HIGH-SIDE MEASUREMENT CURRENT SHUNT MONITOR

Check for Samples: INA138-Q1, INA168-Q1

FEATURES

- **Qualified For Automotive Applications**
- **ESD Protection Exceeds 2000 V Per MIL-STD-883, Method 3015; Exceeds 200 V Using Machine Model (C = 200 pF, R = 0)**
- **Complete Unipolar High-Side Current-Measurement Circuit**
- **Wide Supply And Common-Mode Range**
  - **INA138-Q1: 2.7 V to 36 V**
  - **INA168-Q1: 2.7 V to 60 V**
- **Independent Supply and Input Common-Mode Voltages**
- **Single Resistor Gain Set**
- **Low Quiescent Current (25 μA Typical)**
- **Wide Temperature Range: –40°C to 125°C**
- **TSSOP−8 and SOT23−5 Packages**

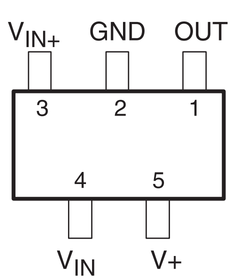
APPLICATIONS

- **Current Shunt Measurement**
- **Portable and Battery-Backup Systems**
- **Battery Chargers**
- **Power Management**
- **Precision Current Source**

PW PACKAGE (TOP VIEW)

NC − No internal connection

DBV PACKAGE (TOP VIEW)



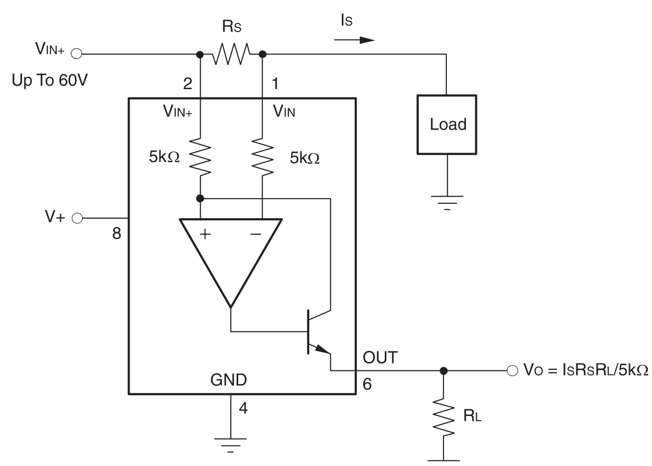
DESCRIPTION

The INA138-Q1 and INA168-Q1 are high-side, unipolar, current shunt monitors. Wide input common-mode voltage range, low quiescent current, and tiny TSSOP and SOT23 packaging enable uses in a variety of applications.

Input common-mode and power-supply voltages are independent and can range from 2.7 V to 36 V for the INA138-Q1 and 2.7 V to 60 V for the INA168-Q1. Quiescent current is only 25 μA, which permits connecting the power supply to either side of the current-measurement shunt with minimal error.

The device converts a differential input voltage to a current output. This current is converted back to a voltage with an external load resistor that sets any gain from 1 to over 100. Although designed for current shunt measurement, the circuit invites creative applications in measurement and level shifting.

Both the INA138-Q1 and INA168-Q1 are available in TSSOP−8 and SOT23−5 and are specified for the –40°C to 125°C temperature range.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

ORDERING INFORMATION(1)

PRODUCT	PACKAGE−LEAD	PACKAGE DESIGNATOR(2)	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	TRANSPORT MEDIA, QUANTITY
INA138QPWRQ1	TSSOP−8	PW	−40°C to 125°C	INA138	Tape and reel, 2000
INA168QPWRQ1	TSSOP−8	PW	−40°C to 125°C	INA168	Tape and reel, 2000
INA168QDBVRQ1	SOT23-5	DBV	−40°C to 125°C	LUIQ	Tape and reel, 3000

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI Web site at www.ti.com.
(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

		VALUE
Supply voltage, V_+	INA138-Q1	−0.3 V to 60 V
	INA168-Q1	−0.3 V to 75 V
Analog inputs, V_{IN+}, V_{IN-} , common-mode	INA138-Q1	−0.3 V to 60 V
	INA168-Q1	−0.3 V to 75 V
Analog inputs, $(V_{IN+}) - (V_{IN-})$, differential		−40 V to 2 V
Analog output, out		−0.3 V to 40 V
Operating temperature		−55°C to 150°C
Storage temperature		−65°C to 150°C
Junction temperature		150°C
Thermal resistance, junction-to-ambient, $R_{\Theta JA}$	PW	150°C/W
	DBV	200°C/W

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

T_A = −40°C to 125°C, V_S = 5 V, V_{IN+} = 12 V, and R_{OUT} = 125 kΩ unless otherwise noted

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input						
Full-scale sense voltage	$V_{SENSE} = V_{IN+} - V_{IN-}$			100	500	mV
Common-mode input range		INA138-Q1	2.7		36	V
		INA168-Q1	2.7		60	V
Common-mode rejection	V_{IN+} = 2.7 V to 36 V, V_{SENSE} = 50 mV	INA138-Q1	100	120		dB
	V_{IN+} = 2.7 V to 60 V, V_{SENSE} = 50 mV	INA168-Q1	100	120		dB
Offset voltage(1)				±0.2	±2	mV
Offset voltage versus temperature				1		μV/°C
Offset voltage versus power supply, V_+	V_+ = 2.7 V to 36 V, V_{SENSE} = 50 mV	INA138-Q1		0.1	10	μV/V
	V_+ = 2.7 V to 60 V, V_{SENSE} = 50 mV	INA168-Q1		0.1	10	μV/V
Input bias current	$VI_{N+} = V_{IN-}$ = 12 V				10	μA

(1) Defined as the amount of input voltage, V_{SENSE}, to drive the output to zero.

ELECTRICAL CHARACTERISTICS (continued)

T_A = −40°C to 125°C, V_S = 5 V, V_{IN+} = 12 V, and R_{OUT} = 125 kΩ unless otherwise noted

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Output						
Transconductance	V_{SENSE} = 10 mV − 150 mV		194		206	μA/V
Transconductance versus temperature	V_{SENSE} = 100 mV			10		nA/°C
Nonlinearity error	V_{SENSE} = 10 mV to 150 mV			±0.01%	±0.2 %	
Total output error	V_{SENSE} = 100 mV			±0.5	±3.2	%
Output impedance				1		GΩ
				5		pF
Voltage output swing to power supply, V_+				$(V_+) - 0.8$	$(V_+) - 1.2$	V
Voltage output swing to common mode, V_{CM}				$V_{CM} - 0.5$	$V_{CM} - 1.2$	V
Frequency Response						
Bandwidth		R_{OUT} = 5 kΩ		800		kHz
		R_{OUT} = 125 kΩ		32		kHz
Settling time (0.1%)	5-V step	R_{OUT} = 5 kΩ		1.8		μs
		R_{OUT} = 125 kΩ		30		μs
Noise						
Output-current noise density	T_A = 25°C			9		pA/√Hz
Total output-current noise	BW = 100 kHz			3		nA RMS
Power Supply						
Operating range, V_+		INA138-Q1	2.7		36	V
		INA168-Q1	2.7		60	V
Quiescent current	V_{SENSE} = 0, IO = 0			25	60	μA

TYPICAL CHARACTERISTICS

T_A = 25°C, V_+ = 5 V, V_{IN+} = 12 V, and R_L = 125 kΩ, unless otherwise noted.

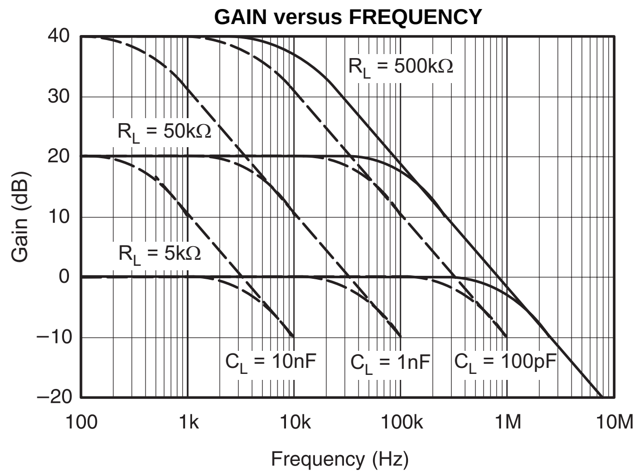


Figure 1.

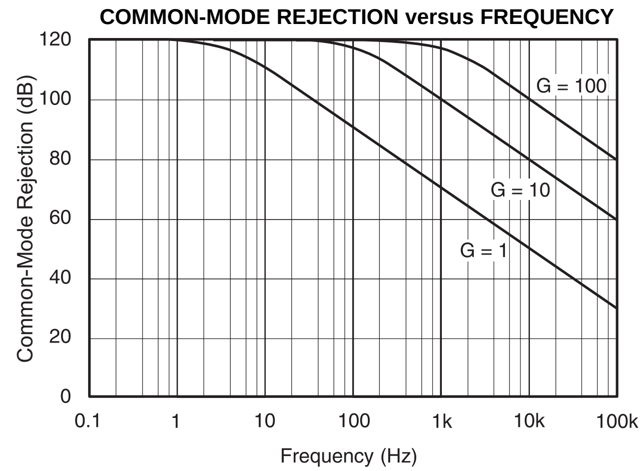


Figure 2.

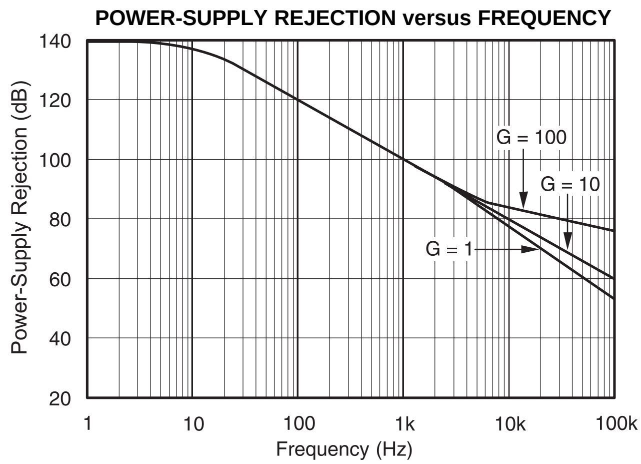


Figure 3.

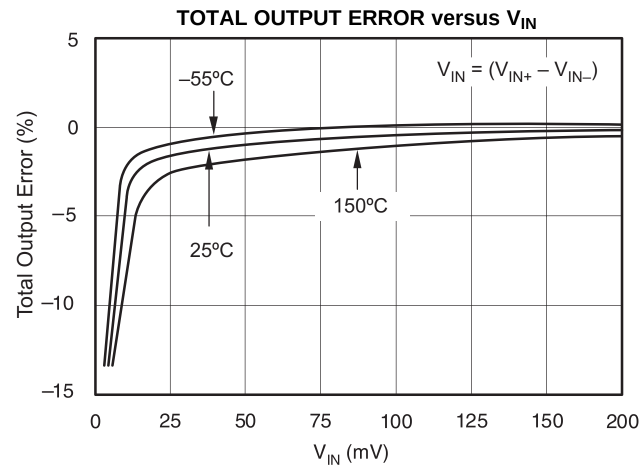


Figure 4.

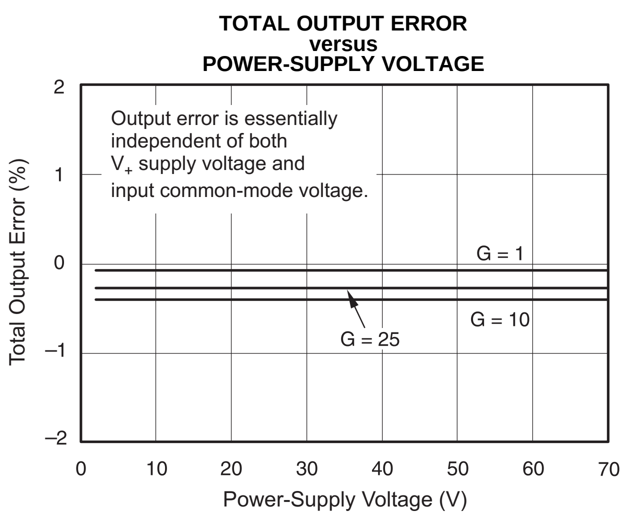


Figure 5.

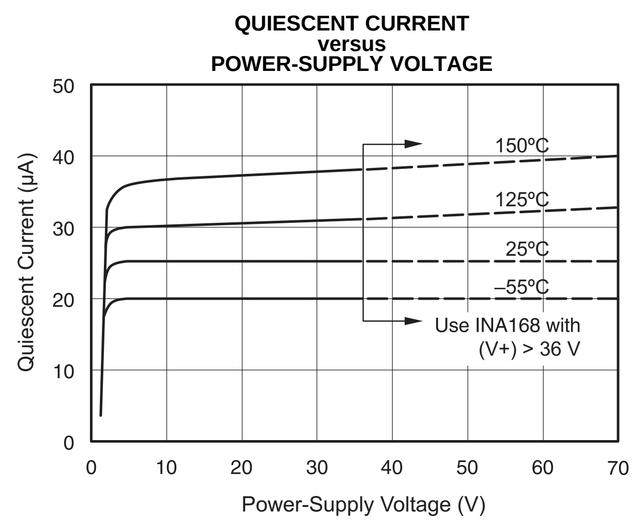


Figure 6.

TYPICAL CHARACTERISTICS (continued)

T_A = 25°C, V_+ = 5 V, V_{IN+} = 12 V, and R_L = 125 kΩ, unless otherwise noted.

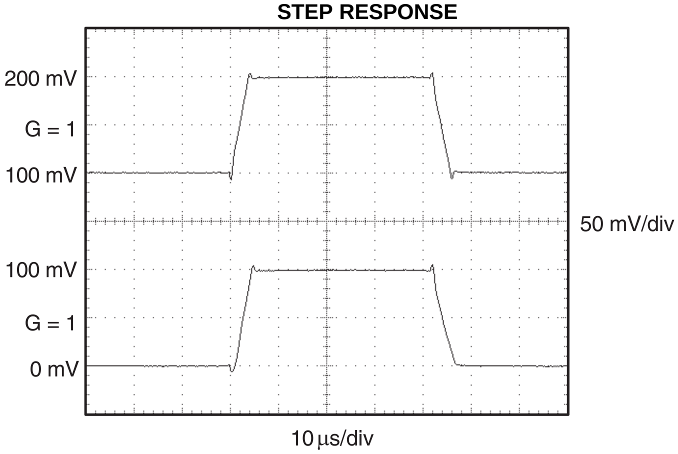


Figure 7.

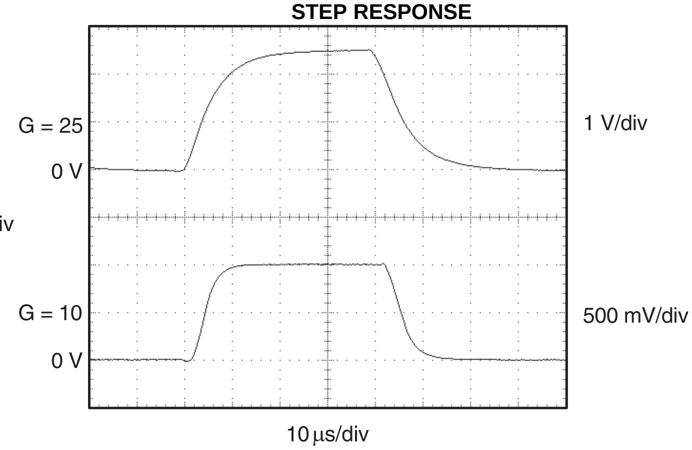


Figure 8.

APPLICATION INFORMATION

Figure 9 illustrates the basic circuit diagram for both the INA138-Q1 and INA168-Q1. Load current I_S is drawn from supply V_S through shunt resistor R_S. The voltage drop V_S in the shunt resistor is forced across R_{G1} by the internal op amp, causing current to flow into the collector of Q1. External resistor R_L converts the output current to a voltage, V_{OUT}, at the OUT pin. The transfer function for the INA138-Q1 is:

$$I_O = g_m (V_{IN+} - V_{IN-})$$

where g_m = 200 µA/V.

In the circuit of Figure 9, the input voltage, $(V_{IN+} - V_{IN-})$, is equal to $I_S \times R_S$ and the output voltage, V_{OUT}, is equal to $I_O \times R_L$. The transconductance, g_m, of the INA138-Q1 is 200 µA/V. The complete transfer function for the current measurement amplifier in this application is:

$$V_{OUT} = (I_S)\ (R_S)\ (200\ \mu A/V)\ (R_L)$$

The maximum differential input voltage for accurate measurements is 0.5 V, which produces a 10 µA output current. A differential input voltage of up to 2 V does not cause damage. Differential measurements (pins 3 and 4) must be unipolar with a more-positive voltage applied to pin 3. If a more-negative voltage is applied to pin 3, the output current, I_O, is zero, but it does not cause damage.

BASIC CONNECTION

Figure 9 shows the basic connection of the INA138-Q1. The input pins, V_{IN+} and V_{IN-}, should be connected as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistance. The output resistor, R_L, is shown connected between pin 1 and ground. Best accuracy is achieved with the output voltage measured directly across R_L. This is especially important in high-current systems where load current could flow in the ground connections, affecting the measurement accuracy.

No power-supply bypass capacitors are required for stability of the INA138-Q1. However, applications with noisy or high-impedance power supplies may require decoupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

POWER SUPPLIES

The input circuitry of the INA138-Q1 can accurately measure beyond its power-supply voltage, V_+. For example, the V_+ power supply can be 5 V, whereas the load power supply voltage is up to 36 V (or 60 V with the INA168-Q1). The output voltage range of the OUT terminal, however, is limited by the lesser of the two voltages (see Output Voltage Range section).

SELECTING R_S AND R_L

The value chosen for the shunt resistor, R_S, depends on the application and is a compromise between small-signal accuracy and maximum permissible voltage loss in the measurement line. High values of R_S provide better accuracy at lower currents by minimizing the effects of offset, while low values of R_S minimize voltage loss in the supply line. For most applications, the best performance is attained with an R_S value that provides a full-scale shunt voltage range of 50 mV to 100 mV. Maximum input voltage for accurate measurements is 500 mV.

R_L is chosen to provide the desired full-scale output voltage. The output impedance of the INA138-Q1 OUT terminal is very high, which permits using values of R_L up to 500 kΩ with excellent accuracy. The input impedance of any additional circuitry at the output should be much higher than the value of R_L to avoid degrading accuracy.

Some analog-to-digital (A/D) converters have input impedances that significantly affects measurement gain. The input impedance of the A/D converter can be included as part of the effective R_L if its input can be modeled as a resistor to ground. Alternatively, an op amp can be used to buffer the A/D converter input. Figure 9 shows the recommended values of R_L.

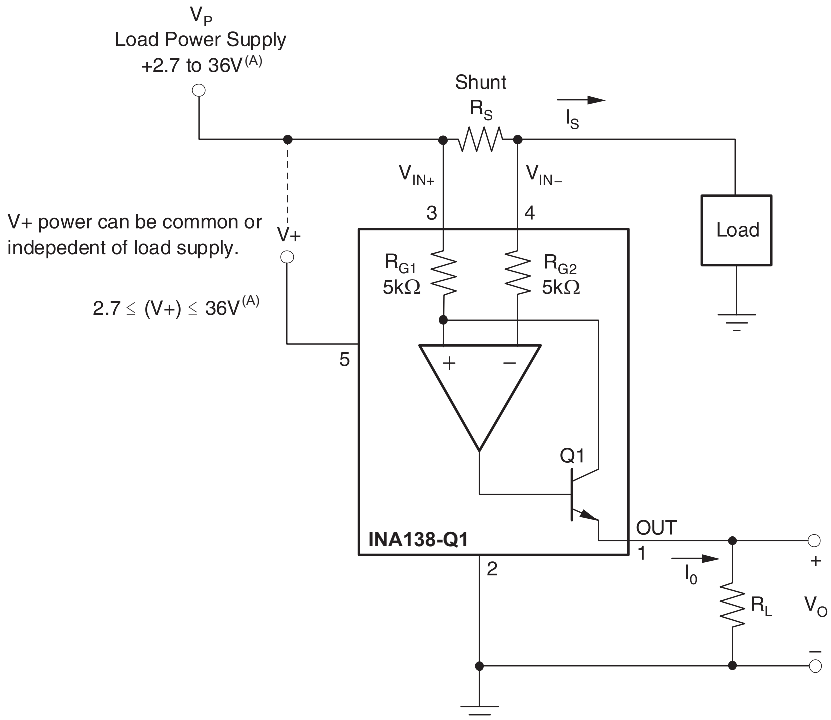


Figure 9. Basic Circuit Connections

OUTPUT VOLTAGE RANGE

The output of the INA138-Q1 is a current, which is converted to a voltage by the load resistor, R_L. The output current remains accurate within the compliance voltage range of the output circuitry. The shunt voltage and the input common-mode and power-supply voltages limit the maximum possible output swing. The maximum output voltage compliance is limited by the lower of the two equations below:

$$V_{out\ max} = (V_+) - 0.7\ V - (V_{VIN+} - V_{IN-})$$

or

$$V_{out\ max} = V_{IN-} - 0.5\ V$$

(whichever is lower)

BANDWIDTH

Measurement bandwidth is affected by the value of the load resistor, R_L. High gain produced by high values of R_L yields a narrower measurement bandwidth (see the Typical Characteristics section). For widest possible bandwidth, keep the capacitive load on the output to a minimum. Reduction in bandwidth due to capacitive load is shown in the Typical Characteristics section.

If bandwidth limiting (filtering) is desired, a capacitor can be added to the output (see Figure 12). This does not cause instability.

APPLICATIONS

The INA138-Q1 is designed for current-shunt measurement circuits, as shown in Figure 9, but its basic function is useful in a wide range of circuitry. An engineer may find many unforeseen uses in measurement and level-shifting circuits. A few ideas are illustrated in Figure 10 through Figure 15.

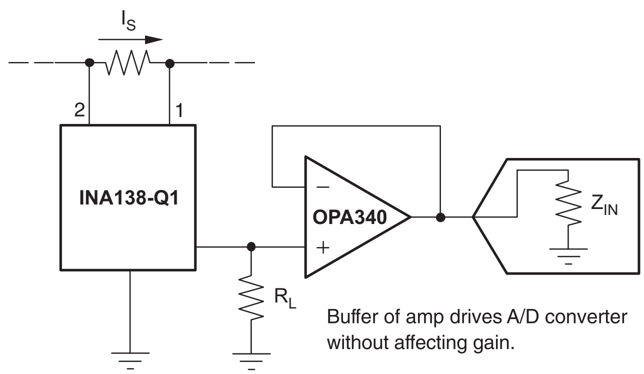


Figure 10. Buffering Output to Drive and A/D Converter

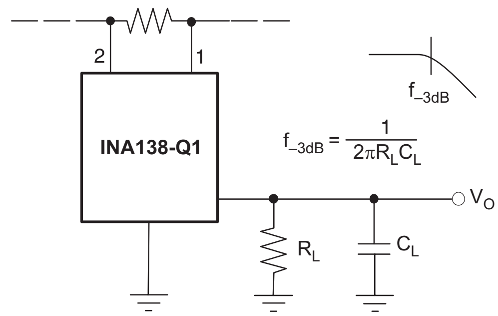
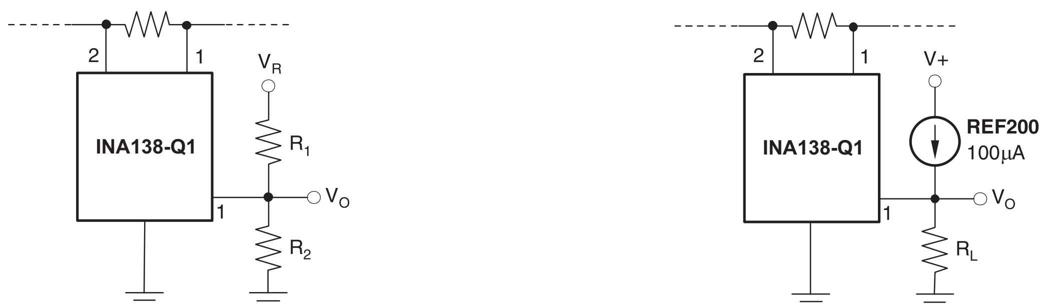


Figure 11. Output Filter



Gain Set by $R_1 \,||\, R_2$

Output Offset = $\frac{(V_R)R_2}{R_1 + R_2}$

a) Using resistor divider.

Gain Set by R_L

Output Offset = (100 µA)(R_L)

(independent of V+)

b) Using current source.

Figure 12. Offsetting the Output Voltage

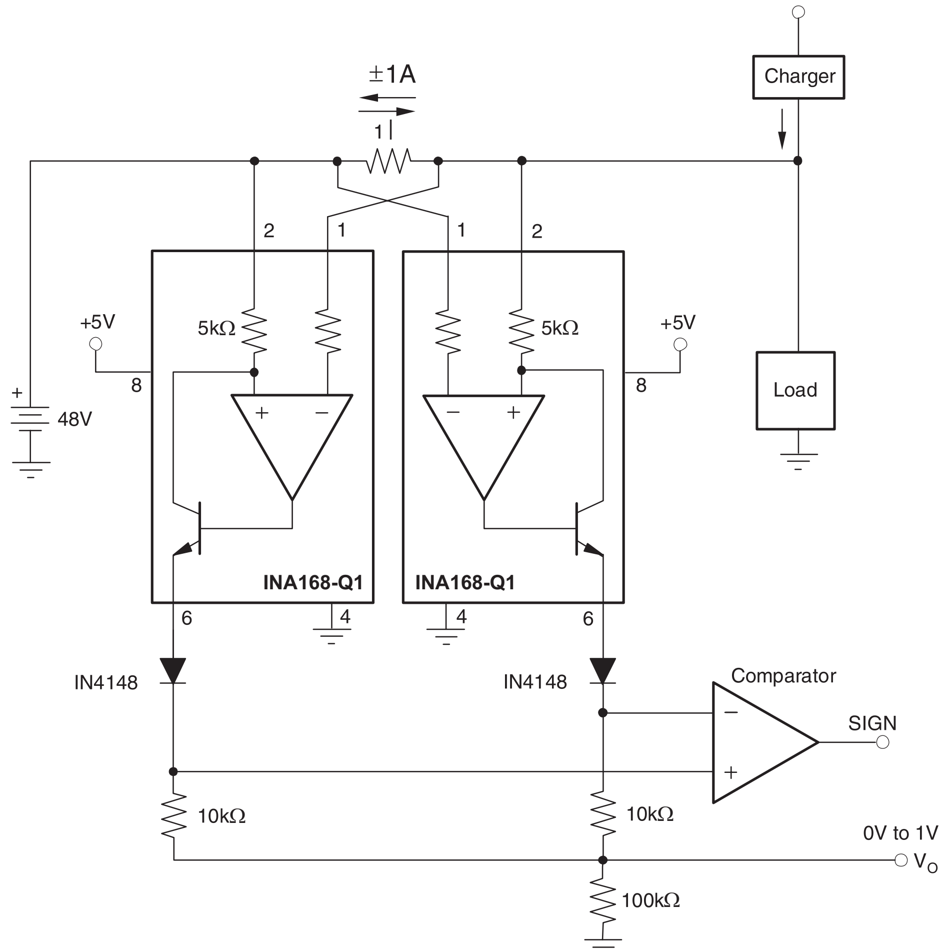
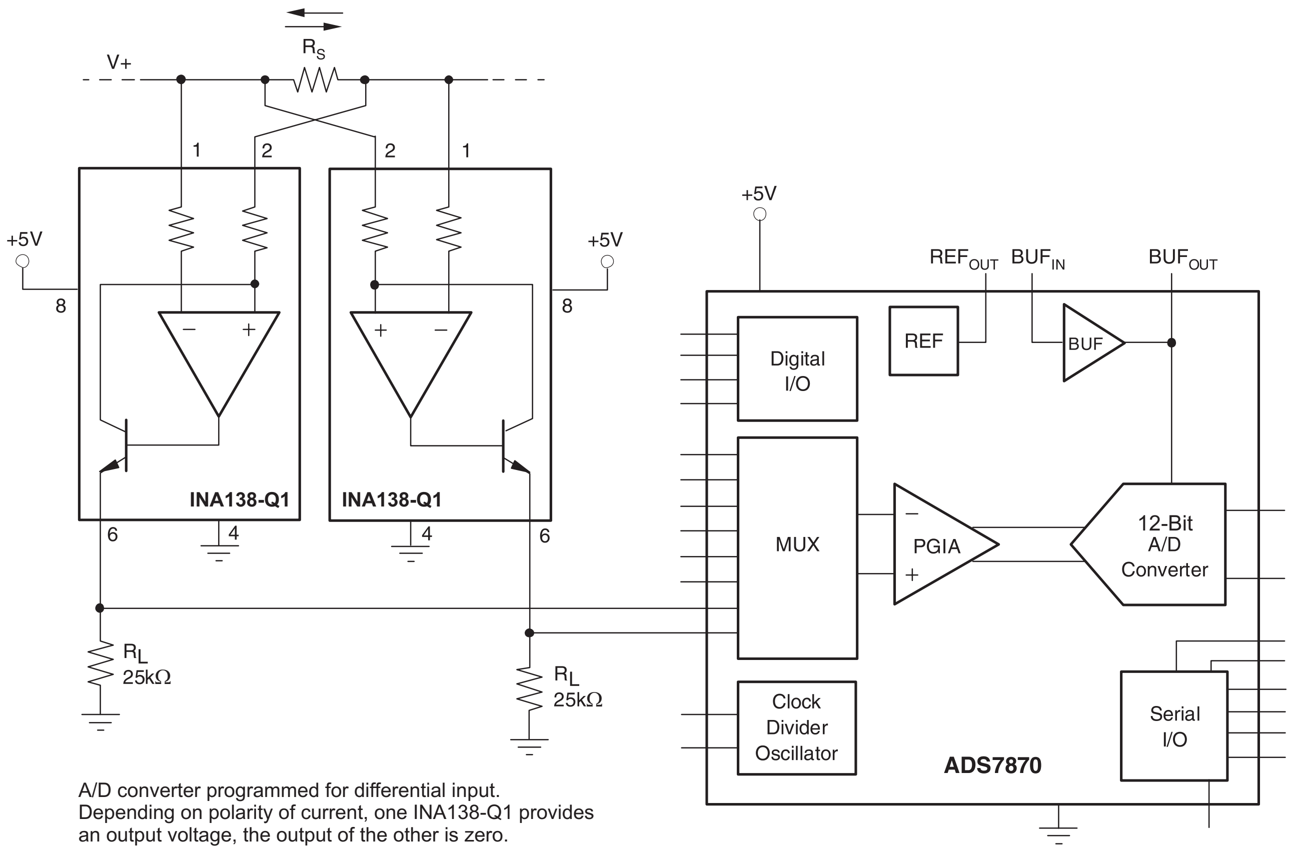


Figure 13. Bipolar Current Measurement



A/D converter programmed for differential input.
Depending on polarity of current, one INA138-Q1 provides an output voltage, the output of the other is zero.

Figure 14. Bipolar Current Measurement Using Differential Input of A/D Converter

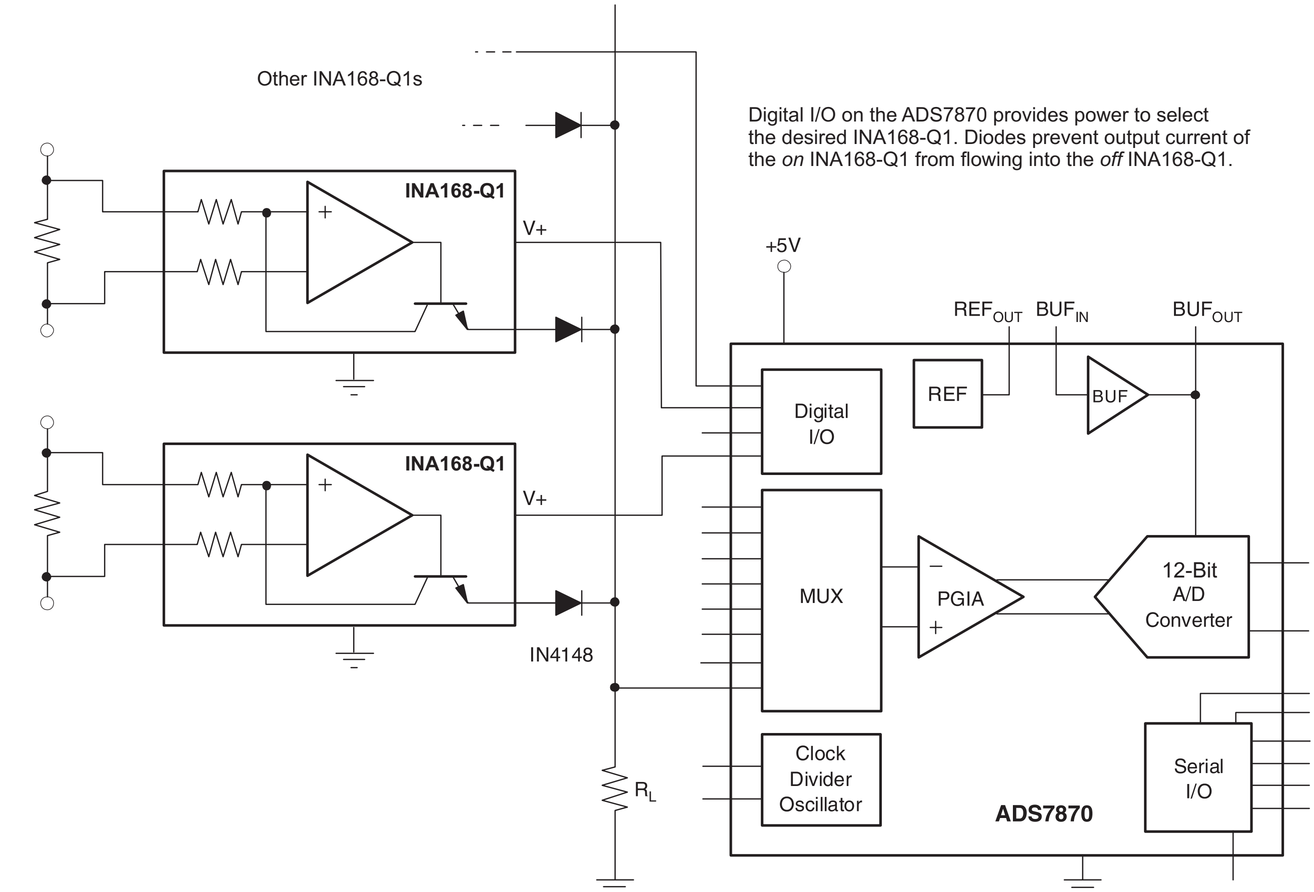


Figure 15. Multiplexed Measurement Using Logic Signal for Power

REVISION HISTORY

Changes from Revision F (November 2013) to Revision G	Page
• Changed part number from IN168-Q1 to INA168-Q1 in multiple locations throughout the document	1

Changes from Revision E (September 2012) to Revision F	Page
• Corrected Y-axis label of QUIESCENT CURRENT versus POWER-SUPPLY VOLTAGE graph	4

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
INA138QPWRQ1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	INA138	Samples
INA168QDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	LUIQ	Samples
INA168QPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	INA168	Samples
INA168QPWRQ1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	INA168	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF INA138-Q1, INA168-Q1 :

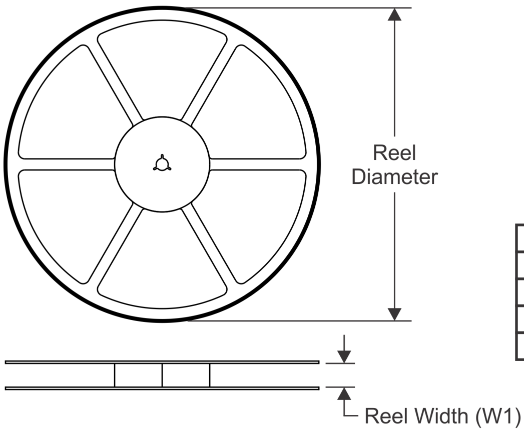
- Catalog: INA138, INA168

NOTE: Qualified Version Definitions:

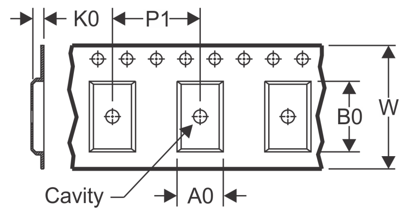
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

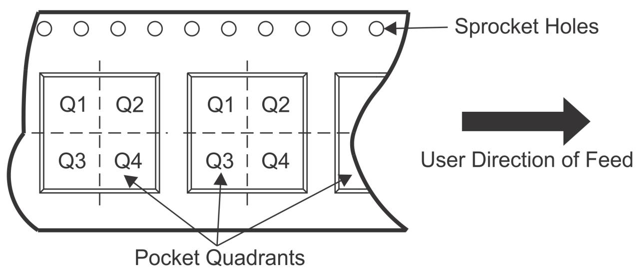


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

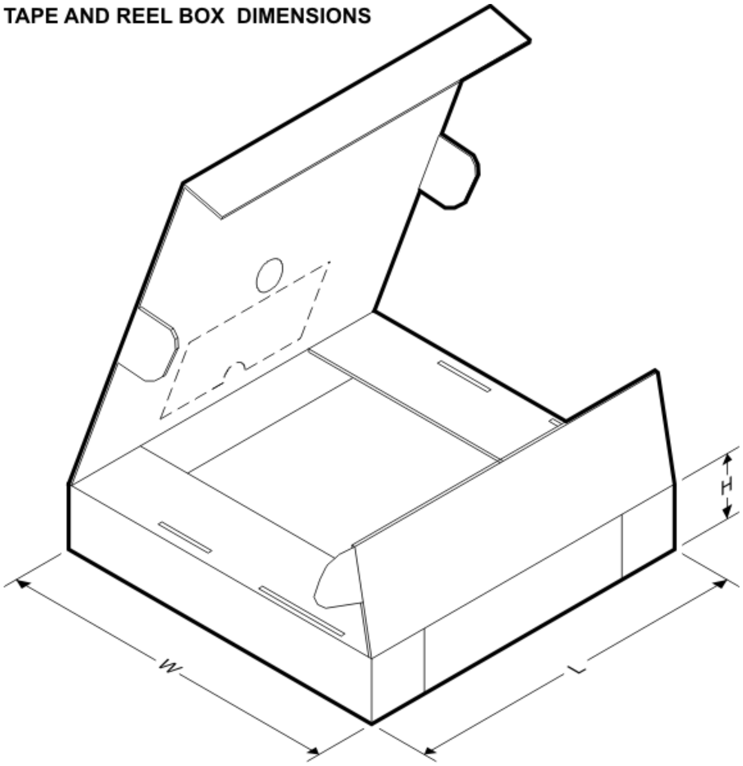
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
INA168QDBVRQ1	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.1	1.39	4.0	8.0	Q3

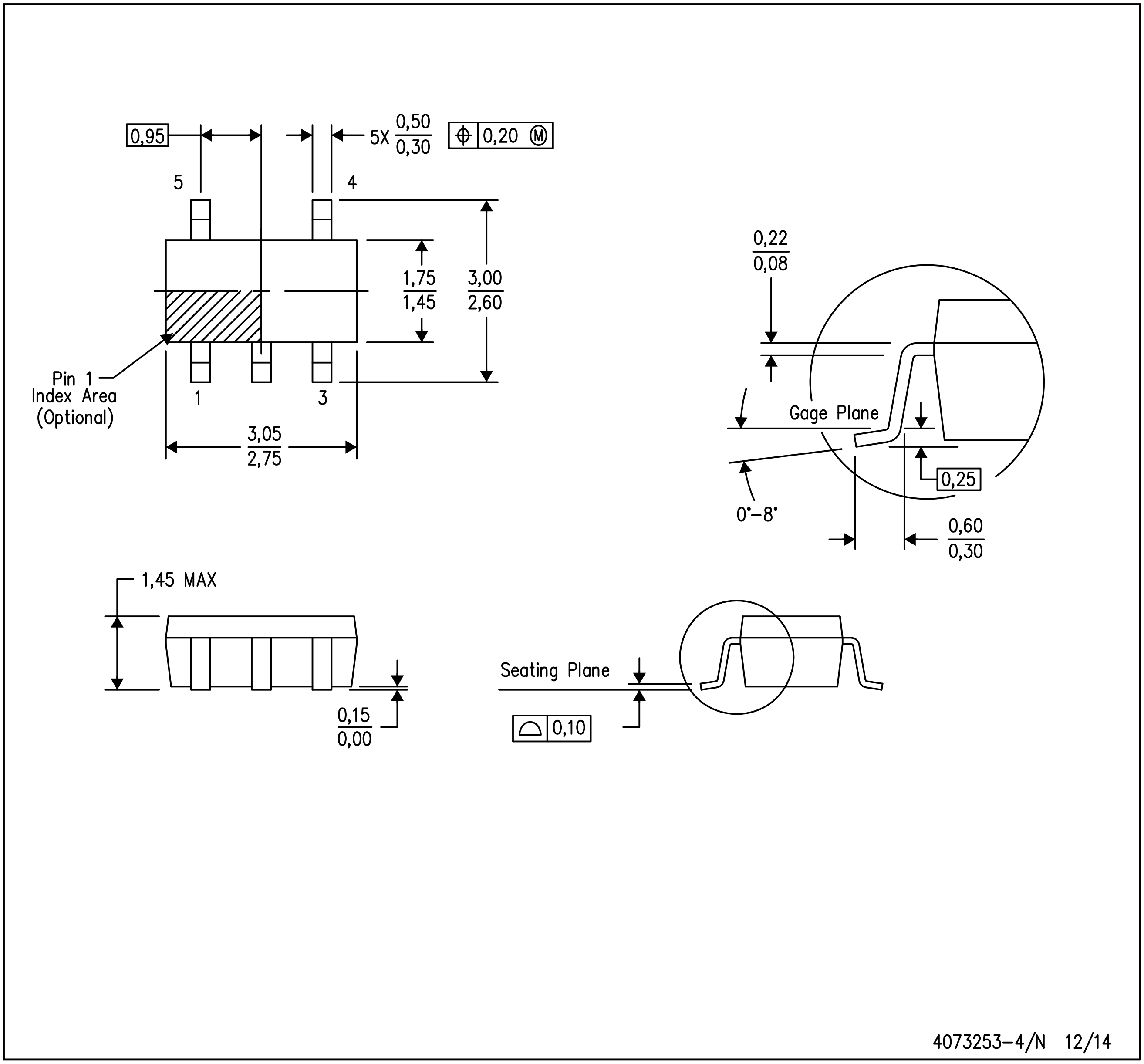
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

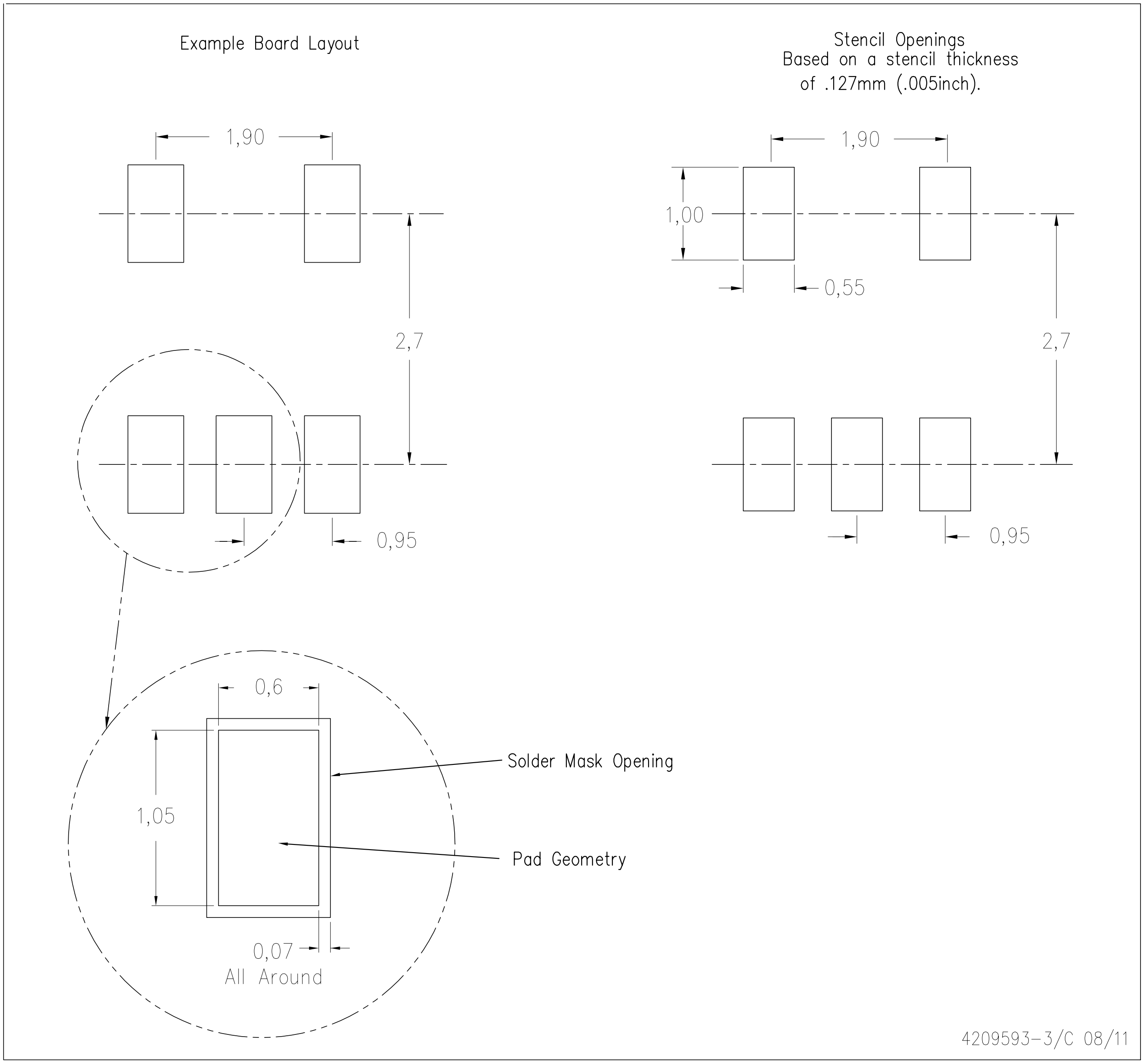
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA168QDBVRQ1	SOT-23	DBV	5	3000	210.0	185.0	35.0

DBV (R-PDSO-G5) PLASTIC SMALL-OUTLINE PACKAGE



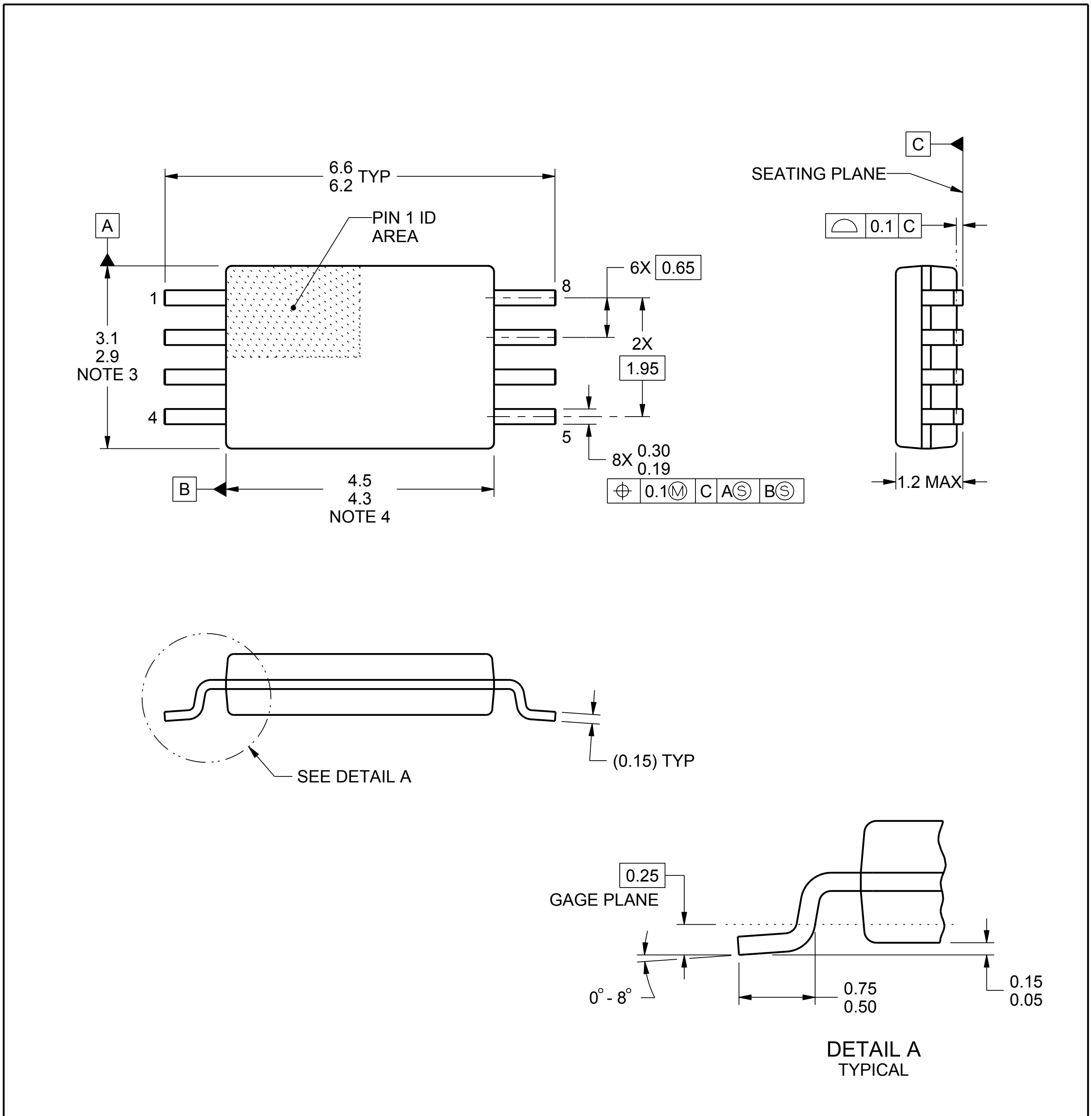
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
- D. Falls within JEDEC MO-178 Variation AA.

DBV (R-PDSO-G5) PLASTIC SMALL OUTLINE



NOTES:

A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC-7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.



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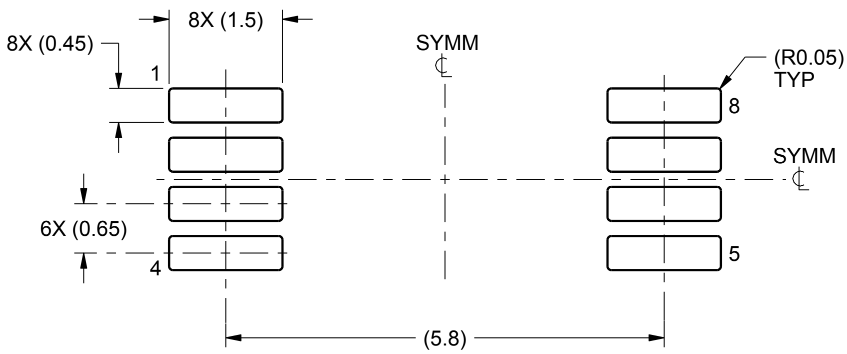
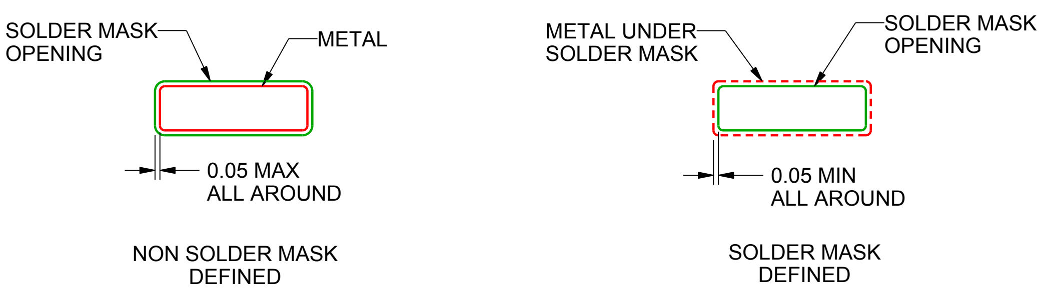
NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.



LAND PATTERN EXAMPLE
SCALE:10X



SOLDER MASK DETAILS
NOT TO SCALE

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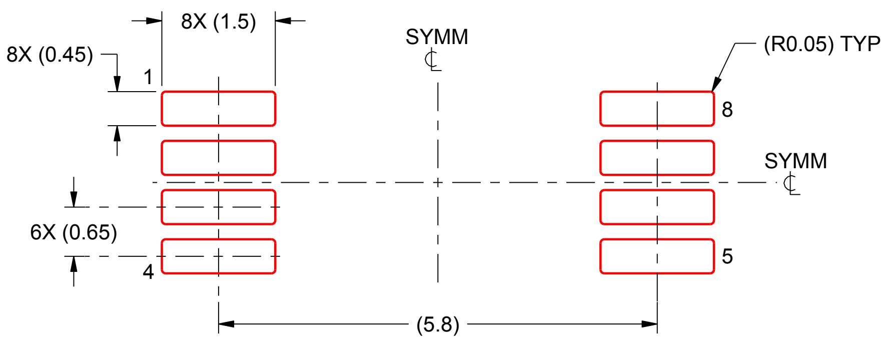
NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

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NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

IMPORTANT NOTICE

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