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Acoustic Noise Test Report for the SWIFT Wind Turbine in Boulder, CO

Jason Roadman and Arlinda Huskey
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-58244
April 2013

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE11.0206

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Acoustic Noise Test Report

for the

SWIFT Wind Turbine

in
Boulder, CO

Conducted for

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401

Jason Roadman
Arlinda Huskey

28 February 2013

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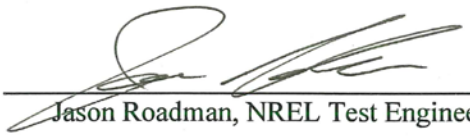
Approval By:  8 APR 2013

Jason Roadman, NREL Test Engineer — Date

Review By: Arlinda Huskey 8 April 2013

Arlinda Huskey, NREL Test Engineer — Date

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1 Background

An acoustic noise test was conducted as part of the U.S. Department of Energy's (DOE's) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small wind turbines. Several turbines were selected for testing at the National Wind Technology Center (NWTC), as a part of the Small Wind Turbine Independent Testing project. Acoustic noise testing is one of up to five tests that may be performed on turbines. Other tests include duration, safety and function, power performance, and power quality. Located in Grand Rapids, Michigan, Cascade Engineering is the North American distributor of the SWIFT turbine (manufactured by Renewable Devices). Cascade Engineering was the recipient of the DOE grant and provided the turbine for testing.

The primary goal of this test was to characterize the acoustic emissions of the SWIFT wind turbine in accordance with the International Electrotechnical Commission's (IEC) standard, *Wind Turbine Generator Systems - Part 11: Acoustic Noise Measurement Techniques*, IEC 61400-11, Edition 2.1, 2006-11; hereafter referred to as the "Standard." This test report documents the measurement techniques, turbine configuration, test site, test equipment, and results for the following quantities at integer wind speeds from 6 to 11 m/s:

- Apparent sound power level
- Third octave band levels
- Tonality.

Engineers at the NWTC conducted the acoustic noise test in accordance with the National Renewable Energy Laboratory's (NREL's) quality system procedures to ensure that this final test report meets the full requirements accreditation by A2LA. NREL's quality system procedures require that the test meet all applicable requirements specified by A2LA and ISO/IEC 17025 (or to note any exceptions in the test report).

2 Test Summary

The turbine was tested in accordance with the Standard. Turbine acoustic emissions and meteorological data were collected on 6 April 2012, 24 May 2012, and 28 May 2012. Standardized wind speed (at 10 m) was derived from wind speed measured at hub height (14.28 m). Table 1 gives a summary of the test results.

Table 1. Test Results Summary

Standardized wind speed at 10 m height, V_s [m/s]	**6**	**7**	**8**	**9**	**10**	**11**
Electrical power output calculated from power curve [kilowatts (kW)]	0.05	0.13	0.25	0.43	0.65	0.90
Measured pitch angle [°]	6	6	6	6	6	6
Measured rotor speed [1/min]	-	-	-	-	-	-
Apparent sound power level [dBA]	NR	*	82.6	84.4	85.0	85.6
Combined uncertainty in the sound power level, U_C [dBA]	-	2.9	2.6	1.8	1.7	1.5
Frequency of the most prevalent tone [hertz (Hz)]	-	-	-	-	3849	3921
Tonality, $\mathbf{\Delta L_k}$ [dBA]	-	-	-	-	-1.45	-2.53
Tonal audibility, $\mathbf{\Delta L_{a,k}}$ [dBA]	-	-	-	-	2.77	1.71

* The difference between total and background noise was less than 6 dB, but greater than 3 dB. Per Section 8.2 of the Standard, these data points were not used in the determination of the apparent sound power level, but were used for one-third octave and tonality. A standard background correction of 1.3 dB was applied.

NR The difference between total and background noise was less than 3 dB. According to Section 8.2 of the Standard, the wind turbine noise was less than the background noise.

3 Test Turbine Configuration

Table 2 lists the configuration of the SWIFT turbine that was tested at the NWTC.

Table 2. SWIFT Wind Turbine General Data

Turbine manufacturer and address	Renewable Devices Ltd AeroMarine House, Turnhouse Aerodrome Turnhouse Road, Edinburgh EH12 9DN Scotland, UK
Turbine distributor and address	Cascade Engineering 4855 Thirty-Seven St. SE Grand Rapids, MI 49512
Model	SWIFT
Rated power (kW)	1
Rated wind speed (m/s)	11
Serial number	N000780-N
Blade make, type, serial number	Injection-molded nano-fiber reinforced polymer, F000648
Generator make, type, serial number	Ginlong, Permanent Magnet, N000780-N
Gearbox make, type, serial number	N/A, direct drive
Control software	Kaco Blueplanet 1502x, Software V2.05
Wind turbine type	Horizontal-axis, upwind
Tower type	Trunk – conical tubular
Number of blades	5
Hub height (m)	14.28*
Rotor diameter (m)	2.134 with outer ring*
Horizontal distance from rotor center to tower axis (m)	0.27
Speed control	Passive stall with furling
Constant or variable speed	Variable
Rotational speed at standardized integer wind speed from 6 to 10 m/s (rpm)	210-364
Pitch angle at standardized integer wind speeds from 6 to 10 m/s	Fixed at 6° at the tip
Rotor control devices	Diffuser ring

*Measurements verified the rotor diameter and hub height.

Figure 1. SWIFT test turbine at the NWTC

(*Photo by Ismael Mendoza, NREL 22083*)

4 Test Site Description

The SWIFT wind turbine was located at test site 3.1 of the NWTC, approximately 8 km south of Boulder, Colorado. The site consists of mostly flat terrain with short vegetation (see Appendix A for photos) and has prevailing winds bearing 292° relative to true north. Figure 2 shows the turbine and meteorological tower locations, as well as nearby obstructions. NREL limited assessments of power and energy production to data obtained when winds were within the 178° to 311° measurement sector. In this measurement sector, the influence of terrain and obstructions on the anemometer is small and meets the requirements of IEC 61400-12-1(without conducting a site calibration test). Table 3 lists the nearby turbines and whether or not they were operating during data collection.

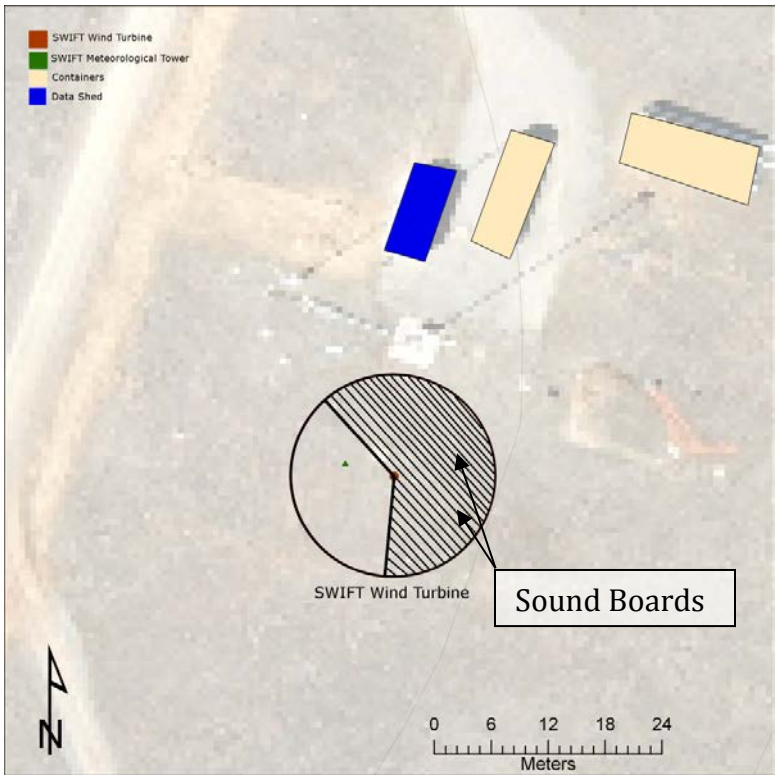


Figure 2. Map of the test site
(Source: NREL 2011)

Table 3. Sources of Noise Near the Turbine

Source	Location	Shutdown for noise test
E 1.5	4.0	Yes
Alstom ECO100 3.0 MW	4.1	Yes
Controls Advanced Research Turbine (CART)-3	4.3	Yes
CART-2	4.3	Yes
Siemens 2.3 MW	4.4	No
Southwest Windpower Skystream (Two turbines)	3.2	Yes
Viryd CS8	3.3	Yes
NW100	1.2	No
Test shed heating, ventilating, and air conditioning (HVACs)	3.1, 3.2, 3.3	Yes

5 Test Equipment

5.1 Equipment Descriptions

Table 4 shows the equipment used for the test. All instruments meet the requirements defined by the Standard.

Table 4. Equipment Used for Acoustic Test

Instrument	Manufacturer	Model Number	Serial Number	Calibration Due Date
Digital recorder and signal analyzer	Delta Acoustics	NoiseLab	1258E43	9 Nov 2012
Microphone	Bruel & Kjaer	4189-A-021	2395209 2395206	8 Nov 2012 8 Nov 2012
Preamplifier	Bruel & Kjaer	4012	2373721 2373719	8 Nov 2012 8 Nov 2012
Calibrator	Bruel & Kjaer	4231	2388951	19 Dec 2012
Anemometer	Thies	First Class	0609006	7 Apr 2012
Wind vane	Met One	SS 201	W5515	25 Oct 2012
Nacelle anemometer	NA	NA	NA	NA
Pressure sensor	Vaisala	PTB101B	C1040008	25 Oct 2012
Temperature sensor	Met One	T-200	0603-1	20 Oct 2012
Power transducer	Secondwind	Phaser 5FM-4A20	04607	8 Nov 2012
Data acquisition	National Instruments	CompactDAQ w/ LabView cDAQ-9172 NI 9229 NI 9217 NI 9205	 13AB4F9 14A34EE 1494F69 1496266	 NA 22 Mar 2012 22 Mar 2012 22 Mar 2012

The calibration on the primary anemometer and the data acquisition modules expired during the test. Post-test calibration sheets are included in Appendix C. The anemometer and modules were found to be within tolerance.

5.2 Instrument Locations

The primary anemometer on the meteorological tower was used to derive the standardized wind speed. This tower was located 5.20 m from the test turbine, at a bearing of 302° true north, with the anemometer at a height of 14.33 m. The wind vane was mounted at a height of 11.35 m on the meteorological tower. The turbine was 2.4 rotor diameters from the meteorological tower, within the range of 2 and 4 rotor diameters specified in the Standard.

Table 5 provides the location of the microphone for the measurement sessions.

Table 5. Reference Microphone Positions for Turbine and Background Measurements

Microphone	Distance Turbine [m]	Slant Distance [m]	Position Relative to Turbine [deg true]
6 Apr 2012	16.54	22.05	80
24 May 2012	16.34	21.90	110
28 May 2012	16.34	21.90	110

6 Results

6.1 Test Conditions

The analysis was done using the measured wind speed and 10-second averages of the data. NREL engineers have found that using 10-second averages instead of 1-minute averages better characterizes the dynamic nature of small turbines. The range of standardized wind speeds and wind directions used for the analysis were 2.1 to 18.1 m/s and 245.8 to 304.8 degrees, respectively. The range of temperature and pressure were 9.7°C to 18.1°C and 80.4 kPa to 81.3 kPa, respectively.

6.2 Standardized Wind Speed Calculation

Standardized wind speed, V_s, was calculated using Equation 1 and the values in Table 6, where V_z is the measured wind speed.

$$V_s = V_z \left[\frac{\ln\left(\frac{z_{ref}}{z_{0ref}}\right)\ln\left(\frac{H}{z_0}\right)}{\ln\left(\frac{H}{z_{0ref}}\right)\ln\left(\frac{z}{z_0}\right)} \right] \quad (1)$$

Table 6. Test Parameters Used in Wind Speed Calculations

Parameter	Name	Value
Hub Height, (m)	H	14.28
Roughness length, (m)	Z_o	0.05
Anemometer height, (m)	Z	14.33
Reference roughness length, (m)	Z_{0ref}	0.05
Reference height, (m)	Z_{ref}	10.00

6.3 Apparent Sound Power Level

Sound pressure levels were binned by wind speed. Integer wind speeds values were calculated using interpolation between bins and extrapolation at the ends. The sound pressure levels were then background corrected according to the Standard. Figure 3 shows the scatter plot of the sound pressure levels of the validated total (operating plus background) and background noise, along with the binned sound pressure levels. At low wind speeds, background levels were close to turbine levels, resulting in the 6 and 7 m/s bins being unreportable. The measured and background corrected apparent sound pressure level at standardized wind speeds of 6 through 11 m/s are shown in Table 7, along with the calculated sound power levels. Figure 4 shows the sound power levels graphed against the standardized wind speed.

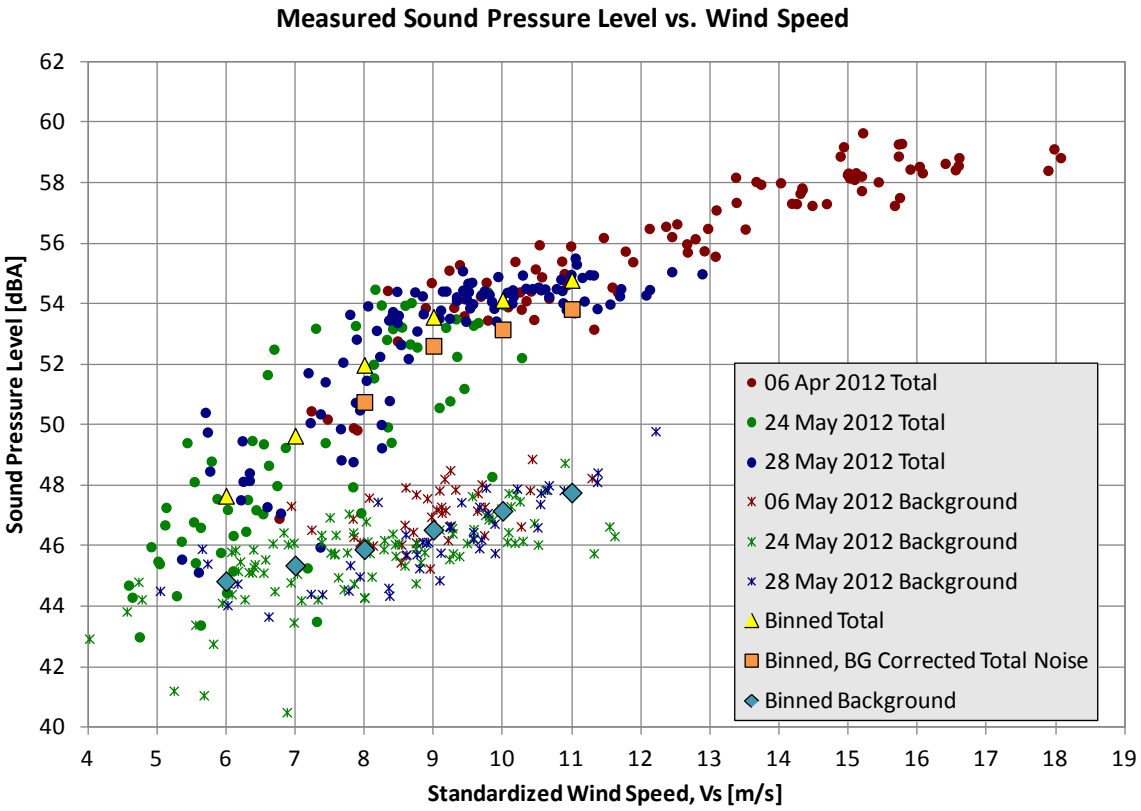


Figure 3. Measured and binned sound pressure levels as a function of the standardized wind speed

Table 7. Sound Pressure and Power Levels for Standardized Integer Wind Speeds (6 m/s Through 11 m/s)

Wind Speed Bin [m/s]	Total Sound Pressure Level [dBA)]	Background Sound Pressure Level [dBA]	Background Corrected Sound Pressure Level [dBA]	Sound Power Level [dBA]	Type A Uncert. [dBA]	Type B Uncert. [dBA]	Combined Uncert. [dBA]
6	47.7	44.8	NR	NR	NR	NR	NR
7	49.6	45.4	48.3	*	2.7	1.1	2.9
8	52.0	45.9	50.8	82.6	2.4	1.1	2.6
9	53.6	46.5	52.6	84.4	1.5	0.9	1.8
10	54.1	47.2	53.2	85.0	1.5	0.9	1.7
11	54.8	47.8	53.8	85.6	1.2	0.9	1.5

* The difference between total and background noise was less than 6 dB but greater than 3 dB. According to Section 8.2 of the Standard, these data points were not used to determine the apparent sound power level.

NR The difference between total and background noise was less than 3 dB. According to Section 8.2 of the Standard, the wind turbine noise was less than the background noise.

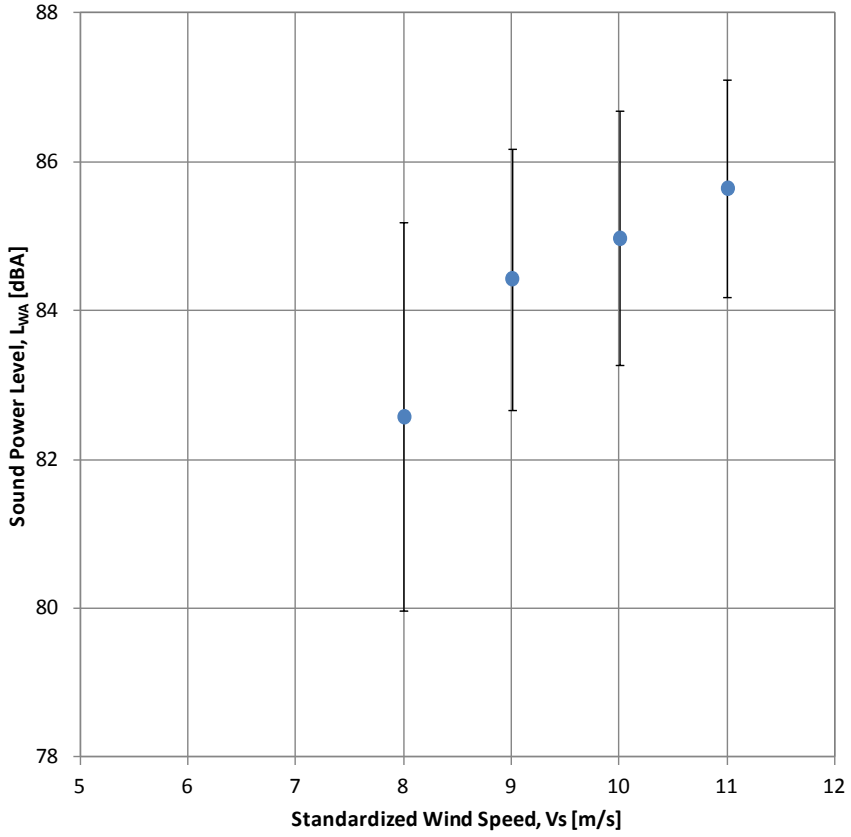


Figure 4. Sound power levels as a function of the standardized wind speed

6.4 One-Third Octave Analysis

One-third octave levels were analyzed at standardized wind speeds of 6, 7, 8, 9, 10, and 11 m/s. The results (with uncertainty) are provided in Table 8, Table 9, and Figure 5.

Table 8. One-Third Octave Analysis for Wind Speed Bins 6 Through 8 m/s

Center Frequency	6 m/s One-Third Octave Levels	7 m/s One-Third Octave Levels	8 m/s One-Third Octave Levels
[Hz]	[dBA]	[dBA]	[dBA]
50	NR	NR	NR
63	NR	NR	NR
80	29.6* ± 2.3	NR	NR
100	NR	NR	NR
125	NR	NR	NR
160	NR	NR	NR
200	38.8* ± 2.1	NR	NR
250	NR	39.8 ± 2.2	42.3 ± 1.9
315	NR	NR	38.7* ± 2.1
400	NR	NR	NR
500	35.4* ± 2.1	40.2 ± 2.1	40.4 ± 1.9
630	34.9* ± 2.0	37.7* ± 2.1	40.6 ± 2.0
800	NR	37.6* ± 2.2	41.5 ± 2.0
1000	34.6* ± 2.1	38.7 ± 2.1	42.5 ± 2.0
1250	36.3 ± 2.0	38.9 ± 2.1	42.6 ± 2.0
1600	32.0 ± 2.1	36.3 ± 2.2	40.4 ± 2.0
2000	29.5 ± 2.1	32.6 ± 2.1	36.4 ± 2.0
2500	NR	27.4* ± 2.2	31.9 ± 2.1
3150	NR	NR	27.7* ± 2.1
4000	28.4 ± 2.4	NR	25.3* ± 2.0
5000	NR	NR	NR
6300	NR	NR	NR
8000	NR	NR	NR
10000	NR	NR	NR

* The difference between total and background noise was less than 6 dB but greater than 3 dB. A standard background correction of 1.3 dB was applied according to Section 8.2 of the Standard.

NR The difference between total and background noise was less than 3 dB. According to Section 8.2 of the Standard, the wind turbine noise was less than the background noise.

Table 9. One-Third Octave Analysis for Wind Speed Bins 9 Through 11 m/s

Center Frequency	9 m/s One-Third Octave Levels	10 m/s One-Third Octave Levels	11 m/s One-Third Octave Levels
[Hz]	[dBA]	[dBA]	[dBA]
50	NR	NR	NR
63	NR	NR	NR
80	NR	NR	NR
100	NR	NR	NR
125	NR	NR	NR
160	NR	NR	NR
200	NR	NR	39.3* ± 2.1
250	41.8 ± 2.0	38.8* ± 2.0	38.3* ± 2.0
315	41.7* ± 2.1	45.8 ± 2.0	47.8 ± 1.9
400	NR	NR	38.6* ± 2.0
500	39.9* ± 2.0	38.9* ± 2.0	39.1* ± 2.0
630	42.1 ± 1.9	41.4 ± 1.9	40.8* ± 2.0
800	43.2 ± 1.8	42.9 ± 1.9	42.0 ± 1.9
1000	44.8 ± 1.8	45.0 ± 1.8	44.8 ± 1.8
1250	45.1 ± 1.9	45.7 ± 1.8	45.5 ± 1.8
1600	43.5 ± 1.9	44.4 ± 1.8	44.6 ± 1.8
2000	39.7 ± 1.9	41.1 ± 1.9	42.9 ± 1.9
2500	35.9 ± 1.9	37.3 ± 1.9	38.7 ± 1.9
3150	31.3 ± 2.0	32.9 ± 2.0	34.7 ± 1.9
4000	27.4* ± 2.0	30.6 ± 2.2	35.3 ± 2.3
5000	NR	NR	NR
6300	NR	NR	NR
8000	NR	NR	NR
10000	NR	NR	NR

* The difference between total and background noise was less than 6 dB but greater than 3 dB. A standard background correction of 1.3 dB was applied according to Section 8.2 of the Standard.

NR The difference between total and background noise was less than 3 dB. According to Section 8.2 of the Standard, the wind turbine noise was less than the background noise.

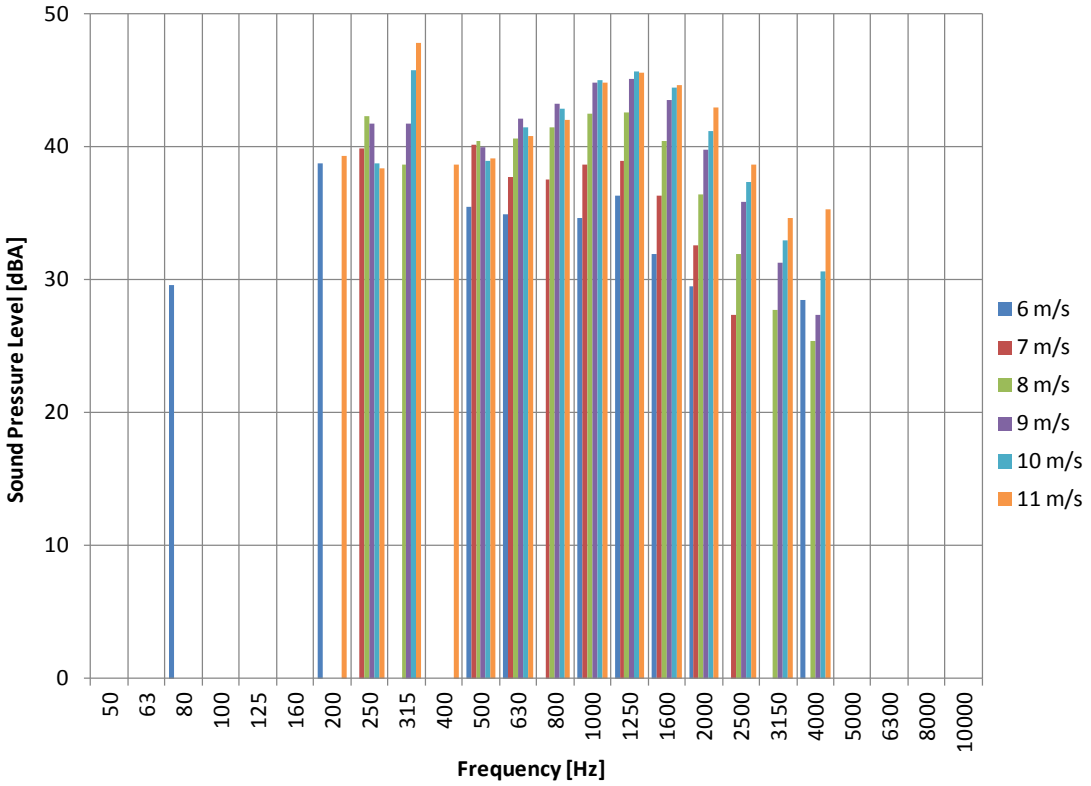


Figure 5. One-third octave levels

6.5 Tonality

The tonality analysis resulted in reportable tones for 10 and 11 m/s, as shown in Table 10. NREL engineers believe that these tones originated from the furling mechanism. The furling mechanism activated at $V_s \sim 10$ m/s and generated enough noise that it was impossible to collect valid background data above 10 m/s. On 6 Apr 2012, the mechanism was lubricated and the audible squeak was no longer noticeable. As a result, no audible tones existed for the 24 May 2012 or 28 May 2012 measurement sessions.

Additionally, engineers heard a rattle emanating from the nose cone in low wind speeds. As the turbine speed increased, the rattle disappeared. However, no quantitative comments can be made concerning this rattle, as the background levels at these wind speeds were within 3 dBA of the turbine levels.

Cascade Engineering was made aware of both of these noises.

Table 10. Tonality Results (In dBA)

Wind Speed:	10 m/s	11m/s
f [Hz]	3,849	3,921
ΔLtn,1	-21.5	-21.5
ΔLtn,2	-3.7	-21.5
ΔLtn,3	-21.5	-21.5
ΔLtn,4	-21.5	-21.5
ΔLtn,5	-21.5	-21.5
ΔLtn,6	-21.5	-21.5
ΔLtn,7	-21.5	-21.5
ΔLtn,8	-21.5	-21.5
ΔLtn,9	-21.5	-21.5
ΔLtn,10	-21.5	-21.5
ΔLtn,11	-21.5	-21.5
ΔLtn,12	9.1	8.1
ΔLk	-1.5	-2.5
ΔLa,k	2.77	1.7
U_A	N/A[1]	N/A[1]
U_B	2.1	2.1
U_C	N/A[1]	N/A[1]

Figure 6 and Figure 7 show a 10-second energy averaged spectrum indicating the classification of spectral lines for each of the identified tones.

[1] Tone was intermittent. Type A uncertainty was not calculated for the bipolar sample distribution.

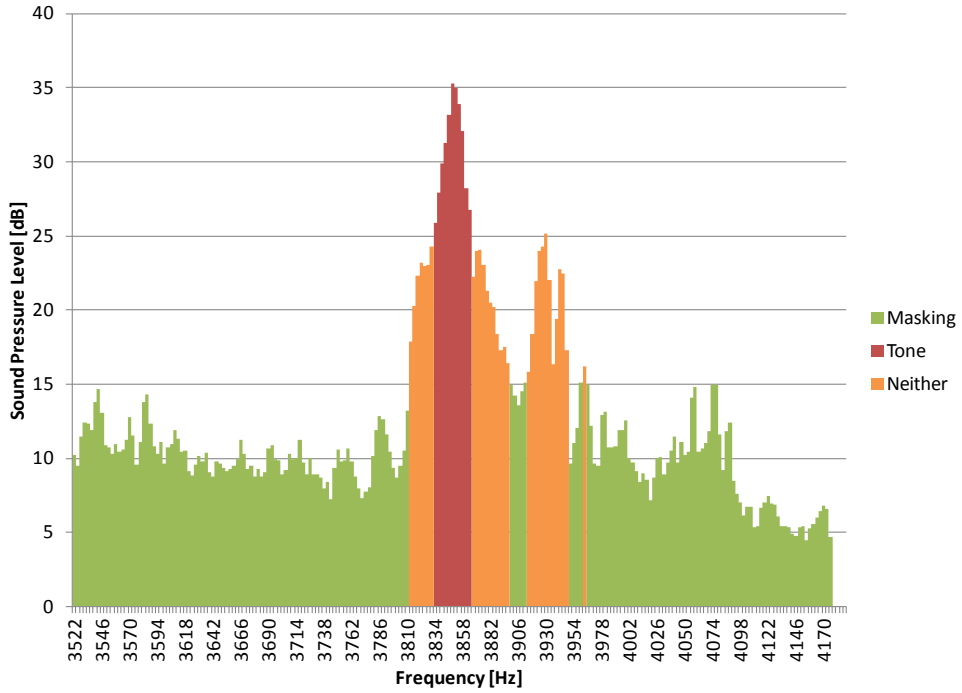


Figure 6. Classification of spectral lines for the 3,849 Hz tone (typical in the 10 m/s bin)

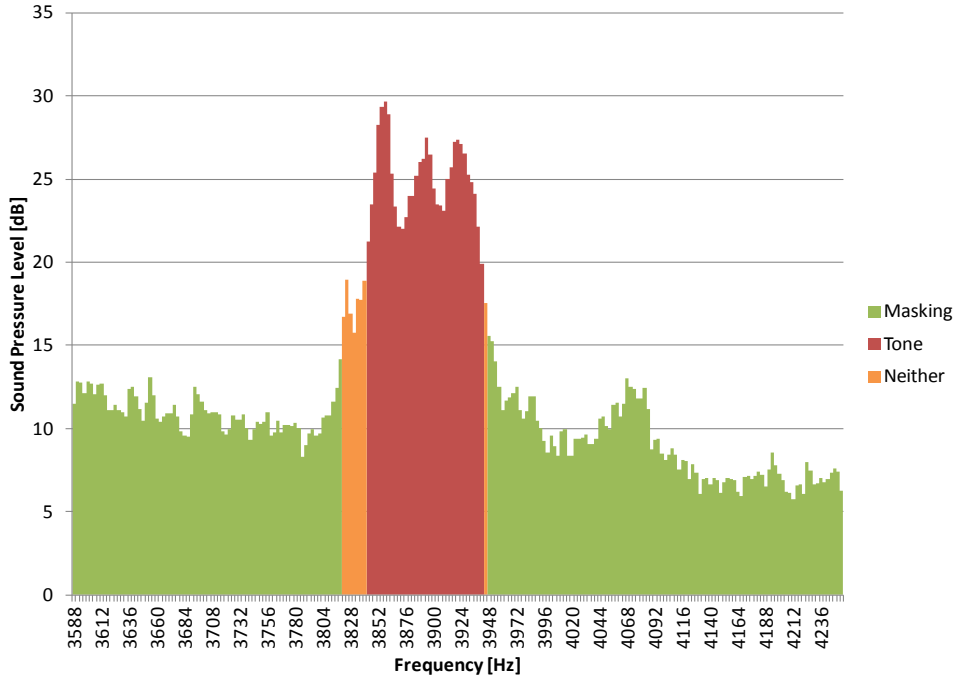


Figure 7. Classification of spectral lines for the 3,921 Hz tone (typical in the 11 m/s bin)

6.6 Uncertainty

The type A uncertainties for sound power levels, one-third octave levels, and tonality were calculated using the methods prescribed in the Standard. The type B uncertainty components are shown in Table 11.

Table 11. Type B Uncertainty Components for Sound Power Levels and Tonality

Var	Description	Type B Uncertainty for Sound Power Level (SPL) dBA	Type B Uncertainty for 1/3 Octave Levels (TOB) dBA	Type B Uncertainty for Tonality dBA	Comment
U_{B1}	Calibration	0.2	0.2	0.1	Assumption, used typical value
U_{B2}	Instrument	0.2	0.2	0.2	Assumption, used typical value
U_{B3}	Board	0.3	1.7	1.7	The board was placed well and used the typical value
U_{B4}	Distance	0.1	0.1	0.05	Assumption, used typical value
U_{B5}	Impedance	0.1	0.1	0.1	Assumption, used typical value
U_{B6}	Turbulence	0.4	0.4	0.2	Assumption, used typical value
U_{B7}	Wind speed, measured	Varies with wind speed	Varies with wind speed and one-third octave center frequency bin	0.6	Calculated per IEC 61400-12-1 Ed. 1.0, 205-12, and converted to dBA for SPL and TOB. Typical value for tonality
U_{B8}	Direction	0.3	0.3	0.3	Assumption, used typical value
U_{B9}	Background	Varies with wind speed	Varies with wind speed and one-third octave center frequency bin	Varies by tone	Standard deviation of the applied correction

7 Exceptions

7.1 Exceptions to the Standard

The analysis prescribed in the standard was altered for the small wind turbine by using 10-second averages instead of 1-minute averages to better characterize the dynamic nature of this turbine. In addition, binning by wind speed was used instead of regression analysis, and the integer values were calculated by interpolating between bins and extrapolating at the ends.

7.2 Exceptions to the Quality Assurance System

The primary anemometer and data acquisition modules were used past the calibration due dates. The instruments and modules were post-test calibrated. The anemometer and modules were found to be within tolerances.

References

International Electrotechnical Commission (IEC). (2006). Wind Turbine Generator Systems – Part 11 Acoustic Noise Measurement Techniques, IEC 61400-11, Ed 2.1, 2006-11, Geneva, Switzerland.

Appendix A. American Wind Energy Association Standard Acoustic Analysis

The American Wind Energy Association (AWEA) standard requires that the wind turbine sound levels be measured and reported in accordance with the IEC 61400-11 standard, and includes the following modifications:

- Using a 10-second averaging period
- Using the measured wind speed
- Using the method of bins
- Covering a wide wind speed range as possible
- Describing any obvious changes in sound at high wind speeds
- Reporting the AWEA Rated Sound Level.

During the test, NREL engineers analyzed the data to calculate the 10-second averages. To ensure that the acoustic data was downwind from the turbine, the wind direction was filtered to assure that the measurement board was within 15 degrees of the downwind position. The data were also filtered by the provided status to determine the total (operating plus background), background, and interrupted/excluded data. The data were binned by the standardized wind speed into 1m/s wind speed bins centered on the integer wind speed. The bin centers were calculated by interpolation (and extrapolation at the ends).

The AWEA Rated Sound Level is defined as: the sound level that will not be exceeded 95% of the time (assuming an average wind speed of 5 m/s); a Rayleigh wind speed distribution; 100% availability; and an observer location that is 60 m from the rotor center. This requirement defines the AWEA wind speed to be 9.8 m/s at hub height. The total and background noise for 9.8 m/s were obtained by interpolation between the 9 and 10 m/s binned values. The two values are used to obtain the background corrected sound pressure level. Next, the sound power level is calculated. The AWEA Rated Sound Level is then calculated using this value.

Table 12. AWEA Rated Sound Level

AWEA Rated Sound Level dBA	Combined Uncertainty dBA
38.3	1.9

Appendix B. Pictures

Figure B1. Picture of the sound board during the test

(*Photo by Jason Roadman, NREL*)

Figure B2. The test turbine as viewed from the reference microphone position

(*Photo by Jason Roadman, NREL*)

Figure B3. The test turbine as viewed from the meteorological mast

(*Photo by Ismael Mendoza, NREL 22083*)

Appendix C. Calibration Sheets

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1
and relevant requirements of ISO 9002:1994
ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.22817

Instrument: **Microphone Unit**
Model: **4189-A-021**
Manufacturer: **Brüel & Kjær**
Serial number: **2406811**
Composed of: **Microphone 4189 s/n 2395209**
Preamplifier 2671 s/n 2373721

Date Calibrated: **11/8/2010** *Cal Due:*

Status:	Received	Sent
In tolerance:	X	X
Out of tolerance:		
See comments:		

Contains non-accredited tests: __Yes _X_ No

Customer: **National Renewable Energy Laboratory**
Tel/Fax: **303-384-7183/**
Address: **16253 Denver West Parkway**
Golden, CO 80401-3393

Tested in accordance with the following procedures and standards:
Procedure for Calibration of Measurement Microphones, Scantek Inc., 06/15/2005
Procedure for Microphone calibration using acoustical calibrator, Scantek, Inc., June 2005

Instrumentation used for calibration: N-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Dec 24, 2009	Scantek, Inc./ NVLAP	Dec 24, 2010
DS-360-SRS	Function Generator	61646	Nov 13, 2009	ACR Env. / A2LA	Nov 13, 2011
34401A-Agilent Technologies	Digital Multimeter	MY41022043	Nov 12, 2009	ACR Env. / A2LA	Nov 12, 2010
DPI 141-Druck	Pressure Indicator	790/00-04	Nov 21, 2008	Transcat / NVLAP	Nov 21, 2010
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	Nov 25, 2009	ACR Env./ A2LA	May 25, 2011
PC Program 1017 Norsonic	Calibration software	v.5.0	Validated July 2009	-	-
1253-Norsonic	Calibrator	28326	Dec 7, 2009	Scantek, Inc./ NVLAP	Dec 7, 2010
1203-Norsonic	Preamplifier	14059	Jan 4, 2010	Scantek, Inc./ NVLAP	Jan 4, 2011
4180-Brüel&Kjær	Microphone	2246115	Dec 14, 2009	NPL (UK) / UKAS	Dec 14, 2011

Instrumentation and test results are traceable to SI - BIPM through standards maintained by NPL (UK) and NIST (USA)

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/08/2010	Date	11/10/2010

Calibration Certificates or Test Reports shall not be reproduced, except in full, without written approval of the laboratory.
This Calibration Certificate or Test Reports shall not be used to claim product certification, approval or endorsement by NVLAP, NIST, or any agency of the federal government.
Document stored as: Z:\Calibration Lab\Mic 2010\B&K4189_A_021_2406811_M1.doc

Page 1 of 2

Figure C1. Calibration sheet for the microphone 2406811

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1
and relevant requirements of ISO 9002:1994
ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.22816

Instrument: **Microphone Unit**
Model: **4189-A-021**
Manufacturer: **Brüel & Kjær**
Serial number: **2406809**
Composed of: **Microphone 4189 s/n 2395206**
Preamplifier 2671 s/n 2373719

Date Calibrated: **11/8/2010** *Cal Due:*

Status:	Received	Sent
In tolerance:	X	X
Out of tolerance:		
See comments:		

Contains non-accredited tests: __Yes _X_ No

Customer: **National Renewable Energy Laboratory**
Tel/Fax: **303-384-7183/**
Address: **16253 Denver West Parkway**
Golden, CO 80401-3393

Tested in accordance with the following procedures and standards:
Procedure for Calibration of Measurement Microphones, Scantek Inc., 06/15/2005
Procedure for Microphone calibration using acoustical calibrator, Scantek, Inc., June 2005

Instrumentation used for calibration: N-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Dec 24, 2009	Scantek, Inc./ NVLAP	Dec 24, 2010
DS-360-SRS	Function Generator	61646	Nov 13, 2009	ACR Env. / A2LA	Nov 13, 2011
34401A-Agilent Technologies	Digital Multimeter	MY41022043	Nov 12, 2009	ACR Env. / A2LA	Nov 12, 2010
DPI 141-Druck	Pressure Indicator	790/00-04	Nov 21, 2008	Transcat / NVLAP	Nov 21, 2010
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	Nov 25, 2009	ACR Env./ A2LA	May 25, 2011
PC Program 1017 Norsonic	Calibration software	v.5.0	Validated July 2009	-	-
1253-Norsonic	Calibrator	28326	Dec 7, 2009	Scantek, Inc./ NVLAP	Dec 7, 2010
1203-Norsonic	Preamplifier	14059	Jan 4, 2010	Scantek, Inc./ NVLAP	Jan 4, 2011
4180-Brüel&Kjær	Microphone	2246115	Dec 14, 2009	NPL (UK) / UKAS	Dec 14, 2011

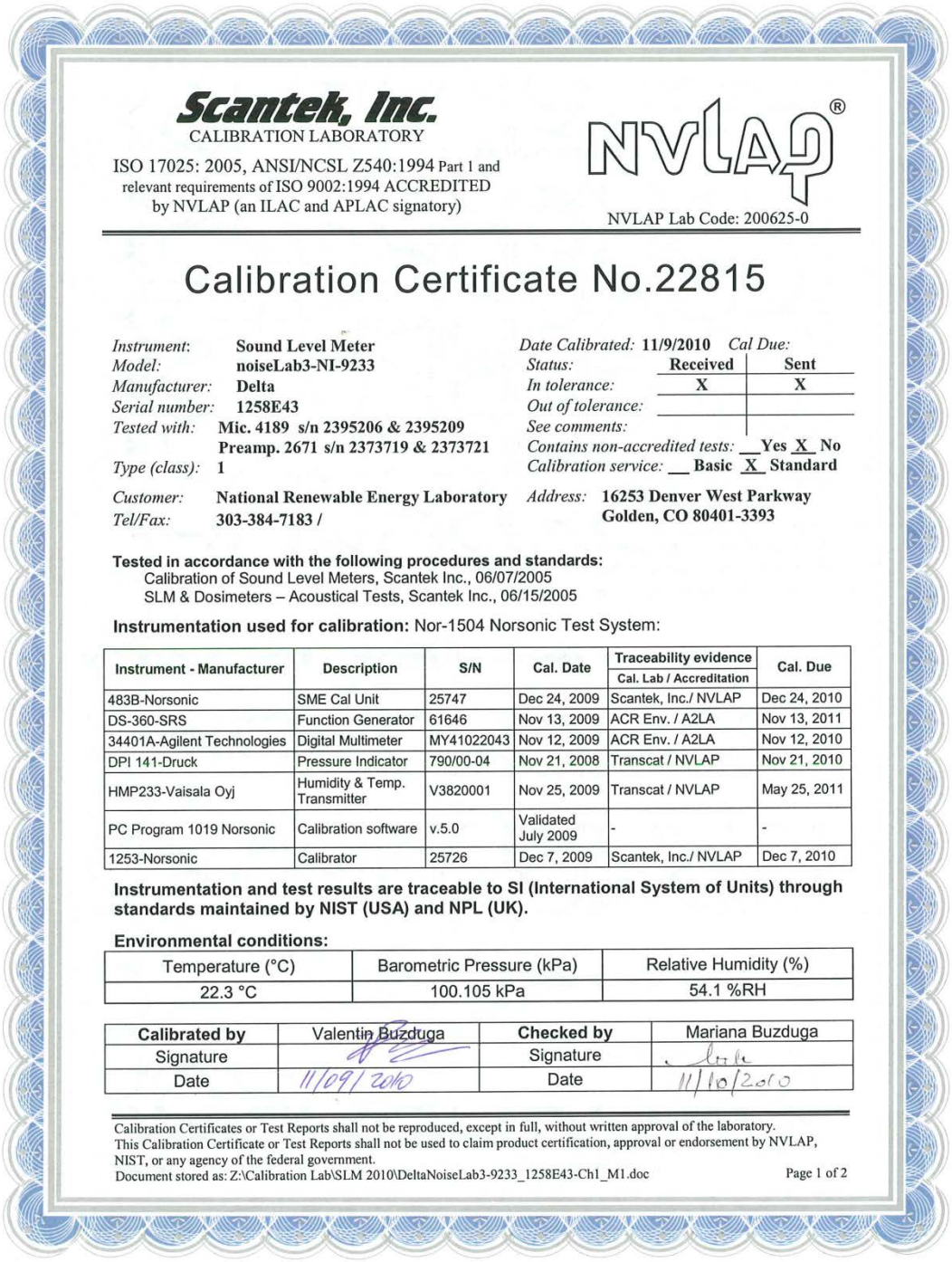
Instrumentation and test results are traceable to SI - BIPM through standards maintained by NPL (UK) and NIST (USA)

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/08/2010	Date	11/10/2010

Calibration Certificates or Test Reports shall not be reproduced, except in full, without written approval of the laboratory.
This Calibration Certificate or Test Reports shall not be used to claim product certification, approval or endorsement by NVLAP, NIST, or any agency of the federal government.
Document stored as: Z:\Calibration Lab\Mic 2010\B&K4189_A_021_2406809_M1.doc

Page 1 of 2

Figure C2. Calibration sheet for the microphone 2406809



Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1 and relevant requirements of ISO 9002:1994 ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.22815

Instrument: **Sound Level Meter**
Model: **noiseLab3-NI-9233**
Manufacturer: **Delta**
Serial number: **1258E43**
Tested with: **Mic. 4189 s/n 2395206 & 2395209**
Preamp. 2671 s/n 2373719 & 2373721
Type (class): **1**

Date Calibrated: **11/9/2010** *Cal Due:*

Status:	Received	Sent
In tolerance:	X	X
Out of tolerance:		
See comments:		

Contains non-accredited tests: __Yes X No
Calibration service: __ Basic X Standard

Customer: **National Renewable Energy Laboratory**
Tel/Fax: **303-384-7183 /**
Address: **16253 Denver West Parkway**
Golden, CO 80401-3393

Tested in accordance with the following procedures and standards:
Calibration of Sound Level Meters, Scantek Inc., 06/07/2005
SLM & Dosimeters – Acoustical Tests, Scantek Inc., 06/15/2005

Instrumentation used for calibration: Nor-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Dec 24, 2009	Scantek, Inc./ NVLAP	Dec 24, 2010
DS-360-SRS	Function Generator	61646	Nov 13, 2009	ACR Env. / A2LA	Nov 13, 2011
34401A-Agilent Technologies	Digital Multimeter	MY41022043	Nov 12, 2009	ACR Env. / A2LA	Nov 12, 2010
DPI 141-Druck	Pressure Indicator	790/00-04	Nov 21, 2008	Transcat / NVLAP	Nov 21, 2010
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	Nov 25, 2009	Transcat / NVLAP	May 25, 2011
PC Program 1019 Norsonic	Calibration software	v.5.0	Validated July 2009	-	-
1253-Norsonic	Calibrator	25726	Dec 7, 2009	Scantek, Inc./ NVLAP	Dec 7, 2010

Instrumentation and test results are traceable to SI (International System of Units) through standards maintained by NIST (USA) and NPL (UK).

Environmental conditions:

Temperature (°C)	Barometric Pressure (kPa)	Relative Humidity (%)
22.3 °C	100.105 kPa	54.1 %RH

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/09/2010	Date	11/10/2010

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This Calibration Certificate or Test Reports shall not be used to claim product certification, approval or endorsement by NVLAP, NIST, or any agency of the federal government.
Document stored as: Z:\Calibration Lab\SLM 2010\DeltaNoiseLab3-9233_1258E43-Ch1_M1.doc

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Figure C3. Calibration sheet for the sound level meter

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1 ACCREDITED
by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.25175

Instrument:	**Acoustical Calibrator**	*Date Calibrated:*	**12/19/2011**	*Cal Due:*	
Model:	**4231**	*Status:*	**Received**	**Sent**
Manufacturer:	**Brüel and Kjær**	*In tolerance:*	**X**	**X**
Serial number:	**2388951**	*Out of tolerance:*		
Class (IEC 60942):	**1**	*See comments:*		
Barometer type:		*Contains non-accredited tests:*	**__Yes _X_ No**	
Barometer s/n:				

Customer: **National Renewable Energy Laboratory** *Address:* **1617 Cole Blvd.**
Tel/Fax: **303-384-6385 / -6391** **Golden, CO 80401-3305**

Tested in accordance with the following procedures and standards:
Calibration of Acoustical Calibrators, Scantek Inc., Rev. 10/1/2010

Instrumentation used for calibration: Nor-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Jul 1, 2011	Scantek, Inc./ NVLAP	Jul 1, 2012
DS-360-SRS	Function Generator	61646	Nov 16, 2011	ACR Env./ A2LA	Nov 16, 2013
34401A-Agilent Technologies	Digital Voltmeter	MY41022043	Dec 9, 2011	ACR Env. / A2LA	Dec 9, 2012
DPI 141-Druck	Pressure Indicator	790/00-04	Dec 13, 2010	ACR Env./ A2LA	Dec 13, 2012
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	Jul 29, 2011	Vaisala / A2LA	Jul 29, 2012
8903A-HP	Audio Analyzer	2514A05691	Dec 1, 2010	ACR Env./ A2LA	Dec 1, 2013
PC Program 1018 Norsonic	Calibration software	v.5.2	Validated March 2011	Scantek, Inc.	-
4134-Brüel&Kjær	Microphone	173368	Dec 13, 2011	Scantek, Inc. / NVLAP	Dec 13, 2012
1203-Norsonic	Preamplifier	14059	Jan 5, 2011	Scantek, Inc./ NVLAP	Jan 5, 2012

Instrumentation and test results are traceable to SI (International System of Units) through standards maintained by NIST (USA) and NPL (UK)

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	12/19/2011	Date	12/21/2011

Document stored as: Z:\Calibration Lab\Cal 2011\BNK4231_2388951_M1.doc

Figure C4. Calibration sheet for the acoustic calibrator

Svend Ole Hansen ApS
SCT. JORGENS ALLE 7 · DK-1615 KOBENHAVN V · DENMARK
TEL: (+45) 33 25 38 38 · FAX: (+45) 33 25 38 39 · WWW.SOHANSEN.DK

WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 09.02.3131 **Date of issue:** June 15, 2009

Type: Thies 4.3351.10.000 **Serial number:** 0609006

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 13, 2009

Calibrated by: jj **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared and approved by: Calibration engineer, soh Svend Ole Hansen

Calibration equation obtained: v [m/s] = 0.04630 · f [Hz] + 0.22992

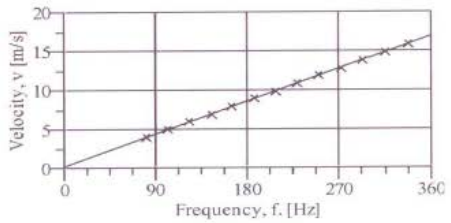
Standard uncertainty, slope: 0.00126 **Standard uncertainty, offset:** 0.05660

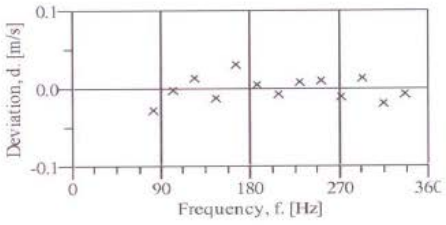
Covariance: -0.0000007 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999991$

Absolute maximum deviation: 0.032 m/s at 7.911 m/s

Barometric pressure: 1005.4 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.03	32.3	23.3	3.978	81.5163	-0.027	0.029
4	14.04	32.1	23.2	4.958	102.1571	-0.002	0.033
6	20.23	32.0	23.2	5.950	123.2216	0.014	0.038
8	27.39	31.9	23.2	6.923	144.8197	-0.013	0.044
10	35.79	31.8	23.2	7.911	165.2051	0.032	0.050
12	45.41	31.8	23.2	8.910	187.3624	0.005	0.056
13-last	56.18	31.7	23.1	9.911	209.1977	-0.006	0.062
11	67.73	31.8	23.2	10.884	229.8895	0.009	0.068
9	80.53	31.9	23.2	11.869	251.1191	0.011	0.074
7	94.07	32.0	23.2	12.830	272.3620	-0.011	0.080
5	109.65	32.1	23.2	13.855	293.9411	0.014	0.086
3	125.49	32.2	23.3	14.825	315.6078	-0.019	0.092
1-first	143.09	32.4	23.3	15.838	337.2206	-0.007	0.099





ilac-MRA DANAK CAL Reg.nr. 452 Accreditation to ISO 17025 measnet

Figure C5. Calibration sheet for the primary anemometer

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 12.02.6727 **Date of issue:** August 24, 2012

Type: Thies 4.3351.10.000 **Serial number:** 0609006

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

Anemometer received: August 13, 2012 **Anemometer calibrated:** August 23, 2012

Calibrated by: asj **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared by: ca **Approved by:** Calibration engineer, ml

Calibration equation obtained: v [m/s] = 0.04654 · f [Hz] + 0.15404

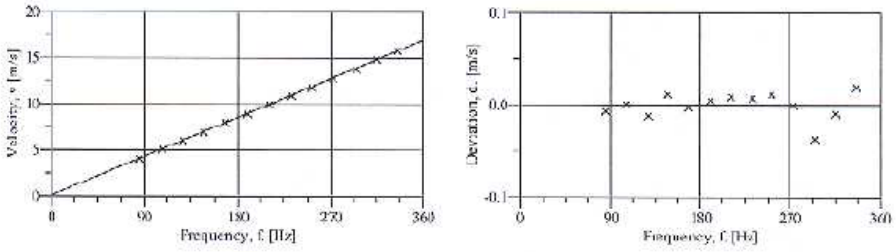
Standard uncertainty, slope: 0.00114 **Standard uncertainty, offset:** 0.07713

Covariance: -0.0000006 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999993$

Absolute maximum deviation: -0.036 m/s at 13.844 m/s

Barometric pressure: 1009.3 hPa **Relative humidity:** 27.6%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.65	33.4	25.5	4.112	85.1908	-0.007	0.021
4	14.95	33.3	25.5	5.119	106.6331	0.002	0.025
6	21.07	33.1	25.4	6.075	127.4800	-0.012	0.029
8	28.26	33.1	25.4	7.035	147.5747	0.012	0.033
10	36.34	33.0	25.4	7.977	168.1495	-0.003	0.037
12	45.88	33.0	25.4	8.962	189.1365	0.005	0.042
13-last	56.70	32.9	25.4	9.963	210.5526	0.009	0.046
11	68.46	33.0	25.4	10.948	231.7626	0.007	0.051
9	80.56	33.1	25.4	11.878	251.6408	0.012	0.055
7	94.56	33.1	25.4	12.870	273.2038	0.000	0.059
5	109.38	33.2	25.4	13.844	294.9135	-0.036	0.064
3	125.53	33.4	25.5	14.833	315.5930	-0.009	0.068
1-first	141.94	33.6	25.5	15.780	335.3141	0.020	0.073



DANAK
CAL Reg.nr. 452
Accreditation to ISO 17025

Figure C6. Post-test calibration sheet for the primary anemometer

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer DOE #: 03503C

Model # : Phaser-5-485-4A 20 S/N : 04607

Calibration Date: 10/20/2010 Due Date: 10/20/2012

A. Set-Up for Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.

Calibrator Output		Transducer Input/Output		
Current (AAC)	Power 2*V*I (W)	Input Current (AAC)	Input Power 2*n*V*I (W)	Analog Output-1 (VDC)
-9	-2160	N/A	N/A	.997
-8	-1920	"	"	1.078
-6	-1440	"	"	1.557
-4	-960	"	"	2.037
-2	-480	"	"	2.516
-1	-240	"	"	2.754
0	0	"	"	2.994
1	240	"	"	3.234
2	480	"	"	3.473
4	960	"	"	3.953
6	1440	"	"	4.432
8	1920	"	"	4.911
9	2160	"	"	4.991

Page 1 of 3

Figure C7. Page 1 of the power transducer calibration sheet

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03511C

Model # : PTB101B S/N : C1040008

Calibration Date: 09/27/2011 Due Date: 09/27/2012

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only
			As Found	As Left	
*	Absolute Pressure				
		65	0.270		
		70	0.543		
		75	0.814		
		80	1.086		
		85	1.357		
		90	1.629		
		95	1.901		
		100	2.173		
		103	2.337		
	Notes: 1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2. 2. Calibration was performed at 23°C and 43% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02301C and 128120.				

Calibrated By: P. Morse
Date: 09/27/2011

Approved By: Reda
Date: 09/27/2011

Figure C8. Calibration sheet for the pressure transducer

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD DOE #: 03465C

Model # : T200A S/N : 0603-1

Calibration Date: 10/20/2011 Due Date: 10/20/2012

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	-15	94.475	Same	
		0	100.372	"	
		15	106.236	"	
		30	112.060	"	
	Notes: - Calibration was performed using instruments that are traceable to NIST. DOE#s 124272, 108603, and 108604. - Calibration was performed at temperature = 22 °C, and relative humidity = 44%. - Uncertainty of nominal values = ± 0.03 °C with k = 2.				

Figure C9. Calibration sheet for the temperature sensor

Wind Vane Calibration Report

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Customer:
National Wind Technology Center - Certification Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Calibration Location:
National Wind Technology Center
Cert Lab

Calibration Date: 11-Oct-11

Report Number: W5515-111011

Page: 1 of 1

Procedure:
NWTC-CT: C104 Calibrate Wind Vane_091209.docx

Deviations from procedure:
Output of Wind vane was set for 5 Volts.Inclinometer out of calibration by 11 days.Inclinometer was sent out for a post cal.

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**W5515**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**71.96**	**deg/V**
Offset to boom:	**90.55**	**deg**
Max error:	0.90	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.51

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	5-Oct-11
Voltmeter:	HP 3458A	2823A05145	15-Sep-11

Calibration by: Mark Murphy — 11-Oct-11 Date

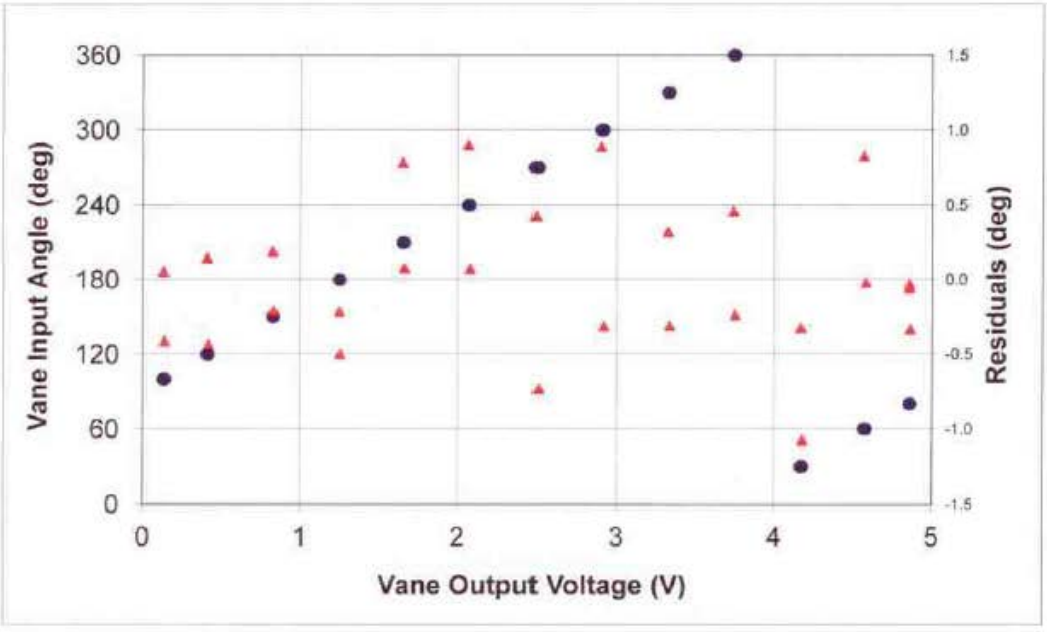


Figure C10. Calibration sheet for the wind vane

Calibration Performance Test Data

DUT Information

Type: NI 9205
Tracking Number: 04170C
Serial Number: 1496266
Notes: Verification only was performed.

Customer Information

Name: NATIONAL RENEWABLE EMERGY LAB.
Address: 16253 DENVER WEST PKWY. GOLDEN, CO 80401
Work Order: 490596
Notes:

Environmental Conditions

Temperature: 23.0 C
Humidity: 47.0 %

Operator Information

Operator Name: Wayne Getchell
Calibration Date: Tuesday, March 22, 2011 12:51:36
Notes:

Version Information

Calibration Executive Version: 3.4
Procedure Version: 3.0.0.1
NI-DAQmx 8.9

Standards used for Calibration

Type	Tracking Number	Calibration Due Date	Notes
Fluke 5700A Multifunction Calibrator	15-0048	5/4/2011	

Calibration Results

Analog Input

Calibration				As Found				As Left			
LowerRange	UpperRange	Channel	Test Value	Low Limit	Reading	High Limit	PassFail	Low Limit	Reading	High Limit	PassFail
-10 V	10 V	ai0	9.98000 V	9.97684 V	9.98025 V	9.98316 V	Passed	9.97684 V	9.98025 V	9.98316 V	Passed
-5 V	5 V	ai0	4.99000 V	4.98830 V	4.99012 V	4.99170 V	Passed	4.98830 V	4.99012 V	4.99170 V	Passed
-1 V	1 V	ai0	0.998000 V	0.997617 V	0.998024 V	0.998383 V	Passed	0.997617 V	0.998024 V	0.998383 V	Passed
-0.200 V	0.200 V	ai0	0.199600 V	0.199489 V	0.199609 V	0.199711 V	Passed	0.199489 V	0.199609 V	0.199711 V	Passed
-10 V	10 V	ai0	0.00000 V	-0.00141 V	-0.00010 V	0.00141 V	Passed	-0.00141 V	-0.00010 V	0.00141 V	Passed
-5 V	5 V	ai0	0.000000 V	-0.000718 V	-0.000031 V	0.000718 V	Passed	-0.000718 V	-0.000031 V	0.000718 V	Passed
-1 V	1 V	ai0	0.000000 V	-0.000168 V	-0.000005 V	0.000168 V	Passed	-0.000168 V	-0.000005 V	0.000168 V	Passed
-0.200 V	0.200 V	ai0	0.0000000 V	-0.0000559 V	0.0000029 V	0.0000559 V	Passed	-0.0000559 V	0.0000029 V	0.0000559 V	Passed
-0.200 V	0.200 V	ai0	-0.199600 V	-0.199711 V	-0.199604 V	-0.199489 V	Passed	-0.199711 V	-0.199604 V	-0.199489 V	Passed
-1 V	1 V	ai0	-0.998000 V	-0.998383 V	-0.998033 V	-0.997617 V	Passed	-0.998383 V	-0.998033 V	-0.997617 V	Passed
-5 V	5 V	ai0	-4.99000 V	-4.99170 V	-4.99012 V	-4.98830 V	Passed	-4.99170 V	-4.99012 V	-4.98830 V	Passed
-10 V	10 V	ai0	-9.98000 V	-9.98316 V	-9.98032 V	-9.97684 V	Passed	-9.98316 V	-9.98032 V	-9.97684 V	Passed

Figure C11. Calibration sheet for the signal conditioning module 1496266

CALIBRATION PERFORMANCE TEST DATA

DUT Information

Type:	NI 9205
Tracking Number:	2261870001
Serial Number:	1496266
Notes:	As Found Notes: Verification and adjustment were performed. ; As Left Notes: Verification and adjustment were performed.

Customer Information

Name:	National Renewable Energy Laboratory
Address:	16253 Denver West Parkway Golden, CO US 80401
Work Order:	101320
Notes:	

Environmental Conditions

Temperature:	73.0 F / 73.0 F
Humidity:	47.0 % / 47.0 %

Operator Information

Operator Name:	administrator
Calibration Date:	As Found Date: Thursday, August 16, 2012 18:15:13 ; As Left Date: Thursday, August 16, 2012 18:22:24
Notes:	

Version Information

Calibration Executive Version:	3.5 / 3.5
Procedure Version:	3.0.0.1 / 3.0.0.1
NI-DAQmx:	9.4.0 / 9.4.0

Standards used during Calibration

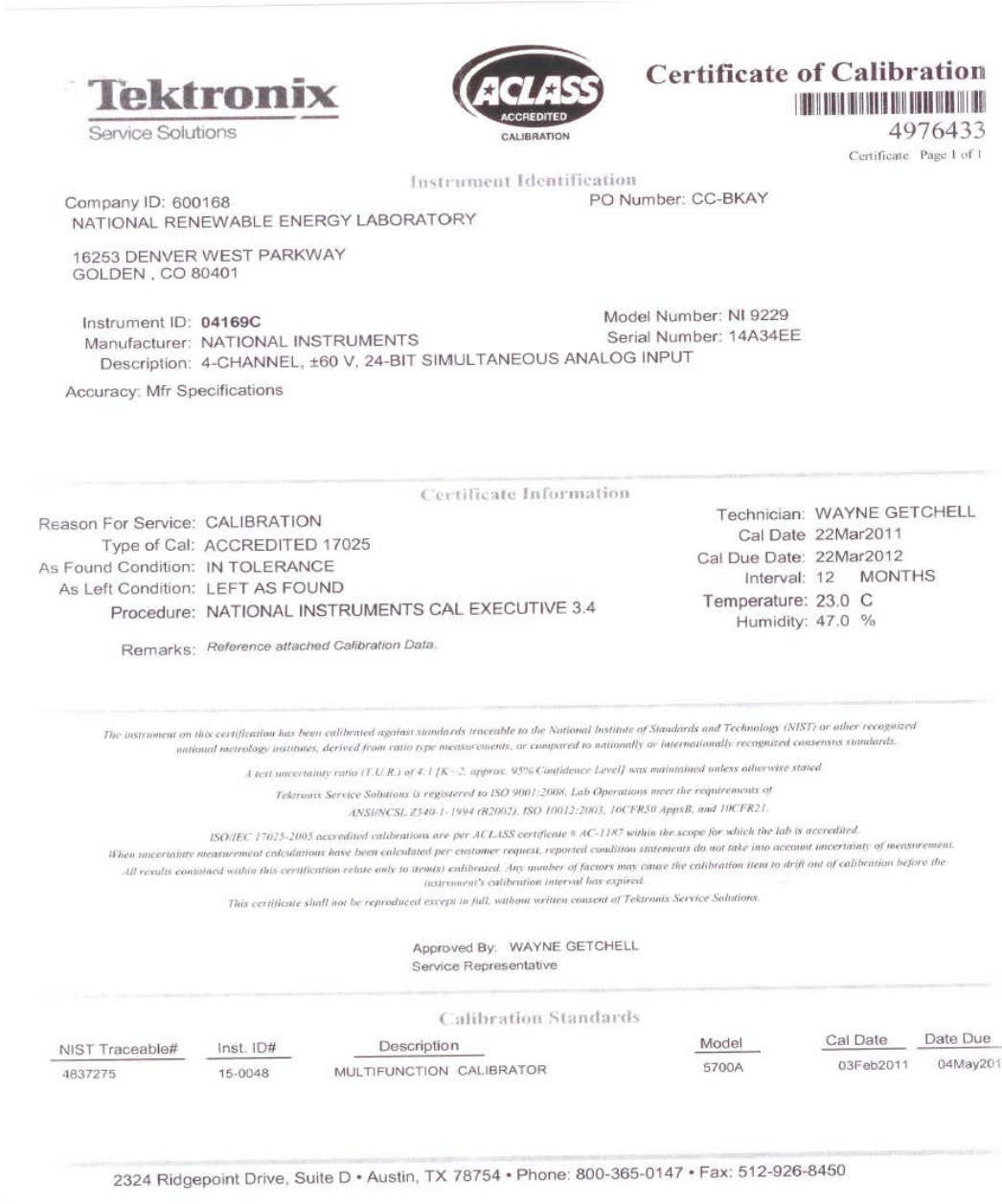
Type	Tracking Number	Calibration Due Date	Notes
Fluke 5700A Multifunction Calibrator	2250250103	11/10/2012	Used for As Found and As Left measurements.

Calibration Results

Analog Input

Calibration				As Found				As Left			
LowerRange	UpperRange	Channel	Test Value	Low Limit	Reading	High Limit	PassFail	Low Limit	Reading	High Limit	PassFail
-10 V	10 V	ai0	9.98000 V	9.97684 V	9.98005 V	9.98316 V	Passed	9.97684 V	9.98002 V	9.98316 V	Passed
-5 V	5 V	ai0	4.99000 V	4.98830 V	4.99000 V	4.99170 V	Passed	4.98830 V	4.99000 V	4.99170 V	Passed
-1 V	1 V	ai0	0.998000 V	0.997617 V	0.998015 V	0.998383 V	Passed	0.997617 V	0.998012 V	0.998383 V	Passed
-0.200 V	0.200 V	ai0	0.199800 V	0.199489 V	0.199607 V	0.199711 V	Passed	0.199489 V	0.199605 V	0.199711 V	Passed
-10 V	10 V	ai0	0.00000 V	-0.00141 V	-0.00005 V	0.00141 V	Passed	-0.00141 V	-0.00006 V	0.00141 V	Passed
-5 V	5 V	ai0	0.000000 V	-0.000718 V	-0.000026 V	0.000718 V	Passed	-0.000718 V	-0.000025 V	0.000718 V	Passed
-1 V	1 V	ai0	0.000000 V	-0.000168 V	0.000002 V	0.000168 V	Passed	-0.000168 V	0.000001 V	0.000168 V	Passed
-0.200 V	0.200 V	ai0	0.0000000 V	-0.0000559 V	0.0000053 V	0.0000559 V	Passed	-0.0000559 V	0.0000053 V	0.0000559 V	Passed
-0.200 V	0.200 V	ai0	-0.199800 V	-0.199711 V	-0.199596 V	-0.199489 V	Passed	-0.199711 V	-0.199596 V	-0.199489 V	Passed
-1 V	1 V	ai0	-0.998000 V	-0.998383 V	-0.998000 V	-0.997617 V	Passed	-0.998383 V	-0.998005 V	-0.997617 V	Passed
-5 V	5 V	ai0	-4.99000 V	-4.99170 V	-4.99001 V	-4.98830 V	Passed	-4.99170 V	-4.99002 V	-4.98830 V	Passed
-10 V	10 V	ai0	-9.98000 V	-9.98316 V	-9.98007 V	-9.97684 V	Passed	-9.98316 V	-9.98006 V	-9.97684 V	Passed

Figure C12. Post-test calibration sheet for the signal conditioning module 1496266



Tektronix
Service Solutions

ACCREDITED
CALIBRATION

Certificate of Calibration

4976433

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04169C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 14A34EE

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4

Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure C13. Calibration sheet for the signal conditioning module 14A34EE

CALIBRATION PERFORMANCE TEST DATA

DUT Information

Type:	NI 9229
Tracking Number:	2261870002
Serial Number:	14A34EE
Notes:	Verification only was performed

Customer Information

Name:	National Renewable Energy Laboratory
Address:	16253 Denver West Parkway Golden, CO US 80401
Work Order:	101320
Notes:	

Environmental Conditions

Temperature:	75.6 F
Humidity:	47.0 %

Operator Information

Operator Name:	administrator
Calibration Date:	Thursday, August 16, 2012 18:28:09
Notes:	

Version Information

Calibration Executive Version:	3.5
Procedure Version:	3.3.0.0
NI-DAQmx:	9.4.0

Standards used during Calibration

Type	Tracking Number	Calibration Due Date	Notes
Fluke 5730A Multifunction Calibrator	2250250103	11/10/2012	

Calibration Results

Analog Input

Calibration			As Found				As Left			
Channel	Range	Test Value	Low Limit	Reading	High Limit	Pass/Fail	Low Limit	Reading	High Limit	Pass/Fail
ai0	60 V	57.0000 V	56.9695 V	57.0015 V	57.0305 V	Passed	56.9695 V	57.0015 V	57.0305 V	Passed
ai0	60 V	0.00000 V	-0.00766 V	-0.00050 V	0.00766 V	Passed	-0.00766 V	-0.00050 V	0.00766 V	Passed
ai0	60 V	-57.0000 V	-57.0305 V	-57.0005 V	-56.9695 V	Passed	-57.0305 V	-57.0005 V	-56.9695 V	Passed
ai1	60 V	57.0000 V	56.9695 V	57.0033 V	57.0305 V	Passed	56.9695 V	57.0033 V	57.0305 V	Passed
ai1	60 V	0.00000 V	-0.00766 V	0.00037 V	0.00766 V	Passed	-0.00766 V	0.00037 V	0.00766 V	Passed
ai1	60 V	-57.0000 V	-57.0305 V	-57.0003 V	-56.9695 V	Passed	-57.0305 V	-57.0003 V	-56.9695 V	Passed
ai2	60 V	57.0000 V	56.9695 V	56.9974 V	57.0305 V	Passed	56.9695 V	56.9974 V	57.0305 V	Passed
ai2	60 V	0.00000 V	-0.00766 V	0.00023 V	0.00766 V	Passed	-0.00766 V	0.00023 V	0.00766 V	Passed
ai2	60 V	-57.0000 V	-57.0305 V	-56.9949 V	-56.9695 V	Passed	-57.0305 V	-56.9949 V	-56.9695 V	Passed
ai3	60 V	57.0000 V	56.9695 V	56.9988 V	57.0305 V	Passed	56.9695 V	56.9988 V	57.0305 V	Passed
ai3	60 V	0.00000 V	-0.00766 V	-0.00070 V	0.00766 V	Passed	-0.00766 V	-0.00070 V	0.00766 V	Passed
ai3	60 V	-57.0000 V	-57.0305 V	-56.9983 V	-56.9695 V	Passed	-57.0305 V	-56.9983 V	-56.9695 V	Passed

Figure C14. Post-test calibration sheet for the signal conditioning module 14A34EE

Calibration Performance Test Data

DUT Information

Type: NI 9217
Tracking Number: 04171C
Serial Number: 1494F69
Notes: Verification only was performed.

Customer Information

Name: NATIONAL RENEWABLE EMERGY LAB.
Address: 16253 DENVER WEST PKWY. GOLDEN, CO 80401
Work Order: 490596
Notes:

Environmental Conditions

Temperature: 23.0 C
Humidity: 47.0 %

Operator Information

Operator Name: Wayne Getchell
Calibration Date: Tuesday, March 22, 2011 12:58:18
Notes:

Version Information

Calibration Executive Version: 3.4
Procedure Version: 3.3.1.0
NI-DAQmx 8.9

Standards used for Calibration

Type	Tracking Number	Calibration Due Date	Notes
HP 3458A Digital Multimeter	A144598	5/24/2011	
GENERAL RADIO 1433-F	15-0020	10/26/2011	
GENERAL RADIO 1433-F	15-0020	10/26/2011	
GENERAL RADIO 1433-F	15-0020	10/26/2011	

Calibration Results

Verify Resistance

Calibration				As Found				As Left			
LowerRange	UpperRange	Channel	Test Value	Low Limit	Reading	High Limit	PassFail	Low Limit	Reading	High Limit	PassFail
0 Ohm	400 Ohm	0	350.0080 Ohm	349.9482 Ohm	350.0202 Ohm	350.0677 Ohm	Passed	349.9482 Ohm	350.0202 Ohm	350.0677 Ohm	Passed
0 Ohm	400 Ohm	1	350.0074 Ohm	349.9476 Ohm	350.0234 Ohm	350.0671 Ohm	Passed	349.9476 Ohm	350.0234 Ohm	350.0671 Ohm	Passed
0 Ohm	400 Ohm	2	350.0074 Ohm	349.9476 Ohm	350.0178 Ohm	350.0671 Ohm	Passed	349.9476 Ohm	350.0178 Ohm	350.0671 Ohm	Passed
0 Ohm	400 Ohm	3	350.0081 Ohm	349.9483 Ohm	350.0266 Ohm	350.0678 Ohm	Passed	349.9483 Ohm	350.0266 Ohm	350.0678 Ohm	Passed
0 Ohm	400 Ohm	0	100.0011 Ohm	99.9851 Ohm	100.0045 Ohm	100.0171 Ohm	Passed	99.9851 Ohm	100.0045 Ohm	100.0171 Ohm	Passed
0 Ohm	400 Ohm	1	99.9996 Ohm	99.9836 Ohm	100.0062 Ohm	100.0156 Ohm	Passed	99.9836 Ohm	100.0062 Ohm	100.0156 Ohm	Passed

Figure C15. Calibration sheet for the signal conditioning module 1494F69

CALIBRATION PERFORMANCE TEST DATA

DUT Information

Type:	NI 9217
Tracking Number:	2261870003
Serial Number:	1494F69
Notes:	Verification only was performed

Customer Information

Name:	National Renewable Energy Laboratory
Address:	16253 Denver West Parkway Golden, CO US 80401
Work Order:	101320
Notes:	

Environmental Conditions

Temperature:	72.5 F
Humidity:	51.0 %

Operator Information

Operator Name:	administrator
Calibration Date:	Wednesday, August 15, 2012 18:55:12
Notes:	

Version Information

Calibration Executive Version:	3.5
Procedure Version:	3.3.1.0
NI-DAQmx:	9.4.0

Standards used during Calibration

Type	Tracking Number	Calibration Due Date	Notes
HP 3458A Digital Multimeter	2182620007	8/23/2012	
RS925	2062190012	1/5/2013	
RS925	2062190010	1/5/2012	
RS925	2062190010	1/5/2013	

Calibration Results

Verify Resistance

Calibration				As Found				As Left			
LowerRange	UpperRange	Channel	Test Value	Low Limit	Reading	High Limit	PassFail	Low Limit	Reading	High Limit	PassFail
0 Ohm	400 Ohm	0	349.9596 Ohm	349.8999 Ohm	349.9789 Ohm	350.0194 Ohm	Passed	349.8999 Ohm	349.9789 Ohm	350.0194 Ohm	Passed
0 Ohm	400 Ohm	1	349.9596 Ohm	349.8999 Ohm	349.9811 Ohm	350.0194 Ohm	Passed	349.8999 Ohm	349.9811 Ohm	350.0194 Ohm	Passed
0 Ohm	400 Ohm	2	349.9596 Ohm	349.8999 Ohm	349.9787 Ohm	350.0194 Ohm	Passed	349.8999 Ohm	349.9787 Ohm	350.0194 Ohm	Passed
0 Ohm	400 Ohm	3	349.9596 Ohm	349.8999 Ohm	349.9843 Ohm	350.0194 Ohm	Passed	349.8999 Ohm	349.9843 Ohm	350.0194 Ohm	Passed
0 Ohm	400 Ohm	0	99.9968 Ohm	99.9808 Ohm	99.9941 Ohm	100.0128 Ohm	Passed	99.9808 Ohm	99.9941 Ohm	100.0128 Ohm	Passed
0 Ohm	400 Ohm	1	99.9968 Ohm	99.9808 Ohm	99.9954 Ohm	100.0128 Ohm	Passed	99.9808 Ohm	99.9954 Ohm	100.0128 Ohm	Passed

Figure C16. Post-test calibration sheet for the signal conditioning module 1494F69