

## FEATURES

- Laser-Trimmed to High Accuracy:**  
10.000 Volts  $\pm 5\text{mV}$  (L and U)
- Trimmed Temperature Coefficient:**  
5ppm/ $^{\circ}\text{C}$  max, 0 to  $+70^{\circ}\text{C}$  (L)  
10ppm/ $^{\circ}\text{C}$  max,  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  (U)
- Excellent Long-Term Stability:**  
25ppm/1000 hrs. (Non-Cumulative)
- Negative 10 Volt Reference Capability**
- Low Quiescent Current: 1.0mA max**
- 10mA Current Output Capability**
- 3-Terminal TO-5 Package**

## PRODUCT DESCRIPTION

The AD581 is a three-terminal, temperature compensated, monolithic band-gap voltage reference which provides a precise 10.00 volt output from an unregulated input level from 12 to 30 volts. Laser Wafer Trimming (LWT) is used to trim both the initial error at  $+25^{\circ}\text{C}$  as well as the temperature coefficient, which results in high precision performance previously available only in expensive hybrids or oven-regulated modules. The 5mV initial error tolerance and 5ppm/ $^{\circ}\text{C}$  guaranteed temperature coefficient of the AD581L represent the best performance combination available in a monolithic voltage reference.

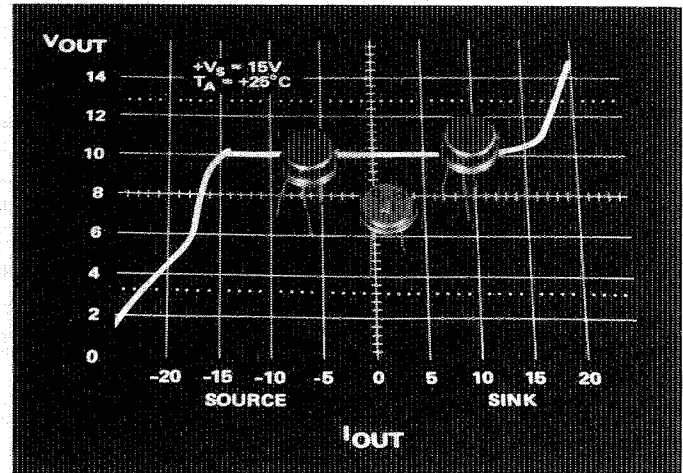
The band-gap circuit design used in the AD581 offers several advantages over classical zener breakdown diode techniques. Most important, no external components are required to achieve full accuracy and stability of significance to low power systems. In addition, total supply current to the device, including the output buffer amplifier (which can supply up to 10mA) is typically  $750\mu\text{A}$ . The long-term stability of the band-gap design is equivalent or superior to selected zener reference diodes.

The AD581 is recommended for use as a reference for 8-, 10- or 12-bit D/A converters which require an external precision reference. The device is also ideal for all types of A/D converters up to 14 bit accuracy, either successive approximation or integrating designs, and in general can offer better performance than that provided by standard self-contained references.

The AD581J, K, and L are specified for operation from 0 to  $+70^{\circ}\text{C}$ ; the AD581S, T, and U are specified for the  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  range. All grades are packaged in a hermetically-sealed three-terminal TO-5 metal can.

\*Covered by Patent Nos. 3,887,863; RE 30,586

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## PRODUCT HIGHLIGHTS

1. Laser trimming of both initial accuracy and temperature coefficient results in very low errors over temperature without the use of external components. The AD581L has a maximum deviation from 10.000 volts of  $\pm 7.25\text{mV}$  from 0 to  $+70^{\circ}\text{C}$ , while the AD581U guarantees  $\pm 15\text{mV}$  maximum total error without external trims from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .
2. Since the laser trimming is done on the wafer prior to separation into individual chips, the AD581 will be extremely valuable to hybrid designers for its ease of use, lack of required external trims, and inherent high performance.
3. The AD581 can also be operated in a two-terminal "Zener" mode to provide a precision negative 10 volt reference with just one external resistor to the unregulated supply. The performance in this mode is nearly equal to that of the standard three-terminal configuration.
4. Advanced circuit design using the band-gap concept allows the AD581 to give full performance with an unregulated input voltage down to 13 volts. With an external resistor, the device will operate with a supply as low as 11.4 volts.

# SPECIFICATIONS (@ $V_{IN} = +15V$ and $25^{\circ}C$ )

Model	AD581J			AD581K			AD581L			Units
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
OUTPUT VOLTAGE TOLERANCE (Error from nominal 10,000V output)			<b>± 30</b>			<b>± 10</b>			<b>± 5</b>	mV
OUTPUT VOLTAGE CHANGE Maximum Deviation from +25°C Value, $T_{min}$ to $T_{max}$ (Temperature Coefficient)			<b>± 13.5</b> 30			<b>± 6.75</b> 15			<b>± 2.25</b> 5	mV ppm/°C
LINE REGULATION $15V \leq V_{IN} \leq 30V$  $13V \leq V_{IN} \leq 15V$			<b>3.0</b> (0.002) <b>1.0</b> (0.005)			<b>3.0</b> (0.002) <b>1.0</b> (0.005)			<b>3.0</b> (0.002) <b>1.0</b> (0.005)	mV %/V mV %/V
LOAD REGULATION $0 \leq I_{OUT} \leq 5mA$			<b>200</b> <b>500</b>			<b>200</b> <b>500</b>			<b>200</b> <b>500</b>	$\mu V/mA$
QUIESCENT CURRENT			<b>0.75</b> <b>1.0</b>			<b>0.75</b> <b>1.0</b>			<b>0.75</b> <b>1.0</b>	mA
TURN-ON SETTLING TIME TO 0.1% <sup>1</sup>			<b>200</b>			<b>200</b>			<b>200</b>	$\mu s$
NOISE (0.1 to 10Hz)			<b>50</b>			<b>50</b>			<b>50</b>	$\mu V/p-p$
LONG-TERM STABILITY			<b>25</b>			<b>25</b>			<b>25</b>	ppm/1000 hrs.
SHORT CIRCUIT CURRENT			<b>30</b>			<b>30</b>			<b>30</b>	mA
OUTPUT CURRENT Source @ +25°C Source $T_{min}$ to $T_{max}$ Sink $T_{min}$ to $T_{max}$ Sink -55°C to +85°C	<b>10</b> <b>5</b> <b>5</b> -			<b>10</b> <b>5</b> <b>5</b> -			<b>10</b> <b>5</b> <b>5</b> -			mA mA mA mA
TEMPERATURE RANGE Specified Operating	<b>0</b> -65		<b>+70</b> <b>+150</b>	<b>0</b> -65		<b>+70</b> <b>+150</b>	<b>0</b> -65		<b>+70</b> <b>+150</b>	°C °C

Model	AD581S			AD581T			AD581U			Units
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
OUTPUT VOLTAGE TOLERANCE (Error from nominal 10,000V output)			<b>± 30</b>			<b>± 10</b>			<b>± 5</b>	mV
OUTPUT VOLTAGE CHANGE Maximum Deviation from +25°C Value, $T_{min}$ to $T_{max}$ (Temperature Coefficient)			<b>± 30</b> 30			<b>± 15</b> 15			<b>± 10</b> 10	mV ppm/°C
LINE REGULATION $15V \leq V_{IN} \leq 30V$  $13V \leq V_{IN} \leq 15V$			<b>3.0</b> (0.002) <b>1.0</b> (0.005)			<b>3.0</b> (0.002) <b>1.0</b> (0.005)			<b>3.0</b> (0.002) <b>1.0</b> (0.005)	mV %/V mV %/V
LOAD REGULATION $0 \leq I_{OUT} \leq 5mA$			<b>200</b> <b>500</b>			<b>200</b> <b>500</b>			<b>200</b> <b>500</b>	$\mu V/mA$
QUIESCENT CURRENT			<b>0.75</b> <b>1.0</b>			<b>0.75</b> <b>1.0</b>			<b>0.75</b> <b>1.0</b>	mA
TURN-ON SETTLING TIME TO 0.1% <sup>1</sup>			<b>200</b>			<b>200</b>			<b>200</b>	$\mu s$
NOISE (0.1 to 10Hz)			<b>50</b>			<b>50</b>			<b>50</b>	$\mu V/p-p$
LONG-TERM STABILITY			<b>25</b>			<b>25</b>			<b>25</b>	ppm/1000 hrs.
SHORT CIRCUIT CURRENT			<b>30</b>			<b>30</b>			<b>30</b>	mA
OUTPUT CURRENT Source @ +25°C Source $T_{min}$ to $T_{max}$ Sink $T_{min}$ to $T_{max}$ Sink -55°C to +85°C	<b>10</b> <b>5</b> <b>200</b> <b>5</b>			<b>10</b> <b>5</b> <b>200</b> <b>5</b>			<b>10</b> <b>5</b> <b>200</b> <b>5</b>			mA mA $\mu A$ mA
TEMPERATURE RANGE Specified Operating	<b>-55</b> -65		<b>+125</b> <b>+150</b>	<b>-55</b> -65		<b>+125</b> <b>+150</b>	<b>-55</b> -65		<b>+125</b> <b>+150</b>	°C °C

**NOTE**

<sup>1</sup>See Figure 8.

Specifications subject to change without notice.

Specifications shown in boldface are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in boldface are tested on all production units.

**ABSOLUTE MAX RATINGS**

Input Voltage  $V_{IN}$  to Ground . . . . . 40V  
 Power Dissipation @ +25°C . . . . . 600mW  
 Operating Junction Temperature Range . . -55°C to +150°C

Lead Temperature  
 Soldering 10sec) . . . . . +300°C  
 Thermal Resistance  
 Junction-to-Ambient . . . . . 150°C/W

**APPLYING THE AD581**

The AD581 is easy to use in virtually all precision reference applications. The three terminals are simply primary supply, ground, and output, with the case grounded. No external components are required even for high precision applications; the degree of desired absolute accuracy is achieved simply by selecting the required device grade. The AD581 requires less than 1mA quiescent current from an operating supply range of 12 to 30 volts.

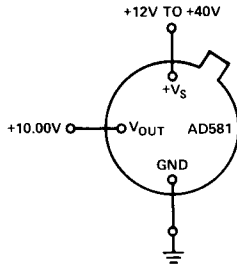


Figure 1. AD581 Pin Configuration (Top View)

An external fine trim may be desired to set the output level to exactly 10.000 volts within less than a millivolt (calibrated to a main system reference). System calibration may also require a reference slightly different from 10.00 volts. In either case, the optional trim circuit shown in Figure 2 can offset the output by up to  $\pm 30$  millivolts (with the  $22\Omega$  resistor), if needed, with minimal effect on other device characteristics.

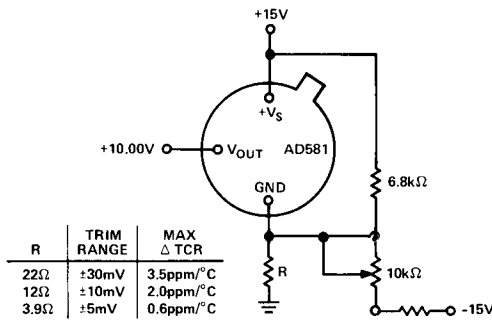
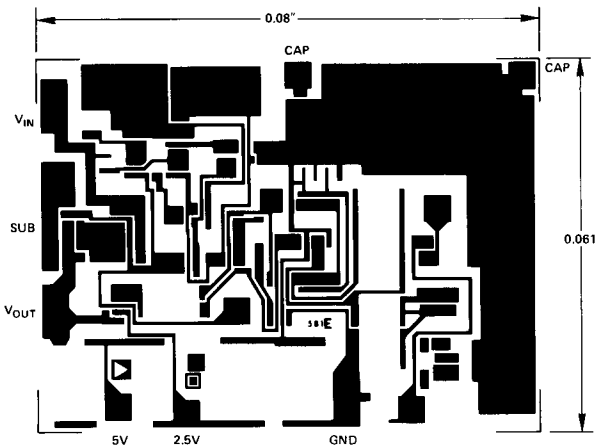


Figure 2. Optional Fine Trim Configuration



THE AD581 IS ALSO AVAILABLE IN LASER-TRIMMED CHIP FORM WITH ALL SPECIFICATIONS GUARANTEED TO J-GRADE. THE CHIP HAS ADDITIONAL APPLICATION FLEXIBILITY NOT AVAILABLE IN THE THREE-TERMINAL PACKAGED DEVICE. CONSULT FACTORY FOR FURTHER DETAILS.

Figure 3. AD581 Bonding Diagram

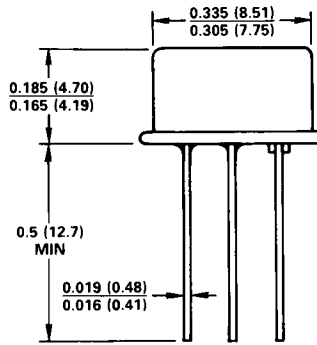
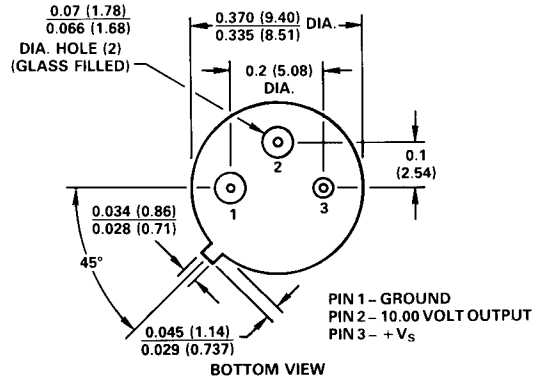


Figure 4. Outline Dimensions and Pin Designations. Dimensions shown in inches and (mm).

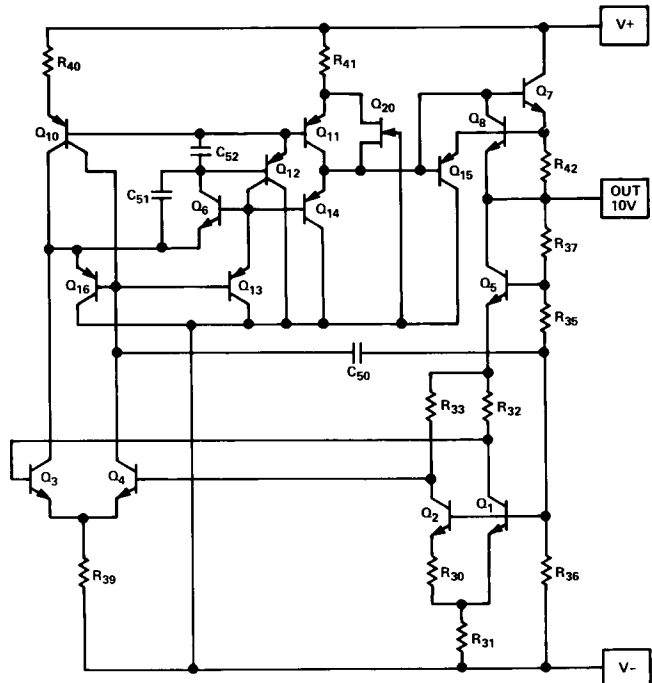


Figure 5. Simplified Schematic

### VOLTAGE VARIATION vs. TEMPERATURE

Some confusion exists in the area of defining and specifying reference voltage error over temperature. Historically, references have been characterized using a maximum deviation per degree Centigrade; i.e., 10ppm/°C. However, because of nonlinearities in temperature characteristics, which originated in standard zener references (such as "S" type characteristics) most manufacturers have begun to use a maximum limit error band approach to specify devices. This technique involves measurement of the output at 3, 5 or more different temperatures to guarantee that the output voltage will fall within the given error band. The temperature characteristic of the AD581 consistently follows the S-curve shown in Figure 6. Five-point measurement of each device guarantees the error band over the -55°C to +125°C range; three-point measurement guarantees the error band from 0 to +70°C.

The error band which is guaranteed with the AD581 is the maximum deviation from the initial value at +25°C; this error band is of more use to a designer than one which simply guarantees the maximum total change over the entire range (i.e., in the latter definition, all of the changes could occur in the positive direction). Thus, with a given grade of the AD581, the designer can easily determine the maximum total error from initial tolerance plus temperature variation (e.g., for the AD581T, the initial tolerance is ±10mV, the temperature error band is ±15mV, thus the unit is guaranteed to be 10.000 volts ±25mV from -55°C to +125°C).

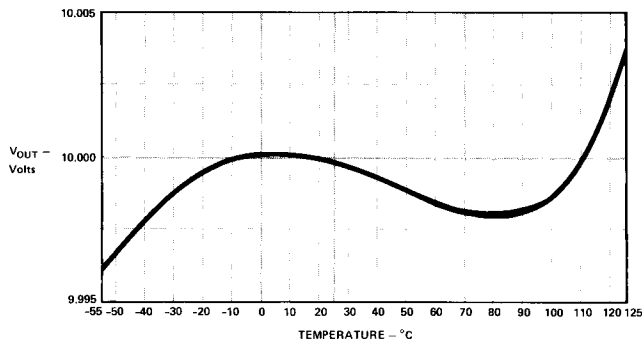


Figure 6. Typical Temperature Characteristic

### OUTPUT CURRENT CHARACTERISTICS

The AD581 has the capability to either source or sink current and provide good load regulation in either direction, although it has better characteristics in the source mode (positive current into the load). The circuit is protected for shorts to either positive supply or ground. The output voltage vs. output current characteristics of the device are shown in Figure 7. Source current is displayed as negative current in the figure; sink current is displayed as positive current in the figure.

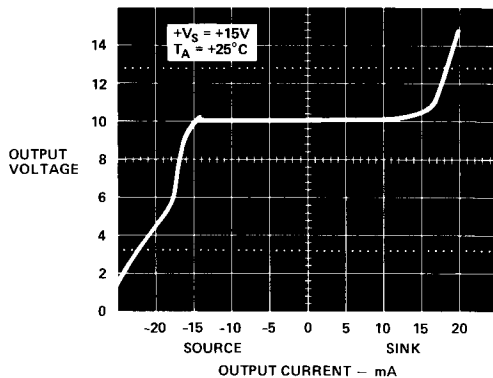


Figure 7. AD581 Output Voltage vs. Sink and Source Current

rent is positive. Note that the short circuit current (i.e., zero volts output) is about 28mA; when shorted to +15 volts, the sink current goes to about 20mA.

### DYNAMIC PERFORMANCE

Many low power instrument manufacturers are becoming increasingly concerned with the turn-on characteristics of the components being used in their systems. Fast turn-on components often enable the end user to keep power off when not needed, and yet respond quickly when the power is turned on for operation. Figure 8 displays the turn-on characteristic of the AD581. This characteristic is generated from cold-start operation and represents the true turn-on waveform after an extended period with the supplies off. The figure shows both the coarse and fine transient characteristics of the device; the total settling time to within ±1 millivolt is about 180µs, and there is no long thermal tail appearing after the point.

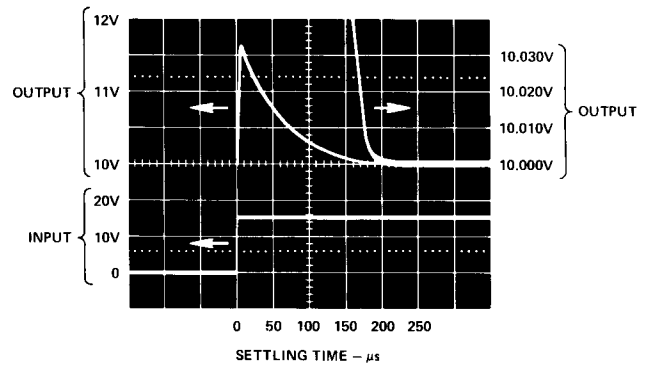


Figure 8. Output Settling Characteristic

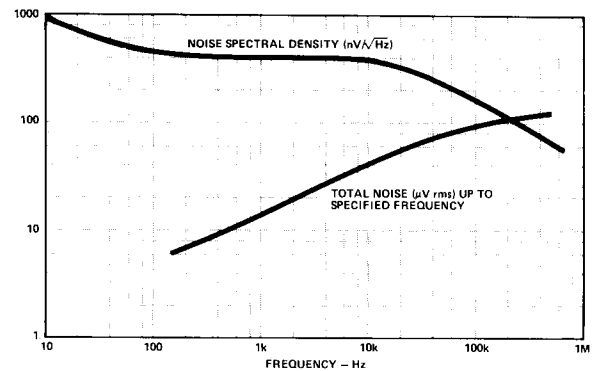


Figure 9. Spectral Noise Density and Total rms Noise vs. Frequency

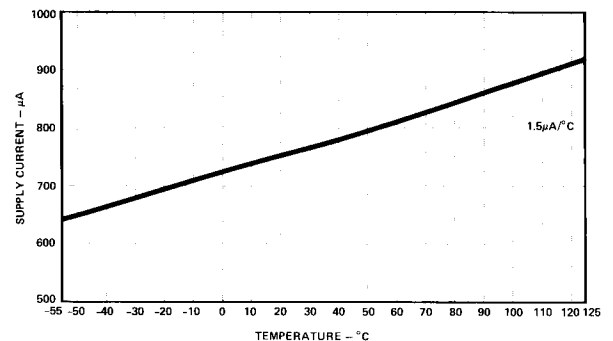


Figure 10. Quiescent Current vs. Temperature

### PRECISION HIGH CURRENT SUPPLY

The AD581 can be easily connected with power pnp or power darlington pnp devices to provide much greater output current capability. The circuit shown in Figure 11 delivers a precision 10 volt output with up to 4 amperes supplied to the load. The 0.1 $\mu$ F capacitor is required only if the load has a significant capacitive component. If the load is purely resistive, improved high frequency supply rejection results from removing the capacitor.

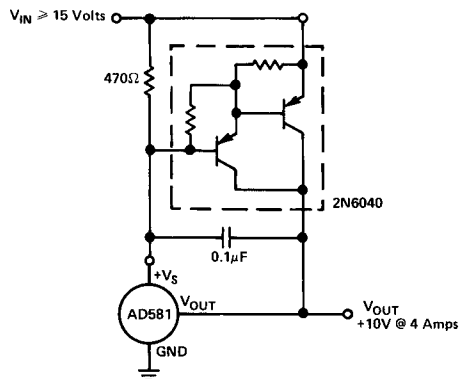


Figure 11. High Current Precision Supply

### CONNECTION FOR REDUCED PRIMARY SUPPLY

While line regulation is specified down to 13 volts, the typical AD581 will work as specified down to 12 volts or below. The current sink capability allows even lower supply voltage capability such as operation from 12V  $\pm$ 5% as shown in Figure 12. The 560 $\Omega$  resistor reduces the current supplied by the AD581 to a manageable level at full 5mA load. Note that other band-gap references, without current sink capability, may be damaged by use in this circuit configuration.

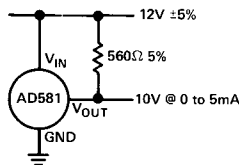


Figure 12. 12-Volt Supply Connection

### THE AD581 AS A CURRENT LIMITER

The AD581 represents an alternative to current limiter diodes which require factory selection to achieve a desired current. This approach often results in temperature coefficients of 1%/°C. The AD581 approach is not limited to a defined set current limit; it can be programmed from 0.75 to 5mA with the insertion of a single external resistor. Of course, the minimum voltage required to drive the connection is 13 volts. The AD580, which is a 2.5 volt reference, can be used in this type of circuit with compliance voltage down to 4.5 volts.

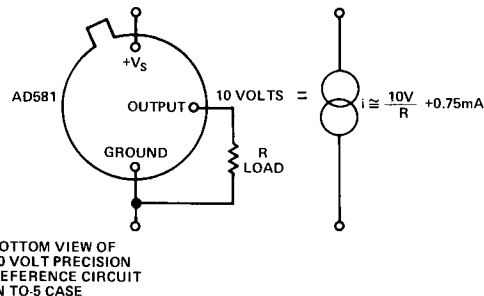


Figure 13. A Two-Component Precision Current Limiter

### NEGATIVE 10-VOLT REFERENCE

The AD581 can also be used in a two-terminal "zener" mode to provide a precision -10.00 volt reference. As shown in Figure 14, the V\_IN and V\_OUT terminals are connected together to the high supply (in this case, ground). The ground pin is connected through a resistor to the negative supply. The output is now taken from the ground pin instead of V\_OUT. With 1mA flowing through the AD581 in this mode, a typical unit will show a 2mV increase in output level over that produced in the three-terminal mode. Note also that the effective output impedance in this connection increases from 0.2 $\Omega$  typical to 2 ohms. It is essential to arrange the output load and the supply resistor, R<sub>S</sub>, so that the net current through the AD581 is always between 1 and 5mA. The temperature characteristics and long-term stability of the device will be essentially the same as that of a unit used in the standard three-terminal mode. The operating temperature range is limited to -55°C to +85°C.

The AD581 can also be used in a two-terminal mode to develop a positive reference. V\_IN and V\_OUT are tied together and to the positive supply through an appropriate supply resistor. The performance characteristics will be similar to those of the negative two-terminal connection. The only advantage of this connection over the standard three-terminal connection is that a lower primary supply can be used, as low as 10.5 volts. This type of operation will require considerable attention to load and primary supply regulation to be sure the AD581 always remains within its regulating range of 1 to 5mA.

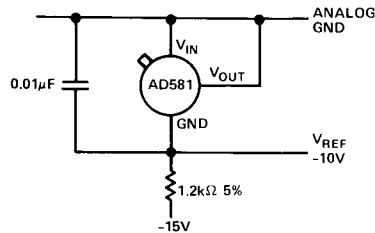


Figure 14. Two-Terminal -10 Volt Reference

### 10 VOLT REFERENCE WITH MULTIPLYING CMOS D/A OR A/D CONVERTERS

The AD581 is ideal for application with the entire AD7533 series of 10- and 12-bit multiplying CMOS D/A converters, especially for low power applications. It is equally suitable for the AD7574 8-bit A/D converter. In the standard hook-up, as shown in Figure 15, the +10 volt reference is inverted by the amplifier/DAC configuration to produce a 0 to -10 volt range. If an AD308 amplifier is used, total quiescent supply current will typically be 2mA. If a 0 to +10 volt full scale range is desired, the AD581 can be connected to the CMOS DAC in its -10 volt "zener" mode, as shown in Figure 14 (the -10V<sub>REF</sub> output is connected directly to the V<sub>REF IN</sub> of the CMOS DAC). The AD581 will normally be used in the -10 volt mode with the AD7574 to give a 0 to +10 volt ADC range. This is shown in Figure 16. Bipolar output applications and other operating details can be found in the data sheets for the CMOS products.

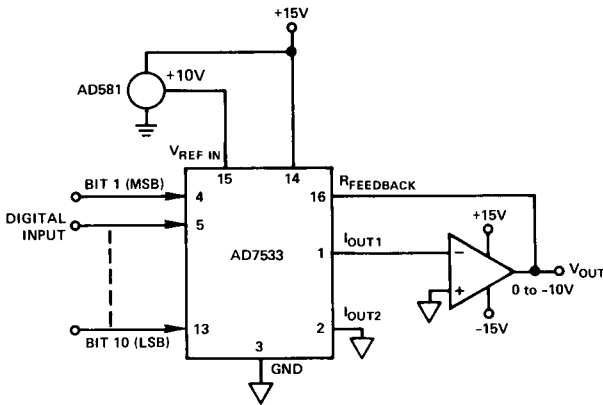
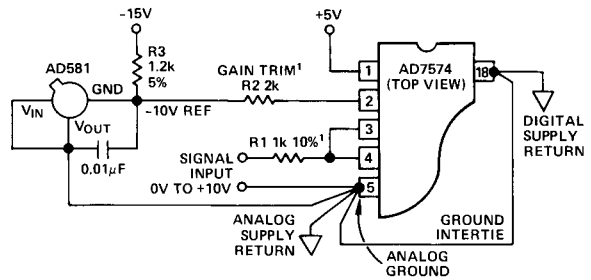


Figure 15. Low Power 10-Bit CMOS DAC Application

### PRECISION 12-BIT D/A CONVERTER REFERENCE

The AD562, like most D/A converters, is designed to operate with a +10 volt reference element. In the AD562, this 10 volt reference voltage is converted into a reference current of approximately 0.5mA via the internal 19.95kΩ resistor (in series with the external 100Ω trimmer). The gain temperature coefficient of the AD562 is primarily governed by the temperature tracking of the 19.95kΩ resistor and the 5k/10k span resistors; this gain T.C. is guaranteed to 3ppm/°C. Thus, using the AD581L (at 5ppm/°C) as the 10 volt reference guarantees a maximum full scale temperature coefficient of 8ppm/°C over the commercial range. The 10 volt reference also supplies the normal 1mA bipolar offset current through the 9.95k bipolar offset resistor. The bipolar offset T.C. thus depends only on the T.C. matching of the bipolar offset resistor to the input reference resistor and is guaranteed to 3ppm/°C.



NOTE 1: R1 AND R2 CAN BE OMITTED IF GAIN TRIM IS NOT REQUIRED

Figure 16. AD581 as Negative 10-Volt Reference for CMOS ADC

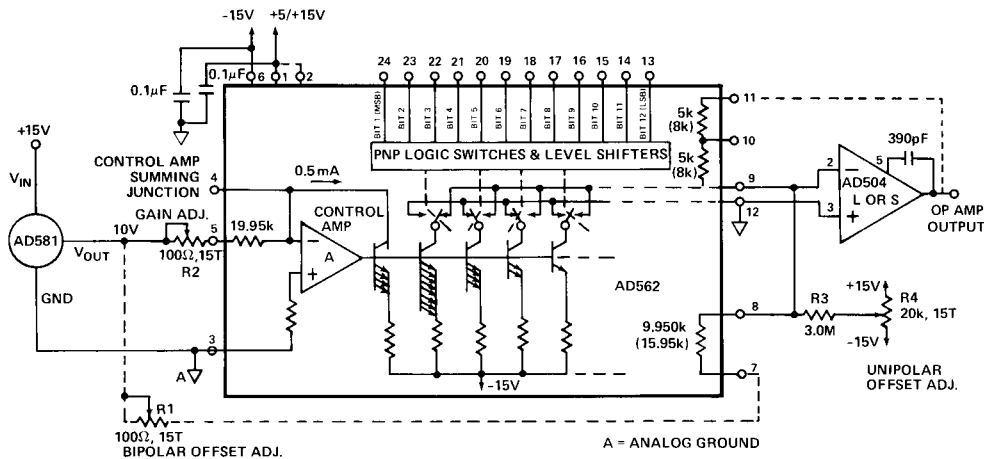


Figure 17. Precision 12-Bit D/A Converter