ANALOG DEVICES

Low-Noise Micropower Precision Voltage Reference

Preliminary ADR293

FEATURES
- Voltage Output 5.0 V
- 5.5 V to 15 V Supply Range
- Supply Current 20 µA max
- Initial Accuracy ±3 mV max
- Temperature Coefficient 8 ppm/°C max
- Low-Noise 12 µVp–p (0.1 - 10 Hz)
- High Output Current 5 mA min
- Temperature Range −40°C to +125°C
- REF02/REF19x Pinout

APPLICATIONS
- Portable Instrumentation
- Precision Reference for 5 V Systems
- A/D and D/A Converter Reference
- Solar Powered Applications
- Loop-Current Powered Instruments

GENERAL DESCRIPTION

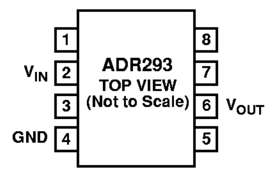
The ADR293 is a low-noise, micropower precision voltage reference that utilize an XFET™ reference circuit. The new XFET™ architecture offers significant performance improvements over traditional bandgap and zener based references. Improvements include: one quarter the voltage noise output of bandgap references operating at the same current, very low and ultra-linear temperature drift, low thermal hysteresis, and excellent long-term stability.

The ADR293 is a series voltage reference providing stable and accurate output voltage from a 5.5 V supply. Quiescent current is only 20 µA making this device ideal for battery powered instrumentation. Three electrical grades are available offering initial output accuracy's of ±3 mV, ±4 mV, and ±6 mV. Temperature coefficients for the three grades are 8 ppm/°C, 15 ppm/°C, and 25 ppm/°C max. Line regulation and load regulation are typically 30 ppm/V and 30 ppm/mA, maintaining the reference's overall high performance.

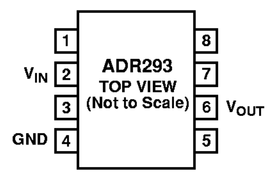
The ADR293 is specified over the extended industrial temperature range of -40°C to +125°C. This device is available in the 8-pin SOIC, 8-pin TSSOP, and the TO-92 package.

PIN CONFIGURATIONS

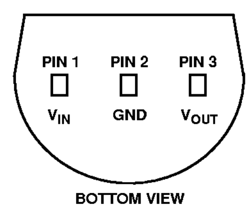
8-Lead Narrow Body SO (R Suffix)



8-Lead TSSOP (RU Suffix)



3-Pin TO-92 (T9 Suffix)



Part Number	Nominal Output Voltage (V)	
ADR290	2.048	See seperate datasheet
ADR291	2.500	See seperate datasheet
ADR292	4.096	See seperate datasheet
ADR293	5.000	

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REV. 0.6

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ADR293–SPECIFICATIONS

Electrical Specifications (V_S = +5.5 V, T_A = +25°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
INITIAL ACCURACY						
"E" Grade	V_O	I_{OUT} = 0 mA	4.997	5.000	5.003	V
"F" Grade			4.996		5.004	V
"G" Grade			4.994		5.006	V
LINE REGULATION						
"E/F" Grades	$\Delta V_O/\Delta V_{IN}$	5.5 V to 15 V, I_{OUT} = 0 mA		30	100	ppm/V
"G" Grade				40	125	ppm/V
LOAD REGULATION						
"E/F" Grades	$\Delta V_O/\Delta I_{LOAD}$	V_S = 5.5 V, 0 mA to 5 mA		30	100	ppm/mA
"G" Grade				40	125	ppm/mA
LONG TERM STABILITY	ΔV_O	1000 hrs @ +25°C, V_S = +15 V		0.2		ppm
NOISE VOLTAGE	e_N	0.1 Hz to 10 Hz		12		μV p-p
WIDEBAND NOISE DENSITY	e_N	at 1 kHz		640		nV/√Hz

Electrical Specifications (V_S = +5.5 V, T_A = –25°C ≤ T_A ≤ +85°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
TEMPERATURE COEFFICIENT						
"E" Grade	TCV_O/°C	I_{OUT} = 0 mA		3	8	ppm/°C
"F" Grade				5	15	ppm/°C
"G" Grade				10	25	ppm/°C
LINE REGULATION						
"E/F" Grades	$\Delta V_O/\Delta V_{IN}$	5.5 V to 15 V, I_{OUT} = 0 mA		35	125	ppm/V
"G" Grade				50	150	ppm/V
LOAD REGULATION						
"E/F" Grades	$\Delta V_O/\Delta I_{LOAD}$	V_S = 5.5 V, 0 mA to 5 mA		20	125	ppm/mA
"G" Grade				30	150	ppm/mA

Electrical Specifications (V_S = +5.5 V, T_A = –40°C ≤ T_A ≤ +125°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
TEMPERATURE COEFFICIENT						
"E" Grade	TCV_O/°C	I_{OUT} = 0 mA		3	10	ppm/°C
"F" Grade				5	20	ppm/°C
"G" Grade				10	30	ppm/°C
LINE REGULATION						
"E/F" Grades	$\Delta V_O/\Delta V_{IN}$	5.5 V to 15 V, I_{OUT} = 0 mA		40	200	ppm/V
"G" Grade				70	250	ppm/V
LOAD REGULATION						
"E/F" Grades	$\Delta V_O/\Delta I_{LOAD}$	V_S = 5.5 V, 0 mA to 5 mA		20	200	ppm/mA
"G" Grade				30	300	ppm/mA
SUPPLY CURRENT				15	20	μA
THERMAL HYSTERESIS		TO-92, SO-8, TSSOP-8		50		ppm

NOTE
Specifications subject to change without notice.

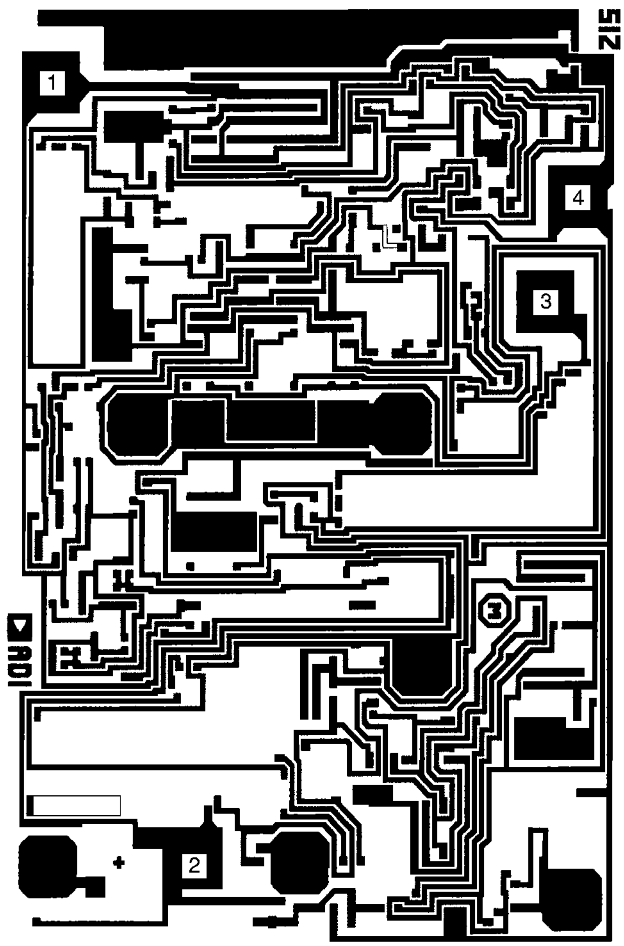
WAFER TEST LIMITS (@ I_{LOAD} = 0 mA, T_A = +25°C unless otherwise noted)

Parameter	Symbol	Conditions	Limits	Units
INITIAL ACCURACY	V_O		4.994/5.006	V
LINE REGULATION	$\Delta V_O/\Delta V_{IN}$	V_O + 1 V < V_{IN} < 15 V, I_{OUT} = 0 mA	125	ppm/V
LOAD REGULATION	$\Delta V_O/\Delta I_{LOAD}$	0 to 5 mA, V_{IN} = V_O + 1 V	125	ppm/mA
SUPPLY CURRENT		No load	15	µA

NOTES
Electrical tests are performed as wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualification through sample lot assembly and testing.
Specifications subject to change without notice.

DICE CHARACTERISTICS

Die Size 0.074 × 0.052 inch, 3848 sq. mils
(1.88 × 1.32 mm, 2.48 sq. mm)
Transistor Count: 52



1. V_{IN}
2. GND
3. $V_{OUT(FORCE)}$
4. $V_{OUT(SENSE)}$

For additional DICE ordering information, refer to databook.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage . . . . +18 V
Output Short-Circuit Duration . . . . Indefinite
Storage Temperature Range
T9, R, RU Package . . . . –65°C to +150°C
Operating Temperature Range . . . . –40°C to +125°C
Junction Temperature Range
T9, R, RU Package . . . . –65°C to +125°C
Lead Temperature (Soldering, 60 sec) . . . . +300°C

Package Type	θ_{JA}[1]	θ_{JC}	Units
8-Lead SOIC (R)	158	43	°C/W
3-Pin TO-92 (T9)	162	120	°C/W
8-Lead TSSOP (RU)	240	43	°C/W

NOTE
[1] θ_{JA} is specified for worst case conditions, i.e. θ_{JA} is specified for device in socket for PDIP, and θ_{JA} is specified for a device soldered in circuit board for SOIC packages.

*CAUTION

1. Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation at or above this specification is not implied. Exposure to the above maximum rating conditions for extended periods may affect device reliability.
2. Remove power before inserting or removing units from their sockets.
3. Ratings apply to both DICE and packaged parts, unless otherwise noted

ORDERING GUIDE

Model	Temperature Range	Package
ADR293ER, ADR293FR, ADR293GR	–40°C to +125°C	8-Lead SOIC
ADR293ER-REEL, ADR293FR-REEL, ADR293GR-REEL	–40°C to +125°C	8-Lead SOIC
ADR293ER-REEL7, ADR293FR-REEL7, ADR293GR-REEL7	–40°C to +125°C	8-Lead SOIC
ADR293GT9	–40°C to +125°C	3-Pin TO-92
ADR293GT9-REEL	–40°C to +125°C	3-Pin TO-92
ADR293GRU-REEL	–40°C to +125°C	8-Lead TSSOP
ADR293GRU-REEL7	–40°C to +125°C	8-Lead TSSOP
ADR293GBC	+25°C	DICE

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 ADR293 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.

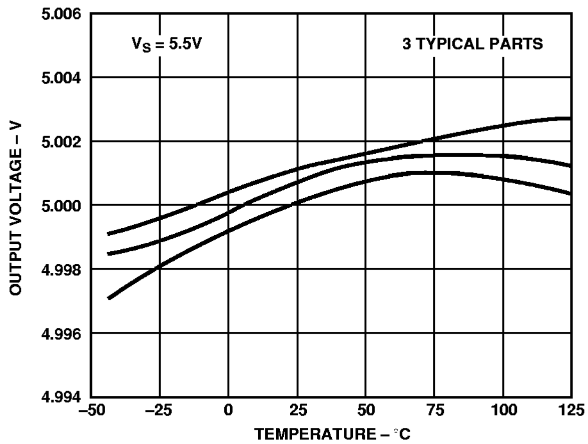


Figure 1. ADR293 V_{OUT} vs. Temperature

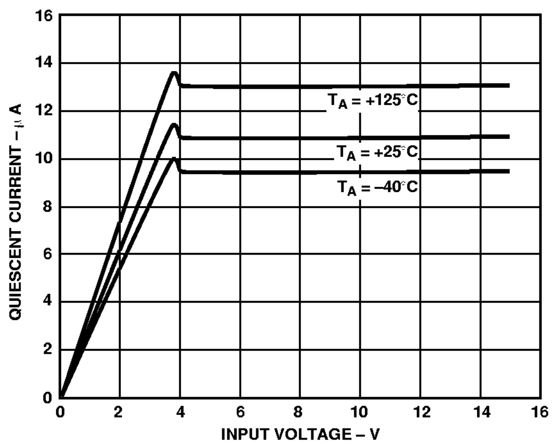


Figure 2. ADR293 Quiescent Current vs. Input Voltage

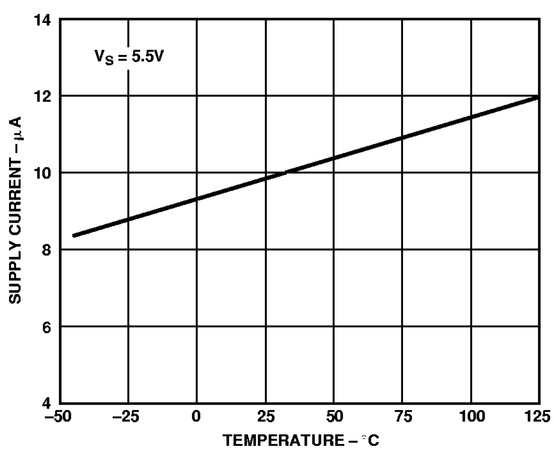


Figure 3. ADR293 Supply Current vs. Temperature

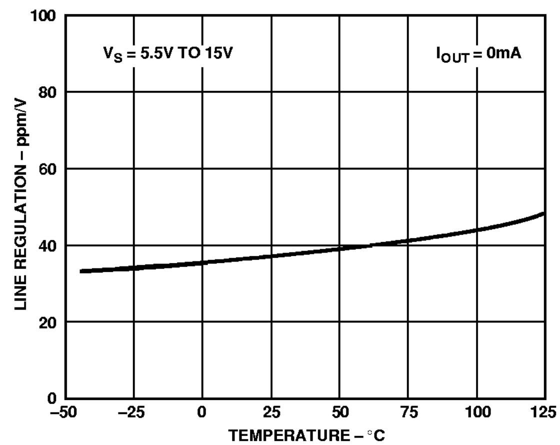


Figure 4. ADR293 Line Regulation vs. Temperature

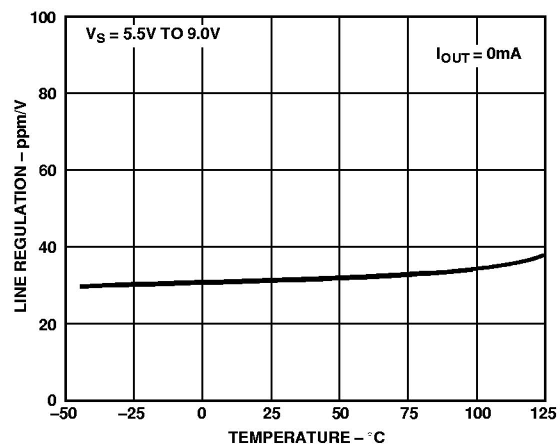


Figure 5. ADR293 Line Regulation vs. Temperature

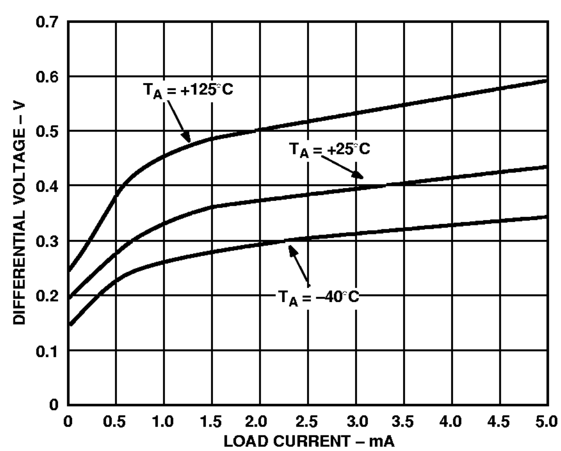


Figure 6. ADR293 Minimum Input-Output Voltage Differential vs. Load Current

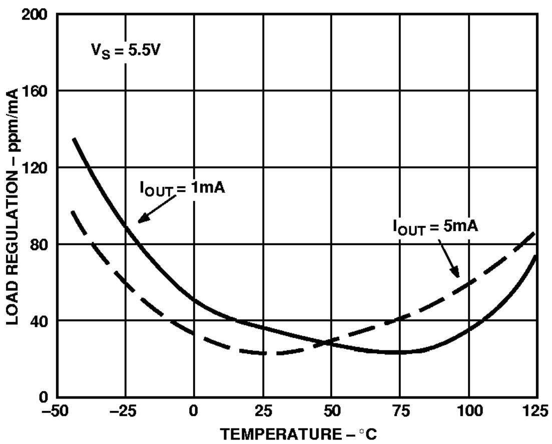


Figure 7. ADR293 Load Regulation vs. Temperature

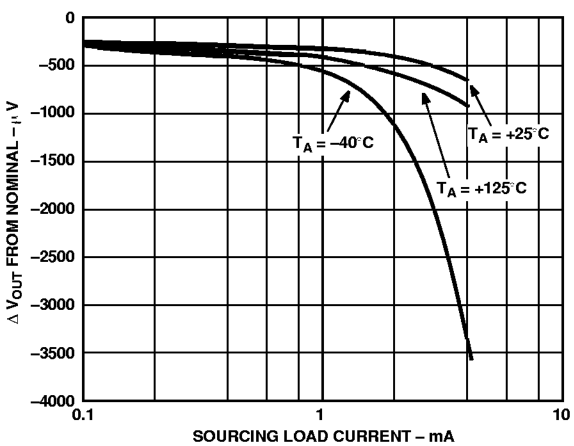


Figure 8. ADR293 ΔV_{OUT} from Nominal vs. Load Current

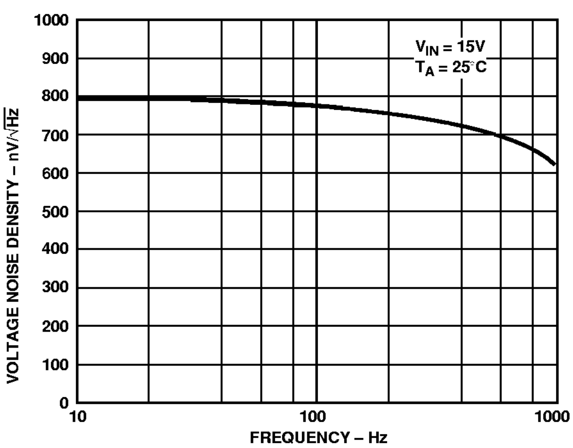


Figure 9. Voltage Noise Density

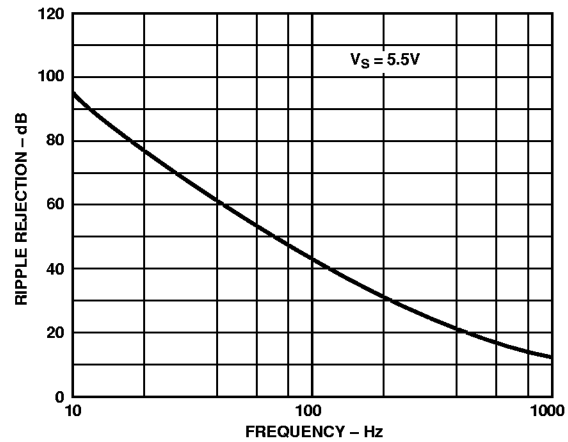


Figure 10. ADR293 Ripple Rejection vs. Frequency

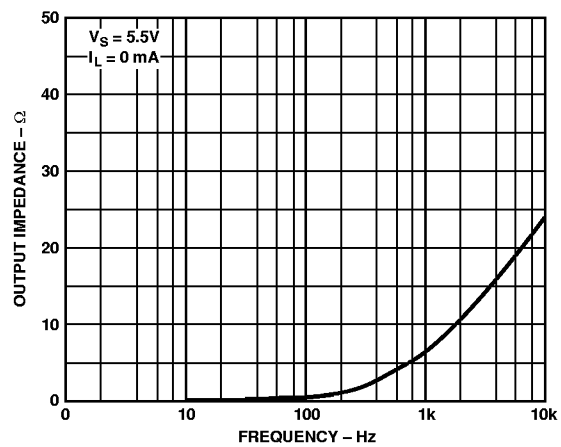


Figure 11. ADR293 Output Impedance vs. Frequency

THEORY OF OPERATION

The ADR293 uses a new reference generation technique known as XFET™ (eXtra implanted junction FET). This technique yields a reference with low noise, low supply current and very low thermal hysteresis.

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/K. This slope is essentially locked 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 less correction is needed) and this results in much lower noise since most of the noise of a bandgap reference comes from the temperature compensation circuitry.

The simplified schematic below shows the basic topology of the ADR293. The temperature correction term is provided by a current source with value designed to be proportional to absolute temperature. The general equation is:

$$V_{OUT} = \Delta V_P \left(\frac{R1 + R2 + R3}{R1} \right) + \left(I_{PTAT} \right)\left(R3 \right)$$

where ΔV_P is the difference in pinch-off voltage between the two FETs and I_{PTAT} is the positive temperature coefficient correction current.

The process used for the XFET reference also features vertical NPN and PNP transistors, the latter of which are used as output devices to provide a very low drop-out voltage.

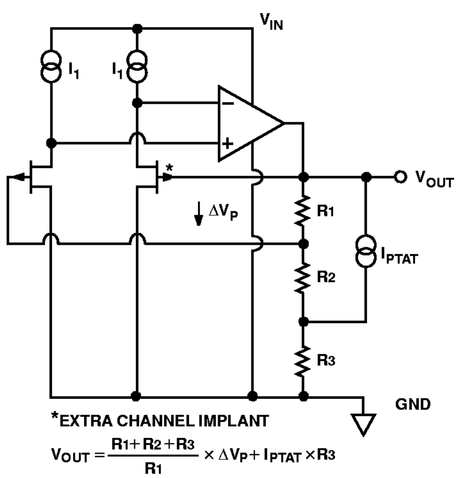


Figure 12. ADR293 Simplified Schematic

Device Power Dissipation Considerations

The ADR293 is guaranteed to deliver load currents to 5 mA with an input voltage that ranges from 5.5 V to 15 V. When this devices is used in applications with large input voltages, care should be exercised to avoid exceeding the published specifications for maximum power dissipation or junction temperature that could result in premature device failure. The following formula should be used to calculate a device's maximum junction temperature or dissipation:

$$P_D = \frac{T_J - T_A}{\theta_{JA}}$$

In this equation, 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

References, in general, require a bypass capacitor connected from the V_{OUT} pin to the GND pin. The circuit in Figure 13 illustrates the basic configuration for the ADR293. Note that the decoupling capacitors are not required for circuit stability.

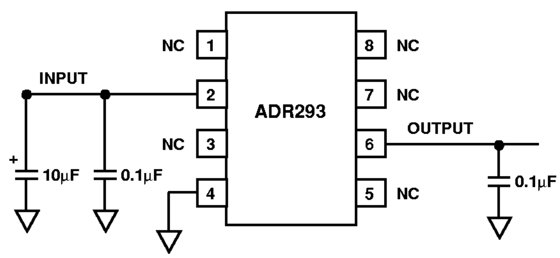


Figure 13. Basic Voltage Reference Configuration

Noise Performance

The noise generated by the ADR293 is typically less than 12 µVp-p over the 0.1 Hz to 10 Hz band. 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.

APPLICATIONS SECTION

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.

The circuit illustrated in Figure 14 avoids the need for tightly matched resistors with the use of an active integrator circuit. In this circuit, the output of the voltage reference provides the input drive for the integrator. The integrator, to maintain circuit equilibrium adjusts its output to establish the proper relationship between the reference's V_{OUT} and GND. Thus, any negative output voltage desired can be chosen by simply substituting for the appropriate reference IC. One caveat with this approach should be mentioned: although rail-to-rail output amplifiers work best in the application, these operational amplifiers require a finite amount (mV) of headroom when required to provide any load current. The choice for the circuit's negative supply should take this issue into account.

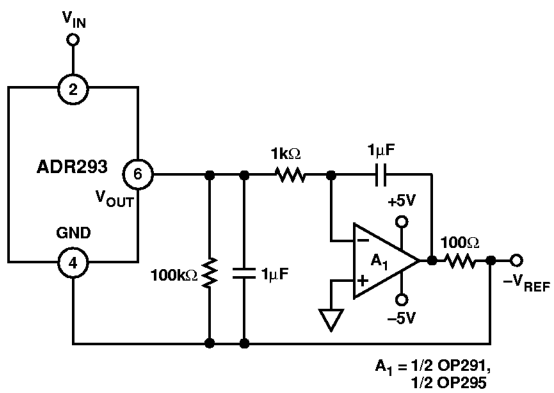


Figure 14. A Negative Precision Voltage Reference Uses No Precision Resistors

A Precision Current Source

Many times in low power applications, the need arises for a precision current source that can operate on low supply voltages. As shown in Figure 15 the ADR293 is configured as a precision current source. The circuit configuration illustrated is a floating current source with a grounded load. The reference's output voltage is bootstrapped across R_{SET}, which sets the output current into the load. With this configuration, circuit precision is maintained for load currents in the range from the reference's supply current, typically 15 mA to approximately 5 mA.

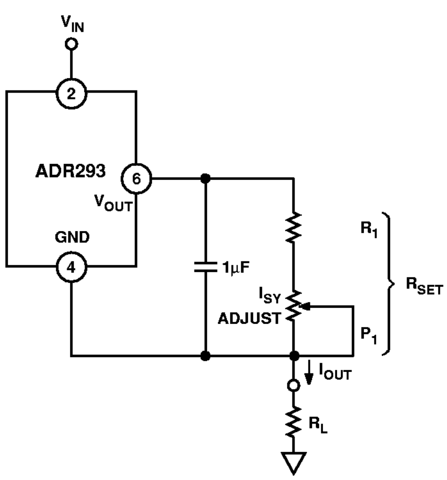


Figure 15. A Precision Current Source

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 mW/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 16, 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.

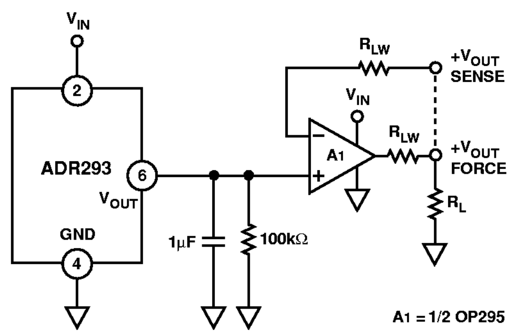


Figure 16. Advantage of Kelvin Connection

Voltage Regulator For Portable Equipment

The ADR293 is ideal for providing a stable, low cost and low power reference voltage in portable equipment power supplies. Figure 17, shows how the ADR293 can be used in a voltage regulator that not only has low output noise (as compared to switch mode design) and low power, but also a very fast recovery after current surges. Some precautions should be taken in the selection of the output capacitors. Too high an ESR (effective series resistance) could endanger the stability of the circuit. A solid tantalum capacitor, 16 V or higher, and an aluminum electrolytic capacitor, 10 V or higher, are recommended for C1 and C2, respectively. Also, the path from the ground side of C1 and C2 to the ground side of R1 should be kept as short as possible.

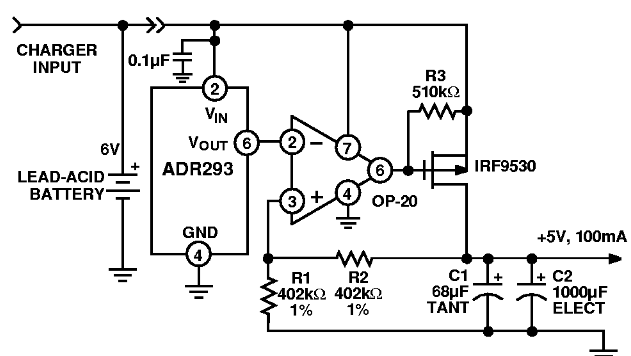
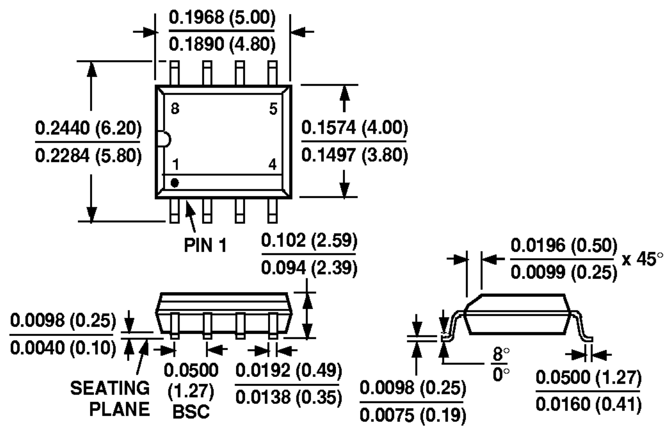


Figure 17. Voltage Regulator for Portable Equipment

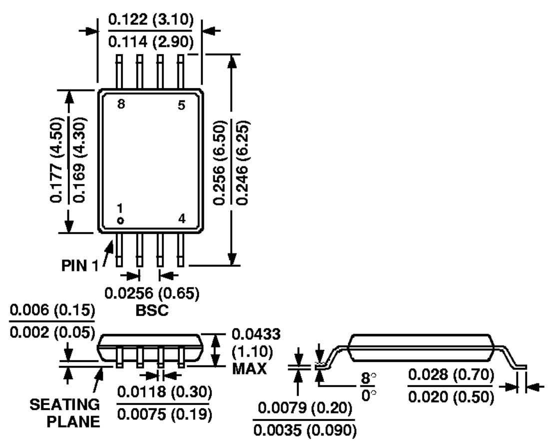
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

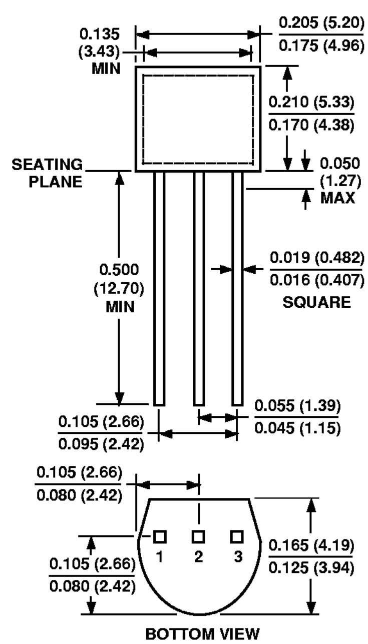
8-Lead Narrow Body SO (R Suffix)



8-Lead TSSOP (RU Suffix)



3-Pin TO-92 (T9 Suffix)



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