Final Report

LINKING
EUROMET PROJECT 633
To
CCEM.RF-K8.CL

“CALIBRATION FACTOR OF THERMISTOR MOUNTS”

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1. Introduction

During the European round of CCEM.RF-K8.CL the Euromet experts concluded that a small follow-up would be useful: - the results from METAS most likely showed a systematic deviation at higher frequencies; - IEN suspected some discrepancies at certain frequencies; - and the stated uncertainties of NPL were quite large due to the measurement procedure followed. This follow-up is the Euromet project 633. After announcement of this project another three laboratories expressed the wish to participate in this project. The Euromet Technical chairman decided that the project should be a key comparison as one participant wants to use this project to create a link to the CCEM comparison, and one wanted to extend its range. It was decided that the same laboratory (NMi Van Swinden Laboratorium: VSL) would act as pilot in the Euromet 633 project, also known under its KCDB code EUROMET.EM.RF-K8.CL.
The results of the two comparisons are presented in [1] and [2]. The latter comparison indicates significantly smaller uncertainties for NPL and no significant deviations of METAS results at higher frequencies. However, the results of IEN led often to doubts at higher frequencies, while for NRC this is limited to the lowest frequency of 10 MHz.
This paper is limited to a discussion how to link Euromet 633 to the CCEM key comparison. The linking is somewhat difficult as NRC and IEN participated as they suspected problems in the first comparison. It seems for IEN that these problems have not been solved during the second comparison. Hence the number of independent realisations of the measurand is sometimes limited to the contributions from only two laboratories.

2. Participants

In the comparison CCEM.RF-K8.CL 21 laboratories participated of which 11 have an independent realisation of the quantity RF power. For the comparison EUROMET.EM.RF-K8.CL (Euromet 633) 7 laboratories participated, of which 4 have an independent realisation of this quantity.

Table 1. List of participants in both comparisons

Acronym	**National Metrology Institute**	**Country**	**Participation in both comparisons**	**Independent realisation of primary power standard**
NMi-VSL	NMi Van Swinden Laboratorium - Pilot	The Netherlands	Yes	Yes
NPL	National Physical Laboratory	United Kingdom	Yes	Yes
IENGF	Istituto Elettrotecnico Nazionale Galileo Ferraris	Italy	Yes	Yes
METAS	Swiss Office of Metrology	Switzerland	Yes	
NRC	National Research Council	Canada	Yes	Yes
SMU	Slovak Institute of Metrology	Slovak Republic	Yes	
SP	SP Sveriges Provnings- och Forskninginstitut	Sweden		

In Table 1 an overview is given of the participants. In the table is indicated which laboratories took part in both comparisons. Also is indicated which laboratories have an independent realisation of the primary standard for power. Results from the last group of laboratories are used in the linking process.

3. Transfer Standard and required measurements

On purpose similar devices were used in the two comparisons: a thermistor mount with Type-N connector and one with PC7-connector. An adapter was provided to "convert" the PC7 device into another Type-N thermistor mount.

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

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

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

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

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

4. Results of the comparisons

4.1. CCEM-comparison

The KCRV of this comparison is based upon the results from those laboratories that are members of the GT-RF and have an independent realisation of the quantity power. An overview is given in Table 2 where the participants in the Euromet 633 are indicated in red. Whether a result indeed contributed to the KRCV was determined using the method described by Randa [3]. At lower frequencies sometimes the results of NRC are excluded, and at higher frequencies this is sometimes the case for IEN.

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

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

4.2. Euromet 633

For the CRV (comparison reference value) in Euromet project 633 a similar procedure is followed. In Table 3 an overview is given of those laboratories that have an independent realisation of the quantity

power. Again the Randa method is used for exclusion of “outliers”. However, at 10 MHz the results from NRC and IENGF show large deviations (4% between the two results) that are significantly larger than the stated k=2 uncertainties.

Table 3: List of laboratories, which have an independent realisation of the quantity power. “X” indicates outlier. “-“ indicates “No measurements”.

Laboratory	Frequency																							
	10 MHz			50 MHz			1 GHz			4 GHz			8 GHz			12 GHz			15 GHz			18 GHz		
DUT (TM4, TM5 or TM6)	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
NPL		-			-			-			-			-			-			-			-	
IEN		-			-		X	-	X	X	-	X		-			-	X		-			-	X
NMi VSL																								
NRC																								

4.3 Comparing the results

Outliers should be considered as well as consistency of results and similarity (reproducibility) of the measurement set-up: how well are the results correlated for the two comparisons? From the information obtained none of the participants indicates that there is a clear correlation. The only exception might be the uncertainty of the laboratory’s reference standards.
First, in section 5, we will investigate how to link the measurements on the thermistor mounts with a type-n connector (TM1 and TM3 in the GT-RF comparisons, and TM4 and TM6 in the Euromet comparison). Afterwards, in section 6, the consequences for the comparisons on PC7 devices will be investigated.

5 The linking procedure for Type-N devices

At present we treat the results from the thermistor mounts TM1 and TM4 (type-N connector) and TM3 and TM6 (type-N connector due to an adapter) as similar devices. If the result for one of the sensors is an outlier all results will be ignored. Where relevant, an additional check will be carried out for TM1 and TM4 because here there will be no influence of the PC7-N adapter.

For each frequency the mean deviation of the laboratories is determined in the two comparions. The individual results are checked for identified outliers, after which a new mean deviation is determined. This process might be repeated for specific reasons, e.g. at 10 MHz.
In each comparison the average of the results of the two DUTs, TM1 and TM3, and TM4 and TM6, respectively, are determined as well as their spread (this is used as an indication of potential problems).

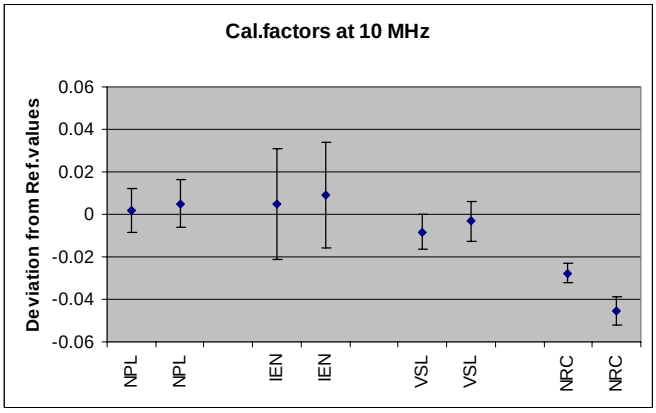
At 10 MHz NRC was an outlier in the CCEM comparison. In the Euromet comparison both IEN and NRC are far away from the CRV but with different signs: hence they are no outliers in the evaluation scheme. For the linking process it might be better to ignore the results of those two laboratories.
For the other frequencies (1, 4, 12 and 18 GHz) the results from IEN are outliers in one or both comparisons, so its contributions should be ignored. The same is valid for NRC at 4 GHz.

The “correction” for the results in the Euromet project should be based on the deviation from the KRCV for these laboratories. If one takes into account the uncertainties in the determination of all comparison values, the correction/shift will applied only if the calculated values for the four participants is larger than 0.0005, and then rounded off to 0.001 steps.

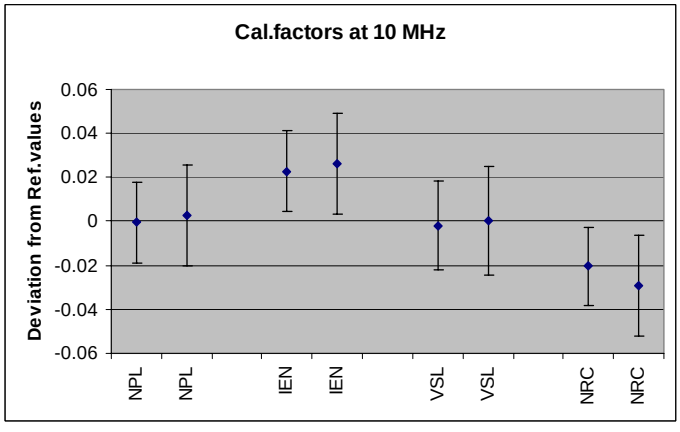
5.1 10 MHz

The results in the two comparisons are given in the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.1.1: Results of CCEM.RF-K8.CL				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0019	0.0105	0.0050	0.0111
IEN	0.0049	0.0262	0.0090	0.0247
NMi-VSL	-0.0082	0.0083	-0.0032	0.0093
NRC	-0.0278	0.0046	-0.0453	0.0067
Comparison	Value	Spread	Value	Spread
Average all:	-0.0073	0.0148	-0.0086	0.0250
Excl. NRC	-0.0005	0.0069	0.0036	0.0062
NPL / VSL	-0.0032	0.0071	0.0009	0.0058



Tabel 4.1.2: Results of Euromet 633 at 10 MHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	-0.0006	0.0181	0.0029	0.023
IEN	0.0229	0.0182	0.0262	0.023
VSL	-0.0019	0.0201	0.0001	0.0248
NRC	-0.0205	0.0179	-0.0292	0.0229
Comparison	Value	Spread	Value	Spread
Average all:	0.0000	0.0178	0.0000	0.0227
Excl. IEN	-0.0077	0.0111	-0.0087	0.0178
Excl. NRC	0.0068	0.0140	0.0097	0.0143
NPL/VSL	-0.0013	0.0009	0.0015	0.0020



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.1.3:

Table 4.1.3: mean deviation from reference value for comparison				
Comparison	K8		633	
	Value	Spread	Value	Spread
Average all:	-0.0080	0.0009	0.0000	0.0000
Excl. IEN	*0.0129*	*0.0022*	*-0.0082*	*0.0008*
Excl. NRC	-0.0016	0.0029	0.0083	0.0141
NPL and VSL	-0.0011	0.0029	0.0001	0.0019

The selection criteria mentioned above leads to the exclusion of NRC. Because the results from NRC and IEN are both suspect in the Euromet project it seems logical to take the results from only NPL and VSL into account: the result for the two laboratories (NPL and VSL) in the Euromet comparison differs from that for the CCEM-comparison by 0.0011. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted downward by 0.001 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.1.4).

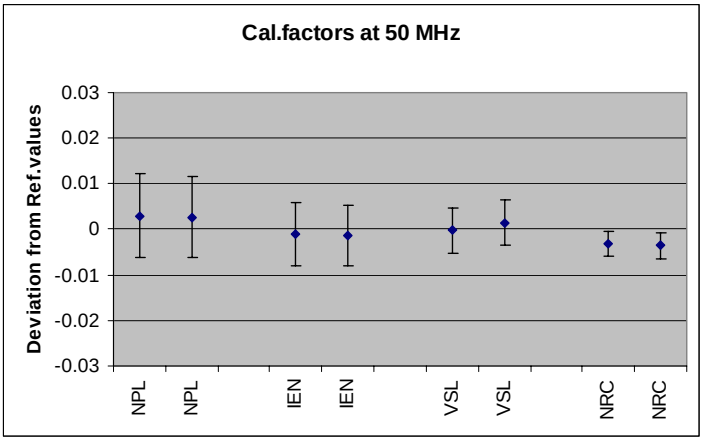
Table 4.1.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	-0.0073	0.0148	0.0000	0.0178
Excl. IEN	-0.0114	0.0151	-0.0077	0.0111
Excl. NRC	*-0.0005*	*0.0069*	*0.0068*	*0.0140*
NPL / VSL	-0.0032	0.0071	-0.0013	0.0009

The same conclusions may be drawn, but in this case the difference is 0.0021. The results obtained in the Euromet 633 should be shifted downward by 0.002 to link the results of all participants to the CCEM.RF-K8.CL.

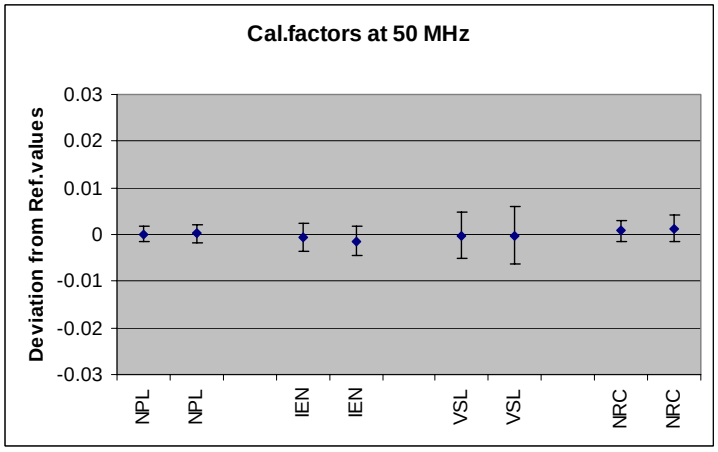
5.2 50 MHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.2.1: Results of CCEM.RF-K8.CL at 50 MHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0030	0.0091	0.0027	0.0088
IEN	-0.0010	0.0070	-0.0013	0.0067
NMi-VSL	-0.0002	0.0050	0.0015	0.0049
NRC	-0.0032	0.0027	-0.0036	0.0028
Comparison	Value	Spread	Value	Spread
Average:	-0.0004	0.0026	-0.0002	0.0028



Tabel 4.2.2: Results of Euromet 633 at 50 MHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0001	0.0017	0.0002	0.0019
IEN	-0.0006	0.0031	-0.0014	0.0032
VSL	-0.0002	0.0049	-0.0002	0.0061
NRC	0.0008	0.0022	0.0013	0.0028
Comparison	Value	Spread	Value	Spread
Average:	0.0000	0.0006	0.0000	0.0011



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.2.3:

Table 4.2.3: mean deviation from reference value for comparison				
Comparison	K8		633	
Average all:	-0.0003	0.0001	0.0000	0.0000

The selection criteria mentioned above leads to no exclusion: the shift in the CRV is 0.000. The results obtained in the Euromet 633 don't need a shift to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.2.4).

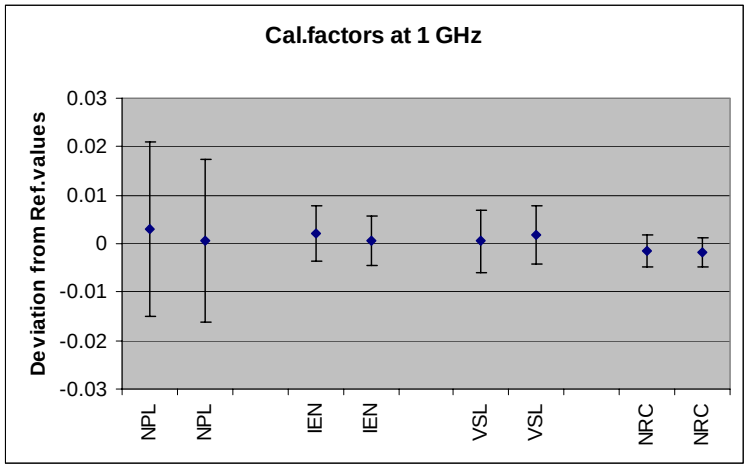
Table 4.2.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	-0.0004	0.0026	0.0000	0.0006

The same conclusions may be drawn: the shift in the CRV is 0.000. The results obtained in the Euromet 633 don't need a shift to link the results of all participants to the CCEM.RF-K8.CL.

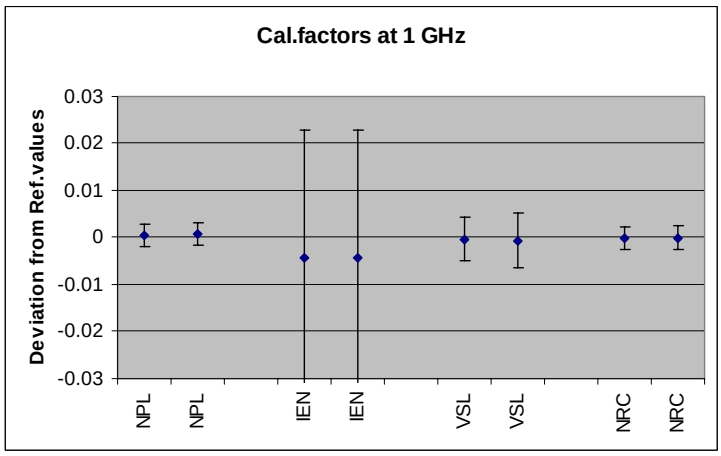
5.3 1 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.3.1: Results of CCEM.RF-K8.CL at 1 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0030	0.0181	0.0006	0.0169
IEN	0.0020	0.0057	0.0006	0.0050
NMi-VSL	0.0005	0.0065	0.0018	0.0060
NRC	-0.0016	0.0033	-0.0018	0.0031
Comparison	Value	Spread	Value	Spread
Average:	0.0010	0.0020	0.0003	0.0015
Excl. IEN	0.0006	0.0023	0.0002	0.0018



Tabel 4.3.2: Results of Euromet 633 at 1 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0004	0.0024	0.0007	0.0024
IEN	-0.0043	0.0271	-0.0042	0.027
VSL	-0.0004	0.0046	-0.0006	0.0057
NRC	-0.0001	0.0024	0.0000	0.0024
Comparison	Value	Spread	Value	Spread
Average:	-0.0011	0.0022	-0.0010	0.0022
Excl. IEN	0.0000	0.0004	0.0000	0.0007



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.3.3:

Table 4.3.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all:	0.0006	0.0005	-0.0011	0.0001
Excl. IEN	0.0004	0.0003	0.0000	0.0000

The selection criteria mentioned above leads to the exclusion of IEN: the shift in the CRV is 0.000. The results obtained in the Euromet 633 don't need a shift to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.3.4).

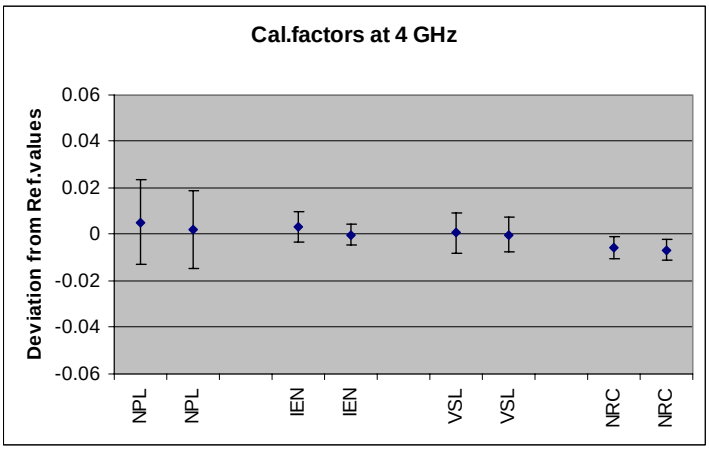
Table 4.3.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	0.0010	0.0020	-0.0011	0.0022
Excl. IEN	0.0006	0.0023	0.0000	0.0004

The same conclusions may be drawn, but the result in the Euromet comparison differs from that in the CCEM-comparison by 0.0006. The results obtained in the Euromet 633 should be shifted upward by 0.001 to link the results of all participants to the CCEM.RF-K8.CL.

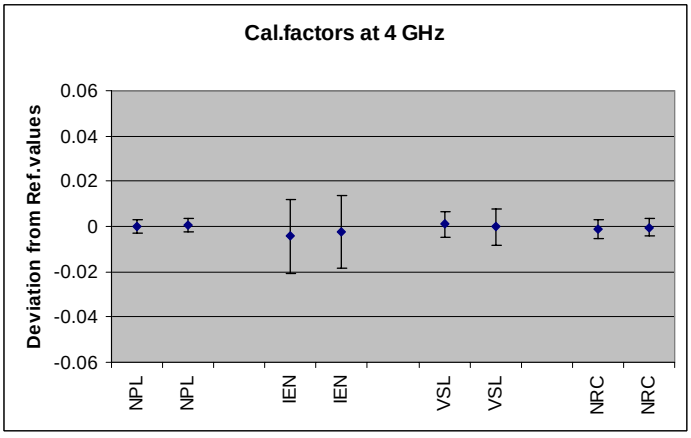
5.4 4 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.4.1: Results of CCEM.RF-K8.CL at 4 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0052	0.0182	0.0020	0.0169
IEN	0.0032	0.0067	0.0000	0.0046
NMi-VSL	0.0006	0.0089	0.0000	0.0076
NRC	-0.0057	0.0046	-0.0067	0.0046
Comparison	Value	Spread	Value	Spread
Average:	0.0008	0.0047	-0.0012	0.0038
Excl. IEN	0.0000	0.0055	-0.0016	0.0046
Excl. NRC	0.0030	0.0023	0.0007	0.0012
NPL / VSL	0.0029	0.0033	0.0010	0.0014



Tabel 4.4.2: Results of Euromet 633 at 4 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0000	0.003	0.0005	0.0028
IEN	-0.0044	0.0162	-0.0022	0.0161
VSL	0.0010	0.0058	-0.0002	0.008
NRC	-0.0011	0.004	-0.0004	0.0038
Comparison	Value	Spread	Value	Spread
Average:	-0.0011	0.0023	-0.0006	0.0012
Excl. IEN	0.0000	0.0011	0.0000	0.0005
Excl. NRC	-0.0011	0.0029	-0.0006	0.0014
NPL / VSL	0.0005	0.0007	0.00015	0.0005



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.4.3:

Table 4.4.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all:	-0.0002	0.0014	-0.0009	0.0004
Excl. IEN	-0.0008	0.0011	0.0000	0.0000
Excl. NRC	0.0018	0.0016	-0.0009	0.0021
NPL and VSL	0.0020	0.0013	0.0003	0.0002

The selection criteria mentioned above leads to the exclusion of IEN and NRC. The result for the two laboratories (NPL and VSL) in the Euromet comparison differs from that for the CCEM-comparison by 0.0017. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted upwards by 0.002 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.4.4).

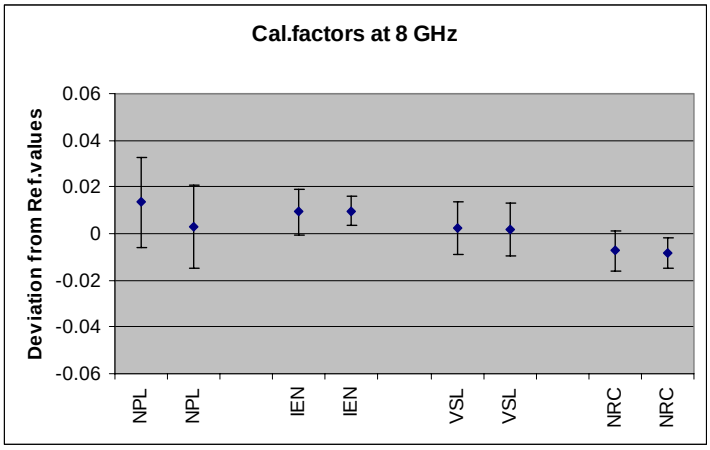
Table 4.4.4: mean deviation from reference value for DUT				
DUT	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	-0.0011	0.0023	-0.0011	0.0023
Excl. IEN	0.0000	0.0011	0.0000	0.0011

In this case only the results of IEN should be excluded: the shift in the CRV is 0.000. The results obtained in the Euromet 633 don't need a shift to link the results of all participants to the CCEM.RF-K8.CL.

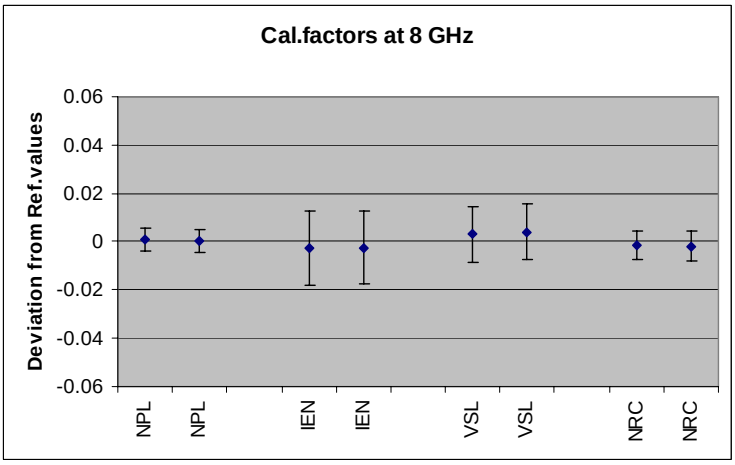
5.5 8 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.5.1: Results of CCEM.RF-K8.CL at 8 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0134	0.0194	0.0028	0.0178
IEN	0.0094	0.0097	0.0098	0.0065
NMi-VSL	0.0023	0.0112	0.0018	0.0115
NRC	-0.0074	0.0085	-0.0083	0.0066
Comparison	Value	Spread	Value	Spread
Average:	0.0044	0.0091	0.0015	0.0075



Tabel 4.5.2: Results of Euromet 633 at 8 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0011	0.0048	0.0003	0.005
IEN	-0.0027	0.0153	-0.0024	0.0153
VSL	0.0030	0.0113	0.0040	0.0116
NRC	-0.0013	0.0059	-0.0019	0.0061
Comparison	Value	Spread	Value	Spread
Average:	0.0000	0.0025	0.0000	0.0029



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.5.3

Table 4.5.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all	0.0030	0.0021	0.0000	0.0000

The selection criteria mentioned above leads to no exclusion. The result in the Euromet comparison differs from that for the CCEM-comparison by 0.0030. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted upwards by 0.003 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.5.4).

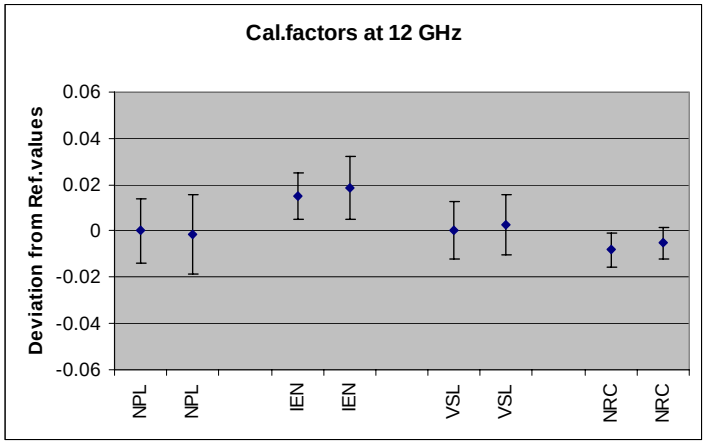
Table 4.5.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	0.0044	0.0091	0.0000	0.0025

The same conclusions may be drawn, but the result in the Euromet comparison differs from that in the CCEM-comparison by 0.0044. The results obtained in the Euromet 633 should be shifted upward by 0.004 to link the results of all participants to the CCEM.RF-K8.CL.

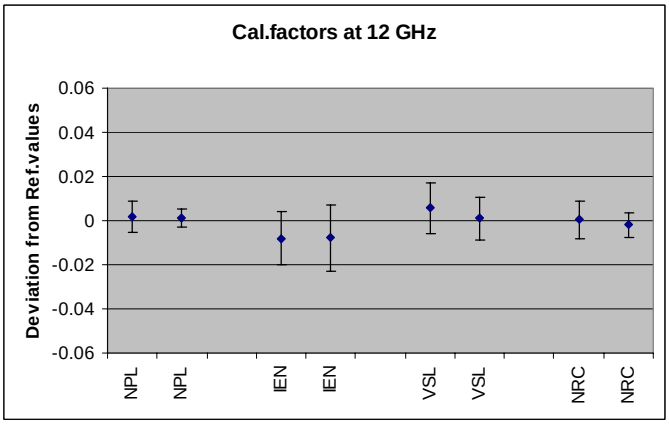
5.6 12 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.6.1: Results of CCEM.RF-K8.CL at 12 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0001	0.0137	-0.0015	0.0171
IEN	0.0151	0.0101	0.0185	0.0135
NMi-VSL	0.0003	0.0125	0.0025	0.0129
NRC	-0.0081	0.0075	-0.0053	0.0066
Comparison	Value	Spread	Value	Spread
Average:	0.0018	0.0097	0.0036	0.0105
Excl. IEN	-0.0026	0.0048	-0.0014	0.0039



Tabel 4.6.2: Results of Euromet 633 at 12 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0018	0.0073	0.0012	0.0041
IEN	-0.008	0.0122	-0.0078	0.0151
VSL	0.0058	0.0114	0.0009	0.0097
NRC	0.0005	0.0085	-0.002	0.0055
Comparison	Value	Spread	Value	Spread
Average:	0.0000	0.0058	-0.0019	0.0042
Excl. IEN	0.0027	0.0028	0.0000	0.0018



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.6.3

Table 4.6.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all	0.0027	0.0012	-0.0010	0.0014
Excl. IEN	-0.0020	0.0008	0.0014	0.0019

The selection criteria mentioned above leads to the exclusion of IEN. The result in the Euromet comparison differs from that for the CCEM-comparison by 0.0034. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted downwards by 0.003 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.6.4).

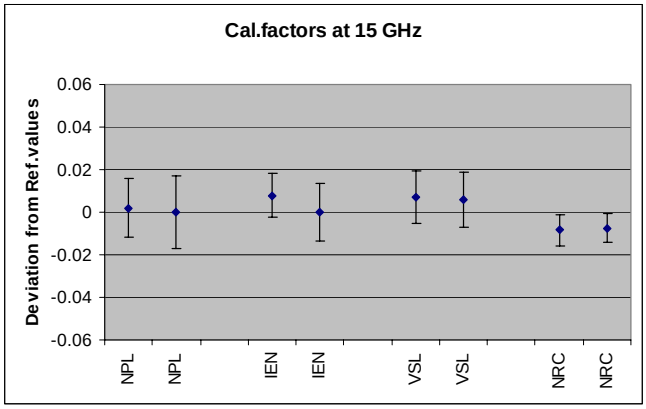
Table 4.6.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	0.0018	0.0097	0.0000	0.0058
Excl. IEN	-0.0026	0.0048	0.0027	0.0028

The same conclusions may be drawn, but the result in the Euromet comparison differs from that in the CCEM-comparison by 0.0053. The results obtained in the Euromet 633 should be shifted downward by 0.005 to link the results of all participants to the CCEM.RF-K8.CL.

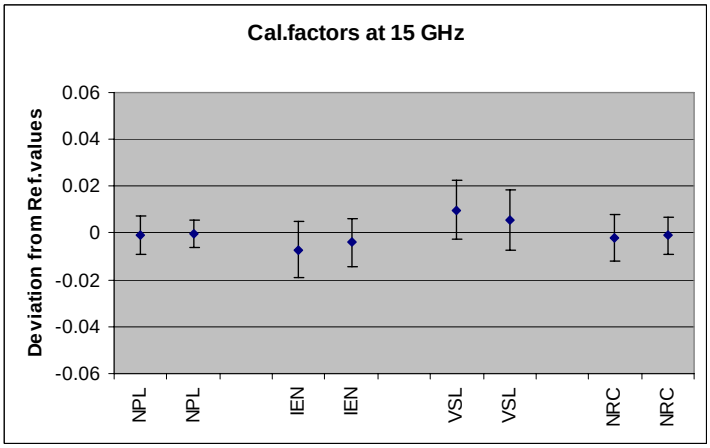
5.7 15 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.7.1: Results of CCEM.RF-K8.CL at 15 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	0.0019	0.0177	0.0002	0.0176
IEN	0.0079	0.0064	0.0002	0.0071
NMi-VSL	0.0072	0.0127	0.0057	0.0128
NRC	-0.0084	0.009	-0.0074	0.0084
Comparison	Value	Spread	Value	Spread
Average:	0.0022	0.0075	-0.0003	0.0054



Tabel 4.7.2: Results of Euromet 633 at 15 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	-0.0008	0.0084	-0.0004	0.006
IEN	-0.0071	0.0119	-0.0040	0.0101
VSL	0.0099	0.0127	0.0055	0.0131
NRC	-0.0021	0.0098	-0.0011	0.0079
Comparison	Value	Spread	Value	Spread
Average:	0.0000	0.0072	0.0000	0.0040



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.7.3

Table 4.7.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all	0.0009	0.0018	0.0000	0.0000

The selection criteria mentioned above leads to no exclusion. The result in the Euromet comparison differs from that for the CCEM-comparison by 0.0009. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted upwards by 0.001 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.7.4).

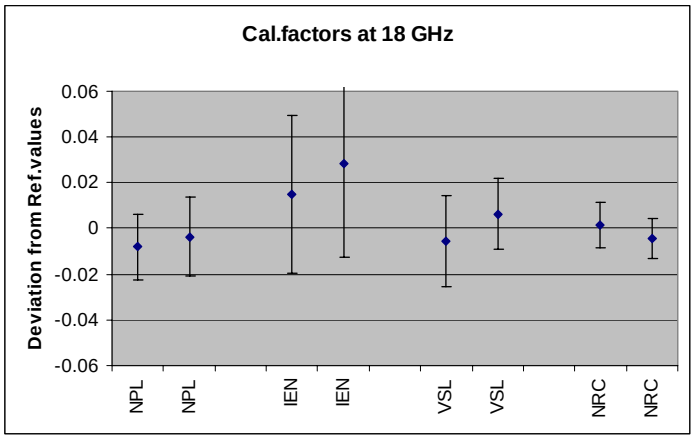
Table 4.7.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	0.0022	0.0075	0.0000	0.0072

The same conclusions may be drawn, but the result in the Euromet comparison differs from that in the CCEM-comparison by 0.0022. The results obtained in the Euromet 633 should be shifted upward by 0.002 to link the results of all participants to the CCEM.RF-K8.CL.

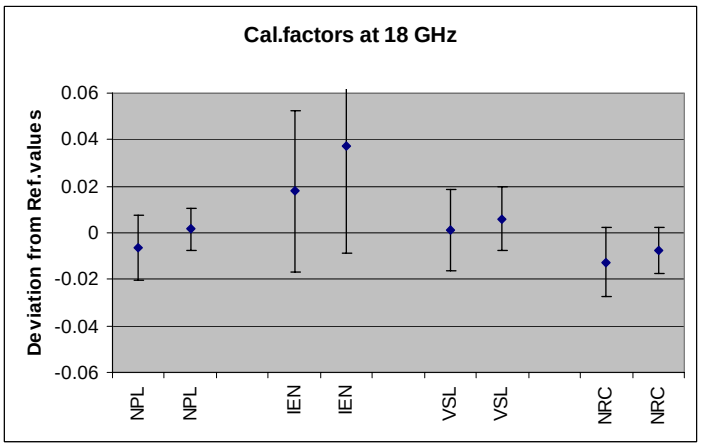
5.8. 18 GHz

The results in the two comparisons are given the next two tables and graphs. The laboratories (and their results) that are not participating in the reference value are indicated in red.

Table 4.8.1: Results of CCEM.RF-K8.CL at 18 GHz				
Laboratory	TM1		TM3	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	-0.0081	0.0142	-0.0037	0.0172
IEN	0.0149	0.0344	0.0283	0.0409
NMi-VSL	-0.0057	0.0200	0.0063	0.0154
NRC	0.0015	0.0101	-0.0045	0.0088
Comparison	Value	Spread	Value	Spread
Average:	0.0006	0.0103	0.0066	0.0153
Excl. IEN	-0.0041	0.0050	-0.0006	0.0060



Tabel 4.8.2: Results of Euromet 633 at 18 GHz				
Laboratory	TM4		TM6	
	Value	Unc (k=2)	Value	Unc (k=2)
NPL	-0.0062	0.0140	0.0015	0.0089
IEN	0.0178	0.0349	0.0370	0.0457
VSL	0.0011	0.0177	0.0060	0.0137
NRC	-0.0126	0.0150	-0.0075	0.0099
Comparison	Value	Spread	Value	Spread
Average:	0.0000	0.0131	0.0093	0.0193
Excl. IEN	-0.0059	0.0069	0.0000	0.0069



Combining the results of TM1and TM3, and of TM4 and TM6 leads to Table 4.8.3.

Table 4.8.3: mean deviation from reference value for comparison				
Comparison:	K8		633	
Average all	0.0036	0.0042	0.0046	0.0065
Excl.IEN	-0.0024	0.0025	-0.0030	0.0042

The selection criteria mentioned above leads to the exclusion of IEN. The result in the Euromet comparison differs from that for the CCEM-comparison by 0.0006. This value is smaller than the spread in the individual results in both cases. The results obtained in the Euromet 633 should be shifted upwards by 0.001 to link the results of all participants to the CCEM.RF-K8.CL.

Limiting the investigation to only the real Type-N thermistor mounts the following result is obtained (see Table 4.8.4).

Table 4.8.4: mean deviation from reference value for DUT				
DUT:	TM1		TM4	
	Value	Spread	Value	Spread
Average all:	0.0006	0.0103	0.0000	0.0131
Excl. IEN	-0.0041	0.0050	-0.0059	0.0069

The same conclusions may be drawn, but the result in the Euromet comparison differs from that in the CCEM-comparison by 0.0018. The results obtained in the Euromet 633 should be shifted upward by 0.002 to link the results of all participants to the CCEM.RF-K8.CL.

5.9. Summary and discussion

In Table 5 the results obtained in sections 5.1 through 5.8 are summarized. All different calculations are given, with in bold the preferred calculation. In addition the result is given when the calculation is limited to the pair TM1 and TM4.

The values of the shift refers by which amount the results obtained in Euromet project 633 should be shifted upward on basis of the previous analysis.

Table 5: shifts calculated to link Euromet 633 results to the worldwide comparison CCEM.RF-K8.CL				
Frequency (GHz)	From all labs	Excl.IEN	NPL/VSL	TM1 and TM4
0.01	-0.008	+0.020	**-0.001**	-0.002
0.05	**+0.000**			+0.000
1.00	+0.002	**+0.000**		+0.001
4.00	-0.002	-0.001	**+0.002**	+0.000
8.00	**+0.003**			+0.004
12.00	+0.004	**-0.003**		-0.005
15.00	**+0.001**			+0.002
18.00	-0.001	**+0.001**		+0.002

The two approaches (two pairs or one pair of DUTs) lead to the same conclusion. In general the difference between the results of the laboratories that participated in the two comparisons is only a few tenths of percent, in most cases significantly within the stated uncertainties. The largest deviation occurs at 8 GHz and 12 GHz, but here the stated uncertainties are of the order of 1%. After the proposal from the pilot laboratory to use the bold numbers given in Table 5 as the shift necessary for the link to the CCEM.RF-K8.CL, the participants adopted this proposal. This proposal was also accepted in the Euromet RF&MW experts meeting in April 2005.

6. Results on PC7 thermistor mounts

Only two laboratories which have an independent realisation of the quantity power in PC7 transmission line participated in both comparisons. At the two lowest frequencies (10 MHz and 50 MHz) only NMi-VSL gave results in the GT-RF comparison.
We follow the procedure used in the previous section to determine the shift required to link the result of the Euromet project to that of the worldwide comparison.

6.1 10 MHz

Table 6.1: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0064	0.0075	0.0146	0.0292
NRC	--	--	-0.0146	0.0292
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0064	#DIV/0!	0.0000	0.0206

The spread in the Euromet results is quite large, not only compared to the value given by NMi-VSL in the GT-RF comparison, but also compared to the result given by the third participant (METAS) which carried out this measurement: the difference of 0.029 between NMi-VSL and NRC is 6x larger than between NMi-VSL and METAS. In addition, the results of NRC at 10 MHz using type-N devices are considered to be doubtful. Hence it seems to logical to ignore the result of NRC at 10 MHz.
Thus, the shift needed to bring the Euromet data in line with CCEM-data is –0.006

6.2 50 MHz

Table 6.2: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	0.0006	0.0039	-0.0004	0.0007
NRC	--	--	0.0004	0.0007
Comparison	Value	Spread	Value	Spread
Average/Spread	0.0006	#DIV/0!	0.0000	0.0006

The result of NRC is in line with that from others. The required shift is +0.001.

6.3 1 GHz

Table 6.3: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0008	0.0034	-0.0005	0.0011
NRC	-0.0007	0.0025	0.0005	0.0011
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0008	0.0001	0.0000	0.0007

The results are quite consistent . The required shift is –0.001

6.4 4 GHz

Table 6.4: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0030	0.0072	0.0007	0.0015
NRC	-0.0052	0.0039	-0.0007	0.0015
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0041	0.0016	0.0000	0.0010

The results are quite consistent . The required shift is –0.004

6.5 8 GHz

Table 6.5: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0015	0.0071	0.0034	0.0068
NRC	-0.0032	0.0042	-0.0034	0.0068
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0024	0.0012	0.0000	0.0048

The results are quite consistent . The required shift is –0.002

6.6 12 GHz

Table 6.6: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	0.0005	0.0076	0.0037	0.0075
NRC	-0.0061	0.0054	-0.0037	0.0075
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0028	0.0047	0.0000	0.0052

The results are quite consistent . The required shift is –0.003

6.7 15 GHz

Table 6.7: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0012	0.0079	0.0025	0.0049
NRC	-0.0041	0.0062	-0.0025	0.0049
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0027	0.0021	0.0000	0.0035

The results are quite consistent . The required shift is –0.003

6.8 18 GHz

Table 6.8: mean deviation from reference value for DUT				
	TM2 (in K8)		TM5 (in 633)	
Laboratory	Value	Spread	Value	Spread
VSL	-0.0034	0.0090	0.0053	0.0106
NRC	-0.0044	0.0071	-0.0053	0.0106
Comparison	Value	Spread	Value	Spread
Average/Spread	-0.0039	0.0007	0.0000	0.0075

The results are not so consistent, but have to be used to determine the shift: the required shift is –0.004

6.9 Summary

In Table 6 the results obtained in sections 6.1 through 6.8 are summarized.
The values of the shift refers by which amount the results obtained in Euromet project 633 should be shifted upward on basis of the previous analysis.

Table 6: shifts calculated to link Euromet 633 results to the worldwide comparison CCEM.RF-K8.CL	
Frequency (GHz)	For PC7 thermistor mount
0.01	-0.006
0.05	+0.001
1.00	-0.001
4.00	-0.004
8.00	-0.002
12.00	-0.003
15.00	-0.003
18.00	-0.004

Surprisingly the largest shift occurs at the lowest frequency. This is due to the fact that the CRV is derived from the results of NMi-VSL and NRC. Due to the large difference between these values, a large change automatically followed if one result is excluded.

7. Summary of results on measurement of Calibration Factor

The Calibration Factors of the DUTs used in the EUROMET.EM.RF-K8.CL comparison were given in Table 6 of [ref.2]. After correcting for the shifts as calculated in section 5 and 6 the final result in terms of Calibration Factor (CF) and statistical uncertainty in the mean are given in Table 7.

Table 7: Calibration Factor of the DUTs			
DUT	TM4	TM5	TM6
Frequency			
10 MHz	0.9674 ± 0.0010	0.9568 ± 0.0016	0.9640 ± 0.0010
50 MHz	0.9938 ± 0.0001	0.9943 ± 0.0001	0.9930 ± 0.0001
1 GHz	0.9929 ± 0.0001	0.9921 ± 0.0002	0.9908 ± 0.0001
4 GHz	0.9851 ± 0.0005	0.9811 ± 0.0004	0.9800 ± 0.0001
8 GHz	0.9791 ± 0.0007	0.9754 ± 0.0010	0.9692 ± 0.0007
12 GHz	0.9653 ± 0.0006	0.9609 ± 0.0002	0.9504 ± 0.0005
15 GHz	0.9614 ± 0.0007	0.9531 ± 0.0012	0.9396 ± 0.0004
18 GHz	0.9530 ± 0.0012	0.9331 ± 0.0016	0.9220 ± 0.0011

8. Conclusion

The results obtained by the participants in the two comparisons are consistent. The largest shift necessary to link the reference value in the Euromet 633 project (EUROMET.EM.RF-K8.CL) is 0.4% at frequencies around 10 GHz for measurements on Type-N thermistor mounts. For the PC7 thermistor mount the shifts are of the same order, but the statistical basis is quite small to draw conclusions. The largest shift of 0.6% is mainly due to the exclusion of one participant from the linking process.

9. References

[1] Jan P.M. de Vreede, Final Report: “CCEM.RF-K8.CL COMPARISON - CALIBRATION FACTOR OF THERMISTOR MOUNTS”, May 2005

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

[3] 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.