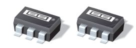


High-Side Measurement CURRENT SHUNT MONITOR

FEATURES

- COMPLETE UNIPOLAR HIGH-SIDE CURRENT MEASUREMENT CIRCUIT
- WIDE SUPPLY AND COMMON-MODE RANGE
- INA138: 2.7V to 36V
- INA168: 2.7V to 60V
- INDEPENDENT SUPPLY AND INPUT COMMON-MODE VOLTAGES
- SINGLE RESISTOR GAIN SET
- LOW QUIESCENT CURRENT (25µA typ)
- WIDE TEMPERATURE RANGE: –40°C to +125°C
- SOT23-5 PACKAGE

APPLICATIONS

- CURRENT SHUNT MEASUREMENT: Automotive, Telephone, Computers
- PORTABLE AND BATTERY-BACKUP SYSTEMS
- BATTERY CHARGERS
- POWER MANAGEMENT
- CELL PHONES
- PRECISION CURRENT SOURCE

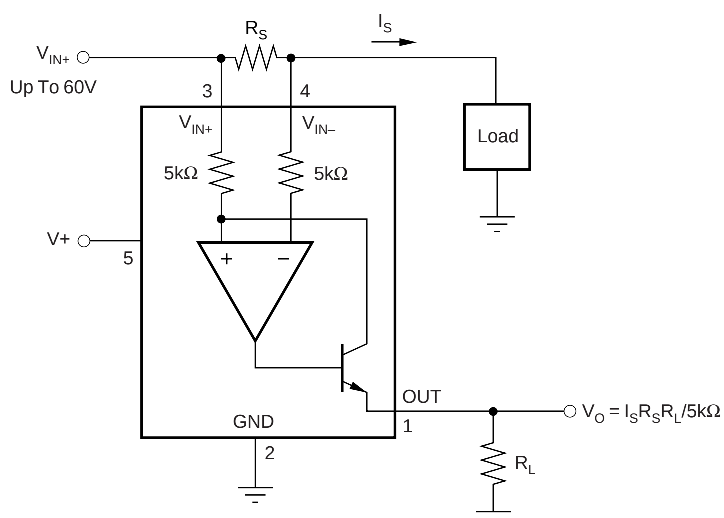
DESCRIPTION

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

Input common-mode and power-supply voltages are independent and can range from 2.7V to 36V for the INA138 and 2.7V to 60V for the INA168. Quiescent current is only 25µA, 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 and INA168 are available in SOT23-5 and are specified for the –40°C to +125°C temperature range.



PACKAGE/ORDERING INFORMATION[1]

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
INA138	SOT23-5 Surface-Mount	DBV	–40°C to +125°C	B38	INA138NA/250	Tape and Reel, 250
"	"	"	"	"	INA138NA/3K	Tape and Reel, 3000
INA168	SOT23-5 Surface-Mount	DBV	–40°C to +125°C	A68	INA168NA/250	Tape and Reel, 250
"	"	"	"	"	INA168NA/3K	Tape and Reel, 3000

NOTE: (1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

ABSOLUTE MAXIMUM RATINGS[1]

Supply Voltage, V+
- INA138 .... –0.3V to 60V
- INA168 .... –0.3V to 75V

Analog Inputs, V_{IN+}, V_{IN-}
- INA138
  - Common Mode[2] .... –0.3V to 60V
  - Differential (V_{IN+}) – (V_{IN-}) .... –40V to 2V
- INA168
  - Common Mode[2] .... –0.3V to 75V
  - Differential (V_{IN+}) – (V_{IN-}) .... –40V to 2V

Analog Output, Out[2] .... –0.3V to 40V
Input Current Into Any Pin 10mA
Operating Temperature .... –55°C to +150°C
Storage Temperature .... –65°C to +150°C
Junction Temperature .... +150°C

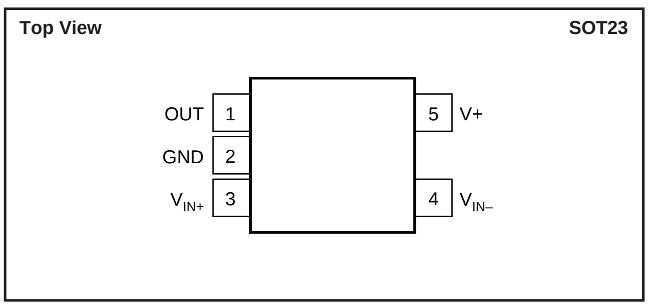
NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied. (2) The input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 10mA.

ELECTROSTATIC DISCHARGE SENSITIVITY

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.

PIN CONFIGURATION



ELECTRICAL CHARACTERISTICS

Boldface limits apply over the specified temperature range, **T_A = –40°C to +125°C.**

All other characteristics at T_A = +25°C, V_S = 5V, V_{IN+} = 12V, and R_{OUT} = 125kΩ, unless otherwise noted.

PARAMETER	CONDITION	INA138NA			INA168NA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
INPUT								
Full-Scale Sense Voltage	$V_{SENSE} = V_{IN+} – V_{IN–}$		100	500		✻	✻	mV
Common-Mode Input Range		2.7		36	✻		60	V
Common-Mode Rejection	V_{IN+} = 2.7V to 40V, V_{SENSE} = 50mV	100	120					dB
	V_{IN+} = 2.7V to 60V, V_{SENSE} = 50mV				100	120		dB
Offset Voltage(1)			±0.2	±1		✻	✻	mV
Over Temperature				**±2**			✻	**mV**
vs Temperature			**1**			✻		**µV/°C**
vs Power Supply, V+	V– = 2.7V to 40V, V_{SENSE} = 50mV		0.1	10				µV/V
	V– = 2.7V to 60V, V_{SENSE} = 50mV					0.1	10	µV/V
Input Bias Current			2			✻		µA
vs Temperature				**10**				**µA**
OUTPUT								
Transconductance	T_A = +25°C, V_{SENSE} = 10mV – 150mV	198	200	202	✻	✻	✻	µA/V
Over Temperature		**196**		**204**	✻		✻	**µA/V**
vs Temperature	**V_{SENSE} = 100mV**		**10**			✻		**nA/°C**
Nonlinearity Error	V_{SENSE} = 10mV to 150mV		±0.01	±0.1		✻	✻	%
Total Output Error	V_{SENSE} = 100mV		±0.5	±2		✻	✻	%
Over Temperature			**±2.5**			✻		**%**
Output Impedance			1 || 5			✻		GΩ || pF
Voltage Output								
Swing to Power Supply, V+			(V+) – 0.8	(V+) – 1.0		✻	✻	V
Swing to Common Mode, V_{CM}			V_{CM} – 0.5	V_{CM} – 0.8		✻	✻	V
FREQUENCY RESPONSE								
Bandwidth	R_{OUT} = 5kΩ		800			✻		kHz
	R_{OUT} = 125kΩ		32			✻		kHz
Settling Time (0.1%)	5V Step, R_{OUT} = 5kΩ		1.8			✻		µs
	5V Step, R_{OUT} = 125kΩ		30			✻		µs
NOISE								
Output-Current Noise Density			9			✻		pA/√Hz
Total Output-Current Noise	BW = 100kHz		3			✻		nA RMS
POWER SUPPLY								
Operating Range, V+		2.7		36	✻		60	V
Quiescent Current	T_A = +25°C, V_{SENSE} = 0, I_O = 0		25	45		✻	✻	µA
Over Temperature				**60**			✻	**µA**
TEMPERATURE RANGE								
Specification, T_{MIN} to T_{MAX}		–40		125	✻		✻	°C
Operating		–55		150	✻		✻	°C
Storage		–65		150	✻		✻	°C
Thermal Resistance θ_{JA}			200			✻		°C/W

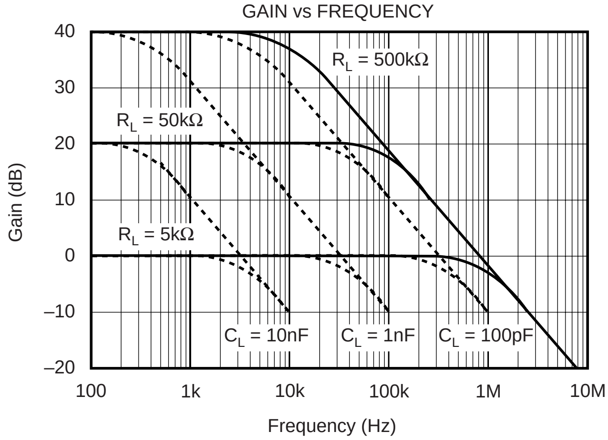
✻ specification same as INA138NA

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

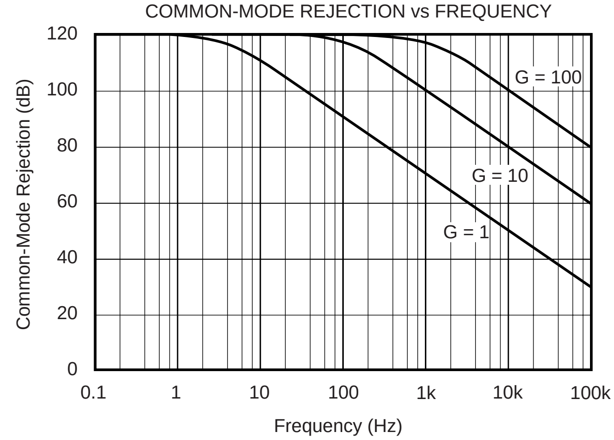
TYPICAL CHARACTERISTICS

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

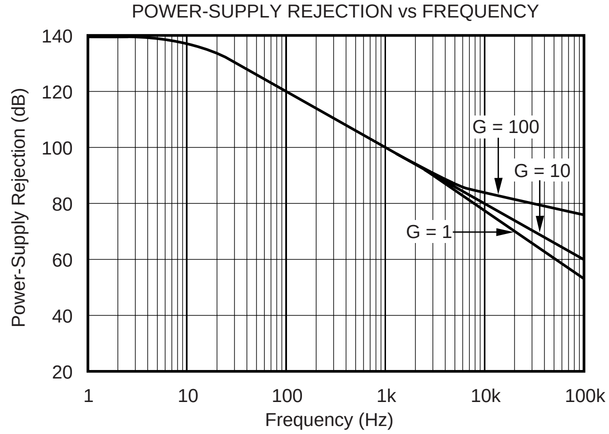
GAIN vs FREQUENCY



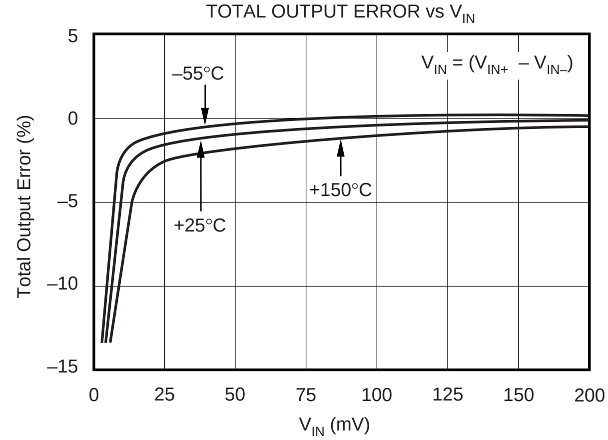
COMMON-MODE REJECTION vs FREQUENCY



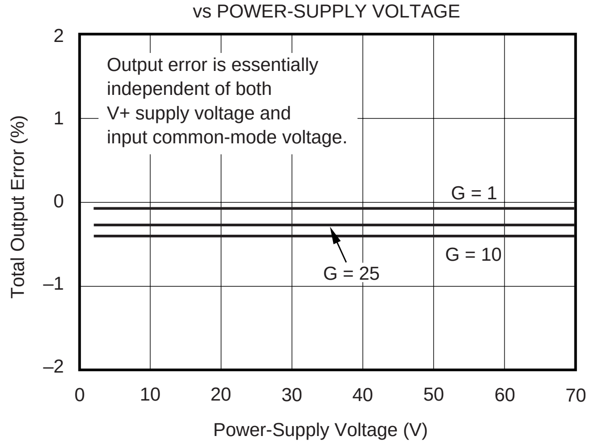
POWER-SUPPLY REJECTION vs FREQUENCY



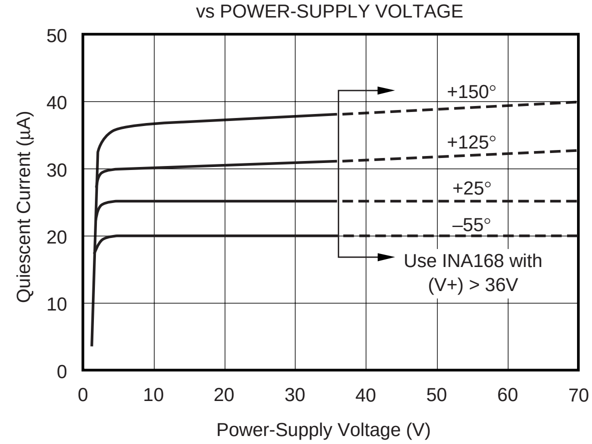
TOTAL OUTPUT ERROR vs V_{IN}



TOTAL OUTPUT ERROR vs POWER-SUPPLY VOLTAGE



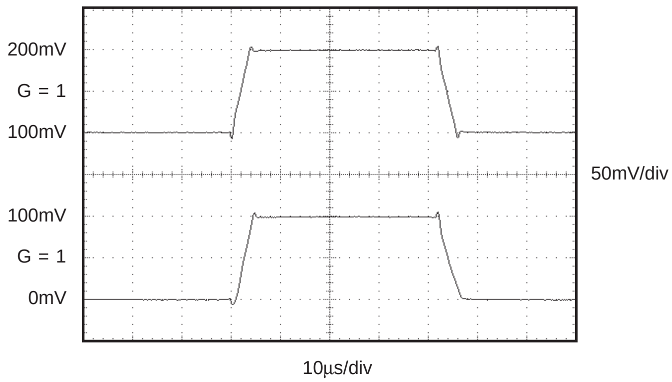
QUIESCENT CURRENT vs POWER-SUPPLY VOLTAGE



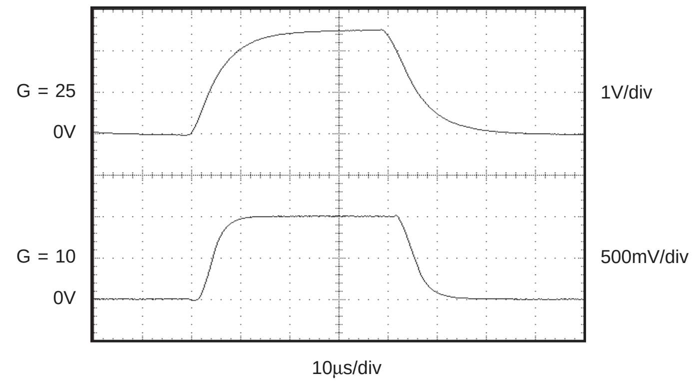
TYPICAL CHARACTERISTICS (Cont.)

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

STEP RESPONSE



STEP RESPONSE



OPERATION

Figure 1 illustrates the basic circuit diagram for both the INA138 and INA168. Load current I_S is drawn from supply V_S through shunt resistor R_S. The voltage drop in shunt resistor V_S 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 is:

$$I_O = g_m (V_{IN+} - V_{IN-}) \qquad (1)$$

where g_m = 200µA/V.

In the circuit of Figure 1, the input voltage, $(V_{IN+} - V_{IN-})$, is equal to $I_S \bullet R_S$ and the output voltage, V_{OUT}, is equal to $I_O \bullet R_L$. The transconductance, g_m, of the INA138 is 200µA/V. The complete transfer function for the current measurement amplifier in this application is:

$$V_{OUT} = (I_S)\ (R_S)\ (200\mu A/V)\ (R_L) \qquad (2)$$

The maximum differential input voltage for accurate measurements is 0.5V, which produces a 100µA output current. A differential input voltage of up to 2V will 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, will be zero, but it will not cause damage.

BASIC CONNECTION

Figure 1 shows the basic connection of the INA138. 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. 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.

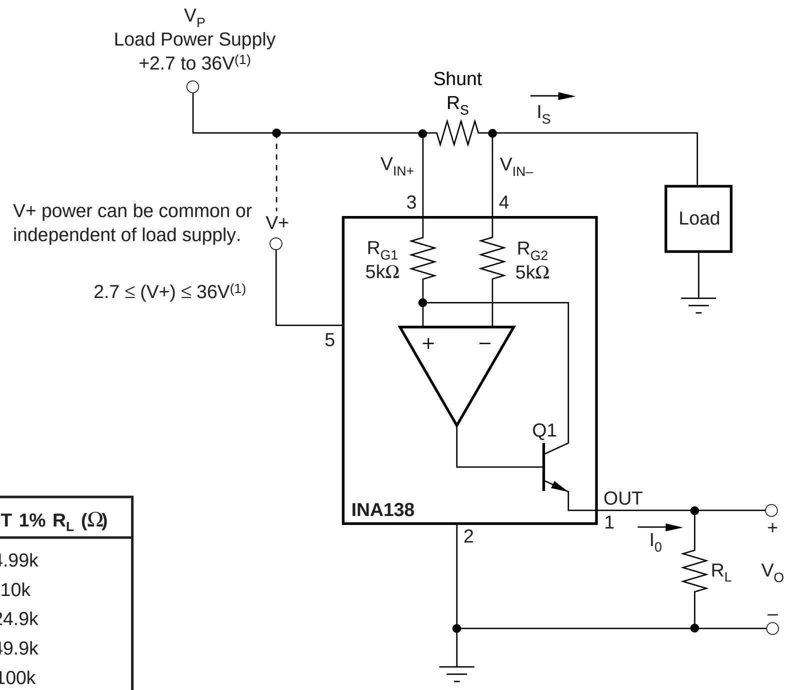
POWER SUPPLIES

The input circuitry of the INA138 can accurately measure beyond its power-supply voltage, V+. For example, the V+ power supply can be 5V, whereas the load power supply voltage is up to +36V (or +60V with the INA168). 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, best performance is attained with an R_S value that provides a full-scale shunt voltage range of 50mV to 100mV. Maximum input voltage for accurate measurements is 500mV.

R_L is chosen to provide the desired full-scale output voltage. The output impedance of the INA138 OUT terminal is very high which permits using values of R_L up to 500kΩ 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.



VOLTAGE GAIN	EXACT R_L (Ω)	NEAREST 1% R_L (Ω)
1	5k	4.99k
2	10k	10k
5	25k	24.9k
10	50k	49.9k
20	100k	100k
50	250k	249k
100	500k	499k

NOTE: (1) Maximum V_P and V+ voltage is 60V with INA168.

FIGURE 1. Basic Circuit Connections.

Some Analog-to-Digital (A/D) converters have input impedances that will significantly affect 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 1 shows the recommended values of R_L.

OUTPUT VOLTAGE RANGE

The output of the INA138 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:

$$V_{out\ max} = (V+) - 0.7V - (V_{IN+} - V_{IN-}) \qquad (3)$$

or

$$V_{out\ max} = V_{IN-} - 0.5V \qquad (4)$$

(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 will yield a narrower measurement bandwidth (see Typical Characteristics). 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.

If bandwidth limiting (filtering) is desired, a capacitor can be added to the output (see Figure 3). This will not cause instability.

APPLICATIONS

The INA138 is designed for current shunt measurement circuits, as shown in Figure 1, but its basic function is useful in a wide range of circuitry. A creative engineer will find many unforeseen uses in measurement and level shifting circuits. A few ideas are illustrated in Figures 2 through 7.

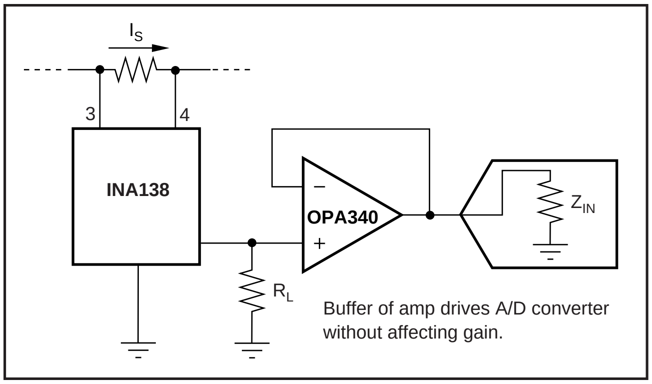


FIGURE 2. Buffering Output to Drive an A/D Converter.

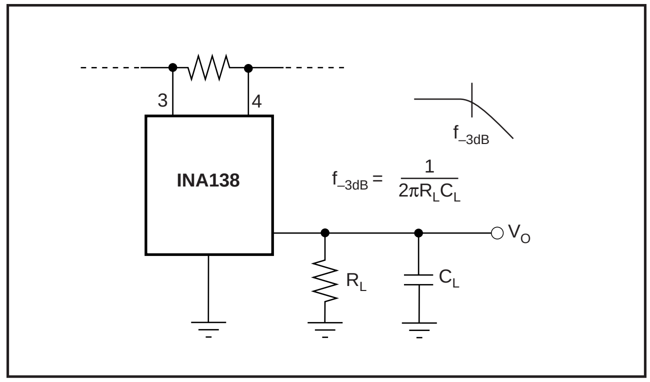


FIGURE 3. Output Filter.

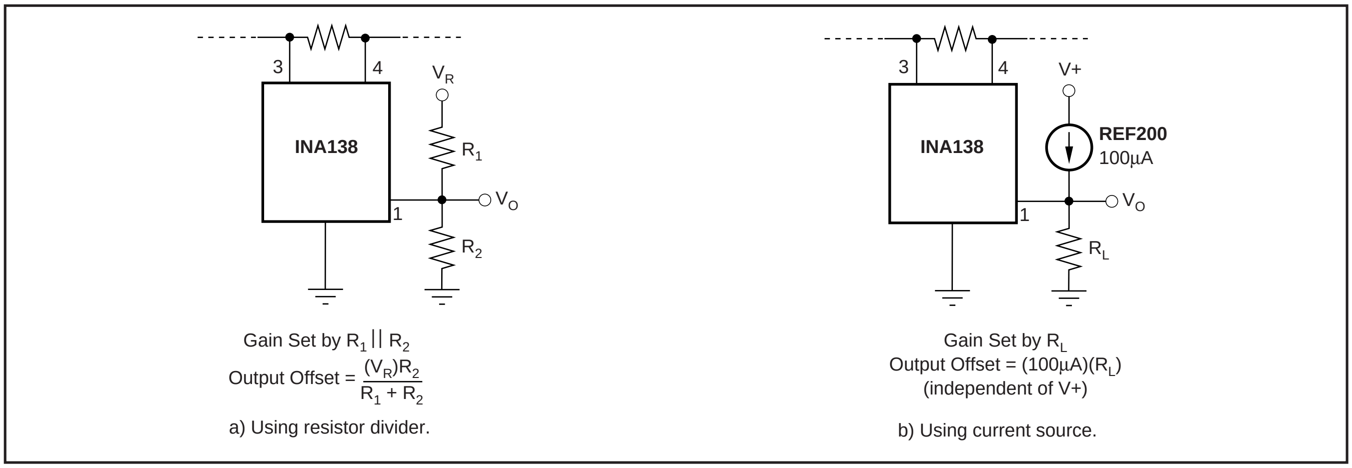


FIGURE 4. Offsetting the Output Voltage.

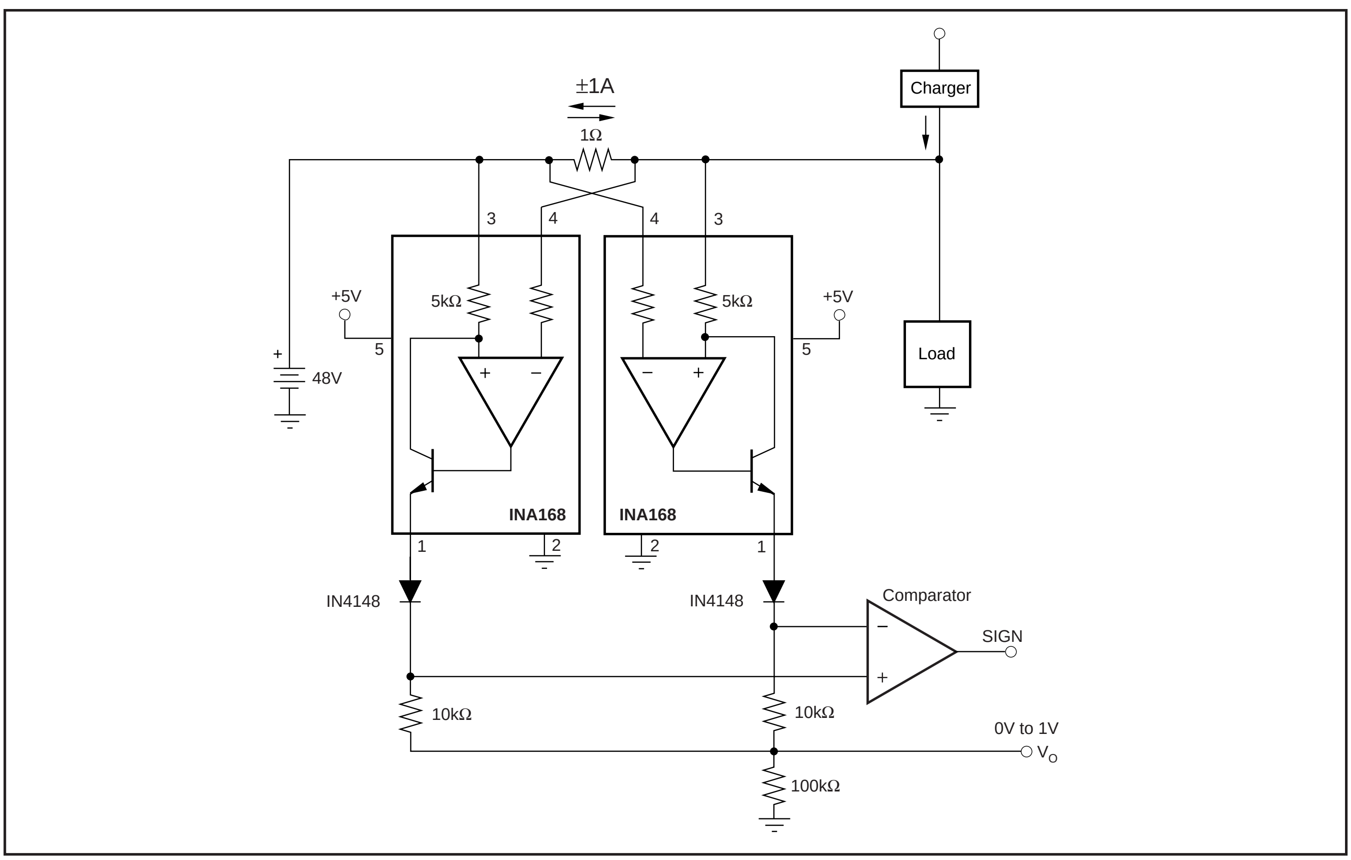


FIGURE 5. Bipolar Current Measurement.

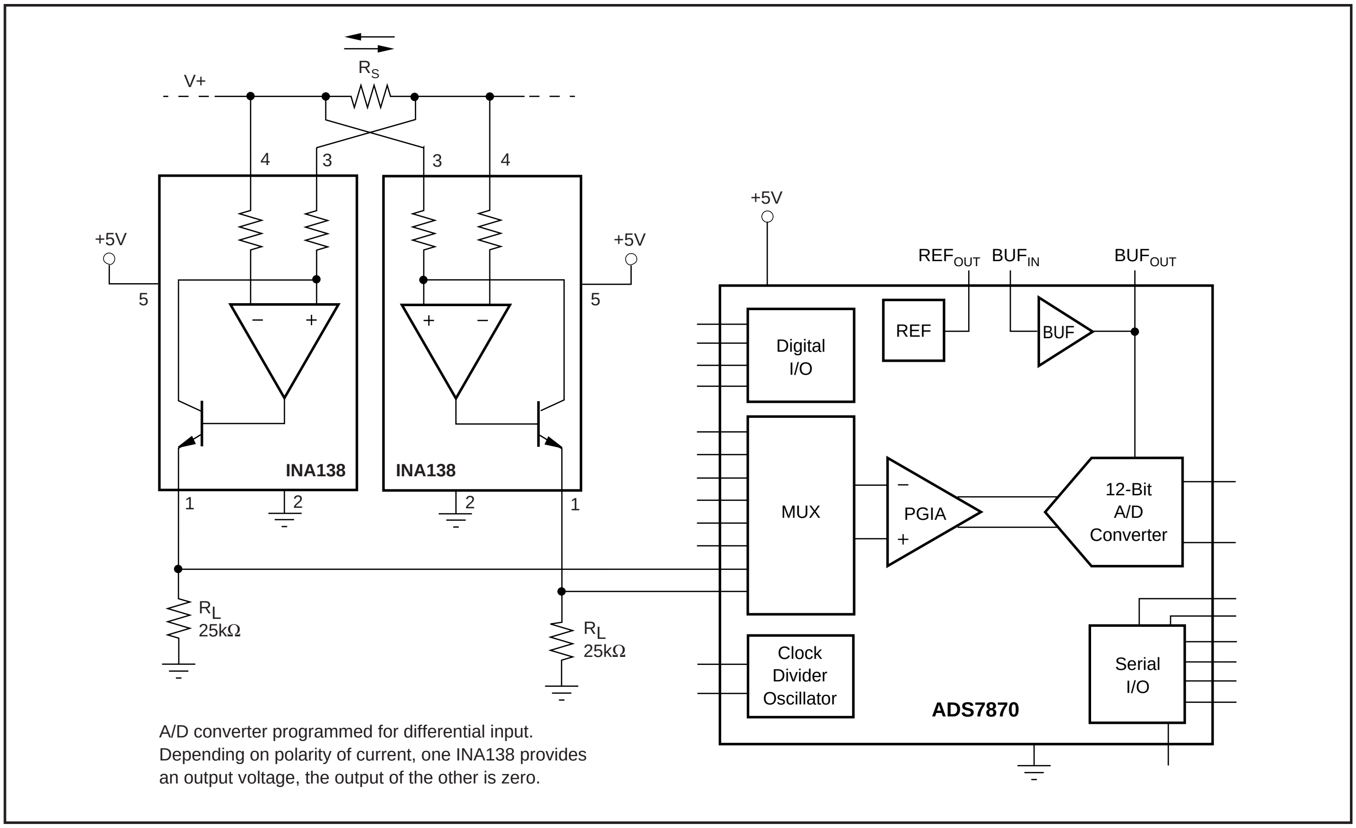


FIGURE 6. Bipolar Current Measurement Using Differential Input of A/D Converter.

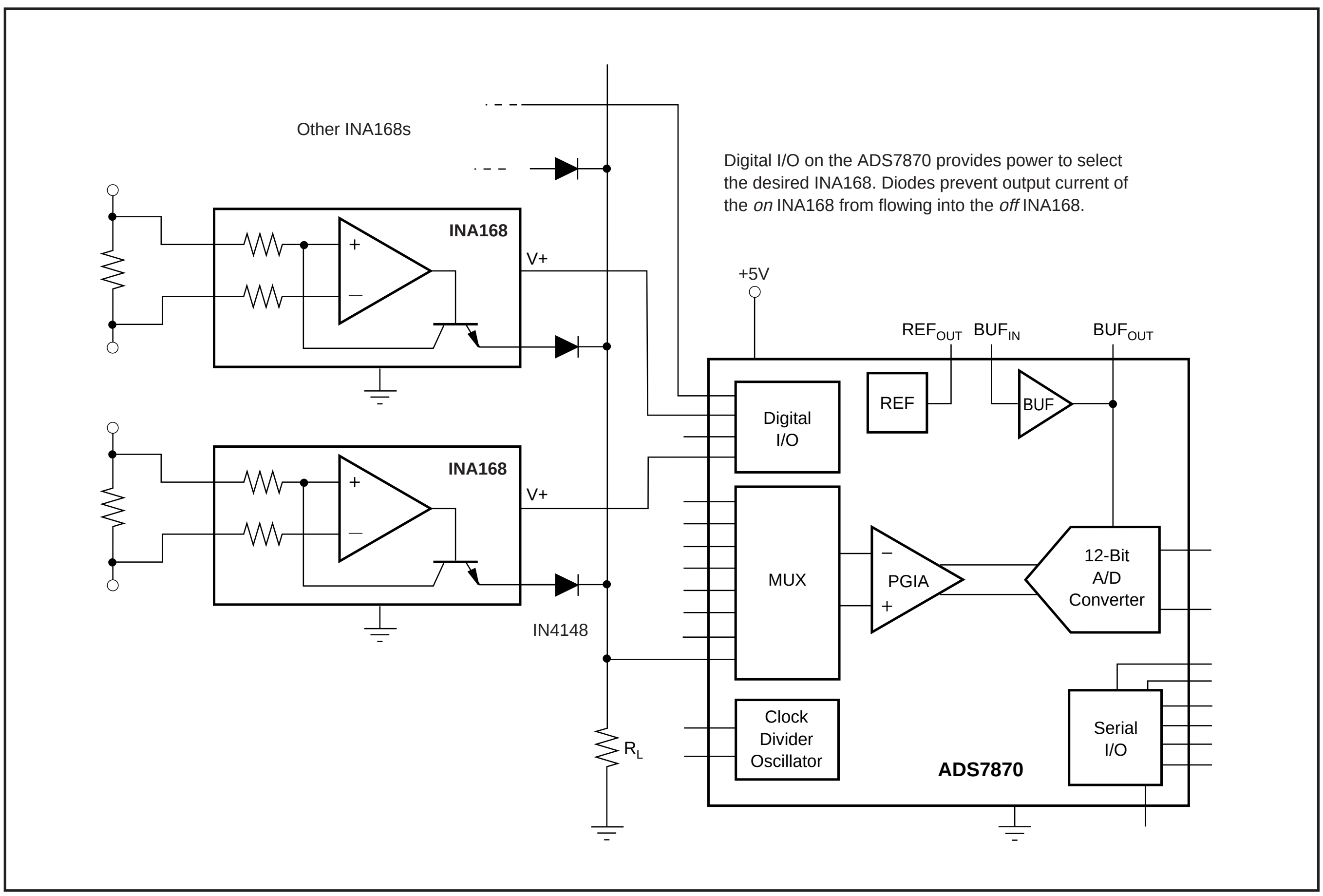


FIGURE 7. Multiplexed Measurement Using Logic Signal for Power.

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
INA138NA/250	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA138NA/250G4	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA138NA/3K	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA138NA/3KG4	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA168NA/250	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA168NA/250G4	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA168NA/3K	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA168NA/3KG4	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

[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.

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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, INA168 :

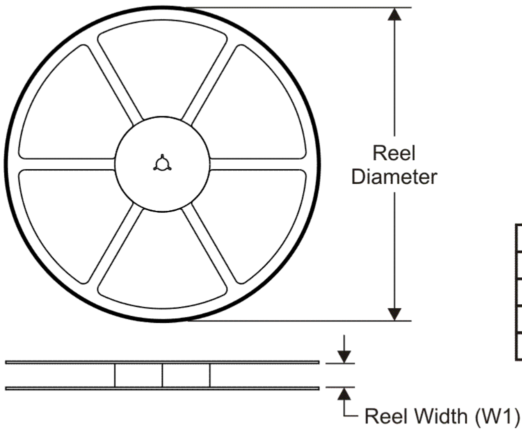
- Automotive: INA138-Q1, INA168-Q1

NOTE: Qualified Version Definitions:

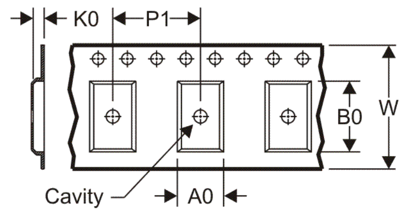
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

REEL DIMENSIONS

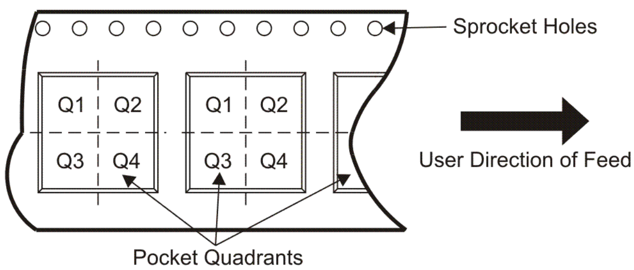


TAPE DIMENSIONS



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

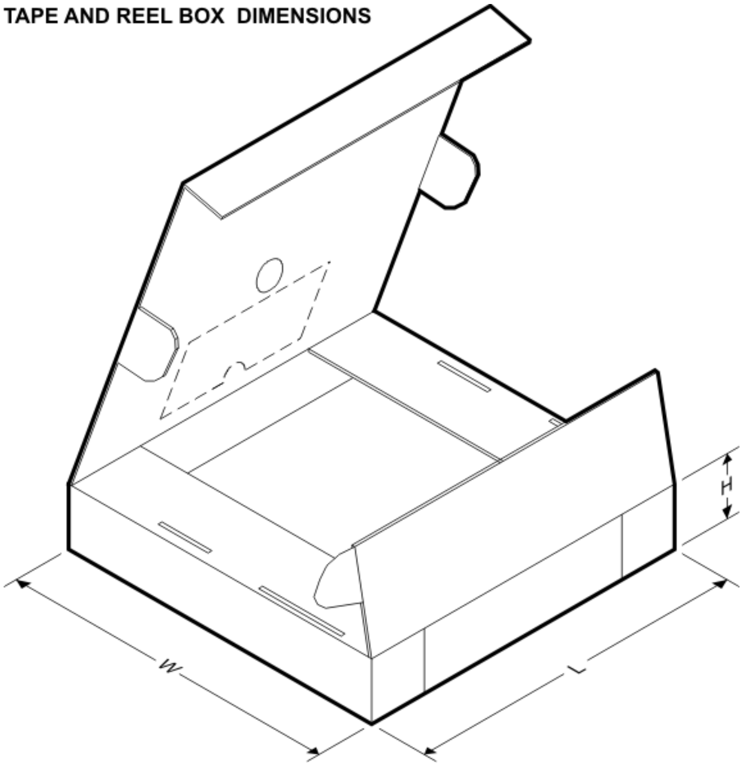
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
INA138NA/250	SOT-23	DBV	5	250	180.0	8.4	3.2	3.1	1.39	4.0	8.0	Q3
INA138NA/3K	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.1	1.39	4.0	8.0	Q3
INA168NA/250	SOT-23	DBV	5	250	180.0	8.4	3.2	3.1	1.39	4.0	8.0	Q3
INA168NA/3K	SOT-23	DBV	5	3000	180.0	8.4	3.2	3.1	1.39	4.0	8.0	Q3

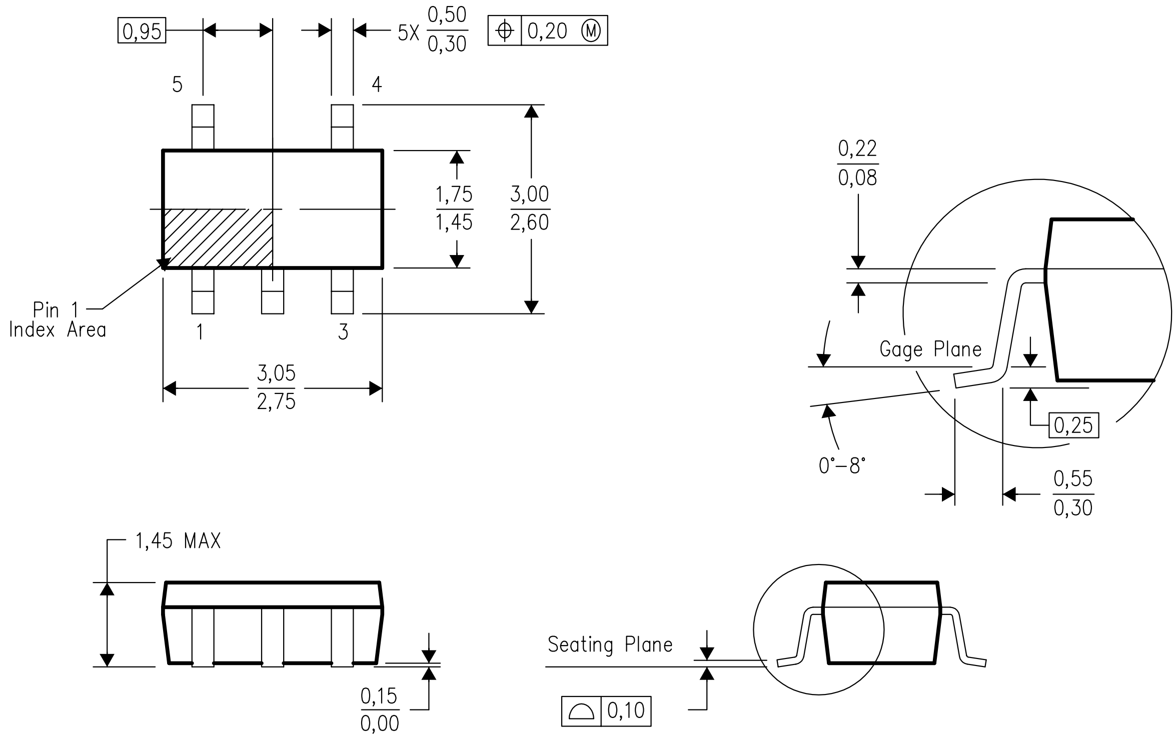
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA138NA/250	SOT-23	DBV	5	250	190.5	212.7	31.8
INA138NA/3K	SOT-23	DBV	5	3000	190.5	212.7	31.8
INA168NA/250	SOT-23	DBV	5	250	190.5	212.7	31.8
INA168NA/3K	SOT-23	DBV	5	3000	190.5	212.7	31.8

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



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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.

IMPORTANT NOTICE

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Clocks and Timers	www.ti.com/clocks	Digital Control	www.ti.com/digitalcontrol
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
RF/IF and ZigBee® Solutions	www.ti.com/lprf	Video & Imaging	www.ti.com/video
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