



# Dual/Quad Rail-to-Rail Operational Amplifiers

## OP-295/OP-495

### 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: 1000 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

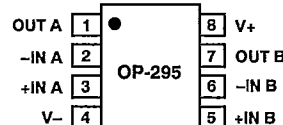
Rail-to-rail output swing combined with dc accuracy are the key features of the OP-495 quad and OP-295 dual CBCMOS operational amplifiers. By using a bipolar front end, lower noise and higher accuracy than CMOS designs have been achieved. Both input and output ranges include the negative supply providing the user "zero-in/zero-out" capability. For users of 3.3 volt systems such as lithium batteries, the OP-295/OP-495 is specified for three volt operation.

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

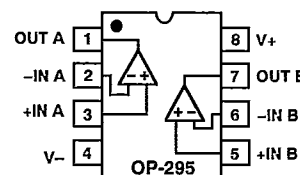
The ability to swing rail-to-rail and supply  $\pm 15$  mA to the load makes the OP-295/OP-495 an ideal driver for power transistors and "H" bridges. This allows designs to achieve higher efficiencies and to transfer more power to the load than previously possible without the use of discrete components. 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

### PIN CONNECTIONS

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

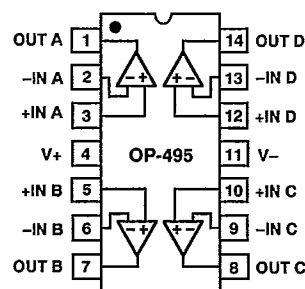


#### 8-Lead Epoxy DIP (P Suffix)

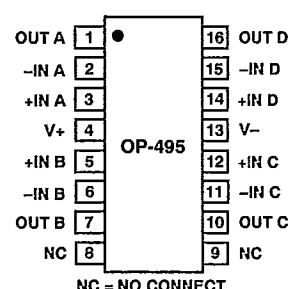


#### 14-Lead Epoxy DIP (P Suffix)

#### 14-Lead Ceramic DIP (Y Suffix)



#### 16-Lead SOL (300 Mil) (S Suffix)



rail-to-rail amplifiers. This is useful for driving coax cable or large FET transistors. The OP-295/OP-495 is stable with loads in excess of 300 pF.

The OP-295 and OP-495 are specified over the extended industrial ( $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ ) temperature range. OP-295s are available in 8-pin plastic and ceramic DIP plus SO-8 surface mount packages. OP-495s are available in 14-pin plastic and ceramic DIP plus SOL-16 surface mount packages. Contact your local sales office for MIL-STD-883 data sheet.

### REV. 0

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# OP-295/OP-495—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	Units	
INPUT CHARACTERISTICS							
Offset Voltage	V <sub>OS</sub>	-40°C ≤ T <sub>A</sub> ≤ +85°C		30	300	μV	
Offset Voltage	V <sub>OS</sub>				600	μV	
Input Bias Current	I <sub>B</sub>	-40°C ≤ T <sub>A</sub> ≤ +85°C		8	20	nA	
Input Bias Current	I <sub>B</sub>				30	nA	
Input Offset Current	I <sub>OS</sub>	-40°C ≤ T <sub>A</sub> ≤ +85°C		1	±3	nA	
Input Offset Current	I <sub>OS</sub>				±5	nA	
Input Voltage Range	V <sub>CM</sub>	0 V ≤ V <sub>CM</sub> ≤ 4.0 V, -40°C ≤ T <sub>A</sub> ≤ +85°C	0		+4.0	V	
Common-Mode Rejection	CMR		90	110		dB	
Large Signal Voltage Gain	A <sub>VO</sub>		R <sub>L</sub> = 10 kΩ, 0.005 ≤ V <sub>OUT</sub> ≤ 4.0 V	1000	10,000		V/mV
Large Signal Voltage Gain	A <sub>VO</sub>		R <sub>L</sub> = 10 kΩ, -40°C ≤ T <sub>A</sub> ≤ +85°C	500			V/mV
Offset Voltage Drift	ΔV <sub>OS</sub> /ΔT			1	5	μV/°C	
OUTPUT CHARACTERISTICS							
Output Voltage Swing High	V <sub>OH</sub>	R <sub>L</sub> = 100 kΩ to GND	4.98	5.0		V	
Output Voltage Swing High	V <sub>OH</sub>	R <sub>L</sub> = 10 kΩ to GND	4.90	4.94		V	
Output Voltage Swing High	V <sub>OH</sub>	R <sub>L</sub> = 2 kΩ to GND		4.7		V	
Output Voltage Swing Low	V <sub>OL</sub>	R <sub>L</sub> = 100 kΩ to GND		0.7	2	mV	
Output Voltage Swing Low	V <sub>OL</sub>	R <sub>L</sub> = 10 kΩ to GND		0.7	2	mV	
Output Current	I <sub>OUT</sub>		±11	±18		mA	
POWER SUPPLY							
Power Supply Rejection Ratio	PSRR	±1.5 V ≤ V <sub>S</sub> ≤ ±15 V	90	110		dB	
Power Supply Rejection Ratio	PSRR	±1.5 V ≤ V <sub>S</sub> ≤ ±15 V, -40°C ≤ T <sub>A</sub> ≤ +85°C	85			dB	
Supply Current Per Amplifier	I <sub>SY</sub>	V <sub>OUT</sub> = 2.5 V, R <sub>L</sub> = ∞, -40°C ≤ T <sub>A</sub> ≤ +85°C			150	μA	
DYNAMIC PERFORMANCE							
Slew Rate	SR	R <sub>L</sub> = 10 kΩ		0.03		V/μs	
Gain Bandwidth Product	GBP				75		kHz
Phase Margin	θ <sub>O</sub>				86		Degrees
NOISE PERFORMANCE							
Voltage Noise	e <sub>n p-p</sub>	0.1 Hz to 10 Hz		1.5		μV p-p	
Voltage Noise Density	e <sub>n</sub>	f = 1 kHz		51		nV/√Hz	
Current Noise Density	i <sub>n</sub>	f = 1 kHz		0.6		pA/√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	Units	
INPUT CHARACTERISTICS							
Offset Voltage	V <sub>OS</sub>	0 V ≤ V <sub>CM</sub> ≤ 2.0 V, −40°C ≤ T <sub>A</sub> ≤ +85°C R <sub>L</sub> = 10 kΩ		100	500	μV	
Input Bias Current	I <sub>B</sub>			8	20	nA	
Input Offset Current	I <sub>OS</sub>			1	±3	nA	
Input Voltage Range	V <sub>CM</sub>			0		+2.0	V
Common-Mode Rejection	CMR			90	110		dB
Large Signal Voltage Gain	A <sub>VO</sub>				750		V/mV
Offset Voltage Drift	ΔV <sub>OS</sub> /ΔT				1		μV/°C
OUTPUT CHARACTERISTICS							
Output Voltage Swing High	V <sub>OH</sub>	R <sub>L</sub> = 10 kΩ to GND	2.9			V	
Output Voltage Swing Low	V <sub>OL</sub>	R <sub>L</sub> = 10 kΩ to GND		0.7	2	mV	
POWER SUPPLY							
Power Supply Rejection Ratio	PSRR	±1.5 V ≤ V <sub>S</sub> ≤ ±15 V	90	110		dB	
Power Supply Rejection Ratio	PSRR	±1.5 V ≤ V <sub>S</sub> ≤ ±15 V, −40°C ≤ T <sub>A</sub> ≤ +85°C	85			dB	
Supply Current Per Amplifier	I <sub>SY</sub>	V <sub>OUT</sub> = 1.5 V, R <sub>L</sub> = ∞, −40°C ≤ T <sub>A</sub> ≤ +85°C			150	μA	
DYNAMIC PERFORMANCE							
Slew Rate	SR	R <sub>L</sub> = 10 kΩ		0.03		V/μs	
Gain Bandwidth Product	GBP				75		kHz
Phase Margin	θ <sub>O</sub>				85		Degrees
NOISE PERFORMANCE							
Voltage Noise	e <sub>n p-p</sub>	0.1 Hz to 10 Hz		1.6		μV p-p	
Voltage Noise Density	e <sub>n</sub>	f = 1 kHz		53		nV/√Hz	
Current Noise Density	i <sub>n</sub>	f = 1 kHz		0.6		pA/√Hz	

Specifications subject to change without notice.

## OP-295/OP-495

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

Parameter	Symbol	Conditions	Min	Typ	Max	Units
<b>INPUT CHARACTERISTICS</b>						
Offset Voltage	$V_{OS}$			300	500	$\mu\text{V}$
Offset Voltage	$V_{OS}$	$-40^\circ\text{C} \leq T_A \leq -85^\circ\text{C}$			750	$\mu\text{V}$
Input Bias Current	$I_B$	$V_{CM} = 0$ V		7	20	nA
Input Bias Current	$I_B$	$V_{CM} = 0$ V, $-40^\circ\text{C} \leq T_A \leq -85^\circ\text{C}$			30	nA
Input Offset Current	$I_{OS}$	$V_{CM} = 0$ V		1	$\pm 3$	nA
Input Offset Current	$I_{OS}$	$V_{CM} = 0$ V, $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$			$\pm 5$	nA
Input Voltage Range	$V_{CM}$		-15		$+13.5$	V
Common-Mode Rejection	CMR	$-15.0$ V $\leq V_{CM} \leq +13.5$ V, $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$	90	110		dB
Large Signal Voltage Gain	$A_{VO}$	$R_L = 10$ k $\Omega$	1000	4000		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	$V_{OH}$	$R_L = 100$ k $\Omega$ to GND	14.95			V
Output Voltage Swing High	$V_{OH}$	$R_L = 10$ k $\Omega$ to GND	14.80			V
Output Voltage Swing Low	$V_{OL}$	$R_L = 100$ k $\Omega$ to GND			-14.95	V
Output Voltage Swing Low	$V_{OL}$	$R_L = 10$ k $\Omega$ to GND			-14.85	V
Output Current	$I_{OUT}$		$\pm 15$	$\pm 25$		mA
<b>POWER SUPPLY</b>						
Power Supply Rejection Ratio	PSRR	$V_S = \pm 1.5$ V to $\pm 15$ V	90	110		dB
Power Supply Rejection Ratio	PSRR	$V_S = \pm 1.5$ V to $\pm 15$ V, $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$	85			dB
Supply Current	$I_{SY}$	$V_O = 0$ V, $R_L = \infty$ , $V_S = \pm 18$ V, $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$			175	$\mu\text{A}$
Supply Voltage Range	$V_S$		$+3$ ( $\pm 15$ )		$+36$ ( $\pm 18$ )	V
<b>DYNAMIC PERFORMANCE</b>						
Slew Rate	SR	$R_L = 10$ 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	$e_{n\text{F-P}}$	0.1 Hz to 10 Hz		1.25		$\mu\text{V p-p}$
Voltage Noise Density	$e_n$	$f = 1$ kHz		45		nV/ $\sqrt{\text{Hz}}$
Current Noise Density	$i_n$	$f = 1$ kHz		0.6		pA/ $\sqrt{\text{Hz}}$

Specifications subject to change without notice.

**WAFER TEST LIMITS** (@  $V_S = +5.0$  V,  $V_{CM} = 2.5$  V,  $T_A = +25^\circ\text{C}$  unless otherwise noted)

Parameter	Symbol	Conditions	Limit	Units
Offset Voltage	$V_{OS}$		300	$\mu\text{V max}$
Input Bias Current	$I_B$		20	nA max
Input Offset Current	$I_{OS}$		$\pm 2$	nA max
Input Voltage Range <sup>1</sup>	$V_{CM}$		0 to +4	V min
Common-Mode Rejection	CMRR	$0$ V $\leq V_{CM} \leq 4$ V	90	dB min
Power Supply Rejection Ratio	PSRR	$\pm 1.5$ V $\leq V_S \leq \pm 15$ V	90	$\mu\text{V/V}$
Large Signal Voltage Gain	$A_{VO}$	$R_L = 10$ k $\Omega$	1000	V/mV min
Output Voltage Swing High	$V_{OH}$	$R_L = 10$ k $\Omega$	4.9	V min
Supply Current Per Amplifier	$I_{SY}$	$V_{OUT} = 2.5$ V, $R_L = \infty$	150	$\mu\text{A max}$

## NOTES

Electrical tests and wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualifications through sample lot assembly and testing.

<sup>1</sup> Guaranteed by CMR test.

## ORDERING GUIDE

Model	Temperature Range	Package Option	Model	Temperature Range	Package Option
OP295AZ/883	$-55^\circ\text{C}$ to $+125^\circ\text{C}$	8-Pin Cerdip	OP495AY/883	$-55^\circ\text{C}$ to $+125^\circ\text{C}$	14-Pin Cerdip
OP295GP	$-40^\circ\text{C}$ to $+85^\circ\text{C}$	8-Pin Plastic DIP	OP495GP	$-40^\circ\text{C}$ to $+85^\circ\text{C}$	14-Pin Plastic DIP
OP295GS	$-40^\circ\text{C}$ to $+85^\circ\text{C}$	8-Pin SOIC	OP495GS	$-40^\circ\text{C}$ to $+85^\circ\text{C}$	16-Pin SOL
OP295GBC	$-25^\circ\text{C}$	DICE	OP495GBC	$+25^\circ\text{C}$	DICE

# OP-295/OP-495

## 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	
Y, Z Package	−65°C to +175°C
P, S Package	−65°C to +150°C
Operating Temperature Range	
OP-295A, OP-495A	−55°C to +125°C
OP-295G, OP-495G	−40°C to +85°C
Junction Temperature Range	
Y, Z Package	−65°C to +175°C
P, S Package	−65°C to +150°C
Lead Temperature Range (Soldering, 60 Sec)	+300°C

Package Type	$\theta_{JA}$ <sup>3</sup>	$\theta_{JC}$	Units
8-Pin Cerdip (Z)	148	16	°C/W
8-Pin Plastic DIP (P)	103	43	°C/W
8-Pin SOIC (S)	158	43	°C/W
14-Pin Cerdip (Y)	108	16	°C/W
14-Pin Plastic DIP (P)	83	39	°C/W
16-Pin SOL (S)	98	30	°C/W

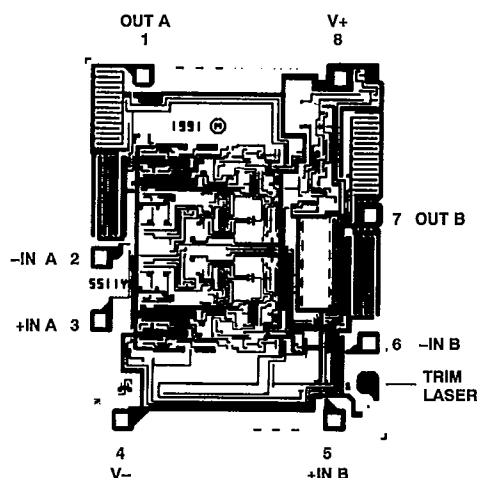
## NOTES

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

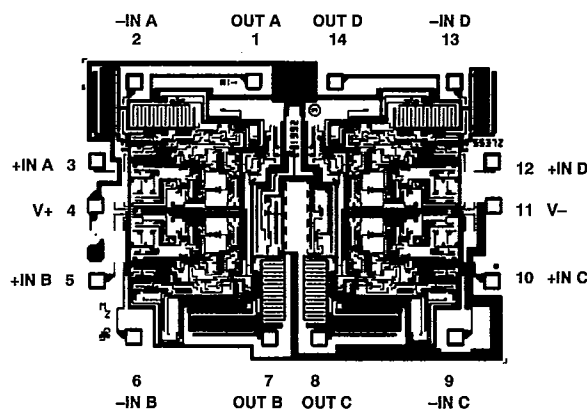
<sup>2</sup>For supply voltages less than ±18 V, the absolute maximum input voltage is equal to the supply voltage.

<sup>3</sup> $\theta_{JA}$  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.

## DICE CHARACTERISTICS

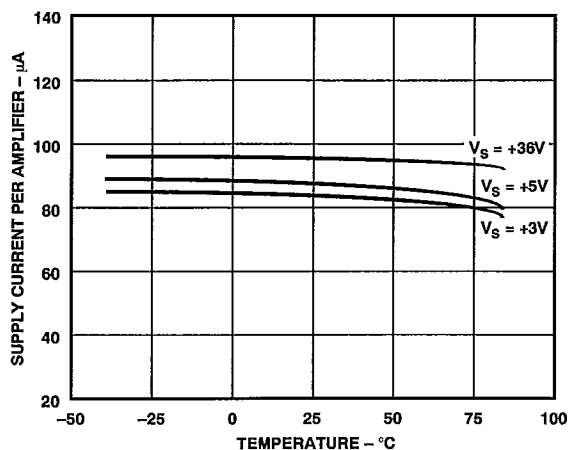


OP-295 Die Size 0.066 × 0.080 inch, 5,280 sq. mils.  
Substrate (Die Backside) Is Connected to V+.  
Transistor Count, 74.

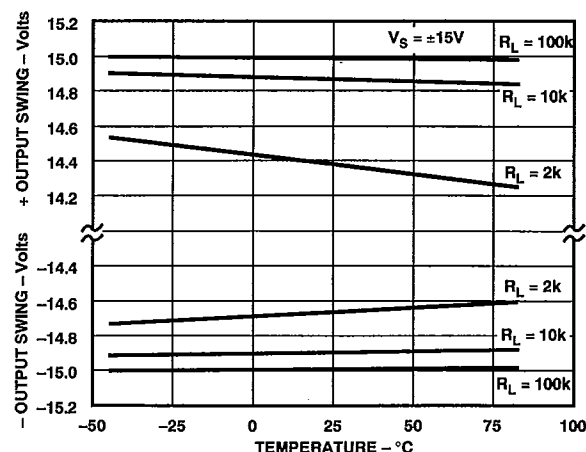


OP-495 Die Size 0.113 × 0.083 inch, 9,380 sq. mils.  
Substrate (Die Backside) Is Connected to V+.  
Transistor Count, 196.

## Typical Characteristics—OP-295/OP-495

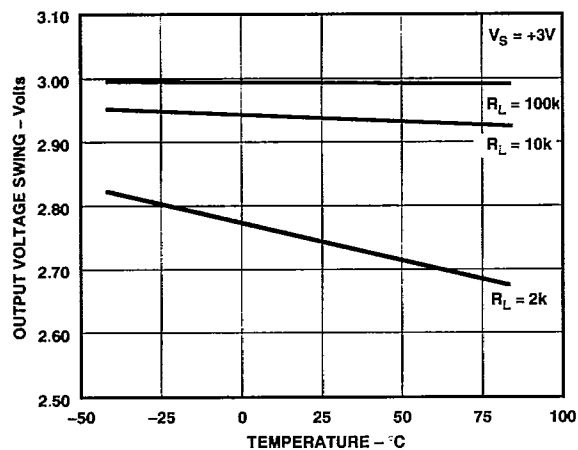


Supply Current Per Amplifier vs. Temperature

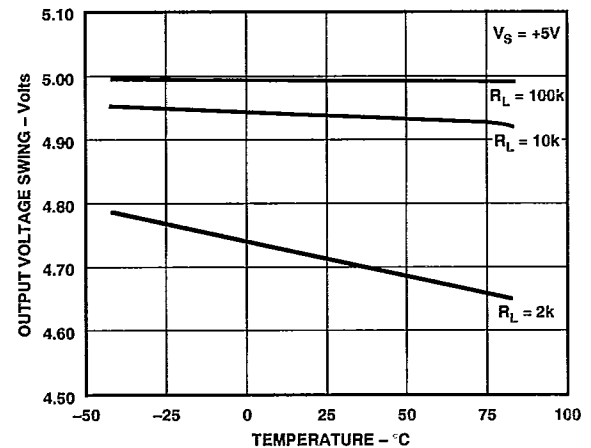


Output Voltage Swing vs. Temperature

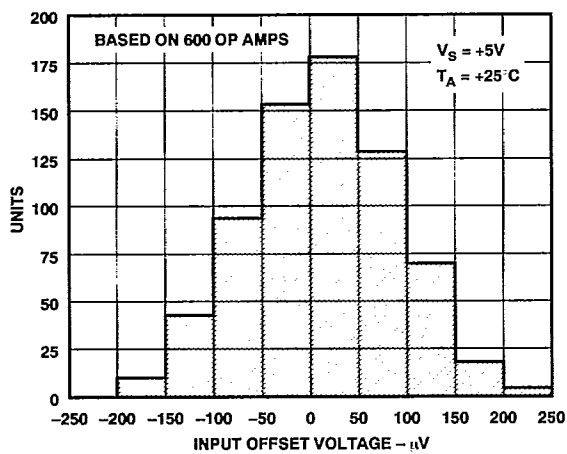
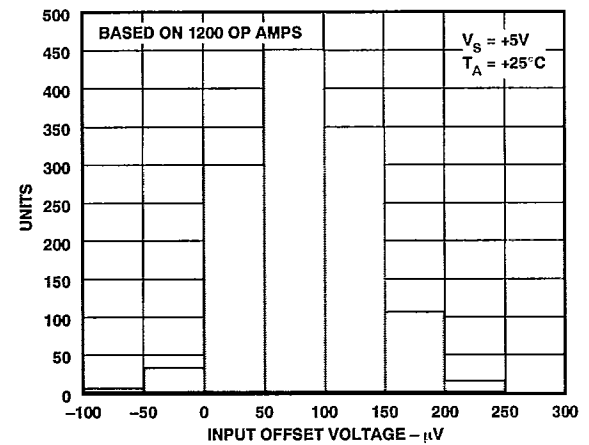
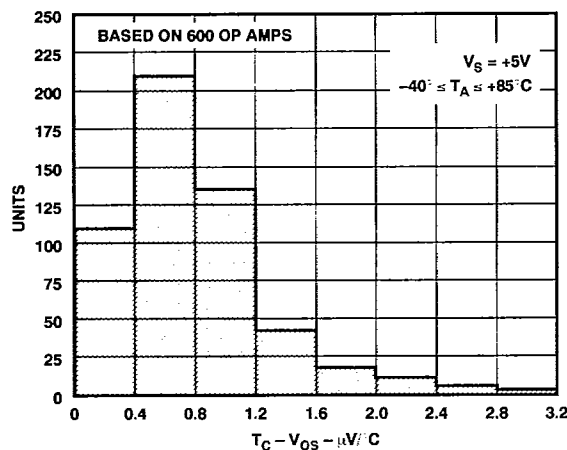
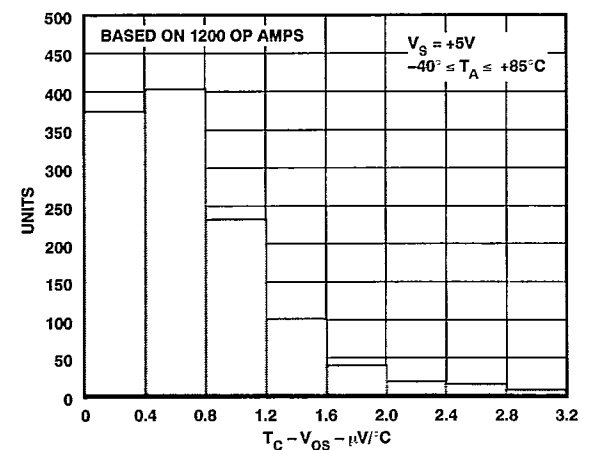
# Typical Characteristics—OP-295/OP-495



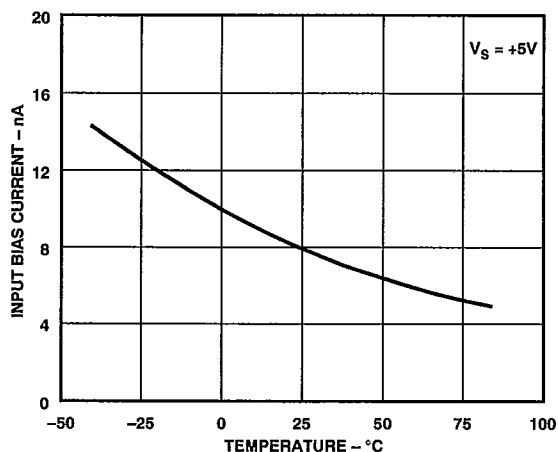
Output Voltage Swing vs. Temperature



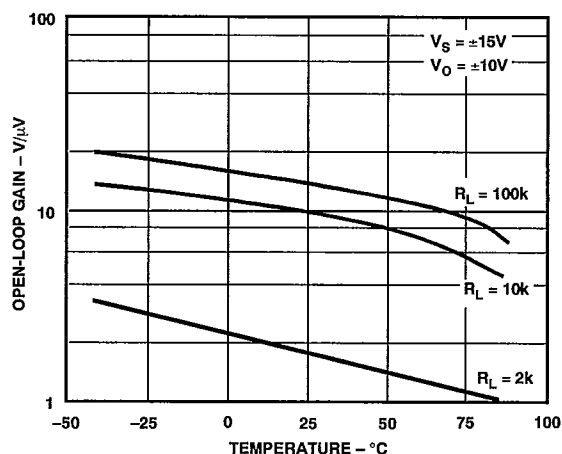
Output Voltage Swing vs. Temperature

OP-295 Input Offset ( $V_{OS}$ ) DistributionOP-495 Input Offset ( $V_{OS}$ ) DistributionOP-295  $T_C - V_{OS}$  DistributionOP-495  $T_C - V_{OS}$  Distribution

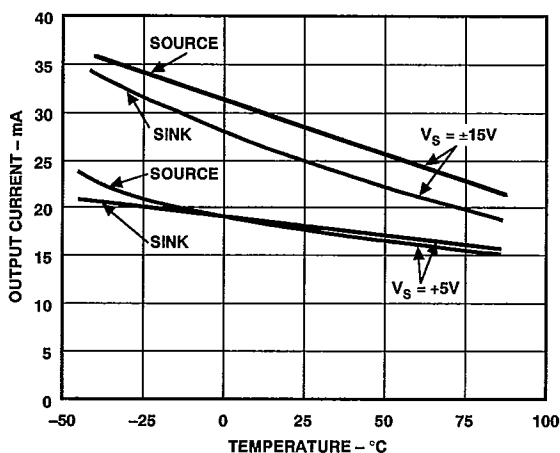
# OP-295/OP-495—Typical Characteristics



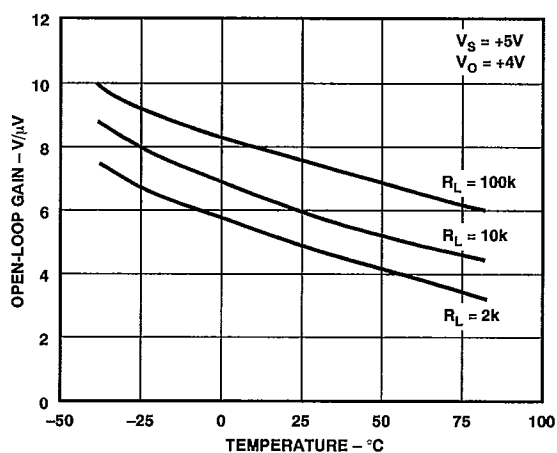
Input Bias Current vs. Temperature



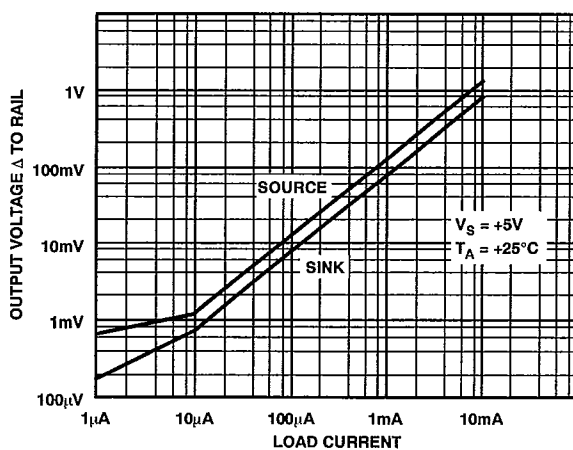
Open-Loop Gain vs. Temperature



Output Current vs. Temperature



Open-Loop Gain vs. Temperature



Output Voltage to Supply Rail vs. Sink and Source Load Current

## OP-295/OP-495

## APPLICATIONS

## Rail-to-Rail Applications Information

The OP-295/OP-495 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 OP-295/OP-495 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 OP-295/OP-495 can be used to gain up a 2.5 V or other low voltage reference to 4.5 volts for use with high resolution A/D converters that operate from +5 volt 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 volt supply.

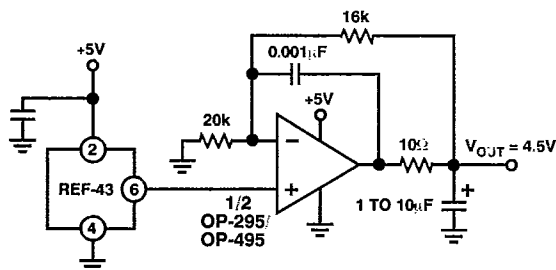


Figure 1. 4.5 Volt, Low Drop-Out Reference

## 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 to 60 nV/√Hz and single supply amplifiers with noise below 5 nV/√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 OP-295/OP-495 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 nV/√Hz at 100 Hz. R5 and R6 set the gain of 1000, making this circuit ideal for maximizing dynamic range when amplifying low level signals in single supply applications. The OP-295/OP-495 provides rail-to-rail output swings allowing this circuit to operate with 0 to 5 volt outputs. Only half of the OP-295/OP-495 is used leaving the other uncommitted op amp for use elsewhere.

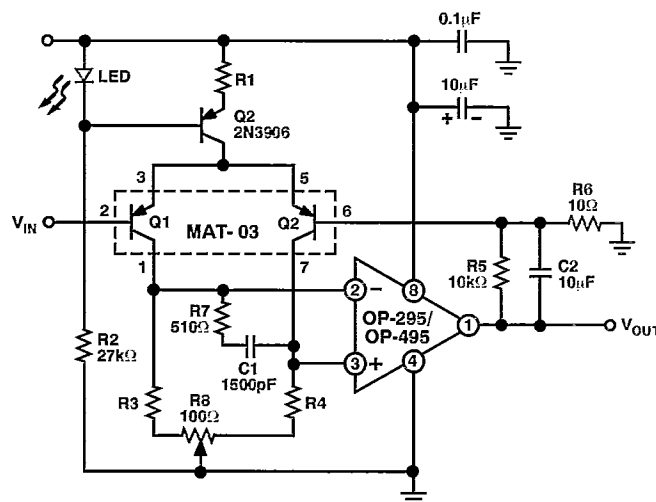


Figure 2. Low Noise Single Supply Preamplifier

The input noise is controlled by the MAT-03 transistor pair and its 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 nV/√Hz and 10 nV/√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 MAT-03 has an  $h_{FE} = 165$ . This leads to bias currents of 11 μA and 3 μA, respectively. Based on high bias currents, this circuit is best suited for applications with low source impedance such as magnetic pickups or low impedance strain gauges. Furthermore, a high source impedance will degrade the noise performance. For example, a 1 kΩ resistor generates 4 nV/√Hz of broad band noise, which is already greater than the preamp.

The collector current is set by R1 in combination with the LED and Q2. The LED is a 1.6 V "Zener" that has 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 Ω, 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 have to 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 OP-90 as the output amplifier with a savings of about 185 μA of supply current. However, the output swing will not include the positive rail, and the bandwidth will reduce to approximately 250 Hz.

# OP-295/OP-495

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	1000	1000

## Driving Heavy Loads

The OP-295/OP-495 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 OP-295/OP-495 because of its ability to drive capacitive loads of several hundred picofarads without oscillating.

Without the addition of external transistors the OP-295/OP-495 can drive loads in excess of  $\pm 15 \text{ mA}$  with  $\pm 15$  or 30 volt supplies. This drive capability is somewhat decreased at lower supply voltages. At  $\pm 5$  volt 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 volt supply this driver is capable of driving loads from 0.8 to 4.2 volts 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

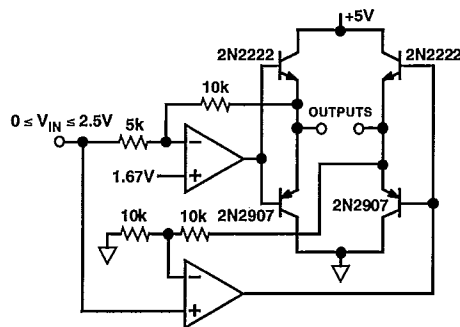


Figure 3a. "H" Bridge

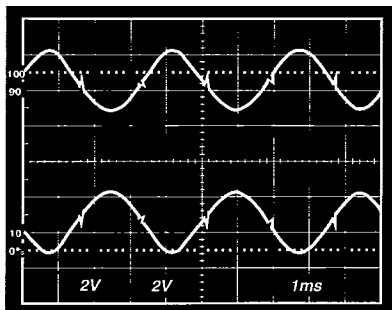


Figure 3b. "H" Bridge Outputs

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.

## Direct Access Arrangement

OP-295/OP-495 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 DAA capable of operating from a single +5 volt supply and it may also work on +3 volt 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 OP-295/OP-495's ability to drive capacitive loads, and to save power in single supply applications.

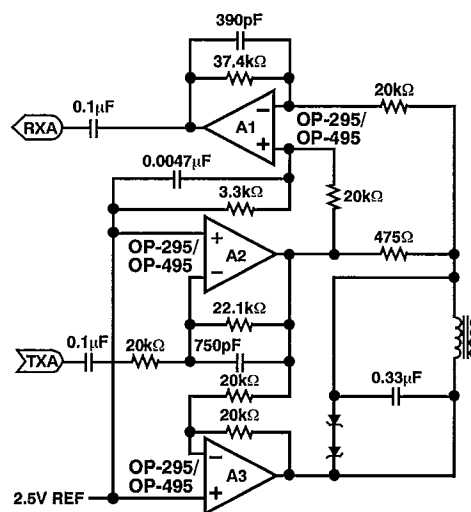


Figure 4. Direct Access Arrangement

## A Single Supply Instrumentation Amplifier

The OP-295/OP-495 can be configured as a single supply instrumentation amplifier as in Figure 5. The input common-mode voltage range includes ground and the output swings to both rails.

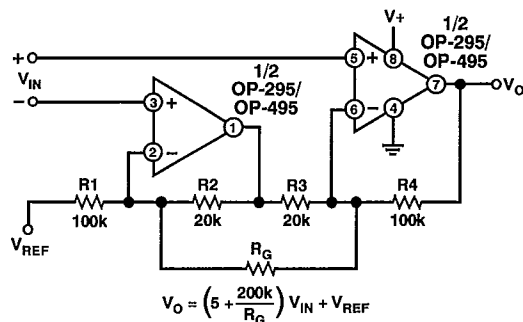


Figure 5. Single Supply Instrumentation Amplifier

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 volts.



## OP-295/OP-495

**A Single Supply RTD Thermometer Amplifier**

This RTD amplifier takes advantage of the rail-to-rail swing of the OP-295/OP-495 to achieve a high bridge voltage in spite of a low 5 V supply. The OP-295/OP-495 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 a equal line resistance drop in both 100  $\Omega$  legs of the bridge, thus improving the accuracy.

The AMP-04 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.

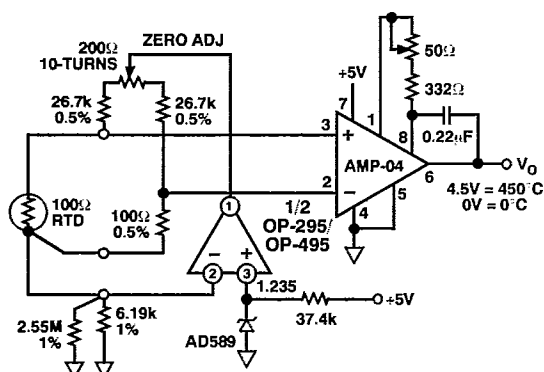


Figure 6. Low Power RTD Amplifier

**A Cold Junction Compensated, Battery Powered Thermocouple Amplifier**

The OP-295/OP-495'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 temperature 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.

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

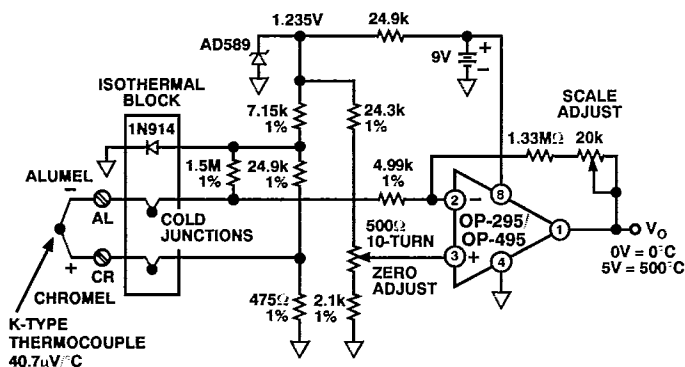


Figure 7. Battery Powered, Cold-Junction Compensated Thermocouple Amplifier

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 volts, 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.

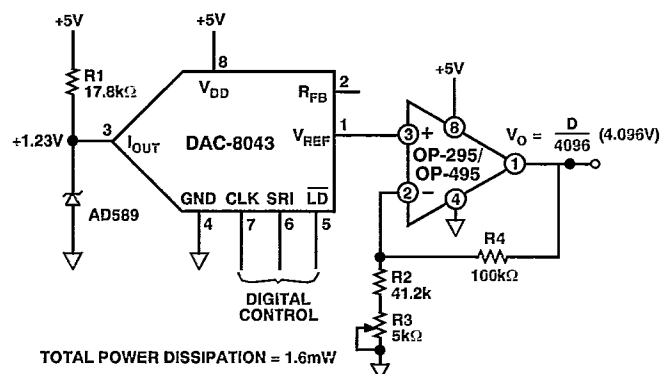


Figure 8. A 5 Volt 12-Bit DAC with 0 V to +4.095 Output Swing

**4–20mA Current Loop Transmitter**

Figure 9 shows a self-powered 4–20 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

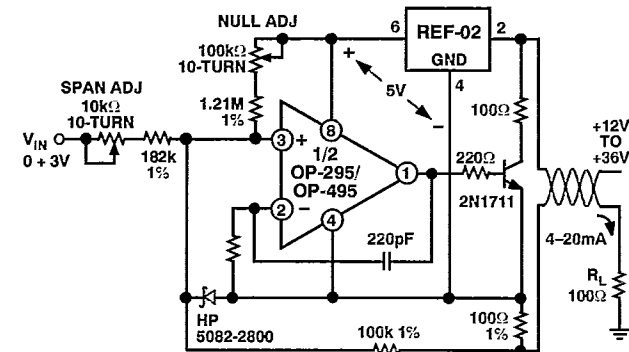


Figure 9. 4–20 mA Current Loop Transmitter

## OP-295/OP-495

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.

### A 3 Volt 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 OP-295/OP-495'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 OP-295/OP-495 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.

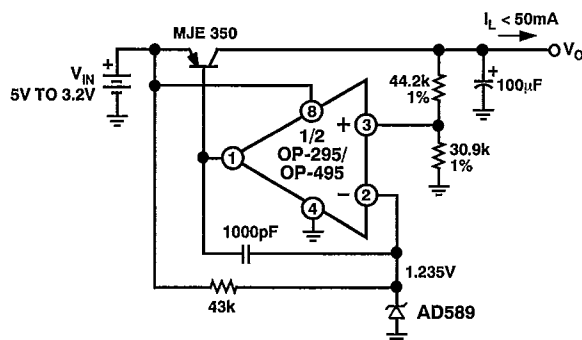


Figure 10. 3 V Low Dropout Voltage Regulator

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

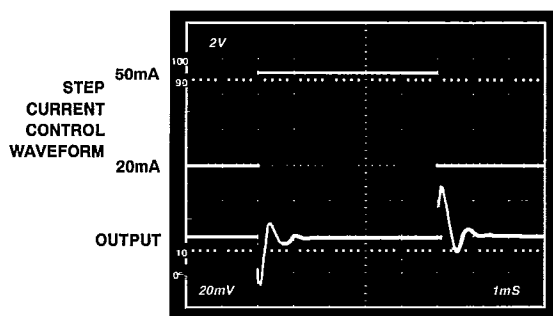


Figure 11. Output Step Load Current Recovery

### 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 provides 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 ampere, 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  $\Omega$  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 OP-295's rail-to-rail swing exerts higher gate drive to the power MOSFET, providing a fuller enhancement to the transistor. The regulator exhibits 0.2 V drop-out at 500 mA of load current. At 1 amp output, the drop-out voltage is typically 5.6 volts.

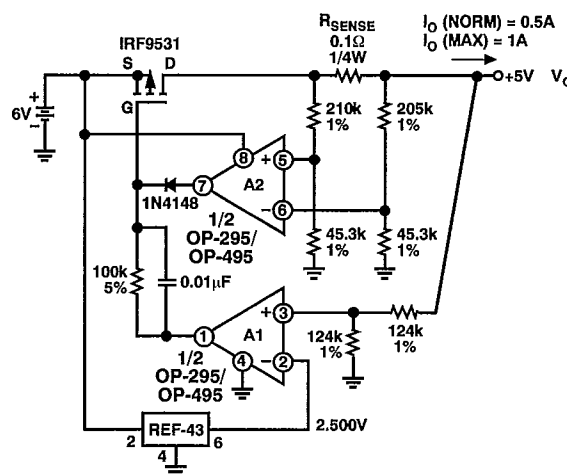


Figure 12. Low Dropout, 500 mA Voltage Regulator with Fold-back Current Limiting

### Square Wave Oscillator

The oscillator circuit in Figure 13 shows the rail-to-rail swing helps maintain a constant oscillation frequency even though the supply voltage varies considerably. This works great in a battery powered system where no voltage regulation is required. The constant frequency comes from the fact that the 58.7 k $\Omega$  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, remain constant independent of supply voltage. The slew rate of the amplifier limits the oscillation frequency to a maximum of about 800 Hz at +5 V supply.

### Single Supply Differential Speaker Driver

Connected as a differential speaker driver, the OP-295/OP-495 can deliver a minimum of 10 mA to the load. With a 600  $\Omega$  load, the OP-295/OP-495 can swing close to 5 volts peak-to-peak across the load.

## OP-295/OP-495

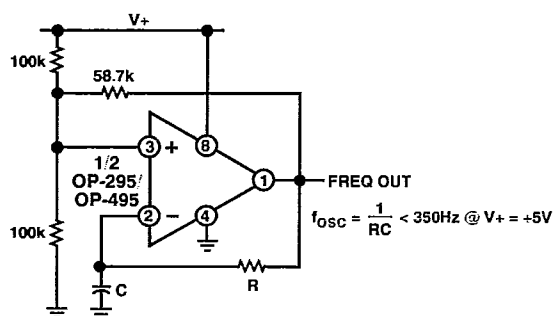


Figure 13. Square Wave Oscillator Has Stable Frequency Regardless of Supply Changes

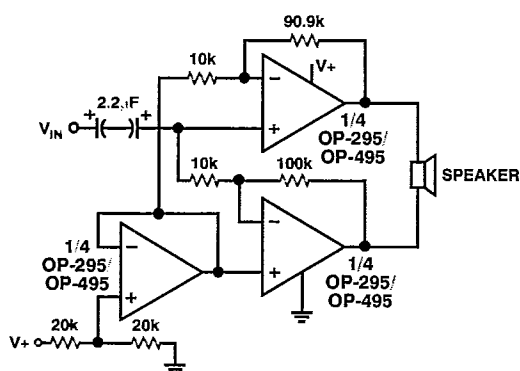


Figure 14. Single Supply Differential Speaker Driver

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

The OP-295/OP-495 makes an accurate open-loop comparator. With single  $\pm 5$  V supply, the offset error is less than  $300 \mu\text{V}$ . Figure 15 shows the OP-295/OP-495's response time operating open-loop with  $4 \text{ mV}$  overdrive. It exhibits a  $4 \text{ ms}$  response time at the rising edge and a  $1.5 \text{ ms}$  response time at the falling edge.

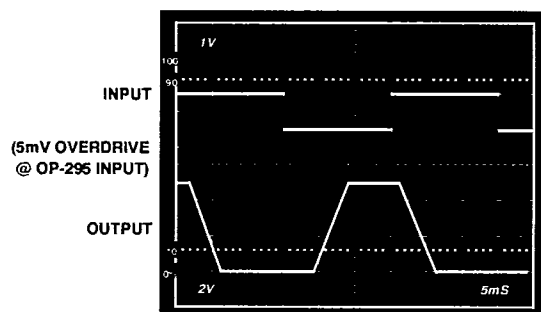


Figure 15. Open-Loop Comparator Response Time with  $5 \text{ mV}$  Overdrive

### OP-295/OP-495 SPICE MODEL Macro-Model

#### \* Node Assignments

	Noninverting Input	Inverting Input	Positive Supply	Negative Supply	Output
* SUBCKT OP-295	1	2	99	50	20

#### \* INPUT STAGE

Il	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
VOS	7	6	30E-6
Q1	8	5	4
Q2	9	7	4
R3	8	50	25.8E3
R4	9	50	25.8E3

#### \* GAIN STAGE

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

#### \* 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 AS=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 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 WD=1E-6 NSUB=1.53E16 UO=650 DELTA=10  
 VMAX=2E5

## OP-295/OP-495

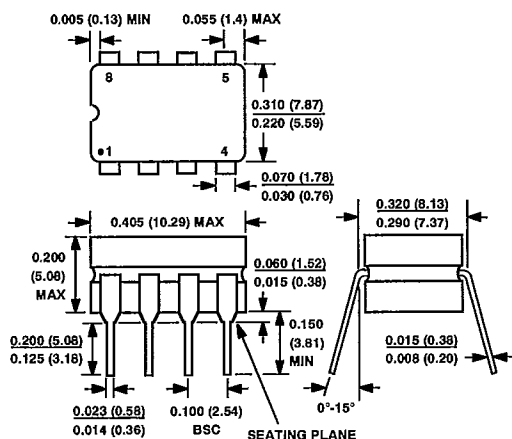
+ XJ=1.75E-6 KAPPA=0.8 ETA=0.066 THETA=0.01 TPG=1 CJ=2.9E-4  
 PB=0.837  
 + MJ=0.407 CJSW=0.5E-9 MJSW=0.33)  
 .MODEL MP PMOS (LEVEL=3 VTO=-1.1 RS=0.7 RD=0.7  
 + TOX=9.5E-8 LD=1.4E-6 WD=1E-6 NSUB=2.4E15 UO=650 DELTA =5.6  
 VMAX=1E5

+ 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)  
 .ENDS OP-295/OP-495

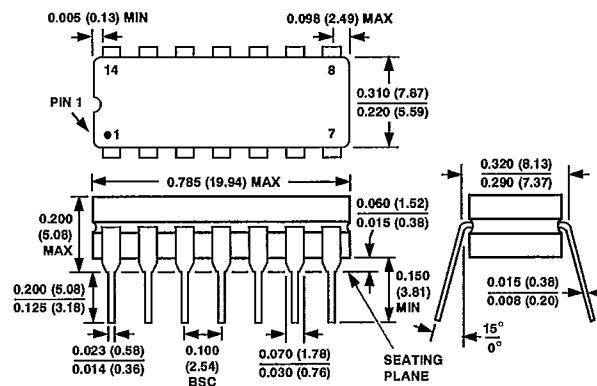
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

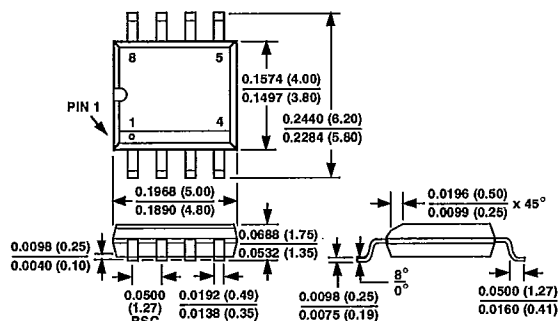
## 8-Lead Cerdip (Suffix Z)



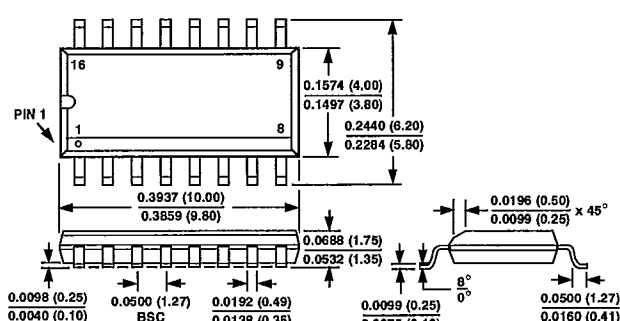
## 14-Lead Cerdip (Y Suffix)



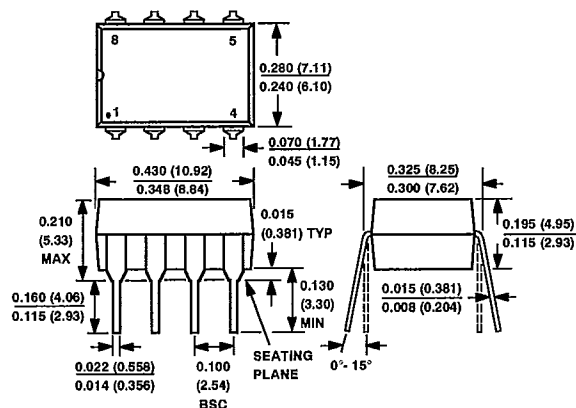
## 8-Lead Narrow-Body SO (S Suffix)



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



## 8-Lead Plastic DIP (P Suffix)



## 14-Lead Plastic DIP (P Suffix)

