MOTOROLA

MC33502

Prototype Information

One Volt SMARTMOS™ Rail-to-Rail Dual Operational Amplifier

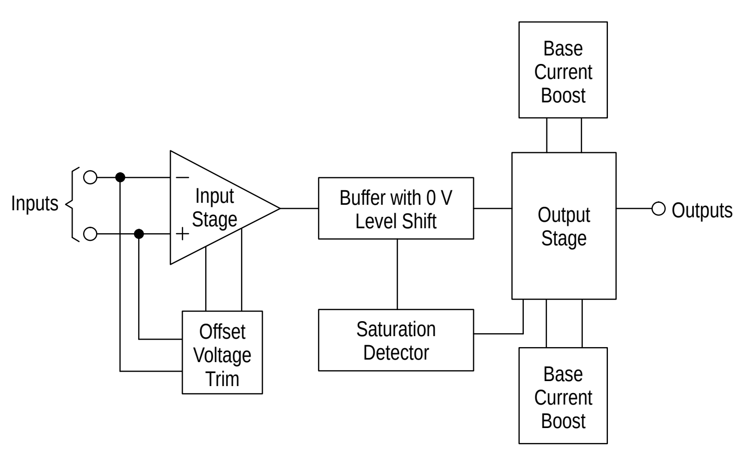
The MC33502 operational amplifier provides rail–to–rail operation on both the input and output. The output can swing within 50 mV of each rail. This rail–to–rail operation enables the user to make full use of the entire supply voltage range available. It is designed to work at very low supply voltages (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: Less than 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 mA @ 5.0 V, 10 mA @ 1.0 V)
- Output Voltage Swings within 50 mV of Both Rails
- Input Voltage Range Includes Both Supply Rails
- High Voltage Gain: 100 dB
- No Phase Reversal on the Output for Over–Driven Input Signals
- Input Offset Trimmed to <500 μV Typical
- Low Supply Current (I_D = 1.2 mA, Typical)
- 600 Ω Drive Capability
- Extended Operating Temperature Range (–40° to +105°C)

APPLICATIONS

- Single Cell NiCd/Ni MH Powered Systems
- Single Cell Lithium Powered Systems
- Portable Communication Devices
- Low Voltage Active Filters
- General Systems Requiring Battery Power

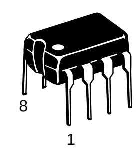
Simplified Block Diagram



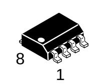
This device contains 98 active transistors per amplifier.

LOW VOLTAGE RAIL–TO–RAIL DUAL OPERATIONAL AMPLIFIER

SEMICONDUCTOR TECHNICAL DATA

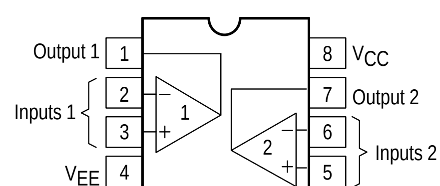


P SUFFIX
PLASTIC PACKAGE
CASE 626



D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

PIN CONNECTIONS



(Dual, Top View)

ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC33502P	T_A = – 40° to +105°C	Plastic DIP
MC33502D		SO–8

This document contains information on a product under development. Motorola reserves the right to change or discontinue this product without notice.

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 ±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°C, unless otherwise noted.)

Characteristic	Figure	Symbol	Min	Typ	Max	Unit
Input Offset Voltage	–	V_{IO}				mV
V_{CC} = 1.0 V						
T_A = +25°C			–	0.5	–	
T_A = –40° to +105°C			–	1.0	–	
V_{CC} = 3.0 V, V_{CM} = 0 to V_{CC}						
T_A = +25°C			–	0.5	–	
T_A = –40° to +105°C			–	1.0	–	
V_{CC} = 5.0 V, V_{CM} = 0 to V_{CC}						
T_A = +25°C			–	0.5	–	
T_A = –40° to +105°C			–	1.0	–	
Input Offset Voltage Temperature Coefficient (R_S = 50 Ω) T_A = –40° to +105°C	–	$\Delta V_{IO}/\Delta T$	–	2.0	–	µV/°C
Input Bias Current	–	$\lvert I_{IB} \rvert$				fA
V_{CC} = 1.0 V			–	40	–	
V_{CC} = 3.0 V			–	40	–	
V_{CC} = 5.0 V			–	40	–	
Common Mode Input Voltage Range	–	V_{ICR}	V_{EE}	–	V_{CC}	V
Large Signal Voltage Gain	–	A_{VOL}				kV/V
V_{CC} = 1.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	100	–	
R_L = 1.0 kΩ			–	50	–	
V_{CC} = 1.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 1.0 kΩ			–	–	–	
V_{CC} = 3.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	500	–	
R_L = 1.0 kΩ			–	100	–	
V_{CC} = 3.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 1.0 kΩ			–	–	–	
V_{CC} = 5.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	500	–	
R_L = 1.0 kΩ			–	200	–	
V_{CC} = 5.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 1.0 kΩ			–	–	–	

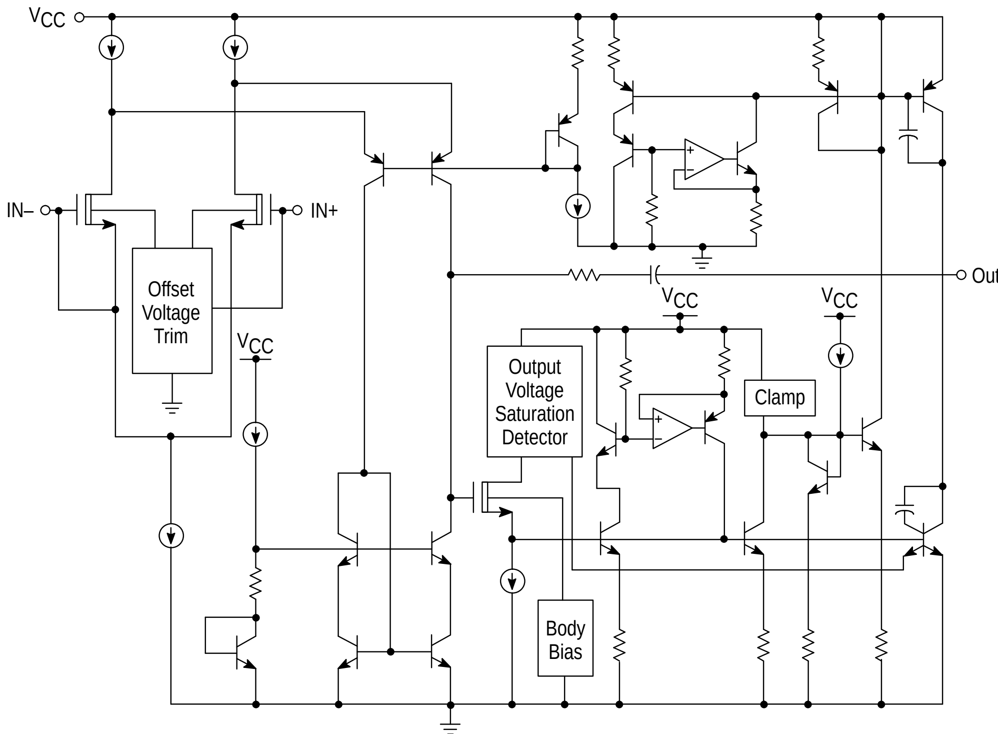
DC ELECTRICAL CHARACTERISTICS (continued) (V_{CC} = 5.0 V, V_{EE} = 0 V, V_{CM} = V_O = V_{CC}/2, R_L to V_{CC}/2, T_A = 25°C, unless otherwise noted.)

Characteristic	Figure	Symbol	Min	Typ	Max	Unit
Output Voltage Swing, High (V_{ID} = ±0.2 V)	–	V_{OH}				V
V_{CC} = 1.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	0.95	–	
R_L = 600 Ω			–	0.88	–	
V_{CC} = 1.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
V_{CC} = 3.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	2.93	–	
R_L = 600 Ω			–	2.84	–	
V_{CC} = 3.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
V_{CC} = 5.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	4.92	–	
R_L = 600 Ω			–	4.81	–	
V_{CC} = 5.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
Output Voltage Swing, Low (V_{ID} = ±0.2 V)	–	V_{OL}				V
V_{CC} = 1.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	0.016	–	
R_L = 600 Ω			–	0.047	–	
V_{CC} = 1.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
V_{CC} = 3.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	0.02	–	
R_L = 600 Ω			–	0.08	–	
V_{CC} = 3.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
V_{CC} = 5.0 V (T_A = +25°C)						
R_L = 10 kΩ			–	0.024	–	
R_L = 600 Ω			–	0.10	–	
V_{CC} = 5.0 V (T_A = –40° to +105°C)						
R_L = 10 kΩ			–	–	–	
R_L = 600 Ω			–	–	–	
Common Mode Rejection (V_{in} = 0 to 5.0 V)	–	CMR	–	74	–	dB
Power Supply Rejection Ratio	–	PSRR				µV/V
V_{CC}/V_{EE} = 5.0 V/Ground to 3.0 V/Ground			–	50	–	
V_{CC}/V_{EE} = 3.0 V/Ground to 1.0 V/Ground			–	50	–	
Output Short Circuit Current (V_{in} Diff = ±1.0 V)	–	I_{SC}				mA
V_{CC} = 1.0 V						
Source			–	13	–	
Sink			–	13	–	
V_{CC} = 3.0 V						
Source			–	32	–	
Sink			–	64	–	
V_{CC} = 5.0 V						
Source			–	40	–	
Sink			–	70	–	
Power Supply Current (Per Amplifier, V_O = 0 V)	–	I_D				mA
V_{CC} = 1.0 V			–	1.2	–	
V_{CC} = 3.0 V			–	1.5	–	
V_{CC} = 5.0 V			–	1.65	–	

AC ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = 0 V, V_{CM} = V_O = V_{CC}/2, T_A = 25°C, unless otherwise noted.)

Characteristic	Figure	Symbol	Min	Typ	Max	Unit
Slew Rate (V_S = ±2.5 V, V_O = –2.0 V to 2.0 V, R_L = 600 Ω, A_V = 1.0)	–	SR				V/µs
Positive Slope			–	4.0	–	
Negative Slope			–	–3.0	–	
Unity Gain Bandwidth	–	BW				MHz
V_{CC} = 1.0 V			–	4.0	–	
V_{CC} = 3.0 V			–	5.0	–	
V_{CC} = 5.0 V			–	5.0	–	
Gain Margin (R_L =10 kΩ, C_L = 0 pF)	–	Am	–	6.5	–	dB
Phase Margin (R_L = 10 kΩ, C_L = 0 pF)	–	∅m	–	60	–	Deg
Channel Separation (f = 1.0 Hz to 20 kHz, R_L = 600 Ω)	–	CS	–	120	–	dB
Power Bandwidth (V_O = 4.0 Vpp, R_L = 1.0 kΩ, THD ≤1.0%)	–	BW_P	–	200	–	kHz
Total Harmonic Distortion (V_O = 4.5 Vpp, R_L = 600 Ω, A_V = 1.0)	–	THD				%
f = 1.0 kHz			–	0.004	–	
f = 10 kHz			–	0.01	–	
Differential Input Resistance (V_{CM} = 0 V)	–	R_{in}	–	>1.0	–	terraΩ
Differential Input Capacitance (V_{CM} = 0 V)	–	C_{in}	–	2.0	–	pF
Equivalent Input Noise Voltage (V_{CC} = 1.0 V, V_{CM} = 0 V, V_{EE} = Gnd, R_S = 100 Ω)	–	e_n				nV/√Hz
f = 10 kHz			–	60	–	
f = 1.0 kHz			–	30	–	

Figure 1. Representative Block Diagram



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/µs is achieved with high speed depletion mode NMOS (DNMOS) and vertical PNP transistors. This device is characterized over a temperature range of –40°C to 105°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 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. 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. 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 Ω load. 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 V to 7.0 V and ground. 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

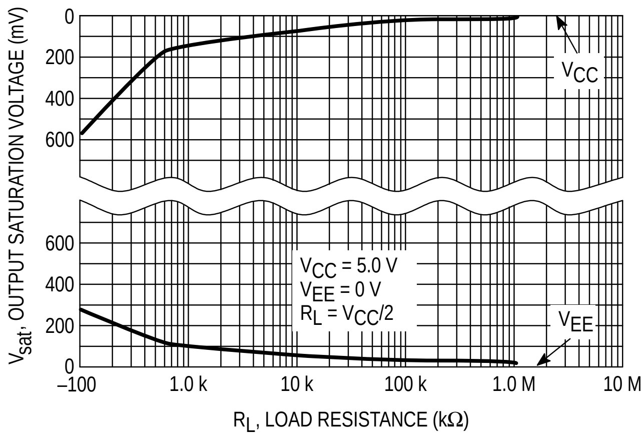


Figure 3. Output Saturation Voltage versus Load Current

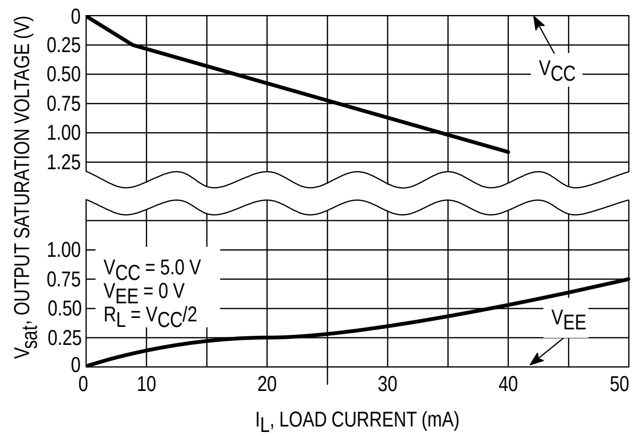


Figure 4. Input Current versus Temperature

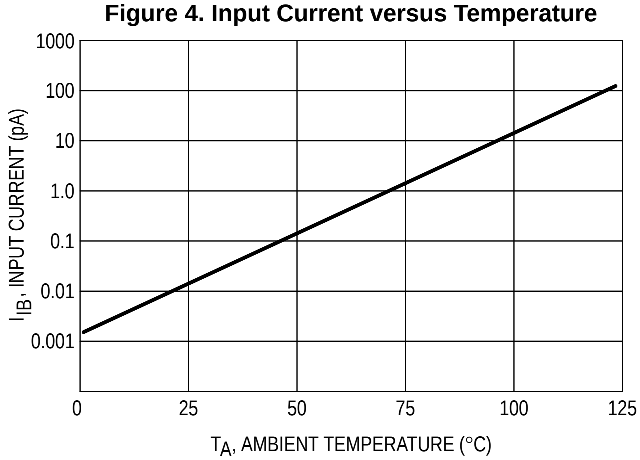


Figure 5. Gain and Phase versus Frequency

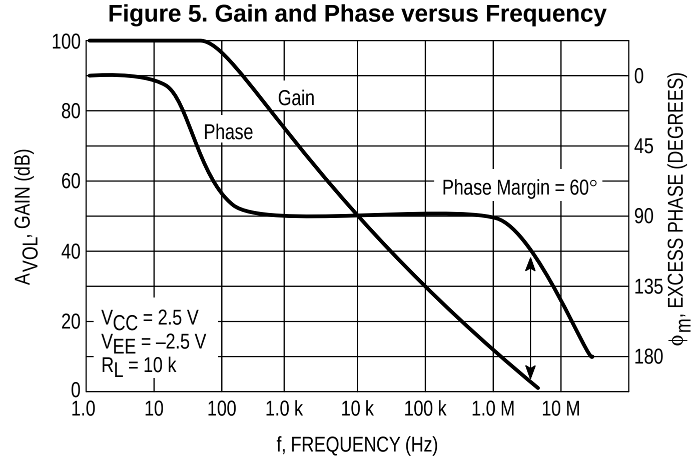
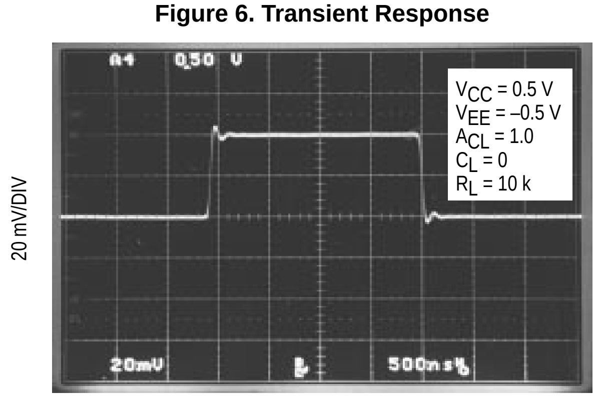
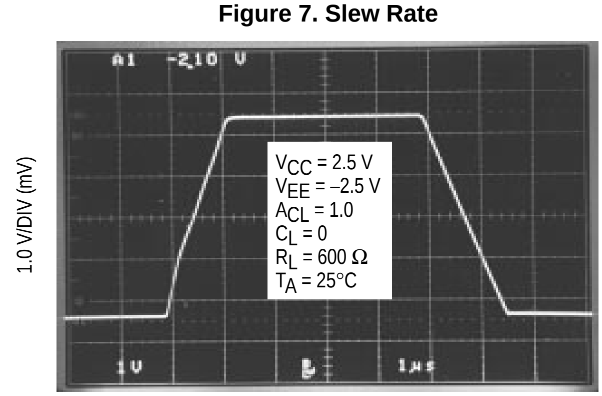


Figure 6. Transient Response



t, TIME (500 μs/DIV)

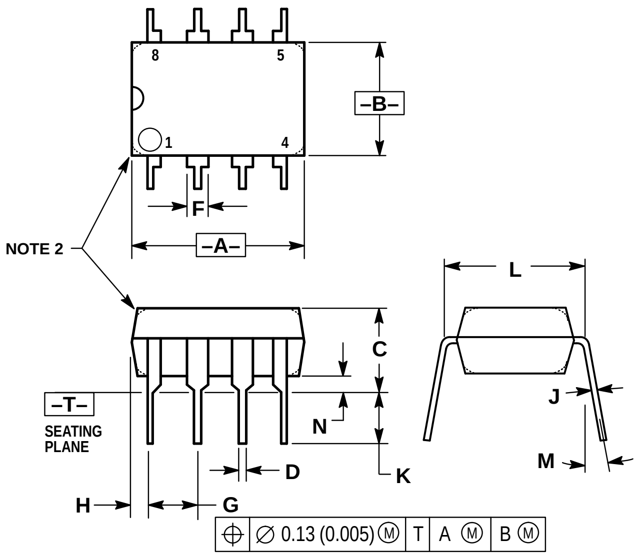
Figure 7. Slew Rate



t, TIME (1.0 μs/DIV)

OUTLINE DIMENSIONS

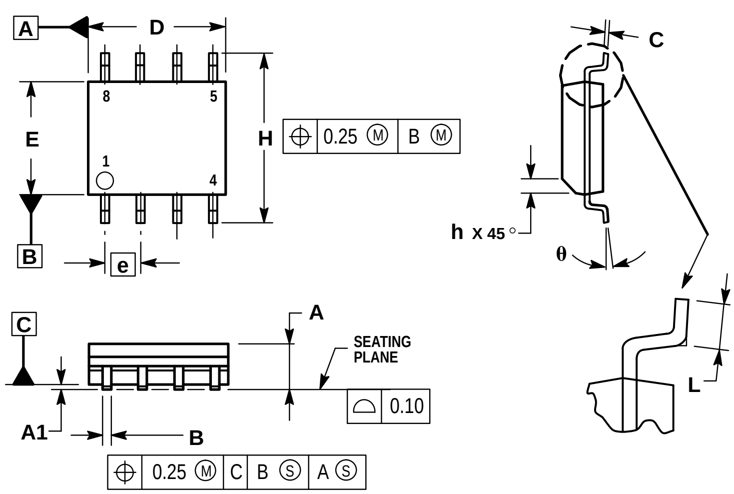
P SUFFIX
PLASTIC PACKAGE
CASE 626–05
ISSUE K



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

	MILLIMETERS		INCHES	
DIM	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 751–05
(SO–8)
ISSUE R



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

	MILLIMETERS	
DIM	MIN	MAX
A	1.35	1.75
A1	0.10	0.25
B	0.35	0.49
C	0.18	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
θ	0°	7°

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ASIA / PACIFIC: Motorola Semiconductors H.K. Ltd.; 8B Tai Ping Industrial Park, 51 Ting Kok Road, Tai Po, N.T., Hong Kong. 852–26629298