MR-16 LED REPLACEMENT LAMPS:

ELECTRICAL COMPATIBILITY AND PERFORMANCE

CALIFORNIA LIGHTING TECHNOLOGY CENTER

CALIFORNIA LIGHTING TECHNOLOGY CENTER

PREPARED FOR:

Pacific Gas and Electric Company
Codes & Standards

245 Market Street
Mail Code N6G, P.O. Box 770000
San Francisco, CA 94177-0001

PREPARED BY:

Daniel Stuart
Development Engineer

Nicole Graeber
Project Manager

Keith Graeber
Director of Engineering

Michael Siminovitch
Principal Investigator

California Lighting Technology Center
University of California, Davis
633 Peña Drive
Davis, CA 95618

cltc.ucdavis.edu

ABOUT CLTC

California Lighting Technology Center's mission is to stimulate the development and application of energy-efficient lighting by conducting technology development and demonstrations, outreach and educational activities, in partnership with lighting manufacturers, lighting professionals, the electric utility community, and governmental agencies. CLTC was established as a collaborative effort between the California Energy Commission and UC Davis, with support by the U.S. Department of Energy and the National Electrical Manufacturers Association (NEMA).

TABLE OF CONTENTS

TABLES

FIGURES

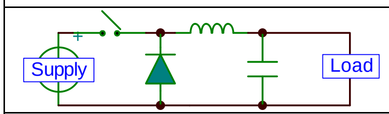
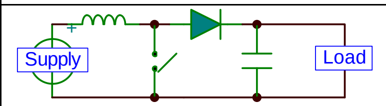
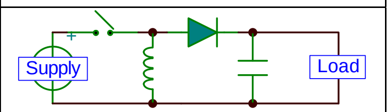
1.0 INTRODUCTION

As light emitting diode (LED) MR-16 lamps become more prevalent in the commercial market, both residential and commercial end-users are considering these lamps as replacements for currently installed halogen incandescent MR-16 sources. While the energy savings associated with LED lamp replacements is evident, the compatibility of LED MR-16 lamps with existing electrical hardware is not. In one-to-one lamp retrofits, MR-16 LED lamps often demonstrate negative performance characteristics such as visible flicker and audible humming. Generally, these issues are linked to the use of an LED lamp combined with a dimmer or electronic low-voltage transformer. Because of these types of performance issues, and in an effort to better understand the current state of the MR-16 LED replacement lamp market, Pacific Gas and Electric (PG&E) funded the California Lighting Technology Center (CLTC) to evaluate a cross-section of lamps from the LED MR-16 product category for their electrical compatibility with application-appropriate, low-voltage transformers and phase-cut dimmers.

2.0 BACKGROUND

To address LED MR-16 lamp electrical compatibility issues, manufacturers have devised a number of LED driver circuit-design strategies. Three main driver topologies used with MR-16 LED lamps are defined by their switched mode power supply (SMPS) component: buck, boost, and buck-boost. Table 1 provides descriptions of each driver topology. By identifying the type of driver topology LED MR-16 lamps use, and evaluating the lamps when operated with various types of low-voltage transformers and phase-cut dimmers, a correlation can potentially be made between the topology type and lamp performance.

Table 1 – Typical LED MR-16 lamp driver topologies

Buck	Boost	Buck-Boost
		
Output voltage that is less than input voltage	Output voltage that is more than input voltage	Output voltage that can be more or less than input voltage

Two general types of transformers exist: magnetic low voltage transformers (MLVT) and electronic low voltage transformers (ELVT). Magnetic transformers have been replaced by electronic transformers, which are typically lighter, less expensive, and more energy efficient. MLVTs utilize a relatively simple design as compared to ELVTs. MLVTs typically consist of copper coils surrounded by an inductive core. ELVT use a switching converter circuit that consists of a combination of inductors, capacitors, and switching components to reduce the voltage. This results in an output waveform that is a 30,000-100,000 Hz oscillation within a 120 Hz sine wave envelope.[1]

Halogen lamps are the traditional light source used with both transformer types. Flicker and noise problems associated with LED MR-16 lamps are linked to the lower power consumption of the LED MR-16 lamps as compared to halogen MR-16 lamps. Transformers were designed to operate with the larger, linear load associated with halogen lamps. Traditional ELVTs require a significantly larger load than the LED MR-16 lamp can deliver to start the oscillating circuitry after the signal zero crossing of the envelope sine wave.

For LED MR-16 lamps paired with an ELVT, turning on at each half cycle and remaining on for the duration of the half cycle is difficult and results in the observed negative performance characteristics of visual flicker and audible humming. The use of a dimmer further reduces the lamp power consumption, resulting in a longer required timeframe before sufficient load can be generated to stabilize the system's performance.

An ELVT paired with an LED MR-16 lamp is illustrated in Figure 1. The green and purple wave have prolonged periods of zero magnitude represented by the horizontal (flat) portion of the signal. There is a time delay after the input voltage (yellow) crosses zero before sufficient load is generated to start the ELVT oscillation. This delay is often the cause of the visible flicker and humming.

---

[1] Najmi, Kamal. Low-voltage LED lamps present unique driver challenge. LEDs Magazine. Feb, 2012. www.ledsmagazine.com/features/9/2/10

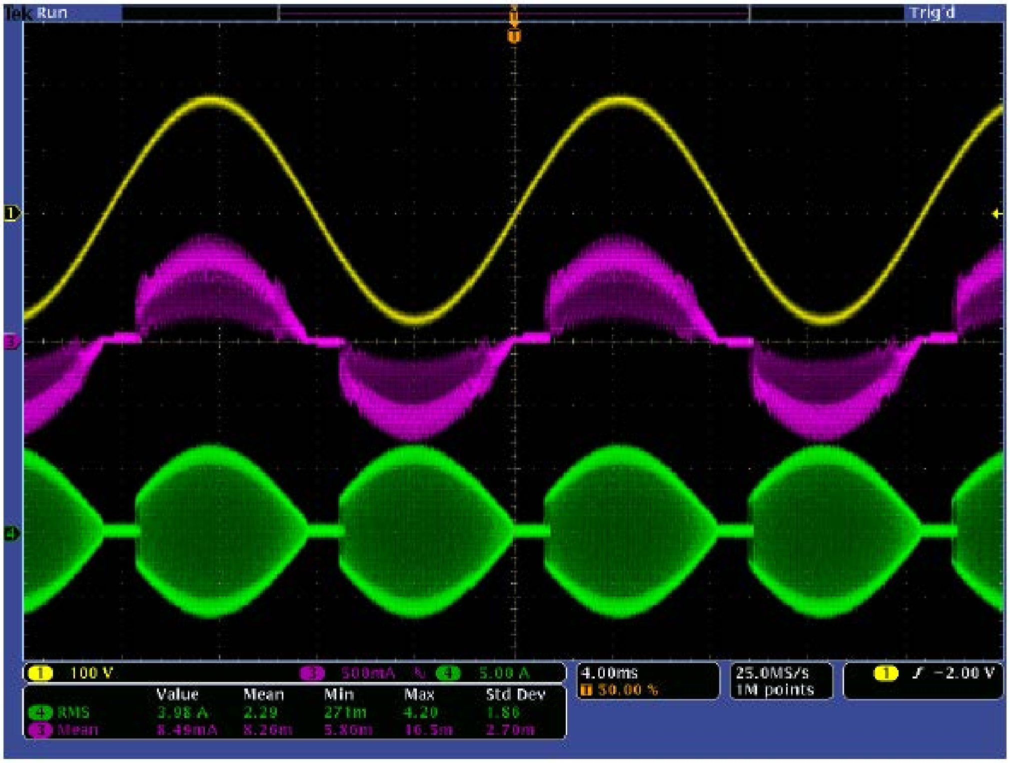


Figure 1 – ELVT and Halogen MR-16 lamp system functionality for timeframe before sufficient load is generated.[2] *Zero reference for each waveform is identified by respective arrows (arrow and waveform color match) on left side of image.*

[2] Najmi, Kamal. Low-voltage LED lamps present unique driver challenge. LEDs Magazine. Feb, 2012. www.ledsmagazine.com/features/9/2/10

3.0 METHODOLOGY

The test methodology to determine compatibility between low-voltage transformers, phase-cut dimmers and LED MR-16 lamps consists of four basic steps.

1. Identify and procure a cross-section of commercially available LED MR-16 lamps
2. Deconstruct one lamp per product sample set to identify its electrical circuit architecture
3. Conduct electrical characterization tests of the deconstructed and additional lamps in the sample set when operated in combination with select transformers and dimmers
4. Compare circuit topology and transformer/dimmer combination to performance to determine overall product compatibility

3.1 COMPONENT SELECTION AND PROCUREMENT

There are many different types of LED MR-16 lamps and low voltage transformers. This methodology and testing focuses on 12 Volt Alternating Current (VAC) LED MR-16 lamps with GU5.3 bases. Twenty products were selected for testing to represent the current commercial offering of LED MR-16 lamps. Five samples of each product were procured to allow for the deconstruction and testing activities described below.

MLVTs for use with MR-16 lamps consist of a transformer with two sets of copper coils surrounding a ferrite core. The resulting output has the same waveform as the input 120 VAC, but at 12 VAC.

Two ELVT were selected for inclusion in the compatibility evaluation with LED MR-16 lamps (Table 2). The “A Electronic” transformer had the broadest lamp compatibility of transformers considered. It has an input voltage of 120 VAC, a nominal output voltage of 11.5 Volts, and is marketed as being for LED lamps. The “B Electronic” transformer has more manufacturer listed lamp incompatibilities than the other transformers considered. It has a rated input voltage of 120 V, a rated output voltage of 11.7 Volts, and is marketed as being for halogen lamps.

Table 2 – Transformer types selected for testing

Transformer Types
A Electronic
B Electronic
Magnetic

Two types of dimmers were selected for use in this work. The products are a forward phase (marketed as for electronic transformers) and reverse phase (marketed as for magnetic transformers) control unit (Table 3).

Table 3 – Dimmer types selected for testing

Dimmer Types
Reverse phase control
Forward phase control

3.2 LAMP DECONSTRUCTION

To identify the driver topology used in each selected product, each lamp was deconstructed into its integral parts. To reveal the circuit board, fasteners, lenses and potting compound encasing the circuit boards was removed (Figure 2). With the circuit board revealed, the driver integrated circuit (IC) was identified based on the "top code", or the markings printed/etched onto the chip. With the model and manufacturer identified, datasheets for the IC were referenced to identify the specifications of the driver, and the type of SMPS used. As discussed in Section 2.0, SMPS types include: buck, boost, and buck-boost. Some driver ICs are designed to be set up in multiple SMPS configurations. For these drivers, the reference circuit diagrams in the specification sheets were utilized. Based on these diagrams, continuity is checked between the IC pins that would correspond to each of the possible topologies to determine which was used.

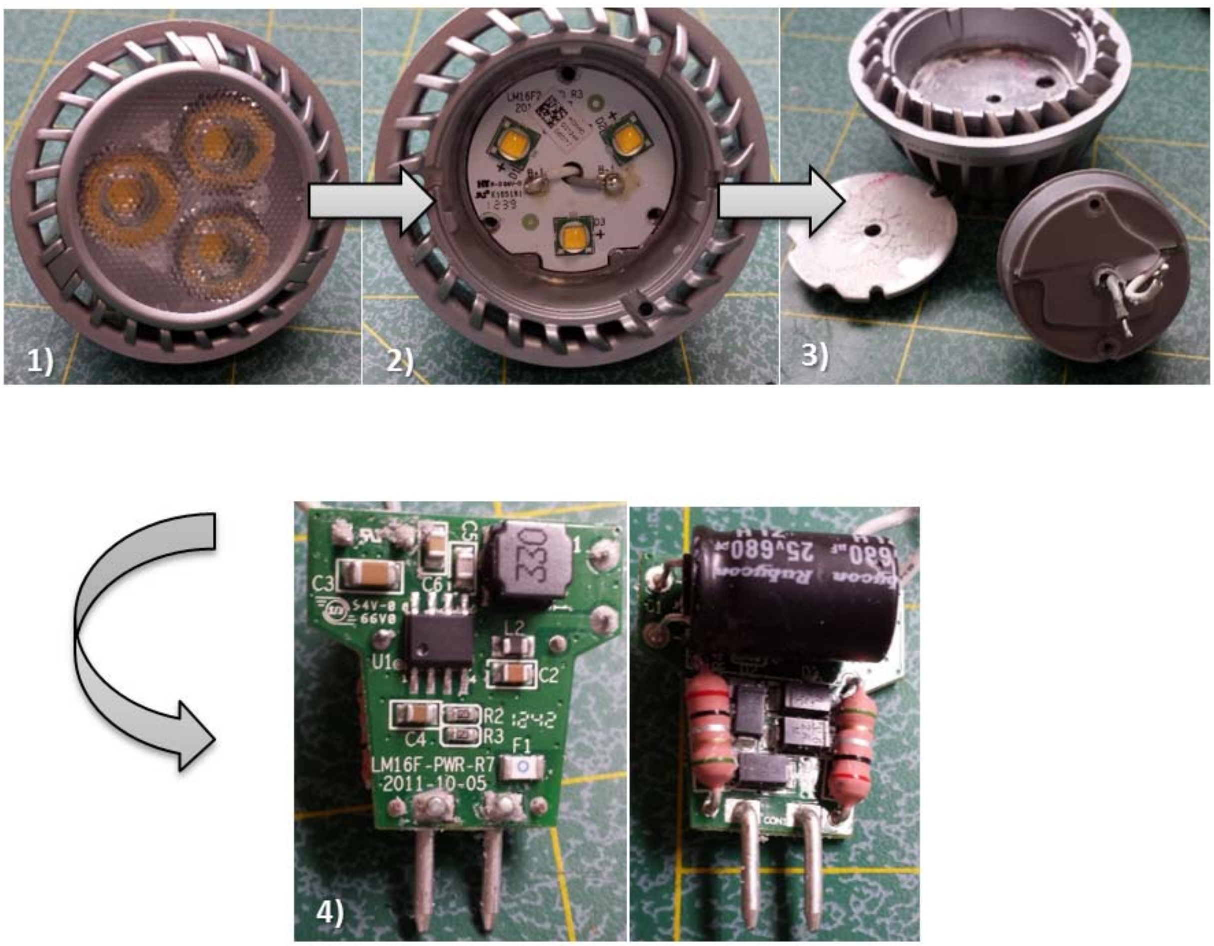


Figure 2 – Lamp deconstruction: 1) Lens removed. 2) LED board leads de-soldered. 3) Driver board encased in potting compound removed from heat sink. 4) Potting compound removed, both sides of board illustrated.

For lamps where deconstruction activities did not reveal what type of switching circuit was used, manufacturers were contacted by CLTC staff to discuss participation in the project and the details of their design. CLTC also reached out to NEMA to identify transformer manufacturers that would be appropriate for contributing design and compatibility information beyond manufacturer specification sheets.

3.3 ELECTRICAL TESTING METHODS

The electrical test procedure focuses on evaluating the compatibility of LED MR-16 replacement lamps in combination with both MLVT and ELVT transformers and dimmers to characterize the electrical traits of the systems such as the system efficiency and the efficiencies of each subsystem. There are four subsystems of interest, shown in Figure 3: the dimmer, transformer, driver, and LED package. To understand each subsystem and the interactions between these subsystems, it is necessary to measure the electrical characteristics downstream of each subsystem by capturing voltage and current simultaneously between each.

As shown in Figure 3, there are two sets of measurements points (A3, V3, A4, and V4) after the transformer and before the driver: measurement point three characterizes the load from all four devices under test, and measurement point four isolates the single deconstructed lamp.

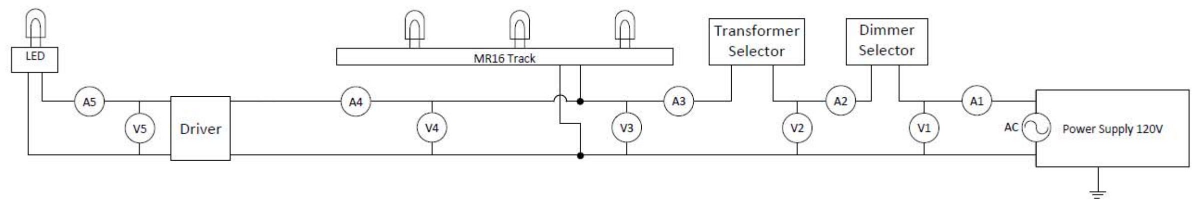


Figure 3 – Electrical testing measurement diagram. A1-A5 and V1-V5 refer to the current and voltage measurement points for the data acquisition system

To prepare each deconstructed lamp for testing, the lens of the lamp was removed to access the lamp's LED package and lead wires from the driver. To allow for measurements between these components, these wires are de-soldered to separate the LED package from the driver. Lead wires are then soldered onto both the LED package and driver as shown in Figure 4.

The data acquisition system described in section 3.3.2 "Testing Apparatus" logs and stores each voltage and current measurement. Test results and data analysis will be provided in the final version of this report.

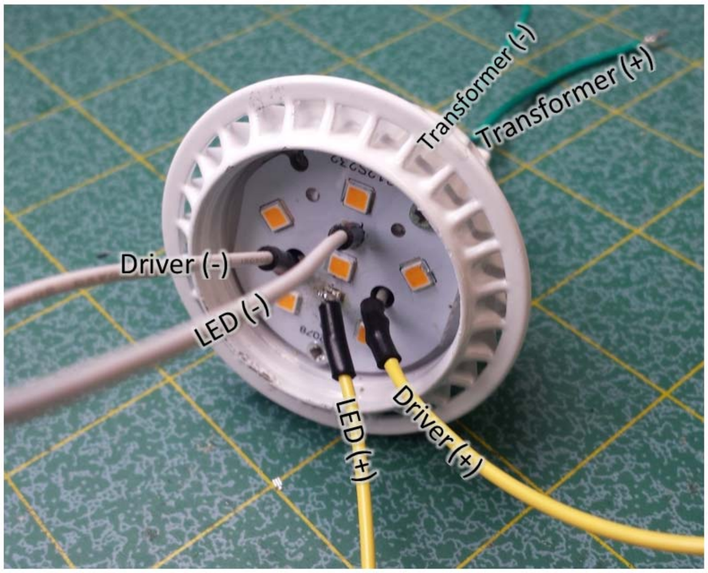


Figure 4 – Deconstructed lamp prepared for testing

3.3.1 TEST SAMPLE CONFIGURATIONS

The electrical characteristics of each subsystem will be characterized when operating with a variety of transformers, dimmers, and dimming levels. The following configurations will be tested: 20 lamps (**Error! Reference source not found.**), three transformers (Table 2), two dimmer options (Table 3) plus operation with no dimmer, two configurations of varying lamp quantities of each product tested (Table 4), and two dimming levels (Table 5). This yields 30 different test combinations for each of the 20 lamps resulting in 600 overall test combinations.

Table 4 – Lamp testing configurations

Configuration 1	Configuration 2
1 Lamp	4 Lamps

Table 5 – Dimming levels selected for testing

Dimming Level 1	Dimming Level 2
100% Power	50% Power

3.3.2 TESTING APPARATUS

The testing apparatus for this evaluation was built with quick connections to allow for switching between lamps, transformers and dimmer components (Figure 5). The testing apparatus is equipped with measurement devices at the locations described in Figure 3.

Figure 5 – MR-16 Electrical characterization measurement testing apparatus

Electrical measurements were taken using a National Instruments CompactDAQ chassis with voltage and current measuring modules. The combination of modules allowed for all five sets of voltage and current measurements to be taken simultaneously (see section 3.3.1). The NI 9223 module was used for locations 3 and 4 to capture the high frequency response of the electric transformers. The NI 9225 and NI 9227 where used at the other locations where less bandwidth is needed. In addition to the summary Table 6 and 7, specification sheets for all measurement equipment are included in the appendix of this report.

Table 6 – Data acquisition module specifications

Module	Measurement Locations	Range	Gain error (typical)	Offset error (typical)
NI 9223	A3,V3,A4,V4	±10V, 1MS/s	0.02%	0.01%
NI 9225	V1,V2,V5	±300V_{rms} range, 50kS/s	0.05%	0.008%
NI 9227	A1,A2,A5	±5A_{rms}, 50kS/s	0.1%	0.05%

Signal conditioning is required to translate the signal levels to the appropriate range for use with the NI 9223. For current measurements, high precision current transformers in conjunction with precision current shunts were used. To step down the voltage, voltage divider-type attenuators were constructed from precision resistors. All resistors were characterized to create calibration curves for the instruments. Table 7 includes specification for the current transformer.

Table 7 – Current transformer specification

Model	Bandwidth	Basic Accuracy	Measurement Range
ZES Zimmer PSU60	0-800 kHz	0.02%	60 A

Software to control the data acquisition hardware was built in LabVIEW. It collects waveforms of voltage and current at the five subsystem locations identified in Figure 3 for a total of ten measurements, with collection rate and duration for each location given in Table 8. The collected waveforms are then reduced to determine factors like power, power factor, and harmonic distortion.

Table 8 – Data acquisition specification

Location	Collection Rate	Collection Duration
3,4	1 MS/s	1 second
1,2,5	50 kS/s	1 second

3.3.3 ELECTRICAL EFFICIENCY DATA REDUCTION

One of the methods employed to quantify the performance of the LED MR-16 lamps when paired with different transformer and dimmer combinations, was to consider the efficiencies of the various sub-systems (Figure 3). To determine the efficiency of each sub-system, first the power for each sub-system was calculated. To do this, the voltage and current waveforms are multiplied together, the product is integrated using the trapezoidal method, and then divided by the time duration to achieve average power (Eq. 1).

$$P_{avg}=\frac{1}{t2-t1}\int_{t1}^{t2}V(t)I(t)dt \qquad (1)$$

The efficiency of each subsystem was calculated by dividing the power out of the system by the power in to the system (e.g. the power out of the dimmer divided by the power in to the transformer) (Eq. 2, Figure 3).

$$\eta=\frac{P_{out}}{P_{in}} \qquad (2)$$

System efficiency is calculated differently for the one-lamp configuration and the four-lamp configuration based on the way the system measurements are collected. The system efficiency for the one-lamp configuration is calculated as the driver power divided by the supply power. The system efficiency for the four-lamp configuration is based on the supply power which corresponds to that drawn by four lamps and the driver power for a single lamp. The system efficiency for the four-lamp configuration is the transformer power divided by the supply power, and multiplied by the driver efficiency measured for the single lamp.

For the overall system and each sub-system, average efficiencies are calculated for each configuration of each test dimension (dimmer type, dim level, transformer type, lamp number, and driver topology) as shown in Eq. 3. For example, the effect of the dim level test dimension is determined by averaging the efficiencies calculated for all test conditions at each of the dim level configurations (50% and 100%). The percent difference between the condition of maximum efficiency and minimum efficiency is then calculated to understand the significance of variations in that parameter.

$$\eta_{avg\ of\ test\ configuration} = \frac{\sum_{(test\ conditions)\in(test\ configuration)}(\eta_{test\ condition})}{n((test\ conditions)\in(test\ configuration))} \quad (3)$$

3.4 VISIBLE FLICKER TESTING METHODS

The second method employed to quantify the performance of the LED MR-16 lamps with paired with different transformer and dimmer combinations was to consider the severity of visible flicker. Each combination of lamp/transformer/dimmer was observed by one test operator, who recorded the severity of the visible flicker. Observations were made for five seconds at startup. These observations were made separately from the stabilized electrical measurements. This was done to reduce the test time so that a single operator could perform all of the observations. This was to avoid potential issues with different operators having different levels of flicker sensitivity. A scale of zero to four is used to record the severity of the visible flicker (Table 9), with zero corresponding to 'no visible flicker', one corresponding to 'faint visible flicker', two corresponding to 'visible flicker', three corresponding to 'strong visible flicker' and four corresponding to the lamp turning off when the operator has energized the lamp.

Table 9 – Visible flicker severity key

Flicker Level	Severity Value
0	No Visible Flicker
1	Faint Visible Flicker
2	Visible Flicker
3	Strong Visible Flicker
4	Lamp turns off

3.4.1 VISIBLE FLICKER ANALYSIS METHODS

Correlations between visible flicker severity and the specific test dimensions (lamp, number of lamps, dimmer, dim level, and transformer) were calculated to understand how important each test dimension was to visible flicker severity. First, visible flicker severity for each test condition is summed over all of the lamps (Eq. 4).

$$Visible\ Flicker\ Severity_{test\ condition} = \sum_{all\ lamps} visible\ flicker\ severity_{lamp} \quad (4)$$

Next, the average visible flicker severity for each configuration within each test dimension is calculated (Eq. 5).

$$Average\ Visible\ Flicker\ Severity_{test\ configuration} = \frac{\sum_{(test\ conditions)\in(test\ configuration)}(visible\ flicker\ severity_{lamp})}{n((test\ conditions)\in(test\ configuration))} \quad (5)$$

The average visible flicker severities for each configuration are then compared with each other within each test dimension by dividing the average flicker severity by the maximum flicker severity within each test dimension (Eq. 6).

$$Ratio\ of\ Visible\ Flicker\ Severity_{test\ configuration} = \frac{Average\ Visible\ Flicker\ Severity_{test\ configuration}}{\max(Average\ Visible\ Flicker\ Severity_{test\ dimension})} \quad (6)$$

The greatest difference in visible flicker performance is then calculated by taking the normalized ratio of the smallest flicker severity to largest. Lastly, the difference in visible flicker performance is ranked to understand which test dimension has the largest contribution to flicker.

4.0 RESULTS

The results of the lamp deconstruction, electrical testing and visible flicker testing identifying the driver topology for each lamp, the system efficiencies and the corresponding visible flicker severity are provided in this section.

4.1 DRIVER TOPOLOGY

Through the deconstruction of lamps, the driver ICs were identified based on their top codes. The lamp products, the associated driver and the corresponding driver topology is provided in Table 10. Twelve products utilized buck topology, which was the most prevalent among the products examined. Four products utilized the boost topology, which was the least common type of IC topology in the sample set. Three products utilized a buck-boost topology, and one product's IC topology could not be identified. CLTC was unable to get confirmation on the identity (and hence also the topology) of a few of the drivers with ambiguous markings. These are identified with an asterisk.

Table 10 – Lamp product driver ICs and topologies

Lamp	Driver	Topology
1	a	Buck
2	b*	Boost
3	c	Buck
4	d	Buck
5	e	Buck
6	Discrete Electrical Circuit Components	Unknown
7	f	Boost
8	a	Buck
9	f	Buck-Boost
10	Unidentifiable	Boost
11	g	Buck
12	h*	Buck
13	g	Buck
14	h*	Buck
15	i	Buck
16	g	Buck
17	j	Buck-Boost
18	k*	Buck
19	l	Boost
20	f	Buck-Boost

4.2 FAILED LAMPS

During electrical testing, failures occurred for two of the lamp products. The lamp 6 lamp twice rendered the “A Electronic” transformer inoperable, and two of the lamp 14 lamps stopped producing light during testing. Due to these failures, testing was not completed on these products. The products were omitted from the results section.

4.3 ELECTRICAL EFFICIENCY

As described in equation 6, efficiency is calculated using the ratio of the power-out to power-in. Efficiencies for the overall system and each subsystem for all test conditions are given in Table 11. For all dimmer and transformer test conditions, the average overall efficiency was calculated. Eighteen products are provided in Table 11.

Table 11 – Efficiencies for overall system and each sub-system for all test conditions

		Dim Level			100%																		50%												Avg Efficiency
		Transformer			A Electronic						Magnetic						B Electronic						A Electronic				Magnetic				B Electronic				
		Dimmer			None		Reverse		Forward		None		Reverse		Forward		None		Reverse		Forward		Reverse		Forward		Reverse		Forward		Reverse		Forward		
		Number of Lamps			4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	
	Lamp	Driver	Topology	Electronic Transformer Compatibility																															
System	2	b*	boost*	not mentioned*	0.77	0.57	0.76	0.70	0.77	0.73	0.64	0.43	0.64	0.43	0.64	0.44	0.76	0.74	0.76	0.70	0.76	0.72	0.73	0.62	0.73	0.66	0.62	0.43	0.63	0.45	0.73	0.65	0.72	0.66	0.65
	4	d	buck	not mentioned	0.77	0.65	0.76	0.60	0.76	0.65	0.58	0.31	0.60	0.33	0.59	0.33	0.79	0.73	0.78	0.67	0.78	0.68	0.75	0.61	0.73	0.60	0.60	0.48	0.64	0.46	0.77	0.62	0.77	0.67	0.64
	9	f	buckBoost	yes	0.75	0.73	0.75	0.69	0.75	0.72	0.63	0.40	0.62	0.42	0.63	0.41	0.73	0.72	0.71	0.68	0.70	0.71	0.69	0.62	0.70	0.66	0.60	0.45	0.60	0.45	0.67	0.62	0.63	0.62	0.64
	10	Unidentifiable	boost	NA	0.71	0.73	0.69	0.70	0.69	0.71	0.61	0.49	0.60	0.49	0.61	0.49	0.67	0.68	0.66	0.66	0.67	0.67	0.61	0.61	0.62	0.63	0.53	0.49	0.51	0.48	0.58	0.57	0.55	0.53	0.61
	7	f	boost	yes	0.73	0.70	0.72	0.65	0.73	0.65	0.59	0.38	0.59	0.39	0.59	0.38	0.71	0.67	0.71	0.63	0.70	0.65	0.67	0.57	0.68	0.63	0.57	0.41	0.56	0.41	0.66	0.57	0.63	0.58	0.60
	12	h*	buck*	not mentioned*	0.73	0.65	0.71	0.59	0.71	0.62	0.57	0.35	0.54	0.32	0.56	0.34	0.74	0.69	0.72	0.63	0.73	0.66	0.67	0.53	0.66	0.56	0.56	0.36	0.56	0.35	0.69	0.54	0.69	0.60	0.59
	3	c	buck	not mentioned	0.70	0.67	0.70	0.65	0.66	0.63	0.58	0.40	0.59	0.44	0.54	0.39	0.67	0.62	0.67	0.60	0.56	0.53	0.59	0.56	0.59	0.49	0.54	0.51	0.50	0.39	0.56	0.48	0.57	0.50	0.56
	5	e	buck	not mentioned	0.75	0.63	0.73	0.59	0.70	0.57	0.53	0.28	0.54	0.29	0.50	0.26	0.74	0.63	0.65	0.57	0.70	0.55	0.70	0.55	0.62	0.47	0.59	0.40	0.55	0.33	0.66	0.46	0.56	0.26	0.54
	20	f	buckBoost	yes	0.68	0.66	0.67	0.62	0.67	0.64	0.56	0.40	0.56	0.38	0.56	0.36	0.66	0.62	0.67	0.60	0.66	0.61	0.55	0.46	0.52	0.49	0.45	0.34	0.48	0.34	0.55	0.44	0.54	0.40	0.54
	19	l	boost	yes	0.68	0.66	0.66	0.62	0.66	0.65	0.54	0.36	0.53	0.35	0.54	0.35	0.65	0.63	0.66	0.60	0.66	0.62	0.52	0.47	0.51	0.49	0.44	0.34	0.43	0.36	0.52	0.45	0.48	0.42	0.53
	1	a	buck	not mentioned	0.70	0.64	0.69	0.61	0.69	0.61	0.58	0.37	0.57	0.39	0.56	0.38	0.65	0.58	0.64	0.56	0.61	0.00	0.64	0.55	0.64	0.51	0.53	0.45	0.56	0.41	0.60	0.47	0.60	0.00	0.53
	8	a	buck	not mentioned	0.70	0.63	0.69	0.59	0.66	0.59	0.54	0.32	0.55	0.34	0.53	0.32	0.65	0.59	0.64	0.55	0.59	0.52	0.61	0.54	0.54	0.47	0.50	0.47	0.53	0.40	0.57	0.45	0.57	0.11	0.53
	15	i	buck	not mentioned	0.72	0.67	0.72	0.63	0.69	0.64	0.58	0.36	0.59	0.38	0.58	0.37	0.70	0.63	0.69	0.60	0.00	0.00	0.70	0.61	0.62	0.55	0.58	0.51	0.60	0.46	0.65	0.52	0.00	0.00	0.51
	16	g	buck	not mentioned	0.76	0.65	0.75	0.61	0.73	0.63	0.57	0.31	0.58	0.33	0.57	0.32	0.73	0.65	0.72	0.59	0.00	0.00	0.71	0.60	0.65	0.53	0.59	0.48	0.61	0.42	0.66	0.50	0.00	0.00	0.51
	13	g	buck	not mentioned	0.71	0.58	0.69	0.54	0.64	0.51	0.49	0.26	0.51	0.27	0.46	0.25	0.71	0.61	0.68	0.54	0.63	0.51	0.66	0.54	0.55	0.43	0.58	0.39	0.53	0.34	0.63	0.46	0.54	0.00	0.51
	17	j	buckBoost	not mentioned	0.64	0.63	0.64	0.61	0.53	0.48	0.54	0.37	0.54	0.39	0.46	0.33	0.56	0.57	0.56	0.54	0.52	0.49	0.56	0.52	0.46	0.40	0.49	0.46	0.46	0.36	0.55	0.46	0.49	0.40	0.50
	18	k*	buck*	not mentioned*	0.68	0.58	0.67	0.54	0.67	0.57	0.50	0.26	0.51	0.28	0.50	0.28	0.63	0.56	0.62	0.52	0.53	0.46	0.54	0.46	0.51	0.42	0.45	0.40	0.48	0.34	0.48	0.38	0.51	0.34	0.49
	11	g	buck	not mentioned	0.58	0.51	0.58	0.48	0.54	0.46	0.43	0.24	0.44	0.25	0.41	0.22	0.57	0.49	0.56	0.43	0.00	0.00	0.53	0.45	0.47	0.38	0.45	0.33	0.44	0.29	0.49	0.29	0.02	0.00	0.38
		Avg Efficiency			**0.72**	**0.65**	**0.71**	**0.62**	**0.69**	**0.62**	**0.57**	**0.36**	**0.57**	**0.37**	**0.55**	**0.35**	**0.69**	**0.64**	**0.68**	**0.60**	**0.58**	**0.49**	**0.64**	**0.55**	**0.61**	**0.53**	**0.54**	**0.43**	**0.54**	**0.40**	**0.62**	**0.51**	**0.52**	**0.36**	
Dimmer	10	Unidentifiable	boost	NA	1.00	1.00	0.99	0.96	0.99	0.99	1.00	1.00	0.97	0.96	0.99	0.99	1.00	1.00	0.99	0.96	0.99	0.99	0.98	0.94	0.98	0.96	0.95	0.94	0.98	0.95	0.98	0.94	0.97	0.92	0.97
	3	c	buck	not mentioned	1.00	1.00	0.99	0.96	0.99	0.98	1.00	1.00	0.98	0.95	0.99	0.99	1.00	1.00	0.99	0.96	0.99	0.98	0.98	0.94	0.99	0.96	0.93	0.93	0.97	0.93	0.98	0.93	0.98	0.97	0.97
	17	j	buckBoost	buckBoost	1.00	1.00	0.98	0.95	0.98	0.98	1.00	1.00	0.97	0.92	0.99	0.99	1.00	1.00	0.99	0.95	0.98	0.98	0.98	0.91	0.96	0.95	0.94	0.93	0.97	0.94	0.98	0.91	0.98	0.95	0.97
	2	b*	boost*	not mentioned*	1.00	1.00	0.98	0.94	0.99	0.98	1.00	1.00	0.97	0.95	0.99	0.98	1.00	1.00	0.98	0.93	0.99	0.98	0.97	0.90	0.98	0.93	0.95	0.92	0.97	0.94	0.97	0.89	0.96	0.94	0.97
	9	f	buckBoost	yes	1.00	1.00	0.98	0.94	0.99	0.98	1.00	1.00	0.97	0.95	0.99	0.98	1.00	1.00	0.98	0.94	0.99	0.98	0.97	0.90	0.98	0.93	0.95	0.92	0.97	0.93	0.97	0.89	0.96	0.94	0.97
	19	l	boost	yes	1.00	1.00	0.98	0.94	0.99	0.98	1.00	1.00	0.97	0.95	0.99	0.99	1.00	1.00	0.98	0.94	0.99	0.98	0.97	0.90	0.98	0.93	0.95	0.92	0.97	0.94	0.97	0.90	0.96	0.90	0.97
	20	f	buckBoost	yes	1.00	1.00	0.98	0.94	0.99	0.98	1.00	1.00	0.97	0.95	0.99	0.98	1.00	1.00	0.98	0.93	0.99	0.98	0.97	0.90	0.97	0.93	0.95	0.92	0.97	0.94	0.97	0.88	0.96	0.89	0.96
	7	f	boost	yes	1.00	1.00	0.98	0.94	0.99	0.94	1.00	1.00	0.97	0.95	0.99	0.98	1.00	1.00	0.98	0.92	0.99	0.98	0.97	0.89	0.97	0.94	0.95	0.91	0.97	0.93	0.96	0.87	0.96	0.93	0.96
	12	h*	buck*	not mentioned*	1.00	1.00	0.97	0.92	0.99	0.97	1.00	1.00	0.96	0.92	0.99	0.98	1.00	1.00	0.97	0.91	0.99	0.98	0.96	0.87	0.97	0.91	0.94	0.90	0.96	0.93	0.95	0.84	0.98	0.95	0.96
	4	d	buck	not mentioned	1.00	1.00	0.97	0.92	0.99	0.97	1.00	1.00	0.95	0.89	0.99	0.98	1.00	1.00	0.97	0.91	0.99	0.98	0.96	0.87	0.97	0.91	0.90	0.89	0.96	0.91	0.95	0.86	0.98	0.97	0.96
	1	a	buck	not mentioned	1.00	1.00	0.98	0.94	0.98	0.98	1.00	1.00	0.96	0.91	0.99	0.98	1.00	1.00	0.98	0.95	0.99	0.83	0.97	0.91	0.97	0.94	0.91	0.91	0.97	0.93	0.97	0.90	0.97	0.80	0.95
	8	a	buck	not mentioned	1.00	1.00	0.98	0.93	0.99	0.98	1.00	1.00	0.96	0.90	0.99	0.98	1.00	1.00	0.98	0.93	0.99	0.98	0.96	0.89	0.98	0.93	0.89	0.91	0.96	0.92	0.97	0.88	0.98	0.78	0.95
	18	k*	buck*	not mentioned*	1.00	1.00	0.97	0.91	0.99	0.97	1.00	1.00	0.95	0.89	0.99	0.98	1.00	1.00	0.97	0.91	0.99	0.98	0.95	0.87	0.97	0.92	0.88	0.90	0.95	0.91	0.95	0.86	0.96	0.89	0.95
	5	e	buck	not mentioned	1.00	1.00	0.97	0.91	0.99	0.97	1.00	1.00	0.95	0.89	0.99	0.98	1.00	1.00	0.94	0.88	0.99	0.96	0.95	0.86	0.96	0.90	0.93	0.90	0.95	0.91	0.94	0.80	0.96	0.89	0.95
	15	i	buck	not mentioned	1.00	1.00	0.98	0.94	0.99	0.98	1.00	1.00	0.96	0.91	0.99	0.98	1.00	1.00	0.98	0.94	0.83	0.83	0.97	0.90	0.98	0.93	0.90	0.91	0.97	0.92	0.97	0.88	0.79	0.80	0.94
	13	g	buck	not mentioned	1.00	1.00	0.97	0.85	0.98	0.96	1.00	1.00	0.94	0.89	0.99	0.98	1.00	1.00	0.96	0.88	0.99	0.97	0.95	0.85	0.96	0.89	0.94	0.90	0.95	0.91	0.94	0.79	0.92	0.80	0.94
	16	g	buck	not mentioned	1.00	1.00	0.97	0.92	0.99	0.97	1.00	1.00	0.96	0.90	0.99	0.98	1.00	1.00	0.97	0.91	0.81	0.85	0.96	0.87	0.97	0.92	0.90	0.90	0.96	0.91	0.96	0.86	0.78	0.78	0.93
	11	g	buck	not mentioned	1.00	1.00	0.97	0.92	0.99	0.97	1.00	1.00	0.95	0.89	0.99	0.98	1.00	1.00	0.97	0.88	0.83	0.83	0.96	0.88	0.97	0.91	0.93	0.90	0.96	0.91	0.95	0.77	0.83	0.79	0.93
		Avg Efficiency			**1.00**	**1.00**	**0.98**	**0.93**	**0.99**	**0.97**	**1.00**	**1.00**	**0.96**	**0.92**	**0.99**	**0.98**	**1.00**	**1.00**	**0.98**	**0.93**	**0.98**	**0.96**	**0.97**	**0.89**	**0.97**	**0.93**	**0.93**	**0.91**	**0.96**	**0.93**	**0.96**	**0.88**	**0.96**	**0.90**	
Transformer	10	Unidentifiable	boost	NA	0.87	0.88	0.87	0.88	0.87	0.89	0.77	0.62	0.78	0.67	0.78	0.64	0.84	0.83	0.83	0.84	0.84	0.84	0.84	0.87	0.84	0.88	0.77	0.73	0.75	0.73	0.80	0.84	0.80	0.83	0.81
	19	l	boost	yes	0.90	0.85	0.89	0.85	0.89	0.85	0.76	0.50	0.78	0.54	0.77	0.52	0.88	0.80	0.89	0.80	0.89	0.79	0.88	0.83	0.88	0.86	0.80	0.62	0.80	0.64	0.87	0.80	0.88	0.79	0.79
	9	f	buckBoost	yes	0.88	0.84	0.88	0.84	0.89	0.85	0.74	0.48	0.78	0.55	0.75	0.51	0.87	0.82	0.87	0.84	0.86	0.83	0.86	0.82	0.87	0.85	0.79	0.63	0.78	0.62	0.87	0.84	0.87	0.84	0.79
	20	f	buckBoost	yes	0.89	0.86	0.90	0.85	0.90	0.86	0.76	0.53	0.77	0.54	0.76	0.54	0.88	0.80	0.89	0.81	0.89	0.81	0.89	0.81	0.89	0.84	0.78	0.59	0.77	0.58	0.88	0.80	0.89	0.78	0.79
	2	b*	boost*	not mentioned*	0.89	0.75	0.89	0.85	0.89	0.86	0.76	0.52	0.78	0.55	0.77	0.54	0.87	0.83	0.88	0.83	0.88	0.83	0.87	0.81	0.88	0.84	0.79	0.58	0.79	0.59	0.87	0.82	0.88	0.81	0.79
	3	c	buck	not mentioned	0.86	0.85	0.86	0.86	0.84	0.86	0.73	0.52	0.77	0.59	0.72	0.55	0.82	0.85	0.83	0.85	0.75	0.84	0.80	0.85	0.80	0.84	0.77	0.75	0.72	0.71	0.75	0.84	0.76	0.84	0.78
	7	f	boost	yes	0.89	0.84	0.88	0.84	0.89	0.84	0.73	0.47	0.77	0.53	0.74	0.49	0.87	0.80	0.88	0.80	0.87	0.80	0.87	0.80	0.88	0.84	0.78	0.60	0.78	0.59	0.86	0.79	0.86	0.79	0.78
	17	j	buckBoost	not mentioned	0.84	0.83	0.86	0.84	0.78	0.83	0.73	0.51	0.75	0.58	0.69	0.56	0.79	0.82	0.80	0.83	0.75	0.82	0.82	0.85	0.76	0.82	0.76	0.73	0.72	0.69	0.79	0.82	0.74	0.80	0.76
	4	d	buck	not mentioned	0.87	0.77	0.88	0.77	0.88	0.79	0.66	0.37	0.72	0.44	0.68	0.40	0.90	0.84	0.90	0.85	0.88	0.83	0.86	0.80	0.84	0.80	0.73	0.63	0.75	0.60	0.87	0.82	0.85	0.81	0.76
	12	h*	buck*	not mentioned*	0.89	0.81	0.89	0.79	0.89	0.80	0.71	0.44	0.70	0.44	0.70	0.44	0.87	0.79	0.88	0.79	0.88	0.79	0.87	0.78	0.88	0.81	0.76	0.52	0.75	0.50	0.87	0.79	0.86	0.78	0.75
	18	k*	buck*	not mentioned*	0.86	0.75	0.88	0.76	0.88	0.78	0.65	0.35	0.71	0.42	0.68	0.38	0.85	0.82	0.86	0.83	0.82	0.83	0.84	0.84	0.82	0.83	0.77	0.72	0.76	0.68	0.82	0.83	0.79	0.67	0.75
	8	a	buck	not mentioned	0.86	0.78	0.87	0.79	0.85	0.80	0.68	0.41	0.73	0.48	0.69	0.45	0.83	0.80	0.83	0.80	0.78	0.81	0.82	0.82	0.77	0.80	0.76	0.72	0.75	0.67	0.78	0.80	0.77	0.26	0.73
	1	a	buck	not mentioned	0.87	0.82	0.88	0.83	0.88	0.84	0.73	0.48	0.76	0.56	0.74	0.52	0.84	0.84	0.85	0.85	0.82	0.01	0.85	0.85	0.85	0.84	0.77	0.71	0.77	0.67	0.81	0.84	0.81	0.01	0.73
	5	e	buck	not mentioned	0.87	0.76	0.88	0.76	0.85	0.74	0.64	0.34	0.69	0.40	0.62	0.34	0.85	0.78	0.83	0.80	0.83	0.78	0.87	0.78	0.81	0.74	0.77	0.54	0.72	0.48	0.83	0.77	0.76	0.52	0.71
	13	g	buck	not mentioned	0.86	0.74	0.87	0.79	0.82	0.71	0.62	0.33	0.68	0.39	0.60	0.34	0.84	0.79	0.84	0.79	0.79	0.78	0.86	0.79	0.75	0.72	0.78	0.55	0.72	0.52	0.83	0.78	0.73	0.00	0.69
	15	i	buck	not mentioned	0.87	0.82	0.88	0.82	0.86	0.83	0.72	0.45	0.75	0.52	0.72	0.49	0.83	0.84	0.84	0.84	0.00	0.01	0.85	0.84	0.80	0.82	0.76	0.71	0.76	0.67	0.80	0.82	0.00	0.00	0.66
	16	g	buck	not mentioned	0.87	0.77	0.88	0.77	0.86	0.78	0.67	0.38	0.72	0.45	0.68	0.42	0.83	0.81	0.83	0.81	0.01	0.02	0.86	0.82	0.80	0.79	0.77	0.66	0.76	0.62	0.79	0.80	0.00	0.00	0.64
	11	g	buck	not mentioned	0.87	0.78	0.88	0.78	0.84	0.77	0.66	0.38	0.71	0.44	0.65	0.38	0.84	0.78	0.85	0.78	0.01	0.01	0.87	0.81	0.80	0.76	0.77	0.59	0.74	0.55	0.82	0.76	0.22	0.01	0.64
		Avg Efficiency			**0.87**	**0.81**	**0.88**	**0.82**	**0.87**	**0.82**	**0.71**	**0.45**	**0.74**	**0.51**	**0.71**	**0.48**	**0.85**	**0.82**	**0.86**	**0.82**	**0.74**	**0.67**	**0.85**	**0.82**	**0.83**	**0.82**	**0.77**	**0.65**	**0.75**	**0.62**	**0.83**	**0.81**	**0.72**	**0.56**	
Driver	4	d	buck	not mentioned	0.89	0.85	0.89	0.86	0.88	0.85	0.88	0.86	0.88	0.87	0.88	0.86	0.88	0.87	0.88	0.87	0.89	0.86	0.92	0.89	0.90	0.85	0.90	0.87	0.89	0.86	0.93	0.89	0.92	0.88	0.88
	2	b*	boost*	not mentioned*	0.87	0.77	0.88	0.88	0.87	0.88	0.84	0.85	0.84	0.84	0.84	0.84	0.88	0.91	0.88	0.91	0.88	0.90	0.86	0.86	0.85	0.85	0.82	0.83	0.82	0.82	0.87	0.90	0.85	0.88	0.86
	9	f	buckBoost	yes	0.85	0.88	0.86	0.88	0.86	0.88	0.84	0.85	0.83	0.83	0.84	0.84	0.83	0.89	0.83	0.89	0.82	0.89	0.82	0.85	0.82	0.84	0.80	0.80	0.79	0.79	0.79	0.85	0.76	0.82	0.84
	12	h*	buck*	not mentioned*	0.82	0.82	0.82	0.81	0.80	0.80	0.81	0.81	0.80	0.81	0.81	0.80	0.85	0.89	0.85	0.89	0.84	0.88	0.81	0.80	0.78	0.77	0.79	0.80	0.78	0.78	0.83	0.84	0.82	0.84	0.82
	5	e	buck	not mentioned	0.85	0.84	0.86	0.85	0.83	0.82	0.83	0.83	0.83	0.83	0.82	0.81	0.87	0.84	0.84	0.83	0.86	0.77	0.84	0.84	0.80	0.75	0.82	0.82	0.80	0.77	0.84	0.79	0.76	0.60	0.81
	7	f	boost	yes	0.83	0.84	0.83	0.84	0.82	0.84	0.81	0.82	0.80	0.79	0.81	0.80	0.82	0.85	0.82	0.86	0.81	0.84	0.80	0.80	0.79	0.81	0.76	0.76	0.75	0.75	0.80	0.83	0.76	0.80	0.81
	10	Unidentifiable	boost	NA	0.81	0.84	0.81	0.84	0.81	0.83	0.79	0.82	0.79	0.79	0.79	0.80	0.80	0.84	0.80	0.84	0.80	0.83	0.74	0.78	0.75	0.77	0.73	0.74	0.70	0.72	0.74	0.77	0.71	0.72	0.78
	13	g	buck	not mentioned	0.82	0.81	0.82	0.81	0.80	0.77	0.79	0.80	0.79	0.80	0.78	0.77	0.84	0.80	0.84	0.80	0.81	0.72	0.81	0.81	0.76	0.71	0.79	0.80	0.77	0.74	0.81	0.77	0.81	0.00	0.76
	8	a	buck	not mentioned	0.82	0.81	0.82	0.81	0.78	0.77	0.79	0.78	0.79	0.78	0.77	0.73	0.79	0.76	0.79	0.75	0.76	0.69	0.77	0.76	0.72	0.66	0.75	0.74	0.74	0.67	0.76	0.67	0.76	0.55	0.75
	3	c	buck	not mentioned	0.82	0.80	0.82	0.80	0.79	0.76	0.79	0.79	0.79	0.79	0.76	0.73	0.82	0.75	0.82	0.75	0.76	0.67	0.76	0.72	0.74	0.64	0.76	0.75	0.72	0.61	0.76	0.65	0.77	0.64	0.75
	16	g	buck	not mentioned	0.88	0.87	0.87	0.87	0.86	0.84	0.85	0.85	0.85	0.84	0.84	0.83	0.88	0.83	0.88	0.83	0.00	0.00	0.87	0.85	0.83	0.78	0.85	0.83	0.84	0.80	0.87	0.78	0.00	0.00	0.73
	20	f	buckBoost	yes	0.76	0.78	0.77	0.79	0.76	0.77	0.75	0.76	0.75	0.74	0.75	0.70	0.76	0.80	0.77	0.81	0.75	0.79	0.64	0.64	0.60	0.64	0.61	0.64	0.65	0.63	0.65	0.64	0.64	0.60	0.71
	15	i	buck	not mentioned	0.83	0.84	0.83	0.83	0.82	0.81	0.82	0.81	0.82	0.81	0.81	0.79	0.84	0.79	0.84	0.79	0.00	0.00	0.84	0.83	0.79	0.77	0.83	0.81	0.83	0.78	0.85	0.76	0.00	0.00	0.71
	1	a	buck	not mentioned	0.80	0.79	0.80	0.79	0.80	0.77	0.79	0.78	0.77	0.77	0.77	0.75	0.77	0.72	0.77	0.72	0.74	0.00	0.77	0.73	0.78	0.67	0.76	0.72	0.76	0.68	0.76	0.65	0.76	0.00	0.71
	18	k*	buck*	not mentioned*	0.79	0.78	0.79	0.78	0.77	0.77	0.76	0.77	0.76	0.76	0.75	0.75	0.75	0.71	0.75	0.70	0.66	0.60	0.67	0.65	0.64	0.58	0.67	0.64	0.66	0.59	0.64	0.57	0.65	0.58	0.70
	19	l	boost	yes	0.75	0.78	0.75	0.79	0.75	0.79	0.71	0.73	0.71	0.70	0.72	0.70	0.74	0.81	0.76	0.81	0.75	0.81	0.61	0.64	0.60	0.62	0.58	0.62	0.55	0.62	0.61	0.65	0.57	0.60	0.69
	17	j	buckBoost	not mentioned	0.76	0.78	0.76	0.78	0.70	0.62	0.74	0.75	0.74	0.75	0.67	0.63	0.71	0.71	0.71	0.71	0.70	0.64	0.70	0.69	0.62	0.55	0.69	0.70	0.67	0.59	0.72	0.65	0.67	0.56	0.69
	11	g	buck	not mentioned	0.67	0.67	0.67	0.67	0.65	0.63	0.65	0.65	0.65	0.65	0.63	0.62	0.68	0.65	0.68	0.65	0.00	0.00	0.64	0.65	0.61	0.58	0.63	0.64	0.62	0.60	0.63	0.54	0.12	0.00	0.56
		Avg Efficiency			**0.82**	**0.82**	**0.82**	**0.82**	**0.81**	**0.80**	**0.80**	**0.80**	**0.80**	**0.79**	**0.79**	**0.77**	**0.81**	**0.81**	**0.81**	**0.81**	**0.70**	**0.64**	**0.78**	**0.77**	**0.75**	**0.72**	**0.76**	**0.76**	**0.75**	**0.72**	**0.78**	**0.75**	**0.66**	**0.53**	

*Driver IC model could not be confirmed

Topology
Buck
buckBoost
Boost

Efficiency Scale										
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0

4.4 VISIBLE FLICKER

The severity of visible flicker is ranked on the scale defined in Table 9 of the methodology. To rank the LED MR-16 lamp product's visible flicker performance under all testing conditions, the sum of the visible flicker ranking was used. The lamps are then sorted in order of the sum of their flicker severity. Eighteen lamps are reported in this section. Twenty products will be reported in the final version of this report.

Table 12 – Visible flicker severity results

	Dim Level			100%																		50%												Sum(Flicker Severity)
	Transformer			A Electronic						Magnetic						B Electronic						A Electronic				Magnetic				B Electronic				
	Dimmer			None		Reverse		Forward		None		Reverse		Forward		None		Reverse		Forward		Reverse		Forward		Reverse		Forward		Reverse		Forward		
	Number of Lamps																																	
Lamp	Driver	Topology	Electronic Transformer Compatibility	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	
20	f	buckBoost	yes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	l	boost	yes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	f	buckBoost	yes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	h*	buck*	not mentioned*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Unidentifiable	boost	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	f	boost	yes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	g	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	4	9
4	d	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	3	1	9
8	a	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	3	3	10
18	k*	buck*	not mentioned*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	3	10
1	a	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	2	1	0	4	11
3	c	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	2	0	3	11
5	e	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	1	0	0	0	0	0	0	0	0	3	1	3	3	15
17	j	buckBoost	not mentioned	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	3	0	0	0	0	0	2	0	3	3	16
2	b*	boost*	not mentioned*	1	0	0	0	0	0	1	0	2	0	0	0	0	0	1	0	0	1	1	0	1	0	2	0	1	0	1	2	1	2	17
16	g	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	3	3	4	4	22
11	g	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	3	3	4	4	22
15	i	buck	not mentioned	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	3	3	4	4	22
	Sum(Flicker Severity)			1	0	0	0	3	0	1	0	2	0	0	0	3	0	3	0	13	18	1	0	7	0	2	0	1	0	30	20	31	38	

*Driver IC model could not be confirmed

Topology
Buck
buckBoost
Boost

Flicker Level	Severity Value
0	No Visible Flicker
1	Faint Visible Flicker
2	Visible Flicker
3	Strong Visible Flicker
4	Lamp turns off

5.0 DISCUSSION

For this evaluation, a high performing system (LED MR-16 lamp, transformer, and dimmer) is defined as a system that maximizes the amount of power to the LED compared to the energy consumed (high efficiency), while providing no visible flicker. The discussion below analyzes the test results, identifying system components that can contribute to a low performing system.

5.1 ELECTRICAL EFFICIENCY

Electrical efficiency data was reduced using the methods in section 3.3.3 for each of the test dimensions (Figure 6, 7, 8, and 9). Each of the following four figures corresponds to the reduction of data from the rows of Table 11 corresponding to the relevant system (overall, dimmer, transformer, and driver).

Overall system efficiency was analyzed in regard to each of the five test dimensions and the different configurations of each dimension. Each bar represents the average efficiency of all test combinations when operating with a specific type of component and/or configuration. Transformer type, and dimmer type were found to have a relatively large effect on overall system efficiency. Changes in transformer used resulted in as much as 31% difference in efficiency. Driver topology had little effect in overall, average system efficiency as there was only an 8% difference based on a change of driver topology. With respect to the number of lamps connected to the system, the average, overall system efficiecy was 22% less when using a single lamp as compared to the system with four lamps. Dimming to 50% also decreased the average overall efficiency of the system by 12%.

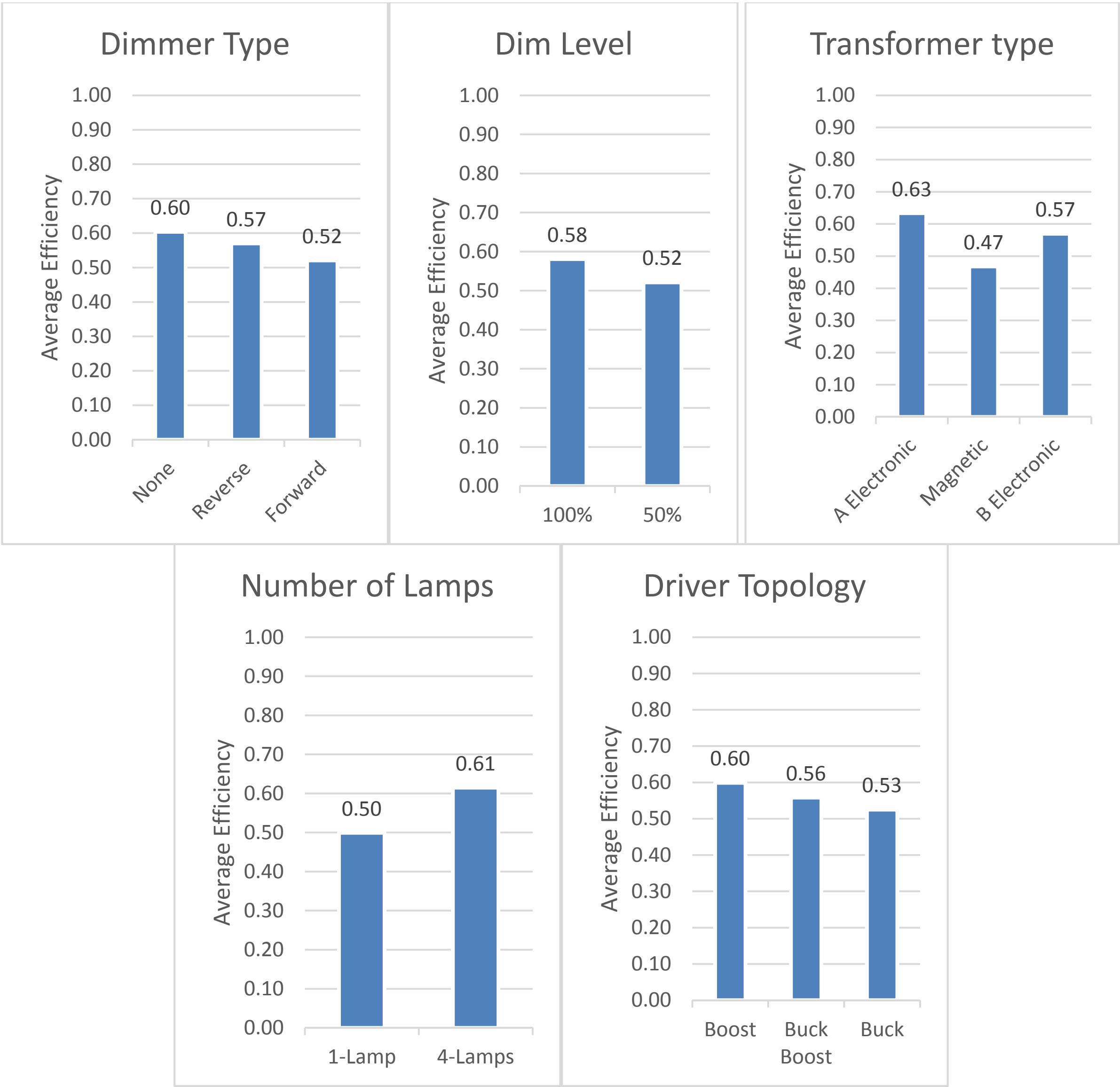


Figure 6 – Average overall system efficiencies for each configuration of the five test dimensions

Beyond average, overall system efficiency, the maximum difference in efficiency between the configurations of a test dimension are calculated and ranked from largest (1 = most significant) difference to smallest (5 = least significant) difference. Details on each subsystem and configuration are presented in Figure 7 - 9.

Table 13 – Rankings of the significance of each test dimension on subsystem efficiencies with maximum percent differences in efficiency between configurations for each test dimension

Rank	System		Dimmer		Transformer		Driver	
1	Transformer Type	30%	Dimmer Type	6%	Transformer Type	27%	Dimmer Type	12%
2	Number of Lamps	21%	Dim Level	5%	Number of Lamps	13%	Dim Level	8%
3	Dimmer Type	15%	Number of Lamps	3%	Driver Topology	10%	Transformer Type	8%
4	Driver Topology	13%	Driver Topology	2%	Dimmer Type	9%	Driver Topology	6%
5	Dim Level	11%	Transformer Type	1%	Dim Level	1%	Number of Lamps	3%

Dimmer efficiency was analyzed in regard to each of the five test dimensions and the different configurations of each dimension. Efficiency of the dimmer was found to generally be high regardless of the test configuration. The lowest average, overall dimmer efficiency was 0.92 when a system was operating at a 50% dim level. In addition, dimmers utilized on a system with electronic driver and only one lamp displayed the lowest efficiency at 0.88, on average.

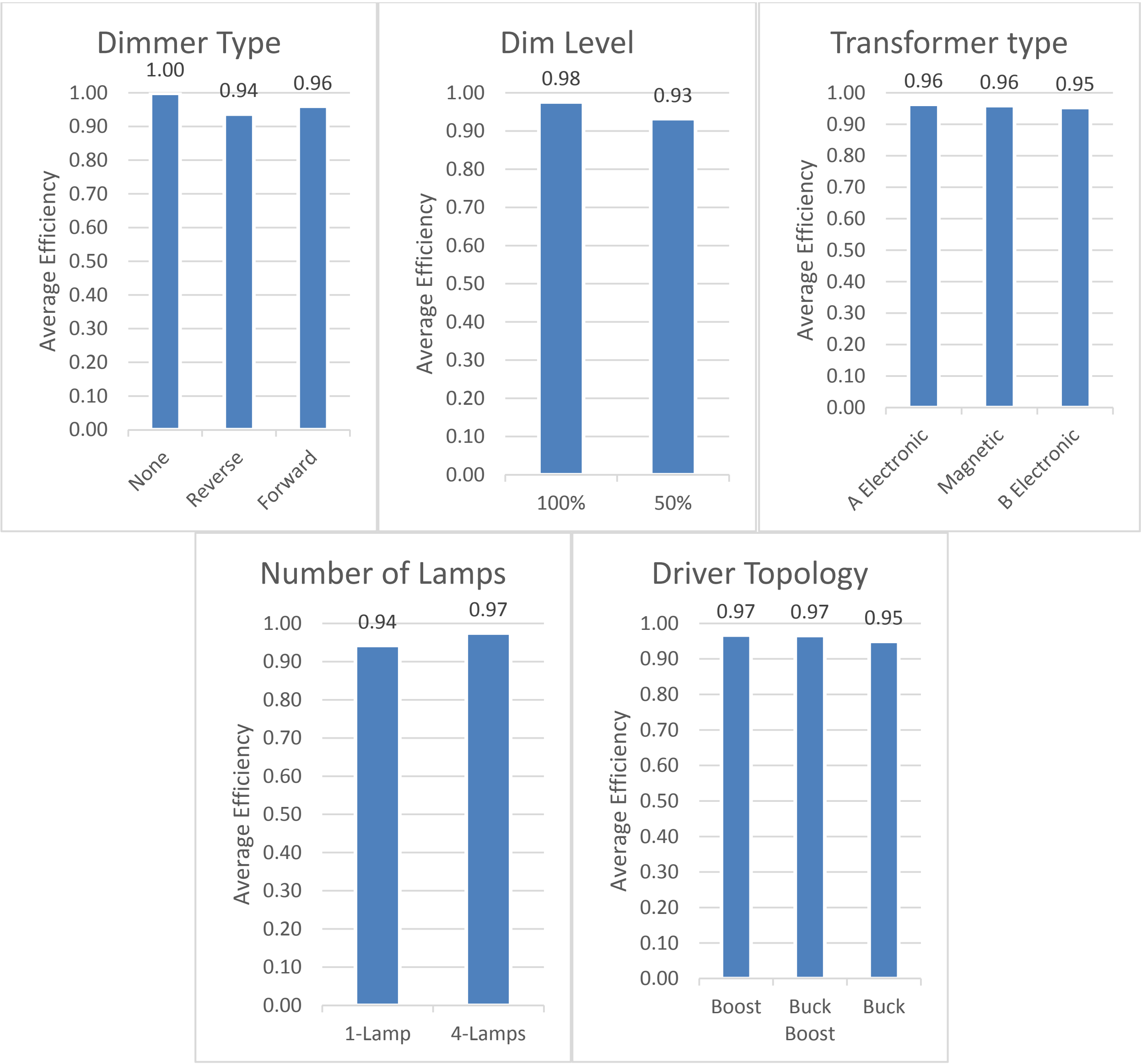


Figure 7– Average dimmer efficiencies for each configuration of the five test dimensions

Transformer efficiency was analyzed in regard to each of the five test dimensions and the different configurations of each dimension. Transformer type and dimmer type were found to have a relatively large effect on transformer efficiency, while dim level had very little effect with only 1%.

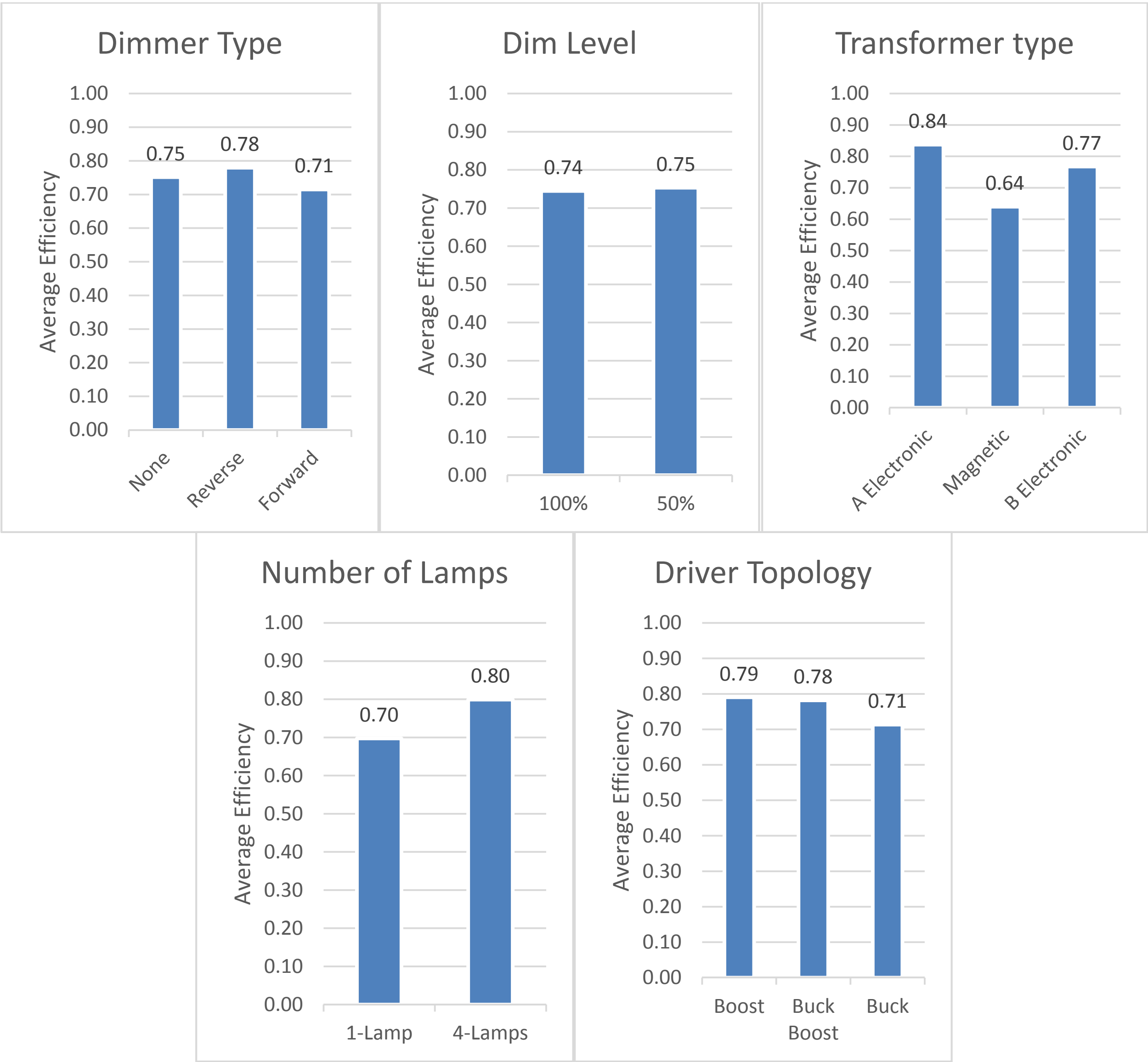


Figure 8 – Average transformer efficiencies for each configuration of the five test dimensions

Driver efficiency was analyzed in regard to each of the five test dimensions and the different configurations of each dimension. Transformer type and dimmer type were found to have relatively strong effects on driver efficiency while driver topology and the number of lamps did not.

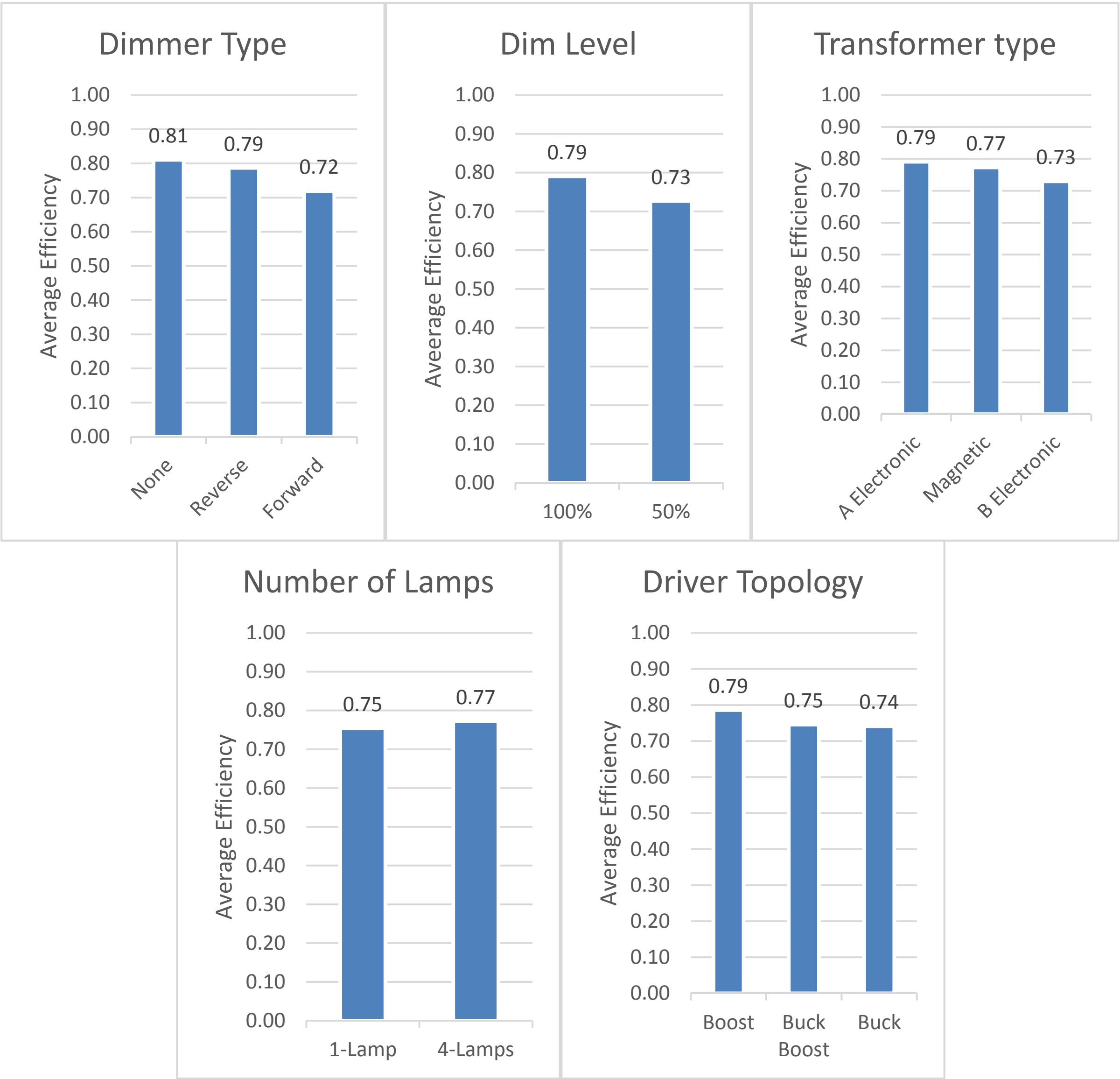


Figure 9 – Average driver efficiencies for each configuration of the five test dimensions

In the context of driver efficiency, the average driver efficiencies associated with each topology were similar. However, there were strong correlations between topology type, and the efficiency of other subsystems, such as the dimmer and transformer, where all buck drivers were out-performed by boost and buck-boost drivers.

The effect of each subsystem on overall system efficiency is not simply the result of the efficiencies of the different test conditions measured at that subsystem (it is not a sum of its parts). The interaction between subsystem components is often much more significant than the individual performance of a single component. In the context of dimmer efficiency, the three dimmer options performed similarly. When the overall system efficiency is considered, there is a much more significant correlation between the dimmer type and the overall system efficiency, than dimmer efficiency alone.

As provided in Table 13, the efficiency of the system is most dependent on the components separate from the lamp (transformer, number of lamps, dimmer type, and dimmer level) as opposed to the lamp driver topology, which was found to be the least important factor. Even so, the most efficient lamp in regard to system efficiency (lamp 2) is approximately 70% more efficient than the least efficient lamp (lamp 11). In general, drivers with boost and buck-boost topologies are more efficient than drivers using the buck topology. However, there are examples counter to this generalization such as lamp 12 that has a high efficiency and a buck driver topology.

For some of the lamps that use the same driver IC, it is observed that the system efficiency varies. Examples of this system efficiency variance are observed for the “driver 13”, which varied between 38% and 51%, and “driver f” which varied between 54% and 64%.

5.2 VISIBLE FLICKER

The presence of visible flicker appears highly dependent on transformer type. The worst performing configuration was the “B Electronic” transformer which was associated with 90% of the weighted flicker severity as a weighted average (Figure 10). The best performing transformer was the “magnetic” at 3% weighted flicker severity.

With respect to driver topology, the correlation between the lamp’s driver topology and the visible flicker severity shows better performance with the boost or buck-boost topology as compared to buck (with 57% of the weighted flicker severity). However, two lamps with performance counter to this trend are the high visible flicker severity of lamp 2 that uses a boost driver, and observation of no visible flicker for lamp 12 that uses a buck driver.

For a high performing LED MR-16 system, the transformer type is important to both efficiency and flicker, with a large discrepancy in performance between the “A Electronic” and “B Electronic” transformers. The number of lamps was found to be second most significant to efficiency, but least important to visible flicker severity.

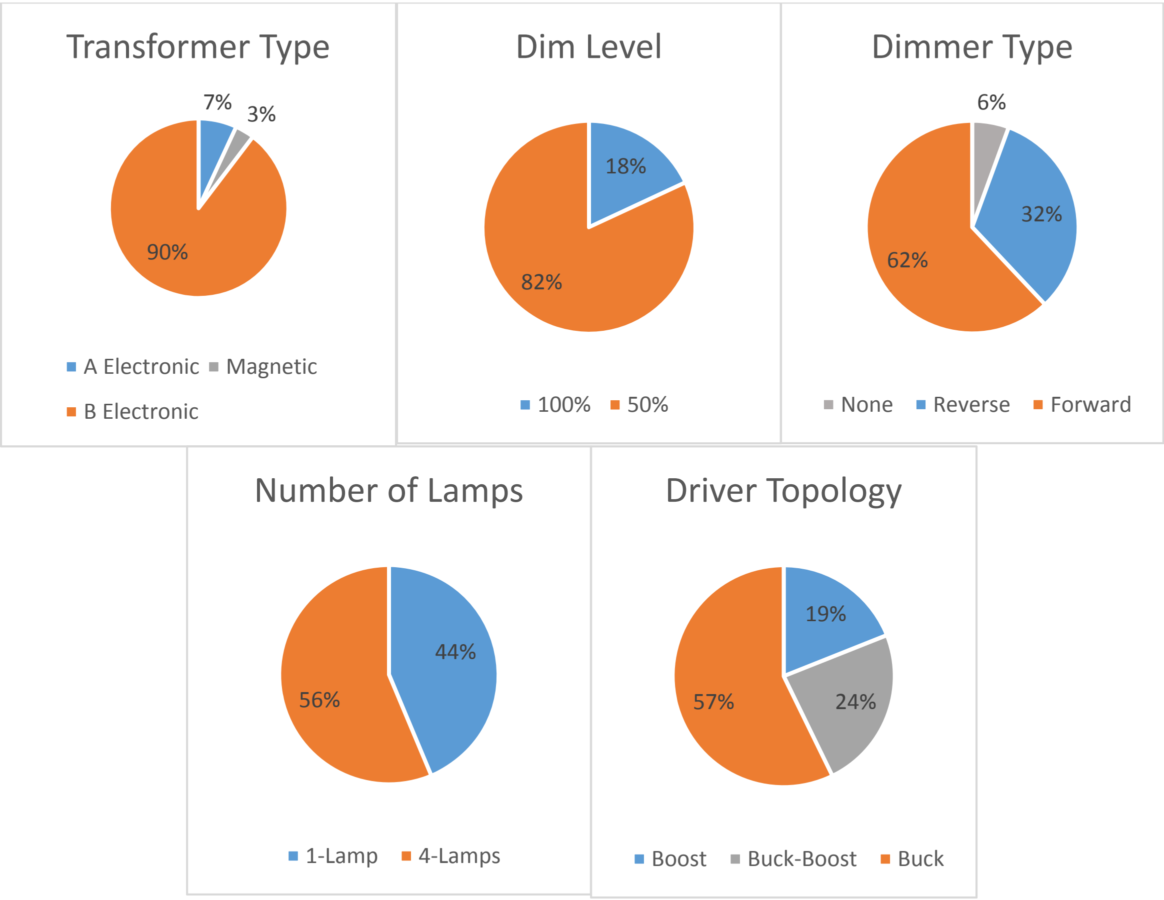


Figure 10 – Ratio of Visible Flicker Severity Sum for Technology Type vs. All Types per Technology

Flicker severity was ranked based on the ratio of the maximum to minimum values of average flicker severity for the configurations within each test dimension. The factors determined most important to least important, when examining visible flicker, are transformer type, dimmer type, dim level, driver topology, and number of lamps as shown in Table 14.

Table 14 – Rankings of the significance of each test dimension on Visible Flicker Severity

Significance Rank	Test Dimension	Ratio of highest to lowest Performance
1	Transformer Type	26.00
2	Dimmer Type	11.10
3	Dim Level	4.43
4	Driver Topology	3.02
5	Number of Lamps	1.29

6.0 CONCLUSIONS

Each test dimension (transformer type, dimmer type, number of lamps, driver topology, and dim level) was found to have different effects on the system efficiency and flicker severity.

6.1.1 TRANSFORMER TYPE

Transformer type was the most significant and influential factor to both flicker severity and efficiency. It was more than twice as important as the second ranked dimension for flicker severity (dimmer type), and about 50% more significant than the second ranked dimension in efficiency. The transformer designed to work well with LEDs (Electronic A) was the most efficient, and contributed little to the overall flicker severity. The magnetic transformer was the least efficient, but also contributed the least to flicker severity. The electronic transformer designed for halogen lamps (Electronic B) was somewhat less efficient than that designed for LEDs, but contributed most significantly to flicker severity.

Several of the LED lamps tested did not exhibit visible flicker when used with the poorer performing "B Electronic" transformer. If electronic transformers designed for halogen lamps (like the "B Electronic") are to be used with LEDs, it is important that those LEDs be high performing ones to reduce likelihood of visible flicker.

6.1.2 DIMMER TYPE

Dimmer type was the second most important factor to flicker severity and the third most important to electrical efficiency. It was found that for the entire set of lamps on average, the addition of a dimmer, increased the flicker severity. Of the two dimmers tested, the reverse phase dimmer (designed to work with ELVTs) contributed to just half of the flicker severity that the forward phase dimmer (designed to work with MLVTs) did. The forward phase dimmer was also about 10% less efficient than the reverse phase, and 15% less efficient than a system that used no dimmer at all.

It can be seen that this difference is more due to the interaction of the other components with the dimmers, than the inefficiencies of the dimmers themselves (~95% efficient).

6.1.3 NUMBER OF LAMPS

The number of lamps had a relatively strong effect on the system efficiency (ranked 2nd), but the smallest effect on flicker severity. The decrease in efficiency from the four lamp condition to the single lamp condition was seen for all transformer types, but was most severe for the magnetic type which was 50-60% less efficient in the configuration with fewer lamps.

6.1.4 DRIVER TOPOLOGY

In general, driver topology was less significant than every other factor, excluding dim level. Topology type was ranked 4th most significant for both flicker severity and system efficiency. Boost topologies were found to be the most efficient and contribute the least to flicker severity. Buck topologies performed the worst of the three types tested and buck-boost performed in between the two. The correlation strength between performance and topology is reduced because of two particular outliers: lamp 12 with a high performing buck driver, and lamp 2 with a low performing boost driver. Since the identification process was unable to confirm the identity of these drivers, it is possible that different drivers were used than that which the ambiguous top codes pointed to. Based on the voltage output of the lamp 12 (lower than the input voltage) it is possible that it is either a buck or buck-boost driver. Based on the voltage output of the lamp 2 (higher than the input voltage) it is possible that it is either a boost or buck-boost driver. If either of the drivers were found to be of different topologies than identified, performance correlations would not change greatly because the poorly performing lamp 2 couldn’t use a buck driver based on its driver voltage waveform.

Several of the driver IC specification sheets mention compatibility with electronic transformers. All products with drivers with this note exhibited no flicker for all test combinations. Using a driver that includes compatibility claims with electronic drivers was found to result in the lamp being compatible with a wide variety of system components.

6.1.5 DIMMING LEVEL

Dimming level was the least significant factor for efficiency, and the third most important factor for flicker severity. Lamp performance is predominantly better at the 100% level than the 50% level.

6.1.6 SUMMARY CONCLUSIONS

In general, several important conclusions can be drawn.

- On average, the system’s efficiency and visible flicker characteristics are effected more greatly by the system components other than the lamps, rather than the lamp’s driver topology itself. Transformer type is the most significant factor in regards to overall lamp performance.
- Although the correlation of topology to performance wasn’t the most significant factor, it was found that there is a large variation in flicker severity based on the lamp’s driver topology. Several high performing lamps did not flicker in any of the test conditions. More often than not, those high performing lamps have drivers with boost or buck-boost topologies.
- In general, to safely avoid visible flicker in a LED MR-16 system, one should either choose a high performing lamp with a driver designed to be compatible with electronic transformers, or use an electronic transformer designed for LED lamps, and used in combination with either no dimmer or a reverse-phase dimmer.

6.2 NEXT STEPS

Areas that should be considered for future research:

1. Perform a statistically significant flicker observation study. To date, flicker observations were made by a single observer. It would be useful to have a large group with varying demographics make observations to estimate the mean response of the total population, and understand variation among observers.
2. Build a set of algorithms that predicts the severity of perceived flicker based on the analysis of the driver current waveform, and compare this to the observation study.

APPENDIX 1: EQUIPMENT SPECIFICATION SHEETS

2.15 Precision current transducer 60A (PSU60)

Figure 36: PSU60

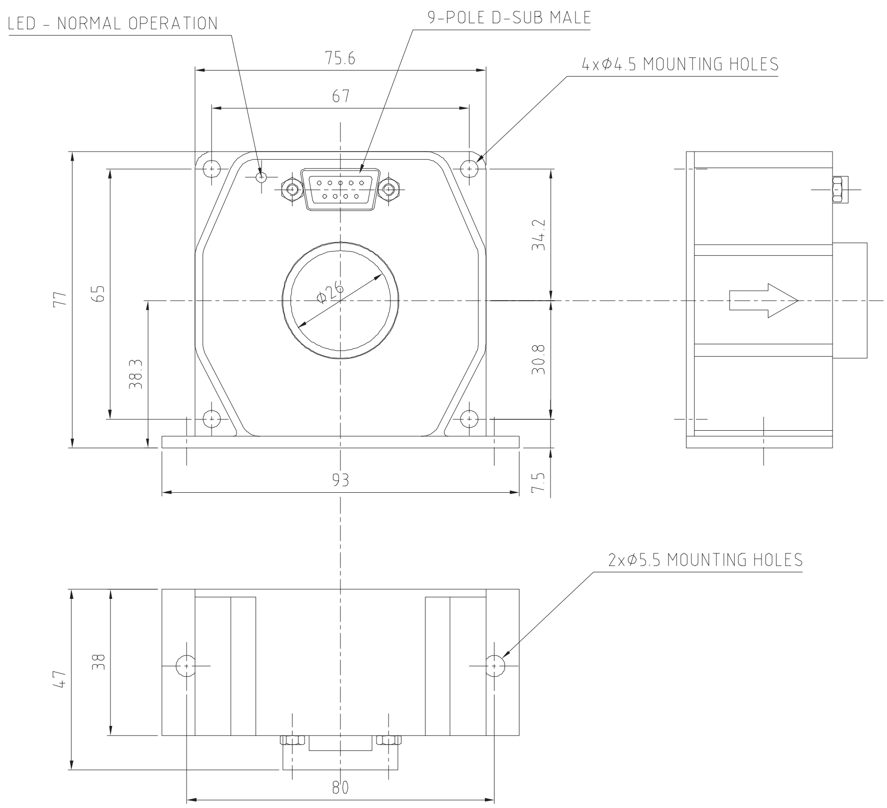


Figure 37: Dimensions of the PSU60

2.15.1 ⚠ Safety warning!

Always connect the sensor first to the meter, and afterwards to the device under test.

Dont allow primary current without supply of the PSU!

Please refer to chapter 1.1: ‘Safety precautions’!

2.15.2 Specifications

Nominal input current	60A
Transformation ratio	600:1
Measuring range PSU	±60Apk
Maximum input overload	66Aeff 3min 300A 100ms
Bandwidth (small signal 0.5% of nominal input current) ±1dB ±3dB	 DC to 500kHz DC to >800kHz
Slew rate (10%-90%)	>25A/us
Response time (to 90% of nominal input current)	<1us
Burden Rb	0 .. 20 ohms
Isolation	• rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 2000V with IEC 61010-1 standards and following conditions: over voltage category III, pollution degree 2 • rms voltage, AC isolation test, 50/60Hz, 1min: 5.4kV • impuls withstand voltage 1.2/50us: 9.9kV • rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 1000V with EN50178 standards and following conditions: over voltage category III, pollution degree 2 • creepage distance: 11mm • clearance distance: 11mm • comparative tracking index CTI: 600V **Attention: when using Busbar without isolation regard DSUB cable isolation or avoid contact!!**
Degree of pollution	2
Operating temperature	+10°C to +50°C (operation down to -20°C is possible, please note: ‘non condensing ambient conditions’ and ‘specified temperature drift in the range of -20°C to +10°C is typical, not guaranteed’)
Storage temperature	-20°C to +85°C
Humidity (non condensing)	20-80% RH
Weight	approx. 0.3kg

Output connection	depending on adapter cable to LMGxx
supply	±15V / 180mA

The transformers are only allowed to operate with cables which - according to the printing on the cable - are designed for this individual transformer.

2.15.3 Accuracy

Accuracies based on: sinusoidal current, frequency DC to 100Hz, ambient temperature 23±3°C, calibration interval 1 year, conductor in the middle of the transducer.

Amplitude error ±(% of meas.value+% of measuring range PSU)	0.015%+0.005%
Phase error	0.02°
Temperature coefficient (+10°C to +50°C)	< ±0.15mA/K

See specification of the LMG connection cable for the LMG measuring ranges and to calculate the accuracy of the complete system.

2.15.4 Sensor operation without supply

It is important to assure a stable power supply of the sensor before switching on the load current! The **operation** of the sensor with load current and **without supply will cause damage** of the sensor and/or of the LMG/supply unit!

To remove the LMG/supply unit from the test location without removing the PSU sensors from the current path, you can do alternatively:

- Leave the PSU at the current path and disconnect the cable at the PSU side.
  Disconnect the DSUB9 plug from the PSU and interconnect all of the 9 pins with the shield at the **PSU** plug.

or:

- Leave the PSU and the connection cable at the current path and disconnect the cable at the LMG/supply unit side.

1. Systems with supply via LMG:
   Disconnect the HDSUB15 plug from the LMG and connect all of the 15 pins and the shield at the **cable** plug together

2. Systems with supply via supply unit SSU4:
   Disconnect the HDSUB15 plug from the LMG and disconnect the DSUB9 plug from the supply unit SSU4. Connect all of the 15 pins and the shield at the **LMG cable** plug together and connect all of the 9 pins and the shield at the **SSU4 cable** plug together

To do this, the load current has to be switched off!

2.15.5 Connection of the sensor with LMG90/310 or other instruments with current input

Use sensor suppy unit SSU4 with modification for PSU60/200/400/700 (SSU4-MOD) and PSU-K3/K5/K10 and SSU4-K-L31 and direct current inputs I* and I.

2.15.6 Connection of the sensor with LMG95

Use PSU60/200/400/700-K-L95, supply via LMG95, no additional error terms, but only one range and not suitable for small currents.

With slightly less accuracy at fullrange, but with considerably more dynamic range and so better accuracy at small currents it is also possible to use PSU60-K-L50 and L95-Z07. With this assembly you get 8 ranges and a good dynamic down to a few Amps, but a small additional error term from the PSU60-K-L50 cable. Set LMG current scaling factor appropriate to the scaling factor marked on the label on L95-Z07.

It depends on the magnitude and the dynamic of the measuring current, which connection is better.

2.15.7 Connection of the sensor with LMG450 (PSU60-K-L45)

Use PSU60-K-L45 and SSU4 (standard version, without modification).

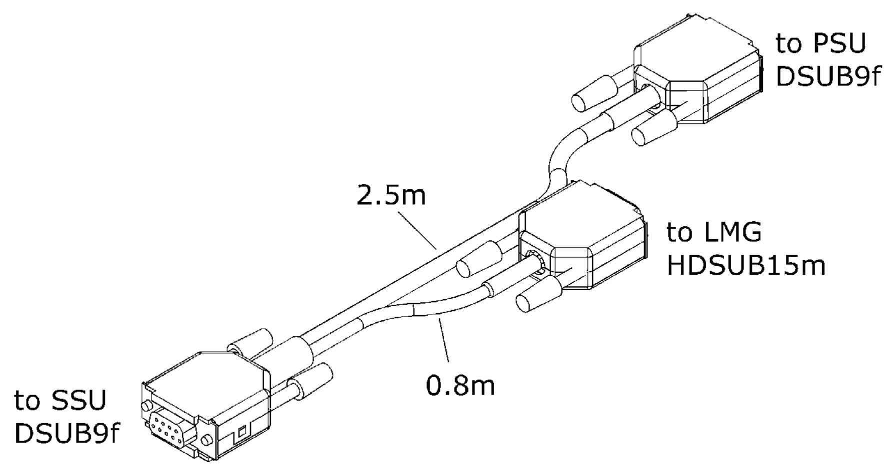


Figure 38: PSU60-K-L45, to connect the PSU60 to the LMG450 and the SSU4

This cable ‘PSU60-K-L45’ is used to connect a precision current sensor PSU60 to a power meter LMG450 and to supply it by a sensor supply unit SSU4.

In the connector to the LMG450 the adjustment data of the PSU60 head are available as well as it’s serial number. For this reason this connector is delivered already mounted to the PSU60 head and the screws are sealed, when you have ordered the package ‘PSU60-L45’. This should prevent, that the wrong PSU60 head is connected to the cable.

The connection is quiet simple:

- Switch all power off and plug the connector labeled ‘SSU-4’ to the SSU-4.
- Plug the connector labeled ‘LMG450’ to the LMG450 external sensor input.
- Now you can switch on the power and make your measurements. The power of the EUT should be switched on at least.

Measuring ranges (sensor input)

nominal value	1A	2A	4A	8A	16A	32A
max. trms value	1.875A	3.75A	7.5A	15A	30A	60A
max. peak value	1.875A	3.75A	7.5A	15A	30A	60A

limited by PSU60 to max. 60Apk!

Accuracy

Use PSU60 and LMG450 specifications to calculate the accuracy of the complete system. Add ±9mA (to the primary current) DC offset tolerance.

2.15.8 Connection of the sensor with LMG500 (PSU60-K-L50)

Use PSU60-K-L50 and L50-Z14, supply via LMG500.

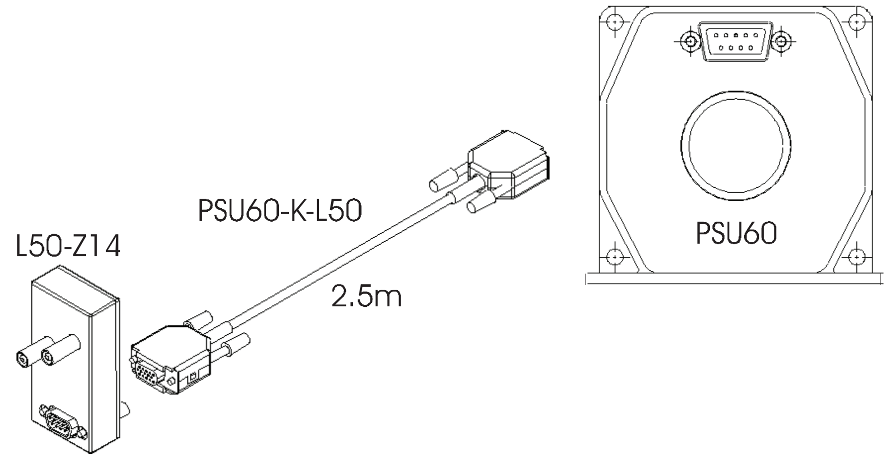


Figure 39: PSU60-K-L50, to connect PSU60 and LMG500

This cable ‘PSU60-K-L50’ is used to connect a precision current sensor PSU60 to the power meter LMG500.

In the connector to the LMG500 the adjustment data of the PSU60 head are available as well as it’s serial number. For this reason this connector is delivered already mounted to the PSU60 head and the screws are sealed, when you have ordered the package ‘PSU60-L50’. This should prevent, that the wrong PSU60 head is connected to the cable.

The connection is quiet simple:
Switch all power off, plug the connector labeled ‘LMG500’ to the adapter L50-Z14 mounted on the LMG500 current channel. Now you can switch on the power and make the measurements. The range names of LMG500, the sensor name and calibration data are read out of the sensor EEPROM automaticaly.

Measuring ranges (sensor input)

nominal value	0.25A	0.5A	1A	2A	4A	8A	16A	32A
max. trms value	0.469A	0.938A	1.875A	3.75A	7.5A	15A	30A	60A
max. peak value	0.469A	0.938A	1.875A	3.75A	7.5A	15A	30A	60A

limited by PSU60 to max. 60Apk!

Accuracy

Use PSU60 and LMG500 specifications to calculate the accuracy of the complete system. Add ±9mA (to the primary current) DC offset tolerance.

2.15.9 Connection elongation

To use the current sensor with a longer connection length between power meter and PSU connect a well shielded 1:1 extention cable between the PSU (DSUB9f plug) and the PSU connection cable (DSUB9m plug) and screw both plugs together. This extention cable is available at ZES (LMG-Z-DVxx). Required length (up to 15m) is to be given by customer along with the order. Interference from strong electromagnetical disturbed environments may affect the measurement accuracy. This depends from the respective installation in the complete system and is out of responsibility of ZES ZIMMER.

2.16 Precision current transducer 200A (PSU200)

Figure 40: PSU200

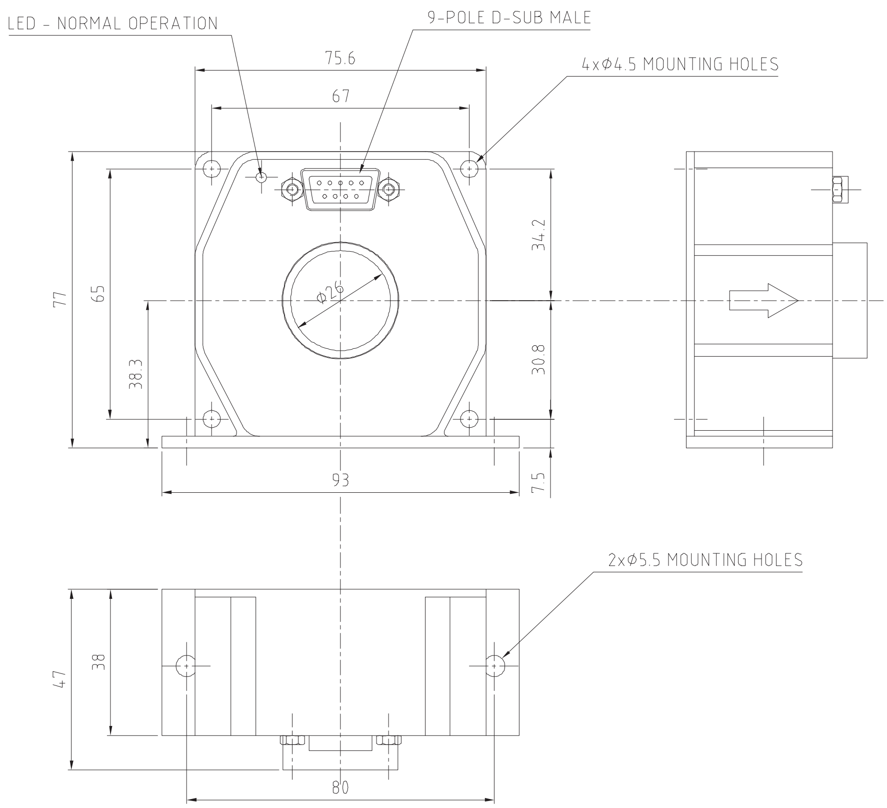


Figure 41: Dimensions of the PSU200

2.16.1 ⚠ Safety warning!

Always connect the sensor first to the meter, and afterwards to the device under test.

Dont allow primary current without supply of the PSU!

Please refer to chapter 1.1: ‘Safety precautions’!

2.16.2 Specifications

Nominal input current	200A
Transformation ratio	1000:1
Measuring range PSU	±200Apk
Maximum input overload	220Aeff 3min 1kA 100ms
Bandwidth (small signal 0.5% of nominal input current) ±1dB ±3dB	 DC to 150kHz DC to >500kHz
Slew rate (10%-90%)	>100A/us
Response time (to 90% of nominal input current)	<1us
Burden Rb	0 .. 30 ohms
Isolation	• rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 2000V with IEC 61010-1 standards and following conditions: over voltage category III, pollution degree 2 • rms voltage, AC isolation test, 50/60Hz, 1min: 5.4kV • impuls withstand voltage 1.2/50us: 9.9kV • rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 1000V with EN50178 standards and following conditions: over voltage category III, pollution degree 2 • creepage distance: 11mm • clearance distance: 11mm • comparative tracking index CTI: 600V **Attention: when using Busbar without isolation regard DSUB cable isolation or avoid contact!!**
Degree of pollution	2
Operating temperature	+10°C to +50°C (operation down to -20°C is possible, please note: ‘non condensing ambient conditions’ and ‘specified temperature drift in the range of -20°C to +10°C is typical, not guaranteed’)
Storage temperature	-20°C to +85°C
Humidity (non condensing)	20-80% RH
Weight	approx. 0.3kg

Output connection	depending on adapter cable to LMGxx
supply	±15V / 280mA

The transformers are only allowed to operate with cables which - according to the printing on the cable - are designed for this individual transformer.

2.16.3 Accuracy

Accuracies based on: sinusoidal current, frequency DC to 100Hz, ambient temperature 23±3°C, calibration interval 1 year, conductor in the middle of the transducer.

Amplitude error ±(% of meas.value+% of measuring range PSU)	0.015%+0.005%
Phase error	0.02°
Temperature coefficient (+10°C to +50°C)	< ±0.4mA/K

See specification of the LMG connection cable for the LMG measuring ranges and to calculate the accuracy of the complete system.

2.16.4 Sensor operation without supply

It is important to assure a stable power supply of the sensor before switching on the load current! The **operation** of the sensor with load current and **without supply will cause damage** of the sensor and/or of the LMG/supply unit!

To remove the LMG/supply unit from the test location without removing the PSU sensors from the current path, you can do alternatively:

- Leave the PSU at the current path and disconnect the cable at the PSU side.
  Disconnect the DSUB9 plug from the PSU and interconnect all of the 9 pins with the shield at the **PSU** plug.

or:

- Leave the PSU and the connection cable at the current path and disconnect the cable at the LMG/supply unit side.

1. Systems with supply via LMG:
   Disconnect the HDSUB15 plug from the LMG and connect all of the 15 pins and the shield at the **cable** plug together

2. Systems with supply via supply unit SSU4:
   Disconnect the HDSUB15 plug from the LMG and disconnect the DSUB9 plug from the supply unit SSU4. Connect all of the 15 pins and the shield at the **LMG cable** plug together and connect all of the 9 pins and the shield at the **SSU4 cable** plug together

To do this, the load current has to be switched off!

2.16.5 Connection of the sensor with LMG90/310 or other instruments with current input

Use sensor suppy unit SSU4 with modification for PSU60/200/400/700 and PSU-K3/K5/K10 and SSU4-K-L31 and direct current inputs I* and I.

2.16.6 Connection of the sensor with LMG95

Use PSU60/200/400/700-K-L95, supply via LMG95, no additional error terms, but only one range and not suitable for small currents.

With slightly less accuracy at fullrange, but with considerably more dynamic range and so better accuracy at small currents it is also possible to use PSU200-K-L50 and L95-Z07. With this assembly you get 8 ranges and a good dynamic down to a few Amps, but a small additional error term from the PSU200-K-L50 cable. Set LMG current scaling factor appropriate to the scaling factor marked on the label on L95-Z07.

It depends on the magnitude and the dynamic of the measuring current, which connection is better.

2.16.7 Connection of the sensor with LMG450 (PSU200-K-L45)

Use PSU200-K-L45 and SSU4 (standard version, without modification).

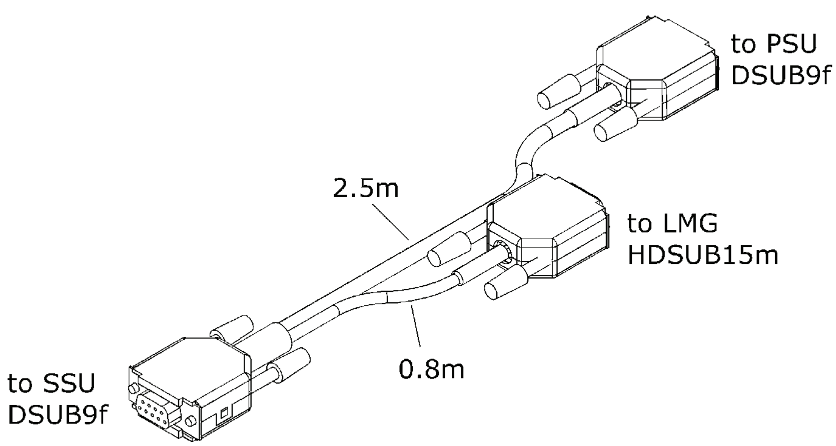


Figure 42: PSU200-K-L45, to connect the PSU200 to the LMG450 and the SSU4

This cable ‘PSU200-K-L45’ is used to connect a precision current sensor PSU200 to a power meter LMG450 and to supply it by a sensor supply unit SSU4.

In the connector to the LMG450 the adjustment data of the PSU200 head are available as well as it’s serial number. For this reason this connector is delivered already mounted to the PSU200 head and the screws are sealed, when you have ordered the package ‘PSU200-L45’. This should prevent, that the wrong PSU200 head is connected to the cable.

The connection is quiet simple:

- Switch all power off and plug the connector labeled ‘SSU-4’ to the SSU-4.
- Plug the connector labeled ‘LMG450’ to the LMG450 external sensor input.
- Now you can switch on the power and make your measurements. The power of the EUT should be switched on at least.

Measuring ranges (sensor input)

nominal value	3.13A	6.25A	12.5A	25A	50A	100A
max. trms value	6.25A	12.5A	25A	50A	100A	200A
max. peak value	6.25A	12.5A	25A	50A	100A	200A

limited by PSU200 to max. 200Apk!

Accuracy

Use PSU200 and LMG450 specifications to calculate the accuracy of the complete system. Add ±30mA (to the primary current) DC offset tolerance.

2.16.8 Connection of the sensor with LMG500 (PSU200-K-L50)

Use PSU200-K-L50 and L50-Z14, supply via LMG500.

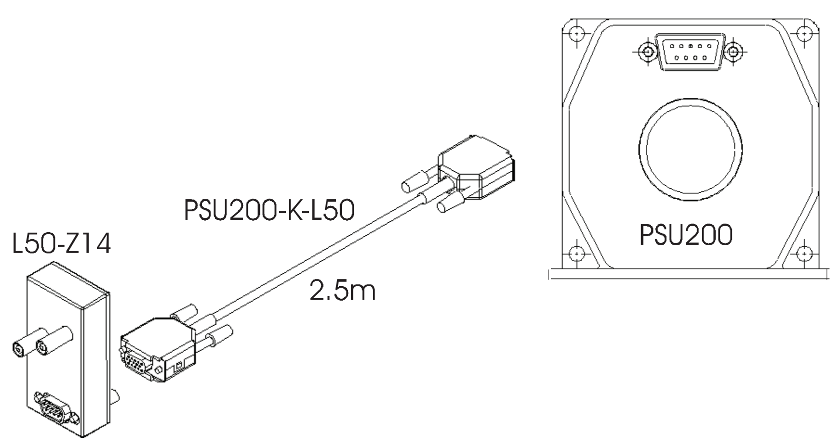


Figure 43: PSU200-K-L50, to connect PSU200 and LMG500

This cable ‘PSU200-K-L50’ is used to connect a precision current sensor PSU200 to the power meter LMG500.

In the connector to the LMG500 the adjustment data of the PSU200 head are available as well as it’s serial number. For this reason this connector is delivered already mounted to the PSU200 head and the screws are sealed, when you have ordered the package ‘PSU200-L50’. This should prevent, that the wrong PSU200 head is connected to the cable.

The connection is quiet simple:
Switch all power off, plug the connector labeled ‘LMG500’ to the adapter L50-Z14 mounted on the LMG500 current channel. Now you can switch on the power and make the measurements. The rangenames of LMG500, the sensor name and calibration data are read out of the sensor EEPROM automaticaly.

Measuring ranges (sensor input)

nominal value	0.75A	1.5A	3.13A	6.25A	12.5A	25A	50A	100A
max. trms value	1.56A	3.13A	6.25A	12.5A	25A	50A	100A	200A
max. peak value	1.56A	3.13A	6.25A	12.5A	25A	50A	100A	200A

limited by PSU200 to max. 200Apk!

Accuracy

Use PSU200 and LMG500 specifications to calculate the accuracy of the complete system. Add ±30mA (to the primary current) DC offset tolerance.

2.16.9 Connection elongation

To use the current sensor with a longer connection length between power meter and PSU connect a well shielded 1:1 extention cable between the PSU (DSUB9f plug) and the PSU connection cable (DSUB9m plug) and screw both plugs together. This extention cable is available at ZES (LMG-Z-DVxx). Required length (up to 15m) is to be given by customer along with the order. Interference from strong electromagnetical disturbed environments may affect the measurement accuracy. This depends from the respective installation in the complete system and is out of responsibility of ZES ZIMMER.

2.17 Precision current transducer 200A (PSU200HF)

Figure 44: PSU200HF

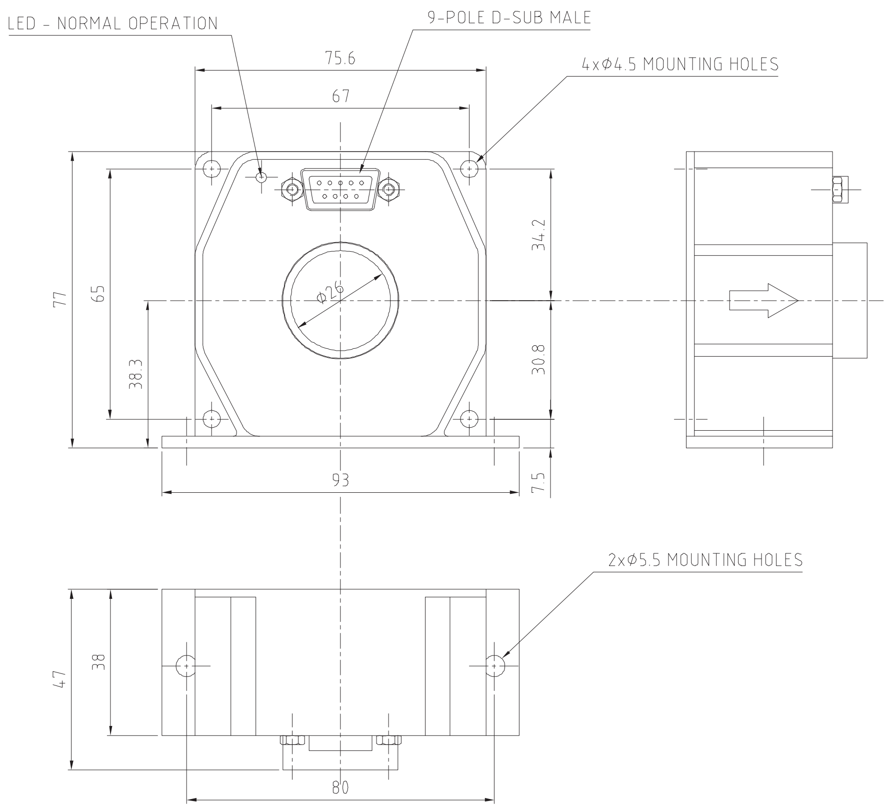


Figure 45: Dimensions of the PSU200HF

2.17.1 Safety warning!

Always connect the sensor first to the meter, and afterwards to the device under test.

Dont allow primary current without supply of the PSU!

Please refer to chapter 1.1: 'Safety precautions'!

2.17.2 Specifications

Nominal input current	200A
Transformation ratio	1000:1
Measuring range PSU	±200Apk
Maximum input overload	220Aeff 3min 1kA 100ms
Bandwidth (small signal 20App, Rb=2.5Ohm, primary current in the middle of the transducer head) ±0.4dB (equivalent to ±4.7%) ±3dB (typical)	 DC to 150kHz DC to >1MHz
Slew rate (10%-90%)	>100A/us
Burden Rb	0 .. 30 ohms
Isolation	• rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 2000V with IEC 61010-1 standards and following conditions: over voltage category III, pollution degree 2 • rms voltage, AC isolation test, 50/60Hz, 1min: 5.4kV • impuls withstand voltage 1.2/50us: 9.9kV • rated isolation voltage rms, reinforced isolation: 600V rated isolation voltage rms, single isolation: 1000V with EN50178 standards and following conditions: over voltage category III, pollution degree 2 • creepage distance: 11mm • clearance distance: 11mm • comparative tracking index CTI: 600V **Attention: when using Busbar without isolation regard DSUB cable isolation or avoid contact!!**
Degree of pollution	2
Operating temperature	+10°C to +50°C (operation down to -20°C is possible, please note: ‘non condensing ambient conditions’ and ‘specified temperature drift in the range of -20°C to +10°C is typical, not guaranteed’)
Storage temperature	-20°C to +85°C
Humidity (non condensing)	20-80% RH
Weight	approx. 0.3kg

Output connection	depending on adapter cable to LMGxx
supply	±15V / 280mA

The transformers are only allowed to operate with cables which - according to the printing on the cable - are designed for this individual transformer.

2.17.3 Accuracy

Accuracies based on: sinusoidal current, frequency DC to 100Hz, ambient temperature 23±3°C, calibration interval 1 year, conductor in the middle of the transducer.

Amplitude error ±(% of meas.value+% of measuring range PSU)	0.015%+0.005%
Phase error	0.02°
Temperature coefficient (+10°C to +50°C)	< ±0.4mA/K

See specification of the LMG connection cable for the LMG measuring ranges and to calculate the accuracy of the complete system.

2.17.4 Sensor operation without supply

It is important to assure a stable power supply of the sensor before switching on the load current! The **operation** of the sensor with load current and **without supply will cause damage** of the sensor and/or of the LMG/supply unit!

To remove the LMG/supply unit from the test location without removing the PSU sensors from the current path, you can do alternatively:

- Leave the PSU at the current path and disconnect the cable at the PSU side.
  Disconnect the DSUB9 plug from the PSU and interconnect all of the 9 pins with the shield at the **PSU** plug.

or:

- Leave the PSU and the connection cable at the current path and disconnect the cable at the LMG/supply unit side.

1. Systems with supply via LMG:
   Disconnect the HDSUB15 plug from the LMG and connect all of the 15 pins and the shield at the **cable** plug together

2. Systems with supply via supply unit SSU4:
   Disconnect the HDSUB15 plug from the LMG and disconnect the DSUB9 plug from the supply unit SSU4. Connect all of the 15 pins and the shield at the **LMG cable** plug together and connect all of the 9 pins and the shield at the **SSU4 cable** plug together

To do this, the load current has to be switched off!

2.17.5 Connection of the sensor with LMG90/310 or other instruments with current input

Use sensor suppy unit SSU4 with modification for PSU60/200/400/700 and PSU-K3/K5/K10 and SSU4-K-L31 and direct current inputs I* and I.

2.17.6 Connection of the sensor with LMG95

Use PSU60/200/400/700-K-L95, supply via LMG95, no additional error terms, but only one range and not suitable for small currents.

With slightly less accuracy at fullrange, but with considerably more dynamic range and so better accuracy at small currents it is also possible to use PSU200HF-K-L50 and L95-Z07. With this assembly you get 8 ranges and a good dynamic down to a few Amps, but a small additional error term from the PSU200HF-K-L50 cable. Set LMG current scaling factor appropriate to the scaling factor marked on the label on L95-Z07.

It depends on the magnitude and the dynamic of the measuring current, which connection is better.

2.17.7 Connection of the sensor with LMG450

You can use PSU200-K-L45 and SSU4 (standard version, without modification), but it is not recommended to use this high frequency sensor with the LMG450.

2.17.8 Connection of the sensor with LMG500 (PSU200HF-K-L50)

Use PSU200HF-K-L50 and L50-Z14, supply via LMG500.

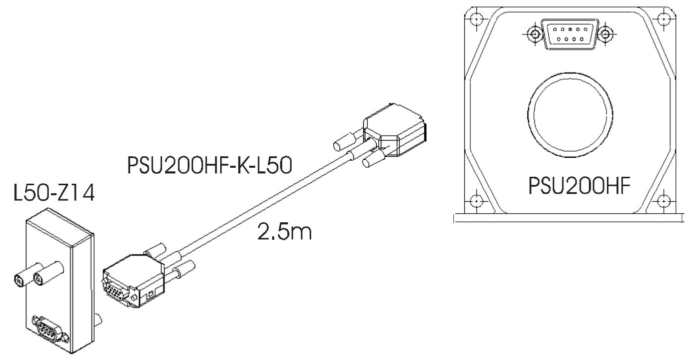


Figure 46: PSU200HF-K-L50, to connect PSU200HF and LMG500

This cable ‘PSU200HF-K-L50’ is used to connect a precision current sensor PSU200HF to the power meter LMG500.

In the connector to the LMG500 the adjustment data of the PSU200HF head are available as well as it’s serial number. For this reason this connector is delivered already mounted to the PSU200HF head and the screws are sealed, when you have ordered the package ‘PSU200HF-L50’. This should prevent, that the wrong PSU200HF head is connected to the cable.

The connection is quiet simple:
Switch all power off, plug the connector labeled ‘LMG500’ to the adapter L50-Z14 mounted on the LMG500 current channel. Now you can switch on the power and make the measurements. The rangenames of LMG500, the sensor name and calibration data are read out of the sensor EEPROM automaticaly.

Measuring ranges (sensor input)

nominal value	0.75A	1.5A	3.13A	6.25A	12.5A	25A	50A	100A
max. trms value	1.56A	3.13A	6.25A	12.5A	25A	50A	100A	200A
max. peak value	1.56A	3.13A	6.25A	12.5A	25A	50A	100A	200A

limited by PSU200HF to max. 200Apk!

Accuracy

Use PSU200HF and LMG500 specifications to calculate the accuracy of the complete system. Add ±30mA (to the primary current) DC offset tolerance.

2.17.9 Connection elongation

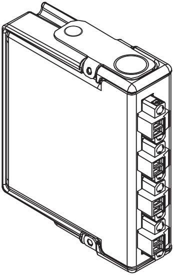
To use the current sensor with a longer connection length between power meter and PSU connect a well shielded 1:1 extention cable between the PSU (DSUB9f plug) and the PSU connection cable (DSUB9m plug) and screw both plugs together. This extention cable is available at ZES (LMG-Z-DVxx). Required length (up to 15m) is to be given by customer along with the order. Interference from strong electromagnetical disturbed environments may affect the measurement accuracy. This depends from the respective installation in the complete system and is out of responsibility of ZES ZIMMER.

OPERATING INSTRUCTIONS AND SPECIFICATIONS

NI 9222/9223

4-Channel, ±10 V, 16-Bit Simultaneous, Channel-to-Channel Isolated Analog Input Modules

Français	Deutsch	日本語	한국어	简体中文
ni.com/manuals				



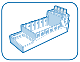
NATIONAL INSTRUMENTS™

This document describes how to use the National Instruments 9222 and National Instruments 9223 and includes specifications and terminal assignments for the NI 9222 and NI 9223. In this document, the NI 9222 and NI 9223 are referred to inclusively as the NI 9222/9223.

Note The safety guidelines and specifications in this document are specific to the NI 9222/9223. The other components in the system might not meet the same safety ratings and specifications. Refer to the documentation for each component in the system to determine the safety ratings and specifications for the entire system.

Related Information

NI CompactDAQ & NI CompactRIO Documentation
ni.com/info ⇨ cseriesdoc



Chassis Compatibility
ni.com/info ⇨ compatibility

Software Support
ni.com/info ⇨ softwareversion

Services
ni.com/services

Safety Guidelines

Operate the NI 9222/9223 only as described in these operating instructions.

Hot Surface This icon denotes that the component may be hot. Touching this component may result in bodily injury.

Caution Do not operate the NI 9222/9223 in a manner not specified in these operating instructions. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to National Instruments for repair.

Safety Guidelines for Hazardous Locations

The NI 9222/9223 is suitable for use in Class I, Division 2, Groups A, B, C, D, T4 hazardous locations; Class I, Zone 2, AEx nA IIC T4, and Ex nA IIC T4 hazardous locations; and nonhazardous locations only. Follow these guidelines if you are installing the NI 9222/9223 in a potentially explosive environment. Not following these guidelines may result in serious injury or death.

Caution Do *not* disconnect I/O-side wires or connectors unless power has been switched off or the area is known to be nonhazardous.

Caution Do *not* remove modules unless power has been switched off or the area is known to be nonhazardous.

Caution Substitution of components may impair suitability for Class I, Division 2.

Caution For Division 2 and Zone 2 applications, install the system in an enclosure rated to at least IP 54 as defined by IEC 60529 and EN 60529.

Special Conditions for Hazardous Locations Use in Europe

This equipment has been evaluated as Ex nA IIC T4 equipment under DEMKO Certificate No. 07 ATEX 0626664X. Each module is marked ⟨Ex⟩ II 3G and is suitable for use in Zone 2 hazardous locations, in ambient temperatures of $-40\ °C \leq \ Ta \leq \ 70\ °C$. If you are using the NI 9222/9223 in Gas Group IIC hazardous locations, you must use the device in an NI chassis that has been evaluated as Ex nC IIC T4, EEx nC IIC T4, Ex nA IIC T4, or Ex nL IIC T4 equipment.

Caution You *must* make sure that transient disturbances do not exceed 140% of the rated voltage.

Caution The system shall be mounted in an ATEX certified enclosure with a minimum ingress protection rating of at least IP54 as defined in IEC/EN 60529 and used in an environment of not more than Pollution Degree 2.

Caution The enclosure must have a door or cover accessible only by the use of a tool.

Electromagnetic Compatibility Guidelines

This product was tested and complies with the regulatory requirements and limits for electromagnetic compatibility (EMC) as stated in the product specifications. These requirements and limits are designed to provide reasonable protection against harmful interference when the product is operated in its intended operational electromagnetic environment.

This product is intended for use in industrial locations. There is no guarantee that harmful interference will not occur in a particular installation, when the product is connected to a test object, or if the product is used in residential areas. To minimize the potential for the product to cause interference to radio and television reception or to experience unacceptable performance degradation, install and use this product in strict accordance with the instructions in the product documentation.

Furthermore, any changes or modifications to the product not expressly approved by National Instruments could void your authority to operate it under your local regulatory rules.

Caution To ensure the specified EMC performance, operate this product only with double-shielded, twisted pair cables and shielded accessories.

Caution Electrostatic Discharge (ESD) can damage this product. To prevent damage, use industry-standard ESD prevention measures during installation, maintenance, and operation.

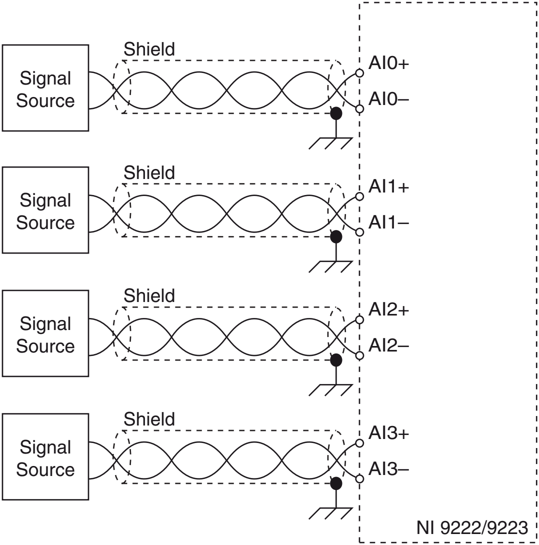
Caution To ensure the specified EMC performance, the length of all I/O cables must be no longer than 30 m (100 ft).

Cable Requirements for EMC Compliance

Select and install cables for the NI 9222/9223 in accordance with the following requirements:

- Connect the cable shield to the chassis ground (grounding screw of the chassis) using the shortest length of wire possible.
- Use shielded, twisted-pair cables (Belden 9451 or equivalent).

Figure 1. NI 9222/9223 Cable Connections for EMC Compliance



Special Guidelines for Marine Applications

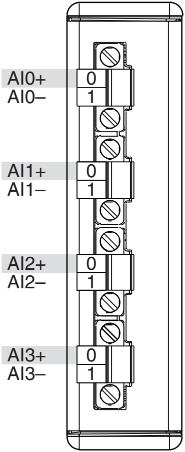
Some products are Lloyd's Register (LR) Type Approved for marine (shipboard) applications. To verify Lloyd's Register certification for a product, visit `ni.com/certification` and search for the LR certificate, or look for the Lloyd's Register mark on the product label.

Caution In order to meet the EMC requirements for marine applications, install the product in a shielded enclosure with shielded and/or filtered power and input/output ports. In addition, take precautions when designing, selecting, and installing measurement probes and cables to ensure that the desired EMC performance is attained.

Connecting the NI 9222/9223

The NI 9222/9223 provides connections for four simultaneously sampled, isolated analog input channels.

Figure 2. NI 9222/9223 Terminal Assignments



Connectors

The NI 9222/9223 has four 2-terminal detachable screw-terminal connectors.

Note You must use 2-wire ferrules to create a secure connection when connecting more than one wire to a single terminal on the NI 9222/9223.

Connecting Differential Voltage Signals

You can connect ground-referenced or floating signal sources to the NI 9222/9223. Connect the positive signal of the signal source to the AI+ terminal, and connect the negative signal of the signal source to the AI- terminal. If you make a ground-referenced connection between the signal source and the NI 9222/9223, make sure the voltage on the AI+ and AI- connections are in the channel-to-earth safety voltage range to ensure proper operation of the NI 9222/9223. Refer to the *Specifications* section for more information about operating voltages and overvoltage protection. Refer to Figures 3 and 4 for illustrations of how to connect grounded and floating signal sources to the NI 9222/9223.

Figure 3. Connecting a Grounded Signal Source to the NI 9222/9223

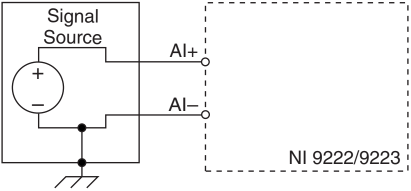
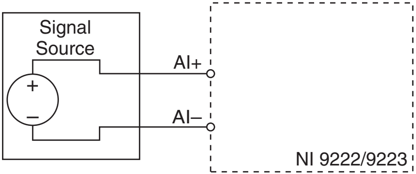


Figure 4. Connecting a Floating Signal Source to the NI 9222/9223

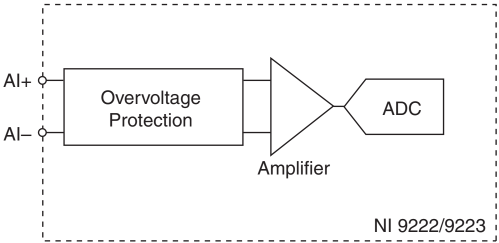


Circuitry

The NI 9222/9223 analog input channels are floating with respect to earth ground and each other. The incoming analog signal on each channel is buffered, conditioned, and then sampled by a 16-bit successive approximation register ADC.

Each channel provides an independent signal path and ADC, enabling you to sample all four channels simultaneously. Refer to Figure 5 for an illustration of the circuitry for one channel.

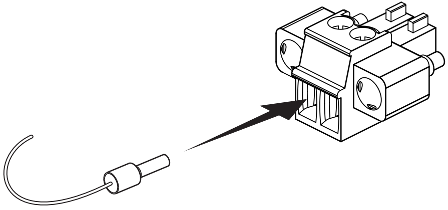
Figure 5. Input Circuitry for One Channel of the NI 9222/9223



Wiring for High-Vibration Applications

If an application is subject to high vibration, National Instruments recommends that you either use ferrules to terminate wires to the detachable screw-terminal connector or use the NI 9971 backshell kit to protect the connections. Refer to Figure 6 for an illustration of wiring a terminal using ferrules.

Figure 6. 2-Terminal Detachable Screw-Terminal Connector with Ferrule



Sleep Mode

This module supports a low-power sleep mode. Support for sleep mode at the system level depends on the chassis that the module is plugged into. Refer to the chassis manual for information about support for sleep mode. If the chassis supports sleep mode, refer to the software help for information about enabling sleep mode. Visit `ni.com/info` and enter `cseriesdoc` for information about C Series documentation.

Typically, when a system is in sleep mode, you cannot communicate with the modules. In sleep mode, the system consumes minimal power and may dissipate less heat than it does in normal mode. Refer to the *Specifications* section for more information about power consumption and thermal dissipation.

Specifications

The following specifications are typical for the range -40 to 70 °C unless otherwise noted. All voltages are relative to the AI- signal on each channel unless otherwise noted. The specifications are the same for the NI 9222 and the NI 9223 unless otherwise noted.

Input Characteristics

Number of channels .... 4 analog input channels

ADC resolution .... 16 bits

Type of ADC...................................... Successive approximation register (SAR)

Input voltage ranges[1]

Measurement Voltage, AI+ to AI-		
Minimum*	**Typical**	**Maximum**
±10.5 V	±10.6 V	±10.7 V
* The *minimum measurement voltage range* is the largest voltage the NI 9222/9223 is guaranteed to accurately measure.		

Overvoltage protection .... ±30 V

[1] Refer to the *Safety Guidelines* section for more information about safe operating voltages.

Maximum Sampling Rate

Module	CompactDAQ	RIO	
	NI-DAQmx	FPGA User-Controlled I/O Sampling*	FPGA I/O Nodes
NI 9222	500 kS/s	500 kS/s	300 kS/s
NI 9223	1 MS/s	1 MS/s	350 kS/s

* FPGA User-Controlled I/O Sampling provides low level access to sample acquisition and transfer, and higher sample rates. Visit `ni.com/info` and enter `samplerate` for information about FPGA User-Controlled I/O Sampling for the NI 9222/9223.

Accuracy

Measurement Conditions	Percent of Reading (Gain Error)	Percentage of Range* (Offset Error)
Calibrated, max (-40 to 70 °C)	±0.20%	±0.10%
Calibrated, typ (23 °C, ±5 °C)	±0.02%	±0.01%
Uncalibrated, max (-40 °C to 70 °C)	±0.40%	±0.40%
Uncalibrated, typ (23 °C, ±5 °C)	±0.20%	±0.10%
* Range equals 10.6 V		

Stability

Gain drift .... 6 ppm/°C

Offset drift .... 29 µV/°C

CMRR (f_{in} = 60 Hz) .... 100 dB

-3 dB bandwidth

NI 9222 .... >500 kHz

NI 9223 .... >1 MHz

Input impedance .... >1 GΩ

Noise .... 0.75 LSB_{rms}

Total Harmonic Distortion (THD)
(20 V_{pp} at 10 kHz) .... -85 dB

Crosstalk (20 V_{pp} at 1 kHz) .... -100 dB

MTBF .... Contact NI for Bellcore MTBF or MIL-HDBK-217F specifications.

Power Requirements

Power consumption from chassis

Active mode .... 1 W max

Sleep mode .... 5 mW max

Thermal dissipation (at 70 °C)

Active mode .... 1.3 W max

Sleep mode .... 430 mW max

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Note For two-dimensional drawings and three-dimensional models of the C Series module and connectors, visit `ni.com/dimensions` and search by module number.

Screw-terminal wiring	2.053 mm diameter (12 AWG) to 0.511 mm diameter (24 AWG) copper conductor wire with 10 mm (0.39 in.) of insulation stripped from the end
Torque for screw terminals	0.5 to 0.6 N · m (4.4 to 5.3 lb · in.)
Ferrules	0.25 mm^2 to 2.5 mm^2
Weight	138 g (4.9 oz)

Safety

Safety Voltages

Connect only voltages that are within the following limits.

Isolation

Channel-to-channel

Continuous .... 60 VDC, Measurement Category I

Withstand .... 1000 V_{rms}, verified by a 5 s dielectric withstand test

Channel-to-earth ground

Continuous .... 60 VDC, Measurement Category I

Withstand .... 1000 V_{rms}, verified by a 5 s dielectric withstand test

Division 2 and Zone 2 hazardous locations applications

(Channel-to-channel and channel-to-earth ground) .... 60 VDC, Measurement Category I

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as *MAINS* voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

Caution Do *not* connect the NI 9222/9223 to signals or use for measurements within Measurement Categories II, III, or IV.

Note Measurement Categories CAT I and CAT O (Other) are equivalent. These test and measurement circuits are not intended for direct connection to the MAINs building installations of Measurement Categories CAT II, CAT III, or CAT IV.

Hazardous Locations

U.S. (UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nA IIC T4
Canada (C-UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, Ex nA IIC T4
Europe (DEMKO)	Ex nA IIC T4

Safety Standards

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Industrial immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (perCISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

Note For EMC declarations and certifications, refer to the *Online Product Certification* section.

CE Compliance CE

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

To obtain product certifications and the Declaration of Conformity (DoC) for this product, visit `ni.com/certification`, search by module number or product line, and click the appropriate link in the Certification column.

Shock and Vibration

To meet these specifications, you must panel mount the system and either affix ferrules to the ends of the terminal wires or use the NI 9971 backshell kit to protect the connections.

Operating vibration

Random (IEC 60068-2-64)......... 5 g_{rms}, 10 to 500 Hz

Sinusoidal (IEC 60068-2-6) .... 5 g, 10 to 500 Hz

Operating shock (IEC 60068-2-27).............................. 30 g, 11 ms half sine, 50 g, 3 ms half sine, 18 shocks at 6 orientations

Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature (IEC 60068-2-1, IEC 60068-2-2) ..... -40 °C to 70 °C

Storage temperature (IEC 60068-2-1, IEC 60068-2-2) ..... -40 °C to 85 °C

Ingress protection............................. IP 40

Operating humidity (IEC 60068-2-56)	10 to 90% RH, noncondensing
Storage humidity (IEC 60068-2-56)	5 to 95% RH, noncondensing
Maximum altitude	2,000 m
Pollution Degree	2

Indoor use only

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at `ni.com/environment`. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all products *must* be sent to a WEEE recycling center. For more information about WEEE recycling centers, National Instruments WEEE initiatives, and compliance with WEEE Directive 2002/96/EC on Waste and Electronic Equipment, visit `ni.com/environment/weee`.

电子信息产品污染控制管理办法 （中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。 (For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

Calibration

You can obtain the calibration certificate and information about calibration services for the NI 9222/9223 at `ni.com/calibration`.

Calibration interval .... 1 year

Where to Go for Support

The National Instruments website is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit ni.com/services for NI Factory Installation Services, repairs, extended warranty, and other services.

Visit ni.com/register to register your National Instruments product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification. If your product supports calibration, you can obtain the calibration certificate for your product at ni.com/calibration.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world. For telephone support in the United States, create your service request at ni.com/support or dial 512 795 8248. For telephone support outside the United States, visit the Worldwide Offices section of ni.com/niglobal to access the branch office websites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

374223B-01 Jul13

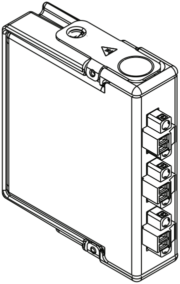
OPERATING INSTRUCTIONS AND SPECIFICATIONS

NI 9225

3-Channel, 300 V_{rms}, 24-Bit Simultaneous, Channel-to-Channel Isolated Analog Input Module

Français	Deutsch	日本語	한국어	简体中文

ni.com/manuals



NATIONAL INSTRUMENTS™

This document describes how to use the National Instruments 9225 and includes specifications and pin assignments for the NI 9225.

Note The safety guidelines and specifications in this document are specific to the NI 9225. The other components in the system might not meet the same safety ratings and specifications. Refer to the documentation for each component in the system to determine the safety ratings and specifications for the entire system.

Related Information

NI CompactDAQ & NI CompactRIO Documentation
ni.com/info ⇨ cseriesdoc

Chassis Compatibility
ni.com/info ⇨ compatibility

Software Support
ni.com/info ⇨ softwareversion

Services
ni.com/services

Safety Guidelines

Operate the NI 9225 only as described in these operating instructions.

Hot Surface This icon denotes that the component may be hot. Touching this component may result in bodily injury.

Hazardous Voltage This icon denotes a warning advising you to take precautions to avoid electrical shock.

Caution Do not operate the NI 9242 in a manner not specified in this manual. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to National Instruments for repair.

Safety Guidelines for Hazardous Voltages

If hazardous voltages are connected to the module, take the following precautions. A hazardous voltage is a voltage greater than 42.4 V_{pk} or 60 VDC to earth ground.

Caution Ensure that hazardous voltage wiring is performed only by qualified personnel adhering to local electrical standards.

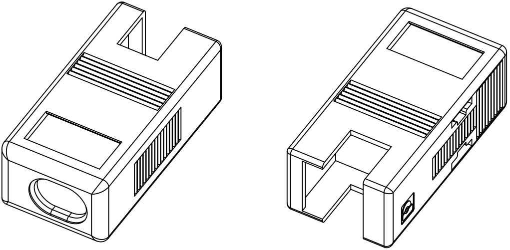
Caution Do *not* mix hazardous voltage circuits and human-accessible circuits on the same module.

Caution Make sure that devices and circuits connected to the module are properly insulated from human contact.

Caution When module terminals are hazardous voltage LIVE (>42.4 V_{pk}/60 VDC), you must ensure that devices and circuits connected to the module are properly insulated from human contact. You must use the NI 9971 connector backshell kit to ensure that the terminals are *not* accessible.

Figure 1 shows the NI 9971 connector backshell.

Figure 1. NI 9971 Connector Backshell



Safety Guidelines for Hazardous Locations

The NI 9225 is suitable for use in Class I, Division 2, Groups A, B, C, D, T4 hazardous locations; Class I, Zone 2, AEx nA IIC T4, and Ex nA IIC T4 hazardous locations; and nonhazardous locations only. Follow these guidelines if you are installing the NI 9225 in a potentially explosive environment. Not following these guidelines may result in serious injury or death.

Caution Do *not* disconnect I/O-side wires or connectors unless power has been switched off or the area is known to be nonhazardous.

Caution Do *not* remove modules unless power has been switched off or the area is known to be nonhazardous.

Caution Substitution of components may impair suitability for Class I, Division 2.

Caution For Zone 2 applications, install the system in an enclosure rated to at least IP 54 as defined by IEC 60529 and EN 60529.

Special Conditions for Marine Applications

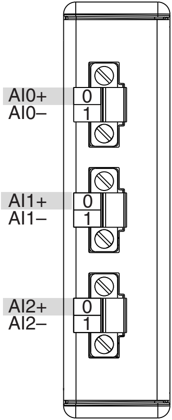
Some modules are Lloyd's Register (LR) Type Approved for marine applications. To verify Lloyd's Register certification, visit `ni.com/certification` and search for the LR certificate, or look for the Lloyd's Register mark on the module.

Caution To meet radio frequency emission requirements for marine applications, use shielded cables and install the system in a metal enclosure. Suppression ferrites must be installed on power supply inputs near power entries to modules and controllers. Power supply and module cables must be separated on opposite sides of the enclosure and must enter and exit through opposing enclosure walls.

Connecting the NI 9225

The NI 9225 has three 2-terminal detachable screw-terminal connectors that provide connections for three simultaneously sampled, isolated analog input channels.

Figure 2. NI 9225 Terminal Assignments



You can connect ground-referenced or floating signal sources to the NI 9225. Connect the positive signal of the signal source to the AI+ terminal, and connect the negative signal of the signal source to the AI- terminal. If you make a ground-referenced connection between the signal source and the NI 9225, make sure the voltage on the AI+ and AI- connections are in the channel-to-earth safety voltage range to ensure proper operation of the NI 9225. Refer to the *Specifications* section for more information about operating voltages and overvoltage protection.

Note You must use 2-wire ferrules to create a secure connection when connecting more than one wire to a single terminal on the NI 9225.

Refer to Figures 3 and 4 for illustrations of how to connect grounded and floating signal sources to the NI 9225.

Figure 3. Connecting a Grounded Signal Source to the NI 9225

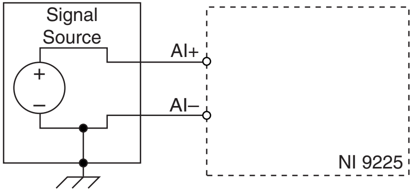
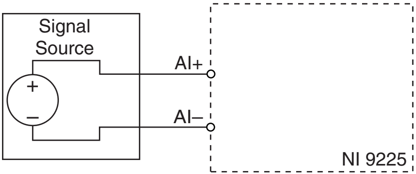


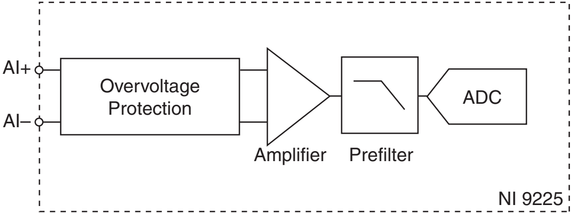
Figure 4. Connecting a Floating Signal Source to the NI 9225



The NI 9225 analog input channels are floating with respect to earth ground and each other. The incoming analog signal on each channel is conditioned, buffered, and then sampled by a 24-bit Delta-Sigma ADC.

Each channel provides an independent signal path and ADC, enabling you to sample all three channels simultaneously. Refer to Figure 5 for an illustration of the circuitry for one channel of the NI 9225.

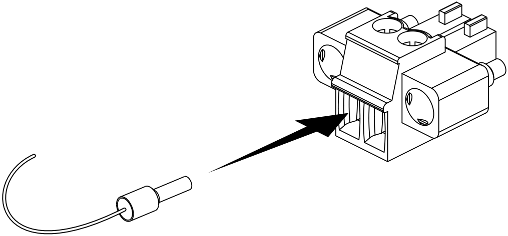
Figure 5. Input Circuitry for One Channel of the NI 9225



Wiring for High-Vibration Applications

If an application is subject to high vibration, National Instruments recommends that you either use ferrules to terminate wires to the detachable screw-terminal connector or use the NI 9971 backshell kit to protect the connections. Refer to Figure 6 for an illustration of using ferrules. Refer to Figure 1 for an illustration of the NI 9971 connector backshell.

Figure 6. 2-Terminal Detachable Screw-Terminal Connector with Ferrule



Understanding NI 9225 Filtering

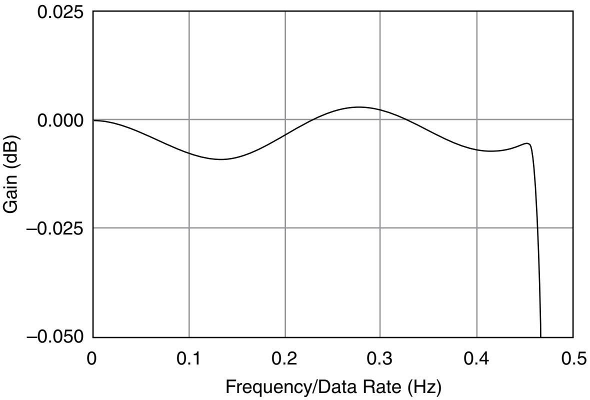
The NI 9225 uses a combination of analog and digital filtering to provide an accurate representation of in-band signals while rejecting out-of-band signals. The filters discriminate between signals based on the frequency range, or bandwidth, of the signal. The three important bandwidths to consider are the passband, the stopband, and the alias-free bandwidth.

The NI 9225 represents signals within the passband, as quantified primarily by passband flatness and phase nonlinearity. All signals that appear in the alias-free bandwidth are either unaliased signals or signals that have been filtered by at least the amount of the stopband rejection.

Passband

The signals within the passband have frequency-dependent gain or attenuation. The small amount of variation in gain with respect to frequency is called the passband flatness. The digital filters of the NI 9225 adjust the frequency range of the passband to match the data rate. Therefore, the amount of gain or attenuation at a given frequency depends on the data rate. Figure 7 shows typical passband flatness for the NI 9225.

Figure 7. Typical Passband Response of the NI 9225



Stopband

The filter significantly attenuates all signals above the stopband frequency. The primary goal of the filter is to prevent aliasing. Therefore, the stopband frequency scales precisely with the data rate. The stopband rejection is the minimum amount of attenuation applied by the filter to all signals with frequencies within the stopband.

Alias-Free Bandwidth

Any signal that appears in the alias-free bandwidth of the NI 9225 is not an aliased artifact of signals at a higher frequency. The alias-free bandwidth is defined by the ability of the filter to reject frequencies above the stopband frequency and equals the data rate minus the stopband frequency.

Understanding NI 9225 Data Rates

The frequency of a master timebase (f_M) controls the data rate (f_s) of the NI 9225. The NI 9225 includes an internal master timebase with a frequency of 12.8 MHz, but the module also can accept an external master timebase or export its own master timebase. To synchronize the data rate of an NI 9225 with other modules that use master timebases to control sampling, all of the modules must share a single master timebase source. Refer to the software help for information about configuring the master timebase source for the NI 9225. Visit `ni.com/info` and enter `cseriesdoc` for information about C Series documentation.

The following equation provides the available data rates of the NI 9225:

$$f_s = \frac{f_M \div 256}{n}$$

where n is any integer from 1 to 31.

However, the data rate must remain within the appropriate data rate range. Refer to the *Specifications* section for more information about the data rate range. When using the internal master timebase of 12.8 MHz, the result is data rates of 50 kS/s, 25 kS/s, 16.667 kS/s, and so on down to 1.613 kS/s, depending on the value of n. When using an external timebase with a frequency other than 12.8 MHz, the NI 9225 has a different set of data rates.

Note The cRIO-9151 R Series Expansion chassis does not support sharing timebases between modules.

Sleep Mode

This module supports a low-power sleep mode. Support for sleep mode at the system level depends on the chassis that the module is plugged into. Refer to the chassis manual for information about support for sleep mode. If the chassis supports sleep mode, refer to the software help for information about enabling sleep mode. Visit `ni.com/info` and enter `cseriesdoc` for information about C Series documentation.

Typically, when a system is in sleep mode, you cannot communicate with the modules. In sleep mode, the system consumes minimal power and may dissipate less heat than it does in normal mode. Refer to the *Specifications* section for more information about power consumption and thermal dissipation.

Specifications

The following specifications are typical for the range -40 to 70 °C unless otherwise noted. All voltages are relative to the AI- signal on each channel unless otherwise noted.

Input Characteristics

Number of channels .... 3 analog input channels

ADC resolution .... 24 bits

Type of ADC .... Delta-Sigma (with analog prefiltering)

Sampling mode .... Simultaneous

Internal master timebase (f_M)

Frequency .... 12.8 MHz

Accuracy .... ±100 ppm max

Data rate range (f_s) using internal master timebase

Minimum .... 1.613 kS/s

Maximum .... 50 kS/s

Data rate range (f_s) using external master timebase

Minimum .... 390.625 S/s

Maximum .... 51.36 kS/s

Data rates[1] (f_s) .... $\frac{f_M \div 256}{n}$, $n = 1, 2, ..., 31$

Operating voltage ranges[2]

Minimum .... 294 V_{rms}

Typical .... 300 V_{rms}

Typical scaling coefficient .... 50.66 µV/LSB

Overvoltage protection .... ±450 VDC

Input coupling .... DC

Input impedance (AI+ to AI-) .... 1 MΩ

[1] The data rate must remain within the appropriate data rate range. Refer to the *Understanding NI 9225 Data Rates* section for more information.

[2] Refer to the *Safety Guidelines* section for more information about safe operating voltages.

Accuracy

Measurement Conditions	Percent of Reading (Gain Error)	Percent of Range[*] (Offset Error)
Calibrated max (-40 to 70 °C)	±0.23%	±0.05%
Calibrated typ (25 °C, ±5 °C)	±0.05%	±0.008%
Calibrated max (25 °C, ±15 °C)	±0.084%	±0.016%
Uncalibrated max (-40 to 70 °C)	±1.6%	±0.66%
Uncalibrated typ (25 °C, ±5 °C)	±0.4%	±0.09%
[*] Range equals 425 V.		

Input noise .... 2 mV_{rms}

Stability

Gain drift .... ±10 ppm/°C

Offset drift .... ±970 μV/°C

Post calibration gain match
(ch-to-ch, 20 kHz)............................ ±0.25 dB max

Crosstalk (60 Hz) .... –130 dB

Phase match

Ch-to-ch, max .... 0.035°/kHz

Module-to-module, max .... 0.035°/kHz + 360° · f_{in}/f_M

Phase linearity (f_s = 50 kS/s) .... 0.22° max

Input delay .... $40\frac{5}{512}/f_s + 3.6\ \mu s$

Passband

Frequency .... $0.453 \cdot f_s$

Flatness (f_s = 50 kS/s) .... ±100 mdB max

Stopband

Frequency .... $0.547 \cdot f_s$

Rejection.................................... -100 dB

Alias-free bandwidth .... $0.453 \cdot f_s$

-3 dB bandwidth (f_s = 50 kS/s).......... 24.56 kHz

CMRR (f_{in} = 60 Hz)......................... 104 dB

SFDR (1 kHz, -60 dBFS)................. 128 dBFS

Total Harmonic Distortion (THD)
(1 kHz, -20 dB) .... -95 dB

MTBF .... 301,606 hours at 25 °C; Bellcore Issue 2, Method 1, Case 3, Limited Part Stress Method

Note Contact NI for Bellcore MTBF specifications at other temperatures or for MIL-HDBK-217F specifications.

Power Requirements

Power consumption from chassis

Active mode .... 495 mW max

Sleep mode .... 25 μW max

Thermal dissipation (at 70 °C)

Active mode .... 760 mW max

Sleep mode .... 265 mW max

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Screw-terminal wiring .... 16 to 28 AWG copper conductor wire with 7 mm (0.28 in.) of insulation stripped from the end

Torque for screw terminals .... 0.22 to 0.25 N · m (1.95 to 2.21 lb · in.)

Ferrules .... 0.25 mm^2 to 0.5 mm^2

Weight.. 141 g (5.0 oz)

Safety

Maximum Voltage

Connect only voltages that are within the following limits.

AI+ to AI- .... 300 V_{rms} max

Isolation Voltages

Channel-to-channel

Continuous .... 600 V_{rms}, Measurement Category II

Withstand.................................. 2,300 V_{rms}, verified by a 5 s dielectric withstand test

Channel-to-earth ground

Continuous .... 300 V_{rms}, Measurement Category II

Withstand.................................. 2,300 V_{rms}, verified by a 5 s dielectric withstand test

Measurement Category II is for measurements performed on circuits directly connected to the electrical distribution system. This category refers to local-level electrical distribution, such as that provided by a standard wall outlet, for example, 115 V for U.S. or 230 V for Europe.

Caution Do *not* connect the NI 9225 to signals or use for measurements within Measurement Categories III or IV.

Safety Standards

This product is designed to meet the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or visit `ni.com/certification`, search for the module number or product line, and click the appropriate link in the Certification column.

Hazardous Locations

U.S. (UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nA IIC T4
Canada (C-UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, Ex nA IIC T4

Environmental

National Instruments C Series modules are intended for indoor use only but may be used outdoors if installed in a suitable enclosure. Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature
(IEC 60068-2-1, IEC 60068-2-2) ..... -40 to 70 °C

Storage temperature
(IEC 60068-2-1, IEC 60068-2-2) ..... -40 to 85 °C

Ingress protection.............................. IP 40

Operating humidity
(IEC 60068-2-56).............................. 10 to 90% RH, noncondensing

Storage humidity
(IEC 60068-2-56).............................. 5 to 95% RH, noncondensing

Maximum altitude............................ 2,000 m

Pollution Degree (IEC 60664).......... 2

Shock and Vibration

To meet these specifications, you must panel mount the system and either affix ferrules to the ends of the terminal wires or use the NI 9971 backshell kit to protect the connections.

Operating vibration

Random (IEC 60068-2-64)......... 5 g_{rms}, 10 to 500 Hz

Sinusoidal (IEC 60068-2-6) .... 5 g, 10 to 500 Hz

Operating shock
(IEC 60068-2-27).............................. 30 g, 11 ms half sine,
50 g, 3 ms half sine,
18 shocks at 6 orientations

Electromagnetic Compatibility

This product is designed to meet the requirements of the following standards of EMC for electrical equipment for measurement, control, and laboratory use:

- EN 61326 EMC requirements; Industrial Immunity
- EN 55011 Emissions; Group 1, Class A
- CE, C-Tick, ICES, and FCC Part 15 Emissions; Class A

Note For EMC compliance, operate this device with shielded cabling.

CE Compliance CE

This product meets the essential requirements of applicable European directives, as amended for CE markings, as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Note Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, visit `ni.com/certification`, search by module number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at `ni.com/environment`. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all products *must* be sent to a WEEE recycling center. For more information about WEEE recycling centers, National Instruments WEEE initiatives, and compliance with WEEE Directive 2002/96/EC on Waste and Electronic Equipment, visit `ni.com/environment/weee`.

电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

Calibration

You can obtain the calibration certificate and information about calibration services for the NI 9225 at ni.com/calibration.

Calibration interval .... 1 year

Worldwide Support and Services

The National Instruments website is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit ni.com/services for NI Factory Installation Services, repairs, extended warranty, and other services.

Visit ni.com/register to register your National Instruments product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification. If your product supports calibration, you can obtain the calibration certificate for your product at ni.com/calibration.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world. For telephone support in the United States, create your service request at ni.com/support or dial 1 866 ASK MYNI (275 6964). For telephone support outside the United States, visit the Worldwide Offices section of ni.com/niglobal to access the branch office websites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

374707E-01 Jul14

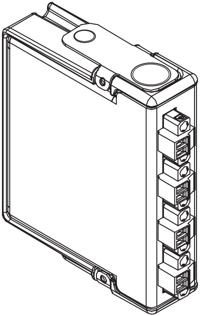
OPERATING INSTRUCTIONS AND SPECIFICATIONS

NI 9227

4-Channel, 5 A_{rms}, 24-Bit, Simultaneous, Channel-to-Channel Isolated Analog Input Module

Français	Deutsch	日本語	한국어	简体中文

ni.com/manuals



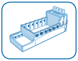
NATIONAL INSTRUMENTS™

This document describes how to use the National Instruments 9225 and includes specifications and pin assignments for the NI 9225.

Note The safety guidelines and specifications in this document are specific to the NI 9225. The other components in the system might not meet the same safety ratings and specifications. Refer to the documentation for each component in the system to determine the safety ratings and specifications for the entire system.

Related Information

NI CompactDAQ & NI CompactRIO Documentation
ni.com/info ⇨ cseriesdoc



Chassis Compatibility
ni.com/info ⇨ compatibility

Software Support
ni.com/info ⇨ softwareversion

Services
ni.com/services

Safety Guidelines

Operate the NI 9227 only as described in these operating instructions.

Hot Surface This icon denotes that the component may be hot. Touching this component may result in bodily injury.

Hazardous Voltage This icon denotes a warning advising you to take precautions to avoid electrical shock.

Caution Do not operate the NI 9242 in a manner not specified in this manual. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to National Instruments for repair.

Safety Guidelines for Hazardous Voltages

If hazardous voltages are connected to the module, take the following precautions. A hazardous voltage is a voltage greater than 42.4 V_{pk} or 60 VDC to earth ground.

Caution Ensure that hazardous voltage wiring is performed only by qualified personnel adhering to local electrical standards.

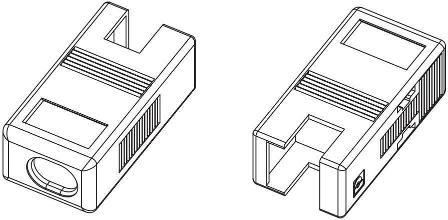
Caution Do *not* mix hazardous voltage circuits and human-accessible circuits on the same module.

Caution Make sure that devices and circuits connected to the module are properly insulated from human contact.

Caution When module terminals are hazardous voltage LIVE (>42.4 V_{pk}/60 VDC), you must ensure that devices and circuits connected to the module are properly insulated from human contact. You must use the NI 9971 connector backshell kit to ensure that the terminals are *not* accessible.

Figure 1 shows the NI 9971 connector backshell.

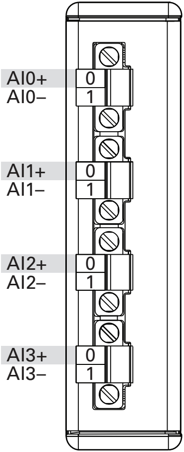
Figure 1. NI 9971 Connector Backshell



Connecting the NI 9227

The NI 9227 has four 2-terminal detachable screw-terminal connectors that provide connections for four simultaneously sampled, isolated analog input channels.

Figure 2. NI 9227 Terminal Assignments



You can connect ground-referenced or floating current sources to the NI 9227. Connect the positive side of the current source to the AI+ terminal, and connect the negative side of the current source to the AI- terminal. If you make a ground-referenced connection between the current source and the NI 9227, make sure the voltage on the AI+ and AI- connections are in the channel-to-earth safety voltage range to ensure proper operation of the NI 9227. Refer to the *Specifications* section for more information about operating voltages.

Note You must use 2-wire ferrules to create a secure connection when connecting more than one wire to a single terminal on the NI 9227.

Refer to Figures 3 and 4 for illustrations of how to connect grounded and floating current sources to the NI 9227.

Figure 3. Connecting a Grounded Current Source to the NI 9227

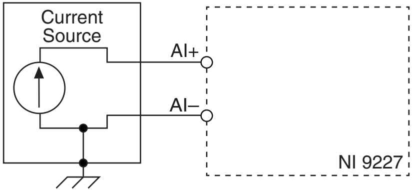
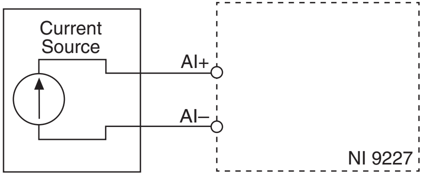


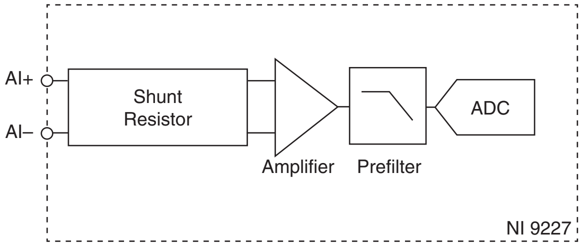
Figure 4. Connecting a Floating Current Source to the NI 9227



The NI 9227 analog input channels are floating with respect to earth ground and each other. The incoming analog signal on each channel is conditioned, buffered, and then sampled by a 24-bit Delta-Sigma ADC.

Each channel provides an independent signal path and ADC, enabling you to sample all four channels simultaneously. Refer to Figure 5 for an illustration of the circuitry for one channel of the NI 9227.

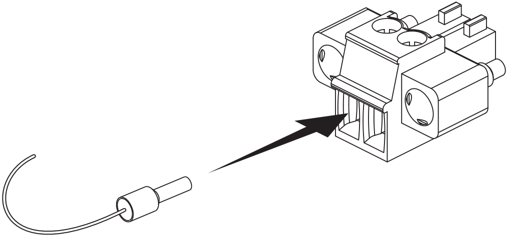
Figure 5. Input Circuitry for One Channel of the NI 9227



Wiring for High-Vibration Applications

If an application is subject to high vibration, National Instruments recommends that you either use ferrules to terminate wires to the detachable screw-terminal connector or use the NI 9971 backshell kit to protect the connections. Refer to Figure 6 for an illustration of using ferrules. Refer to Figure 1 for an illustration of the NI 9971 connector backshell.

Figure 6. 2-Terminal Detachable Screw-Terminal Connector with Ferrule



Understanding NI 9227 Filtering

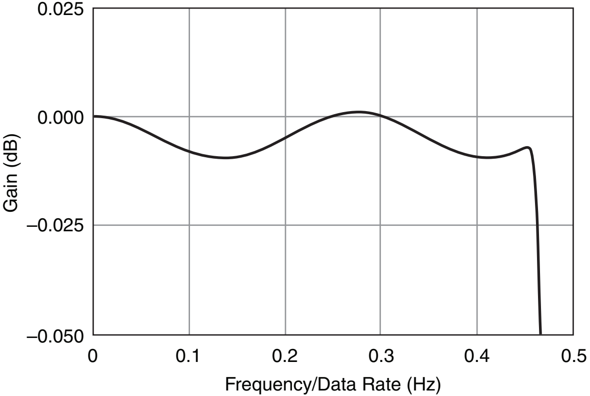
The NI 9227 uses a combination of analog and digital filtering to provide an accurate representation of in-band signals while rejecting out-of-band signals. The filters discriminate between signals based on the frequency range, or bandwidth, of the signal. The three important bandwidths to consider are the passband, the stopband, and the alias-free bandwidth.

The NI 9227 represents signals within the passband, as quantified primarily by passband flatness and phase nonlinearity. All signals that appear in the alias-free bandwidth are either unaliased signals or signals that have been filtered by at least the amount of the stopband rejection.

Passband

The signals within the passband have frequency-dependent gain or attenuation. The small amount of variation in gain with respect to frequency is called the passband flatness. The digital filters of the NI 9227 adjust the frequency range of the passband to match the data rate. Therefore, the amount of gain or attenuation at a given frequency depends on the data rate. Figure 7 shows typical passband flatness for the NI 9227.

Figure 7. Typical Passband Flatness for the NI 9227



Stopband

The filter significantly attenuates all signals above the stopband frequency. The primary goal of the filter is to prevent aliasing. Therefore, the stopband frequency scales precisely with the data rate. The stopband rejection is the minimum amount of attenuation applied by the filter to all signals with frequencies within the stopband.

Alias-Free Bandwidth

Any signal that appears in the alias-free bandwidth of the NI 9227 is not an aliased artifact of signals at a higher frequency. The alias-free bandwidth is defined by the ability of the filter to reject frequencies above the stopband frequency, and it is equal to the data rate minus the stopband frequency.

Understanding NI 9227 Data Rates

The frequency of a master timebase (f_M) controls the data rate (f_s) of the NI 9227. The NI 9227 includes an internal master timebase with a frequency of 12.8 MHz, but the module also can accept an external master timebase or export its own master timebase. To synchronize the data rate of an NI 9227 with other modules that use master timebases to control sampling, all of the modules must share a single master timebase source. Refer to the software help for information about configuring the master timebase source for the NI 9227. Visit `ni.com/info` and enter `cseriesdoc` for information about C Series documentation.

The following equation provides the available data rates of the NI 9227:

$$f_s = \frac{f_M \div 256}{n}$$

where n is any integer from 1 to 31.

However, the data rate must remain within the appropriate data rate range. Refer to the *Specifications* section for more information about the data rate range. When using the internal master timebase of 12.8 MHz, the result is data rates of 50 kS/s, 25 kS/s, 16.667 kS/s, and so on down to 1.613 kS/s, depending on the value of n. When using an external timebase with a frequency other than 12.8 MHz, the NI 9227 has a different set of data rates.

Note The NI cRIO-9151 R Series Expansion chassis does not support sharing timebases between modules.

Sleep Mode

This module supports a low-power sleep mode. Support for sleep mode at the system level depends on the chassis that the module is plugged into. Refer to the chassis manual for information about support for sleep mode. If the chassis supports sleep mode, refer to the software help for information about enabling sleep mode. Visit `ni.com/info` and enter `cseriesdoc` for information about C Series documentation.

Typically, when a system is in sleep mode, you cannot communicate with the modules. In sleep mode, the system consumes minimal power and may dissipate less heat than it does in normal mode. Refer to the *Specifications* section for more information about power consumption and thermal dissipation.

Specifications

The following specifications are typical for the range -40 to 70 °C unless otherwise noted. All voltages are relative to the AI- signal on each channel unless otherwise noted.

Caution The input terminals of this device are not protected for electromagnetic interference. As a result, this device may experience reduced measurement accuracy or other temporary performance degradation when connected cables are routed in an environment with radiated or conducted radio frequency electromagnetic interference. To limit radiated emissions and to ensure that this device functions within specifications in its operational electromagnetic environment, take precautions when designing, selecting, and installing measurement probes and cables.

Input Characteristics

Number of channels .... 4 analog input channels

ADC resolution .... 24 bits

Type of ADC .... Delta-Sigma (with analog prefiltering)

Sampling mode .... Simultaneous

Internal master timebase (f_M)

- Frequency .... 12.8 MHz
- Accuracy .... ±100 ppm max

Data rate range (f_s) using internal master timebase

- Minimum .... 1.613 kS/s
- Maximum .... 50 kS/s

Data rate range (f_s) using external master timebase

- Minimum .... 390.625 S/s
- Maximum .... 51.36 kS/s

Data rates[1] (f_s) .... $\dfrac{f_M \div 256}{n}$, $n = 1, 2, ..., 31$

Safe operating input range[2, 3] .... 5 A_{rms}

Overcurrent handling[4] .... 10 A_{rms} for 1 s max with 19 s minimum cool down time at 5 A_{rms}

Instantaneous measuring range[5]

Minimum .... 14.051 A peak

Typical .... 14.977 A peak, at 23 ±5 °C

Typical scaling coefficient .... 1.785397 µA/LSB

Input coupling .... DC

---

[1] The data rate must remain within the appropriate data rate range. Refer to the *Understanding NI 9227 Data Rates* section for more information.

[2] Refer to the *Safety Guidelines* section for more information about safe operating voltages.

[3] The maximum recommended continuous RMS current value applied simultaneously on all 4 channels to keep the power dissipation inside the module within safe operating limits.

[4] Overcurrent conditions to keep the module operating within specified limits.

[5] The maximum DC current that produces a non-saturated reading.

Input impedance (AI+ to AI-)........... 12 mΩ

Input noise (f_s = 50 kS/s)................... 400 μA$_{rms}$

Accuracy at safe operating range of 5 A$_{rms}$

Measurement Conditions	Percent of Reading (Gain Error)	Percent of Range* (Offset Error)
Calibrated max (-40 to 70 °C)	±0.37%	±0.18%
Calibrated typ (23 °C, ±5 °C)	±0.1%	±0.05%
Uncalibrated max (-40 to 70 °C)	±5.0%	±2.4%
Uncalibrated typ (23 °C, ±5 °C)	±2.5%	±1.0%
* Range equals 7.07 A peak (5 A$_{rms}$).		

Accuracy at operating range of 10 A$_{rms}$

Measurement Conditions	Percent of Reading (Gain Error)	Percent of Range* (Offset Error)
Calibrated max (-40 to 70 °C)	±0.38%	±0.19%
* Range equals 7.07 A peak (5 A$_{rms}$).		

Stability

Gain drift .... ±21 ppm/°C

Offset drift .... ±51 μA/°C

Post calibration gain match
(channel-to-channel, f_{in} = 20 kHz) .... ±130 mdB max

Crosstalk

(f_{in} = 1 kHz) .... -90 dB

(f_{in} = 50 Hz) .... -115 dB

Phase match

Channel-to-channel, max .... 0.1°/kHz

Module-to-module, max .... 0.1°/kHz + 360° $\cdot f_{in}/f_M$

Phase linearity (f_s = 50 kS/s) .... 0.1° max

Input delay .... $40\frac{5}{512}/f_s + 2.9$ μs

Passband

Frequency .... $0.453 \cdot f_s$

Flatness (f_s = 50 kS/s) .... ±100 mdB max

Stopband

Frequency .... $0.547 \cdot f_s$

Rejection...................................... 100 dB

Alias-free bandwidth .... $0.453 \cdot f_s$

-3 dB bandwidth (f_s = 50 kS/s).......... 24.609 kHz

CMRR (f_{in} = 50 Hz).......................... 150 dB

SFDR (f_{in} = 1 kHz, -60 dBFS).......... 110 dB

Total Harmonic Distortion (THD)
(f_{in} = 1 kHz, -1 dBFS)....................... -95 dB

MTBF .... Contact NI for Bellcore MTBF or MIL-HDBK-217F specifications.

Power Requirements

Power consumption from chassis

Active mode .... 730 mW max

Sleep mode .... 50 μW max

Thermal dissipation (at 70 °C)[1]

Active mode .... 1.23 W max

Sleep mode .... 500 mW max

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Note For two-dimensional drawings and three-dimensional models of the C Series module and connectors, visit `ni.com/dimensions` and search by module number.

Screw-terminal wiring .... 16 to 28 AWG copper conductor wire with 7 mm (0.28 in.) of insulation stripped from the end

Torque for screw terminals .... 0.22 to 0.25 N · m (1.95 to 2.21 lb · in.)

Ferrules .... 0.25 mm² to 0.5 mm²

Weight... 145 g (5.1 oz)

---

[1] Measured with 5 A_{rms} on each channel.

Safety

Isolation Voltages

Connect only voltages that are within the following limits.

Channel-to-channel

Continuous .... 250 V_{rms}, Measurement Category II

Withstand.................................. 1,390 V_{rms}, verified by a 5 s dielectric withstand test

Channel-to-earth ground

Continuous .... 250 V_{rms}, Measurement Category II

Withstand.................................. 2,300 V_{rms}, verified by a 5 s dielectric withstand test

Measurement Category II is for measurements performed on circuits directly connected to the electrical distribution system. This category refers to local-level electrical distribution, such as that provided by a standard wall outlet, for example, 115 V for U.S. or 230 V for Europe.

Caution Do *not* connect to signals or use for measurements within Measurement Categories III or IV.

Safety Standards

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-2-1 (IEC 61326-2-1): Class A emissions; Industrial immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

Note For the standards applied to assess the EMC of this product, refer to the *Online Product Certification* section.

Note For EMC compliance, operate this device with shielded cables.

CE Compliance

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit `ni.com/certification`, search by module number or product line, and click the appropriate link in the Certification column.

Shock and Vibration

To meet these specifications, you must panel mount the system and either affix ferrules to the ends of the terminal wires or use the NI 9971 backshell kit to protect the connections.

Operating vibration

Random (IEC 60068-2-64)......... 5 g_{rms}, 10 to 500 Hz

Sinusoidal (IEC 60068-2-6) .... 5 g, 10 to 500 Hz

Operating shock (IEC 60068-2-27).... 30 g, 11 ms half sine, 50 g, 3 ms half sine, 18 shocks at 6 orientations

Environmental

National Instruments C Series modules are intended for indoor use only but may be used outdoors if installed in a suitable enclosure. Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature (IEC 60068-2-1, IEC 60068-2-2) ..... -40 to 70 °C

Storage temperature (IEC 60068-2-1, IEC 60068-2-2) ..... -40 to 85 °C

Ingress protection............................ IP 40

Operating humidity (IEC 60068-2-56)............................ 10 to 90% RH, noncondensing

Storage humidity (IEC 60068-2-56)............................ 5 to 95% RH, noncondensing

Maximum altitude............................ 2,000 m

Pollution Degree 2

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at `ni.com/environment`. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all products *must* be sent to a WEEE recycling center. For more information about WEEE recycling centers, National Instruments WEEE initiatives, and compliance with WEEE Directive 2002/96/EC on Waste and Electronic Equipment, visit `ni.com/environment/weee`.

电子信息产品污染控制管理办法 （中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

Calibration

You can obtain the calibration certificate and information about calibration services for the NI 9227 at `ni.com/calibration`.

Calibration interval .... 1 year

Worldwide Support and Services

The National Instruments website is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit ni.com/services for NI Factory Installation Services, repairs, extended warranty, and other services.

Visit ni.com/register to register your National Instruments product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification. If your product supports calibration, you can obtain the calibration certificate for your product at ni.com/calibration.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world. For telephone support in the United States, create your service request at `ni.com/support` or dial 1 866 ASK MYNI (275 6964). For telephone support outside the United States, visit the Worldwide Offices section of `ni.com/niglobal` to access the branch office websites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

375101E-01 Jul14