State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “Ukrmetrteststandard”)

Linking of Results of Key Comparisons CCEM-K5 and COOMET.EM-K5

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December 2018
Kyiv, Ukraine

Pilot laboratory propose that the results COOMET.EM-K5 [1] be linked to CCEM-K5 [2] for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at frequency 53 Hz.

The degrees of equivalence of *i*-th NMI with respect to linking to CCEM-K5 is estimated as

$$d_i = D_i + \Delta\,, \tag{1}$$

where: D_i is result from COOMET.EM-K5 for a NMI participant in COOMET.EM-K5 only;

d_i is best estimate of result from NMI *i* to linking to CCEM-K5.

Measurements from the linking NMIs provide estimates

$$\Delta_{iLINK} = d_{iLINK} - D_{iLINK} \tag{2}$$

for the correction Δ.

The correction Δ is then calculated as the weighted mean of the linking NMIs estimates, that is:

$$\Delta = \sum_{iLINK} w_{iLINK}\Delta_{iLINK}\,, \tag{3}$$

where: d_{iLINK} is result from CCEM-K5 for a linking NMI;

D_{iLINK} is result from COOMET.EM-K5 for a linking NMI;

$$w_{iLINK} = \frac{s^2(\Delta)}{s^2(\Delta_{iLINK})};\ s^2(\Delta) = 1\Big/\sum_{iLINK}\frac{1}{s^2(\Delta_{iLINK})}. \tag{4}$$

$s(\Delta_{iLINK})$ is the uncertainty associated with Δ_{iLINK} given by [2] as the root-sum-square of u_T, $u(p_i)$, r_{iLINK}, where u_T is the transfer uncertainty in the CCEM-K5 comparison, $u(p_i)$ is the transfer uncertainty in the COOMET.EM-K5.1 comparison, and r_{iLINK} is the uncertainty associated with the imperfect reproducibility of the results of NMI$_{i\text{LINK}}$ in the time period spanning its two measurements (whence the factor of 2 for this term in the RSS equation) in the CCEM-K5 and COOMET.EM-K5 comparisons.

The linking NMIs are VNIIM and NIM. No significant changes to the method of measurement used in CCEM-K5 and COOMET.EM-K5 were made by VNIIM and NIM. The calculated linking correction is Δ with a standard deviation $s(\Delta)$. Table 1 lists the values of the quantities used in the calculation for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at 53 Hz.

Table 1 CCEM-K5 and COOMET.EM-K5 comparisons results and standard uncertainties (k = 1) for linking NMIs for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead, μW/VA

Linking NMI	d_{iLINK}	D_{iLINK}	Δ_{iLINK}	u_T	$u(p_i)$	r_{iLINK}	$s(\Delta_{iLINK})$	w_{iLINK}	Δ	$s(\Delta)$
PF = 1.0										
VNIIM	10.0	1.7	8.3	9.0	4.5	1.1	10.1	0.44	0.9	6.7
NIM	-1.0	4.0	-5.0	6.0	6.0	3.0	9.0	0.56		
PF = 0.5 Lag										
VNIIM	-25.0	3.3	-28.3	14.0	3.7	1.1	14.5	0.27	-15.7	7.6
NIM	-14.0	-3.0	-11.0	6.0	6.0	2.5	8.8	0.73		

Linking NMI	d_{iLINK}	D_{iLINK}	Δ_{iLINK}	u_T	$u(p_i)$	r_{iLINK}	$s(\Delta_{iLINK})$	w_{iLINK}	Δ	Δ
PF = 0.5 Lead										
VNIIM	-15.0	-3.6	-11.4	14.0	3.7	1.1	14.5	0.28	2.3	7.7
NIM	13.0	5.4	7.6	6.0	6.0	3.0	9.0	0.72		
PF = 0.0 Lag										
VNIIM	-11.0	5.8	-16.8	12.0	3.7	1.1	12.6	0.31	-6.9	7.0
NIM	-7.0	-4.4	-2.6	6.0	5.0	3.0	8.4	0.69		
PF = 0.0 Lead										
VNIIM	9.0	-3.9	12.9	12.0	3.7	1.1	12.6	0.31	3.7	7.0
NIM	3.0	3.4	-0.4	6.0	5.0	3.0	8.4	0.69		

The best estimate of the result from NMI *i* had it participated in CCEM-K5 is calculated using (7). The standard uncertainty is calculated as:

$$u^2(d_i) = u^2(D_i) + u^2(\Delta) = u^2(D_i) + s^2(\Delta) + u^2(m_{ref}), \quad (5)$$

where: $u(m_{ref})$ is the uncertainty in the CCEM-K5 KCRV. The expanded uncertainty is $U(d_i) = k_{d_i} u(d_i)$ where is chosen k_{d_i} = 2 to give 95 % coverage.

The calculated degrees of equivalence with respect to CCEM-K5 KCRV for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at 53 Hz are tabulated in d_i Table 2.

Table 2 Degrees of equivalence for NMI participants relative to the CCEM-K5 KCRV and expanded uncertainties (*k*=2) for linking NMIs for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at 53 Hz, μW/VA

NMI	PF = 1.0		PF = 0.5 Lag		PF = 0.5 Lead		PF = 0.0 Lag		PF = 0.0 Lead	
	d_i	$U(d_i)$	d_i	$U(d_i)$	d_i	$U(d_i)$	d_i	$U(d_i)$	d_i	$U(d_i)$
UMTS	3.9	25.3	-19.5	32.5	7.7	32.7	-10.1	29.9	10.1	30.2
BelGIM	2.1	44.7	-25.5	45.4	6.2	45.6	-17.1	44.8	12.1	44.8
UME	-6.0	27.4	-27.7	28.9	6.0	29.0	-22.3	28.3	8.9	28.3
GEOSTM	17.6	91.1	-6.9	137.1	4.5	137.1	-2.3	203.8	-3.9	203.8
MASM	4.0	76.9	8.3	116.0	-24.0	79.1	13.7	86.0	-19.1	86.1
SMU	-50.0	59.6	-17.1	71.8	-9.5	71.9	13.7	79.4	59.5	79.4
QCC EMI	-7.3	27.8	-21.4	31.2	-0.5	30.9	-6.0	26.9	5.6	27.0
NIS	-4.6	40.0	6.4	40.8	24.4	41.8	-38.0	44.2	-16.8	42.3
SASO-NMCC	-15.0	42.8	-36.7	44.3	8.0	44.4	-10.1	29.9	17.9	44.7

The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|d_i| < 2u_c(d_i). \quad (6)$$

Degrees of equivalence D_i, with respect to the CCEM-K5 KCRV, for CCEM-K5 (red diamonds), EUROMET.EM-K5 (blue circles), EUROMET.EM-K5.1 (green triangles), SIM.EM-K5 (orange circles) and COOMET.EM-K5 (brown squares) for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at frequency 53 Hz are shown on Figure 1-5.

Where NMI *i* participated only in COOMET.EM-K5 and NMI *j* participated in COOMET.EM-K5, the pair-wise degrees of equivalence d_{ij} with its uncertainties are those calculated in [1], that is

$$d_{ij} = D_{ij} \text{ and } U(d_{ij}) = U(D_{ij}). \quad (7)$$

Where NMI *i* participated only in COOMET.EM-K5 and NMI *j* participated in CCEM-K5 or EUROMET.EM-K5 or EUROMET.EM-K5.1 or SIM.EM-K5 but not in COOMET.EM-K5, then

$$d_{ij} = d_i - d_j, \quad (8)$$

$$u^2(d_{ij}) = u^2(d_i) + u^2(d_j) - 2u^2(m_{ref}) - 2u_r^2, \quad (9)$$

where: u_r is the standard uncertainty associated with a common reference standard (relevant only if laboratory *i* derives its traceability from NMI *j*, or if NMI *i* and NMI *j* both derive.

Proposed degrees of equivalence and expanded uncertainties (k=2) for participants in CCEM-K5 (red diamonds), EUROMET.EM-K5 (blue circles), EUROMET.EM-K5.1 (green triangles), SIM.EM-K5 (orange circles) and COOMET.EM-K5 (brown squares) for power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead at frequency 53 Hz are shown on Table 3-7.

References

[1] O. Velychko, S. Karpenko. Final Report on COOMET Key Comparison of Power (COOMET.EM-K5), SE “Ukrmetrteststandard”, December 2018, Kyiv, Ukraine. – 136 p.

[2] N. Oldham, T. Nelson, N. F. Zhang, and H.-k. Liu, Final Report of CCEM-K5 Comparison of 50/60 Hz Power, June 2002.

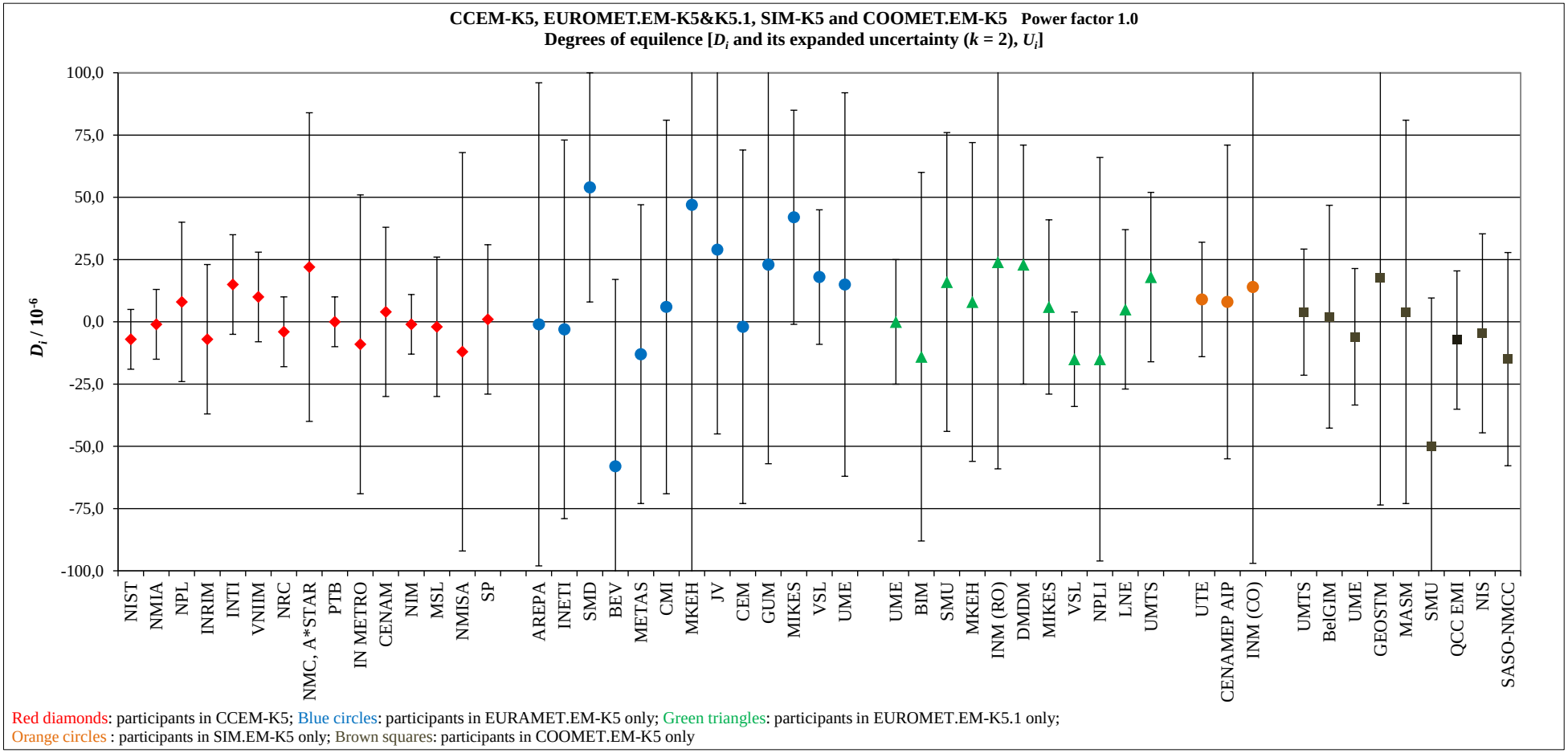

Figure 1 Degrees of equivalence d_i with respect to the CCEM-K5 key comparison reference value for PF = 1.0

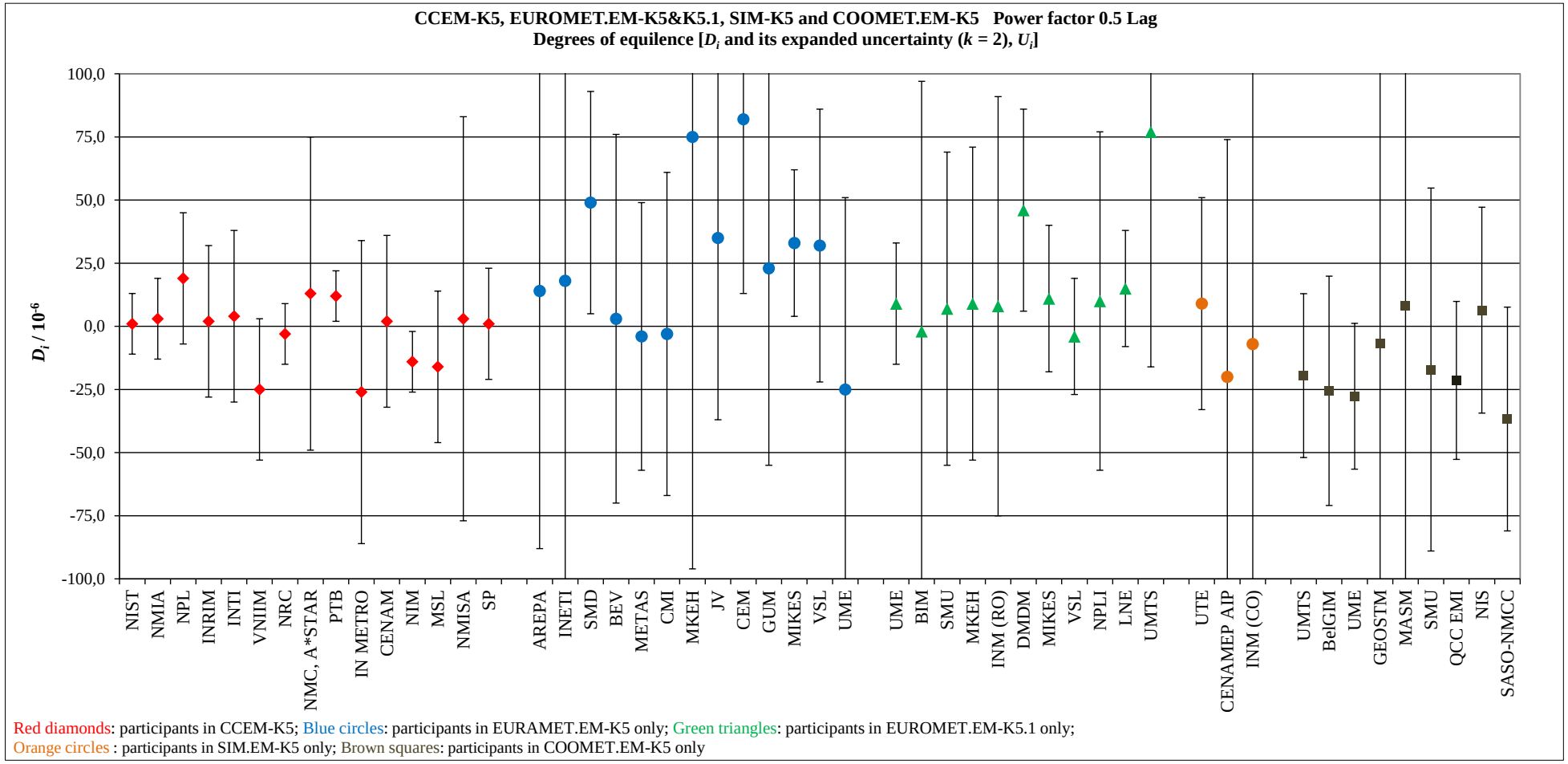

Figure 2 Degrees of equivalence d_i with respect to the CCEM-K5 key comparison reference value for PF = 0.5 Lag

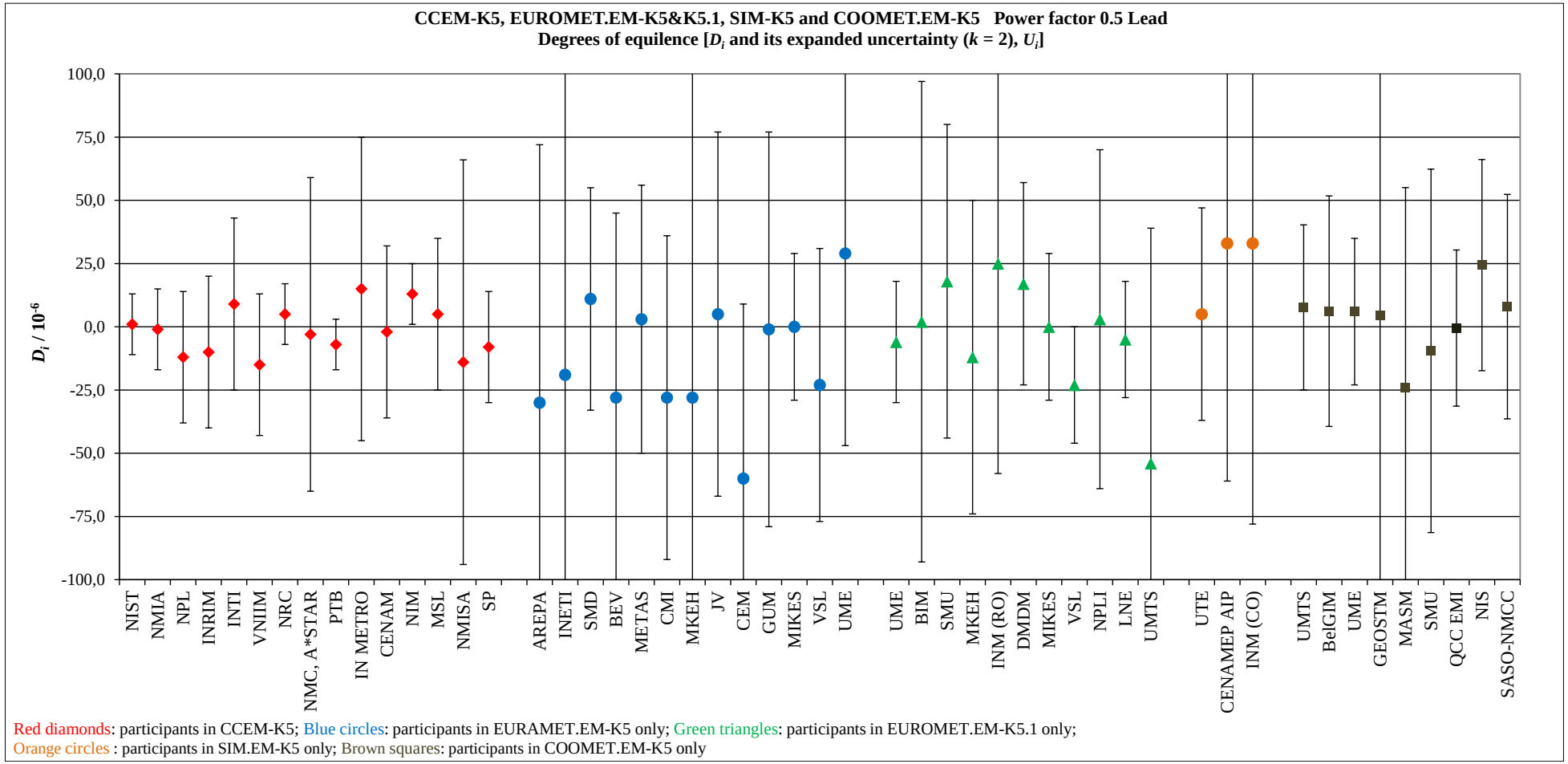

Figure 3 Degrees of equivalence d_i with respect to the CCEM-K5 key comparison reference value for PF = 0.5 Lead

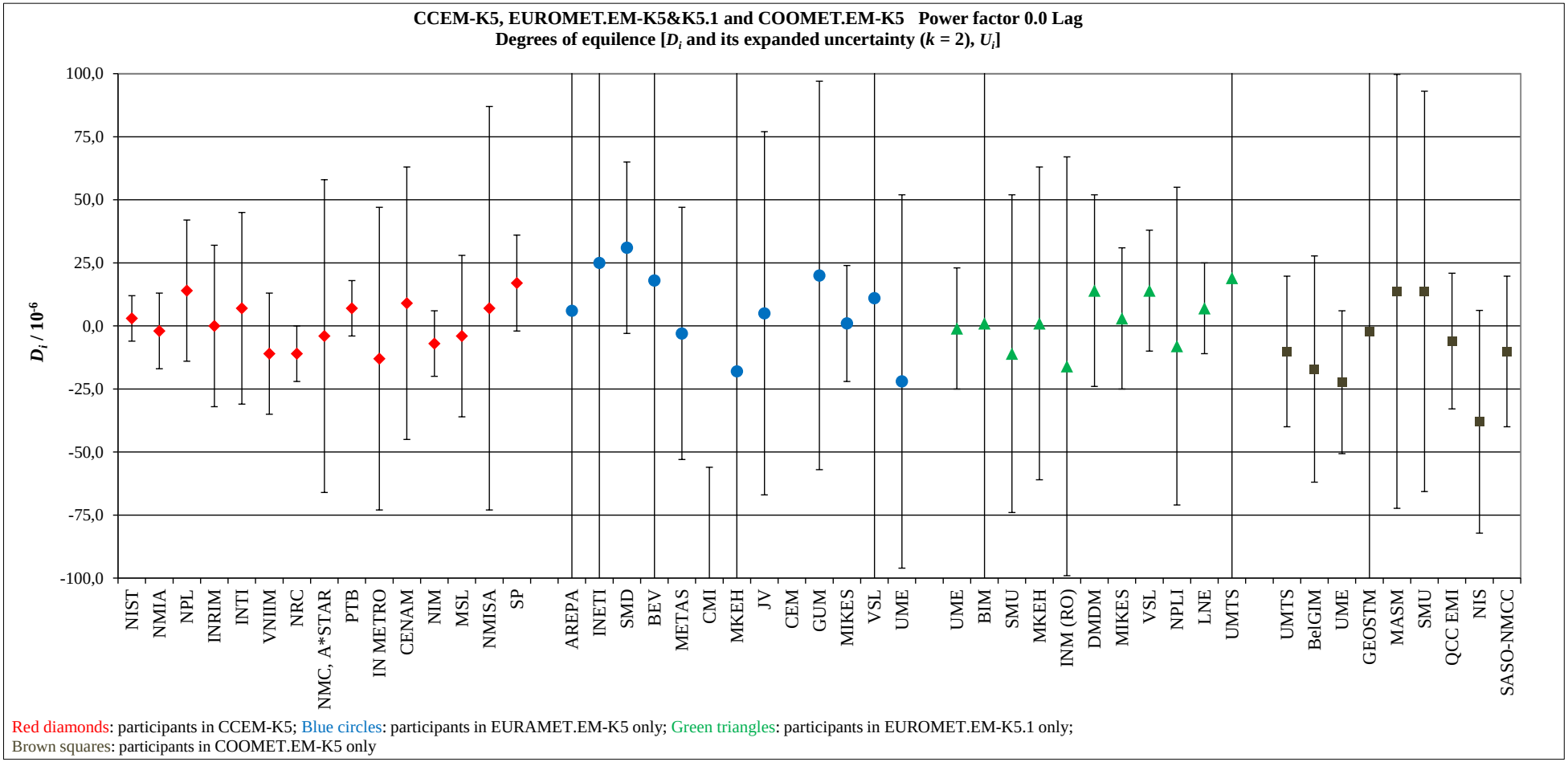

Figure 4 Degrees of equivalence d_i with respect to the CCEM-K5 key comparison reference value for PF = 0.0 Lag

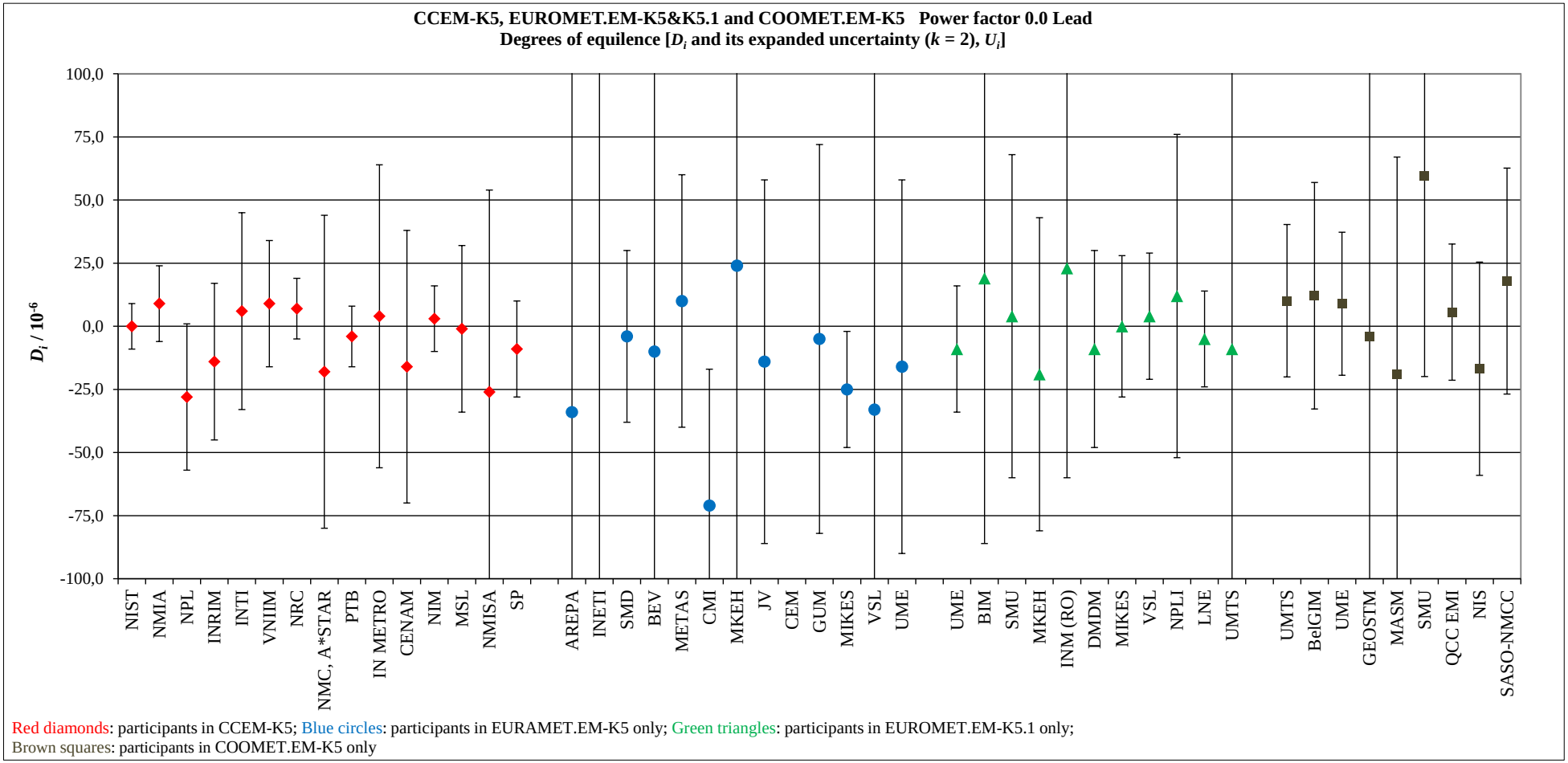

Figure 5 Degrees of equivalence d_i with respect to the CCEM-K5 key comparison reference value for PF = 0.0 Lead

Table 3 Proposed pair degrees of equivalence for participants in CCEM-K5 (red), EUROMET.EM-K5 (blue), EUROMET.EM-K5.1 (green), SIM.EM-K5 (orange), and COOMET.EM-K5 (brow) for PF = 1.0, μW/VA

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
NIST	-7	12	11	24	9	44	1	26	25	91	11	77	-43	59	0	27	2	39	-8	42
NMIA	-1	14	5	25	3	45	-5	27	19	91	5	77	-49	60	-6	28	-4	40	-14	43
NPL	8	32	-4	38	-6	53	-14	40	10	96	-4	82	-58	66	-15	40	-13	49	-23	52
INRIM	-7	30	11	37	9	52	1	38	25	95	11	81	-43	65	0	38	2	48	-8	50
INTI	15	20	-11	29	-13	47	-21	31	3	92	-11	78	-65	61	-22	31	-20	42	-30	45
VNIIM	10	18	-6	28	-8	46	-16	30	8	92	-6	78	-60	61	-17	30	-15	41	-25	44
NRC	-4	14	8	25	6	45	-2	27	22	91	8	77	-46	60	-3	28	-1	40	-11	43
NMC, A*STAR	22	62	-18	65	-20	75	-28	66	-4	109	-18	98	-72	85	-29	66	-27	72	-37	74
PTB	0	10	4	23	2	44	-6	26	18	91	4	76	-50	59	-7	26	-5	39	-15	42
IN METRO	-9	60	13	64	11	73	3	64	27	108	13	97	-41	83	2	65	4	71	-6	72
CENAM	4	34	0	40	-2	54	-10	41	14	96	0	83	-54	67	-11	42	-9	51	-19	53
NIM	-1	12	5	24	3	44	-5	26	19	91	5	77	-49	59	-6	27	-4	39	-14	42
MSL	-2	28	6	35	4	51	-4	37	20	94	6	81	-48	64	-5	37	-3	47	-13	49
NMISA	-12	80	16	83	14	91	6	83	30	120	16	110	-38	99	5	84	7	88	-3	90
SP	1	30	3	37	1	52	-7	38	17	95	3	81	-51	65	-8	38	-6	48	-16	50
AREPA	-1	97	5	99	3	106	-5	100	19	132	5	123	-49	113	-6	100	-4	104	-14	105
INETI	-3	76	7	79	5	87	-3	80	21	118	7	107	-47	96	-4	80	-2	85	-12	86
SMD	54	46	-50	51	-52	63	-60	52	-36	101	-50	89	-104	74	-61	52	-59	59	-69	61
BEV	-58	75	62	78	60	86	52	79	76	117	62	107	8	95	51	79	53	84	43	85
METAS	-13	60	17	64	15	73	7	64	31	108	17	97	-37	83	6	65	8	71	-2	72
CMI	6	75	-2	78	-4	86	-12	79	12	117	-2	107	-56	95	-13	79	-11	84	-21	85
MKEH	47	172	-43	173	-45	178	-53	174	-29	194	-43	188	-97	181	-54	174	-52	176	-62	177
JV	29	74	-25	77	-27	85	-35	78	-11	117	-25	106	-79	94	-36	78	-34	83	-44	84
CEM	-2	71	6	74	4	83	-4	75	20	115	6	104	-48	92	-5	75	-3	80	-13	82
GUM	23	80	-19	83	-21	91	-29	83	-5	120	-19	110	-73	99	-30	84	-28	88	-38	90
MIKES	42	43	-38	48	-40	60	-48	49	-24	100	-38	87	-92	72	-49	49	-47	57	-57	59

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
VSL	18	27	-14	34	-16	50	-24	36	0	94	-14	80	-68	64	-25	36	-23	46	-33	49
UME	15	77	-11	80	-13	88	-21	80	3	118	-11	108	-65	96	-22	81	-20	86	-30	87
UME	0	25	4	33	2	49	-6	34	18	93	4	80	-50	63	-7	35	-5	45	-15	48
BIM	-14	74	18	77	16	85	8	78	32	117	18	106	-36	94	7	78	9	83	-1	84
SMU	16	60	-12	64	-14	73	-22	64	2	108	-12	97	-66	83	-23	65	-21	71	-31	72
MKEH	8	64	-4	67	-6	77	-14	68	10	110	-4	99	-58	86	-15	68	-13	74	-23	76
INM (RO)	24	83	-20	86	-22	93	-30	86	-6	122	-20	112	-74	101	-31	86	-29	91	-39	92
DMDM	23	48	-19	52	-21	64	-29	53	-5	102	-19	90	-73	75	-30	54	-28	61	-38	63
MIKES	6	35	-2	41	-4	55	-12	42	12	97	-2	83	-56	68	-13	42	-11	51	-21	53
VSL	-15	19	19	28	17	47	9	30	33	92	19	78	-35	61	8	31	10	42	0	45
NPLI	-15	81	19	84	17	91	9	84	33	121	19	111	-35	100	8	84	10	89	0	91
LNE	5	32	-1	38	-3	53	-11	40	13	96	-1	82	-55	66	-12	40	-10	49	-20	52
UMTS	18	34	-14	40	-16	54	-24	41	0	96	-14	83	-68	67	-25	42	-23	51	-33	53
UTE	9	23	-5	31	-7	48	-15	33	9	93	-5	79	-59	62	-16	33	-14	44	-24	46
CENAMEP AIP	8	63	-4	66	-6	76	-14	67	10	110	-4	98	-58	86	-15	67	-13	73	-23	75
INM (CO)	14	111	-10	113	-12	119	-20	113	4	143	-10	134	-64	125	-21	114	-19	117	-29	118
UMTS	5	25	0	0	-2	49	-10	35	14	94	0	80	-54	63	-11	35	-9	45	-19	48
BelGIM	3	45	2	49	0	0	-8	51	16	101	2	88	-52	73	-9	51	-7	58	-17	60
UME	-5	27	10	35	8	51	0	0	24	94	10	80	-44	64	-1	36	1	46	-9	49
GEOSTM	19	91	-14	94	-16	101	-24	94	0	0	-14	118	-68	108	-25	94	-22	99	-33	100
MASM	5	77	0	80	-2	88	-10	80	14	118	0	0	-54	96	-11	81	-9	86	-19	87
SMU	-49	60	54	63	52	73	44	64	68	108	54	96	0	0	43	64	45	70	35	72
QCC EMI	-6	28	11	35	9	51	1	36	25	94	11	81	-43	64	0	0	3	47	-8	49
NIS	-4	40	9	45	7	58	-1	46	22	99	9	86	-45	70	-3	47	0	0	-10	57
SASO-NMCC	-14	43	19	50	17	60	9	49	33	100	19	87	-35	72	8	49	10	57	0	0

Table 4 Proposed pair degrees of equivalence for participants in CCEM-K5 (red), EUROMET.EM-K5 (blue), EUROMET.EM-K5.1 (green), SIM.EM-K5 (orange), and COOMET.EM-K5 (brow) for PF = 0.5 Lag, μW/VA

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
NIST	1	12	-21	32	-27	45	-29	28	-8	137	7	116	-18	71	-22	30	5	40	-38	44
NMIA	3	16	-23	33	-29	46	-31	30	-10	137	5	116	-20	72	-24	32	3	41	-40	45
NPL	19	26	-39	39	-45	50	-47	36	-26	139	-11	118	-36	75	-40	38	-13	46	-56	49
INRIM	2	30	-22	42	-28	53	-30	39	-9	140	6	119	-19	77	-23	41	4	49	-39	52
INTI	4	34	-24	45	-30	55	-32	42	-11	141	4	120	-21	78	-25	44	2	51	-41	54
VNIIM	-25	28	6	40	-1	51	-3	38	18	139	33	119	8	76	4	39	31	47	-12	50
NRC	-3	12	-17	32	-23	45	-25	28	-4	137	11	116	-14	71	-18	30	9	40	-34	44
NMC, A*STAR	13	62	-33	69	-39	76	-41	67	-20	150	-5	131	-30	94	-34	68	-7	73	-50	75
PTB	12	10	-32	31	-38	44	-40	27	-19	137	-4	116	-29	71	-33	30	-6	40	-49	43
IN METRO	-26	60	7	67	1	74	-2	65	19	149	34	130	9	93	5	66	32	71	-11	73
CENAM	2	34	-22	45	-28	55	-30	42	-9	141	6	120	-19	78	-23	44	4	51	-39	54
NIM	-14	12	-6	32	-12	45	-14	28	7	137	22	116	-3	71	-7	30	20	40	-23	44
MSL	-16	30	-4	42	-10	53	-12	39	9	140	24	119	-1	77	-5	41	22	49	-21	52
NMISA	3	80	-23	85	-29	91	-31	84	-10	158	5	140	-20	107	-24	85	3	89	-40	90
SP	1	22	-21	37	-27	48	-29	33	-8	138	7	117	-18	74	-22	35	5	44	-38	47
AREPA	14	102	-34	106	-40	111	-42	105	-21	170	-6	154	-31	124	-35	106	-8	109	-51	110
INETI	18	195	-38	197	-44	200	-46	197	-25	238	-10	226	-35	207	-39	197	-12	199	-55	199
SMD	49	44	-69	53	-75	62	-77	51	-56	143	-41	123	-66	83	-70	52	-43	58	-86	61
BEV	3	73	-23	79	-29	85	-31	77	-10	155	5	136	-20	101	-24	78	3	82	-40	84
METAS	-4	53	-16	61	-22	68	-24	59	-3	146	12	127	-13	88	-17	60	10	65	-33	68
CMI	-3	64	-17	70	-23	77	-25	69	-4	151	11	132	-14	95	-18	70	9	75	-34	77
MKEH	75	171	-95	173	-101	177	-103	173	-82	219	-67	206	-92	185	-96	173	-69	175	-112	176
JV	35	72	-55	78	-61	84	-63	76	-42	154	-27	136	-52	101	-56	77	-29	82	-72	83
CEM	82	69	-102	75	-108	81	-110	73	-89	153	-74	134	-99	99	-103	74	-76	79	-119	81
GUM	23	78	-43	83	-49	89	-51	82	-30	157	-15	139	-40	105	-44	83	-17	87	-60	89
MIKES	33	29	-53	41	-59	52	-61	38	-40	139	-25	119	-50	76	-54	40	-27	48	-70	51

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
VSL	32	54	-52	61	-58	69	-60	60	-39	147	-24	127	-49	89	-53	61	-26	66	-69	68
UME	-25	76	6	81	-1	87	-3	80	18	156	33	138	8	104	4	81	31	85	-12	87
UME	9	24	-29	38	-35	49	-37	35	-16	138	-1	118	-26	74	-30	37	-3	45	-46	48
BIM	-2	99	-18	103	-24	108	-26	102	-5	169	10	152	-15	122	-19	103	8	106	-35	108
SMU	7	62	-27	69	-33	76	-35	67	-14	150	1	131	-24	94	-28	68	-1	73	-44	75
MKEH	9	62	-29	69	-35	76	-37	67	-16	150	-1	131	-26	94	-30	68	-3	73	-46	75
INM (RO)	8	83	-28	88	-34	94	-36	87	-15	160	0	142	-25	109	-29	88	-2	91	-45	93
DMDM	46	40	-66	50	-72	59	-74	47	-53	142	-38	122	-63	81	-67	49	-40	55	-83	58
MIKES	11	29	-31	41	-37	52	-39	38	-18	139	-3	119	-28	76	-32	40	-5	48	-48	51
VSL	-4	23	-16	37	-22	49	-24	34	-3	138	12	117	-13	74	-17	36	10	45	-33	48
NPLI	10	67	-30	73	-36	80	-38	72	-17	152	-2	133	-27	97	-31	73	-4	77	-47	79
LNE	15	23	-35	37	-41	49	-43	34	-22	138	-7	117	-32	74	-36	36	-9	45	-52	48
UMTS	77	93	-97	97	-103	103	-105	96	-84	165	-69	148	-94	117	-98	97	-71	101	-114	102
UTE	9	42	-29	51	-35	60	-37	49	-16	143	-1	123	-26	82	-30	50	-3	57	-46	59
CENAMEP AIP	-20	94	1	98	-6	103	-8	97	13	166	28	149	3	117	-1	98	26	101	-17	103
INM (CO)	-7	132	-13	135	-19	139	-21	134	0	190	15	175	-10	150	-14	135	13	137	-30	139
UMTS	-21	32	0	0	-6	54	-8	41	13	140	28	120	2	78	-2	43	26	50	-17	53
BelGIM	-27	45	6	54	0	0	-2	52	19	144	34	124	8	84	4	53	32	59	-11	62
UME	-29	29	8	41	2	52	0	0	21	139	36	119	11	76	6	40	34	48	-9	51
GEOSTM	-8	137	-13	140	-19	144	-21	139	0	0	15	179	-10	154	-15	140	13	142	-30	143
MASM	7	116	-28	120	-34	124	-36	119	-15	179	0	0	-25	136	-30	119	-2	122	-45	123
SMU	-19	72	-2	78	-8	84	-11	76	10	154	25	136	0	0	-4	77	24	81	-20	83
QCC EMI	-23	31	2	43	-4	53	-6	40	15	140	30	119	4	77	0	0	28	49	-15	52
NIS	5	41	-26	50	-32	59	-34	48	-13	142	2	122	-24	81	-28	49	0	0	-43	59
SASO-NMCC	-38	44	17	55	11	62	9	51	30	143	45	123	20	83	15	52	43	59	0	0

Table 5 Proposed pair degrees of equivalence for participants in CCEM-K5 (red), EUROMET.EM-K5 (blue), EUROMET.EM-K5.1 (green), SIM.EM-K5 (orange), and COOMET.EM-K5 (brow) for PF = 0.5 Lead, μW/VA

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
NIST	1	12	7	32	5	45	5	28	4	137	-25	79	-11	71	-2	30	23	41	7	44
NMIA	-1	16	9	33	7	46	7	30	6	137	-23	79	-9	72	1	32	25	42	9	45
NPL	-12	26	20	39	18	51	18	36	17	139	-12	82	3	75	12	38	36	47	20	49
INRIM	-10	30	18	42	16	53	16	39	15	140	-14	83	1	77	10	41	34	49	18	52
INTI	9	34	-1	45	-3	55	-3	42	-5	141	-33	85	-19	78	-10	44	15	52	-1	54
VNIIM	-15	28	23	41	21	52	21	38	20	139	-9	83	6	76	15	39	39	48	23	51
NRC	5	12	3	32	1	45	1	28	-1	137	-29	79	-15	71	-6	30	19	41	3	44
NMC, A*STAR	-3	62	11	69	9	76	9	67	8	150	-21	99	-7	94	3	68	27	73	11	75
PTB	-7	10	15	31	13	44	13	27	12	137	-17	78	-3	71	7	29	31	41	15	43
IN METRO	15	60	-7	67	-9	74	-9	65	-11	149	-39	98	-25	93	-16	66	9	72	-7	73
CENAM	-2	34	10	45	8	55	8	42	7	141	-22	85	-8	78	2	44	26	52	10	54
NIM	13	12	-5	32	-7	45	-7	28	-9	137	-37	79	-23	71	-14	30	11	41	-5	44
MSL	5	30	3	42	1	53	1	39	-1	140	-29	83	-15	77	-6	41	19	49	3	52
NMISA	-14	80	22	85	20	91	20	84	19	158	-10	112	5	107	14	85	38	89	22	90
SP	-8	22	16	37	14	49	14	34	13	138	-16	81	-2	74	8	35	32	45	16	47
AREPA	-30	102	38	106	36	111	36	105	35	170	6	128	21	124	30	106	54	109	38	110
INETI	-19	152	27	155	25	158	25	154	24	204	-5	171	10	168	19	154	43	157	27	158
SMD	11	44	-3	53	-5	62	-5	51	-7	143	-35	89	-21	83	-12	52	13	59	-3	61
BEV	-28	73	36	79	34	85	34	77	33	155	4	107	19	101	28	78	52	83	36	84
METAS	3	53	5	61	3	68	3	59	2	146	-27	94	-13	88	-4	60	21	66	5	68
CMI	-28	64	36	70	34	77	34	69	33	151	4	101	19	95	28	70	52	75	36	77
MKEH	-28	171	36	174	34	177	34	173	33	219	4	188	19	185	28	173	52	175	36	176
JV	5	72	3	78	1	84	1	76	-1	154	-29	106	-15	101	-6	77	19	82	3	83
CEM	-60	69	68	75	66	81	66	73	65	153	36	104	51	99	60	74	84	79	68	81
GUM	-1	78	9	83	7	89	7	82	6	157	-23	110	-9	105	1	83	25	87	9	89
MIKES	0	29	8	41	6	52	6	38	5	139	-24	83	-10	76	-1	40	24	49	8	51

NMI			BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC		UMTS	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
VSL	-23	54	31	61	29	69	29	60	28	147	-1	95	14	89	23	61	47	67	31	68
UME	29	76	-21	81	-23	87	-23	80	-25	156	-53	109	-39	104	-30	81	-5	86	-21	87
UME	-6	24	14	38	12	50	12	35	11	138	-18	81	-4	74	6	36	30	46	14	48
BIM	2	95	6	99	4	104	4	98	3	166	-26	123	-12	118	-3	99	22	103	6	104
SMU	18	62	-10	69	-12	76	-12	67	-14	150	-42	99	-28	94	-19	68	6	73	-10	75
MKEH	-12	62	20	69	18	76	18	67	17	150	-12	99	3	94	12	68	36	73	20	75
INM (RO)	25	83	-17	88	-19	94	-19	87	-21	160	-49	114	-35	109	-26	87	-1	92	-17	93
DMDM	17	40	-9	50	-11	59	-11	47	-13	142	-41	87	-27	81	-18	48	7	56	-9	58
MIKES	0	29	8	41	6	52	6	38	5	139	-24	83	-10	76	-1	40	24	49	8	51
VSL	-23	23	31	37	29	49	29	34	28	138	-1	81	14	74	23	36	47	46	31	48
NPLI	3	67	5	73	3	80	3	72	2	152	-27	103	-13	97	-4	72	21	78	5	79
LNE	-5	23	13	37	11	49	11	34	10	138	-19	81	-5	74	5	36	29	46	13	48
UMTS	-54	93	62	98	60	103	60	96	59	165	30	121	45	117	54	97	78	101	62	102
UTE	5	42	3	51	1	60	1	49	-1	143	-29	88	-15	82	-6	50	19	58	3	59
CENAMEP AIP	33	94	-25	98	-27	103	-27	97	-29	166	-57	122	-43	117	-34	98	-9	102	-25	103
INM (CO)	33	111	-25	115	-27	119	-27	114	-29	176	-57	136	-43	131	-34	114	-9	118	-25	119
UMTS	11	33	0	0	-2	54	-2	41	-3	140	-32	84	-17	78	-8	43	17	51	0	53
BelGIM	9	46	2	54	0	0	0	52	-2	144	-30	90	-16	84	-7	53	18	60	2	62
UME	9	29	2	41	0	52	0	0	-2	139	-30	83	-16	76	-7	40	18	49	2	51
GEOSTM	7	137	3	140	2	144	2	139	0	0	-29	158	-14	154	-5	140	20	143	4	143
MASM	-21	79	32	84	30	90	30	83	29	158	0	0	15	106	24	84	48	88	32	90
SMU	-7	72	17	78	16	84	16	76	14	154	-15	106	0	0	9	77	34	82	18	83
QCC EMI	2	31	8	43	7	53	7	40	5	140	-24	84	-9	77	0	0	25	50	9	52
NIS	27	42	-17	51	-18	60	-18	49	-20	143	-48	88	-34	82	-25	50	0	0	-16	59
SASO-NMCC	11	44	0	55	-2	62	-2	51	-4	143	-32	90	-18	83	-9	52	16	59	0	0

Table 6 Proposed pair degrees of equivalence for participants in CCEM-K5 (red), EUROMET.EM-K5 (blue), EUROMET.EM-K5.1 (green), and COOMET.EM-K5 (brow) for PF = 0.0 Lag, µW/VA

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
NIST	3	9	-13	28	-20	43	-25	26	-5	204	11	85	11	79	-9	25	-41	43	-13	28
NMIA	-2	15	-8	30	-15	45	-20	29	0	204	16	86	16	80	-4	27	-36	44	-8	30
NPL	14	28	-24	38	-31	51	-36	37	-16	205	0	89	0	83	-20	36	-52	50	-24	38
INRIM	0	32	-10	41	-17	53	-22	40	-2	206	14	91	14	84	-6	39	-38	53	-10	41
INTI	7	38	-17	46	-24	57	-29	45	-9	207	7	93	7	87	-13	44	-45	57	-17	46
VNIIM	-11	24	1	36	-6	49	-11	34	9	205	25	88	25	82	5	33	-27	48	1	36
NRC	-11	11	1	29	-6	44	-11	27	9	204	25	86	25	79	5	25	-27	43	1	29
NMC, A*STAR	-4	62	-6	67	-13	75	-18	67	2	213	18	105	18	100	-2	66	-34	75	-6	67
PTB	7	11	-17	29	-24	44	-29	27	-9	204	7	86	7	79	-13	25	-45	43	-17	29
IN METRO	-13	60	3	66	-4	74	-9	65	11	212	27	104	27	99	7	64	-25	73	3	66
CENAM	9	54	-19	60	-26	69	-31	59	-11	210	5	101	5	95	-15	59	-47	68	-19	60
NIM	-7	13	-3	29	-10	44	-15	28	5	204	21	86	21	79	1	26	-31	44	-3	29
MSL	-4	32	-6	41	-13	53	-18	40	2	206	18	91	18	84	-2	39	-34	53	-6	41
NMISA	7	80	-17	84	-24	91	-29	84	-9	219	7	117	7	79	-13	83	-45	90	-17	84
SP	17	19	-27	32	-34	47	-39	31	-19	204	-3	87	-3	13	-23	30	-55	46	-27	32
AREPA	6	141	-16	143	-23	147	-28	143	-8	247	8	165	8	140	-12	143	-44	147	-16	143
INETI	25	296	-35	297	-42	299	-47	297	-27	359	-11	308	-11	296	-31	297	-63	299	-35	297
SMD	31	34	-41	43	-48	54	-53	42	-33	206	-17	91	-17	31	-37	41	-69	54	-41	43
BEV	18	221	-28	223	-35	225	-40	222	-20	300	-4	237	-4	221	-24	222	-56	225	-28	223
METAS	-3	50	-7	56	-14	66	-19	56	1	209	17	99	17	48	-3	55	-35	65	-7	56
CMI	-110	54	100	60	93	69	88	59	108	210	124	101	124	52	104	59	72	68	100	60
MKEH	-18	171	8	173	1	176	-4	173	16	266	32	191	32	170	12	173	-20	176	8	173
JV	5	72	-15	77	-22	84	-27	76	-7	216	9	111	9	71	-11	76	-43	83	-15	77
CEM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GUM	20	77	-30	81	-37	88	-42	81	-22	217	-6	115	-6	76	-26	80	-58	88	-30	81
MIKES	1	23	-11	35	-18	48	-23	34	-3	205	13	88	13	18	-7	32	-39	48	-11	35

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
VSL	11	171	-21	173	-28	176	-33	173	-13	266	3	191	3	170	-17	173	-49	176	-21	173
UME	-22	74	12	79	5	85	0	78	20	216	36	113	36	73	16	77	-16	85	12	79
UME	-1	24	-9	36	-16	49	-21	34	-1	205	15	88	15	19	-5	33	-37	48	-9	36
BIM	1	103	-11	106	-18	111	-23	106	-3	228	13	133	13	102	-7	106	-39	111	-11	106
SMU	-11	63	1	68	-6	76	-11	68	9	213	25	106	25	61	5	67	-27	76	1	68
MKEH	1	62	-11	67	-18	75	-23	67	-3	213	13	105	13	60	-7	66	-39	75	-11	67
INM (RO)	-16	83	6	87	-1	93	-6	87	14	220	30	119	30	82	10	86	-22	93	6	87
DMDM	14	38	-24	46	-31	57	-36	45	-16	207	0	93	0	35	-20	44	-52	57	-24	46
MIKES	3	28	-13	38	-20	51	-25	37	-5	205	11	89	11	24	-9	36	-41	50	-13	38
VSL	14	24	-24	36	-31	49	-36	34	-16	205	0	88	0	19	-20	33	-52	48	-24	36
NPLI	-8	63	-2	68	-9	76	-14	68	6	213	22	106	22	61	2	67	-30	76	-2	68
LNE	7	18	-17	32	-24	46	-29	30	-9	204	7	87	7	11	-13	29	-45	46	-17	32
UMTS	19	155	-29	157	-36	161	-41	157	-21	256	-5	177	-5	154	-25	157	-57	161	-29	157
UMTS	-11	30	0	0	-7	52	-12	39	8	206	24	90	24	84	4	38	-28	51	0	40
BelGIM	-18	45	7	52	0	0	-5	51	15	208	31	96	31	90	11	50	-21	61	7	52
UME	-23	28	12	39	5	51	0	0	20	205	36	89	36	83	16	36	-16	51	12	39
GEOSTM	-3	204	-8	206	-15	208	-20	205	0	0	16	221	16	218	-4	205	-36	208	-8	206
MASM	13	86	-24	90	-31	96	-36	89	-16	221	0	0	0	116	-20	89	-52	96	-24	90
SMU	13	79	-24	84	-31	90	-36	83	-16	218	0	116	0	0	-20	83	-52	90	-24	84
QCC EMI	-7	27	-4	38	-11	50	-16	36	4	205	20	89	20	83	0	0	-32	50	-4	38
NIS	-39	44	28	51	21	61	16	51	36	208	52	96	52	90	32	50	0	0	28	51
SASO-NMCC	-11	30	0	40	-7	52	-12	39	8	206	24	90	24	84	4	38	-28	51	0	0

Table 7 Proposed pair degrees of equivalence for participants in CCEM-K5 (red), EUROMET.EM-K5 (blue), EUROMET.EM-K5.1 (green), and COOMET.EM-K5 (brow) for PF = 0.0 Lead, 53 Hz, µW/VA

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
NIST	0	9	10	28	12	43	9	26	-4	204	-19	85	60	79	6	25	-17	41	18	43
NMIA	9	15	1	31	3	45	0	29	-13	204	-28	86	51	80	-3	27	-26	43	9	45
NPL	-28	29	38	39	40	51	37	38	24	205	9	90	88	83	34	37	11	49	46	51
INRIM	-14	31	24	41	26	53	23	40	10	206	-5	90	74	84	20	39	-3	50	32	53
INTI	6	39	4	47	6	58	3	46	-10	207	-25	93	54	87	0	45	-23	56	12	58
VNIIM	9	25	1	37	3	49	0	35	-13	205	-28	89	51	82	-3	34	-26	47	9	49
NRC	7	12	3	29	5	44	2	27	-11	204	-26	86	53	79	-1	26	-24	42	11	44
NMC, A*STAR	-18	62	28	67	30	75	27	67	14	213	-1	105	78	100	24	66	1	74	36	75
PTB	-4	12	14	29	16	44	13	27	0	204	-15	86	64	79	10	26	-13	42	22	44
IN METRO	4	60	6	66	8	74	5	65	-8	212	-23	104	56	99	2	64	-21	72	14	73
CENAM	-16	54	26	60	28	69	25	59	12	210	-3	101	76	95	22	59	-1	67	34	69
NIM	3	13	7	30	9	44	6	28	-7	204	-22	86	57	79	3	26	-20	42	15	44
MSL	-1	33	11	42	13	54	10	41	-3	206	-18	91	61	85	7	40	-16	52	19	54
NMISA	-26	80	36	84	38	91	35	84	22	219	7	117	86	79	32	83	9	89	44	91
SP	-9	19	19	33	21	47	18	31	5	204	-10	87	69	13	15	30	-8	44	27	47
AREPA	-34	141	44	143	46	147	43	143	30	247	15	165	94	140	40	143	17	147	52	147
INETI	-230	482	240	483	242	484	239	483	226	523	211	489	290	482	236	483	213	484	248	484
SMD	-4	34	14	43	16	54	13	42	0	206	-15	92	64	31	10	41	-13	52	22	54
BEV	-10	221	20	223	22	225	19	222	6	300	-9	237	70	221	16	222	-7	225	28	225
METAS	10	50	0	57	2	66	-1	56	-14	209	-29	99	50	48	-4	55	-27	64	8	66
CMI	-71	54	81	60	83	69	80	59	67	210	52	101	131	52	77	59	54	67	89	69
MKEH	24	171	-14	173	-12	176	-15	173	-28	266	-43	191	36	170	-18	173	-41	176	-6	176
JV	-14	72	24	77	26	84	23	76	10	216	-5	111	74	71	20	76	-3	82	32	84
CEM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GUM	-5	77	15	81	17	88	14	81	1	217	-14	115	65	76	11	80	-12	87	23	88
MIKES	-25	23	35	35	37	48	34	34	21	205	6	88	85	18	31	33	8	46	43	48

NMI			UMTS		BelGIM		UME		GEOSTM		MASM		SMU		QCC EMI		NIS		SASO-NMCC	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
VSL	-33	171	43	173	45	176	42	173	29	266	14	191	93	170	39	173	16	176	51	176
UME	-16	74	26	79	28	85	25	78	12	216	-3	113	76	73	22	77	-1	84	34	85
UME	-9	25	19	37	21	49	18	35	5	205	-10	89	69	21	15	34	-8	47	27	49
BIM	19	105	-9	108	-7	113	-10	108	-23	229	-38	135	41	104	-13	107	-36	112	-1	113
SMU	4	64	6	69	8	77	5	69	-8	213	-23	106	56	62	2	68	-21	75	14	77
MKEH	-19	62	29	67	31	75	28	67	15	213	0	105	79	60	25	66	2	74	37	75
INM (RO)	23	83	-13	87	-11	93	-14	87	-27	220	-42	119	37	82	-17	86	-40	92	-5	93
DMDM	-9	39	19	47	21	58	18	46	5	207	-10	93	69	36	15	45	-8	56	27	58
MIKES	0	28	10	39	12	51	9	37	-4	205	-19	89	60	24	6	36	-17	49	18	51
VSL	4	25	6	37	8	49	5	35	-8	205	-23	89	56	21	2	34	-21	47	14	49
NPLI	12	64	-2	69	0	77	-3	69	-16	213	-31	106	48	62	-6	68	-29	75	6	77
LNE	-5	19	15	33	17	47	14	31	1	204	-14	87	65	13	11	30	-12	44	23	47
UMTS	-9	147	19	149	21	153	18	149	5	251	-10	170	69	146	15	149	-8	152	27	153
UMTS	12	30	0	0	2	52	-1	39	-14	206	-29	90	49	84	-5	38	-27	50	8	52
BelGIM	14	45	-2	52	0	0	-3	51	-16	208	-31	96	47	90	-7	50	-29	60	6	62
UME	10	28	1	39	3	51	0	0	-13	205	-28	90	51	83	-3	36	-26	49	9	51
GEOSTM	-3	204	14	206	16	208	13	205	0	0	-15	221	63	218	10	205	-13	208	22	208
MASM	-18	86	29	90	31	96	28	90	15	221	0	0	79	116	25	89	2	95	37	96
SMU	61	79	-49	84	-47	90	-51	83	-63	218	-79	116	0	0	-54	83	-76	89	-42	90
QCC EMI	7	27	5	38	7	50	3	36	-10	205	-25	89	54	83	0	0	-22	48	12	50
NIS	-15	42	27	50	29	60	26	49	13	208	-2	95	76	89	22	48	0	0	35	60
SASO-NMCC	19	45	-8	52	-6	62	-9	51	-22	208	-37	96	42	90	-12	50	-35	60	0	0