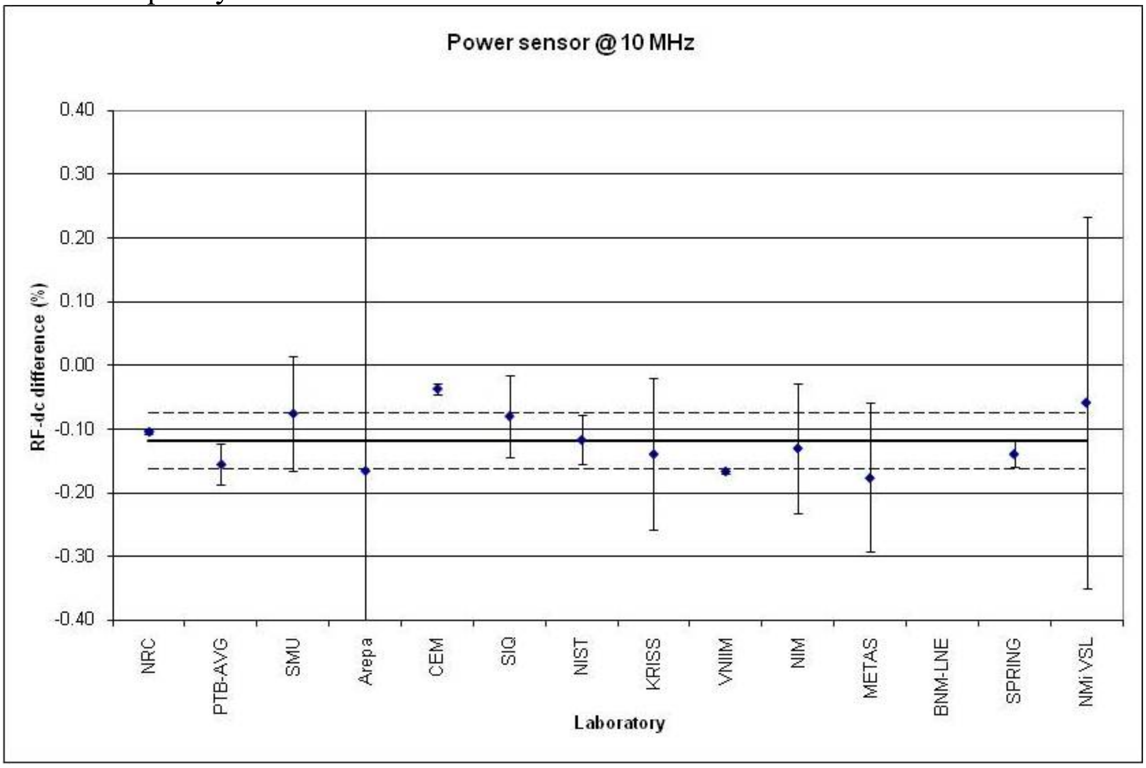
Figure 12: Overview of the results obtained at a frequency of 1 MHz. The same data are given in Table 4. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 4: Results at 1 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	-0.028	0.002			
PTB	0.002	0.015	PTB	-0.002	0.010
SMU	-0.006	0.036	SMU	0.001	0.030
Arepa	-0.011	0.610	Arepa	-0.004	0.610
CEM	-0.009	0.005	CEM	0.017	0.004
SIQ	-0.020	0.050	SIQ	0.020	0.046
NIST	-0.033	0.035	NIST	0.002	0.035
KRISS	-0.001	0.077	KRISS	-0.008	0.077
VNIIM	-0.002	0.003	VNIIM	0.001	0.001
NIM	-0.020	0.014	NIM	0.004	0.009
METAS	-0.001	0.115	METAS	0.005	0.115
			BNM-LNE	-0.003	0.002
SPRING	0.018	0.010	SPRING	0.007	0.011
VSL	-0.016	0.380	VSL	0.029	0.374
Average	-0.010	0.104	Average	0.005	0.102
Stdev.	0.014	0.183	Stdev.	0.011	0.183

In general there is a good agreement among the participants, although there are several cases in which pairs of laboratories differ by more than their stated uncertainties, and there are some laboratories that have significantly larger uncertainties.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.2 Frequency 10 MHz



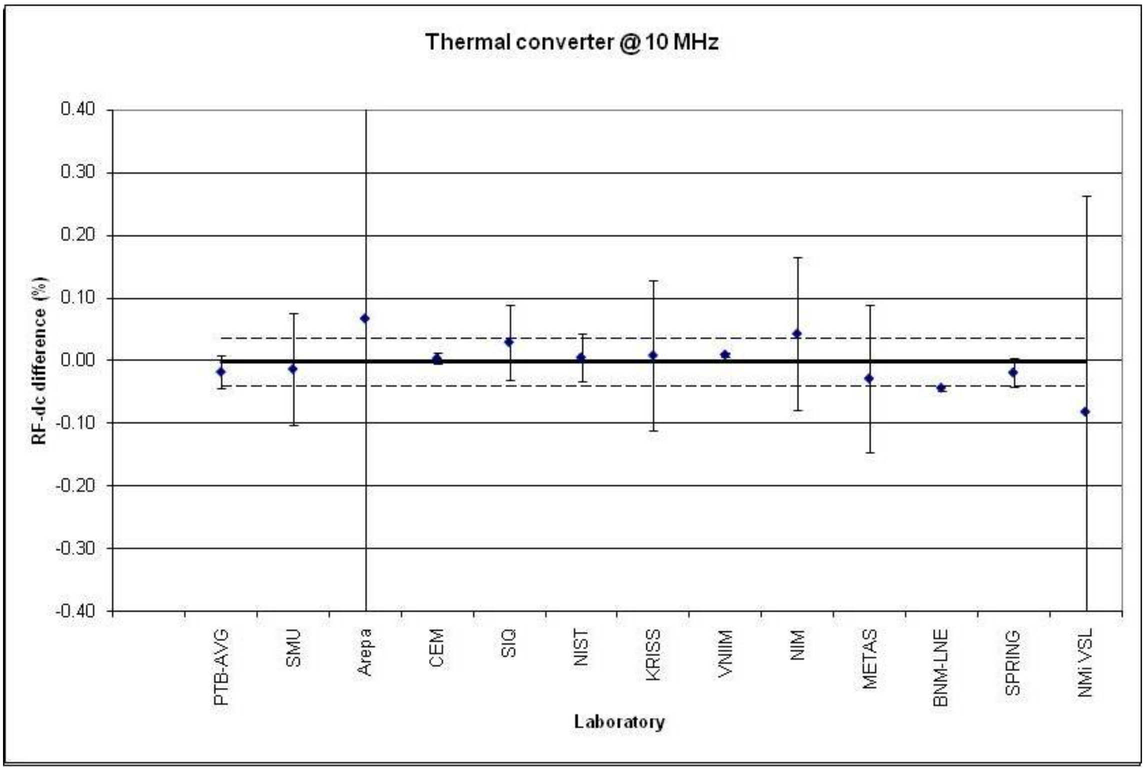


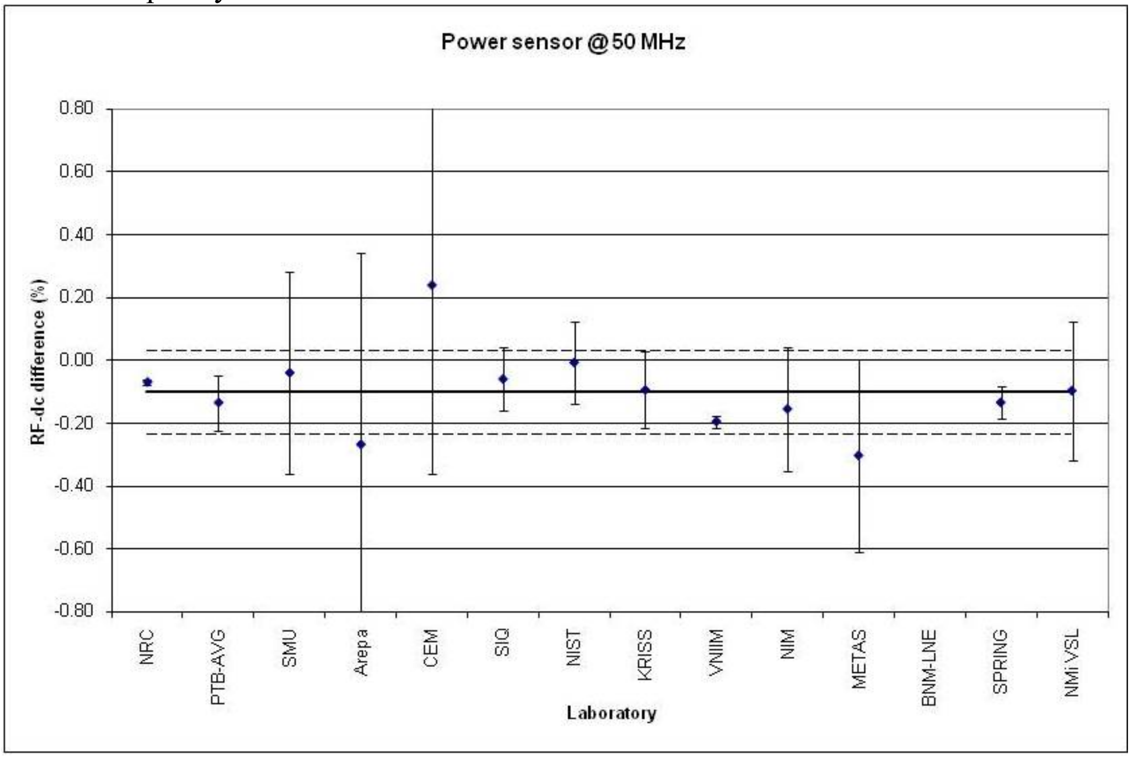
Figure 13: Overview of the results obtained at a frequency of 10 MHz. The same data are given in Table 5. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 5: Results at 10 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	-0.104	0.003			
PTB	-0.155	0.033	PTB	-0.018	0.027
SMU	-0.076	0.090	SMU	-0.013	0.090
Arepa	-0.165	0.610	Arepa	0.068	0.610
CEM	-0.038	0.008	CEM	0.004	0.008
SIQ	-0.080	0.065	SIQ	0.030	0.060
NIST	-0.117	0.039	NIST	0.006	0.039
KRISS	-0.139	0.120	KRISS	0.009	0.120
VNIIM	-0.166	0.004	VNIIM	0.010	0.003
NIM	-0.130	0.102	NIM	0.044	0.121
METAS	-0.176	0.117	METAS	-0.028	0.118
			BNM-LNE	-0.043	0.004
SPRING	-0.139	0.020	SPRING	-0.019	0.022
VSL	-0.059	0.291	VSL	-0.081	0.346
Average	-0.119	0.116	Average	-0.002	0.121
Stdev.	0.044	0.168	Stdev.	0.038	0.173

In general there is a good agreement among the participants, although there are several cases in which pairs of laboratories differ by more than their stated uncertainties, and there are some laboratories that have significantly larger uncertainties.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.3 Frequency 50 MHz



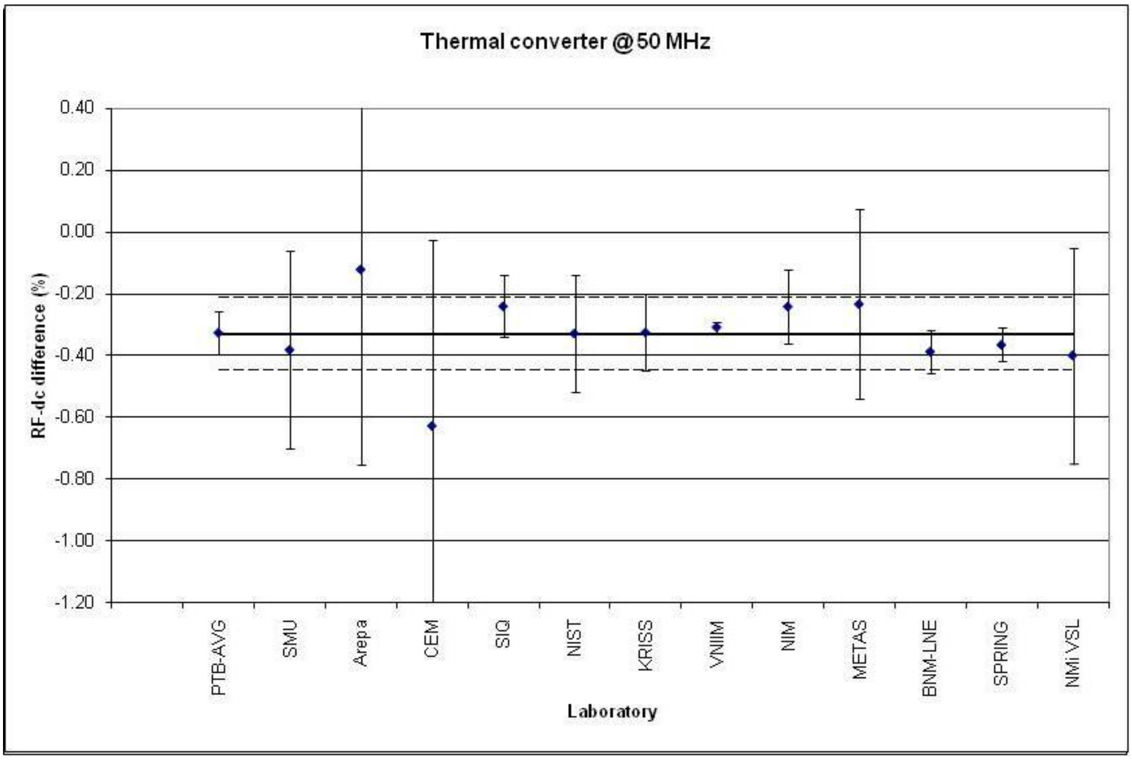


Figure 14: Overview of the results obtained at a frequency of 50 MHz. The same data are given in Table 6. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

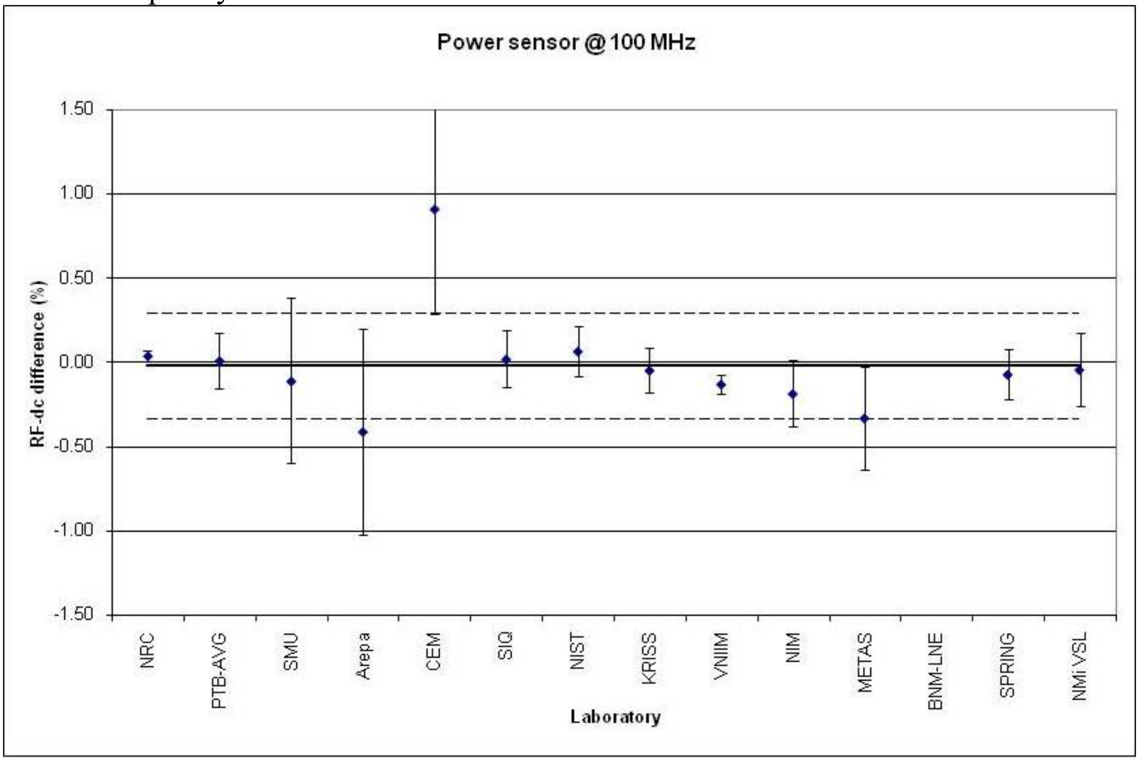
Table 6: Results at 50 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	-0.070	0.010			
PTB	-0.135	0.087	PTB	-0.325	0.070
SMU	-0.040	0.320	SMU	-0.380	0.320
Arepa	-0.268	0.610	Arepa	-0.121	0.630
CEM	0.239	0.600	CEM	-0.625	0.600
SIQ	-0.060	0.100	SIQ	-0.240	0.100
NIST	-0.008	0.130	NIST	-0.327	0.190
KRISS	-0.094	0.123	KRISS	-0.324	0.124
VNIIM	-0.195	0.019	VNIIM	-0.307	0.017
NIM	-0.155	0.196	NIM	-0.241	0.119
METAS	-0.303	0.307	METAS	-0.233	0.307
			BNM-LNE	-0.386	0.068
SPRING	-0.134	0.050	SPRING	-0.364	0.055
VSL	-0.097	0.220	VSL	-0.398	0.348
Average	-0.102	0.213	Average	-0.328	0.227
Stdev.	0.133	0.199	Stdev.	0.118	0.203

In general there is a good agreement among the participants, although some have significantly larger uncertainties, and there is one pair of laboratories that differ by more than their stated uncertainties.

In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.4 Frequency 100 MHz



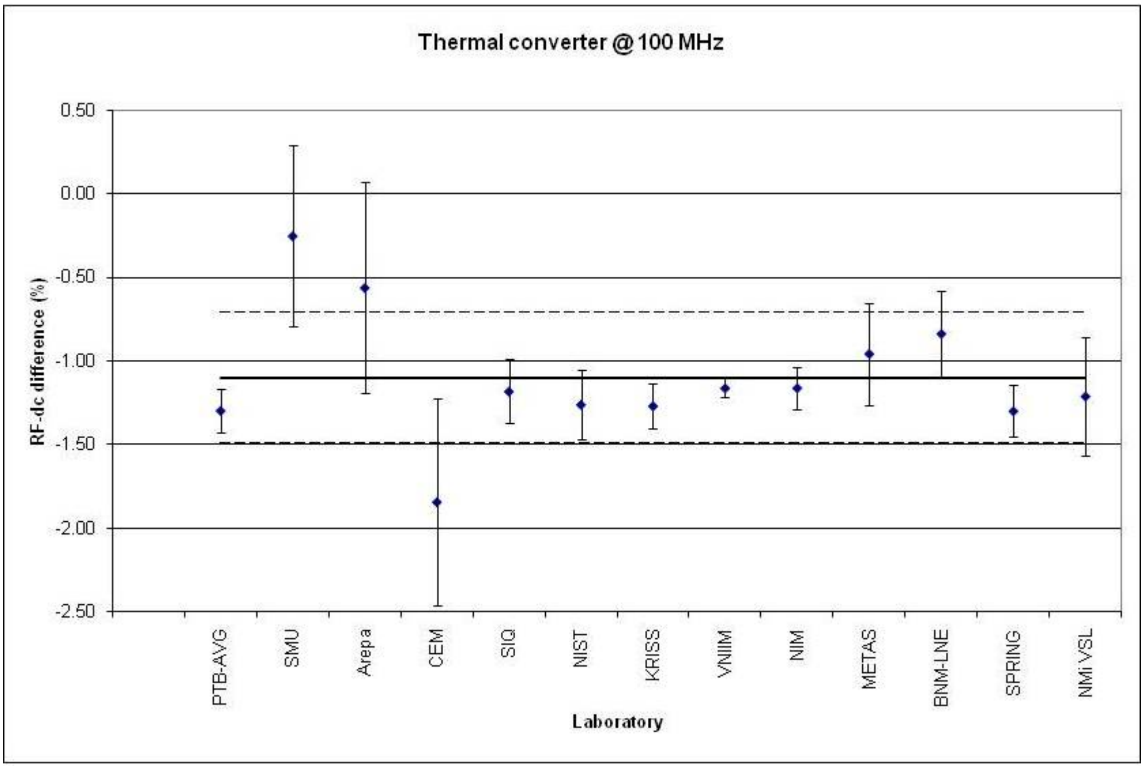


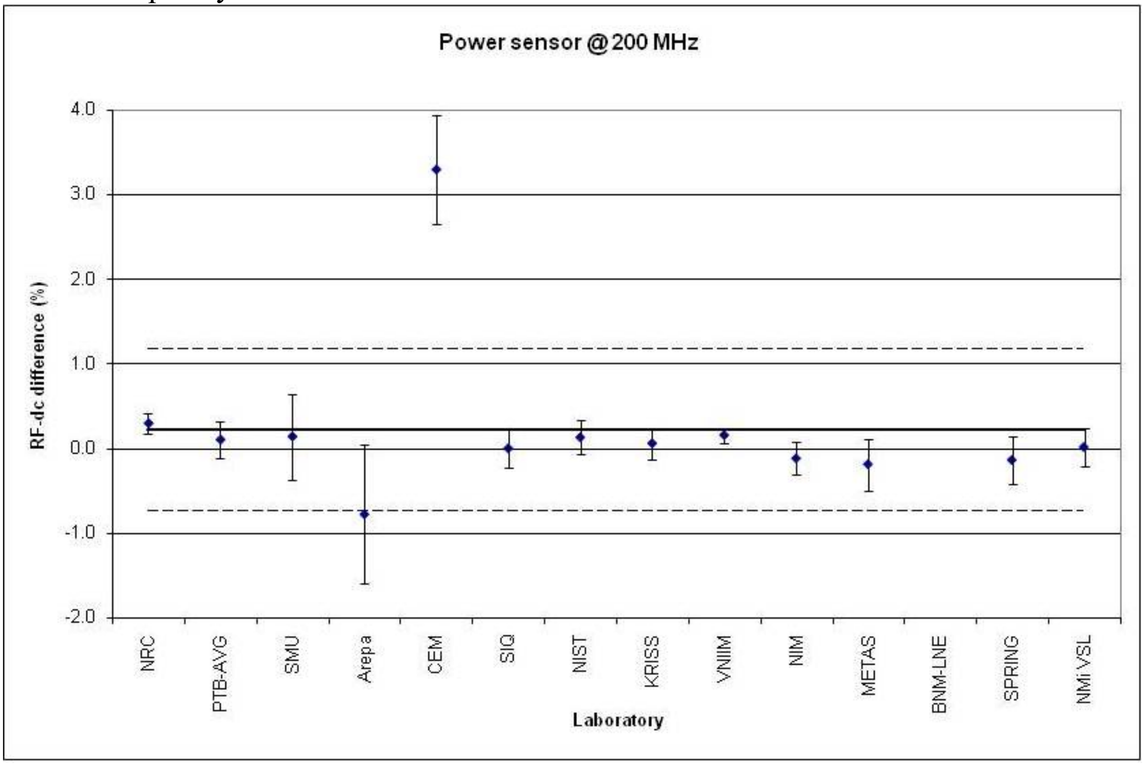
Figure 15: Overview of the results obtained at a frequency of 100 MHz. The same data are given in Table 7. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 7: Results at 100 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	0.040	0.031			
PTB	0.012	0.163	PTB	-1.295	0.130
SMU	-0.110	0.490	SMU	-0.250	0.540
Arepa	-0.410	0.610	Arepa	-0.560	0.630
CEM	0.910	0.620	CEM	-1.842	0.620
SIQ	0.020	0.170	SIQ	-1.180	0.190
NIST	0.067	0.150	NIST	-1.259	0.210
KRISS	-0.046	0.134	KRISS	-1.267	0.136
VNIIM	-0.129	0.057	VNIIM	-1.160	0.057
NIM	-0.184	0.196	NIM	-1.160	0.126
METAS	-0.329	0.307	METAS	-0.955	0.307
			BNM-LNE	-0.835	0.256
SPRING	-0.071	0.150	SPRING	-1.298	0.155
VSL	-0.042	0.218	VSL	-1.209	0.352
Average	-0.021	0.254	Average	-1.098	0.285
Stdev.	0.313	0.197	Stdev.	0.389	0.195

In general there is a good agreement among the participants, although some have significantly larger uncertainties.
The results from CEM show a relatively large deviation from the others. For SMU and Arepa the results show a much smaller deviation.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.5 Frequency 200 MHz



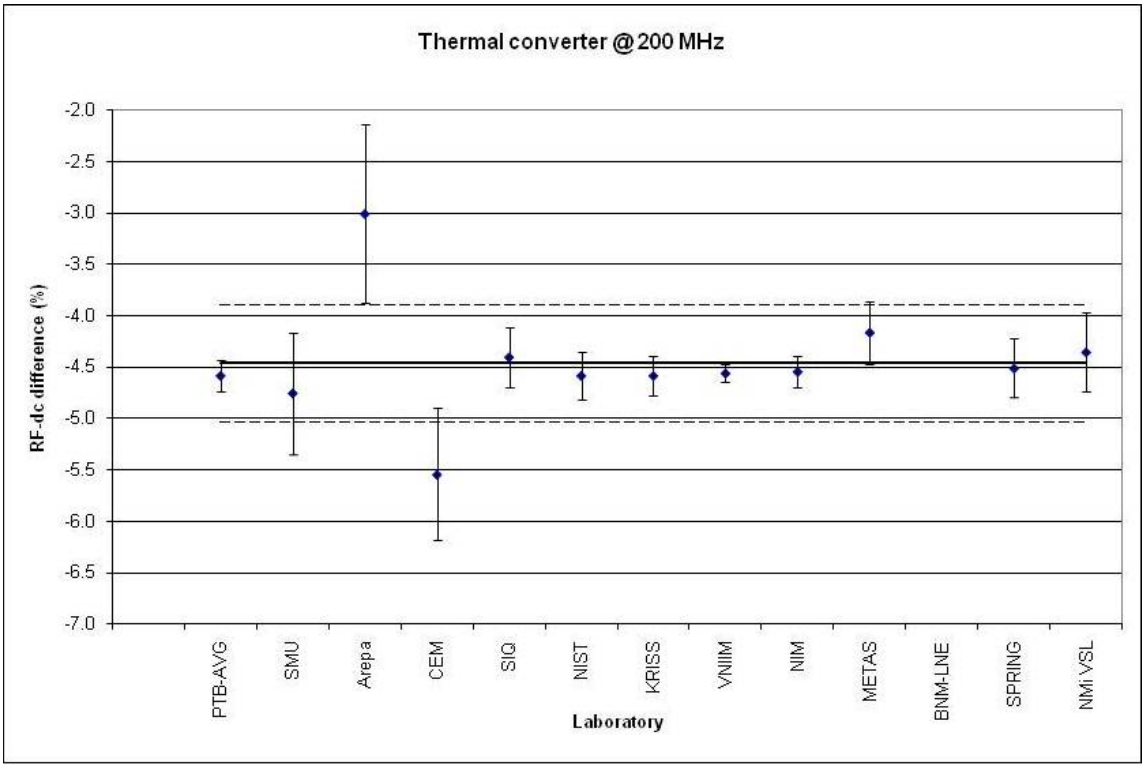


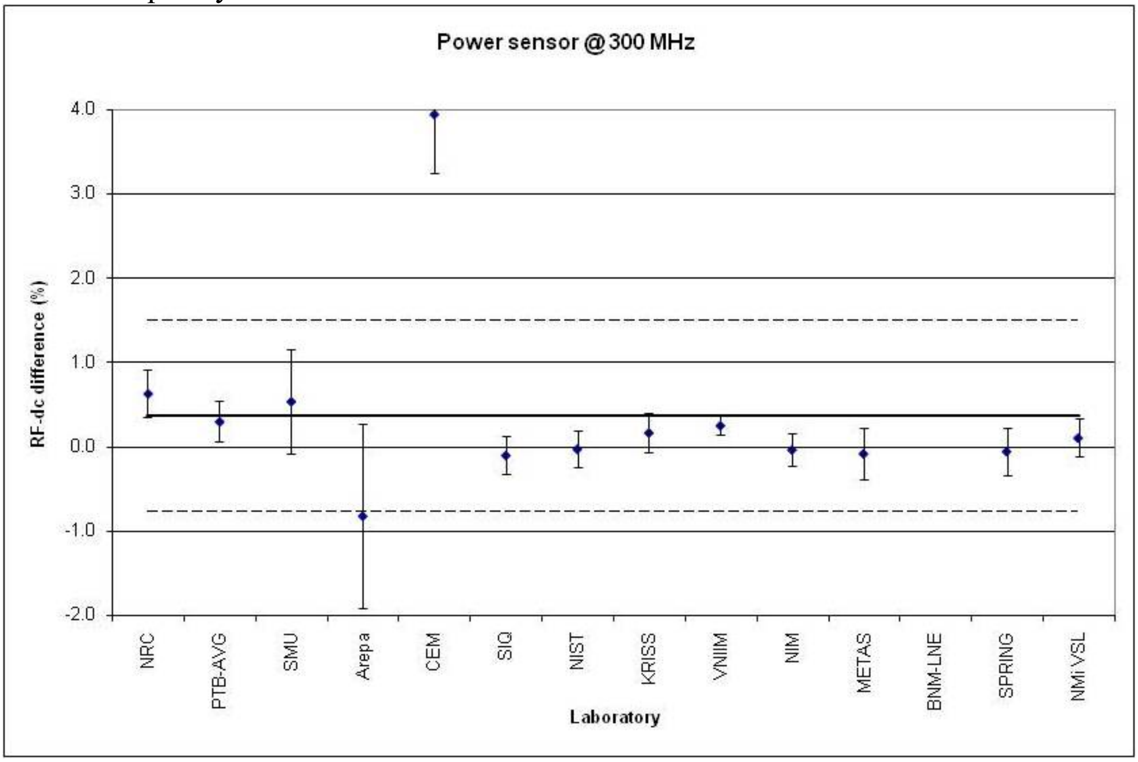
Figure 16: Overview of the results obtained at a frequency of 200 MHz. The same data are given in Table 8. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 8: Results at 200 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	0.297	0.127			
PTB	0.103	0.220	PTB	-4.580	0.150
SMU	0.140	0.510	SMU	-4.750	0.590
Arepa	-0.780	0.820	Arepa	-3.010	0.870
CEM	3.296	0.640	CEM	-5.539	0.640
SIQ	0.000	0.230	SIQ	-4.400	0.290
NIST	0.130	0.200	NIST	-4.580	0.230
KRISS	0.060	0.184	KRISS	-4.580	0.194
VNIIM	0.157	0.087	VNIIM	-4.556	0.087
NIM	-0.117	0.191	NIM	-4.541	0.149
METAS	-0.187	0.307	METAS	-4.162	0.307
			BNM-LNE		
SPRING	-0.137	0.280	SPRING	-4.509	0.285
VSL	0.016	0.220	VSL	-4.352	0.387
Average	0.229	0.309	Average	-4.463	0.348
Stdev.	0.958	0.216	Stdev.	0.565	0.236

In general there is a good agreement among the participants, although some have significantly larger uncertainties.
The results from CEM show a clear deviation from the others, while the Arepa results show a much smaller deviation.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.6 Frequency 300 MHz



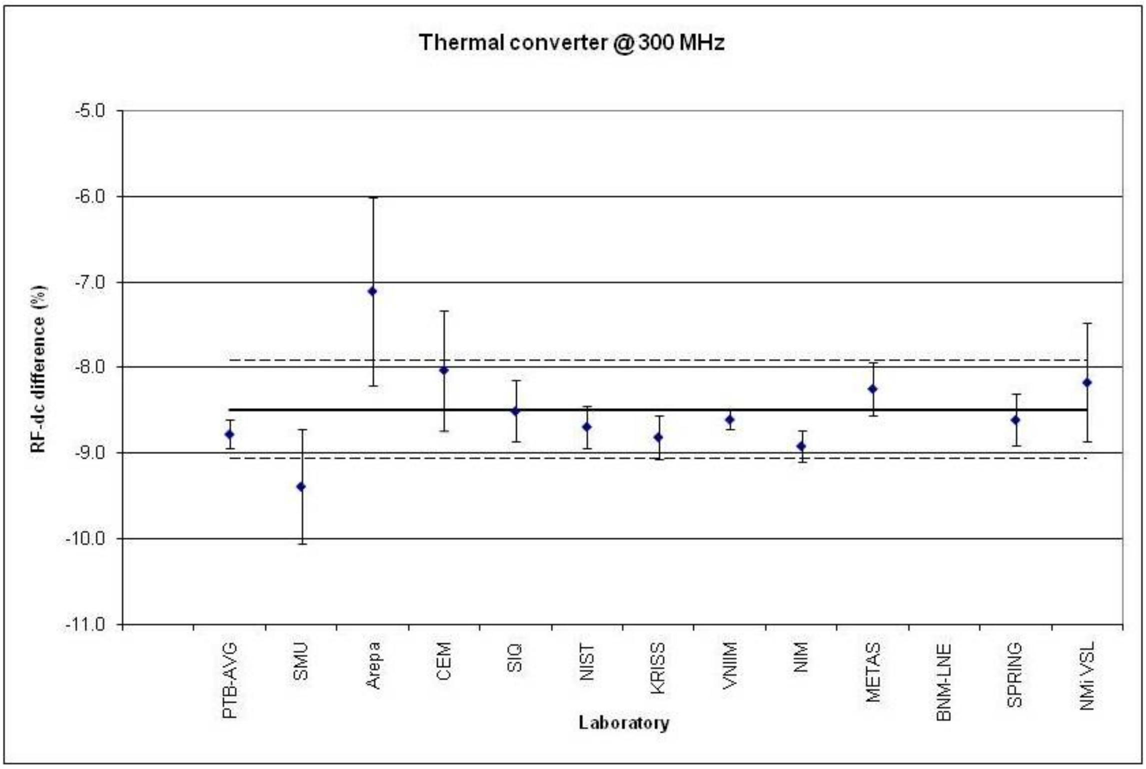


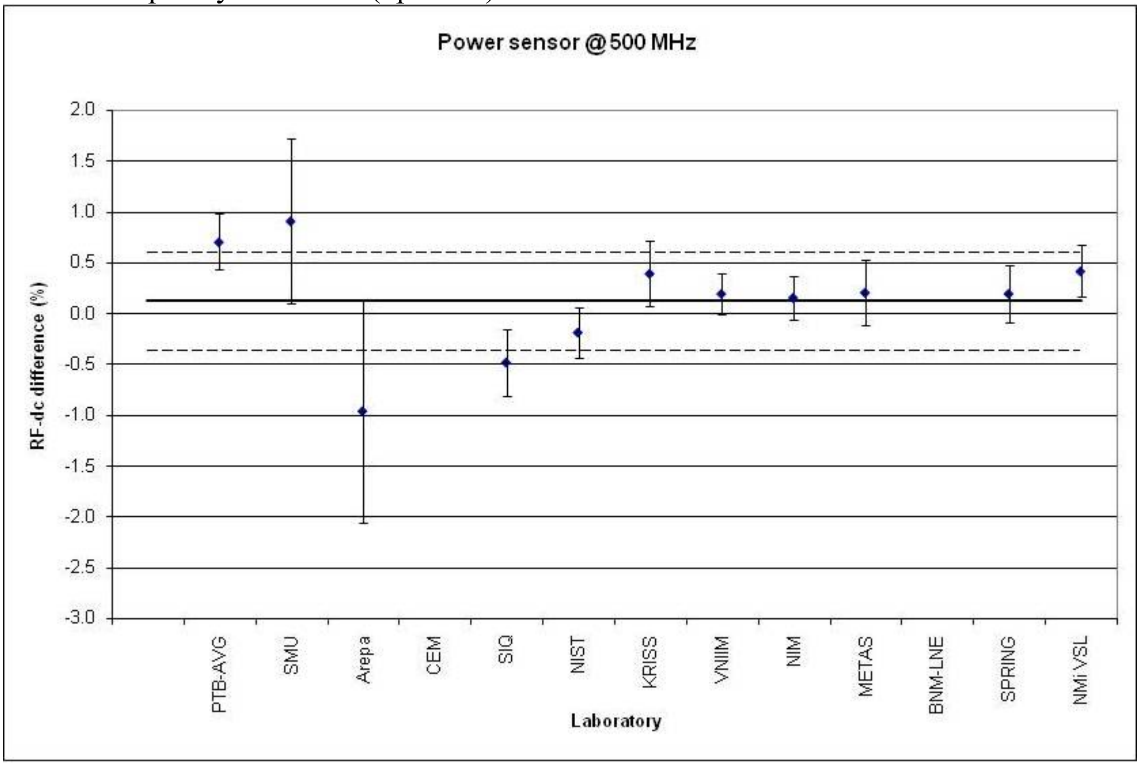
Figure 17: Overview of the results obtained at a frequency of 300 MHz. The same data are given in Table 9. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 9: Results at 300 MHz.

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
NRC	0.633	0.287			
PTB	0.300	0.240	PTB	-8.770	0.170
SMU	0.540	0.620	SMU	-9.380	0.670
Arepa	-0.820	1.100	Arepa	-7.100	1.100
CEM	3.948	0.700	CEM	-8.022	0.700
SIQ	-0.100	0.230	SIQ	-8.500	0.360
NIST	-0.025	0.210	NIST	-8.683	0.250
KRISS	0.169	0.232	KRISS	-8.804	0.258
VNIIM	0.254	0.117	VNIIM	-8.598	0.117
NIM	-0.032	0.200	NIM	-8.908	0.182
METAS	-0.079	0.307	METAS	-8.241	0.307
			BNM-LNE		
SPRING	-0.053	0.280	SPRING	-8.602	0.300
VSL	0.107	0.224	VSL	-8.164	0.690
Average	0.372	0.365	Average	-8.481	0.425
Stdev.	1.131	0.277	Stdev.	0.566	0.297

In general there is a good agreement among the participants, although some have significantly larger uncertainties.
The results from CEM show a clear deviation from the others, while the Arepa results show a much smaller deviation. This is especially the case for the power sensor.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.7 Frequency 500 MHz (optional)



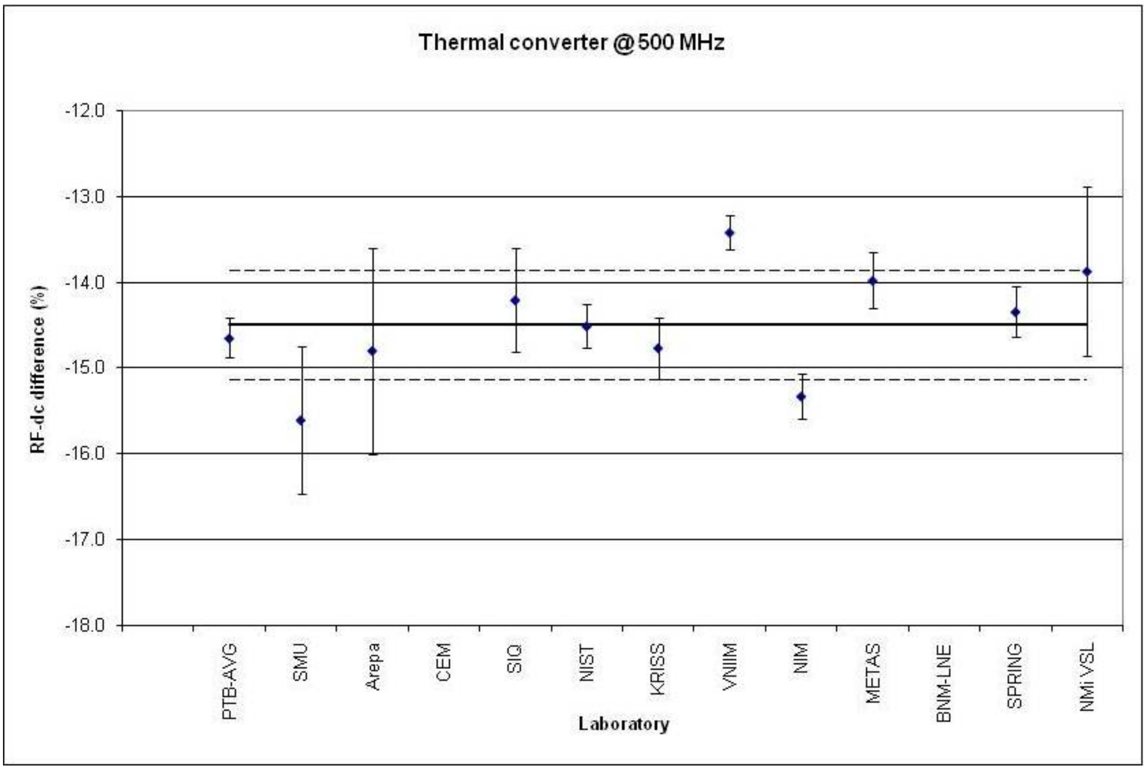


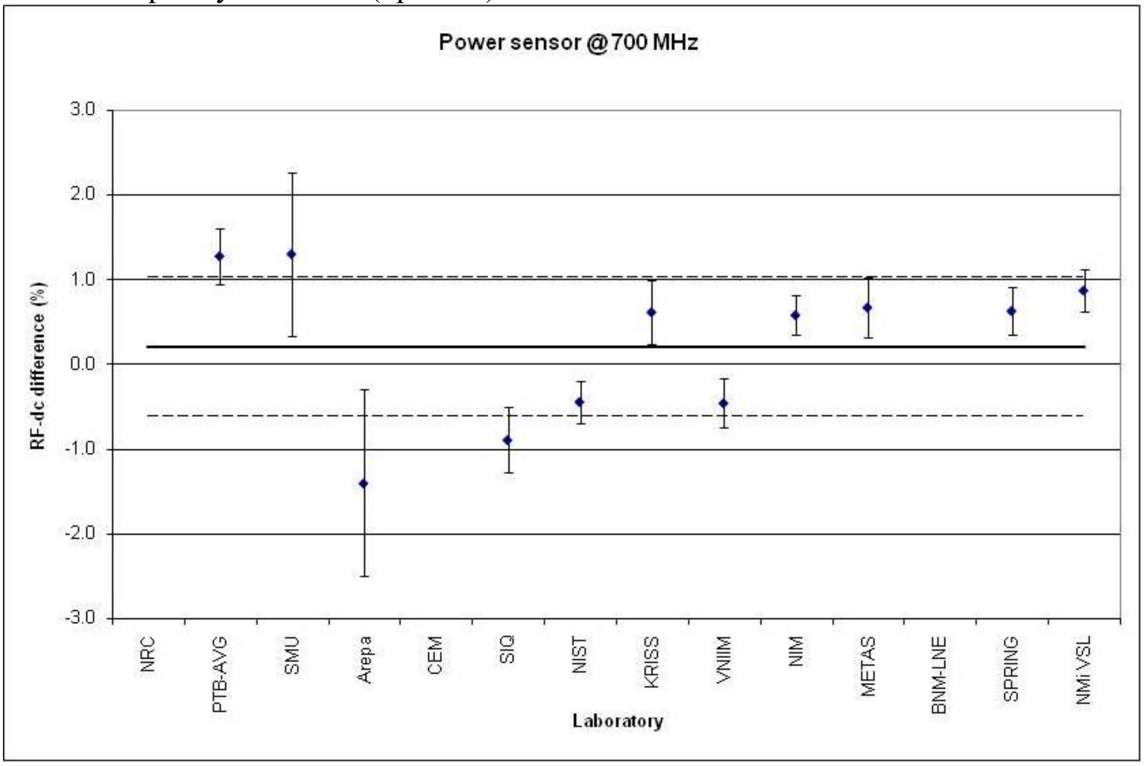
Figure 18: Overview of the results obtained at a frequency of 500 MHz. The same data are given in Table 10. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 10: Results at 500 MHz (optional frequency).

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
PTB	0.705	0.275	PTB	-14.645	0.230
SMU	0.910	0.810	SMU	-15.600	0.860
Arepa	-0.960	1.100	Arepa	-14.790	1.200
CEM			CEM		
SIQ	-0.480	0.330	SIQ	-14.200	0.600
NIST	-0.185	0.250	NIST	-14.504	0.250
KRISS	0.395	0.316	KRISS	-14.759	0.357
VNIIM	0.197	0.203	VNIIM	-13.412	0.204
NIM	0.157	0.212	NIM	-15.323	0.265
METAS	0.207	0.327	METAS	-13.972	0.327
			BNM-LNE		
SPRING	0.196	0.280	SPRING	-14.337	0.300
VSL	0.417	0.252	VSL	-13.864	0.982
Average	0.120	0.335	Average	-14.491	0.507
Stdev.	0.483	0.301	Stdev.	0.636	0.231

CEM did not measure at this frequency. In general there is a good agreement between the participants**.**
The Arepa result for the power sensor shows a somewhat large deviation. A few others show smaller deviations.
For the thermal converter the uncertainty statements are quite small compared to the spread in the results.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.8 Frequency 700 MHz (optional)



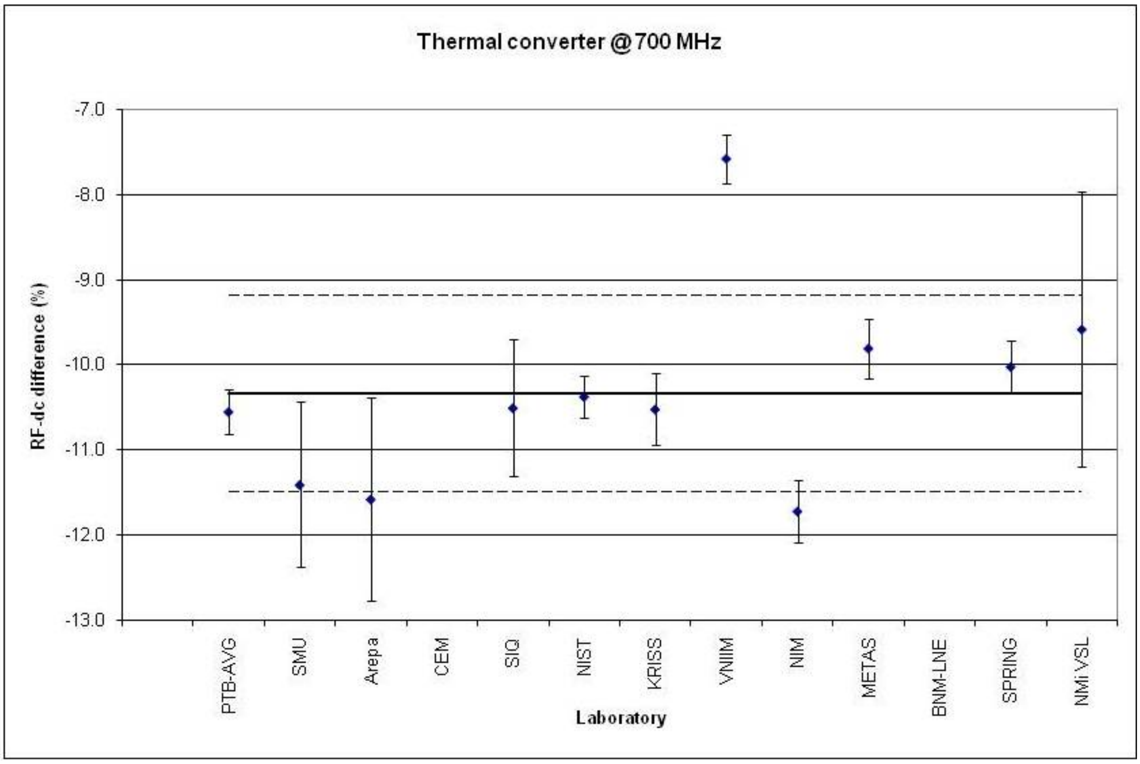


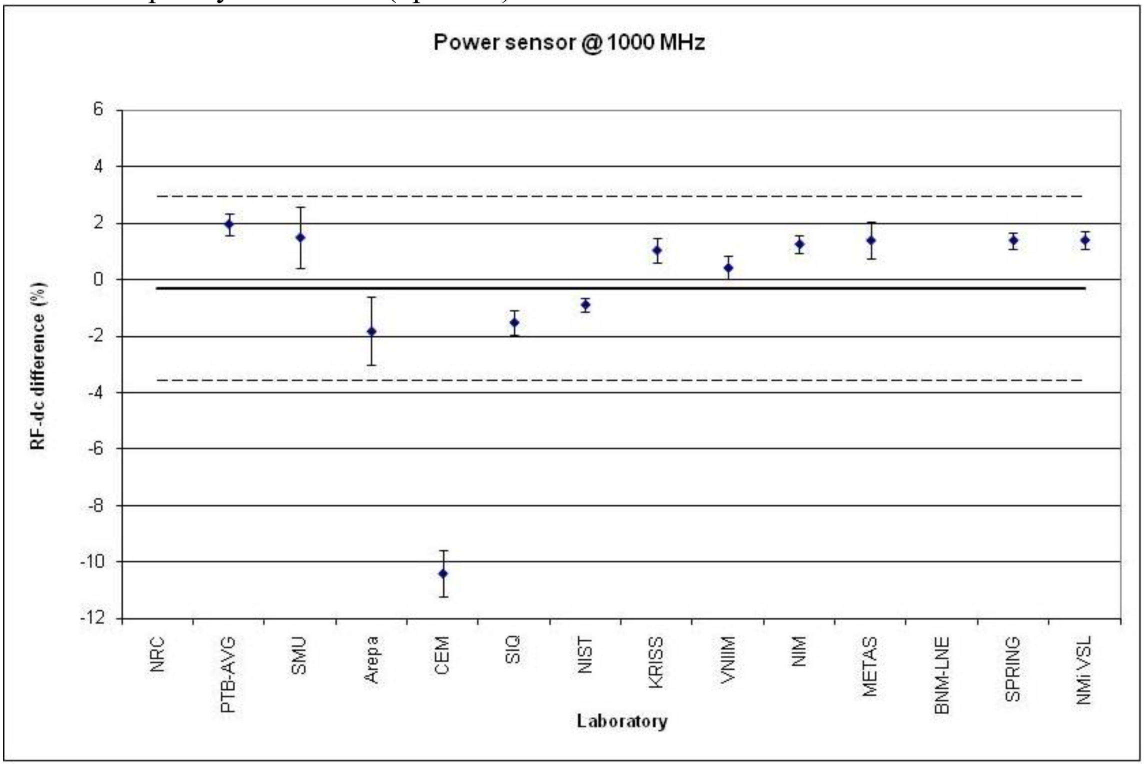
Figure 19: Overview of the results obtained at a frequency of 700 MHz. The same data are given in Table 11. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 11: Results at 700 MHz (optional frequency).

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
PTB	1.275	0.330	PTB	-10.545	0.260
SMU	1.300	0.970	SMU	-11.400	0.970
Arepa	-1.400	1.100	Arepa	-11.570	1.200
CEM			CEM		
SIQ	-0.890	0.380	SIQ	-10.500	0.800
NIST	-0.441	0.250	NIST	-10.368	0.250
KRISS	0.615	0.377	KRISS	-10.515	0.417
VNIIM	-0.456	0.291	VNIIM	-7.578	0.293
NIM	0.581	0.239	NIM	-11.711	0.361
METAS	0.671	0.353	METAS	-9.801	0.352
			BNM-LNE		
SPRING	0.630	0.280	SPRING	-10.017	0.300
VSL	0.870	0.255	VSL	-9.578	1.610
Average	0.212	0.371	Average	-10.326	0.619
Stdev.	0.827	0.320	Stdev.	1.150	0.461

CEM did not measure at this frequency.
In general there is a wide spread in the results from the participants**.**
The VNIIM result for the thermal converter shows a large deviation compared to its uncertainty.
For the thermal converter the uncertainty statements are often quite small compared to the spread in the results.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.3.9 Frequency 1000 MHz (optional)



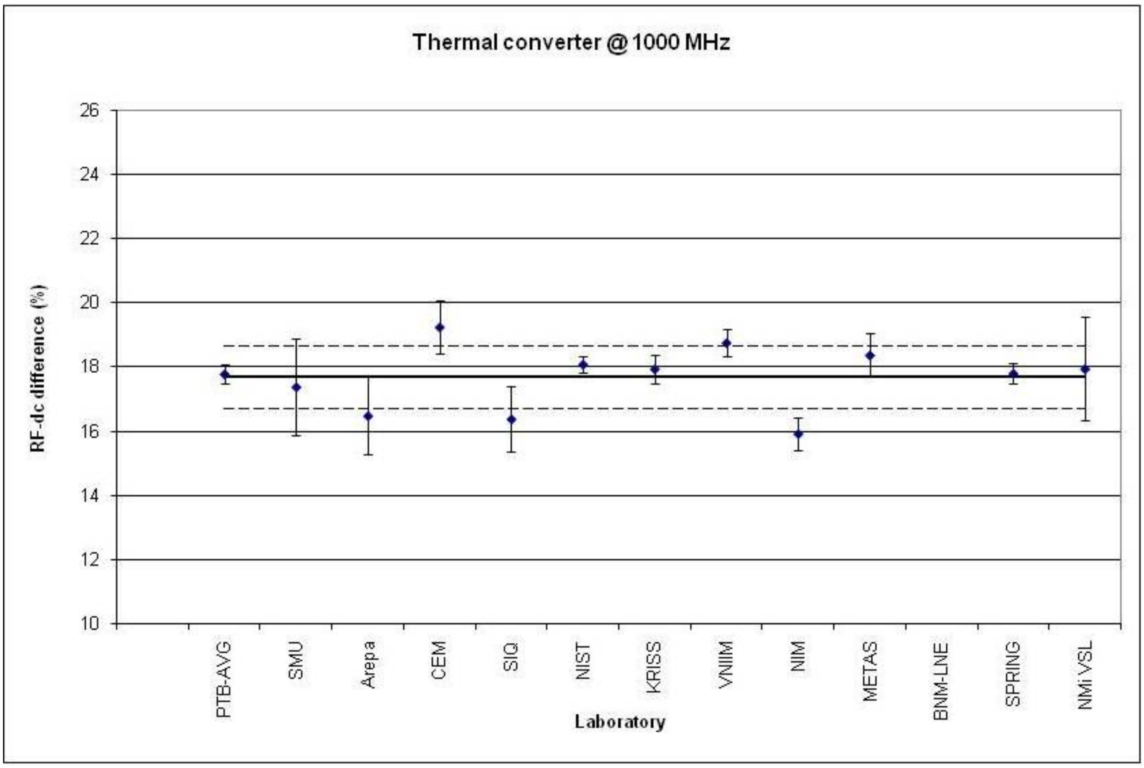


Figure 20: Overview of the results obtained at a frequency of 1000 MHz. The same data are given in Table 12. The bold line refers to the unweighted mean and the dashed lines indicate the k=1 lines.

Table 12: Results at 1000 MHz (optional frequency).

Power sensor			Thermal converter		
Laboratory	Value (%)	Unc (k=1)	Laboratory	Value (%)	Unc (k=1)
PTB	1.970	0.380	PTB	17.805	0.310
SMU	1.500	1.070	SMU	17.400	1.500
Arepa	-1.820	1.200	Arepa	16.500	1.200
CEM	-10.388	0.830	CEM	19.266	0.830
SIQ	-1.510	0.440	SIQ	16.400	1.000
NIST	-0.878	0.250	NIST	18.105	0.250
KRISS	1.047	0.435	KRISS	17.959	0.440
VNIIM	0.423	0.406	VNIIM	18.780	0.408
NIM	1.264	0.313	NIM	15.941	0.500
METAS	1.397	0.667	METAS	18.391	0.667
			BNM-LNE		
SPRING	1.400	0.290	SPRING	17.823	0.320
VSL	1.404	0.298	VSL	17.964	1.614
Average	-0.322	0.506	Average	17.695	0.753
Stdev.	3.264	0.343	Stdev.	0.988	0.476

In general there is a wide spread in the results from the participants compared to the stated uncertainties. This is influnced by the deviating value from CEM for the power sensor.
For the thermal converter the uncertainty statements are often quite small compared to the spread in the results.
In the bottom row the first entry refers to the statistical spread in the values, whereas the second one refers to the statistical spread in the stated uncertainty.

7.4 Uncertainty budgets

All participants were requested to submit detailed uncertainty budgets for their measurements. The comparison protocol (**Appendix C**) included a form that could be used for this purpose, and most participants used this form or something similar. The uncertainty budgets of the participants are compiled in **Appendix D**.

8 Conclusions

A long time has passed since the start of the comparison. Due to breakdown of devices and analysis problems at the pilot laboratory, a critical evaluation of the comparison is not simple. In general the stated uncertainties range from 100 ppm at low frequencies up to 0.3 % at 300 MHz and up to 0.5 % at the optional frequency of 1 GHz. Most results are in line with the stated uncertainties, but there are a number of cases in which pairs of laboratories differ by more than their stated uncertainties. The definition of RF-dc transfer warrants further discussion.

9 Follow-up

It is not clear in what way a suitable follow-up can be carried out. A major problem is that many laboratories have indicated a reduced interest in this field.

10 References

[1] Final report on CCEM-K6c, Metrologia, 2005, **42**, Tech. Suppl., 01002.

[2] *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.org).*

[3] Guidelines for CIPM key comparisons (www.bipm.org).

[4] GT-RF 75-A5: "Voltage (1 V) in 50 ohm coaxial line at 100, 250, 500 and 1000 MHz", Metrologia, 20, 1984, pp.115-126

[5] C.J. van Mullem, W.J.G.D. Janssen and J.P.M. de Vreede, "Evaluation of the Calculable High Frequency AC-DC Standard", IEEE Trans. Instrum.Meas., Vol. IM-46, April 1997, pp.361-364.

[6] 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.

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

[8] EA document EA-04/02.

Appendix A. Original Time Schedule

Time schedule after stop at Swiss Telecom (September 1997)

Laboratory	Contact Person	Arrival date
SMU	Ivan Petras	6 March 1998
CMI	Frantisek Hejsek	10 April 1998
OFMET	Peter Merki / Mark Flueli	15 May 1998
VSL	Jan de Vreede	19 June 1998
Arepa	Torsten Lippert	7 August 1998
CEM	Miguel Neira	11 September 1998
IENGF	Luciano Brunetti	16 October 1998
BNM-LCIE	Luc Erard	20 November 1998
VSL	Jan de Vreede	25 December 1998
SIQ	Rado Lapuh	15 January 1999
NIST	George Free Joseph Kinard	19 February 1999
KRISS	Jeong Hwan Kim	2 April 1999
CSIRO	Joe Petranovic	7 May 1999
VSL	Jan de Vreede	11 June 1999
VNIIM	Dr. V.S. Alexandrow	2 July 1999
VSL	Jan de Vreede	6 August 1999

Appendix B. Contact Persons

Canada: NRC **Alain Michaud**	*E-mail: alain.michaud@nrc.ca*
China: NIM **He Zhao**	*E-mail: hezhao@nim.ac.cn*
Czech Republic: CMI **Mr. Frantisek Hejsek** Microwave Measurement Laboratory Radiova 3 102 00 Praha 10 CZECH REPUBLIC	*Tel.: + 420 2 66020 172* *Fax: + 429 2 704 852* *e-mail: fhejsek@cmi.cz*
Denmark: Arepa **Mr. Torsten Lippert**	*E-mail : tl@arepa.dk*
France: LNE **Mr. Andre Poletaeff**	*E-mail: andre.poletaeff@lne.fr*
Germany: PTB **Dr. Dieter Janik** Bundesallee 100 38116 Braunschweig GERMANY	*e-mail: dieter.janik@ptb.de*
Italy: INRIM (formerly IEN) **Dr. Luciano Brunetti**	*Tel.: + 39 011 3919421* *Fax: + 39 011 346384* *e-mail: brunetti@inrim.it*
Korea: KRISS **Mr. Jeong Hwan Kim** Korea Research Institute of Standards and Science P.O. Box 102, Yusong Taejon 305-600 KOREA	*Tel.: + 82 42 868 5170* *Fax: + 82 42 868 5018* *e-mail: kimjh@kriss.re.kr*
The Netherlands: VSL **Erik Dierikx**	*e-mail: edierikx@nmi.nl*

Singapore: NMC (formerly SPRING) **Dr Yueyan Shan** Electromagnetic Metrology Department National Metrology Centre (NMC) Singapore 1 Science Park Drive, Singapore 118221 SINGAPORE	Tel: +65 – 6279 1929 Fax: +65 – 6279 1995 *E-mail: shan_yueyan@nmc.a-star.edu.sg*
Slovak Republic: SMU **Mr. Ivan Petráš** Slovak Institute of Metrology Karloveská 63 842 55 Bratislava SLOVAKIA	*Tel.: +421 7 60294243* *Fax: +421 7 65429592* *email: petras@smu.gov.sk* *ralbovsky@smu.gov.sk*
Slovenia: SIQ **Mr. Rado Lapuh** Metrology Department Tržaška cesta 2 1000 Ljubljana SLOVENIA	*Tel.: +386 1 4770 300* *Fax: +386 1 4778 303* *email: r.lapuh@siq.si*
Spain: CEM **Dr. Miguel Neira**	*E-mail: mneira@cem.es*
Switzerland: METAS (formerly OFMET) **Mr. Jurg Furrer** EAM-HEV Lindenweg 50 CH-3003 Bern-Wabern SWITZERLAND	*Tel.: + 41 31 323 3111* *Fax: + 41 31 323 32 10* *e-mail*: juerg.furrer@metas.ch
USA: NIST **Joseph Kinard** National Institute of Standards and Technology 100 Bureau Drive Mailstop 8171 Gaithersburg, MD 20899 USA	*Tel.: (+1) 301-975-4250* *e-mail: joseph.kinard@nist.gov*
Russia: VNIIM **Dr. V. Telitchenko**	*E-mail: Alexander.Katkov@ptb.de* *Telitchenko@vniim.ru*

Appendix C. Technical Protocol

GT-RF comparison 92-6
CCEM.RF – K4b.CL

RF voltage measurements
at frequencies between 1 MHz and 1000 MHz

Technical Protocol

1. Scope

During the last decades significant progress has been made in the development of AC calibration and measurement equipment. The equipment is now more user-friendly, can be operated by less qualified personel, but also generates signals to a higher frequency range where standard low frequency procedures might be no longer valid (with the small uncertainties associated with low-frequency measurements). One of the main parameters to be generated is AC voltage, but more appropiate above 1 MHz described as RF voltage. The scope of this comparison is to determine at which level worldwide traceability for the quantity RF Voltage (or RF/DC transfer) can be obtained. During the GT-RF meeting of September 2000 it was decided that the last loop of the GT-RF 92-6 should be separated from the earlier loops. Instead of the latter code CCEM.RF-K4.CL (or K4a.CL) its key comparison code is now CCEM.RF-K4b.CL. It is the intention that only one final report will be written covering both comparisons.

2. Definition of the measurand

As indicated in the scope there is some ambiguity about the quantity to be measured. This is mainly due to the specific measurement set-up used and the frequency range.

At *low frequencies* the usual measurement set-up will be an AC/DC transfer set-up with an (additional) DC voltage measurement if an absolute value of the AC voltage is required. The uncertainty in the latter measurement will most likely depend mainly on the long-term stability of the thermocouple output.
For AC/DC transfer the relevant quantity is the AC/DC transfer difference, now more suitable called RF/DC transfer difference.
The RF/DC transfer difference of a thermal converter (*) is defined as:

$$\delta = \frac{V_{rf} - V_{dc}}{V_{dc}}$$

With Uth,rf=Uth,dc

Where Vrf is the rms value of the applied RF voltage;

Vdc is the mean value of the direct and reversed dc voltages, which produce the same output voltage Uth of the converter as Vrf

At *high frequencies* the usual measurement set-up will be a determination of a calibration factor of a power sensor with a reference level at some high frequency, usually 50 MHz. In this way an absolute power level is obtained. The voltage level is then calculated using a nominal or measured impedance value. The relevant quantity here is voltage (absolute), but can be converted to a similar quantity as above (relative difference).

Neglecting loading problems of the signal generator, it is, however, possible to use these systems also the other way around. Therefore we have decided on a set of transfer standards which can be used in both these types of measurement set-up.

3. The travelling standards

Two devices are used as travelling standards. As indicated below they are based upon different design:

- A Ballantine 1396A thermal converter
- A Rohde und Schwarz power meter NRVD with power sensor NRV-Z51.

For each device a short description is given below.

1) thermal converter

A commercial (Ballantine model 1396A) thermal converter is used as representative of RF/DC thermal transfer devices. In contrast to the normal type of converters the device is equipped with a built-in Tee at its input connector (type-N male) and has a type-N male signal output (apparently meant to be terminated in a 50 Ω system). The thermal detector output is an MS 3102A-105L-3P connector. An adapter to banana connectors is supplied. The main specifications are:

Input voltage:	1,3 V
Output voltage:	7 mV (at nominal input voltage)
Input resistance:	200 Ω (nominal)
Output resistance:	7 Ω (nominal)

The reference plane is at the midplane of the built-in Tee.

Using the requested input voltage of 1,0 V an output of about 4 mV is to be expected when terminated with 50 Ω. Please remember that there will be a significant change in applied voltage if a 50 Ω termination is removed from the measurement set-up: therefore a blow-up of the converter is very likely.

2) Power meter with sensor

In contrast to most high frequency power sensors the R&S power sensor NRV-Z51 has its lower frequency limit at DC. Therefore, together with its read-out unit NRVD, it can also be considered to be a RF/DC transfer with built-in display: hence acting as a RF voltmeter. The standard is equipped with a male type-N connector. The meter can be controlled via IEEE-488 interface. Manuals and the relevant IEEE-commando's are also provided (see page 7/9).

The main specifications are:

Impedance:	50 ohms
Input power:	-20 dBm to +20 dBm (0,01 mW to 100 mW)
equivalent voltage:	22 mV to 2,2 V (visible by changing display parameter)

3.1 Quantity to be measured

As indicated before, care has to be taken about what really is being measured. Hence we suggest the following approach for measuring the NRVD-system. If during the measuring process the voltage reading of the NRVD system is kept constant (i.e. the same voltage reading at the NRVD display), the system can be considered to act as a thermal converter: one has to compare the RF voltage at the input connector of the NRVD (or in the center of the T: **please, specify your choice**) with the DC voltage giving the same indication (voltage) at the NRVD display. In this case there is no need to calibrate the NRVD before, nor you have to use the 50 MHz source.

If no RF voltage standard is available, the NRVD can be calibrated by determining the calibration factor and measuring the input impedance at RF and DC.

Note, when measuring the combination of the Ballantine and the NRVD-system (section 5.2), the output of the Ballantine should be kept constant. Its output is much more frequency dependent.

4. Measuring conditions

The participating laboratories are asked to follow their usual measurement procedure to their best measurement capabilities in respect to the allowed time frame (1 month) for the comparison. Hence, the measurand (RF/DC transfer or RF voltage) might be determined directly or in a two-step process using an intermediate frequency of e.g. 1 kHz.

Note: It has been suggested that more reproducable results are obtained if the DUT and reference connections to the Tee are exchanged and averaged. This is, of course, not possible when using the Ballantine only.

Important points to be mentioned in the report are:

- The reference plane for the calibration

- Where relevant, the input and the output of the transfer devices have to be earthed in order to protect the insulation between the heater and the thermocouple.
- the accuracy and stability of the frequency (the measuring frequency has a significant influence on the RF/DC transfer)
- Is the final result due to an average using an exchange of the Tee-connections?

5. Measuring scheme

1) Calibration of the separate travelling standards

The requested measurand has to be measured at the prescribed voltage (**nominal 1 V**), if possible. The measurement frequencies are given in the table below with six required frequencies and the other three are optional.

f_{meas} (MHz)	1	10	50	100	200	300
Optional (MHz)	500	700	1000			

The requested measurand is the RF/DC transfer difference for the Ballantine, and the RF/DC voltage difference for the NRV-system (the latter might be converted into a RF/DC transfer difference: **please, make clear which option is used**).

2) Calibration of the two travelling standards against each other (if possible)

A measurement at the six frequencies (1, 10, 50, 100, 200 and 300 MHz) is required of both travelling standards at **the nominal input voltage of 1 V**. For this purpose a female-female adapter is provided together with an insertion ring. This ring should be inserted in the adapter at the connector interface with the Ballantine (*on the adapter is indicated in which connector the ring has to be inserted*). In this case the relation between the two measurands (i.e. the RF/DC difference of the Ballantine using constant output voltage of the Ballantine) should be reported.

3) Additional check measurements

To keep track of the performance of the devices we ask you to carry out, at least once, the following check measurements, if possible:
- output of Ballantine using exactly 1,00.. V DC-input (while terminated in 50 Σ)
- output of NRV-system using exactly 1,00.. V DC-input
- output of NRV-system using the 50 MHz reference output
- input impedance of NRV-Z51 sensor at the frequencies used.

6. Uncertainty statements

The measurements should be performed at the lowest possible uncertainty level. A detailed uncertainty analysis for the measurements has to be reported in accordance with the GUIDE TO EXPRESSION OF UNCERTAINTY IN MEASUREMENT, first published in 1993 by BIPM/IEC/IFCC/ ISO/IUPAP/OIML, based on the RECOMMENDATION INC-1 (1980) of the working group and the CIPM on the Statement of Uncertainties, English version published in Metrologia 17 (1981), p. 73. Participants are asked to assign Type A and B evaluation of the uncertainties mentioned, and to report sources and values separately. At the end the standard measurement uncertainty should be stated. All uncertainties should be given at a confidence level of 68% (1Φ or k=1 in present nomenclature). Also the degrees of freedom for each source of uncertainty should be given.

7. Report

After carrying out the measurements, each participating laboratory should send a report to the pilot laboratory *within 6 weeks* including the form 'Results of GT-RF 92-6 Comparison'. Short response time is necessary to check the status of the standards and to finish the comparison in the shortest time frame possible.

The report should contain at least:

- A detailed description of the measurement set-up including some drawings, which can be used in the final report and a publication of the results;
- A detailed description of the measurement procedure;
- The mean measurement value and the statistical spread of the measurands of the standards for each frequency measured, together with the number of measurements to produce this mean value;
- A detailed uncertainty budget in accordance with the GUIDE TO EXPRESSION OF UNCERTAINTY IN MEASUREMENT, first published in 1993 by BIPM/IEC/IFCC/ ISO/IUPAP/OIML.

  See also the form 'Uncertainty budget of the GT-RF 92-6 comparison', which is attached to this instruction set;
- The form 'Results of GT-RF 92-6 Comparison'.

The report should be sent as a hardcopy by mail. It would be appreciated if an electronic version would be sent by e-mail (preferably with the same lay-out as proposed in this instruction set). However, in case of problems the hardcopy version will be considered to be the official one.

8. Transportation and customs

The devices should be (hand-) carried by car, train or plane as it appears the safest for the devices. **The devices are stored as one package. This case is provided by the pilot laboratory !** Changing or deleting this case should be reported immediately to the pilot laboratory, with explanation.

Each laboratory is responsible for the devices from the receipt of the DUTs until arrival of the DUTs at the next laboratory: this means it should cover the costs, if damages occur during the stay at the laboratory and the following transport.

Inside the European Union no custom papers are necessary. For all the participants outside the European Union, an ATA-carnet will be provided, if applicable.

*If your country accepts this document for temporary import, make sure that the document is used in the proper way both during entry and during exit (each time it should be submitted to customs!!). The ATA document should **not** be put inside the package*.
The contents of the package is given at the end of the instructions set (page 7).

9. Circulation time schedule

After the trial loop (participants: VSL, NRC and PTB) at the beginning of 1997 the CCEM.RF-K4.CL has started started in October 1997. Unfortunately problems with the ATA-carnet and damage to equipment occurred. It is restarted at the beginning of March 1998 and was expected to finish sometime in 1999. Due to additional problems the final measurements of CCEM.RF-K4a.CL have been done at the end of 2000. In this part of the comparison the following laboratories participated: NIST (USA), KRISS (South Korea), CSIRO-NML (Australia), IENGF (Italy), SMU (Slovakia), CMI (Czechia) and VSL. In the CCEM.RF-K4b.CL comparison the following laboratories are participating: VNIIM (Russia), BNM-LNE (France), NIM (China), PSB (Singapore) and METAS (Switzerland). Intermediate checks will be carried out at VSL and PTB.
The time allotted for each laboratory is 5 weeks (incl.transport). Updates of the schedule will be given to the participants as soon as possible.

10. Organisation

The pilot laboratory for the comparison is the NMi Van Swinden Laboratorium (VSL). Each participant will receive information about the next participant as soon as possible.
It is the responsibility of the participating laboratory to inform the next participant in advance to arrange the transportation of the standards to him, and to inform the pilot laboratory about the date of transportation (see forms on pages 10 and 11).

11. Contact person

If there are any questions concerning the comparison, the contact person at the pilot laboratory 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 15 00
Telefax: + 31-15 261 29 71
E-mail: JdeVreede@nmi.nl

==

Contents of package for GT-RF 92-6

1: Ballantine RF/dc transfer converter: Model 1396 A-1-10 sn: 621
2: Rohde und Schwarz display unit: Model NRVD sn: 841234 / 024
3: Rohde und Schwarz power sensor: Model NRV-Z51 sn: 837895 / 040 (sticker Z41)
4: MS-banana adapter for Ballantine converter
5: Suhner adapter type-N Model 31 N-50-0-51 (female - female)
6: insertion ring (provided by PTB; slightly damaged due to use)
7: manual for Ballantine 1396A
8: manual for Rohde und Schwarz NRVD
9: manual for Rohde und Schwarz NRV-Z51

Note: Items 5 and 6 are mounted in item 1 (for safety purposes). A single bended piece of wire is provided (in the same package) for removal and insertion of item 6 into item 5.

Additional information concerning use of NRV-system

- The sensor NRV-Z51 should be inserted in the interface slot A (the cable should be on the left side of the slot).
- Read-out of the instrument is only possible by IEEE-commands or by eye !
- The following set-up has to be used:
  - NRVD to voltage read-out: press knobs: <Unit> and <V>
  - NRVD in high resolution mode: press knobs: <displ>, <resol> and <high>
  - NRVD in SCPI mode: press knobs: <spec>, <more> (4 times), <LNG> and <SCPI>
- relevant IEEE-commands (in SCPI-mode) ("IEEE-command"):
  - read-out voltage: "*trg"

Results of GT-RF 92-6 Comparison

On this form, the participant is kindly requested to present an overview of the results of his/her measurements on the travelling standards: the number of measurements (# meas.), the average of the measurand (V or ∗) and the corresponding total uncertainty (Φ_t) expressed as a 1Φ value. (It can be handwritten.)

Institute:

Date:

Remarks:

Travelling standard: Ballantine

frequency (MHz)	1	10	50	100	200	300	500 *(optional)*	700 *(optional)*	1000 *(optional)*
# meas.									
∗ (ppm)									
Φ_t (ppm)									

Travelling standard: NRV-Z51

frequency (MHz)	1	10	50	100	200	300	500 *(optional)*	700 *(optional)*	1000 *(optional)*
# meas.									
∗V (ppm)									
Φ_t (ppm)									

Also, the measurement results of the Ballantine versus the NRV-Z51 can be put on this form with:

∗ is the measured $*_{DUT}$-$*_{REF}$;

Φ_m is the standard deviation of the measurements.

Travelling standards: **Ballantine versus NRV-Z51**

REFERENCE:...............

DUT: ....

frequency (MHz)	1	10	50	100	200	300	500 *(optional)*	700 *(optional)*	1000 *(optional)*
# meas.									
∗ (ppm)									
Φ_t (ppm)									

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute:

Date:

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement						
reference standard						
measurement set-up						
connectors						
....						
....						
....						

total uncertainty (1Φ):				

Travelling standard: NRV-Z51

Contribution of:	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement						
reference standard						
measurement set-up						
connectors						
....						
....						
....						

total uncertainty (1Φ):				

Notice of receipt of the GT-RF 92-6 package

<u>To be sent to the pilot laboratory</u> ***<u>and</u>*** *<u>to the next laboratory in the schedule</u>*

Laboratory :
Contact person :

Herewith we inform you that we have received the package on: ………………………………..

Arrival of the ATA-carnet with the package: yes / no

Remarks concerning the package itself :

Remarks concerning the devices:

Expected date of finishing the measurements of the devices:………………….

Expected date of dispatch of the devices to the next laboratory:……………………………

===

Notice of dispatch of the GT-RF 92-6 package

*To be sent to the pilot laboratory **and** to the next laboratory in the schedule*

Laboratory :
Contact person :

Herewith we inform you that we have dispatched the package on: ……………..………to the next participant :……………………………….

We have checked that the ATA-carnet is sent with the package (but not inside the package): yes / no
(*Note: see the instruction set!!)*

Remarks concerning the package itself :

Remarks concerning the devices:

Appendix D. Submitted Results

NRC

f(MHz)	NRVZ51 delta	*u*(k=1)	Ballantine delta	*u*(k=1)	Check delta	*u*(k=1)
1	-281	21			240	
10	-1043	34			1070	
50	-697	98			3800	
100	399	312			12300	
200	2974	1270			43800	
300	6326	2872			84500	
500					141000	
700					99000	
1000					-179000	

PTB-1

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-70	150	10	100	-100	120
10	-1400	330	130	270	-1430	300
50	-800	870	3200	700	-3800	750
100	300	1630	12900	1300	-12300	1400
200	2000	2200	45900	1500	-43800	1700
300	3500	2400	87900	1700	-84900	1900
500	6700	2750	147200	2300	-141700	2500
700	11200	3300	105700	2600	-100000	2800
1000	15800	3800	-178300	3100	179400	3300

VSL-1

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	338	3550	-24	3002	-27	120
10	-1011	2900	-1068	3015	-1074	300
50	-844	2700	-3566	3092	-3572	750
100	-271	2700	-11995	3311	-11993	1400
200	684	2700	-43379	3448	-43365	1700
300	1205	2700	-84243	3551	-84214	1900
500	3702	2950	-141159	3905	-141104	2500
700	7455	3000	-99088	4104	-99034	2800
1000	12106	3650	179570	4460	179537	3300

VSL-2

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-267	3550	-38	3002	-41	120
10	-591	2950	-1090	3015	-1096	300
50	-636	2750	-3051	3092	-3057	750
100	89	2700	-11109	3311	-11107	1400
200	1118	2700	-42138	3448	-42124	1700
300	2541	2750	-82316	3551	-82287	1900
500	6372	2950	-137357	3905	-137302	2500
700	10983	3000	-95659	4104	-95605	2800
1000	15355	3100	179912	4460	179879	3300

SMU

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-60	360	-10	300	70	200
10	-760	900	130	900	-820	400
50	-400	3200	3800	3200	-3200	1000
100	-1100	4900	2500	5400	-11000	3000
200	1400	5100	47500	5900	-41000	3000
300	5400	6200	93800	6700	-76000	3000
500	9100	8100	**156000**	8600	-122000	6000
700	13000	9700	114000	9700	-88000	6000
1000	15000	10700	-174000	15000	228000	12000

VSL-3

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-267	3550	155	3002	152	120
10	-591	2950	-820	3015	-826	300
50	-636	2750	-3831	3092	-3837	750
100	89	2700	-13349	3311	-13347	1400
200	1118	2700	-48481	3448	-48467	1700
300	2541	2750	-94564	3551	-94535	1900
500	6372	2950	-166100	3905	-166045	2500
700	10983	3000	-135094	4104	-135040	2800
1000	15355	3100	151191	4460	151158	3300

Arepa

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-110	6100	40	6100	130	50
10	-1650	6100	-680	6100	910	50
50	-2680	6100	1210	6300	3740	30
100	-4100	6100	5600	6300	13200	300
200	-7800	8200	30100	8700	48100	400
300	-8200	11000	71000	11000	94200	600
500	-9600	11000	147900	12000	165900	1000
700	-14000	11000	115700	12000	135400	1000
1000	-18200	12000	-165000	12000	-149800	900

CEM

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-87	47	-173	44	-32	22
10	-375	82	-40	82	-354	15
50	2388	6000	6250	6000	-1561	27
100	9100	6200	18420	6200	**-6263**	18
200	32961	6400	55391	6400	-23135	10
300	39479	7000	80219	7000	-45988	18
500						
700						
1000	-103880	8300	-192660	8300	77235	21

VSL-4

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-267	3550	-309	3079	-1615	16753
10	-591	2950	-108	3132	-840	165
50	-636	2750	-2980	3001	-3059	266
100	89	2700	-11648	3000	-12254	847
200	1118	2700	-42742	3118	-47068	820
300	2541	2750	-83886	3098	-92221	362
500	6372	2950	-141939	3000	-161843	301
700	10983	3000	-100174	3110	-130453	451
1000	15355	3100	181338	3006	153749	613

SIQ

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-200	500	-200	460	-200	440
10	-800	650	-300	600	0	600
50	-600	1000	2400	1000	2900	1000
100	200	1700	11800	1900	12700	1900
200	0	2300	44000	2900	47000	2900
300	-1000	2300	85000	3600	91000	3600
500	-4800	3300	142000	6000	156000	6000
700	-8900	3800	105000	8000	124000	8000
1000	-15100	4400	-164000	10000	**-164000**	10000

NIST

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-333	350	-15	350	-53	480
10	-1169	390	-56	390	-130	510
50	-75	1300	3272	1900	3474	220
100	666	1500	12591	2100	13154	2300
200	1304	2000	45801	2300	46445	2700
300	-251	2100	86831	2500	87246	2900
500	-1849	2500	145042	2500	145520	3190
700	-4406	2500	103677	2500	104392	3450
1000	-181048	2500	-181048	2500	-181884	3500

VSL-5

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-267	3550	286	3209	-138	344
10	-591	2950	-1015	3085	-816	763
50	-636	2750	-4548	3070	-3305	445
100	89	2700	-12666	3069	-12442	450
200	1118	2700	-43939	3048	-46748	708
300	2541	2750	-82961	3062	-92180	738
500	6372	2950	-135332	3078	-161261	331
700	10983	3000	-89124	3033	-129609	582
1000	15355	3100	190585	3138	153321	944

KRISS

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-8	771	78	768	62	35
10	-1388	1195	-90	1196	1301	26
50	-944	1230	3242	1239	4167	20
100	-461	1339	12674	1359	13059	28
200	596	1837	45795	1937	44955	29
300	1688	2324	88038	2575	85764	34
500	3950	3161	147589	3570	142385	91
700	6153	3771	105154	4168	97506	38
1000	10473	4353	-179592	4398	-188283	71

VSL-6.0

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-267	3550	-570	21218	-570	21218
10	-591	2950	-892	3148	-892	3148
50	-636	2750	-4872	3018	-4872	3018
100	89	2700	-12791	3043	-12791	3043
200	1118	2700	-43281	3056	-43281	3056
300	2541	2750	-82473	3008	-82473	3008
500	6372	2950	-135232	3065	-135232	3065
700	10983	3000	-88415	3053	-88415	3053
1000	15355	3100	191187	3014	191187	3014

VSL-6

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	28	5866.902	13425	3066	13312	250
10	-217	4249.669	-1173	3000	-1182	419
50	-586	1753.115	-5340	3012	-4828	208
100	-298	1741.834	-12528	3121	-13611	398
200	251	1751.564	-43237	3053	-44063	539
300	994	1760.192	-78354	6332	-78676	5779
500	3761	2106.877	-134214	3288	-134772	2065
700	8273	2151.733	-94596	7949	-95423	6236
1000	15282	2381.969	175924	17786	175682	16779

VNIIM

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-20	28	-8.6	7	-75	23
10	-1658	38	-98.7	27	1480	56
50	-1950	188	3070	168	4890	78
100	-1290	574	11600	567	13400	91
200	1570	874	45560	869	43600	110
300	2540	1168	85980	1168	82400	140
500	1970	2034	134120	2038	133120	210
700	-4560	2913	**75780**	2931	81530	450
1000	4230	4060	-187800	4081	-195500	510

VSL-7

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	28	5866.902	16	3000	267	131
10	-217	4249.669	-1552	3088	-1612	247
50	-586	1753.115	-4683	3205	-4615	566
100	-298	1741.834	-12925	3104	-13080	18
200	251	1751.564	-43284	3000	-43833	39
300	994	1760.192	-78290	7950	-78546	7519
500	3761	2106.877	-134996	3141	-134104	2881
700	8273	2151.733	-94548	9559	-94313	7829
1000	15282	2381.969	177598	20319	178225	21285

NIM

f(MHz)	NRVZ51 delta	$u(k=1)$	Ballantine delta	$u(k=1)$	Check delta	$u(k=1)$
1	-198	136	-42	89	365	6
10	-1299	1024	-436	1212	-922	50
50	-1552	1955	2406	1193	-4216	89
100	-1842	1962	11596	1261	-12588	114
200	-1172	1905	45406	1490	-41699	239
300	-321	1999	89081	1819	-76621	414
500	1570	2123	153229	2648		
700	5813	2386	117105	3609		
1000	12637	3132	-159411	4996		

VSL-8

f(MHz)	NRVZ51 delta	$u(k=1)$	Ballantine delta	$u(k=1)$	Check delta	Std. Dev.
1	28	5866.902	1298	5000	64	1885
10	-217	4249.669	-868	5000	-1141	553
50	-586	1753.115	-4016	5000	-5150	285
100	-298	1741.834	-12945	5000	-13076	307
200	251	1751.564	-44737	5000	-44303	617
300	994	1760.192	-73471	5000	-77017	5985
500	3761	2106.877	-135706	5000	-134813	3440
700	8273	2151.733	-102476	5000	-96359	6527
1000	15282	2381.969	161561	5000	173784	16851

PTB-3

f(MHz)	NRVZ51 delta	$u(k=1)$	Ballantine delta	$u(k=1)$	Check delta	$u(k=1)$
1	100	150	30	100	130	120
10	-1700	330	220	270	-1650	300
50	-1900	870	3300	700	-1910	750
100	-70	1630	13000	1300	-300	1400
200	60	2200	45700	1500	1500	1700
300	2500	2400	87500	1700	3700	1900
500	7400	2750	145700	2300	9100	2500
700	14300	3300	105200	2600	15500	2800
1000	23600	3800	-177800	3100	18800	3300

METAS

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	-8	1148	-46	1149	-172	1149
10	-1759	1168	281	1184	-108	1182
50	-3030	3069	2328	3066	1705	3066
100	-3290	3066	9547	3066	9624	3066
200	-1874	3067	41616	3066	42115	3103
300	-790	3067	82412	3068	82117	3066
500	2072	3267	139720	3268	138539	3521
700	6707	3525	98007	3522	96763	4172
1000	13969	6666	-183913	6668	-182740	7580

VSL-9

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-341	2500	-294	3007	-416	1768
10	-817	1500	-811	3132	-1664	1122
50	-1950	1050	-3893	3072	-4981	422
100	-1452	1050	-12049	3025	-13534	283
200	-1720	1150	-43179	3013	-44191	216
300	-1364	1250	-76700	5177	-72522	564
500	1074	1650	-132111	3138	-131866	591
700	5753	1600	-81752	13682	-96649	654
1000	11253	2650	185823	17717	166821	1114

BNM-LNE

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1			33	23	1462	130
10			431	40	1435	130
50			3859	684	-114	190
100			8345	2564	-7059	650
200						
300						
500						
700						
1000						

VSL-10

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev. (one meas.)
1	-341	2500	97	3000	95	0
10	-817	1500	-1900	3000	-905	0
50	-1950	1050	-5095	3000	-4537	0
100	-1452	1050	-10793	3000	-13505	0
200	-1720	1150	-43012	3000	-43745	0
300	-1364	1250	-80850	3000	-83242	0
500	1074	1650	-133241	3000	-133283	0
700	5753	1600	-73685	3000	-74476	0
1000	11253	2650	195423	3000	197186	0

NMC

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	*u*(*k*=1)
1	184	100	-70	110	-83	7
10	-1389	200	186	220	1640	16
50	-1344	500	3639	550	4872	12
100	-706	1500	12976	1550	13376	48
200	-1370	2800	45087	2850	43890	94
300	-530	2800	86024	3000	82412	114
500	1960	2800	143369	3000		
700	6300	2800	100168	3000		
1000	14000	2900	-178226	3200		

VSL-11

f(MHz)	NRVZ51 delta	*u*(*k*=1)	Ballantine delta	*u*(*k*=1)	Check delta	Std. Dev.
1	-341	2500	-617	3207	-676	805
10	-817	1500	1535	3224	-1535	302
50	-1950	1050	-1859	3001	-4201	994
100	-1452	1050	-10330	3094	-13059	693
200	-1720	1150	-40858	3048	-43941	387
300	-1364	1250	-81635	3001	-77904	7028
500	1074	1650	-136307	3956	-130135	1658
700	5753	1600	-94736	3181	-90494	9112
1000	11253	2650	185628	3106	182033	22124

Appendix E. Participants' Uncertainty Budgets

Uncertainty budget of the GT-RF 92-6 Intercomparison.

Institute: AREPA Test & Calibration

Date: 16.09.98

Remarks:

Travelling standard: Ballantine

Contribution u_i of: (%)	Unc. 1 MHz	Unc. 10 MHz	Unc. 50 MHz	Unc. 100 MHz	Unc. 200 MHz	Type A or B	Shape of distribution
Std.-dev. of meas.	0.001	0.04	0.18	0.15	0.31	A	Gaussian
Reference standard	0.6	0.6	0.6	0.6	0.8	B	Gaussian
Set-up	0.001	0.002	0.01	0.02	0.03	B	Uniform
Connectors	0.001	0.005	0.02	0.05	0.08	B	Uniform
Sensitivity	0.02	0.03	0.05	0.07	0.08	B	Uniform

Uncertainty (1σ)	0.61	0.61	0.63	0.63	0.87

Contribution u_i of: (%)	Unc. 300 MHz	Unc. 500 MHz	Unc. 700 MHz	Unc. 1 GHz	Type A or B	Shape of distribution
Std.-dev. of meas.	0.33	0.55	0.51	0.43	A	Gaussian
Reference standard	1	1	1	1	B	Gaussian
Set-up	0.05	0.07	0.1	0.1	B	Uniform
Connectors	0.15	0.3	0.5	0.8	B	Uniform
Sensitivity	0.1	0.1	0.1	0.1	B	Uniform

Uncertainty (1σ)	1.1	1.2	1.2	1.2

Table 2: Uncertainty budget (68 %).

Uncertainty budget of the GT-RF 92-6 Intercomparison.

Institute: AREPA Test & Calibration

Date: 16.09.98

Remarks:

Travelling standard: NRV-Z51

Contribution u_i of: (%)	Unc. 1 MHz	Unc. 10 MHz	Unc. 50 MHz	Unc. 100 MHz	Unc. 200 MHz	Type A or B	Shape of distribution
Std.-dev. of meas.	0.002	0.06	0.08	0.09	0.15	A	Gaussian
Reference standard	0.6	0.6	0.6	0.6	0.8	B	Gaussian
Set-up	0.001	0.002	0.01	0.02	0.03	B	Uniform
Connectors	0.001	0.005	0.02	0.05	0.08	B	Uniform
Sensitivity	0.02	0.03	0.05	0.07	0.08	B	Uniform

Uncertainty (1σ)	0.61	0.61	0.61	0.61	0.82

Contribution u_i of: (%)	Unc. 300 MHz	Unc. 500 MHz	Unc. 700 MHz	Unc. 1 GHz	Type A or B	Shape of distribution
Std.-dev. of meas.	0.25	0.15	0.14	0.21	A	Gaussian
Reference standard	1	1	1	1	B	Gaussian
Set-up	0.05	0.07	0.1	0.1	B	Uniform
Connectors	0.15	0.3	0.5	0.8	B	Uniform
Sensitivity	0.1	0.1	0.1	0.1	B	Uniform

Uncertainty (1σ)	1.1	1.1	1.1	1.2

Table 2: Uncertainty budget (68 %).

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: CENTRO ESPAÑOL DE METROLOGÍA . CEM. (SPAIN)

Date: 24/11/98

Remarks: VALUES IN PPM . n= 12 MEASUREMENTS FOR EACH POINT

Travelling standard: Ballantine

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f:100MHz	Unc. f:300MHz	Type A or B	Shape of distribution
st. dev. of measurement	12	12	6	14	A	
reference standard	5	10	6000	6000	B	Rectangular
measurement set-up	30	70	1200	3000	B	Rectangular
connectors and lines	30	40	800	1500	B	Rectangular
....						
....						
....						

total uncertainty (1σ):	44	82	6171	6874

Travelling standard: NRV-Z51

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f:100MHz	Unc. f:300MHz	Type A or B	Shape of distribution
st. dev. of measurement	20	20	10	20	A	
reference standard	5	10	6000	6000	B	Rectangular
measurement set-up	30	70	1200	3000	B	Rectangular
connectors and lines	30	40	800	1500	B	Rectangular
....						
....						
....						

total uncertainty (1σ):	47	84	6171	6874

IEN -1/2/99

Travelling Standard: Ballantine 1396A-1									
Freq. [MHz]	1	10	50	100	200	300	500	700	1000
# measur.	6	6	6	6	6	6	6	6	6
δ [ppm]	23	60	51	242	1146	2550	10259	-28855	-17360
σ [ppm]	9	53	29	55	23	41	111	1433	398

Travelling Standard: Ballantine 1396A-1; Contributions of uncertainty [ppm]										Type	Shape
Freq. [MHz]	1	10	50	100	200	300	500	700	1000		
σ of measur.	9	53	29	55	23	41	111	1433	398	A	normal
Refer. Stand.	5	10	50	1000	15000	30000	50000	75000	100000	B	rectang.
DC volt. meas.	14	14	14	14	14	14	14	14	14	B	rectang.
T-asymmetry	0	1	28	112	469	1146	4072	11538	120441	B	U-shaped
Total uncert.	18	56	66	1008	15007	30022	50166	75896	156545		

Table 1 : Travelling Standard Ballantine.

IEN -1/2/99

Travelling Standard: NRV-51									
Freq. [MHz]	1	10	50	100	200	300	500	700	1000
# measur.	6	6	6	6	6	6	6	6	6
δ [ppm]	-284	-1120	-2865	-10135	-36940	-69917	-113289	-79353	238938
σ [ppm]	54	57	22	145	72	69	385	255	676

Travelling Standard: NRV-51; Contributions of uncertainty [ppm]										Type	Shape
Freq. [MHz]	1	10	50	100	200	300	500	700	1000		
σ of measur.	54	57	22	145	72	69	385	255	676	A	normal
Refer. Stand.	5	10	50	1000	15000	30000	50000	75000	100000	B	rectang.
DC volt. meas.	14	14	14	14	14	13	13	13	18	B	rectang.
T-asymmetry	1	37	247	802	2877	6137	14258	21719	23322	B	U-shaped
Total uncert.	57	70	254	1290	15274	30621	51995	78082	102686		

Table 2: Travelling Standard NRV-Z51

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: BNM-LNE

Date: October 9th to 23rd, 2003 (date of measurements)

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f: 1 MHz	Unc. f:10 MHz	Unc. f:50 MHz	Unc. f:100MHz	Type A or B	Shape of distribution
st. dev. of measurement	1.2	1.1	3.2	13.4	-	-
reference standard	12	17	316	1205	-	-
measurement set-up	3.6	24	397	1363	-	-
connectors	5	5	150	500	-	-
....	-	-	-	-	-	-
....	-	-	-	-	-	-
....	-	-	-	-	-	-

total uncertainty (1σ):	15	30	530	1900

Uncertainty budget of the GT-RF 92-6 comparison

Institute: METAS

Date: 5. September 2003

Remarks:

Travelling standards: Ballantine versus NRV-Z51
REFERENCE: NRV-Z51 sn 838947 / 040
DUT: Ballantine 1396A-1-10 sn 621

Contribution of	Type	Shape	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000MHz
CalFactor of Power Reference Standard	B	norm.	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Nonlinearity of Power Reference at 13 dBm (1V)	B	norm.	0	0	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03
Impedance Measurement of Power Reference	B	norm.	0	0	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03
PWR Meter Reading (REF resolut.)	A	rect.	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04
DC Voltmeter unc	B	norm.	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06
AC Voltmeter 1kHz unc	B	norm.	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
RF Connector Repeatability	A	norm.	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04
Drift of RF-Source	B	norm.	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04
Type A uncert of # n measurements	A	norm.	5.50E-05	1.00E-05	5.50E-05	1.40E-05	4.80E-04	5.00E-05	2.00E-05	9.00E-05	2.50E-04
VSWR Correction Error	B	rect.	1.00E-04	3.00E-04	1.00E-03	1.00E-03	1.00E-03	1.00E-03	2.00E-03	3.00E-03	7.00E-03
Total Uncertainty (1 σ)			0.0011	0.0012	0.0031	0.0031	0.0031	0.0031	0.0035	0.0042	0.0076

Uncertainty budget of the GT-RF 92-6 comparison

Institute: METAS

Date: 5. September 2003

Remarks:

Travelling standard: NRV-Z51 sn 838947 / 040

Contribution of	Type	Shape	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000MHz
CalFactor of Power Reference Standard	B	norm.	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Nonlinearity of Power Reference at 13 dBm (1V)	B	norm.	0.0E+00	0.0E+00	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03
Impedance Measurement of Power Reference	B	norm.	0.0E+00	0.0E+00	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03
PWR Meter Reading (REF resolut.)	A	rect.	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04
DC Voltmeter unc	B	norm.	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06
AC Voltmeter 1kHz unc	B	norm.	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
RF Connector Repeatability	A	norm.	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04
Drift of RF-Source	B	norm.	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04
Type A uncert of # n measurements	A	norm.	3.00E-05	1.00E-04	1.50E-04	3.00E-05	1.00E-04	1.00E-04	1.50E-04	1.60E-04	2.00E-04
VSWR Correction Error	B	rect.	1.00E-04	3.00E-04	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.50E-03	2.00E-03	6.00E-03
Total Uncertainty (1 σ)			0.0011	0.0012	0.0031	0.0031	0.0031	0.0031	0.0033	0.0035	0.0067

Uncertainty budget of the GT-RF 92-6 comparison

Institute: METAS

Date: 5. September 2003

Remarks:

Travelling standard: Ballantine 1396A-1-10 sn 621

Contribution of	Type	Shape	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000MHz
CalFactor of Power Reference Standard	B	norm.	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Nonlinearity of Power Reference at 13 dBm (1V)	B	norm.	0.0E+00	0.0E+00	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03
Impedance Measurement of Power Reference	B	norm.	0.0E+00	0.0E+00	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03	2.20E-03
PWR Meter Reading (REF resolut.)	A	rect.	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04	2.40E-04
DC Voltmeter unc	B	norm.	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06
AC Voltmeter 1kHz unc	B	norm.	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
RF Connector Repeatability	A	norm.	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04
Drift of RF-Source	B	norm.	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04	1.40E-04
Type A uncert of # n measurements	A	norm.	6.00E-05	6.00E-05	6.00E-05	6.50E-05	7.00E-05	1.10E-04	1.70E-04	1.00E-04	2.60E-04
VSWR Correction Error	B	rect.	1.00E-04	3.00E-04	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.50E-03	2.00E-03	6.00E-03
Total Uncertainty (1 σ)			0.0011	0.0012	0.0031	0.0031	0.0031	0.0031	0.0033	0.0035	0.0067

Uncertainty statements

Institute: National Institute of Metrology, China

Date: 2/27/02～4/3/02

References standard: f =1MHz: NIM Coaxial Thermal Voltage Converter

f =>10MHz: Bolo-voltage standard

Measurement system: f =1MHz: ac-dc transfer system(automatic)

f =>10MHz: rf-dc transfer system (manual)

Travelling standard: NRV-Z51 **(ppm)** table 1

Contribution:	Unc. f:10 MHz	Unc. f:50 MHz	Unc. f:100 MHz	Unc. f:200 MHz	Unc. f:300 MHz	Unc. f:500 MHz	Unc. f:700 MHz	Unc. f:1000 MHz	Type A or B	Shape of distribution
st. dev. of measurement	85	46	141	114	111	125	178	154	Type A	Normal distribution
reference standard	833.33	833.33	833.33	833.33	833.33	833.33	833.33	833.33	Type B	Normal distribution
resolution of RF source	577.35	577.35	577.35	577.35	577.35	577.35	577.35	577.35	Type B	uniform distribution
transfer error	/	55.43	117.78	145.00	407.03	817.53	1354.46	2438.73	Type B	uniform distribution
standard of RF impedance	/	1666.67	1666.67	1666.67	1666.67	1666.67	1666.67	1666.67	Type B	Normal distribution
standard of DC voltage	9.12	9.12	9.12	9.12	9.12	9.12	9.12	9.12	Type B	uniform distribution
st. dev. of measurement of the DC voltage	33	33	33	33	33	33	33	33	Type A	Normal distribution
NRVD stability	115.47	115.47	115.47	115.47	115.47	115.47	115.47	115.47	Type B	uniform distribution

table 2

item	Unc. *f*:10 MHz	Unc. *f*:50 MHz	Unc. *f*:100 MHz	Unc. *f*:200 MHz	Unc. *f*:300 MHz	Unc. *f*:500 MHz	Unc. *f*:700 MHz	Unc. *f*:1000 MHz
total uncertainty (1 σ) (ppm)	1024	1955	1962	1905	1999	2123	2386	3132

Degrees of freedom	258	92	93	84	100	121	143	111

Uncertainty statements

Institute: National Institute of Metrology, China

Date: 3/14/2002-3/25/2002

References standard: NIM Coaxial Thermal Voltage Converter

Measurement system: f =1MHz: ac-dc transfer system (automatic)

f =>10MHz: rf-dc transfer system (automatic)

Travelling standard: Ballantine 1396A (ppm) table 5

Contribution:	Unc. f:1 MHz	Unc. f:10 MHz	Unc. f:50 MHz	Unc. f:100 MHz	Unc. f:200 MHz	Unc. f:300 MHz	Unc. f:500 MHz	Unc. f:700 MHz	Unc. f:1000 MHz	Type A or B	Shape of distribution
st. dev. of measurement	4	27	28	28	14	22	60	133	178	Type A	Normal distribution
reference standard	40	1100	1100	1200	1400	1800	2600	3600	5000	Type B	Normal distribution
resolution of RF source	/	577.35	577.35	577.35	577.35	577.35	577.35	577.35	577.35	Type B	uniform distribution
stability of the output voltage of the reference standard	57.74	57.74	57.74	57.74	115.47	115.47	115.47	115.47	115.47	Type B	uniform distribution
stability of the output voltage of the Ballantine	57.74	57.74	57.74	57.74	115.47	115.47	115.47	115.47	115.47	Type B	uniform distribution
standard of DC voltage	9.12	9.12	9.12	9.12	9.12	9.12	9.12	9.12	9.12	Type B	uniform distribu[illegible]
stability of the DC source	1.91	0.75	Neglect	Neglect	Neglect	Neglect	Neglect	Neglect	Neglect	Type B	uniform distribution

table 6

item	Unc. *f*:1 MHz	Unc. *f*:10 MHz	Unc. *f*:50 MHz	Unc. *f*:100 MHz	Unc. *f*:200 MHz	Unc. *f*:300 MHz	Unc. *f*:500 MHz	Unc. *f*:700 MHz	Unc. *f*:1000 MHz
total uncertainty (1 σ) (ppm)	89	1212	1193	1261	1490	1819	2648	3609	4996

Degrees of freedom	3943	136	143	170	172	129	78	64	57

NIST

Analysis of the Type B uncertainty for the NRV-Z51 power meter. Values are in percent.

Type B components	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000 MHz
Thermistor resistance			0.05	0.07	0.10	0.10	0.10	0.10	0.10
Thermistor reactance			0.07	0.04	0.03	0.04	0.05	0.05	0.03
Effective Efficiency			0.08	0.08	0.08	0.08	0.09	0.09	0.06
DC on measurement of Thermistor			0.01	0.01	0.01	0.01	0.01	0.01	0.01
DC off measurement of Thermistor			0.01	0.01	0.01	0.02	0.02	0.02	0.02
DC + measurement of TVC	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DC - measurement of TVC	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
DC offset voltage	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Unknown resistance			0.05	0.07	0.10	0.10	0.10	0.10	0.10
Unknown reactance			0.01	0.01	0.02	0.04	0.06	0.06	0.03
Gam_g standard			0.10	0.11	0.11	0.12	0.12	0.12	0.13
Connect-disconnect	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Gam_g unknown			0.10	0.11	0.11	0.12	0.12	0.12	0.13
Low frequency TVC factor	0.01	0.02							
DC + of lf TVC	0.01	0.01							
DC - of lf TVC	0.00	0.00							
Sum of Squares	0.001	0.001	0.036	0.043	0.053	0.061	0.064	0.064	0.062
Square Root of Sum of Squares	0.03	0.04	0.19	0.21	0.23	0.25	0.25	0.25	0.25

NIST

Analysis of Type B uncertainty for the measurement of the Ballantine TVC. Values are in percent.

Type B component	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000 MHz
Thermistor resistance			0.05	0.07	0.10	0.10	0.10	0.10	0.10
Thermistor reactance			0.07	0.04	0.03	0.04	0.07	0.07	0.03
Effective Efficiency			0.08	0.08	0.08	0.08	0.09	0.09	0.06
Adapter Electrical Length	0.000	0.001	0.01	0.02	0.05	0.08	0.14	0.18	0.19
DC on measurement of Thermistor			0.01	0.01	0.01	0.01	0.01	0.01	0.01
DC off measurement of Thermistor			0.02	0.02	0.02	0.02	0.02	0.02	0.02
DC + measurement of TVC	0.005	0.005	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DC - measurement of TVC	0.005	0.005	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DC offset voltage	0.009	0.009	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Gam-g error	0.03	0.03	0.05	0.05	0.05	0.05	0.07	0.07	0.10
Connect-disconnect	0.005	0.005	0.03	0.05	0.05	0.05	0.050	0.05	0.05
Low frequency TVC factor	0.01	0.02							
DC + of lf TVC	0.005	0.005							
DC - of lf TVC	0.005	0.005							
Sum of Squares	0.001206	0.001507	0.017	0.018	0.025	0.030	0.049	0.064	0.064
Square Root of Sum of Squares	0.03	0.04	0.13	0.14	0.16	0.17	0.22	0.25	0.25

NMC

Table 5: Uncertainty budget: Travelling standard — Ballantine 1396A (ppm)

Uncerntainty Contribution of:	Unc. 1MHz	Unc. 10 MHz	Unc. 50 MHz	Unc. 100 MHz	Unc. 200MHz	Unc. 300MHz	Unc. 500MHz	Unc. 700MHz	Unc. 1000MHz	Type	Shape of distribution
std dev. of measurement	6	7	32	62	110	139	205	249	175	A	t
reference standard (k=1)	100	200	500	1500	2800	2800	2800	2800	2900	B	normal
measurement set-up	22	121	139	109	171	375	718	453	829	B	rectangular
connectors	10	10	50	50	100	200	350	400	400	B	rectangular
Parameter determination	0	14	45	131	446	844	1379	898	-1962	B	rectangular
Thermal Emf	2	2	2	2	20	20	20	20	20	B	rectangular
Nano-voltmeter resolution	2	2	2	2	2	2	2	2	2	B	rectangular
Power meter resolution	10	10	10	10	100	100	100	100	100	B	rectangular
Level dependence	50	100	100	100	100	100	100	100	100	B	rectangular
total uncertainty (1σ):	110	220	550	1550	2850	3000	3000	3000	3200		

NMC

Table 6: Uncertainty budget: Travelling standard — NRV-Z51 (ppm)

Uncertainty contribution due to:	200 MHz	300 MHz	500 MHz	700 MHz	1000 MHz	Type	Shape of distribution
# Calibration Factor, K_{DUT}	1475	1474	1512	1529	1571	B	Rectangle
Reflection coeff, Γ	2337	2340	2338	2342	2335	B	Rectangle
Reflection coeff, Γ_{DC}	53	53	53	53	54	B	Rectangle
Standard deviation of measurement	100	82	65	97	120	A	t
Total uncertainty (1σ):	2800	2800	2800	2800	2900		

#Includes uncertainties for reference power standard, measurement setup and mismatch.

National Research Council Canada
Conseil national de recherches Canada

Institute for National Measurement Standards
Institut des étalons nationaux de mesure

Ottawa, Canada
K1A 0R6

NRC·CNRC

Uncertainty budget of the GT/RF 92-6 Comparison

Travelling standard: NRV-Z51

	Estimated 1 sigma uncertainty (ppm) at frequencies of:						
Contribution of:	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	Type of uncert.
stdev of meas.	20	26	19	18	30	24	A
working std.	5.4	17	94	308	1240	2810	B
meas. set-up	1	3	7	10	20	30	B
Type N connectors and tee	0.8	7	17	45	272	587	B
dev. of ac-dc diff. from zero	2.8	10.4	7	4	30	63	B
Root sum square (1 sigma):-->	21	34	98	312	1270	2872	

April 28, 1998 Richard F. Clark

Canada

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: PTB, Germany

Date: May 31, 2002

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	30	33	30	30	A	Gauss
reference standard	70	250	600	1.200	B	u.
measurement set-up	70	100	300	400	B	Rect
connectors	70	140	400	600	B	Rect
....						
....						
....						

total uncertainty (1σ):	100	270	700	1.300

Travelling standard: NRV-Z51

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	40	40	40	40	A	Gauss
reference standard	100	300	800	1.500	B	Gauss
measurement set-up	70	100	300	400	B	Rect
connectors	150	200	500	1.000	B	Rect
....						
....						
....						

total uncertainty (1σ):	150	330	870	1.620

Sept. 9. 2003

Uncertainty budget of the CCE 92-05 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Bundesallee 100 D-38116 Braunschweig

Date: 21. to 29. of April 1997

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	30	30	30	30	A	Gauß
reference standard	70	250	600	1200	B	Gauß
measurement set-up	70	100	300	400	B	Rect.
connectors	70	100	400	600	B	Rect.
....						
....						
....						

total uncertainty (1σ):	100	270	700	1300

Travelling standard: NRV-Z51

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	40	40	40	40	A	Gauß
reference standard	100	300	800	1500	B	Gauß
measurement set-up	70	100	300	400	B	Rect.
connectors	150	200	500	1000	B	Rect.
....						
....						
....						

total uncertainty (1σ):	150	330	870	1630

Uncertainty budget of the CCE 92-05 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Bundesallee 100 D-38116 Braunschweig

Date:
21. to 29. of April 1997

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f:200 MHz	Unc. f:300 MHz	Unc. f:500 MHz	Unc. f:700 MHz	Type A or B	Shape of distribution
st. dev. of measurement	30	30	30	30	A	Gauß
reference standard	1,400	1,600	2,200	2,500	B	Gauß
measurement set-up	500	600	800	1,000	B	Rect.
connectors	700	800	1,000	1,000	B	Rect.
....						
....						
....						

total uncertainty (1σ):	1,500	1,700	2,300	2,600

Travelling standard: NRV-Z51

Contribution of:	Unc. f:200 MHz	Unc. f:300 MHz	Unc. f:500 MHz	Unc. f:700 MHz	Type A or B	Shape of distribution
st. dev. of measurement	40	40	40	40	A	Gauß
reference standard	2,000	2,200	2,600	3,000	B	Gauß
measurement set-up	500	600	800	1,000	B	Rect.
connectors	1200	1500	1800	2000	B	Rect.
....						
....						
....						

total uncertainty (1σ):	2,200	2,400	2,750	3,300

Uncertainty budget of the CCE 92-05 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example.
Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Bundesallee 100 D-38116 Braunschweig

Date:
21. to 29. of April 1997

Remarks:

Travelling standard: Ballantine

Contribution of:	Unc. f: 100 MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement	30				A	Gauß
reference standard	3000				B	Gauß
measurement set-up	1000				B	Rect.
connectors	1000				B	Rect.
....						
....						
....						

total uncertainty (1σ):	3100			

Travelling standard: NRV-Z51

Contribution of:	Unc. f: 100 MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement	40				A	Gauß
reference standard	3500				B	Gauß
measurement set-up	1000				B	Rect.
connectors	2500				B	Rect.
....						
....						
....						

total uncertainty (1σ):	3800			

Combined, the skin effect has much smaller effect than standing waves at distance change of 1 mm or less. Reflection is therefore the only effect which is considered as uncertainty source. Sensitivity coefficient $c_9 = 1$.

u_{10} uncertainty due to spread of measured values. Typically, three to five RF – DC – RF sequences are repeated at the same frequency. Sensitivity coefficient $c_{10} = 1$.

Two examples are presented in the table as uncertainty calculations, first when both devices are power sensors and second when standard device is power sensor and measured device is TVC.

5.3.3 Examples of uncertainty budget

1. example

The RF/DC difference was measured at 300 MHz using NRV-Z51 as standard and measured device. Symbol *d* replaces ∂. The measured results were as follows:

Udc	1	V
δx1	-2,684	mV/V
δx2	-2,799	mV/V
δx3	-2,728	mV/V
δx4	-2,845	mV/V
mean	-2,764	mV/V
STDEV	0,041	mV/V

f = 300 MHz N - male connector, 52 ohm device

Symbol *Xi*	source of uncertainty	estimate *Xi*		standard uncertainty *u(Xi)*	probability distribution	*div.*	sens. coef. *ci*	uncertainty contribution *ui(P)*	*vi*
δs (u1)	standard RF/DC transfer diference	4,0	mV/V	4,0E-03	normal, k = 2	2,00	1,000	2,0E-03	1E+05
dδsL (u2)	drift of δs	0,000	mV/V	1,3E-03	rectangular	1,73	1,000	7,7E-04	8E+05
dδT (u3)	repeatability	2,400	mV/V	8,0E-04	rectangular	1,73	1,000	4,6E-04	2E+06
ΔEs (u4)	voltage difference measurement - standard device	0,004	V	6,0E-04	rectangular	1,73	1,000	3,5E-04	4E+06
ΔEx (u5)	voltage difference measurement - measured device	0,007	V	6,0E-04	rectangular	1,73	1,000	3,5E-04	4E+06
Ss (u6)	sensitivity - standard device	1,000	V	0,00	normal, k = 1	1,00	0,004	0,00	3E+24
Sx (u7)	sensitivity - measured device	1,000	V	0,00	normal, k = 1	1,00	0,007	0,00	1E+24
dδR (u8)	RF/RF procedure	0	mV/V	2,5E-04	rectangular	1,73	1,000	1,4E-04	2E+07
dδP(u9)	distance deviation	0	mV/V	7,4E-05	rectangular	1,73	1,000	4,3E-05	3E+08
uA (u9)	Repeatability	0	mV/V	4,1E-05	normal	1,00	1,000	4,1E-05	3
δx	Combined uncertainty				normal			2,3E-03	198626
	Expanded uncertainty				2			4,5E-03	

Measured value of transfer difference δ_x is: -2,76 mV/V ± 0,45 mV/V.

2. example

The RF/DC difference was measured at 300 MHz using NRV-Z51 as standard device and Ballantine 1396H-1 200 Ω measured device. The reference plane of NRV-Z51 was extended by 13,25 mm, which affects *u9*. Symbol *D* replaces ∂ and *d* replaces δ. The measured results were as follows:

Udc	1	V
δx1	89,73	mV/V
δx2	89,59	mV/V
δx3	89,71	mV/V
δx4	89,66	mV/V
mean	89,67	mV/V
STDEV	0,03	mV/V
s	4E-04	

f = 300 MHz N - male connector, 200 ohm device

Symbol *Xi*	source of uncertainty	estimate *Xi*		standard uncertainty *u(Xi)*	probability distribution	div.	sens. coef. *ci*	uncertainty contribution *ui(P)*	*vi*
δs (u1)	standard RF/DC transfer diference	4,0	mV/V	4,0E-03	normal, k = 2	2,00	1,000	2,0E-03	1E+05
dδsL (u2)	drift of δs	0,000	mV/V	1,3E-03	rectangular	1,73	1,000	7,7E-04	8E+05
dδT (u3)	repeatability	2,400	mV/V	8,0E-04	rectangular	1,73	1,000	4,6E-04	2E+06
ΔEs (u4)	voltage measurement - standard device	100,0	mV	6,0E-04	rectangular	1,73	1,000	3,5E-04	4E+06
ΔEx (u5)	voltage measurement - measured device	0,030	mV	8,0E-08	rectangular	1,73	83	3,8E-06	3E+10
Ss (u6)	sensitivity - standard device	1,000	V	0,00	normal	1,00	0,100	0,00	5E+21
Sx (u7)	sensitivity - measured device	0,012	V	1,0E-03	normal	1,00	0,208	2,1E-04	1E+07
dδR (u8)	RF/RF procedure	0	mV/V	2,5E-04	rectangular	1,73	1,000	1,4E-04	2E+07
dδP(u9)	distance deviation	0	mV/V	4,9E-03	rectangular	1,73	1,000	2,8E-03	6E+04
uA (u10)	Repeatability	0	mV/V	3,4E-05	normal	1,00	1,000	3,4E-05	3
Prfabs	Combined uncertainty				normal			3,6E-03	146304
	Expanded uncertainty				2			7,2E-03	

Measured value of transfer difference δ_x is: 89,7 mV/V ± 5,2 mV/V.

It should be noted that the reference plane was established using N-female to N-female adapter internal T-junction was used. This has changed the distance of NRV-Z51 to reference plane by 13,25 mm. This would add additional uncertinty due skin effect of 0,15 mV/V and due to reflection of 4,88 mV/V.

Uncertainty budget of the GT – RF 92-6 comparison

Institute : Slovak Institute of Metrology – SMÚ

Date : 11.3. – 6.4.1998

Remarks : Values of uncertainty contribution are given in %

Travelling Standard : Ballantine

Contribution of	Uncertainty (%) 1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000 MHz	Type A or B	Shape of distribution
st. dev. of measurement (%)	0,006	0,005	0,008	0,007	0,008	0,004	0,015	0,017	0,008	A	trapezoidal
reference standard (%)	0,02	0,08	0,3	0,45	0,5	0,6	0,7	0,8	0,9	B	-
spectral purity of RF signal (%)	-	-	0,001	0,06	0,05	0,02	0,085	0,2	1,1	B	-
measurement set-up (%)	0,02	0,04	0,9	0,3	0,3	0,3	0,5	0,5	0,5	B	-
Total uncertainty u_C (1σ) (%) :	0,03	0,09	0,32	0,54	0,59	0,67	0,86	0,97	1,51		

Travelling Standard : NRV-Z51

Contribution of	1 MHz	10 MHz	50 MHz	100 MHz	200 MHz	300 MHz	500 MHz	700 MHz	1000 MHz	Type A or B	Shape of distribution
st. dev. of measurement (%)	0,005	0,005	0,004	0,004	0,004	0,008	0,01	0,008	0,008	A	trapezoidal
reference standard (%)	0,02	0,08	0,3	0,45	0,5	0,6	0,7	0,8	0,9	B	-
unsymetry of T (%)	0,002	0,002	0,01	0,015	0,02	0,03	0,08	0,2	0,3	B	-
spectral purity of RF signal (%)	-	-	-	-	-	-	0,002	0,033	0,020	B	-
measurement set-up (%)	0,03	0,04	0,1	0,2	0,1	0,15	0,4	0,5	0,5	B	-
Total uncertainty u_C (1σ) (%) :	0,036	0,09	0,32	0,49	0,51	0,62	0,81	0,97	1,07		

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example. Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: VNIIM, Russia

Date: 24. 12. 2001 – 01. 02. 2002

Remarks:

Travelling standard: Ballantine

Contribution of $.10^{-6}$	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	4	4	5	8	A	normal
reference standard	9	45	290	980	B	uniform
measurement set-up	2	4	10	10	B	uniform
connectors	3	10	30	50	B	uniform
change in external condition	2	4	4	4	B	uniform

total uncertainte (1σ)	7	27	168	567

Travelling standard: NRV-Z51

Contribution of $.10^{-6}$	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	27	27	84	90	A	normal
reference standard	9	45	290	980	B	uniform
measurement set-up	2	4	10	10	B	uniform
connectors	3	10	30	50	B	uniform
change in external condition	2	4	4	4	B	uniform

total uncertainte (1σ)	28	38	188	574

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example. Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: VNIIM, Russia

Date: 24. 12. 2001 – 01. 02. 2002

Remarks:

Travelling standard: NRV-Z51

Contribution of $.10^{-6}$	Unc. f: 200 MHz	Unc. f: 300 MHz	Unc. f: 500 MHz	Unc. f: 700 MHz	Type A or B	Shape of distribution
st. dev. of measurement	45	130	200	370	A	normal
reference standard	1500	2000	3500	5000	B	uniform
measurement set-up	10	15	40	80	B	uniform
connectors	100	200	400	600	B	uniform
change in external condition	10	10	10	15	B	uniform

total uncertainte (1σ)	869	1168	2038	2931

Travelling standard: Ballantine

Contribution of $.10^{-6}$	Unc. f: 200 MHz	Unc. f: 300 MHz	Unc. f: 500 MHz	Unc. f: 700 MHz	Type A or B	Shape of distribution
st. dev. of measurement	100	120	150	180	A	normal
reference standard	1500	2000	3500	5000	B	uniform
measurement set-up	10	15	20	80	B	uniform
connectors	100	200	300	600	B	uniform
change in external condition	10	10	10	15	B	uniform

total uncertainte (1σ)	874	1168	2034	2913

Uncertainty budget of the GT-RF 92-6 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty, this is just an example. Our main goal is to have an uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute: VNIIM, Russia

Date: 24. 12. 2001 – 01. 02. 2002

Remarks:

Travelling standard: Ballantine

Contribution of $.10^{-6}$	Unc. f: 1000 MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement	490				A	normal
reference standard	7000				B	uniform
measurement set-up	100				B	uniform
connectors	800				B	uniform
change in external condition	20				B	uniform

total uncertainte (1σ)	4081			

Travelling standard: NRV-Z51

Contribution of $.10^{-6}$	Unc. f: 1000 MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement	250				A	normal
reference standard	7000				B	uniform
measurement set-up	50				B	uniform
connectors	500				B	uniform
change in external condition	20				B	uniform

total uncertainte (1σ)	4060			