Precision Low Drift 2.048 V/2.500 V SOT-23 Voltage References with Shutdown

ADR390/ADR391

FEATURES
- **Load Regulation: 60 ppm/mA**
- **Line Regulation: 25 ppm/V**
- **Wide Operating Range:**
  - **2.4 V–18 V for ADR390**
  - **2.8 V–18 V for ADR391**
- **Low Power: 120 μA Max**
- **Shutdown to Less than 3 μA Max**
- **High Output Current: 5 mA Min**
- **Wide Temperature Range: –40°C to +85°C**
- **Tiny SOT-23-5 Package**

APPLICATIONS
- **Battery-Powered Instrumentation**
- **Portable Medical Instruments**
- **Data Acquisition Systems**
- **Industrial and Process Control Systems**
- **Hard Disk Drives**
- **Automotive**

PIN CONFIGURATION
5-Lead SOT-23
(RT Suffix)

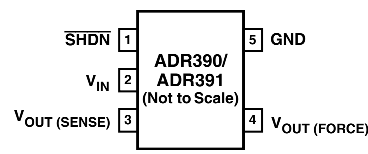

Table I. ADR39x Products

Part Number	Output Voltage (V)	Initial Accuracy mV	%	Tempco ppm/°C, Max
ADR390	2.048	±6	±0.29	25
ADR391	2.500	±6	±0.24	25

GENERAL DESCRIPTION

The ADR390 and ADR391 are precision 2.048 V and 2.5 V bandgap voltage references featuring high accuracy and stability and low power consumption in a tiny footprint. Patented temperature drift curvature correction techniques minimize nonlinearity of the voltage change with temperature. The wide operating range and low power consumption with additional shutdown capability make them ideal for 3 V to 5 V battery-powered applications. The V_{OUT} Sense Pin enables greater accuracy by supporting full Kelvin operation in systems using very fine or long circuit traces.

The ADR390 and ADR391 are micropower, Low Dropout Voltage (LDV) devices that provide a stable output voltage from supplies as low as 300 mV above the output voltage. They are specified over the industrial (–40°C to +85°C) temperature range. Each is available in the tiny 5-lead SOT-23 package.

The combination of V_{OUT} sense and shutdown functions also enables a number of unique applications combining precision reference/regulation with fault decision and overcurrent protection. Details are provided in the Applications section.

REV. A

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ADR390 SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (@ V_{IN} = 5 V, T_A = 25°C unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	V_O		2.042	2.048	2.054	V
Initial Accuracy	V_{OERR}		–6		+6	mV
			–0.29		+0.29	%
Temperature Coefficient	TCV_O	–40°C < T_A < +85°C		5	25	ppm/°C
		0°C < T_A < 70°C		3	21	ppm/°C
Minimum Supply Voltage Headroom	$V_{IN} – V_O$	I_L ≤ 3 mA		300		mV
Line Regulation	$\Delta V_O/\Delta V_{IN}$	V_{IN} = 2.5 V to 15 V				
		–40°C < T_A < +85°C		10	25	ppm/V
Load Regulation	$\Delta V_O/\Delta I_{LOAD}$	V_{IN} = 3 V,				
		I_{LOAD} = 0 mA to 5 mA				
		–40°C < T_A < +85°C			60	ppm/mA
Quiescent Current	I_{IN}	No Load		100	120	µA
		–40°C < T_A < +85°C			140	µA
Voltage Noise	e_N	0.1 Hz to 10 Hz		5		µV p-p
Turn-On Settling Time	t_R			20		µs
Long-Term Stability	ΔV_O	See Figure 1		50		ppm
Output Voltage Hysteresis	V_{O_HYS}			40		ppm
Ripple Rejection Ratio	RRR	f_{IN} = 60 Hz		85		dB
Short Circuit to GND	I_{SC}			30		mA
Shutdown Supply Current	I_{SHDN}				3	µA
Shutdown Logic Input Current	I_{LOGIC}				500	nA
Shutdown Logic Low	V_{INL}				0.8	V
Shutdown Logic High	V_{INH}		2.4			V

Specifications subject to change without notice.

ELECTRICAL CHARACTERISTICS (@ V_{IN} = 15 V, T_A = 25°C unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	V_O		2.042	2.048	2.054	V
Initial Accuracy	V_{OERR}		–6		+6	mV
			–0.29		+0.29	%
Temperature Coefficient	TCV_O	–40°C < T_A < +85°C		5	25	ppm/°C
		0°C < T_A < 70°C		3	21	ppm/°C
Minimum Supply Voltage Headroom	$V_{IN} – V_O$	I_L ≤ 3 mA		300		mV
Line Regulation	$\Delta V_O/\Delta V_{IN}$	V_{IN} = 2.5 V to 15 V				
		–40°C < T_A < +85°C		10	25	ppm/V
Load Regulation	$\Delta V_O/\Delta I_{LOAD}$	V_{IN} = 3 V,				
		I_{LOAD} = 0 mA to 5 mA				
		–40°C < T_A < +85°C			60	ppm/mA
Quiescent Current	I_{IN}	No Load		100	120	µA
		–40°C < T_A < +85°C			140	µA
Voltage Noise	e_N	0.1 Hz to 10 Hz		5		µV p-p
Turn-On Settling Time	t_R			20		µs
Long-Term Stability	ΔV_O	See Figure 1		50		ppm
Output Voltage Hysteresis	V_{O_HYS}			40		ppm
Ripple Rejection Ratio	RRR	f_{IN} = 60 Hz		85		dB
Short Circuit to GND	I_{SC}			30		mA
Shutdown Supply Current	I_{SHDN}				3	µA
Shutdown Logic Input Current	I_{LOGIC}				500	nA
Shutdown Logic Low	V_{INL}				0.8	V
Shutdown Logic High	V_{INH}		2.4			V

Specifications subject to change without notice.

ADR391 SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (@ V_{IN} = 5 V, T_A = 25°C unless otherwise noted).

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	V_O		2.494	2.5	2.506	V
Initial Accuracy	ΔV_{OERR}		–6		+6	mV
			–0.24		+0.24	%
Temperature Coefficient	TCV_O	–40°C < T_A < +85°C		5	25	ppm/°C
		0°C < T_A < 70°C		3	21	ppm/°C
Minimum Supply Voltage Headroom	$V_{IN} - V_O$	$I_L \leq 2$ mA		300		mV
Line Regulation	$\Delta V_O/\Delta V_{IN}$	V_{IN} = 2.8 V to 15 V				
		–40°C < T_A < +85°C		10	25	ppm/V
Load Regulation	$\Delta V_O/\Delta I_{LOAD}$	V_{IN} = 3.5 V,				
		I_{LOAD} = 0 mA to 5 mA				
		–40°C < T_A < +85°C			60	ppm/mA
Quiescent Current	I_{IN}	No Load		100	120	µA
		–40°C < T_A < +85°C			140	µA
Voltage Noise	e_N	0.1 Hz to 10 Hz		5		µV p-p
Turn-On Settling Time	t_R			20		µs
Long-Term Stability	ΔV_O	See Figure 1		50		ppm
Output Voltage Hysteresis	V_{O_HYS}			75		ppm
Ripple Rejection Ratio	RRR	f_{IN} = 60 Hz		85		dB
Short Circuit to GND	I_{SC}			25		mA
Shutdown Supply Current	I_{SHDN}				3	µA
Shutdown Logic Input Current	I_{LOGIC}				500	nA
Shutdown Logic Low	V_{INL}				0.8	V
Shutdown Logic High	V_{INH}		2.4			V

Specifications subject to change without notice.

ELECTRICAL CHARACTERISTICS (@ V_{IN} = 15 V, T_A = 25°C unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	V_O		2.494	2.5	2.506	V
Initial Accuracy	V_{OERR}		–6		+6	mV
			–0.24		+0.24	%
Temperature Coefficient	TCV_O	–40°C < T_A < +85°C		5	25	ppm/°C
		0°C < T_A < 70°C		3	21	ppm/°C
Minimum Supply Voltage Headroom	$V_{IN} - V_O$	$I_L \leq 2$ mA		300		mV
Line Regulation	$\Delta V_O/\Delta V_{IN}$	V_{IN} = 2.8 V to 15 V				
		–40°C < T_A < +85°C		10	25	ppm/V
Load Regulation	$\Delta V_O/\Delta I_{LOAD}$	V_{IN} = 3.5 V,				
		I_{LOAD} = 0 mA to 5 mA				
		–40°C < T_A < +85°C			60	ppm/mA
Quiescent Current	I_{IN}	No Load		100	120	µA
		–40°C < T_A < +85°C			140	µA
Voltage Noise	e_N	0.1 Hz to 10 Hz		5		µV p-p
Turn-On Settling Time	t_R			20		µs
Long-Term Stability	ΔV_O	See Figure 1		50		ppm
Output Voltage Hysteresis	V_{O_HYS}			75		ppm
Ripple Rejection Ratio	RRR	f_{IN} = 60 Hz		85		dB
Short Circuit to GND	I_{SC}			30		mA
Shutdown Supply Current	I_{SHDN}				3	µA
Shutdown Logic Input Current	I_{LOGIC}				500	nA
Shutdown Logic Low	V_{INL}				0.8	V
Shutdown Logic High	V_{INH}		2.4			V

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage . . . . 18 V
Shutdown Logic Level . . . . 18 V
  Or Supply Voltage, Whichever is Lower . . . . 18 V
Output Short-Circuit Duration to GND . . . . Indefinite
Storage Temperature Range
  RT Package . . . . –65°C to +150°C
Operating Temperature Range
  ADR390/ADR391 . . . . –40°C to +85°C
Junction Temperature Range
  RT Package . . . . –65°C to +150°C
Lead Temperature Range (Soldering, 60 sec) . . . . 300°C

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Package Type	θ_{JA}*	θ_{JC}	Unit
5-Lead SOT-23 (RT)	230	–	°C/W

*θ_{JA} is specified for worst-case conditions, i.e., θ_{JA} is specified for device in socket for SOT packages.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option	Top Mark	Output Voltage	Number of Parts Per Reel
ADR390ART–REEL7	–40°C to +85°C	5-Lead SOT	RT-5	R0A	2.048	3,000
ADR390ART–REEL	–40°C to +85°C	5-Lead SOT	RT-5	R0A	2.048	10,000
ADR391ART–REEL7	–40°C to +85°C	5-Lead SOT	RT-5	R1A	2.500	3,000
ADR391ART–REEL	–40°C to +85°C	5-Lead SOT	RT-5	R1A	2.500	10,000

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 ADR390/ADR391 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.

PARAMETER DEFINITION

Temperature Coefficient (TCV_O)

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

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

Where:

$V_O(25°C)$ = V_O at 25°C.

$V_O(T_1)$ = V_O at temperature1.

$V_O(T_2)$ = V_O at temperature2.

Line Regulation ($\Delta V_O/\Delta V_{IN}$)

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 ($\Delta V_O/\Delta I_{LOAD}$)

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 Ω of dc output resistance.

Input Capacitor

Input capacitors are not required on the ADR390/ADR391. 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 ADR390/ADR391 does not need output capacitors for stability under any load condition. An output capacitor, typically 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.

Long Term Stability

Typical shift in output voltage over 1000 hours at a controlled temperature. Figure 1 shows a sample of parts measured at different intervals in a controlled environment of 50°C for 1000 hours.

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

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

Where:

$V_O(t_0)$ = V_O at at time 0.

$V_O(t_1)$ = V_O after 1000 hours operation at a controlled temperature.

Thermal Hysteresis (V_{O_HYS})

The change of output voltage after the device is cycled through temperature from +25°C to –40°C to +85°C and back to +25°C. This is a typical value from a sample of parts put through such a cycle.

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

$$V_{O\_HYS}\left[ppm\right] = \frac{V_O(25°C) - V_{O\_TC}}{V_O(25°C)} \times 10^6$$

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 +85°C and back to +25°C.

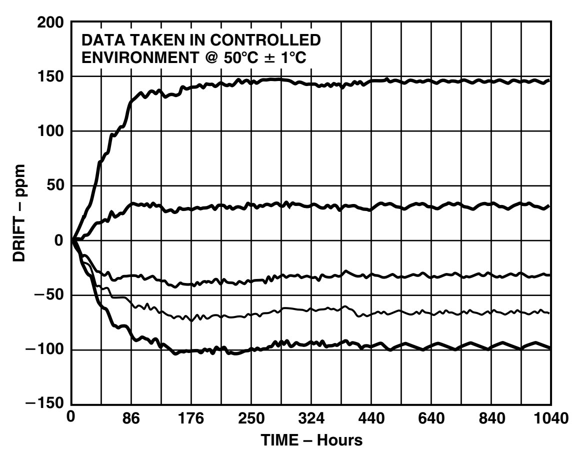
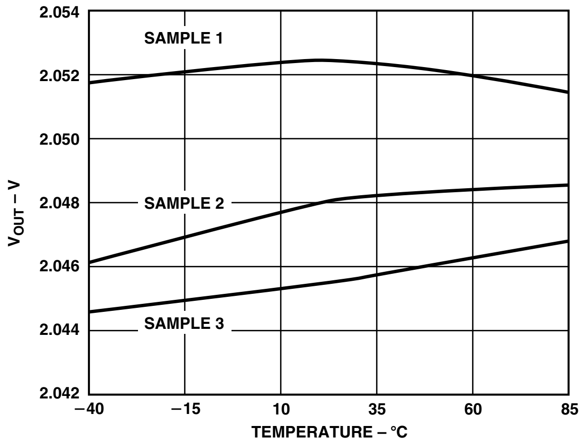
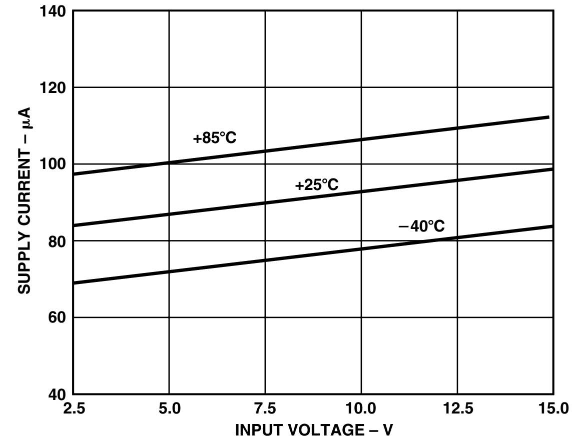


Figure 1. ADR391 Typical Long-Term Drift over 1000 Hours

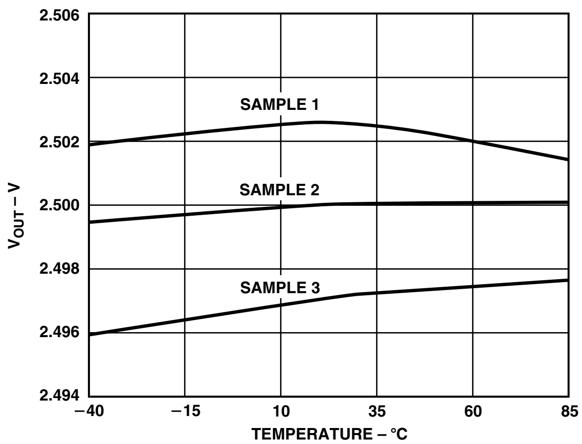
ADR390/ADR391–Typical Performance Characteristics



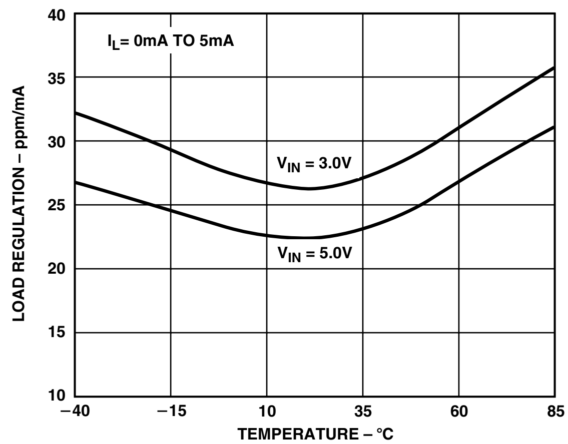
TPC 1. ADR390 Output Voltage vs. Temperature



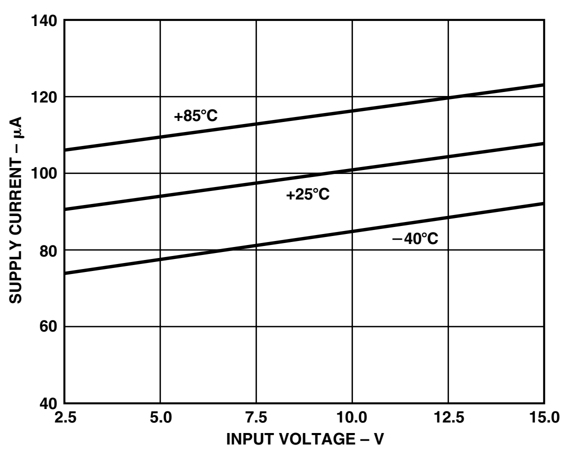
TPC 4. ADR391 Supply Current vs. Input Voltage



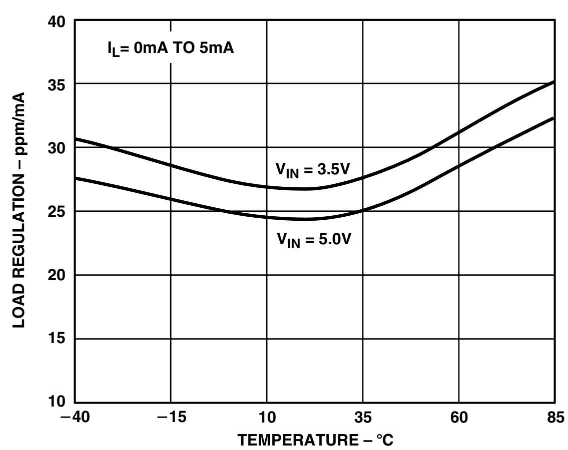
TPC 2. ADR391 Output Voltage vs. Temperature



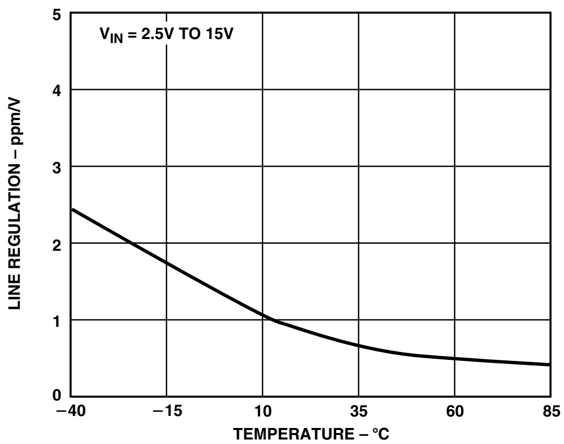
TPC 5. ADR390 Load Regulation vs. Temperature



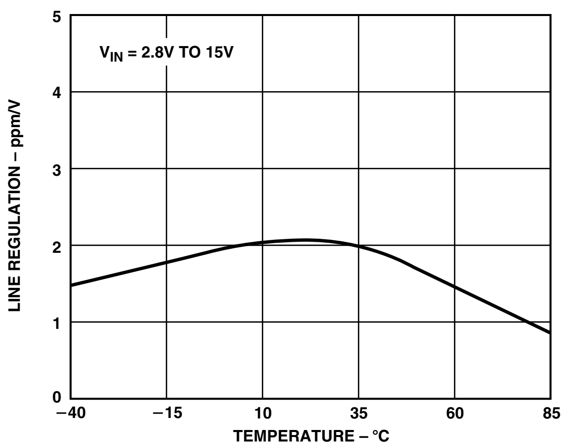
TPC 3. ADR390 Supply Current vs. Input Voltage



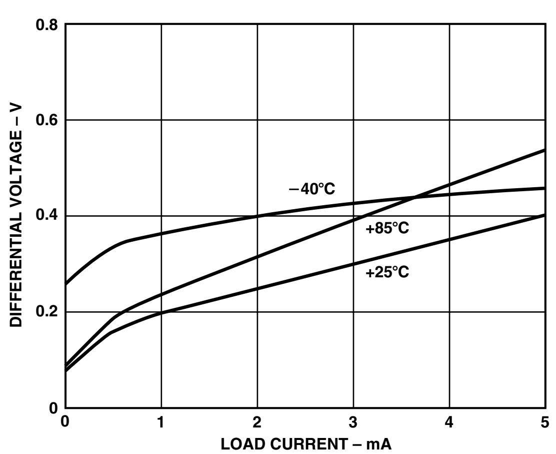
TPC 6. ADR391 Load Regulation vs. Temperature



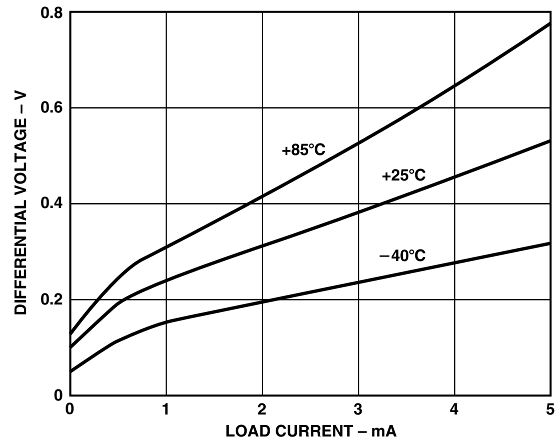
TPC 7. ADR390 Line Regulation vs. Temperature



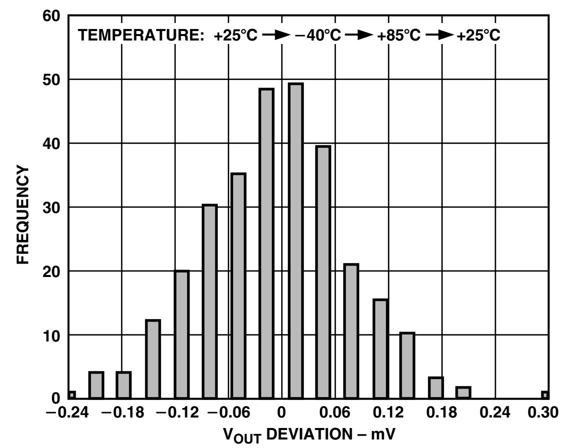
TPC 8. ADR391 Line Regulation vs. Temperature



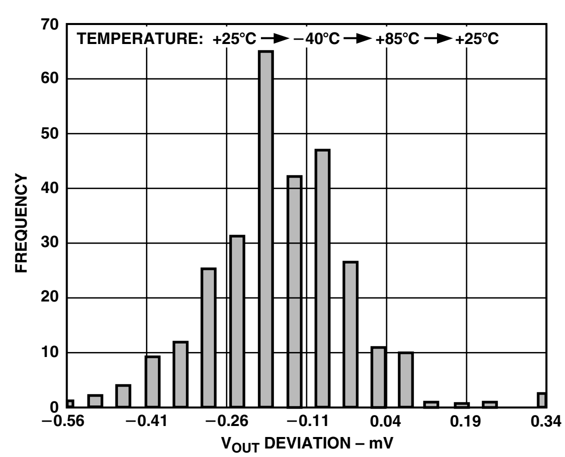
TPC 9. ADR390 Minimum Input-Output Voltage Differential vs. Load Current



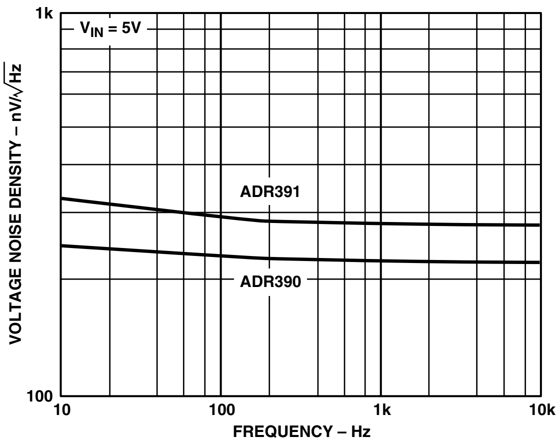
TPC 10. ADR391 Minimum Input-Output Voltage Differential vs. Load Current



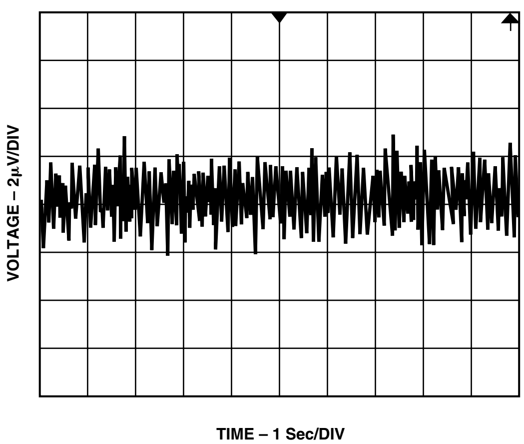
TPC 11. ADR390 V_{OUT} Hysteresis Distribution



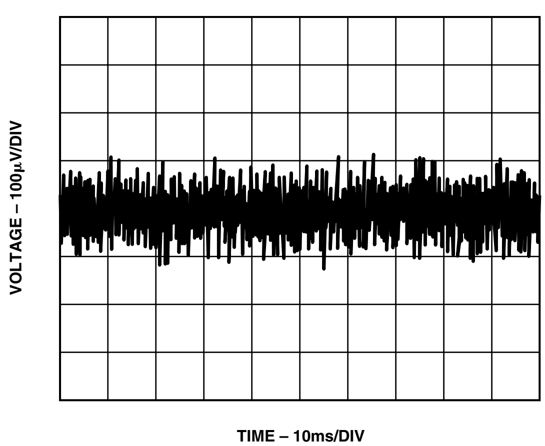
TPC 12. ADR391 V_{OUT} Hysteresis Distribution



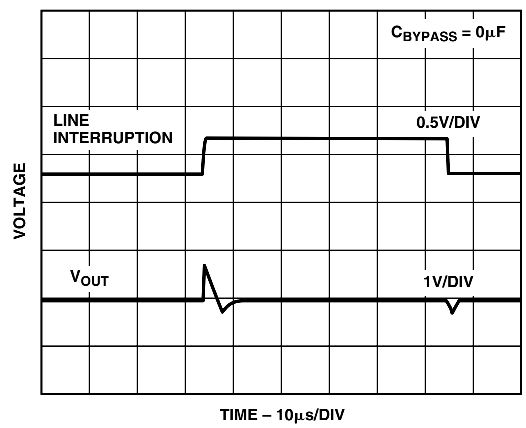
TPC 13. Voltage Noise Density vs. Frequency



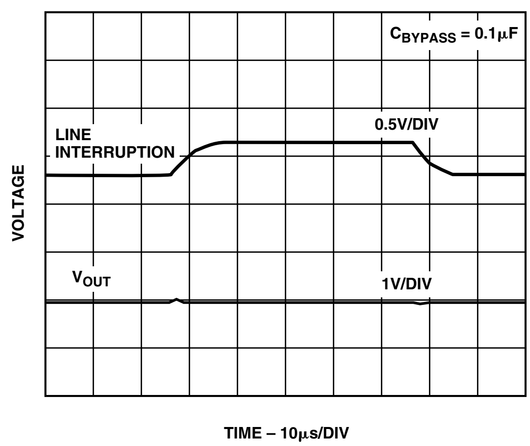
TPC 14. ADR391 Typical Voltage Noise 0.1 Hz to 10 Hz



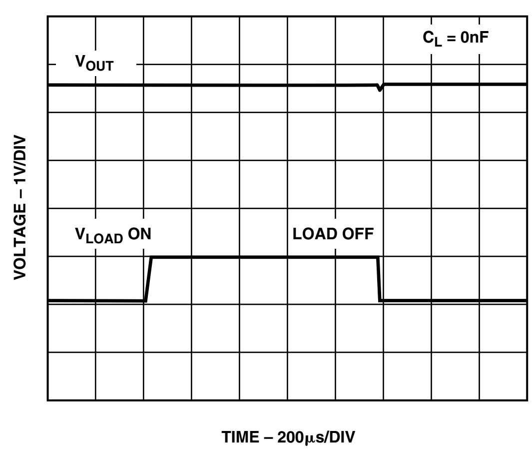
TPC 15. ADR391 Voltage Noise 10 Hz to 10 kHz



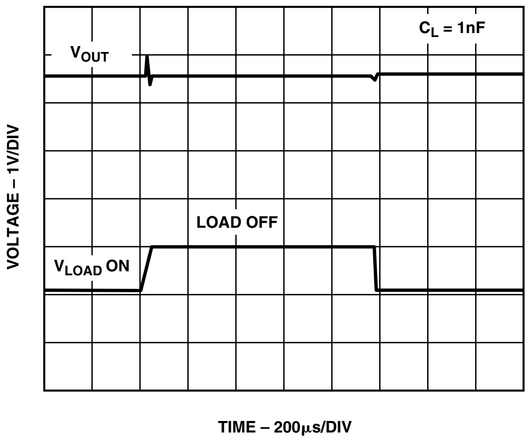
TPC 16. ADR391 Line Transient Response



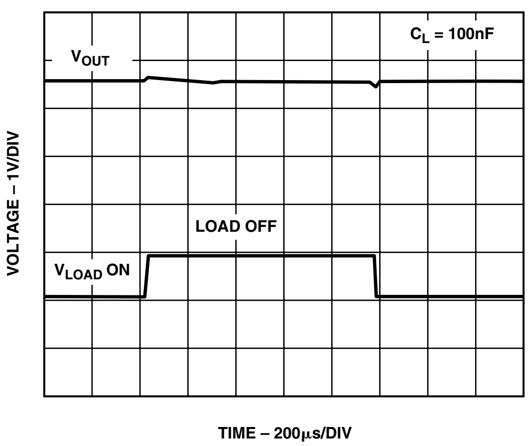
TPC 17. ADR391 Line Transient Response



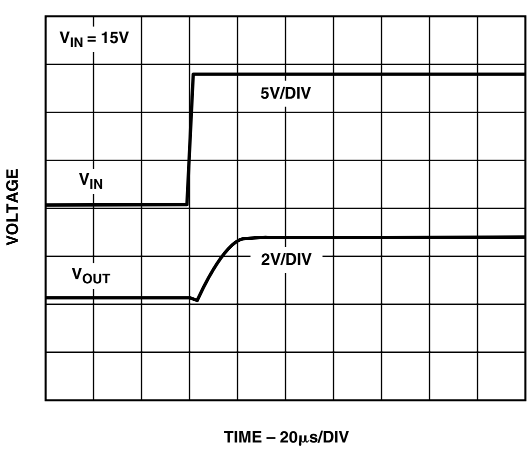
TPC 18. ADR391 Load Transient Response



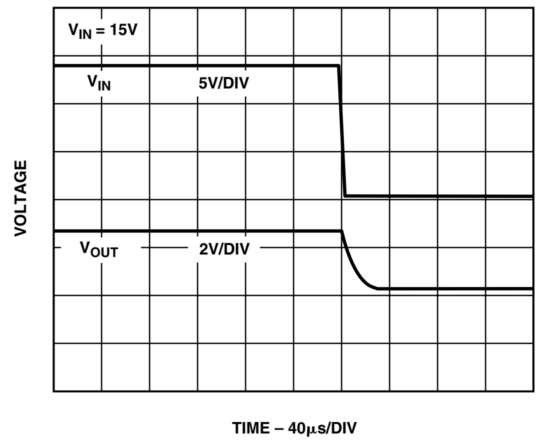
TPC 19. ADR391 Load Transient Response



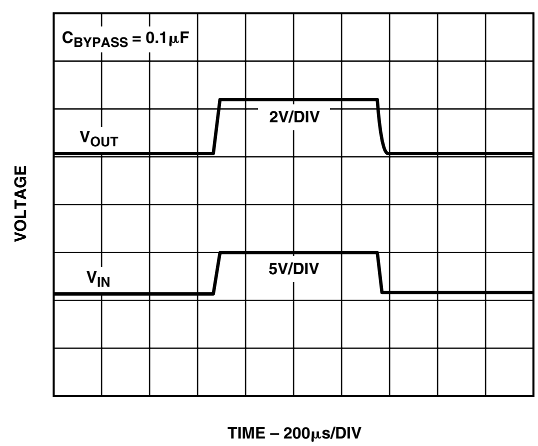
TPC 20. ADR391 Load Transient Response



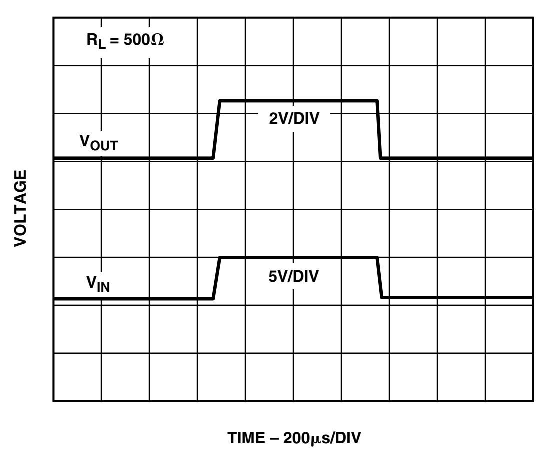
TPC 21. ADR391 Turn-On Response Time at 15 V



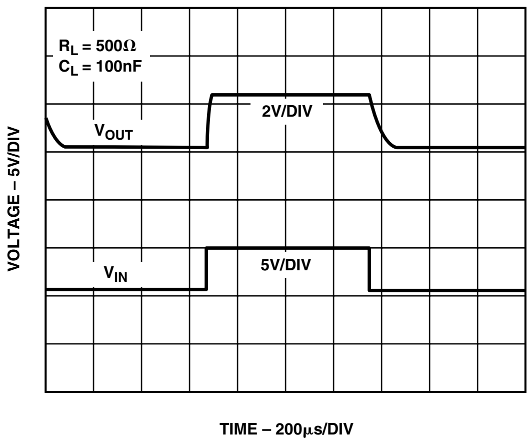
TPC 22. ADR391 Turn-Off Response at 15 V



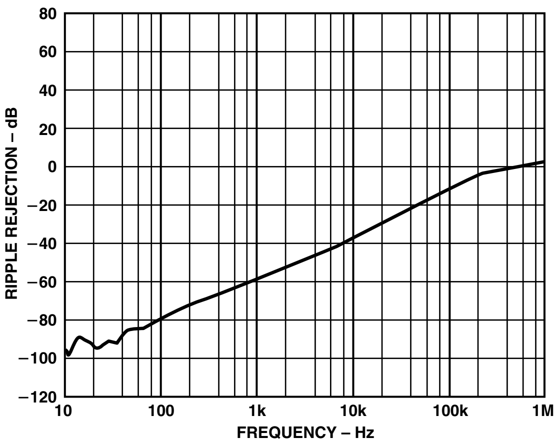
TPC 23. ADR391 Turn-On/Turn-Off Response at 5 V



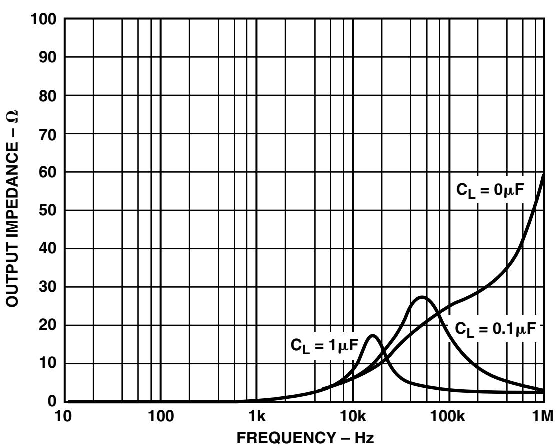
TPC 24. ADR391 Turn-On/Turn-Off Response at 5 V



TPC 25. ADR391 Turn-On/Turn-Off Response at 5 V



TPC 26. Ripple Rejection vs. Frequency



TPC 27. Output Impedance vs. Frequency

THEORY OF OPERATION

Bandgap references are the high-performance solution for low supply voltage and low power voltage reference applications, and the ADR390/ADR391 is no exception. The uniqueness of this product lies in its architecture. By observing Figure 2, the ideal zero TC bandgap voltage is referenced to the output, not to ground. Therefore, if noise exists on the ground line, it will be greatly attenuated on V_{OUT}. The bandgap cell consists of the pnp pair Q51 and Q52, running at unequal current densities. The difference in V_{BE} results in a voltage with a positive TC which is amplified up by the ratio of $2\times\frac{R58}{R54}$. This PTAT voltage, combined with V_{BE}s of Q51 and Q52 produce the stable bandgap voltage.

Reduction in the bandgap curvature is performed by the ratio of the resistors R44 and R59, one of which is linearly temperature dependent. Precision laser trimming and other patented circuit techniques are used to further enhance the drift performance.

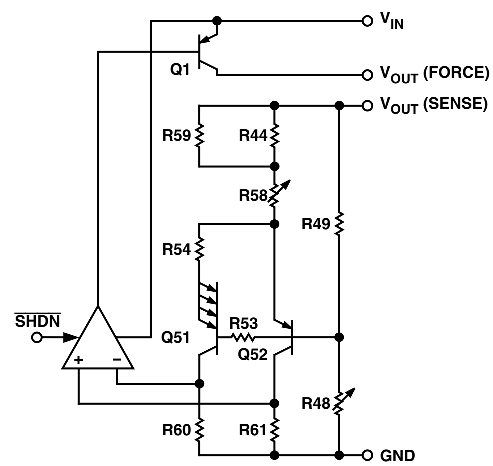


Figure 2. Simplified Schematic

Device Power Dissipation Considerations

The ADR390/ADR391 is capable of delivering load currents to 5 mA with an input voltage that ranges from 2.8 V (ADR391 only) to 15 V. When this device is used in applications with large input voltages, care should be taken to avoid exceeding the specified 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, respectively, the junction and ambient temperatures, P_D is the device power dissipation, and θ_{JA} is the device package thermal resistance.

Shutdown Mode Operation

The ADR390/ADR391 includes a shutdown feature that is TTL/CMOS level compatible. A logic LOW or a zero volt condition on the $\overline{SHDN}$ pin is required to turn the device off. During shutdown, the output of the reference becomes a high impedance state where its potential would then be determined by external circuitry. If the shutdown feature is not used, the $\overline{SHDN}$ pin should be connected to V_{IN} (Pin 2).

APPLICATIONS

BASIC VOLTAGE REFERENCE CONNECTION

The circuit in Figure 3 illustrates the basic configuration for the ADR39x family. Decoupling capacitors are not required for circuit stability. The ADR39x family is capable of driving capacitive loads from 0 µF to 10 µF. However, a 0.1 µF ceramic output capacitor is recommended to absorb and deliver the charge as is required by a dynamic load.

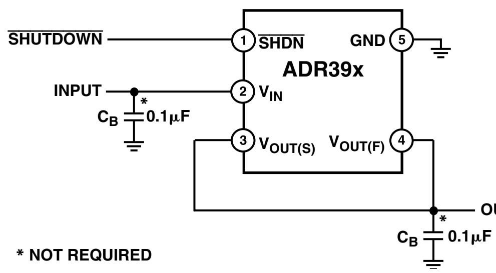


Figure 3.

Stacking Reference ICs for Arbitrary Outputs

Some applications may require two reference voltage sources which are a combined sum of standard outputs. The following circuit shows how this "stacked output" reference can be implemented:

OUTPUT TABLE

U1/U2	V_{OUT1} (V)	V_{OUT2} (V)
ADR390/ADR390	2.048	4.096
ADR391/ADR391	2.5	5.0

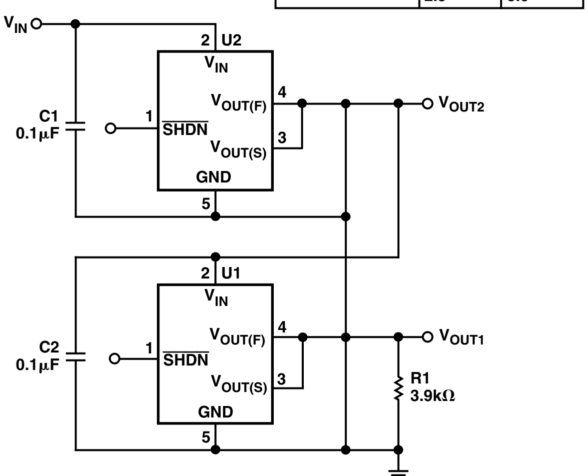


Figure 4. Stacking Voltage References with the ADR390/ADR391

Two reference ICs are used, fed from an unregulated input, V_{IN}. The outputs of the individual ICs are simply connected in series which provides two output voltages V_{OUT1} and V_{OUT2}. V_{OUT1} is the terminal voltage of U1, while V_{OUT2} is the sum of this voltage and the terminal voltage of U2. U1 and U2 are simply chosen for the two voltages that supply the required outputs (see Output Table). For example, if both U1 and U2 are ADR391s, V_{OUT1} is 2.5 V and V_{OUT2} is 5.0 V.

While this concept is simple, a precaution is in order. Since the lower reference circuit must sink a small bias current from U2, plus the base current from the series PNP output transistor in U2, either the external load of U1 or R1 must provide a path for this current. If the U1 minimum load is not well defined, the resistor R1 should be used, set to a value that will conservatively pass 600 µA of current with the applicable V_{OUT1} across it. Note that the two U1 and U2 reference circuits are locally treated as macrocells, each having its own bypasses at input and output for best stability. Both U1 and U2 in this circuit can source dc currents up to their full rating. The minimum input voltage, $V_{IN,}$ is determined by the sum of the outputs, V_{OUT2}, plus the dropout voltage of U2.

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 this approach is that the largest single source of error in the circuit is the relative matching of the resistors used.

A Negative Precision Reference without Precision Resistors

A negative reference can be easily generated by adding an op amp, A1 and configured as Figure 5 below. V_{OUTF} and V_{OUTS} are 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 rail-to-rail if the negative supply voltage is close to the reference output.

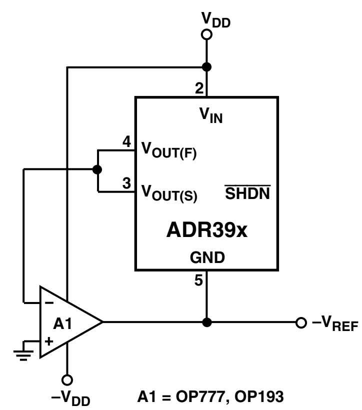


Figure 5.

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 the following figure, the ADR390/ADR391 can be 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 90 µA to approximately 5 mA.

The ADR390/ADR391 includes a shutdown feature that is TTL/CMOS level compatible. A logic LOW or a zero volt condition on the $\overline{SHDN}$ pin is required to turn the device off. During shutdown, the output of the reference becomes a high-impedance state where its potential would then be determined by the external circuitry. If the shutdown feature is not used, the $\overline{SHDN}$ pin should be connected to V_{IN} (Pin 2).

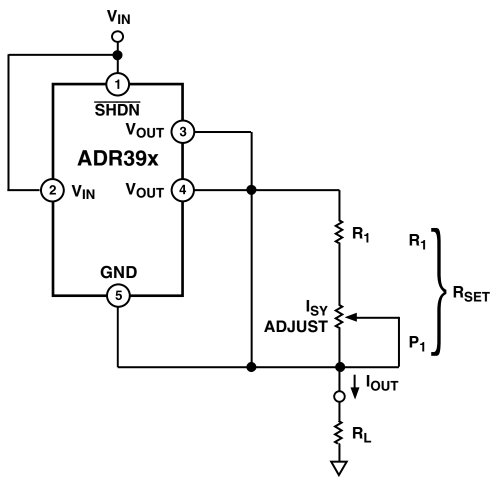


Figure 6. A Precision Current Source

High-Power Performance with Current Limit

In some cases, the user may want higher output current delivered to a load and still achieve better than 0.5% accuracy out of the ADR390/ADR391. The accuracy for a reference is normally specified on the data sheet with no load. However, the output voltage changes with load current.

The circuit below provides high current without compromising the accuracy of the ADR390/ADR391. The series pass transistor Q1 provides up to 1 A load current. The ADR390/ADR391 delivers only the base drive to Q1 through the force pin. The sense pin of the ADR390/ADR391 is a regulated output and is connected to the load.

The transistor Q2 protects Q1 during short circuit limit faults by robbing its base drive. The maximum current is $I_{LMAX} \approx 0.6\ V/R_S$.

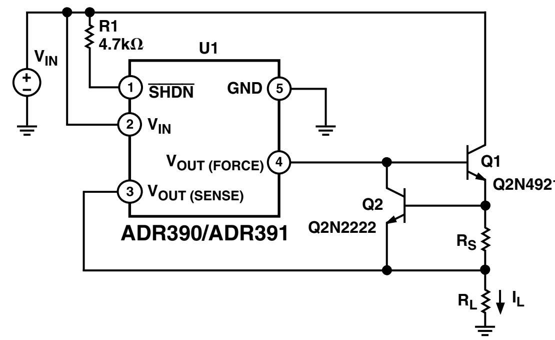


Figure 7. ADR390/ADR391 for High-Power Performance with Current Limit

A similar circuit function can also be achieved with the Darlington transistor configuration, see Figure 8.

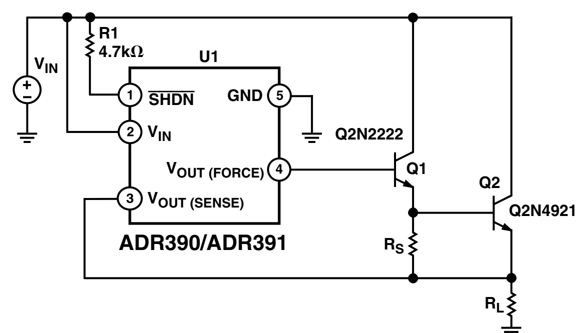


Figure 8. ADR390/ADR391 High Output Current with Darlington Drive Configuration

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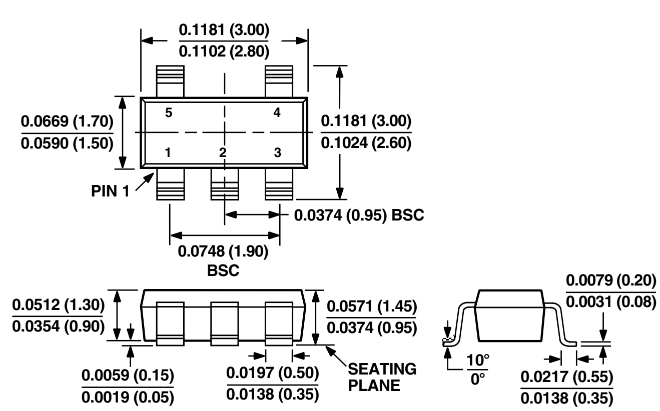
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

5-Lead SOT-23
(RT Suffix)



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