

## OP295/OP495

### FEATURES

**Rail-to-Rail Output Swing**  
**Single-Supply Operation: 3 V to 36 V**  
**Low Offset Voltage: 300  $\mu$ V**  
**Gain Bandwidth Product: 75 kHz**  
**High Open-Loop Gain: 1,000 V/mV**  
**Unity-Gain Stable**  
**Low Supply Current/Per Amplifier: 150  $\mu$ A max**

### APPLICATIONS

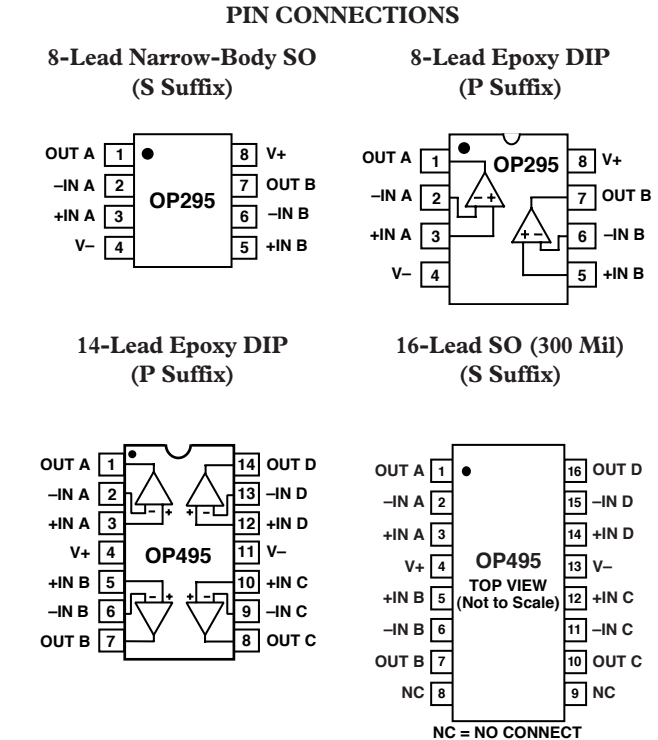
**Battery-Operated Instrumentation**  
**Servo Amplifiers**  
**Actuator Drives**  
**Sensor Conditioners**  
**Power Supply Control**

### GENERAL DESCRIPTION

Rail-to-rail output swing combined with dc accuracy are the key features of the OP495 quad and OP295 dual CBCMOS operational amplifiers. By using a bipolar front end, lower noise and higher accuracy than that of CMOS designs has been achieved. Both input and output ranges include the negative supply, providing the user "zero-in/zero-out" capability. For users of 3.3 V systems such as lithium batteries, the OP295/OP495 is specified for 3 V operation.

Maximum offset voltage is specified at 300  $\mu$ V for 5 V operation, and the open-loop gain is a minimum of 1000 V/mV. This yields performance that can be used to implement high accuracy systems, even in single-supply designs.

The ability to swing rail-to-rail and supply 15 mA to the load makes the OP295/OP495 an ideal driver for power transistors and "H" bridges. This allows designs to achieve higher efficiencies and to transfer more power to the load than previously possible without the use of discrete components. For applications that require



driving inductive loads, such as transformers, increases in efficiency are also possible. Stability while driving capacitive loads is another benefit of this design over CMOS rail-to-rail amplifiers. This is useful for driving coax cable or large FET transistors. The OP295/OP495 is stable with loads in excess of 300 pF.

The OP295 and OP495 are specified over the extended industrial ( $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ) temperature range. OP295s are available in 8-lead plastic DIP plus SO-8 surface-mount packages. OP495s are available in 14-lead plastic and SO-16 surface-mount packages. Contact your local sales office for MIL-STD-883 data sheet.

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# OP295/OP495—SPECIFICATIONS

## ELECTRICAL CHARACTERISTICS (@ $V_S = 5.0\text{ V}$ , $V_{CM} = 2.5\text{ V}$ , $T_A = 25^\circ\text{C}$ unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
<b>INPUT CHARACTERISTICS</b>						
Offset Voltage	$V_{OS}$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		30	300	$\mu\text{V}$
Input Bias Current	$I_B$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		8	20	nA
Input Offset Current	$I_{OS}$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		$\pm 1$	$\pm 3$	nA
Input Voltage Range	$V_{CM}$	$0\text{ V} \leq V_{CM} \leq 4.0\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	0		4.0	V
Common-Mode Rejection Ratio	CMRR	$R_L = 10\text{ k}\Omega$ , $0.005 \leq V_{OUT} \leq 4.0\text{ V}$	90	110		dB
Large Signal Voltage Gain	$A_{VO}$	$R_L = 10\text{ k}\Omega$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	1,000	10,000		V/mV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$			1	5	$\mu\text{V}/^\circ\text{C}$
<b>OUTPUT CHARACTERISTICS</b>						
Output Voltage Swing High	$V_{OH}$	$R_L = 100\text{ k}\Omega$ to GND $R_L = 10\text{ k}\Omega$ to GND	4.98 4.90	5.0 4.94		V V
Output Voltage Swing Low	$V_{OL}$	$I_{OUT} = 1\text{ mA}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$ $R_L = 100\text{ k}\Omega$ to GND $R_L = 10\text{ k}\Omega$ to GND		4.7 0.7	2	V mV
Output Current	$I_{OUT}$	$I_{OUT} = 1\text{ mA}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	$\pm 11$	$\pm 18$		mV mA
<b>POWER SUPPLY</b>						
Power Supply Rejection Ratio	PSRR	$\pm 1.5\text{ V} \leq V_S \leq \pm 15\text{ V}$ $\pm 1.5\text{ V} \leq V_S \leq \pm 15\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	90	110		dB
Supply Current Per Amplifier	$I_{SY}$	$V_{OUT} = 2.5\text{ V}$ , $R_L = \infty$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			150	$\mu\text{A}$
<b>DYNAMIC PERFORMANCE</b>						
Skew Rate	SR	$R_L = 10\text{ k}\Omega$		0.03		V/ $\mu\text{s}$
Gain Bandwidth Product	GBP			75		kHz
Phase Margin	$\theta_o$			86		Degrees
<b>NOISE PERFORMANCE</b>						
Voltage Noise	$e_n$ p-p	0.1 Hz to 10 Hz		1.5		$\mu\text{V p-p}$
Voltage Noise Density	$e_n$	$f = 1\text{ kHz}$		51		$\text{nV}/\sqrt{\text{Hz}}$
Current Noise Density	$i_n$	$f = 1\text{ kHz}$		<0.1		$\text{pA}/\sqrt{\text{Hz}}$

Specifications subject to change without notice.

## ELECTRICAL CHARACTERISTICS (@ $V_S = 3.0\text{ V}$ , $V_{CM} = 1.5\text{ V}$ , $T_A = 25^\circ\text{C}$ unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
<b>INPUT CHARACTERISTICS</b>						
Offset Voltage	$V_{OS}$			30	500	$\mu\text{V}$
Input Bias Current	$I_B$			8	20	nA
Input Offset Current	$I_{OS}$			$\pm 1$	$\pm 3$	nA
Input Voltage Range	$V_{CM}$		0		2.0	V
Common-Mode Rejection Ratio	CMRR	$0\text{ V} \leq V_{CM} \leq 2.0\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	90	110		dB
Large Voltage Gain	$A_{VO}$	$R_L = 10\text{ k}\Omega$		750		V/mV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$			1		$\mu\text{V}/^\circ\text{C}$
<b>OUTPUT CHARACTERISTICS</b>						
Output Voltage Swing High	$V_{OH}$	$R_L = 10\text{ k}\Omega$ to GND	2.9			V
Output Voltage Swing Low	$V_{OL}$	$R_L = 10\text{ k}\Omega$ to GND		0.7	2	mV
<b>POWER SUPPLY</b>						
Power Supply Rejection Ratio	PSRR	$\pm 1.5\text{ V} \leq V_S \leq \pm 15\text{ V}$ $\pm 1.5\text{ V} \leq V_S \leq \pm 15\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	90	110		dB
Supply Current Per Amplifier	$I_{SY}$	$V_{OUT} = 1.5\text{ V}$ , $R_L = \infty$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			150	$\mu\text{A}$
<b>DYNAMIC PERFORMANCE</b>						
Slew Rate	SR	$R_L = 10\text{ k}\Omega$		0.03		V/ $\mu\text{s}$
Gain Bandwidth Product	GBP			75		kHz
Phase Margin	$\theta_o$			85		Degrees
<b>NOISE PERFORMANCE</b>						
Voltage Noise	$e_n$ p-p	0.1 Hz to 10 Hz		1.6		$\mu\text{V p-p}$
Voltage Noise Density	$e_n$	$f = 1\text{ kHz}$		53		$\text{nV}/\sqrt{\text{Hz}}$
Current Noise Density	$i_n$	$f = 1\text{ kHz}$		<0.1		$\text{pA}/\sqrt{\text{Hz}}$

Specifications subject to change without notice.

**ELECTRICAL CHARACTERISTICS** (@  $V_S = \pm 15.0\text{ V}$ ,  $T_A = 25^\circ\text{C}$  unless otherwise noted.)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
<b>INPUT CHARACTERISTICS</b>						
Offset Voltage	$V_{OS}$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		30	300	$\mu\text{V}$
Input Bias Current	$I_B$	$V_{CM} = 0\text{ V}$		7	20	nA
Input Offset Current	$I_{OS}$	$V_{CM} = 0\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		$\pm 1$	30	nA
Input Voltage Range	$V_{CM}$	$V_{CM} = 0\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	-15		$\pm 5$	nA
Common-Mode Rejection Ratio	CMRR	$-15.0\text{ V} \leq V_{CM} \leq +13.5\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	90	110	13.5	V
Large Signal Voltage Gain	$A_{VO}$	$R_L = 10\text{ k}\Omega$	1,000	4,000		V/mV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$			1		$\mu\text{V}/^\circ\text{C}$
<b>OUTPUT CHARACTERISTICS</b>						
Output Voltage Swing High	$V_{OH}$	$R_L = 100\text{ k}\Omega$ to GND	14.95			V
Output Voltage Swing Low	$V_{OL}$	$R_L = 10\text{ k}\Omega$ to GND	14.80			V
Output Current	$I_{OUT}$	$R_L = 100\text{ k}\Omega$ to GND			-14.95	V
		$R_L = 10\text{ k}\Omega$ to GND			-14.85	V
			$\pm 15$	$\pm 25$		mA
<b>POWER SUPPLY</b>						
Power Supply Rejection Ratio	PSRR	$V_S = \pm 1.5\text{ V}$ to $\pm 15\text{ V}$	90	110		dB
Supply Current	$I_{SY}$	$V_S = \pm 1.5\text{ V}$ to $\pm 15\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	85			dB
Supply Voltage Range	$V_S$	$V_O = 0\text{ V}$ , $R_L = \infty$ , $V_S = \pm 18\text{ V}$ , $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			175	$\mu\text{A}$
			3 ( $\pm 1.5$ )		36 ( $\pm 18$ )	V
<b>DYNAMIC PERFORMANCE</b>						
Slew Rate	SR	$R_L = 10\text{ k}\Omega$		0.03		V/ $\mu\text{s}$
Gain Bandwidth Product	GBP			85		kHz
Phase Margin	$\theta_O$			83		Degrees
<b>NOISE PERFORMANCE</b>						
Voltage Noise	$e_n$ p-p	0.1 Hz to 10 Hz		1.25		$\mu\text{V p-p}$
Voltage Noise Density	$e_n$	$f = 1\text{ kHz}$		45		$\text{nV}/\sqrt{\text{Hz}}$
Current Noise Density	$i_n$	$f = 1\text{ kHz}$		<0.1		$\text{pA}/\sqrt{\text{Hz}}$

Specifications subject to change without notice.

# OP295/OP495

## ABSOLUTE MAXIMUM RATINGS<sup>1</sup>

Supply Voltage	±18 V
Input Voltage <sup>2</sup>	±18 V
Differential Input Voltage <sup>2</sup>	36 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range	
P, S Package	-65°C to +150°C
Operating Temperature Range	
OP295G, OP495G	-40°C to +125°C
Junction Temperature Range	
P, S Package	-65°C to +150°C
Lead Temperature Range (Soldering, 60 Sec)	300°C

## NOTES

<sup>1</sup>Absolute maximum ratings apply to packaged parts, unless otherwise noted.

<sup>2</sup>For supply voltages less than ±18 V, the absolute maximum input voltage is equal to the supply voltage.

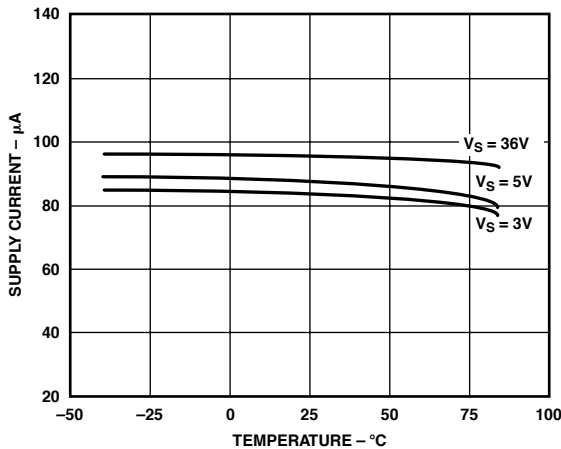
Package Type	$\theta_{JA}$ *	$\theta_{JC}$	Unit
8-Lead Plastic DIP (P)	103	43	°C/W
8-Lead SOIC (S)	158	43	°C/W
14-Lead Plastic DIP (P)	83	39	°C/W
16-Lead SO (S)	98	30	°C/W

\* $\theta_{JA}$  is specified for the worst case conditions, i.e.,  $\theta_{JA}$  is specified for device in socket for cerdip, P-DIP, and LCC packages;  $\theta_{JA}$  is specified for device soldered in circuit board for SOIC package.

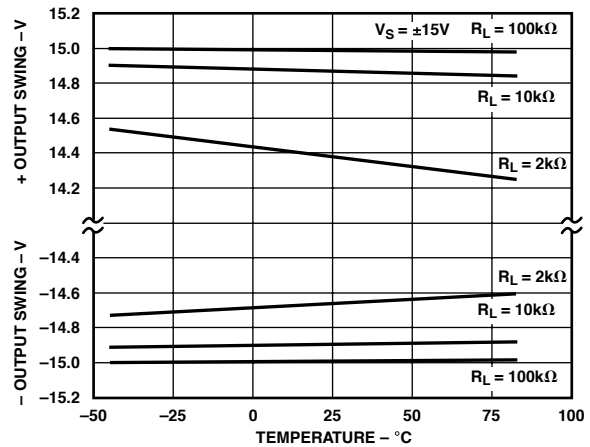
## ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
OP295GP	-40°C to +125°C	8-Lead Plastic DIP	N-8
OP295GS	-40°C to +125°C	8-Lead SOIC	SO-8
OP495GP	-40°C to +125°C	14-Lead Plastic DIP	N-14
OP495GS	-40°C to +125°C	16-Lead SOL	R-16

## Typical Performance Characteristics



TPC 1. Supply Current Per Amplifier vs. Temperature

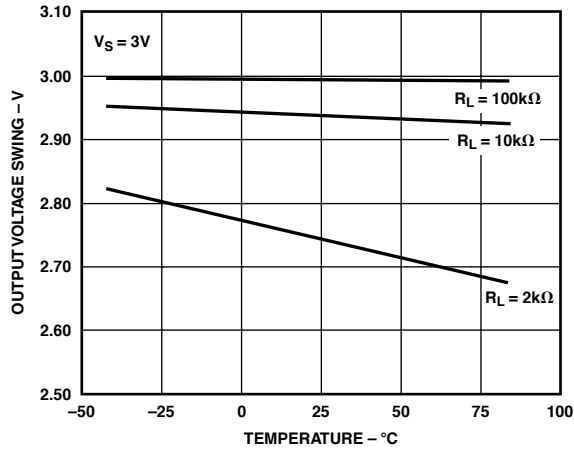


TPC 2. Output Voltage Swing vs. Temperature

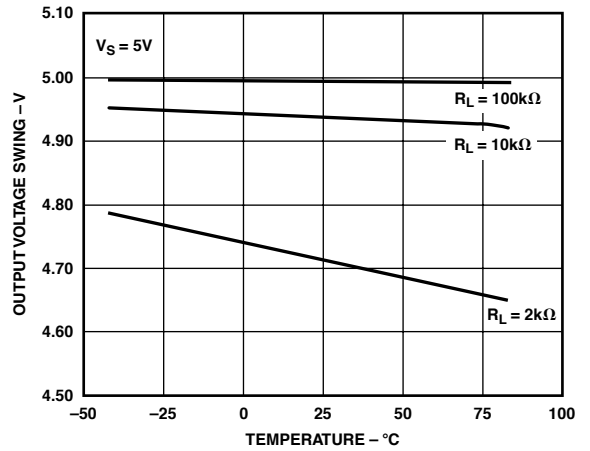
## CAUTION

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 OP295/OP495 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.

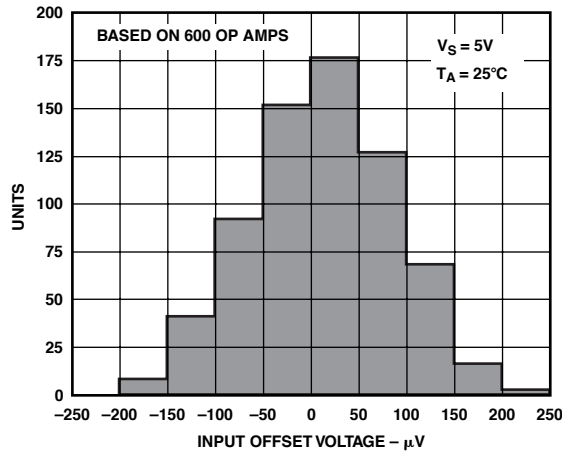




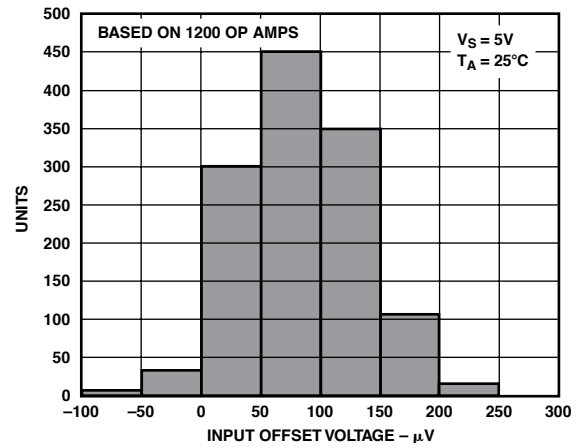
TPC 3. Output Voltage Swing vs. Temperature



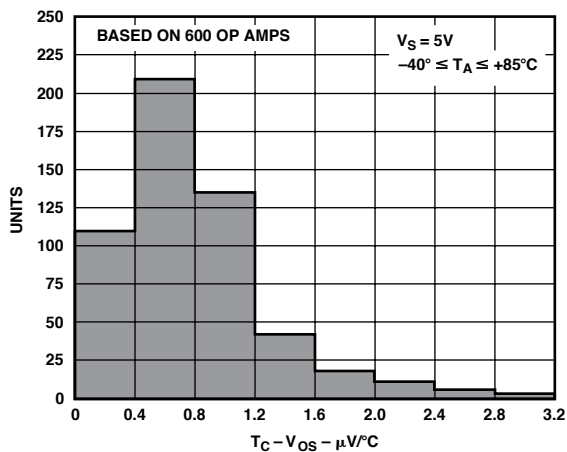
TPC 6. Output Voltage Swing vs. Temperature



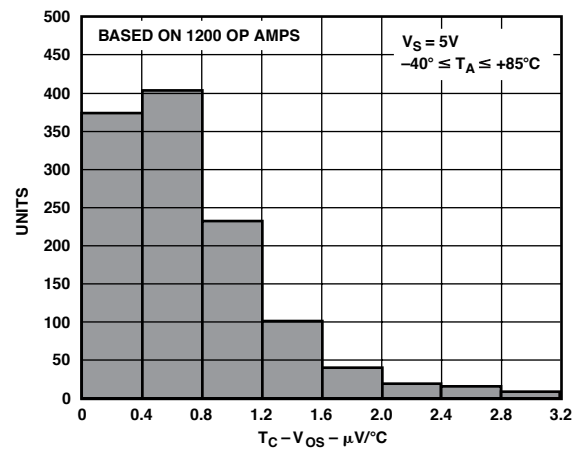
TPC 4. OP295 Input Offset ( $V_{OS}$ ) Distribution



TPC 7. OP495 Input Offset ( $V_{OS}$ ) Distribution

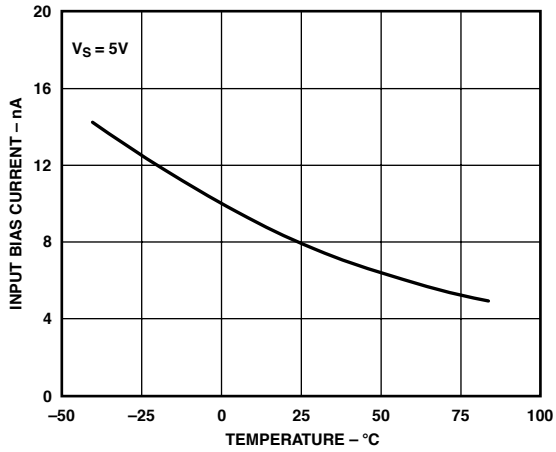


TPC 5. OP295  $TC-V_{OS}$  Distribution

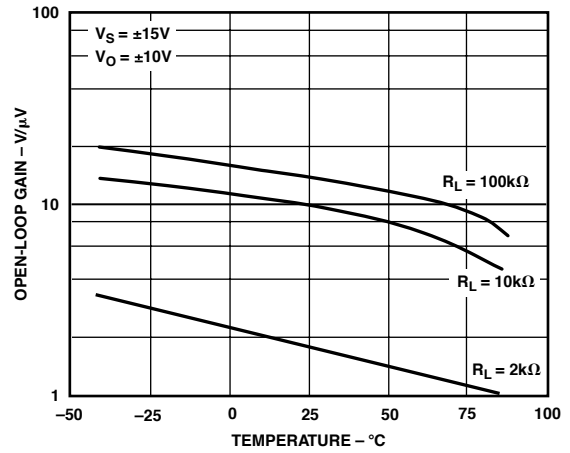


TPC 8. OP495  $TC-V_{OS}$  Distribution

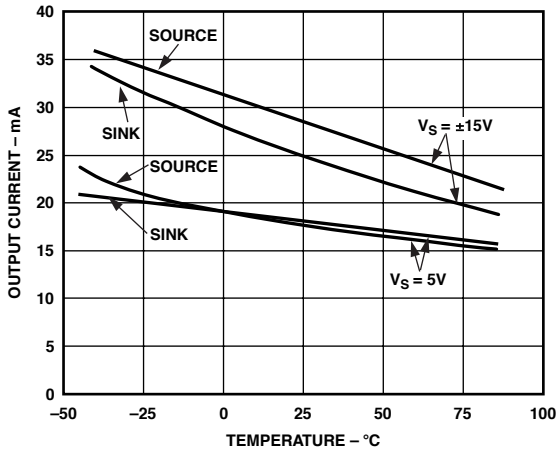
# OP295/OP495



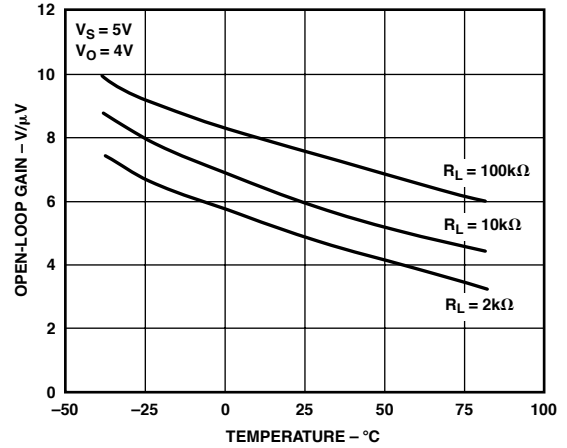
TPC 9. Input Bias Current vs. Temperature



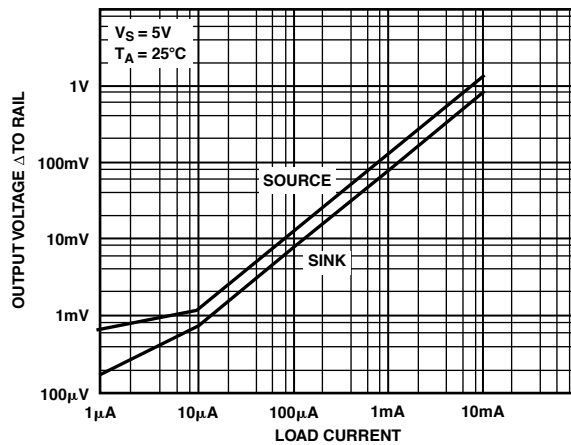
TPC 11. Open-Loop Gain vs. Temperature



TPC 10. Output Current vs. Temperature



TPC 12. Open-Loop Gain vs. Temperature



TPC 13. Output Voltage to Supply Rail vs. Load Current

## APPLICATIONS

### Rail-to-Rail Application Information

The OP295/OP495 has a wide common-mode input range extending from ground to within about 800 mV of the positive supply. There is a tendency to use the OP295/OP495 in buffer applications where the input voltage could exceed the common-mode input range. This may initially appear to work because of the high input range and rail-to-rail output range. But above the common-mode input range the amplifier is, of course, highly nonlinear. For this reason it is always required that there be some minimal amount of gain when rail-to-rail output swing is desired. Based on the input common-mode range, this gain should be at least 1.2.

### Low Drop-Out Reference

The OP295/OP495 can be used to gain up a 2.5 V or other low voltage reference to 4.5 V for use with high resolution A/D converters that operate from 5 V only supplies. The circuit in Figure 1 will supply up to 10 mA. Its no-load drop-out voltage is only 20 mV. This circuit will supply over 3.5 mA with a 5 V supply.

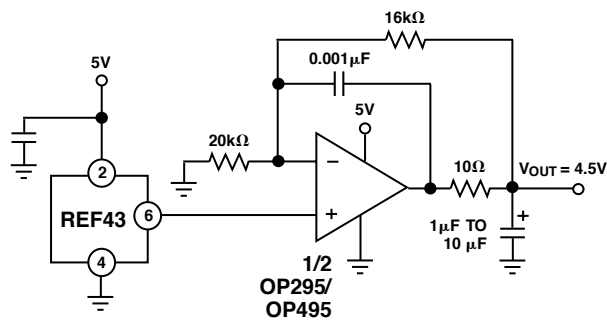


Figure 1. 4.5 V, Low Drop-Out Reference

### Low Noise, Single-Supply Preamplifier

Most single-supply op amps are designed to draw low supply current, at the expense of having higher voltage noise. This tradeoff may be necessary because the system must be powered by a battery. However, this condition is worsened because all circuit resistances tend to be higher; as a result, in addition to the op amp's voltage noise, Johnson noise (resistor thermal noise) is also a significant contributor to the total noise of the system.

The choice of monolithic op amps that combine the characteristics of low noise and single-supply operation is rather limited. Most single-supply op amps have noise on the order of  $30 \text{ nV}/\sqrt{\text{Hz}}$  to  $60 \text{ nV}/\sqrt{\text{Hz}}$  and single-supply amplifiers with noise below  $5 \text{ nV}/\sqrt{\text{Hz}}$  do not exist.

In order to achieve both low noise and low supply voltage operation, discrete designs may provide the best solution. The circuit on Figure 2 uses the OP295/OP495 rail-to-rail amplifier and a matched PNP transistor pair—the MAT03—to achieve zero-in/zero-out single-supply operation with an input voltage noise of  $3.1 \text{ nV}/\sqrt{\text{Hz}}$  at 100 Hz. R5 and R6 set the gain of 1,000, making this circuit ideal for maximizing dynamic range when amplifying low level signals in single-supply applications. The OP295/OP495 provides rail-to-rail output swings, allowing this circuit to operate with 0 V to 5 V outputs. Only half of the OP295/OP495 is used, leaving the other uncommitted op amp for use elsewhere.

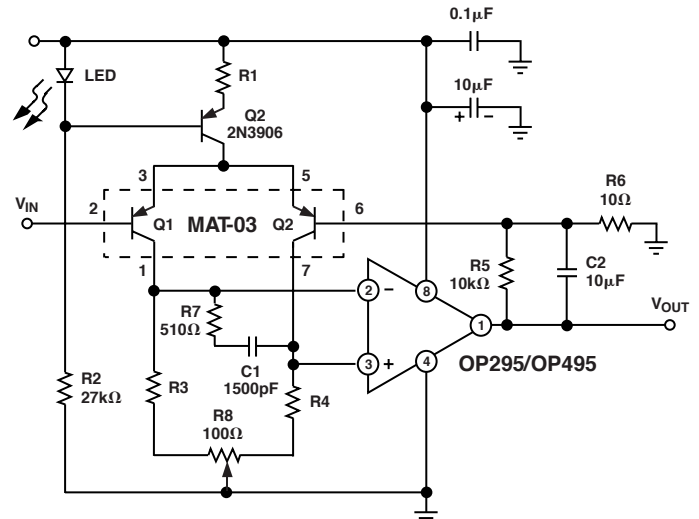


Figure 2. Low Noise Single-Supply Preamplifier

The input noise is controlled by the MAT03 transistor pair and the collector current level. Increasing the collector current reduces the voltage noise. This particular circuit was tested with 1.85 mA and 0.5 mA of current. Under these two cases, the input voltage noise was  $3.1 \text{ nV}/\sqrt{\text{Hz}}$  and  $10 \text{ nV}/\sqrt{\text{Hz}}$ , respectively. The high collector currents do lead to a tradeoff in supply current, bias current, and current noise. All of these parameters will increase with increasing collector current. For example, typically the MAT03 has an  $h_{FE} = 165$ . This leads to bias currents of 11  $\mu\text{A}$  and 3  $\mu\text{A}$ , respectively. Based on the high bias currents, this circuit is best suited for applications with low source impedance such as magnetic pickups or low impedance strain gages. Furthermore, a high source impedance will degrade the noise performance. For example, a 1 k $\Omega$  resistor generates  $4 \text{ nV}/\sqrt{\text{Hz}}$  of broadband noise, which is already greater than the noise of the preamp.

The collector current is set by R1 in combination with the LED and Q2. The LED is a 1.6 V Zener diode that has a temperature coefficient close to that of Q2's base-emitter junction, which provides a constant 1.0 V drop across R1. With R1 equal to 270  $\Omega$ , the tail current is 3.7 mA and the collector current is half that, or 1.85 mA. The value of R1 can be altered to adjust the collector current. Whenever R1 is changed, R3 and R4 should also be adjusted. To maintain a common-mode input range that includes ground, the collectors of the Q1 and Q2 should not go above 0.5 V—otherwise they could saturate. Thus, R3 and R4 must be small enough to prevent this condition. Their values and the overall performance for two different values of R1 are summarized in Table I. Lastly, the potentiometer, R8, is needed to adjust the offset voltage to null it to zero. Similar performance can be obtained using an OP90 as the output amplifier with a savings of about 185  $\mu\text{A}$  of supply current. However, the output swing will not include the positive rail, and the bandwidth will reduce to approximately 250 Hz.



# OP295/OP495

**Table I. Single-Supply Low Noise Preamp Performance**

	$I_C = 1.85 \text{ mA}$	$I_C = 0.5 \text{ mA}$
R1	270 $\Omega$	1.0 k $\Omega$
R3, R4	200 $\Omega$	910 $\Omega$
$e_n$ @ 100 Hz	3.15 nV/ $\sqrt{\text{Hz}}$	8.6 nV/ $\sqrt{\text{Hz}}$
$e_n$ @ 10 Hz	4.2 nV/ $\sqrt{\text{Hz}}$	10.2 nV/ $\sqrt{\text{Hz}}$
$I_{SY}$	4.0 mA	1.3 mA
$I_B$	11 $\mu\text{A}$	3 $\mu\text{A}$
Bandwidth	1 kHz	1 kHz
Closed-Loop Gain	1,000	1,000

## Driving Heavy Loads

The OP295/OP495 is well suited to drive loads by using a power transistor, Darlington or FET to increase the current to the load. The ability to swing to either rail can assure that the device is turned on hard. This results in more power to the load and an increase in efficiency over using standard op amps with their limited output swing. Driving power FETs is also possible with the OP295/OP495 because of its ability to drive capacitive loads of several hundred picofarads without oscillating.

Without the addition of external transistors, the OP295/OP495 can drive loads in excess of  $\pm 15 \text{ mA}$  with  $\pm 15 \text{ V}$  or  $+30 \text{ V}$  supplies. This drive capability is somewhat decreased at lower supply voltages. At  $\pm 5 \text{ V}$  supplies, the drive current is  $\pm 11 \text{ mA}$ .

Driving motors or actuators in two directions in a single-supply application is often accomplished using an "H" bridge. The principle is demonstrated in Figure 3a. From a single 5 V supply this driver is capable of driving loads from 0.8 V to 4.2 V in both directions. Figure 3b shows the voltages at the inverting and noninverting outputs of the driver. There is a small crossover glitch that is frequency dependent and would not cause problems unless this was a low distortion application such as audio. If this is used to drive inductive loads, be sure to add diode clamps to protect the bridge from inductive kickback.

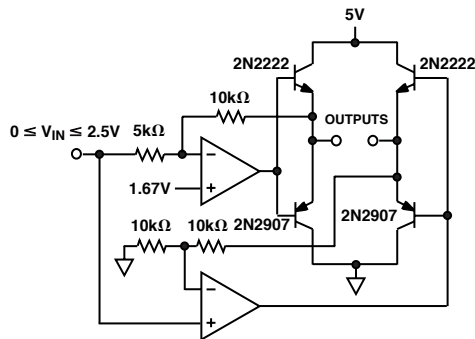


Figure 3a. "H" Bridge

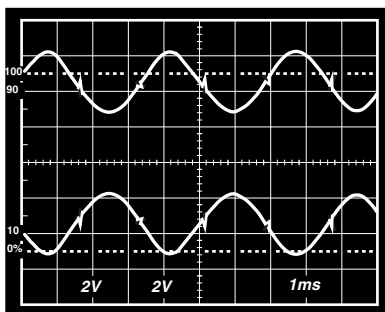


Figure 3b. "H" Bridge Outputs

## Direct Access Arrangement

OP295/OP495 can be used in a single-supply Direct Access Arrangement (DAA) as is shown in Figure 4. This figure shows a portion of a typical DM capable of operating from a single 5 V supply and it may also work on 3 V supplies with minor modifications. Amplifiers A2 and A3 are configured so that the transmit signal TXA is inverted by A2 and is not inverted by A3. This arrangement drives the transformer differentially so that the drive to the transformer is effectively doubled over a single amplifier arrangement. This application takes advantage of the OP295/OP495's ability to drive capacitive loads, and to save power in single-supply applications.

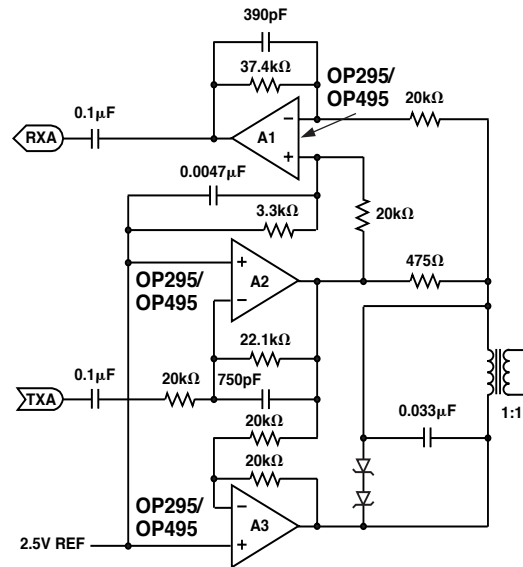


Figure 4. Direct Access Arrangement

## A Single-Supply Instrumentation Amplifier

The OP295/OP495 can be configured as a single-supply instrumentation amplifier as in Figure 5. For our example,  $V_{REF}$  is set equal to  $\frac{V_+}{2}$  and  $V_O$  is measured with respect to  $V_{REF}$ . The input common-mode voltage range includes ground and the output swings to both rails.

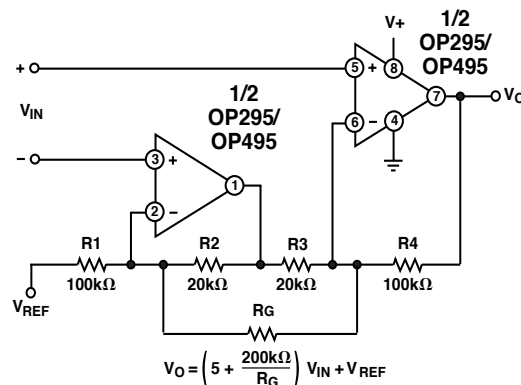


Figure 5. Single-Supply Instrumentation Amplifier

Resistor  $R_G$  sets the gain of the instrumentation amplifier. Minimum gain is 6 (with no  $R_G$ ). All resistors should be matched in absolute value as well as temperature coefficient to maximize



common-mode rejection performance and minimize drift. This instrumentation amplifier can operate from a supply voltage as low as 3 V.

### A Single-Supply RTD Thermometer Amplifier

This RTD amplifier takes advantage of the rail-to-rail swing of the OP295/OP495 to achieve a high bridge voltage in spite of a low 5 V supply. The OP295/OP495 amplifier serves a constant 200  $\mu$ A current to the bridge. The return current drops across the parallel resistors 6.19 k $\Omega$  and the 2.55 M $\Omega$ , developing a voltage that is servoed to 1.235 V, which is established by the AD589 bandgap reference. The 3-wire RTD provides an equal line resistance drop in both 100  $\Omega$  legs of the bridge, thus improving the accuracy.

The AMP04 amplifies the differential bridge signal and converts it to a single-ended output. The gain is set by the series resistance of the 332  $\Omega$  resistor plus the 50  $\Omega$  potentiometer. The gain scales the output to produce a 4.5 V full scale. The 0.22  $\mu$ F capacitor to the output provides a 7 Hz low-pass filter to keep noise at a minimum.

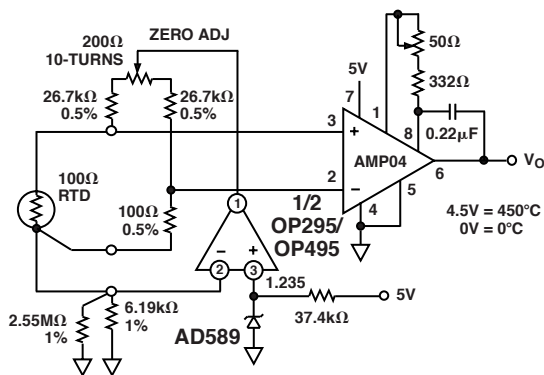


Figure 6. Low Power RTD Amplifier

### A Cold Junction Compensated, Battery-Powered Thermocouple Amplifier

The OP295/OP495's 150  $\mu$ A quiescent current per amplifier consumption makes it useful for battery-powered temperature measuring instruments. The K-type thermocouple terminates into an isothermal block where the terminated junctions' ambient temperatures can be continuously monitored and corrected by summing an equal but opposite thermal EMF to the amplifier, thereby canceling the error introduced by the cold junctions.

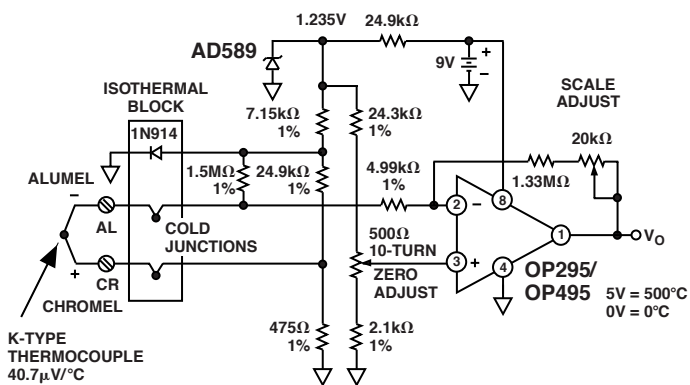


Figure 7. Battery-Powered, Cold-Junction Compensated Thermocouple Amplifier

To calibrate, immerse the thermocouple measuring junction in a 0°C ice bath, adjust the 500  $\Omega$  Zero Adjust pot to zero volts out. Then immerse the thermocouple in a 250°C temperature bath or oven and adjust the Scale Adjust pot for an output voltage of 2.50 V, which is equivalent to 250°C. Within this temperature range, the K-type thermocouple is quite accurate and produces a fairly linear transfer characteristic. Accuracy of  $\pm 3^\circ\text{C}$  is achievable without linearization.

Even if the battery voltage is allowed to decay to as low as 7 V, the rail-to-rail swing allows temperature measurements to 700°C. However, linearization may be necessary for temperatures above 250°C where the thermocouple becomes rather nonlinear. The circuit draws just under 500  $\mu$ A supply current from a 9 V battery.

### A 5 V Only, 12-Bit DAC That Swings 0 V to 4.095 V

Figure 8 shows a complete voltage output DAC with wide output voltage swing operating off a single 5 V supply. The serial input 12-bit D/A converter is configured as a voltage output device with the 1.235 V reference feeding the current output pin ( $I_{\text{OUT}}$ ) of the DAC. The  $V_{\text{REF}}$  which is normally the input now becomes the output.

The output voltage from the DAC is the binary weighted voltage of the reference, which is gained up by the output amplifier such that the DAC has a 1 mV per bit transfer function.

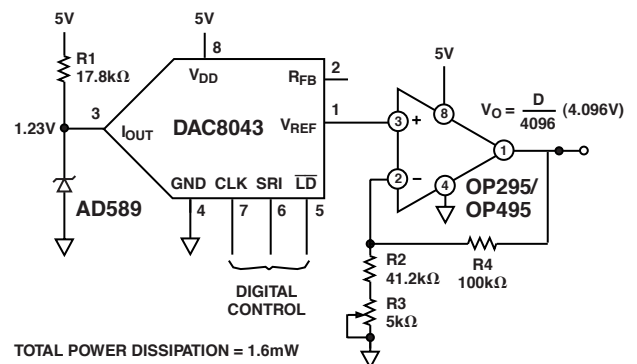


Figure 8. A 5 V 12-Bit DAC with 0 V to 4.095 V Output Swing

### 4 mA to 20 mA Current Loop Transmitter

Figure 9 shows a self powered 4 mA to 20 mA current loop transmitter. The entire circuit floats up from the single-supply (12 V to 36 V) return. The supply current carries the signal within the 4 mA to 20 mA range. Thus the 4 mA establishes the baseline current budget with which the circuit must operate. This circuit consumes only 1.4 mA maximum quiescent current, making 2.6 mA of current available to power additional signal conditioning circuitry or to power a bridge circuit.

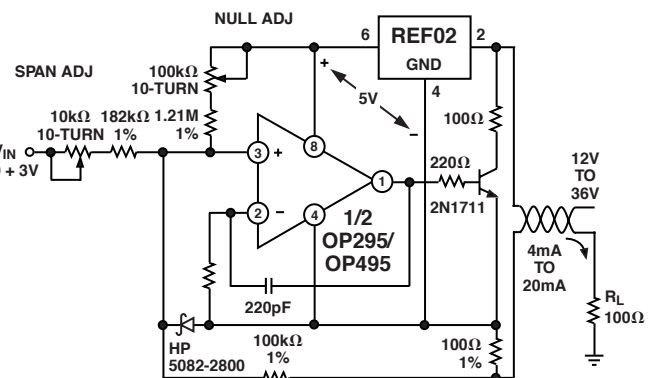


Figure 9. 4 mA to 20 mA Current Loop Transmitter

# OP295/OP495

## A 3 V Low-Dropout Linear Voltage Regulator

Figure 10 shows a simple 3 V voltage regulator design. The regulator can deliver 50 mA load current while allowing a 0.2 V dropout voltage. The OP295/OP495's rail-to-rail output swing handily drives the MJE350 pass transistor without requiring special drive circuitry. At no load, its output can swing less than the pass transistor's base-emitter voltage, turning the device nearly off. At full load, and at low emitter-collector voltages, the transistor beta tends to decrease. The additional base current is easily handled by the OP295/OP495 output.

The amplifier serves the output to a constant voltage, which feeds a portion of the signal to the error amplifier.

Higher output current, to 100 mA, is achievable at a higher dropout voltage of 3.8 V.

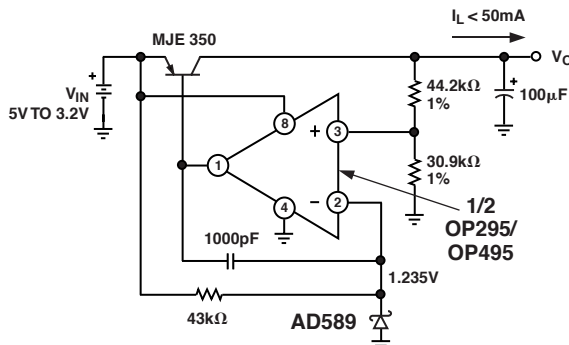


Figure 10. 3 V Low Dropout Voltage Regulator

Figure 11 shows the regulator's recovery characteristic when its output underwent a 20 mA to 50 mA step current change.

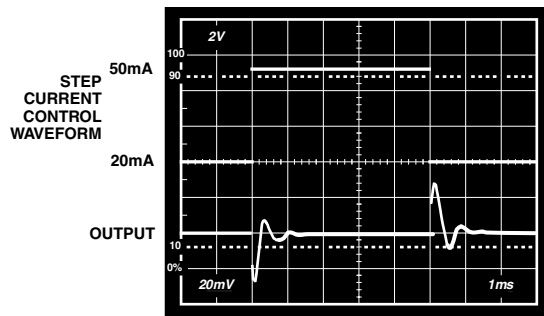


Figure 11. Output Step Load Current Recovery

## Low-Dropout, 500 mA Voltage Regulator with Fold-Back Current Limiting

Adding a second amplifier in the regulation loop as shown in Figure 12 provides an output current monitor as well as fold-back current limiting protection.

Amplifier A1 provides error amplification for the normal voltage regulation loop. As long as the output current is less than 1 A, amplifier A2's output swings to ground, reverse biasing the diode and effectively taking itself out of the circuit. However, as the output current exceeds 1 amp, the voltage that develops across the 0.1 Ω sense resistor forces the amplifier A2's output to go high, forward-biasing the diode, which in turn closes the current limit loop. At this point A2's lower output resistance dominates the drive to the power MOSFET transistor, thereby effectively removing the A1 voltage regulation loop from the circuit.

If the output current greater than 1 amp persists, the current limit loop forces a reduction of current to the load, which causes a corresponding drop in output voltage. As the output voltage drops, the current limit threshold also drops fractionally, resulting in a decreasing output current as the output voltage decreases, to the limit of less than 0.2 A at 1 V output. This "fold-back" effect reduces the power dissipation considerably during a short circuit condition, thus making the power supply far more forgiving in terms of the thermal design requirements. Small heat sinking on the power MOSFET can be tolerated.

The OP295's rail-to-rail swing exacts higher gate drive to the power MOSFET, providing a fuller enhancement to the transistor. The regulator exhibits 0.2 V dropout at 500 mA of load current. At 1 amp output, the dropout voltage is typically 5.6 V.

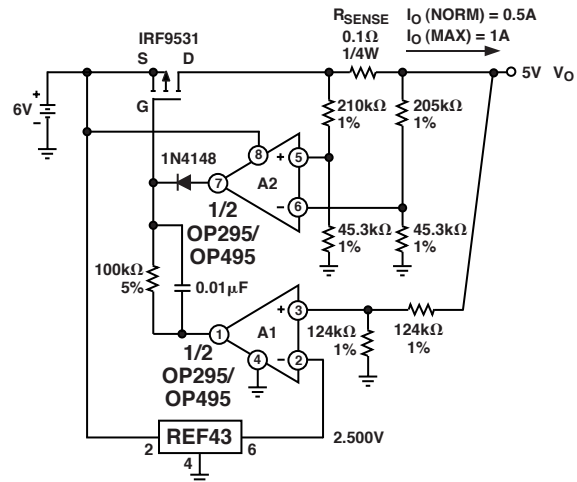


Figure 12. Low Dropout, 500 mA Voltage Regulator with Fold-Back Current Limiting

## Square Wave Oscillator

The circuit in Figure 13 is a square wave oscillator (note the positive feedback). The rail-to-rail swing of the OP295/OP495 helps maintain a constant oscillation frequency even if the supply voltage varies considerably. Consider a battery powered system where the voltages are not regulated and drop over time. The rail-to-rail swing ensures that the noninverting input sees the full  $V_{+}/2$ , rather than only a fraction of it.

The constant frequency comes from the fact that the 58.7 kΩ feedback sets up Schmitt Trigger threshold levels that are directly proportional to the supply voltage, as are the RC charge voltage levels. As a result, the RC charge time, and therefore, the frequency, remains constant independent of supply voltage. The slew rate of the amplifier limits oscillation frequency to a maximum of about 800 Hz at a 5 V supply.

## Single-Supply Differential Speaker Driver

Connected as a differential speaker driver, the OP295/OP495 can deliver a minimum of 10 mA to the load. With a 600 Ω load, the OP295/OP495 can swing close to 5 V peak-to-peak across the load.

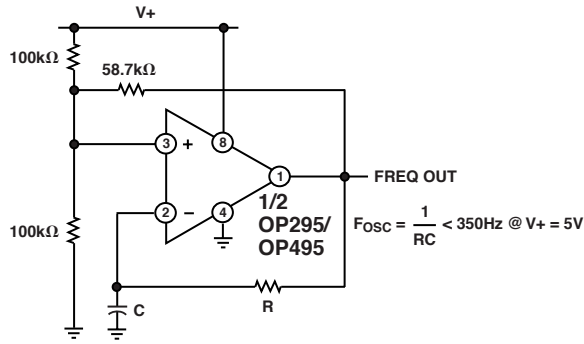


Figure 13. Square Wave Oscillator Has Stable Frequency Regardless of Supply Changes

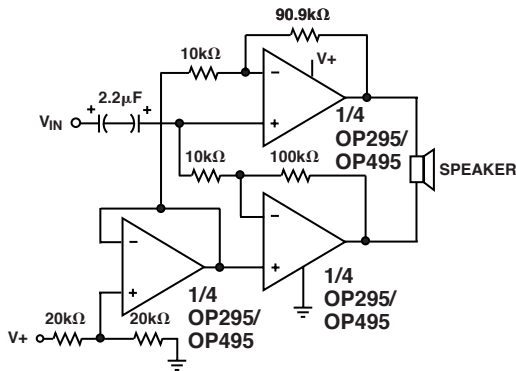


Figure 14. Single-Supply Differential Speaker Driver

### High Accuracy, Single-Supply, Low Power Comparator

The OP295/OP495 makes an accurate open-loop comparator. With a single 5 V supply, the offset error is less than 300 µV. Figure 15 shows the OP295/OP495's response time when operating open-loop with 4 mV overdrive. It exhibits a 4 ms response time at the rising edge and a 1.5 ms response time at the falling edge.

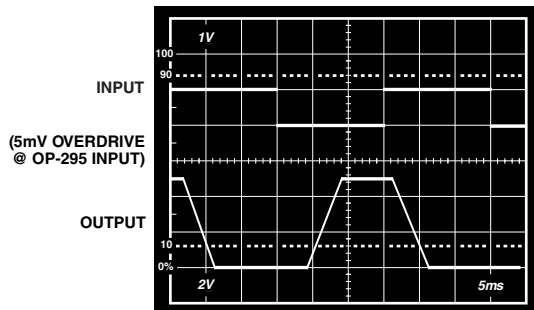
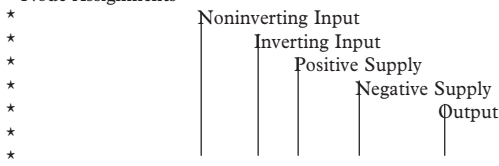


Figure 15. Open-Loop Comparator Response Time with 5 mV Overdrive

### OP295/OP495 SPICE MODEL Macro-Model

\* Node Assignments



```
.SUBCKT OP295 1 2 99 50 20
```

\* INPUT STAGE

```
I1 99 4 2E-6
R1 1 6 5E3
```

```
R2 2 5 5E3
CIN 1 2 2E-12
IOS 1 2 0.5E-9
D1 5 3 DZ
D2 6 3 DZ
EOS 7 6 POLY (1) (31,39) 30E-6 0.024
Q1 8 5 4 QP
Q2 9 7 4 QP
R3 8 50 25.8E3
R4 9 50 25.8E3
*
```

\* GAIN STAGE

```
R7 10 98 270E6
G1 98 10 POLY (1) (9,8) -4.26712E-9 27.8E-6
EREF 98 0 (39, 0) 1
R5 99 39 100E3
R6 39 50 100E3
*
```

\* COMMON MODE STAGE

```
ECM 30 98 POLY(2) (1,39) (2,39) 0 0.5 0.5
R12 30 31 1E6
R13 31 98 100
*
```

\* OUTPUT STAGE

```
I2 18 50 1.59E-6
V2 99 12 DC 2.2763
Q4 10 14 50 QNA 1.0
R11 14 50 33
M3 15 10 13 13 MN L=9E-6 W=102E-6 AD=15E-10 AD=15E-10
M4 13 10 50 50 MN L=9E-6 W=50E-6 AD=75E-11 AS=75E-11
D8 10 22 DX
V3 22 50 DC 6
M2 20 10 14 14 MN L=9E-6 W=2000E-6 AD=30E-9 AS=30E-9
Q5 17 17 99 QPA 1.0
Q6 18 17 99 QPA 4.0
R8 18 99 2.2E6
Q7 18 19 99 QPA 1.0
R9 99 19 8
C2 18 99 20E-12
M6 15 12 17 99 MP L=9E-6 W=27E-6 AD=405E-12 AS=405E-12
M1 20 18 19 99 MP L=9E-6 W=2000E-6 AD=30E-9 AS=30E-9
D4 21 18 DX
V4 99 21 DC 6
R10 10 11 6E3
C3 11 20 50E-12
```

```
.MODEL QNA NPN (IS=1.19E-16 BF=253 NF=0.99 VAF=193 IKF=2.76E-3
+ ISE=2.57E-13 NE=5 BR=0.4 NR=0.988 VAR=15 IKR=1.465E-4
+ ISC=6.9E-16 NC=0.99 RB=2.0E3 IRB=7.73E-6 RBM=132.8 RE=4
RC=209
```

```
+ CJE=2.1E-13 VJE=0.573 MJE=0.364 FC=0.5 CJC=1.64E-13 VJC=0.534
MJC=0.5
```

```
+ CJS=1.37E-12 VJS=0.59 MJS=0.5 TF=0.43E-9 PTF=30)
```

```
.MODEL QPA PNP (IS=5.21E-17 BF=131 NF=0.99 VAF=62 IKF=8.35E-4
+ ISE=1.09E-14 NE=2.61 BR=0.5 NR=0.984 VAR=15 IKR=3.96E-5
+ ISC=7.58E-16 NC=0.985 RB=1.52E3 IRB=1.67E-5 RBM=368.5 RE=6.31
RC=354.4
```

```
+ CJE=1.1E-13 VJE=0.745 MJE=0.33 FC=0.5 CJC=2.37E-13 VJC=0.762
MJC=0.4
```

```
+ CJS =7.11E-13 VJS=0.45 MJS=0.412 TF=1.0E-9 PTF=30)
```

```
.MODEL MN NMOS (LEVEL=3 VTO=1.3 RS=0.3 RD=0.3
```

```
+ TOX=8.5E-8 LD=1.48E-6 NSUB=1.53E16 UO=650 DELTA=10 VMAX=2E5
+ XJ=1.75E-6 KAPPA=0.8 ETA=0.066 THETA=0.01 TPG=1 CJ=2.9E-4
PB=0.837
```

```
+ MJ=0.407 CJSW=0.5E-9 MJSW=0.33)
```

```
.MODEL MP PMOS (LEVEL=3 VTO=-1.1 RS=0.7 RD=0.7
```

```
+ TOX=9.5E-8 LD=1.4E-6 NSUB=2.4E15 UO=650 DELTA=5.6 VMAX=1E5
+ XJ=1.75E-6 KAPPA=1.7 ETA=0.71 THETA=5.9E-3 TPG=-1 CJ=1.55E-4
PB=0.56
```

```
+ MJ=0.442 CJSW=0.4E-9 MJSW=0.33)
```

```
.MODEL DX D (IS=1E-15)
```

```
.MODEL DZ D (IS=1E-15, BV=7)
```

```
.MODEL QP PNP (BF=125)
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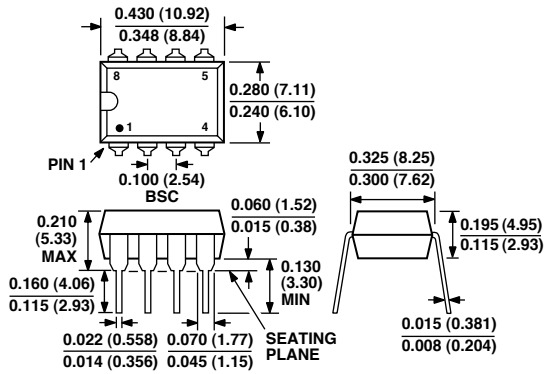
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.ENDS
```

# OP295/OP495

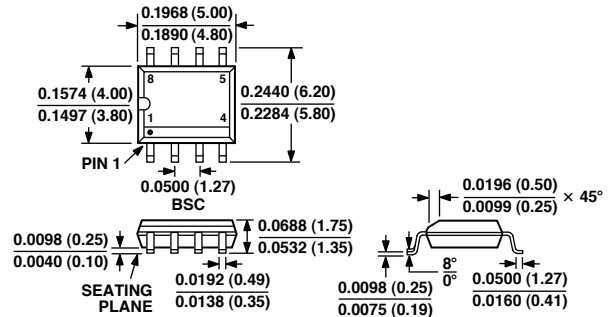
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm)

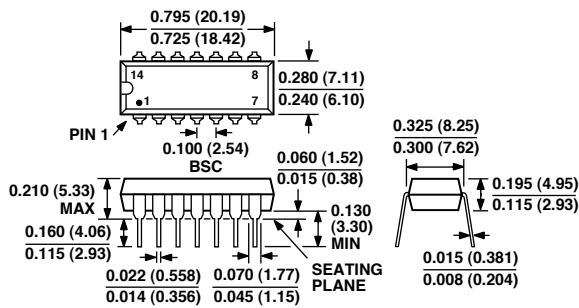
**8-Lead Plastic DIP  
(P Suffix)**



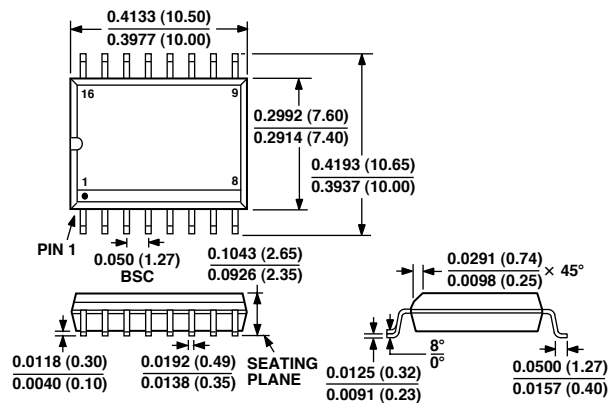
**8-Lead Narrow-Body SO  
(S Suffix)**



**14-Lead Plastic DIP  
(P Suffix)**



**16-Lead Wide-Body SO  
(S Suffix)**



## Revision History

Location	Page
03/02—Data Sheet changed from REV. B to REV. C.	
Figure changes to PIN CONNECTIONS .....	1
Deletion of OP295GBC and OP495GBC from ORDERING GUIDE .....	3
Deletion of WAFER TEST LIMITS table .....	3
Changes to ABSOLUTE MAXIMUM RATINGS.....	4
Deletion of DICE CHARACTERISTICS .....	4