SIM COMPARISON OF ELECTRICAL UNITS

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Abstract. An international comparison of dc and low-frequency electrical units conducted between 19 laboratories in 16 countries in the Americas is described. The comparison was conducted between 1997 and 1999 and sponsored by the Interamerican Metrology System and the Organization of American States.

Keywords: *SIM, Electricity, Laboratory, Comparison.*

1. INTRODUCTION

Periodic comparisons of the measurement units maintained in each country are critical elements in facilitating international trade through mutual recognition arrangements. In the past several decades, much of the world has been divided into recognized metrology regions. This simplifies comparisons which can be made between pivot laboratories in each region. The pivot laboratories run local comparisons within the region, thus distributing the effort required to conduct large-scale international comparisons.

In 1996 the Organization of American States and the member countries of the Interamerican Metrology System (SIM), decided to sponsor an international comparison of electrical units using precision digital multimeters (DMMs) as traveling standards. Hewlett-Packard Company, Keithley Instruments Inc., and Wavetek each donated two DMMs for the comparison and the National Institute of Standards and Technology (NIST) agreed to serve as the pilot laboratory. NIST is the National Metrology Institute (NMI) of the United States. Each SIM member country has a similar NMI and/or one or more university or industrial laboratories that perform official measurements.

SIM is divided into five Metrology Regions: ANDIMET (northern South America), CAMET (Central America), CARIMET (Caribbean), NORAMET (North America), and SURAMET (central and southern South America). One NMI (or affiliated laboratory) in each region was selected to serve as a pivot laboratory within that region for the SIM electrical comparison.

The main purpose of SIM international comparisons is to verify that each country's claimed measurement capabilities are consistent with actual measurements. This is crucial for the movement of goods between countries and for future free trade agreements within the hemisphere.

2. COMPARISON

In March 1997, representatives from the following laboratories met at NIST to decide how the comparison would be conducted:

ANDIMET – SIC, Colombia (Orlando Cedeño)
CAMET – ICE, Costa Rica (Harold Sánchez)
CARIMET – JBS, Jamaica (Desmond Bennett)
NORAMET – NIST, USA (Nile Oldham, Mark Parker)
SURAMET – INTI, Argentina (Héctor Laiz)

Comparison test points and procedures were agreed upon and a report was issued describing the proposed comparison. The DMMs were distributed during this meeting and each representative carried a NIST-calibrated DMM back to his laboratory. Results of the NIST tests were not released to the pivot laboratories until they had tested the DMMs and sent the results to NIST electronically. This was the first step of the comparison – determining the agreement between the pilot and the four pivot laboratories.

Invitations were sent to all of the SIM-member NMIs to participate in the comparison. Over the next two years, the DMMs were circulated to the following participating laboratories within each metrology region:

AEROMAN, El Salvador
CALI, Ecuador
CENAM, Mexico
CONACYT, El Salvador
ICAITI, Guatemala
ICE, Costa Rica, CAMET pivot lab, http://www.ice.go.cr
INEN, Ecuador
INMETRO, Brazil
INN, Chile

INTI, Argentina, SURAMET pivot lab, http://www.inti.gov.ar
INTN, Paraguay
JBS, Jamaica, CARIMET pivot lab, http://jbs.org.jm
LATU, Uruguay
NIST, United States of America, Pilot lab and NORAMET pivot lab, http://www.nist.gov
NRC, Canada
SIC, Colombia, ANDIMET pivot lab, http://www.sic.gov.co
T&TBS, Trinidad/Tobago
USAC, Guatemala
UTP, Panama

In some cases, a representative from the pivot laboratory accompanied the traveling DMM to each laboratory in that metrology region, assisting with connections and procedures. While this was time-consuming and expensive for the pivot laboratory, it minimized customs problems and ensured that the tests were performed properly and on time. In others cases, the DMM was sent by commercial carrier and met at the airport by a laboratory customs agent. Measurements were generally made at the pivot laboratory before and after measurement at the other laboratories in the region. Test and recommended uncertainty analysis procedures were provided with the traveling standard and on a website.

Each test laboratory was asked to submit measurement results and combined uncertainties for as many of the 29 test points (see Appendix) as possible.

By 1997, many of the NMIs in SIM were connected to the Internet and some data for the SIM electrical comparison was transmitted electronically via email attachments. In 1998 several of the laboratories involved in the comparison began experimenting with Internet-based video conferencing software and video cameras to enhance communications. Later that year, a project began at NIST to provide Internet-based communications between the SIM laboratories. In December 1998, a network of computers (dubbed SIMnet) was inaugurated between 12 SIM laboratories (Filipski & Oldham,1999; Schneeman, 1999; Anderson, Oldham & Parker, 2000). The network, supported by the Organization of American States, is available for use by all NMIs (and affiliated laboratories) in SIM.

In March 1999, all of the traveling DMMs were returned to NIST for follow-up tests. An Internet video connection was established between NIST and interested laboratories and procedures, connections, and results were transmitted via SIMnet. Results were sent electronically and the DMMs were prepared for return to the pivot laboratories for the final tests.

The plan had been to return the DMMs to the pivot laboratories, where they would reside permanently, or until the next SIM comparison. However, since the DMMs had been donated to SIM and were on loan to the pivot laboratories, additional paperwork had to be filed before the instruments could be legally returned. It was not until November 1999 that the last DMM finally left NIST.

3. RESULTS

The final results of the SIM electrical comparison were submitted to the pilot laboratory in early 2000. Determining how to analyze and present 551 (19 NMIs x 29 test points) test results and as many uncertainties, proved to be a daunting problem. Because there were five different traveling standards, all referred to a NIST calibration, it was decided to compute each NMI's difference from the NIST measured values. These differences are given in tabular form in the Appendix. Since this is the first SIM electrical comparison, the laboratories are identified only by number. In future comparisons, a reference value (a weighted mean of all measurements) will be computed and the NMI differences from this value will be published.

To give a better sense of the wide range of capabilities at different laboratories within SIM, results at selected test points are plotted in Figs. 1 – 5. The absolute values of the differences from the NIST mean are plotted in log scale. Values that lie directly on the 100000 line (corresponding to a 10% difference) indicate that the laboratory had no measurement capability at that point.

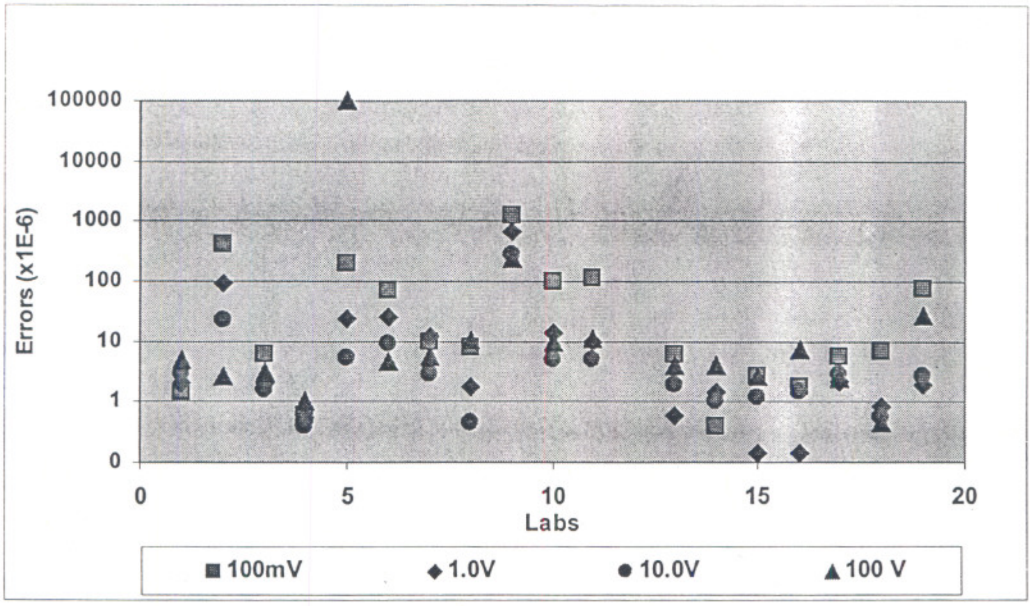

Figure 1 - DC Voltage (NMI - NIST)

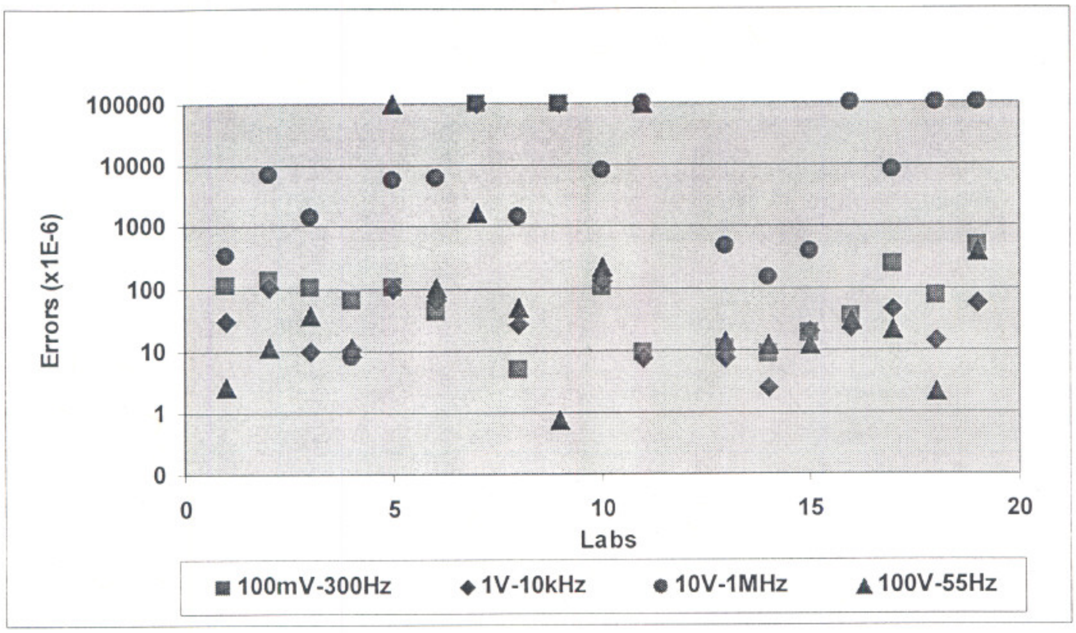

Figure 2 - AC Voltage (NMI - NIST)

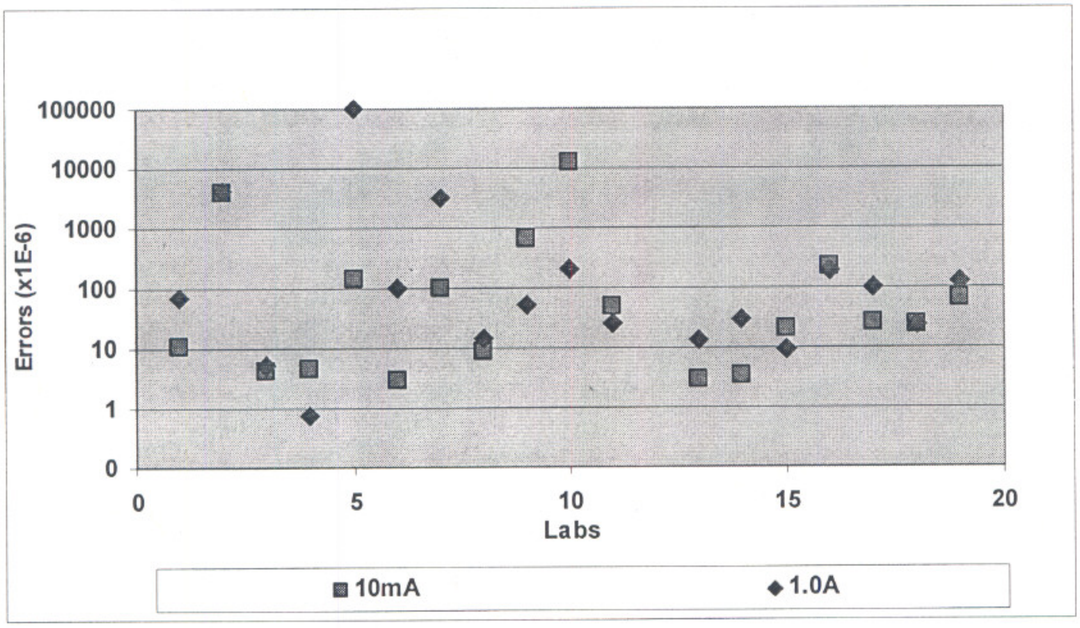

Figure 3 - DC Current (NMI - NIST)

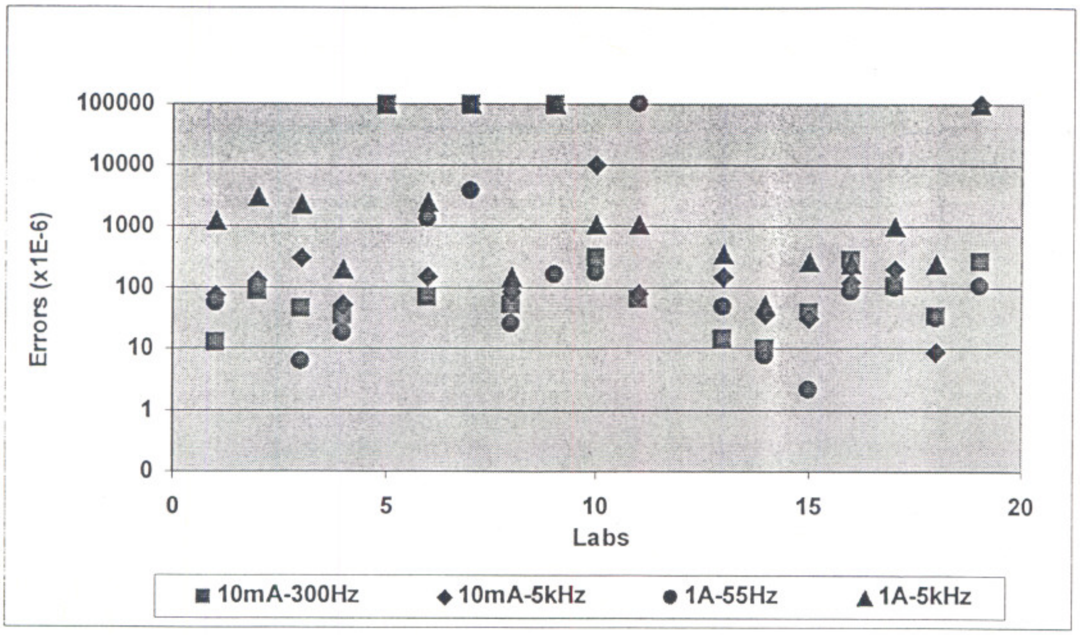

Figure 4 - AC Current (NMI - NIST)

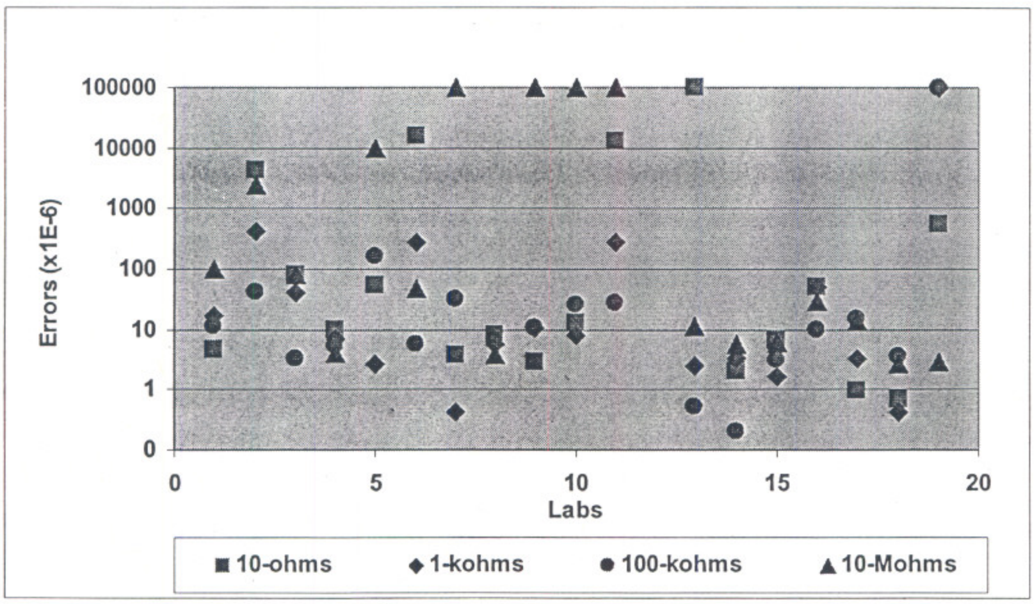

Figure 5 - Resistance (NMI - NIST)

4. PROBLEMS

The problems involved with shipping delicate instruments across international borders are well recognized. Not only is there the potential for damage during shipment, but also the inconvenience of long delays processing paperwork for each country's customs. It was not uncommon to take over a month to get an instrument from one laboratory to another. The fastest solution was to hand-carry the instruments, but this comes with added cost to the pivot laboratory and time of the lead metrologist. ATA Carnets (often referred to as merchandise passports) were designed to ease the customs problems. Unfortunately, carnets are not recognized in most SIM countries.

Two years were required to complete the measurements for the first SIM electrical comparison. It is hoped that lessons learned during this comparison will lead to a one-year (or less) measurement period for the next comparison – scheduled to begin in 2001.

There were a number of other minor problems. For example, different laboratories have different measurement capabilities and in some cases it was not clear which laboratory had the official responsibility for the measurements. In other cases, the country's NMI had little or no capability to perform electrical measurements. Some laboratories performed measurements but did not provide measurement uncertainties. While most laboratories used techniques described in the "ISO Guide to the Expression of Uncertainty in Measurements", many were not clear how to interpret the methods of combining uncertainty components and confidence intervals.

5. CONCLUSIONS

The SIM international comparison described in this paper was the first such comparison in the area of electrical metrology. The results indicate that there is good agreement between some laboratories and large differences between others. This was expected as some NMIs have a long history of precision electrical metrology while others have only a few years experience. The important point is that these 19 laboratories have come together to see how well they agree and to publish the results of their measurements. For this first comparison, only the overall results are being published. In the follow-up comparison, laboratories will be identified with the data. A weighted mean, computed from measurements at each NMI, will serve as the reference.

The elements of this comparison were consistent with recommendations outlined in ISO Guide 43 (part 1 & 2). Such comparisons are critical components of mutual recognition agreements and laboratory accreditation. Discussions are underway to resolve laboratory differences that fall outside the combined uncertainties. Where such differences occur, corrective action is required for the sake of international trade as well as the laboratory's customers.

Poor communication and long delays between some measurements diminished the potential usefulness of the comparison but a great deal was learned about the process. The expanding Internet proved to be an invaluable tool in bridging many communication gaps. Email, in particular, allowed data to be transmitted in standard formats that could be used by all participants. Future comparisons will make use of SIMnet and its added capabilities. The present SIMnet configuration (which allows up to 24 participants to send and receive audio and video, share applications and a common electronic notebook, and control remote computers) is a powerful tool for facilitating international comparisons and collaborating within SIM. An associated website is evolving, which provides general SIMnet and SIM information, procedures and control software for the SIM electrical comparison, as well as comparison results and data. This site can be accessed at: http://www.eeel.nist.gov/SIMNET-DMM/

Digital multimeters turned out to be excellent traveling standards, and while they generally are not as stable as the best fixed artifacts, they offer a wide range of test parameters, amplitudes, and frequencies. DMMs also offer the ability to automate setup and data collection, which can improve the laboratory-to-laboratory transfer accuracy by better defining settling periods, allowing extensive averaging, and using the same control software, all to ensure that the measurements are made exactly the same way at each laboratory.

It should be noted that international comparisons are generally funded by the participating NMIs. While there was some assistance from the Organization of American States for this comparison, each NMI must decide to what extent it is willing to provide staff and operating costs to accomplish the objective.

A follow-up SIM electrical comparison (using the same DMMs) and a similar comparison of 50/60 Hz electric energy are scheduled to begin in 2001.

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Appendix

Results of SIM International Comparison of Electrical Units (1997 - 1999)

NMI-NIST Differences (x1E-6)

SIM Test Points		1*	2	3	4*	5	6	7	8	9	10*	11	13	14	15*	16	17	18	19
Applied Amplitude	Frequency (kHz)																		
DC Voltage (V)																			
0,1		-1	420	-6	1	-200	70	-10	-8	1300	98	110	6	0	3	-2	6	7	74
1		-2	92	-2	-1	-23	-25	-12	-2	-680	14	10	1	-1	0	0	-2	-1	-2
10		-3	22	-2	0	5	-9	-3	-1	-270	5	5	2	1	-1	-1	-3	-1	-3
100		-5	-3	-3	1	na	-5	-6	-11	-240	10	11	4	4	-3	8	-3	0	28
AC Voltage (V)																			
0,1	0,3	-110	-130	-100	62	-100	-42	na	-5	na	-100	-9	11	-9	18	35	240	75	480
0,1	10	-92	-120	-120	63	280	-12	na	-17	na	-150	-2	-6	-30	45	120	220	88	570
0,1	100	-220	480	-59	28	1100	na	na	-130	na	-700	na	220	53	5	230	360	-19	470
1	0,3	9	-11	18	9	130	-4	na	17	na	-130	-13	-17	-7	-25	-33	-34	-23	-57
1	10	29	-101	10	10	96	-64	na	26	na	-130	7	-8	-3	-19	23	-45	-14	-56
1	1000	300	6300	-1250	40	7800	na	na	-650	na	6300	na	490	-290	-390	na	-7200	na	na
10	0,01	25	-150	87	13	170	na	na	110	na	91	na	-3	-23	-9	660	-18	-5	39
10	0,3	-3	27	3	6	250	-30	na	17	na	-120	0	-8	-13	-2	-3	12	-6	39
10	10	-13	90	-12	1	300	67	na	-1	na	-39	84	-17	-18	-7	54	8	-4	41
10	1000	330	7100	-1460	-8	-5800	-6200	na	-1400	na	8200	na	460	-150	-390	na	-8100	na	na
100	0,055	-3	11	36	12	na	100	-1610	48	-1	220	na	-14	-12	12	-29	21	2	370
100	1	-1	8	37	25	na	20	na	45	na	-59	-27	-8	-12	17	27	11	13	2720
100	100	280	600	400	8	na	na	na	39	na	-130	na	-82	-98	11	-130	-120	16	na
DC Current (A)																			
0,01		-11	3800	4	4	140	-3	-100	8	-660	12800	49	-3	3	21	-220	26	23	66
1		-69	4200	-5	1	na	100	-3100	-14	-53	210	26	13	-31	-9	190	-100	-24	130
AC Current (A)																			
0,01	0,3	12	-85	44	33	na	-68	na	50	na	-300	62	-15	-10	38	-270	100	33	260
0,01	5	74	-120	-290	50	na	-150	na	86	na	-9700	-80	-150	-37	32	-120	190	-9	na
1	0,055	-57	-94	-6	18	na	-1300	3600	26	-150	-170	na	47	8	2	-82	-97	-31	110
1	0,3	-15	-150	64	41	na	-1400	na	51	-1300	-160	-380	48	17	16	-34	-49	-36	120
1	5	-1170	-2900	-2290	190	na	-2400	na	150	na	-1000	-1100	-350	51	260	-240	990	-240	na
DC Resistance (Ω)																			
1		-80	9	-250	1	80	222000	24	17	13	-21	114000	na	-2	-39	-22	12	3	1200
10		-4	4300	-81	-10	54	15000	-4	-8	-3	13	12000	na	2	-7	-50	-1	-1	560
1 k		17	410	-40	-7	-3	270	0	-5	11	-8	270	3	3	2	-50	3	0	na
100 k		11	41	-3	-5	160	6	32	-6	10	25	27	-1	0	-3	10	15	-4	na
10 M		-100	2500	-81	4	-10000	-47	na	4	na	na	na	12	6	-6	-30	14	3	3

na: indicates no measurement capability
Pilot laboratory: NIST (number 12 on plots)
*: Pivot laboratories in each metrology region