ANALOG DEVICES

2.5 V/3.0 V
High Precision Reference

AD780

FEATURES

Pin-Programmable 2.5 V or 3.0 V Output
Ultralow Drift: 3 ppm/°C max
High Accuracy: 2.5 V or 3.0 V ± 1 mV max
Low Noise: 100 nV/$\sqrt{Hz}$
Noise Reduction Capability
Low Quiescent Current: 1 mA max
Output Trim Capability
Plug-In Upgrade for Present References
Temperature Output Pin
Series or Shunt Mode Operation (±2.5 V, ±3.0 V)

PRODUCT DESCRIPTION

The AD780 is an ultrahigh precision bandgap reference voltage which provides a 2.5 V or 3.0 V output from inputs between 4.0 V and 36 V. Low initial error and temperature drift combined with low output noise and the ability to drive any value of capacitance make the AD780 the ideal choice for enhancing the performance of high resolution ADCs and DACs and for any general purpose precision reference application. A unique low headroom design facilitates a 3.0 V output from a 5.0 V ± 10% input, providing a 20% boost to the dynamic range of an ADC, over performance with existing 2.5 V references.

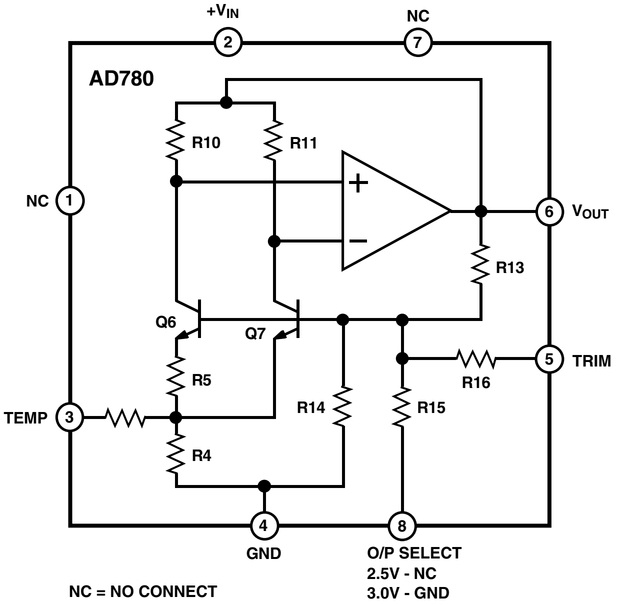
The AD780 can be used to source or sink up to 10 mA and can be used in series or shunt mode, thus allowing positive or negative output voltages without external components. This makes it suitable for virtually any high performance reference application. Unlike some competing references, the AD780 has no "region of possible instability." The part is stable under all load conditions when a 1 µF bypass capacitor is used on the supply.

A temperature output pin is provided on the AD780. This provides an output voltage that varies linearly with temperature, allowing the AD780 to be configured as a temperature transducer while providing a stable 2.5 V or 3.0 V output.

The AD780 is a pin-compatible performance upgrade for the LT1019(A)–2.5 and the AD680. The latter is targeted toward low power applications.

The AD780 is available in three grades in plastic DIP, SOIC, and cerdip packages. The AD780AN, AD780AR, AD780BN, AD780BR, and AD780CR are specified for operation from –40°C to +85°C.

FUNCTIONAL BLOCK DIAGRAM



PRODUCT HIGHLIGHTS

1. The AD780 provides a pin-programmable 2.5 V or 3.0 V output from a 4 V to 36 V input.
2. Laser trimming of both initial accuracy and temperature coefficients results in low errors over temperature without the use of external components. The AD780BN has a maximum variation of 0.9 mV from –40°C to +85°C.
3. For applications requiring even higher accuracy, an optional fine-trim connection is provided.
4. The AD780 noise is extremely low, typically 4 µV p-p from 0.1 Hz to 10 Hz and a wideband spectral noise density of typically 100 nV/$\sqrt{Hz}$. This can be further reduced if desired, by simply using two external capacitors.
5. The temperature output pin enables the AD780 to be configured as a temperature transducer while providing a stable output reference voltage.

REV. B

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AD780–SPECIFICATIONS (T_A = +25°C, V_{IN} = +5 V unless otherwise noted)

	AD780AN/AR			AD780CR			AD780BN/BR			
Parameter	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Unit
OUTPUT VOLTAGE										
2.5 V Out	2.495		2.505	2.4985		2.5015	2.499		2.501	Volts
3.0 V Out	2.995		3.005	2.9950		3.0050	2.999		3.001	Volts
OUTPUT VOLTAGE DRIFT[1]										
–40°C to +85°C			7			7			3	ppm/°C
–55°C to +125°C			20			20				ppm/°C
LINE REGULATION										
2.5 V Output, 4 V ≤ +V_{IN} ≤ 36 V										
T_{MIN} to T_{MAX}			10			*			*	µV/V
3.0 V Output, 4.5 V ≤ +V_{IN} ≤ 36 V										
T_{MIN} to T_{MAX}			10			*			*	µV/V
LOAD REGULATION, SERIES MODE										
Sourcing 0 < I_{OUT} < 10 mA			50			*			*	µV/mA
T_{MIN} to T_{MAX}			75			*			*	µV/mA
Sinking –10 < I_{OUT} < 0 mA			75			*			*	µV/mA
–40°C to +85°C			75			*			*	µV/mA
–55°C to +125°C			150			*			*	µV/mA
LOAD REGULATION, SHUNT MODE										
I < I_{SHUNT} < 10 mA			75			*			*	µV/mA
QUIESCENT CURRENT, 2.5 V SERIES MODE[2]										
–40°C to +85°C		0.75	1.0		*	*		*	*	mA
–55°C to +125°C		0.8	1.3		*	*		*	*	mA
MINIMUM SHUNT CURRENT		0.7	1.0		*	*		*	*	mA
OUTPUT NOISE										
0.1 Hz to 10 Hz		4			*	*		*	*	µV p-p
Spectral Density, 100 Hz		100			*	*		*	*	nV/√Hz
LONG TERM STABILITY[3]		20			*			*		±ppm/ 1000 Hr
TRIM RANGE	4.0			*			*			±%
TEMPERATURE PIN										
Voltage Output @ 25°C	500	560	620	*	*	*	*	*	*	mV
Temperature Sensitivity		1.9			*			*		mV/°C
Output Resistance		3			*			*		kΩ
SHORT CIRCUIT CURRENT TO GROUND		30			*			*		mA
TEMPERATURE RANGE										
Specified Performance (A, B, C)	–40		+85	*		*	*		*	°C
Operating Performance (A, B, C)[4]	–55		+125	*		*	*		*	°C
Specified Performance (S)	–55		+125	*		*	*		*	°C
Operating Performance (S)	–55		+125	*		*	*		*	°C

NOTES

[1] Maximum output voltage drift is guaranteed for all packages.

[2] 3.0 V mode typically adds 100 µA to the quiescent current. Also, Iq increases by 2 µA/V above an input voltage of 5 V.

[3] The long term stability specification is noncumulative. The drift in subsequent 1000 hr. periods is significantly lower than in the first 1000 hr. period.

[4] The operating temperature range is defined as the temperature extremes at which the device will still function. Parts may deviate from their specified performance outside their specified temperature range.

*Same as AD780AN/AR specification.

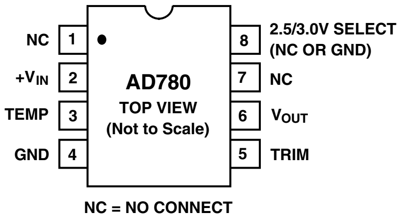
Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

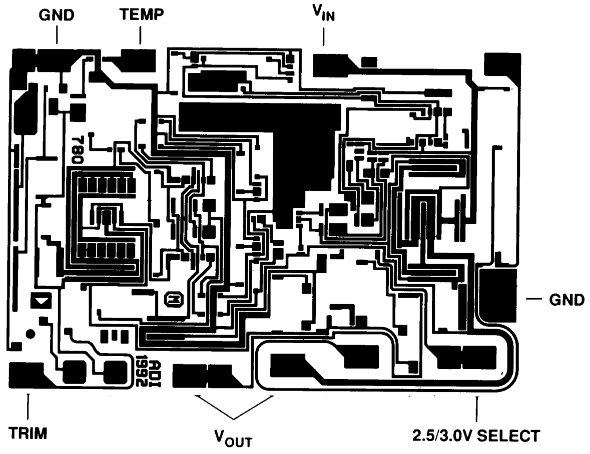
V_{IN} to Ground . . . . 36 V
Trim Pin to Ground . . . . 36 V
Temp Pin to Ground . . . . 36 V
Power Dissipation (25°C) . . . . 500 mW
Storage Temperature . . . . –65°C to +150°C
Lead Temperature (Soldering, 10 sec) . . . . 300°C
Output Protection: Output safe for indefinite short to ground and momentary short to V_{IN}.
ESD Classification . . . . Class 1 (1000 V)

*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 conditions above those indicated in the operational specification is not implied. Exposure to absolute maximum specifications for extended periods may affect device reliability.

PIN CONFIGURATION
8-Lead Plastic DIP, SOIC and Cerdip Packages



DIE LAYOUT



DIE SIZE = 0.096 x 0.067 INCHES

NOTES
Both V_{OUT} pads should be connected to the output
Die Thickness: The standard thickness of Analog Devices Bipolar dice is 24 mils ±2 mils.
Die Dimensions: The dimensions given have a tolerance of ±2 mils.
Backing: The standard backside surface is silicon (not plated). Analog Devices does not recommend gold-backed dice for most applications.
Edges: A diamond saw is used to separate wafers into dice thus providing perpendicular edges half-way through the die.

In contrast to scribed dice, this technique provides a more uniform die shape and size. The perpendicular edges facilitate handling (such as tweezer pick-up) while the uniform shape and size simplifies substrate design and die attach.
Top Surface: The standard top surface of the die is covered by a layer of glassivation. All areas are covered except bonding pads and scribe lines.
Surface Metalization: The metalization to Analog Devices bipolar dice is aluminum. Minimum thickness is 10,000Å.
Bonding Pads: All bonding pads have a minimum size of 4.0 mils by 6.0 mils. The passivation windows have a 3.6 mils by 5.6 mils minimum size.

ORDERING GUIDE

Model	Initial Error	Temperature Range	Temperature Coefficient	Package Options
AD780AN	±5.0 mV	–40°C to +85°C	7 ppm/°C	Plastic Dip
AD780AR	±5.0 mV	–40°C to +85°C	7 ppm/°C	SOIC
AD780AR-REEL7	±5.0 mV	–40°C to +85°C	7 ppm/°C	SOIC
AD780BN	±1.0 mV	–40°C to +85°C	3 ppm/°C	Plastic Dip
AD780BR	±1.0 mV	–40°C to +85°C	3 ppm/°C	SOIC
AD780BR-REEL	±1.0 mV	–40°C to +85°C	3 ppm/°C	SOIC
AD780BR-REEL7	±1.0 mV	–40°C to +85°C	3 ppm/°C	SOIC
AD780CR	±1.5 mV	–40°C to +85°C	7 ppm/°C	SOIC
AD780CR-REEL7	±1.5 mV	–40°C to +85°C	7 ppm/°C	SOIC

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 AD780 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.

WARNING!
ESD SENSITIVE DEVICE

THEORY OF OPERATION

Bandgap references are the high performance solution for low supply voltage and low power voltage reference applications. In this technique a voltage with a positive temperature coefficient is combined with the negative coefficient of a transistor's Vbe to produce a constant *bandgap* voltage.

In the AD780, the bandgap cell contains two npn transistors (Q6 and Q7) which differ in emitter area by 12×. The difference in their Vbe's produces a PTAT current in R5. This in turn produces a PTAT voltage across R4, which when combined with the Vbe of Q7, produces a voltage Vbg that does not vary with temperature. Precision laser trimming of the resistors and other patented circuit techniques are used to further enhance the drift performance.

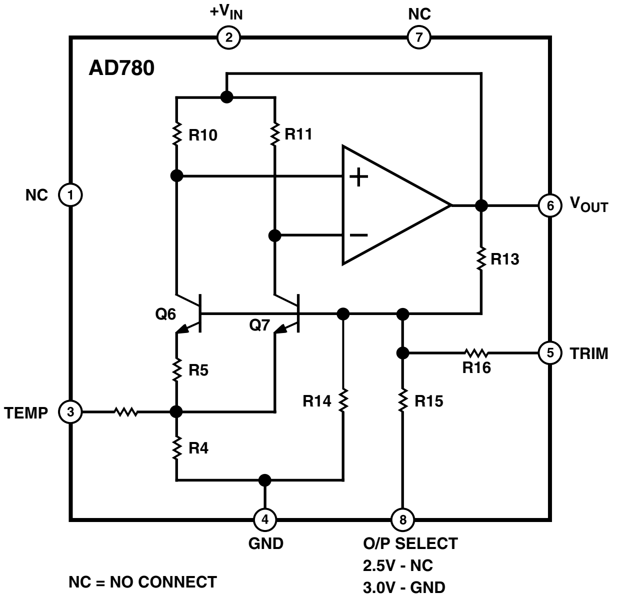


Figure 1. Schematic Diagram

The output voltage of the AD780 is determined by the configuration of resistors R13, R14 and R15 in the amplifier's feedback loop. This sets the output to either 2.5 V or 3.0 V depending on whether R15 (Pin 8) is grounded or not connected.

A unique feature of the AD780 is the low headroom design of the high gain amplifier which produces a precision 3 V output from an input voltage as low as 4.5 V (or 2.5 V from a 4.0 V input). The amplifier design also allows the part to work with $V_{IN} = V_{OUT}$ when current is forced into the output terminal. This allows the AD780 to work as a two terminal shunt regulator providing a –2.5 V or –3.0 V reference voltage output without external components.

The PTAT voltage is also used to provide the user with a thermometer output voltage (at Pin 3) which increases at a rate of approximately 2 mV/°C.

The AD780's NC Pin 7 is a 20 kΩ resistor to V+ which is used solely for production test purposes. Users who are currently using the LT1019 self-heater pin (Pin 7) must take into account the different load on the heater supply.

APPLYING THE AD780

The AD780 can be used without any external components to achieve specified performance. If power is supplied to Pin 2 and Pin 4 is grounded, Pin 6 provides a 2.5 V or 3.0 V output depending on whether Pin 8 is left unconnected or grounded.

A bypass capacitor of 1 µF (V_{IN} to GND) should be used if the load capacitance in the application is expected to be greater than 1 nF. The AD780 in 2.5 V mode typically draws 700 µA of Iq at 5 V. This increases by ~2 µA/V up to 36 V.

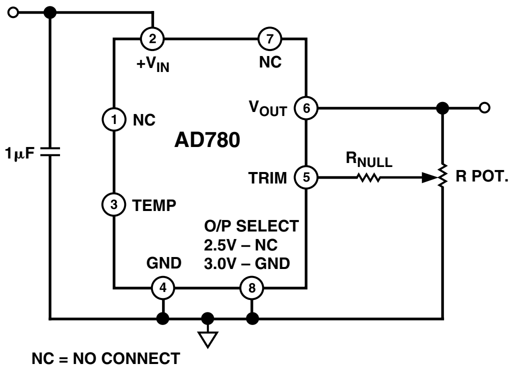


Figure 2. Optional Fine Trim Circuit

Initial error can be nulled using a single 25 kΩ potentiometer connected between V_{OUT}, Trim and GND. This is a coarse trim with an adjustment range of ±4% and is only included here for compatibility purposes with other references. A fine trim can be implemented by inserting a large value resistor (e.g. 1–5 MΩ) in series with the wiper of the potentiometer. See Figure 2 above. The trim range, expressed as a fraction of the output, is simply greater than or equal to 2.1 kΩ/R_{NULL} for either the 2.5 V or 3.0 V mode.

The external null resistor affects the overall temperature coefficient by a factor equal to the percentage of V_{OUT} nulled.

For example a 1 mV (.03%) shift in the output caused by the trim circuit, with a 100 ppm/°C null resistor will add less than 0.06 ppm/°C to the output drift (0.03% × 200 ppm/°C, since the resistors internal to the AD780 also have temperature coefficients of less than 100 ppm/°C).

NOISE PERFORMANCE

The impressive noise performance of the AD780 can be further improved if desired by the addition of two capacitors: a load capacitor C1 between the output and ground, and a compensation capacitor C2 between the TEMP pin and ground. Suitable values are shown in Figure 3.

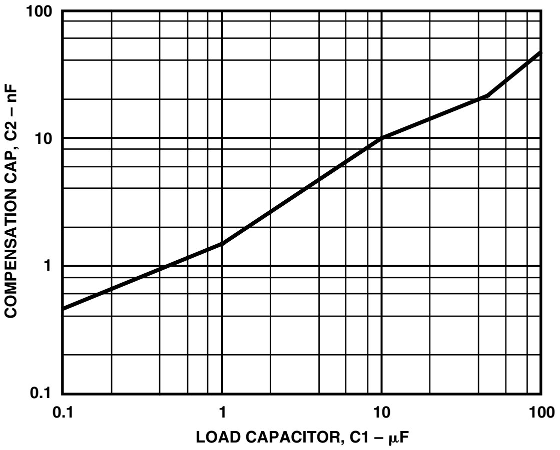


Figure 3. Compensation and Load Capacitor Combinations

C1 and C2 also improve the settling performance of the AD780 when subjected to load transients. The improvement in noise performance is shown in Figures 4, 5 and 6 following.

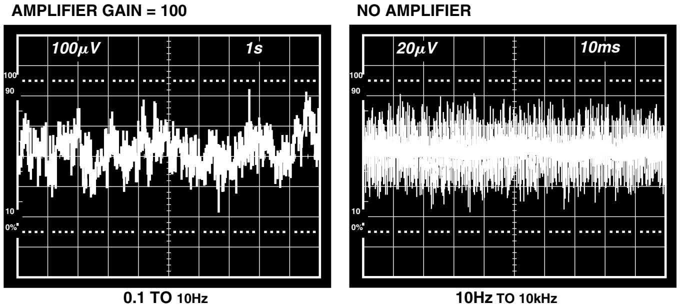


Figure 4. Stand-Alone Noise Performance

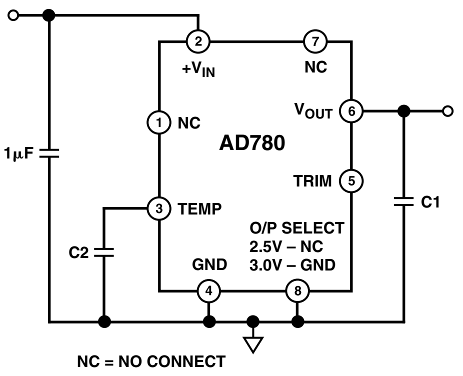


Figure 5. Noise Reduction Circuit

NOISE COMPARISON

The wideband noise performance of the AD780 can also be expressed in ppm. The typical performance with C1, C2 is 0.6 ppm and without external capacitors is 1.2 ppm.

This performance is respectively 7× and 3× lower than the specified performance of the LT1019.

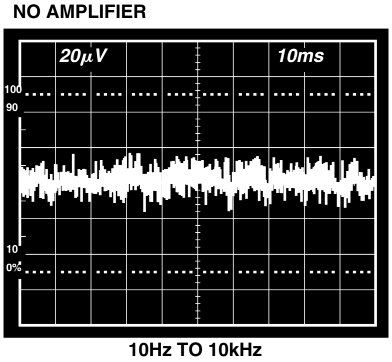


Figure 6. Reduced Noise Performance with C1 = 100 µF, C2 = 100 nF

TEMPERATURE PERFORMANCE

The AD780 provides superior performance over temperature by means of a combination of patented circuit design techniques, precision thin film resistors and drift trimming. Temperature performance is specified in terms of ppm/°C, but because of nonlinearity in the temperature characteristic, the Box-Test method is used to test and specify the part. The nonlinearity takes the form of the characteristic S-shaped curve shown in Figure 7. The Box-Test method forms a rectangular box around this curve, enclosing the maximum and minimum output voltages over the specified temperature range. The specified drift is equal to the slope of the diagonal of this box.

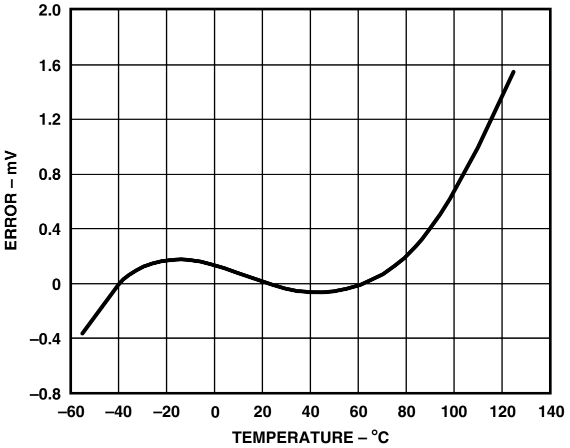


Figure 7. Typical AD780BN Temperature Drift

TEMPERATURE OUTPUT PIN

The AD780 provides a "TEMP" output (Pin 3) that varies linearly with temperature. This output can be used to monitor changes in system ambient temperature and to initiate calibration of the system if desired. The voltage V_{TEMP} is 560 mV at 25°C, and the temperature coefficient is approximately 2 mV/°C. Figure 8 shows the typical V_{TEMP} characteristic curve over temperature taken at the output of the op amp with a noninverting gain of five.

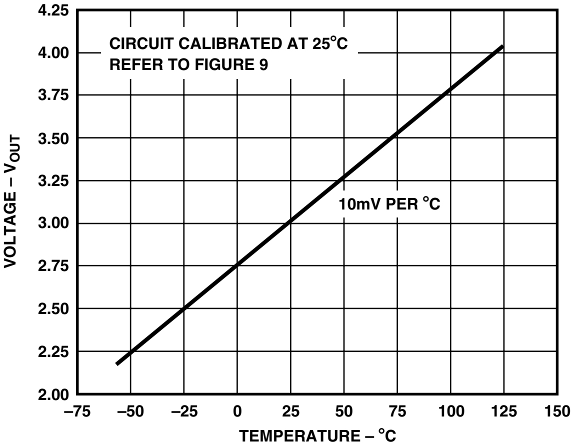


Figure 8. Temperature Pin Transfer Characteristic

Since the TEMP voltage is acquired from the bandgap core circuit, current pulled from this pin will have a significant effect on V_{OUT}. Care *must* be taken to buffer the TEMP output with a suitable op amp, e.g., an OP07, AD820 or AD711 (all of which would result in less than a 100 µV change in V_{OUT}). The relationship between I_{TEMP} and V_{OUT} is as follows:

$$\Delta V_{OUT} = 5.8\ mV/\mu A \times I_{TEMP}\ (2.5\ V\ range)$$

or

$$\Delta V_{OUT} = 6.9\ mV/\mu A \times I_{TEMP}\ (3.0\ V\ range)$$

Notice how sensitive the current dependent factor on V_{OUT} is. A large amount of current, even in tens of microamp, drawn from TEMP pin can cause V_{OUT} and TEMP Output to fail.

The choice of C1 and C2 was dictated primarily by the need for a relatively flat response that rolled off early in the high frequency noise at the output. But there is considerable margin in the choice of these capacitors. For example, the user can actually put a huge C2 on the TEMP pin with none on the output pin. However, one must either put very little or a lot of capacitance at the TEMP pin. Intermediate values of capacitance can sometimes cause oscillation. In any case, the user should follow the recommendation in Figure 3.

TEMPERATURE TRANSDUCER CIRCUIT

The circuit shown in Figure 9 is a temperature transducer which a amplifies the TEMP output voltage by a gain of a little over 5 to provide a wider full scale output range. The trimpot can be used to adjust the output so it varies exactly by 10 mV/°C.

To minimize resistance changes with temperature, resistors with low temperature coefficients, such as metal film resistors should be used.

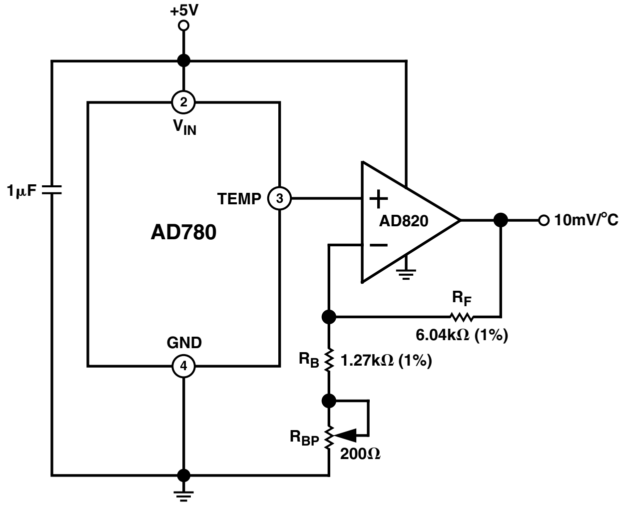


Figure 9. Differential Temperature Transducer

SUPPLY CURRENT OVER TEMPERATURE

The AD780's quiescent current will vary slightly over temperature and input supply range. The test limit is 1 mA over the industrial and 1.3 mA over the military temperature range. Typical performance with input voltage and temperature variation is shown in Figure 10 following.

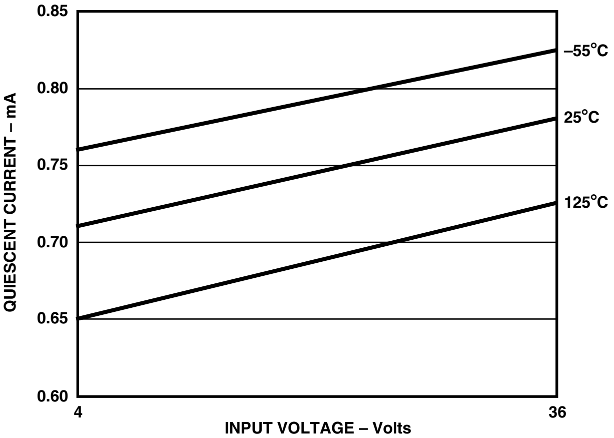


Figure 10. Typical Supply Current over Temperature

TURN-ON TIME

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. The two major factors that affect this are the active circuit settling time and the time for the thermal gradients on the chip to stabilize. Typical settling performance is shown in Figure 11 following. The AD780 settles to within 0.1% of its final value within 10 µs.

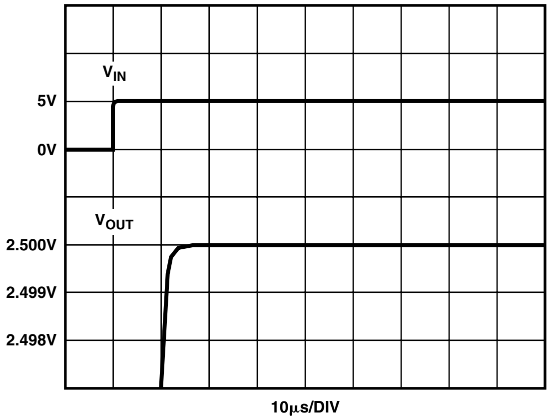


Figure 11. Turn-On Settling Time Performance

DYNAMIC PERFORMANCE

The output stage of the AD780 has been designed to provide superior static and dynamic load regulation.

Figure 12 shows the performance of the AD780 while driving a 0 mA to 10 mA load.

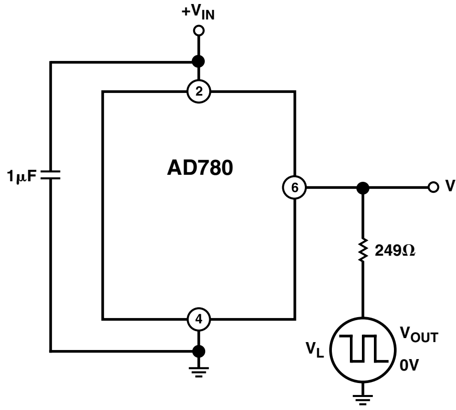


Figure 12a. Transient Resistive Load Test Circuit

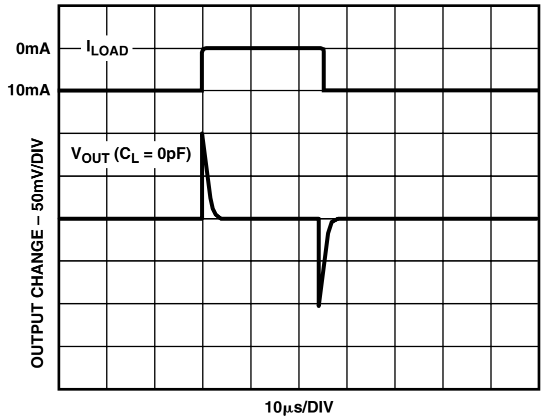


Figure 12b. Settling Under Transient Resistive Load

The dynamic load may be resistive and capacitive. For example the load may be connected via a long capacitive cable. Figure 13 following shows the performance of the AD780 driving a 1000 pF, 0 mA to 10 mA load.

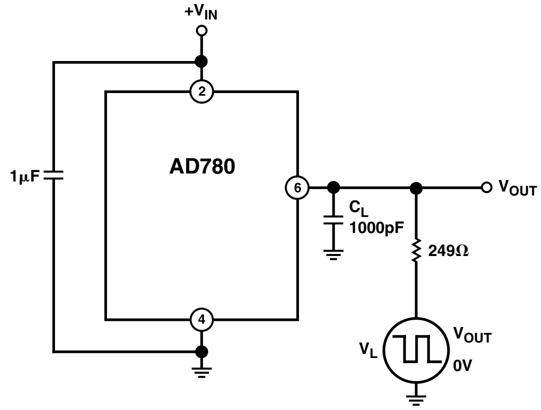


Figure 13a. Capacitive Load Transient Response Test Circuit

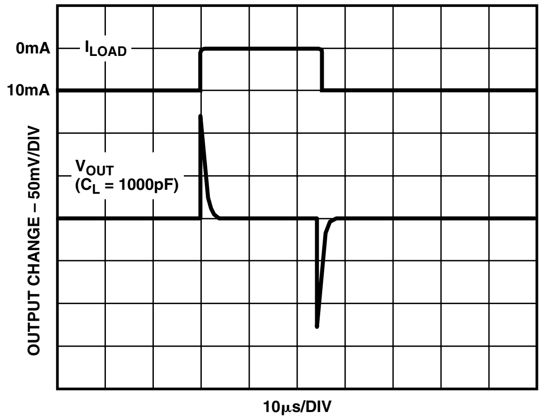


Figure 13b. Settling Under Dynamic Capacitive Load

LINE REGULATION

Line regulation is a measure of the change in output voltage due to a specified change in input voltage. It is intended to simulate worst case unregulated supply conditions and is measured in µV/V. Figure 14 shows typical performance with 4.0 V < V_{IN} < 15.0 V.

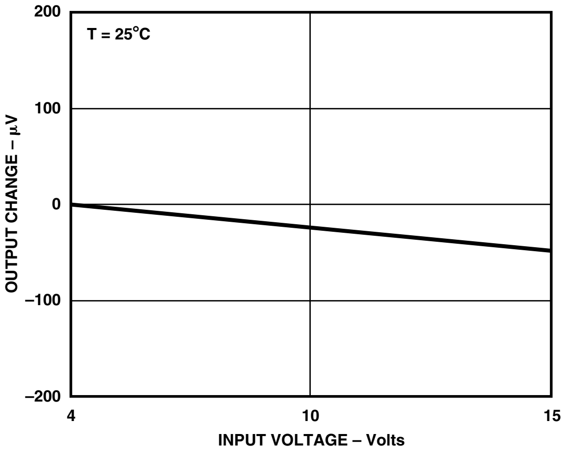


Figure 14. Output Voltage Change vs. Input Voltage

PRECISION REFERENCE FOR HIGH RESOLUTION +5 V DATA CONVERTERS

The AD780 is ideally suited to be the reference for most +5 V high resolution ADCs. The AD780 is stable under any capacitive load, it has superior dynamic load performance, and the 3.0 V output provides the converter with maximum dynamic range without requiring an additional and expensive buffer amplifier. One of the many ADCs that the AD780 is suited for is the AD7884, a 16-bit, high speed sampling ADC. (See Figure 15.) This part previously needed a precision 5.0 V reference, resistor divider and buffer amplifier to do this function.

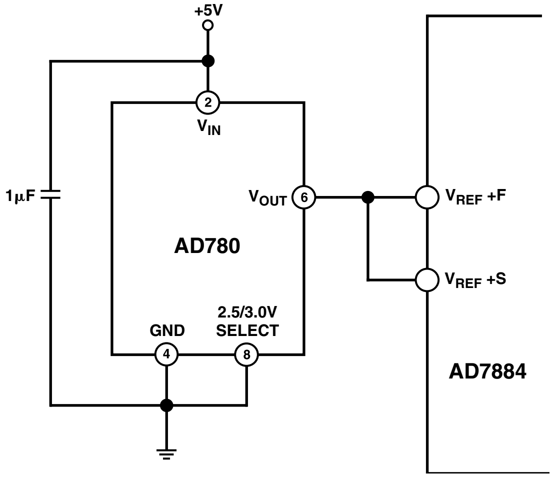


Figure 15. Precision 3.0 V Reference for the AD7884 16-Bit, High Speed ADC

The AD780 is also ideal for use with higher resolution converters such as the AD7710/AD7711/AD7712. (See Figure 16.) While these parts are specified with a 2.5 V internal reference, the AD780 in 3 V mode can be used to improve the absolute accuracy, temperature stability and dynamic range. It is shown following with the two optional noise reduction capacitors.

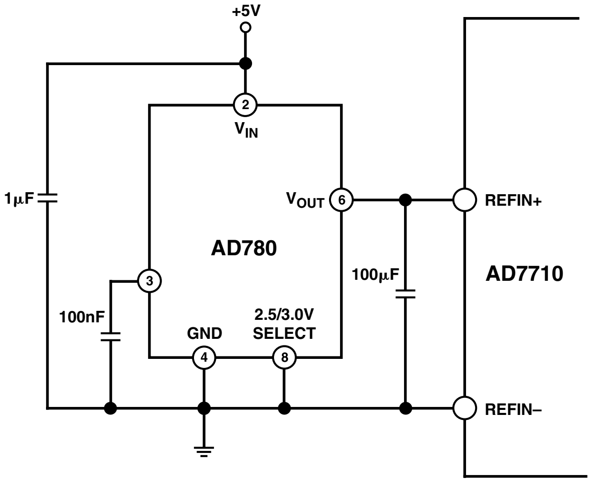


Figure 16. Precision 2.5 V or 3.0 V Reference for the AD7710 High Resolution, Sigma-Delta ADC

+4.5 V REFERENCE FROM +5 V SUPPLY

Some +5 V high resolution ADCs can accommodate reference voltages up to +4.5 V. The AD780 can be used to provide a precision +4.5 V reference voltage from a +5 V supply using the circuit shown following in Figure 17. This circuit will provide a regulated +4.5 V output from a supply voltage as low as +4.7 V. The high quality tantalum 10 µF capacitor in parallel with the ceramic 0.1 µF capacitor and the 3.9 Ω resistor ensure a low output impedance up to around 50 MHz.

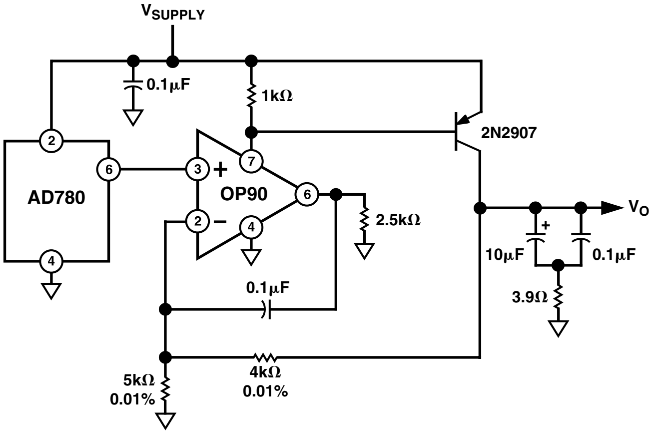


Figure 17. +4.5 V Reference from a Single +5 V Supply

NEGATIVE (–2.5 V OR –3.0 V) REFERENCE

The AD780 can produce a negative output voltage in shunt mode, simply by connecting the input and output to ground connecting the AD780's GND pin to a negative supply via a bias resistor as shown in Figure 18.

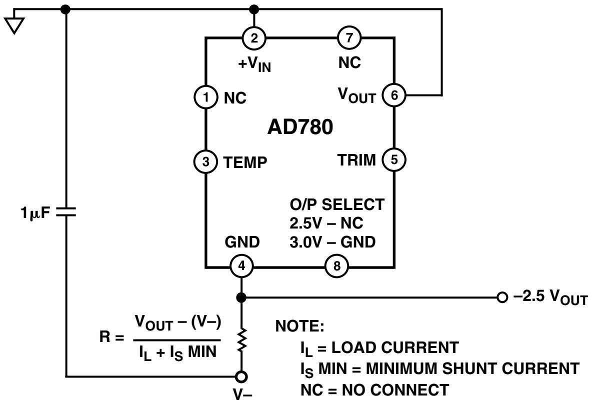


Figure 18. Negative (–2.5 V) Shunt Mode Reference

A precise –2.5 V (or –3.0 V) reference capable of supplying up to 100 mA to a load can be implemented with the AD780 in series mode using the bootstrap circuit following.

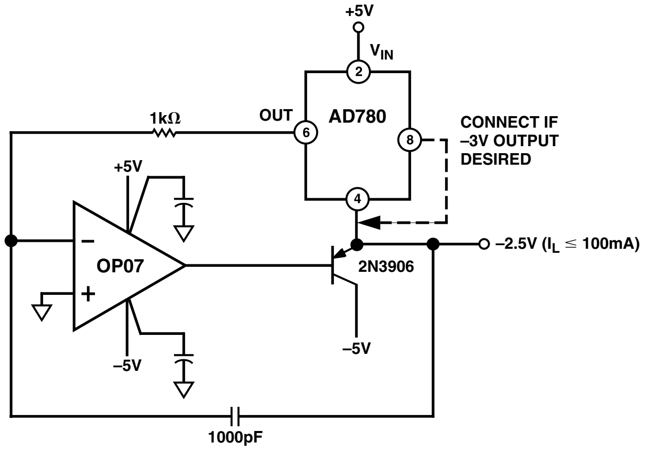
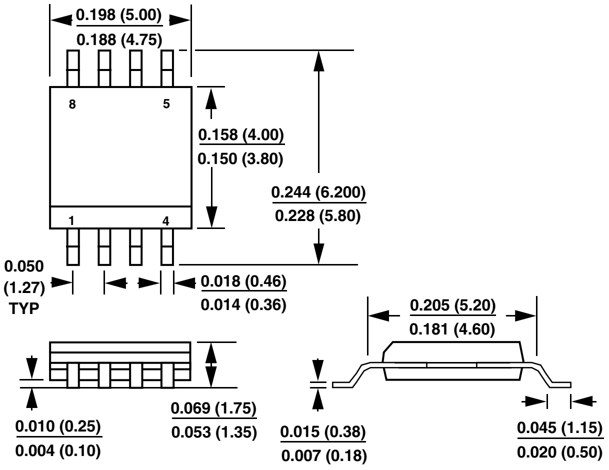


Figure 19. –2.5 V High Load Current Reference

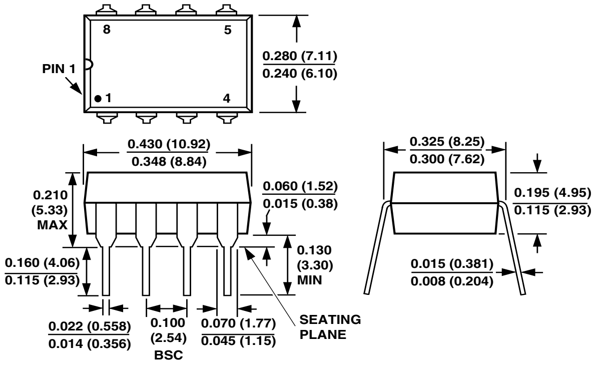
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

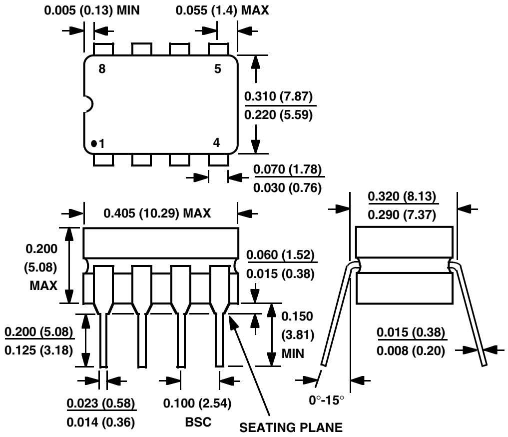
SOIC (R) Package



Plastic Mini-DIP (N) Package



Cerdip (Q) Package



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