Asia Pacific Laboratory Accreditation Cooperation

APLAC APM015

RESISTANCE
PROFICIENCY TESTING PROGRAMME

Final report

2008-06-24

ACKNOWLEDGEMENTS

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CONTENTS

1. FOREWORD

This report summarises the results of the proficiency testing programme on resistance calibration by laboratories accredited by bodies that are members of the Asia Pacific Laboratory Accreditation Cooperation (APLAC) and the Interamerican Accreditation Cooperation (IAAC).

The exercise was coordinated by The Japan Accreditation Board for Conformity Assessment (JAB). Circulation of the resistance artefacts commenced in November 2004 and finished in February 2008.

2. AIM OF THE PROGRAMME

One of APLAC's main purposes is to build up and maintain mutual confidence between national calibration and testing services in order to reach and maintain a state of mutual agreement on the equivalence of the operation of the accreditation bodies and of the certificates issued by their accreditation laboratories. Calibration activities underpin all testing and measurement activities[1].

The programme was designed to evaluate whether the resistance calibration results for two resistance artefacts obtained by laboratories accredited by its member accreditation bodies were in agreement with that of the reference laboratory to within their claimed uncertainties.

3. DESIGN OF THE PROGRAMME

This interlaboratory comparison PT programme involved the only one circulation of two resistance artefacts. The artefacts used in this programme were air-typed resisters ASR-1R0(nominal value 1 ohm) and ASR-103(nominal value 10 kΩ).The photo of one of resisters appears in figure 1.

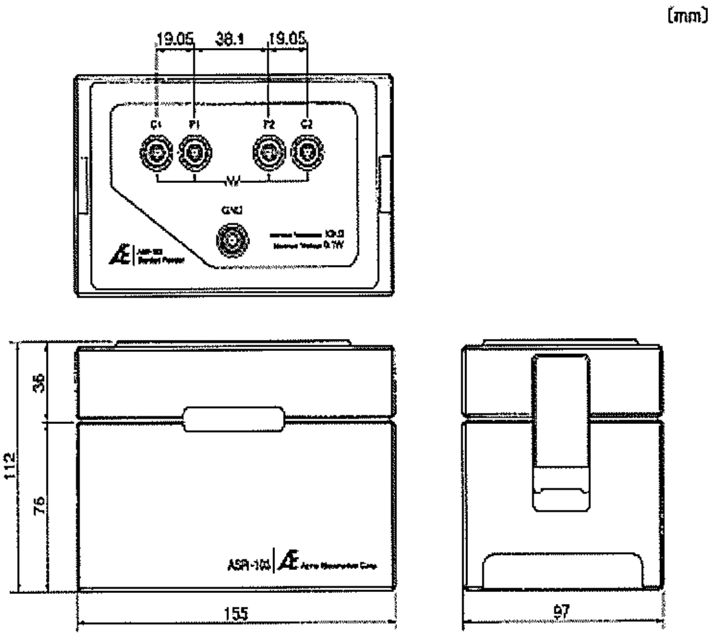


Figure 1 Configuration of resistance artefact (ASR-103)

The nominal values of resistance, maximum voltage and maximum current are listed on the table 1.

Table 1 Specifications of artefacts
(from brochure "standard resistors ASR series" of Alpha Electronics)

Type	Nominal value (Ω)	Max. voltage (V)	Max. current (A)	Stability (ppm/year)
ASR-1R0	1	0.7071	0.7071	±3
ASR-103	10 000	31.6228	0.0032	±3

The change of resistance with temperature for each resister is accurately expressed by the equation:

$$R_t = R_{23} [1 + \alpha (t - 23) + \beta (t - 23)^2]$$

Where

R_t = Resistance at t ℃

R_{23} = Resistance at 23 ℃

α = Slope of the curve at 23℃ (ppm/℃)

β = Rate of change of Slope of the curve (ppm/℃^{2})

Experience shows that the α and β do not change appreciably with time. The values α and β are listed on the table 2.

Table 2 The temperature coefficient constants

Type	α (ppm/℃)	β (ppm/℃^{2})
ASR-1R0	-0.06	0.38
ASR-103	0.00	-3.54

JEMIC(Japan Electric Meters Inspection Corporation) acted as the reference laboratory, deriving the reference values from a series of calibrations of the two resisters.

Participants were required to put the two resisters in their laboratories at least 24 hours before taking data. Measurement method is according to normal procedure of the participating laboratory.

A copy of the instructions to laboratories is attached in Appendix A.

4. PARTICIPANTS

A total 59 laboratories from 21 accreditation bodies participated in the programme. The following economies had laboratories participating in the programme.

Economy	Accreditation body	Number of laboratories
Australia	NATA	2
Brazil	DICLA/INMETRO	2
Chinese Taipei	TAF	3
Canada	NRC	3
Hong Kong, China	HKAS	4
India	NABL	2
Indonesia	KAN	3
Japan	IAJapan	3
Japan	JAB	4
Korea	KOLAS	1
Malaysia	DSM	3
Mexico	EMA	4
New Zealand	IANZ	2
Pakistan	PNAC	1
People's Republic of China	CNAL	4
Thailand	TISI	2
United States of America	A2LA	4
United States of America	ACLASS	4
United States of America	IAS	4
United States of America	NVLAP	3
Vietnam	STAMEQ	1
Total	21	59

A circulation schedule appears in Appendix B. To maintain confidentiality, participating laboratories were assigned a random code number and these numbers are used in the report.

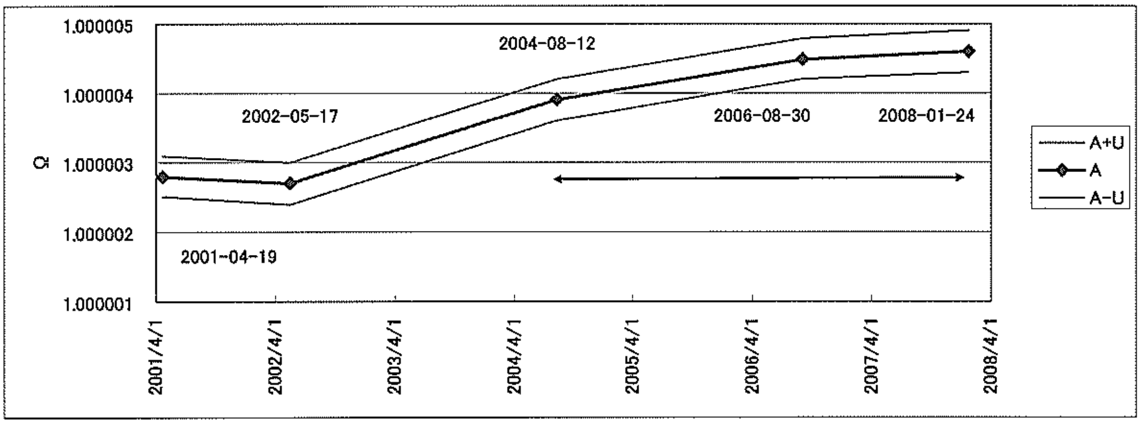
5. CIRCULATION AND STABILITY OF THE ARTEFACTS

The artefacts were calibrated by JEMIC using the 4-wire DCC bridge method referring to national secondary resistance standard(ratio method by DCC bridge).Calibration conditions are 23.0 ℃±0.5 ℃ temperature,50 %±5 % relative humidity and 31 mA for resister with 1 Ω ,and 5 V for resister with 10 kΩ. Expanded uncertainty[2)] was 0.3 ppm(k = 2).

A series of calibrations of the artefacts was carried out by the reference laboratory at beginning, middle and end of the APLAC APM015 PT programme(three times calibration in 3.5 years of APLAC APM015). The results obtained by the reference laboratory are shown in figure 2-1 and figure 2-2. Calibrated values in two and three years advance were also shown in order to know a stability of the artefacts.

In order to evaluate a drift of artefacts, they were calibrated by JAB's contracted laboratory* every time before shipping when artefacts were sent back to the contracted laboratories after completion of the proficiency testing in each economy(20 times calibration in 3.5 years of APLAC APM015).
*NOTE : JAB's contracted laboratory is Yokogawa Rental & Lease Corporation. The contracted laboratory used the 4-wire DCC

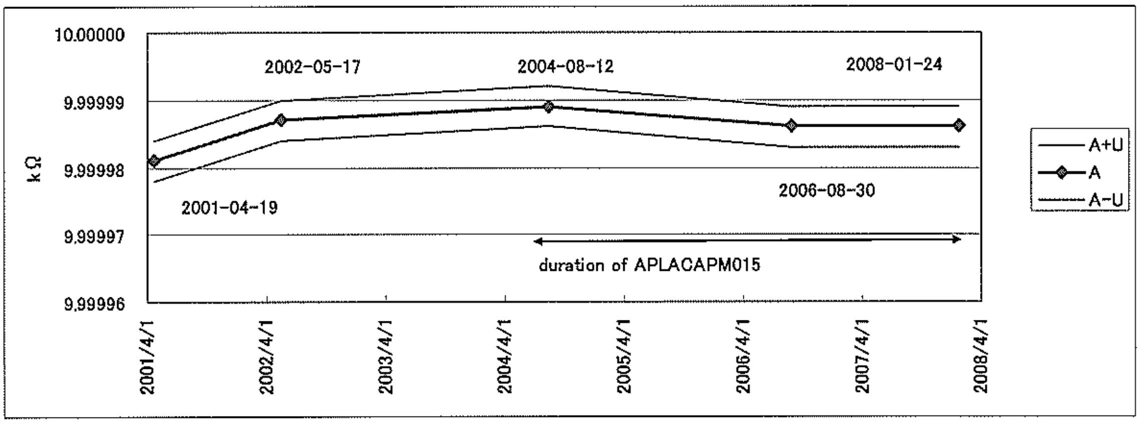
bridge method referring to resistance standard calibrated by JEMIC(ratio method by DCC bridge).The results obtained by the JAB's contracted laboratory are shown in figure 3.



A : calibrated values 1.000 003 9 Ω on 2004-08-12
1.000 004 5 Ω on 2006-08-30
1.000 004 6 Ω on 2008-01-24

U : expanded uncertainty = 0.3 μΩ (0.3 ppm)

Figure 2-1 Calibrated values of ASR-1R0 at reference laboratory



A : calibrated values 9.999 989 kΩ on 2004-08-12
9.999 986 kΩ on 2006-08-30
9.999 986 kΩ on 2008-01-24

U : expanded uncertainty = 3 mΩ (0.3 ppm)

Figure 2-2 Calibrated values of ASR-103 at reference laboratory (A : calibrated value U : expanded uncertainty)

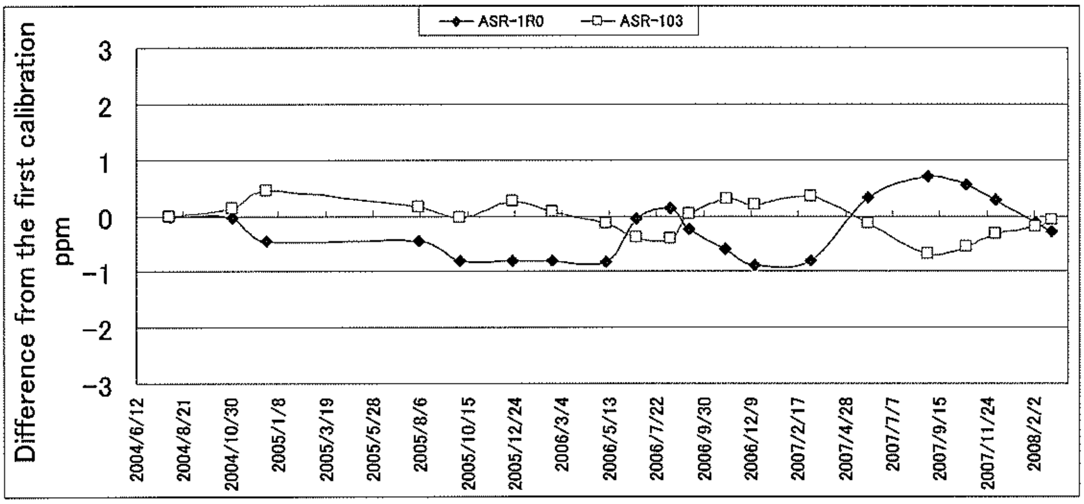


Figure 3 Calibrated values of ASR-1R0 and ASR-103 at contracted laboratory during APLAC APM015

Figure 2-1 seems to show that a drift of increasing trend of aretefact ASR-1R0 is 2 ppm in 7 years(2001 to 2008) and 1 ppm in 3.5 years of APLAC APM015. However figure 3 seems to show that a random drift of aretefact ASR-1R0 is 1 ppm in 3.5 years of APLAC APM015.

Figure 2-2 seems to show that a drift of increasing trend of aretefact ASR-103 is 1 ppm in 3.5 years(2001 to 2004) and a drift of decreasing trend of 0.5 ppm in 3.5 years of APLAC APM015. However figure 3 seems to show that a random drift of aretefact ASR-103 is 0.7 ppm in 3.5 years of APLAC APM015.

6. REFERENCE VALUES AND TWO SET OF UNCERTAINTIES

Based on figure 2-1 and figure 2-2, reference values were assigned as average of two values before and after intermediate calibration on 2006-08-30.

From the observation mentioned in clause 7, it is difficult to conclude an amount of drift during the proficiency test. Where drift might have occurred, the organising body must be very careful in its assumptions so that no laboratory is unfairly disadvantaged[1). Clause 3.10 of APLAC PT 001 recommends to use two set of E_n numbers as one of options.

Following the above recommendation, two set of expanded uncertainties are applied in this report.
One of expanded uncertainties U_1 is set up on the assumption that no random drift have occurred between calibrations at reference laboratory. U_1 is calculated as (difference of two calibrated values)/2 + 0.3 ppm.
Another expanded uncertainty U_2 is calculated on the assumption that random drift have occurred between calibrations at reference laboratory. Therefore U_2 is derived from combined uncertainty[2) of random drift uncertainty(1 ppm for ASR-1R0 and 0.7 ppm for ASR-103) and 0.3 ppm. Results are shown on table 3-1 and table 3-2 for ASR-1R0 and ASR-103 respectively.

Table 3-1 Assigned value and uncertainties for ASR-1R0

	Assigned value	U_1 (k = 2)	U_2 (k = 2)
before 2006-08-30	1.000 004 2 Ω	0.6 μΩ	1.1 μΩ
After 2006-08-30	1.000 004 55 Ω	0.35 μΩ	1.1 μΩ

Table 3-2 Assigned value and uncertainties for ASR-103

	Assigned value	U_1 (k = 2)	U_2 (k = 2)
before 2006-08-30	9.999 987 5 kΩ	4.5 mΩ	7.6 mΩ
After 2006-08-30	9.999 986 kΩ	3 mΩ	7.6 mΩ

7. REPORTING BY PARTICIPANTS

Laboratories were requested to report their test results on a form of results sheet(refer Appendix A). In addition, they were also requested to provide a calibration report in the format normally issued to a customer, the uncertainty calculation and copies of the calibration certificates for the reference standards used in the measurements.

8. SUMMARY OF RESULTS

A summary of the results submitted by the participating laboratory, compared to the reference values, are shown in table 4-1 for ASR-1R0 and in table 4-2 for ASR-103. The figure 4-1 and figure 4-2 show each laboratory's results and the reference value with uncertainties claimed by each laboratory.

In accordance with ISO/IEC Guide 43-1, measurement performance has been assessed on the basis of an E_n number for each measurement. The E_n numbers are derived from the following equation:

$$E_n = \frac{LAB - REF}{\sqrt{U_{LAB}^2 + U_{REF}^2}}$$

where

LAB is participant's result
REF is reference laboratory's assigned value
U_{LAB} is the uncertainty of a participant's result
U_{REF} is the uncertainty of the reference laboratory's assigned value

For E_n numbers:

$|E_n| \leqq 1$ = satisfactory
$|E_n| > 1$ = unsatisfactory

Each laboratory's E_n number is shown on the table 4-1 and table 4-2.

E_{n1} is calculated using an expanded uncertainty U_1 and E_{n2} is calculated using an expanded uncertainty U_2.

Values of $|E_{n1}|$ >1 might not require investigation and corrective action because it might not be caused by a fault of laboratory but by drift of artefact.

Values of $|E_{n2}|$ >1 require investigation and corrective action by both the laboratory concerned and its accreditation body.

9. PERFORMANCE OF PARTICIPANTS

Table 4-1 and table 4-2 show performance of participating laboratories by E_n number. Referring to E_{n2} number, out of 57 results reported, 89 % were in agreement with the reference laboratory for 1 Ω and out of 58 results reported, 95 % were in agreement with the reference laboratory for 10 kΩ.

Table 5-1 and table 5-2 shows standard uncertainties for typical items as well as combined, expanded uncertainty and number of repetition of measurement.

Table 6 shows calibration conditions for each participating laboratory. Calibration methods are divided into following 6 groups. Figure(s) in ( ) show(s) number of laboratories.

(1) ratio measurement by DCC bridge (19)
(2) measurement by DCC bridge (1)
(3) indirect/ratio measurement by DMM (5 for 1Ω, 4 for 1 kΩ)
(4) direct/ratio measurement by DMM (14 for 1Ω, 14 for 1 kΩ)
(5) indirect measurement by DMM (7 for 1Ω, 6 for 1 kΩ)
(6) direct measurement by DMM (12 for 1Ω, 14 for 1 kΩ)

"Ratio measurement" in (1)(3)(4) means that a reference resistance standard is used. Any reference resistance standard is not used in (2)(5)(6).
"Indirect measurement by DMM" in (3)(5) means that some calibrator is used for current/voltage calibration. Any calibrator is not used in "direct measurement by DMM" in (4)(6).

Figure 5-1 and figure 5-2 show range of expanded uncertainties of participants for each group of calibration methods.

Table 5, table 6 and figure 5 might be helpful for more investigation of the PT results and corrective action from view points of calibration method and uncertainty estimation.

10. REMARKS

(1) No reference value was described in the interim reports which were circulated during proficiency testing in order to avoid its disclosure to laboratories which had not yet tested. In the interim report, assigned values calibrated on 2004-08-12 were used as reference values for the laboratories which participated before 2006-08-30 and assigned values calibrated on 2006-08-30 were used as reference values after 2006-08-30 with 0.3 ppm of uncertainty. Therefore it is noted that E_n

numbers shown in the interim reports differ from E_{n1} and E_{n2} numbers in this final report.

(2) In this final report, uncertainty of reference value includes drift component of the artefact. However an uncertainty of participants does not include such component. Uncertainties of some laboratories are smaller than the uncertainty of reference value of this proficiency testing(see figure 5-1 and figure 5-2). In these cases, it is noted that "$|E_n| \leqq 1$ = satisfactory" might not be an evidence of correctness of uncertainty of the participants. It is recommended for those laboratories to participate proficiency testing provided with smaller uncertainty in which drift component is hopefully negligible.

(3) The first proficiency testing of resistance in APLAC was carried out by the Chinese National Laboratory Accreditation(CNLA), Chinese Taipei, from 1994-08 to 1997-12[3]. In order to carry out recent APLAC APM015, we have much referred the final report of APLAC APM003. The contents of the report have been very useful for our works. We acknowledge gratefully their original work of proficiency rest of resistance.

11. REFERENCED DOCUMENTS

1) APLAC PT 001, *Calibration - Interlaboratory comparison* Issue No.5 (2008-03)
2) GUM, *Guide to the Expression of Uncertainty in Measurement*, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML
3)APLAC APM003 Final report : *Resistance - Interlaboratory comparison* (2000-12)

Table 4-1 Measurement results of participants for ASR-1R0(1 Ω)

Lab. code	Measured value *LAB*	Uncertainty U_{LAB}	E_{n1}	E_{n2}
1	1.00000530	9.82	0.11	0.11
2	1.0000038	3.0	−0.13	−0.13
3	1.0031	900	3.44	3.44
4	1.000000	50	−0.08	−0.08
5	1.000005	3.0	0.26	0.25
6	1.00000500	0.64	0.50	0.35
7	1.0000046	1.5	0.03	0.03
8	1.00000489	0.16	0.52	0.31
9	1.000174	86	1.96	1.96
10	1.0000045	0.6	−0.06	−0.04
11	1.0000048	0.34	0.34	0.22
12	1.000000	250	−0.02	−0.02
13	0.99985	900	−0.17	−0.17
14	1.00000389	0.28	−0.47	−0.27
15	1.0000035	1.1	−0.56	−0.45
16	0.99998	550	−0.04	−0.04
17	0.999988	12	−1.35	−1.34
18	1.00000095	3.1	−1.04	−1.00
19	1.0000032	0.3	−1.46	−0.86
20	1.000003	23	−0.05	−0.05
21	−	−	−	−
22	1.000004	1.0	−0.17	−0.13
23	0.999986667	8.5	−2.07	−2.05
24	1.00000314	0.61	−1.24	−0.84
25	0.9999974	8.5	−0.80	−0.79
26	1.0000044	20	0.01	0.01
27	1.0033	1570	2.10	2.10
28	0.999990	25	−0.57	−0.57
29	1.00001	270	0.02	0.02
30	1.000001	67	−0.05	−0.05
31	1.0000046	2.4	0.16	0.15
32	1.00001059	185	0.03	0.03
33	1.0000053	1.70	0.41	0.37
34	0.9999914	27	−0.49	−0.49
35	0.999994	140	−0.08	−0.08
36	1.000000	84	−0.05	−0.05
37	1.000012	15.0	0.50	0.50
38	1.0000048	0.52	0.30	0.21
39	1.00000435	0.30	−0.28	−0.18
40	1.0000	1700	0.00	0.00
41	1.0000047	2.1	0.07	0.06
42	1.0000055	5.0	0.19	0.19

Lab. code	Measured value *LAB*	Uncertainty U_{LAB}	E_{n1}	E_{n2}
43	0.9999973	39	−0.18	−0.18
44	0.9998	9500	−0.02	−0.02
45	1.000001	38	−0.08	−0.08
46	1.0000	5000	0.00	0.00
47	1.000000	65	−0.06	−0.06
48	1.000011	154	0.04	0.04
49	0.9999635	16.6	−2.45	−2.45
50	1.00000319	0.30	−1.51	−0.89
51	–	–	–	–
52	1.00000348	0.97	−0.63	−0.49
53	1.0000040	2.6	−0.07	−0.07
54	1.000000	68	−0.06	−0.06
55	1.000004	70	−0.01	−0.01
56	1.0000035	2.6	−0.39	−0.37
57	1.000001	78	−0.04	−0.04
58	1.0000034	2	−0.38	−0.35
59	0.999995	25	−0.37	−0.37

Table 4-2 Measurement results of participants for ASR-103(10 kΩ)

Lab. code	Measured value *LAB*	Uncertainty U_{LAB}	E_{n1}	E_{n2}
1	9.9999969	18.9	0.48	0.47
2	9.999994	30	0.21	0.21
3	9.99997	490	−0.04	−0.04
4	10.00000	400	0.03	0.03
5	9.99990	40	−2.17	−2.15
6	9.9999880	13.6	0.14	0.13
7	9.999990	15	0.26	0.24
8	9.9999835	1.5	−0.75	−0.35
9	9.999956	130.3	−0.23	−0.23
10	9.999989	12	0.24	0.22
11	9.999990	14	0.28	0.26
12	10.0001	700	0.16	0.16
13	10.0119	19400	0.61	0.61
14	9.9999932	1.7	1.18	0.79
15	9.999994	5	0.97	0.76
16	9.99996	320	−0.09	−0.09
17	9.999985	6.1	−0.33	−0.27
18	9.999994957	14.3	0.50	0.47
19	9.9999951	5.0	1.13	0.88
20	9.99998903	62	0.02	0.02
21	9.999982	40	−0.14	−0.14
22	10.000001	20.8	0.63	0.62
23	9.999994167	34.3	0.19	0.19
24	9.9999947	6.1	0.95	0.78
25	10.000093	8.0	11.49	9.92
26	10.000007	105	0.19	0.19
27	10.000150	129	1.26	1.26
28	9.999978	120	−0.08	−0.08
29	10.000065	100	0.77	0.77
30	10.000000	130	0.10	0.10
31	9.999990	24	0.10	0.10
32	10.000012	146	0.17	0.17
33	9.999949	38	−0.97	−0.96
34	–	–	–	–
35	9.9998918	200	−0.47	−0.47
36	9.99996	720	−0.04	−0.04
37	9.999987	150	0.01	0.01
38	9.999985	6.2	−0.15	−0.11
39	9.999981	3.7	−1.06	−0.63
40	9.99986	530	−0.24	−0.24
41	9.99999	10	0.38	0.33
42	9.999995	50	0.18	0.18

Lab. code	Measured value LAB	Uncertainty U_{LAB}	E_{n1}	E_{n2}
43	9.9999361	141	−0.36	−0.36
44	9.99998	2200	−0.003	0.00
45	9.999999	77	0.15	0.15
46	9.9993	1000	−0.69	−0.69
47	10.00004	110	0.48	0.48
48	9.999984	366	−0.01	−0.01
49	10.000005	230	0.08	0.08
50	9.9999945	4.0	1.16	0.87
51	9.9999	240	−0.36	−0.36
52	9.9999908	6.0	0.44	0.36
53	9.999990	26	0.09	0.09
54	9.999993	135	0.04	0.04
55	10.000044	190	0.31	0.31
56	9.999984	16	−0.12	−0.11
57	10.000000	200	0.06	0.06
58	9.999990	24	0.10	0.10
59	9.99990	120	−0.73	−0.73

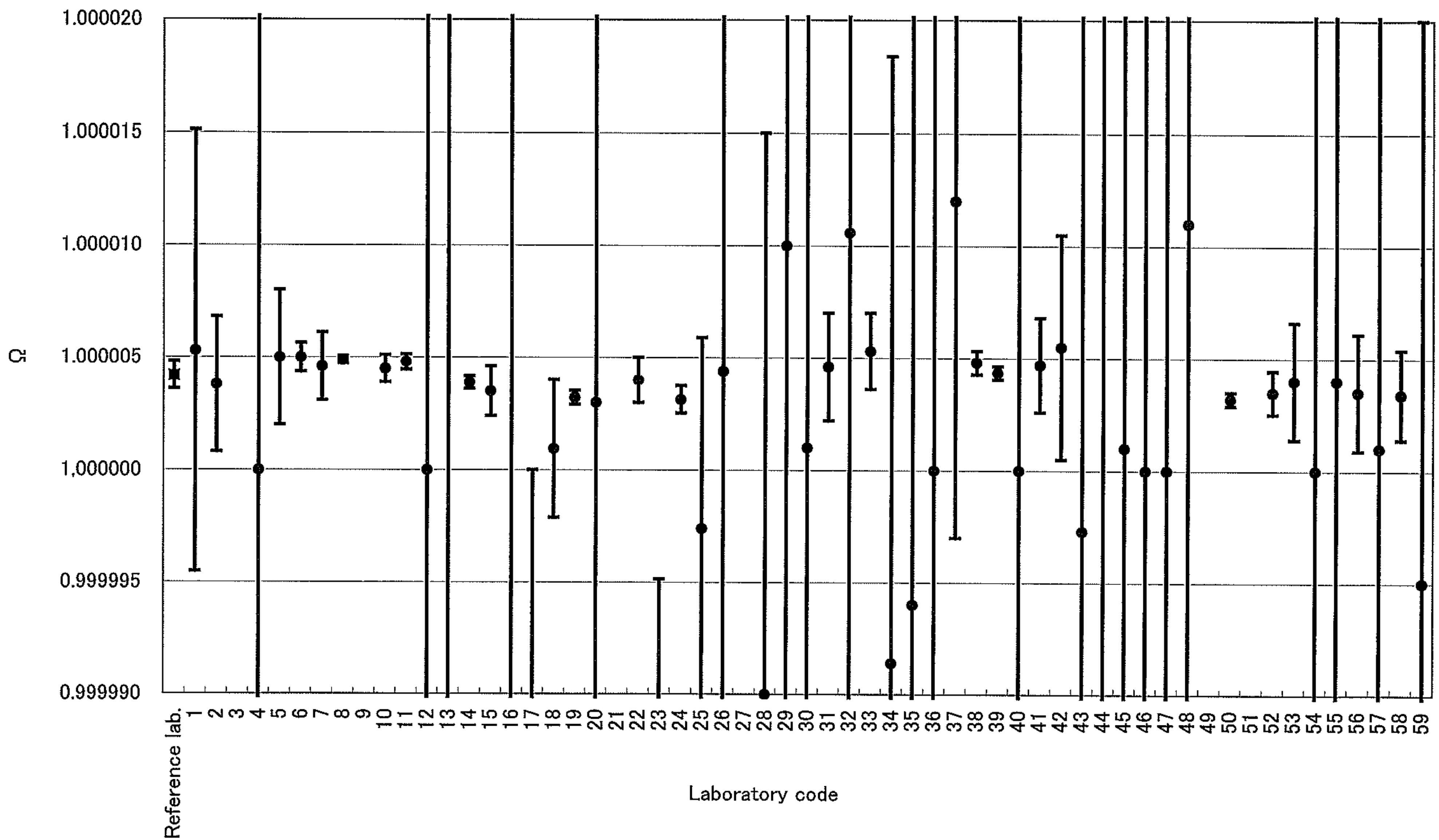


Figure 4-1 Laboratory's results with uncertainties ASR-1R0 1Ω

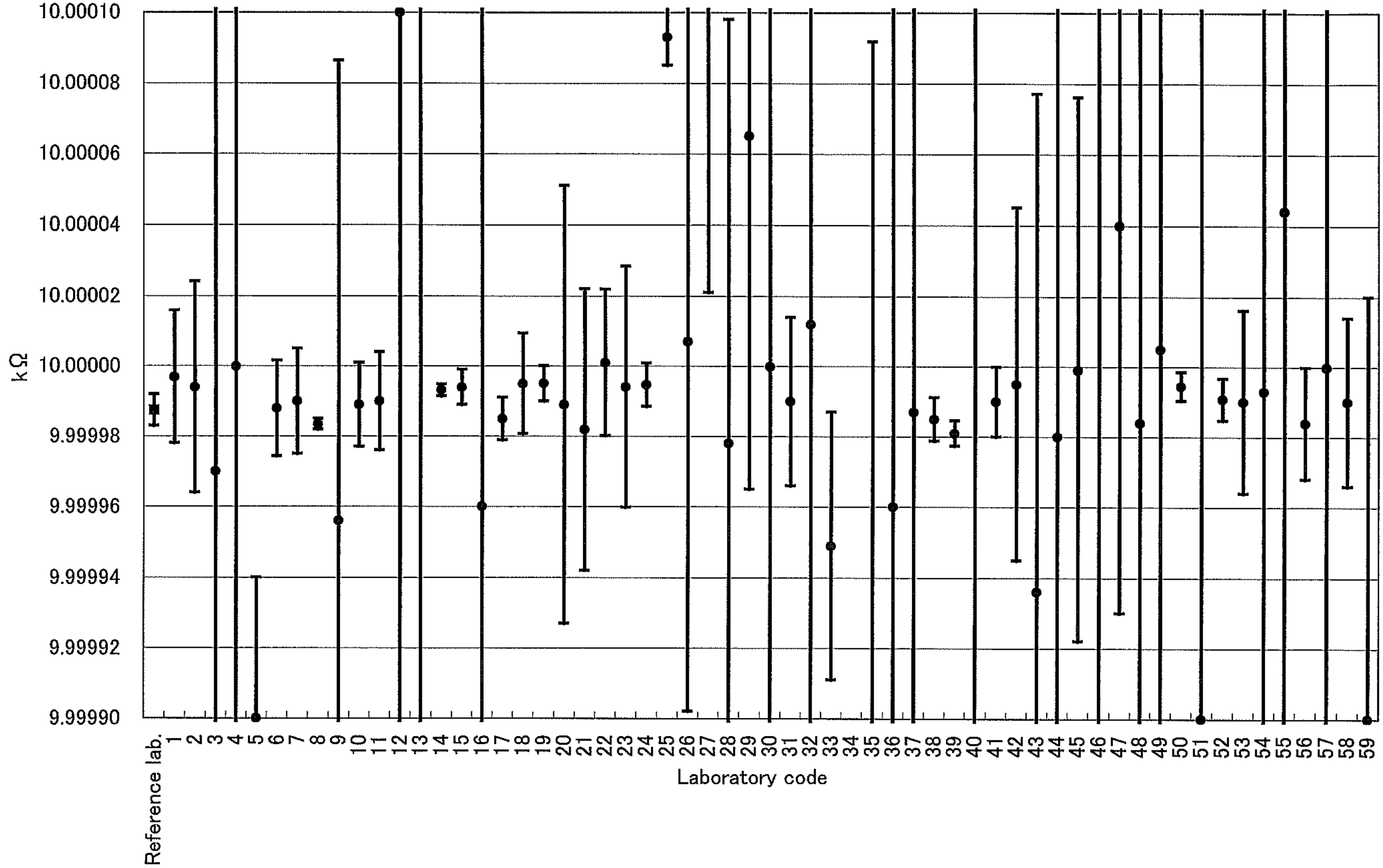


Figure 4-2 Laboratory's results with uncertainties ASR-103 10 kΩ

Table 5-1 Uncertainties (unit: $\mu\Omega$) and repetion of measurement for ASR-1R0 (1 Ω)

Lab. code	Calibration of reference standard	Drift of reference standard	Calibration equipment	Repeatability of measurement	Typical items of the others	Combined uncertainty (k=1)	Expanded uncertainty (k=2)	Number of repetition of measurement
1	–	–	–	–	–	4.91	9.82	20
2	0.2	0.577	1.097	0.011	0.058	1.086	3	90
3	114	364	28.9	126	0.06	403	900	10
4	1.5	17.1	11.5	1.14	15	25.6	50	5
5	–	–	–	–	–	–	3	5
6	0.08	0.29	0.031	–	0.08	0.32	0.64	10
7	0.15	0.38	0.05	0.02	0.57	0.7	1.5	3
8	–	–	–	–	–	–	0.16	12
9	37.52	20	–	4.521	6.35	43.22	86.45	10
10	0.15	0.17	0.035	0.17	0.011	0.28	0.6	20
11	0.083	0.11	0.072	–	0.063	0.17	0.34	10
12	–	–	122	3.66	1.04	120.5	250	12
13	–	–	–	–	–	–	900	5
14	0.02	0.058	0.004	0.011	0.12	0.14	0.28	10
15	0.12	0	0.5	0.89	0.15	0.5	1.1	5
16	–	–	270	6.8	–	270	550	10
17	3	3.5	3.5	0.1	2	6	12	200
18	0.3	1.5	0.041	0.955	0	1.53	3.06	10
19	0.02	0.016	0.058	0.007	0.112	0.129	0.3	9*30
20	–	–	–	–	–	–	23	500
21	–	–	–	–	–	–	–	–
22	0.4	0.22	0.0408	0.139	0.103	0.49	1	3
23	–	–	–	–	–	–	8.464	24
24	–	–	–	–	–	–	0.61	6
25	0.13	0	4.245	0	0	4.244	8.5	10
26	0	0	10	0	0	10	20	10
27	–	–	–	–	–	800	1570	10
28	3	11	2.5	2.9	0.119	12.03	25	5
29	230	–	–	2.5	–	133	270	5
30	–	–	33.486	1.856	0.289	33.359	67	3
31	0.15	1.16	0.0601	0.0007	0.0578	1.17	2.4	101

Lab. code	Calibration of reference standard	Drift of reference standard	Calibration equipment	Repeatability of measurement	Typical items of the others	Combined uncertainty (k=1)	Expanded uncertainty (k=2)	Number of repetition of measurement
32	0.55	18.5	0.668	0.006	0.006	92.59	185.18	20
33	0.25	0.58	0.58	0.01	0.023	0.86	1.7	10
34	–	–	–	–	–	–	27	5
35	3	70	0.2	2	10.31	70	140	10
36	7.5	41.569	0.116	0.169	1.04	42.249	84.497	20
37	0.1	3.46	3.46	0.84	5.77	7.6	15	5
38	0.16	0.15	0.1	0.04	0.1	0.26	0.52	3
39	0.005	0.1	0.05	0.066	0.07	0.148	0.295	4*100
40	–	600	490	173	–	849	1700	3
41	0.11	0.03	1	0.22	0.2	1.05	2.1	10
42	2.5	–	–	0.064	–	2.5	5	10
43	9	12	17	7	0.6	20	39.3	25
44	131	4215	–	40	2367	4836	9500	5
45	3	–	18.5	0	0.29	18.7	38	5
46	–	–	–	1000	–	–	5000	10
47	1.5	32.5	0	2.47	2.9	32	65	5
48	35	0.06	48	0.936	52	77	154	5
49	0	0	8.3	0	0	8.3	16.6	10
50	0.1	0.09	0.1	0.02	–	0.101	0.3	12
51	–	–	–	–	–	–	–	–
52	0.392		0.104	0.0533	0.255	0.482	0.97	40
53	1.25	0.2075	0.0924	0.00942		1.27	2.6	5
54	–	–	34	–	–	34	68	10
55	–	–	–	1.9	–	34.93	70	8
56	1.2	0.2	0.2	0.2	0.4	1.3	2.6	10
57	10	40		0.5	0.3	40	78	10
58	0.47	–	0.776	0.014	–	1	2	125
59	–	–	3	0	12.1	12.5	25	3

Table 5-2 Uncertainties (unit: mΩ) and repetion of measurement for ASR-103 (10 kΩ)

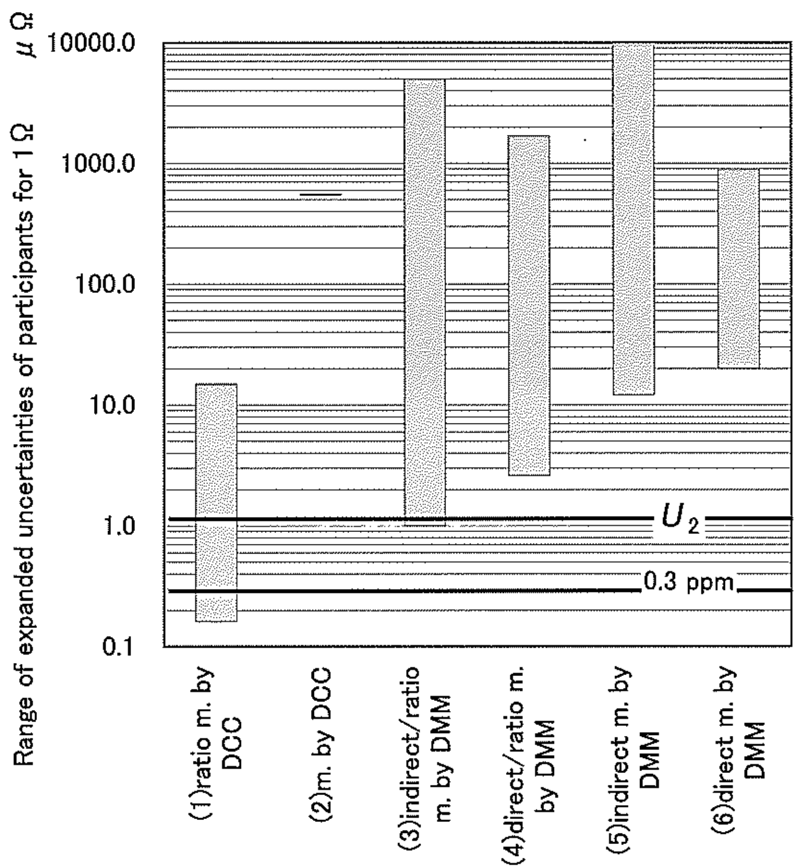
Lab. code	Calibration of reference standard	Drift of reference standard	Calibration equipment	Repeatability of measurement	Typical items of the others	Combined uncertainty (k=1)	Expanded uncertainty (k=2)	Number of repetition of measurement
1	17	0	7.1	0	0	9.4	18.9	20
2	2	5.77	9.24	0.2	0.58	10.63	30	90
3	150	200	2.89	2.99	0.066	250	490	10
4	20	150	68.3	0.38	78	183	400	5
5	–	–	–	–	–	–	40	3
6	1.7	5.8	1.76	–	2.6	6.8	13.6	10
7	1.5	2.9	0.8	0.3	1.6	3.7	15	3
8	0.1	0.5	0.2	0.05	0	0.75	1.5	12
9	60.6	23	0	0.791	6.35	65.13	130.26	10
10	2.5	4.6	0.35	2.8	0.12	5.9	12	20
11	5	1.1	4.1	0.21	0.63	6.6	14	10
12	–	–	334.864	1.487	1.449	334.871	700	12
13	–	–	–	–	–	9700	19400	5
14	0.54	0.58	0.092	0.19	0.23	0.85	1.7	10
15	0.3	0.05	0.5	2.15	0.5	2.2	5	5
16	–	–	160	1.1	0	160	320	10
17	1.5	2.65	0	0.15	0	3.0	6.1	200
18	2.5	6.7	0.02	0.45	0	7.2	14.3	10
19	0.4	0.4	1.08	0.05	1.05	1.61	5	5*30
20	–	–	–	–	–	–	62	500
21	3.6	11.5		1		20	40	5
22	4	3.88	4.08	2.52	7.36	10.4	20.8	3
23	–	–	–	–	–	–	34.32	24
24	–	–	–	–	–	–	6.1	7
25	3.6	0	7.07	0	0	3.97	8	7
26	–	–	52.5	–	–	52.5	105	20
27	–	–	–	–	–	–	129	10
28	20	53	–	2	0.3	56	120	5
29	42.5	–	–	1.3	–	49.1	100	5
30	0	0	63.509	0.333	0.289	65.51	130	3
31	1.5	11.6	0.611	18.0	0.578	11.7	24	101

Lab. code	Calibration of reference standard	Drift of reference standard	Calibration equipment	Repeatability of measurement	Typical items of the others	Combined uncertainty (k=1)	Expanded uncertainty (k=2)	Number of repetition of measurement
32	40.5	60.7	–	0.405	0.578	72.97	146	20
33	0.75	17	5.8	0.21	0.23	19	38	10
34	–	–	–	–	–	–	–	–
35	25	90	0.2	1	9.5	100	200	10
36	21	357.9572	1.1605	2.7212	10.3924	358.675	720	20
37	2	34.6	34.6	2.6	57.7	76	150	5
38	1.1	1.7	1.5	1.4	1	3.1	6.2	3
39	0.05	1.5	0.5	0.59	0.7	1.83	3.66	4*100
40	–	340	350	5.77	–	263	530	3
41	0.6	1.5	3	0.2	2	5	10	10
42	25	–	–	0.18	–	25	50	10
43	10	10	70	0.85	5	72	141	25
44	76.3	923.7875	635.1039	12.2	2.8858	1123.708	2200	5
45	0	0	38.1	0	5	38.4	77	5
46	–	–	–	300	–	–	1000	10
47	10	52.5	–	2.5	29	53	110	5
48	100	0.035	25	10	0	180	366	5
49	–	–	115	–	–	115	230	10
50	1.55	0.8	1	0.05	0	1.56	4	12
51	100	57.7	28.9	1.1		119.2	240	3
52	0.8	0.577	0.0816	2.61	0.999	2.97	6	40
53	12.5	1.1014	2.2517	0.0942		12.7	26	5
54	–	–	67.5	–	–	67.5	135	10
55	–	–	–	–	–	92.1	190	8
56	6	2	2	2	4	8	16	10
57	90	50	–	1	3	100	200	10
58	8.4	–	12	0.047	–	12	24	125
59	0	0	30	0	49	58	120	3

Table 6 Calibration condition

Lab. Code	Measurement method of calibration (m. : measurement)	Calibration equipment	Reference standard resistance	Tested voltage and/or current		Temperature in laboratory ℃	Relative humidity in laboratory %
				1 ohm	10 k ohm		
1	direct/ratio m. by DMM	Fluke 8508A	Fluke742A-1	100 mA	≦ 2V	23±2	50±15
2	ratio m. by DCC bridge	Guild Line 6675	SR104,4025B,4030B,4035B,4210CI	90 mA	0.9 mA	22.8±1.1	46.5±5
3	direct m. by DMM	Schlumberger voltmeter #7061, Fluke #45	-	1.006 mA	0.101 mA	21.2±0.1	48.1±1.0
4	direct/ratio m. by DMM	HP3458A	2792YOKOGAWA	100 mA		21±1	50±15
5	direct/ratio m. by DMM	Fluke 8508A	YEW2791(1),2792(1k)	31 mA	5 V	21±1	55±15
6	ratio m. by DCC bridge	QJ55DC Comparator bridge	2ndary std	100 mA	10 V	20±1	50±20
7	ratio m. by DCC bridge	Guildline Model 6675A Automatic Direct-Current-Comparator Resistance Bridge	ASR-1R0, ASR-103	31 mA	0.5 mA	23±2	50±10
8	interchange method(1 ohm), resistance substitution method(10 k ohm) by DCC bridge	6010C	9210A(1 ohm), 4214(10 k ohm)	31 mA	0.5 mA	23±2	40±10
9	direct/ratio m. by DMM	HP 3458A	ASR-1R0, ASR-103	10 mA	1 V	25±2	50±10
10	ratio m. by DCC bridge	Guildline 6675A	Tinsly 5685(1 ohm), 5685B(10 k ohm)	31 mA	0.5 mA	23±1	55±5
11	ratio m. by DCC bridge	DC Comparator bridge	2ndary std(BZ3, 4210)	100 mA	0.7 mA	20±0.2	55±1
12	direct m. by DMM	Keithly 2001	-	9.2521 mA	.0000253 mA	23.7±0.6	44±11
13	indirect m. by DMM	Agilent 34401A,	calibrator Transmile 2041A	31 mA	5 V	20±5	45±10
14	ratio m. by DCC bridge	Guildline 6675	NML1990(1),ESISR104(10k)	31 mA	0.5 mA	23±1	45±8
15	ratio m. by DCC bridge	Guildline 6675	L&N4210B(1),L&N4035B,ESISR104(10k)	30 mA	3 V	23±3	40±20
16	m. by DCC bridge	bridge ESI 242D	-	47.8 mA	1.22 mA	23.1±0.5	60±5
17	indirect(1), direct(10k) m. by DMM	HP3458A	L&N;Fluke5500A(1)	100 mA	0.1 mA	23±1	47±5
18	indirect/ratio m. by DMM	Fluke5700A/Datron4950(1), Fluke732A/HP3458A(10k)	Fluke742A-1,-10K	100 mA	5 V	22.4±1	38.8±5
19	ratio m. by DCC bridge	MIL6010B,6000B	L&N4210(1),4214(10k)	100 mA	5 V	23±0.5	35±5
20	direct/ratio m. by DMM	Hart Scientific 1590	Fluke 7424-1,10k	0.9997 mA	0.1243 mA	23±0.3	30
21	direct m. by DMM	Agilent 3458A	-	-	0.1 mA	23±1	45±10
22	indirect/ratio m. by DMM	DMM(HP 3458A), DC source(Fluke5220A)	Fluke742A-1,10k	0.1 mA	100 mA	23±0.6	50±20
23	direct/ratio m. by DMM	HP3458A	Fluke 7424-1,10k	9.892mA	10.1537V	23±1	50±15
24	ratio m. by DCC bridge	MIL 6010	L&N4210,esiSR104	31 mA	0.5 mA	23±1	40±15
25	direct/ratio m. by DMM	8508A	ESI SR104, L&N4210	100 mA	0.1 mA	23±1	30±2
26	direct m. by DMM	HP3458A	-	10 mA	0.1 mA	23±1	36±2
27	indirect/ratio m. by DMM	Fluke 87 DMM	Keithley 2000 DMM	0.987 mA	0.0988 mA	22.98±2	33.1±5

Lab. Code	Measurement method of calibration (m. : measurement)	Calibration equipment	Reference standard resistance	Tested voltage and/or current		Temperature in laboratory ℃	Relative humidity in laboratory %
28	direct m. by DMM	Agilent3458A	-	10 mA	0.1 mA	23±1	40±10
29	direct m. by DMM	HP 3458A	-	10 mA	0.1 mA	23±5	50±30
30	direct m. by DMM	Wavetek 1271	-	10 mA	0.1 mA	23±2	55±20
31	ratio m. by DCC bridge	6622(bridge)	6634A	100 mA	1 mA	23.3±0.5	45±5
32	direct/ratio m. by DMM	HP 3458A	ASR-1R0, ASR-103	0.1999992 A		23±2	50±10
33	ratio m. by DCC bridge	MDCC calibrator 9600, Thermotank JKX-B	BZ 20	100 mA	1 mA	20±1	50±5
34	indirect/ratio m. by DMM	5520A, 3458A	5685A	100 mA		23±3	50±15
35	direct/ratio m. by DMM	HP 3458A	standard resitor	10 mA	0.1 mA	23±1.5	59±3
36	direct/ratio m. by DMM	nano-volt micro ohm meter 34420A	ASR-1R0, ASR-103	10 mA	0.1 mA	23±1	50±5
37	ratio m. by DCC bridge	Guildline 9330	ESI 242D	-	-	23±0.5	47±1
38	ratio m. by DCC bridge	Guildline 6675A	L&N 4210, ESI SR-104	31.6 mA	0.1 mA	23±1	40±10
39	ratio m. by DCC bridge	CLAB system No.2, model	model 6634TS	31 mA	0.5 mA	22.6±0.3	36.8±2
40	direct/ratio m. by DMM	DM 8505A	resistance box(Q/3A21CP100-91)	-	-	23	57±1
41	direct/ratio(1), indirect(10k) m. by DMM	Fluke 8508A, 5700A	L&N 4210B,ESI SR-104	100 mA	0.1 mA	23±1	45±10
42	ratio m. by DCC bridge	BZ20&Fluke8508A	2nd grade std BZ20	100 mA	0.1 mA	23±0.1	60±5
43	direct/ratio m. by DMM	HP3458A	Fluke 7424-1,10k			23±2	55±10
44	indirect m. by DMM	calibrator 5500, HP34401	-	1 mA	0.1 mA	23±1	55±5
45	direct m. by DMM	Wavetek 1281	-	10 mA	0.01 mA	23±2	45±10
46	indirect/ratio m. by DMM	CI001 RBS UDL45	CI001 RBS UDL45	1 mA	100 mV	22.3±1	55±10
47	direct m. by DMM	HP3458A	-	10 mA	0.1 mA	22.6±0.2	34±3
48	indirect m. by DMM	Fluke 5520, HP34401, OmegaCL-27	-	31 mA	0.10 mA	23±1	45±5
49	indirct(1),direct(10k) m. by DMM	Fluke5500A,HP3458A	-	31 mA	0.1 mA	22±1	42±2
50	ratio m. by DCC bridge	MIL bridge	L&N4210	31 mA	0.5 mA	23±1	45±10
51	-	-	ASR103, CSR103	-	0.1 mA	23±3	55±20
52	ratio m. by DCC bridge	MIL 6010B	ESI SR104	30 mA	0.1 mA	23±1	47±3
53	ratio m. by DCC bridge	Guild Line 6675A	Fluke742A-1,esiSR104	31 mA	0.5 mA	23±1	50±10
54	direct m. by DMM	HP3458A	-	10 mA	0.1 mA	23±1	38±2
55	indirect m. by DMM	1281, 5720A	-	10 mA	0.1 mA	23±0.5	47±1
56	direct/ratio m. by DMM	Tinsly 5685A	ESI SR-104	100 mA	0.1 mA	23±2	50±10
57	direct m. by DMM	Micro ohm meter HP34420A	-	10 mA	0.1 mA	23±1	64±5
58	direct/ratio m. by DMM	HP3458A	L&N4210, ESI SR104	-	10 V	23±1	65±3
59	direct m. by DMM	RF0298,Fluke8508A	-	100 mA	0.01 mA	20±0.5	45±5



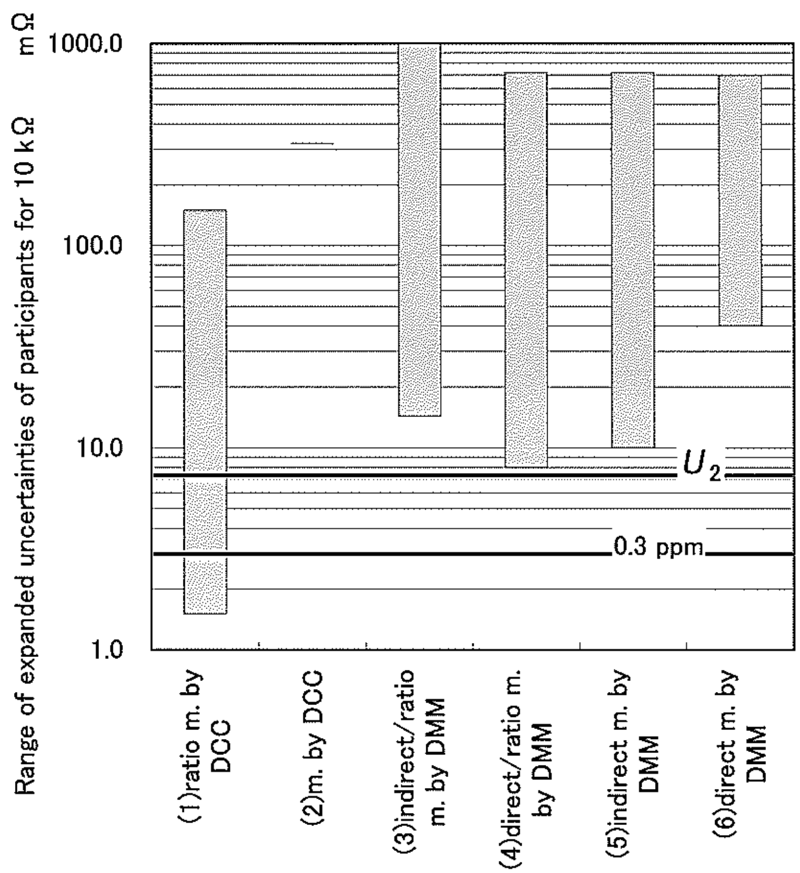


Figure 5-1 Range of expanded uncertainties of participants for 1 Ω

Figure 5-2 Range of expanded uncertainties of participants for 10 kΩ

APPENDIX A

Instructions to laboratories and result sheet

Asia Pacific Laboratory Accreditation Cooperation

APLAC INTERLABORATORY COMPARISON APM015
Resistance
INSTRUCTIONS TO LABORATORIES

PTP code number of Laboratory(confidential) :____________________

1. EQUIPMENT

Full list of equipment, accessories & documentation

1. Electric resistance standards ASR-1R0 S/No.95J0204
2. Electric resistance standards ASR-103 S/No.97E0306

On receipt, unpack the artefacts and inspect them for any defects. *List other specific checks.* Contact your accreditation body if there is any damage.

Details;

Type	Nominal value	Max. current A	Max. voltage V
ASR-1R0	1 ohm	0.7071	0.7071
ASR-103	10 k ohm	0.0032	31.6228

Artifacts of two resistance standards are air types and requires no oil bath. The artifacts are packed in a case, sizes of which are 45 cm * 35 cm and 25 cm height. The weight of the case is approximately 6 kg.

2. MEASUREMENTS TO BE CARRIED OUT

(1) Before taking data, put the two artifacts in the participating laboratory at least 24 hours.

(2) The resisters must be measured in air(23 degree C or at laboratory ambient temperature).

(3) **Measurement method is according to the normal procedure of the participating laboratory.**

(4) Measure the resistance of the resister ASR-1R0 if possible a test current 31mA dc. If a different test current is used(max 707mA), it must be reported in the result sheet.

(5) Measure the resistance of the resister ASR-103 if possible a test voltage 5 volt dc. If a different test voltage is used(max 31 V), it must be reported in the result sheet.

(6) If the measurements were made at a temperature other than 23 degree C, correct the results for 23 degree C by using the temperature coefficient α and β contained on the case of the resisters using the relationship below.

$$Rt = R23 \left[1 + \alpha\,(t-23) + \beta\,(t-23)^2 \right]$$

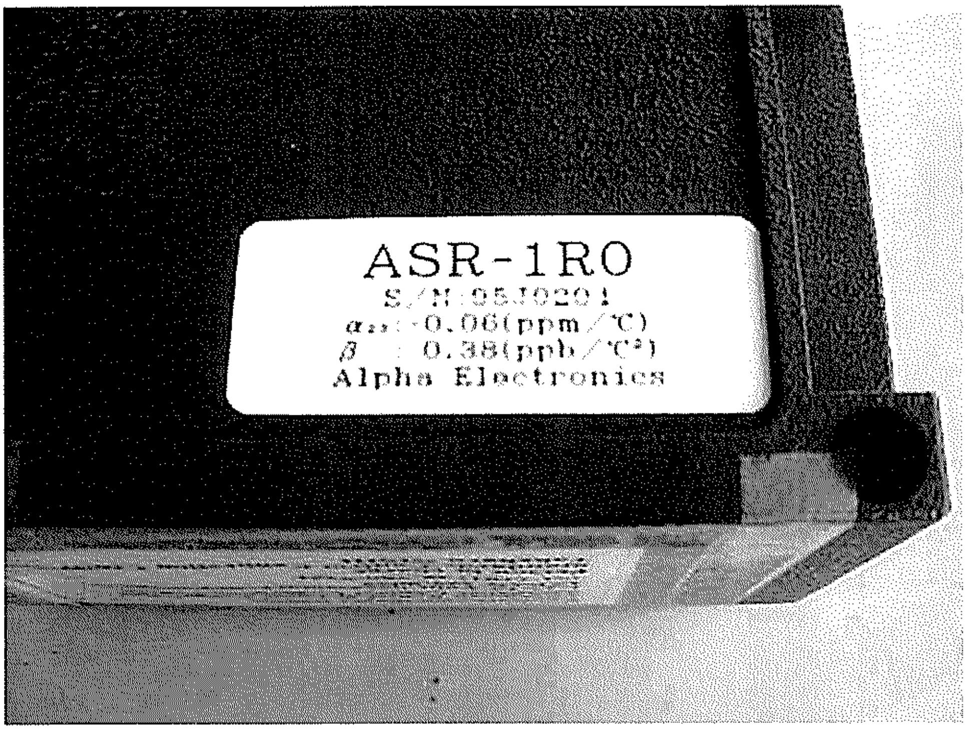
Where

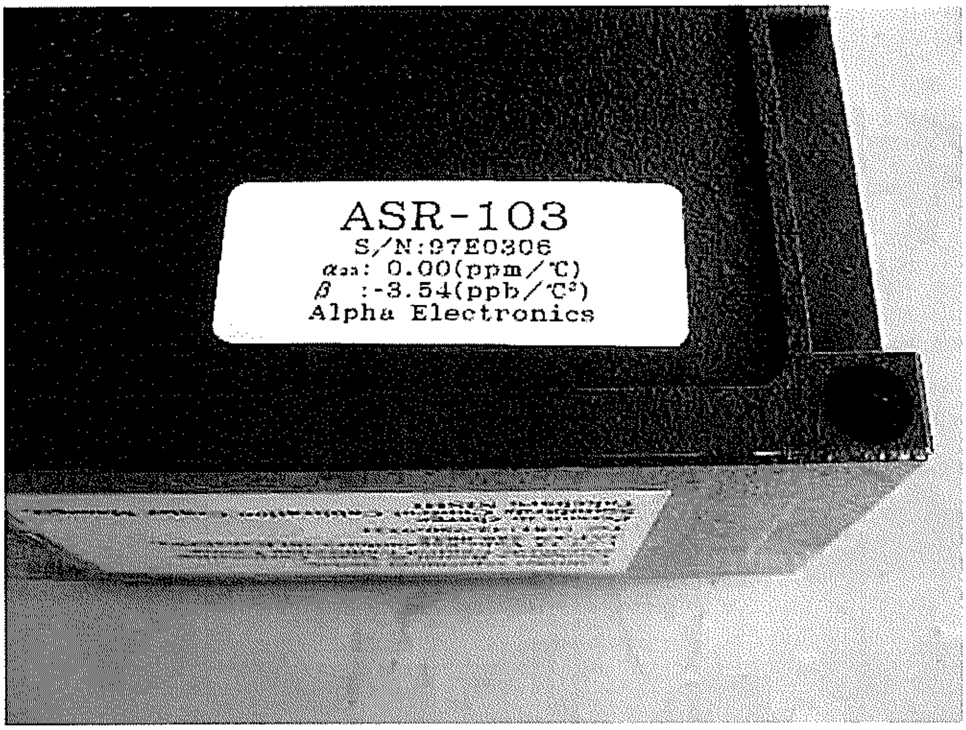
Rt = Resistance at t℃

R23 = Resistance at 23℃

α = Slope of the curve at 23℃(ppm/℃)

β = Rate of change of Slope of the curve (ppm/℃2)





(7) Give a statement of the measurement uncertainties of all stated results to a 95% confidence level. Typical standard uncertainties are preferably given in a result sheet as well as in a format of the laboratory's calculations.
(8) **Information on method of calibration, calibration equipment and reference standard is required.**

3. DOCUMENTS TO BE SUBMITTED

Within two weeks of the completion of the measurements, participating laboratories are required to send the following to their accreditation body:
(1) result sheet (Annex A)
(2) a copy of the laboratory's calculation for determining the uncertainty of measurement for each artifact, resistance standard. Uncertainties should be calculated using the method in the ISO *Guide to the Expression of Uncertainty in Measurement.*
(3) copies of the calibration certificates for the reference standards used in the measurements.

A final report will be issued at the end of the program with each laboratory only identified by a **confidential** code number.

4. GENERAL INFORMATION

For general queries, please contact your accreditation body. Additional information may be obtained from *organiser's contact details* The Japan Accreditation Board for Conformity Assessment(JAB), E-mail:kkakita@jab.or.jp, Fax:+81-3-5475-2780,
Telephone:+81-3-3442-1217 or +81-3-3442-1210

APLAC INTERLABORATORY COMPARISON – APM015

Annex A

RESULT SHEET

PTP code number of Laboratory(confidential) :____________________

Name of Laboratory :______________________________

Date of Measurement :______________________________

Method of calibration :______________________________

Calibration Equipment :______________________________

Reference Standard :______________________________

Environment of Laboratory :Temperature(________ ± ________)℃

Humidity(________ ± ________)%RH

Summary of Measurement Results

Type and Serial No.	Nominal Value	Tested voltage or current	Measured Value	Number of repetition of measurement	Measurement Uncertainty (k=2, Expanded Uncertainty)	Best Measurement Capability
ASR-1R0 95J0204	1 Ω	mA V				

ASR-103 97E0306	10kΩ	mA V				

Uncertainties

Type and Serial No.	Nominal value	Standard uncertainties of typical items					**Combined uncertainty (k=1)**	**Expanded uncertainty (k=2)**
		Calibration of reference standard	**Drift of referenc e standard**	**Calibration Equipment**	**Repeatability of measurement**	**Typical items of the others**		
ASR-1R0 95J0204	1 ohm							
ASR-103 97E0306	10kohm							

APPENDIX B

Calibration schedule

Schedule of APLAC APM015 Resistance

NOTE : JAB* means JAB's contracted laboratory "Yokogawa" which carried out inspection/calibration and transportation of artefacts.

AB and economy	Number of participated laboratories	Arrive at AB	Back to JAB* or arrive at next AB
(IAJapan, JAB) JAPAN	3(IAJapan) 2(JAB)	2004-11	2004-12(JAB)
(A2LA)USA	4	2005-01-03	2005-02-04(AB)
(NVLAP)USA	3	2005-02-04	2005-04-11(AB)
(ACLASS)USA	4	2005-04-11	2005-05-10(AB)
(IAS)USA	4	2005-05-10	2005-06-22(AB)
(EMA)MEXICO	4	2005-06-22	2005-08-03(JAB)
(DICLA/INMETRO) BRASIL	2	2005-08-20	2005-10-03(JAB)
(IANZ) NEW ZEALAND	2	2005-10-10	2005-11-12(AB)
(NATA) AUSTRALIA	2	2005-11-22	2005-12-19(JAB)
(HKAS) HONG KONG, CHINA	4	2005-12-25	2006-02-16(JAB)
(KAN) INDONESIA	3	2006-02-27	2006-05-01(JAB)
(KOLAS) KOREA	1	2006-05-15	2006-06-15(JAB)
(DSM) MALAYSIA	3	2006-07-01	2006-08-10(JAB)
Intermediate calibration at reference laboratory			
(CNAL) PEOPLE'S REPUBLIC OF CHINA	4	2006-09-15	2006-10-31(JAB)
(TISI) THAILAND	2	2006-11-10	2006-12-10(JAB)
(STAMEQ) VIETNAM	1	2006-12-15	2007-03-01(JAB)
(PNAC) PAKISTAN	1	2007-03-09	2007-05-28(JAB)
(NABL) INDIA	2	2007-06-06	2007-08-24(JAB)
(NRC) CANADA	3	2007-09-03	2007-10-22(JAB)
(TAF) CHINESE TAIPEI	3	2007-10-29	2007-12-05(JAB)
Calibration at reference laboratory			
(JAB) JAPAN	2	2008-02	2008-02(JAB)