SANDIA REPORT

SAND2009-4334

Unlimited Release

Printed July 2009

Report of Multijunction Thermal Converter Interlaboratory Comparison Study for Measurements at Sandia National Laboratory

Beverly J. Klemme

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: <http://www.osti.gov/bridge>

Available to the public from

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: <http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online>

SAND2009-4334
Unlimited Release
Printed July 2009

Report of Multijunction Thermal Convertor Interlaboratory Comparison Study for Measurements at Sandia National Laboratory

Beverly J. Klemme
Primary Standards Laboratory
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-MS0665

Abstract

Two Multijunction Thermal Voltage Converters (MJTCs) were provided to the Sandia National Laboratory Primary Standards Laboratory (Sandia PSL) as part of an interlaboratory comparison (ILC). This report summarizes the results of the measurements of the devices (S# 127D1 and S# 127C2) measured at Sandia PSL from March 4 to March 15, 2009.

CONTENTS

1. Introduction.....	7
2. Measurement SYSTEM AND PROCEDURES	8
2.1. Measurement Overview	8
2.2. Data Collection	9
2.3. Traceability	9
2.4. Measurement System Verification.....	9
3. MEASUREMENT RESULTS.....	11
4. STATEMENT OF UNCERTAINTIES	12
3. Conclusions.....	14
Distribution	16

FIGURES

Figure 1: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 0.5 V.	10
Figure 2: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 1.0 V.	10
Figure 3: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 2.0 V.	11

TABLES

Table 1: Devices Under Test (DUTs) and Standards used for the ILC. The DUTs were measured against the standards and each other.	7
Table 2: DUT S# 127D1 measured using the S# 104G3 Standard	11
Table 3: DUT S# 127D1 measured using the S# 117D1 Standard	11
Table 4: DUT S# 127C2 measured using the S# 104G3 Standard	11
Table 5: DUT S# 127C2 measured using the S# 117D1 Standard	12
Table 6: DUT S# 127C2 measured using the S# 127D1 as a Standard	12
Table 7: the difference between the measured values from Table 6 and $\delta DUT - \delta STD$ obtained using the 127D1 standard: (Table 6 – (Table 5 – Table 3)).	12
Table 8: the difference between the measured values from Table 6 and $\delta DUT - \delta STD$ obtained using the 104G3 standard: (Table 6 – (Table 4 – Table 2)).	12
Table 9: Typical uncertainty assignments.	13

1. INTRODUCTION

Two Multijunction Thermal Voltage Converters (MJTCs) were provided to Sandia National Laboratories Primary Standards Laboratory (Sandia PSL) as part of an interlaboratory comparison (ILC). This report summarizes the results of the measurements of the devices (S# 127D1 and S# 127C2) measured at Sandia PSL from March 4 to March 15, 2009. The MJTC under test were measured using thin-film MJTCs as standards (S# 104G3 and S# 117D4, see Table 1).

Serial No.	Model	Type	Use
127D1	NIST/Sandia	MJTC	DUT
127D2	NIST/Sandia	MJTC	DUT
104G3	NIST/Sandia LF-10c	Thin Film MJTC	Standard
117D4	NIST/Sandia LF-10c	Thin Film MJTC	Standard

Table 1: Devices Under Test (DUTs) and Standards used for the ILC. The DUTs were measured against the standards and each other.

2. MEASUREMENT SYSTEM AND PROCEDURES

2.1. Measurement Overview

Data were collected using the Sandia PSL Automated Low Frequency AC-DC Difference Measurement System. The ac-dc difference was measured at the center of a type N tee supplied with the traveling standards. These standards will be referred to in this report as the “DUT” (not to be confused with the “standard” used for comparison in the measurement system). The DUT and a comparison standard were connected at the tee and ac or dc voltage supplied to both using a Fluke 5700A calibrator. The thermocouple output emfs from both devices were measured using Keithley 182 voltmeters. After measuring the emf output of the DUT and standard at the nominal applied ac voltage, the Sandia PSL system uses an automated computer algorithm to adjust the applied dc voltage to match the output emf at the DUT so it is equal to that when the ac voltage is applied. Corrections are then applied to account for the ac-dc difference of the standard.

The ac-dc difference is defined as the ppm difference between the ac and dc voltages necessary to produce equal response of the MJTC thermocouple output at each applied voltage and frequency and is given by,

$$\delta = \frac{V_{AC} - V_{DC}}{V_{DC}}$$

where δ is the ac-dc difference, V_{AC} is the rms ac applied test voltage, and V_{DC} is the applied dc voltage necessary to produce a response equal to that produced by V_{AC} at the DUT. To account for dc reversal errors, the measurement is repeated with both positive and negative dc voltage and the absolute values of those are averaged first to compute V_{DC} . With this definition, a positive ac-dc difference indicates that a higher ac voltage is necessary to produce the same output as a given dc voltage.

In practice, the output emf of the standard is measured for ac and dc voltages matched at the DUT. The equation for the ac-dc differences (as defined above) in terms of the output emf of the standard for this procedure is

$$\delta = \frac{v_{ac} - v_{dc}}{2v_{dc}} + \delta_{STD}$$

where v_{ac} and v_{dc} are the output emfs of the standard for the matched ac and dc voltages respectively, and the factor 2 accounts for the square law dependence of the thermocouple emf on the applied voltage. δ_{STD} is the ac-dc difference of the standard, applied as a correction, and is added algebraically for this method.

2.2. Data Collection

Ten points were collected for each voltage and frequency measured. Outliers were removed using Chauvenet's criteria leaving between 7 and 10 data points left over for subsequent data analysis. The laboratory temperature was 23°C and 40 %RH at the time of test.

2.3. Traceability

The measurement is traceable to NIST through the thin-film MJTC standards. These devices were measured at NIST and the ac-dc differences provided to Sandia in a NIST Report of Special Test.

2.4. Measurement System Verification

Prior to measuring the traveling standards, the measurement system was verified by measuring two high precision MJTCs against each other. These are the same standards that were subsequently used for the measurements of the traveling standards and both were provided with ac-dc differences from a NIST Report of Special Test. The NIST-provided ac-dc differences were used for the MJTC used as the "standard" as corrections to the measurements. The Sandia PSL measurement system data on the other MJTC (the "DUT") were compared with the NIST supplied values for that device. The results are shown in Figs. 1, 2, and 3. Although the results, as measured, typically fall within 10 ppm of the NIST values, the uncertainty of the ac-dc differences provided on the NIST report as well as the Type A (standard deviation of the mean) of the measured points must be considered in evaluating the uncertainty of the measurement system. These are represented by error bars on the graphs. The error bars on the NIST values are taken from the NIST Report of Special Test for the DUT (S#117D4). The error bars on the Sandia PSL measured data are the RSS of the standard deviation of the mean of the points taken (see "Data Collection"), and the uncertainty of the corrections provided by the NIST for the standard (S# 104GS in this case). The error bars on the graphs are the $k=1$ values. Based on this data, the uncertainty of the measurement system was set at 50ppm ($k=2$).

Figure 1: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 0.5 V.

Figure 2: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 1.0 V.

Figure 3: Sandia PSL measured (red circles) and NIST provided (blue crosses) for the S#117D4 MJTC measured against the S#104G3 standard at 2.0 V.

3. MEASUREMENT RESULTS

The results are summarized in the tables below, which show the two devices under test measured against the two standards. The k=2 expanded uncertainty for all of the measurements is 60 ppm, as explained in the “Statement of Uncertainties” section.

MJTCs measured against NIST/Sandia Model LF-10c standards:

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	18	6	2	3	3	10	20	-113	-298
1.0 V	26	21	12	16	22	17	-7	-109	-275
2.0 V	47	20	13	13	13	8	-12	-119	-308

Table 2: DUT S# 127D1 measured using the S# 104G3 Standard

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	21	11	5	2	8	11	19	-110	-277
1.0 V	8	20	19	20	19	18	-7	-101	-262
2.0 V	0	-2	7	11	11	8	-14	-115	-295

Table 3: DUT S# 127D1 measured using the S# 117D1 Standard

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	15	-4	-9	-3	-4	4	7	45	53
1.0 V	18	15	9	20	16	9	-17	31	49
2.0 V	26	13	8	9	9	1	-26	-18	-11

Table 4: DUT S# 127C2 measured using the S# 104G3 Standard

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	-5	-2	-4	-2	-1	2	9	55	61
1.0 V	10	9	14	15	13	6	-16	37	66
2.0 V	2	13	11	10	10	3	-24	-10	-3

Table 5: DUT S# 127C2 measured using the S# 117D1 Standard

:

As a further check, the two MJTCs were measured against each other. In this case, S# 127C2 was the DUT and S#127D1 was the standard:

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	10	3	-5	-5	-2	1	14	153	364
1.0 V	11	17	14	16	14	7	-8	138	377
2.0 V	1	12	3	8	7	0	-25	104	305

Table 6: DUT S# 127C2 measured using the S# 127D1 as a Standard

The measurements from Table 6 should be the $\delta_{DUT} - \delta_{STD}$. Table 7 and Table 8 show the difference between the expected and measured values for both the 127D1 and 104G3 standard. They are all less than 60 ppm, which is a cross-check for the expanded uncertainty estimate of 60 ppm assigned to the measurements.

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	36	16	5	-1	8	10	24	-12	26
1.0 V	9	27	19	20	20	19	1	0	48
2.0 V	-1	-3	-1	8	8	5	-15	-1	13

Table 7: the difference between the measured values from Table 6 and $\delta_{DUT} - \delta_{STD}$ obtained using the 127D1 standard: (Table 6 – (Table 5 – Table 3)).

Applied Voltage	10 Hz	20 Hz	40 Hz	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
0.5 V	14	13	7	1	5	7	26	-5	13
1.0 V	19	23	17	12	19	14	1	-2	53
2.0 V	23	20	8	12	12	6	-11	4	8

Table 8: the difference between the measured values from Table 6 and $\delta_{DUT} - \delta_{STD}$ obtained using the 104G3 standard: (Table 6 – (Table 4 – Table 2)).

4. STATEMENT OF UNCERTAINTIES

The total uncertainty includes the uncertainty of the measurement system and the uncertainty of the ac-dc difference of the standards. The measurement system uncertainty is a combination of Type A and Type B components and is 50ppm (k=2, see “Measurement System Verification”) for the Sandia PSL low frequency ac-dc measurement system for the voltages and frequencies used for this study. The uncertainties for ac-dc difference of the 104G3 and 117D4 standards used were between 1 ppm and 24 ppm depending on the voltage and frequency. The expanded uncertainty (k=2) obtained by computing the root-sum-squares of these two components rarely deviated from 50ppm although it was occasionally 55ppm at higher frequencies. Based on this evaluation, a conservative estimate of 60ppm (k=2) is the assigned uncertainty for all of the measurements in this report. Table 9 below shows a representative breakdown of the uncertainty components:

Type A (ppm)	Standard Unc	Meas. Sys.	Total (k=1)	Total(k=2)
1	6	25	26	51
3	5	25	26	51
2	2	25	25	50
3	1	25	25	50
3	1	25	25	50
4	2	25	25	51
1	3	25	25	50
0	7	25	26	52
1	12	25	28	55

Table 9: Typical uncertainty assignments.

3. CONCLUSIONS

The SNL/NM portion of an interlaboratory comparison of multijunction thermal convertors was successfully completed with a demonstrated measurement uncertainty of 60ppm ($k=2$).

DISTRIBUTION

1 Mr. Thomas E. Lipe, Physicist
 Project Leader, Ac-dc Difference
 Quantum Electrical Metrology Division
 National Institute of Standards and Technology
 100 Bureau Drive, M/S 8171, Gaithersburg, MD 20899-8171, USA

1	MS0665	A. Rod Mahoney	2542
1	MS0665	Larry Azevedo	2542
2	MS9018	Central Technical Files	8944
2	MS0899	Technical Library	4536