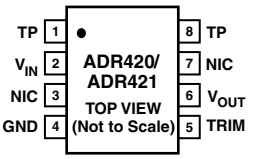
Ultraprecision Low Noise, 2.048 V/2.500 V XFET® Voltage References

ADR420/ADR421

FEATURES
Low Noise 1.75 μV p-p (0.1 Hz to 10 Hz)
Low Temperature Coefficient: 3 ppm/°C
Long-Term Stability: 50 ppm/1000 Hours
Load Regulation: 70 ppm/mA
Line Regulation: 35 ppm/V
Low Hysteresis: 40 ppm Typical
Wide Operating Range
ADR420: 4 V to 18 V
ADR421: 4.5 V to 18 V
Quiescent Current: 0.5 mA Max
High Output Current: 10 mA
Wide Temperature Range: –40°C to +125°C

APPLICATIONS
Precision Data Acquisition Systems
High-Resolution Converters
Battery-Powered Instrumentation
Portable Medical Instruments
Industrial Process Control Systems
Precision Instruments
Optical Network Control Circuits

PIN CONFIGURATION
Surface-Mount Packages
8-Lead SOIC
8-Lead Mini_SOIC



NIC = NO INTERNAL CONNECTION
TP = TEST PIN
(DO NOT CONNECT)

GENERAL DESCRIPTION

The ADR420 and ADR421 are precision 2.048 V and 2.500 V XFET voltage references featuring low noise, high accuracy and stability, and low power consumption in a SOIC and Mini_SOIC footprint. Patented temperature drift curvature correction techniques and XFET (eXtra implanted junction FET) technology minimize nonlinearity of the voltage change with temperature. The wide operating range and low power consumption make them ideal for 5 V battery-powered applications.

The ADR420 and ADR421 trim terminal can be used to adjust the output voltage over a ±0.5% range without affecting the temperature coefficient.

The ADR420 and ADR421 are low power, very low drift voltage references that provide an extremely stable output voltage from a wide supply voltage range. They are specified over the extended industrial (–40°C to +125°C) temperature range.

Table I. ADR42x Products

Model	Output Voltage V_O	Initial Accuracy mV	Initial Accuracy %	Tempco ppm/°C
ADR420AR	2.048	3	0.15	10
ADR420BR	2.048	1	0.05	3
ADR420ARM	2.048	3	0.15	10
ADR421AR	2.50	3	0.12	10
ADR421BR	2.50	1	0.04	3
ADR421ARM	2.50	3	0.12	10

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REV. 0

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ADR420/ADR421–SPECIFICATIONS

ADR420 ELECTRICAL SPECIFICATIONS (@ V_{IN} = 5.0 V to 15.0 V, T_A = 25°C, unless otherwise noted.)

Parameter		Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	A Grade	V_O		2.045	2.048	2.051	V
Initial Accuracy		V_{OERR}		–3		+3	mV
				–0.15		+0.15	%
Output Voltage	B Grade	V_O		2.047	2.048	2.049	V
Initial Accuracy		V_{OERR}		–1		+1	mV
				–0.05		+0.05	%
Temperature Coefficient	A Grade	TCV_O	–40°C < T_A < +125°C		2	10	ppm/°C
	B Grade				1	3	ppm/°C
Supply Voltage Headroom		V_{IN}–V_O		2			V
Line Regulation		$\Delta V_O/\Delta V_{IN}$	V_{IN} = 5 V to 18 V –40°C < T_A < +125°C		10	35	ppm/V
Load Regulation		$\Delta V_O/\Delta I_{LOAD}$	I_{LOAD} = 0 mA to 10 mA –40°C < T_A < +125°C			70	ppm/mA
Quiescent Current		I_{IN}	No Load		390	500	µA
			–40°C < T_A < +125°C			600	µA
Voltage Noise		e_N p-p	0.1 Hz to 10 Hz		1.75		µV p-p
Voltage Noise Density		e_N	1 kHz		60		nV/$\sqrt{Hz}$
Turn-On Settling Time		t_R			10		µs
Long-Term Stability		ΔV_O	1000 Hours		50		ppm
Output Voltage Hysteresis		V_{O_HYS}			40		ppm
Ripple Rejection Ratio		RRR	f_{IN} = 10 kHz		90		dB
Short Circuit to GND		I_{SC}			27		mA

Specifications subject to change without notice.

ADR421 ELECTRICAL SPECIFICATIONS (@ V_{IN} = 5.0 V to 15.0 V, T_A = 25°C, unless otherwise noted.)

Parameter		Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	A Grade	V_O		2.497	2.500	2.503	V
Initial Accuracy		V_{OERR}		–3		+3	mV
				–0.12		+0.12	%
Output Voltage	B Grade	V_O		2.499	2.500	2.501	V
Initial Accuracy		V_{OERR}		–1		+1	mV
				–0.04		+0.04	%
Temperature Coefficient	A Grade	TCV_O	–40°C < T_A < +125°C		2	10	ppm/°C
	B Grade				1	3	ppm/°C
Supply Voltage Headroom		V_{IN}–V_O		2			V
Line Regulation		$\Delta V_O/\Delta V_{IN}$	V_{IN} = 5 V to 18 V –40°C < T_A < +125°C		10	35	ppm/V
Load Regulation		$\Delta V_O/\Delta I_{LOAD}$	I_{LOAD} = 0 mA to 10 mA –40°C < T_A < +125°C			70	ppm/mA
Quiescent Current		I_{IN}	No Load		390	500	µA
			–40°C < T_A < +125°C			600	µA
Voltage Noise		e_N p-p	0.1 Hz to 10 Hz		1.75		µV p-p
Voltage Noise Density		e_N	1 kHz		80		nV/$\sqrt{Hz}$
Turn-On Settling Time		t_R			10		µs
Long-Term Stability		ΔV_O	1000 Hours		50		ppm
Output Voltage Hysteresis		V_{O_HYS}			40		ppm
Ripple Rejection Ratio		RRR	f_{IN} = 10 kHz		60		dB
Short Circuit to GND		I_{SC}			27		mA

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS[1]

Supply Voltage . . . . . 18 V
Output Short-Circuit Duration to GND . . . . . Indefinite
Storage Temperature Range
R, RM Package . . . . . –65°C to +150°C
Operating Temperature Range
ADR420/ADR421 . . . . . –40°C to +125°C
Junction Temperature Range
R, RM Package . . . . . –65°C to +150°C
Lead Temperature Range (Soldering, 60 sec) . . . . . 300°C

Package Type	θ_{JA}[2]	Unit
8-Lead Mini_SOIC (RM)	190	°C/W
8-Lead SOIC (R)	130	°C/W

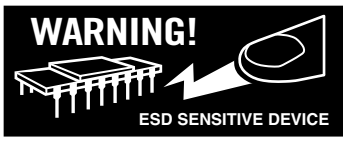
NOTES
[1]Absolute maximum ratings apply at 25°C, unless otherwise noted.
[2]θ_{JA} is specified for the worst-case conditions, i.e., θ_{JA} is specified for device soldered in circuit board for surface-mount packages.

ORDERING GUIDE

Model	Output Voltage V_O	Initial Accuracy mV	Initial Accuracy %	Temperature Coefficient (Max) ppm/°C	Temperature Coefficient (Max) µV/°C	Package Description	Package Option	Number of per Reel	Temperature Range °C	Top Mark
ADR420AR	2.048	3	0.15	10	20	SOIC	R-8	98	–40 to +125	
ADR420AR-Reel7	2.048	3	0.15	10	20	SOIC	R-8	1,000	–40 to +125	
ADR420BR	2.048	1	0.05	3	6	SOIC	R-8	98	–40 to +125	
ADR420BR-Reel7	2.048	1	0.05	3	6	SOIC	R-8	1,000	–40 to +125	
ADR420ARM-Reel7	2.048	3	0.15	10	20	Mini_SOIC	RM-8	1,000	–40 to +125	R4A
ADR421AR	2.50	3	0.12	10	25	SOIC	R-8	98	–40 to +125	
ADR421AR-Reel7	2.50	3	0.12	10	25	SOIC	R-8	1,000	–40 to +125	
ADR421BR	2.50	1	0.04	3	7.5	SOIC	R-8	98	–40 to +125	
ADR421BR-Reel7	2.50	1	0.04	3	7.5	SOIC	R-8	1,000	–40 to +125	
ADR421ARM-Reel7	2.50	3	0.12	10	25	Mini_SOIC	RM-8	1,000	–40 to +125	R5A

CAUTION

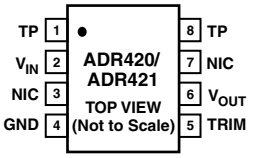
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADR420/ADR421 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high-energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



PIN FUNCTION DESCRIPTIONS

Pin	Mnemonic	Description
1, 8	TP	Test Pin. There are actual connections in TP pins but they are reserved for factory testing purposes. Users should not connect anything to TP pins, otherwise the device may not function properly.
2	V_{IN}	This is the input voltage (5 V to 15 V).
3, 7	NIC	No Internal Connect. NICs have no internal connections.
4	GND	Ground Pin = 0 V.
5	TRIM	Trim Terminal. It can be used to adjust the output voltage over a ±0.5% range without affecting the temperature coefficient.
6	V_{OUT}	Output Voltage.

PIN CONFIGURATION



NIC = NO INTERNAL CONNECTION
TP = TEST PIN
(DO NOT CONNECT)

PARAMETER DEFINITIONS:

Temperature Coefficient

The change of output voltage over the operating temperature range and normalized by the output voltage at 25°C, expressed in ppm/°C. The equation follows:

$$TCV_O\left(ppm/^\circ C\right) = \frac{V_O(T_2) - V_O(T_1)}{V_O(25^\circ C) \times (T_2 - T_1)} \times 10^6$$

where

V_O (25°C) = V_O at 25°C

V_O (T_1) = V_O at Temperature 1

V_O (T_2) = V_O at Temperature 2.

Line Regulation

The change in output voltage due to a specified change in input voltage. It includes the effects of self-heating. Line regulation is expressed in either percent per volt, parts-per-million per volt, or microvolts per volt change in input voltage

Load Regulation

The change in output voltage due to a specified change in load current. It includes the effects of self-heating. Load Regulation is expressed in either microvolts per milliampere, parts-per-million per milliampere, or ohms of dc output resistance.

Long-Term Stability

Typical shift of output voltage at 25°C on a sample of parts subjected to operation life test of 1000 hours at 125°C:

$$\Delta V_O = V_O(t_0) - V_O(t_1)$$

$$\Delta V_O\ (ppm) = \frac{V_O(t_0) - V_O(t_1)}{V_O(t_0)} \times 10^6$$

where

V_O (t_0) = V_O at 25°C at Time 0

V_O (t_1) = V_O at 25°C after 1000 hours operation at 125°C.

Thermal Hysteresis

Thermal Hysteresis is defined as the change of output voltage after the device is cycled through temperature from +25°C to –40°C to +125°C and back to +25°C. This is a typical value from a sample of parts put through such a cycle.

$$V_{O\_HYS} = V_O(25^\circ C) - V_{O\_TC}$$

$$V_{O\_HYS}\ (ppm) = \frac{V_O(25^\circ C) - V_{O\_TC}}{V_O(25^\circ C)} \times 10^6$$

where

V_O (25°C) = V_O at 25°C

V_{O_TC} = V_O at 25°C after temperature cycle at +25°C to –40°C to +125°C and back to +25°C.

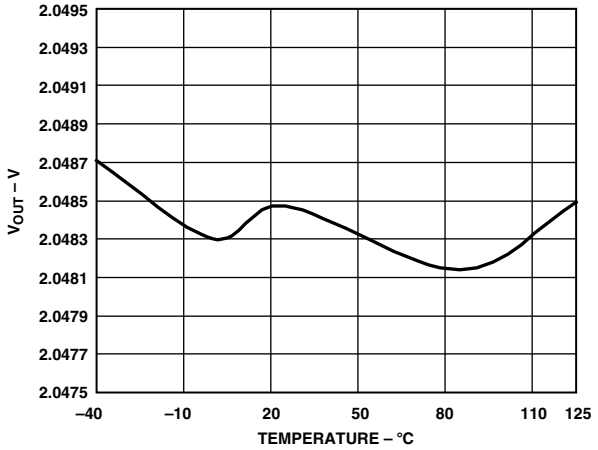
NOTES

Input Capacitor

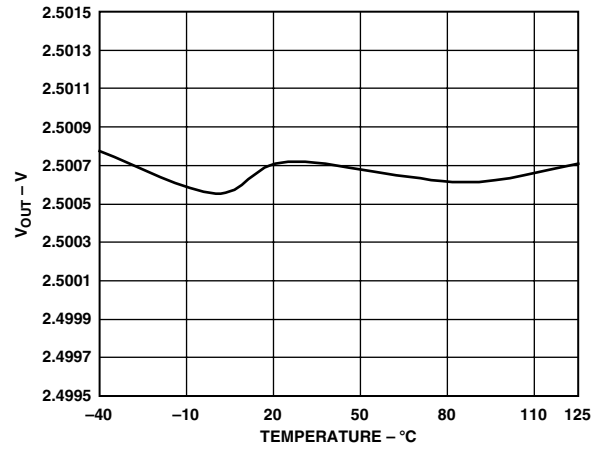
Input capacitors are not required on the ADR420/ADR421. There is no limit for the value of the capacitor used on the input, but a 1 µF to 10 µF capacitor on the input will improve transient response in applications where the supply suddenly changes. An additional 0.1 µF in parallel will also help reducing noise from the supply.

Output Capacitor

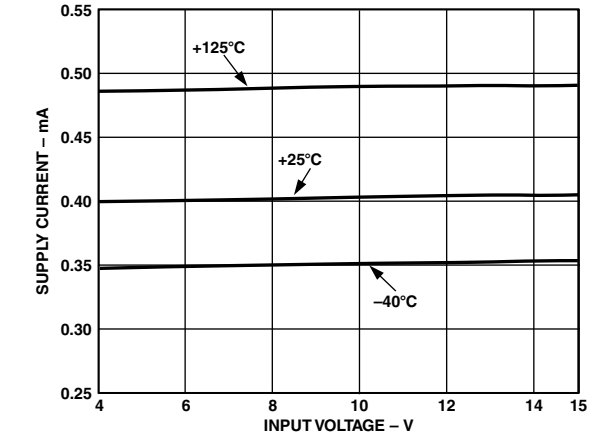
The ADR420/ADR421 does not need output capacitors for stability under any load condition. An output capacitor, typical 0.1 µF, will filter out any low-level noise voltage and will not affect the operation of the part. On the other hand, the load transient response can be improved with an additional 1 µF to 10 µF output capacitor in parallel. A capacitor here will act as a source of stored energy for sudden increase in load current. The only parameter that will degrade, by adding an output capacitor, is turn-on time and it depends on the size of the capacitor chosen.



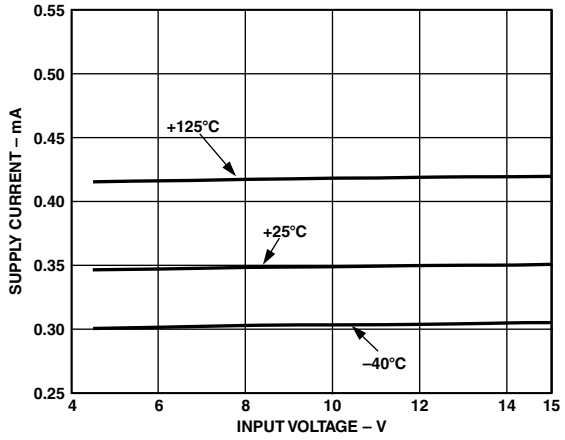
TPC 1. ADR420 Typical Output Voltage vs. Temperature



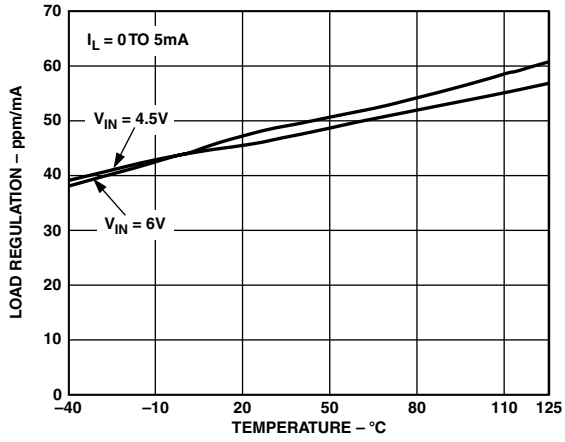
TPC 2. ADR421 Typical Output Voltage vs. Temperature



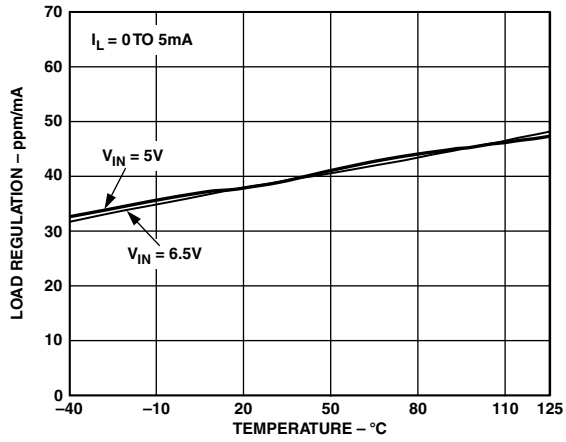
TPC 3. ADR420 Supply Current vs. Input Voltage



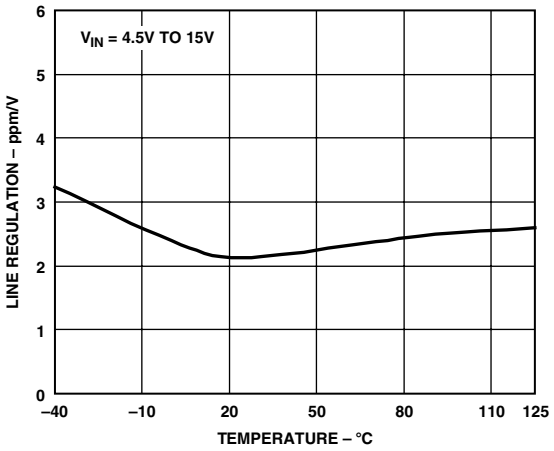
TPC 4. ADR421 Supply Current vs. Input Voltage



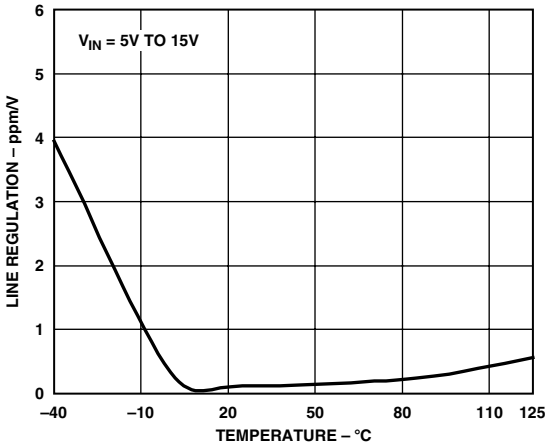
TPC 5. ADR420 Load Regulation vs. Temperature



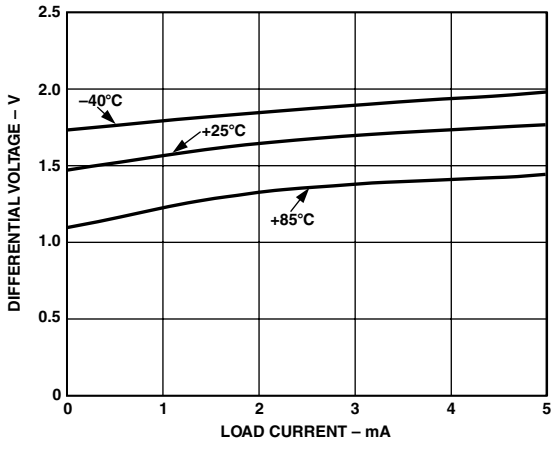
TPC 6. ADR421 Load Regulation vs. Temperature



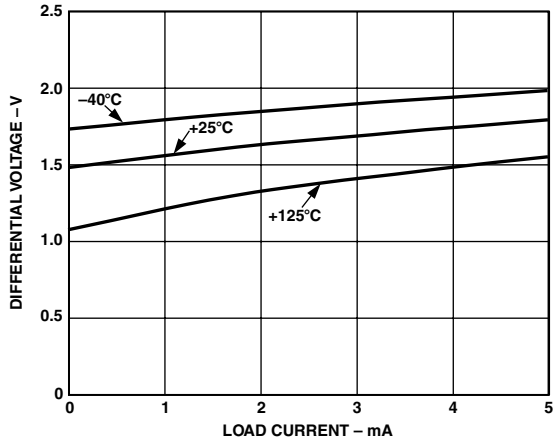
TPC 7. ADR420 Line Regulation vs. Temperature



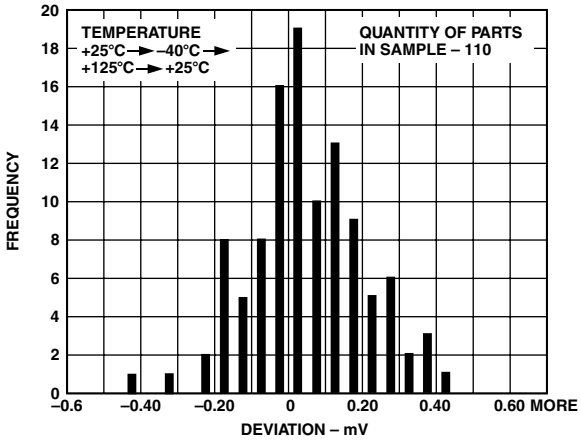
TPC 8. ADR421 Line Regulation vs. Temperature



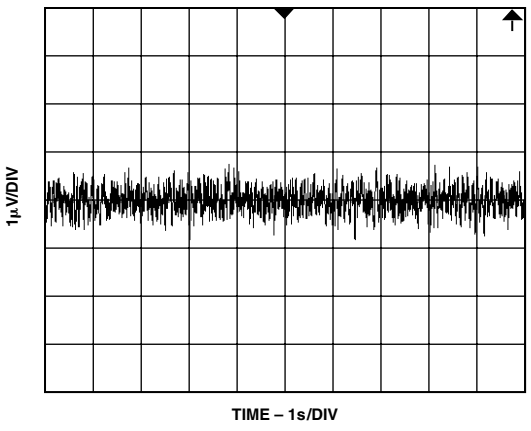
TPC 9. ADR420 Minimum Input-Output Voltage Differential vs. Load Current



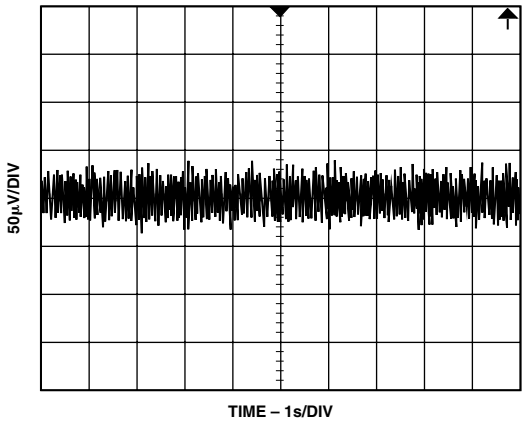
TPC 10. ADR421 Minimum Input-Output Voltage Differential vs. Load Current



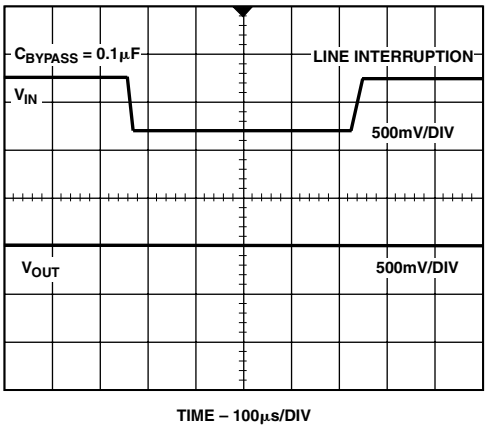
TPC 11. ADR421 Typical Hysteresis



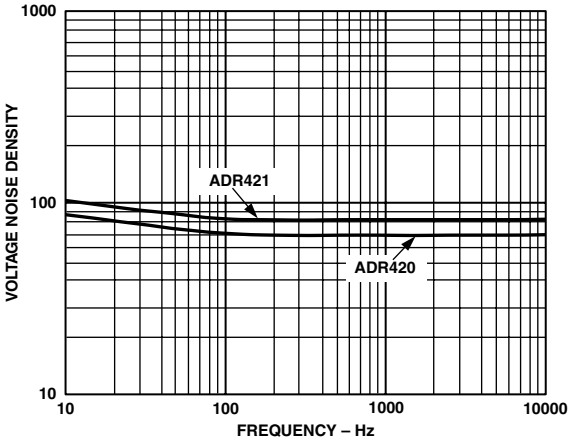
TPC 12. ADR421 Typical Noise Voltage 0.1 Hz to 10 Hz



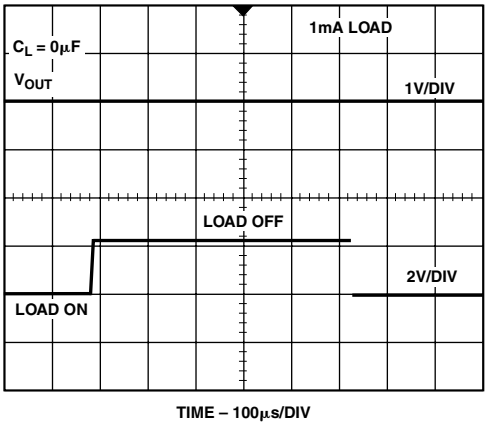
TPC 13. Typical Noise Voltage 10 Hz to 10 kHz



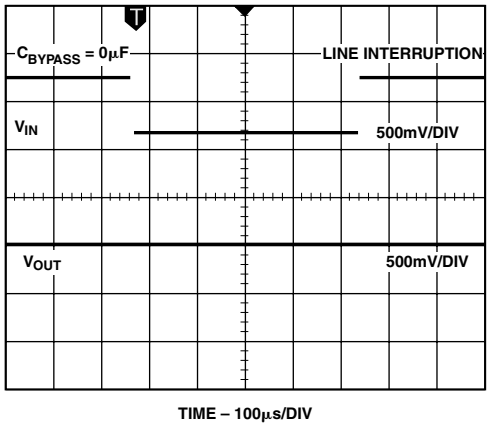
TPC 16. ADR421 Line Transient Response



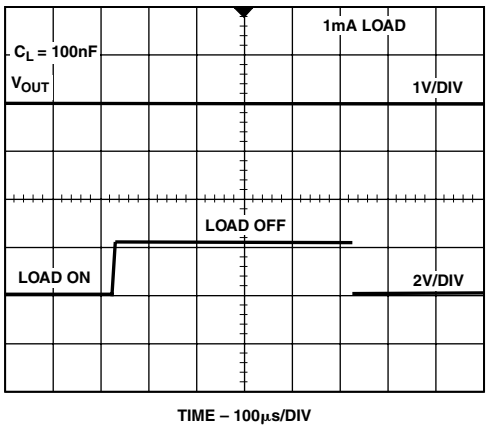
TPC 14. Voltage Noise Density vs. Frequency



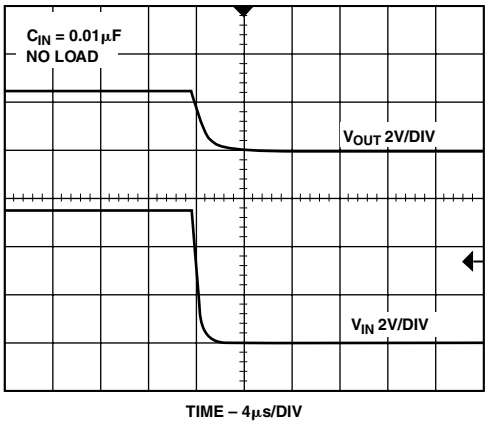
TPC 17. ADR421 Load Transient Response



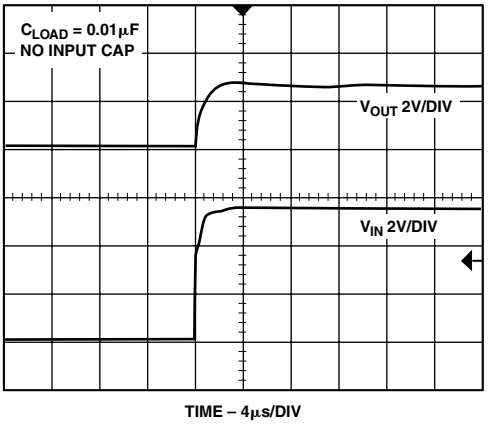
TPC 15. ADR421 Line Transient Response



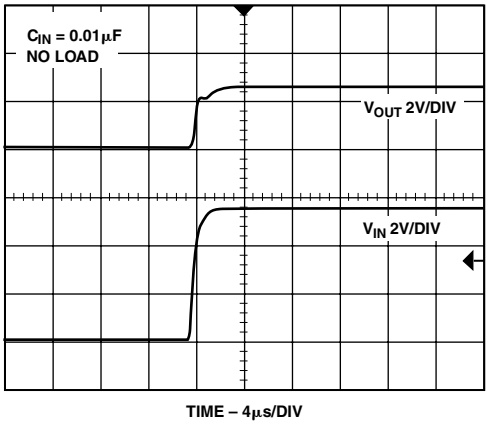
TPC 18. ADR421 Load Transient Response



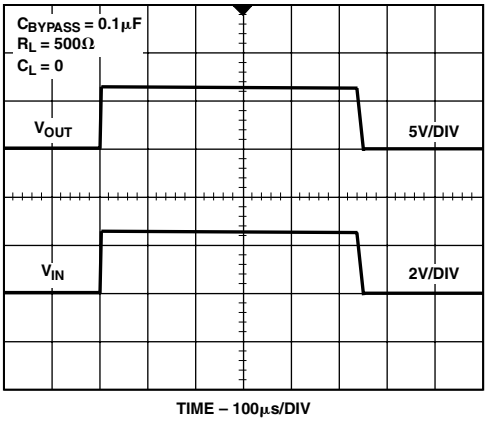
TPC 19. ADR421 Turn-Off Response



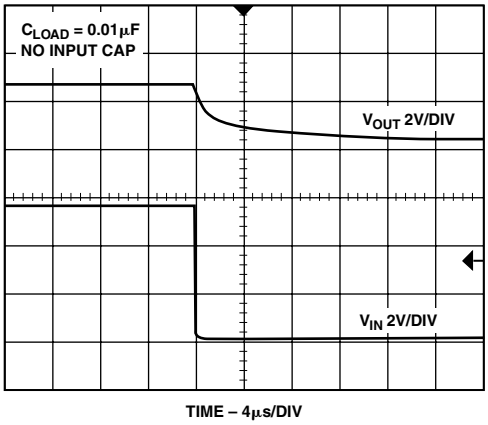
TPC 22. ADR421 Turn-On Response



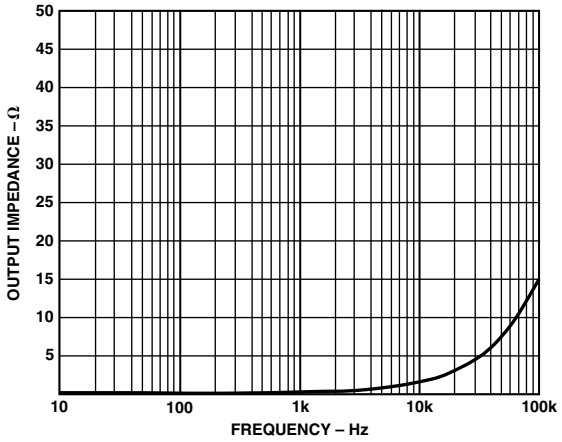
TPC 20. ADR421 Turn-On Response



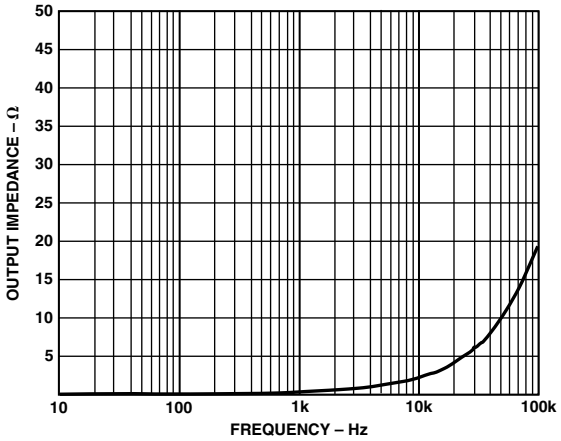
TPC 23. ADR421 Turn-On/Turn-Off Response



TPC 21. ADR421 Turn-Off Response



TPC 24. ADR420 Output Impedance vs. Frequency



TPC 25. ADR421 Output Impedance vs. Frequency

THEORY OF OPERATION

The ADR42x series of references uses a new reference generation technique known as XFET (eXtra implanted junction FET). This technique yields a reference with low supply current, good thermal hysteresis, and exceptionally low noise.

The core of the XFET reference consists of two junction field-effect transistors, one of which has an extra channel implant to raise its pinch-off voltage. By running the two JFETs at the same drain current, the difference in pinch-off voltage can be amplified and used to form a highly stable voltage reference. The intrinsic reference voltage is around 0.5 V with a negative temperature coefficient of about –120 ppm/°C. This slope is essentially constant to the dielectric constant of silicon and can be closely compensated by adding a correction term generated in the same fashion as the proportional-to-temperature (PTAT) term used to compensate bandgap references. The big advantage over a bandgap reference is that the intrinsic temperature coefficient is some thirty times lower (therefore requiring less correction), which results in much lower noise since most of the noise of a bandgap reference comes from the temperature compensation circuitry.

Figure 1 shows the basic topology of the ADR42x series. The temperature correction term is provided by a current source with a value designed to be proportional to absolute temperature. The general equation is:

$$V_{OUT} = G \times (\Delta V_P - R1 \times I_{PTAT})$$

where G is the gain of the reciprocal of the divider ratio, ΔV_P is the difference in pinch-off voltage between the two JFETs, and I_{PTAT} is the positive temperature coefficient correction current. ADR420 and ADR421 are created by on-chip adjustment of R2 and R3 to achieve 2.048 V or 2.500 V at the reference output respectively.

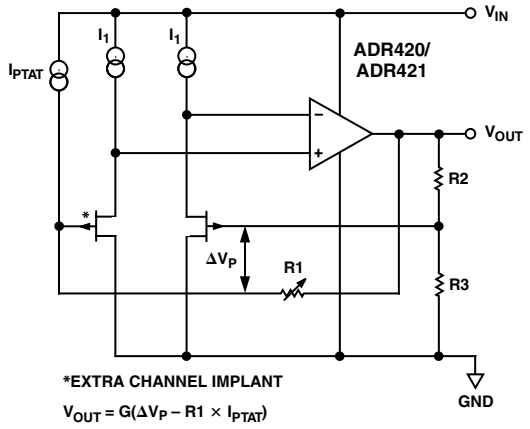


Figure 1. Simplified Schematic

Device Power Dissipation Considerations

The ADR42x family of references is guaranteed to deliver load currents to 10 mA with an input voltage that ranges from 4.5 V to 18 V. When these devices are used in applications at higher current, users should account for the temperature effects due to the power dissipation increases with the following equation:

$$T_J = P_D \times \theta_{JA} + T_A$$

where T_J and T_A are the junction and ambient temperatures, respectively, P_D is the device power dissipation, and θ_{JA} is the device package thermal resistance.

Basic Voltage Reference Connections

Voltage references, in general, require a bypass capacitor connected from V_{OUT} to GND. The circuit in Figure 2 illustrates the basic configuration for the ADR42x family of references. Other than a 0.1 μF capacitor at the output to help improve noise suppression, a large output capacitor at the output is not required for circuit stability.

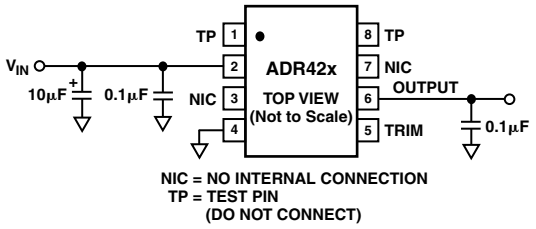


Figure 2. Basic Voltage Reference Configuration

Noise Performance

The noise generated by the ADR42x family of references is typically less than 2 μV p-p over the 0.1 Hz to 10 Hz band. TPC 12 shows the 0.1 Hz to 10 Hz noise of the ADR421, which is only 1.75 μV p-p. The noise measurement is made with a bandpass filter made of a 2-pole high-pass filter with a corner frequency at 0.1 Hz and a 2-pole low-pass filter with a corner frequency at 10 Hz.

Turn-On Time
Upon application of power (cold start), the time required for the output voltage to reach its final value within a specified error band is defined as the turn-on settling time. Two components normally associated with this are the time for the active circuits to settle, and the time for the thermal gradients on the chip to stabilize. TPC 19 to TPC 23 show the turn-on settling time for the ADR421.

APPLICATIONS SECTION

OUTPUT ADJUSTMENT

The ADR420/ADR421 trim terminal can be used to adjust the output voltage over a ±0.5% range. This feature allows the system designer to trim system errors out by setting the reference to a voltage other than the nominal. This is also helpful if the part is used in a system at temperature to trim out any error. Adjustment of the output has negligible effect on the temperature performance of the device. To avoid degrading temperature coefficient, both the trimming potentiometer and the two resistors need to be low temperature coefficient types, preferably < 100 ppm/°C.

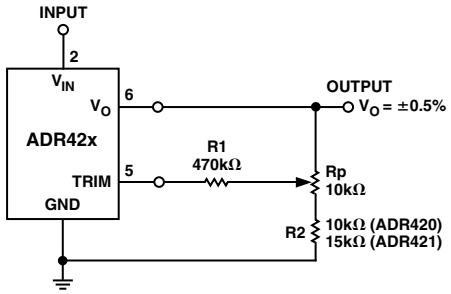


Figure 3. Output Trim Adjustment

Reference for Converters in Optical Network Control Circuits
In the upcoming high-capacity all-optical router network, Figure 4 employs arrays of micro-mirrors to direct and route optical signals from fiber to fiber, without first converting them to electrical form, which reduces the communication speed. The tiny micro-mechanical mirrors are positioned so that each is illuminated by a single wavelength that carries unique information and can be passed to any desired input and output fiber. The mirrors are tilted by the dual-axis actuators controlled by precision ADCs and DACs within the system. Due to the microscopic movement of the mirrors, not only is the precision of the converters important, but the noise associated with these controlling converters is also extremely critical, because total noise within the system can be multiplied by the numbers of converters employed. As a result, the ADR421 is necessary for this application for its exceptional low noise to maintain the stability of the control loop.

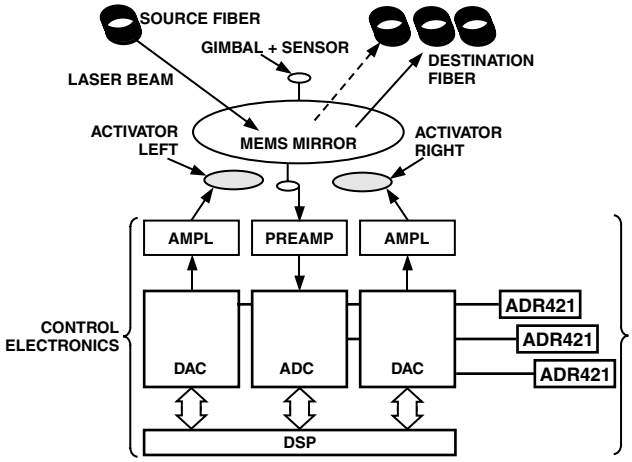


Figure 4. All-Optical Router Network

A Negative Precision Reference without Precision Resistors
In many current-output CMOS DAC applications, where the output signal voltage must be of the same polarity as the reference voltage, it is often required to reconfigure a current-switching DAC into a voltage-switching DAC through the use of a 1.25 V reference, an op amp, and a pair of resistors. Using a current-switching DAC directly requires the need for an additional operational amplifier at the output to reinvert the signal. A negative voltage reference is then desirable from the point that an additional operational amplifier is not required for either reinversion (current-switching mode) or amplification (voltage-switching mode) of the DAC output voltage. In general, any positive voltage reference can be converted into a negative voltage reference through the use of an operational amplifier and a pair of matched resistors in an inverting configuration. The disadvantage to that approach is that the largest single source of error in the circuit is the relative matching of the resistors used.

A negative reference can easily be generated by adding a precision op amp and configured as in Figure 5. V_{OUT} is at virtual ground and therefore the negative reference can be taken directly from the output of the op amp. The op amp must be dual supply, low offset, and have rail-to-rail capability if negative supply voltage is close to the reference output.

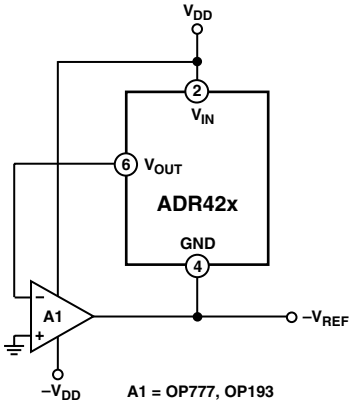


Figure 5. Negative Reference

High-Voltage Floating Current Source

The circuit of Figure 6 can be used to generate a floating current source with minimal self-heating. This particular configuration can operate on high supply voltages determined by the breakdown voltage of the N-channel JFET.

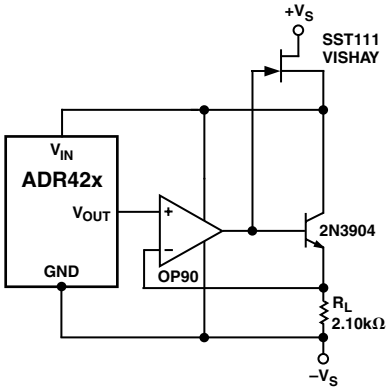


Figure 6. High-Voltage Floating Current Source

Kelvin Connections

In many portable instrumentation applications, where PC board cost and area go hand-in-hand, circuit interconnects are very often of dimensionally minimum width. These narrow lines can cause large voltage drops if the voltage reference is required to provide load currents to various functions. In fact, a circuit's interconnects can exhibit a typical line resistance of 0.45 mΩ/square (1 oz. Cu, for example). Force and sense connections, also referred to as Kelvin connections, offer a convenient method of eliminating the effects of voltage drops in circuit wires. Load currents flowing through wiring resistance produce an error ($V_{ERROR} = R \times I_L$) at the load. However, the Kelvin connection of Figure 7 overcomes the problem by including the wiring resistance within the forcing loop of the op amp. Since the op amp senses the load voltage, op amp loop control forces the output to compensate for the wiring error and to produce the correct voltage at the load.

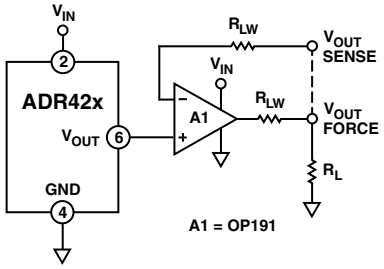


Figure 7. Advantage of Kelvin Connection

Precision Voltage Reference For Data Converters

The ADR42x family has a number of features that make it ideal for use with A/D and D/A converters. The exceptional low noise, tight temperature coefficient, and high accuracy characteristics make the ADR42x ideal for low noise applications such as cellular base station applications.

Another example of ADC for which the ADR421 is also well-suited is the AD7701. Figure 8 shows the ADR421 used as the precision reference for this converter. The AD7701 is a 16-bit A/D converter with on-chip digital filtering intended for the measurement of wide dynamic range and low frequency signals such as those representing chemical, physical, or biological processes. It contains a charge-balancing (sigma-delta) ADC, calibration microcontroller with on-chip static RAM, a clock oscillator, and a serial communications port.

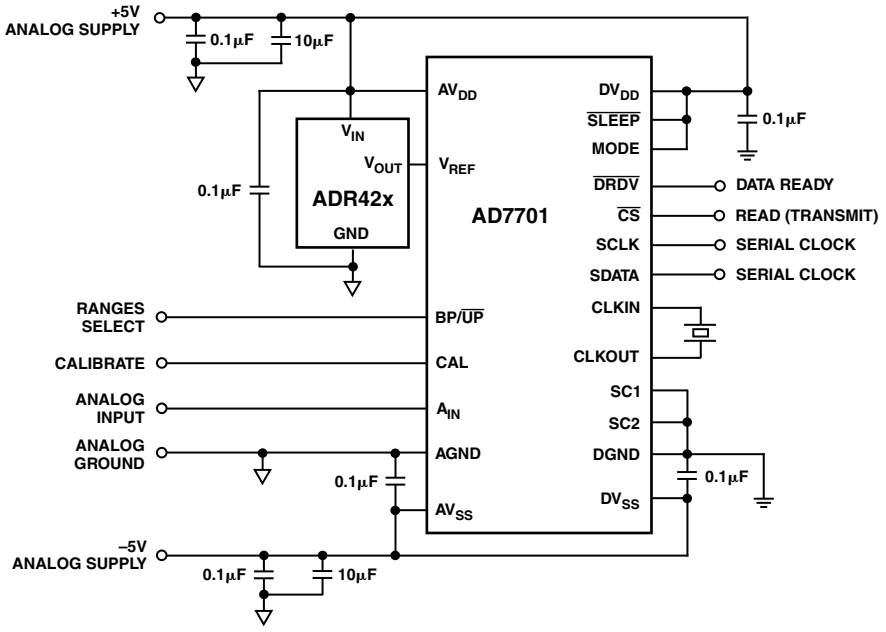


Figure 8. Voltage Reference for 16-Bit A/D Converter AD7701

Precision Voltage Regulator

Together with a precision op amp and discrete MOSFETs, ADR42x can be configured as a precision LDO (Low Dropout Regulator). The advantages of using such an alternative over integrated solutions are the 0.05% accuracy and ultralow noise characteristics, which cannot be achieved with typical LDOs or switching regulators. Other output voltages are also possible if adding a pair of precision resistors, one connected between the drain of M2 and the negative input of the op amp, and another connected between the negative input of the op amp and ground. M1 can be any low-cost N-Channel MOSFET. On the other hand, M2 is a P-Channel MOSFET and is chosen to handle the amount of load current desired. The choice of R1 is the trade-off between the current lost through it and the output turn-off time.

Like most voltage references, ADR42x suffers from low ripple rejection ratio at high frequency. Therefore, users should avoid using the output of a switching power supply as the input of ADR42x.

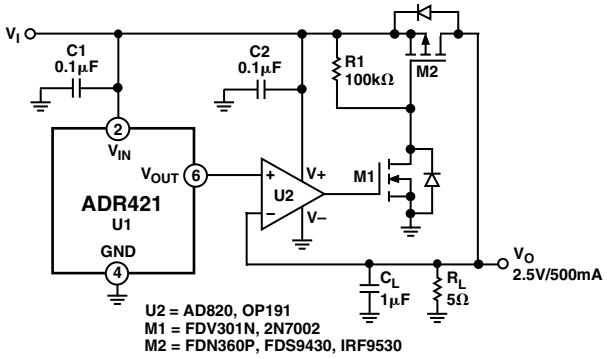


Figure 9. Voltage Regulator for Portable Equipment

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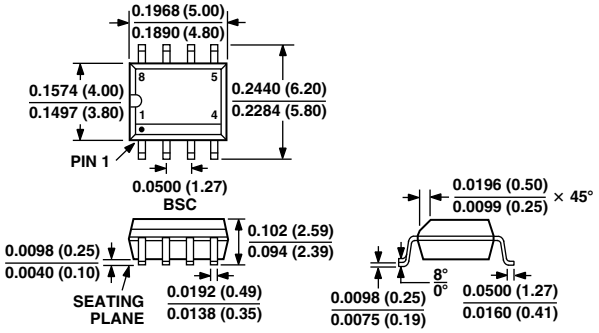
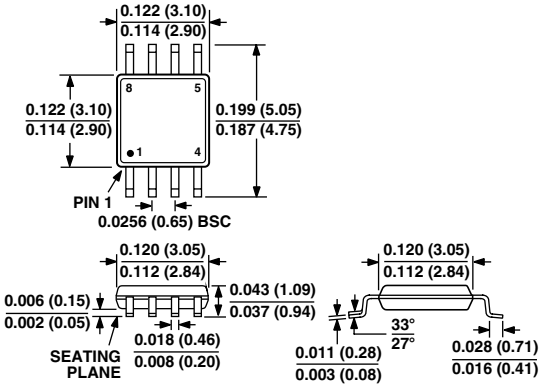
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

8-Lead Narrow Body SO (R-8)



8-Lead Mini_SOIC (RM-8)



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