Asia Pacific Laboratory Accreditation Cooperation

DC CURRENT

INTERLABORATORY COMPARISON
APLAC M020

Final Report – May 2009

ACKNOWLEDGEMENTS

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CONTENTS

1. INTRODUCTION

This report summarises the results of an interlaboratory comparison on DC current calibration by laboratories accredited by bodies that are members of the Asia Pacific Laboratory Accreditation Cooperation (APLAC). The identification code number of this programme is M020. This programme was coordinated by the Department of Standards Malaysia (STANDARDS MALAYSIA).

2. AIM OF THE PROGRAM

One of the APLAC's main aims is to build up and maintain mutual confidence in the technical competence of APLAC members. Interlaboratory comparisons provide objective evidence that laboratories are competent and that they can achieve the level of accuracy for which they are accredited. They also provide a means for improving the quality and performance of laboratories throughout the region.

APLAC M020 DC Current programme was designed to test the participant's ability to perform calibration of a DC current using a digital multimeter over a specified range and to obtain values within their accredited uncertainties of measurement. Secondary aim is to assess the participant's ability to estimate their uncertainty of measurement.

3. DESIGN OF THE PROGRAMME

This interlaboratory comparison involved the simultaneous circulation of three digital multimeter around three groups of participating laboratories, designated as Loop A, B and C. The measurement artefacts comprised of three Agilent 34401A 6½-digits mutimeter, identified as multimeter #5, #6 and #7 were circulated to Loop C, Loop B and Loop A respectively.

National Metrology Laboratory (NML) of SIRIM, Malaysia acted as the Reference Laboratory, deriving values from a series of calibrations of the measurement artefacts at the beginning and the end of the program and at the intervals throughout.

The selected instrument needed to have sufficient resolution, repeatability and stability to be suitable for laboratories.

Participants were required to inject specified DC current from approximately 10 mA to 1 A into the multimeter. Participants were allowed to use their own measurement methods. A copy of the *Instructions to Laboratories* appears in Appendix A.

4. PARTICIPANTS

32 laboratories from 17 accreditation bodies participated in the programme. These laboratories are accredited for various levels of accuracy as defined in their scope of accreditation which lists their least uncertainties of measurement.

To keep to schedule, all the accreditation bodies were asked to strictly follow the circulation period specified. A *Circulation Schedule* listing the accreditation bodies that participated appears in Appendix B.

To maintain confidentiality, participating laboratories were assigned random Lab Code numbers and these numbers are used in the report.

5. CIRCULATION DELAYS

There were delays in the circulation of artefacts. Most delays were only for a few weeks. However, multimeter #7 was held up for four months by the customs of an economy.

6. REPORTING BY PARTICIPANTS

Laboratories were asked to report their test results on a pro-forma *Results Sheet* (refer to Appendix A). They were also requested to provide a formal calibration report and the uncertainty calculations. The participating laboratories were asked to report uncertainties at 95% confidence levels.

7. REFERENCE VALUES AND STABILITY OF THE ARTEFACTS

7.1 Assignment of Reference Values

Before and after each round of circulation, the reference laboratory carried out a series of calibration of the artefacts. The reference values obtained from the calibration of the artefacts are in terms of correction to the readings at various input current levels. Assignment of reference values on the measurement date of each laboratory was based on interpolation using linear regression. The results obtained by the reference laboratory appear in Appendix C.

The method used by the reference laboratory for uncertainty calculation was based on the method described in the ISO document, *Guide to the Expression of Uncertainty in Measurement (GUM) 1995*.

7.2 Stability of Artefacts

The calibrations performed by the reference laboratory before and after the circulation showed that all the artefacts are reasonably stable for all the ranges (see Appendix C) and no significant drift were found.

8. INTERIM REPORTS

8.1 First Interim Reports

In the first interim reports, the interpolated reference correction was used for evaluating the performance of the participating laboratories. The components of reference correction uncertainty were made up of the measurement uncertainty of the reference laboratory and the uncertainty of the interpolated reference value obtained from the regression line.

8.2 Second Interim Reports

In the second interim reports, the analysis method was similar to that used for the first interim reports. However, in addition to the uncertainties accounted for in the first interim reports, the uncertainty due to long-term drift of the artefact is re-estimated. Following these changes, eight results reported in the first interim reports were changed from unsatisfactory to satisfactory.

9. SUMMARY OF RESULTS

In accordance with the international practice, measurement performance has been assessed on the basis of an E_n ratio for each measurement. The E_n ratios are calculated using a standard statistical technique for comparing values and are derived from the following expression:

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

where:

LAB is the correction value measured by the participating laboratory.

REF is the correction value determined from the linear interpolation of the series of measured correction value made before and after the circulations round by the reference laboratory.

U_{LAB} is the expanded uncertainties of the correction provided by the participating laboratories.

U_{REF} is the expanded uncertainties of the correction evaluated by the reference laboratory and the uncertainty of the regression line.

For the results to be acceptable, values of $|E_n| < 1$ are required. Values of $|E_n| > 1$ require investigation and corrective action by both the laboratory concerned and its accreditation body.

A summary of results returned by the participating laboratories is summarized in Tables 1 to 3 below, along with the results of the performance analysis by the E_n number. The graphs in Figures 1 to 18 plot the differences between each laboratory's result and the reference value (*LAB –REF*) and its associated uncertainty.

Table 1 – Summary of Reported Results (Loop A)

DC Current: 10 mA

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	mA	-0.00010	-0.00002	0.00011	-0.00013	0.00023	-0.00008	0.00004	-0.00009	-0.00003	-0.00006
LAB-REF	mA	-0.00001	-0.00002	0.00018	-0.00012	0.00032	-0.00005	0.00004	-0.00011	0.00007	0.00001
Coverage Factor: *k*	-	1.97	2.01	2	1.96	2	2	2.025	2	2.01	2
Expanded Uncertainty: *U*	mA	0.00323	0.00023	0.01570	0.78400	0.00208	0.00059	0.00098	0.00050	0.00017	0.00007
$\|E_n\|$	-	0.00	0.06	0.01	0.00	0.15	0.08	0.04	0.20	0.25	0.04

DC Current: -10 mA

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	mA	0.00000	0.00003	0.00000	0.00000	-0.00035	0.00026	0.00005	0.00009	0.00003	
LAB-REF	mA	-0.00017	-0.00006	-0.00014	-0.00009	-0.00051	0.00015	-0.00004	0.00001	-0.00015	
Coverage Factor: *k*	-	1.97	2.01	2	1.96	2	2	2.025	2	2.01	
Expanded Uncertainty: *U*	mA	0.00323	0.00023	0.01570	0.78400	0.00208	0.00059	0.00098	0.00040	0.00017	
$\|E_n\|$	-	0.05	0.19	0.01	0.00	0.24	0.24	0.04	0.01	0.54	

Table 1 – Summary of Reported Results (Loop A)

DC Current: 100 mA

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	mA	-0.0004	-0.0010	0.0010	0.0024	0.0004	-0.0024	-0.0026	-0.0022	0.0006	-0.0018
LAB-REF	mA	0.0021	0.0002	0.0032	0.0037	0.0028	-0.0008	-0.0014	-0.0013	0.0033	0.0002
Coverage Factor: k	-	2	2.01	2	1.96	2	2	2.025	2	1.96	2
Expanded Uncertainty: U	mA	0.0272	0.0029	0.0248	2.5970	0.0309	0.0069	0.0098	0.0060	0.0004	0.0005
$\|E_n\|$	-	0.08	0.05	0.13	0.00	0.09	0.11	0.14	0.20	1.25	0.08

DC Current: -100 mA

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	mA	-0.0002	0.0013	-0.0003	0.0082	-0.0017	0.0030	0.0031	0.0025	-0.0003	
LAB-REF	mA	-0.0032	-0.0004	-0.0030	0.0064	-0.0046	0.0009	0.0014	0.0011	-0.0035	
Coverage Factor: k	-	2	2.01	2	1.96	2	2	2.025	2	1.96	
Expanded Uncertainty: U	mA	0.0272	0.0029	0.0248	2.5970	0.0309	0.0069	0.0098	0.0060	0.0004	
$\|E_n\|$	-	0.12	0.10	0.12	0.00	0.15	0.12	0.14	0.17	1.33	

Table 1 – Summary of Reported Results (Loop A)

DC Current: 1 A

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	A	0.000037	-0.000002	0.000147	-0.000065	-0.000084	-0.000026	0.000018	-0.000016	0.000011	-0.000024
LAB-REF	A	0.000089	0.000014	0.000194	-0.000044	-0.000033	0.000004	0.000035	-0.000005	0.000066	0.000019
Coverage Factor: *k*	-	1.98	2.01	2	1.96	2	2	2.025	2	2.02	2
Expanded Uncertainty: *U*	A	0.000146	0.000043	0.000055	0.000179	0.000211	0.000107	0.000127	0.000090	0.000004	0.000005
$\|E_n\|$	-	0.57	0.20	2.48	0.23	0.15	0.03	0.26	0.05	1.20	0.34

DC Current: -1 A

Lab Code	Unit	907	908	922	936	953	961	975	983	984	999
Correction	A	-0.000047	0.000002	-0.000143	-0.000037	0.000076	0.000093	-0.000017	0.000058	-0.000013	
LAB-REF	A	-0.000101	-0.000017	-0.000189	-0.000059	0.000024	0.000063	-0.000037	0.000040	-0.000070	
Coverage Factor: *k*	-	1.98	2.01	2	1.96	2	2	2.025	2	2.02	
Expanded Uncertainty: *U*	A	0.000146	0.000043	0.000055	0.000179	0.000211	0.000107	0.000127	0.000090	0.000004	
$\|E_n\|$	-	0.65	0.24	2.44	0.32	0.11	0.52	0.27	0.38	1.27	

Figure 1 - Injected DC current (+10 mA) for Loop A

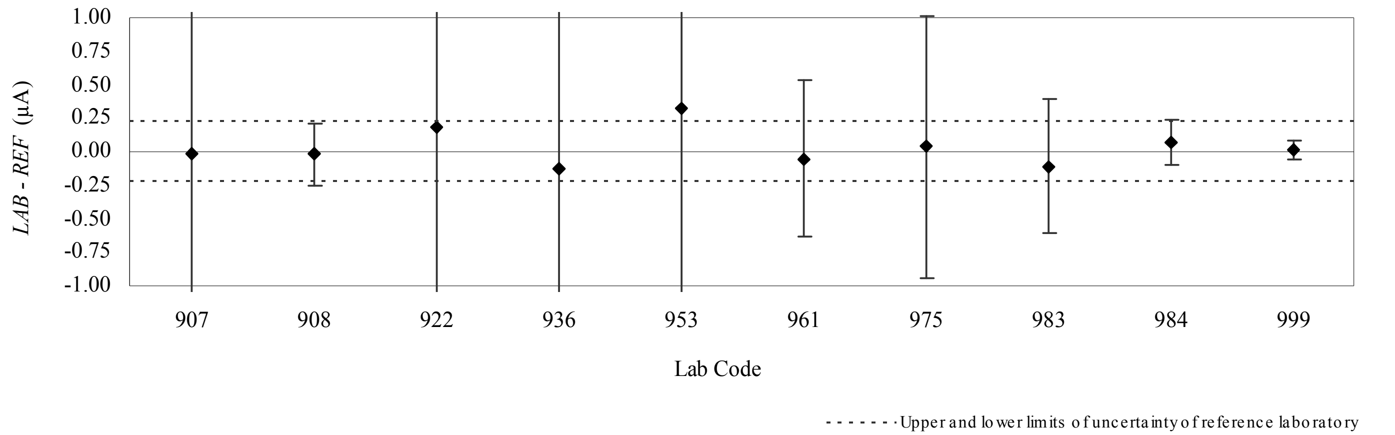


Figure 2 - Injected DC current (-10 mA) for Loop A

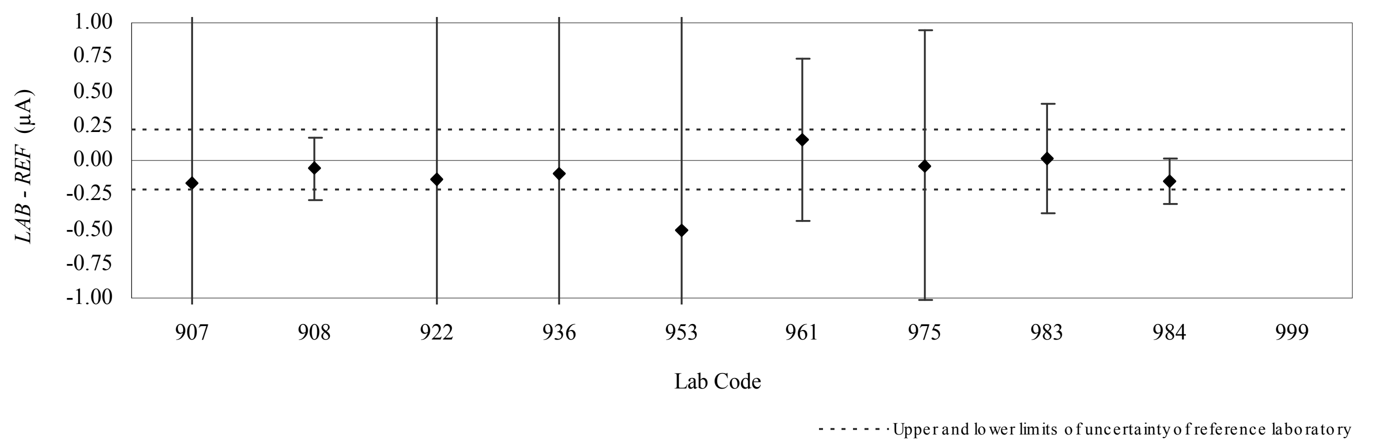


Figure 3 - Injected DC current (+100 mA) for Loop A

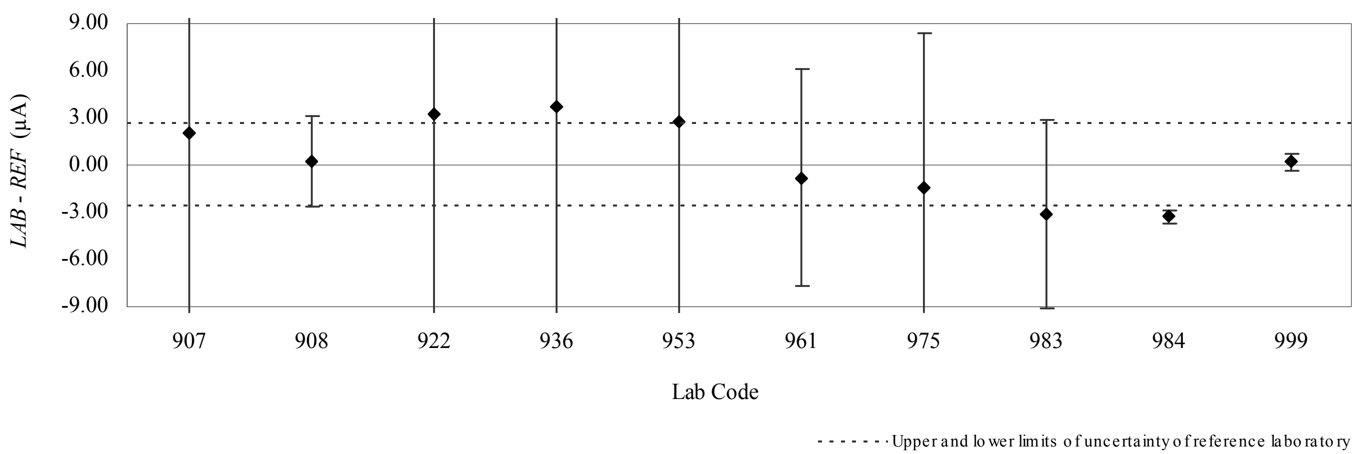
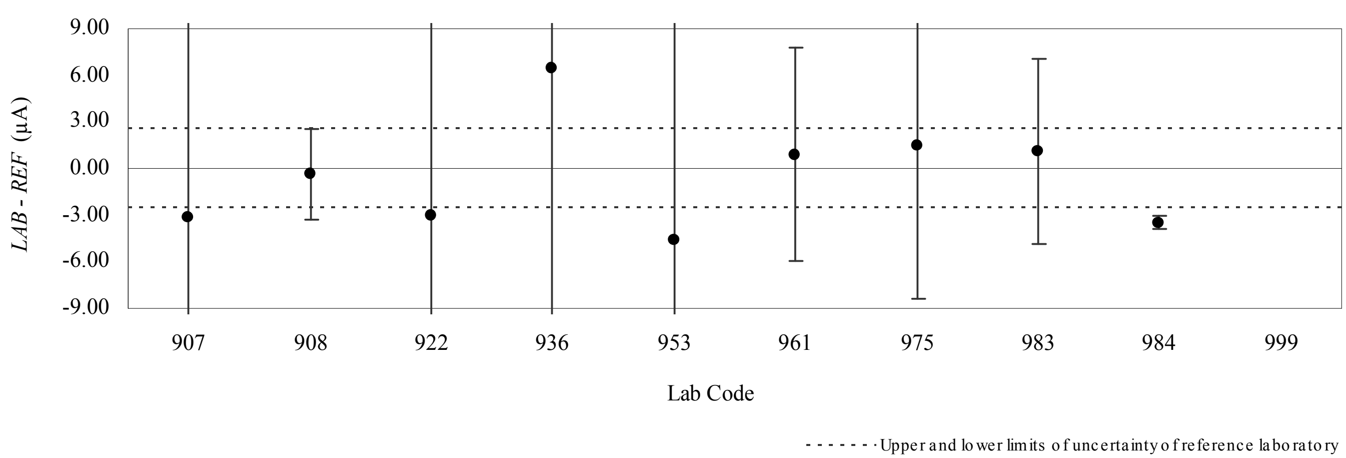


Figure 4 - Injected DC current (-100 mA) for Loop A



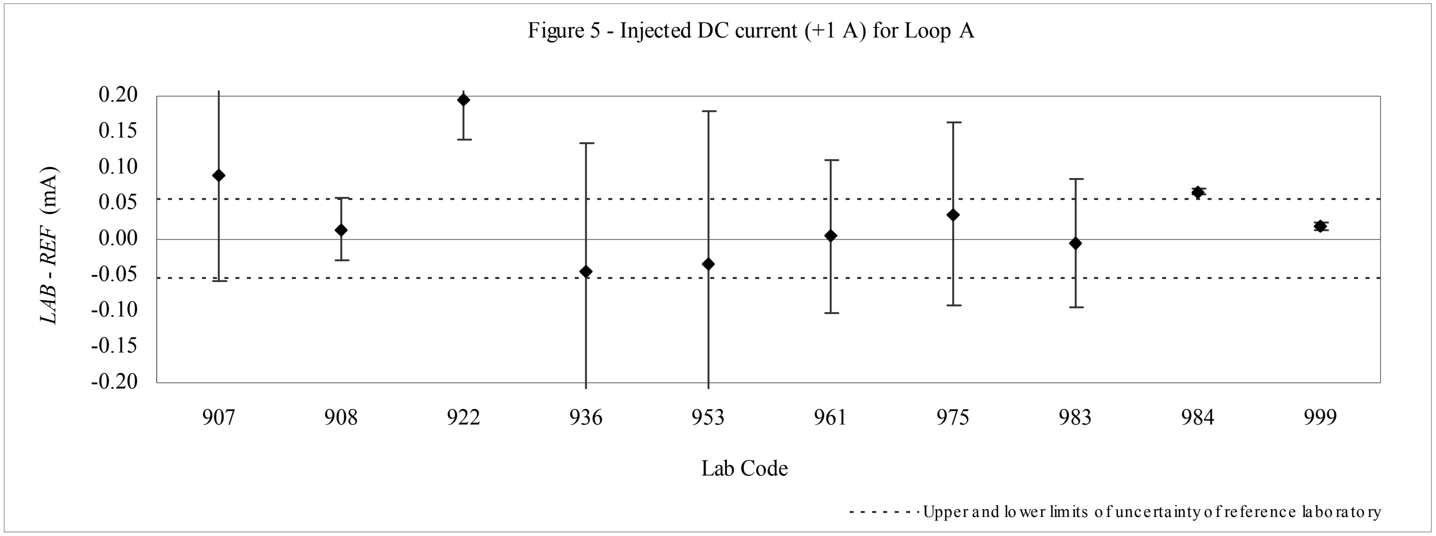


Figure 5 - Injected DC current (+1 A) for Loop A
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
LAB - REF (mA)
907
908
922
936
953
961
975
983
984
999
Lab Code
Upper and lower limits of uncertainty of reference laboratory

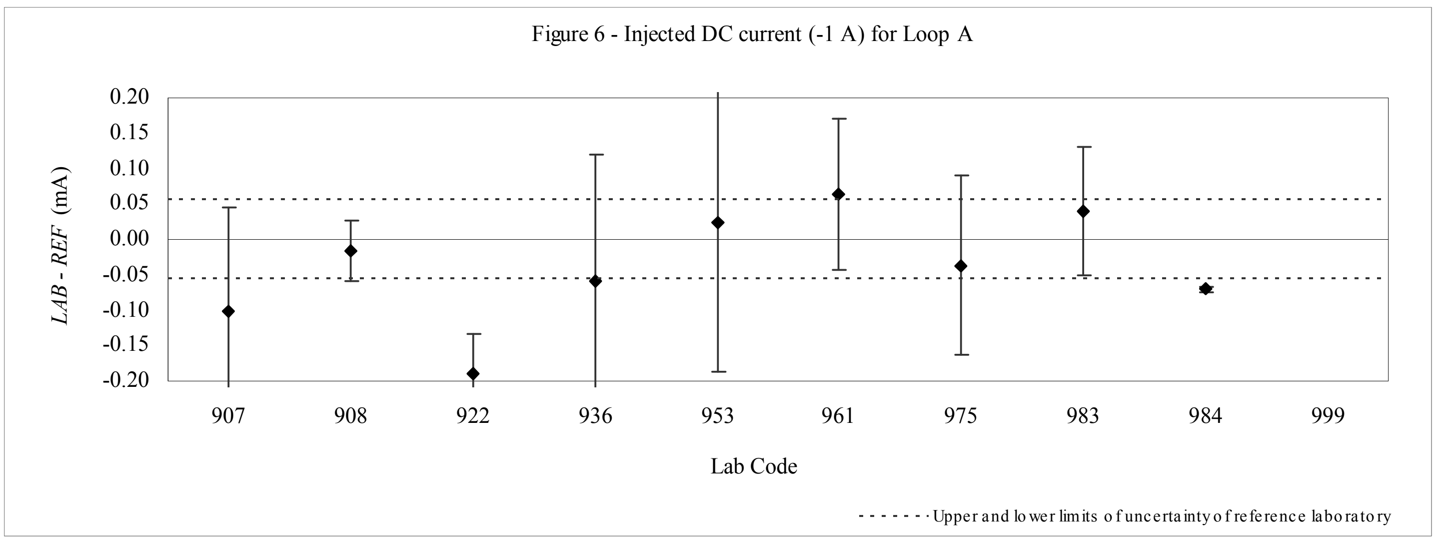


Figure 6 - Injected DC current (-1 A) for Loop A
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
LAB - REF (mA)
907
908
922
936
953
961
975
983
984
999
Lab Code
Upper and lower limits of uncertainty of reference laboratory

Table 2 – Summary of Reported Results (Loop B)

DC Current: 10 mA

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	mA	-0.00086	0.00148	-0.00033	-0.00012	-0.00027	0.00004	-0.00002	-0.00005	-0.00037	-0.00006	-0.00045
LAB-REF	mA	-0.00072	0.00166	-0.00022	0.00000	-0.00016	0.00016	0.00009	0.00009	-0.00024	0.00005	-0.00032
Coverage Factor: *k*	-	2	1.96	1.96	1.96	2	2	2	2	2	2	2
Expanded Uncertainty: *U*	mA	0.00230	0.00682	0.00020	0.00040	0.00400	0.00041	0.00130	0.00058	0.00052	0.00004	0.00120
$\|E_n\|$	-	0.31	0.24	0.76	0.00	0.04	0.34	0.07	0.14	0.43	0.22	0.26

DC Current: -10 mA

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	mA	-0.00013	0.00101	0.00008	0.00042	0.00018	-0.00028	-0.00003	0.00008	0.00038	0.00007	0.00035
LAB-REF	mA	-0.00036	0.00075	-0.00006	0.00025	0.00003	-0.00046	-0.00017	-0.00016	0.00017	-0.00007	0.00014
Coverage Factor: *k*	-	2	1.96	1.96	1.96	2	2	2	2	2	2	2
Expanded Uncertainty: *U*	mA	0.00230	0.00794	0.00020	0.00041	0.00400	0.00041	0.00130	0.00058	0.00052	0.00004	0.00120
$\|E_n\|$	-	0.16	0.09	0.21	0.54	0.01	0.99	0.13	0.26	0.30	0.31	0.11

Table 2 – Summary of Reported Results (Loop B)

DC Current: 100 mA

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	mA	-0.0045	-0.0151	-0.0019	-0.0029	-0.0032	-0.0026	-0.0004	0.0002	-0.0002	-0.0027	-0.0036
LAB-REF	mA	-0.0017	-0.0120	0.0004	-0.0005	-0.0009	-0.0002	0.0019	0.0030	0.0024	-0.0003	-0.0010
Coverage Factor: k	-	2	1.96	1.96	1.96	2	2	2	2	2	2.23	2
Expanded Uncertainty: U	mA	0.0256	0.0573	0.0015	0.0053	0.0430	0.0056	0.0130	0.0068	0.0052	0.0001	0.0120
$\|E_n\|$	-	0.07	0.21	0.18	0.09	0.02	0.03	0.14	0.42	0.44	0.17	0.08

DC Current: -100 mA

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	mA	0.0100	-0.0161	0.0015	0.0033	0.0033	0.0027	0.0003	0.0001	0.0005	0.0027	0.0040
LAB-REF	mA	0.0072	-0.0192	-0.0009	0.0009	0.0010	0.0002	-0.0020	-0.0028	-0.0022	0.0003	0.0013
Coverage Factor: k	-	2	1.96	1.96	1.96	2	2	2	2	2	2.78	2
Expanded Uncertainty: U	mA	0.0256	0.0570	0.0015	0.0053	0.0430	0.0056	0.0130	0.0068	0.0052	0.0002	0.0120
$\|E_n\|$	-	0.28	0.34	0.39	0.16	0.02	0.03	0.15	0.39	0.40	0.17	0.11

Table 2 – Summary of Reported Results (Loop B)

DC Current: 1 A

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	A	0.000019	-0.000987	0.000727	0.000106	0.000056	0.000140	-0.000087	-0.000003	0.000088	0.000035	-0.000072
LAB-REF	A	-0.000102	-0.001107	0.000614	-0.000015	-0.000060	0.000019	-0.000202	-0.000124	-0.000033	-0.000076	-0.000193
Coverage Factor: *k*	-	2	1.96	1.96	1.96	2	2	2	2	2	1.96	2
Expanded Uncertainty: *U*	A	0.000720	0.000872	0.000035	0.000093	0.000310	0.000110	0.000240	0.000110	0.000120	0.000071	0.000240
$\|E_n\|$	-	0.14	1.27	12.17	0.15	0.19	0.16	0.83	1.07	0.26	0.95	0.80

DC Current: -1 A

Lab Code	Unit	600	605	616	632	641	647	650	663	685	692	696
Correction	A	-0.000030	0.000958	0.000526	-0.000111	-0.000040	-0.000145	0.000116	0.000000	-0.000092	-0.000050	0.000109
LAB-REF	A	0.000094	0.001081	0.000644	0.000014	0.000081	-0.000020	0.000235	0.000124	0.000032	0.000065	0.000233
Coverage Factor: *k*	-	2	1.96	1.96	1.96	2	2	2	2	2	2	2
Expanded Uncertainty: *U*	A	0.000720	0.000872	0.000035	0.000093	0.000310	0.000110	0.000240	0.000110	0.000120	0.000071	0.000240
$\|E_n\|$	-	0.13	1.24	12.77	0.14	0.26	0.17	0.97	1.07	0.26	0.82	0.96

Figure 7 - Injected DC current (+10 mA) for Loop B

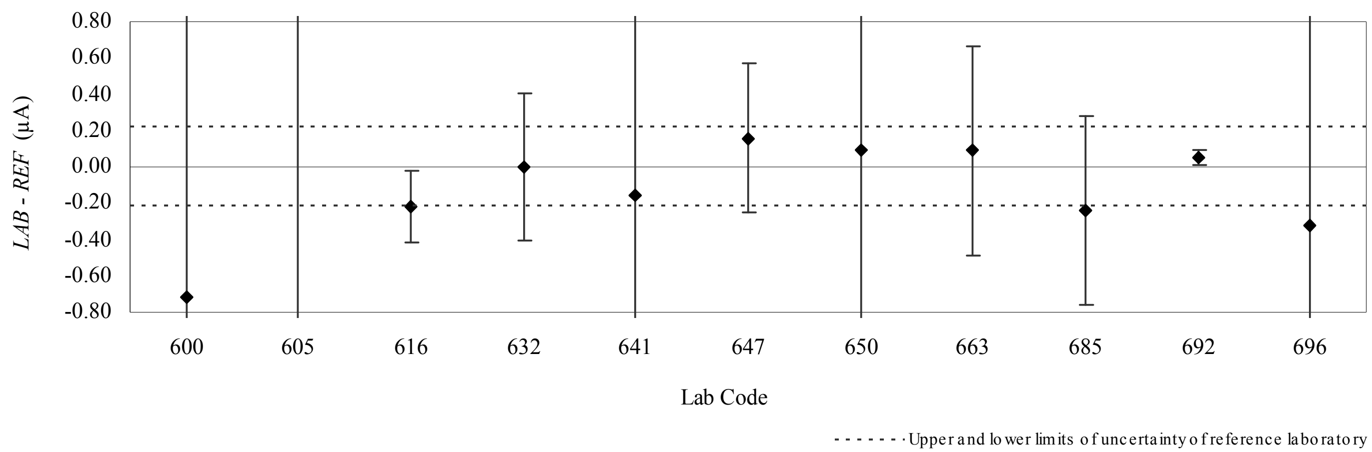


Figure 8 - Injected DC current (-10 mA) for Loop B

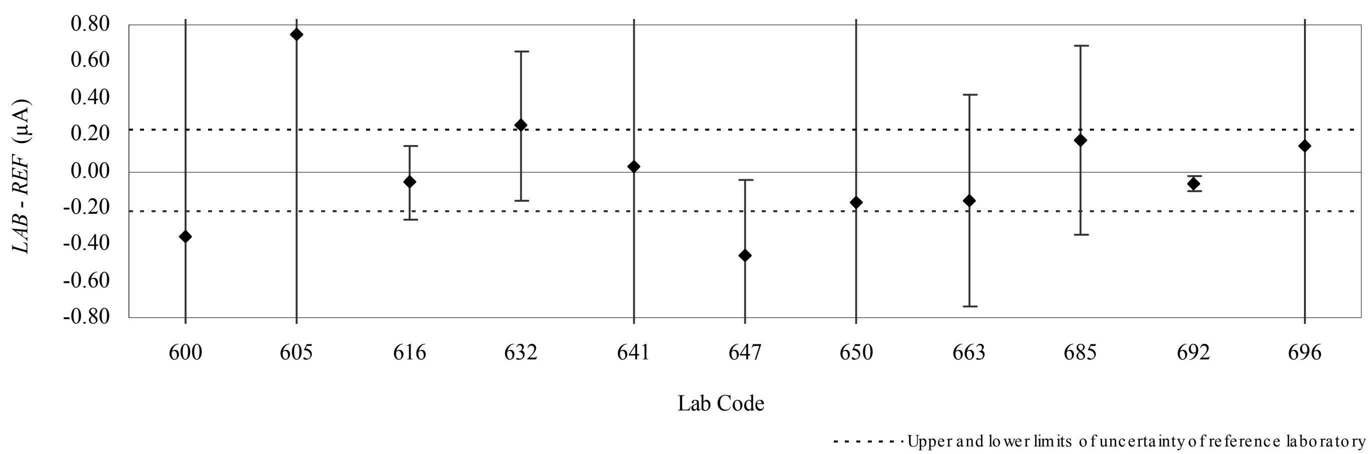


Figure 9 - Injected DC current (+100 mA) for Loop B

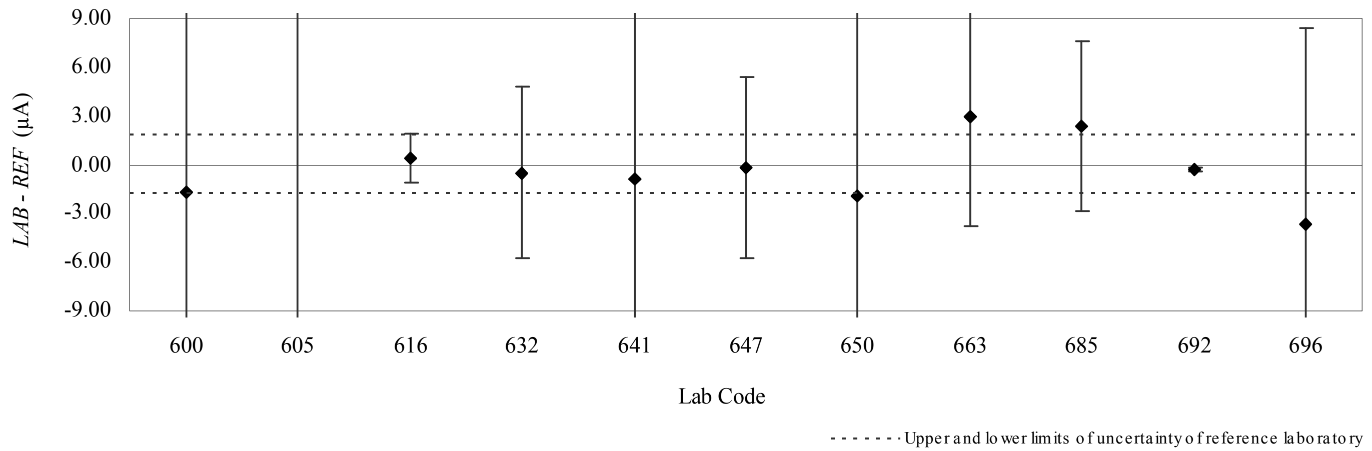
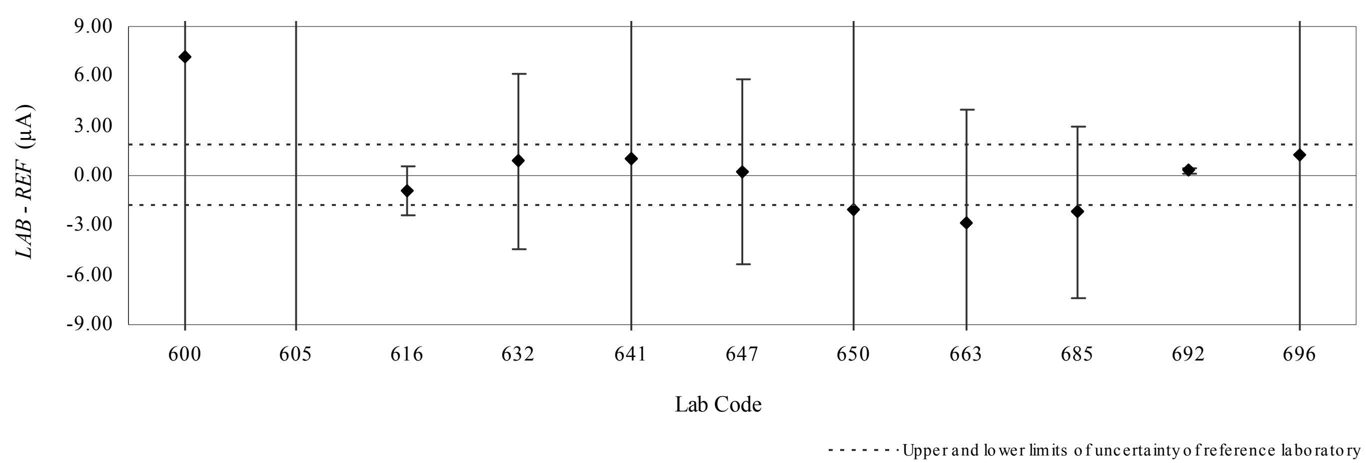


Figure 10 - Injected DC current (-100 mA) for Loop B



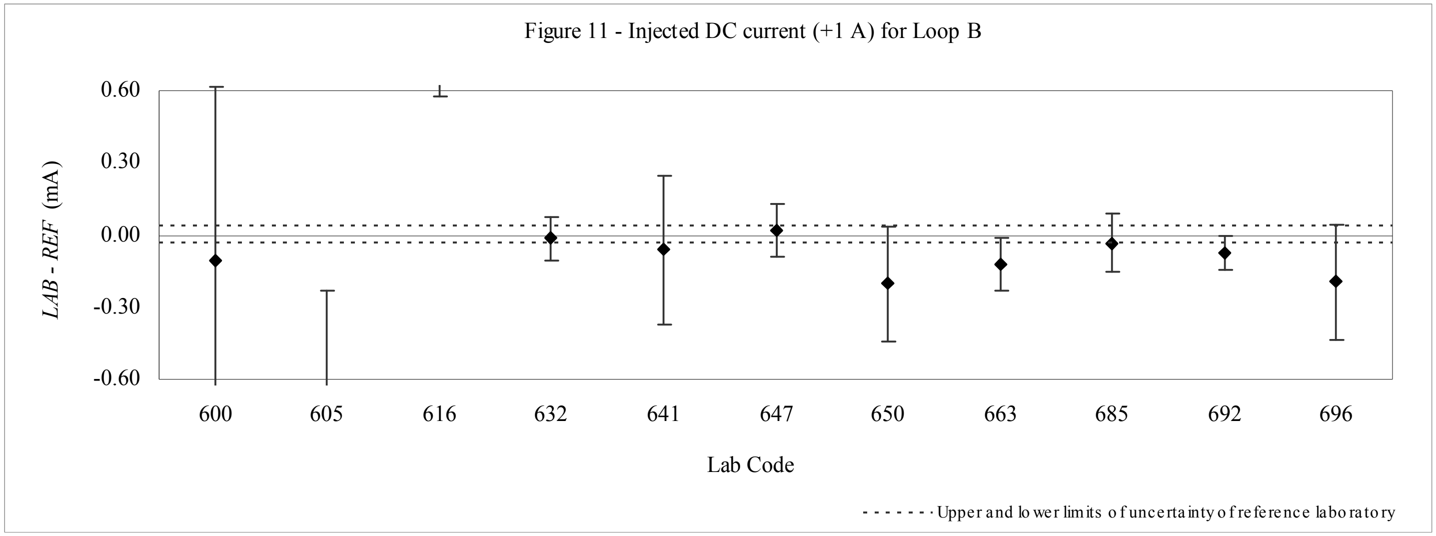


Figure 11 - Injected DC current (+1 A) for Loop B
0.60
0.30
0.00
-0.30
-0.60
LAB - REF (mA)
600
605
616
632
641
647
650
663
685
692
696
Lab Code
Upper and lower limits of uncertainty of reference laboratory

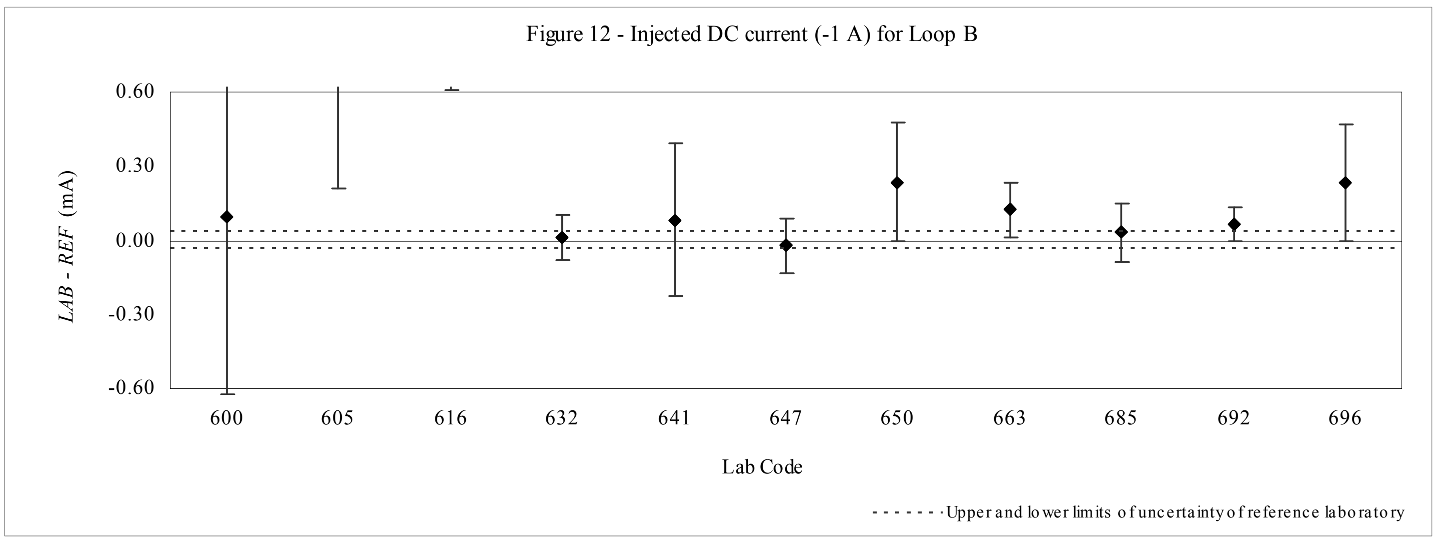


Figure 12 - Injected DC current (-1 A) for Loop B
0.60
0.30
0.00
-0.30
-0.60
LAB - REF (mA)
600
605
616
632
641
647
650
663
685
692
696
Lab Code
Upper and lower limits of uncertainty of reference laboratory

Table 3 – Summary of Reported Results (Loop C)

DC Current: 10 mA

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	mA	0.00011	0.00121	0.00020	0.00000	0.00004	-0.00019	0.00012	0.00011	0.00006	0.00005	-0.00004
LAB-REF	mA	0.00012	0.00122	0.00021	0.00001	0.00007	-0.00018	0.00013	0.00012	0.00007	0.00006	-0.00003
Coverage Factor: *k*	-	2	2	2.01	1.96	1.96	2	2	1.96	2	2	2
Expanded Uncertainty: *U*	mA	0.00052	0.00047	0.00033	0.00079	0.00069	0.00080	0.00101	0.00027	0.00039	0.00038	0.00018
$\|E_n\|$	-	0.22	2.43	0.56	0.01	0.09	0.22	0.13	0.37	0.16	0.14	0.12

DC Current: -10 mA

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	mA	-0.00020	-0.00112	-0.00043	-0.00003	-0.00028	0.00018	-0.00009	-0.00011	-0.00004	-0.00006	0.00005
LAB-REF	mA	-0.00021	-0.00112	-0.00047	-0.00003	-0.00032	0.00018	-0.00010	-0.00014	-0.00004	-0.00008	0.00005
Coverage Factor: *k*	-	2	2	2.01	1.96	1.96	2	2	1.96	2	2	2
Expanded Uncertainty: *U*	mA	0.00052	0.00038	0.00033	0.00079	0.00069	0.00081	0.00101	0.00027	0.00039	0.00038	0.00018
$\|E_n\|$	-	0.38	2.66	1.25	0.04	0.45	0.22	0.10	0.43	0.09	0.19	0.20

Table 3 – Summary of Reported Results (Loop C)

DC Current: 100 mA

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	mA	0.0001	0.0151	-0.0014	-0.0023	-0.0015	-0.0065	0.0053	-0.0014	-0.0018	-0.0027	-0.0031
LAB-REF	mA	0.0029	0.0177	0.0017	0.0003	0.0014	-0.0039	0.0079	0.0017	0.0008	0.0002	-0.0005
Coverage Factor: k	-	2	2	2.01	1.96	1.96	2	2	1.96	2	2	2
Expanded Uncertainty: U	mA	0.0060	0.0094	0.0048	0.0113	0.0189	0.0097	0.0113	0.0027	0.0039	0.0050	0.0020
$\|E_n\|$	-	0.46	1.86	0.33	0.03	0.08	0.40	0.69	0.52	0.18	0.04	0.17

DC Current: -100 mA

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	mA	-0.0001	-0.0150	0.0012	0.0023	-0.0006	0.0070	-0.0069	0.0016	0.0024	0.0021	0.0032
LAB-REF	mA	-0.0033	-0.0180	-0.0023	-0.0007	-0.0038	0.0040	-0.0099	-0.0019	-0.0006	-0.0012	0.0002
Coverage Factor: k	-	2	2	2.01	1.96	1.96	2	2	1.96	2	2	2
Expanded Uncertainty: U	mA	0.0060	0.0085	0.0048	0.0113	0.0187	0.0097	0.0113	0.0027	0.0039	0.0050	0.0020
$\|E_n\|$	-	0.53	2.06	0.45	0.06	0.20	0.41	0.87	0.59	0.15	0.23	0.07

Table 3 – Summary of Reported Results (Loop C)

DC Current: 1 A

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	A	0.000039	0.000162	0.000018	0.000001	0.000096	0.000018	0.000029	0.000062	0.000060	0.000017	0.000006
LAB-REF	A	0.000002	0.000114	-0.000010	-0.000040	0.000042	-0.000024	-0.000023	0.000033	0.000017	-0.000017	-0.000041
Coverage Factor: k	-	2	2	2.01	1.96	1.96	2	2	1.97	2	2	2
Expanded Uncertainty: U	A	0.000110	0.000110	0.000048	0.000141	0.000140	0.000154	0.000197	0.000026	0.000094	0.000084	0.000037
$\|E_n\|$	-	0.02	0.95	0.15	0.27	0.28	0.15	0.11	0.59	0.16	0.17	0.68

DC Current: -1 A

Lab Code	Unit	509	510	512	523	535	547	559	562	568	571	581
Correction	A	-0.000037	-0.000158	-0.000015	-0.000007	-0.000101	-0.000019	-0.000035	-0.000060	-0.000048	-0.000021	0.000001
LAB-REF	A	-0.000001	-0.000111	0.000010	0.000036	-0.000054	0.000024	0.000014	-0.000033	-0.000004	0.000012	0.000047
Coverage Factor: k	-	2	2	2.01	1.96	1.96	2	2	1.97	2	2	2
Expanded Uncertainty: U	A	0.000110	0.000082	0.000048	0.000141	0.000127	0.000154	0.000197	0.000026	0.000094	0.000084	0.000037
$\|E_n\|$	-	0.01	1.16	0.15	0.24	0.39	0.15	0.07	0.60	0.03	0.12	0.77

Figure 13 - Injected DC current (+10 mA) for Loop C

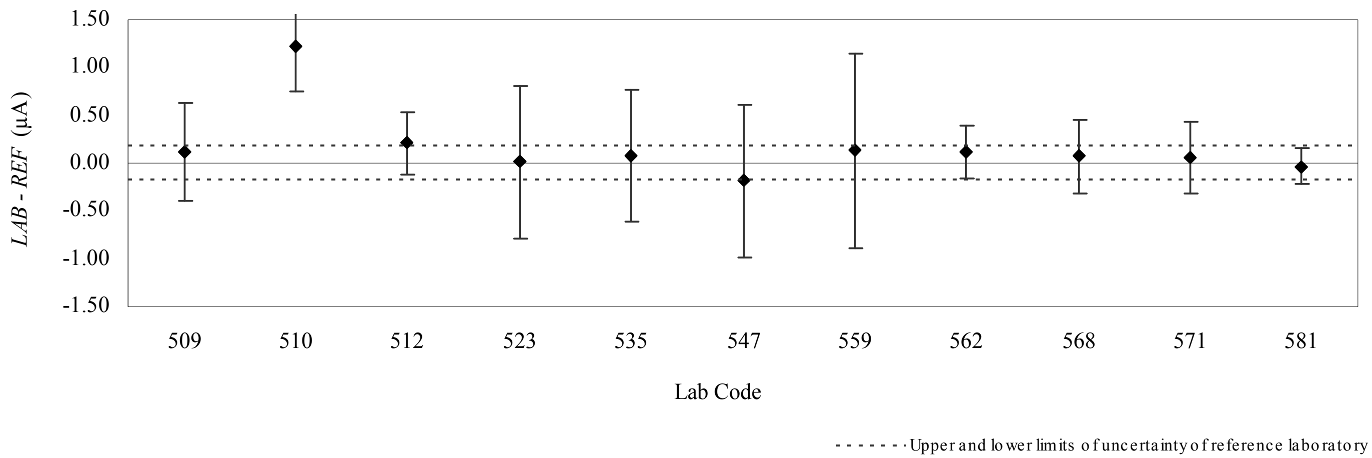


Figure 14 - Injected DC current (-10 mA) for Loop C

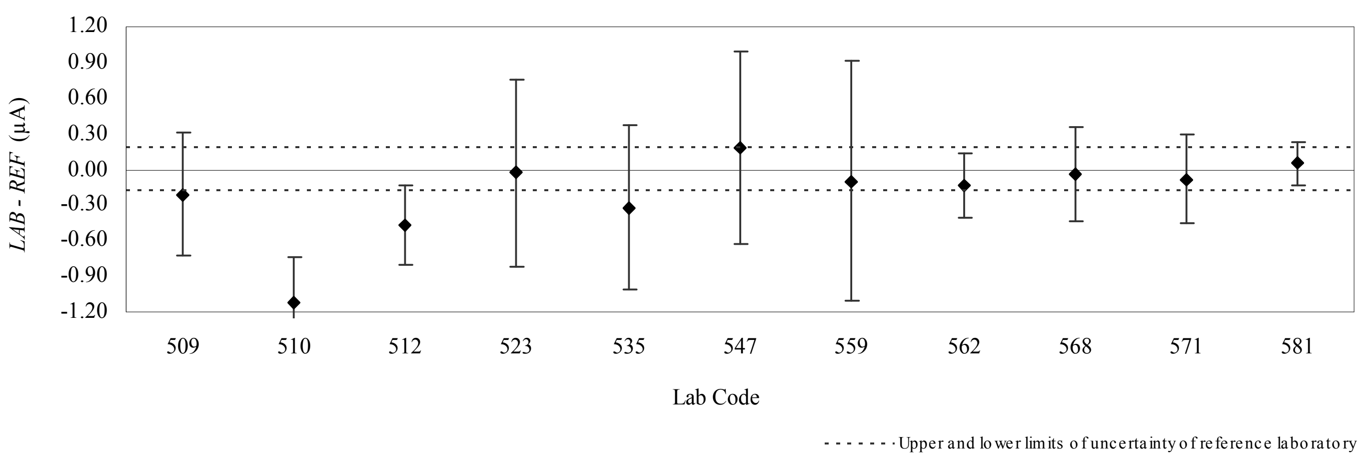


Figure 15 - Injected DC current (+100 mA) for Loop C

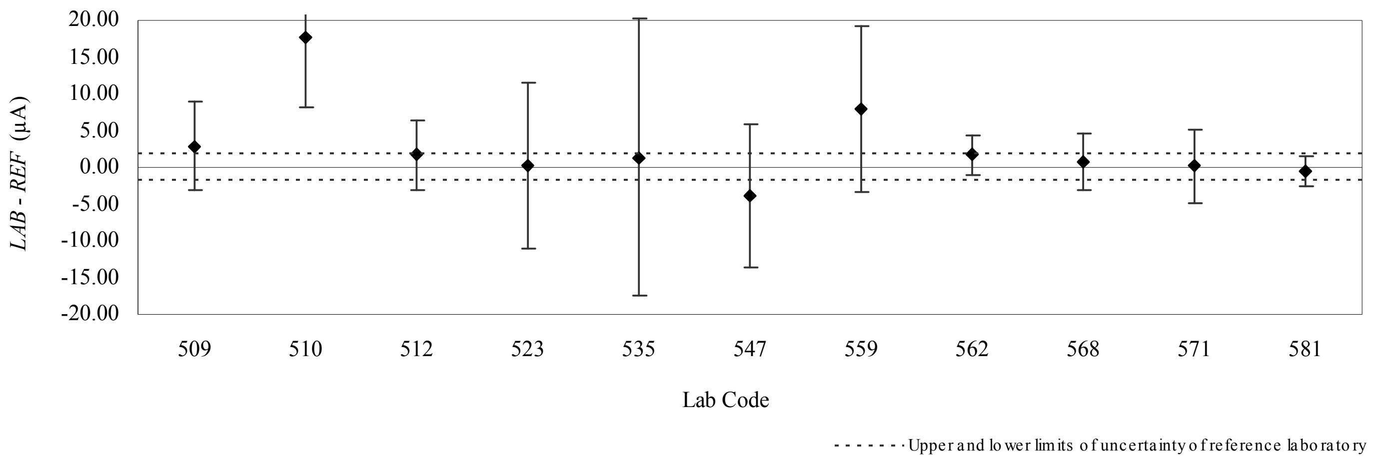


Figure 16 - Injected DC current (-100 mA) for Loop C

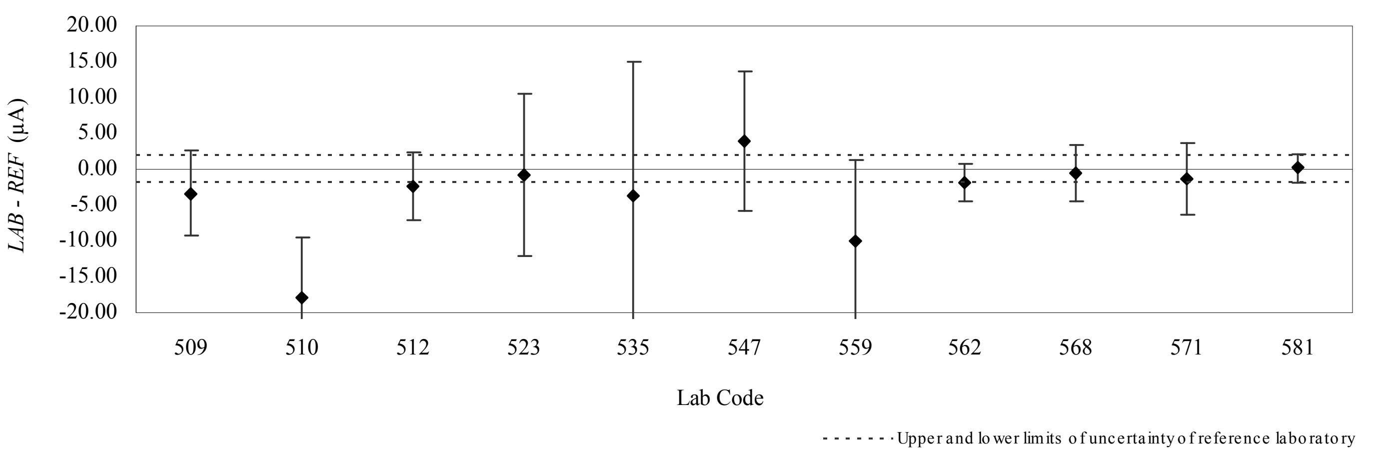


Figure 17 - Injected DC current (+1 A) for Loop C

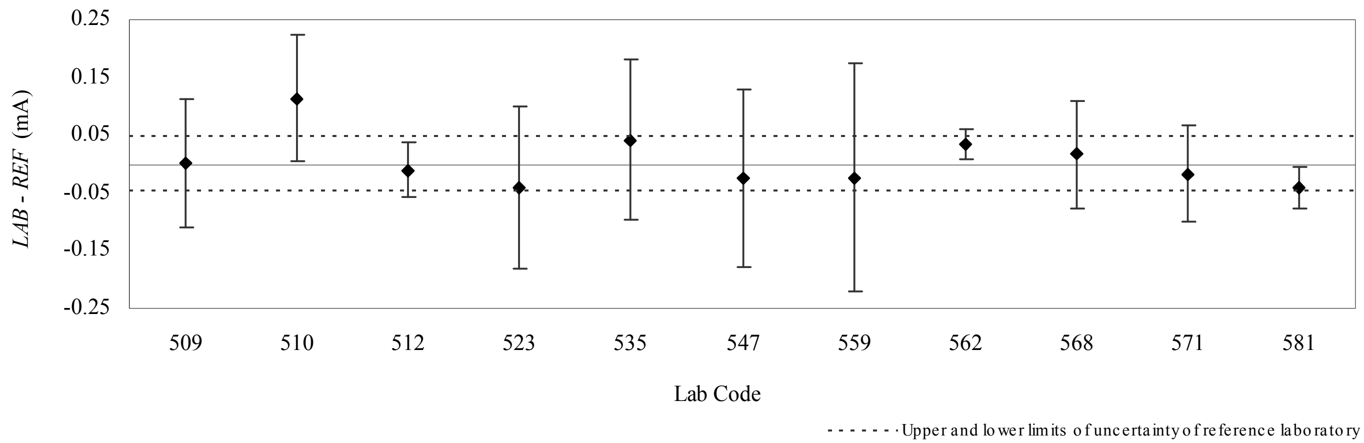
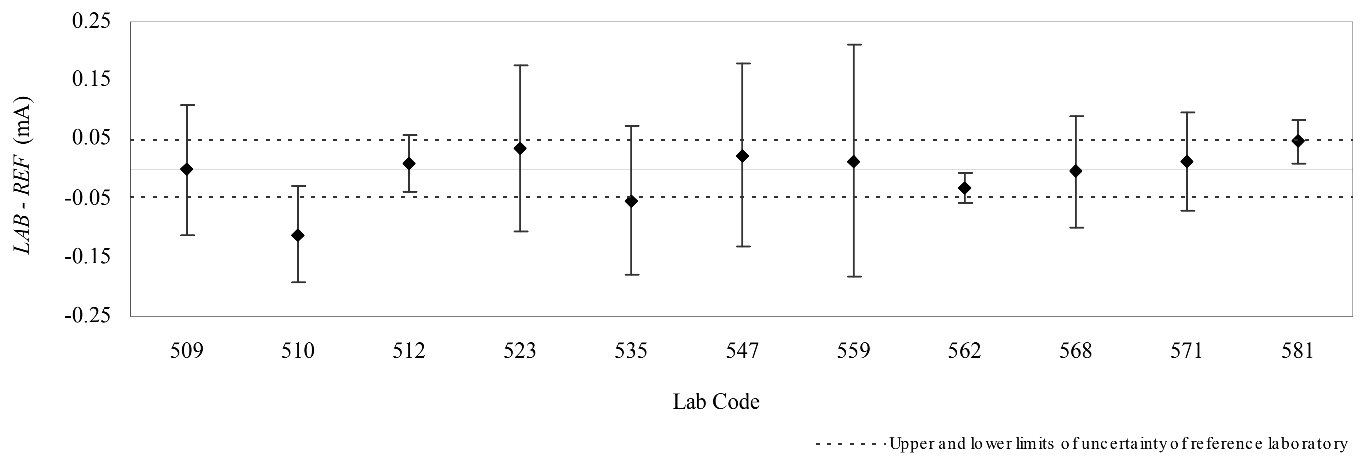


Figure 18 - Injected DC current (-1 A) for Loop C



10. PERFORMANCE OF PARTICIPANTS

Tables 1 to 3 for the $|E_n|$ ratios show an overall good performance by the majority of the participating laboratories. The following is the summary of performance of participating laboratories.

10.1 Circulation Loop A

10 laboratories were registered to participate in measurement loop A. For measurement at +10 mA and -10 mA, the performance of all participating laboratories was excellent as indicated by the fact that no laboratory had an $|E_n|$ value greater than 1.

Lab Code 999 did not provide results at -10 mA, -100 mA and -1 A.

Lab Code 922 have two results with an $|E_n|$ value exceeded 1 significantly at +1 A and -1A.

Lab Code 984 have four results with an $|E_n|$ value exceeded 1 at +100 mA, -100 mA, +1 A and -1 A.

10.2 Circulation Loop B

11 laboratories were registered to participate in measurement loop B. For measurement at +10 mA, -10 mA, +100 mA and -100 mA the performance of all participating laboratories was excellent as indicated by the fact that no laboratory had an $|E_n|$ value greater than 1.

Lab Code 605, 616 and 663 each have two results with an $|E_n|$ number exceeded 1 at +1 A and -1 A. The $|E_n|$ values of Lab Code 616 are greater than unity significantly.

10.3 Circulation Loop C

11 laboratories were registered to participate in measurement loop C.

Lab Code 510 have five results with an $|E_n|$ values exceeded 1 and Lab Code 512 has one result with an $|E_n|$ value exceeded 1 at -10 mA.

As shown in Figure 19 for 189 reported results, 90% were in agreement with the reference laboratory and 10% were outliers.

Figure 19 – Summary of 189 Reported Results

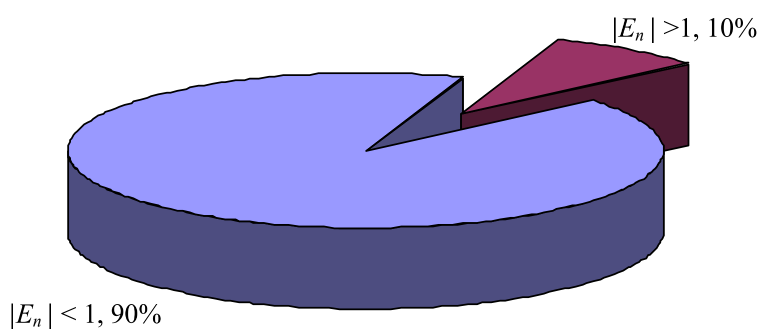
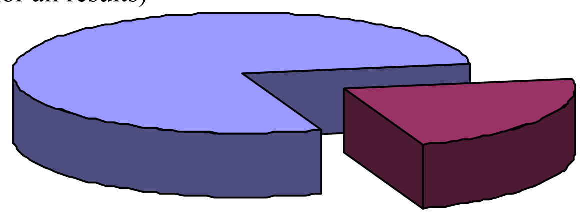


Figure 20 shows that 78% of the participating laboratories obtained an excellent performance with an $|E_n|$ value of less than unity for all the measurements, 22% of the participating laboratories each had one or more results with an $|E_n|$ value exceeded 1.

Figure 20 - Summary of 32 Participating Laboratories



11. UNCERTAINTIES OF MEASUREMENT

Uncertainty calculations were generally adequate and covered the major sources of uncertainty. Lab Code 641 reported the BMC as the expanded uncertainty. Lab Code 936 reported large uncertainties for measurement at 10 mA and 100 mA ranges compared to other laboratories using the same reference standard. This laboratory has probably made unintentional typographical error related to unit multipliers.

A sample of uncertainty calculation following the ISO Guide is provided in Appendix D.

12. CORRECTIVE ACTIONS

Details of corrective action are not included in this report. The respective accreditation bodies (ABs) have to ensure that any outlier under their purview has the problem rectified and procedures to prevent recurrence have been put in place.

13. REFERENCES

1. APLAC PT001 Calibration Interlaboratory Comparisons revised 1999.
2. ISO Guide to the Expression of Uncertainty in Measurement, 1995.

APPENDIX A

INSTRUCTIONS TO

LABORATORIES AND RESULT SHEET

Study Plan

APLAC PROFICIENCY TESTING PROGRAMME M020

APLAC M020 – DC Current measurement

1. Introduction

The purpose of M020 proficiency testing programme is to compare the calibration results of accredited laboratories within APLAC in the field of DC Current measurement. Four different digital multimeters of the same model will be used in four different circulations, A, B, C and D among the accredited laboratories of the APLAC members.

2. Coordinator

The coordinator of this PT Programme is the Department of Standards Malaysia. The complete information is as follows:

Department of Standards Malaysia (STANDARDS MALAYSIA)
Ministry of Science, Technology and Innovation
Level 1 & 2, Block C4, Complex C
Federal Government Administrative Centre
62502 Putrajaya
MALAYSIA

Contact person for	Mr. Ahmad Razif B. Abd. Rahim
Department of Standards Malaysia	Tel: +60 3 8885 8705
	Fax : +60 3 8889 4100
	E-mail: razif@standardsmalaysia.gov.my

3. Reference Laboratory

The reference values for the DC Current measurement will be provided by the National Metrology Laboratory, SIRIM Berhad, (NML-SIRIM), Malaysia. Complete information on NML-SIRIM is as follows:

National Metrology Laboratory
SIRIM Berhad
Lot PT 4803, Bandar Baru Salak Tinggi
43900 Sepang
MALAYSIA

Contact person for NML-SIRIM

Mr. Abdul Rashid B. Hj. Zainal Abidin
National Metrology Laboratory
SIRIM Berhad
Lot PT 4803, Bandar Baru Salak Tinggi
43900 Sepang
Malaysia

Tel: +60 3 8778 1664
Fax : +60 3 8778 1661
E-mail: abd.rashid_z.abidin@sirim.my

4. Artefact

The measuring instrument which is to be calibrated by the accredited laboratories is a 6½ digits digital multimeter (DMM) model Agilent 34401A. It will be shipped together with a pair of test leads and the operation manual. There will be three digital multimeters (DMM) which will be circulated with different serial numbers.

5. Calibration Procedure

The routine calibration procedure of the participant laboratory should be followed. During the calibration, the DMM should be supplied with 240 V ± 10%, 50 Hz. A minimum warm-up time of two hours should be allowed.

The details of the DC currents to be injected are as follows:

Table 1. **Required Test Points**

Function	Range	DC current to be injected
DCI	10 mA	+10 mA, -10 mA
DCI	100 mA	+100 mA, -100 mA
DCI	1 A	+1 A, -1 A

6. Environmental Conditions

Assure that the calibration ambient temperature is stable and within 18 °C to 28 °C and the ambient relative humidity is less than 80 %.

The actual environmental conditions during calibration should be reported.

7. Reporting of calibration results

The following documents should be submitted by participating laboratories to their local laboratory accreditation body (AB) for forwarding to STANDARDS MALAYSIA **within 2 weeks after completing the calibration**:

(a) completed proforma result sheets
(b) calibration certificates for the artefact in accordance with the format normally issued to a client of the laboratory.
(c) completed laboratory's budgets for estimating the uncertainty of measurement per Appendices F1, F2 and F3.

8. Analysis of results

STANDARDS MALAYSIA will analyze the results and produce interim and final reports in consultation with the reference laboratory.

M020 | | | | |
For official use only

Result Sheet

Name of laboratory	
Measurement Date	Day _______ Month _______ Year ________
Mains Power Supply	_____ VAC ± _____ VAC, _____ Hz
Ambient Temperature (°C)	_____ °C ± _____ °C
Ambient Relative Humidity (%)	_____ % ± _____%
Equipment used to inject dc currents	Description: Maker: Model: Serial no.:
Complete Self-Test of DMM	☐ Pass ☐ Fail (Please tick ✓)

DCI **DMM Range**	**Corrected Value of Injected DC Current**	**Relative Expanded Uncertainty of injected current @ 95% Confidence Level**	**DMM Indications/Readings**			
			Maximum	Minimum	Average	No. of DMM readings to derive the average value
+ 10 mA	+ mA	µA/A	mA	mA	mA	
- 10 mA	- mA	µA/A	mA	mA	mA	
+ 100 mA	+ mA	µA/A	mA	mA	mA	
- 100 mA	- mA	µA/A	mA	mA	mA	
+ 1 A	+ A	µA/A	A	A	A	
- 1 A	- A	µA/A	A	A	A	

Note:
1. Each average value is the mean of the repeated number of readings indicated in the last column of above table.
2. The maximum and minimum readings will be used for the purpose of evaluating the stability of the DMM during calibration at each participant's laboratory..

Calibrated By: Checked By:

Date: Date:

Instructions to Accreditation Bodies

APLAC PROFICIENCY TESTING PROGRAMME M020 – DC CURRENT MEASUREMENT

1. EQUIPMENT

On receipt, unpack the audit pack and inspect the artefact for any defects. *List other specific checks.*
Complete the attached "*RECEIPT FORM*" and fax to the organising body.

Please note, these instructions and attached *Result Sheet* are master copies and must remain in the box from country to country. The national accreditation body should make copies for distribution to the participating laboratories in their country.

2. TRANSPORT

The artefacts can be carried by hand, car or by plane, whatever is considered the safest way.

3. CUSTOMS

NO ATA Carnet is provided with these artefacts. A *Declaration to Customs Officials and Shipping Agents* is enclosed in the plastic envelope attached to the outside of the box. Please make sure it is in place before dispatching to the next country otherwise it will not pass through their Customs authorities. Please attach 3 extra photocopies of the *Declaration*.

4. MEASUREMENTS TO BE CARRIED OUT

Please refer to *INSTRUCTIONS TO LABORATORIES* enclosed. If necessary, these should be translated into the appropriate language by the accreditation body.

5. CIRCULATION SCHEME

At the beginning and at the end of the circulation scheme, measurements will be performed by the reference laboratory, National Metrology Laboratory, Malaysia.

It is the responsibility of the accreditation body to make sure that the artefact is dispatched to the next participant by the date specified. Two weeks have been allowed for each international transport and customs clearance. If a delay occurs with one laboratory then the number of participating laboratories in that country will have to be reduced so that the artefact leave by the scheduled date. When ready for dispatch, fill in the attached *DISPATCH FORM* and fax to the next participant and to Department of Standards Malaysia.

6. DOCUMENTS TO BE SUBMITTED

Within one week of the completion of the measurements, participating laboratories are required to fax or send the *Result Sheet* together with their formal calibration report to their accreditation body. The accreditation body is required to ensure that the *Result Sheet* has been filled in correctly and completely. The accreditation body should provide details of any problems that their laboratories had. The accreditation body is required to fax the documentation to the organising body within two weeks of dispatching the artefact.

On receipt of the information, the organising body for this APLAC proficiency testing programme will prepare interim reports on each laboratory which are then sent back to the national accreditation body. A final report will be issued at the end of the program with each laboratory only identified by a **confidential** code number.

7. GENERAL INFORMATION

For general queries, please contact:

Department of Standards Malaysia (STANDARDS MALAYSIA)
Ministry of Science, Technology and Innovation
Level 1 & 2, Block C4, Complex C
Federal Government Administrative Centre
62502 Putrajaya
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim
Tel: +60 3 8885 8705
Fax : +60 3 8889 4100
E-mail: razif@standardsmalaysia.gov.my

Instructions to Laboratories

1. Equipment

The contents of the audit pack are as follows:

i. Agilent 34401A 61/2 Digit Multimeter, S/No. MY45032553
ii. User's Guide for Agilent 34401A Multimeter
iii. Measuring Leads
iv. Power cord
v. Measurement Instructions, consisting of the following:

- Study plan
- Proforma result sheets
- Instructions to laboratories
- Instructions to accreditation bodies
- Circulation schedule
- List of contact persons
- Receipt form
- Liaison form
- Dispatch form

Figure 1. Photo of artefact

2. On Receipt

On receipt, unpack the audit pack and inspect the artefact for any defects.

Read the following instructions before starting the measurement.

2.1 Fill-in the Receipt Form (Item 3) and fax to pilot laboratory.

2.2 Please handle artefact with care.

2.3 Do not tamper with or adjust the test artefact.

2.4 Notify the local AB of any damage or erratic operation of the test artefact as soon as possible.

3. Measurement Considerations for the Artefact

3.1 Power up the artefact using 240 VAC, 50 Hz supply from the mains.

3.2 Warm-up all equipment sufficiently. Allow a 2-hour warm-up for the DMM.

3.3 Perform a complete self-test on the artefact. Hold down [Shift] as you press the [Power] switch to turn on the multimeter; hold down the key for more than 5 seconds.

3.4 The DMM should be configured as follows:

Resolution: 6½ digits
Measurement Mode: Slow
Range setting: Manual
Trigger setting: Internal

Note: Please refer to the equipment manual for correct settings of the DMM

3.5 Assure that the calibration ambient temperature is stable and between 18 °C and 28 °C.

3.6 Assure that the ambient relative humidity is less than 80 %.

3.7 Do not exceed current input for each range.

3.8 Use the provided measurement leads.

3.9 For DC current measurements, take care to ensure that the calibrator “0” output is correct. If necessary, the multimeter measurements can be referenced to the calibrator’s “0” output using the multimeter front panel NULL function. You will need to repeat this procedure for each range of the measuring function being verified.

3.10 Participant should decide the number of measurements for each test points.

3.11 Perform test at required nominal set points as shown in Table 2 below.

Table 2. Test points and recommended settling time

Function	Range	DC current to be injected	Settling time of DMM before start taking readings
DCI	10 mA	+10 mA	At least 5 minutes
DCI	10 mA	-10 mA	At least 5 minutes
DCI	100 mA	+100 mA	At least 10 minutes
DCI	100 mA	-100 mA	At least 10 minutes
DCI	1 A	+1 A	At least 30 minutes
DCI	1 A	-1 A	At least 30 minutes

3.12 Take your readings as you normally do when calibrating a digital multimeter. Allow the recommended settling times as in Table 2 before taking readings for all ranges.

3.13 Report the average of readings taken for each test point.

3.14 Report data in appropriate measurement units.

3.15 Provide a formal report, as you would normally do for your clients.

3.16 Complete the Result Sheet and the measurement uncertainty evaluation.

4. Completion of measurements

Upon completion of measurement, please contact the local accreditation body.

5. Documents to be submitted

Within one week of the completion of the measurements, participating laboratories are required to send the attached *Result Sheet* (Appendix A) and their calibration report to their accreditation body. Laboratories should make a copy of the *Result Sheet* for their own records.

In addition to the above, participating laboratories are required to submit uncertainty budgets for both positive and negative current measurements which are prepared in accordance with the ISO *Guide to the Expression of Uncertainty in Measurement.* See Appendices F1, F2 and F3.

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

6. General Information

For general queries, please contact your accreditation body. Additional information may be obtained from

Department of Standards Malaysia (STANDARDS MALAYSIA)
Ministry of Science, Technology and Innovation
Level 1 & 2, Block C4, Complex C
Federal Government Administrative Centre
62502 Putrajaya
MALAYSIA

Attention: Mr. Ahmad Razif B. Abd. Rahim
Tel: +60 3 8885 8705
Fax : +60 3 8889 4100
E-mail: razif@standardsmalaysia.gov.my

Uncertainty Budget for 10 mA Measurement

Quantity	Value	Limits	Divisor	Standard Uncertainty	Probability Distribution	Degree of Freedom	Sensitivity Coefficient	Uncertainty Contribution
X_i	x_i	$\pm\Delta(x_i)$		$u(x_i)$		ν_i	c_i	$u_i(y)$

Result

Average Value = ___________ mA

Relative Combined Uncertainty, $u_c(y)$ = ___________ μA/A

Effective degrees of freedom, ν_{eff} = ___________

Coverage factor, k = ___________

Relative Expanded Uncertainty, $k \times u_c(y)$ = ___________ μA/A

Notes:
1. (Add any comments here)

Uncertainty Budget for 100 mA Measurement

Quantity	Value	Limits	Divisor	Standard Uncertainty	Probability Distribution	Degree of Freedom	Sensitivity Coefficient	Uncertainty Contribution
X_i	x_i	$\pm\Delta(x_i)$		$u(x_i)$		ν_i	c_i	$u_i(y)$

Result

Average Value = ___________ mA

Relative Combined Uncertainty, $u_c(y)$ = ___________ μA/A

Effective degrees of freedom, ν_{eff} = ___________

Coverage factor, k = ___________

Relative Expanded Uncertainty, $k \times u_c(y)$ = ___________ μA/A

Notes:
2. (Add any comments here)

Uncertainty Budget for 1 A Measurement

Quantity	Value	Limits	Divisor	Standard Uncertainty	Probability Distribution	Degree of Freedom	Sensitivity Coefficient	Uncertainty Contribution
X_i	x_i	$\pm\Delta(x_i)$		$u(x_i)$		ν_i	c_i	$u_i(y)$

Result

Average Value = ___________ mA

Relative Combined Uncertainty, $u_c(y)$ = ___________ μA/A

Effective degrees of freedom, ν_{eff} = ___________

Coverage factor, k = ___________

Relative Expanded Uncertainty, $k \times u_c(y)$ = ___________ μA/A

Notes:
3. (Add any comments here)

APPENDIX B

CIRCULATION SCHEDULE

Table B1 – Circulation schedule for loop A

Economy	Accreditation Body	No. of Lab	Receipt	Dispatch
Malaysia	NML (Ref Lab)	-	-	28 Jun 07
Australia	NATA	1	5 Jul 07	19 Jul 07
New Zealand	IANZ	2	25 Jul 07	13 Aug 07
Indonesia	KAN	1	21 Aug 07	7 Sep 07
Malaysia	NML (Ref Lab)	-	received	21 Sep 07
Japan	IAJapan	1	26 Sep 07	12 Oct 07
USA	International Accreditation Service	2	not reported	not reported
Mexico	EMA	2	not reported	not reported
Malaysia	NML (Ref Lab)	-	received	15 Apr 08
Malaysia	STANDARDS MALAYSIA	1	15 Apr 08	7 May 08

Table B2 – Circulation Schedule for loop B

Economy	Accreditation Body	No. of Lab	Receipt	Dispatch
Malaysia	NML (Ref Lab)	-	-	28 Jun 07
Philippines	Philippine Accreditation Office	2	4 July 07	not reported
Singapore	Singapore Accreditation Council	2	23 Jul 07	7 Aug 07
Malaysia	NML (Ref Lab)	-	10 Aug 07	29 Aug 07
Japan	JAB	2	4 Sep 07	20 Sep 07
Thailand	Thai Industrial Standards Instute (TISI)	2	not reported	not reported
USA	A2LA	2	24 Oct 07	8 Nov 07
Malaysia	NML (Ref Lab)	-	received	7 Dec 07
Malaysia	STANDARDS MALAYSIA	1	7 Dec 07	27 Dec 07

Table B3 – Circulation Schedule for loop C

Economy	Accreditation Body	No. of Lab	Receipt	Dispatch
Malaysia	NML (Ref Lab)	-	-	28 Jun 07
Taiwan	TAF	2	5 Jul 07	19 Jul 07
China	CNAS	2	27 Jul 07	23 Aug 07
Malaysia	NML (Ref Lab)	-	Received	12 Sep 07
Hong Kong	HKAS	2	not reported	3 Oct 07
India	NABL	2	23 Oct 07	8 Nov 07
Mongolia	MASM	2	23 Nov 07	sent
Malaysia	NML (Ref Lab)	-	Received	4 Jan 08
Malaysia	STANDARDS MALAYSIA	1	4 Jan 08	15 Jan 08

APPENDIX C

STABILITY OF ARTEFACTS

Table C1 - Stability of multimeter #7, measurement loop A.

Injected DCI	+10 mA	-10 mA		+100 mA	-100 mA		+1 A	-1 A	
Date	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)
04 May 07	-0.22	0.28	±0.22 μA	-3.7	4.3	±2.6 μA	-82	69	±55 μA
08 May 07	-0.13	0.20		-2.9	3.5		-70	67	
10 May 07	-0.17	0.26		-3.6	4.2		-69	72	
17 May 07	-0.14	0.26		-3.4	4.0		-46	86	
07 Jun 07	-0.05	0.20		-2.8	3.3		-57	66	
15 Jun 07	-0.05	0.23		-2.9	3.3		-58	67	
14 Sep 07	-0.07	0.14		-2.1	2.7		-49	49	
17 Sep 07	-0.07	0.13		-2.0	2.4		-53	44	
17 Sep 07	-0.09	0.13		-2.2	2.7		-51	46	
18 Sep 07	-0.08	0.11		-2.0	2.6		-39	41	
19 Sep 07	-0.05	0.11		-1.8	2.3		-32	30	
14 Mar 08	-0.02	0.14		-1.8	2.3		-12	26	
17 Mar 08	0.01	0.10		-1.2	1.6		-23	37	
03 Apr 08	0.01	0.05		-0.8	1.4		-8	6	
09 Apr 08	0.03	0.05		-0.7	1.3		-4	5	
10 Apr 08	0.04	0.05		-0.8	1.2		-6	-1	
08 May 08	0.02	0.11		-0.8	1.2		-13	36	
08 May 08	0.01	0.06		-1.2	1.4		-28	23	
09 May 08	0.07	0.07		-0.1	0.5		-3	18	
09 May 08	0.07	0.12		-0.8	1.0		-10	4	
12 May 08	0.01	0.12		-0.8	1.1		-6	19	
12 May 08	0.02	0.07		-0.8	0.9		-22	14	
13 May 08	0.04	0.02		-0.6	1.2		11	28	

Table C2 – Stability of multimeter #6, measurement loop B.

Injected DCI	+10 mA	-10 mA		+100 mA	-100 mA		+1 A	-1 A	
Date	Correction (μA)	Correction (μA)	Expanded Uncertainty (k=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (k=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (k=2)
03 May 07	-0.11	0.10	±0.22 μA	-2.1	2.1	±1.8 μA	81	-87	±36 μA
08 May 07	-0.08	0.09		-2.2	2.1		93	-96	
09 May 07	-0.07	0.05		-2.0	1.9		103	-106	
16 May 07	-0.12	0.18		-3.2	3.0		104	-103	
06 Jun 07	-0.09	0.11		-2.6	2.4		102	-109	
14 Jun 07	-0.12	0.19		-2.7	2.7		109	-105	
19 Jun 07	-0.09	0.18		-2.7	2.8		113	-120	
16 Aug 07	-0.16	0.21		-2.8	2.8		117	-121	
20 Aug 07	-0.10	0.20		-2.4	2.6		122	-124	
21 Aug 07	-0.11	0.16		-2.2	2.3		118	-126	
22 Aug 07	-0.11	0.16		-2.2	2.4		123	-125	
23 Aug 07	-0.09	0.14		-2.0	2.1		120	-129	
24 Aug 07	-0.12	0.10		-2.0	2.0		120	-126	
27 Aug 07	-0.11	0.07		-1.9	1.8		122	-130	
20 Nov 07	-0.24	0.29		-3.6	3.6		118	-96	
21 Nov 07	-0.23	0.26		-3.2	3.3		138	-117	
22 Nov 07	-0.19	0.27		-3.2	3.2		123	-126	
23 Nov 07	-0.14	0.26		-3.0	3.1		121	-133	
27 Nov 07	-0.11	0.26		-2.8	2.9		112	-117	
28 Nov 07	-0.12	0.34		-3.1	3.2		114	-133	
29 Nov 07	-0.17	0.24		-2.9	2.9		120	-134	

Table C2 – Stability of multimeter #6, measurement loop B (*continue*)

Injected DCI	+10 mA	-10 mA		+100 mA	-100 mA		+1 A	-1 A	
Date	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)	Correction (μA)	Correction (μA)	Expanded Uncertainty (*k*=2)
30 Nov 07	-0.10	0.20	±0. 22 μA	-2.5	2.6	±1.8 μA	127	-133	±36 μA
03 Dec 07	-0.16	0.34		-3.1	3.2		110	-114	
04 Dec 07	-0.11	0.23		-2.7	2.9		119	-118	
05 Dec 07	-0.11	0.26		-2.7	2.8		128	-124	
06 Dec 07	-0.13	0.24		-2.8	2.9		127	-130	
03 Jan 08	-0.31	0.33		-3.6	3.4		128	-133	
04 Jan 08	-0.15	0.18		-2.7	2.8		130	-134	
07 Jan 08	-0.21	0.27		-3.2	3.3		109	-116	
08 Jan 08	-0.21	0.24		-2.8	3.0		117	-128	
14 Jan 08	-0.25	0.31		-3.4	3.4		104	-110	
15 Jan 08	-0.20	0.22		-2.8	2.9		118	-117	
16 Jan 08	-0.20	0.29		-3.7	3.8		122	-128	

Table C3 – Stability of multimeter #5, measurement loop C

Injected DCI	+10 mA	-10 mA		+100 mA	-100 mA		+1 A	-1 A	
Date	Correction (µA)	Correction (µA)	Expanded Uncertainty (*k*=2)	Correction (µA)	Correction (µA)	Expanded Uncertainty (*k*=2)	Correction (µA)	Correction (µA)	Expanded Uncertainty (*k*=2)
03 May 07	-0.03	0.14	±0.18 µA	-3.6	4.0	±1.8 µA	-3	11	±48 µA
08 May 07	-0.08	0.08		-3.7	4.0		-1	-7	
09 May 07	-0.01	0.04		-3.2	3.6		18	-8	
16 May 07	-0.01	0.12		-3.6	4.2		16	-6	
06 Jun 07	0.02	0.08		-3.3	3.8		23	-13	
14 Jun 07	0.00	0.03		-4.0	4.1		24	-13	
19 Jun 07	0.04	0.03		-3.3	3.7		54	-44	
30 Aug 07	-0.06	-0.05		-2.5	2.9		46	-47	
03 Sep 07	-0.04	0.03		-2.8	3.2		23	-24	
04 Sep 07	0.01	0.01		-2.5	2.9		37	-41	
05 Sep 07	0.03	-0.01		-2.6	2.9		42	-47	
06 Sep 07	-0.01	0.00		-2.6	3.3		46	-46	
18 Dec 07	-0.01	0.06		-2.7	3.0		53	-55	
19 Dec 07	-0.02	0.01		-2.7	3.2		64	-60	
21 Dec 07	0.02	-0.01		-2.3	2.4		65	-65	
26 Dec 07	-0.03	0.04		-2.7	3.0		44	-40	
27 Dec 07	-0.02	-0.04		-2.5	2.7		53	-53	
28 Dec 07	0.01	-0.02		-2.4	2.8		59	-61	
31 Dec 07	0.00	0.02		-3.1	3.8		50	-24	
02 Jan 08	-0.02	0.02		-2.3	2.7		59	-55	
16 Jan 08	-0.13	0.14		-4.2	4.5		16	-13	
17 Jan 08	-0.12	0.14		-4.0	4.3		40	-34	
18 Jan 08	-0.09	-0.01		-3.9	4.3		59	-43	
22 Jan 08	0.03	0.00		-2.2	2.5		66	-50	
28 Jan 08	0.04	0.00		-2.3	2.3		72	-69	

APPENDIX D

EXAMPLE OF EVALUATION OF UNCERTAINTY OF MEASUREMENT

CALIBRATION OF DC CURRENT

The measurement involves the calibration of DC current using multimeter. Measurement was done by injecting the DC current from a source to the under test multimeter. Voltage across the standard resistor was measured using a reference multimeter and the actual current is calculated using Ohm's Law.

The uncertainty for the injected current and multimeter correction is shown in two budget tables. None of the uncertainty contributions is considered to be correlated to any significant extent.

Uncertainty of Injected 10 mA DC Current

Model Equation:

$$I_s = \frac{V_m - \delta V_{m(offset)} + \delta V_{m(report)} + \delta V_{m(drift)} + \delta V_{m(resl)}}{R_s + \delta R_s}$$

Quantity	Unit	Definition
I_s	mA	Reference injected current by model 5700A calibrator
V_m	V	Voltage readings of the model 3458A multimeter
$\delta V_{m(offset)}$	V	Voltage offset reading of the model 3458A multimeter
$\delta V_{m(report)}$	V	Voltage correction from the calibration of the model 3458A multimeter
$\delta V_{m(drift)}$	V	Correction due to drift of the model 3458A multimeter
$\delta V_{m(resl)}$	V	Correction due to resolution of the model 3458A multimeter
R_s	Ω	Reported value of the standard resistor
δR_s	Ω	Correction due to drift of the standard resistor

V_m

The uncertainty of the mean voltage can be determined using standard statistical means from the repeatability of results of voltage readings across the standard resistor. The mean of the measured voltage is 0.099998155 V with standard deviation of 0.04 µV. The standard uncertainty of the mean is calculated by dividing the standards deviation by the square root of the number of readings (i.e $0.04/\sqrt{5} = 0.018$ µV). The number of degrees of freedom is number of readings minus one (i.e 5 -1 = 4).

$\delta V_{m(offset)}$

The uncertainty of the voltage offset readings can be determined using statistical means from the repeatability of results of voltage readings obtained by shorting the output of the multimeter. The mean of the offset voltage is 0.000000334 V with standard deviation 0.04 µV. The standard uncertainty of the mean is calculated by dividing the standards deviation by the square root of the number of readings (i.e $0.05/\sqrt{5} = 0.022$ µV). The number of degrees of freedom is number of readings minus one (i.e 5 -1 = 4).

$\delta V_{m(report)}$

The calibration certificate states that the correction to be applied to the voltage measured by the multimeter is 0.000 V with an expanded uncertainty of ± 0.14 µV (coverage factor $k = 2$).

$\delta V_{m(drift)}$

The drift of the multimeter since its last calibration is estimated to be zero with an expanded uncertainty of ± 1 µV (coverage factor $k = 2$).

$\delta V_{m(resl)}$

The least significant digit of the multimeter display correspond to 0.1 µV. Correction due to the finite resolution of the display is estimated to be zero with limits of ±0.05 µV (i.e. one half of the magnitude of the least significant digit).

R_s

The calibration of certificate for the standard resistor gives a resistance value of 9.999848 Ω ± 3 µΩ (coverage factor $k = 2$) at temperature of 23 °C ± 1 °C.

δR_s

The drift of the standard resistor since its last calibration is estimated from its calibration history to be zero with an expanded uncertainty of ± 30 µΩ (coverage factor $k = 2$).

Table D1 – Uncertainty budget for injected current

Quantity X_i	**Unit**	**Value** x_i	**Limits** $\pm\Delta(x_i)$	**Divisor**	**Standard Uncertainty** $\pm u(x_i)$	**Probability Distribution**	**Degrees of Freedom** ν_i	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $\pm u_i(y)$
V_m	V	0.099998155	0.018 µV	1	0.018	Normal Type A	4	0.100	0.002
$\delta V_{m(offset)}$	V	-0.000000334	0.022 µV	1	0.022	Normal Type A	4	0.100	0.002
$\delta V_{m(report)}$	V	0.000	0.14 µV	2	0.070	Normal Type B	50	0.100	0.007
$\delta V_{m(drift)}$	V	0.000	1 µV	2	0.500	Normal Type B	50	0.100	0.050
$\delta V_{m(resl)}$	V	0.000	0.05 µV	√3	0.029	Rectangular Type B	∞	0.100	0.003
R_s	Ω	9.999848	3 µΩ	2	1.500	Normal Type B	50	-0.001	-0.002
δR_s	Ω	0.000000	30 µΩ	2	15.000	Normal Type B	50	-0.001	-0.015
								u_c	**0.06 µA**
I_s	**mA**	**10.0000053**						ν_{eff}	**62**
								Coverage factor, *k*	**2**
								Expanded Uncertainty, *U*	**0.12 µA**

Uncertainty of Correction of Multimeter at 10 mA.

Model Equation:

$$\Delta I = I_s - (I_x + \delta I_{x(drift)} + \delta I_{x(resl)})$$

Quantity	Unit	Definition
ΔI	mA	Correction to the model 34401A multimeter
I_s	mA	Reference injected current
I_x	mA	Mean of measured current by the model 34401A multimeter
$\delta I_{x(drift)}$	mA	Drift of the model 34401A multimeter
$\delta I_{x(resl)}$	mA	Correction due to resolution of the model 34401A multimeter

I_s

The reference current injected to the 34401A multimeter as calculated in the previous worksheet is 10.00001 mA with the standard uncertainty of ±0.06 µA.

I_x

The uncertainty of the mean current readings can be determined using standard statistical means from the repeatability of results of current readings measured by the 34401A multimeter. The mean of the measured current is 10.00008 mA with standard deviation of 0.021 µA. The standard uncertainty of the mean is calculated by dividing the standards deviation by the square root of the number of readings (i.e $0.021/\sqrt{5} = 0.009$ µA). The number of degrees of freedom is number of readings minus one (i.e 5 -1 = 4).

$\delta I_{x(drift)}$

The drift of the 34401A multimeter is estimated from its calibration history to be zero within the limits of ± 0.150 µA.

$\delta I_{x(resl)}$

The least significant digit of the multimeter display correspond to 0.01 µV. Correction due to the finite resolution of the display is estimated to be zero with limits of ±0.005 µV (i.e. one half of the magnitude of the least significant digit).

Table D2 – Uncertainty budget for correction to multimeter

Quantity X_i	Unit	Value x_i	Limits $\pm\Delta(x_i)$	Divisor	Standard Uncertainty $\pm u(x_i)$	Probability Distribution	Degrees of Freedom ν_i	Sensitivity Coefficient c_i	Uncertainty Contribution $\pm u_i(y)$
I_s	mA	10.00001	0.060 µA	1	0.060	Normal Type A	62	1	0.060
I_x	mA	10.00008	0.021 µA	1	0.009	Normal Type A	4	1	0.009
$\delta I_{x(drift)}$	mA	0.000	0.150 µA	√3	0.087	Rectangular Type B	∞	1	0.087
$\delta I_{x(resl)}$	mA	0.000	0.005 µA	√3	0.003	Rectangular Type B	∞	1	0.003
								u_c	0.11
Corr	**mA**	**-0.00007**	**mA**					ν_{eff}	**594**
								Coverage factor, k	**2**
								Expanded Uncertainty, U	**0.22 µA**

Interpolation of Reference Correction Value

The interpolation of reference correction values and uncertainties are determined in accordance with ISO GUM 1995. The interpolated value is determined from the measured value of the artefact before and after the circulation to respective laboratory within the loop.

An example of the interpolated value from the regression line and its associated uncertainty is shown below:

$$\Delta I_{Int} = m(x - x_0) + c$$

$$u(\Delta I_{Int}) = \sqrt{u^2(c) + (x - x_0)^2 u^2(m) + 2(x - x_0)u(c)u(m)r(c,m)}$$

where m is the slope of the regression line, m = 0.000569 μA/day

x is the measurement date of participating laboratory, x = 16 July 2007

x_o is the measurement date of reference laboratory, x_o = 4 May 2007

c is the intercept of the regression line, c = -0.143 μA

$u(c)$ is the uncertainty of the intercept of the regression line = 0.045 μA

$u(m)$ is the uncertainty of the slope of the regression line = 0.000224 μA/day

$r(c,m)$ is the correlation coefficient = -0.7595

Therefore,

$$\Delta I_{Int} = (0.000569 \times 73) - 0.143 = -0.00010\ mA$$

$$u(\Delta I_{Int}) = \sqrt{0.045^2 + (73^2 \times 0.000224^2) + 2 \times (73 \times 0.045 \times 0.000224 \times -0.7595)} = 0.00002\ mA$$

The combined uncertainty of the reference laboratory used in the interim report is obtained by taking the RSS of the standard uncertainty of reference laboratory correction as shown in Table D2 and the standard uncertainty of the interpolated value as follows:

$$u_{Ref} = \sqrt{u^2(\Delta I) + u^2(\Delta I_{Int})}$$

$$u_{Ref} = \sqrt{0.00011^2 + 0.00003^2} = 0.00011\ mA$$

The expanded uncertainty of the reference correction value at 95% confidence level, with a coverage factor of $k = 2$ is

$$U_{Ref} = 0.00011\ mA \times 2 = 0.00022\ mA$$