Final Report

EUROMET PROJECT 818
CALIBRATION FACTOR OF THERMISTOR MOUNTS

Jan P.M. de Vreede

Department of Electricity, Radiation and Length
NMi Van Swinden Laboratorium
Thijsseweg 11, 2629 JA Delft, the Netherlands
e-mail: JdeVreede@nmi.nl

January 2007

Abstract:

In this bilateral comparison between NMi-VSL and MIKES the calibration factor and reflection coefficient of thermistor mounts were measured at 8 frequencies between 10 MHz and 18 GHz.
The maximum comparison uncertainty for the calibration factor ranges from 0.8 % at 50 MHz to 2.2 % at 18 GHz. All results are consistent within the comparison uncertainty, using k=2.
The uncertainty stated for the reflection coefficient was up to 0.02, consistent within the claimed uncertainty.
Taking these facts into account, the results show a good agreement for both the calibration factor and the reflection coefficient.
Also the DoE of MIKES is calculated for entry in the KCDB as part of the key comparison EUROMET.EM.RF-K8.CL

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1. Introduction

In recent years European national metrology institutes had the possibility to participate in two key comparisons in the field of power measurements using thermistor mounts as device under test [1,2]. The first one (CCEM.RF-K8.CL) was under the auspices of the Comite Consultatif d'Ēlectricité et Magnetisme (CCEM) and its working group for radiofrequency quantities (GT-RF). The second one (EUROMET.EM.RF-K8.CL; Euromet project 633) was a follow-up exercise of the first one to investigate some problems found in the first one, but also to provide some laboratories with a direct link to the other national laboratories. NMi Van Swinden Laboratorium (NMi-VSL) acted as pilot laboratory for both comparisons.
A few years ago MIKES, the national metrology institute of Finland, built facilities in the radio frequency field. After obtaining experience in practical work it now wants to verify formally the performance in this field. As power is one of the most important quantities, MIKES expressed the wish to participate in a bilateral comparison with one of the participants in the previous comparisons. The most logical candidate would be the pilot laboratory of these comparisons.
The bilateral comparison is formalized as Euromet project 818 and has been entered in the KCDB under the code EUROMET.EM.RF-K8.1.CL. In essence the same technical procedure is followed as in CCEM.RF-K8.CL and Euromet 633.

2. Participants and schedule

After some discussion about the most convenient way to carry out the comparison it was decided to use DUTs from both laboratories. Each laboratory would measure its own device at the beginning and the end of the exercise and measure the other DUT while its own DUT was still in the laboratory. The measurements are considered to be of a routine nature.
Table 1 gives the basic information on the comparison.

Table 1. List of participants and measurement dates.

Acronym	National Metrology Institute	Country	Standard at the laboratory	Date of submission of report
NMi-VSL	NMi Van Swinden Laboratorium - Pilot	The Netherlands	December 2004 – February 2005	July 2005
MIKES	Centre for Metrology and Accreditation	Finland	December 2004 – February 2005	June 2005

3. Transfer Standard and required measurements

Because the project is a follow-up of previous comparisons it was decided to use a set of similar devices. Hence the following DUTs were used:

- Hewlett Packard model 8478B Opt.H48 (sn.3318 A 25650), owner NMi-VSL; the code DUT1 is used in this report;
- Hewlett Packard model 8478B (sn.2106 A 23988), owner MIKES; the code DUT2 is used in this report.

All devices are equipped with a Type-N connector.

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

The quantity under investigation in this comparison is the calibration factor K, which is defined by:

$K= P_{DC}/P_{inc}$ with:

P_{DC} - the DC substitution power determined by the thermistor bridge of the participant and

P_{inc} - the RF power incident to the thermistor mount (DUT) at the measurement frequency.

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

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

In the Technical Protocol no requirements are given concerning the ambient conditions.

4. Behaviour of the transfer standard

As the DUTs are property of the participants, the in-house stability is known. Based upon the experience obtained in previous comparisons and the small number of participants, no additional checks concerning stability for transport have been performed.

The two measurements done at each laboratory on its own device are used to obtain an idea about possible drift and transport influences. No significant influence is found. Hence, the official results are based upon the average result for the laboratory's own device. The VSL-mount had a little dent on the outer connector contact end. Some instabilities (informal information) in that mount were found at MIKES, but not at NMi-VSL.

5. Measurement methods

As indicated in the guidelines each laboratory should use the same measurement instrumentation as used for "high level" calibration for external customers. All systems are based on a (in)direct comparison between a (working) standard and the DUT.
For each laboratory the measurement procedure (including traceability) is briefly described here. Also information about the measurement of the reflection is given.

<u>NMi-VSL – pilot laboratory:</u>
A substitution system is used, where the signal comes from a stable signal generator, with a 10 dB attenuator to improve the VSWR of the output port. The standard and DUT are placed alternatively on

the output port of the generator, and are of similar design (thermistor mounts). The response of the thermistor mounts is obtained using the recorder output of a self-balancing bridge, HP 432A. The recorder output has been characterised during normal maintenance using V_{RF} and V_{comp} readings. The DUT is measured against at least two standards in different orientations.
Traceability is based on the primary VSL power facility (microcalorimeter): the working standards are calibrated in the microcalorimeter every half year.
The reflection coefficients are measured using Vector Network Analysers (HP 8753E with external test set and Wiltron 360A).

<u>MIKES:</u>
A power splitter system is used with an Agilent 8481A power sensor permanently attached to one arm. The DUT and the standard are attached alternatively to the other arm of the splitter. An HP 432B bridge and an Agilent 34970A Data Acquisition system is used for reading three signals: V_{RF}, V_{comp} and their difference. From these values the power reading of the DUT and the standard is calculated. The DUT and the standard were measured in three different positions 120 degrees apart.
The standard (another HP 8478B thermistor mount) is traceable to NPL, UK. The reflection coefficients are measured using Agilent 8510C and E8357A VNAs.

6. Technical protocol

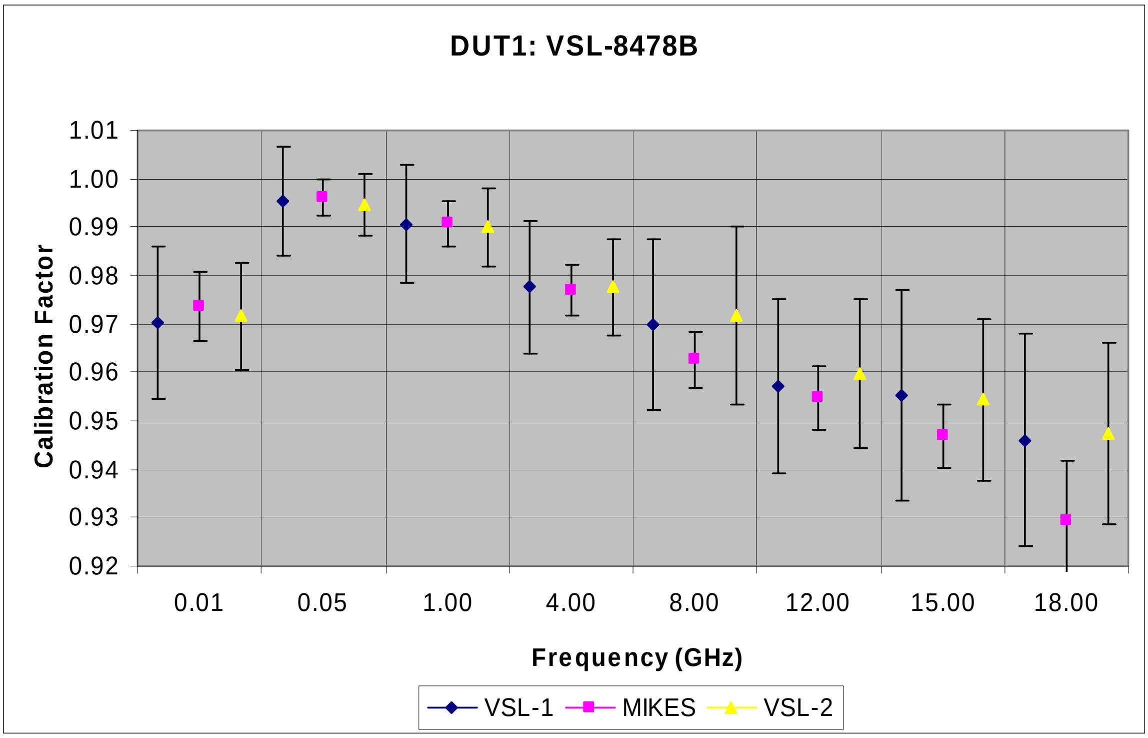
In the protocol ("Technical Protocol for the comparison", see Appendix C1) participants were asked to present their measurement results in the format of the mean of the calibration factor and the magnitude of the reflection coefficient at the 8 frequencies, including a statement of uncertainty with a coverage factor of $k = 1$. 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. Reference was made to the EA document on uncertainty (EA-04/02) [3] that gives guidance for providing such an uncertainty budget, and to the uncertainty budgets as given the Euromet project 393. Also the traceability for the standards used should be provided to ascertain that correlation between measurement results would not be overlooked.

7. Measurement results

7.1. General results

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

Figures 1 and 2 give an overview over all data relevant for the comparison. Figure 1 contains the three series of data concerning the calibration factor and Figure 2 contains the results on the reflection coefficient as measured by the two laboratories. The uncertainty bars are the k=2 values based upon the information given by each of the laboratories.
In general the pilot laboratory gave larger uncertainties for its measurements.



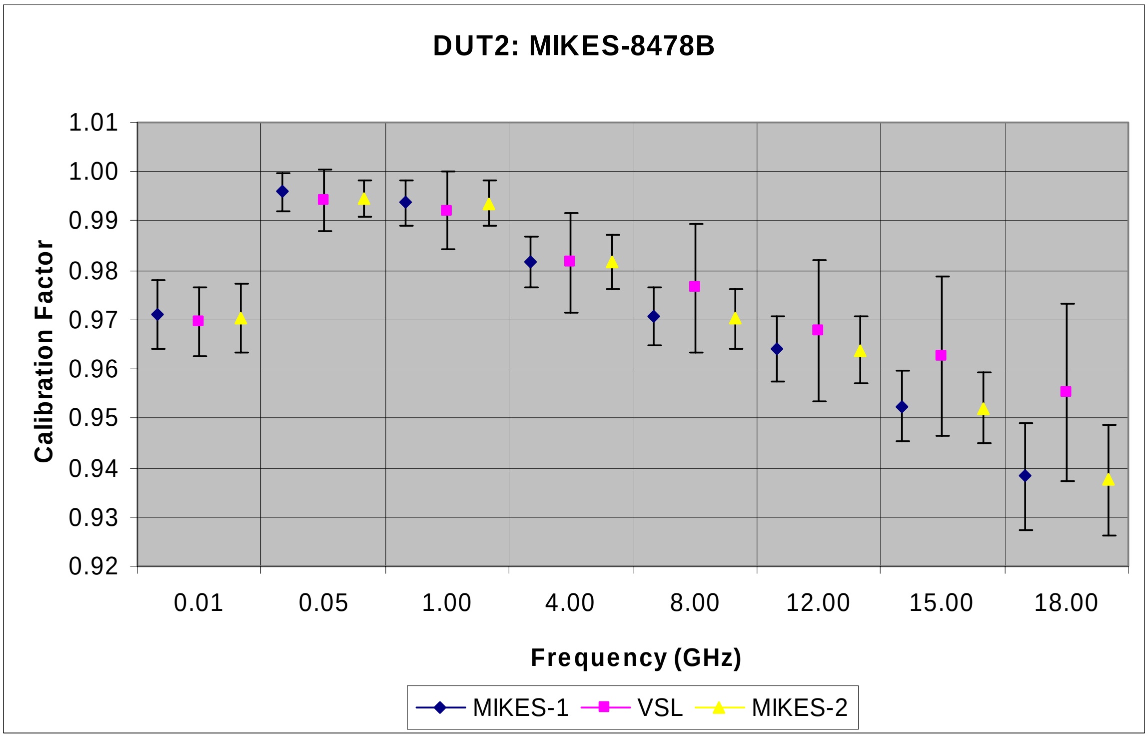
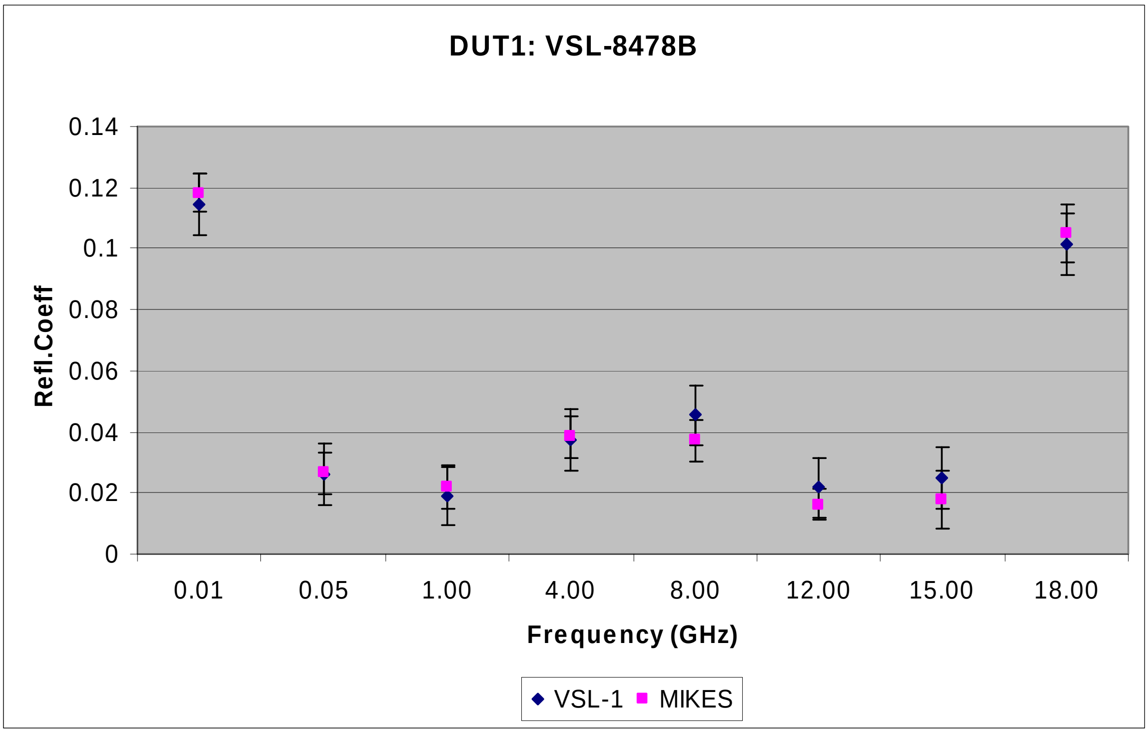


Figure 1: The calibration factor as function of frequency as determined by the two participants. Each laboratory has measured its own thermistor mount at the beginning and at the end of the comparison. The uncertainty bars refer to the expanded standard deviation (k=2) in the results of the participants.



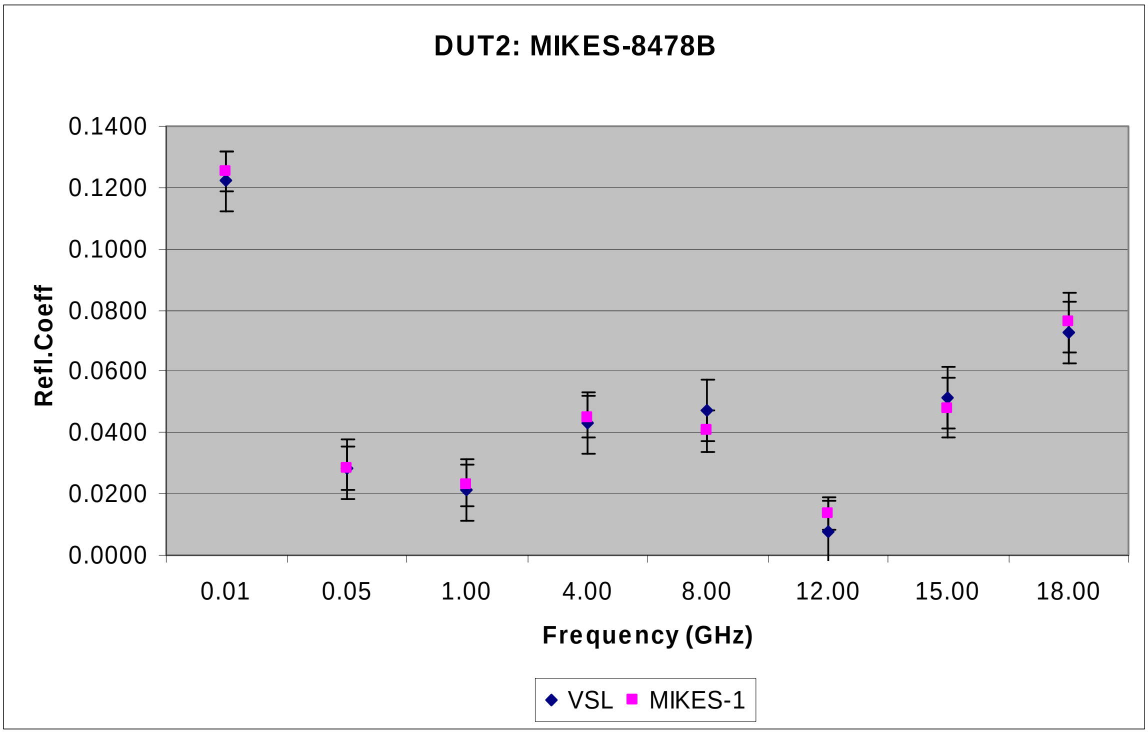


Figure 2: The reflection coefficient as function of frequency as determined by the two participants. The uncertainty bars refer to the standard deviation (*k*=1) in the results of the participants.

7.2. Determining the Reference Value

For this bilateral comparison the result from the pilot laboratory is taken as the reference value. In the analysis process the difference in results between the two laboratories is taken to be the official result of the comparison. If a laboratory has measured the device twice, the average value of the two measurements are used. For the associated uncertainty the average value of the two uncertainties is used, as the uncertainty of the Type-B evaluation is dominant in almost all cases and the measurement set-ups were not changed in between. As can be seen in Table 2, the differences between the two DUTs is small compared to the uncertainty. Hence, a mathematically more accurate model is not applied, as we expect only negligible changes will occur.

The result presented is defined as:

Result = dCF = CF(MIKES) - CF(NMi-VSL),

where CF is the calibration factor measured at a specific frequency.
In Table 2 and Figure 3 the results for DUT1 and DUT2 are given. The error bars are based on the RSS value of the individual uncertainty budgets. A slight systematic deviation as function of frequency seems to be present, but still within the combined uncertainty for *k*=2.

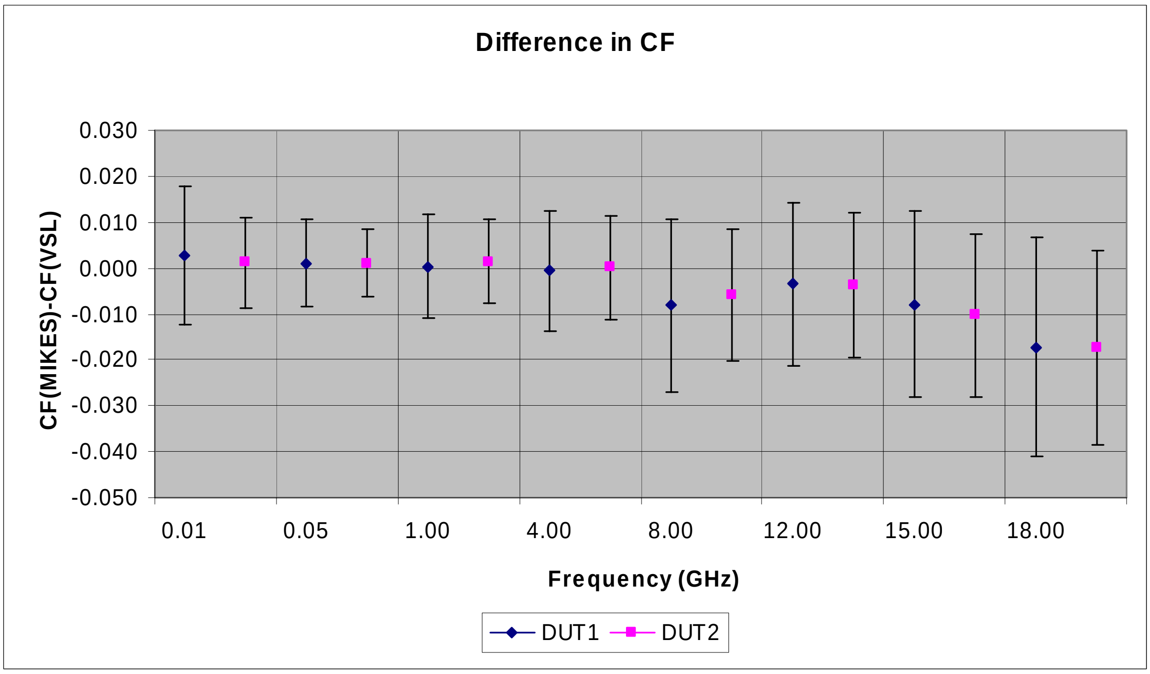


Figure 3: The difference in measured calibration factor as function of frequency. The calibration factor determined by the pilot is taken as reference. The error bars are based on the RSS value of the individual uncertainty budgets, using *k*=2.

Table 2: Differences in measured Calibration Factor per DUT and averaged to one result per frequency						
Frequency	DUT1		DUT2		Average	
GHz	dCF	Unc	dCF	Unc	dCF	Unc
0.01	0.0026	0.0151	0.0011	0.0099	0.0019	0.0125
0.05	0.0011	0.0096	0.0010	0.0073	0.0010	0.0085
1.00	0.0004	0.0112	0.0015	0.0092	0.0009	0.0102
4.00	-0.0007	0.0129	0.0001	0.0113	-0.0003	0.0121
8.00	-0.0081	0.0189	-0.0059	0.0144	-0.0070	0.0167
12.00	-0.0035	0.0179	-0.0038	0.0159	-0.0036	0.0169
15.00	-0.0079	0.0203	-0.0103	0.0176	-0.0091	0.0190
18.00	-0.0173	0.0238	-0.0173	0.0211	-0.0173	0.0225

7.2.1. Linking to SI:

As already mentioned above MIKES is traceable to NPL, UK, for the quantity of power. Whether part of the "systematic deviation" is due to the different traceability chains, can be investigated using the results of NPL and NMi-VSL in previous comparisons. As this comparison should be linked directly to Euromet project 633 (EUROMET.EM.RF-K8.CL) it is logical to use this comparison for a potential systematic deviation in the realisation of the quantity power at NPL and NMi-VSL.
In Table 3 this information is given (obtained from [4]), using the average of the measured values on the devices TM4 and TM6. The column "Spread" refers to the standard deviation for the two results obtained in project 633 (their uncertainties are not used here). In Figure 4 the difference between the results from NPL and NMi-VSL is given as function of frequency, together with the results from Figure 3 by averaging the results for DUT1 and DUT2 and using the average of the uncertainty statements.

Table 3: Differences between NPL and NMi-VSL as measured in EUROMET.EM.RF-K8.CL		
	NPL-VSL	
Frequency [GHz]	Average:	Spread:
0.01	0.0021	0.0011
0.05	0.0004	0.0001
1.00	0.0011	0.0004
4.00	-0.0002	0.0012
8.00	-0.0028	0.0013
12.00	-0.0019	0.0030
15.00	-0.0083	0.0034
18.00	-0.0059	0.0020

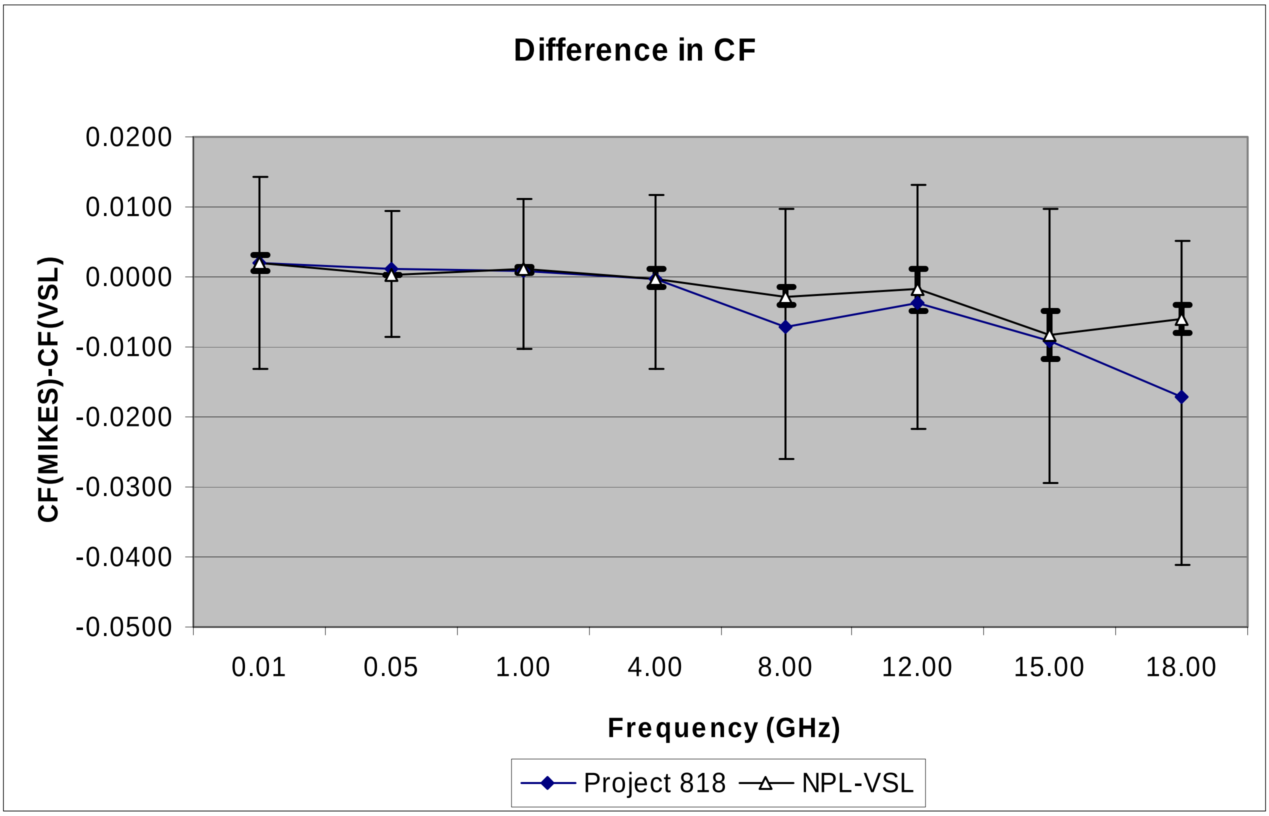


Figure 4: The data of project 818 refer to the measured difference in Calibration Factor between MIKES and NMi-VSL (using the data from Table 2). The data marked as "NPL-VSL" refer to similar results in project 633 between NPL and NMi-VSL (using the information from Table 3).

Both comparisons shows a similar trend, but of slightly different magnitude. Between NMi-VSL and MIKES a small systematic deviation might exist. Informal information indicates that the difference in results between NPL and VSL might be somewhat larger than found in Table 3, especially at 18 GHz.

7.3 Degrees of Equivalence for MIKES

The final step in linking the present comparison to the previous one (project 633) can now be done using the Degrees of Equivalence (DoE) of NMi-VSL in the previous comparison (see Table 4). The DoE consists of the difference of the results of VSL from the KCRV and the associated uncertainty.

Table 4: Degrees of Equivalence for NMi-VSL in EUROMET.EM.RF-K8.CL

Frequency [GHz]	Value	Uncertainty (*k*=2)
0.01	-0.0009	0.0224
0.05	-0.0002	0.0055
1.00	-0.0005	0.0051
4.00	0.0004	0.0069
8.00	0.0035	0.0114
12.00	0.0033	0.0106
15.00	0.0077	0.0129
18.00	0.0035	0.0157

The value for the final result is obtained as:

CF(MIKES)= dCF + DoE(NMi-VSL: value)

where dCF is obtained from Table 2 and DoE from Table 4.

For the uncertainty we have to look to the correlation in the measurement results of NMi-VSL, and especially the uncertainty part of the DoE.
The uncertainty in the KCRV itself is in general less than 0.001 and at 18 GHz less than 0.004. This means that this part is negligible compared to the expanded uncertainties given by NMi-VSL.
In Table 5 the uncertainty contributions given by NMi-VSL are compared. The contribution due to statistical spread in the measurements (Type A) is usually small compared to the systematic contributions. Except for 10 MHz, the latter contributions in this comparison are larger than in the previous comparison. This is mainly due to the variations found in the calibration of the working standards in the microcalorimeter (dominant term in the uncertainty: see Table B1). The power ratio drift (or variation) between DUT and standard is much smaller. This indicates that the reproducibility of the measurement system is small enough to neglect effects due to the time interval between the two comparisons 633 and 818.
As the systematic contributions for NMi-VSL should be taken into account only once, it is decided to use the uncertainty evaluation results obtained in Table 2.

Table 5: Uncertainties relevant in linking CF (MIKES) to EUROMET.EM.RF-K8.CL

	Uncertainties (k=2) for measurements at NMi-VSL			
Frequency [GHz]	Typical values for Type A	Expanded values in 633	Expanded values in 818	Expanded uncertainty in measurement result (Table 2)
0.01	0.001	0.0224	0.0112	0.0125
0.05	0.001	0.0055	0.0080	0.0085
1.00	0.002	0.0051	0.0094	0.0102
4.00	0.002	0.0069	0.0112	0.0121
8.00	0.004	0.0114	0.0164	0.0167
12.00	0.006	0.0106	0.0159	0.0169
15.00	0.008	0.0129	0.0182	0.0190
18.00	0.010	0.0157	0.0196	0.0225

Comparing the data in the last two columns it is clear that the uncertainty statement of the linking laboratory plays a significant role in the overall uncertainty. The result is presented in Figure 5 and Table 6.

Table 6: Final result of comparison: MIKES relative to reference value of EUROMET.EM.RF-K8.CL

Frequency [GHz]	Deviation in CF	Uncertainty (k=2)
0.01	0.0009	0.0125
0.05	0.0008	0.0085
1.00	0.0004	0.0102
4.00	0.0001	0.0121
8.00	-0.0035	0.0167
12.00	-0.0003	0.0169
15.00	-0.0015	0.0190
18.00	-0.0138	0.0225

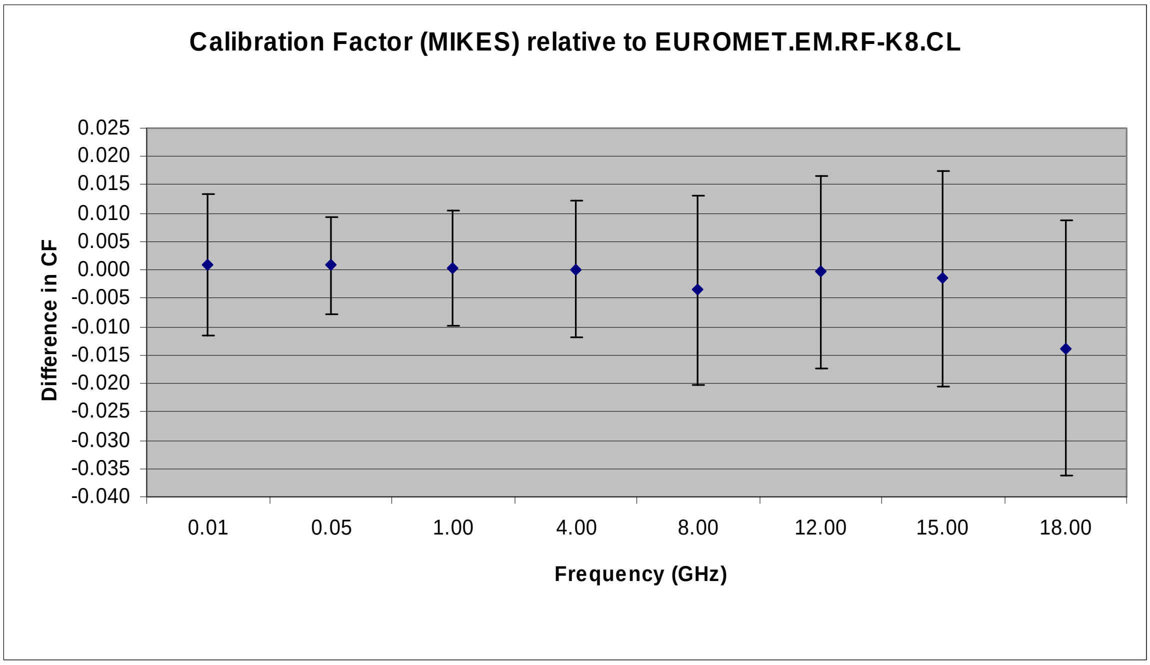


Figure 5: The average difference between the results from MIKES and the reference value obtained in the EUROMET.EM.RF-K8.CL

7.4. Uncertainty budgets

For the uncertainty budget the EA guidance document is followed. Compared to the previous comparisons NMi-VSL has changed the lay-out of the budget to be in line with that of MIKES.

8.1. Reflection coefficient

The two laboratories agree very well in their results.

8.2. Torque wrench

In the previous comparisons the use of a torque wrench was requested. In this comparison the technical protocol did not ask for it explicitly, as DUT2 (owned by MIKES) did not have a suitable surface. Both laboratories have used a torque wrench, when possible.

9. Conclusions

The comparison uncertainty for the calibration factor ranges from 0.8 % at 50 MHz to 2.2 % at 18 GHz, using k=2. The overall uncertainty is largely dominated by the measurement uncertainty of NMi-VSL. All results are consistent within the claimed uncertainty.
The uncertainty stated for the reflection coefficient was up to 0.02, consistent within the claimed uncertainty.
Taking these facts into account, the results show a good agreement for both the calibration factor and the reflection coefficient.

10. References

[1] Jan P M de Vreede, "Final Report of the comparison CCEM.RF-K8.CL: Calibration factor of thermistor mounts", 2005, *Metrologia* **42** 01008

[2] Jan P.M. de Vreede, Final Report: "EUROMET.EM.RF-K8.CL COMPARISON - CALIBRATION FACTOR OF THERMISTOR MOUNTS - September 2006"

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

[4] Jan P.M. de Vreede, Final Report "LINKING EUROMET PROJECT 633 To CCEM.RF-K8.CL (CALIBRATION FACTOR OF THERMISTOR MOUNTS) – September 2006"

APPENDIX A

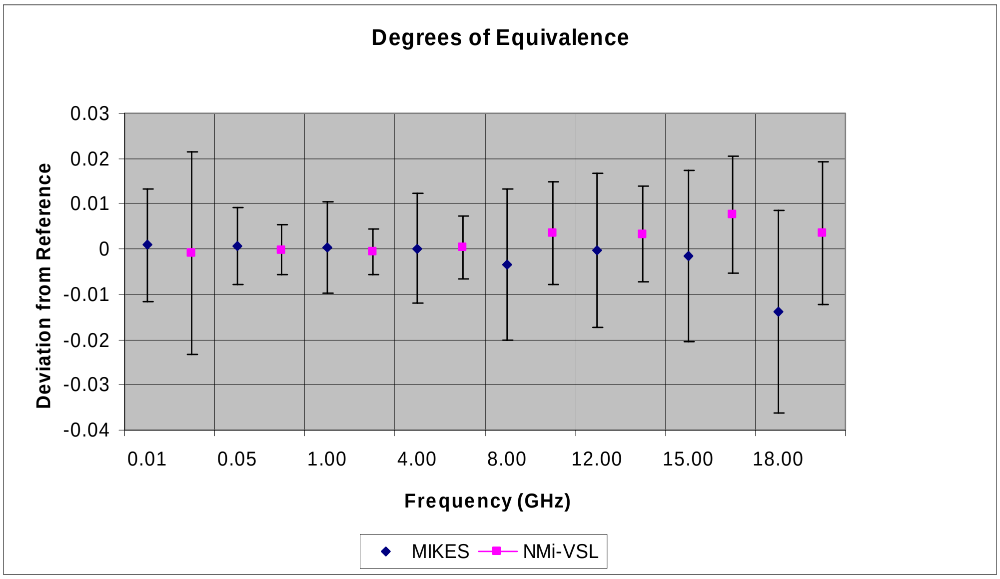
Degrees of equivalence for calibration factor of MIKES

Regional Key comparison: Euromet.EM.RF-K8.1.CL

Measurand: calibration factor in coaxial 7 mm transmission line Nominal value: 1.00
Pilot laboratory: NMi-VSL
Travelling standards: two thermistor mounts identified as DUT1 and DUT2; both have a male type N 50 ohm connector

As the actual calibration factors of the DUTs are not relevant for the quality of the measurement results, the comparison reference value is shifted to zero. As the comparison is aimed at linking the results from MIKES to the key comparison EUROMET.EM.RF-K8.CL, the results from the pilot laboratory are adjusted in such a way that they agree in value with the DoE of the key comparison mentioned above.
The uncertainty in the DoE of the pilot laboratory is not taken into account, as otherwise the contributions of systematic nature to the uncertainties would be counted twice.
D_i = the difference from the reference value for laboratory i
U_i = the uncertainty of $D_{,i}$ taken into account the uncertainty of the bilateral comparison.

Frequency GHz	Laboratory	D_i	U_i
0.01	MIKES	0.0009	0.0125
	NMi-VSL	-0.0009	0.0224
0.05	MIKES	0.0008	0.0085
	NMi-VSL	-0.0002	0.0055
1.0	MIKES	0.0004	0.0102
	NMi-VSL	-0.0005	0.0051
4.0	MIKES	0.0001	0.0121
	NMi-VSL	0.0004	0.0069
8.0	MIKES	-0.0035	0.0167
	NMi-VSL	0.0035	0.0114
12.0	MIKES	-0.0003	0.0169
	NMi-VSL	0.0033	0.0106
15.0	MIKES	-0.0015	0.0190
	NMi-VSL	0.0077	0.0129
18.0	MIKES	-0.0138	0.0225
	NMi-VSL	0.0035	0.0157



Appendix B
Participant uncertainty budget for a thermistor mount

Pilot laboratory: NMi-VSL

The uncertainty budget refers to an individual measurement and not to the average of a series of measurements. The data are indicative for the frequency range and the type of DUT.

The calibration factor in each measurement series is determined as:

$$K_X = K_S * P_R * p_c * \frac{M_X}{M_S}$$

where
K_X = calibration factor of the DUT
K_S = calibration factor of the standard
M_X = mismatch factor for the DUT
M_S = mismatch factor for the standard
p_c = linearity correction factor
P_R = Ratio of the power readings for the DUT and standard.

Table B.1 shows a *typical example for a measurement* on DUT2, where uKx indicates the calculated uncertainty for this measurement.

Table B.1: Uncertainty budget for a specific measurement during EUROMET.EM.RF-K8.1.CL

Frequency GHz	P_R (%)	p_c (%)	M_S (%)	M_X (%)	K_S (%)	K_X (%)	uKx (%, k=2)
0.01	0.09	0.20	0.24	0.21	0.41	96.79	1.13
0.05	0.00	0.20	0.07	0.06	0.21	99.46	0.61
1	0.03	0.20	0.03	0.03	0.31	99.24	0.74
4	0.13	0.20	0.05	0.10	0.41	98.15	0.98
8	0.39	0.20	0.17	0.16	0.56	97.55	1.49
12	0.38	0.20	0.27	0.04	0.66	96.49	1.67
15	0.08	0.20	0.47	0.27	0.65	96.11	1.75
18	0.19	0.20	0.21	0.11	0.90	95.16	1.93

MIKES

The calibration factor was determined as

$$K_X = (K_S + \delta K_D)\frac{M_X}{M_S}\, p_C \,\frac{p_X}{p_S}$$

where

K_X unknown sensor calibration factor
K_S standard sensor calibration factor
δK_D drift of standard sensor calibration factor
M_X mismatch factor for unknown power sensor
M_S mismatch factor for standard power sensor
p_C linearity correction factor
p_X power ratio of standard sensor to reference
p_S power ratio of unknown sensor to reference

Note that that here the calibration factor is defined with respect to the DC substitution power, unlike in EA-4/02 where the calibration factor was defined with respect to the 50 MHz reference value.

Table 1 shows a typical example of the uncertainty budget breakdown.

Table 1. HP 8478B SN 2106A 23988 first round

Frequency [GHz]	$u(p_S)$ [abs. %]	$u(p_X)$ [abs. %]	$u(p_C)$ [abs. %]	$u(M_S)$ [abs. %]	$u(M_X)$ [abs. %]	$u(\delta K_D)$ [abs. %]	$u(K_S)$ [abs. %]	K_X [abs. %]	$u(K_X)$ [abs. %]	ν_{eff}
0,01	0,0119	0,0076	0,0097	0,1532	0,1575	0,1005	0,2514	97,12	0,35	142
0,05	0,0211	0,0096	0,0100	0,0296	0,0298	0,1000	0,1500	99,59	0,19	100
1,00	0,0214	0,0143	0,0099	0,0237	0,0249	0,1003	0,2005	99,37	0,23	79
4,00	0,0257	0,0141	0,0098	0,0926	0,0968	0,1004	0,2007	98,16	0,26	128
8,00	0,0304	0,0177	0,0097	0,0835	0,0682	0,1007	0,2518	97,08	0,29	89
12,00	0,0333	0,0153	0,0096	0,0707	0,0363	0,1007	0,3022	96,41	0,33	70
15,00	0,0366	0,0167	0,0095	0,0489	0,1336	0,1005	0,3014	95,25	0,35	87
18,00	0,0294	0,0666	0,0094	0,2233	0,3408	0,1001	0,3504	93,82	0,55	180

Note: the stated $u(K_X)$ refers to a coverage factor of k=1.

APPENDIX C

C1) Technical Protocol

Technical Protocol for Euromet project 818

Scope:
This project is a follow-up of Euromet project 633. This project is a bilateral comparison to link MIKES to the participants of Euromet projects 393 and 633. In essence the same procedure will be followed as in Euromet 393 and its international extensions CCEM.RF-K8.CL and Euromet 633 (EUROMET.EM.RF-K8.CL). In this way a firm link may be obtained with the other comparisons.

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

Travelling standards
A set of two thermistor mounts is used, both with type-N male connector:

1: travelling standard
- Hewlett Packard
- model 8478b Option H48
- sn. 3318 A 25650
- connector: Type-N male
- Ident: H48.25

2: travelling standard
- Hewlett Packard
- model 8478b
- sn. 2106 A 23988
- connector: Type-N male

Measurement procedure
As already indicated, the normal laboratory procedure for high level calibration of power sensors should be used. Hence, no attempt should be made to improve facilities just for this comparison.
Usually customers expect to be served within a couple of weeks. This is also the main reason for allowing a relative short turn-around time for the measurements.
The two travelling standards are to be calibrated at the following frequencies (in GHz): 0.010, 0.050, 1.00, 4.00, 8.00, 12.00, 15.00 and 18.00.

Submission of results
Each laboratory is expected to submit its report to the coordinator within **6 weeks** after the end of its measuring period.
Anyway, the pilot laboratory needs sufficient information to make a first evaluation of the results before a general discussion can take place on the draft report as prepared by the pilot laboratory.

A breakdown of the uncertainty budget is an essential part of evaluating measurement results. According to the CIPM guidelines the ISO Guide on the Calculation of Uncertainties in Measurements (GUM) should be

followed. A practical implementation of this document within the European Accreditation bodies is the EA-04/02 (1999) document. (this document is available on the EA website: www.european-accreditation.org).
The report should also contain at least a short description of the measurement set-up, preferably with some schematic drawing, the relevant statistical information on the individual measurement results and traceability chain.
An example of presenting a summary of the basic results is given in the table below.

Results of Euromet project XXX				
Laboratory:				
Frequency [GHz]	Calibration factor	Uncertainty (k=1)	Reflection coefficient	Uncertainty in refl. coefficient (k=1)
0.01				
0.05				
1.00				
4.00				
8.00				
12.00				
15.00				
18.00				

Contributions to the uncertainty
In Euromet project 393 and 633 the following contributions were considered mainly to be responsible for the uncertainty in the determination of the calibration factor:
- reflection coefficient of the source
- reflection coefficient of the internal working standard
- reflection coefficient of the travelling standard
- uncertainty in the calibration factor of the internal working standard.

The term “internal working standard” is used here to describe the power sensor used directly in calibrating the travelling standards.
The BIPM Guideline, which is also used for Euromet comparisons with minor changes, requests an uncertainty evaluation at the level of one standard uncertainty, giving also the number of degrees of freedom.

Discussion of results
It is expected that an open discussion will take place as quickly as possible after distributing a draft report containing a compilation of the results and a first attempt of interpretation.
Afterwards the final result can be published in Metrologia (in short form) and preferably as a full paper in the open literature as well.

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

Transport and customs

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

Circulation time schedule
The circulation schedule is agreed upon between the original participants.
Updates of the schedule will be sent when and where necessary. A turn-around time between laboratories of 3 weeks is used. It is the responsibility of each participating laboratory to inform the next participant in advance to arrange the transportation of the standards, and to inform the coordinator about the date of transportation.

The time schedule is as follows:

Institute	Measuring Period	DUT	Contact person
NMi VSL	November / December 2004	VSL	Jan de Vreede
MIKES	December 2004 / January 2005	MIKES/VSL	Kari Ojasalo
NMi VSL	January 2005	MIKES/VSL	Jan de Vreede
MIKES	February 2005	MIKES	Kari Ojasalo

Coordinator
The pilot laboratory for this comparison is NMi Van Swinden Laboratorium (VSL). The coordinator for this comparison is:
Dr. Jan P.M. de Vreede
NMi Van Swinden Laboratorium
Schoemakerstraat 97
P.O. Box 654
2600 AR Delft
The Netherlands

Telephone: +31 - 15 269 1500
Fax: +31 - 15 261 2971
E-mail: JdeVreede@nmi.nl

C2) Contact Persons

Finland: MIKES **Mr. Kari Ojasalo** MIKES (Centre of Metrology and Accreditation) Electricity and Acoustics P.O.Box 9 (Tekniikantie 1) FIN-02151 ESPOO FINLAND	Tel.: + 358 010 6054 423 Fax: + 358 010 6054 299 e-mail: kari.ojasalo@mikes.fi
The Netherlands: NMi VSL **Dr. Jan P.M. de Vreede** Department of Electricity, Radiation and Length Postbus 654 2600 AR DELFT THE NETHERLANDS	Tel.: +31 15 269 1500 Fax: +31 15 261 2971 e-mail: JdeVreede@nmi.nl