Small Size, Low Power, Current Shunt Monitor

Features

- Common-mode voltage: 1.8 V to 5.5 V
- Low quiescent current: 17 μA (typ.)
- High accuracy:
  - Low offset voltage
  - ±0.1% max total output error
- Choice of gains, bandwidth:
  - DIO2216A: 25 V/V, 20 kHz
  - DIO2216B: 50 V/V, 10 kHz
  - DIO2216C: 100 V/V, 5 kHz
  - DIO2216D: 200 V/V, 2.5 kHz
- Buffered voltage output: No additional Op Amp needed
- Operating temperature: -40°C to 125°C

Applications

- Battery charger
- Laptop
- E-cigarette
- Smartphone

Package Information

Part Number	Package	Body Size
DIO2216	WLCSP-4	0.76 mm × 0.76 mm

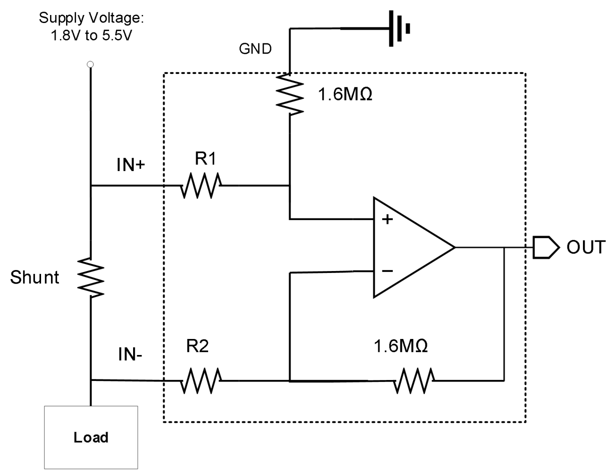
Description

The DIO2216 is a high-side voltage output current shunt monitor that senses the voltage drop across the shunt at a 1.8 V to 5.5 V common-mode voltage. It is available in four fixed gains: 25 V/V, 50 V/V, 100 V/V and 200 V/V.

The DIO2216 has a low maximum offset voltage. The DIO2216 total output error is as low as ±0.1%, which greatly improves the accuracy and simplifies the design of system.

The DIO2216 series is specified over the -40°C to 125°C temperature range and is available in ultra-small WLCSP-4 package.

Simplified Schematic



Part Number	Gain	R1=R2
DIO2216A	25	64 kΩ
DIO2216B	50	32 kΩ
DIO2216C	100	16 kΩ
DIO2216D	200	8 kΩ

Ordering Information

Ordering Part No.	Top Marking	MSL	RoHS	T_A	Package	
DIO2216AWL4	W6A	1	Green	-40 to 125°C	WLCSP-4	Tape & Reel, 5000
DIO2216BWL4	W6B	1	Green	-40 to 125°C	WLCSP-4	Tape & Reel, 5000
DIO2216CWL4	W6C	1	Green	-40 to 125°C	WLCSP-4	Tape & Reel, 5000
DIO2216DWL4	W6D	1	Green	-40 to 125°C	WLCSP-4	Tape & Reel, 5000

If you encounter any issue in the process of using the device, please contact our customer service at marketing@dioo.com or phone at (+86)-21-62116882. If you have any improvement suggestions regarding the datasheet, we encourage you to contact our technical writing team at docs@dioo.com. Your feedback is invaluable for us to provide a better user experience.

Table of Contents

List of Figures

List of Tables

1. Pin Assignment and Functions

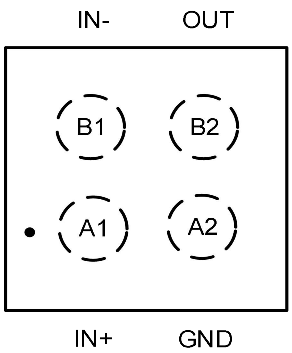


Figure 1. WLCSP-4 (Top view)(1)(2)

Pin No.	Pin Name	Description
A1	IN+	Positive input
A2	GND	Ground
B1	IN-	Negative input
B2	OUT	Output

Note:

(1) Bump side down. Drawing not to scale.

(2) Power supply is derived from shunt.

2. Absolute Maximum Ratings

Exceeding the maximum ratings listed under Absolute Maximum Ratings when designing is likely to damage the device permanently. Do not design to the maximum limits because long-time exposure to them might impact the device's reliability. The ratings are obtained over an operating free-air temperature range unless otherwise specified.

Symbol	Parameter		Rating	Unit
	Supply voltage (Maximum)		7	V
V_{IN+}, V_{IN-} (1)	Analog inputs	Differential (V_{IN+}) - (V_{IN-})	-5.5 to 5.5	V
		Common-mode(2)	GND-0.3 to 5.5	V
	Output(2)		GND-0.3 to (V+) + 0.3	V
	Input current into any pin(2)		5	mA
T_A	Operating temperature		-55 to 150	°C
T_{STG}	Storage temperature		-65 to 150	°C
T_J	Junction temperature (Maximum)		150	°C

Note:

(1) V_{IN+} and V_{IN-} are the voltages at the IN+ and IN– pins respectively.

(2) Input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 5 mA.

3. Recommended Operating Conditions

Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. The ratings are obtained over an operating free-air temperature range unless otherwise specified.

Symbol	Parameter	Rating	Unit
V_{CM}	Common-mode input voltage	1.8 to 5.5	V
	Supply voltage	1.8 to 5.5	V
T_A	Operating temperature	-40 to 125	°C

4. ESD Ratings

When a statically-charged person or object touches an electrostatic discharge sensitive device, the electrostatic charge might be drained through sensitive circuitry in the device. If the electrostatic discharge possesses sufficient energy, damage might occur to the device due to localized overheating.

Model	Condition	Value	Unit
Human-body model	ANSI/ESDA/JEDEC JS-001	±8	kV
Charged-device model	ANSI/ESDA/JEDEC JS-002	±2	kV

5. Thermal Considerations

The thermal resistance determines the heat insulation property of a material. The higher the thermal resistance is, the lower the heat loss. Accumulation of heat energy degrades the performance of semiconductor components.

Symbol	Metric	Value	Unit
$R_{\theta JA}$	Junction-to-ambient thermal resistance	160	°C/W
$R_{\theta JC}$	Junction-to-case thermal resistance	75	°C/W

6. Electrical Characteristics

At T_A = 25°C and V_{CM} = V_{IN+} = 4.2 V, unless otherwise noted.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Power supply						
V_{IN+}			1.8		5.5	V
I_Q	Quiescent current		10	17	23	µA
t_{ON}	Turn-on time	V_{IN+} = 0 to 2.5 V, V_{SENSE} = 10 mV, V_{OUT} ± 0.5%		200		µs
Input						
V_{OS}	Offset voltage, RTI (1)			±10	±75	µV
dV_{OS}/dT	V_{OS} vs. temperature	DIO2216C, T_A = -40 to 125°C		0.09		µV/°C
V_{CM}	Common-mode input range		1.8		5.5	V
CMRR	Common-mode rejection(2)	V_{IN+} = 1.8 to 5.5 V	90	110		dB
PSRR	Power-supply rejection	V_{IN+} = 1.8 to 5.5 V	90	110		dB
I_{IN-}	Input bias current			2.6		µA
Output						
G	Gain	DIO2216A		25		V/V
		DIO2216B		50		
		DIO2216C		100		
		DIO2216D		200		
	Gain error	DIO2216C, V_{OUT} = 0.2 to 2.5 V		0.02	±0.1	%
	Nonlinearity error			±0.01		%
C_{LOAD}	Maximum capacitive load			750		pF
	Swing to V+	R_L = 10 kΩ to GND, T_A = -40 to 125°C		(V+)-0.025		V
	Swing to GND	R_L = 10 kΩ to GND, T_A = -40 to 125°C		GND+0.001		V
Frequency response						
BW	Bandwidth	DIO2216C, C_{LOAD} = 10 pF		5		kHz
SR	Slew rate			0.03		V/µs
e_n	Voltage noise density	At 1 kHz		60		nV/√Hz

Note:

(1) RTI means "referred to input".

(2) CMRR and PSRR are the same because V_{CM} is the supply voltage.

(3) Specifications subject to change without notice.

7. Typical Characteristics

At T_A = 25°C, V_{IN+} = 4.2 V, unless otherwise noted.

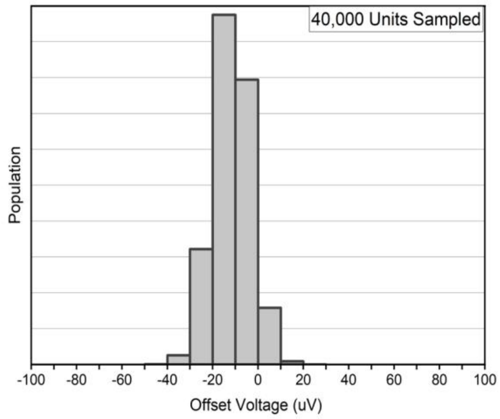


Figure 2. V_{OS} production distribution

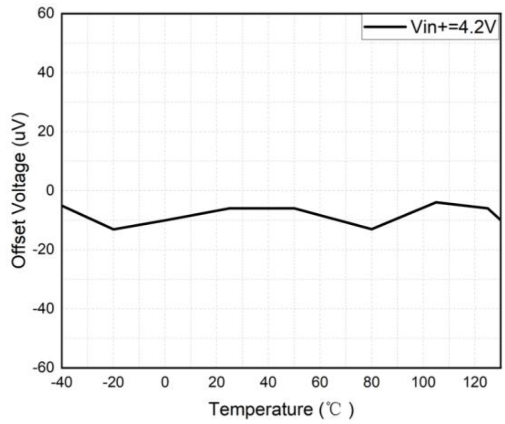


Figure 3. Offset voltage vs. Temperature

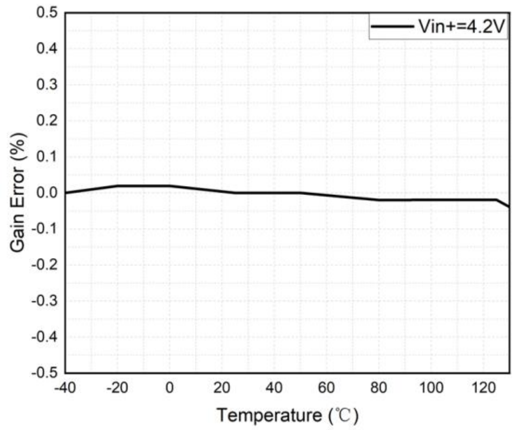


Figure 4. Gain error vs. Temperature

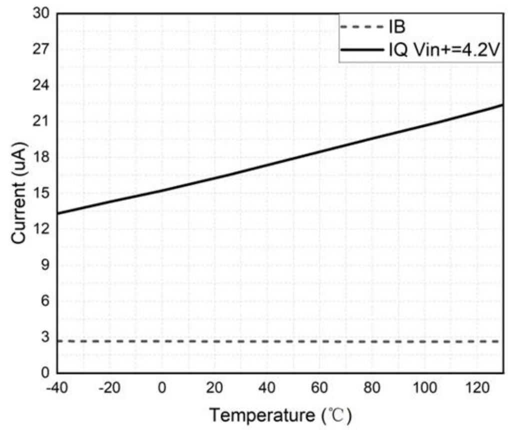


Figure 5. Quiescent current vs. Temperature

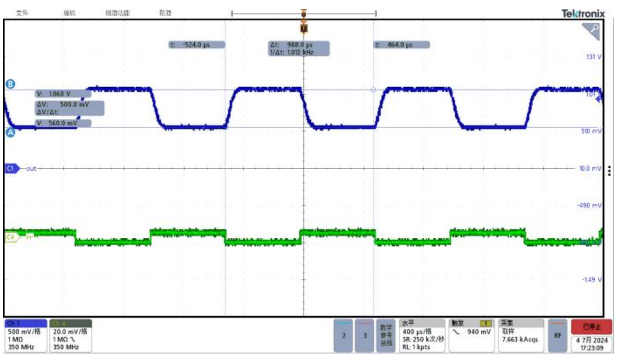


Figure 6. Step response at V_{DM}= 5 mV

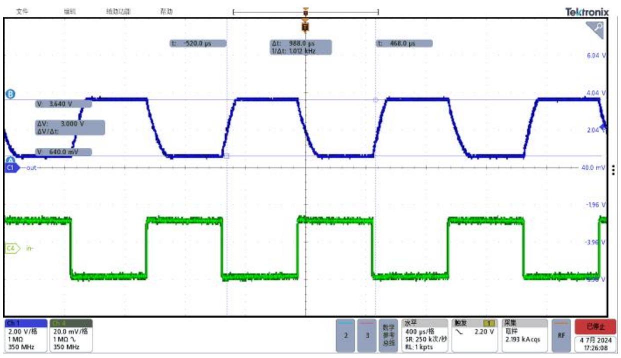


Figure 7. Step response at V_{DM} = 30 mV

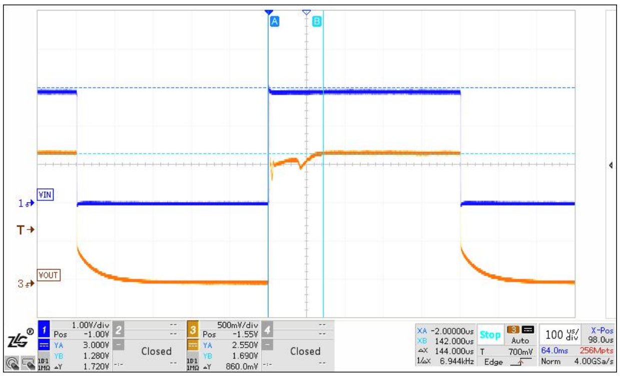


Figure 8. Startup

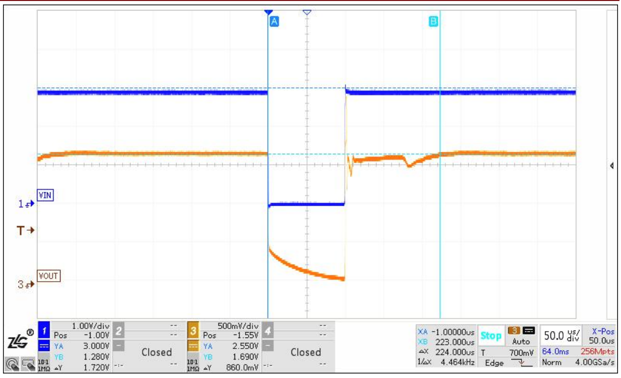


Figure 9. Brownout

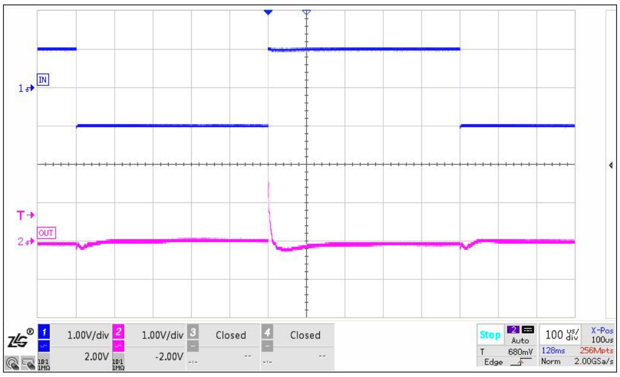


Figure 10. V_{CM} transient response

8. Application Information

Important notice: Validation and testing are the most reliable ways to confirm system functionality. The application information is not part of the specification and is for reference purposes only.

8.1. Power supply

The DIO2216 lacks a specific pin for the power supply; instead, it utilizes an internal link to the IN+ pin to power the device. For the DIO2216 being powered from the IN+ pin, the common-mode input range is limited to a minimum of 1.8 V on the lower end. So it's not possible for the DIO2216 to be used as a low-side current shunt monitor.

8.2. Basic Connections

To minimize any resistance in series with the shunt resistance, the IN+ and IN– pins should be connected as closely as possible to the shunt resistor. The basic connections of the DIO2216 is shown below.

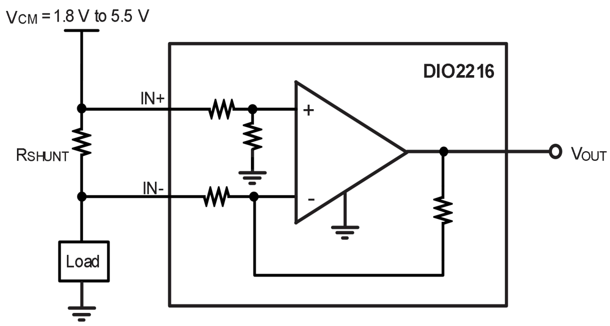


Figure 11. Typical application

The DIO2216 is connected to a shunt resistor that has extra trace resistance in series with the shunt positioned between the input pins where the current shunt is monitoring them (see Figure 12). The differential voltage at the DIO2216 input pins can be greatly impacted by even tiny quantities of extra impedance connected in series with the shunt resistor, given the generally low values of shunt resistors utilized in these applications.

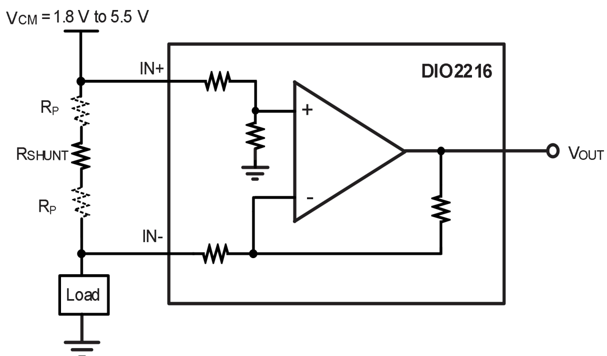


Figure 12. Shunt resistance measurement Including trace resistance, R_P

A proper Kelvin, or four-wire, connection between the shunt resistor and the DIO2216 input pins is shown in Figure 13 below. By making this connection, the shunt resistor is ensured to be the only impedance between the current monitor input pins.

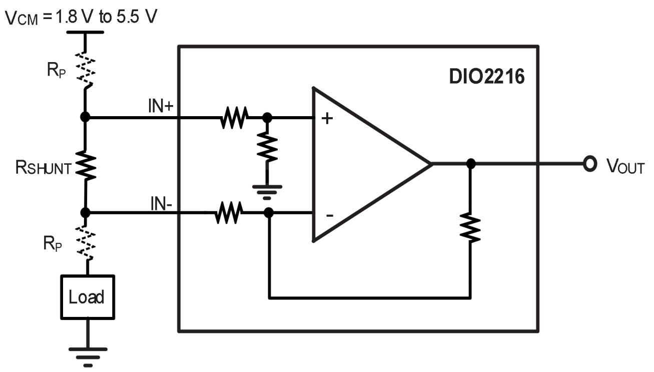


Figure 13. Shunt resistance measurement using a Kelvin connection

8.3. R_S selection

Selecting the value of the shunt resistor (R_S) is based on the specific operating conditions and requirements of the application. Firstly, the desired full-scale output from the DIO2216 should be decided. There are four available options of gain: 25, 50, 100, and 200. If the proper gain device is employed, there are four differential input voltages that can be used to generate the desired full-scale output voltage by dividing the intended full-scale output by each of the gain options. The decision on the maximum amount of drop allowed in the application must be made, with four values available for the total voltage to be dropped across the shunt. Most applications have a maximum drop allowed in order to guarantee that the load receives the necessary voltage to operate. Assuming that there are multiple shunt voltages that are acceptable according to the design criteria, the accuracy can decide the value of shunt resistor. Because of the auto-zero architecture of the device, the input offset voltage is extremely low. However, even 75 µV maximum input offset voltage specification can affect the choice of shunt resistor value. The larger shunt voltage is present at the current shunt monitor input, the less error is introduced by the input offset voltage.

These elements will decide the value of shunt resistor based on the full-scale value, while many applications require accurate measurements at levels as low as 10% of the full-scale value. At this level, the input offset voltage of the current shunt monitor becomes a larger percentage of the shunt voltage, contributing a larger error to the output. To calculate the percentage of error created by the input offset voltage relative to the shunt voltage, please refer to Equation (1).

$$Error\_V_{OS} = \frac{V_{OS}}{V_{SENSE}} \times 100 \quad (1)$$

To reduce the impacts of the input offset voltage, it would be ideal to increase the differential input voltage at 10%. However, the full-scale output voltage on the DIO2216 is limited to 200 mV below the supply voltage (IN+). At the low operating range of the load current , selecting a shunt resistor to increase the shunt voltage could easily saturate the output of the current shunt monitor at the full-scale load current. If the application needs a larger range of accuracy, a lower gain option is selected, and therefore a larger differential input voltage is selected. If the application needs a minimal voltage drop on the line to power the load, a higher gain option is selected, and therefore a smaller differential input voltage is selected.

For example, if a design requires a full-scale output voltage of 4 V, a load current of 10 A (max), and a voltage drop on the common-mode line of 25 mV (max). Then 25 mV (max) voltage drop requirement and a 4 V full-scale output will limit the gain option to the 200 V/V. Similarly, if a 100 V/V setting is required, then it needs voltage drop of 40 mV (max) with the other two lower gain versions to create larger voltage drops. For the device with gain of 200 and a 4 V full-scale output, the differential input voltage would be 20 mV (max). To create a 20 mV drop with a 10 A load current, the shunt resistor is 2 mΩ.

It's highly recommended to consider that at higher currents, the power dissipation in the shunt resistor becomes greater when choose the shunt resistor. So, it's important to assess the drift of the sense resistor as a result of power dissipation and choose a suitable resistor depending on its power wattage rating.

8.4. Calculating total error

The typical individual errors are mentioned in the EC table, such as gain error, offset error and nonlinearity error. However, total error, which includes all of the individual error components, is not shown in the EC table. To calculate the error accurately, the operating conditions of the device should be considered firstly. For some current shunt monitors, a total error in shown in the product data sheet. However, specifying such total error has little practical value because this total error term is accurate under only one particular set of operating conditions. It means that any deviation from these specific operating conditions will change the total error value. For the device under normal operating conditions, this section will discuss the individual error sources and how to apply them to calculate the total error value.

The typical error sources that have the largest impact on the total error of the device are input offset voltage, common-mode voltage rejection, gain error, and nonlinearity error.

Compared to the gain error specification, the nonlinearity error is relatively low. It leads to a gain error that can be expected to be relatively constant throughout the linear input range of the device. Although gain error keeps constant across the linear input range of the device, the error associated with the input offset voltage is subject to change. As the differential input voltage across the shunt resistor at the DIO2216's input decreases, the inherent input offset voltage constitutes a larger proportion of the measured input signal, thereby increasing the measurement error. This type of error, which is common to all current shunt monitors, is influenced by the ratio of the input offset voltage to the sensed voltage. Despite this, the DIO2216's low input offset voltages reduce the impact of the offset on the total error.

Here are the equations to calculate the error terms.

Table 1. Equations of error terms

Term	Label	Equation
Maximum initial input offset voltage	VIO	/
Added input offset voltage as result of common-mode voltage	VIO_CM	$\frac{1}{10^{(\frac{CMRR\_dB}{20})}} \times \lvert 4.2V - V_{CM} \rvert$
Total input offset voltage	VIO_Total	$\sqrt{(VIO)^2 + (VIO\_CM)^2}$
Error because of input offset voltage	Error_VIO	$\frac{VIO\_Total}{V_{SENSE}} \times 100$
Gain error	Error_Gain	/
Nonlinearity error	Error_Lin	/
Total error		$\sqrt{(Error\_VIO)^2 + (Error\_Gain)^2 + (Error\_Lin)^2}$

8.5. Input filtering

While the inputs of a device is an ideal place for filtering, DIOO does not recommend to put an input filter in front of the DIO2216. If it's decided to be necessary, it's important to note that this could result in an additional gain error that may exceed the device's maximum gain error specification of ±0.1%. For DIO2216, the nominal current into the IN+ pin is 17 μA while the bias current into the IN– pin is approximately 2.6 μA. The current flowing into the IN+ pin includes both the input bias current and the quiescent current. Where the issue of input filtering begins to become more of an issue is that as the quiescent current of the DIO2216 also flows through the IN+ pin, when the output begins to drive current, this additional current also flows through the IN+ pin, resulting in a larger error.

Placing a typical common-mode filter of 10 Ω in series with each input and a 0.1 μF capacitor across the input pins introduces an additional gain error into the system (see Figure 14). For example, consider an application using the DIO2216C with a full-scale output of 4 V, assuming that the device is not driving any output current. The shunt voltage needed to create the 4 V output with a gain of 100 is 40 mV. With 10 Ω filter resistors on each input, there is a difference voltage created that subtracts from the 40 mV full-scale differential current. To get the value, please refer to the Equation (2).

$$Error\_R_{FILTER} = \frac{(I_{IN+} - I_{IN-}) \times R_{FILTER}}{V_{SHUNT}} \times 100 \quad (2)$$

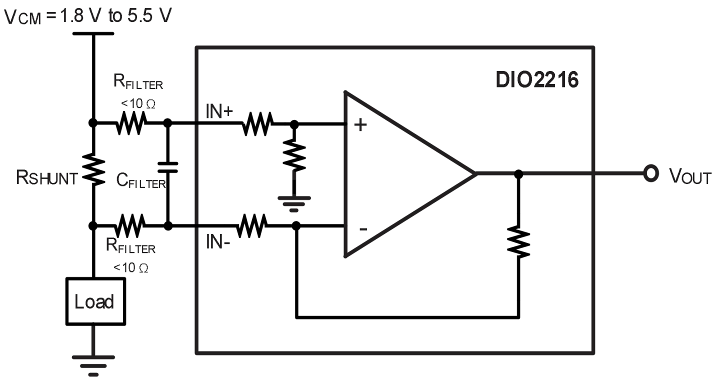


Figure 14. Input filter

When the output begins to drive current, the current flowing into the IN+ pin increases because the quiescent current also flows into the IN+ pin. The previous example resulted in an additional gain error of 0.3% as a result of the 10 Ω filter resistors (assuming the output stage was not driving any current). When a 100 kΩ load is connected to the 4 V output, the current will increase by 40 μA additionally. Therefore, the additional gain error from 0.3% to 1.3% will be changed.

A filter can be implemented following the DIO2216 when filtering is required for the application and the gain error introduced by the input filter resistors is over the available error budget. Placing a filter at the output of the current shunt monitor is not typically the ideal location because the benefit of the low impedance output of the amplifier is lost. For applications requiring the low impedance output, an additional buffer amplifier that follows the post current shunt monitor filter is needed.

8.6. Using the DIO2216 with transients above 5.5 V

The DIO2216 can be used in circuits subject to transients above 5.5 V with a small amount of additional circuitry. Use only zener diode or zener-type transient absorbers, which are sometimes referred to as Transzorbs. Using any other type of transient absorber will cause an unacceptable time delay. To use these protection devices, the resistors that serve as a working impedance for the zener are required in series with the DIO2216 inputs (see Figure 15). It is recommended to keep these resistors as small as possible because of the error as mentioned before. These protection resistors are most often approximately 10 Ω. Larger values means the greater impact to the total gain error. Because this circuit limits only short-term transients, many applications are satisfied with a 10 Ω resistor along with conventional zener diodes of the lowest power rating that can be found. With this combination, the least amount of board space is possible. These protection components can protect the DIO2216 from damage when it is applied with common large transients.

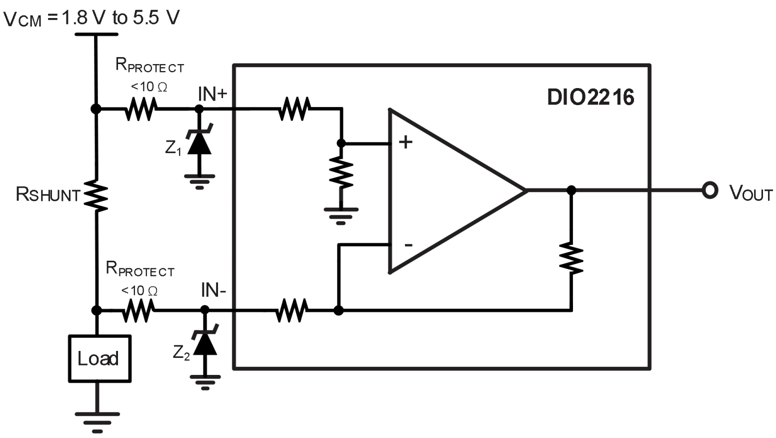
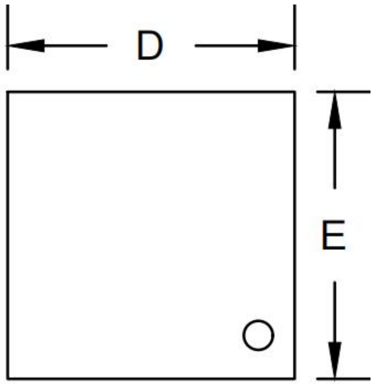
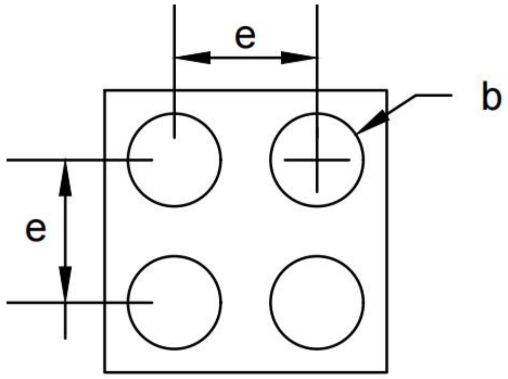


Figure 15. Transient protection using dual Zener diodes

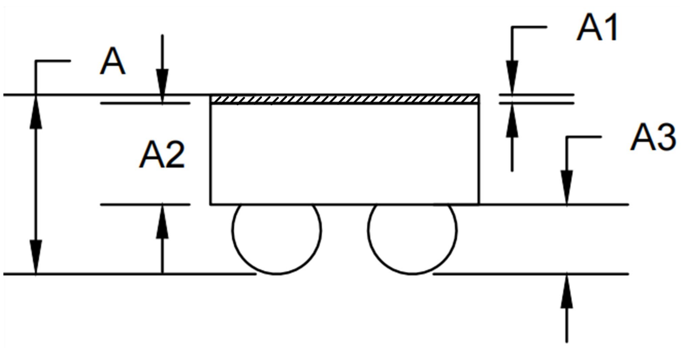
9. Physical Dimensions: WLCSP-4



Top view



Bottom view



Side view

Common Dimensions (Units of measure = Millimeter)			
Symbol	Min	Nom	Max
A	0.468	0.506	0.544
A1	0.020	0.025	0.030
A2	0.260	0.275	0.290
A3	0.186	0.206	0.226
b	0.238	0.258	0.278
D	0.740	0.765	0.790
E	0.740	0.765	0.790
e	0.400 BSC		

Disclaimer

This specification and information contained herein are provided on an “AS IS” basis and WITH ALL FAULTS. All product specifications, statements, information, and data (collectively, the “Information”) in this datasheet or made available on the website of www.dioo.com are subject to change without notice. The customer is responsible for checking and verifying the extent to which the Information contained in this publication is applicable to his/her application. All Information given herein is believed to be accurate and reliable, but it is presented without guarantee, warranty, or responsibility of any kind, express or implied.

