



# Advance Information

## One Volt SMARTMOS™

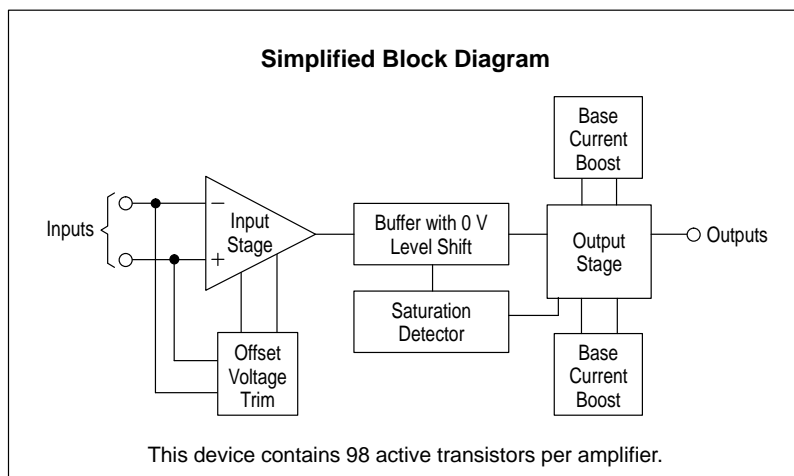
### Rail-to-Rail Dual Operational Amplifier

The MC33502 operational amplifier provides rail-to-rail operation on both the input and output. The output can swing within 50 mV of each rail. This rail-to-rail operation enables the user to make full use of the entire supply voltage range available. It is designed to work at very low supply voltages (1.0 V and ground), yet can operate with a supply of up to 7.0 V and ground. Output current boosting techniques provide high output current capability while keeping the drain current of the amplifier to a minimum.

- Low Voltage, Single Supply Operation (1.0 V and Ground to 7.0 V and Ground)
- High Input Impedance: Typically 40 fA Input Current
- Typical Unity Gain Bandwidth @ 5.0 V = 5.0 MHz, @ 1.0 V = 4.0 MHz
- High Output Current ( $I_{SC} = 50 \text{ mA @ } 5.0 \text{ V}$ ,  $10 \text{ mA @ } 1.0 \text{ V}$ )
- Output Voltage Swings within 50 mV of Both Rails @ 1.0 V
- Input Voltage Range Includes Both Supply Rails
- High Voltage Gain: 100 dB Typical @ 1.0 V
- No Phase Reversal on the Output for Over-Driven Input Signals
- Input Offset Trimmed to 0.5 mV Typical
- Low Supply Current ( $I_D = 1.2 \text{ mA/per Amplifier}$ , Typical)
- 600  $\Omega$  Drive Capability
- Extended Operating Temperature Range ( $-40$  to  $105^\circ\text{C}$ )

#### APPLICATIONS

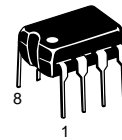
- Single Cell NiCd/Ni MH Powered Systems
- Interface to DSP
- Portable Communication Devices
- Low Voltage Active Filters
- Telephone Circuits
- Instrumentation Amplifiers
- Audio Applications
- Power Supply Monitor and Control
- Compatible with VCX Logic



## MC33502

### LOW VOLTAGE RAIL-TO-RAIL DUAL OPERATIONAL AMPLIFIER

#### SEMICONDUCTOR TECHNICAL DATA

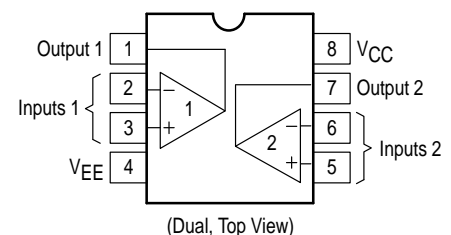


**P SUFFIX**  
PLASTIC PACKAGE  
CASE 626



**D SUFFIX**  
PLASTIC PACKAGE  
CASE 751  
(SO-8)

#### PIN CONNECTIONS



#### ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC33502P	$T_A = -40^\circ$ to $+105^\circ\text{C}$	Plastic DIP
MC33502D		SO-8

# MC33502

## MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Supply Voltage ( $V_{CC}$ to $V_{EE}$ )	$V_S$	7.0	V
ESD Protection Voltage at any Pin Human Body Model	$V_{ESD}$	2000	V
Voltage at Any Device Pin	$V_{DP}$	$V_S \pm 0.3$	V
Input Differential Voltage Range	$V_{IDR}$	$V_{CC}$ to $V_{EE}$	V
Common Mode Input Voltage Range	$V_{CM}$	$V_{CC}$ to $V_{EE}$	V
Output Short Circuit Duration	$t_S$	(Note 1)	s
Maximum Junction Temperature	$T_J$	150	°C
Storage Temperature Range	$T_{stg}$	-65 to 150	°C
Maximum Power Dissipation	$P_D$	(Note 1)	mW

**NOTES:** 1. Power dissipation must be considered to ensure maximum junction temperature ( $T_J$ ) is not exceeded.

2. ESD data available upon request.

**DC ELECTRICAL CHARACTERISTICS** ( $V_{CC} = 5.0$  V,  $V_{EE} = 0$  V,  $V_{CM} = V_O = V_{CC}/2$ ,  $R_L$  to  $V_{CC}/2$ ,  $T_A = 25^\circ\text{C}$ , unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Input Offset Voltage ( $V_{CM} = 0$ to $V_{CC}$ ) $V_{CC} = 1.0$ V $T_A = 25^\circ\text{C}$ $T_A = -40^\circ$ to $105^\circ\text{C}$ $V_{CC} = 3.0$ V $T_A = 25^\circ\text{C}$ $T_A = -40^\circ$ to $105^\circ\text{C}$ $V_{CC} = 5.0$ V $T_A = 25^\circ\text{C}$ $T_A = -40^\circ$ to $105^\circ\text{C}$	$V_{IO}$	-5.0 -7.0	0.5 -	5.0 7.0	mV
Input Offset Voltage Temperature Coefficient ( $R_S = 50 \Omega$ ) $T_A = -40^\circ$ to $105^\circ\text{C}$	$\Delta V_{IO}/\Delta T$	-	8.0	-	$\mu\text{V}/^\circ\text{C}$
Input Bias Current ( $V_{CC} = 1.0$ to $5.0$ V)	$ I_{IB} $	-	40	-	fA
Common Mode Input Voltage Range	$V_{ICR}$	$V_{EE}$	-	$V_{CC}$	V
Large Signal Voltage Gain $V_{CC} = 1.0$ V ( $T_A = 25^\circ\text{C}$ ) $R_L = 10 \text{ k}\Omega$ $R_L = 1.0 \text{ k}\Omega$ $V_{CC} = 3.0$ V ( $T_A = 25^\circ\text{C}$ ) $R_L = 10 \text{ k}\Omega$ $R_L = 1.0 \text{ k}\Omega$ $V_{CC} = 5.0$ V ( $T_A = 25^\circ\text{C}$ ) $R_L = 10 \text{ k}\Omega$ $R_L = 1.0 \text{ k}\Omega$	$A_{VOL}$	25 5.0	100 50	- -	kV/V

# MC33502

**DC ELECTRICAL CHARACTERISTICS (continued)** ( $V_{CC} = 5.0\text{ V}$ ,  $V_{EE} = 0\text{ V}$ ,  $V_{CM} = V_O = V_{CC}/2$ ,  $R_L$  to  $V_{CC}/2$ ,  $T_A = 25^\circ\text{C}$ , unless otherwise noted.)

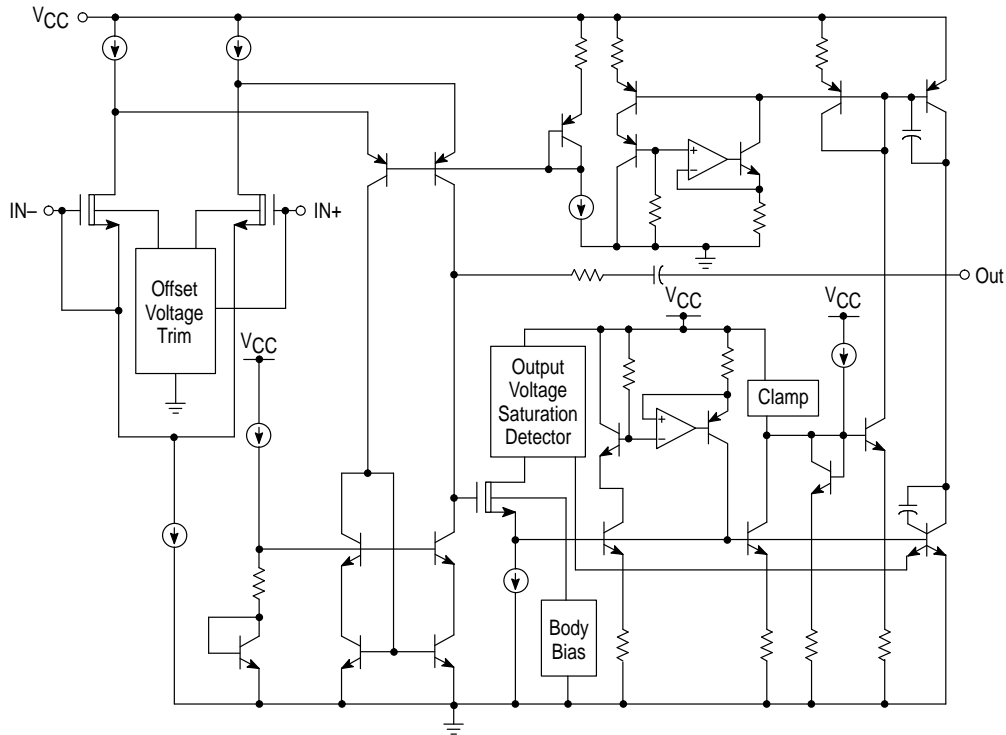
Characteristic	Symbol	Min	Typ	Max	Unit
Output Voltage Swing, High ( $V_{ID} = \pm 0.2\text{ V}$ ) $V_{CC} = 1.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 1.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 3.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 3.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 5.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 5.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$	$V_{OH}$	0.9 0.85 0.85 0.8 2.9 2.8 2.85 2.75 4.9 4.75 4.85 4.7	0.95 0.88 – – 2.93 2.84 – – 4.92 4.81 – –	– – – – – – – – – – – –	V
Output Voltage Swing, Low ( $V_{ID} = \pm 0.2\text{ V}$ ) $V_{CC} = 1.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 1.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 3.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 3.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 5.0\text{ V}$ ( $T_A = 25^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$ $V_{CC} = 5.0\text{ V}$ ( $T_A = -40^\circ$ to $105^\circ\text{C}$ ) $R_L = 10\text{ k}\Omega$ $R_L = 600\ \Omega$	$V_{OL}$	0.05 0.1 0.1 0.15 0.05 0.1 0.1 0.15 0.05 0.15 0.1 0.2	0.02 0.05 – – 0.02 0.08 – – 0.02 0.1 – –	– – – – – – – – – – – –	V
Common Mode Rejection ( $V_{in} = 0$ to $5.0\text{ V}$ )	CMR	60	75	–	dB
Power Supply Rejection Ratio $V_{CC}/V_{EE} = 5.0\text{ V}/\text{Ground}$ to $3.0\text{ V}/\text{Ground}$	$V_{OL}$	60	75	–	$\mu\text{V/V}$
Output Short Circuit Current ( $V_{in}$ Diff = $\pm 1.0\text{ V}$ ) $V_{CC} = 1.0\text{ V}$ Source Sink $V_{CC} = 3.0\text{ V}$ Source Sink $V_{CC} = 5.0\text{ V}$ Source Sink	$I_{SC}$	6.0 10 15 40 20 40	13 13 32 64 40 70	26 26 60 140 140 140	mA
Power Supply Current (Per Amplifier, $V_O = 0\text{ V}$ ) $V_{CC} = 1.0\text{ V}$ $V_{CC} = 3.0\text{ V}$ $V_{CC} = 5.0\text{ V}$ $V_{CC} = 1.0\text{ V}$ ( $T_A = -40$ to $105^\circ\text{C}$ ) $V_{CC} = 3.0\text{ V}$ ( $T_A = -40$ to $105^\circ\text{C}$ ) $V_{CC} = 5.0\text{ V}$ ( $T_A = -40$ to $105^\circ\text{C}$ )	$I_D$	– – – – – –	1.2 1.5 1.65 – – –	1.75 2.0 2.25 2.0 2.25 2.5	mA

# MC33502

**AC ELECTRICAL CHARACTERISTICS** ( $V_{CC} = 5.0\text{ V}$ ,  $V_{EE} = 0\text{ V}$ ,  $V_{CM} = V_O = V_{CC}/2$ ,  $T_A = 25^\circ\text{C}$ , unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Slew Rate ( $V_S = \pm 2.5\text{ V}$ , $V_O = -2.0\text{ to }2.0\text{ V}$ , $R_L = 2.0\text{ k}\Omega$ , $A_V = 1.0$ ) Positive Slope Negative Slope	SR	2.0 2.0	3.0 3.0	6.0 6.0	$\text{V}/\mu\text{s}$
Unity Gain Bandwidth $V_{CC} = 1.0\text{ V}$ $V_{CC} = 3.0\text{ V}$ $V_{CC} = 5.0\text{ V}$	BW	3.0 3.5 4.0	4.0 4.5 5.0	6.0 7.0 8.0	MHz
Gain Margin ( $R_L = 10\text{ k}\Omega$ , $C_L = 0\text{ pF}$ )	$A_m$	–	6.5	–	dB
Phase Margin ( $R_L = 10\text{ k}\Omega$ , $C_L = 0\text{ pF}$ )	$\phi_m$	–	60	–	Deg
Channel Separation ( $f = 1.0\text{ Hz to }20\text{ kHz}$ , $R_L = 600\ \Omega$ )	CS	–	120	–	dB
Power Bandwidth ( $V_O = 4.0\text{ V}_{pp}$ , $R_L = 1.0\text{ k}\Omega$ , $\text{THD} \leq 1.0\%$ )	BWp	–	200	–	kHz
Total Harmonic Distortion ( $V_O = 4.5\text{ V}_{pp}$ , $R_L = 600\ \Omega$ , $A_V = 1.0$ ) $f = 1.0\text{ kHz}$ $f = 10\text{ kHz}$	THD	– –	0.004 0.01	– –	%
Differential Input Resistance ( $V_{CM} = 0\text{ V}$ )	$R_{in}$	–	>1.0	–	terra $\Omega$
Differential Input Capacitance ( $V_{CM} = 0\text{ V}$ )	$C_{in}$	–	2.0	–	pF
Equivalent Input Noise Voltage ( $V_{CC} = 1.0\text{ V}$ , $V_{CM} = 0\text{ V}$ , $V_{EE} = \text{Gnd}$ , $R_S = 100\ \Omega$ ) $f = 1.0\text{ kHz}$ $f = 10\text{ kHz}$	$e_n$	– –	30 60	– –	$\text{nV}/\sqrt{\text{Hz}}$

**Figure 1. Representative Block Diagram**



## MC33502

### GENERAL INFORMATION

The MC33502 dual operational amplifier is unique in its ability to provide 1.0 V rail-to-rail performance on both the input and output by using a SMARTMOS process. The amplifier output swings within 50 mV of both rails and is able to provide 50 mA of output drive current with a 5.0 V supply, and 10 mA with a 1.0 V supply. A 5.0 MHz bandwidth and a slew rate of 3.0 V/ $\mu$ s is achieved with high speed depletion mode NMOS (DNMOS) and vertical PNP transistors. This device is characterized over a temperature range of  $-40^{\circ}\text{C}$  to  $105^{\circ}\text{C}$ .

### CIRCUIT INFORMATION

#### Input Stage

One volt rail-to-rail performance is achieved in the MC33502 at the input by using a single pair of depletion mode NMOS devices (DNMOS) to form a differential amplifier with a very low input current of 40 fA. The normal input common mode range of a DNMOS device, with an ion implanted negative threshold, includes ground and relies on the body effect to dynamically shift the threshold to a positive value as the gates are moved from ground towards the positive supply. Because the device is manufactured in a p-well process, the body effect coefficient is sufficiently large to ensure that the input stage will remain substantially saturated when the inputs are at the positive rail. This also applies at very low supply voltages. The 1.0 V rail-to-rail input stage consists of a DNMOS differential amplifier, a folded cascode, and a low voltage balanced mirror. The low voltage cascoded balanced mirror provides high 1st stage gain and base current cancellation without sacrificing signal integrity. Also, the input offset voltage is trimmed to less than 1.0 mV because of the limited available supply voltage. The body voltage of the input DNMOS differential pair is internally trimmed to minimize the input offset voltage. A common mode feedback path is also employed to enable the offset voltage to track over the input common mode voltage. The total operational amplifier quiescent current drop is 1.3 mA/amp.

#### Output Stage

An additional feature of this device is an "on demand" base current cancellation amplifier. This feature provides base drive to the output power devices by making use of a buffer amplifier to perform a voltage-to-current conversion. This is done in direct proportion to the load conditions. This "on demand" feature allows these amplifiers to consume only a few micro-amps of current when the output stage is in its quiescent mode. Yet it provides high output current when required by the load. The rail-to-rail output stage current boost circuit provides 50 mA of output current with a 5.0 V supply (For a 1.0 V supply output stage will do 10 mA) enabling the operational amplifier to drive a 600  $\Omega$  load. A buffer is necessary to isolate the load current effects in the output stage from the input stage. Because of the low voltage conditions, a DNMOS follower is used to provide an essentially zero voltage level shift. This buffer isolates any load current changes on the output stage from loading the input stage. A high speed vertical PNP transistor provides excellent frequency performance while sourcing current. The operational amplifier is also internally compensated to provide a phase margin of 60 degrees. It has a unity gain of 5.0 MHz with a 5.0 V supply and 4.0 MHz with a 1.0 V supply.

#### LOW VOLTAGE OPERATION

The MC33502 will operate at supply voltages from 0.9 to 7.0 V and ground. When using the MC33502 at supply voltages of less than 1.2 V, input offset voltage may increase slightly as the input signal swings within approximately 50 mV of the positive supply rail. This effect occurs only for supply voltages below 1.2 V, due to the input depletion mode MOSFETs starting to transition between the saturated to linear region, and should be considered when designing high side dc sensing applications operating at the positive supply rail. Since the device is rail-to-rail on both input and output, high dynamic range single battery cell applications are now possible.

Figure 2. Output Saturation versus Load Resistance

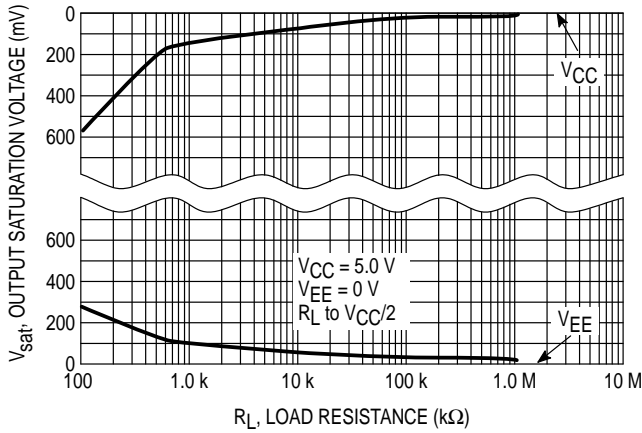


Figure 3. Drive Output Source/Sink Saturation Voltage versus Load Current

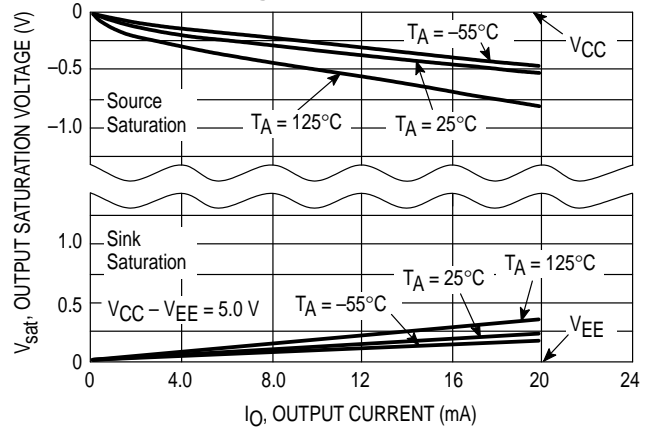


Figure 4. Input Current versus Temperature

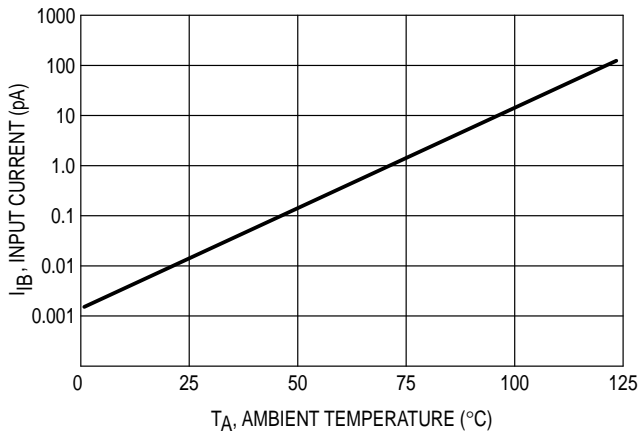


Figure 5. Gain and Phase versus Frequency

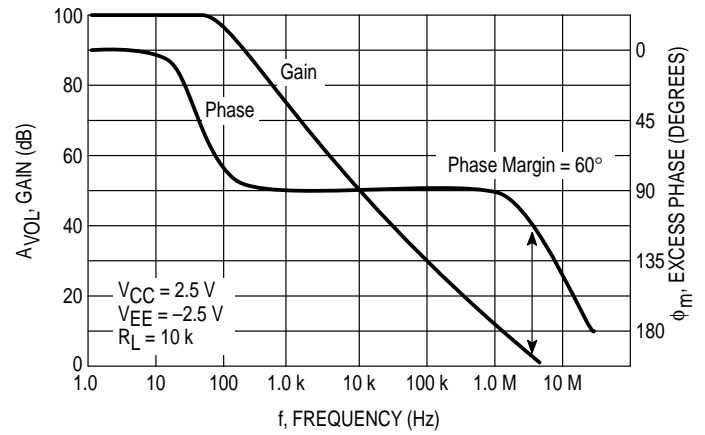


Figure 6. Transient Response

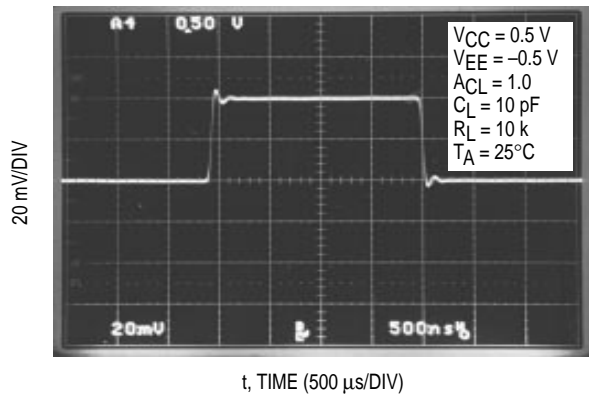


Figure 7. Slew Rate

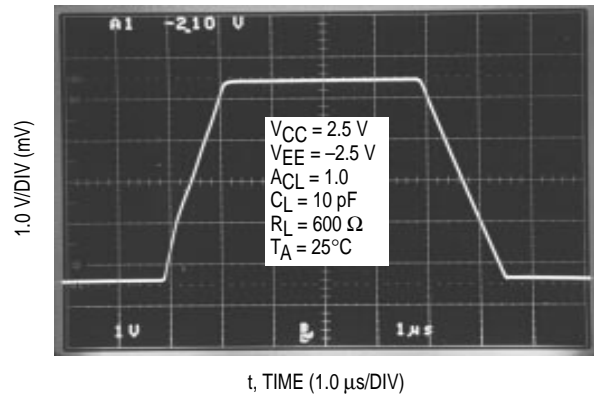


Figure 8. Maximum Power Dissipation versus Temperature

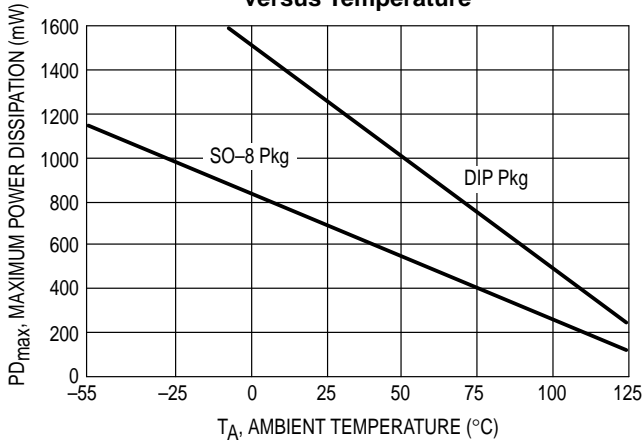


Figure 9. Open Loop Voltage Gain versus Temperature

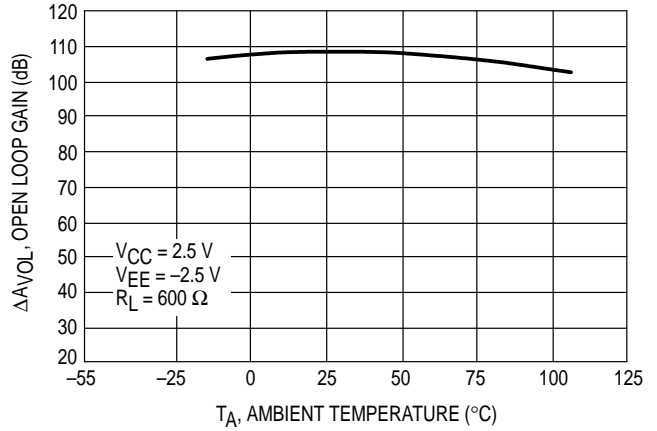


Figure 10. Output Voltage versus Frequency

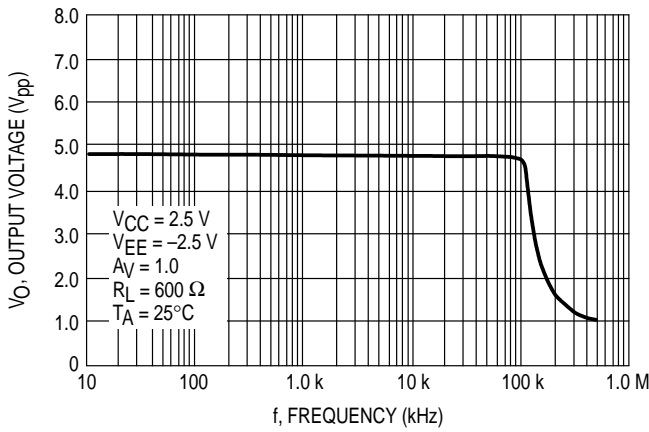


Figure 11. Common Mode Rejection versus Frequency

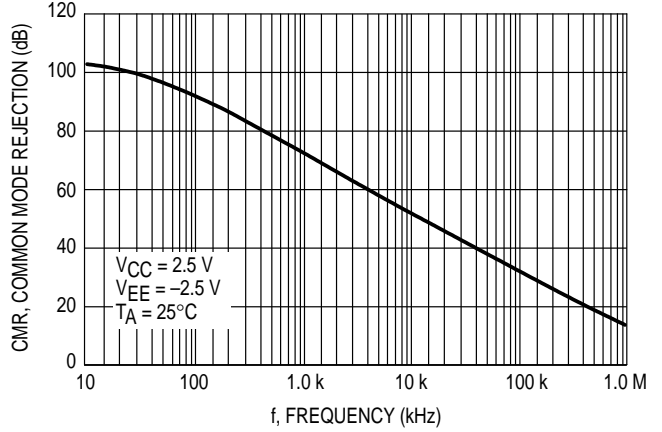


Figure 12. Power Supply Rejection versus Frequency

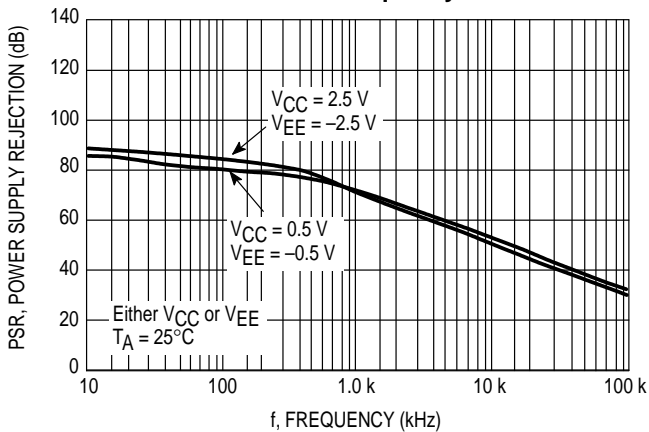


Figure 13. Output Short Circuit Current versus Output Voltage

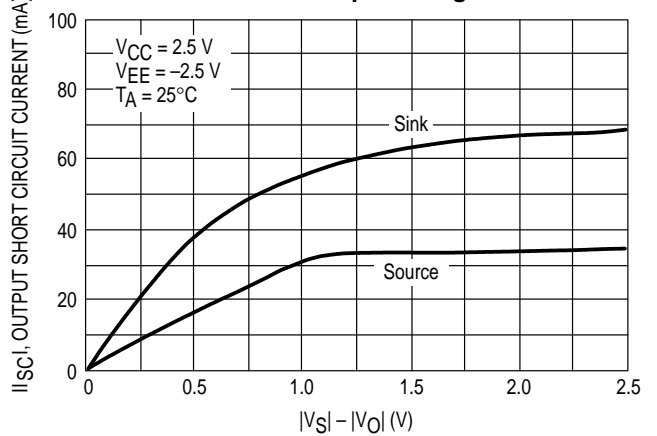


Figure 14. Output Short Circuit Current versus Temperature

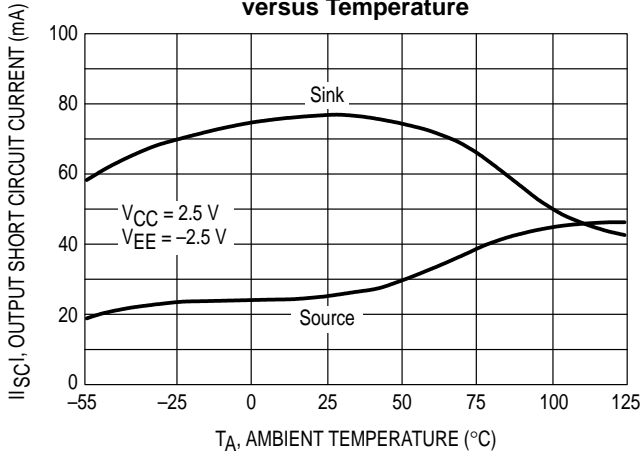


Figure 15. Supply Current per Amplifier versus Supply Voltage with No Load

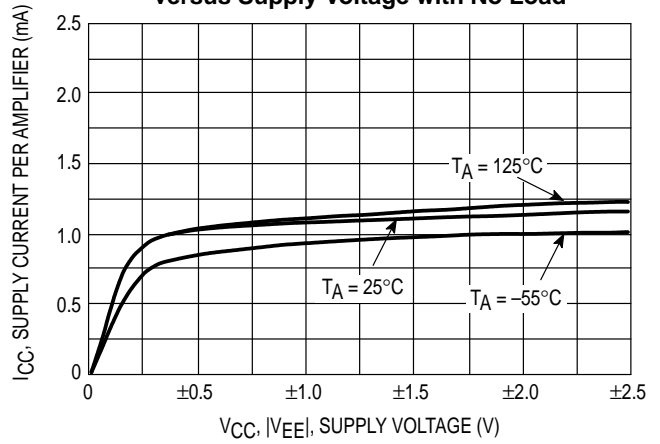


Figure 16. Input Offset Voltage Temperature Coefficient Distribution

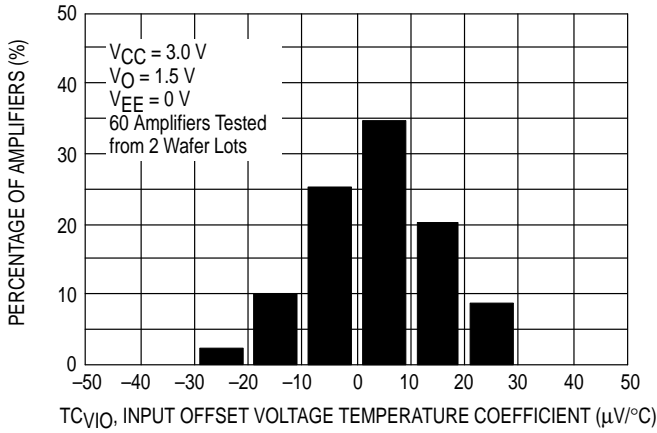


Figure 17. Input Offset Voltage Distribution

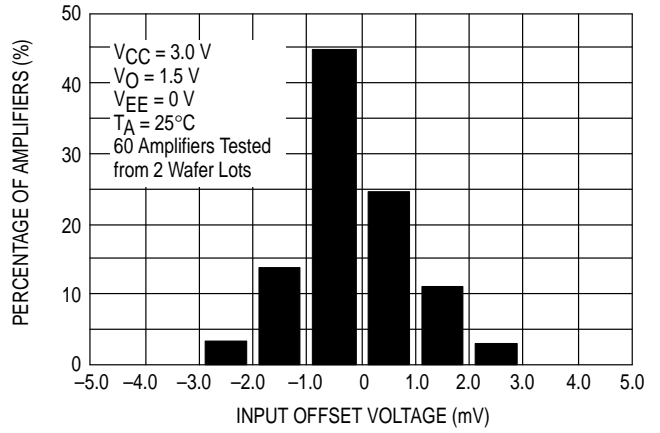


Figure 18. Total Harmonic Distortion versus Frequency with 1.0 V Supply

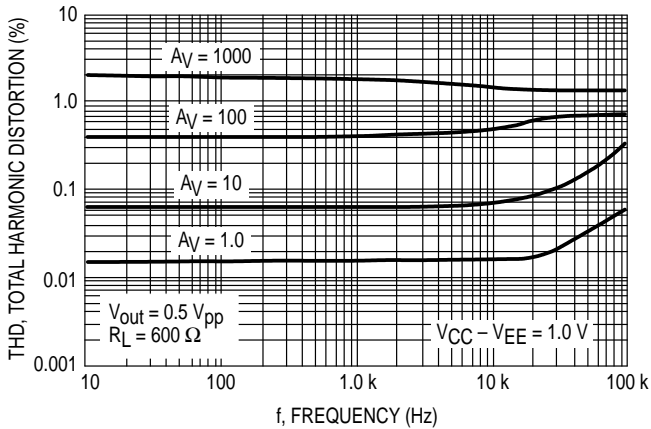


Figure 19. Total Harmonic Distortion versus Frequency with 5.0 V Supply

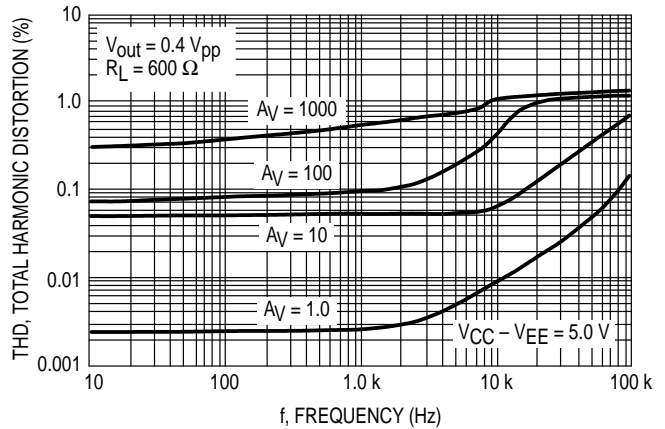




Figure 20. Slew Rate versus Temperature

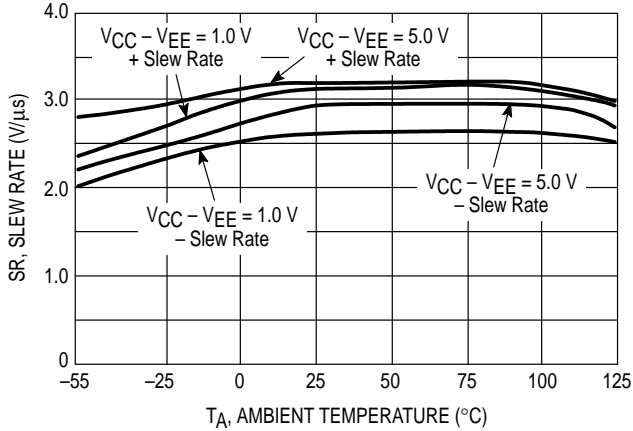


Figure 21. Gain Bandwidth Product versus Temperature

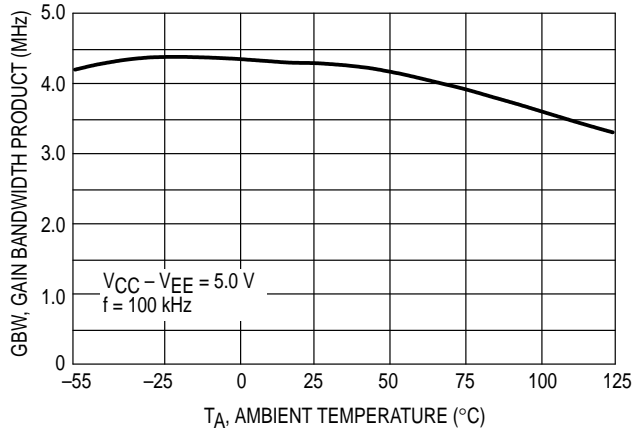


Figure 22. Voltage Gain and Phase versus Frequency

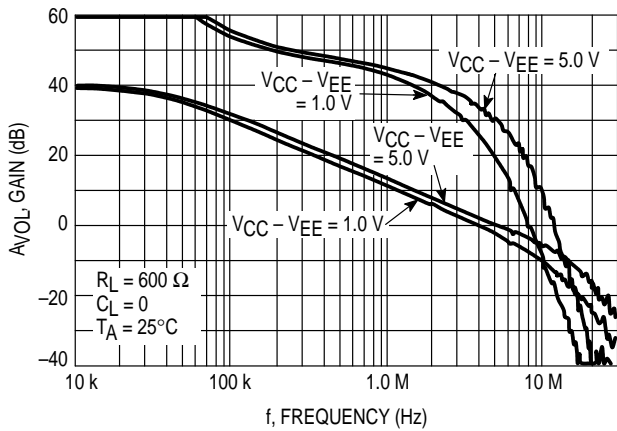


Figure 23. Gain and Phase Margin versus Temperature

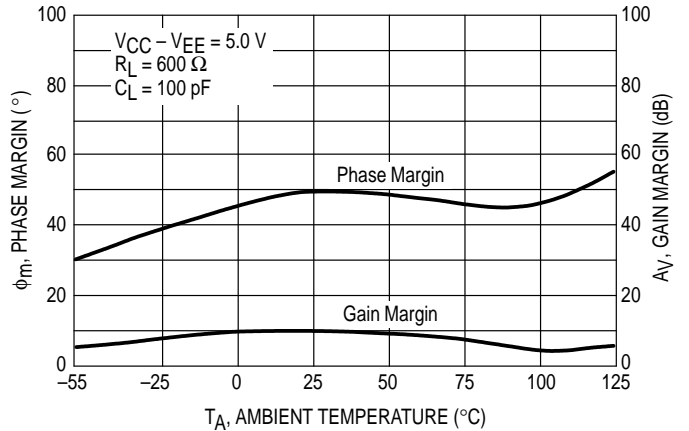


Figure 24. Gain and Phase Margin versus Differential Source Resistance

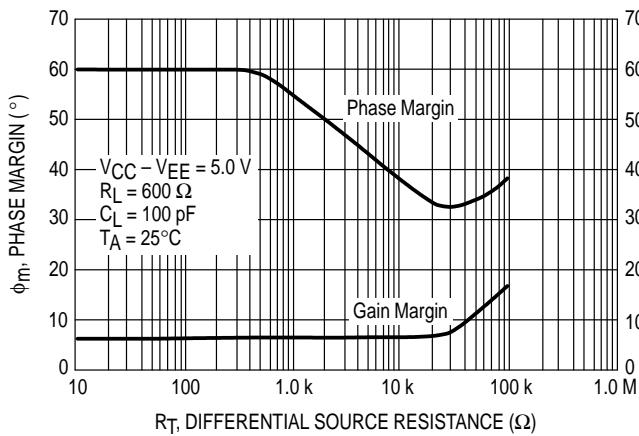


Figure 25. Feedback Loop Gain and Phase versus Capacitive Load

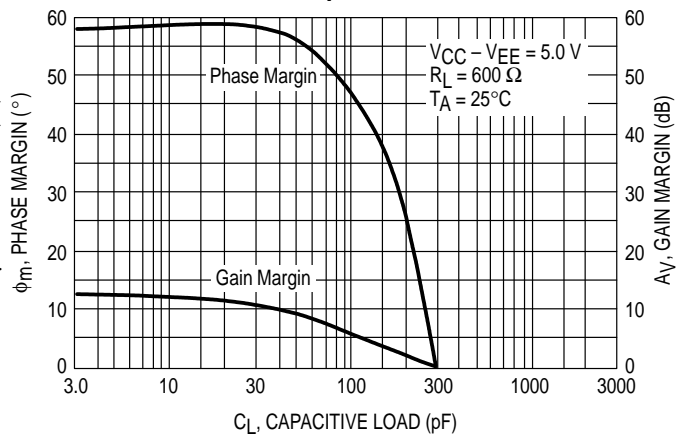


Figure 26. Channel Separation versus Frequency

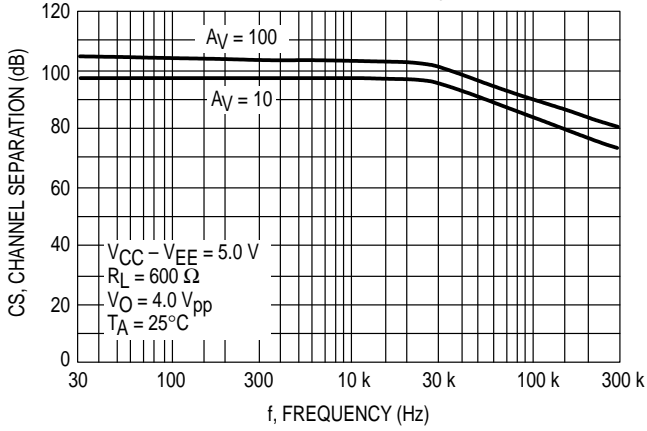


Figure 27. Output Voltage Swing versus Supply Voltage

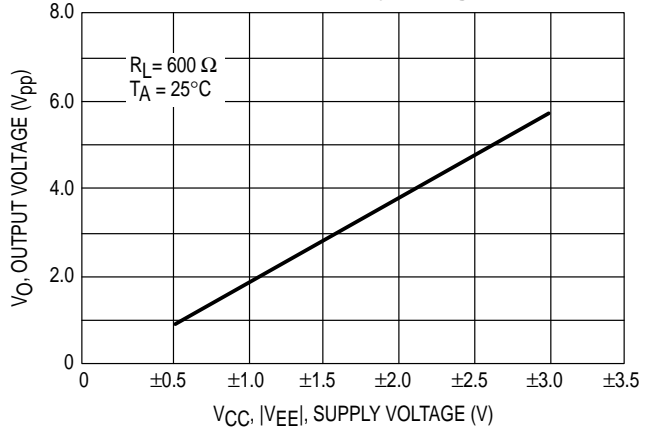


Figure 28. Equivalent Input Noise Voltage versus Frequency

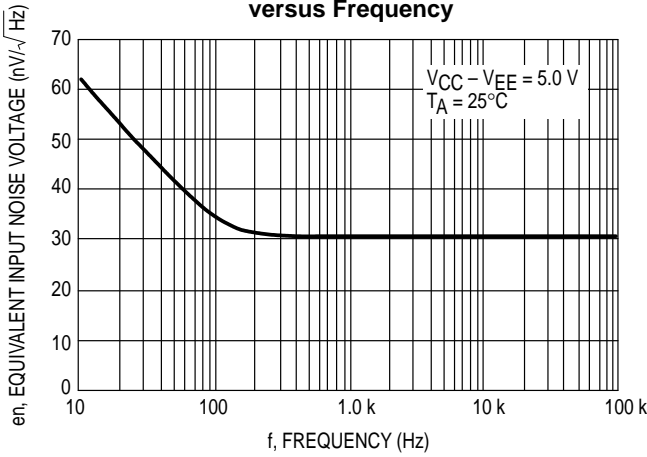


Figure 29. Gain and Phase Margin versus Supply Voltage

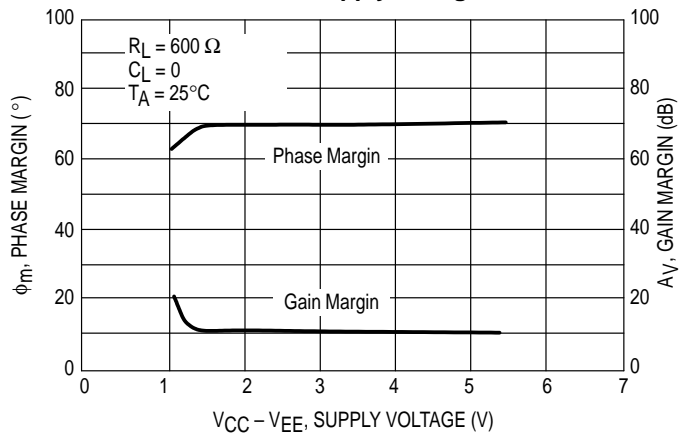


Figure 30. Useable Supply Voltage versus Temperature

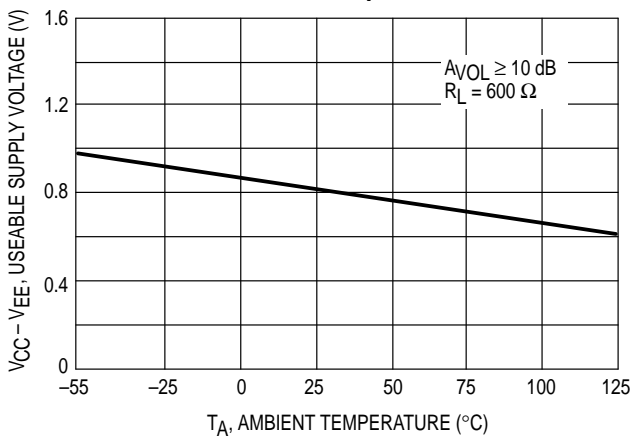
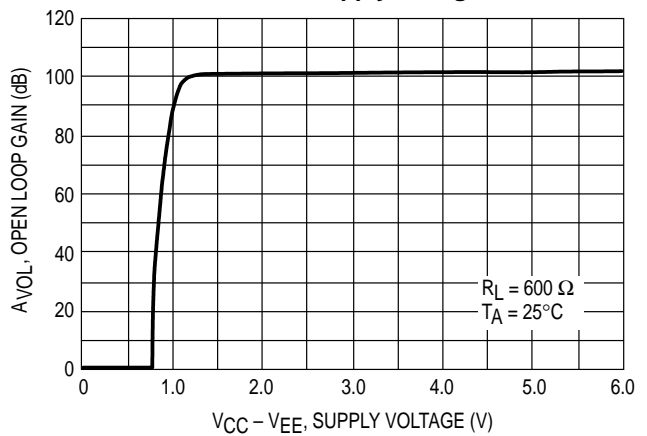
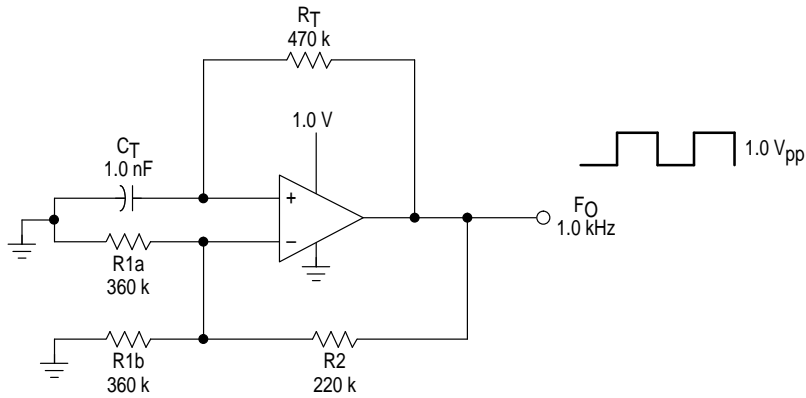


Figure 31. Open Loop Gain versus Supply Voltage



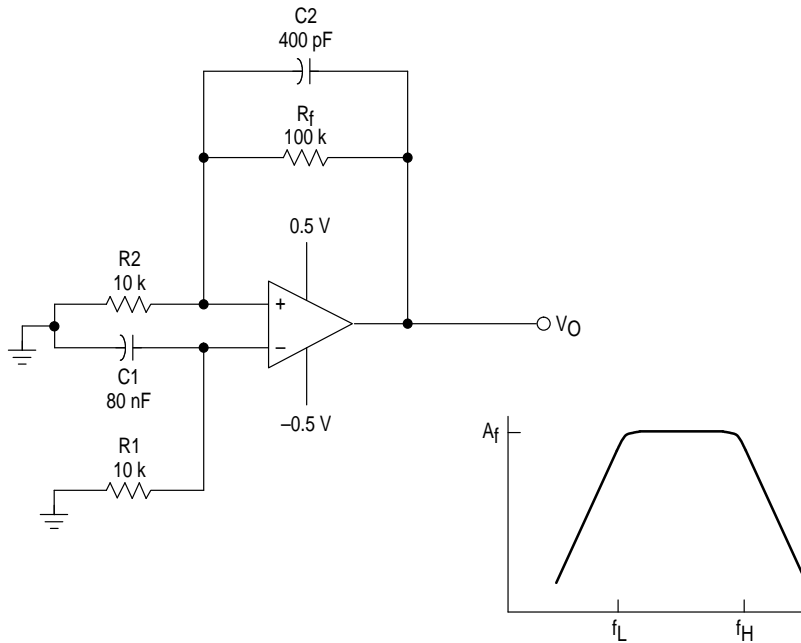
# MC33502

**Figure 32. 1.0 V Oscillator**



$$F_O = \frac{1}{\left\{ 2R_T C_T \ln \left[ \frac{2(R1a + R1b)}{R2} \right] \right\}}$$

**Figure 33. 1.0 V Voiceband Filter**



$$f_L = \frac{1}{2\pi R1 C1} \approx 200 \text{ Hz}$$

$$f_H = \frac{1}{2\pi R_f C_f} \approx 4.0 \text{ kHz}$$

$$A_f = \frac{1 + R_f}{R2} = 11$$

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Figure 34. Power Supply Application

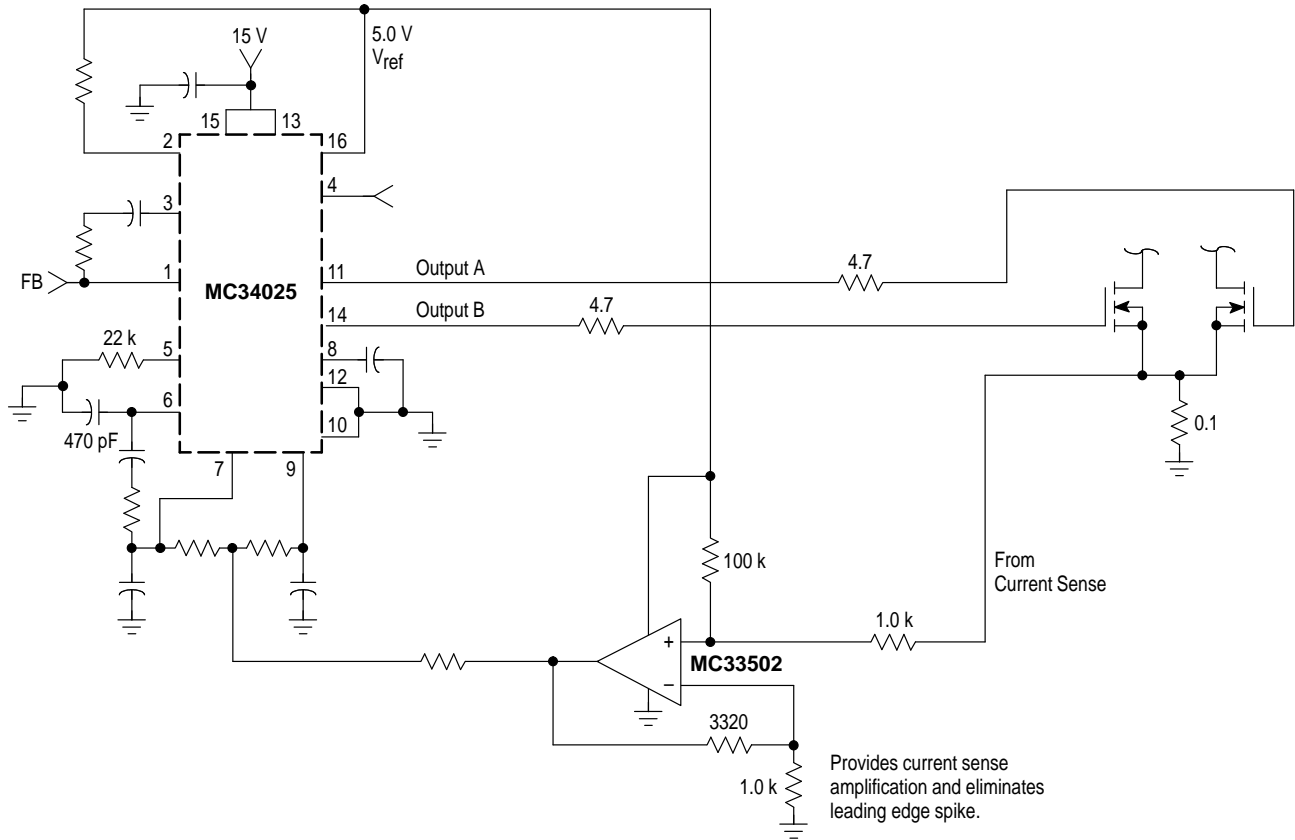
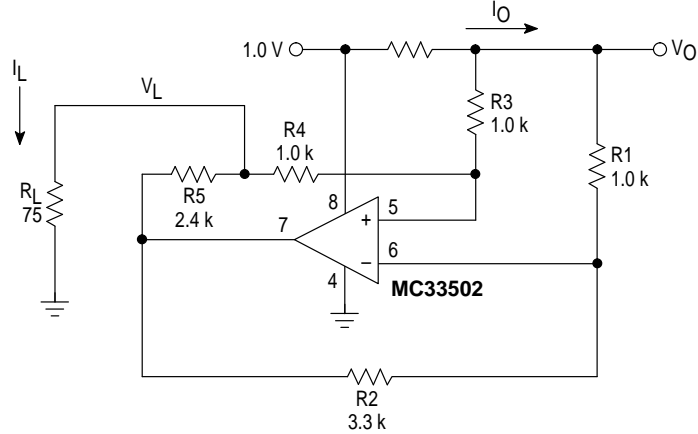


Figure 35. 1.0 V Current Pump



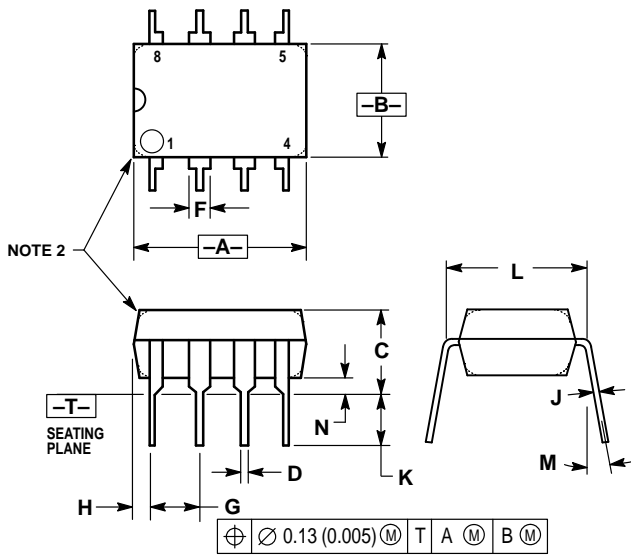
For best performance, use close tolerance resistors.

$I_O$	$I_L$	$\Delta I_O / \Delta I_L$
435 mA	463 $\mu$ A	$-120 \times 10^{-6}$
212 mA	492 $\mu$ A	

# MC33502

## OUTLINE DIMENSIONS

### P SUFFIX PLASTIC PACKAGE CASE 626-05 ISSUE K

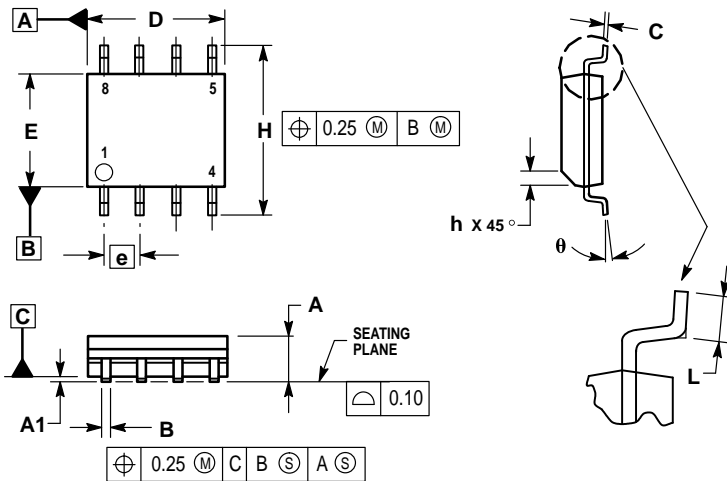


NOTES:

- DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
- PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
- DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	—	10°	—	10°
N	0.76	1.01	0.030	0.040


### D SUFFIX PLASTIC PACKAGE CASE 751-06 (SO-8) ISSUE T



NOTES:

- DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
- DIMENSIONS ARE IN MILLIMETER.
- DIMENSION D AND E DO NOT INCLUDE MOLD PROTRUSION.
- MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.
- DIMENSION B DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 TOTAL IN EXCESS OF THE B DIMENSION AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS	
	MIN	MAX
A	1.35	1.75
A1	0.10	0.25
B	0.35	0.49
C	0.19	0.25
D	4.80	5.00
E	3.80	4.00
e	1.27 BSC	
H	5.80	6.20
h	0.25	0.50
L	0.40	1.25
$\theta$	0°	7°

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