![TEXAS INSTRUMENTS]

INA191, INA2191
JAJSGY6C – FEBRUARY 2019 – REVISED AUGUST 2021

INAx191 40V、双方向、超高精度の電流センス・アンプ、ピコアンペア (pA) IB、イネーブル付き、WCSP パッケージ

1 特長

- 低消費電力：
  - 電源電圧 (V$_S$)：1.7V～5.5V
  - シャットダウン電流：100nA (最大値、INA191)
  - 静止電流：25 ℃ で 43µA (INA191)
- 低い入力バイアス電流：100pA (標準値) (マイクロアンペアの電流測定が可能)
- 双方向電流測定 (INA2191)
- 精度：
  - 最大ゲイン誤差：±0.25% (A2～A5 デバイス)
  - ゲイン・ドリフト：7ppm/℃ (最大値)
  - オフセット電圧： ±12µV (最大値)
  - オフセット・ドリフト：0.13µV/℃ (最大値)
- 広い同相電圧範囲：-0.2V～+40V
- ゲイン・オプション
  - INAx191A1：25 V/V
  - INAx191A2：50V/V
  - INAx191A3：100V/V
  - INAx191A4：200V/V
  - INAx191A5：500V/V
- パッケージ：
  - INA191：0.895mm^2 DSBGA
  - INA2191：1.79mm^2 DSBGA

2 アプリケーション

- ノート PC
- 携帯電話
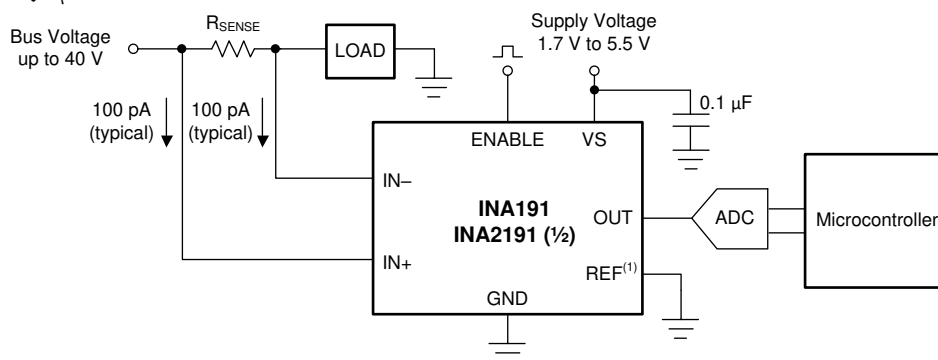- バッテリ駆動デバイス
- 通信機器
- パワー・マネージメント
- バッテリ・チャージャ

3 概要

INAx191 は低消費電力、電圧出力の電流シャント・モニタ (電流センス・アンプとも呼ばれます) で、過電流からの保護、システム最適化を行うための高精度の電流測定、または閉ループ帰還回路に一般的に使用されます。このデバイスは、電源電圧にかかわらず、-0.2V～+40V の同相電圧でシャントでの電圧降下を検出できます。INAx191 は入力バイアス電流が低いことから、より大きな電流センス抵抗を使用できるため、µA の範囲で正確に電流を測定できます。5 つの固定ゲインを利用可能：25 V/V、50V/V、100V/V、200V/V、500V/V。ゼロ・ドリフト・アーキテクチャによりオフセット電圧が低いため、電流測定のダイナミック・レンジが拡大し、より小さなセンス抵抗を使用でき、電力損失を低減しながら正確な電流測定を行えます。

INA191 は 1.7V～5.5V の単一電源で動作し、消費電流はイネーブル時に最大 65µA で、ディセーブル時にはわずか 100nA です。このデバイスは -40℃～+125℃ の温度範囲で動作が規定されており、DSBGA-6 (INA191) および DSBGA-12 (INA2191) パッケージで供給されます。

製品情報[1]

部品番号	パッケージ	本体サイズ (公称)
INA191	DSBGA (6)	1.17mm × 0.765mm
INA2191	DSBGA (12)	1.17 mm × 1.53 mm

(1) 利用可能なすべてのパッケージについては、このデータシートの末尾にあるパッケージ・オプションについての付録を参照してください。


(1) REF pin only available on INA2191

概略回路図

English Data Sheet: SLYS020

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5 Pin Configuration and Functions
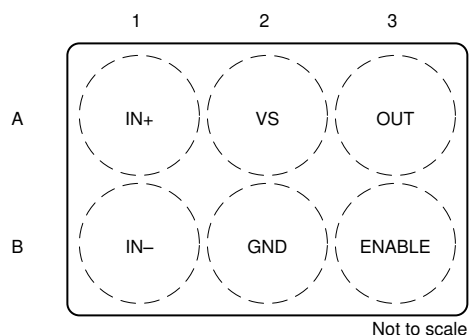
図 5-1. INA191 YFD Package 6-Pin DSBGA Top View

表 5-1. Pin Functions (INA191)

PIN NAME	PIN NO.	TYPE	DESCRIPTION
ENABLE	B3	Digital input	Enable pin. When this pin is driven to V_S, the device is on and functions as a current sense amplifier. When this pin is driven to GND, the device is off, the supply current is reduced, and the output is placed in a high-impedance state. This pin must be driven externally, or connected to V_S if not used.
GND	B2	Analog	Ground.
IN+	A1	Analog input	Current-shunt monitor positive input. For high-side applications, connect this pin to the bus voltage side of the sense resistor. For low-side applications, connect this pin to the load side of the sense resistor.
IN–	B1	Analog input	Current-shunt monitor negative input. For high-side applications, connect this pin to the load side of the sense resistor. For low-side applications, connect this pin to the ground side of the sense resistor.
OUT	A3	Analog output	This pin provides an analog voltage output that is the amplified voltage difference from the IN+ to the IN– pins.
VS	A2	Analog	Power supply, 1.7 V to 5.5 V.

Product Folder Links: *INA191 INA2191*

English Data Sheet: *SLYS020*
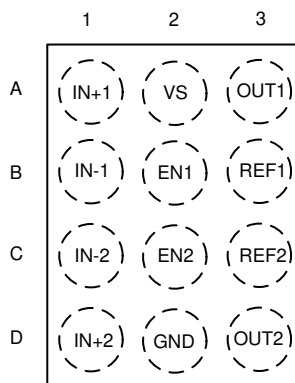
図 5-2. INA2191 YBJ Package 12-Pin DSBGA Top View

表 5-2. Pin Functions (INA2191)

PIN		TYPE	DESCRIPTION
NAME	NO.		
ENABLE1	B2	Digital input	Enable pin for output 1. When this pin is driven to V_S, channel 1 is on and functions as a current sense amplifier. When both enable pins are driven to GND, the device is off and the supply current is reduced. This pin must be driven externally, or connected to V_S if not used.
ENABLE2	C2	Digital input	Enable pin for output 2. When this pin is driven to V_S, channel 2 is on and functions as a current sense amplifier. When both enable pins are driven to GND, the device is off and the supply current is reduced. This pin must be driven externally, or connected to V_S if not used.
GND	D2	Analog	Ground.
IN+1	A1	Analog input	Current-shunt monitor positive input for channel 1. For high-side applications, connect this pin to the bus voltage side of the sense resistor. For low-side applications, connect this pin to the load side of the sense resistor.
IN+2	D1	Analog input	Current-shunt monitor positive input for channel 2. For high-side applications, connect this pin to the bus voltage side of the sense resistor. For low-side applications, connect this pin to the load side of the sense resistor.
IN–1	B1	Analog input	Current-shunt monitor negative input for channel 1. For high-side applications, connect this pin to the load side of the sense resistor. For low-side applications, connect this pin to the ground side of the sense resistor.
IN–2	C1	Analog input	Current-shunt monitor negative input for channel 2. For high-side applications, connect this pin to the load side of the sense resistor. For low-side applications, connect this pin to the ground side of the sense resistor.
OUT1	A3	Analog output	This pin provides an analog voltage output that is the amplified voltage difference from the IN+1 to the IN–1 pins, and is offset by the voltage applied to the REF1 pin.
OUT2	D3	Analog output	This pin provides an analog voltage output that is the amplified voltage difference from the IN+2 to the IN–2 pins, and is offset by the voltage applied to the REF2 pin.
REF1	B3	Analog input	Reference input for channel 1. Enables bidirectional current sensing for channel 1 with an externally applied voltage.
REF2	C3	Analog input	Reference input for channel 2. Enables bidirectional current sensing for channel 2 with an externally applied voltage.
VS	A2	Analog	Power supply, 1.7 V to 5.5 V.

Product Folder Links: *INA191 INA2191*

English Data Sheet: *SLYS020*

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

			MIN	MAX	UNIT
V_S	Supply voltage			6	V
V_{IN+}, V_{IN-}	Analog inputs	Differential $(V_{IN+}) - (V_{IN-})$[2]	–42	42	V
		V_{IN+}, V_{IN-}, with respect to GND[3]	GND – 0.3	42	
V_{ENABLE}	ENABLE		GND – 0.3	6	V
	REF, OUT[3]		GND – 0.3	(V_S) + 0.3	V
	Input current into any pin[3]			5	mA
T_A	Operating temperature		–55	150	°C
T_J	Junction temperature			150	°C
T_{stg}	Storage temperature		–65	150	°C

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

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

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

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101[2]	±1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input range	– 0.2		40	V
V_{IN+}, V_{IN-}	Input pin voltage range	– 0.2		40	V
V_S	Operating supply voltage	1.7		5.5	V
V_{REF}	Reference pin voltage range	0		V_S	V
T_A	Operating free-air temperature	–40		125	°C

6.4 Thermal Information

		INA191	INA2191	UNIT
THERMAL METRIC[1]		**YFD (DSBGA)**	**YBJ (DSBGA)**	
		6 PINS	**12 PINS**	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	141.4	94.1	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	1.1	0.6	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	45.7	23.8	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	0.4	0.3	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	45.3	23.8	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

6.5 Electrical Characteristics

at T_A = 25°C, V_{SENSE} = V_{IN+} – V_{IN-}, V_S = 1.8 V to 5.0 V, V_{IN+} = 12 V, V_{REF} = V_S / 2 (INA2191), and V_{ENABLE} = V_S (unless otherwise noted)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
INPUT							
CMRR	Common-mode rejection ratio, RTI[1]	V_{IN+} = –0.1 V to 40 V, T_A = –40°C to +125°C		132	150		dB
V_{OS}	Offset voltage, RTI[1]	V_S = 1.8 V			–2.5	±12	µV
dV_{OS}/dT	Offset drift, RTI	T_A = –40°C to +125°C			10	130	nV/°C
PSRR	Power-supply rejection ratio, RTI	V_S = 1.7 V to 5.5 V			–1	±5	µV/V
I_{IB}	Input bias current	V_{SENSE} = 0 mV			0.1	3	nA
I_{IO}	Input offset current	V_{SENSE} = 0 mV			±0.07		nA
OUTPUT							
G	Gain	A1 devices			25		V/V
		A2 devices			50		
		A3 devices			100		
		A4 devices			200		
		A5 devices			500		
E_G	Gain error	V_{OUT} = 0.1 V to V_S – 0.1 V	A1 devices, INA191		–0.17%	±0.35%	
			A1 devices, INA2191		+0.05%	±0.25%	
			A2, A3, A4, A5 devices		–0.04%	±0.25%	
	Gain error drift	T_A = –40°C to +125°C			2	7	ppm/°C
	Nonlinearity error	V_{OUT} = 0.1 V to V_S – 0.1 V			±0.01%		
RVRR	Reference voltage rejection ratio	INA2191 only, V_{REF} = 100 mV to V_S – 100 mV, T_A = –40°C to +125°C	A1 devices		±2	±12	µV/V
			A2 devices		±1	±6	
			A3 devices		±0.5	±4	
			A4, A5 devices		±0.25	±3	
	Maximum capacitive load	No sustained oscillation			1		nF
VOLTAGE OUTPUT							
V_{SP}	Swing to V_S power-supply rail	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C			(V_S) – 23	(V_S) – 40	mV
V_{SN}	Swing to GND	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = –10 mV, V_{REF} = 0 V (INA2191)			(V_{GND}) + 0.05	(V_{GND}) + 1	mV
V_{ZL}	Zero current output voltage	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = 0 mV, for INA2191 V_{REF} = 0 V	A1, A2, A3 devices		(V_{GND}) + 1	(V_{GND}) + 3	mV
			A4 devices		(V_{GND}) + 2	(V_{GND}) + 4	mV
			A5 devices		(V_{GND}) + 3	(V_{GND}) + 7	mV
FREQUENCY RESPONSE							
BW	Bandwidth	C_{LOAD} = 10 pF	A1 devices		45		kHz
			A2 devices		37		
			A3 devices		35		
			A4 devices		33		
			A5 devices		27		
SR	Slew rate	V_S = 5.0 V, V_{OUT} = 0.5 V to 4.5 V			0.3		V/µs
t_S	Settling time	From current step to within 1% of final value			30		µs

Product Folder Links: *INA191 INA2191*

at T_A = 25°C, V_{SENSE} = V_{IN+} – V_{IN-}, V_S = 1.8 V to 5.0 V, V_{IN+} = 12 V, V_{REF} = V_S / 2 (INA2191), and V_{ENABLE} = V_S (unless otherwise noted)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
NOISE, RTI[1]						
	Voltage noise density			75		nV/√Hz
ENABLE						
I_{EN}	Leakage input current	0 V ≤ V_{ENABLE} ≤ V_S		1	100	nA
V_{IH}	High-level input voltage	T_A = –40°C to +125°C	1.35		5.5	V
V_{IL}	Low-level input voltage	T_A = –40°C to +125°C	0		0.4	V
V_{HYS}	Hysteresis			100		mV
I_{ODIS}	Output leakage disabled	V_S = 1.8 V, V_{OUT} = 0 V to 1.8 V, V_{ENABLE} = 0 V		1	5	µA
	Output leakage disabled (INA2191)	V_S = 5 V, V_{OUT} = 0 V to 5.0 V, V_{ENABLE} = 0 V		1	5	µA
POWER SUPPLY						
I_Q	Quiescent current (INA191)	V_S = 1.8 V, V_{SENSE} = 0 mV		43	65	µA
		V_S = 1.8 V, V_{SENSE} = 0 mV, T_A = –40°C to +125°C			85	µA
	Quiescent current (INA2191)	V_S = 1.8 V, V_{SENSE} = 0 mV (Dual Channel)		96	130	µA
		V_S = 1.8 V, V_{SENSE} = 0 mV, T_A = –40°C to +125°C			180	µA
I_{QDIS}	Quiescent current disabled (INA191)	V_{ENABLE} < 0.4 V, V_{SENSE} = 0 mV (Single Channel)		10	100	nA
I_{QDIS}	Quiescent current disabled (INA2191)	$V_{ENABLE1}$ < 0.4 V, $V_{ENABLE2}$ = < 0.4 V, V_{SENSE} = 0 mV		20	200	nA

(1)   RTI = referred-to-input.

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6.6 Typical Characteristics

at T_A = 25 °C, V_S = 1.8 V, V_{IN+} = 12 V, V_{ENABLE} = V_S, V_{REF} = GND and all gain options (unless otherwise noted)
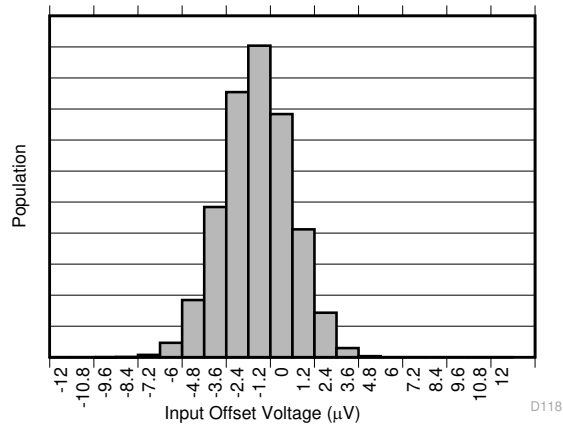
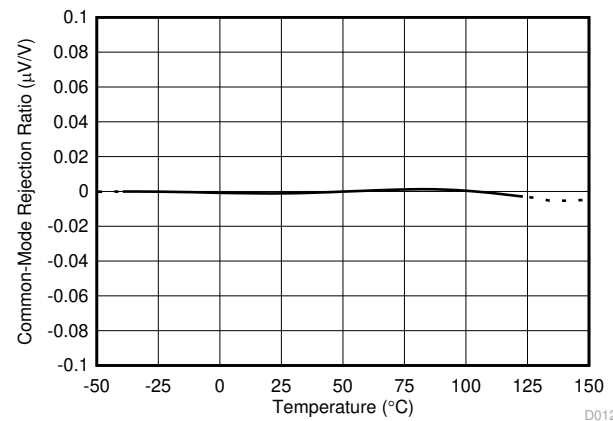図 6-1. Input Offset Voltage Production Distribution
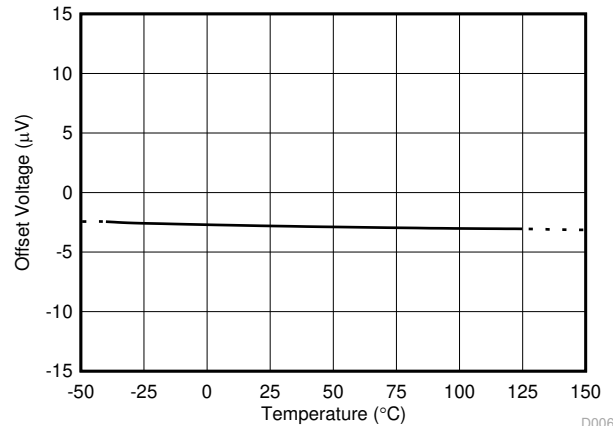
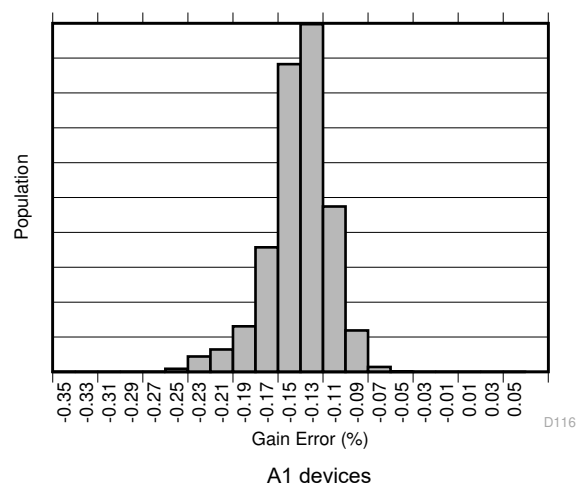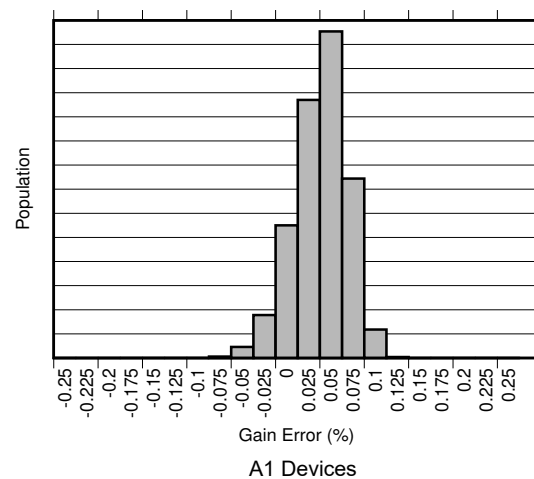図 6-2. Offset Voltage vs. Temperature
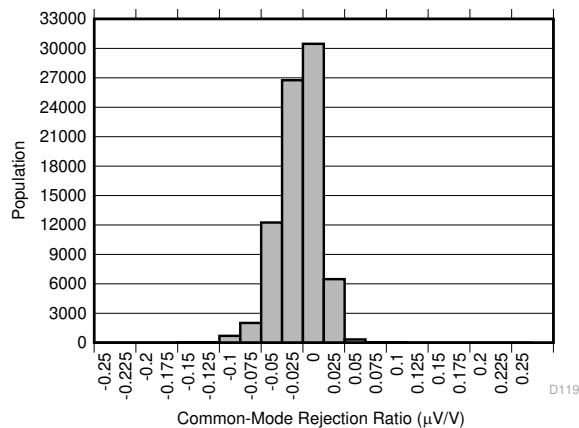
図 6-3. Common-Mode Rejection Production Distribution

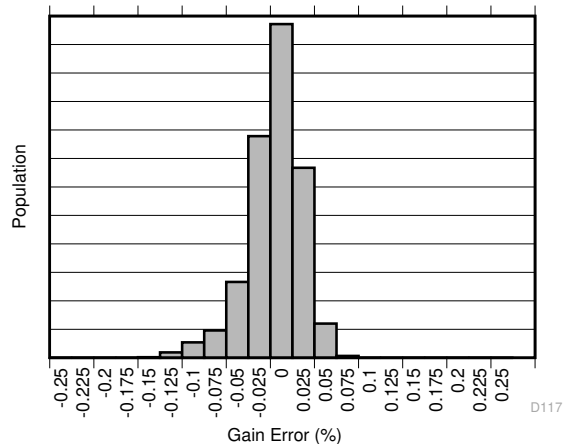図 6-4. Common-Mode Rejection Ratio vs. Temperature

A1 devices

図 6-5. Gain Error Production Distribution (INA191)

A1 Devices

図 6-6. Gain Error Production Distribution (INA2191)

Product Folder Links: *INA191 INA2191*

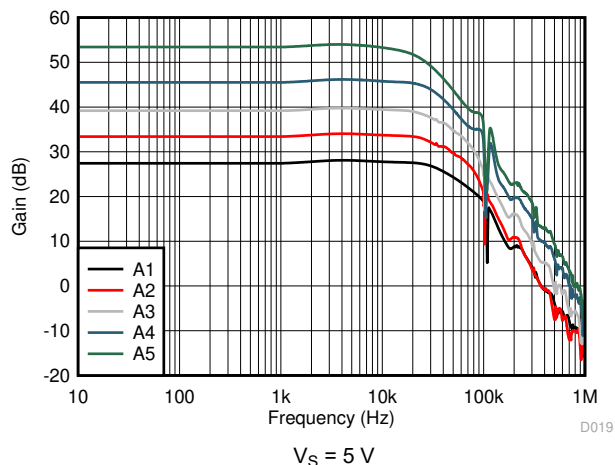English Data Sheet: SLYS020

A2, A3, A4, A5 devices

図 6-7. Gain Error Production Distribution
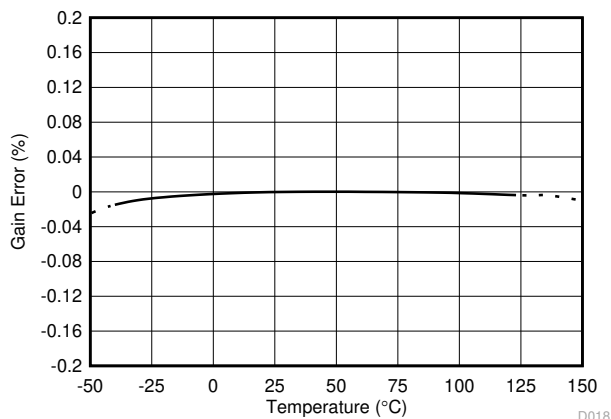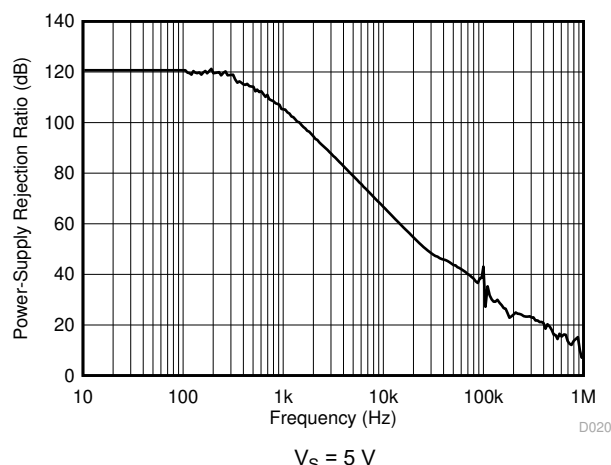

図 6-8. Gain Error vs. Temperature

V_S = 5 V

図 6-9. Gain vs. Frequency

V_S = 5 V

図 6-10. Power-Supply Rejection Ratio vs. Frequency
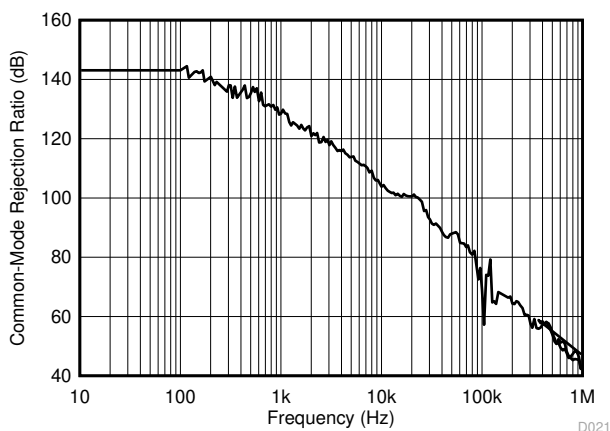
図 6-11. Common-Mode Rejection Ratio vs. Frequency
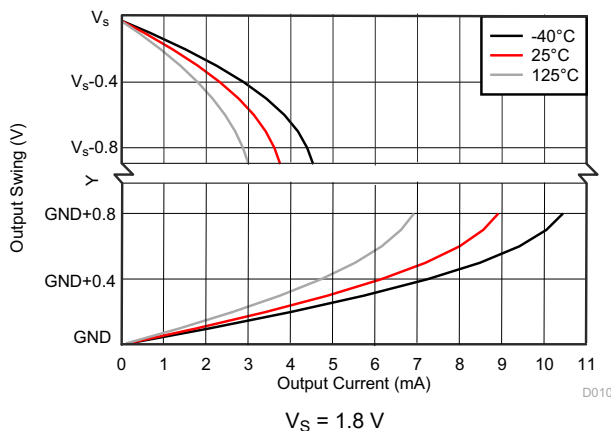
V_S = 1.8 V

図 6-12. Output Voltage Swing vs. Output Current
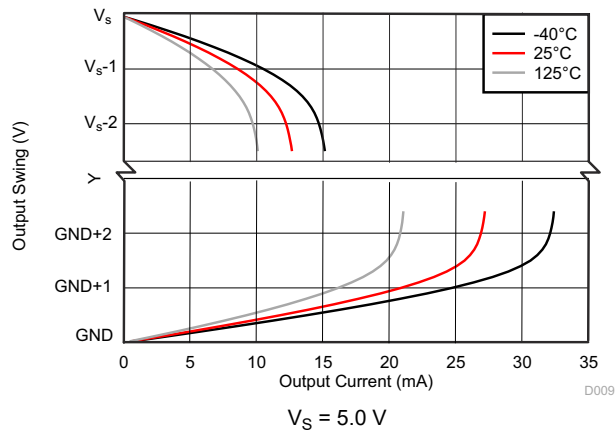
図 6-13. Output Voltage Swing vs. Output Current

$V_S = 5.0\ V$
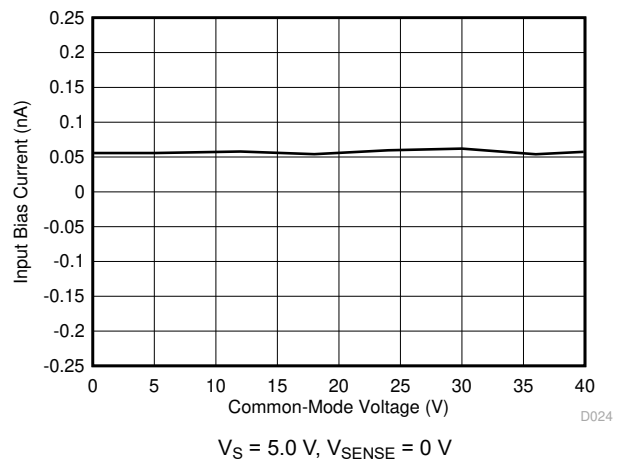
図 6-14. Input Bias Current vs. Common-Mode Voltage

$V_S = 5.0\ V,\ V_{SENSE} = 0\ V$
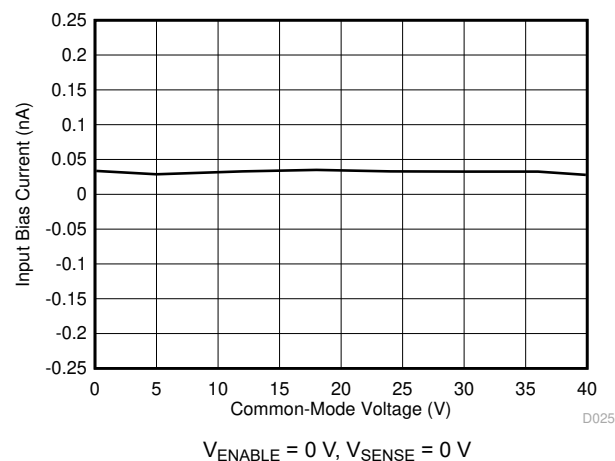
図 6-15. Input Bias Current vs. Common-Mode Voltage (Shutdown)

$V_{ENABLE} = 0\ V,\ V_{SENSE} = 0\ V$
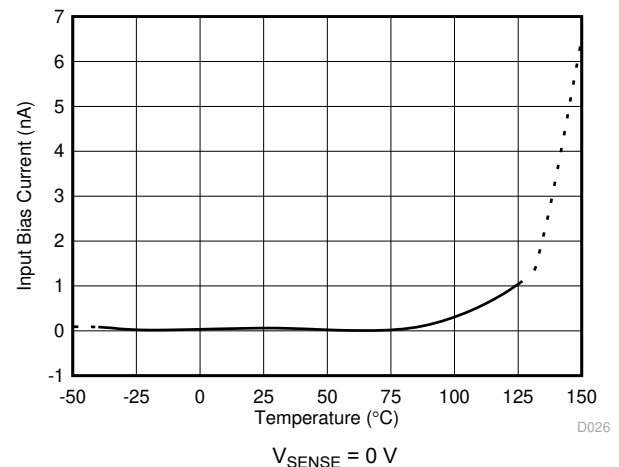
図 6-16. Input Bias Current vs. Temperature

$V_{SENSE} = 0\ V$
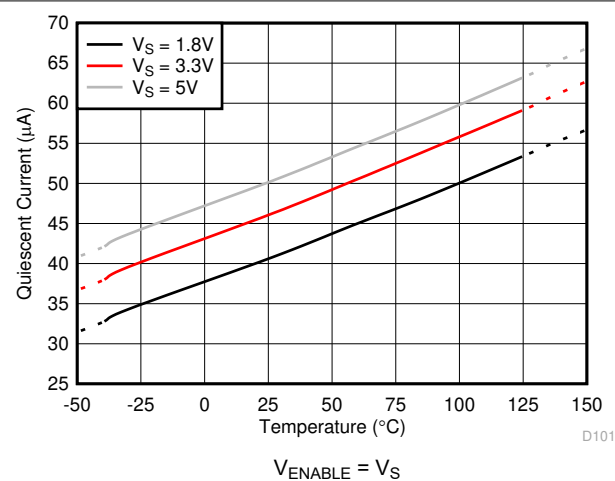
図 6-17. Quiescent Current vs. Temperature (INA191)

$V_{ENABLE} = V_S$

図 6-18. Quiescent Current vs. Temperature (INA2191)

Single channel enabled, $V_{REF} = V_S\ /2$

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$V_{ENABLE1} = V_{ENABLE2} = V_S$
, $V_{REF} = V_S /2$
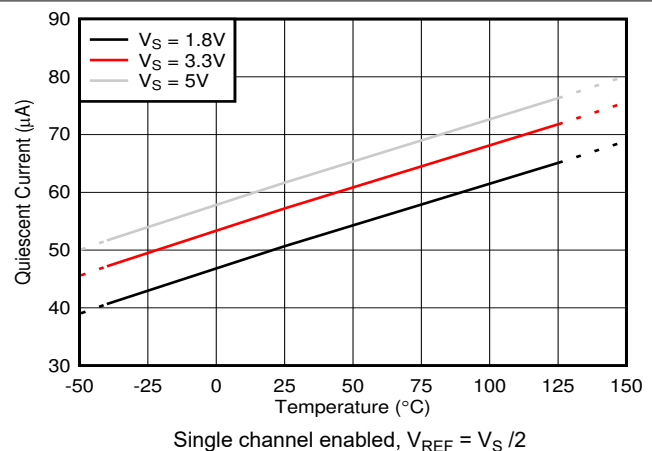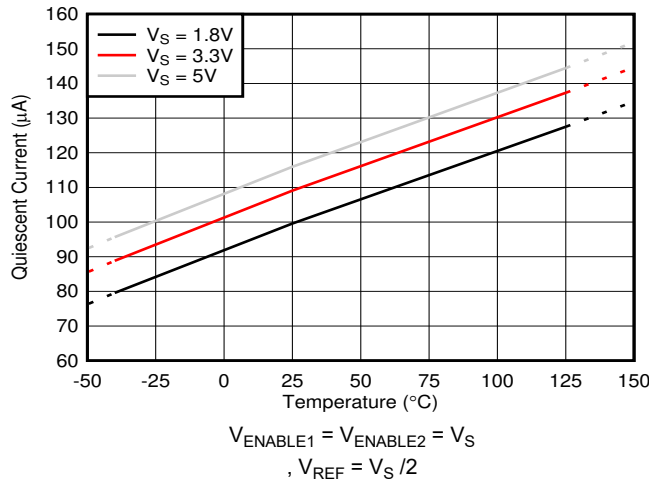
図 6-19. Quiescent Current vs. Temperature (INA2191)

$V_{ENABLE} = 0 V$
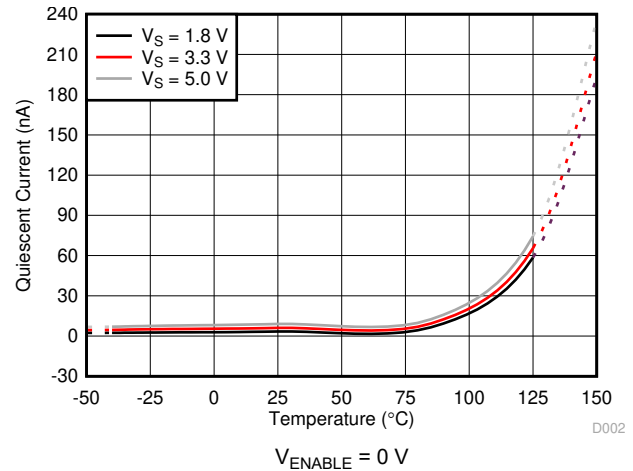
図 6-20. Quiescent Current vs. Temperature (INA191 Disabled)

$V_{ENABLE1} = V_{ENABLE2} = 0 V$, $V_{REF} = V_S /2$
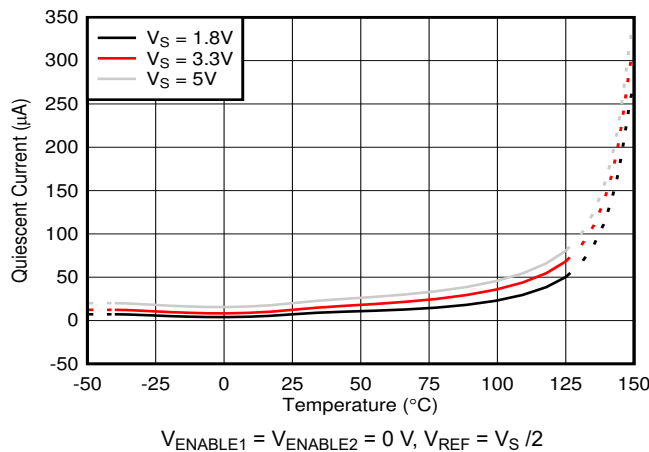
図 6-21. Quiescent Current vs. Temperature (INA2191 Disabled)
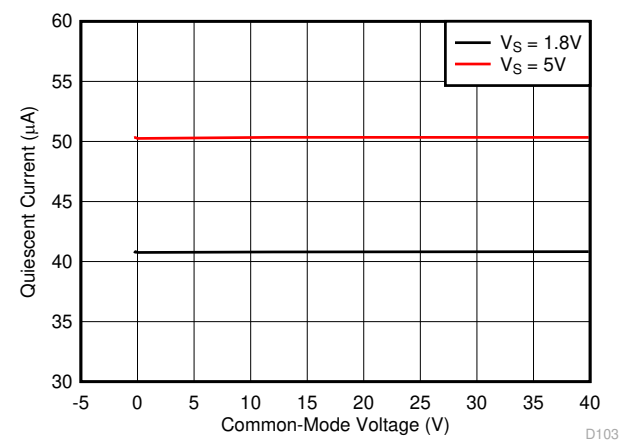
図 6-22. Quiescent Current vs. Common-Mode Voltage (INA191)

$V_{REF} = V_S /2$
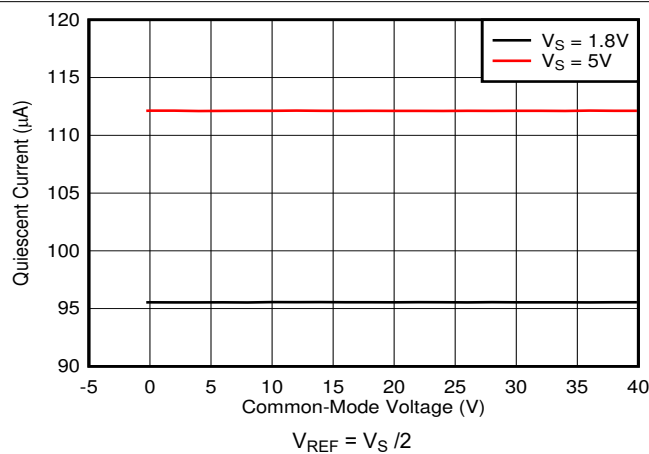
図 6-23. Quiescent Current vs. Common-Mode Voltage (INA2191)
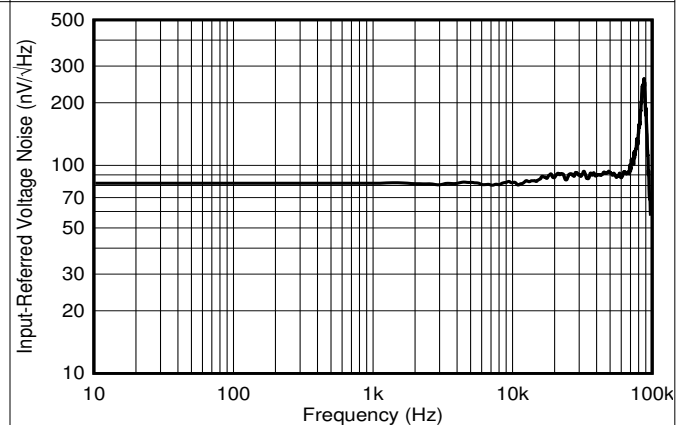
図 6-24. Input-Referred Voltage Noise vs. Frequency

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020
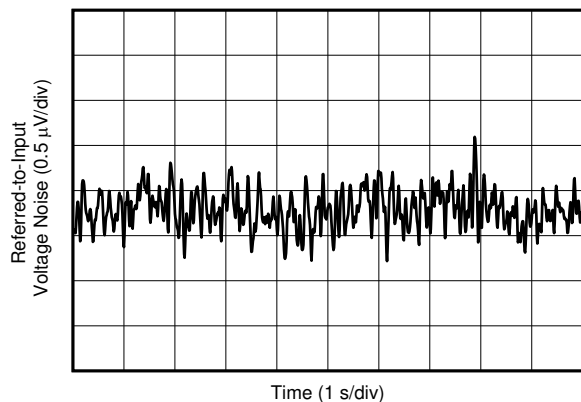
図 6-25. 0.1-Hz to 10-Hz Input-Referred Voltage Noise
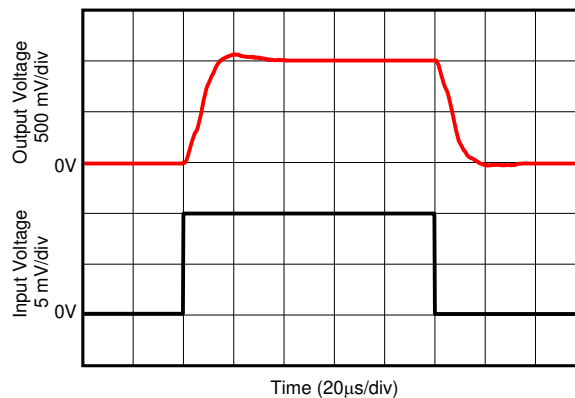
V_S = 5.0 V, 10-mV$_{PP}$ input step

図 6-26. Step Response
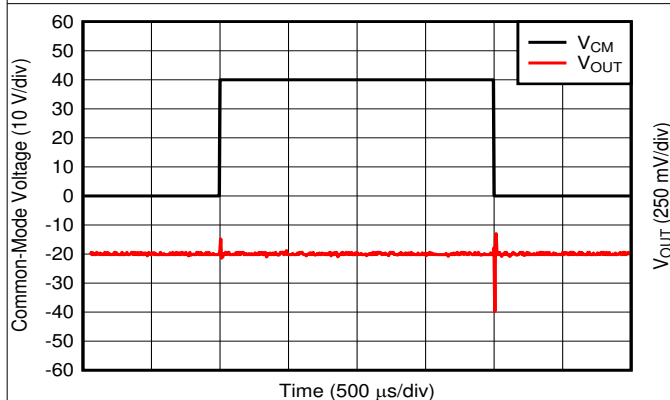
図 6-27. Common-Mode Voltage Transient Response
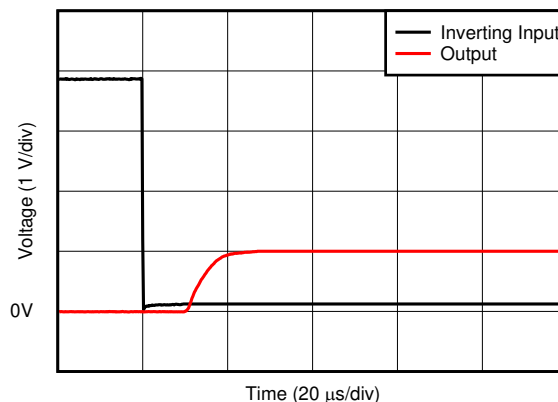
図 6-28. Inverting Differential Input Overload Recovery
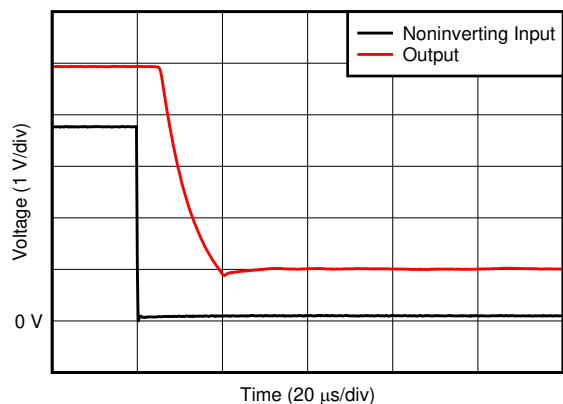
V_S = 5.0 V

図 6-29. Noninverting Differential Input Overload Recovery
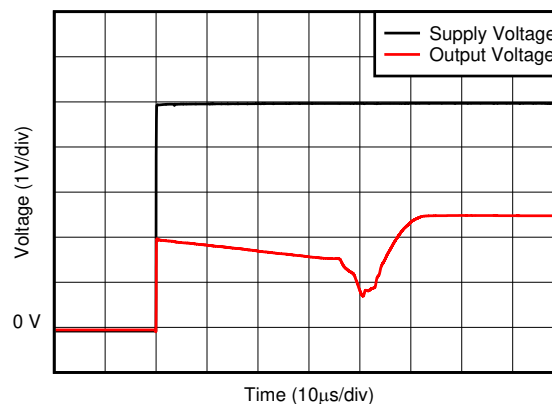
V_S = 5.0 V, A2 device

図 6-30. Start-Up Response

Product Folder Links: *INA191 INA2191*
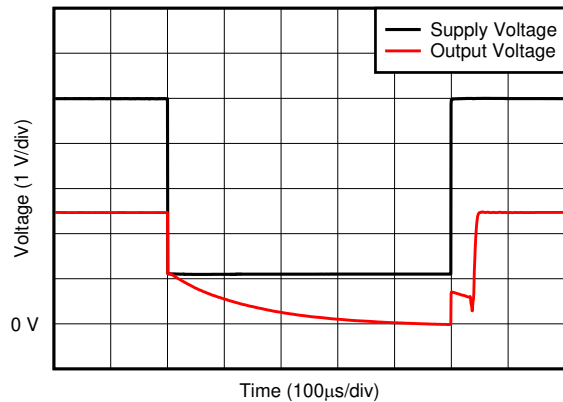
V_S = 5.0 V, A3 device

図 6-31. Brownout Recovery
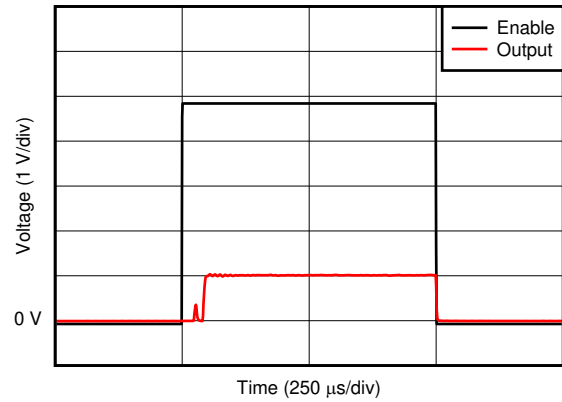
V_S = 5.0 V, A3 device

図 6-32. Enable and Disable Response
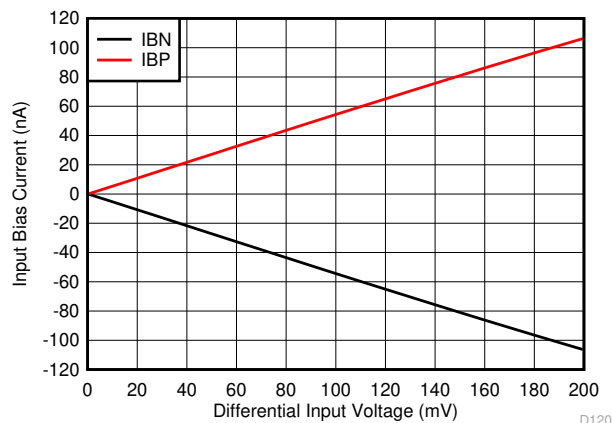
V_S = 5.0 V, A1 device

図 6-33. IB+ and IB– vs. Differential Input Voltage (INA191)
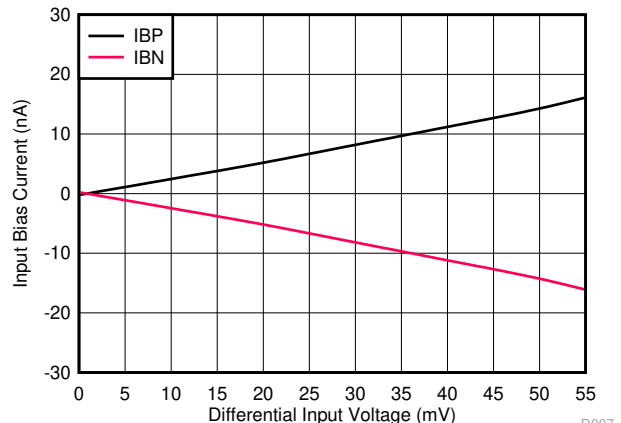
V_S = 5.0 V, A2, A3, A4, A5 devices

図 6-34. IB+ and IB– vs. Differential Input Voltage (INA191)
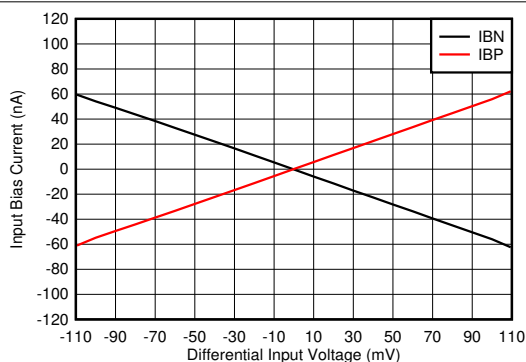
V_S = 5.0 V, V_{REF} = V_S /2, A1 device

図 6-35. IB+ and IB– vs. Differential Input Voltage (INA2191)
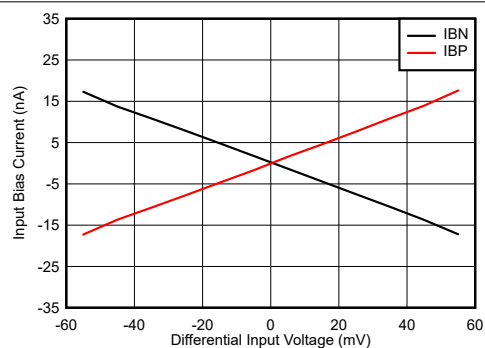
V_S = 5.0 V, V_{REF} = V_S /2, A2, A3, A4, A5 devices

図 6-36. IB+ and IB– vs. Differential Input Voltage (INA2191)
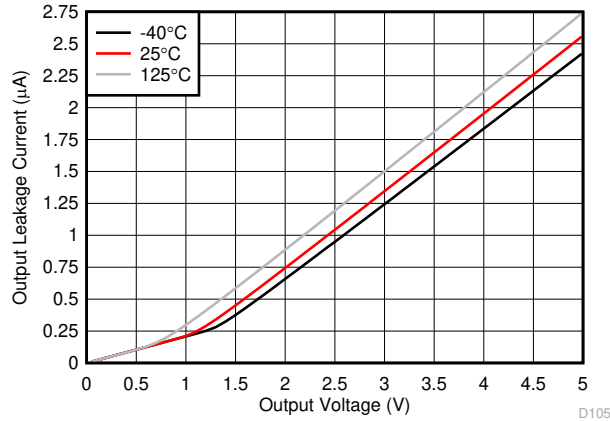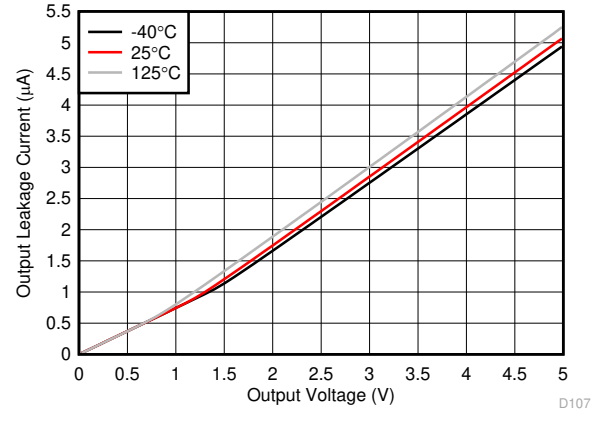
Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

V_S = 5.0 V, V_{ENABLE} = 0 V, A1, A2, A3 devices

図 6-37. Output Leakage vs. Output Voltage

V_S = 5.0 V, V_{ENABLE} = 0 V, A4, A5 devices

図 6-38. Output Leakage vs. Output Voltage

V_S = 5.0 V, V_{ENABLE} = 0 V, V_{REF} = 2.5 V, A1, A2, A3 devices

図 6-39. Output Leakage vs. Output Voltage (INA2191)

V_S = 5.0 V, V_{ENABLE} = 0 V, V_{REF} = 2.5 V, A4, A5 devices
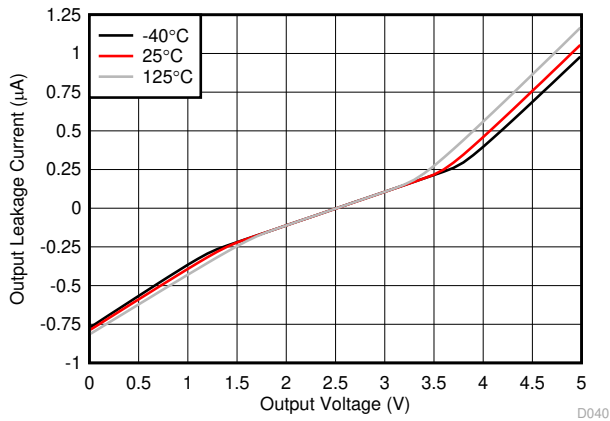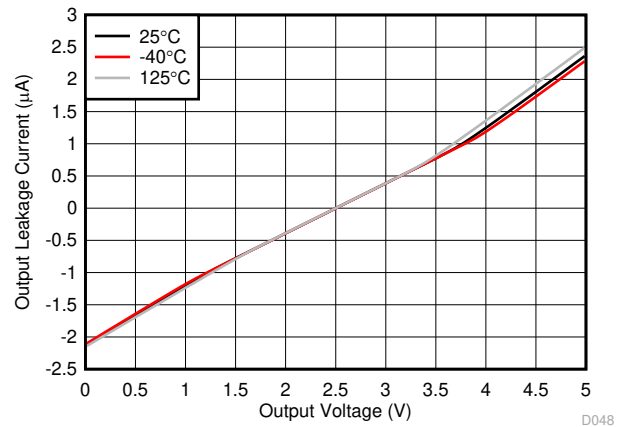
図 6-40. Output Leakage vs. Output Voltage (INA2191)

V_S = 5.0 V, V_{CM} = 0 V
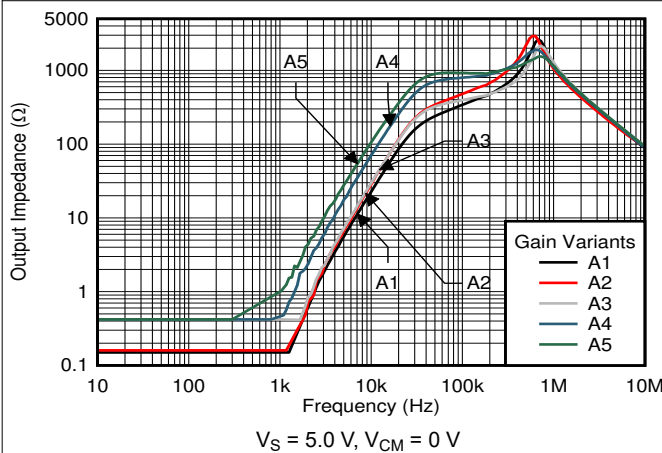
図 6-41. Output Impedance vs. Frequency

V_S = 5.0 V, V_{CM} = 0 V, V_{REF} = V_S/2
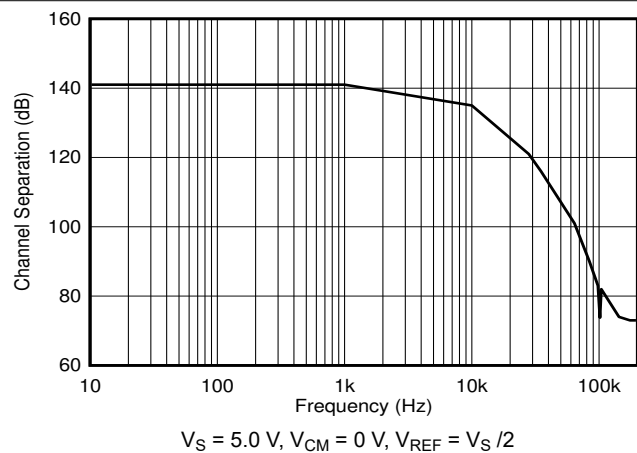
図 6-42. Channel Separation vs. Frequency (INA2191)

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

7 Detailed Description

7.1 Overview

The INAx191 is a low bias current, 40-V common-mode, current-sensing amplifier with an enable pin. When disabled, the output goes to a high-impedance state, and the supply current draw is reduced to less than 0.1 µA per channel. The INAx191 is intended for use in either low-side and high-side current-sensing configurations where high accuracy and low current consumption are required. The INAx191 is a specially designed current-sensing amplifier, that accurately measure voltages developed across current-sensing resistors on common-mode voltages that far exceed the supply voltage. Current can be measured on input voltage rails as high as 40 V, with a supply voltage (V_S) as low as 1.7 V.

7.2 Functional Block Diagram

図 7-1. INA191 Diagram

図 7-2. INA2191 Diagram

Product Folder Links: *INA191 INA2191*

English Data Sheet: *SLYS020*
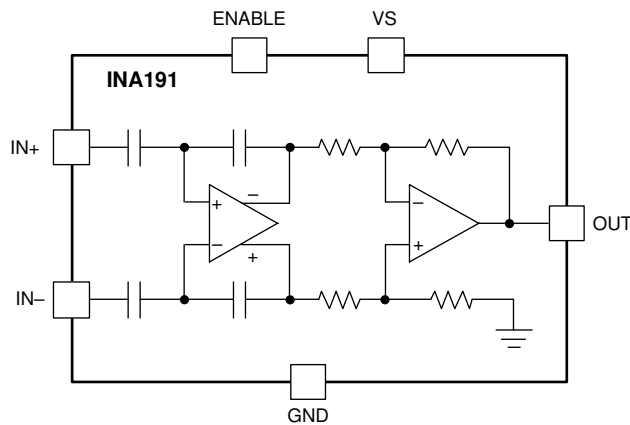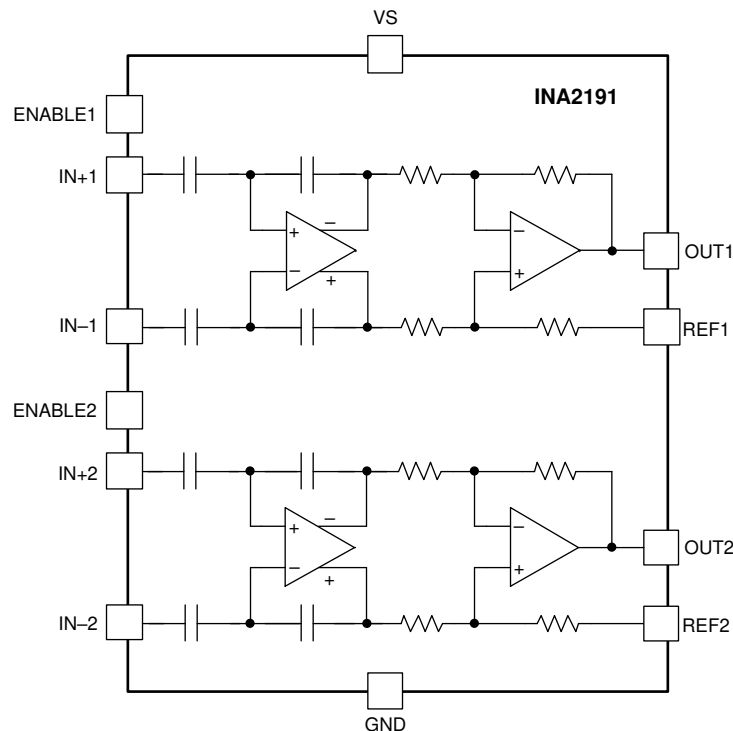
7.3 Feature Description

7.3.1 Precision Current Measurement

The INAx191 provides accurate current measurements over a wide dynamic range. The high accuracy of the device is attributable to the low gain error and offset specifications. The offset voltage of the INAx191 is less than 12 µV. In this case, the low offset improves the accuracy at light loads when V_{IN+} approaches V_{IN-}.

Another advantage of low offset is the ability to use a lower-value shunt resistor that reduces the power loss in the current-sense circuit, and improves the power efficiency of the end application.

The maximum gain error of the INAx191 is specified to be within 0.25% for most gain options. As the sensed voltage becomes much larger than the offset voltage, the gain error becomes the dominant source of error in the current-sense measurement. When the device monitors currents near the full-scale output range, the total measurement error approaches the value of the gain error.

7.3.2 Low Input Bias Current

The INAx191 is different from many current-sense amplifiers because this device offers very low input bias current. The low input bias current of the INAx191 has three primary benefits.

The first benefit is the reduction of the current consumed by the device in both the enabled and disabled states. Classical current-sense amplifier topologies typically consume tens of microamps of current at the inputs. For these amplifiers, the input current is the result of the resistor network that sets the gain and additional current to bias the input amplifier. To reduce the bias current to near zero, the INAx191 uses a capacitively coupled amplifier on the input stage, followed by a difference amplifier on the output stage.

The second benefit of low bias current is the ability to use input filters to reject high-frequency noise before the signal is amplified. In a traditional current-sense amplifier, the addition of input filters comes at the cost of reduced accuracy. However, as a result of the low bias currents, input filters have little effect on the measurement accuracy of the INAx191.

The third benefit of low bias current is the ability to use a larger current-sense resistor. This ability allows the device to accurately monitor currents as low as 1 µA.

7.3.3 Low Quiescent Current With Output Enable

The device features low quiescent current (I_Q), while still providing sufficient small-signal bandwidth to be usable in most applications. The quiescent current of the INA191 is only 43 µA (typical), while providing a small-signal bandwidth of 35 kHz in a gain of 100. The low I_Q and good bandwidth allow the device to be used in many portable electronic systems without excessive drain on the battery. Because many applications only need to periodically monitor current, the INAx191 features an enable pin for each output that turns off the device until needed. When in the disabled state, the INAx191 typically draws 10 nA of total supply current per channel.

7.3.4 Bidirectional Current Monitoring (INA2191 Only)

The INA2191 can sense current flow through a sense resistor in both directions. The bidirectional current-sensing capability is achieved by applying a voltage at the REF pin to offset the desired output voltage. A positive differential voltage sensed at the inputs results in an output voltage that is greater than the applied reference voltage. Likewise, a negative differential voltage at the inputs results in output voltage that is less than the applied reference voltage. The output voltage of the current-sense amplifier is shown in 式 1. Equation variables such as V_{OUT} are valid for either V_{OUT1} or V_{OUT2} depending on which channel used.

$$V_{OUT} = (I_{LOAD} \times R_{SENSE} \times GAIN) + V_{REF} \tag{1}$$

where

- I_{LOAD} is the load current to be monitored.
- R_{SENSE} is the current-sense resistor.
- GAIN is the gain option of the selected device.
- V_{REF} is the voltage applied to the REF pin.

7.3.5 High-Side and Low-Side Current Sensing

The INAx191 supports input common-mode voltages from –0.2 V to +40 V. Because of the internal topology, the common-mode range is not restricted by the power-supply voltage (V_S). The ability to operate with common-mode voltages greater or less than V_S allows the INAx191 to be used in high-side and low-side current-sensing applications, as shown in 図 7-3.
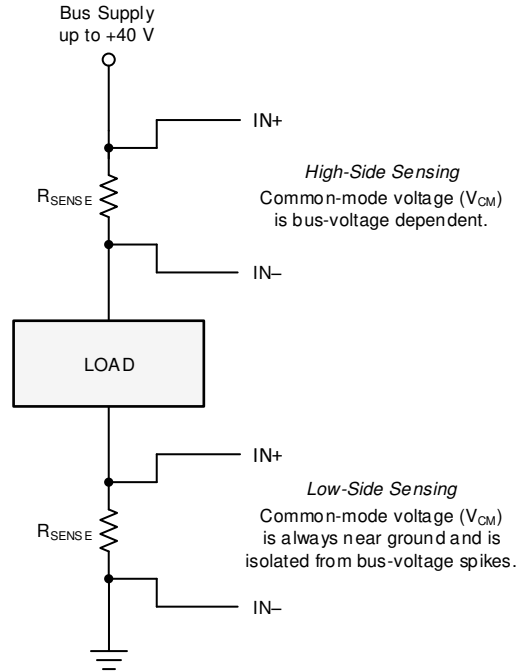
図 7-3. High-Side and Low-Side Sensing Connections

7.3.6 High Common-Mode Rejection

The INAx191 uses a capacitively coupled amplifier on the front end. Therefore, dc common-mode voltages are blocked from downstream circuits, resulting in very high common-mode rejection. The common-mode rejection of the INAx191 is 150 dB (typical). The ability to reject changes in the DC common-mode voltage allows the INAx191 to monitor both high- and low-voltage rail currents with very little change in the offset voltage.

7.3.7 Rail-to-Rail Output Swing

The INAx191 supports linear current-sensing operation with the output close to the supply rail and ground. The maximum specified output swing to the positive rail is V_S – 40 mV, and the maximum specified output swing to GND is only GND + 1 mV with –10 mV of differential overdrive. For cases where the sense current is zero, the swing to ground is determined by the zero current output specification. The value of the zero current output voltage can differ from the specified value depending on the common-mode voltage, supply voltage, and output load. The close-to-rail output swing maximizes the usable output range, particularly when operating the device from a 1.8-V supply.

7.4 Device Functional Modes

7.4.1 Normal Operation

The INAx191 is in normal operation when the following conditions are met:

- The power-supply voltage (V_S) is between 1.7 V and 5.5 V.
- The common-mode voltage (V_{CM}) is within the specified range of –0.2 V to +40 V.
- The maximum differential input signal times the gain plus V_{REF} is less than the positive output voltage swing V_{SP}. V_{REF} = 0 V for INA191.
- The ENABLE pin is driven or connected to V_S.
- The minimum differential input signal times the gain plus V_{REF} is greater than the swing to GND, V_{ZL} (see セクション 7.3.7). V_{REF} = 0 V for INA191.

During normal operation, this device produces an output voltage that is the *amplified* representation of the difference voltage from IN+ to IN– plus the voltage applied to the REF pin. For devices without a REF pin the REF voltage is 0 V.

7.4.2 Unidirectional Mode

The INA191 always monitors current flow in a single direction, however, the INA2191 can be configured to monitor current flowing in one direction (unidirectional) or in both directions (bidirectional) depending on how the REF pin is connected. The most common case is unidirectional where the output is set to ground when no current is flowing by connecting the REF pin to ground, as shown in 図 7-4. When the current flows from the bus supply to the load, the input voltage from IN+ to IN– increases and causes the output voltage at the OUT pin to increase. Pin names such as OUT apply to either OUT1 or OUT2 in the diagrams below depending on which channel is used.
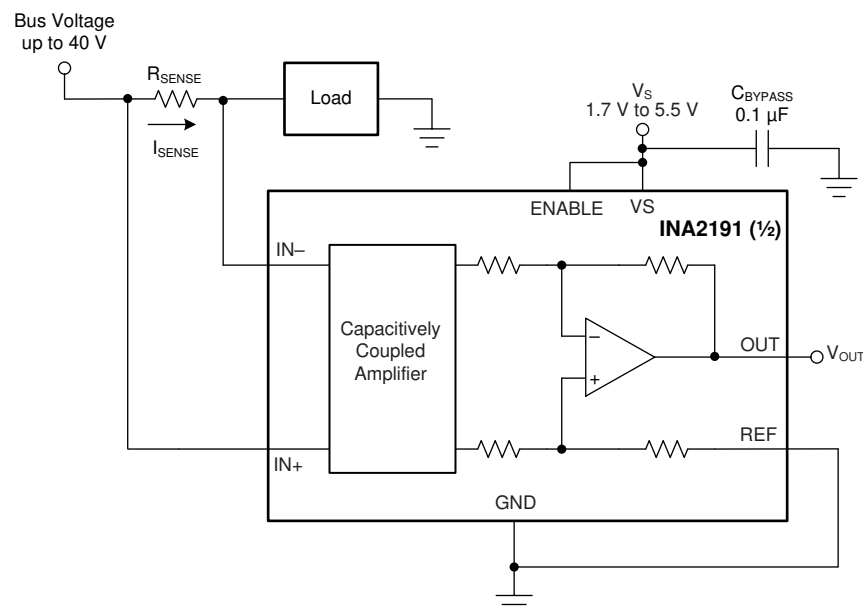
図 7-4. Typical Unidirectional Application

The linear range of the output stage is limited by how close the output voltage can approach ground under zero input conditions. The zero current output voltage of the INA2191 is very small and for most unidirectional applications the REF pin is simply grounded. However, if the measured current multiplied by the current sense resistor and device gain is less than the zero current output voltage then bias the REF pin to a convenient value above the zero current output voltage to get the output into the linear range of the device. To limit reference rejection errors, buffer the reference voltage connected to the REF pin.

A less-frequently used output biasing method is to connect the REF pin to the power-supply voltage, V_S. This method results in the output voltage saturating at 40 mV less than the supply voltage when no differential input

voltage is present. This method is similar to the output saturated low condition with no differential input voltage when the REF pin is connected to ground. The output voltage in this configuration only responds to currents that develop negative differential input voltage relative to the device IN– pin. Under these conditions, when the negative differential input signal increases, the output voltage moves downward from the saturated supply voltage. The voltage applied to the REF pin must not exceed V_S.

Another use for the REF pin in unidirectional operation is to level shift the output voltage. 図 7-5 shows an application where the device ground is set to a negative voltage so currents biased to negative supplies, as seen in optical networking cards, can be measured. The GND of the INA2191 can be set to negative voltages, as long as the inputs do not violate the common-mode range specification and the voltage difference between VS and GND does not exceed 5.5 V. In this example, the output of the INA2191 is fed into a positive-biased ADC. By grounding the REF pin, the voltages at the output will be positive and not damage the ADC. To make sure the output voltage never goes negative, the supply sequencing must be the positive supply first, followed by the negative supply.
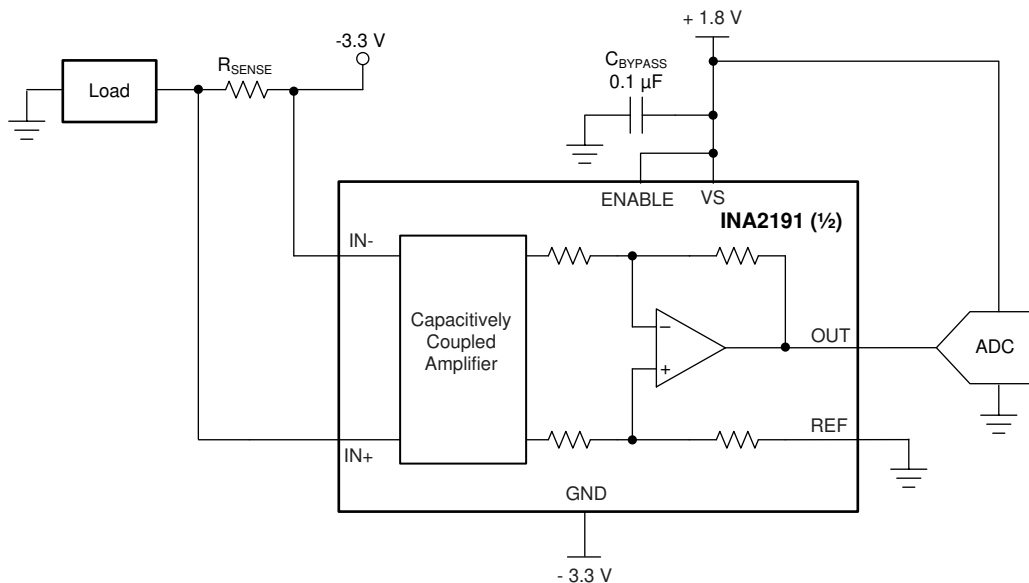

図 7-5. Using the REF Pin to Level-Shift Output Voltage

Product Folder Links: INA191 INA2191

English Data Sheet: SLYS020

7.4.3 Bidirectional Mode (INA2191 Only)

The INA2191 is a dual channel bidirectional current-sense amplifier capable of measuring currents through a resistive shunt in two directions. This bidirectional monitoring is common in applications that include charging and discharging operations where the current flowing through the resistor can change directions.
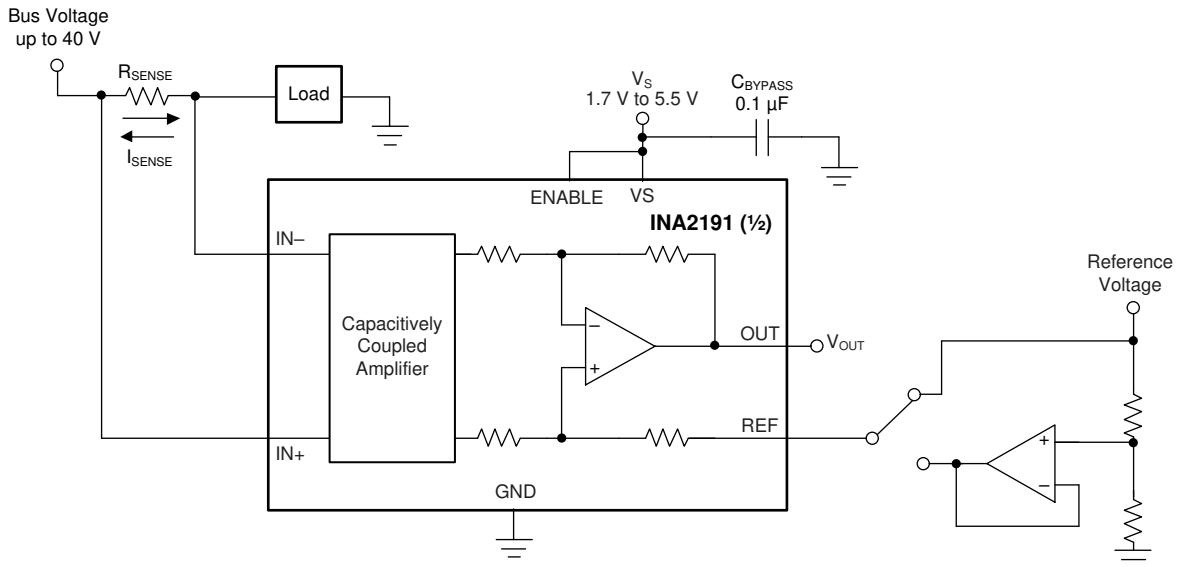
図 7-6. Bidirectional Application

The ability to measure this current flowing in both directions is achieved by applying a voltage to the REF pin, as shown in 図 7-6. The voltage applied to REF (V_{REF}) sets the output state that corresponds to the zero-input level state. The output then responds by increasing above V_{REF} for positive differential signals (relative to the IN– pin) and responds by decreasing below V_{REF} for negative differential signals. This reference voltage applied to the REF pin can be set anywhere between 0 V to V_S. For bidirectional applications, V_{REF} is typically set at $V_S/2$ for equal signal range in both current directions. In some cases, V_{REF} is set at a voltage other than $V_S/2$, like when the bidirectional current and corresponding output signal do not need to be symmetrical.

7.4.4 Input Differential Overload

If the differential input voltage ($V_{IN+} - V_{IN-}$) times gain (plus V_{REF} for INA2191) exceeds the voltage swing specification, the INAx191 drives the output as close as possible to the positive supply or ground, and does not provide accurate measurement of the differential input voltage. If this input overload occurs during normal circuit operation, then reduce the value of the shunt resistor or use a lower-gain version with the chosen sense resistor to avoid this mode of operation. If a differential overload occurs in a fault event, then the output of the INAx191 returns to the expected value approximately 40 µs after the fault condition is removed. When the differential voltage exceeds approximately 300 mV, the differential input impedance reduces to 3.3 kΩ, and results in a rapid increase in bias currents as the differential voltage increases. A 3.3-kΩ resistance exists between IN+ and IN– during a differential overload condition; therefore, currents flowing into the IN+ pin flow out of the IN– pin. An increase in bias currents during a input differential overload occurs even with the device is powered down. Input differential overloads less than the absolute maximum voltage rating do not damage the device or result in an output inversion.

7.4.5 Shutdown

The INAx191 features an active-high ENABLE pin(s) that shuts down the device when pulled to ground. When the device is shut down, the quiescent current is reduced to 10 nA per channel (typical), the input bias currents are further reduced, and the disabled output goes to a high-impedance state. When disabled, the low quiescent and input currents extend the battery lifetime when the current measurement is not needed. When the ENABLE pin is driven above the enable threshold voltage, the device turns back on. When enabled, the typical output settling time is 130 µs.

The output of the INAx191 goes to a high-impedance state when disabled; therefore, it is possible to connect multiple outputs of the INAx191 together to a single ADC or measurement device, as shown in 図 7-7. When connected in this way, enable only one INAx191 at a time, and make sure both devices have the same supply voltage. Using the INA2191 with the same approach as shown in 図 7-7 provides the capability to monitor two currents with a single device.
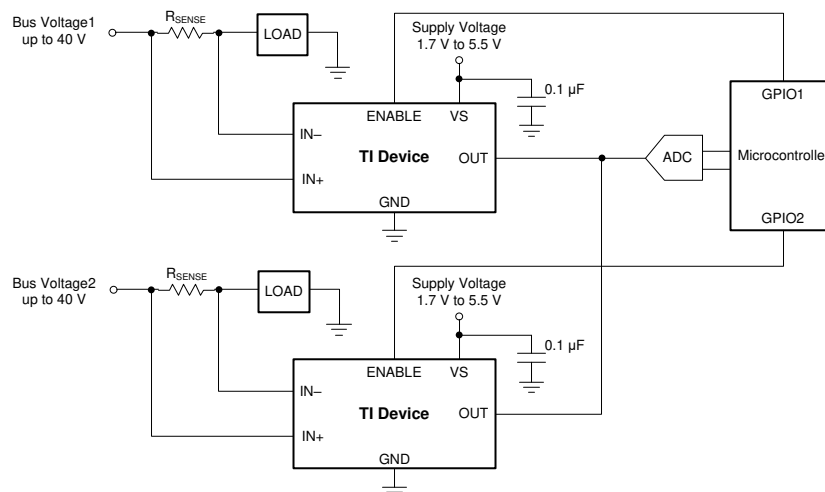
図 7-7. Multiplexing Multiple Devices With the ENABLE Pin

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

8 Application and Implementation

注

以下のアプリケーション情報は、TI の製品仕様に含まれるものではなく、TI ではその正確性または完全性を保証いたしません。個々の目的に対する製品の適合性については、お客様の責任で判断していただくことになります。お客様は自身の設計実装を検証しテストすることで、システムの機能を確認する必要があります。

8.1 Application Information

The INAx191 amplifies the voltage developed across a current-sensing resistor as current flows through the resistor to the load or ground.

8.1.1 Basic Connections

図 8-1 shows the basic connections of the INAx191. Connect the input pins (IN+ and IN−) as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistor. The ENABLE pin must be controlled externally or connected to VS if not used.
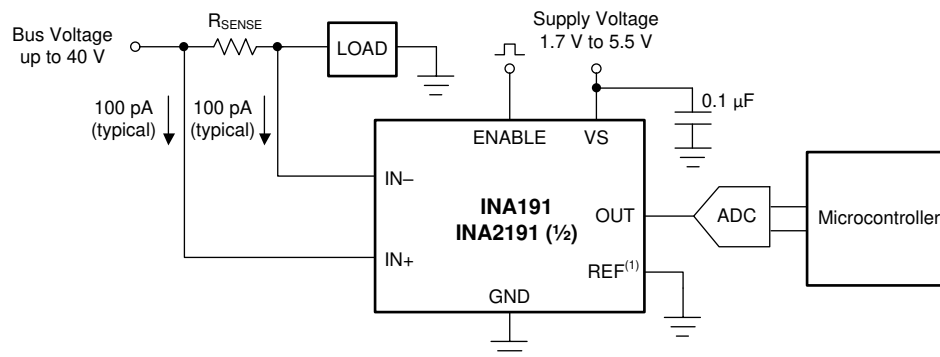
(1) REF pin only available on INA2191

図 8-1. Basic Connections for the INAx191

A power-supply bypass capacitor of at least 0.1 µF is required for proper operation. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

8.1.2 R_{SENSE} and Device Gain Selection

The accuracy of any current-sense amplifier is maximized by choosing the current-sense resistor to be as large as possible. A large sense resistor maximizes the differential input signal for a given amount of current flow and reduces the error contribution of the offset voltage. However, there are practical limits as to how large the current-sense resistor can be in a given application because of the resistor size and maximum allowable power dissipation. 式 2 gives the maximum value for the current-sense resistor for a given power dissipation budget:

$$R_{SENSE} < \frac{PD_{MAX}}{I_{MAX}^2}$$

(2)

where:

- PD_{MAX} is the maximum allowable power dissipation in R_{SENSE}.
- I_{MAX} is the maximum current that flows through R_{SENSE}.

An additional limitation on the size of the current-sense resistor and device gain is due to the power-supply voltage, V_S, and device swing-to-rail limitations. In order to make sure that the current-sense signal is properly passed to the output, both positive and negative output swing limitations must be examined. 式 3 provides the maximum values of R_{SENSE} and GAIN to keep the device from hitting the positive swing limitation.

$$I_{MAX} \times R_{SENSE} \times GAIN < V_{SP} - V_{REF}$$

(3)

where:

- I_{MAX} is the maximum current that flows through R_{SENSE}.
- GAIN is the gain of the current-sense amplifier.
- V_{SP} is the positive output swing as specified in the data sheet.
- V_{REF} is the reference input. This is node is internally grounded for the INA191 and a value of 0 V should be used for that device.

To avoid positive output swing limitations when selecting the value of R_{SENSE}, there is always a trade-off between the value of the sense resistor and the gain of the device under consideration. If the sense resistor selected for the maximum power dissipation is too large, then it is possible to select a lower-gain device in order to avoid positive swing limitations.

The zero current output voltage places a limit on how small of a sense resistor can be used in a given application. 式 4 provides the limit on the minimum size of the sense resistor.

$$I_{MIN} \times R_{SENSE} \times GAIN > V_{ZL} - V_{REF}$$

(4)

where:

- I_{MIN} is the minimum current flows through R_{SENSE}.
- GAIN is the gain of the current-sense amplifier.
- V_{ZL} is the zero current output voltage of the device (see the セクション 7.3.7 section for more information).
- V_{REF} is the reference input. This node is internally grounded for the INA191 and a value of 0 V should be used for that device.

8.1.3 Signal Conditioning

When performing accurate current measurements in noisy environments, the current-sensing signal is often filtered. The INAx191 features low input bias currents. Therefore, it is possible to add a differential mode filter to the input without sacrificing the current-sense accuracy. Filtering at the input is advantageous because this action attenuates differential noise before the signal is amplified. 図 8-2 provides an example of how to use a filter on the input pins of the device.

$$f_{3dB} = \frac{1}{4\pi R_F C_F}$$
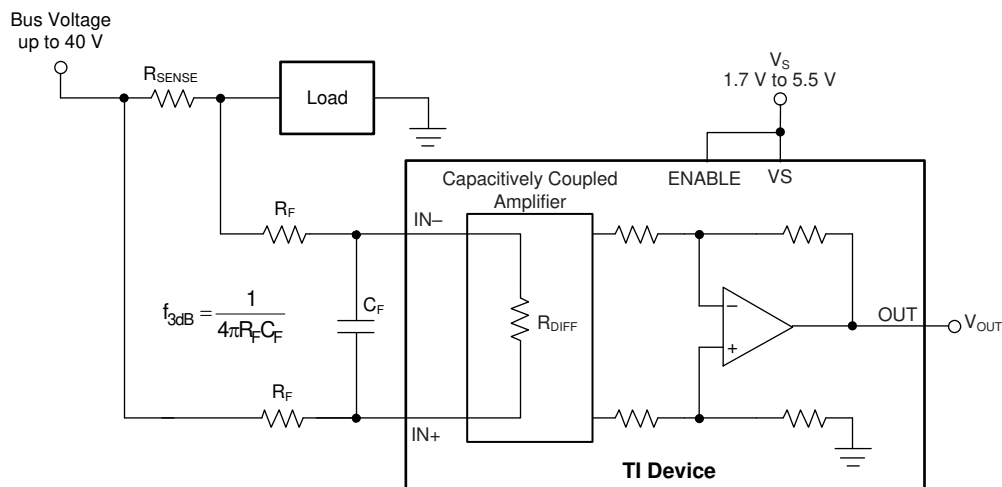
図 8-2. Filter at the Input Pins

The differential input impedance (R_{DIFF}) shown in 図 8-2 limits the maximum value for R_F. The value of R_{DIFF} is a function of the device temperature and gain option, as shown in 図 8-3.
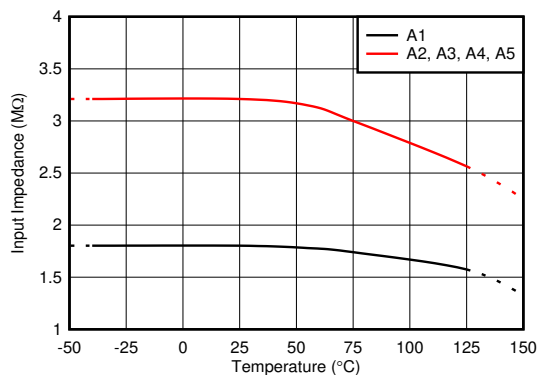
図 8-3. Differential Input Impedance vs. Temperature

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

As the voltage drop across the sense resistor (V_{SENSE}) increases, the amount of voltage dropped across the input filter resistors (R_F) also increases. The increased voltage drop results in additional gain error. The error caused by these resistors is calculated by the resistor divider equation shown in 式 5.

$$Error(\%) = \left(1 - \frac{R_{DIFF}}{R_{SENSE} + R_{DIFF} + (2 \times R_F)}\right) \times 100$$

(5)

where:

- R_{SENSE} is the current sense resistor, as defined in 式 2.
- R_{DIFF} is the differential input impedance.
- R_F is the added value of the series filter resistance.

The input stage of the INAx191 uses a capacitive feedback amplifier topology in order to achieve high DC precision. As a result, periodic high-frequency shunt voltage (or current) transients of significant amplitude (10 mV or greater) and duration (hundreds of nanoseconds or greater) may be amplified by the INAx191, even though the transients are greater than the device bandwidth. Use a differential input filter in these applications to minimize disturbances at the INAx191 output.

The high input impedance and low bias current of the INAx191 provides flexibility in the input filter design without impacting the accuracy of current measurement. For example, set R_F = 100 Ω and C_F = 22 nF to achieve a low-pass filter corner frequency of 36.2 kHz. These filter values significantly attenuate most unwanted high-frequency signals at the input without severely impacting the current-sensing bandwidth or precision. If a lower corner frequency is desired, increase the value of C_F.

Filtering at the input reduces differential noise across the sense resistor. If high-frequency, common-mode noise is a concern, add an RC filter from the OUT pin to ground. The RC filter helps filter out both differential and common mode noise, as well as internally generated noise from the device. The value for the resistance of the RC filter is limited by the impedance of the output load. Any current drawn by the load manifests as an external voltage drop from the INAx191 OUT pin to the load input. To select the optimal values for the output filter when driving SAR ADCs or other dynamic loads, use 図 6-41 and see the *Closed-Loop Analysis of Load-Induced Amplifier Stability Issues Using ZOUT Application Report*

8.1.4 Common-Mode Voltage Transients

With a small amount of additional circuitry, the INAx191 can be used in circuits subject to transients that exceed the absolute maximum voltage ratings. The most simple way to protect the inputs from negative transients is to add resistors in series to the IN– and IN+ pins. Use resistors that are 1 kΩ or less, and limit the current in the ESD structures to less than 5 mA. For example, using 1-kΩ resistors in series with the INAx191 allows voltages as low as –5 V, while limiting the ESD current to less than 5 mA. If protection from high-voltage or more-negative, common-voltage transients is needed, use the circuits shown in 図 8-4 and 図 8-5. When implementing these circuits, use only Zener diodes or Zener-type transient absorbers (sometimes referred to as *transzorbs*); any other type of transient absorber has an unacceptable time delay. Start by adding a pair of resistors as a working impedance for the Zener diode, as shown in 図 8-4. Keep these resistors as small as possible; most often, use around 100 Ω. Larger values can be used with an effect on gain that is discussed in セクション 8.1.3. This circuit limits only short-term transients; therefore, many applications are satisfied with a 100-Ω resistor along with conventional Zener diodes of the lowest acceptable power rating. This combination uses the least amount of board space. These diodes can be found in packages as small as SOT-523 or SOD-523.
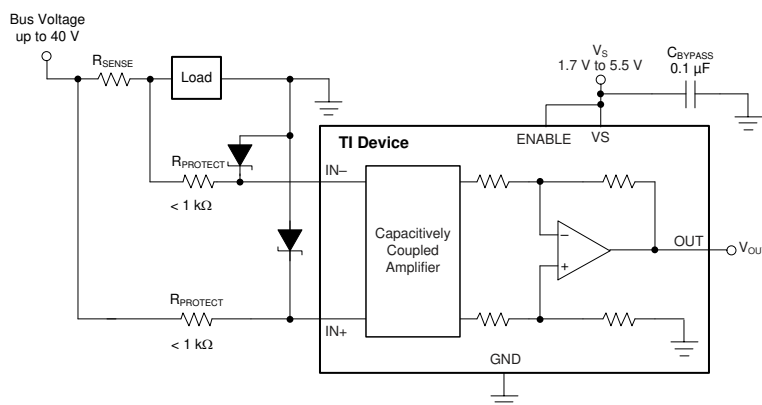
図 8-4. Transient Protection Using Dual Zener Diodes

In the event that low-power Zener diodes do not have sufficient transient absorption capability, a higher-power transzorb must be used. The most package-efficient solution involves using a single transzorb and back-to-back diodes between the device inputs, as shown in 図 8-5. The most space-efficient solutions are dual, series-connected diodes in a single SOT-523 or SOD-523 package. In either of the examples shown in 図 8-4 and 図 8-5, the total board area required by the INA191 with all protective components is less than that of an SO-8 package, and only slightly greater than that of an VSSOP-8 package.
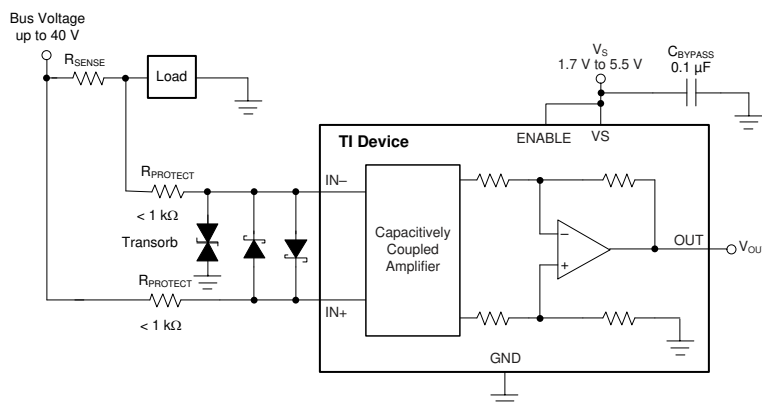
図 8-5. Transient Protection Using a Single Transzorb and Input Clamps

For more information, see *Current Shunt Monitor With Transient Robustness Reference Design*.

8.2 Typical Application

8.2.1 Microamp Current Measurement

The low input bias current of the INAx191 provides accurate monitoring of small-value currents. To accurately monitor currents in the microamp range, increase the value of the sense resistor to increase the sense voltage so that the error introduced by the offset voltage is small. The circuit configuration to monitor low-value currents is shown in 図 8-6. As a result of the differential input impedance of the INAx191, limit the value of R_{SENSE} to 1 kΩ or less for best accuracy.

(1) REF pin only available on INA2191
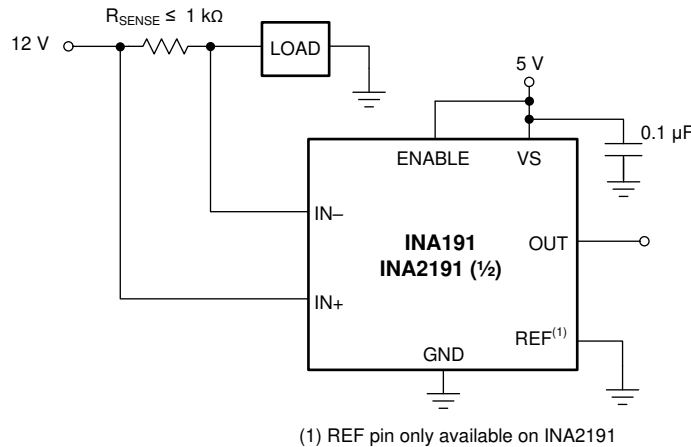
図 8-6. Measuring Microamp Currents

8.2.1.1 Design Requirements

The design requirements for the circuit shown in 図 8-6, are listed in 表 8-1

表 8-1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Power-supply voltage (V_S)	5 V
Bus supply rail (V_{CM})	12 V
Minimum sense current (I_{MIN})	1 µA
Maximum sense current (I_{MAX})	150 µA
Device gain (GAIN)	25 V/V
Unidirectional Application	$V_{REF} = 0$ V

8.2.1.2 Detailed Design Procedure

The maximum value of the current-sense resistor is calculated based on choice of gain, value of the maximum current the be sensed (I_{MAX}), and the power supply voltage (V_S). When operating at the maximum current, the output voltage must not exceed the positive output swing specification, V_{SP}. For the given design parameters, the maximum value for R_{SENSE} calculated in 式 6 is 1.321 kΩ.

$$R_{SENSE} < \frac{V_{SP}}{I_{MAX} \times GAIN} \tag{6}$$

However, because this value exceeds the maximum recommended value for R_{SENSE}, a resistance value of 1 kΩ must be used. When operating at the minimum current value, I_{MIN} the output voltage must be greater than the swing to GND (V_{SN}), specification. For this example, the output voltage at the minimum current (V_{OUTMIN}) calculated in 式 7 is 25 mV, which is greater than the value for V_{SN}.

$$V_{OUTMIN} = I_{MIN} \times R_{SENSE} \times GAIN \tag{7}$$

8.2.1.3 Application Curve

図 8-7 shows the output of the device when disabled and enabled while measuring a 40-µA load current. When disabled, the current draw from the device supply and inputs is less than 106 nA.
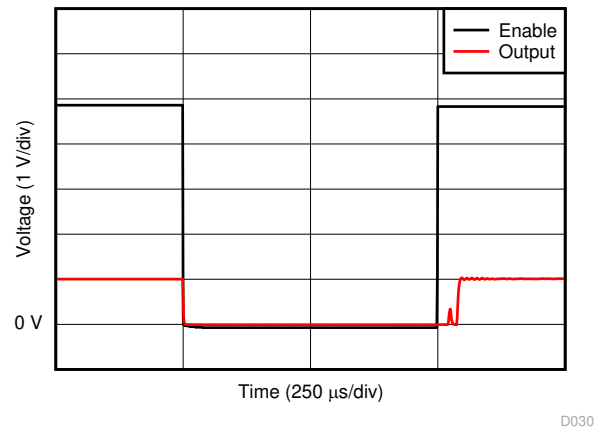
図 8-7. Output Disable and Enable Response

9 Power Supply Recommendations

The input circuitry of the INAx191 accurately measures beyond the power-supply voltage, V_S. For example, V_S can be 5 V, whereas the bus supply voltage at IN+ and IN– can be as high as 40 V. However, the output voltage range of the OUT pin is limited by the voltage on the VS pin. The INAx191 also withstands the full differential input signal range up to 40 V at the IN+ and IN– input pins, regardless of whether or not the device has power applied at the VS pin. There is no sequencing requirement for V_S and V_{IN+} or V_{IN-}.

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

10 Layout

10.1 Layout Guidelines

- Connect the input pins to the sensing resistor using a Kelvin or 4-wire connection. This connection technique makes sure that only the current-sensing resistor impedance is detected between the input pins. Poor routing of the current-sensing resistor commonly results in additional resistance present between the input pins. Given the very low ohmic value of the current resistor, any additional high-current carrying impedance can cause significant measurement errors.
- Place the power-supply bypass capacitor as close as possible to the device power supply and ground pins. The recommended value of this bypass capacitor is 0.1 μF. To compensate for noisy or high-impedance power supplies, add more decoupling capacitance.
- When routing the connections from the current-sense resistor to the device, keep the trace lengths as short as possible. Place input filter capacitor C_F as close as possible to the input pins of the device.

10.2 Layout Examples
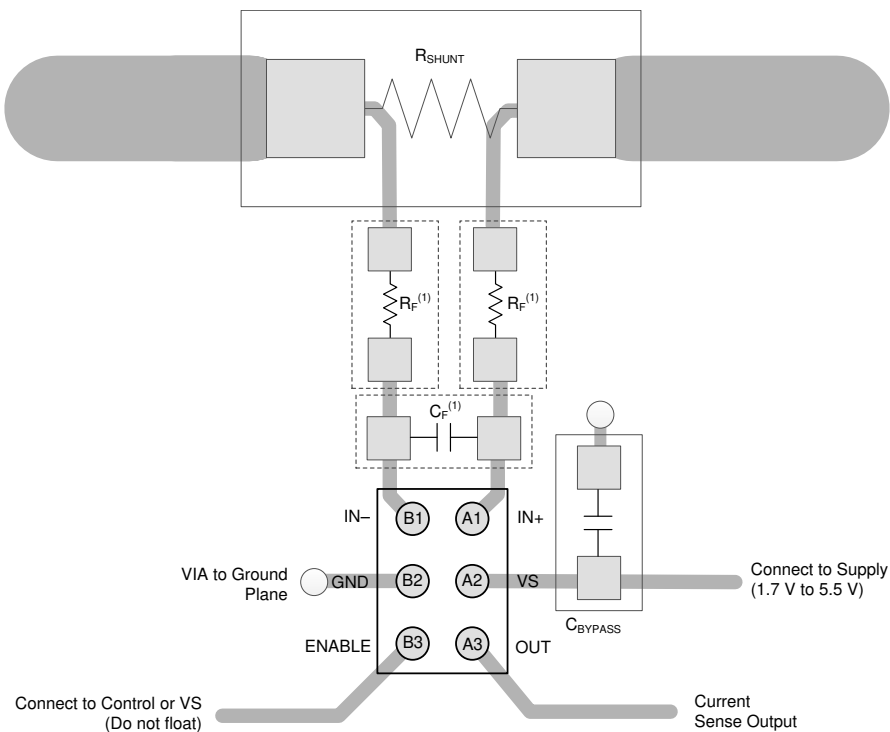
図 10-1. Recommended Layout DSBGA (YFD) Package
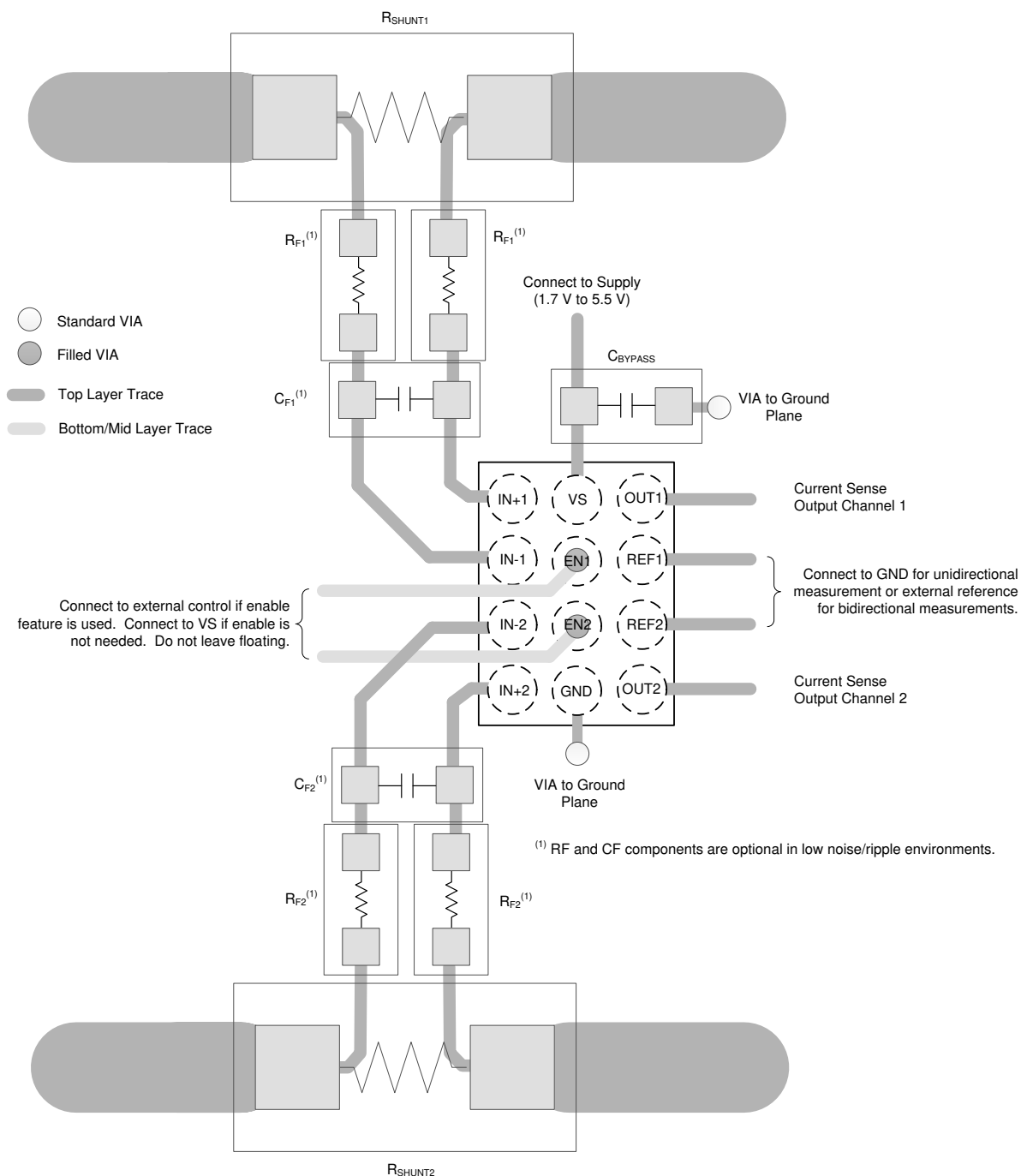
図 10-2. Recommended Layout Dual Channel DSBGA (YBJ) Package

Product Folder Links: *INA191 INA2191*

English Data Sheet: *SLYS020*

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

Texas Instruments, *INA191EVM* user's guide

11.2 ドキュメントの更新通知を受け取る方法

ドキュメントの更新についての通知を受け取るには、ti.com のデバイス製品フォルダを開いてください。「更新の通知を受け取る」をクリックして登録すると、変更されたすべての製品情報に関するダイジェストを毎週受け取れます。変更の詳細については、修正されたドキュメントに含まれている改訂履歴をご覧ください。

11.3 サポート・リソース

TI E2E™ サポート・フォーラムは、エンジニアが検証済みの回答と設計に関するヒントをエキスパートから迅速かつ直接得ることができる場所です。既存の回答を検索したり、独自の質問をしたりすることで、設計で必要な支援を迅速に得ることができます。

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11.5 静電気放電に関する注意事項

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ESD による破損は、わずかな性能低下からデバイスの完全な故障まで多岐にわたります。精密な IC の場合、パラメータがわずかに変化するだけで公表されている仕様から外れる可能性があるため、破損が発生しやすくなっています。

11.6 用語集

テキサス・インスツルメンツ用語集　　この用語集には、用語や略語の一覧および定義が記載されています。

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.
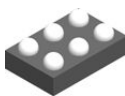
YFD0006-C02

PACKAGE OUTLINE

DSBGA - 0.4 mm max height
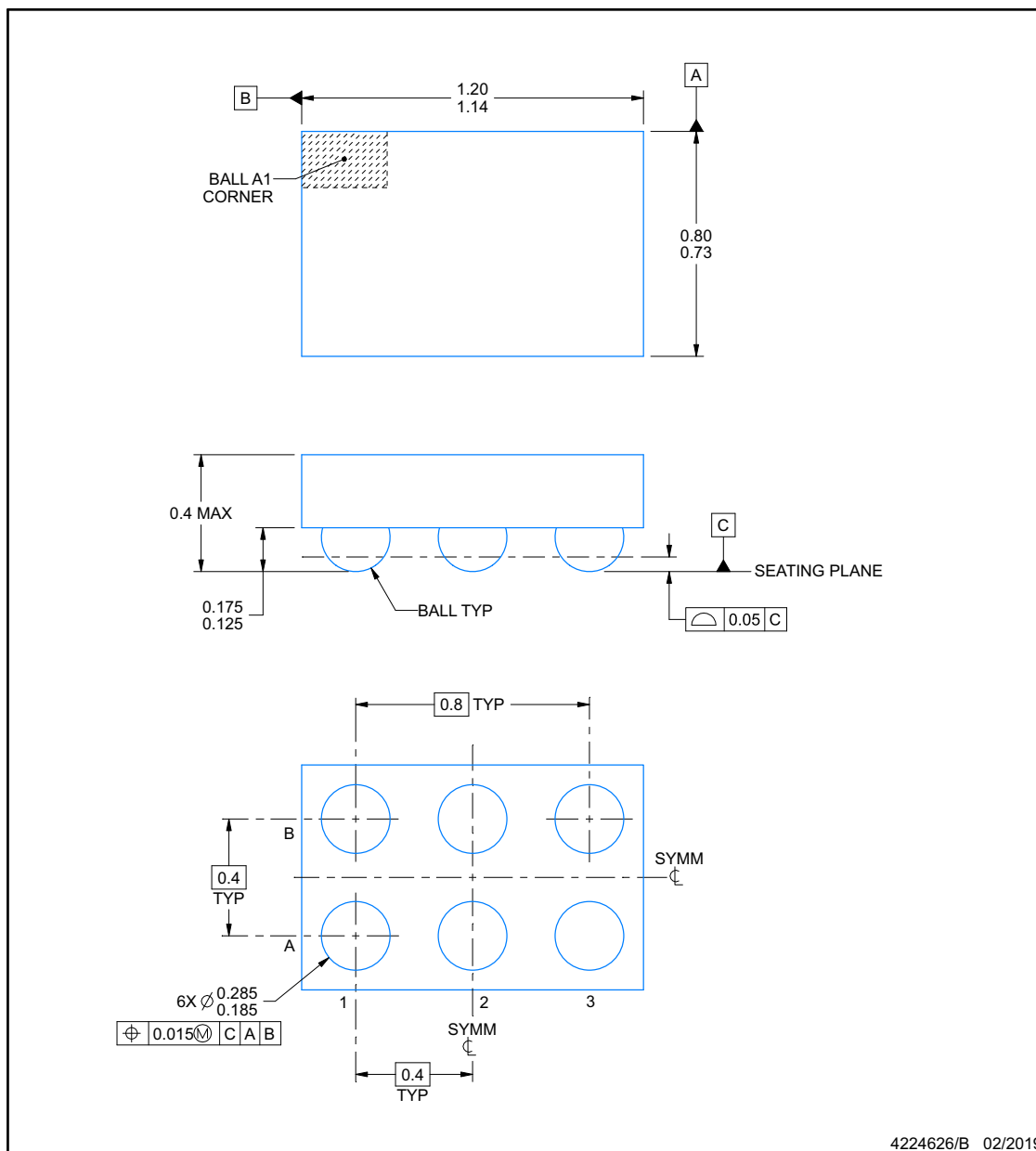
DIE SIZE BALL GRID ARRAY

4224626/B   02/2019

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.

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Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

EXAMPLE BOARD LAYOUT

YFD0006-C02

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY

LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:50X

SOLDER MASK DETAILS
NOT TO SCALE

4224626/B 02/2019

NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints.
   Refer to Texas Instruments Literature No. SNVA009 (www.ti.com/lit/snva009).

TEXAS INSTRUMENTS

www.ti.com

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

EXAMPLE STENCIL DESIGN

YFD0006-C02

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY

SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE:50X

4224626/B   02/2019

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

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Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

PACKAGE OUTLINE

YBJ0012-C01

DSBGA - 0.35 mm max height

DIE SIZE BALL GRID ARRAY
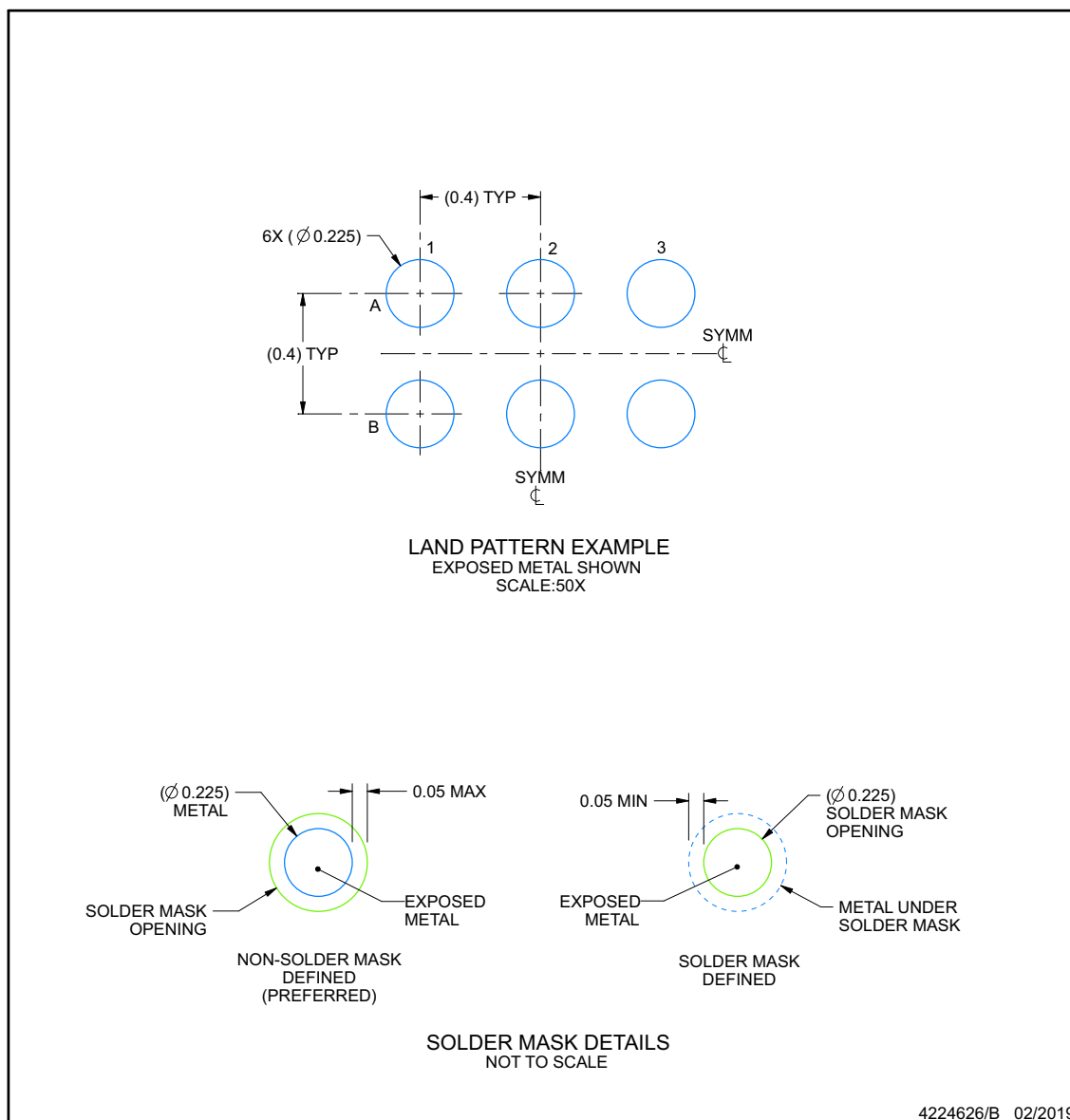

4229771/A   06/2023

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.

TEXAS INSTRUMENTS
www.ti.com

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

EXAMPLE BOARD LAYOUT

YBJ0012-C01

DSBGA - 0.35 mm max height
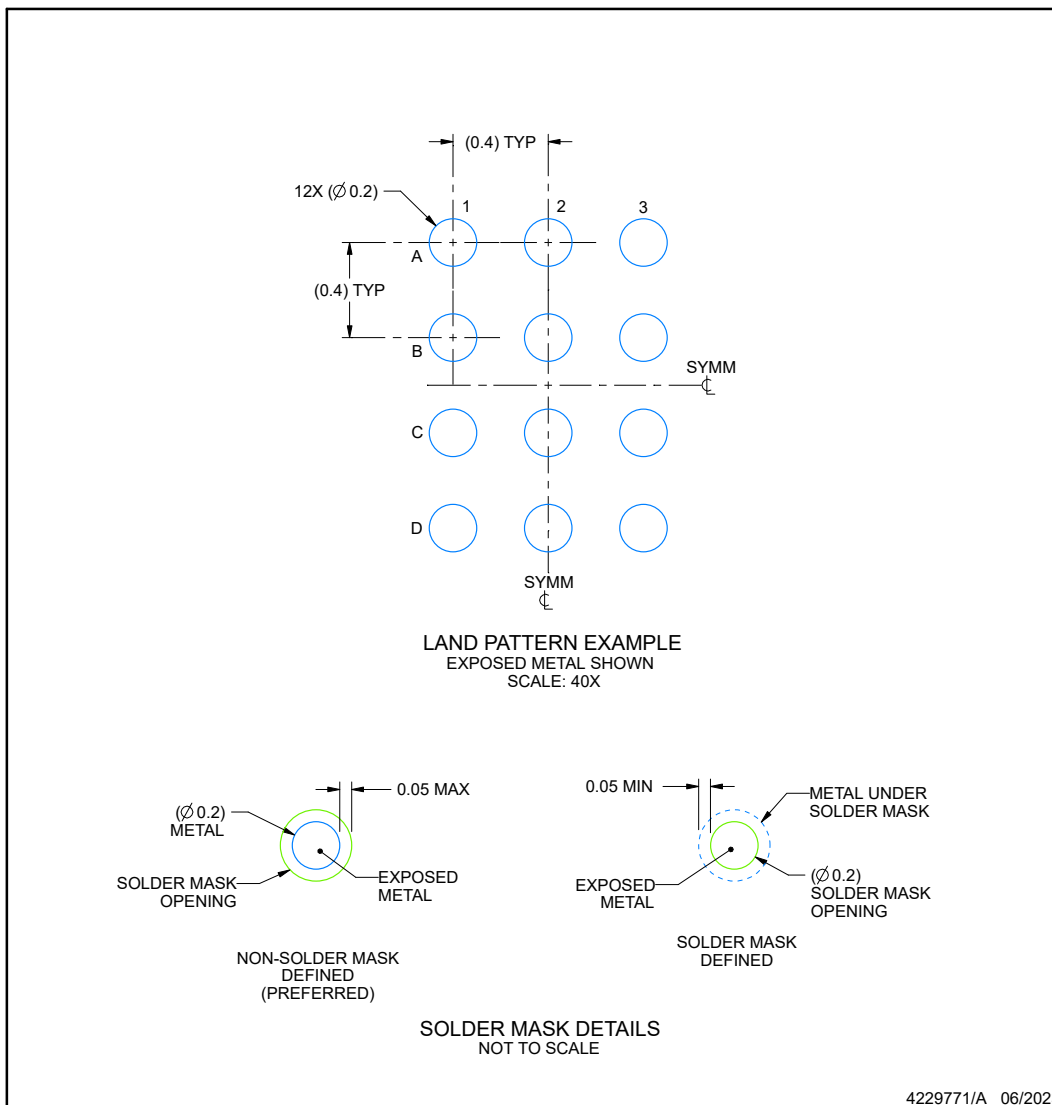
DIE SIZE BALL GRID ARRAY

LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 40X

SOLDER MASK DETAILS
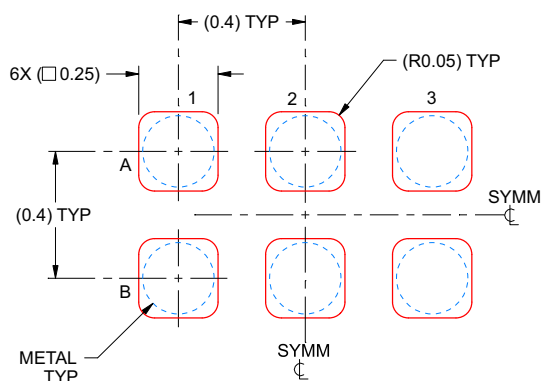NOT TO SCALE

4229771/A   06/2023

NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints.
   See Texas Instruments Literature No. SNVA009 (www.ti.com/lit/snva009).

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Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

EXAMPLE STENCIL DESIGN

YBJ0012-C01

DSBGA - 0.35 mm max height
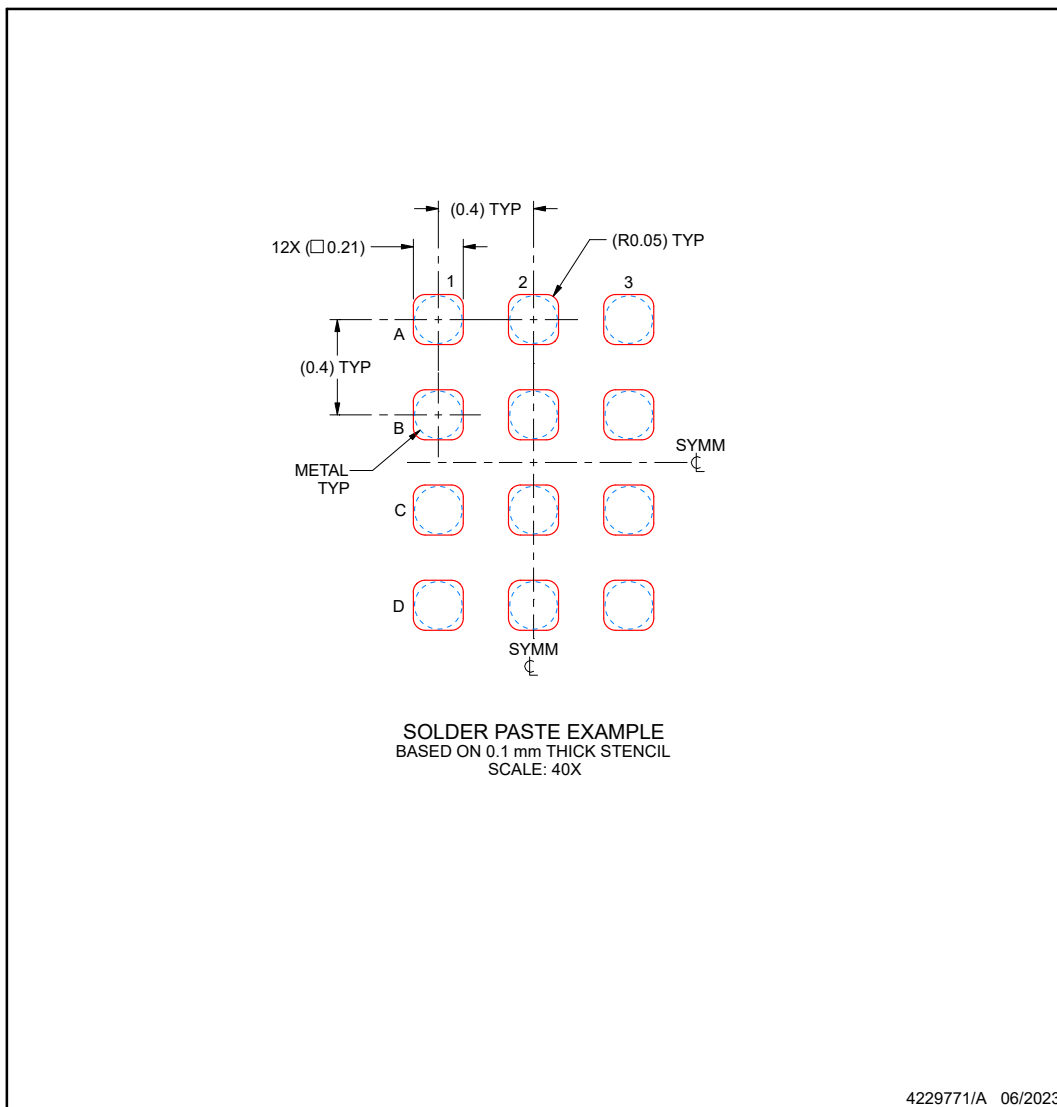
DIE SIZE BALL GRID ARRAY

(0.4) TYP

12X (□0.21)

(R0.05) TYP

(0.4) TYP

METAL
TYP

SYMM ₵

SYMM ₵
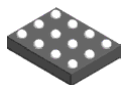
SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE: 40X

4229771/A   06/2023

NOTES: (continued)

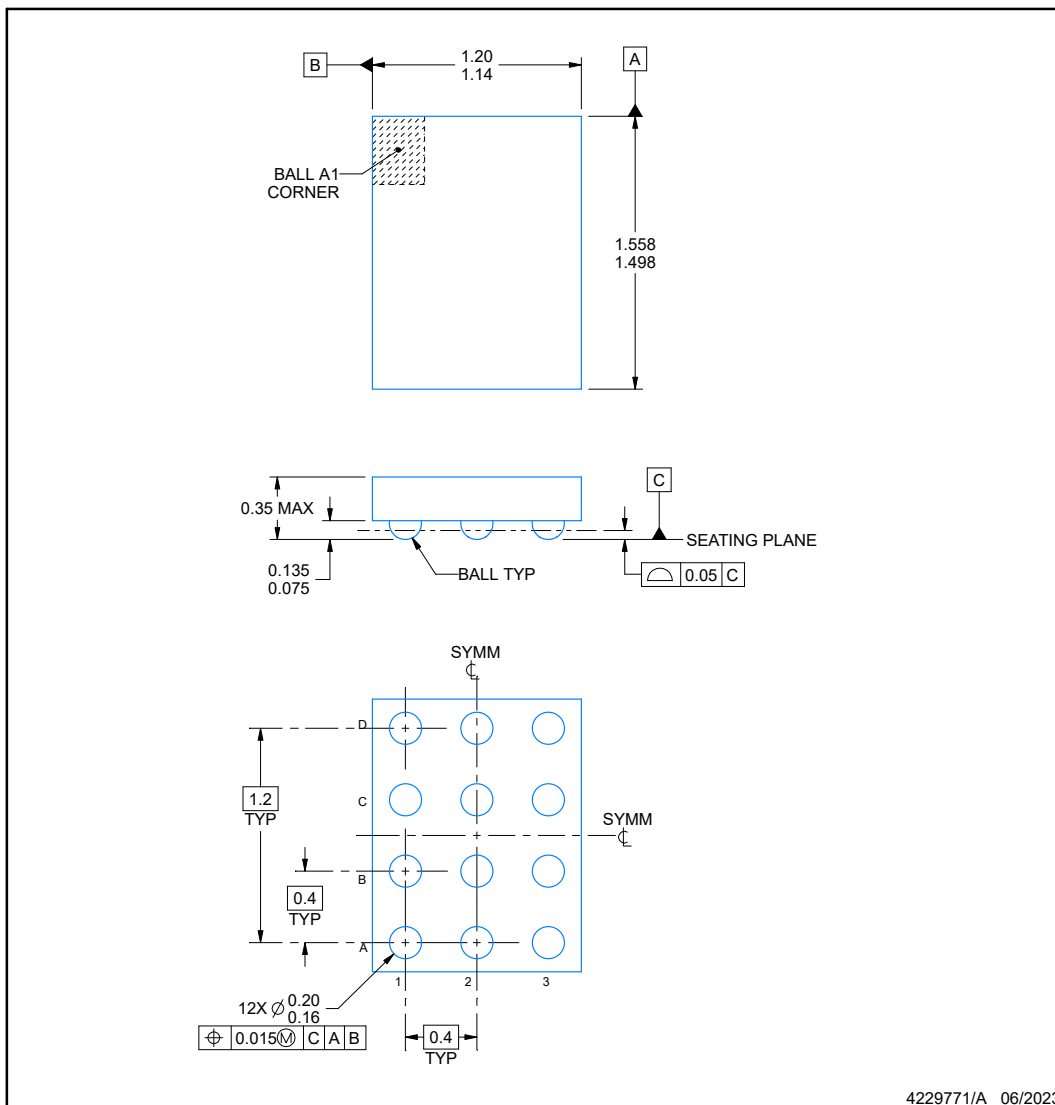4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

Product Folder Links: *INA191 INA2191*

English Data Sheet: SLYS020

PACKAGE OPTION ADDENDUM

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
INA191A1IYFDR	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E3
INA191A1IYFDR.A	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E3
INA191A2IYFDR	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E2
INA191A2IYFDR.A	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E2
INA191A3IYFDR	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E4
INA191A3IYFDR.A	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E4
INA191A4IYFDR	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E5
INA191A4IYFDR.A	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E5
INA191A5IYFDR	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E6
INA191A5IYFDR.A	Active	Production	DSBGA (YFD) | 6	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	1E6
INA2191A1IYBJR	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29J1
INA2191A1IYBJR.A	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29J1
INA2191A2IYBJR	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29K1
INA2191A2IYBJR.A	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29K1
INA2191A3IYBJR	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29L1
INA2191A3IYBJR.A	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29L1
INA2191A4IYBJR	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29M1
INA2191A4IYBJR.A	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29M1
INA2191A5IYBJR	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29N1
INA2191A5IYBJR.A	Active	Production	DSBGA (YBJ) | 12	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	29N1

(1) Status: For more details on status, see our product life cycle.

(2) Material type: When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) RoHS values: Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.
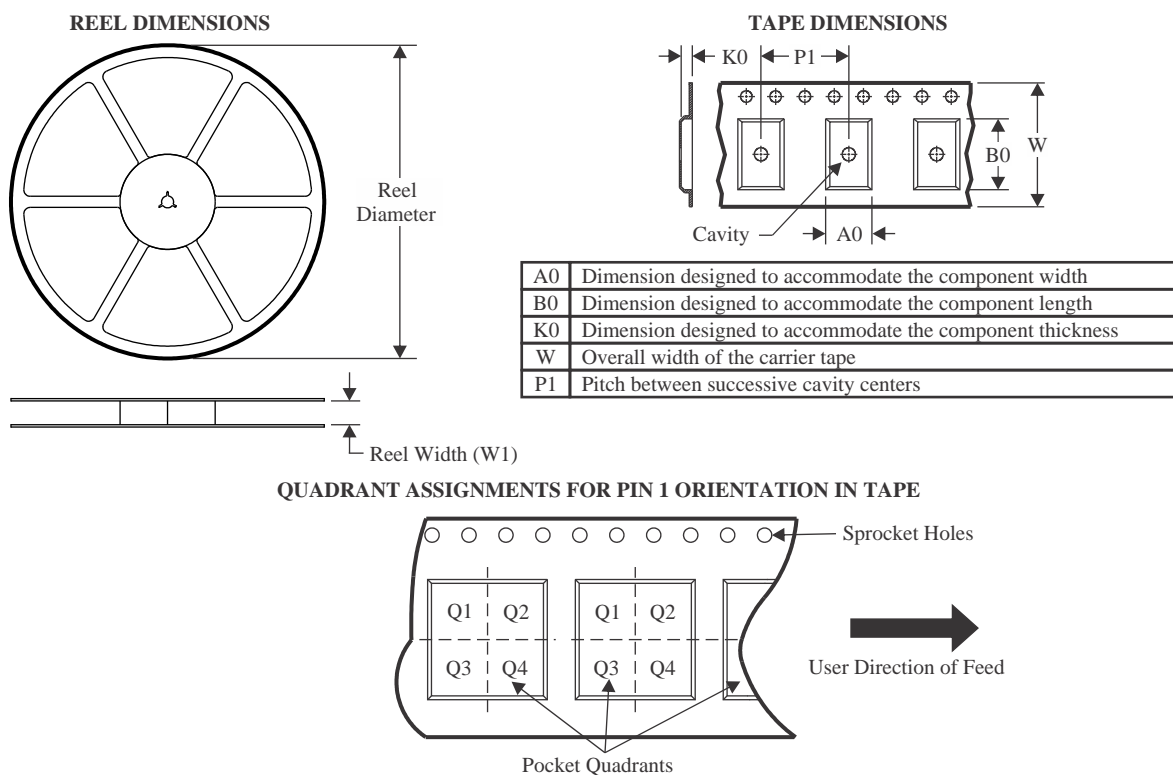
(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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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
INA191A1IYFDR	DSBGA	YFD	6	3000	180.0	8.4	0.84	1.25	0.5	4.0	8.0	Q2
INA191A2IYFDR	DSBGA	YFD	6	3000	180.0	8.4	0.84	1.25	0.5	4.0	8.0	Q2
INA191A2IYFDR	DSBGA	YFD	6	3000	178.0	8.4	0.84	1.27	0.46	4.0	8.0	Q2
INA191A3IYFDR	DSBGA	YFD	6	3000	178.0	8.4	0.84	1.27	0.46	4.0	8.0	Q2
INA191A3IYFDR	DSBGA	YFD	6	3000	180.0	8.4	0.84	1.25	0.5	4.0	8.0	Q2
INA191A4IYFDR	DSBGA	YFD	6	3000	180.0	8.4	0.84	1.25	0.5	4.0	8.0	Q2
INA191A4IYFDR	DSBGA	YFD	6	3000	178.0	8.4	0.84	1.27	0.46	4.0	8.0	Q2
INA191A5IYFDR	DSBGA	YFD	6	3000	178.0	8.4	0.84	1.27	0.46	4.0	8.0	Q2
INA191A5IYFDR	DSBGA	YFD	6	3000	180.0	8.4	0.84	1.25	0.5	4.0	8.0	Q2
INA2191A1IYBJR	DSBGA	YBJ	12	3000	180.0	8.4	1.3	1.66	0.47	4.0	8.0	Q1
INA2191A2IYBJR	DSBGA	YBJ	12	3000	180.0	8.4	1.3	1.66	0.47	4.0	8.0	Q1
INA2191A3IYBJR	DSBGA	YBJ	12	3000	180.0	8.4	1.3	1.66	0.47	4.0	8.0	Q1
INA2191A4IYBJR	DSBGA	YBJ	12	3000	180.0	8.4	1.3	1.66	0.47	4.0	8.0	Q1
INA2191A5IYBJR	DSBGA	YBJ	12	3000	180.0	8.4	1.3	1.66	0.47	4.0	8.0	Q1

![Texas Instruments logo]

PACKAGE MATERIALS INFORMATION

TAPE AND REEL BOX DIMENSIONS
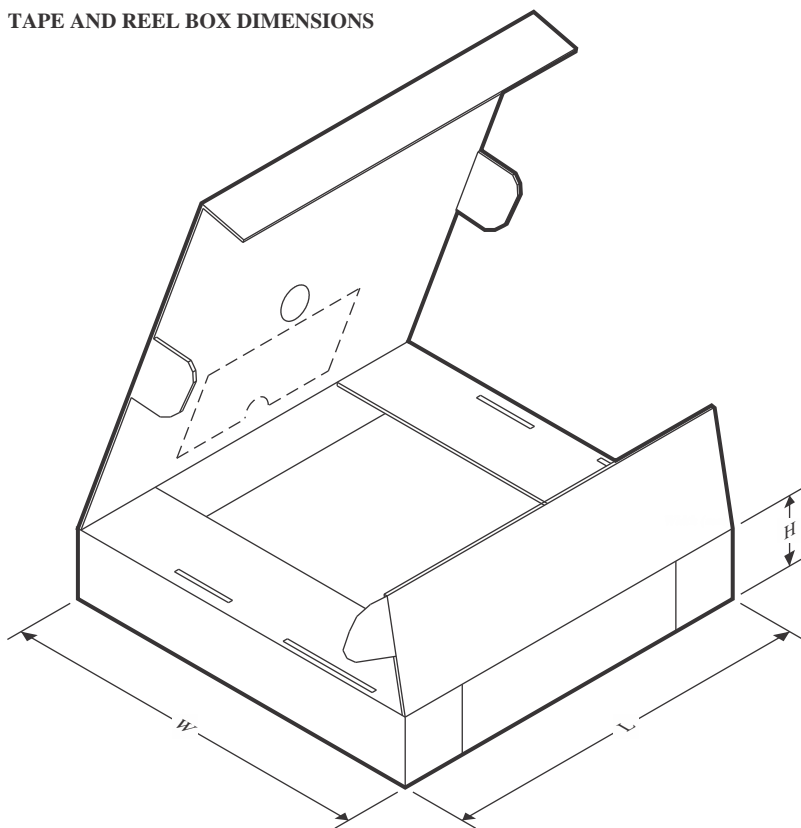
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
INA191A1IYFDR	DSBGA	YFD	6	3000	182.0	182.0	20.0
INA191A2IYFDR	DSBGA	YFD	6	3000	182.0	182.0	20.0
INA191A2IYFDR	DSBGA	YFD	6	3000	220.0	220.0	35.0
INA191A3IYFDR	DSBGA	YFD	6	3000	220.0	220.0	35.0
INA191A3IYFDR	DSBGA	YFD	6	3000	182.0	182.0	20.0
INA191A4IYFDR	DSBGA	YFD	6	3000	182.0	182.0	20.0
INA191A4IYFDR	DSBGA	YFD	6	3000	220.0	220.0	35.0
INA191A5IYFDR	DSBGA	YFD	6	3000	220.0	220.0	35.0
INA191A5IYFDR	DSBGA	YFD	6	3000	182.0	182.0	20.0
INA2191A1IYBJR	DSBGA	YBJ	12	3000	182.0	182.0	20.0
INA2191A2IYBJR	DSBGA	YBJ	12	3000	182.0	182.0	20.0
INA2191A3IYBJR	DSBGA	YBJ	12	3000	182.0	182.0	20.0
INA2191A4IYBJR	DSBGA	YBJ	12	3000	182.0	182.0	20.0
INA2191A5IYBJR	DSBGA	YBJ	12	3000	182.0	182.0	20.0