TL431/TL431A

Programmable Shunt Regulator

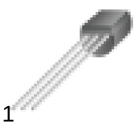
Features

- Programmable Output Voltage to 36 Volts
- Low Dynamic Output Impedance 0.20 Typical
- Sink Current Capability of 1.0 to 100mA
- Equivalent Full-Range Temperature Coefficient of 50ppm/°C Typical
- Temperature Compensated For Operation Over Full Rated Operating Temperature Range
- Low Output Noise Voltage
- Fast Turn-on Response

Description

The TL431/TL431Aare three-terminal adjustable regulator series with a guaranteed thermal stability over applicable temperature ranges. The output voltage may be set to any value between V_{REF} (approximately 2.5 volts) and 36 volts with two external resistors These devices have a typical dynamic output impedance of 0.2W Active output circuitry provides a very sharp turn-on characteristic, making these devices excel lent replacement for zener diodes in many applications.

TO-92



1

1. Ref 2. Anode 3. Cathode

8-DIP

1

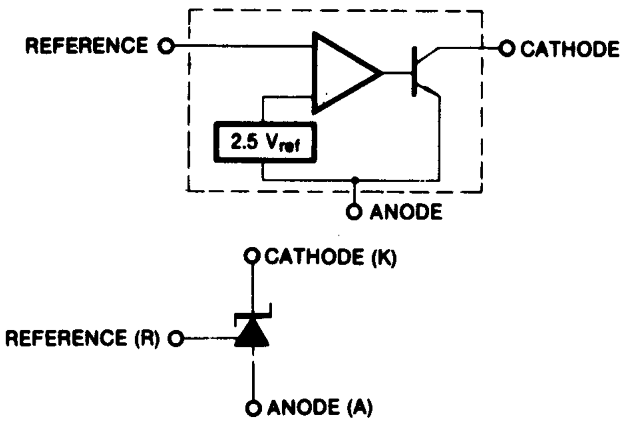
1.Cathode 2.3.4.5.7.NC
6.Anode 8.Ref

8-SOP

1

1. Cathode 2. 3. 6. 7. Anode
8. Ref 4. 5. NC

Internal Block Diagram



Absolute Maximum Ratings

(Operating temperature range applies unless otherwise specified.)

Parameter	Symbol	Value	Unit
Cathode Voltage	V_{KA}	37	V
Cathode Current Range (Continuous)	I_{KA}	-100 ~ +150	mA
Reference Input Current Range	I_{REF}	-0.05 ~ +10	mA
Power Dissipation D, LP Suffix Package P Suffix Package	P_D	 770 1000	 mW mW
Operating Temperature Range	T_{OPR}	-25 ~ +85	°C
Junction Temperature	T_J	150	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Cathode Voltage	V_{KA}	V_{REF}	-	36	V
Cathode Current	I_{KA}	1.0	-	100	mA

Electrical Characteristics

(T_A = +25°C, unless otherwise specified)

Parameter	Symbol	Conditions	TL431 Min.	TL431 Typ.	TL431 Max.	TL431A Min.	TL431A Typ.	TL431A Max.	Unit
Reference Input Voltage	V_{REF}	V_{KA}=V_{REF}, I_{KA}=10mA	2.440	2.495	2.550	2.470	2.495	2.520	V
Deviation of Reference Input Voltage Over-Temperature (Note 1)	$\Delta V_{REF}/\Delta T$	V_{KA}=V_{REF}, I_{KA}=10mA $T_{MIN} \leq T_A \leq T_{MAX}$	-	4.5	17	-	4.5	17	mV
Ratio of Change in Reference Input Voltage to the Change in Cathode Voltage	$\Delta V_{REF}/\Delta V_{KA}$	I_{KA} =10mA, ΔV_{KA}=10V-V_{REF}	-	- 10	-2.7	-	-1.0	-2.7	mV/V
		I_{KA} =10mA, ΔV_{KA}=36V-10V	-	-0.5	-2.0	-	-0.5	-2.0	mV/V
Reference Input Current	I_{REF}	I_{KA}=10mA, R_1=10KΩ,R_2=∞	-	1.5	4	-	1.5	4	µA
Deviation of Reference Input Current Over Full Temperature Range	$\Delta I_{REF}/\Delta T$	I_{KA}=10mA, R_1=10KΩ,R_2=∞ T_A =Full Range	-	0.4	1.2	-	0.4	1.2	µA
Minimum Cathode Current for Regulation	$I_{KA(MIN)}$	V_{KA}=V_{REF}	-	0.45	1.0	-	0.45	1.0	mA
Off - Stage Cathode Current	$I_{KA(OFF)}$	V_{KA}=36V, V_{REF}=0	-	0.05	1.0	-	0.05	1.0	µA
Dynamic Impedance (Note 2)	Z_{KA}	V_{KA}=V_{REF}, I_{KA}=1 to 100mA f ≥1.0KHz	-	0.15	0.5	-	0.15	0.5	Ω

- T_{MIN}= -25 °C, T_{MAX}= +85 °C

Test Circuits

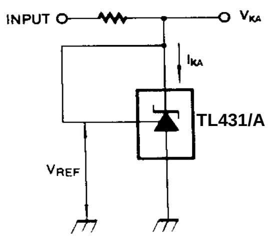


Figure 1. Test Circuit for $V_{KA}=V_{REF}$

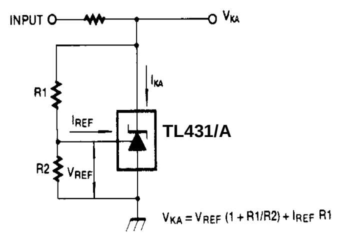


Figure 2. Test Circuit for $V_{KA} \geq V_{REF}$

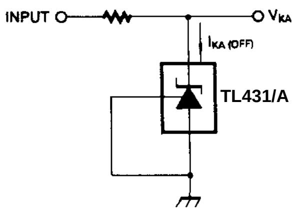


Figure 3. Test Circuit for $I_{KA(OFF)}$

Typical Perfomance Characteristics

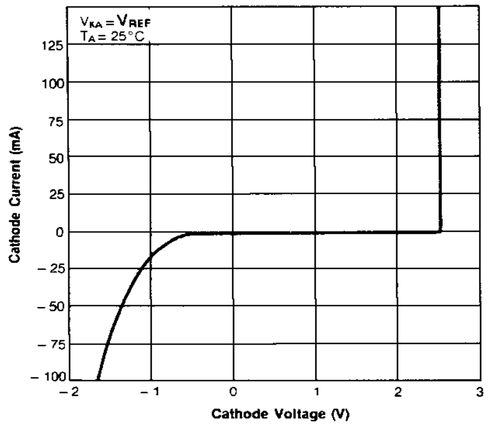


Figure 1. Cathode Current vs. Cathode Voltage

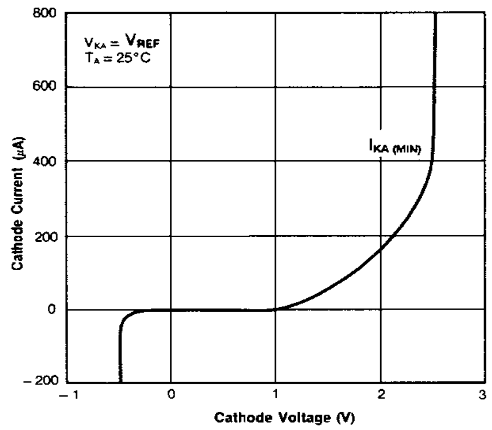


Figure 2. Cathode Current vs. Cathode Voltage

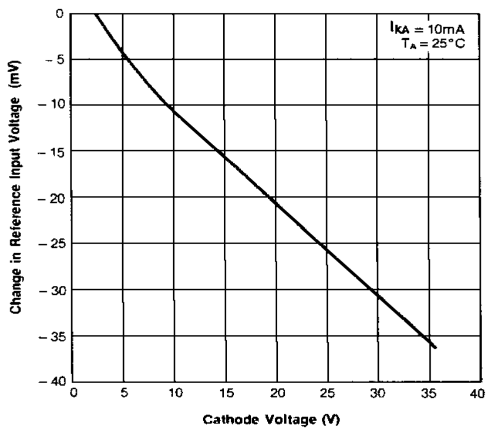


Figure 3. Change In Reference Input Voltage vs. Cathode Voltage

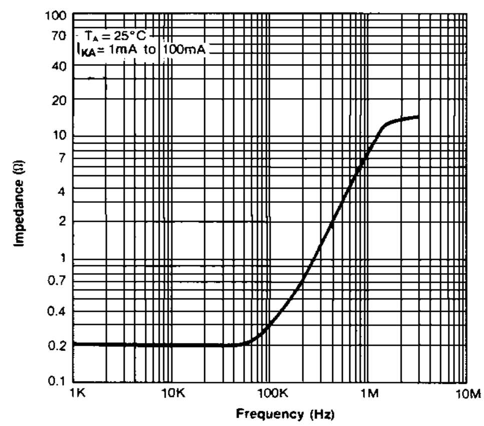


Figure 4. Dynamic Impedance Frequency

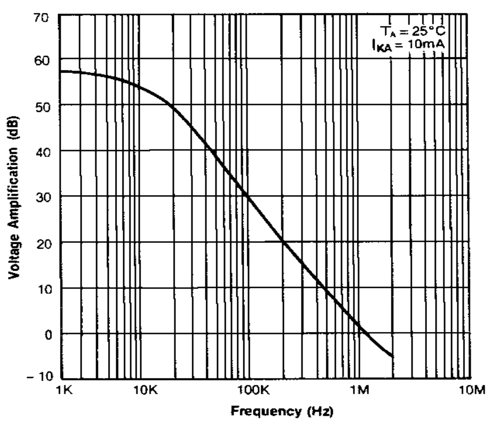


Figure 5. Small Signal Voltage Amplification vs. Frequency

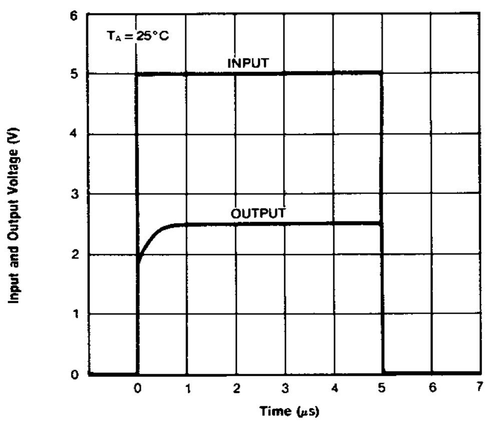


Figure 6. Pulse Response

Typical Application

$$V_O = \left(1 + \frac{R_1}{R_2}\right)V_{ref}$$

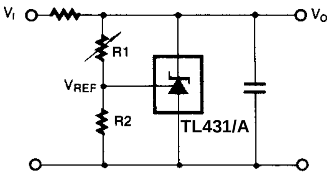


Figure 10. Shunt Regulator

$$V_O = V_{ref}\left(1 + \frac{R_1}{R_2}\right)$$

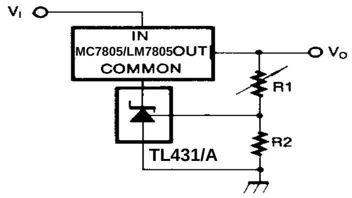


Figure 11. Output Control for Three-Termianl Fixed Regulator

$$V_O = \left(1 + \frac{R_1}{R_2}\right)V_{ref}$$

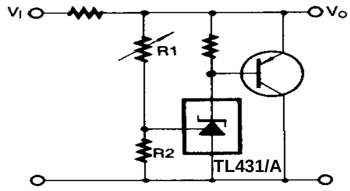
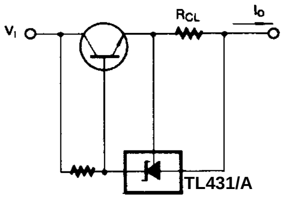
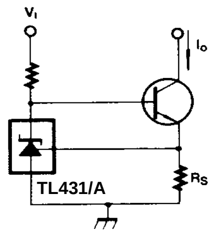


Figure 12. High Current Shunt Regulator



$$I_O = \frac{V_{REF}}{R_{CL}}$$

Figure 13. Current Limit or Current Source

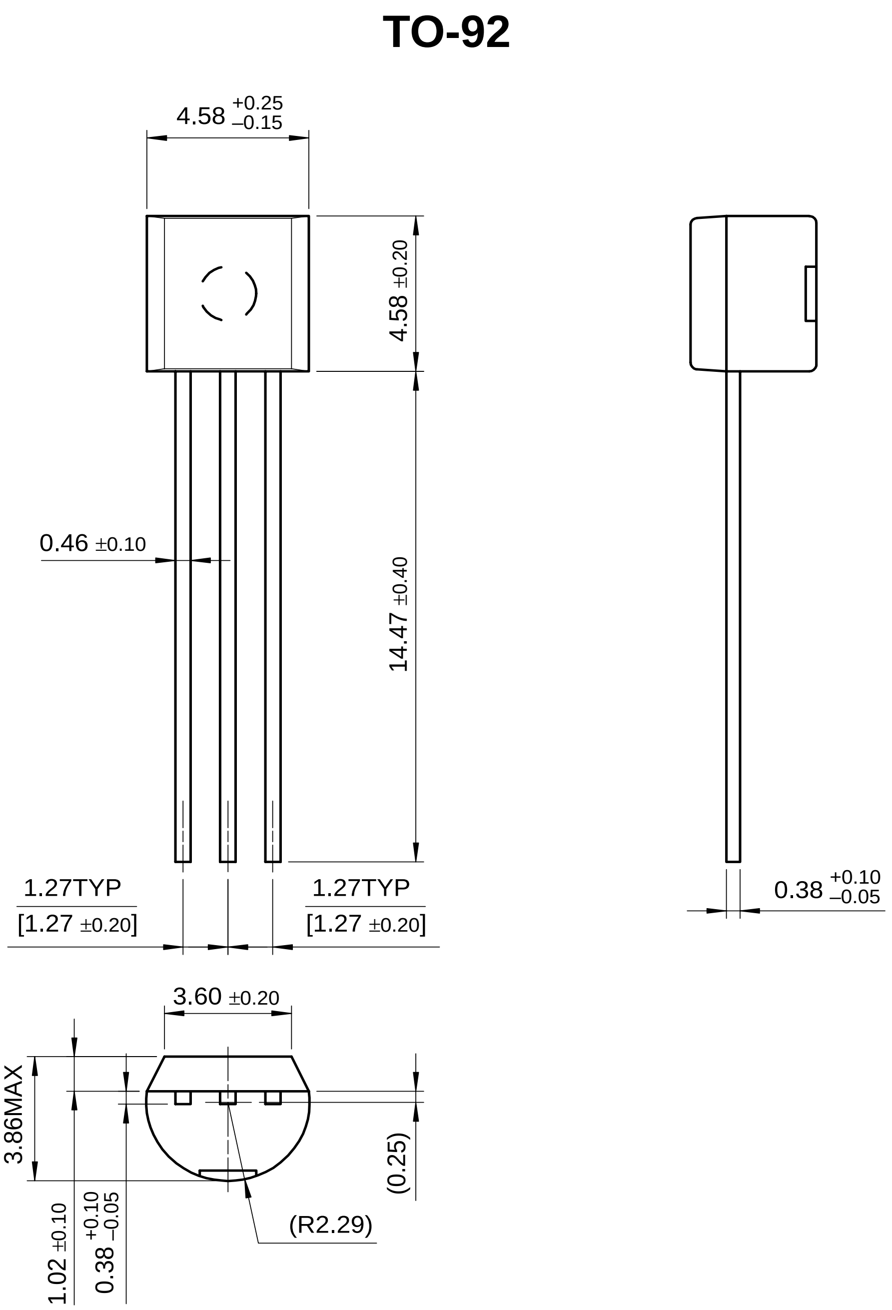


$$I_O = \frac{V_{REF}}{R_S}$$

Figure 14. Constant-Current Sink

Mechanical Dimensions

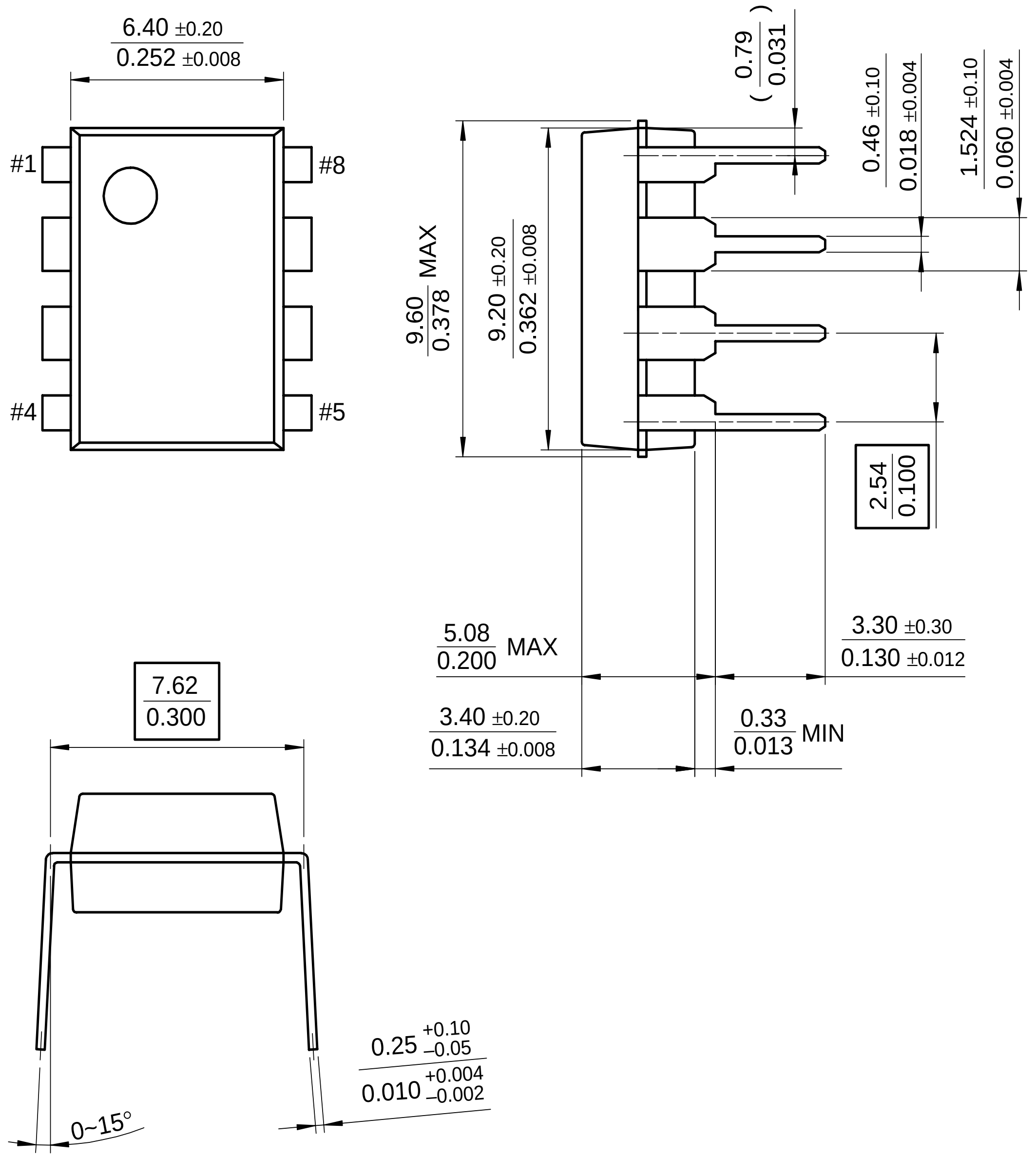
Package



Mechanical Dimensions (Continued)

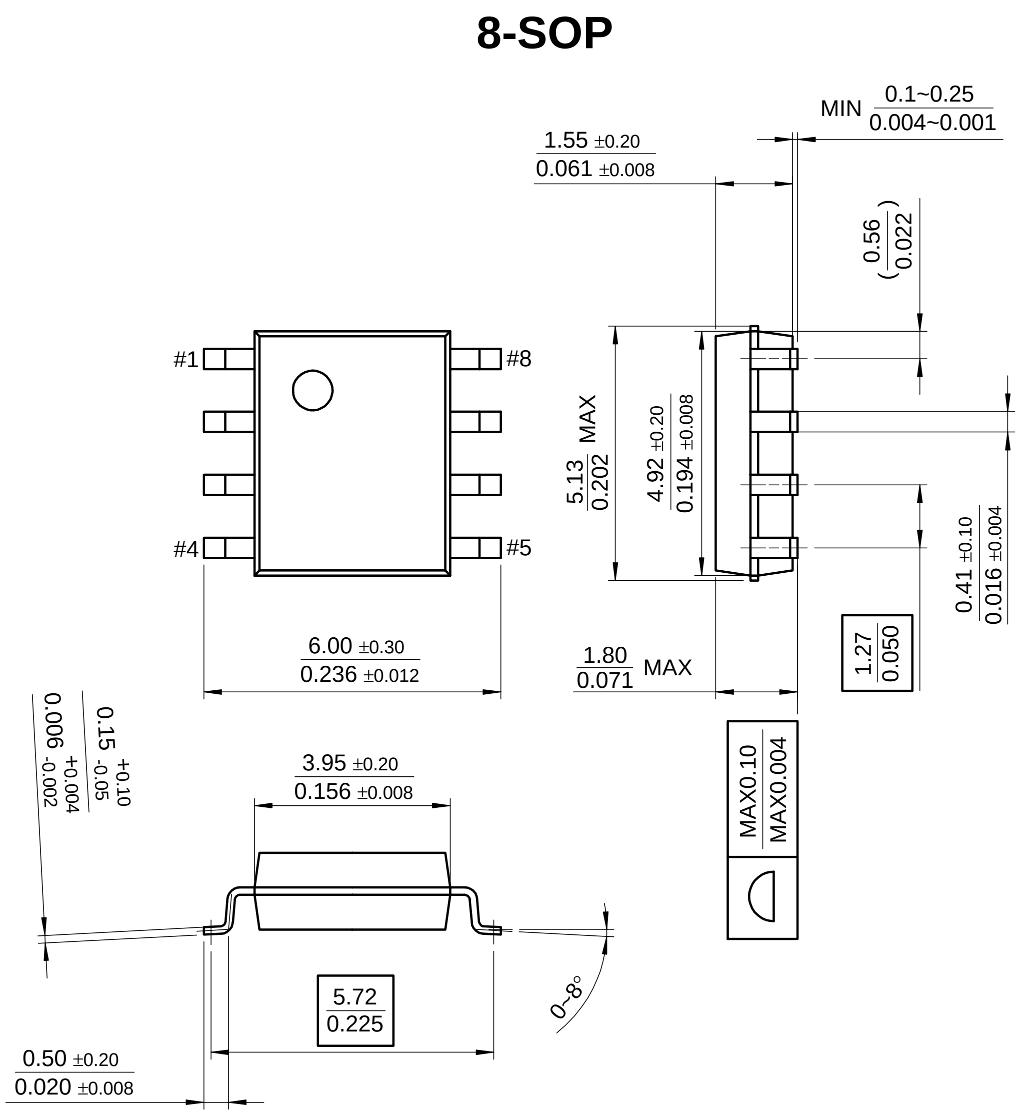
Package

8-DIP



Mechanical Dimensions (Continued)

Package



Ordering Information

Product Number	Output Voltage Tolerance	Package	Operating Temperature
TL431ACLP	1%	TO-92	-25 ~ + 85^{o}C
TL431ACD		8-SOP	
TL431CLP	2%	TO-92	
TL431CP		8-DIP	
TL431CD		8-SOP	

8/4/03 0.0m 001
Stock#DSxxxxxxxx

19-2562; Rev 0; 10/02

76V, High-Side, Current-Sense Amplifiers with Voltage Output

General Description

The MAX4080/MAX4081 are high-side, current-sense amplifiers with an input voltage range that extends from 4.5V to 76V making them ideal for telecom, automotive, backplane, and other systems where high-voltage current monitoring is critical. The MAX4080 is designed for unidirectional current-sense applications and the MAX4081 allows bidirectional current sensing. The MAX4081 single output pin continuously monitors the transition from charge to discharge and avoids the need for a separate polarity output. The MAX4081 requires an external reference to set the zero-current output level (V_{SENSE} = 0V). The charging current is represented by an output voltage from V_{REF} to V_{CC}, while discharge current is given from V_{REF} to GND.

For maximum versatility, the 76V input voltage range applies independently to both supply voltage (V_{CC}) and common-mode input voltage (V_{RS+}). High-side current monitoring does not interfere with the ground path of the load being measured, making the MAX4080/MAX4081 particularly useful in a wide range of high-voltage systems.

The combination of three gain versions (5V/V, 20V/V, 60V/V = F, T, S suffix) and a user-selectable, external sense resistor sets the full-scale current reading and its proportional output voltage. The MAX4080/MAX4081 offer a high level of integration, resulting in a simple, accurate, and compact current-sense solution.

The MAX4080/MAX4081 operate from a 4.5V to 76V single supply and draw only 75µA of supply current. These devices are specified over the automotive operating temperature range (-40°C to +125°C) and are available in a space-saving 8-pin µMAX or SO package.

Applications

- Automotive (12V, 24V, or 42V Batteries)
- 48V Telecom and Backplane Current Measurement
- Bidirectional Motor Control
- Power-Management Systems
- Avalanche Photodiode and PIN-Diode Current Monitoring
- General System/Board-Level Current Sensing
- Precision High-Voltage Current Sources

Features

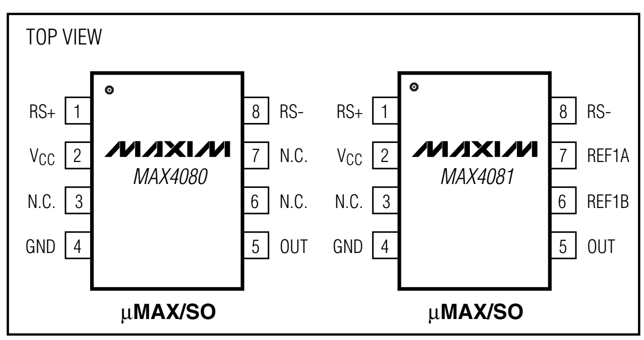
- ♦ **Wide 4.5V to 76V Input Common-Mode Range**
- ♦ **Bidirectional or Unidirectional I_{SENSE}**
- ♦ **Low-Cost, Compact, Current-Sense Solution**
- ♦ **Three Gain Versions Available**
  - **5V/V (MAX4080F/MAX4081F)**
  - **20V/V (MAX4080T/MAX4081T)**
  - **60V/V (MAX4080S/MAX4081S)**
- ♦ **±0.1% Full-Scale Accuracy**
- ♦ **Low 100µV Input Offset Voltage**
- ♦ **Independent Operating Supply Voltage**
- ♦ **75µA Supply Current (MAX4080)**
- ♦ **Reference Input for Bidirectional OUT (MAX4081)**
- ♦ **Available in a Space-Saving 8-Pin µMAX Package**

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX4080FAUA	-40°C to +125°C	8 µMAX
MAX4080FASA	-40°C to +125°C	8 SO
MAX4080TAUA	-40°C to +125°C	8 µMAX
MAX4080TASA	-40°C to +125°C	8 SO
MAX4080SAUA	-40°C to +125°C	8 µMAX
MAX4080SASA	-40°C to +125°C	8 SO
MAX4081FAUA	-40°C to +125°C	8 µMAX
MAX4081FASA	-40°C to +125°C	8 SO
MAX4081TAUA	-40°C to +125°C	8 µMAX
MAX4081TASA	-40°C to +125°C	8 SO
MAX4081SAUA	-40°C to +125°C	8 µMAX
MAX4081SASA	-40°C to +125°C	8 SO

Selector Guide appears at end of data sheet.

Pin Configurations



76V, High-Side, Current-Sense Amplifiers with Voltage Output

ABSOLUTE MAXIMUM RATINGS

V_{CC} to GND ....-0.3V to +80V
RS+, RS- to GND ....-0.3V to +80V
OUT to GND.............-0.3V to the lesser of +18V or (V_{CC} + 0.3V)
REF1A, REF1B to GND
(MAX4081 Only)....-0.3V to the lesser of +18V or (V_{CC} + 0.3V)
Output Short Circuit to GND.......................................Continuous
Differential Input Voltage (V_{RS+} - V_{RS-}) ....±80V
Current into Any Pin..±20mA

Continuous Power Dissipation (T_A = +70°C)
8-Pin µMAX (derate 4.5mW/°C above +70°C) 362mW
8-Pin SO (derate 5.88mW/°C above +70°C)................471mW
Operating Temperature Range ....-40°C to +125°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = V_{RS+} = 4.5V to 76V, V_{REF1A} = V_{REF1B} = 5V (MAX4081 only), V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{LOAD} = 100kΩ, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Voltage Range	V_{CC}	Inferred from PSRR test		4.5		76	V
Common-Mode Range	C_{MVR}	Inferred from CMRR test (Note 3)		4.5		76	V
Supply Current	I_{CC}	V_{CC} = V_{RS+} = 76V, no load	MAX4080		75	190	µA
			MAX4081		103	190	
Leakage Current	I_{RS+}, I_{RS-}	V_{CC} = 0V, V_{RS+} = 76V			0.01	2	µA
Input Bias Current	I_{RS+}, I_{RS-}	V_{CC} = V_{RS+} = 76V			5	12	µA
Full-Scale Sense Voltage (Note 4)	V_{SENSE}	MAX4080F/MAX4081F			±1000		mV
		MAX4080T/MAX4081T			±250		
		MAX4080S/MAX4081S			±100		
Gain	A_V	MAX4080F/MAX4081F			5		V/V
		MAX4080T/MAX4081T			20		
		MAX4080S/MAX4081S			60		
Gain Accuracy	ΔA_V	V_{CC} = V_{RS+} = 48V (Note 5)	T_A = +25°C		±0.1	±0.6	%
			T_A = -40°C to +85°C			±1	
			T_A = T_{MIN} to T_{MAX}			±1.2	
Input Offset Voltage	V_{OS}	V_{CC} = V_{RS+} = 48V (Note 6)	T_A = +25°C		±0.1	±0.6	mV
			T_A = -40°C to +85°C			±1	
			T_A = T_{MIN} to T_{MAX}			±1.2	
Common-Mode Rejection Ratio	CMRR	V_{CC} = 48V, V_{RS+} = 4.5V to 76V		100	124		dB
Power-Supply Rejection Ratio	PSRR	V_{RS+} = 48V, V_{CC} = 4.5V to 76V		100	122		dB
OUT High Voltage	(V_{CC} - V_{OH})	V_{CC} = 4.5V, V_{RS+} = 48V, V_{REF1A} = V_{REF1B} = 2.5V, I_{OUT} (sourcing) = +500µA (Note 8)	MAX4080F/MAX4081F, V_{SENSE} = 1000mV		0.15	0.27	V
			MAX4080T/MAX4081T, V_{SENSE} = 250mV				
			MAX4080S/MAX4081S, V_{SENSE} = 100mV				

DC ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = V_{RS+} = 4.5V to 76V, V_{REF1A} = V_{REF1B} = 5V (MAX4081 only), V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{LOAD} = 100kΩ, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

<table>
<tr><th>PARAMETER</th><th>SYMBOL</th><th colspan="2">CONDITIONS</th><th>MIN</th><th>TYP</th><th>MAX</th><th>UNITS</th></tr>
<tr><td rowspan="2">OUT Low Voltage</td><td rowspan="2">V_{OL}</td><td rowspan="2">V_{CC} = V_{RS+} = 48V, V_{REF1A} = V_{REF1B} = 2.5V, V_{SENSE} = -1000mV (for MAX4081 only)</td><td>I_{OUT} (sinking) = 10µA</td><td></td><td>4</td><td>15</td><td rowspan="2">mV</td></tr>
<tr><td>I_{OUT} (sinking) = 100µA</td><td></td><td>23</td><td>55</td></tr>
<tr><td>REF1A = REF1B Input Voltage Range (MAX4081 Only)</td><td>(V_{REF} - GND)</td><td colspan="2">Inferred from REF1A rejection ratio, V_{REF1A} = V_{REF1B}</td><td>1.5</td><td></td><td>6</td><td>V</td></tr>
<tr><td>REF1A Input Voltage Range (MAX4081 Only)</td><td>(V_{REF1A} - GND)</td><td colspan="2">Inferred from REF1A rejection ratio, V_{REF1B} = GND</td><td>3</td><td></td><td>12</td><td>V</td></tr>
<tr><td>REF1A Rejection Ratio (MAX4081 Only)</td><td></td><td colspan="2">V_{CC} = V_{RS+} = 48V, V_{SENSE} = 0V, V_{REF1A} = V_{REF1B} = 1.5V to 6V</td><td>80</td><td>108</td><td></td><td>dB</td></tr>
<tr><td>REF/REF1A Ratio (MAX4081 Only)</td><td></td><td colspan="2">V_{REF1A} = 10V, V_{REF1B} = GND, V_{CC} = V_{RS+} = 48V (Note 2)</td><td>0.497</td><td>0.500</td><td>0.503</td><td></td></tr>
<tr><td>REF1A Input Impedance (MAX4081 Only)</td><td></td><td colspan="2">V_{REF1B} = GND</td><td></td><td>250</td><td></td><td>kΩ</td></tr>
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AC ELECTRICAL CHARACTERISTICS

(V_{CC} = V_{RS+} = 4.5V to 76V, V_{REF1A} = V_{REF1B} = 5V (MAX4081 only), V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{LOAD} = 100kΩ, C_{LOAD} = 20pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITION		MIN	TYP	MAX	UNITS
Bandwidth	BW	V_{CC} = V_{RS+} = 48V, V_{OUT} = 2.5V	MAX4080F/T/S		250		kHz
			MAX4081F/T/S		150		
OUT Settling Time to 1% of Final Value		V_{SENSE} = 10mV to 100mV			20		µs
		V_{SENSE} = 100mV to 10mV			20		
Capacitive-Load Stability		No sustained oscillations			500		pF
Output Resistance	R_{OUT}	V_{SENSE} = 100mV			0.1		Ω
Power-Up Time		V_{CC} = V_{RS+} = 48V, V_{SENSE} = 100mV (Note 9)			50		µs
Saturation Recovery Time		(Notes 9,10)			50		µs

Note 1: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.

Note 2: V_{REF} is defined as the average voltage of V_{REF1A} and V_{REF1B}. REF1B is usually connected to REF1A or GND. V_{SENSE} is defined as V_{RS+} - V_{RS-}.

Note 3: The common-mode range at the low end of 4.5V applies to the most positive potential at RS+ or RS-. Depending on the polarity of V_{SENSE} and the device's gain, either RS+ or RS- can extend below 4.5V by the device's typical full-scale value of V_{SENSE}.

Note 4: Negative V_{SENSE} applies to MAX4081 only.

Note 5: V_{SENSE} is:
MAX4080F, 10mV to 1000mV
MAX4080T, 10mV to 250mV
MAX4080S, 10mV to 100mV
MAX4081F, -500mV to +500mV
MAX4081T, -125mV to +125mV
MAX4081S, -50mV to +50mV

Note 6: V_{OS} is extrapolated from the gain accuracy test for the MAX4080 and measured as (V_{OUT} - V_{REF})/A_V at V_{SENSE} = 0V, for the MAX4081.

Note 7: V_{SENSE} is:
MAX4080F, 500mV
MAX4080T, 125mV
MAX4080S, 50mV
MAX4081F/T/S, 0V
V_{REF1B} = V_{REF1A} = 2.5V

Note 8: Output voltage is internally clamped not to exceed 18V.

Note 9: Output settles to within 1% of final value.

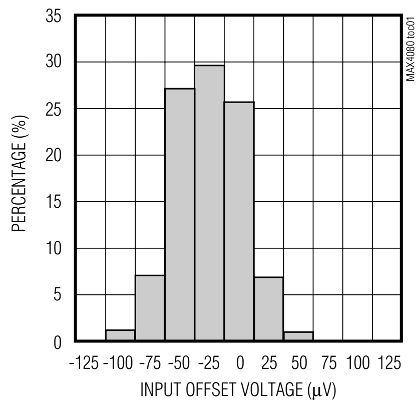
Note 10: The device will not experience phase reversal when overdriven.

76V, High-Side, Current-Sense Amplifiers with Voltage Output

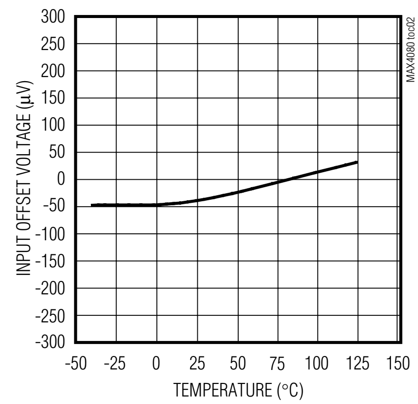
Typical Operating Characteristics

(V_{CC} = V_{RS+} = 48V, V_{SENSE} = 0V, C_{LOAD} = 20pF, R_{LOAD} = ∞, T_A = +25°C, unless otherwise noted.)

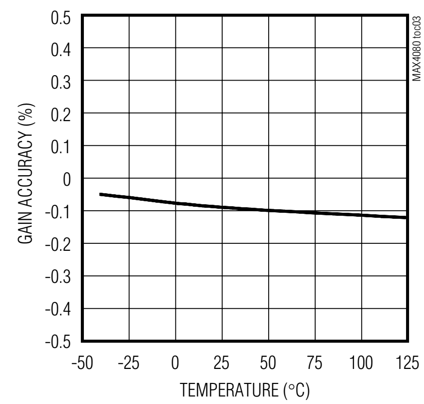
INPUT OFFSET VOLTAGE HISTOGRAM



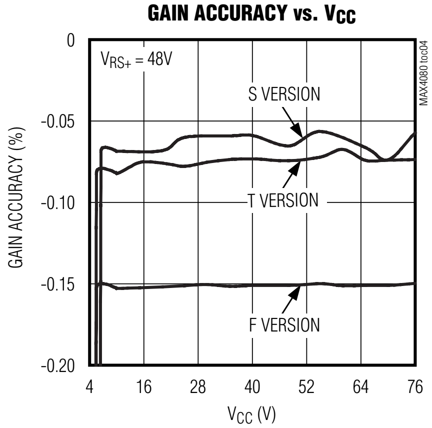
INPUT OFFSET VOLTAGE vs. TEMPERATURE



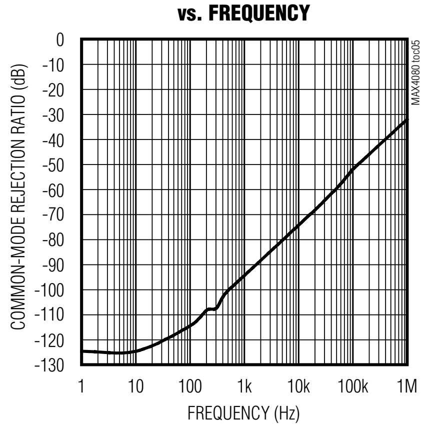
GAIN ACCURACY vs. TEMPERATURE



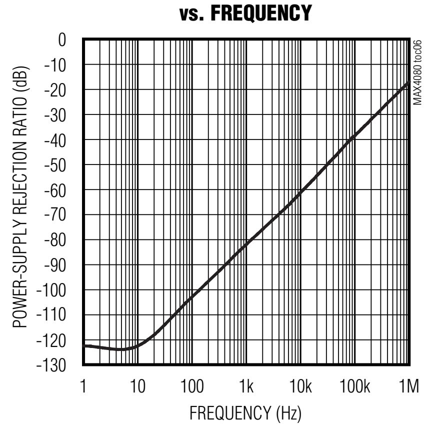
GAIN ACCURACY vs. V_{CC}



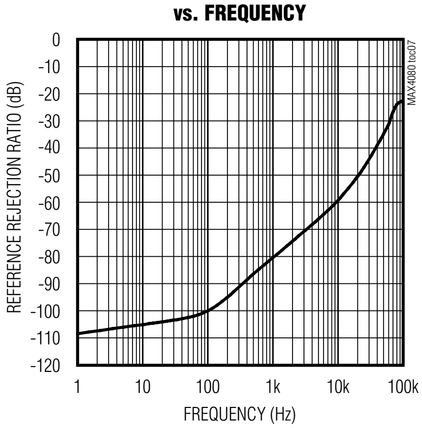
MAX4081F/T/S COMMON-MODE REJECTION RATIO vs. FREQUENCY



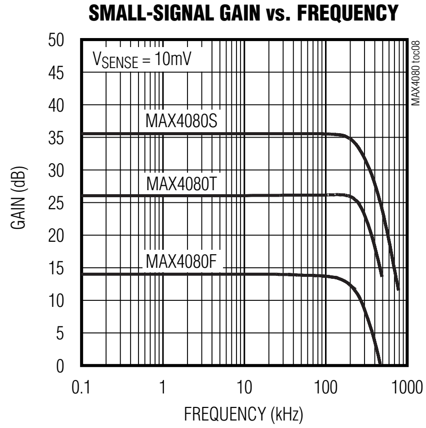
MAX4081F/T/S POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



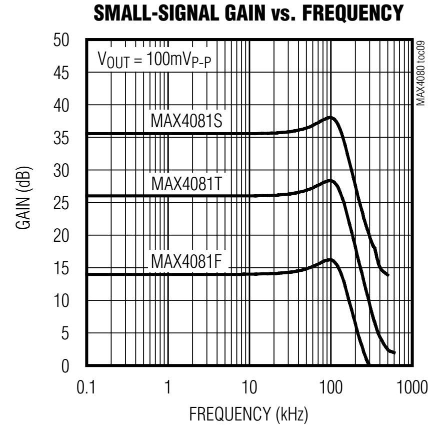
MAX4081F/T/S REFERENCE REJECTION RATIO vs. FREQUENCY



MAX4080F/T/S SMALL-SIGNAL GAIN vs. FREQUENCY



MAX4081F/T/S SMALL-SIGNAL GAIN vs. FREQUENCY

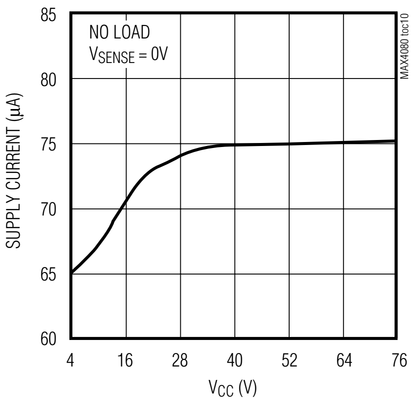


76V, High-Side, Current-Sense Amplifiers with Voltage Output

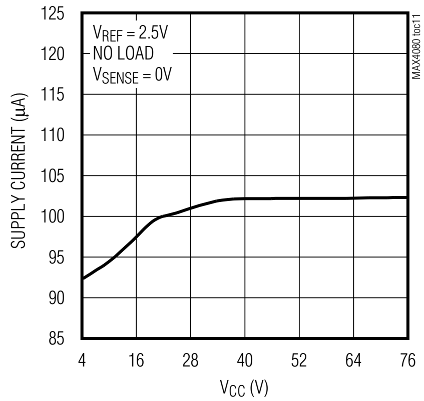
Typical Operating Characteristics (continued)

(V_{CC} = V_{RS+} = 48V, V_{SENSE} = 0V, C_{LOAD} = 20pF, R_{LOAD} = ∞, T_A = +25°C, unless otherwise noted.)

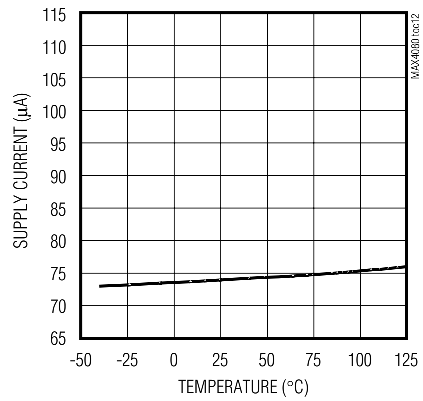
MAX4080
SUPPLY CURRENT vs. V_{CC}



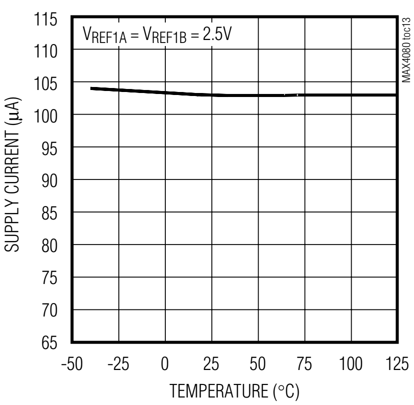
MAX4081
SUPPLY CURRENT vs. V_{CC}



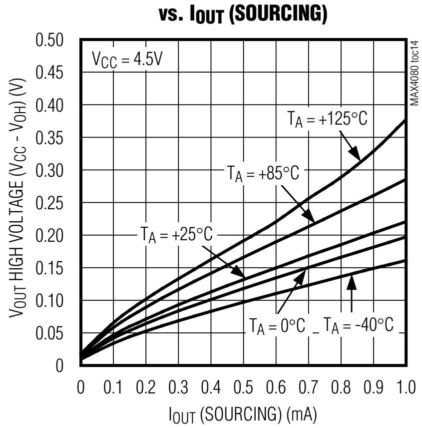
MAX4080
SUPPLY CURRENT vs. TEMPERATURE



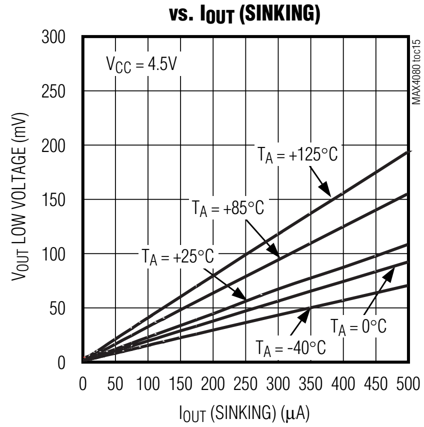
MAX4081
SUPPLY CURRENT vs. TEMPERATURE



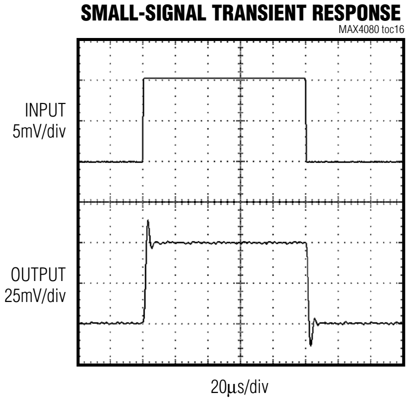
V_{OUT} HIGH VOLTAGE
vs. I_{OUT} (SOURCING)



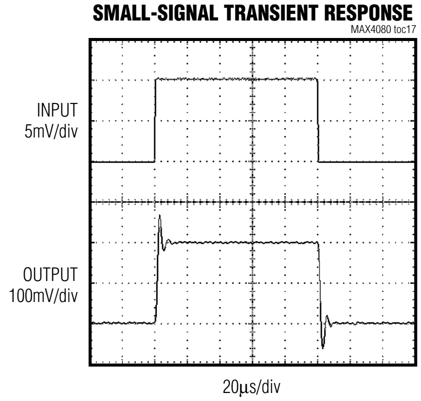
V_{OUT} LOW VOLTAGE
vs. I_{OUT} (SINKING)



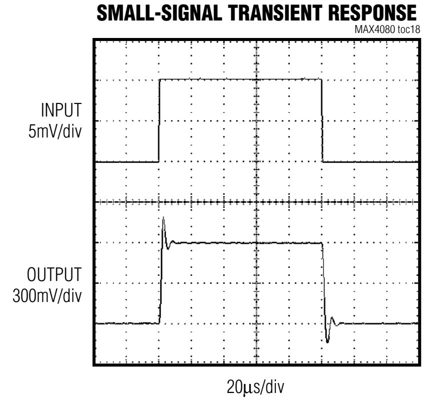
MAX4080F
SMALL-SIGNAL TRANSIENT RESPONSE



MAX4080T
SMALL-SIGNAL TRANSIENT RESPONSE



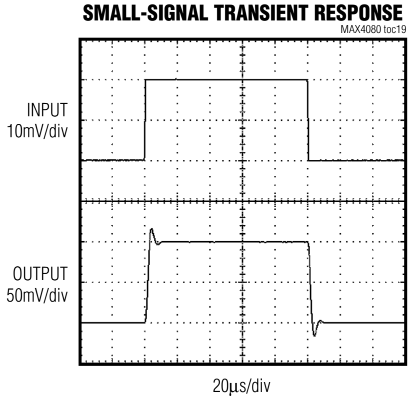
MAX4080S
SMALL-SIGNAL TRANSIENT RESPONSE



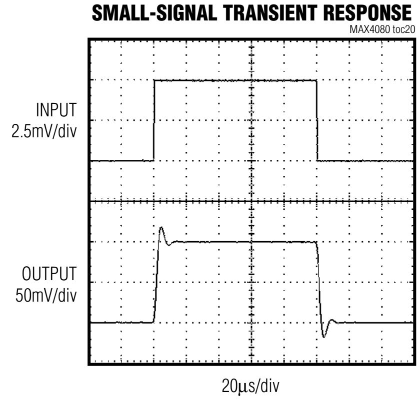
Typical Operating Characteristics (continued)

(V_{CC} = V_{RS+} = 48V, V_{SENSE} = 0V, C_{LOAD} = 20pF, R_{LOAD} = ∞, T_A = +25°C, unless otherwise noted.)

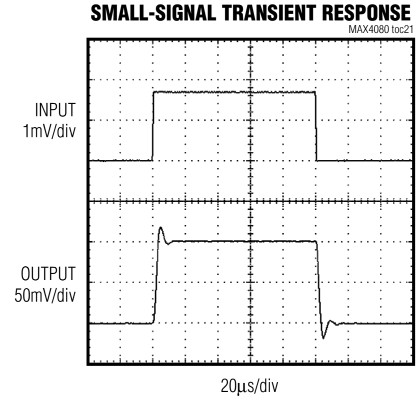
MAX4081F
SMALL-SIGNAL TRANSIENT RESPONSE



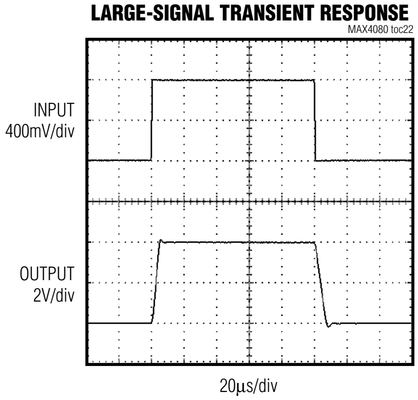
MAX4081T
SMALL-SIGNAL TRANSIENT RESPONSE



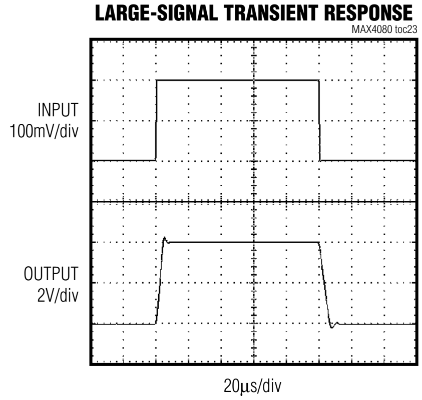
MAX4081S
SMALL-SIGNAL TRANSIENT RESPONSE



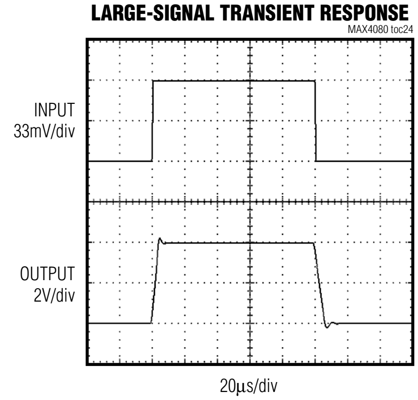
MAX4080F
LARGE-SIGNAL TRANSIENT RESPONSE



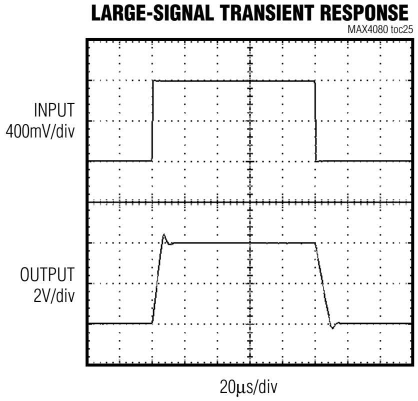
MAX4080T
LARGE-SIGNAL TRANSIENT RESPONSE



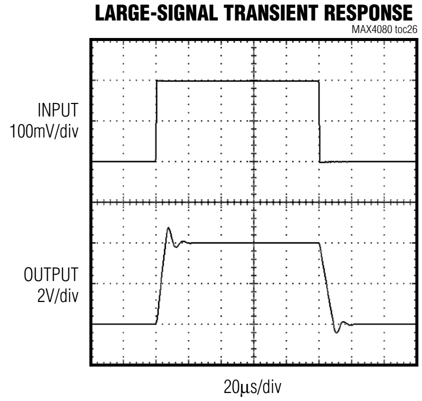
MAX4080S
LARGE-SIGNAL TRANSIENT RESPONSE



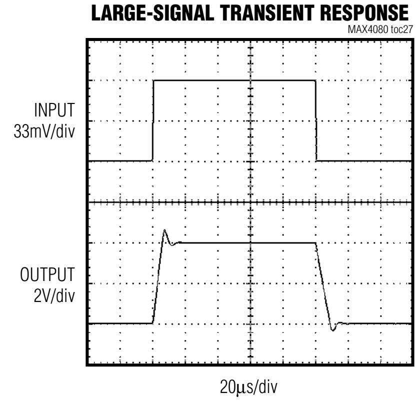
MAX4081F
LARGE-SIGNAL TRANSIENT RESPONSE



MAX4081T
LARGE-SIGNAL TRANSIENT RESPONSE



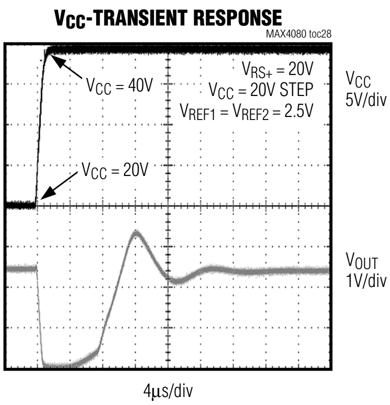
MAX4081S
LARGE-SIGNAL TRANSIENT RESPONSE

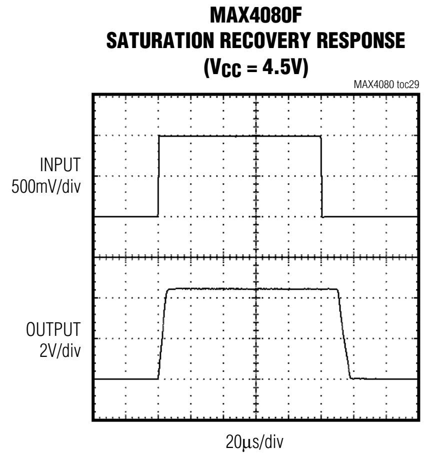


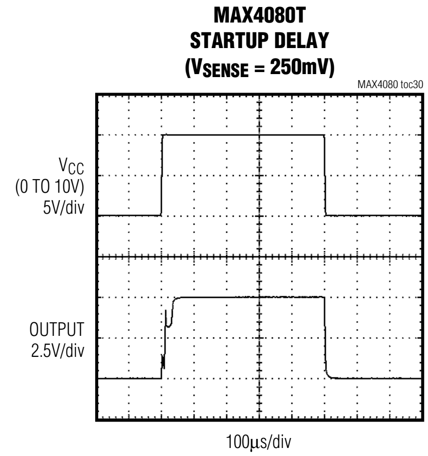
76V, High-Side, Current-Sense Amplifiers with Voltage Output

Typical Operating Characteristics (continued)

(V_{CC} = V_{RS+} = 48V, V_{SENSE} = 0V, C_{LOAD} = 20pF, R_{LOAD} = ∞, T_A = +25°C, unless otherwise noted.)







76V, High-Side, Current-Sense Amplifiers with Voltage Output

Pin Description

PIN		NAME	FUNCTION
MAX4080	MAX4081		
1	1	RS+	Power connection to the external-sense resistor.
2	2	V_{CC}	Supply Voltage Input. Decouple V_{CC} to GND with at least a 0.1µF capacitor to bypass line transients.
3, 6, 7	3	N.C.	No Connection. No internal connection. Leave open or connect to ground.
4	4	GND	Ground
5	5	OUT	Voltage Output. For the unidirectional MAX4080, V_{OUT} is proportional to V_{SENSE}. For the bidirectional MAX4081, the difference voltage (V_{OUT} - V_{REF}) is proportional to V_{SENSE} and indicates the correct polarity.
8	8	RS-	Load connection to the external sense resistor.
—	6	REF1B	Reference Voltage Input: Connect REF1B to REF1A or to GND (see the *External Reference* section).
—	7	REF1A	Reference Voltage Input: Connect REF1A and REF1B to a fixed reference voltage (V_{REF}). V_{OUT} is equal to V_{REF} when V_{SENSE} is zero (see the *External Reference* section).

Detailed Description

The MAX4080/MAX4081 unidirectional and bidirectional high-side, current-sense amplifiers feature a 4.5V to 76V input common-mode range that is independent of supply voltage. This feature allows the monitoring of current out of a battery as low as 4.5V and also enables high-side current sensing at voltages greater than the supply voltage (V_{CC}). The MAX4080/MAX4081 monitors current through a current-sense resistor and amplifies the voltage across the resistor. The MAX4080 senses current unidirectionally, while the MAX4081 senses current bidirectionally.

The 76V input voltage range of the MAX4080/MAX4081 applies independently to both supply voltage (V_{CC}) and common-mode, input-sense voltage (V_{RS+}). High-side current monitoring does not interfere with the ground path of the load being measured, making the MAX4080/MAX4081 particularly useful in a wide range of high-voltage systems.

Battery-powered systems require a precise bidirectional current-sense amplifier to accurately monitor the battery's charge and discharge. The MAX4081 charging current is represented by an output voltage from V_{REF} to V_{CC}, while discharge current is given from V_{REF} to GND. Measurements of OUT with respect to V_{REF} yield a positive and negative voltage during charge and discharge, as illustrated in Figure 1 for the MAX4081T.

Current Monitoring

The MAX4080 operates as follows: current from the source flows through R_{SENSE} to the load (Figure 2), creating a sense voltage, V_{SENSE}. Since the internal-sense amplifier's inverting input has high impedance, negligible current flows through RG2 (neglecting the input bias current). Therefore, the sense amplifier's inverting input voltage equals V_{SOURCE} - (I_{LOAD})(R_{SENSE}). The amplifier's open-loop gain forces its noninverting input to the same voltage as the inverting input. Therefore, the drop across RG1 equals V_{SENSE}. The internal current mirror multiplies I_{RG1} by a current gain factor, β, to give I_{A2} = β × IRG1. Amplifier A2 is used to convert the output current to a voltage and then sent through amplifier A3. Total gain = 5V/V for MAX4080F, 20V/V for the MAX4080T, and 60V/V for the MAX4080S.

The MAX4081 input stage differs slightly from the MAX4080 (Figure 3). Its topology allows for monitoring of bidirectional currents through the sense resistor. When current flows from RS+ to RS-, the MAX4081 matches the voltage drop across the external sense resistor, R_{SENSE}, by increasing the current through the Q1 and RG1. In this way, the voltages at the input terminals of the internal amplifier A1 are kept constant and an accurate measurement of the sense voltage is achieved. In the following amplifier stages of the MAX4081, the output signal of amplifier A2 is level-shifted to the reference voltage (V_{REF} = V_{REF1A} = V_{REF1B}), resulting in a voltage at the output pin (OUT)

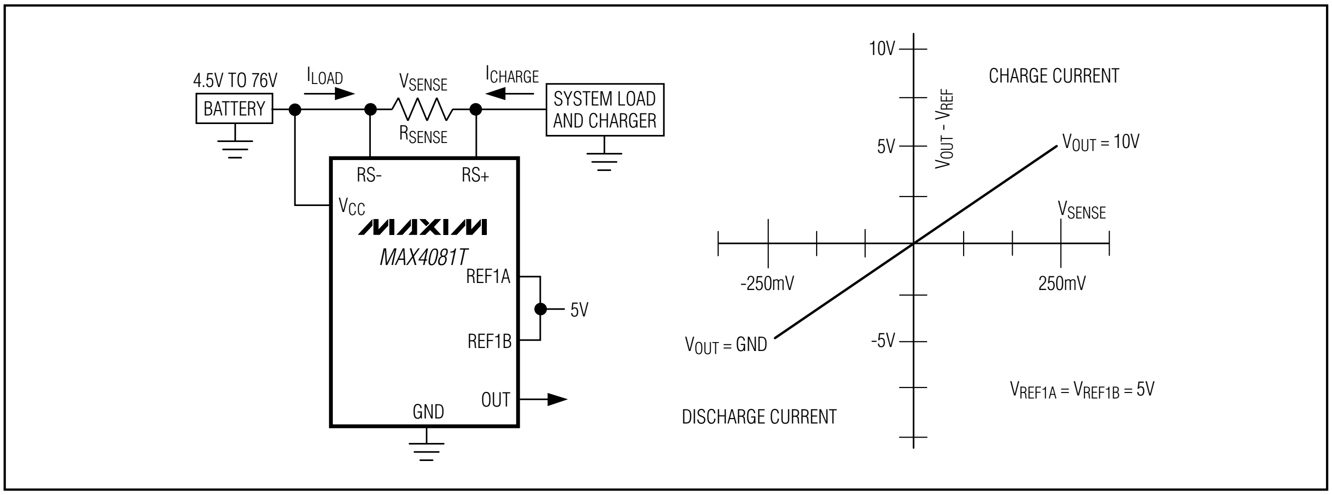


Figure 1. MAX4081T OUT Transfer Curve

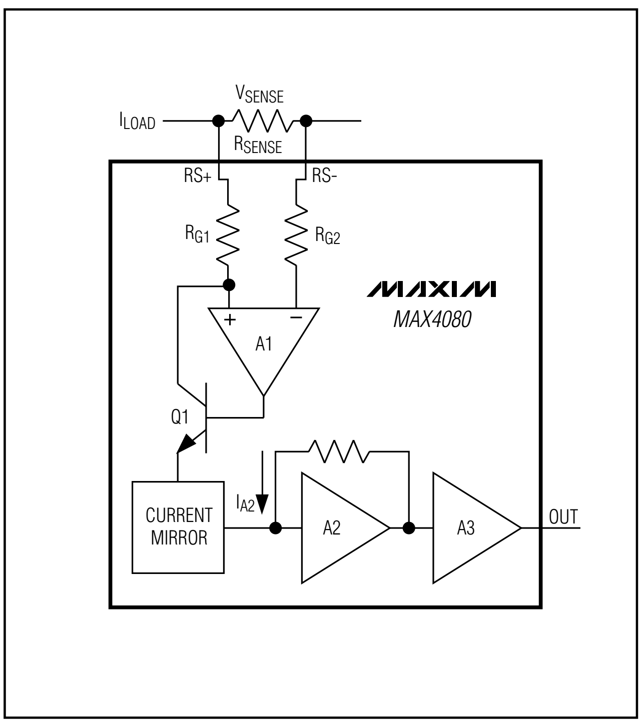


Figure 2. MAX4080 Functional Diagram

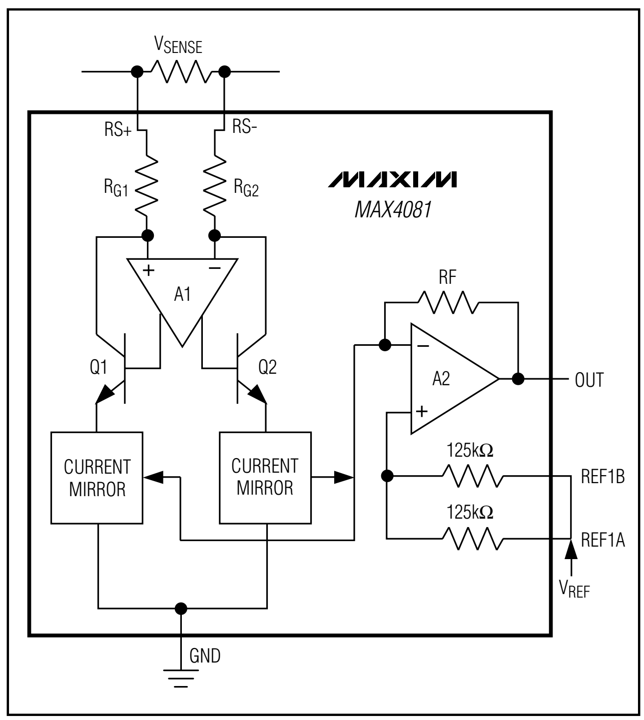


Figure 3. MAX4081 Functional Diagram

that swings above V_{REF} voltage for positive-sense voltages and below V_{REF} for negative-sense voltages. V_{OUT} is equal to V_{REF} when V_{SENSE} is equal to zero.

Set the full-scale output range by selecting R_{SENSE} and the appropriate gain version of the MAX4080/ MAX4081.

Table 1. Typical Component Values

FULL-SCALE LOAD CURRENT, I_{LOAD} (A)	CURRENT-SENSE RESISTOR (mΩ)	GAIN (V/V)	FULL-SCALE V_{SENSE} (mV)	MAX4081 FULL-SCALE OUTPUT VOLTAGE (V_{OUT} - V_{REF}, V)
0.500	1000	5	±500	±2.5
0.125	1000	20	±125	±2.5
0.050	1000	60	±50	±3.0
5.000	100	5	±500	±2.5
1.250	100	20	±125	±2.5
0.500	100	60	±50	±3.0
50.000	10	5	±500	±2.5
12.500	10	20	±125	±2.5
5.000	10	60	±50	±3.0
FULL-SCALE LOAD CURRENT, I_{LOAD} (A)	**CURRENT-SENSE RESISTOR (mΩ)**	**GAIN (V/V)**	**FULL-SCALE V_{SENSE} (mV)**	**MAX4080 FULL-SCALE OUTPUT VOLTAGE (V)**
1.000	1000	5	1000	5.0
0.250	1000	20	250	5.0
0.100	1000	60	100	6.0
10.000	100	5	1000	5.0
2.500	100	20	250	5.0
1.000	100	60	100	6.0
50.000	10	5	500	2.5
25.000	10	20	250	5.0
10.000	10	60	100	6.0

External References (MAX4081)

For the bidirectional MAX4081, the V_{OUT} reference level is controlled by REF1A and REF1B. V_{REF} is defined as the average voltage of V_{REF1A} and V_{REF1B}. Connect REF1A and REF1B to a low-noise, regulated voltage source to set the output reference level. In this mode, V_{OUT} equals V_{REF1A} when V_{SENSE} equals zero (see Figure 4).

Alternatively, connect REF1B to ground, and REF1A to a low-noise, regulated voltage source. In this case, the output reference level (V_{REF}) is equal to V_{REF1A} divided by two. V_{OUT} equals $V_{REF1A}/2$ when V_{SENSE} equals zero.

In either mode, the output swings above the reference voltage for positive current-sensing ($V_{RS+} > V_{RS-}$). The output swings below the reference voltage for negative current-sensing ($V_{RS+} < V_{RS-}$).

Applications Information

Recommended Component Values

Ideally, the maximum load current develops the full-scale sense voltage across the current-sense resistor. Choose the gain needed to yield the maximum output voltage required for the application:

$$V_{OUT} = V_{SENSE} \times A_V$$

where V_{SENSE} is the full-scale sense voltage, 1000mV for gain of 5V/V, 250mV for gain of 20V/V, 100mV for gain of 60V/V, and A_V is the gain of the device.

In applications monitoring a high current, ensure that R_{SENSE} is able to dissipate its own I^2R loss. If the resistor's power dissipation is exceeded, its value may drift or it may fail altogether.

The MAX4080/MAX4081 sense a wide variety of currents with different sense-resistor values. Table 1 lists common resistor values for typical operation.

76V, High-Side, Current-Sense Amplifiers with Voltage Output

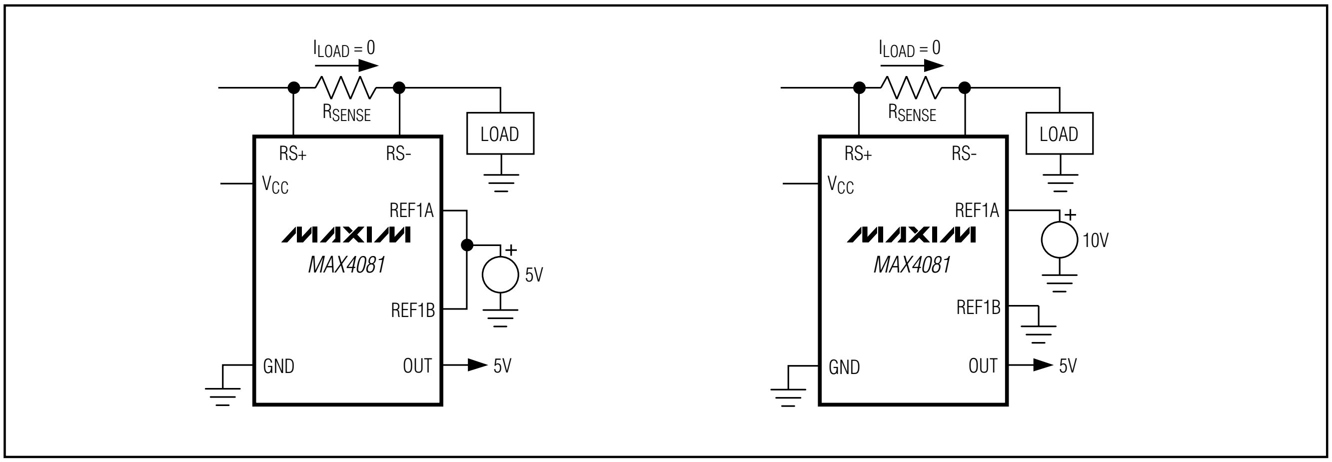


Figure 4. MAX4081 Reference Inputs

The full-scale output voltage is $V_{OUT} = R_{SENSE} \times I_{LOAD(MAX)} \times A_V$, for the MAX4080 and $V_{OUT} = V_{REF} \pm R_{SENSE} \times I_{LOAD(MAX)} \times A_V$ for the MAX4081. $V_{SENSE(MAX)}$ is 1000mV for the 5V/V gain version, 250mV for the 20V/V gain version, and 100mV for the 60V/V gain version.

Choosing the Sense Resistor

Choose R_{SENSE} based on the following criteria:

- **Voltage Loss:** A high R_{SENSE} value causes the power-source voltage to degrade through IR loss. For minimal voltage loss, use the lowest R_{SENSE} value.
- **Accuracy:** A high R_{SENSE} value allows lower currents to be measured more accurately. This is due to offsets becoming less significant when the sense voltage is larger. For best performance, select R_{SENSE} to provide approximately 1000mV (gain of 5V/V), 250mV (gain of 20V/V), or 100mV (gain of 60V/V) of sense voltage for the full-scale current in each application.
- **Efficiency and Power Dissipation:** At high current levels, the I^2R losses in R_{SENSE} can be significant. Take this into consideration when choosing the resistor value and its power dissipation (wattage) rating. Also, the sense resistor's value might drift if it is allowed to heat up excessively.
- **Inductance:** Keep inductance low if I_{SENSE} has a large high-frequency component. Wire-wound resistors have the highest inductance, while metal film is somewhat better. Low-inductance, metal-film resistors are also available. Instead of being spiral-wrapped around a core, as in metal-film or wire-wound resistors, they are a straight band of metal and are available in values under 1Ω.

Because of the high currents that flow through R_{SENSE}, take care to eliminate parasitic trace resistance from causing errors in the sense voltage. Either use a four-terminal current-sense resistor or use Kelvin (force and sense) PC board layout techniques.

Dynamic Range Consideration

Although the MAX4081 have fully symmetrical bidirectional V_{SENSE} input capability, the output voltage range is usually higher from REF to V_{CC} and lower from REF to GND (unless the supply voltage is at the lowest end of the operating range). Therefore, the user must consider the dynamic range of current monitored in both directions and choose the supply voltage and the reference voltage (REF) to make sure the output swing above and below REF is adequate to handle the swings without clipping or running out of headroom.

Power-Supply Bypassing and Grounding

For most applications, bypass V_{CC} to GND with a 0.1µF ceramic capacitor. In many applications, V_{CC} can be connected to one of the current monitor terminals (RS+ or RS-). Because V_{CC} is independent of the monitored voltage, V_{CC} can be connected to a separate regulated supply.

If V_{CC} will be subject to fast-line transients, a series resistor can be added to the power-supply line of the MAX4080/MAX4081 to minimize output disturbance. This resistance and the decoupling capacitor reduce the rise time of the transient. For most applications, 1kΩ in conjunction with a 0.1µF bypass capacitor work well.

The MAX4080/MAX4081 require no special considerations with respect to layout or grounding. Consideration should be given to minimizing errors due to the large charge and discharge currents in the system.

Power Management

The bidirectional capability of the MAX4081 makes it an excellent candidate for use in smart battery packs. In the application diagram (Figure 5), the MAX4081 monitors the charging current into the battery as well as the discharge current out of the battery. The microcontroller stores this information, allowing the system to query the battery's status as needed to make system power-management decisions.

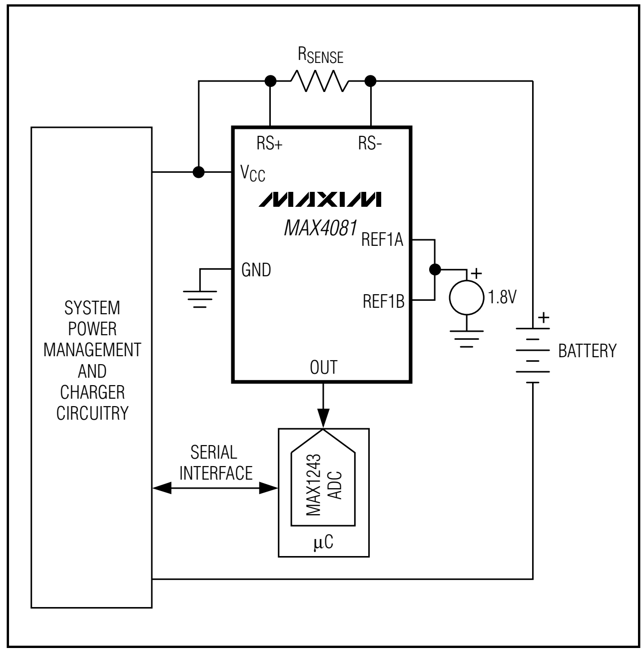
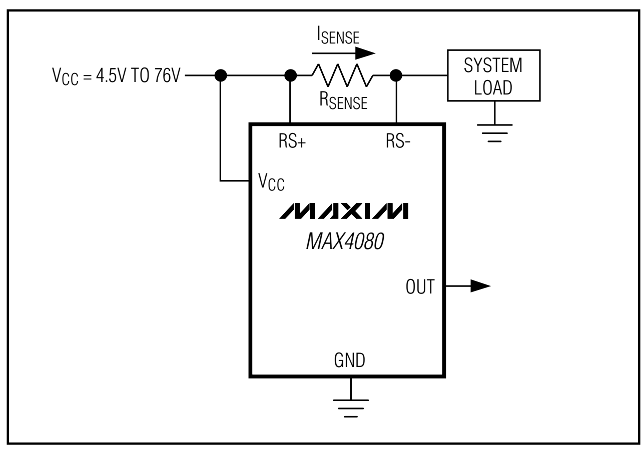


Figure 5. MAX4081 Used In Smart-Battery Application

Selector Guide

PART	GAIN (V/V)	I_{SENSE}
MAX4080FAUA	5	Unidirectional
MAX4080FASA	5	Unidirectional
MAX4080TAUA	20	Unidirectional
MAX4080TASA	20	Unidirectional
MAX4080SAUA	60	Unidirectional
MAX4080SASA	60	Unidirectional
MAX4081FAUA	5	Bidirectional
MAX4081FASA	5	Bidirectional
MAX4081TAUA	20	Bidirectional
MAX4081TASA	20	Bidirectional
MAX4081SAUA	60	Bidirectional
MAX4081SASA	60	Bidirectional

Typical Operating Circuit



Chip Information

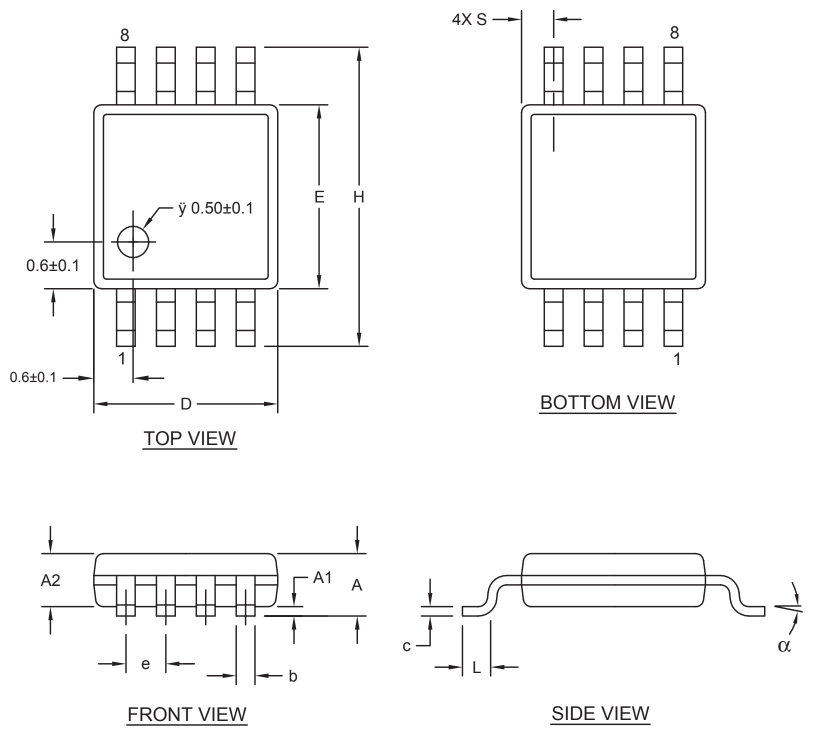
TRANSISTOR COUNT: 185

PROCESS: Bipolar

76V, High-Side, Current-Sense Amplifiers with Voltage Output

Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)



	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	-	0.043	-	1.10
A1	0.002	0.006	0.05	0.15
A2	0.030	0.037	0.75	0.95
b	0.010	0.014	0.25	0.36
c	0.005	0.007	0.13	0.18
D	0.116	0.120	2.95	3.05
e	0.0256 BSC		0.65 BSC	
E	0.116	0.120	2.95	3.05
H	0.188	0.198	4.78	5.03
L	0.016	0.026	0.41	0.66
α	0∞	6∞	0∞	6∞
S	0.0207 BSC		0.5250 BSC	

8LUMAXD.EPS

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15MM (.006").
3. CONTROLLING DIMENSION: MILLIMETERS.
4. MEETS JEDEC MO-187C-AA.

DALLAS SEMICONDUCTOR MAXIM

PROPRIETARY INFORMATION

TITLE: PACKAGE OUTLINE, 8L uMAX/uSOP

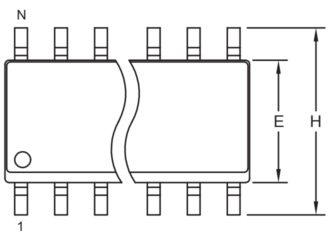
APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21-0036	J	1/1

Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

SOICN .EPS

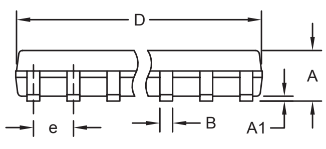
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050 BSC		1.27 BSC	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
L	0.016	0.050	0.40	1.27



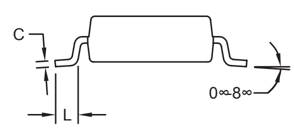
TOP VIEW

VARIATIONS:

	INCHES		MILLIMETERS			
DIM	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	AA
D	0.337	0.344	8.55	8.75	14	AB
D	0.386	0.394	9.80	10.00	16	AC



FRONT VIEW



SIDE VIEW

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15mm (.006").
3. LEADS TO BE COPLANAR WITHIN 0.10mm (.004").
4. CONTROLLING DIMENSION: MILLIMETERS.
5. MEETS JEDEC MS012.
6. N = NUMBER OF PINS.

DALLAS SEMICONDUCTOR MAXIM
PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, .150" SOIC
APPROVAL | DOCUMENT CONTROL NO. 21-0041 | REV. B | 1/1

19-4323; Rev 9; 4/00

+5V-Powered, Multichannel RS-232 Drivers/Receivers

General Description

The MAX220–MAX249 family of line drivers/receivers is intended for all EIA/TIA-232E and V.28/V.24 communications interfaces, particularly applications where ±12V is not available.

These parts are especially useful in battery-powered systems, since their low-power shutdown mode reduces power dissipation to less than 5μW. The MAX225, MAX233, MAX235, and MAX245/MAX246/MAX247 use no external components and are recommended for applications where printed circuit board space is critical.

Applications

Portable Computers

Low-Power Modems

Interface Translation

Battery-Powered RS-232 Systems

Multidrop RS-232 Networks

Features

Superior to Bipolar

- ♦ Operate from Single +5V Power Supply (+5V and +12V—MAX231/MAX239)
- ♦ Low-Power Receive Mode in Shutdown (MAX223/MAX242)
- ♦ Meet All EIA/TIA-232E and V.28 Specifications
- ♦ Multiple Drivers and Receivers
- ♦ 3-State Driver and Receiver Outputs
- ♦ Open-Line Detection (MAX243)

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX220CPE	0°C to +70°C	16 Plastic DIP
MAX220CSE	0°C to +70°C	16 Narrow SO
MAX220CWE	0°C to +70°C	16 Wide SO
MAX220C/D	0°C to +70°C	Dice*
MAX220EPE	-40°C to +85°C	16 Plastic DIP
MAX220ESE	-40°C to +85°C	16 Narrow SO
MAX220EWE	-40°C to +85°C	16 Wide SO
MAX220EJE	-40°C to +85°C	16 CERDIP
MAX220MJE	-55°C to +125°C	16 CERDIP

Ordering Information continued at end of data sheet.

**Contact factory for dice specifications.*

Selection Table

Part Number	Power Supply (V)	No. of RS-232 Drivers/Rx	No. of Ext. Caps	Nominal Cap. Value (μF)	SHDN & Three-State	Rx Active in SHDN	Data Rate (kbps)	Features
MAX220	+5	2/2	4	4.7/10	No	—	120	Ultra-low-power, industry-standard pinout
MAX222	+5	2/2	4	0.1	Yes	—	200	Low-power shutdown
MAX223 (MAX213)	+5	4/5	4	1.0 (0.1)	Yes	✔	120	MAX241 and receivers active in shutdown
MAX225	+5	5/5	0	—	Yes	✔	120	Available in SO
MAX230 (MAX200)	+5	5/0	4	1.0 (0.1)	Yes	—	120	5 drivers with shutdown
MAX231 (MAX201)	+5 and +7.5 to +13.2	2/2	2	1.0 (0.1)	No	—	120	Standard +5/+12V or battery supplies; same functions as MAX232
MAX232 (MAX202)	+5	2/2	4	1.0 (0.1)	No	—	120 (64)	Industry standard
MAX232A	+5	2/2	4	0.1	No	—	200	Higher slew rate, small caps
MAX233 (MAX203)	+5	2/2	0	—	No	—	120	No external caps
MAX233A	+5	2/2	0	—	No	—	200	No external caps, high slew rate
MAX234 (MAX204)	+5	4/0	4	1.0 (0.1)	No	—	120	Replaces 1488
MAX235 (MAX205)	+5	5/5	0	—	Yes	—	120	No external caps
MAX236 (MAX206)	+5	4/3	4	1.0 (0.1)	Yes	—	120	Shutdown, three state
MAX237 (MAX207)	+5	5/3	4	1.0 (0.1)	No	—	120	Complements IBM PC serial port
MAX238 (MAX208)	+5	4/4	4	1.0 (0.1)	No	—	120	Replaces 1488 and 1489
MAX239 (MAX209)	+5 and +7.5 to +13.2	3/5	2	1.0 (0.1)	No	—	120	Standard +5/+12V or battery supplies; single-package solution for IBM PC serial port
MAX240	+5	5/5	4	1.0	Yes	—	120	DIP or flatpack package
MAX241 (MAX211)	+5	4/5	4	1.0 (0.1)	Yes	—	120	Complete IBM PC serial port
MAX242	+5	2/2	4	0.1	Yes	✔	200	Separate shutdown and enable
MAX243	+5	2/2	4	0.1	No	—	200	Open-line detection simplifies cabling
MAX244	+5	8/10	4	1.0	No	—	120	High slew rate
MAX245	+5	8/10	0	—	Yes	✔	120	High slew rate, int. caps, two shutdown modes
MAX246	+5	8/10	0	—	Yes	✔	120	High slew rate, int. caps, three shutdown modes
MAX247	+5	8/9	0	—	Yes	✔	120	High slew rate, int. caps, nine operating modes
MAX248	+5	8/8	4	1.0	Yes	✔	120	High slew rate, selective half-chip enables
MAX249	+5	6/10	4	1.0	Yes	✔	120	Available in quad flatpack package

+5V-Powered, Multichannel RS-232 Drivers/Receivers

ABSOLUTE MAXIMUM RATINGS—MAX220/222/232A/233A/242/243

Supply Voltage (V_{CC}) ....-0.3V to +6V
Input Voltages
T_{IN}..-0.3V to (V_{CC} - 0.3V)
R_{IN} (Except MAX220) ....±30V
R_{IN} (MAX220)..±25V
T_{OUT} (Except MAX220) (Note 1) ....±15V
T_{OUT} (MAX220)..±13.2V
Output Voltages
T_{OUT}...±15V
R_{OUT}...-0.3V to (V_{CC} + 0.3V)
Driver/Receiver Output Short Circuited to GND.........Continuous
Continuous Power Dissipation (T_A = +70°C)
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)....842mW
18-Pin Plastic DIP (derate 11.11mW/°C above +70°C)....889mW
20-Pin Plastic DIP (derate 8.00mW/°C above +70°C) ..440mW
16-Pin Narrow SO (derate 8.70mW/°C above +70°C) ...696mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
18-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
20-Pin Wide SO (derate 10.00mW/°C above +70°C)....800mW
20-Pin SSOP (derate 8.00mW/°C above +70°C) 640mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C).....800mW
18-Pin CERDIP (derate 10.53mW/°C above +70°C).....842mW
Operating Temperature Ranges
MAX2_ _AC_ _, MAX2_ _C_ _............................0°C to +70°C
MAX2_ _AE_ _, MAX2_ _E_ _ ....-40°C to +85°C
MAX2_ _AM_ _, MAX2_ _M_ _.......................-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°C

Note 1: Input voltage measured with T_{OUT} in high-impedance state, $\overline{SHDN}$ or V_{CC} = 0V.
Note 2: For the MAX220, V+ and V- can have a maximum magnitude of 7V, but their absolute difference cannot exceed 13V.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS						
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to GND		±5	±8		V
Input Logic Threshold Low				1.4	0.8	V
Input Logic Threshold High	All except MAX220		2	1.4		V
	MAX220: V_{CC} = 5.0V		2.4			
Logic Pull-Up/Input Current	All except MAX220, normal operation			5	40	µA
	$\overline{SHDN}$ = 0V, MAX222/242, shutdown, MAX220			±0.01	±1	
Output Leakage Current	V_{CC} = 5.5V, $\overline{SHDN}$ = 0V, V_{OUT} = ±15V, MAX222/242			±0.01	±10	µA
	V_{CC} = $\overline{SHDN}$ = 0V, V_{OUT} = ±15V			±0.01	±10	
Data Rate	All except MAX220, normal operation			200	116	kb/s
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V		300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V		±7	±22		mA
RS-232 RECEIVERS						
RS-232 Input Voltage Operating Range					±30	V
RS-232 Input Threshold Low	V_{CC} = 5V	All except MAX243 $R2_{IN}$	0.8	1.3		V
		MAX243 $R2_{IN}$ (Note 2)	-3			
RS-232 Input Threshold High	V_{CC} = 5V	All except MAX243 $R2_{IN}$		1.8	2.4	V
		MAX243 $R2_{IN}$ (Note 2)		-0.5	-0.1	
RS-232 Input Hysteresis	All except MAX243, V_{CC} = 5V, no hysteresis in shdn.		0.2	0.5	1	V
	MAX243			1		
RS-232 Input Resistance			3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA			0.2	0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA		3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND		-2	-10		mA
	Shrinking V_{OUT} = V_{CC}		10	30		

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243 (continued)

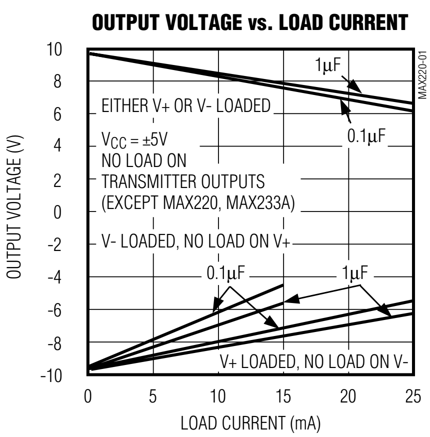
(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

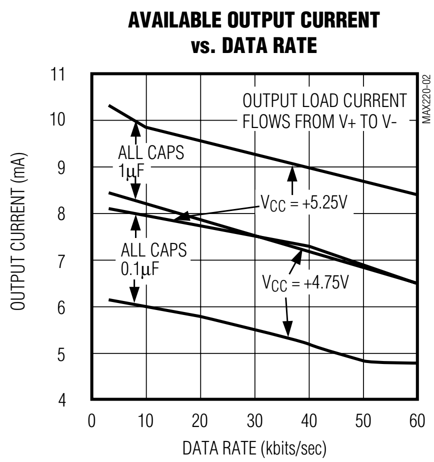
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TTL/CMOS Output Leakage Current	$\overline{SHDN}$ = V_{CC} or $\overline{EN}$ = V_{CC} ($\overline{SHDN}$ = 0V for MAX222), 0V ≤ V_{OUT} ≤ V_{CC}			±0.05	±10	µA
$\overline{EN}$ Input Threshold Low	MAX242			1.4	0.8	V
$\overline{EN}$ Input Threshold High	MAX242		2.0	1.4		V
Operating Supply Voltage			4.5		5.5	V
V_{CC} Supply Current ($\overline{SHDN}$ = V_{CC}), Figures 5, 6, 11, 19	No load	MAX220		0.5	2	mA
		MAX222/232A/233A/242/243		4	10	
	3kΩ load both inputs	MAX220		12		
		MAX222/232A/233A/242/243		15		
Shutdown Supply Current	MAX222/242	T_A = +25°C		0.1	10	µA
		T_A = 0°C to +70°C		2	50	
		T_A = -40°C to +85°C		2	50	
		T_A = -55°C to +125°C		35	100	
$\overline{SHDN}$ Input Leakage Current	MAX222/242				±1	µA
$\overline{SHDN}$ Threshold Low	MAX222/242			1.4	0.8	V
$\overline{SHDN}$ Threshold High	MAX222/242		2.0	1.4		V
Transition Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C, measured from +3V to -3V or -3V to +3V	MAX222/232A/233A/242/243	6	12	30	V/µs
		MAX220	1.5	3	30	
Transmitter Propagation Delay TLL to RS-232 (normal operation), Figure 1	t_{PHLT}	MAX222/232A/233A/242/243		1.3	3.5	µs
		MAX220		4	10	
	t_{PLHT}	MAX222/232A/233A/242/243		1.5	3.5	
		MAX220		5	10	
Receiver Propagation Delay RS-232 to TLL (normal operation), Figure 2	t_{PHLR}	MAX222/232A/233A/242/243		0.5	1	µs
		MAX220		0.6	3	
	t_{PLHR}	MAX222/232A/233A/242/243		0.6	1	
		MAX220		0.8	3	
Receiver Propagation Delay RS-232 to TLL (shutdown), Figure 2	t_{PHLS}	MAX242		0.5	10	µs
	t_{PLHS}	MAX242		2.5	10	
Receiver-Output Enable Time, Figure 3	t_{ER}	MAX242		125	500	ns
Receiver-Output Disable Time, Figure 3	t_{DR}	MAX242		160	500	ns
Transmitter-Output Enable Time ($\overline{SHDN}$ goes high), Figure 4	t_{ET}	MAX222/242, 0.1µF caps (includes charge-pump start-up)		250		µs
Transmitter-Output Disable Time ($\overline{SHDN}$ goes low), Figure 4	t_{DT}	MAX222/242, 0.1µF caps		600		ns
Transmitter + to - Propagation Delay Difference (normal operation)	t_{PHLT} - t_{PLHT}	MAX222/232A/233A/242/243		300		ns
		MAX220		2000		
Receiver + to - Propagation Delay Difference (normal operation)	t_{PHLR} - t_{PLHR}	MAX222/232A/233A/242/243		100		ns
		MAX220		225		

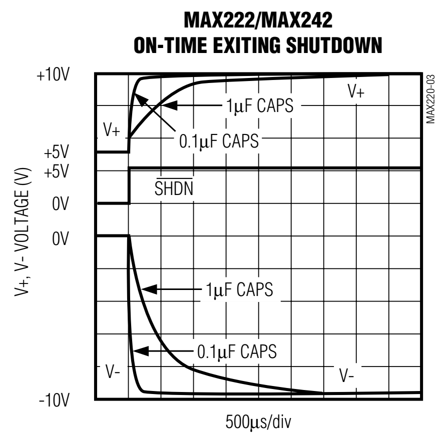
Note 3: MAX243 $R2_{OUT}$ is guaranteed to be low when $R2_{IN}$ is ≥ 0V or is floating.

Typical Operating Characteristics

MAX220/MAX222/MAX232A/MAX233A/MAX242/MAX243







ABSOLUTE MAXIMUM RATINGS—MAX223/MAX230–MAX241

V_{CC} ....-0.3V to +6V
V+ ....(V_{CC} - 0.3V) to +14V
V- ....+0.3V to -14V
Input Voltages
T_{IN} ....-0.3V to (V_{CC} + 0.3V)
R_{IN}..±30V
Output Voltages
T_{OUT} ....(V+ + 0.3V) to (V- - 0.3V)
R_{OUT}...-0.3V to (V_{CC} + 0.3V)
Short-Circuit Duration, T_{OUT} ....Continuous
Continuous Power Dissipation (T_A = +70°C)
14-Pin Plastic DIP (derate 10.00mW/°C above +70°C)....800mW
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)....842mW
20-Pin Plastic DIP (derate 11.11mW/°C above +70°C)....889mW
24-Pin Narrow Plastic DIP
(derate 13.33mW/°C above +70°C) 1.07W
24-Pin Plastic DIP (derate 9.09mW/°C above +70°C)......500mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C).........762mW
20-Pin Wide SO (derate 10 00mW/°C above +70°C).......800mW
24-Pin Wide SO (derate 11.76mW/°C above +70°C).......941mW
28-Pin Wide SO (derate 12.50mW/°C above +70°C) 1W
44-Pin Plastic FP (derate 11.11mW/°C above +70°C) 889mW
14-Pin CERDIP (derate 9.09mW/°C above +70°C)..........727mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C)........800mW
20-Pin CERDIP (derate 11.11mW/°C above +70°C)........889mW
24-Pin Narrow CERDIP
(derate 12.50mW/°C above +70°C) 1W
24-Pin Sidebraze (derate 20.0mW/°C above +70°C)..........1.6W
28-Pin SSOP (derate 9.52mW/°C above +70°C).............762mW
Operating Temperature Ranges
MAX2 _ _ C _ _...0°C to +70°C
MAX2 _ _ E _ _..-40°C to +85°C
MAX2 _ _ M _ _ ....-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX223/MAX230–MAX241

(MAX223/230/232/234/236/237/238/240/241, V_{CC} = +5V ±10; MAX233/MAX235, V_{CC} = 5V ±5%, C1–C4 = 1.0µF; MAX231/MAX239, V_{CC} = 5V ±10%; V+ = 7.5V to 13.2V; T_A = T_{MIN} to T_{MAX}; unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to ground		±5.0	±7.3		V
V_{CC} Power-Supply Current	No load, T_A = +25°C	MAX232/233		5	10	mA
		MAX223/230/234–238/240/241		7	15	
		MAX231/239		0.4	1	
V+ Power-Supply Current		MAX231		1.8	5	mA
		MAX239		5	15	
Shutdown Supply Current	T_A = +25°C	MAX223		15	50	µA
		MAX230/235/236/240/241		1	10	
Input Logic Threshold Low	T_{IN}; EN, $\overline{SHDN}$ (MAX233); $\overline{EN}$, SHDN (MAX230/235–241)				0.8	V
Input Logic Threshold High	T_{IN}		2.0			V
	EN, $\overline{SHDN}$ (MAX223); $\overline{EN}$, SHDN (MAX230/235/236/240/241)		2.4			
Logic Pull-Up Current	T_{IN} = 0V			1.5	200	µA
Receiver Input Voltage Operating Range			-30		30	V

ELECTRICAL CHARACTERISTICS—MAX223/MAX230–MAX241 (continued)

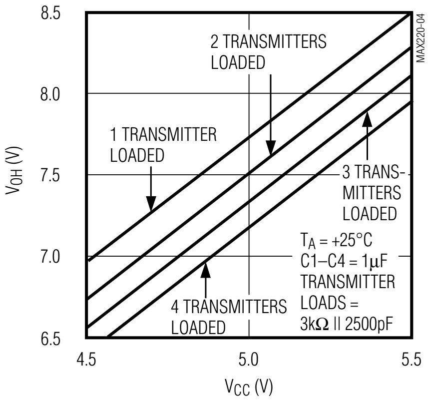
(MAX223/230/232/234/236/237/238/240/241, V_{CC} = +5V ±10; MAX233/MAX235, V_{CC} = 5V ±5%, C1–C4 = 1.0µF; MAX231/MAX239, V_{CC} = 5V ±10%; V+ = 7.5V to 13.2V; T_A = T_{MIN} to T_{MAX}; unless otherwise noted.)

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
RS-232 Input Threshold Low	T_A = +25°C, V_{CC} = 5V	Normal operation $\overline{SHDN}$ = 5V (MAX223) SHDN = 0V (MAX235/236/240/241)		0.8	1.2		V
		Shutdown (MAX223) $\overline{SHDN}$ = 0V, EN = 5V ($R4_{IN}$, $R5_{IN}$)		0.6	1.5		
RS-232 Input Threshold High	T_A = +25°C, V_{CC} = 5V	Normal operation $\overline{SHDN}$ = 5V (MAX223) SHDN = 0V (MAX235/236/240/241)			1.7	2.4	V
		Shutdown (MAX223) $\overline{SHDN}$ = 0V, EN = 5V ($R4_{IN}$, $R5_{IN}$)			1.5	2.4	
RS-232 Input Hysteresis	V_{CC} = 5V, no hysteresis in shutdown			0.2	0.5	1.0	V
RS-232 Input Resistance	T_A = +25°C, V_{CC} = 5V			3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 1.6mA (MAX231/232/233, I_{OUT} = 3.2mA)					0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1mA			3.5	V_{CC} - 0.4		V
TTL/CMOS Output Leakage Current	0V ≤ R_{OUT} ≤ V_{CC}; EN = 0V (MAX223); $\overline{EN}$ = V_{CC} (MAX235–241)				0.05	±10	µA
Receiver Output Enable Time	Normal operation	MAX223			600		ns
		MAX235/236/239/240/241			400		
Receiver Output Disable Time	Normal operation	MAX223			900		ns
		MAX235/236/239/240/241			250		
Propagation Delay	RS-232 IN to TTL/CMOS OUT, C_L = 150pF	Normal operation			0.5	10	µs
		$\overline{SHDN}$ = 0V (MAX223)	t_{PHLS}		4	40	
			t_{PLHS}		6	40	
Transition Region Slew Rate	MAX223/MAX230/MAX234–241, T_A = +25°C, V_{CC} = 5V, R_L = 3kΩ to 7kΩ, C_L = 50pF to 2500pF, measured from +3V to -3V or -3V to +3V			3	5.1	30	V/µs
	MAX231/MAX232/MAX233, T_A = +25°C, V_{CC} = 5V, R_L = 3kΩ to 7kΩ, C_L = 50pF to 2500pF, measured from +3V to -3V or -3V to +3V				4	30	
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V			300			Ω
Transmitter Output Short-Circuit Current					±10		mA

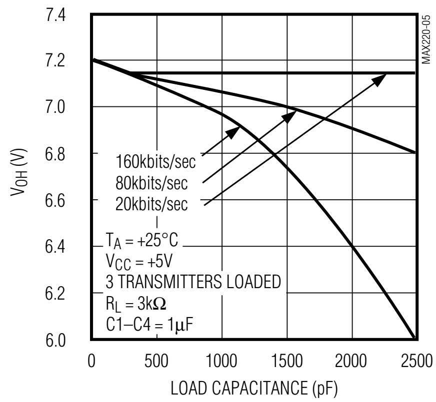
Typical Operating Characteristics

MAX223/MAX230–MAX241

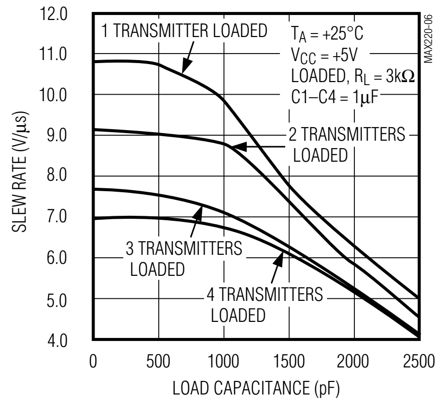
TRANSMITTER OUTPUT VOLTAGE (V_{OH}) vs. V_{CC}



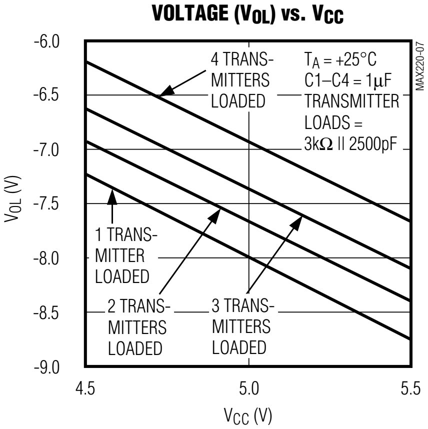
TRANSMITTER OUTPUT VOLTAGE (V_{OH}) vs. LOAD CAPACITANCE AT DIFFERENT DATA RATES



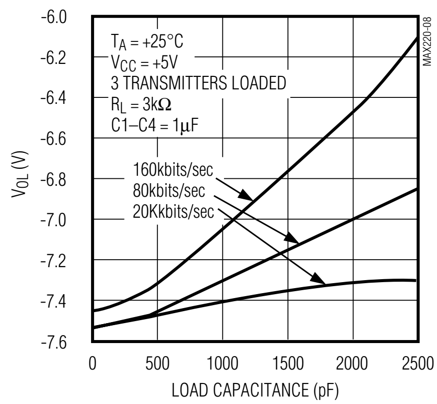
TRANSMITTER SLEW RATE vs. LOAD CAPACITANCE



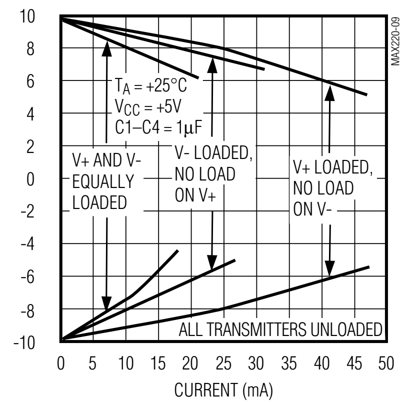
TRANSMITTER OUTPUT VOLTAGE (V_{OL}) vs. V_{CC}



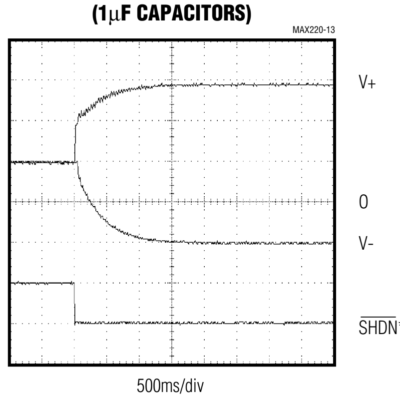
TRANSMITTER OUTPUT VOLTAGE (V_{OL}) vs. LOAD CAPACITANCE AT DIFFERENT DATA RATES



TRANSMITTER OUTPUT VOLTAGE (V+, V-) vs. LOAD CURRENT



V+, V- WHEN EXITING SHUTDOWN (1µF CAPACITORS)



*SHUTDOWN POLARITY IS REVERSED FOR NON MAX241 PARTS

ABSOLUTE MAXIMUM RATINGS—MAX225/MAX244–MAX249

Supply Voltage (V_{CC})..-0.3V to +6V
Input Voltages
T_{IN}, $\overline{ENA}$, $\overline{ENB}$, $\overline{ENR}$, $\overline{ENT}$, $\overline{ENRA}$,
$\overline{ENRB}$, $\overline{ENTA}$, $\overline{ENTB}$.................................-0.3V to (V_{CC} + 0.3V)
R_{IN} ....±25V
T_{OUT} (Note 3)..±15V
R_{OUT} ....-0.3V to (V_{CC} + 0.3V)
Short Circuit (one output at a time)
T_{OUT} to GND...Continuous
R_{OUT} to GND...Continuous

Continuous Power Dissipation (T_A = +70°C)
28-Pin Wide SO (derate 12.50mW/°C above +70°C) 1W
40-Pin Plastic DIP (derate 11.11mW/°C above +70°C) ...611mW
44-Pin PLCC (derate 13.33mW/°C above +70°C) 1.07W
Operating Temperature Ranges
MAX225C_ _, MAX24_C_ _ ....0°C to +70°C
MAX225E_ _, MAX24_E_ _ ....-40°C to +85°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering,10sec) ....+300°C

Note 4: Input voltage measured with transmitter output in a high-impedance state, shutdown, or V_{CC} = 0V.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX225/MAX244–MAX249

(MAX225, V_{CC} = 5.0V ±5%; MAX244–MAX249, V_{CC} = +5.0V ±10%, external capacitors C1–C4 = 1µF; T_A = T_{MIN} to T_{MAX}; unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS						
Input Logic Threshold Low				1.4	0.8	V
Input Logic Threshold High			2	1.4		V
Logic Pull-Up/Input Current	Tables 1a–1d	Normal operation		10	50	µA
		Shutdown		±0.01	±1	
Data Rate	Tables 1a–1d, normal operation			120	64	kbits/sec
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to GND		±5	±7.5		V
Output Leakage Current (shutdown)	Tables 1a–1d	$\overline{ENA}$, $\overline{ENB}$, $\overline{ENT}$, $\overline{ENTA}$, $\overline{ENTB}$ = V_{CC}, V_{OUT} = ±15V		±0.01	±25	µA
		V_{CC} = 0V, V_{OUT} = ±15V		±0.01	±25	
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V (Note 4)		300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V		±7	±30		mA
RS-232 RECEIVERS						
RS-232 Input Voltage Operating Range					±25	V
RS-232 Input Threshold Low	V_{CC} = 5V		0.8	1.3		V
RS-232 Input Threshold High	V_{CC} = 5V			1.8	2.4	V
RS-232 Input Hysteresis	V_{CC} = 5V		0.2	0.5	1.0	V
RS-232 Input Resistance			3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA			0.2	0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA		3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND		-2	-10		mA
	Shrinking V_{OUT} = V_{CC}		10	30		
TTL/CMOS Output Leakage Current	Normal operation, outputs disabled, Tables 1a–1d, 0V ≤ V_{OUT} ≤ V_{CC}, $\overline{ENR\_}$ = V_{CC}			±0.05	±0.10	µA

ELECTRICAL CHARACTERISTICS—MAX225/MAX244–MAX249 (continued)

(MAX225, V_{CC} = 5.0V ±5%; MAX244–MAX249, V_{CC} = +5.0V ±10%, external capacitors C1–C4 = 1µF; T_A = T_{MIN} to T_{MAX}; unless otherwise noted.)

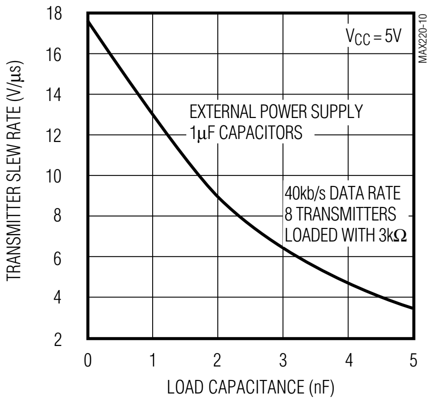
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
POWER SUPPLY AND CONTROL LOGIC						
Operating Supply Voltage		MAX225	4.75		5.25	V
		MAX244–MAX249	4.5		5.5	
V_{CC} Supply Current (normal operation)	No load	MAX225		10	20	mA
		MAX244–MAX249		11	30	
	3kΩ loads on all outputs	MAX225		40		
		MAX244–MAX249		57		
Shutdown Supply Current	T_A = +25°C			8	25	µA
	T_A = T_{MIN} to T_{MAX}				50	
Control Input	Leakage current				±1	µA
	Threshold low			1.4	0.8	V
	Threshold high		2.4	1.4		
AC CHARACTERISTICS						
Transition Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C, measured from +3V to -3V or -3V to +3V		5	10	30	V/µs
Transmitter Propagation Delay TLL to RS-232 (normal operation), Figure 1	t_{PHLT}			1.3	3.5	µs
	t_{PLHT}			1.5	3.5	
Receiver Propagation Delay TLL to RS-232 (normal operation), Figure 2	t_{PHLR}			0.6	1.5	µs
	t_{PLHR}			0.6	1.5	
Receiver Propagation Delay TLL to RS-232 (low-power mode), Figure 2	t_{PHLS}			0.6	10	µs
	t_{PLHS}			3.0	10	
Transmitter + to - Propagation Delay Difference (normal operation)	t_{PHLT} - t_{PLHT}			350		ns
Receiver + to - Propagation Delay Difference (normal operation)	t_{PHLR} - t_{PLHR}			350		ns
Receiver-Output Enable Time, Figure 3	t_{ER}			100	500	ns
Receiver-Output Disable Time, Figure 3	t_{DR}			100	500	ns
Transmitter Enable Time	t_{ET}	MAX246–MAX249 (excludes charge-pump start-up)		5		µs
		MAX225/MAX245–MAX249 (includes charge-pump start-up)		10		ms
Transmitter Disable Time, Figure 4	t_{DT}			100		ns

Note 5: The 300Ω minimum specification complies with EIA/TIA-232E, but the actual resistance when in shutdown mode or V_{CC} = 0V is 10MΩ as is implied by the leakage specification.

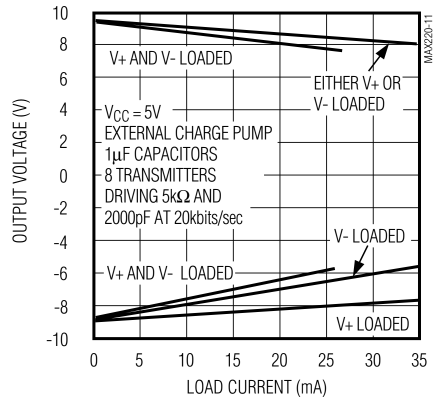
Typical Operating Characteristics

MAX225/MAX244–MAX249

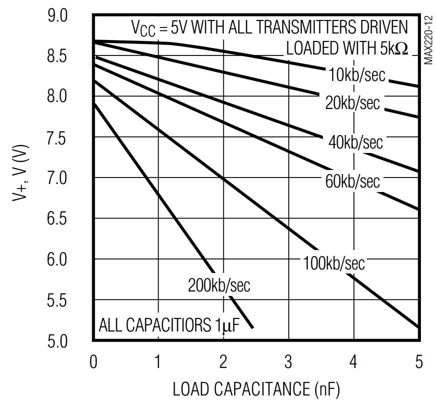
TRANSMITTER SLEW RATE vs. LOAD CAPACITANCE



OUTPUT VOLTAGE vs. LOAD CURRENT FOR V+ AND V-



TRANSMITTER OUTPUT VOLTAGE (V+, V-) vs. LOAD CAPACITANCE AT DIFFERENT DATA RATES



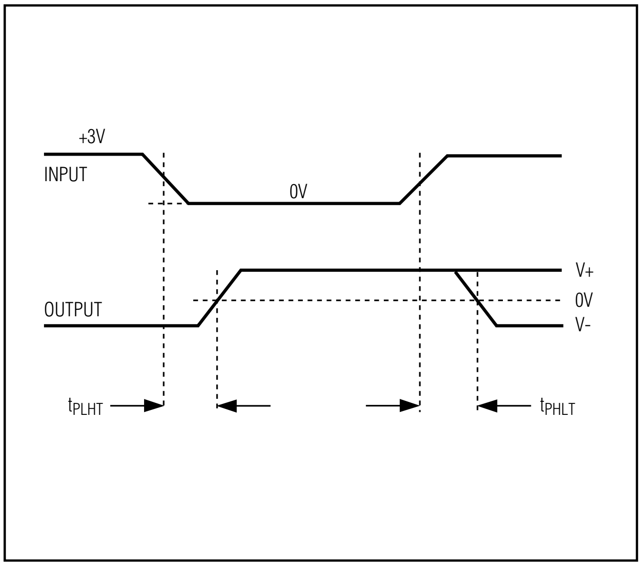


Figure 1. Transmitter Propagation-Delay Timing

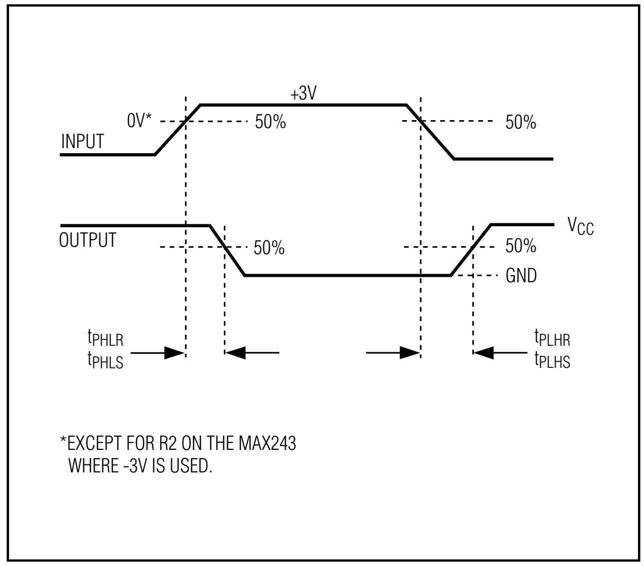


Figure 2. Receiver Propagation-Delay Timing

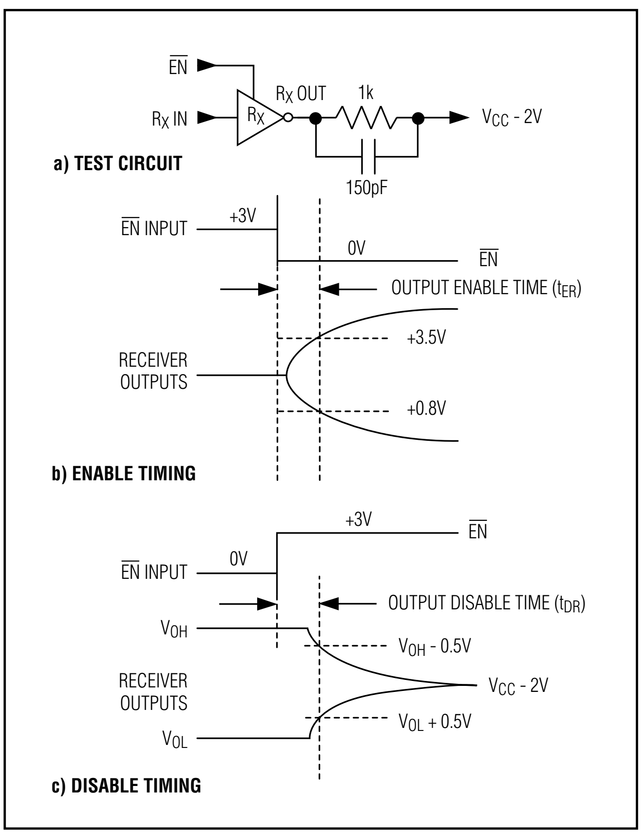


Figure 3. Receiver-Output Enable and Disable Timing

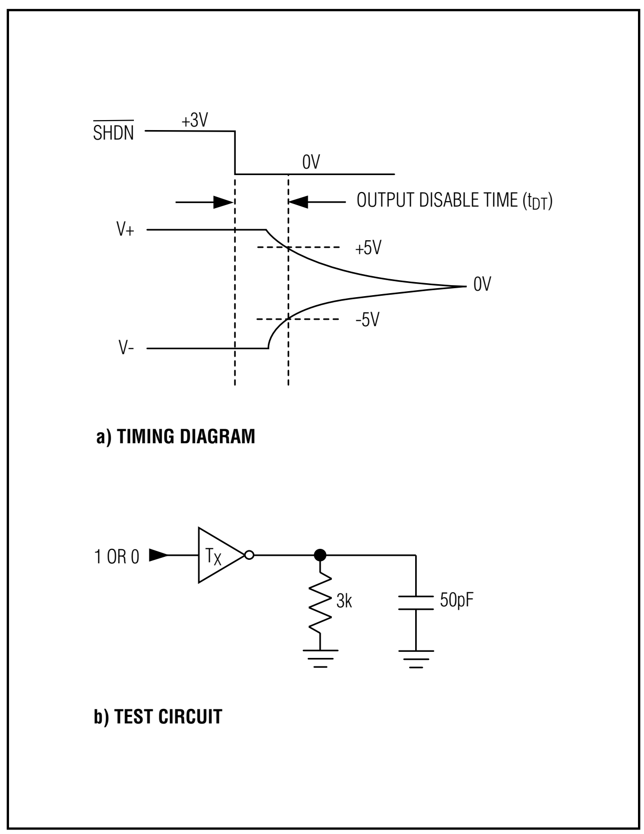


Figure 4. Transmitter-Output Disable Timing

Table 1a. MAX245 Control Pin Configurations

$\overline{ENT}$	$\overline{ENR}$	OPERATION STATUS	TRANSMITTERS	RECEIVERS
0	0	Normal Operation	All Active	All Active
0	1	Normal Operation	All Active	All 3-State
1	0	Shutdown	All 3-State	All Low-Power Receive Mode
1	1	Shutdown	All 3-State	All 3-State

Table 1b. MAX245 Control Pin Configurations

$\overline{ENT}$	$\overline{ENR}$	OPERATION STATUS	TRANSMITTERS		RECEIVERS	
			TA1–TA4	TB1–TB4	RA1–RA5	RB1–RB5
0	0	Normal Operation	All Active	All Active	All Active	All Active
0	1	Normal Operation	All Active	All Active	RA1–RA4 3-State, RA5 Active	RB1–RB4 3-State, RB5 Active
1	0	Shutdown	All 3-State	All 3-State	All Low-Power Receive Mode	All Low-Power Receive Mode
1	1	Shutdown	All 3-State	All 3-State	RA1–RA4 3-State, RA5 Low-Power Receive Mode	RB1–RB4 3-State, RB5 Low-Power Receive Mode

Table 1c. MAX246 Control Pin Configurations

$\overline{ENA}$	$\overline{ENB}$	OPERATION STATUS	TRANSMITTERS		RECEIVERS	
			TA1–TA4	TB1–TB4	RA1–RA5	RB1–RB5
0	0	Normal Operation	All Active	All Active	All Active	All Active
0	1	Normal Operation	All Active	All 3-State	All Active	RB1–RB4 3-State, RB5 Active
1	0	Shutdown	All 3-State	All Active	RA1–RA4 3-State, RA5 Active	All Active
1	1	Shutdown	All 3-State	All 3-State	RA1–RA4 3-State, RA5 Low-Power Receive Mode	RB1–RB4 3-State, RA5 Low-Power Receive Mode

Table 1d. MAX247/MAX248/MAX249 Control Pin Configurations

$\overline{\text{ENTA}}$	$\overline{\text{ENTB}}$	$\overline{\text{ENRA}}$	$\overline{\text{ENRB}}$	OPERATION STATUS		TRANSMITTERS		RECEIVERS	
					MAX247	TA1–TA4	TB1–TB4	RA1–RA4	RB1–RB5
					MAX248	TA1–TA4	TB1–TB4	RA1–RA4	RB1–RB4
					MAX249	TA1–TA3	TB1–TB3	RA1–RA5	RB1–RB5
0	0	0	0	Normal Operation		All Active	All Active	All Active	All Active
0	0	0	1	Normal Operation		All Active	All Active	All Active	All 3-State, except RB5 stays active on MAX247
0	0	1	0	Normal Operation		All Active	All Active	All 3-State	All Active
0	0	1	1	Normal Operation		All Active	All Active	All 3-State	All 3-State, except RB5 stays active on MAX247
0	1	0	0	Normal Operation		All Active	All 3-State	All Active	All Active
0	1	0	1	Normal Operation		All Active	All 3-State	All Active	All 3-State, except RB5 stays active on MAX247
0	1	1	0	Normal Operation		All Active	All 3-State	All 3-State	All Active
0	1	1	1	Normal Operation		All Active	All 3-State	All 3-State	All 3-State, except RB5 stays active on MAX247
1	0	0	0	Normal Operation		All 3-State	All Active	All Active	All Active
1	0	0	1	Normal Operation		All 3-State	All Active	All Active	All 3-State, except RB5 stays active on MAX247
1	0	1	0	Normal Operation		All 3-State	All Active	All 3-State	All Active
1	0	1	1	Normal Operation		All 3-State	All Active	All 3-State	All 3-State, except RB5 stays active on MAX247
1	1	0	0	Shutdown		All 3-State	All 3-State	Low-Power Receive Mode	Low-Power Receive Mode
1	1	0	1	Shutdown		All 3-State	All 3-State	Low-Power Receive Mode	All 3-State, except RB5 stays active on MAX247
1	1	1	0	Shutdown		All 3-State	All 3-State	All 3-State	Low-Power Receive Mode
1	1	1	1	Shutdown		All 3-State	All 3-State	All 3-State	All 3-State, except RB5 stays active on MAX247

+5V-Powered, Multichannel RS-232 Drivers/Receivers

Detailed Description

The MAX220–MAX249 contain four sections: dual charge-pump DC-DC voltage converters, RS-232 drivers, RS-232 receivers, and receiver and transmitter enable control inputs.

Dual Charge-Pump Voltage Converter

The MAX220–MAX249 have two internal charge-pumps that convert +5V to ±10V (unloaded) for RS-232 driver operation. The first converter uses capacitor C1 to double the +5V input to +10V on C3 at the V+ output. The second converter uses capacitor C2 to invert +10V to -10V on C4 at the V- output.

A small amount of power may be drawn from the +10V (V+) and -10V (V-) outputs to power external circuitry (see the *Typical Operating Characteristics* section), except on the MAX225 and MAX245–MAX247, where these pins are not available. V+ and V- are not regulated, so the output voltage drops with increasing load current. Do not load V+ and V- to a point that violates the minimum ±5V EIA/TIA-232E driver output voltage when sourcing current from V+ and V- to external circuitry.

When using the shutdown feature in the MAX222, MAX225, MAX230, MAX235, MAX236, MAX240, MAX241, and MAX245–MAX249, avoid using V+ and V- to power external circuitry. When these parts are shut down, V- falls to 0V, and V+ falls to +5V. For applications where a +10V external supply is applied to the V+ pin (instead of using the internal charge pump to generate +10V), the C1 capacitor must not be installed and the $\overline{SHDN}$ pin must be tied to V_{CC}. This is because V+ is internally connected to V_{CC} in shutdown mode.

RS-232 Drivers

The typical driver output voltage swing is ±8V when loaded with a nominal 5kΩ RS-232 receiver and V_{CC} = +5V. Output swing is guaranteed to meet the EIA/TIA-232E and V.28 specification, which calls for ±5V minimum driver output levels under worst-case conditions. These include a minimum 3kΩ load, V_{CC} = +4.5V, and maximum operating temperature. Unloaded driver output voltage ranges from (V+ -1.3V) to (V- +0.5V).

Input thresholds are both TTL and CMOS compatible. The inputs of unused drivers can be left unconnected since 400kΩ input pull-up resistors to V_{CC} are built in (except for the MAX220). The pull-up resistors force the outputs of unused drivers low because all drivers invert. The internal input pull-up resistors typically source 12µA, except in shutdown mode where the pull-ups are disabled. Driver outputs turn off and enter a high-impedance state—where leakage current is typically microamperes (maximum 25µA)—when in shutdown mode, in three-state mode, or when device power is removed. Outputs can be driven to ±15V. The power-supply current typically drops to 8µA in shutdown mode. The MAX220 does not have pull-up resistors to force the ouputs of the unused drivers low. Connect unused inputs to GND or V_{CC}.

The MAX239 has a receiver three-state control line, and the MAX223, MAX225, MAX235, MAX236, MAX240, and MAX241 have both a receiver three-state control line and a low-power shutdown control. Table 2 shows the effects of the shutdown control and receiver three-state control on the receiver outputs.

The receiver TTL/CMOS outputs are in a high-impedance, three-state mode whenever the three-state enable line is high (for the MAX225/MAX235/MAX236/MAX239–MAX241), and are also high-impedance whenever the shutdown control line is high.

When in low-power shutdown mode, the driver outputs are turned off and their leakage current is less than 1µA with the driver output pulled to ground. The driver output leakage remains less than 1µA, even if the transmitter output is backdriven between 0V and (V_{CC} + 6V). Below -0.5V, the transmitter is diode clamped to ground with 1kΩ series impedance. The transmitter is also zener clamped to approximately V_{CC} + 6V, with a series impedance of 1kΩ.

The driver output slew rate is limited to less than 30V/µs as required by the EIA/TIA-232E and V.28 specifications. Typical slew rates are 24V/µs unloaded and 10V/µs loaded with 3Ω and 2500pF.

RS-232 Receivers

EIA/TIA-232E and V.28 specifications define a voltage level greater than 3V as a logic 0, so all receivers invert. Input thresholds are set at 0.8V and 2.4V, so receivers respond to TTL level inputs as well as EIA/TIA-232E and V.28 levels.

The receiver inputs withstand an input overvoltage up to ±25V and provide input terminating resistors with

Table 2. Three-State Control of Receivers

PART	SHDN	$\overline{SHDN}$	EN	$\overline{EN(R)}$	RECEIVERS
MAX223	—	Low High High	X Low High	—	High Impedance Active High Impedance
MAX225	—	—	—	Low High	High Impedance Active
MAX235 MAX236 MAX240	Low Low High	—	—	Low High X	High Impedance Active High Impedance

nominal 5kΩ values. The receivers implement Type 1 interpretation of the fault conditions of V.28 and EIA/TIA-232E.

The receiver input hysteresis is typically 0.5V with a guaranteed minimum of 0.2V. This produces clear output transitions with slow-moving input signals, even with moderate amounts of noise and ringing. The receiver propagation delay is typically 600ns and is independent of input swing direction.

Low-Power Receive Mode

The low-power receive-mode feature of the MAX223, MAX242, and MAX245–MAX249 puts the IC into shutdown mode but still allows it to receive information. This is important for applications where systems are periodically awakened to look for activity. Using low-power receive mode, the system can still receive a signal that will activate it on command and prepare it for communication at faster data rates. This operation conserves system power.

Negative Threshold—MAX243

The MAX243 is pin compatible with the MAX232A, differing only in that RS-232 cable fault protection is removed on one of the two receiver inputs. This means that control lines such as CTS and RTS can either be driven or left floating without interrupting communication. Different cables are not needed to interface with different pieces of equipment.

The input threshold of the receiver without cable fault protection is -0.8V rather than +1.4V. Its output goes positive only if the input is connected to a control line that is actively driven negative. If not driven, it defaults to the 0 or “OK to send” state. Normally, the MAX243’s other receiver (+1.4V threshold) is used for the data line (TD or RD), while the negative threshold receiver is connected to the control line (DTR, DTS, CTS, RTS, etc.).

Other members of the RS-232 family implement the optional cable fault protection as specified by EIA/TIA-232E specifications. This means a receiver output goes high whenever its input is driven negative, left floating, or shorted to ground. The high output tells the serial communications IC to stop sending data. To avoid this, the control lines must either be driven or connected with jumpers to an appropriate positive voltage level.

Shutdown—MAX222–MAX242

On the MAX222, MAX235, MAX236, MAX240, and MAX241, all receivers are disabled during shutdown. On the MAX223 and MAX242, two receivers continue to operate in a reduced power mode when the chip is in shutdown. Under these conditions, the propagation delay increases to about 2.5μs for a high-to-low input transition. When in shutdown, the receiver acts as a CMOS inverter with no hysteresis. The MAX223 and MAX242 also have a receiver output enable input ($\overline{EN}$ for the MAX242 and EN for the MAX223) that allows receiver output control independent of $\overline{SHDN}$ (SHDN for MAX241). With all other devices, $\overline{SHDN}$ (SHDN for MAX241) also disables the receiver outputs.

The MAX225 provides five transmitters and five receivers, while the MAX245 provides ten receivers and eight transmitters. Both devices have separate receiver and transmitter-enable controls. The charge pumps turn off and the devices shut down when a logic high is applied to the ENT input. In this state, the supply current drops to less than 25μA and the receivers continue to operate in a low-power receive mode. Driver outputs enter a high-impedance state (three-state mode). On the MAX225, all five receivers are controlled by the $\overline{ENR}$ input. On the MAX245, eight of the receiver outputs are controlled by the $\overline{ENR}$ input, while the remaining two receivers (RA5 and RB5) are always active. RA1–RA4 and RB1–RB4 are put in a three-state mode when $\overline{ENR}$ is a logic high.

Receiver and Transmitter Enable Control Inputs

The MAX225 and MAX245–MAX249 feature transmitter and receiver enable controls.

The receivers have three modes of operation: full-speed receive (normal active), three-state (disabled), and low-power receive (enabled receivers continue to function at lower data rates). The receiver enable inputs control the full-speed receive and three-state modes. The transmitters have two modes of operation: full-speed transmit (normal active) and three-state (disabled). The transmitter enable inputs also control the shutdown mode. The device enters shutdown mode when all transmitters are disabled. Enabled receivers function in the low-power receive mode when in shutdown.

Tables 1a–1d define the control states. The MAX244 has no control pins and is not included in these tables.

The MAX246 has ten receivers and eight drivers with two control pins, each controlling one side of the device. A logic high at the A-side control input ($\overline{ENA}$) causes the four A-side receivers and drivers to go into a three-state mode. Similarly, the B-side control input ($\overline{ENB}$) causes the four B-side drivers and receivers to go into a three-state mode. As in the MAX245, one A-side and one B-side receiver (RA5 and RB5) remain active at all times. The entire device is put into shutdown mode when both the A and B sides are disabled ($\overline{ENA}$ = $\overline{ENB}$ = +5V).

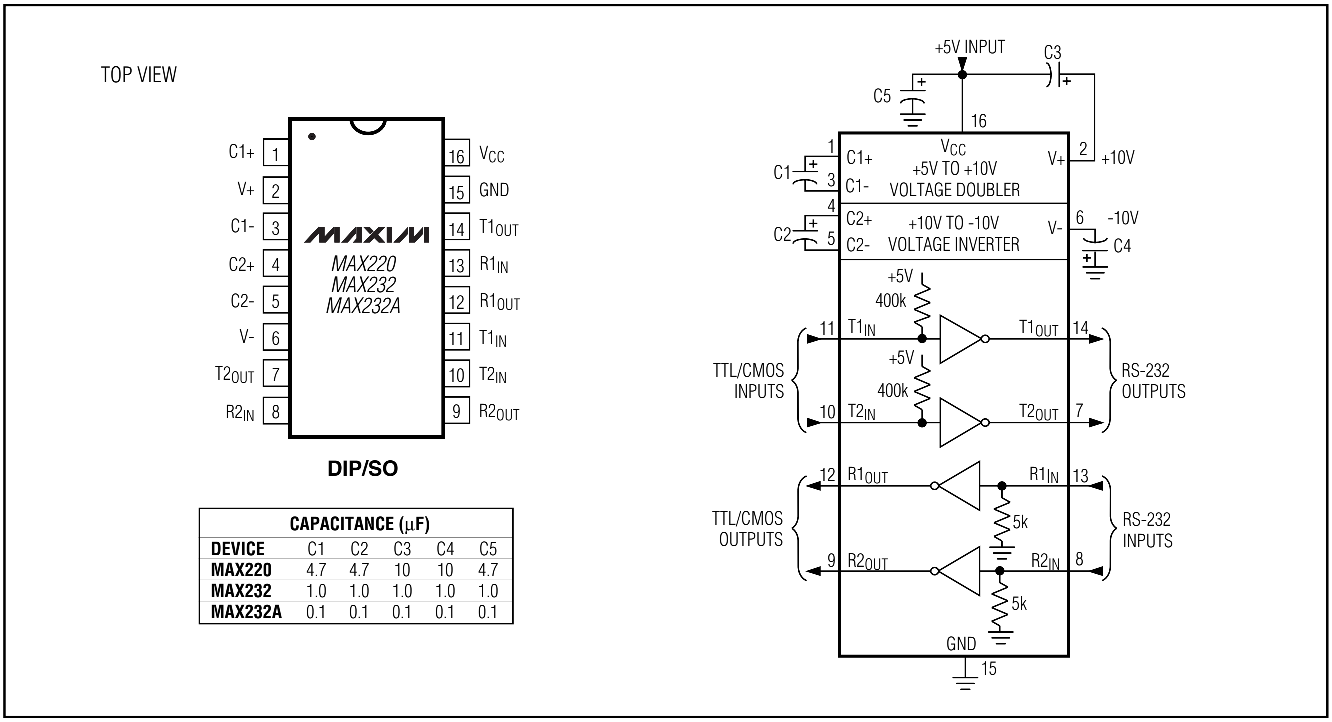
The MAX247 provides nine receivers and eight drivers with four control pins. The $\overline{ENRA}$ and $\overline{ENRB}$ receiver enable inputs each control four receiver outputs. The $\overline{ENTA}$ and $\overline{ENTB}$ transmitter enable inputs each control four drivers. The ninth receiver (RB5) is always active. The device enters shutdown mode with a logic high on both $\overline{ENTA}$ and $\overline{ENTB}$.

The MAX248 provides eight receivers and eight drivers with four control pins. The $\overline{ENRA}$ and $\overline{ENRB}$ receiver enable inputs each control four receiver outputs. The $\overline{ENTA}$ and $\overline{ENTB}$ transmitter enable inputs control four drivers each. This part does not have an always-active receiver. The device enters shutdown mode and transmitters go into a three-state mode with a logic high on both $\overline{ENTA}$ and $\overline{ENTB}$.

The MAX249 provides ten receivers and six drivers with four control pins. The $\overline{ENRA}$ and $\overline{ENRB}$ receiver enable inputs each control five receiver outputs. The $\overline{ENTA}$ and $\overline{ENTB}$ transmitter enable inputs control three drivers each. There is no always-active receiver. The device enters shutdown mode and transmitters go into a three-state mode with a logic high on both $\overline{ENTA}$ and $\overline{ENTB}$. In shutdown mode, active receivers operate in a low-power receive mode at data rates up to 20kbits/sec.

Applications Information

Figures 5 through 25 show pin configurations and typical operating circuits. In applications that are sensitive to power-supply noise, V_{CC} should be decoupled to ground with a capacitor of the same value as C1 and C2 connected as close as possible to the device.



CAPACITANCE (μF)					
DEVICE	C1	C2	C3	C4	C5
MAX220	4.7	4.7	10	10	4.7
MAX232	1.0	1.0	1.0	1.0	1.0
MAX232A	0.1	0.1	0.1	0.1	0.1

Figure 5. MAX220/MAX232/MAX232A Pin Configuration and Typical Operating Circuit

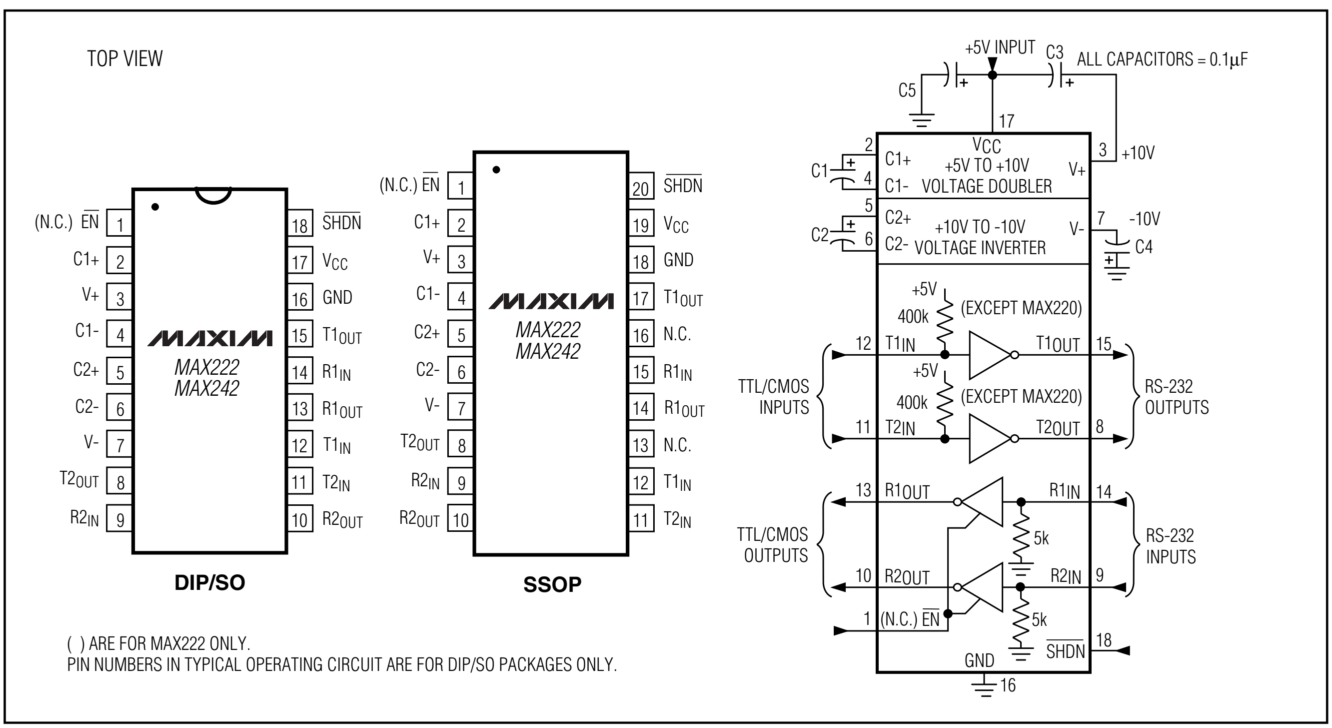


Figure 6. MAX222/MAX242 Pin Configurations and Typical Operating Circuit

+5V-Powered, Multichannel RS-232 Drivers/Receivers

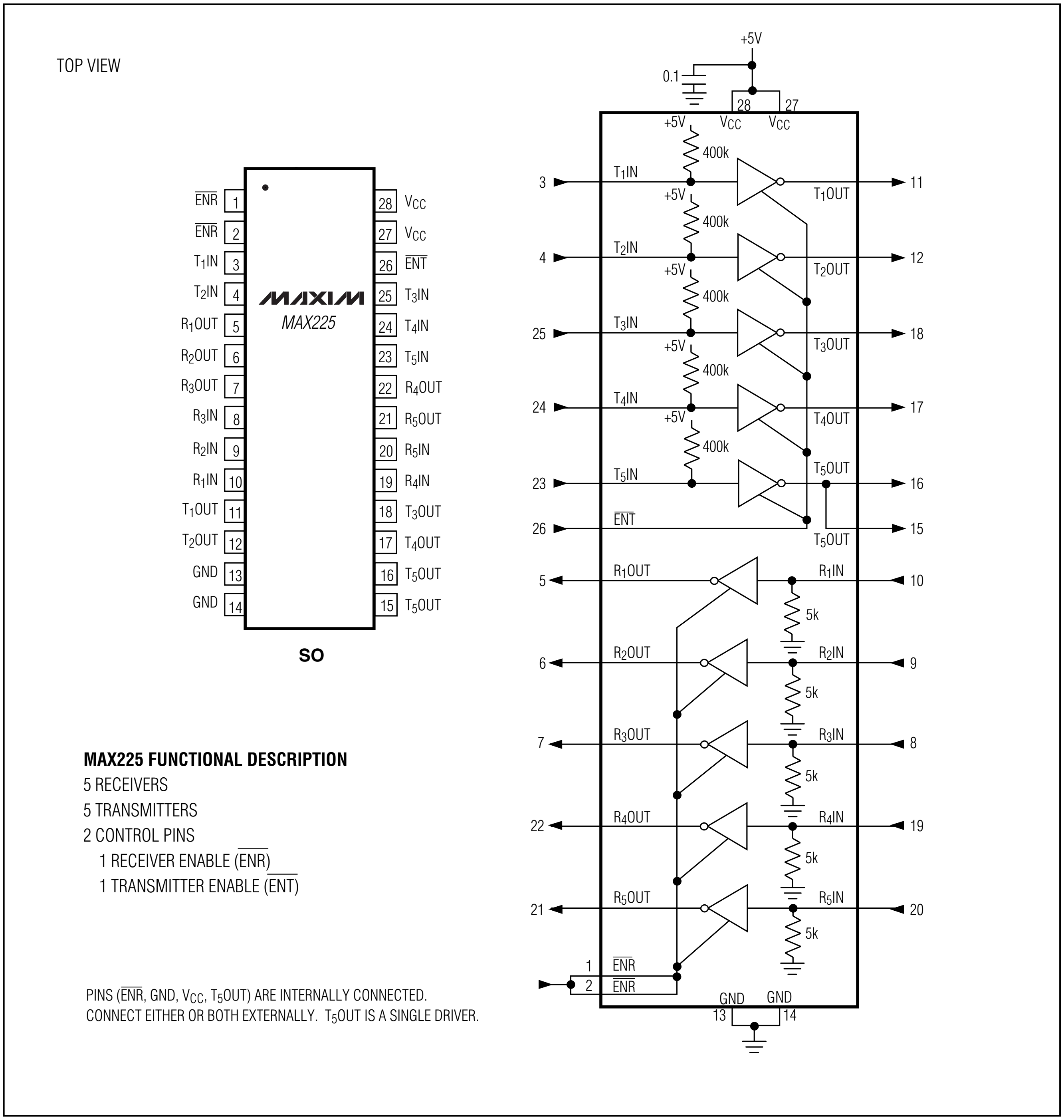


Figure 7. MAX225 Pin Configuration and Typical Operating Circuit

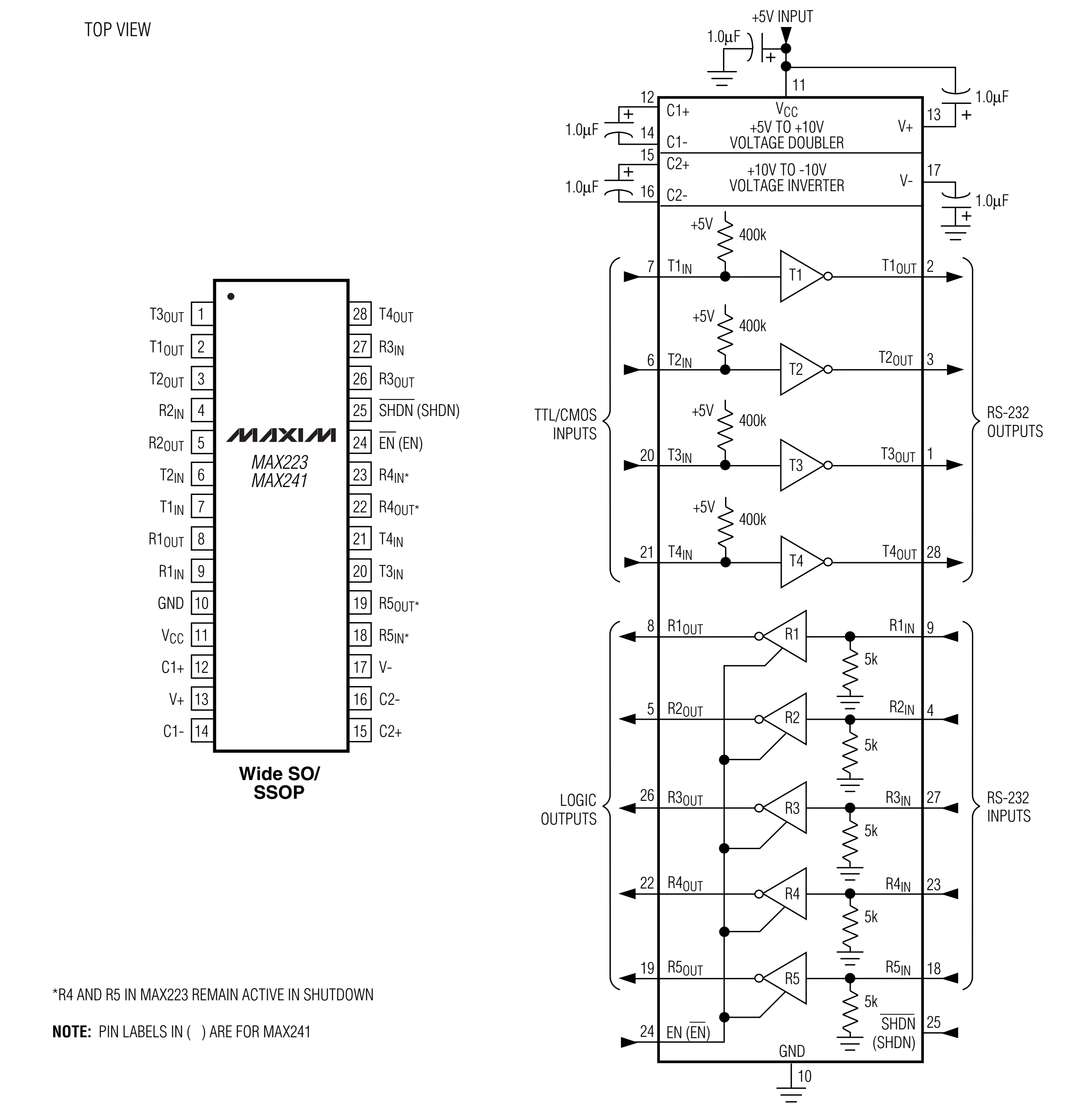


Figure 8. MAX223/MAX241 Pin Configuration and Typical Operating Circuit

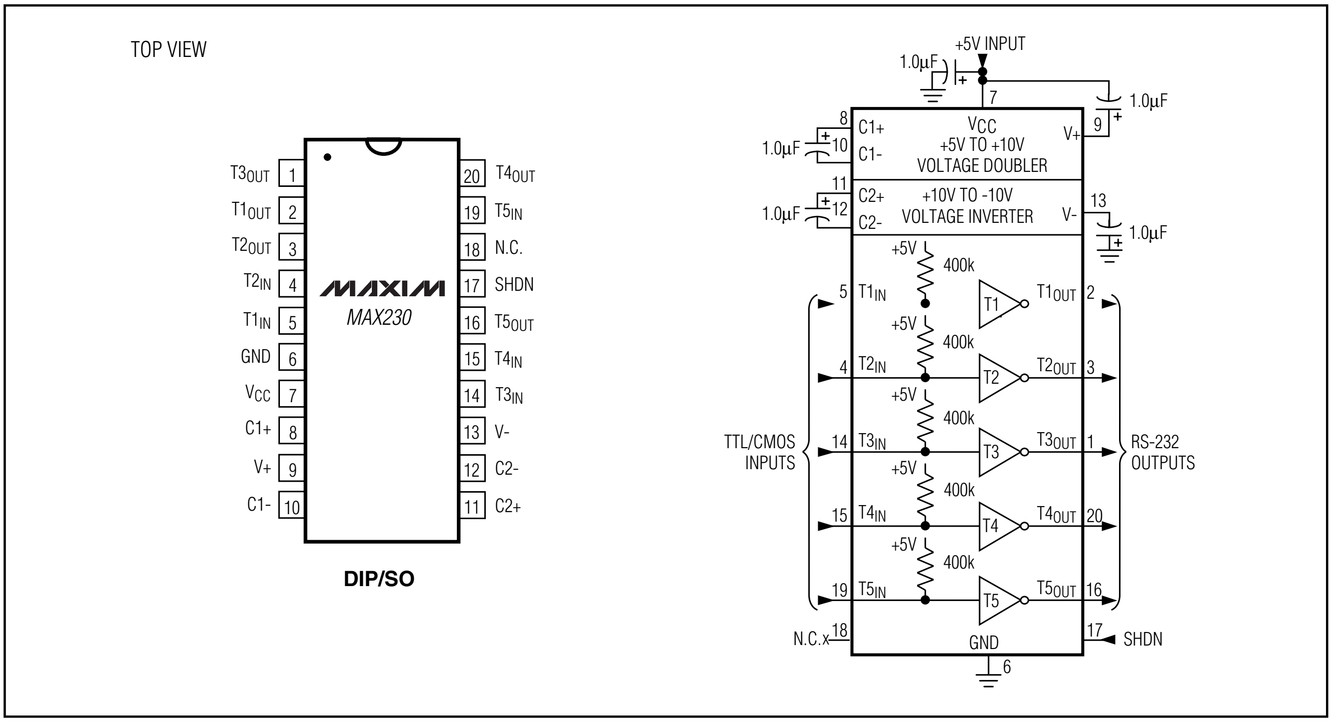


Figure 9. MAX230 Pin Configuration and Typical Operating Circuit

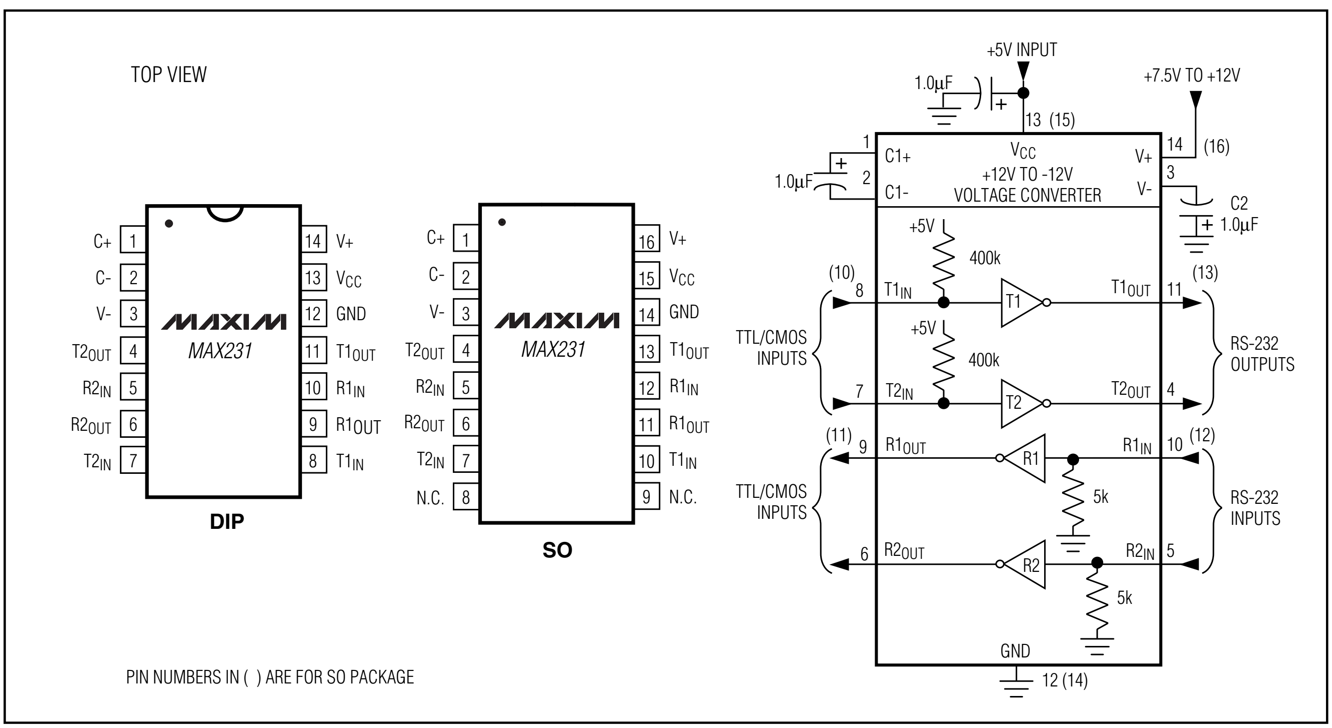


Figure 10. MAX231 Pin Configurations and Typical Operating Circuit

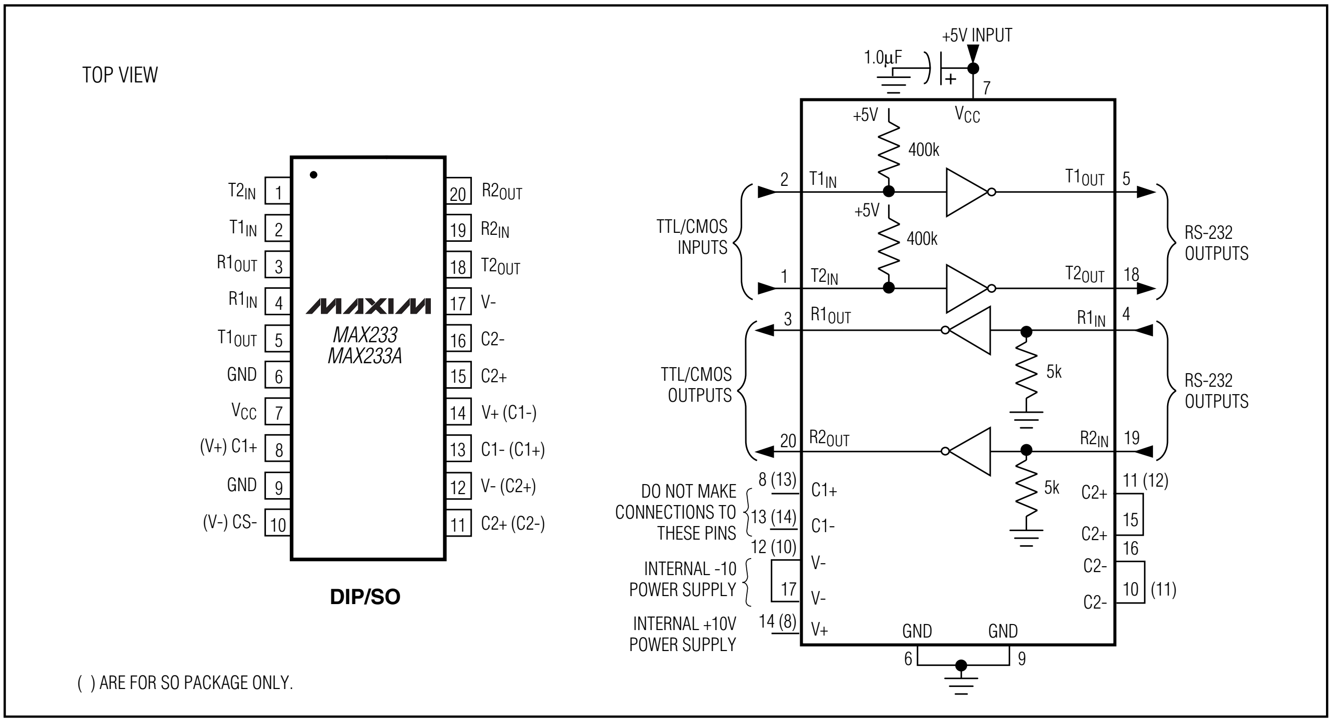


Figure 11. MAX233/MAX233A Pin Configuration and Typical Operating Circuit

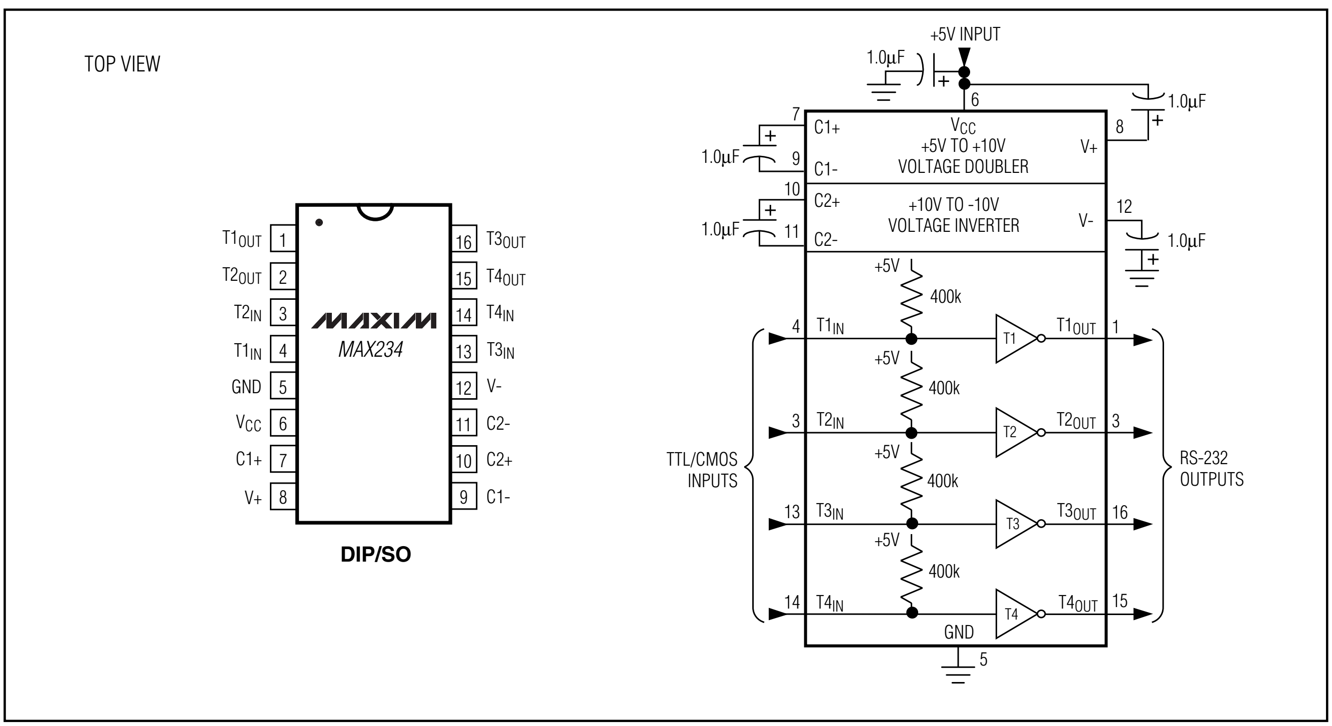


Figure 12. MAX234 Pin Configuration and Typical Operating Circuit

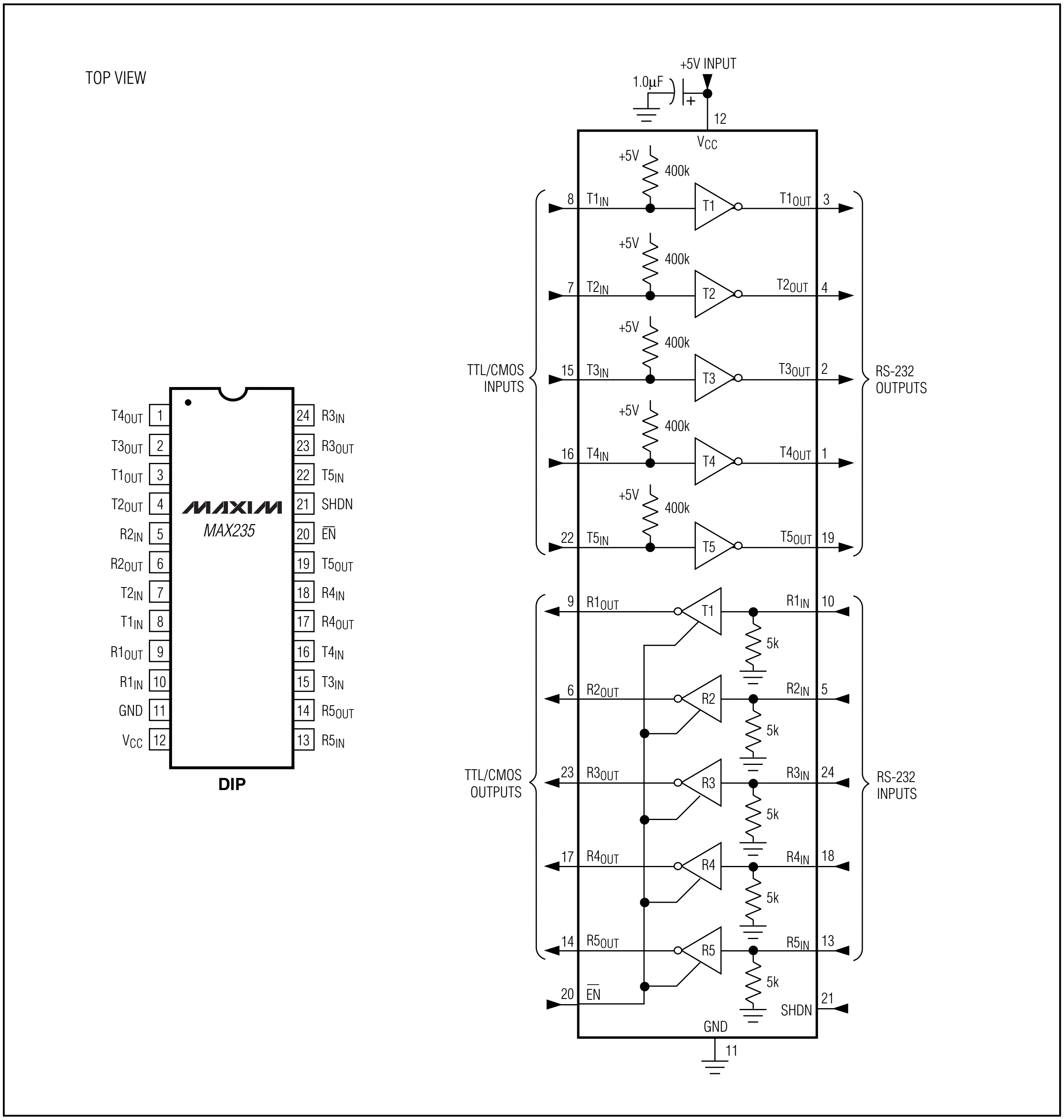


Figure 13. MAX235 Pin Configuration and Typical Operating Circuit

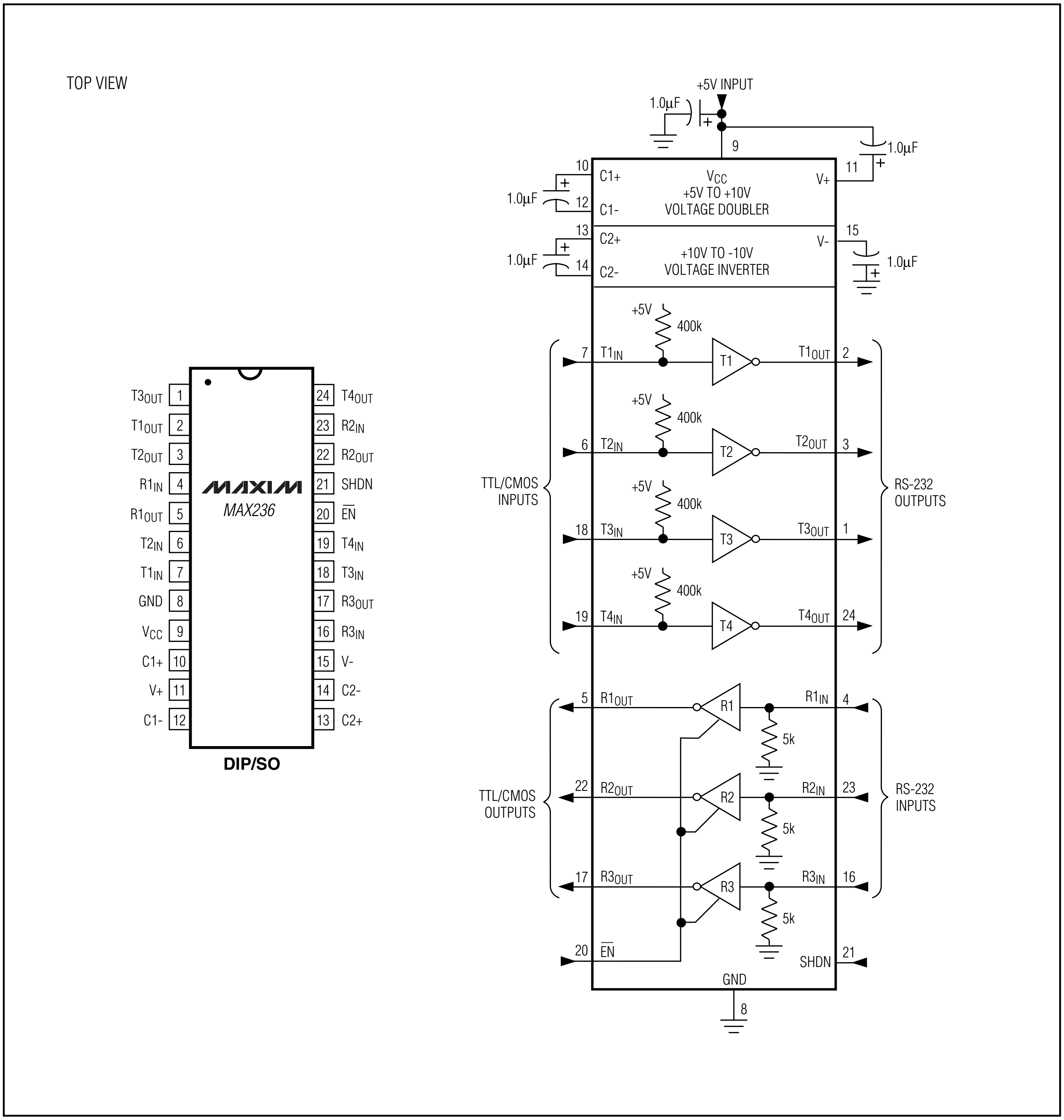


Figure 14. MAX236 Pin Configuration and Typical Operating Circuit

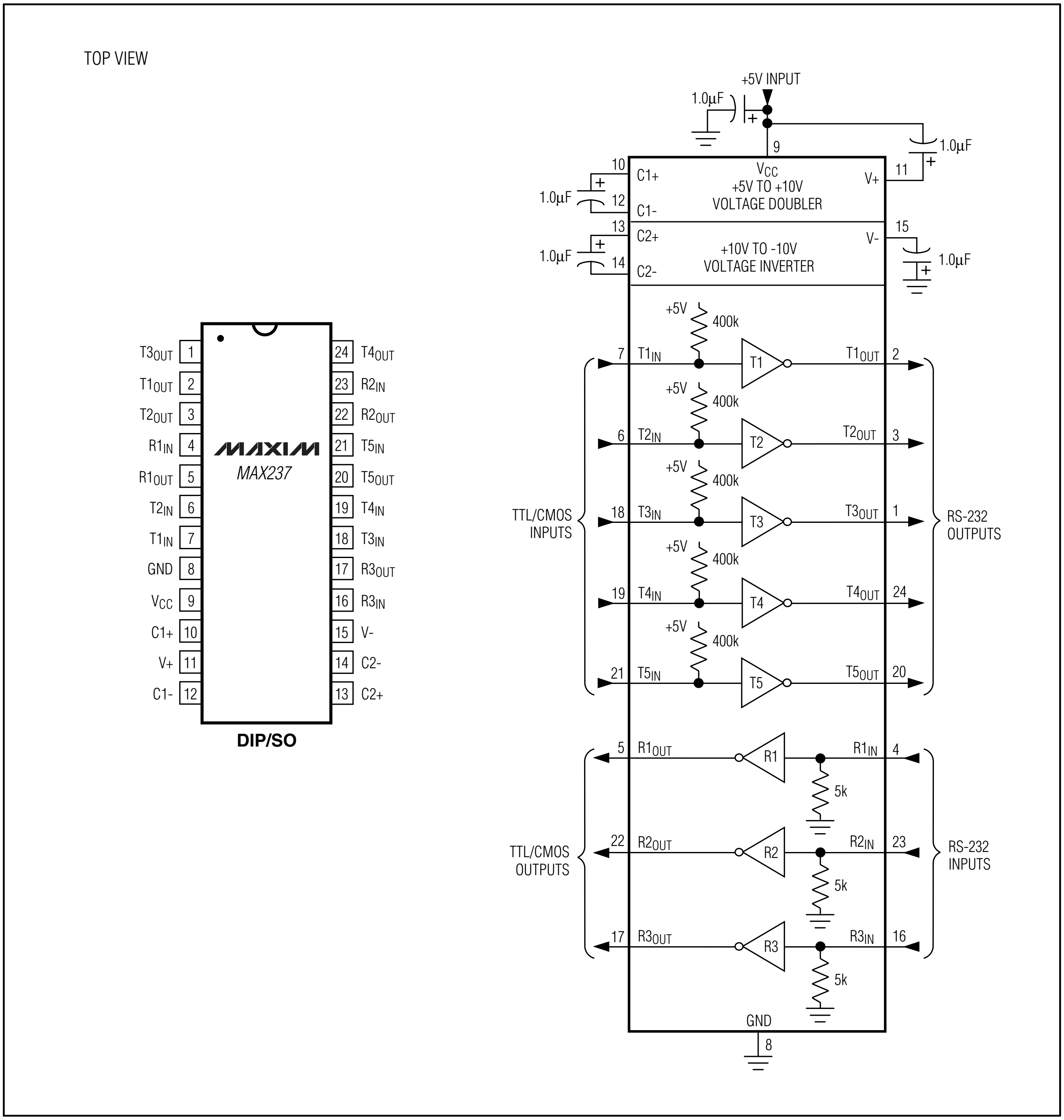


Figure 15. MAX237 Pin Configuration and Typical Operating Circuit

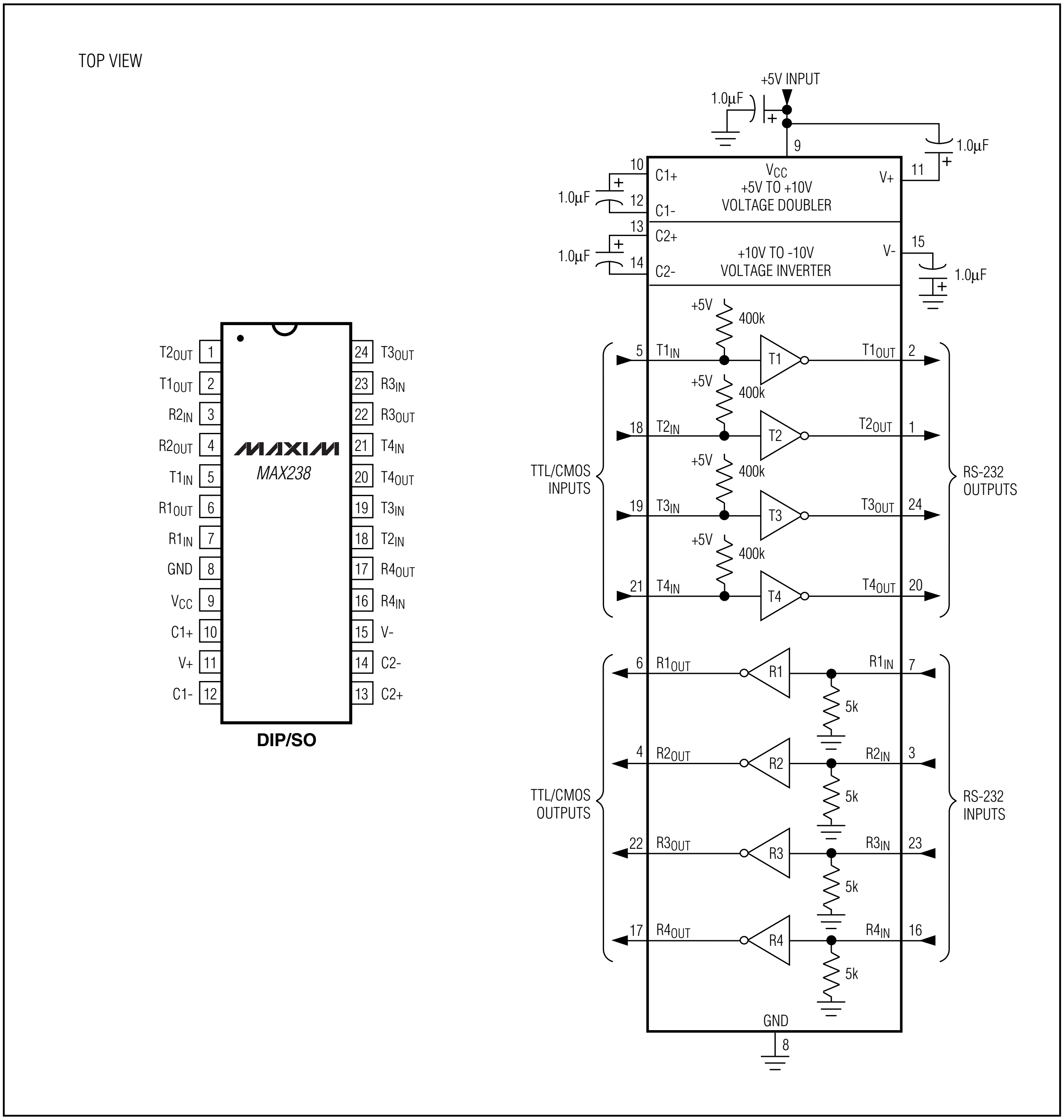


Figure 16. MAX238 Pin Configuration and Typical Operating Circuit

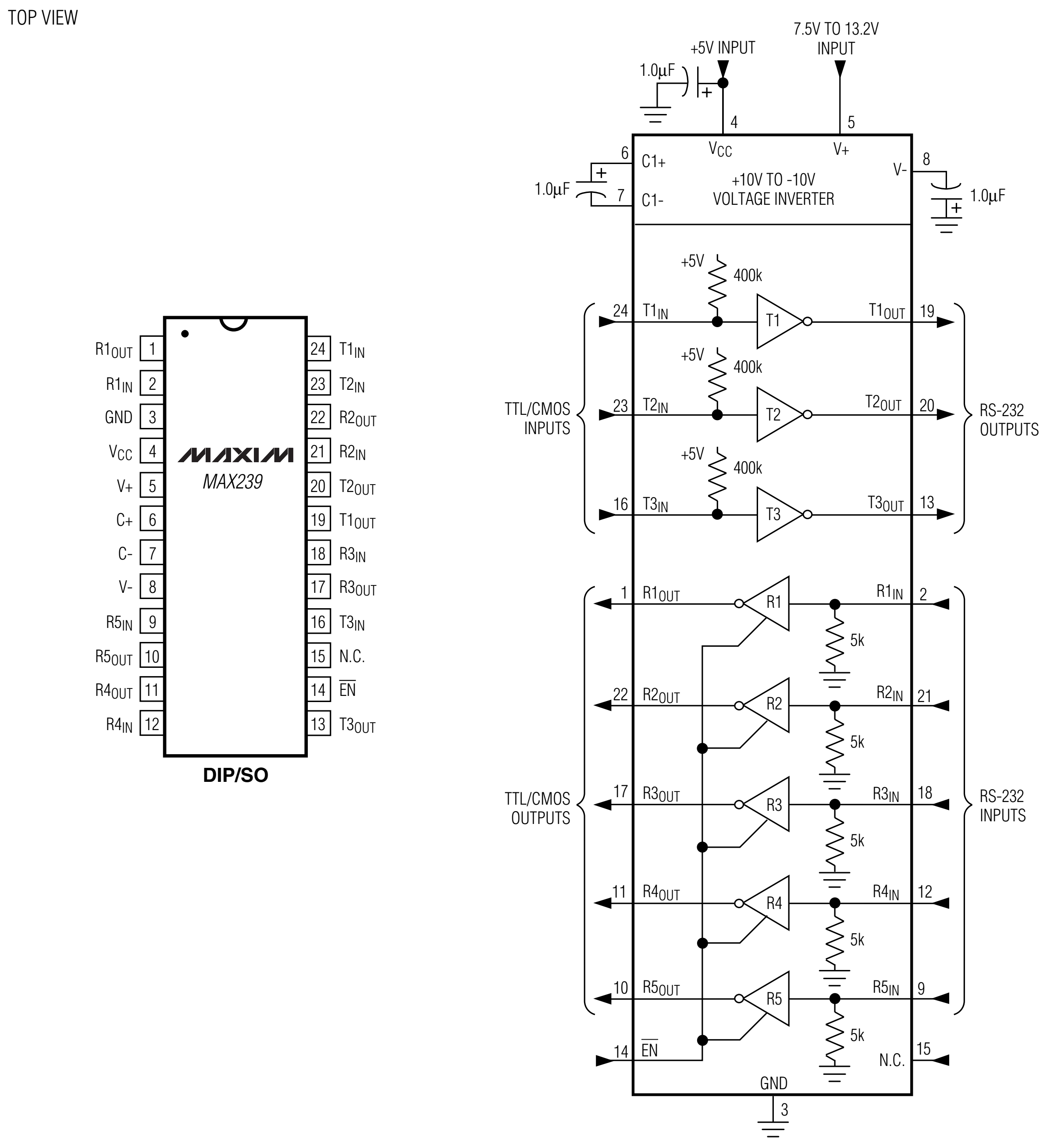


Figure 17. MAX239 Pin Configuration and Typical Operating Circuit

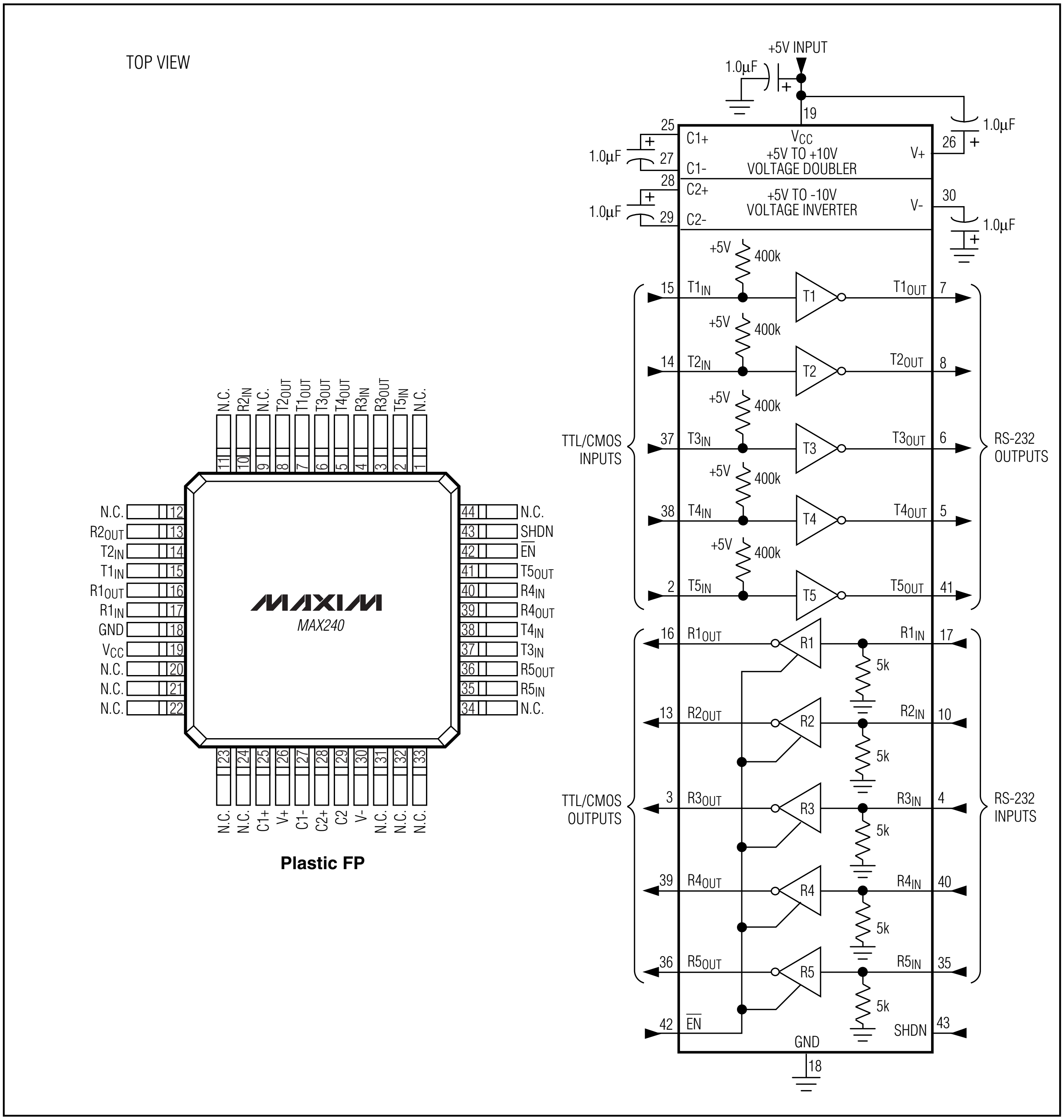
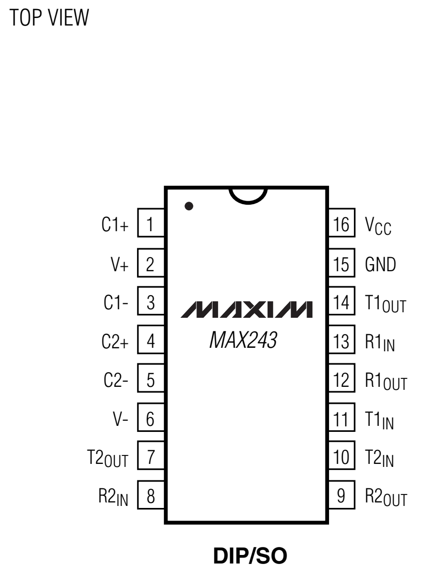
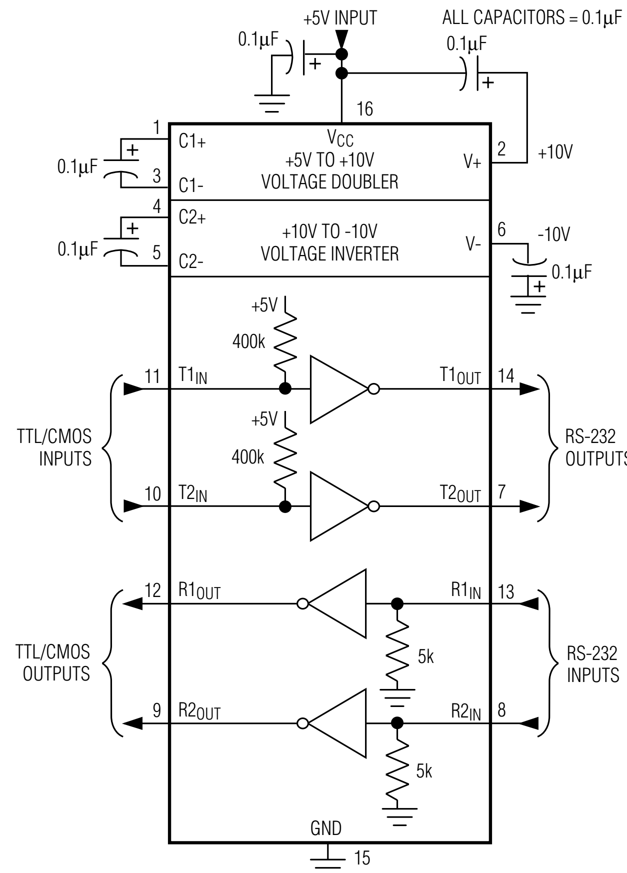


Figure 18. MAX240 Pin Configuration and Typical Operating Circuit

+5V-Powered, Multichannel RS-232 Drivers/Receivers





RECEIVER INPUT	R1 OUTPUT	R2 OUTPUT
≤ -3 V	HIGH	HIGH
OPEN	HIGH	LOW
≥ +3V	LOW	LOW

Figure 19. MAX243 Pin Configuration and Typical Operating Circuit

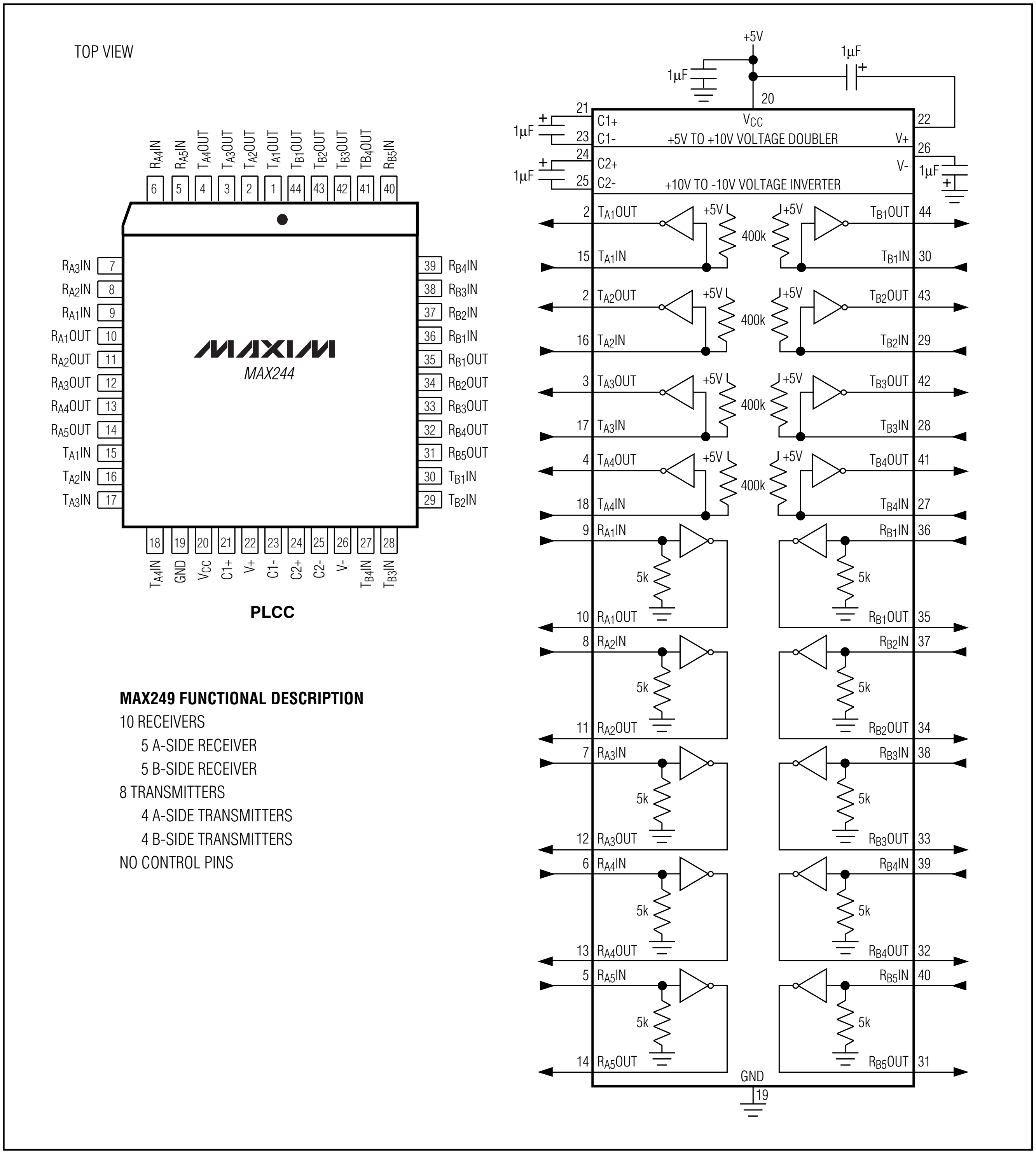
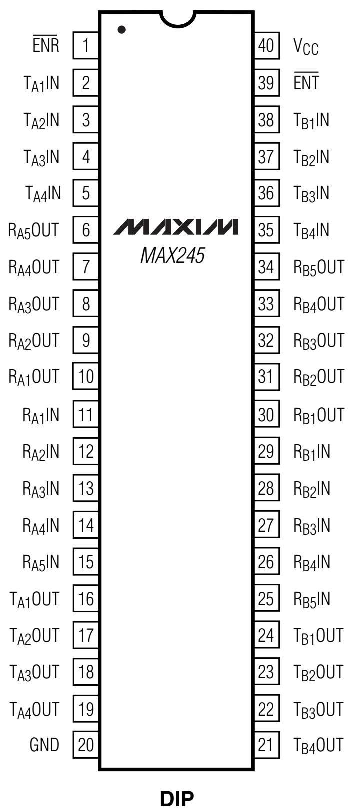
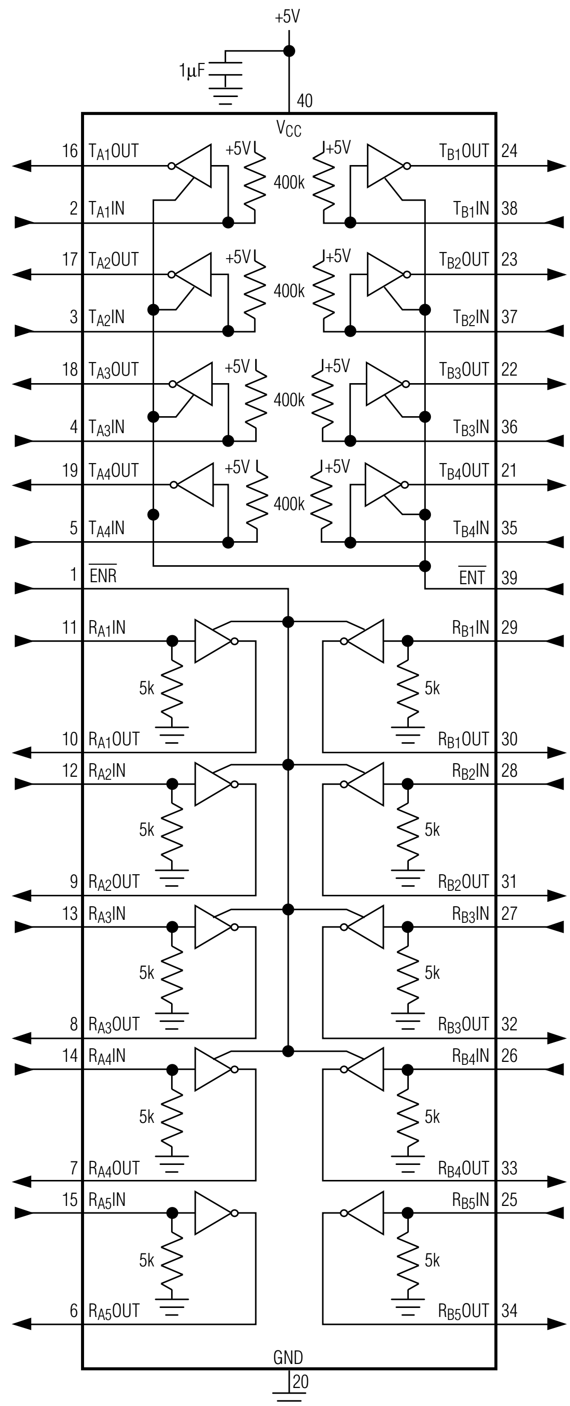


Figure 20. MAX244 Pin Configuration and Typical Operating Circuit

TOP VIEW





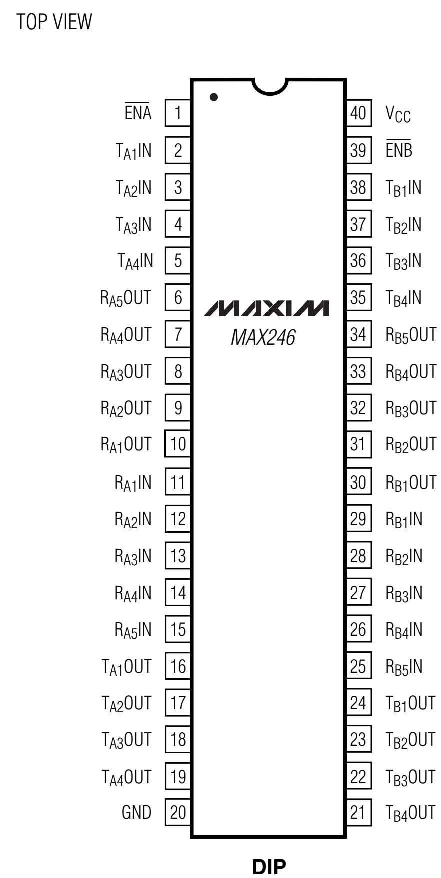
MAX245 FUNCTIONAL DESCRIPTION

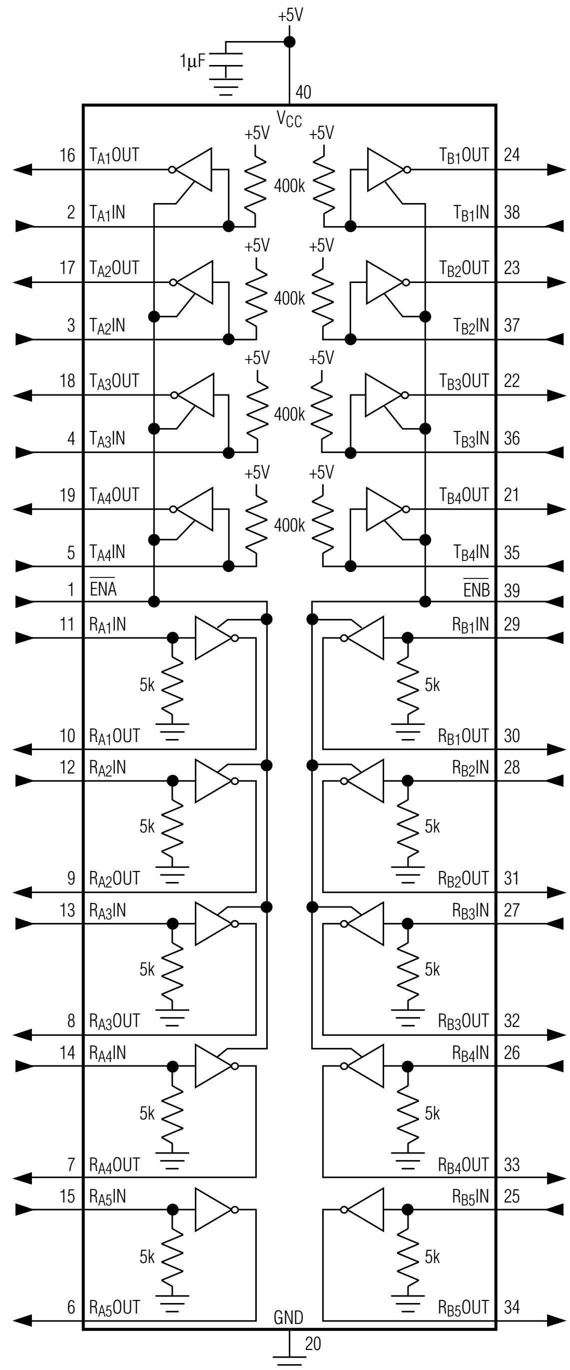
10 RECEIVERS
- 5 A-SIDE RECEIVERS (RA5 ALWAYS ACTIVE)
- 5 B-SIDE RECEIVERS (RB5 ALWAYS ACTIVE)

8 TRANSMITTTERS
- 4 A-SIDE TRANSMITTERS

2 CONTROL PINS
- 1 RECEIVER ENABLE (ENR)
- 1 TRANSMITTER ENABLE (ENT)

Figure 21. MAX245 Pin Configuration and Typical Operating Circuit





MAX246 FUNCTIONAL DESCRIPTION

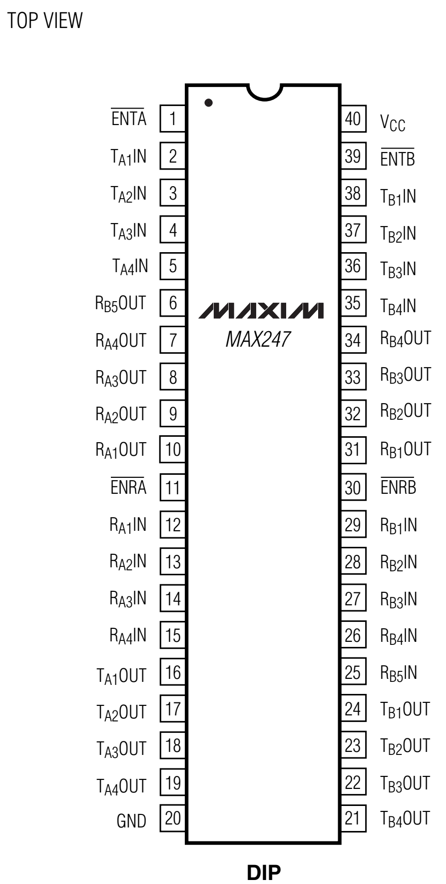
10 RECEIVERS
- 5 A-SIDE RECEIVERS (R_{A5} ALWAYS ACTIVE)
- 5 B-SIDE RECEIVERS (R_{B5} ALWAYS ACTIVE)

8 TRANSMITTERS
- 4 A-SIDE TRANSMITTERS
- 4 B-SIDE TRANSMITTERS

2 CONTROL PINS
- ENABLE A-SIDE ($\overline{ENA}$)
- ENABLE B-SIDE ($\overline{ENB}$)

Figure 22. MAX246 Pin Configuration and Typical Operating Circuit

+5V-Powered, Multichannel RS-232 Drivers/Receivers



MAX247 FUNCTIONAL DESCRIPTION

9 RECEIVERS
- 4 A-SIDE RECEIVERS
- 5 B-SIDE RECEIVERS (R_{B5} ALWAYS ACTIVE)

8 TRANSMITTERS
- 4 A-SIDE TRANSMITTERS
- 4 B-SIDE TRANSMITTERS

4 CONTROL PINS
- ENABLE RECEIVER A-SIDE (ENRA)
- ENABLE RECEIVER B-SIDE (ENRB)
- ENABLE RECEIVER A-SIDE (ENTA)
- ENABLE RECEIVERr B-SIDE (ENTB)

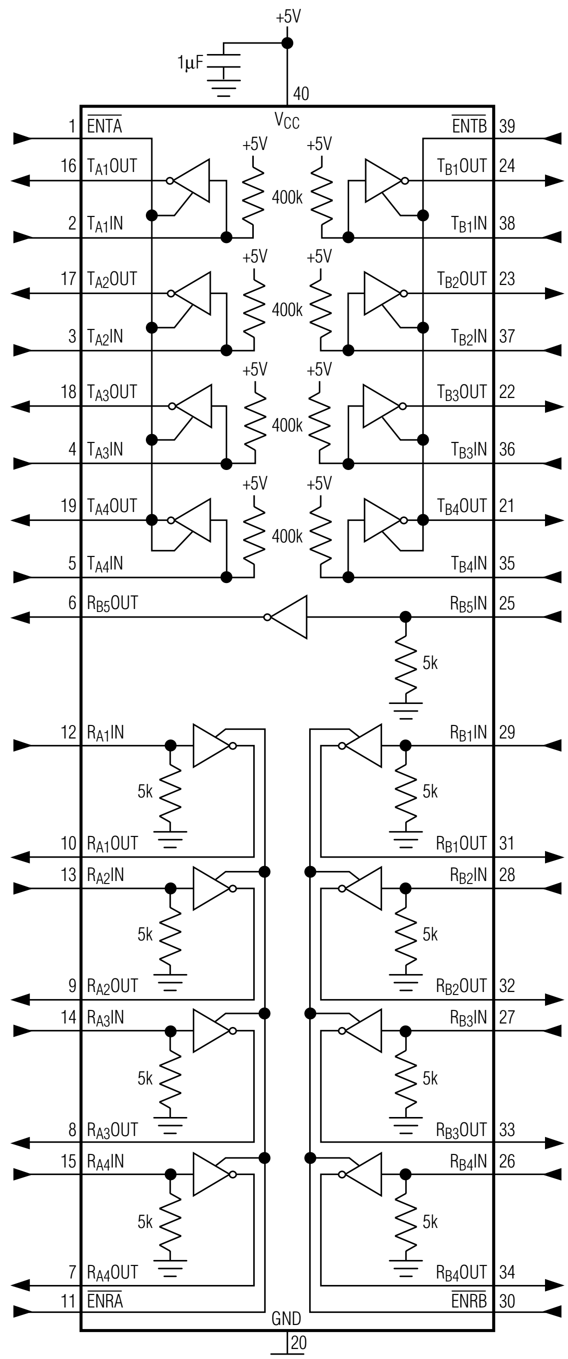
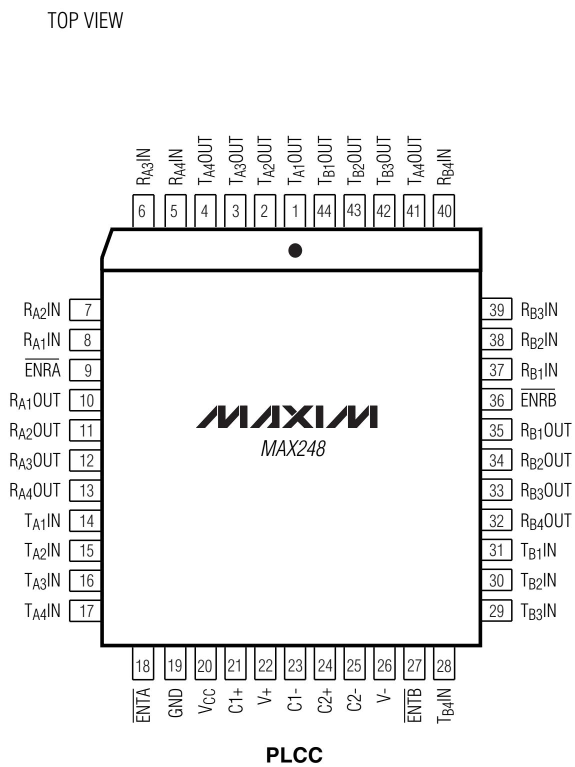
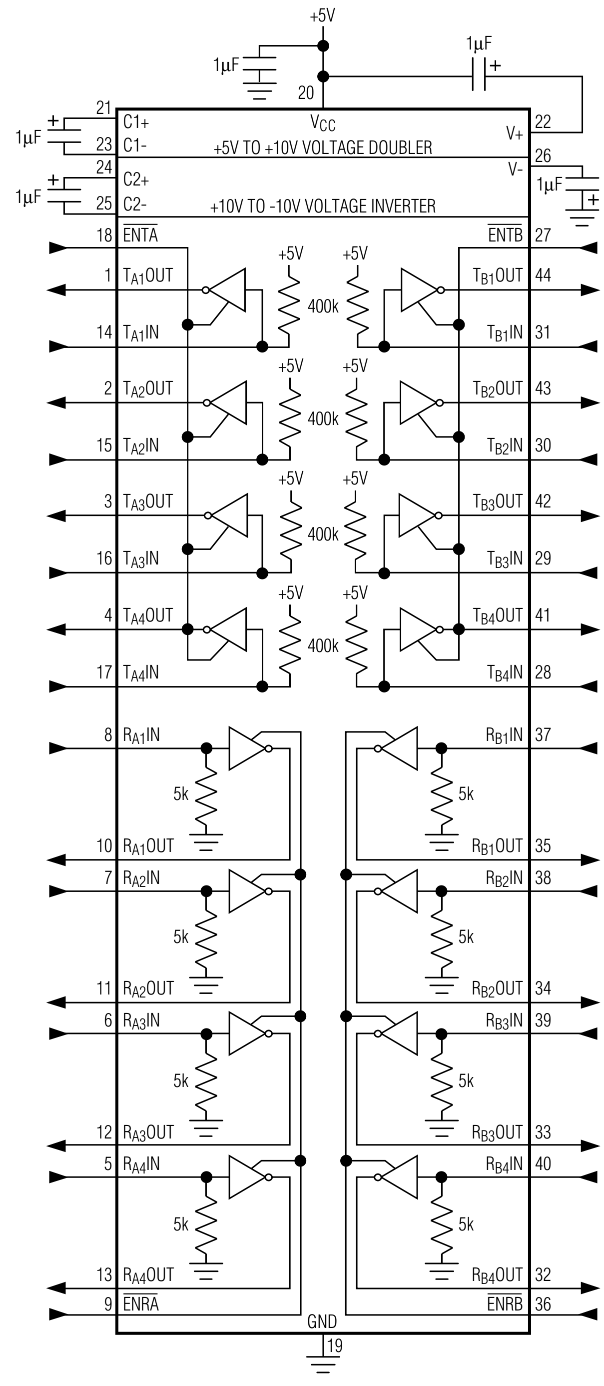


Figure 23. MAX247 Pin Configuration and Typical Operating Circuit





MAX248 FUNCTIONAL DESCRIPTION

8 RECEIVERS
- 4 A-SIDE RECEIVERS
- 4 B-SIDE RECEIVERS

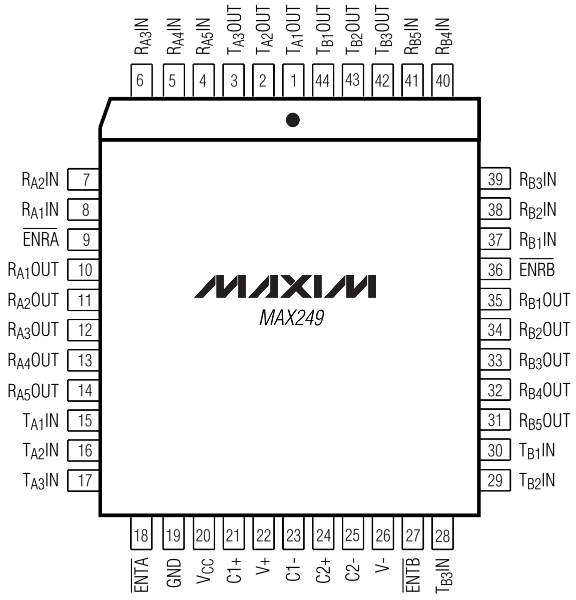
8 TRANSMITTERS
- 4 A-SIDE TRANSMITTERS
- 4 B-SIDE TRANSMITTERS

4 CONTROL PINS
- ENABLE RECEIVER A-SIDE (ENRA)
- ENABLE RECEIVER B-SIDE (ENRB)
- ENABLE RECEIVER A-SIDE (ENTA)
- ENABLE RECEIVER B-SIDE (ENTB)

Figure 24. MAX248 Pin Configuration and Typical Operating Circuit

+5V-Powered, Multichannel RS-232 Drivers/Receivers

TOP VIEW



MAX249 FUNCTIONAL DESCRIPTION

10 RECEIVERS
- 5 A-SIDE RECEIVERS
- 5 B-SIDE RECEIVERS

6 TRANSMITTERS
- 3 A-SIDE TRANSMITTERS
- 3 B-SIDE TRANSMITTERS

4 CONTROL PINS
- ENABLE RECEIVER A-SIDE (ENRA)
- ENABLE RECEIVER B-SIDE (ENRB)
- ENABLE RECEIVER A-SIDE (ENTA)
- ENABLE RECEIVER B-SIDE (ENTB)

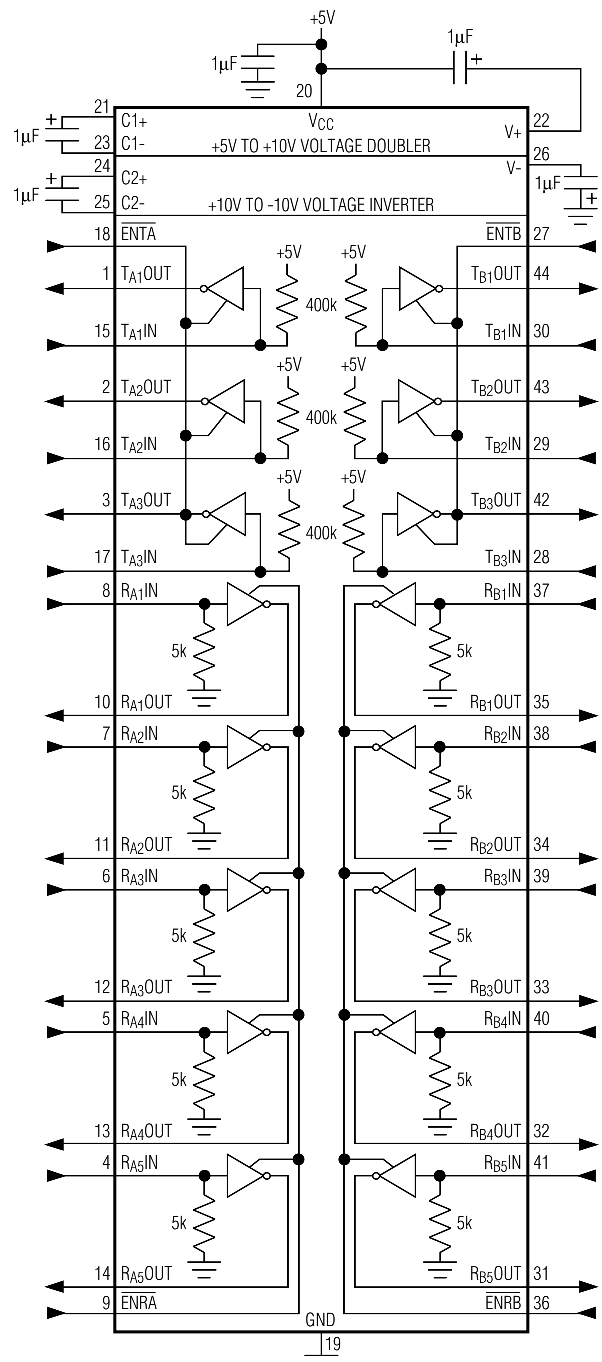


Figure 25. MAX249 Pin Configuration and Typical Operating Circuit

Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX222CPN	0°C to +70°C	18 Plastic DIP
MAX222CWN	0°C to +70°C	18 Wide SO
MAX222C/D	0°C to +70°C	Dice*
MAX222EPN	-40°C to +85°C	18 Plastic DIP
MAX222EWN	-40°C to +85°C	18 Wide SO
MAX222EJN	-40°C to +85°C	18 CERDIP
MAX222MJN	-55°C to +125°C	18 CERDIP
MAX223CAI	0°C to +70°C	28 SSOP
MAX223CWI	0°C to +70°C	28 Wide SO
MAX223C/D	0°C to +70°C	Dice*
MAX223EAI	-40°C to +85°C	28 SSOP
MAX223EWI	-40°C to +85°C	28 Wide SO
MAX225CWI	0°C to +70°C	28 Wide SO
MAX225EWI	-40°C to +85°C	28 Wide SO
MAX230CPP	0°C to +70°C	20 Plastic DIP
MAX230CWP	0°C to +70°C	20 Wide SO
MAX230C/D	0°C to +70°C	Dice*
MAX230EPP	-40°C to +85°C	20 Plastic DIP
MAX230EWP	-40°C to +85°C	20 Wide SO
MAX230EJP	-40°C to +85°C	20 CERDIP
MAX230MJP	-55°C to +125°C	20 CERDIP
MAX231CPD	0°C to +70°C	14 Plastic DIP
MAX231CWE	0°C to +70°C	16 Wide SO
MAX231CJD	0°C to +70°C	14 CERDIP
MAX231C/D	0°C to +70°C	Dice*
MAX231EPD	-40°C to +85°C	14 Plastic DIP
MAX231EWE	-40°C to +85°C	16 Wide SO
MAX231EJD	-40°C to +85°C	14 CERDIP
MAX231MJD	-55°C to +125°C	14 CERDIP
MAX232CPE	0°C to +70°C	16 Plastic DIP
MAX232CSE	0°C to +70°C	16 Narrow SO
MAX232CWE	0°C to +70°C	16 Wide SO
MAX232C/D	0°C to +70°C	Dice*
MAX232EPE	-40°C to +85°C	16 Plastic DIP
MAX232ESE	-40°C to +85°C	16 Narrow SO
MAX232EWE	-40°C to +85°C	16 Wide SO
MAX232EJE	-40°C to +85°C	16 CERDIP
MAX232MJE	-55°C to +125°C	16 CERDIP
MAX232MLP	-55°C to +125°C	20 LCC
MAX232ACPE	0°C to +70°C	16 Plastic DIP
MAX232ACSE	0°C to +70°C	16 Narrow SO
MAX232ACWE	0°C to +70°C	16 Wide SO

MAX232AC/D	0°C to +70°C	Dice*
MAX232AEPE	-40°C to +85°C	16 Plastic DIP
MAX232AESE	-40°C to +85°C	16 Narrow SO
MAX232AEWE	-40°C to +85°C	16 Wide SO
MAX232AEJE	-40°C to +85°C	16 CERDIP
MAX232AMJE	-55°C to +125°C	16 CERDIP
MAX232AMLP	-55°C to +125°C	20 LCC
MAX233CPP	0°C to +70°C	20 Plastic DIP
MAX233EPP	-40°C to +85°C	20 Plastic DIP
MAX233ACPP	0°C to +70°C	20 Plastic DIP
MAX233ACWP	0°C to +70°C	20 Wide SO
MAX233AEPP	-40°C to +85°C	20 Plastic DIP
MAX233AEWP	-40°C to +85°C	20 Wide SO
MAX234CPE	0°C to +70°C	16 Plastic DIP
MAX234CWE	0°C to +70°C	16 Wide SO
MAX234C/D	0°C to +70°C	Dice*
MAX234EPE	-40°C to +85°C	16 Plastic DIP
MAX234EWE	-40°C to +85°C	16 Wide SO
MAX234EJE	-40°C to +85°C	16 CERDIP
MAX234MJE	-55°C to +125°C	16 CERDIP
MAX235CPG	0°C to +70°C	24 Wide Plastic DIP
MAX235EPG	-40°C to +85°C	24 Wide Plastic DIP
MAX235EDG	-40°C to +85°C	24 Ceramic SB
MAX235MDG	-55°C to +125°C	24 Ceramic SB
MAX236CNG	0°C to +70°C	24 Narrow Plastic DIP
MAX236CWG	0°C to +70°C	24 Wide SO
MAX236C/D	0°C to +70°C	Dice*
MAX236ENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX236EWG	-40°C to +85°C	24 Wide SO
MAX236ERG	-40°C to +85°C	24 Narrow CERDIP
MAX236MRG	-55°C to +125°C	24 Narrow CERDIP
MAX237CNG	0°C to +70°C	24 Narrow Plastic DIP
MAX237CWG	0°C to +70°C	24 Wide SO
MAX237C/D	0°C to +70°C	Dice*
MAX237ENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX237EWG	-40°C to +85°C	24 Wide SO
MAX237ERG	-40°C to +85°C	24 Narrow CERDIP
MAX237MRG	-55°C to +125°C	24 Narrow CERDIP
MAX238CNG	0°C to +70°C	24 Narrow Plastic DIP
MAX238CWG	0°C to +70°C	24 Wide SO
MAX238C/D	0°C to +70°C	Dice*
MAX238ENG	-40°C to +85°C	24 Narrow Plastic DIP

** Contact factory for dice specifications.*

Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX238EWG	-40°C to +85°C	24 Wide SO
MAX238ERG	-40°C to +85°C	24 Narrow CERDIP
MAX238MRG	-55°C to +125°C	24 Narrow CERDIP
MAX239CNG	0°C to +70°C	24 Narrow Plastic DIP
MAX239CWG	0°C to +70°C	24 Wide SO
MAX239C/D	0°C to +70°C	Dice*
MAX239ENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX239EWG	-40°C to +85°C	24 Wide SO
MAX239ERG	-40°C to +85°C	24 Narrow CERDIP
MAX239MRG	-55°C to +125°C	24 Narrow CERDIP
MAX240CMH	0°C to +70°C	44 Plastic FP
MAX240C/D	0°C to +70°C	Dice*
MAX241CAI	0°C to +70°C	28 SSOP
MAX241CWI	0°C to +70°C	28 Wide SO
MAX241C/D	0°C to +70°C	Dice*
MAX241EAI	-40°C to +85°C	28 SSOP
MAX241EWI	-40°C to +85°C	28 Wide SO
MAX242CAP	0°C to +70°C	20 SSOP
MAX242CPN	0°C to +70°C	18 Plastic DIP
MAX242CWN	0°C to +70°C	18 Wide SO
MAX242C/D	0°C to +70°C	Dice*
MAX242EPN	-40°C to +85°C	18 Plastic DIP
MAX242EWN	-40°C to +85°C	18 Wide SO
MAX242EJN	-40°C to +85°C	18 CERDIP
MAX242MJN	-55°C to +125°C	18 CERDIP
MAX243CPE	0°C to +70°C	16 Plastic DIP
MAX243CSE	0°C to +70°C	16 Narrow SO
MAX243CWE	0°C to +70°C	16 Wide SO
MAX243C/D	0°C to +70°C	Dice*
MAX243EPE	-40°C to +85°C	16 Plastic DIP
MAX243ESE	-40°C to +85°C	16 Narrow SO
MAX243EWE	-40°C to +85°C	16 Wide SO
MAX243EJE	-40°C to +85°C	16 CERDIP
MAX243MJE	-55°C to +125°C	16 CERDIP
MAX244CQH	0°C to +70°C	44 PLCC
MAX244C/D	0°C to +70°C	Dice*
MAX244EQH	-40°C to +85°C	44 PLCC
MAX245CPL	0°C to +70°C	40 Plastic DIP
MAX245C/D	0°C to +70°C	Dice*
MAX245EPL	-40°C to +85°C	40 Plastic DIP
MAX246CPL	0°C to +70°C	40 Plastic DIP
MAX246C/D	0°C to +70°C	Dice*
MAX246EPL	-40°C to +85°C	40 Plastic DIP
MAX247CPL	0°C to +70°C	40 Plastic DIP
MAX247C/D	0°C to +70°C	Dice*
MAX247EPL	-40°C to +85°C	40 Plastic DIP
MAX248CQH	0°C to +70°C	44 PLCC
MAX248C/D	0°C to +70°C	Dice*
MAX248EQH	-40°C to +85°C	44 PLCC
MAX249CQH	0°C to +70°C	44 PLCC
MAX249EQH	-40°C to +85°C	44 PLCC

** Contact factory for dice specifications.*

March 2005

LM5100A/LM5101A 3.0 Amp High Voltage High Side and Low Side Driver

LM5100A/LM5101A
3.0 Amp High Voltage High Side and Low Side Driver

General Description

The LM5100A/LM5101A High Voltage Gate Drivers are designed to drive both the high side and the low side N-Channel MOSFETs in a synchronous buck or a half bridge configuration. The floating high-side driver is capable of operating with supply voltages up to 100V. The outputs are independently controlled with CMOS input thresholds (LM5100A) or TTL input thresholds (LM5101A). An integrated high voltage diode is provided to charge the high side gate drive bootstrap capacitor. A robust level shifter operates at high speed while consuming low power and providing clean level transitions from the control logic to the high side gate driver. Under-voltage lockout is provided on both the low side and the high side power rails. This device is available in the standard SOIC-8 pin and the LLP-10 pin packages.

Features

- 3.0A Sink/Source current gate drive
- Drives both a high side and low side N-Channel MOSFET
- Independent high and low driver logic inputs (TTL for LM5101A or CMOS for LM5100A)
- Bootstrap supply voltage range up to 118V DC
- Fast propagation times (25 ns typical)
- Drives 1000 pF load with 8 ns rise and fall times
- Excellent propagation delay matching (3 ns typical)
- Supply rail under-voltage lockouts
- Low power consumption
- Pin compatible with HIP2100/HIP2101 and LM5100/LM5101

Typical Applications

- Current Fed push-pull converters
- Half and Full Bridge power converters
- Synchronous buck converters
- Two switch forward power converters
- Forward with Active Clamp converters

Package

- SOIC-8
- LLP-10 (4 mm x 4 mm)

Simplified Block Diagram

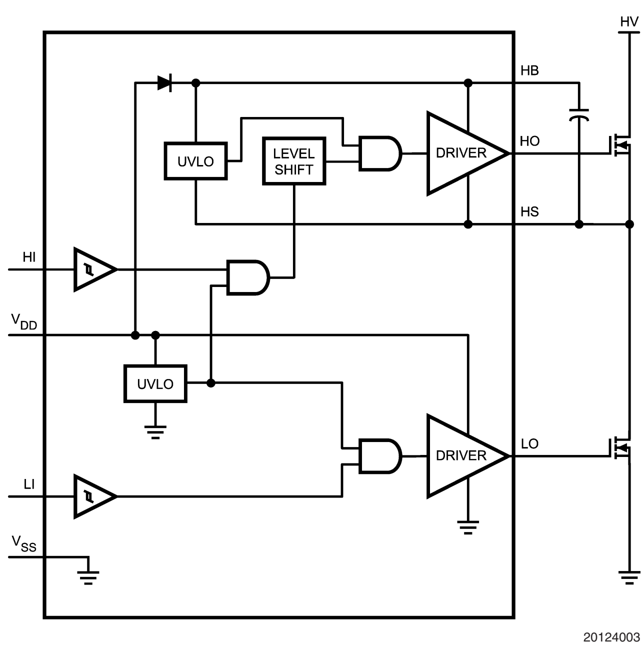


FIGURE 1.

Connection Diagrams

FIGURE 2.

Ordering Information

Ordering Number	Package Type	NSC Package Drawing	Supplied As
LM5100A/01A M	SOIC-8	M08A	Shipped in anti static rails
LM5100A/01A MX	SOIC-8	M08A	2500 shipped as Tape & Reel
LM5100A/01A SD	LLP-10	SDC10A	1000 shipped as Tape & Reel
LM5100A/01A SDX	LLP-10	SDC10A	4500 shipped as Tape & Reel

Pin Description

Pin #		Name	Description	Application Information
SO-8	LLP-10			
1	1	V_{DD}	Positive gate drive supply	Locally decouple to V_{SS} using low ESR/ESL capacitor located as close to IC as possible.
2	2	HB	High side gate driver bootstrap rail	Connect the positive terminal of the bootstrap capacitor to HB and the negative terminal to HS. The Bootstrap capacitor should be place as close to IC as possible.
3	3	HO	High side gate driver output	Connect to gate of high side MOSFET with a short low inductance path.
4	4	HS	High side MOSFET source connection	Connect to bootstrap capacitor negative terminal and the source of the high side MOSFET.
5	7	HI	High side driver control input	The LM5100A inputs have CMOS type thresholds. The LM5101A inputs have TTL type thresholds. Unused inputs should be tied to ground and not left open.
6	8	LI	Low side driver control input	The LM5100A inputs have CMOS type thresholds. The LM5101A inputs have TTL type thresholds. Unused inputs should be tied to ground and not left open.
7	9	V_{SS}	Ground return	All signals are referenced to this ground.
8	10	LO	Low side gate driver output	Connect to the gate of the low side MOSFET with a short low inductance path.

Note: For LLP-10 package, it is recommended that the exposed pad on the bottom of the LM5100A / LM5101A be soldered to ground plane on the PC board, and the ground plane should extend out from beneath the IC to help dissipate the heat. Pins 5 and 6 have no connection.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V_{DD} to V_{SS}	−0.3V to +18V
V_{HB} to V_{HS}	−0.3V to +18V
LI or HI Inputs	−0.3V to V_{DD} +0.3V
LO Output	−0.3V to V_{DD} +0.3V
HO Output	V_{HS} −0.3V to V_{HB} +0.3V
V_{HS} to V_{SS}	−1V to +100V
V_{HB} to V_{SS}	118V
Junction Temperature	+150˚C
Storage Temperature Range	−55˚C to +150˚C
ESD Rating HBM (Note 2)	2 KV

Recommended Operating Conditions

V_{DD}	+9V to +14V
HS	−1V to 100V
HB	V_{HS} +8V to V_{HS} +14V
HS Slew Rate	< 50 V/ns
Junction Temperature	−40˚C to +125˚C

Electrical Characteristics

Specifications in standard typeface are for T_J = +25˚C, and those in **boldface type** apply over the full **operating junction temperature range**. Unless otherwise specified, V_{DD} = V_{HB} = 12V, V_{SS} = V_{HS} = 0V, No Load on LO or HO .

Symbol	Parameter	Conditions	Min	Typ	Max	Units
SUPPLY CURRENTS						
I_{DD}	V_{DD} Quiescent Current	LI = HI = 0V (LM5100A)		0.1	**0.2**	mA
		LI = HI = 0V (LM5101A)		0.25	**0.4**	
I_{DDO}	V_{DD} Operating Current	f = 500 kHz		2.0	**3**	mA
I_{HB}	Total HB Quiescent Current	LI = HI = 0V		0.06	**0.2**	mA
I_{HBO}	Total HB Operating Current	f = 500 kHz		1.6	**3**	mA
I_{HBS}	HB to V_{SS} Current, Quiescent	V_{HS} = V_{HB} = 100V		0.1	**10**	µA
I_{HBSO}	HB to V_{SS} Current, Operating	f = 500 kHz		0.4		mA
INPUT PINS						
V_{IL}	Input Voltage Threshold (LM5100A)	Rising Edge	**4.5**	5.4	**6.3**	V
V_{IL}	Input Voltage Threshold (LM5101A)	Rising Edge	**1.3**	1.8	**2.3**	V
V_{IHYS}	Input Voltage Hysteresis (LM5101A)			50		mV
V_{IHYS}	Input Voltage Hysteresis (LM5100A)			500		mV
R_I	Input Pulldown Resistance		**100**	200	**400**	kΩ
UNDER VOLTAGE PROTECTION						
V_{DDR}	V_{DD} Rising Threshold		**6.0**	6.8	**7.4**	V
V_{DDH}	V_{DD} Threshold Hysteresis			0.5		V
V_{HBR}	HB Rising Threshold		**5.7**	6.6	**7.1**	V
V_{HBH}	HB Threshold Hysteresis			0.4		V
BOOT STRAP DIODE						
V_{DL}	Low-Current Forward Voltage	I_{VDD-HB} = 100 µA		0.52	**0.85**	V
V_{DH}	High-Current Forward Voltage	I_{VDD-HB} = 100 mA		0.80	**1.0**	V
R_D	Dynamic Resistance	I_{VDD-HB} = 100 mA		1.0	**1.65**	Ω
LO GATE DRIVER						
V_{OLL}	Low-Level Output Voltage	I_{LO} = 100 mA		0.12	**0.25**	V
V_{OHL}	High-Level Output Voltage	I_{LO} = −100 mA, V_{OHL} = V_{DD}−V_{LO}		0.24	**0.45**	V
I_{OHL}	Peak Pullup Current	V_{LO} = 0V		3.0		A
I_{OLL}	Peak Pulldown Current	V_{LO} = 12V		3.0		A
HO GATE DRIVER						
V_{OLH}	Low-Level Output Voltage	I_{HO} = 100 mA		0.12	**0.25**	V
V_{OHH}	High-Level Output Voltage	I_{HO} = −100 mA V_{OHH} = V_{HB}−V_{HO}		0.24	**0.45**	V
I_{OHH}	Peak Pullup Current	V_{HO} = 0V		3.0		A
I_{OLH}	Peak Pulldown Current	V_{HO} = 12V		3.0		A

Electrical Characteristics (Continued)

Specifications in standard typeface are for T_J = +25˚C, and those in **boldface type** apply over the full **operating junction temperature range**. Unless otherwise specified, V_{DD} = V_{HB} = 12V, V_{SS} = V_{HS} = 0V, No Load on LO or HO .

Symbol	Parameter	Conditions	Min	Typ	Max	Units
HO GATE DRIVER						
THERMAL RESISTANCE						
θ_{JA}	Junction to Ambient	SOIC-8		170		˚C/W
		LLP-10 (Note 3)		40		

Switching Characteristics

Specifications in standard typeface are for T_J = +25˚C, and those in **boldface type** apply over the full **operating junction temperature range**. Unless otherwise specified, V_{DD} = V_{HB} = 12V, V_{SS} = V_{HS} = 0V, No Load on LO or HO.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
LM5100A						
t_{LPHL}	Lower Turn-Off Propagation Delay (LI Falling to LO Falling)			20	**45**	ns
t_{HPHL}	Upper Turn-Off Propagation Delay (HI Falling to HO Falling)			20	**45**	ns
t_{LPLH}	Lower Turn-On Propagation Delay (LI Rising to LO Rising)			20	**45**	ns
t_{HPLH}	Upper Turn-On Propagation Delay (HI Rising to HO Rising)			20	**45**	ns
t_{MON}	Delay Matching: Lower Turn-On and Upper Turn-Off			1	**10**	ns
t_{MOFF}	Delay Matching: Lower Turn-Off and Upper Turn-On			1	**10**	ns
t_{RC}, t_{FC}	Either Output Rise/Fall Time	C_L = 1000 pF		8		ns
t_R, t_F	Either Output Fall Time (3V to 9V)	C_L = 0.1 µF		0.26		µs
	Either Output Rise Time (3V to 9V)	C_L = 0.1 µF		0.43		
t_{PW}	Minimum Input Pulse Width that Changes the Output			50		ns
t_{BS}	Bootstrap Diode Turn-Off Time	I_F = 100 mA, I_R = 100 mA		38		ns
LM5101A						
t_{LPHL}	Lower Turn-Off Propagation Delay (LI Falling to LO Falling)			22	**56**	ns
t_{HPHL}	Upper Turn-Off Propagation Delay (HI Falling to HO Falling)			22	**56**	ns
t_{LPLH}	Lower Turn-On Propagation Delay (LI Rising to LO Rising)			26	**56**	ns
t_{HPLH}	Upper Turn-On Propagation Delay (HI Rising to HO Rising)			26	**56**	ns
t_{MON}	Delay Matching: Lower Turn-On and Upper Turn-Off			4	**10**	ns
t_{MOFF}	Delay Matching: Lower Turn-Off and Upper Turn-On			4	**10**	ns
t_{RC}, t_{FC}	Either Output Rise/Fall Time	C_L = 1000 pF		8		ns
t_R, t_F	Either Output Fall Time (3V to 9V)	C_L = 0.1 µF		0.26		µs
	Either Output Rise Time (3V to 9V)	C_L = 0.1 µF		0.43		

Switching Characteristics (Continued)

Specifications in standard typeface are for T_J = +25˚C, and those in **boldface type** apply over the full **operating junction temperature range**. Unless otherwise specified, $V_{DD} = V_{HB}$ = 12V, $V_{SS} = V_{HS}$ = 0V, No Load on LO or HO.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
LM5101A						
t_{PW}	Minimum Input Pulse Width that Changes the Output			50		ns
t_{BS}	Bootstrap Diode Turn-Off Time	I_F = 100 mA, I_R = 100 mA		38		ns

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

Note 2: The human body model is a 100 pF capacitor discharged through a 1.5kΩ resistor into each pin. 2 KV for all pins except Pin 2, Pin 3 and Pin 4 which are rated at 1000V.

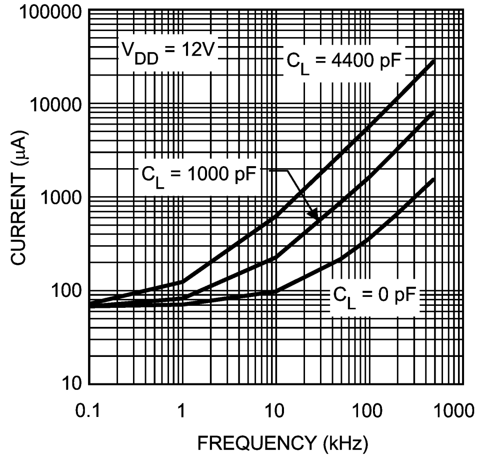
Note 3: 4 layer board with Cu finished thickness 1.5/1/1/1.5 oz. Maximum die size used. 5x body length of Cu trace on PCB top. 50 x 50mm ground and power planes embedded in PCB. See Application Note AN-1187.

Note 4: Min and Max limits are 100% production tested at 25˚C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. Limits are used to calculate National's Average Outgoing Quality Level (AOQL).

Note 5: The θ_{JA} is not a given constant for the package and depends on the printed circuit board design and the operating environment.

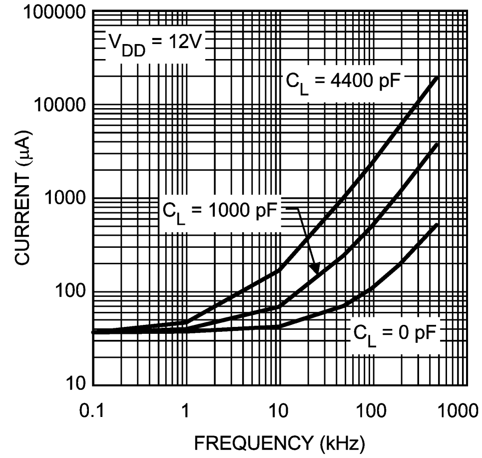
Typical performance Characteristics

LM5100A I_{DD} vs Frequency



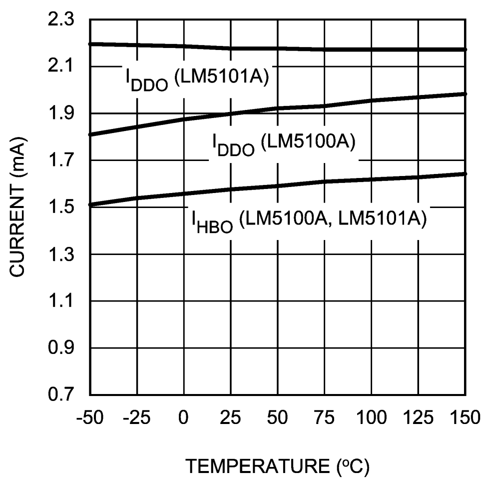
20124009

LM5101A I_{DD} vs Frequency



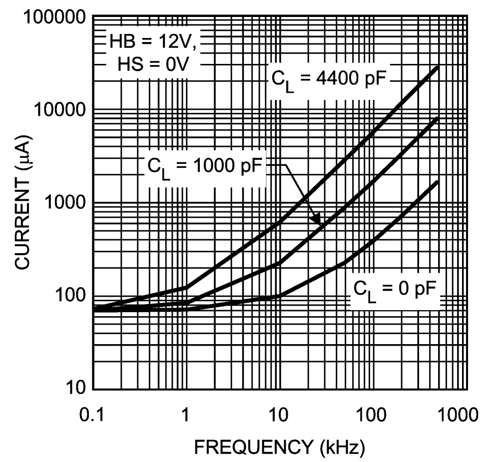
20124010

LM5100A/LM5101A Operating Current vs Temperature



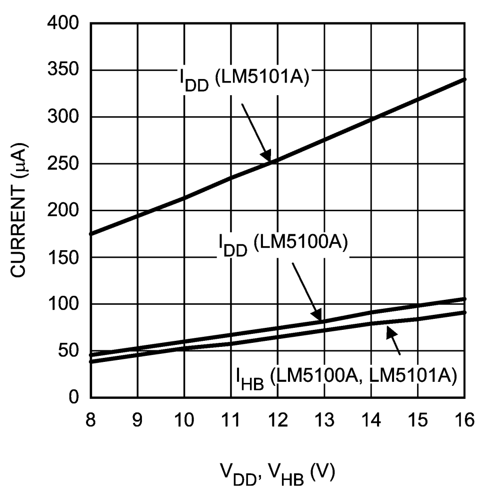
20124011

IHB vs Frequency



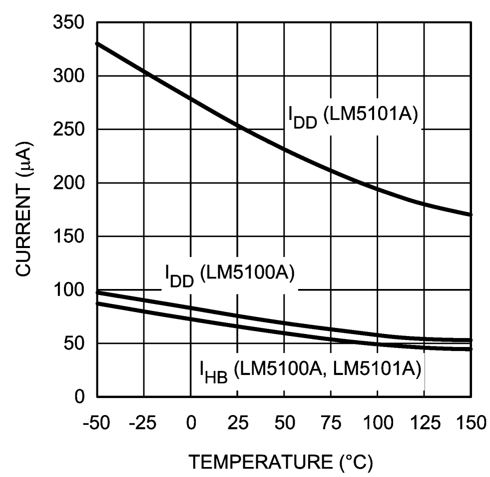
20124014

Quiescent Current vs Supply Voltage



20124018

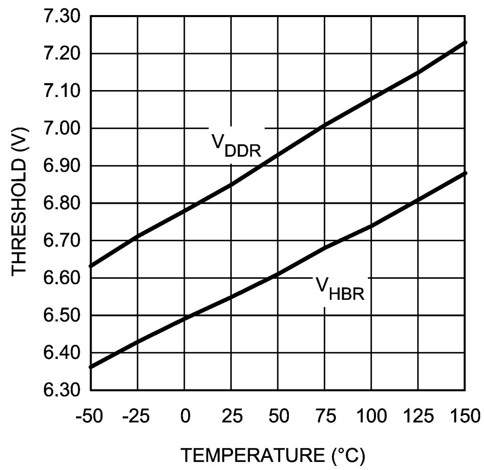
LM5100A/LM5101A Quiescent Current vs Temperature



20124019

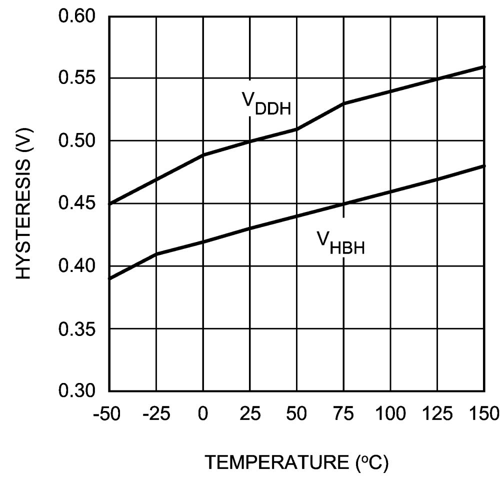
Typical performance Characteristics (Continued)

Undervoltage Rising Thresholds vs Temperature



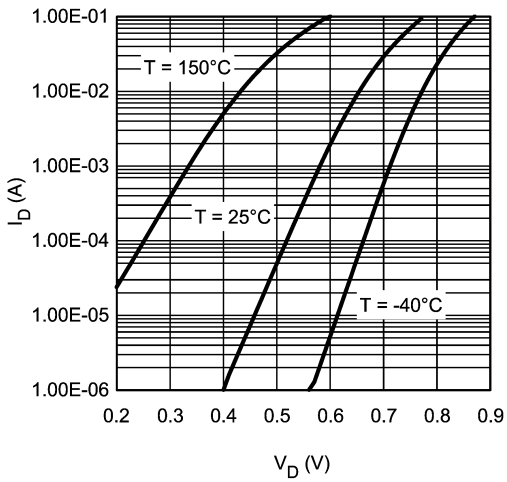
20124022

LM5100A Undervoltage Threshold Hysteresis vs Temperature



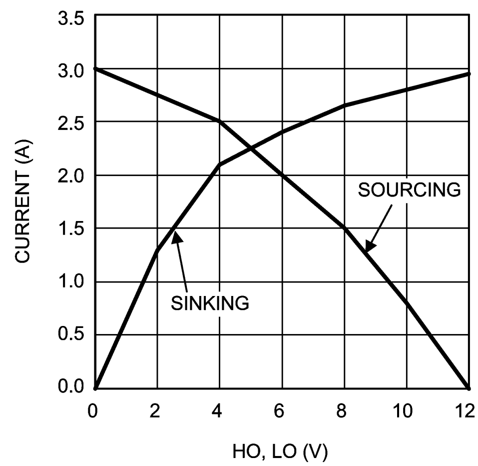
20124017

Bootstrap Diode Forward Voltage



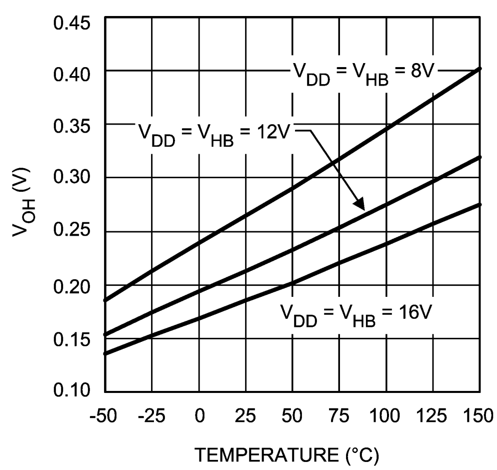
20124015

HO and LO Peak Output Current vs Output Voltage



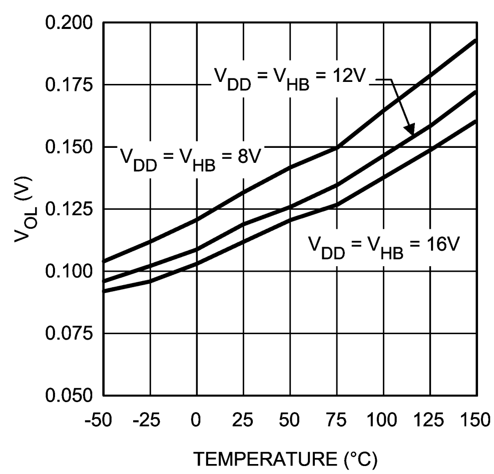
20124016

LO and HO Gate Drive—High Level Output Voltage vs Temperature



20124020

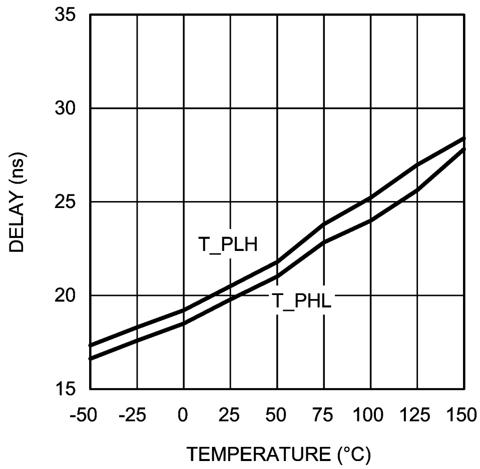
LO and HO Gate Drive—Low Level Output Voltage vs Temperature



20124021

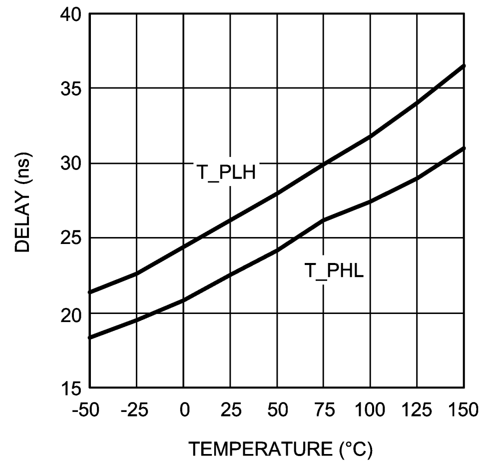
Typical performance Characteristics (Continued)

LM5100A Propagation Delay vs Temperature



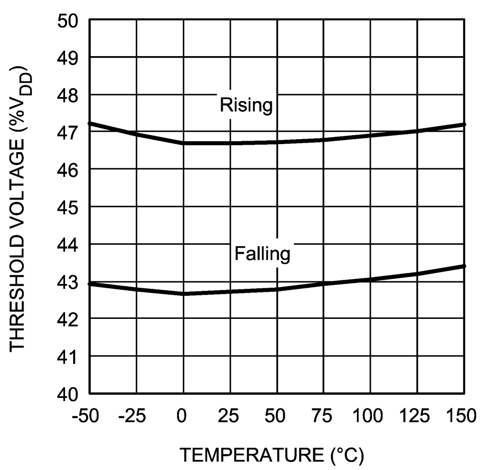
20124012

LM5101A Propagation Delay vs Temperature



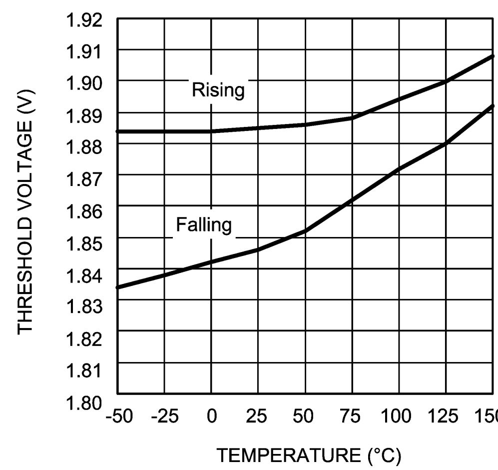
20124013

LM5100A Input Threshold vs Temperature



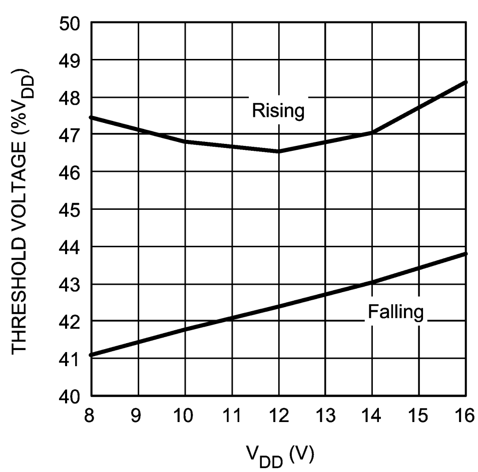
20124023

LM5101A Input Threshold vs Temperature



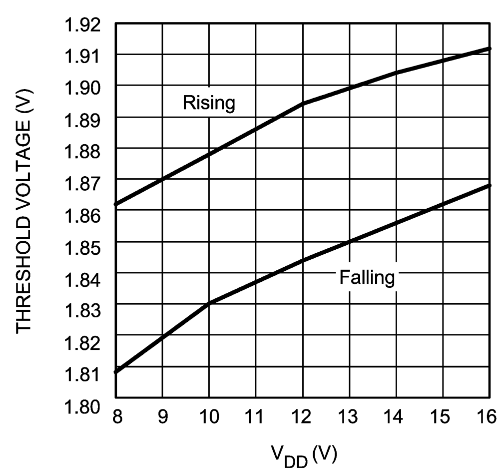
20124024

LM5100A Input Threshold vs V_{DD}



20124025

LM5101A Input Threshold vs V_{DD}



20124026

Timing Diagram

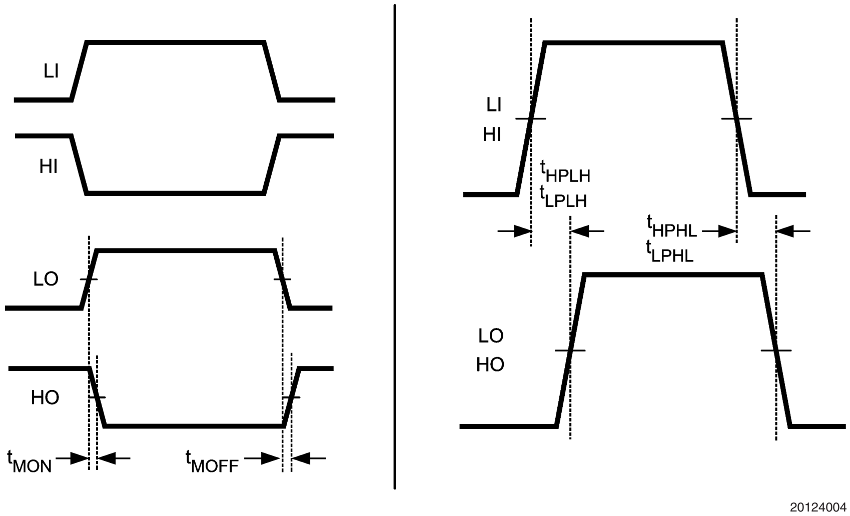


FIGURE 3.

Layout Considerations

The optimum performance of high and low side gate drivers cannot be achieved without taking due considerations during circuit board layout. Following points are emphasized.

1. A low ESR / ESL capacitor must be connected close to the IC, and between V_{DD} and V_{SS} pins and between HB and HS pins to support high peak currents being drawn from VDD during turn-on of the external MOSFET.
2. To prevent large voltage transients at the drain of the top MOSFET, a low ESR electrolytic capacitor must be connected between MOSFET drain and ground (V_{SS}).
3. In order to avoid large negative transients on the switch node (HS) pin, the parasitic inductances in the source of top MOSFET and in the drain of the bottom MOSFET (synchronous rectifier) must be minimized.
4. Grounding Considerations:

   a) The first priority in designing grounding connections is to confine the high peak currents from charging and discharging the MOSFET gate in a minimal physical area. This will decrease the loop inductance and minimize noise issues on the gate terminal of the MOSFET. The MOSFETs should be placed as close as possible to the gate driver.

   b) The second high current path includes the bootstrap capacitor, the bootstrap diode, the local ground referenced bypass capacitor and low side MOSFET body diode. The bootstrap capacitor is recharged on the cycle-by-cycle basis through the bootstrap diode from the ground referenced V_{DD} bypass capacitor. The recharging occurs in a short time interval and involves high peak current. Minimizing this loop length and area on the circuit board is important to ensure reliable operation.

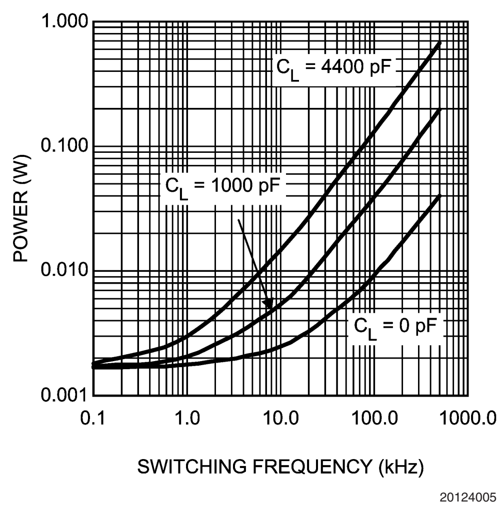
Power Dissipation Considerations

The total IC power dissipation is the sum of the gate driver losses and the bootstrap diode losses. The gate driver losses are related to the switching frequency (f), output load capacitance on LO and HO (C_L), and supply voltage (V_{DD}) and can be roughly calculated as:

$$P_{DGATES} = 2 \bullet f \bullet C_L \bullet V_{DD}^2$$

There are some additional losses in the gate drivers due to the internal CMOS stages used to buffer the LO and HO outputs. The following plot shows the measured gate driver power dissipation versus frequency and load capacitance. At higher frequencies and load capacitance values, the power dissipation is dominated by the power losses driving the output loads and agrees well with the above equation. This plot can be used to approximate the power losses due to the gate drivers.

Gate Driver Power Dissipation (LO + HO)
V_{DD} = 12V, Neglecting Diode Losses



The bootstrap diode power loss is the sum of the forward bias power loss that occurs while charging the bootstrap capacitor and the reverse bias power loss that occurs during reverse recovery. Since each of these events happens once per cycle, the diode power loss is proportional to frequency.

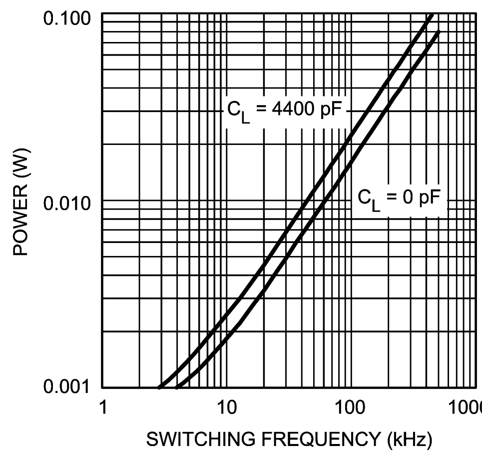
Power Dissipation Considerations

(Continued)

Larger capacitive loads require more current to recharge the bootstrap capacitor resulting in more losses. Higher input voltages (V_{IN}) to the half bridge result in higher reverse recovery losses. The following plot was generated based on calculations and lab measurements of the diode recovery time and current under several operating conditions. This can be useful for approximating the diode power dissipation.

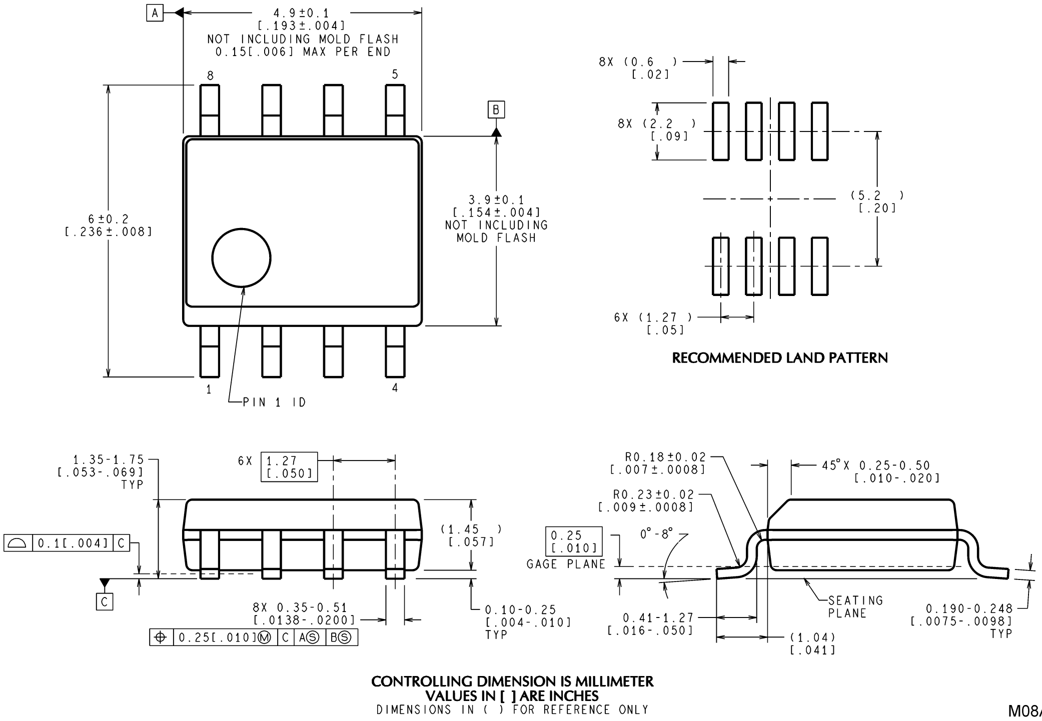
The total IC power dissipation can be estimated from the previous plots by summing the gate drive losses with the bootstrap diode losses for the intended application.

Diode Power Dissipation V_{IN} = 50V



20124006

Physical Dimensions inches (millimeters) unless otherwise noted



M08A (Rev K)

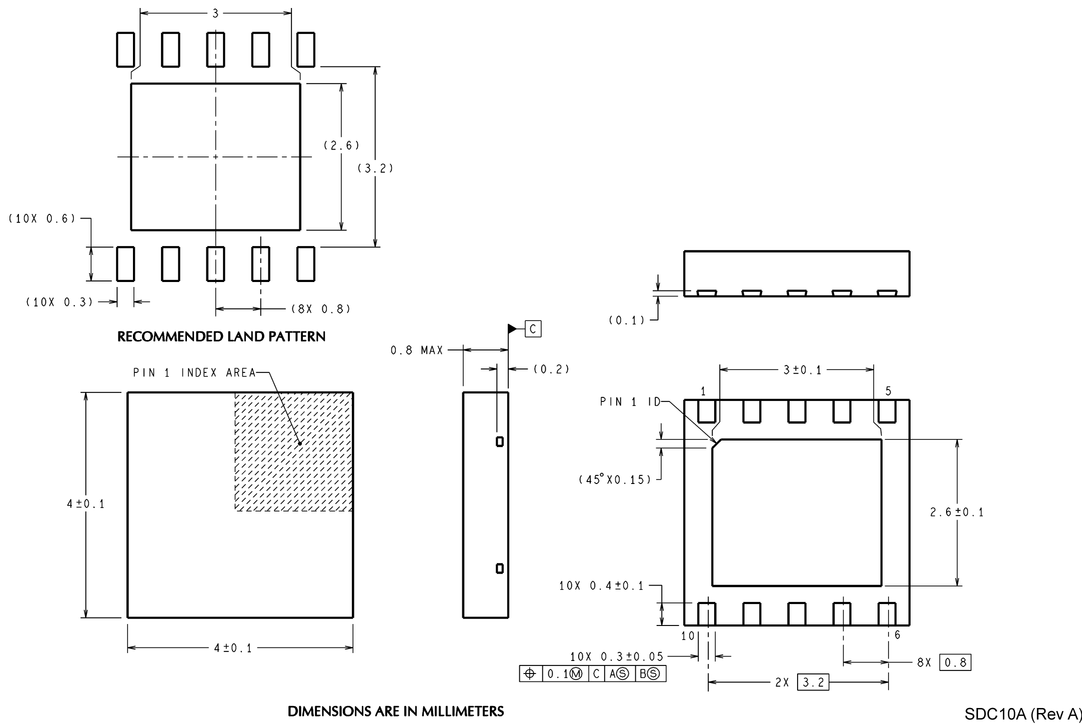
Controlling dimension is inch. Values in [ ] are millimeters.

Notes: Unless otherwise specified.

1. Standard lead finish to be 200 microinches/5.08 micrometers minimum lead/tin (solder) on copper.
2. Dimension does not include mold flash.
3. Reference JEDEC registration MS-012, Variation AA, dated May 1990.

SOIC-8 Outline Drawing
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Notes: Unless otherwise specified.

1. For solder thickness and composition, see "Solder Information" in the packaging section of the National Semiconductor web page (www.national.com).
2. Maximum allowable metal burr on lead tips at the package edges is 76 microns.
3. No JEDEC registration as of May 2003.

LLP-10 Outline Drawing
NS Package Number SDC10A

National Semiconductor
Americas Customer
Support Center
Email: new.feedback@nsc.com
Tel: 1-800-272-9959

National Semiconductor
Europe Customer Support Center
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
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National Semiconductor
Asia Pacific Customer
Support Center
Email: ap.support@nsc.com

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National Semiconductor

May 2003

LM2907/LM2917 Frequency to Voltage Converter

General Description

The LM2907, LM2917 series are monolithic frequency to voltage converters with a high gain op amp/comparator designed to operate a relay, lamp, or other load when the input frequency reaches or exceeds a selected rate. The tachometer uses a charge pump technique and offers frequency doubling for low ripple, full input protection in two versions (LM2907-8, LM2917-8) and its output swings to ground for a zero frequency input.

The op amp/comparator is fully compatible with the tachometer and has a floating transistor as its output. This feature allows either a ground or supply referred load of up to 50 mA. The collector may be taken above V_{CC} up to a maximum V_{CE} of 28V.

The two basic configurations offered include an 8-pin device with a *ground referenced tachometer* input and an internal connection between the tachometer output and the op amp non-inverting input. This version is well suited for single speed or frequency switching or fully buffered frequency to voltage conversion applications.

The more versatile configurations provide differential tachometer input and uncommitted op amp inputs. With this version the tachometer input may be floated and the op amp becomes suitable for active filter conditioning of the tachometer output.

Both of these configurations are available with an active shunt regulator connected across the power leads. The regulator clamps the supply such that stable frequency to voltage and frequency to current operations are possible with any supply voltage and a suitable resistor.

Advantages

- Output swings to ground for zero frequency input
- Easy to use; $V_{OUT} = f_{IN} \times V_{CC} \times R1 \times C1$
- Only one RC network provides frequency doubling
- Zener regulator on chip allows accurate and stable frequency to voltage or current conversion (LM2917)

Features

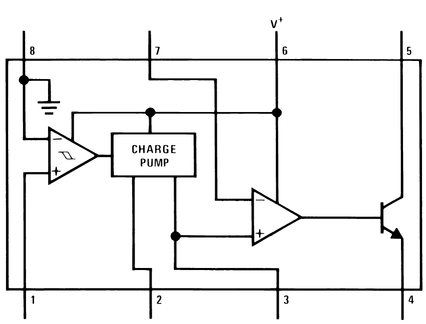
- Ground referenced tachometer input interfaces directly with variable reluctance magnetic pickups
- Op amp/comparator has floating transistor output
- 50 mA sink or source to operate relays, solenoids, meters, or LEDs
- Frequency doubling for low ripple
- Tachometer has built-in hysteresis with either differential input or ground referenced input
- Built-in zener on LM2917
- ±0.3% linearity typical
- Ground referenced tachometer is fully protected from damage due to swings above V_{CC} and below ground

Applications

- Over/under speed sensing
- Frequency to voltage conversion (tachometer)
- Speedometers
- Breaker point dwell meters
- Hand-held tachometer
- Speed governors
- Cruise control
- Automotive door lock control
- Clutch control
- Horn control
- Touch or sound switches

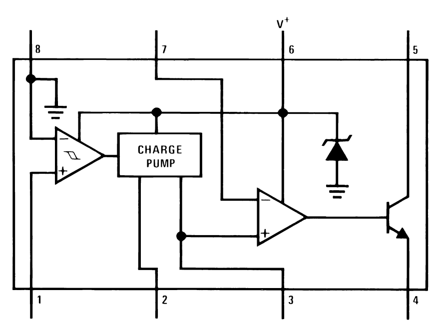
Block and Connection Diagrams

Dual-In-Line and Small Outline Packages, Top Views



00794201

Order Number LM2907M-8 or LM2907N-8
See NS Package Number M08A or N08E

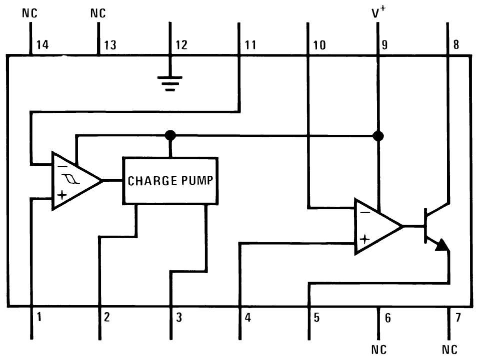


00794202

Order Number LM2917M-8 or LM2917N-8
See NS Package Number M08A or N08E

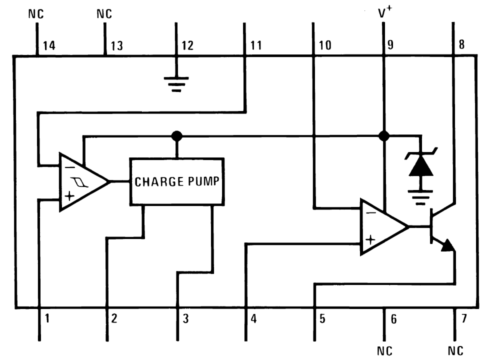
 DS007942

Block and Connection Diagrams Dual-In-Line and Small Outline Packages, Top Views (Continued)



00794203

Order Number LM2907M or LM2907N
See NS Package Number M14A or N14A



00794204

Order Number LM2917M or LM2917N
See NS Package Number M14A or N14A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	28V
Supply Current (Zener Options)	25 mA
Collector Voltage	28V
Differential Input Voltage	
Tachometer	28V
Op Amp/Comparator	28V
Input Voltage Range	
Tachometer	
LM2907-8, LM2917-8	±28V
LM2907, LM2917	0.0V to +28V
Op Amp/Comparator	0.0V to +28V
Power Dissipation	
LM2907-8, LM2917-8	1200 mW
LM2907-14, LM2917-14	1580 mW
See (Note 1)	
Operating Temperature Range	−40˚C to +85˚C
Storage Temperature Range	−65˚C to +150˚C
Soldering Information	
Dual-In-Line Package	
Soldering (10 seconds)	260˚C
Small Outline Package	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

Electrical Characteristics

V_{CC} = 12 V_{DC}, T_A = 25˚C, see test circuit

Symbol	Parameter	Conditions	Min	Typ	Max	Units
TACHOMETER						
	Input Thresholds	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)	±10	±25	±40	mV
	Hysteresis	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)		30		mV
	Offset Voltage	V_{IN} = 250 mVp-p @ 1 kHz (Note 2)				
	LM2907/LM2917			3.5	10	mV
	LM2907-8/LM2917-8			5	15	mV
	Input Bias Current	V_{IN} = ±50 mV_{DC}		0.1	1	μA
V_{OH}	Pin 2	V_{IN} = +125 mV_{DC} (Note 3)		8.3		V
V_{OL}	Pin 2	V_{IN} = −125 mV_{DC} (Note 3)		2.3		V
I_2, I_3	Output Current	V2 = V3 = 6.0V (Note 4)	140	180	240	μA
I_3	Leakage Current	I2 = 0, V3 = 0			0.1	μA
K	Gain Constant	(Note 3)	0.9	1.0	1.1	
	Linearity	f_{IN} = 1 kHz, 5 kHz, 10 kHz (Note 5)	−1.0	0.3	+1.0	%
OP/AMP COMPARATOR						
V_{OS}		V_{IN} = 6.0V		3	10	mV
I_{BIAS}		V_{IN} = 6.0V		50	500	nA
	Input Common-Mode Voltage		0		V_{CC}−1.5V	V
	Voltage Gain			200		V/mV
	Output Sink Current	V_C = 1.0	40	50		mA
	Output Source Current	V_E = V_{CC} −2.0		10		mA
	Saturation Voltage	I_{SINK} = 5 mA		0.1	0.5	V
		I_{SINK} = 20 mA			1.0	V
		I_{SINK} = 50 mA		1.0	1.5	V
ZENER REGULATOR						
	Regulator Voltage	R_{DROP} = 470Ω		7.56		V
	Series Resistance			10.5	15	Ω
	Temperature Stability			+1		mV/˚C
	TOTAL SUPPLY CURRENT			3.8	6	mA

Note 1: For operation in ambient temperatures above 25˚C, the device must be derated based on a 150˚C maximum junction temperature and a thermal resistance of 101˚C/W junction to ambient for LM2907-8 and LM2917-8, and 79˚C/W junction to ambient for LM2907-14 and LM2917-14.

Note 2: Hysteresis is the sum $+V_{TH} - (-V_{TH})$, offset voltage is their difference. See test circuit.

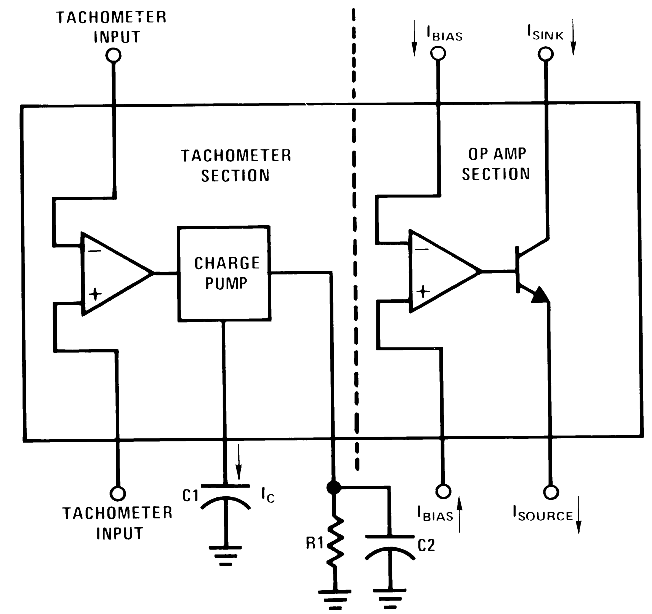
Note 3: V_{OH} is equal to ¾ x V_{CC} − 1 V_{BE}, V_{OL} is equal to ¼ x V_{CC} − 1 V_{BE} therefore $V_{OH} - V_{OL} = V_{CC}/2$. The difference, $V_{OH} - V_{OL}$, and the mirror gain, I_2/I_3, are the two factors that cause the tachometer gain constant to vary from 1.0.

Note 4: Be sure when choosing the time constant R1 x C1 that R1 is such that the maximum anticipated output voltage at pin 3 can be reached with I_3 x R1. The maximum value for R1 is limited by the output resistance of pin 3 which is greater than 10 MΩ typically.

Electrical Characteristics (Continued)

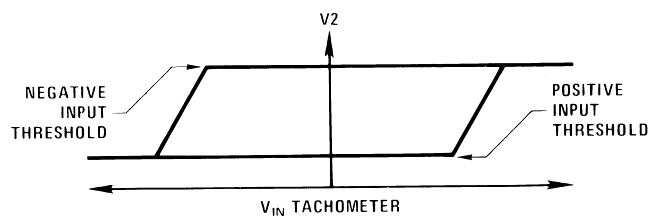
Note 5: Nonlinearity is defined as the deviation of V_{OUT} (@ pin 3) for f_{IN} = 5 kHz from a straight line defined by the V_{OUT} @ 1 kHz and V_{OUT} @ 10 kHz. C1 = 1000 pF, R1 = 68k and C2 = 0.22 mFd.

Test Circuit and Waveform



00794206

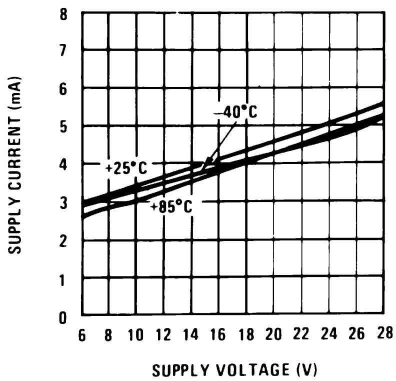
Tachometer Input Threshold Measurement



00794207

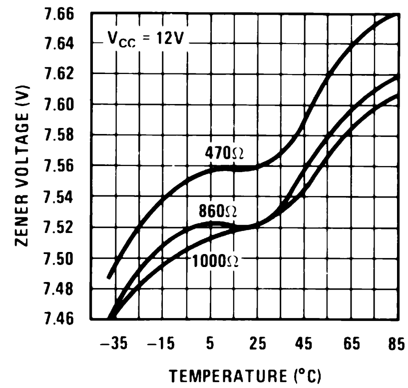
Typical Performance Characteristics

Total Supply Current



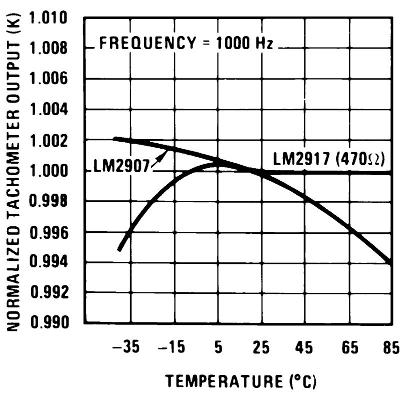
00794240

Zener Voltage vs Temperature



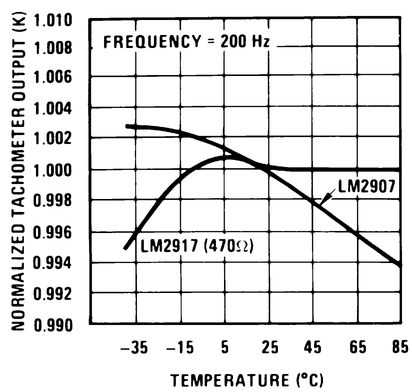
00794241

Normalized Tachometer Output vs Temperature



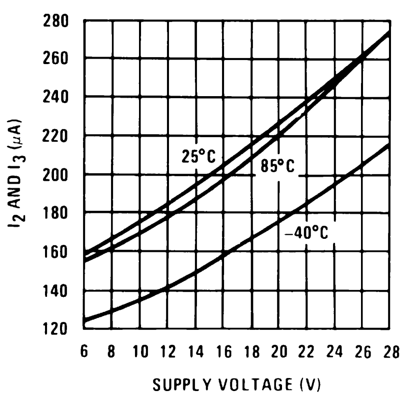
00794242

Normalized Tachometer Output vs Temperature



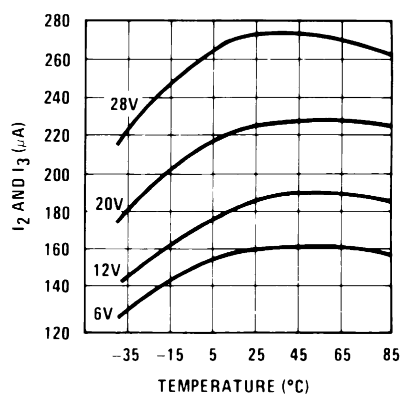
00794243

Tachometer Currents I_2 and I_3 vs Supply Voltage



00794244

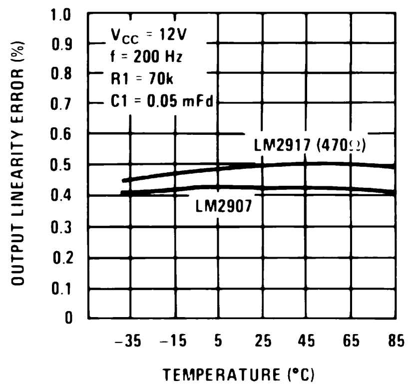
Tachometer Currents I_2 and I_3 vs Temperature



00794245

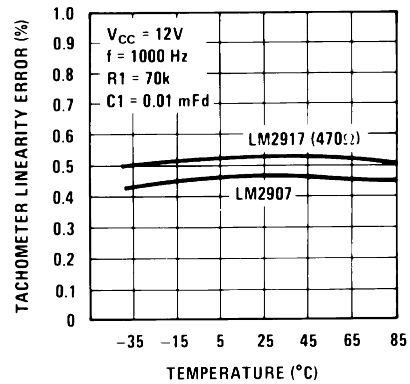
Typical Performance Characteristics (Continued)

Tachometer Linearity vs Temperature



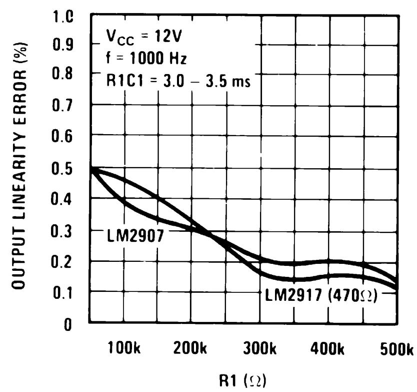
00794246

Tachometer Linearity vs Temperature



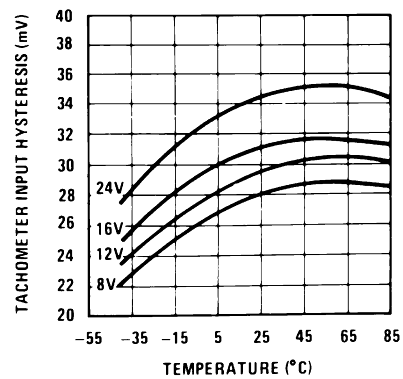
00794247

Tachometer Linearity vs R1



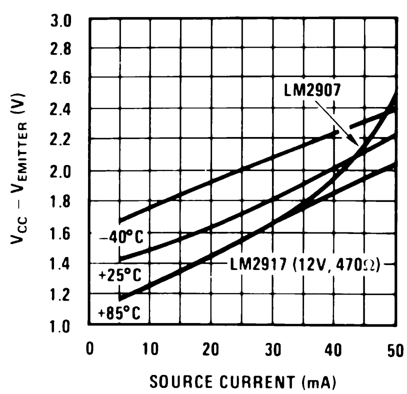
00794248

Tachometer Input Hysteresis vs Temperature



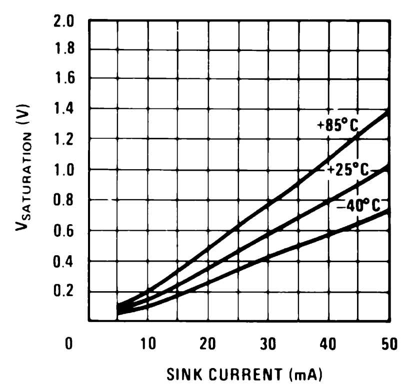
00794249

Op Amp Output Transistor Characteristics



00794250

Op Amp Output Transistor Characteristics



00794251

Applications Information

The LM2907 series of tachometer circuits is designed for minimum external part count applications and maximum versatility. In order to fully exploit its features and advantages let's examine its theory of operation. The first stage of operation is a differential amplifier driving a positive feedback flip-flop circuit. The input threshold voltage is the amount of differential input voltage at which the output of this stage changes state. Two options (LM2907-8, LM2917-8) have one input internally grounded so that an input signal must swing above and below ground and exceed the input thresholds to produce an output. This is offered specifically for magnetic variable reluctance pickups which typically provide a single-ended ac output. This single input is also fully protected against voltage swings to ±28V, which are easily attained with these types of pickups.

The differential input options (LM2907, LM2917) give the user the option of setting his own input switching level and still have the hysteresis around that level for excellent noise rejection in any application. Of course in order to allow the inputs to attain common-mode voltages above ground, input protection is removed and neither input should be taken outside the limits of the supply voltage being used. It is very important that an input not go below ground without some resistance in its lead to limit the current that will then flow in the epi-substrate diode.

Following the input stage is the charge pump where the input frequency is converted to a dc voltage. To do this requires one timing capacitor, one output resistor, and an integrating or filter capacitor. When the input stage changes state (due to a suitable zero crossing or differential voltage on the input) the timing capacitor is either charged or discharged linearly between two voltages whose difference is $V_{CC}/2$. Then in one half cycle of the input frequency or a time equal to 1/2 f_{IN} the change in charge on the timing capacitor is equal to $V_{CC}/2$ x C1. The average amount of current pumped into or out of the capacitor then is:

$$\frac{\Delta Q}{T} = i_{c(AVG)} = C1 \times \frac{V_{CC}}{2} \times (2f_{IN}) = V_{CC} \times f_{IN} \times C1$$

The output circuit mirrors this current very accurately into the load resistor R1, connected to ground, such that if the pulses of current are integrated with a filter capacitor, then $V_O = i_c \times R1$, and the total conversion equation becomes:

$$V_O = V_{CC} \times f_{IN} \times C1 \times R1 \times K$$

Where K is the gain constant — typically 1.0.

The size of C2 is dependent only on the amount of ripple voltage allowable and the required response time.

CHOOSING R1 AND C1

There are some limitations on the choice of R1 and C1 which should be considered for optimum performance. The timing capacitor also provides internal compensation for the charge pump and should be kept larger than 500 pF for very accurate operation. Smaller values can cause an error current on R1, especially at low temperatures. Several considerations must be met when choosing R1. The output current at pin 3 is internally fixed and therefore $V_O/R1$ must be less than or equal to this value. If R1 is too large, it can become a significant fraction of the output impedance at pin 3 which degrades linearity. Also output ripple voltage must be considered and the size of C2 is affected by R1. An expression that describes the ripple content on pin 3 for a single R1C2 combination is:

$$V_{RIPPLE} = \frac{V_{CC}}{2} \times \frac{C1}{C2} \times \left(1 - \frac{V_{CC} \times f_{IN} \times C1}{I_2}\right) \text{pk-pk}$$

It appears R1 can be chosen independent of ripple, however response time, or the time it takes V_{OUT} to stabilize at a new voltage increases as the size of C2 increases, so a compromise between ripple, response time, and linearity must be chosen carefully.

As a final consideration, the maximum attainable input frequency is determined by V_{CC}, C1 and I_2:

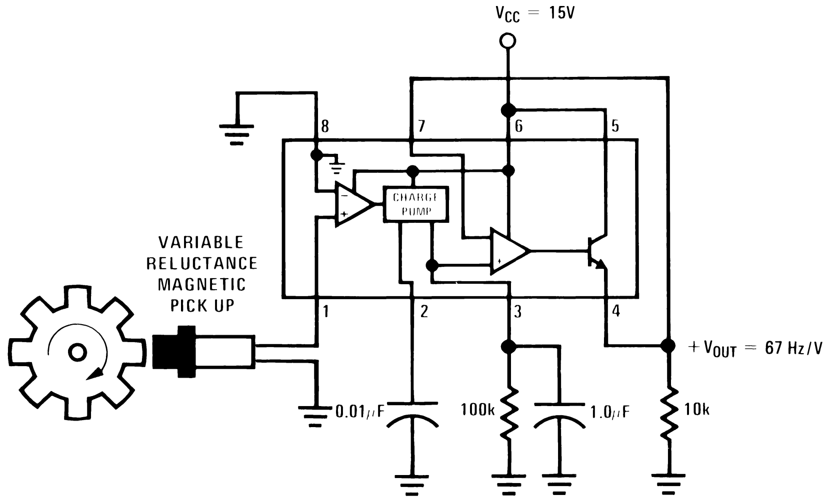
$$f_{MAX} = \frac{I_2}{C1 \times V_{CC}}$$

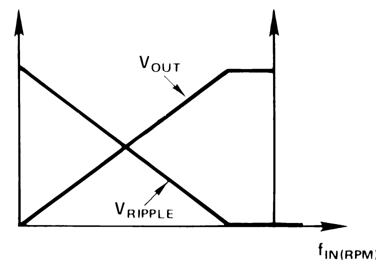
USING ZENER REGULATED OPTIONS (LM2917)

For those applications where an output voltage or current must be obtained independent of supply voltage variations, the LM2917 is offered. The most important consideration in choosing a dropping resistor from the unregulated supply to the device is that the tachometer and op amp circuitry alone require about 3 mA at the voltage level provided by the zener. At low supply voltages there must be some current flowing in the resistor above the 3 mA circuit current to operate the regulator. As an example, if the raw supply varies from 9V to 16V, a resistance of 470Ω will minimize the zener voltage variation to 160 mV. If the resistance goes under 400Ω or over 600Ω the zener variation quickly rises above 200 mV for the same input variation.

Typical Applications

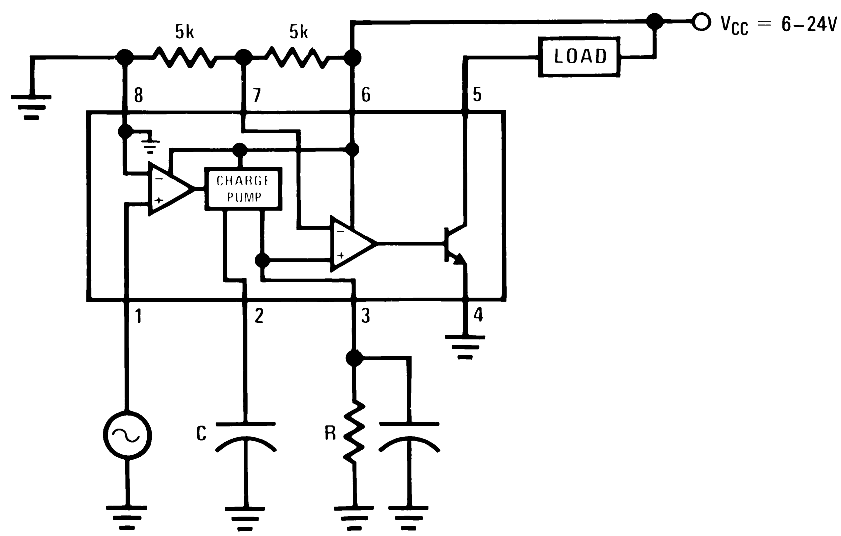
Minimum Component Tachometer





00794208

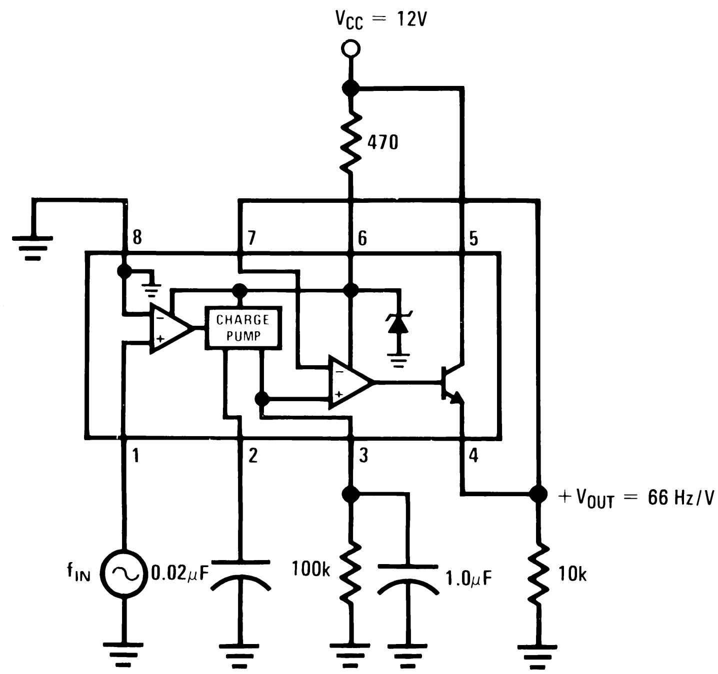
"Speed Switch" Load is Energized When $f_{IN} \geq \frac{1}{2RC}$



00794209

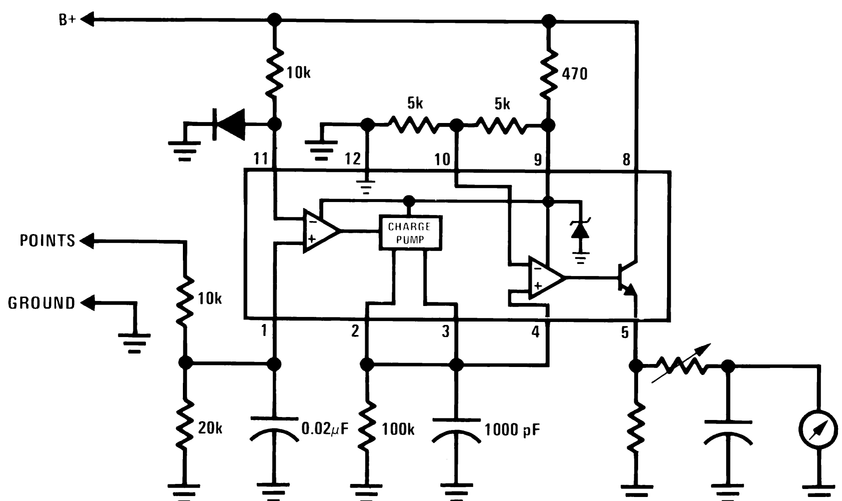
Typical Applications (Continued)

Zener Regulated Frequency to Voltage Converter



00794210

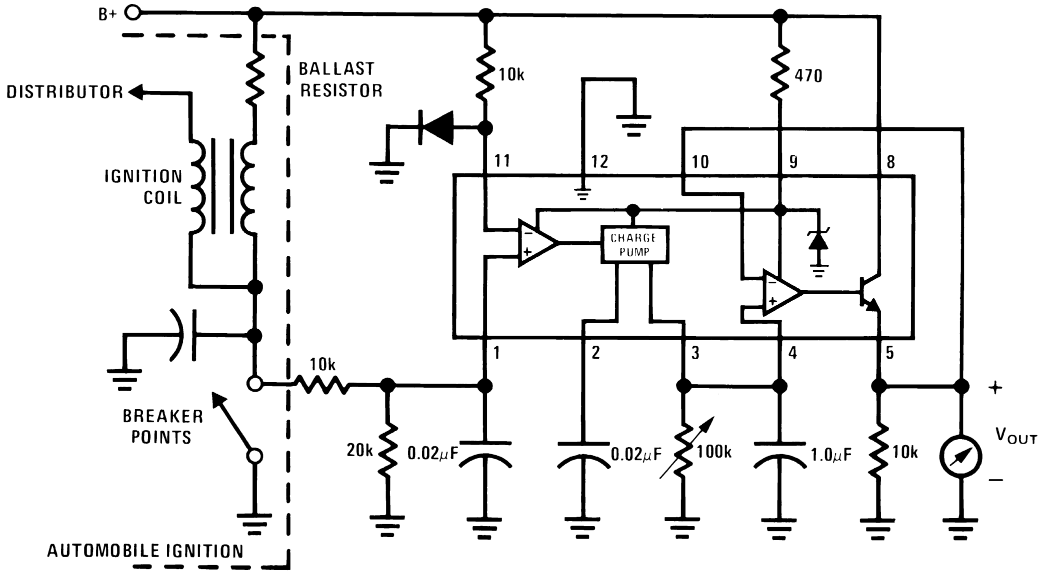
Breaker Point Dwell Meter



00794211

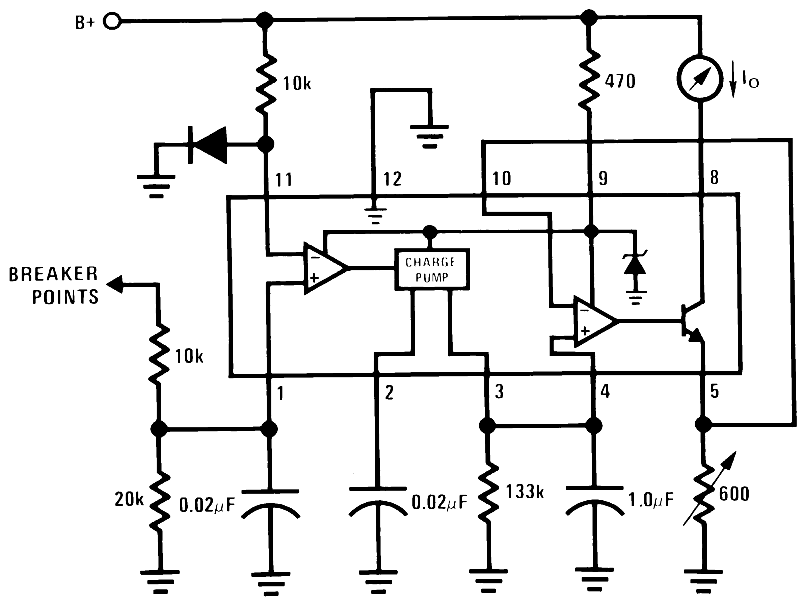
Typical Applications (Continued)

Voltage Driven Meter Indicating Engine RPM
V_O = 6V @ 400 Hz or 6000 ERPM (8 Cylinder Engine)



00794212

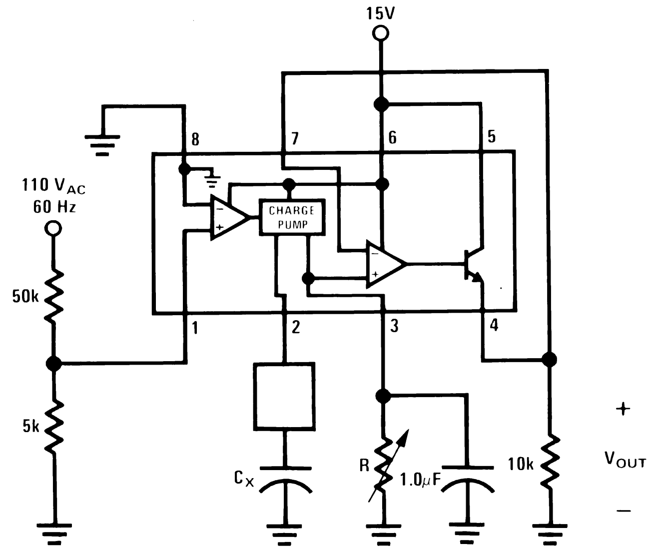
Current Driven Meter Indicating Engine RPM
I_O = 10 mA @ 300 Hz or 6000 ERPM (6 Cylinder Engine)



00794213

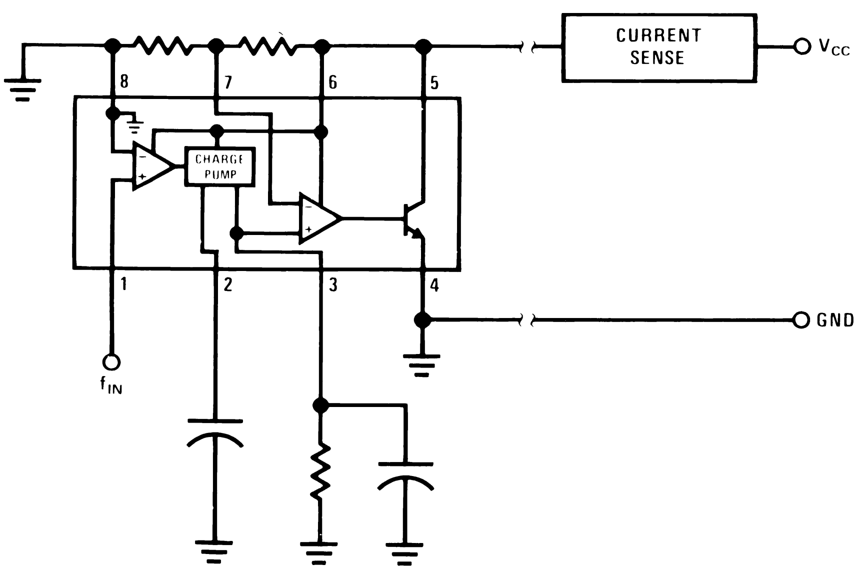
Typical Applications (Continued)

Capacitance Meter
V_{OUT} = 1V–10V for C_X = 0.01 to 0.1 mFd
(R = 111k)



00794214

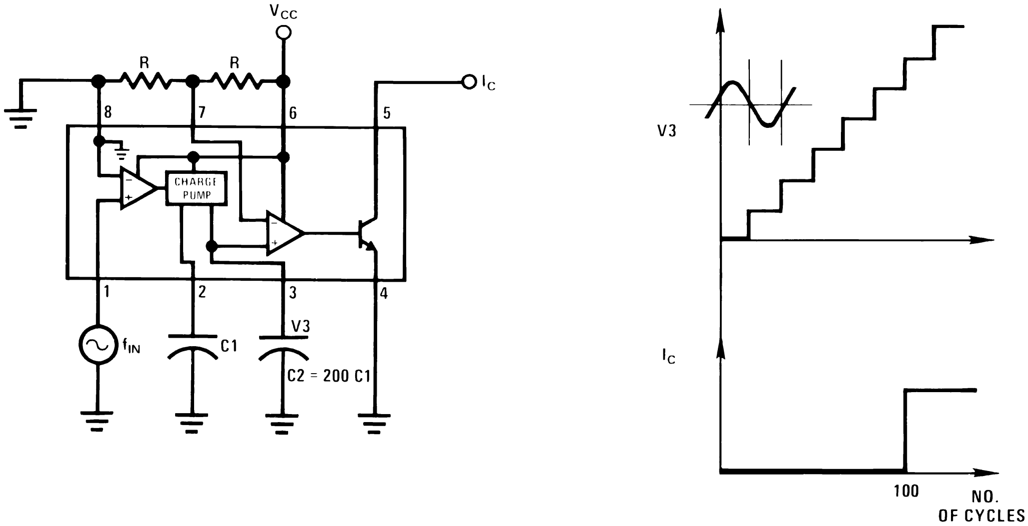
Two-Wire Remote Speed Switch



00794215

Typical Applications (Continued)

100 Cycle Delay Switch



00794216

V3 steps up in voltage by the amount $\frac{V_{CC} \times C1}{C2}$

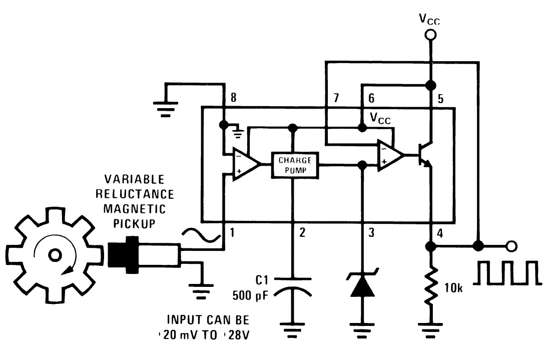
for each complete input cycle (2 zero crossings)

Example:

if C2 = 200 C1 after 100 consecutive input cycles.

V3 = 1/2 V_{CC}

Variable Reluctance Magnetic Pickup Buffer Circuits



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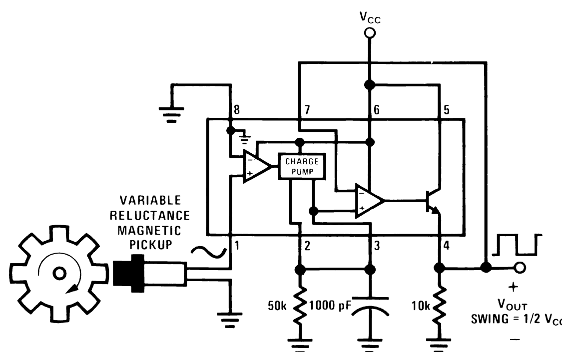


00794217

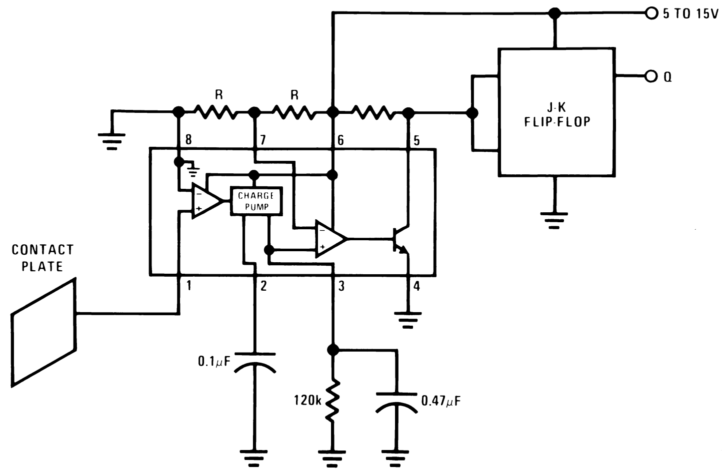
Precision two-shot output frequency equals twice input frequency.

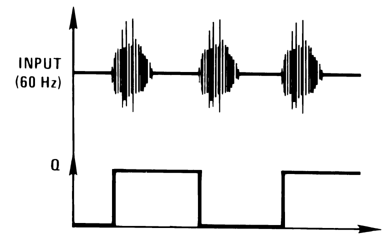
$$\text{Pulse width} = \frac{V_{CC}}{2}\frac{C1}{I2}$$

Pulse height = V_{ZENER}

Typical Applications (Continued)

Finger Touch or Contact Switch

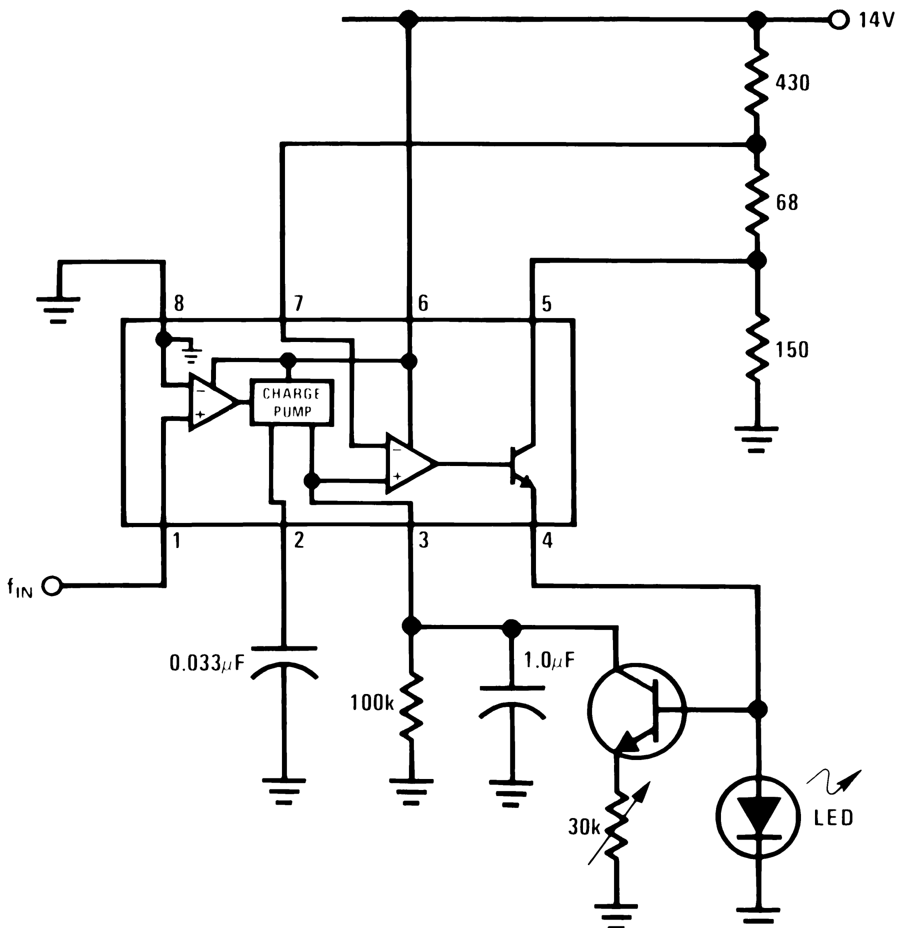




00794219

00794218

Flashing LED Indicates Overspeed

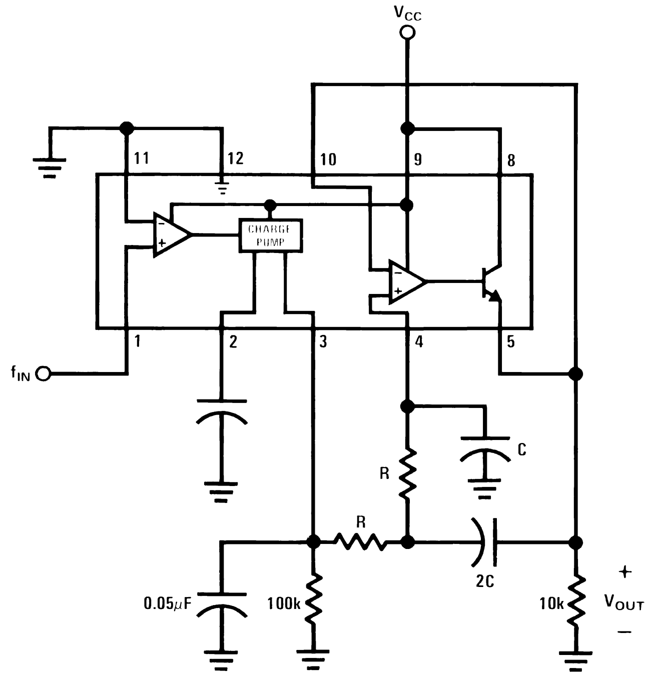


00794220

Flashing begins when $f_{IN} \geq 100$ Hz.
Flash rate increases with input frequency
increase beyond trip point.

Typical Applications (Continued)

Frequency to Voltage Converter with 2 Pole Butterworth Filter to Reduce Ripple

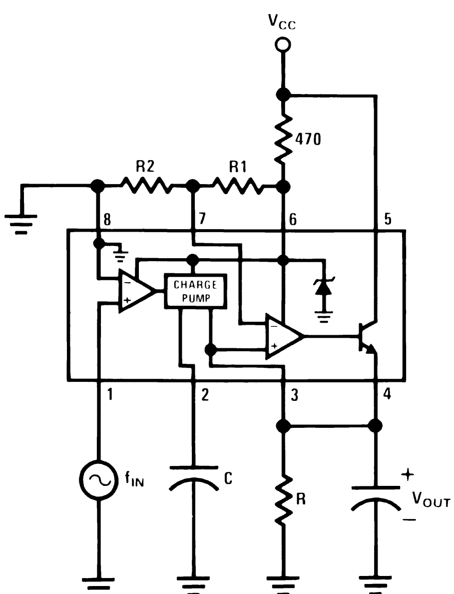


00794221

$$f_{POLE} = \frac{0.707}{2\pi RC}$$

$$\tau_{RESPONSE} = \frac{2.57}{2\pi f_{POLE}}$$

Overspeed Latch



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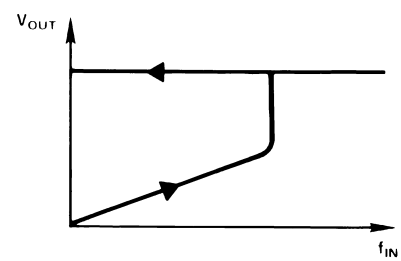


00794223

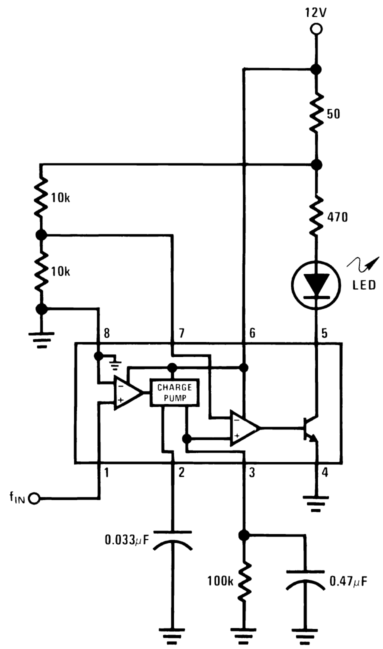
Output latches when

$$f_{IN} = \frac{R2}{R1 + R2} \frac{1}{RC}$$

Reset by removing V_{CC}.

Typical Applications (Continued)

Some Frequency Switch Applications May Require Hysteresis in the Comparator Function Which can be Implemented in Several Ways:



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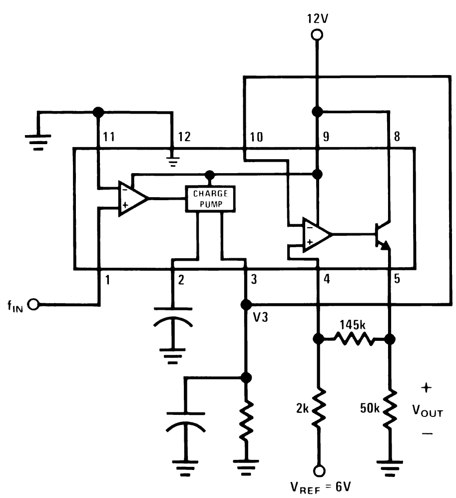

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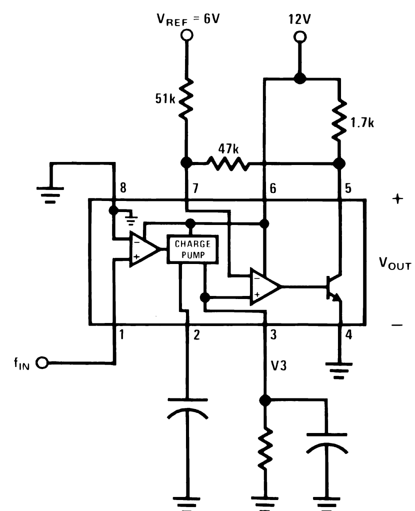

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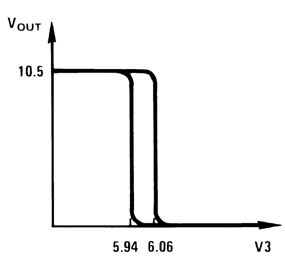

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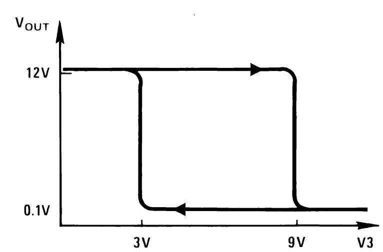
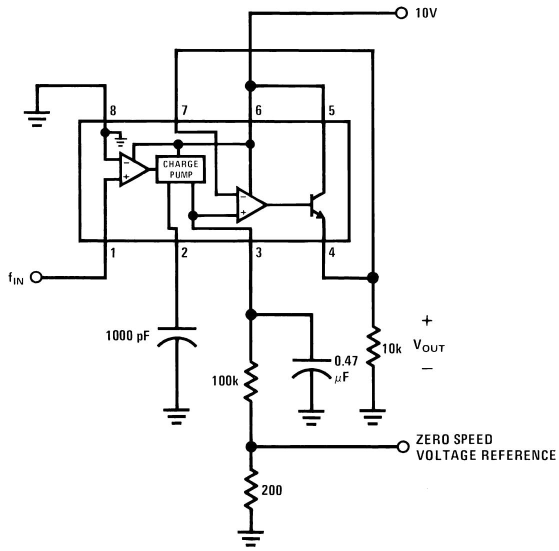


00794228

Typical Applications (Continued)

Changing the Output Voltage for an Input Frequency of Zero



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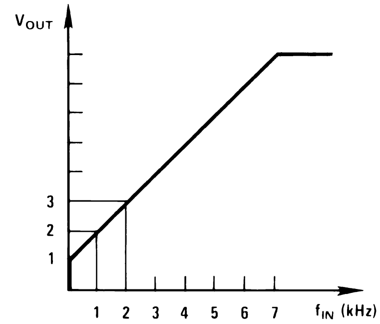
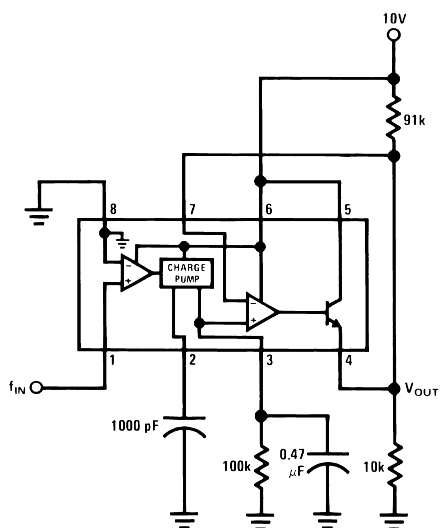
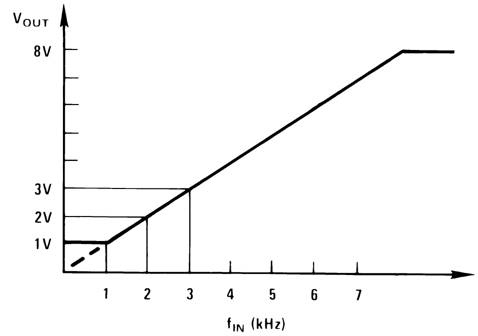


00794230

Changing Tachometer Gain Curve or Clamping the Minimum Output Voltage



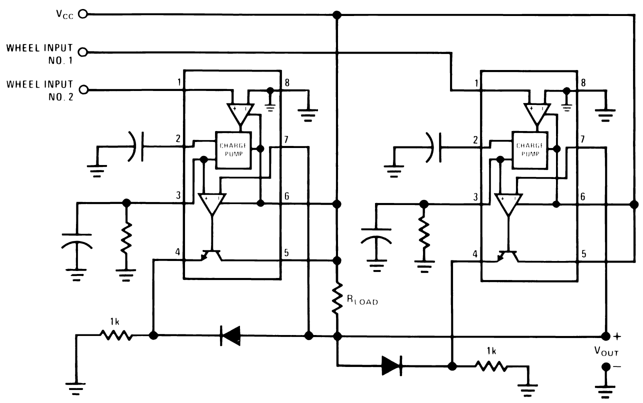
00794231



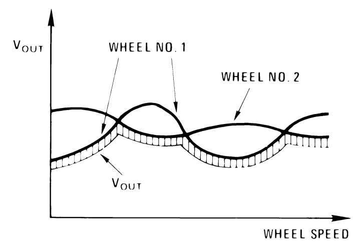
00794232

Anti-Skid Circuit Functions

"Select-Low" Circuit



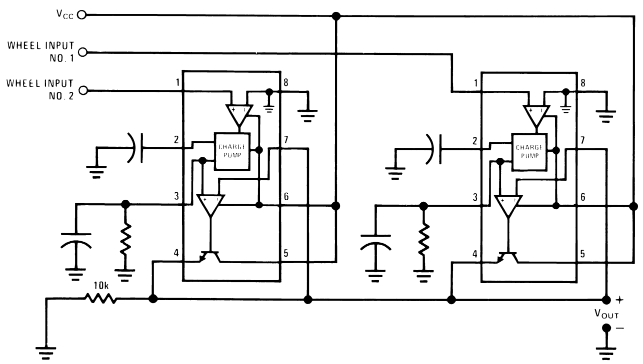
00794233



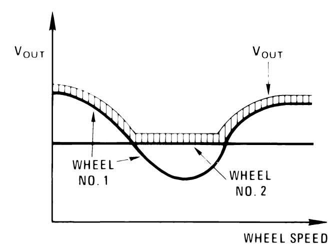
00794234

V_{OUT} is proportional to the lower of the two input wheel speeds.

"Select-High" Circuit



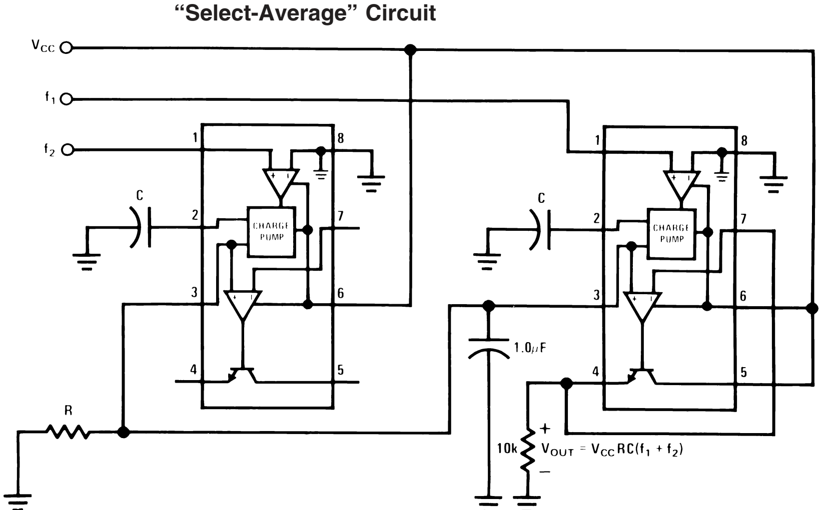
00794235



00794236

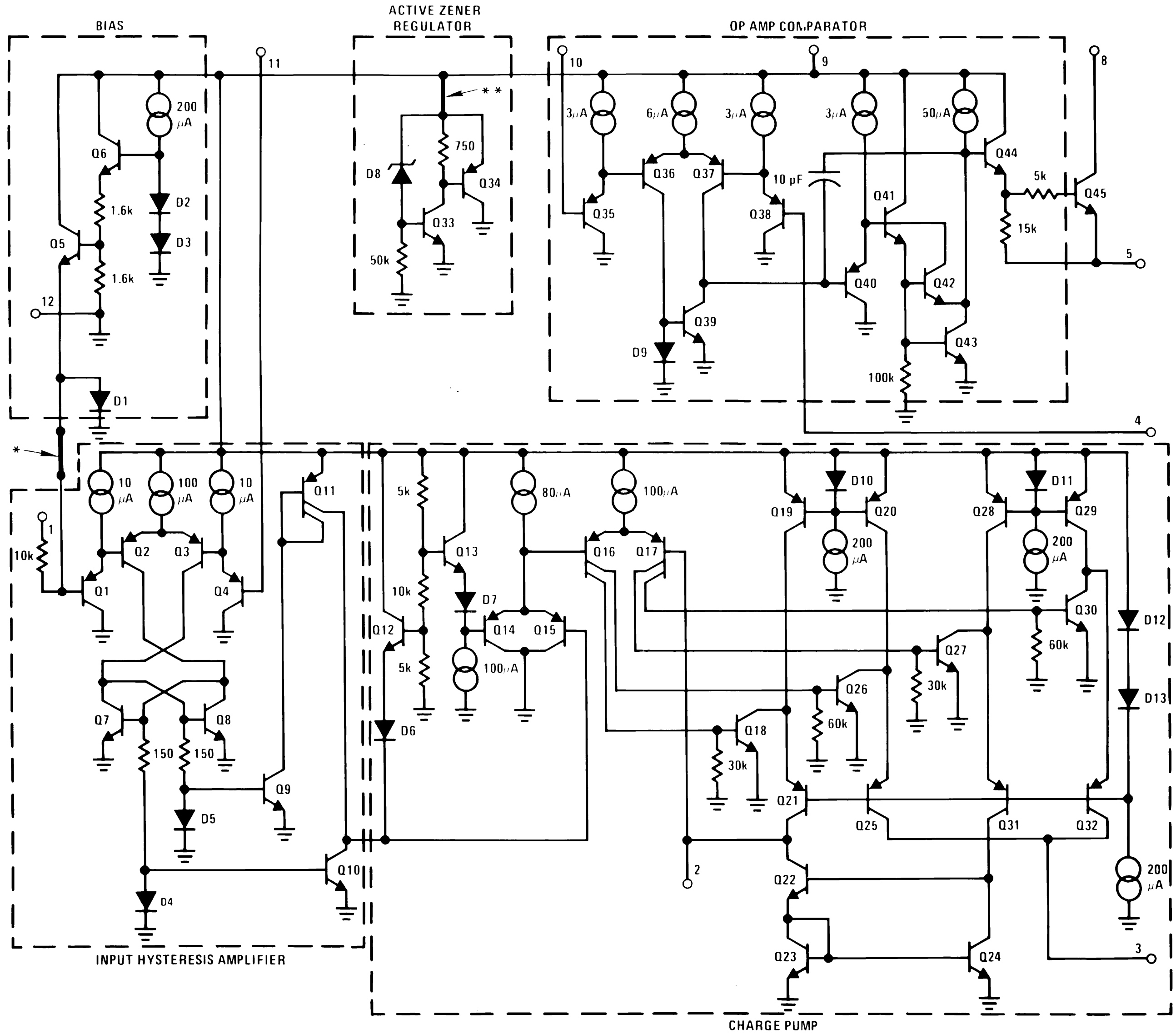
V_{OUT} is proportional to the higher of the two input wheel speeds.

"Select-Average" Circuit



00794237

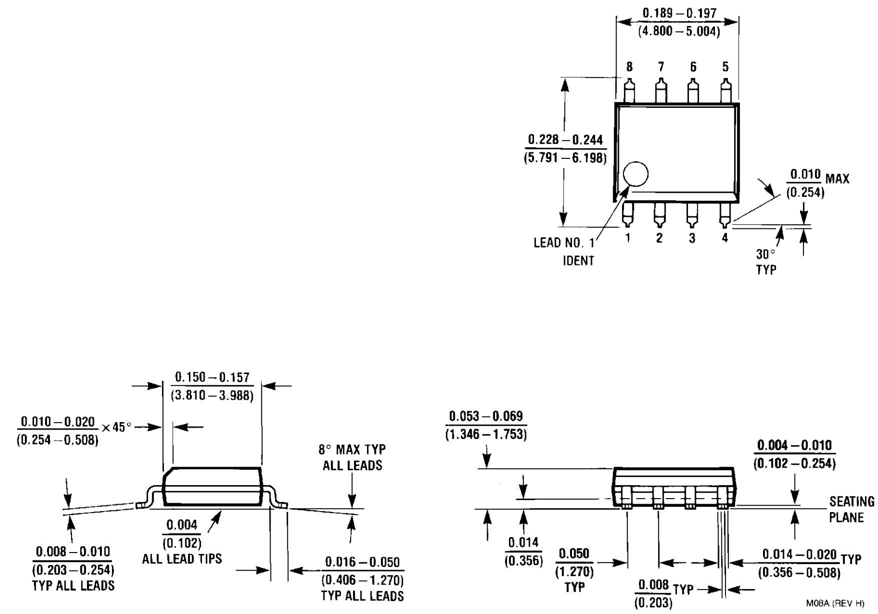
Equivalent Schematic Diagram



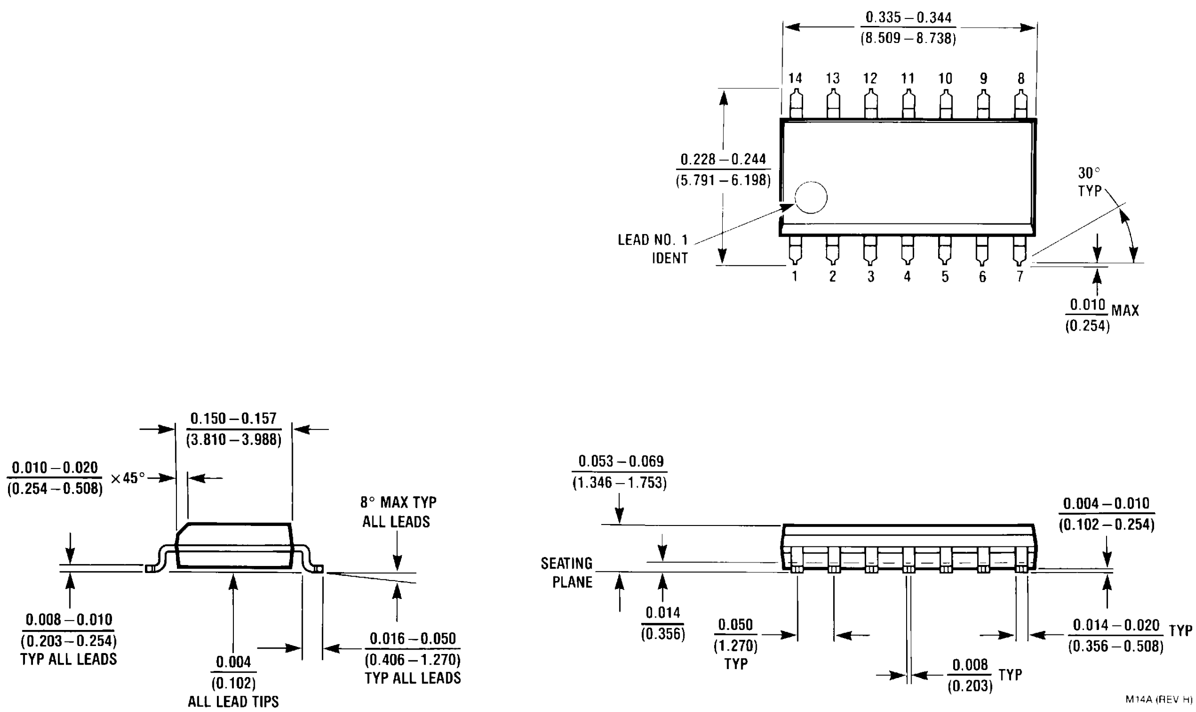
*This connection made on LM2907-8 and LM2917-8 only.

**This connection made on LM2917 and LM2917-8 only.

Physical Dimensions inches (millimeters) unless otherwise noted

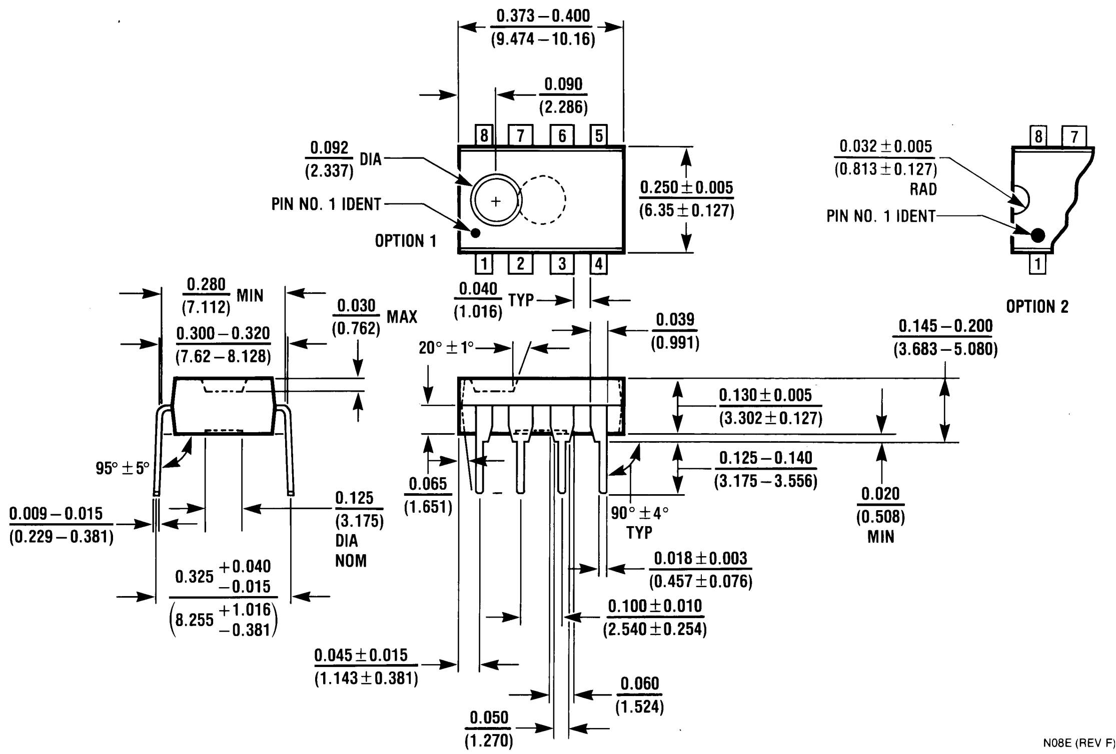


8-Lead (0.150" Wide) Molded Small Outline Package, JEDEC
Order Number LM2907M-8 or LM2917M-8
NS Package Number M08A

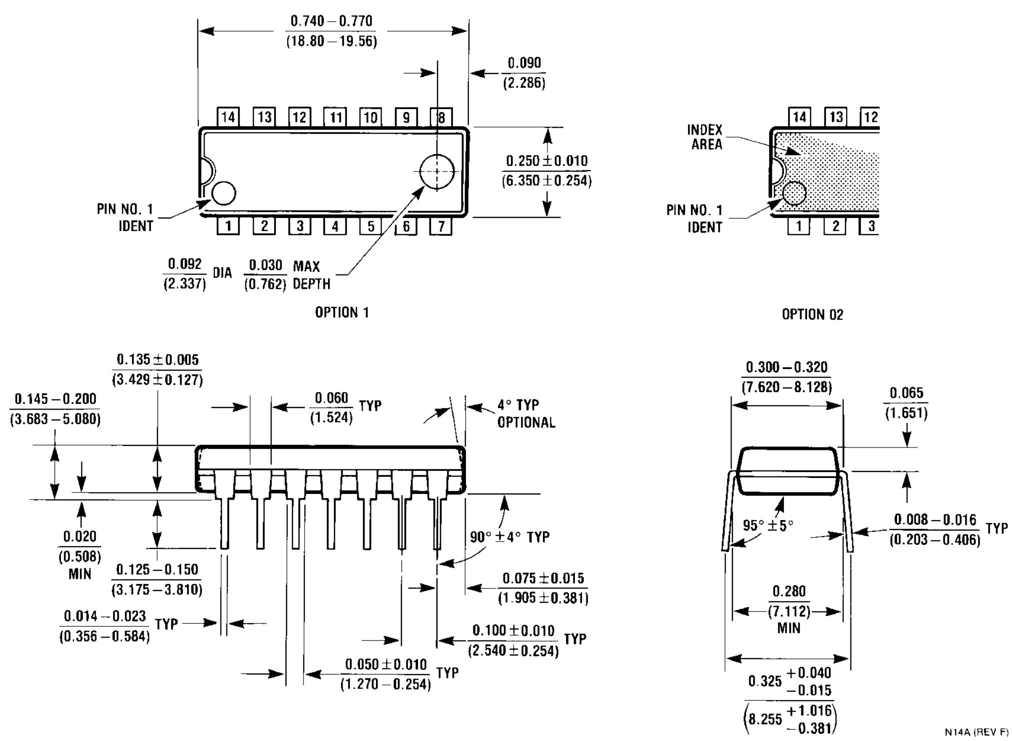


Molded SO Package (M)
Order Number LM2907M or LM2917M
NS Package Number M14A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Molded Dual-In-Line Package (N)
Order Number LM2907N-8 or LM2917N-8
NS Package Number N08E



Molded Dual-In-Line Package (N)
Order Number LM2907N or LM2917N
NS Package Number N14A

Notes

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Support Center
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National Semiconductor
Japan Customer Support Center
Fax: 81-3-5639-7507
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August 2004

LM2576/LM2576HV Series SIMPLE SWITCHER® 3A Step-Down Voltage Regulator

General Description

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 µA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 3A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

Typical Application (Fixed Output Voltage Versions)

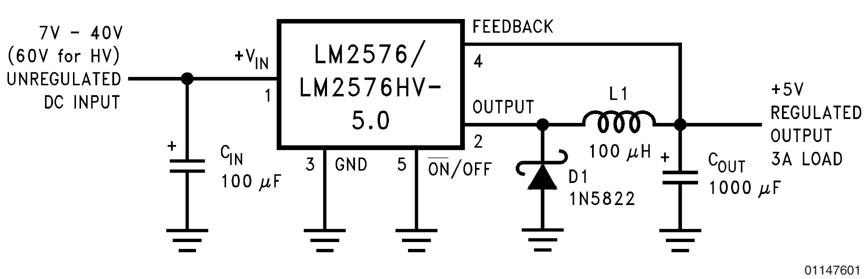
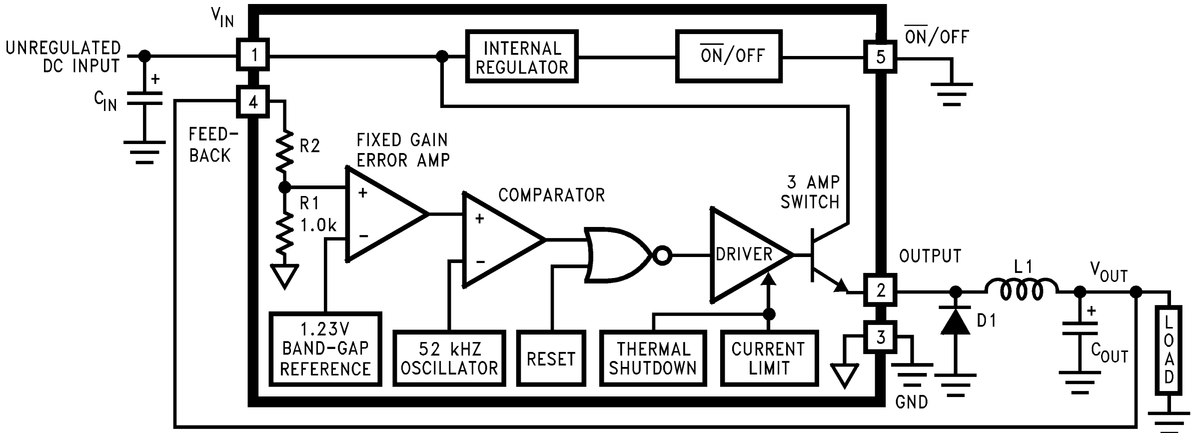


FIGURE 1.

SIMPLE SWITCHER® is a registered trademark of National Semiconductor Corporation.

Block Diagram



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3.3V R2 = 1.7k

5V, R2 = 3.1k

12V, R2 = 8.84k

15V, R2 = 11.3k

For ADJ. Version

R1 = Open, R2 = 0Ω

Patent Pending

Ordering Information

Temperature Range	Output Voltage					NS Package Number	Package Type
	3.3	5.0	12	15	ADJ		
$-40^{\circ}C \le T_A \le 125^{\circ}C$	LM2576HVS-3.3	LM2576HVS-5.0	LM2576HVS-12	LM2576HVS-15	LM2576HVS-ADJ	TS5B	TO-263
	LM2576S-3.3	LM2576S-5.0	LM2576S-12	LM2576S-15	LM2576S-ADJ		
	LM2576HVSX-3.3	LM2576HVSX-5.0	LM2576HVSX-12	LM2576HVSX-15	LM2576HVSX-ADJ	TS5B Tape & Reel	
	LM2576SX-3.3	LM2576SX-5.0	LM2576SX-12	LM2576SX-15	LM2576SX-ADJ		
	LM2576HVT-3.3	LM2576HVT-5.0	LM2576HVT-12	LM2576HVT-15	LM2576HVT-ADJ	T05A	TO-220
	LM2576T-3.3	LM2576T-5.0	LM2576T-12	LM2576T-15	LM2576T-ADJ		
	LM2576HVT-3.3 Flow LB03	LM2576HVT-5.0 Flow LB03	LM2576HVT-12 Flow LB03	LM2576HVT-15 Flow LB03	LM2576HVT-ADJ Flow LB03	T05D	
	LM2576T-3.3 Flow LB03	LM2576T-5.0 Flow LB03	LM2576T-12 Flow LB03	LM2576T-15 Flow LB03	LM2576T-ADJ Flow LB03		

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Maximum Supply Voltage	
LM2576	45V
LM2576HV	63V
$\overline{ON}$ /OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground	
(Steady State)	−1V
Power Dissipation	Internally Limited
Storage Temperature Range	−65˚C to +150˚C
Maximum Junction Temperature	150˚C
Minimum ESD Rating	
(C = 100 pF, R = 1.5 kΩ)	2 kV
Lead Temperature	
(Soldering, 10 Seconds)	260˚C

Operating Ratings

Temperature Range	
LM2576/LM2576HV	$-40˚C \leq T_J \leq +125˚C$
Supply Voltage	
LM2576	40V
LM2576HV	60V

LM2576-3.3, LM2576HV-3.3 Electrical Characteristics

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-3.3 LM2576HV-3.3		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
V_{OUT}	Output Voltage	V_{IN} = 12V, I_{LOAD} = 0.5A Circuit of *Figure 2*	3.3	 3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$6V \leq V_{IN} \leq 40V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$6V \leq V_{IN} \leq 60V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.450/**3.482**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 3A	75		%

LM2576-5.0, LM2576HV-5.0 Electrical Characteristics

Specifications with standard type face are for T_J = 25˚C, and those with *Figure 2* **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-5.0 LM2576HV-5.0		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
V_{OUT}	Output Voltage	V_{IN} = 12V, I_{LOAD} = 0.5A Circuit of *Figure 2*	5.0	 4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.225/**5.275**	V V(Min) V(Max)

LM2576-5.0, LM2576HV-5.0 Electrical Characteristics (Continued)

Specifications with standard type face are for T_J = 25˚C, and those with *Figure 2* **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-5.0 LM2576HV-5.0 Typ	LM2576-5.0 LM2576HV-5.0 Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 3A	77		%

LM2576-12, LM2576HV-12 Electrical Characteristics

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-12 LM2576HV-12 Typ	LM2576-12 LM2576HV-12 Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
V_{OUT}	Output Voltage	V_{IN} = 25V, I_{LOAD} = 0.5A	12		V
		Circuit of *Figure 2*		11.76	V(Min)
				12.24	V(Max)
V_{OUT}	Output Voltage	0.5A ≤ I_{LOAD} ≤ 3A,	12		V
	LM2576	15V ≤ V_{IN} ≤ 40V		11.52/**11.40**	V(Min)
		Circuit of *Figure 2*		12.48/**12.60**	V(Max)
V_{OUT}	Output Voltage	0.5A ≤ I_{LOAD} ≤ 3A,	12		V
	LM2576HV	15V ≤ V_{IN} ≤ 60V		11.52/**11.40**	V(Min)
		Circuit of *Figure 2*		12.54/**12.66**	V(Max)
η	Efficiency	V_{IN} = 15V, I_{LOAD} = 3A	88		%

LM2576-15, LM2576HV-15 Electrical Characteristics

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-15 LM2576HV-15 Typ	LM2576-15 LM2576HV-15 Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
V_{OUT}	Output Voltage	V_{IN} = 25V, I_{LOAD} = 0.5A	15		V
		Circuit of *Figure 2*		14.70	V(Min)
				15.30	V(Max)
V_{OUT}	Output Voltage	0.5A ≤ I_{LOAD} ≤ 3A,	15		V
	LM2576	18V ≤ V_{IN} ≤ 40V		14.40/**14.25**	V(Min)
		Circuit of *Figure 2*		15.60/**15.75**	V(Max)
V_{OUT}	Output Voltage	0.5A ≤ I_{LOAD} ≤ 3A,	15		V
	LM2576HV	18V ≤ V_{IN} ≤ 60V		14.40/**14.25**	V(Min)
		Circuit of *Figure 2*		15.68/**15.83**	V(Max)
η	Efficiency	V_{IN} = 18V, I_{LOAD} = 3A	88		%

LM2576-ADJ, LM2576HV-ADJ Electrical Characteristics

Specifications with standard type face are for $T_J = 25^\circ C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-ADJ LM2576HV-ADJ		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) **Test Circuit *Figure 2***					
V_{OUT}	Feedback Voltage	V_{IN} = 12V, I_{LOAD} = 0.5A V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576	0.5A ≤ I_{LOAD} ≤ 3A, 8V ≤ V_{IN} ≤ 40V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576HV	0.5A ≤ I_{LOAD} ≤ 3A, 8V ≤ V_{IN} ≤ 60V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.273/**1.286**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 3A, V_{OUT} = 5V	77		%

All Output Voltage Versions Electrical Characteristics

Specifications with standard type face are for $T_J = 25^\circ C$, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V_{IN} = 12V for the 3.3V, 5V, and Adjustable version, V_{IN} = 25V for the 12V version, and V_{IN} = 30V for the 15V version. I_{LOAD} = 500 mA.

Symbol	Parameter	Conditions	LM2576-XX LM2576HV-XX		Units (Limits)
			Typ	Limit (Note 2)	
DEVICE PARAMETERS					
I_b	Feedback Bias Current	V_{OUT} = 5V (Adjustable Version Only)	50	100/**500**	nA
f_O	Oscillator Frequency	(Note 11)	52	 47/**42** 58/**63**	kHz kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	I_{OUT} = 3A (Note 4)	1.4	 1.8/**2.0**	V V(Max)
DC	Max Duty Cycle (ON)	(Note 5)	98	 93	% %(Min)
I_{CL}	Current Limit	(Notes 4, 11)	5.8	 4.2/**3.5** 6.9/**7.5**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6, 7): Output = 0V Output = −1V Output = −1V	 7.5 	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$ /OFF Pin = 5V (OFF)	50	 200	μA μA(Max)

All Output Voltage Versions Electrical Characteristics (Continued)

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V_{IN} = 12V for the 3.3V, 5V, and Adjustable version, V_{IN} = 25V for the 12V version, and V_{IN} = 30V for the 15V version. I_{LOAD} = 500 mA.

Symbol	Parameter	Conditions	LM2576-XX LM2576HV-XX		Units (Limits)
			Typ	Limit (Note 2)	
DEVICE PARAMETERS					
θ_{JA}	Thermal Resistance	T Package, Junction to Ambient (Note 8)	65		
θ_{JA}		T Package, Junction to Ambient (Note 9)	45		˚C/W
θ_{JC}		T Package, Junction to Case	2		
θ_{JA}		S Package, Junction to Ambient (Note 10)	50		
$\overline{ON}$ /OFF CONTROL Test Circuit *Figure 2*					
V_{IH}	$\overline{ON}$ /OFF Pin	V_{OUT} = 0V	1.4	2.2/**2.4**	V(Min)
V_{IL}	Logic Input Level	V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	V(Max)
I_{IH}	$\overline{ON}$ /OFF Pin Input Current	$\overline{ON}$ /OFF Pin = 5V (OFF)	12		μA
				30	μA(Max)
I_{IL}		$\overline{ON}$ /OFF Pin = 0V (ON)	0		μA
				10	μA(Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at temperature extremes (bold type face). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2576/LM2576HV is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 7: V_{IN} = 40V (60V for high voltage version).

Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ¼ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

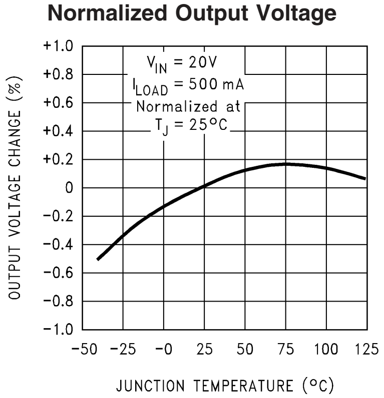
Note 10: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50˚C/W, with 1 square inch of copper area, θ_{JA} is 37˚C/W, and with 1.6 or more square inches of copper area, θ_{JA} is 32˚C/W.

Note 11: The oscillator frequency reduces to approximately 11 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics

(Circuit of *Figure 2*)

Normalized Output Voltage



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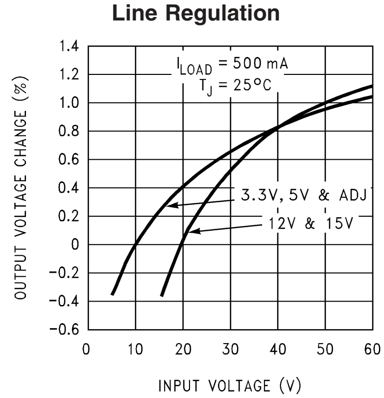
Line Regulation



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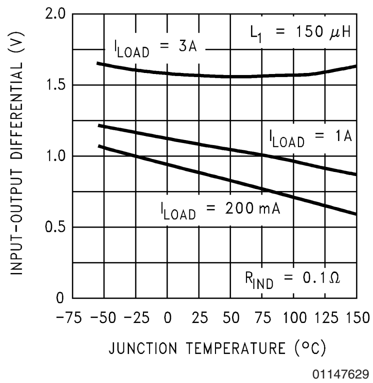
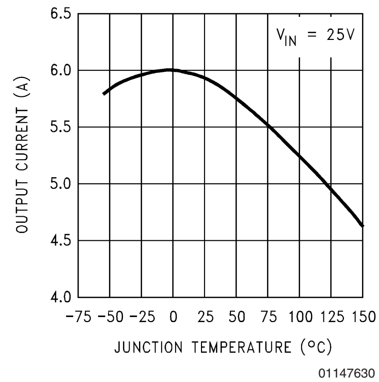
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

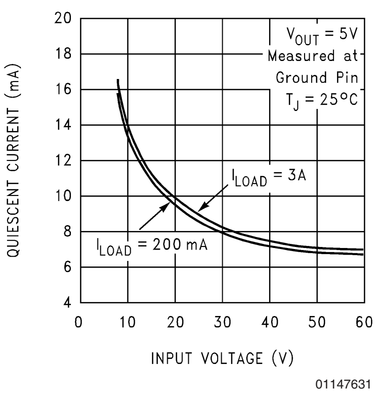
Dropout Voltage



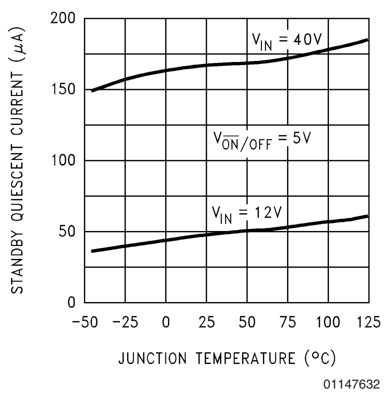
Current Limit



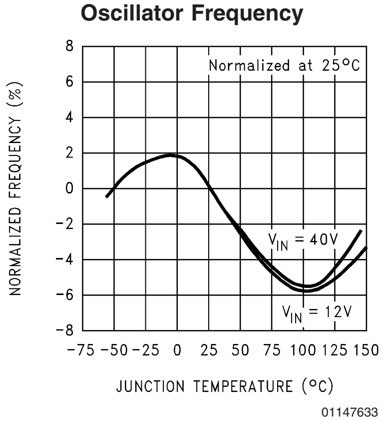
Quiescent Current



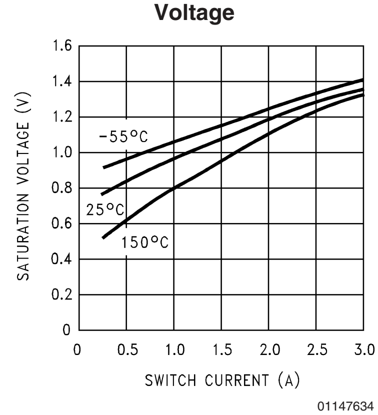
Standby Quiescent Current



Oscillator Frequency

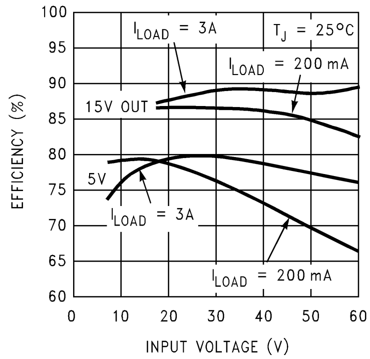


Switch Saturation Voltage



Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Efficiency



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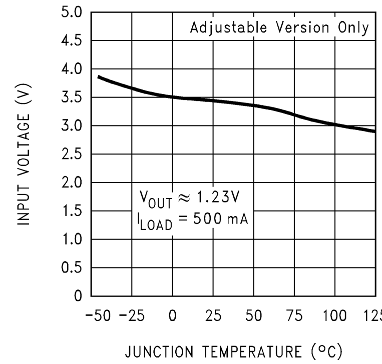
Minimum Operating Voltage



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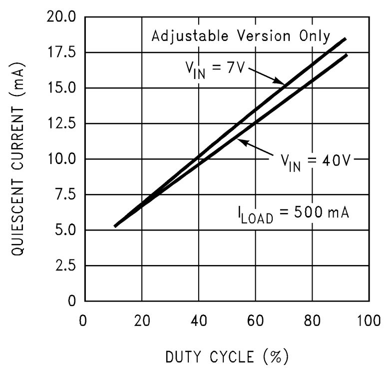
Quiescent Current vs Duty Cycle



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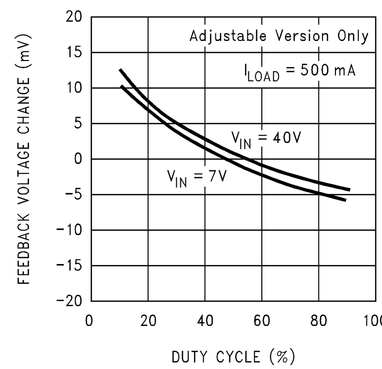
Feedback Voltage vs Duty Cycle



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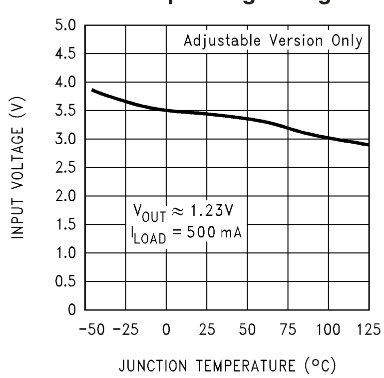
Minimum Operating Voltage



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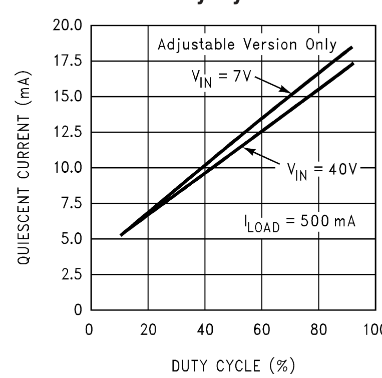
Quiescent Current vs Duty Cycle



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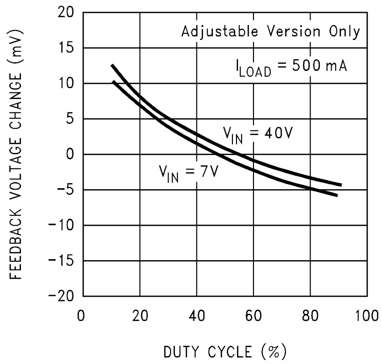
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Feedback Voltage vs Duty Cycle



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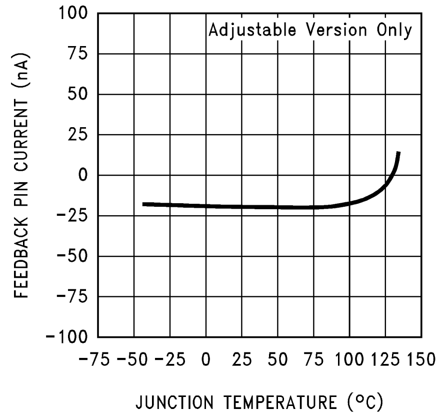
Feedback Pin Current



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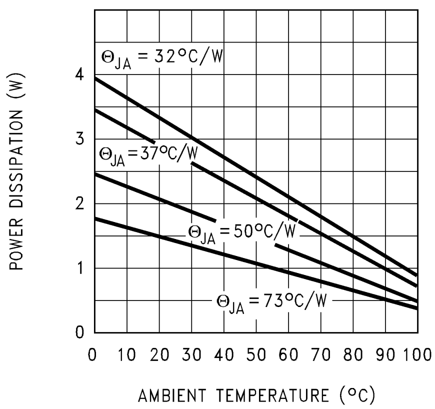
Maximum Power Dissipation (TO-263) (See Note 10)



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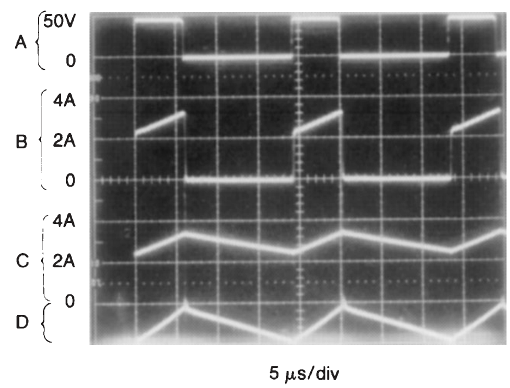
Switching Waveforms



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V_{OUT} = 15V

A: Output Pin Voltage, 50V/div

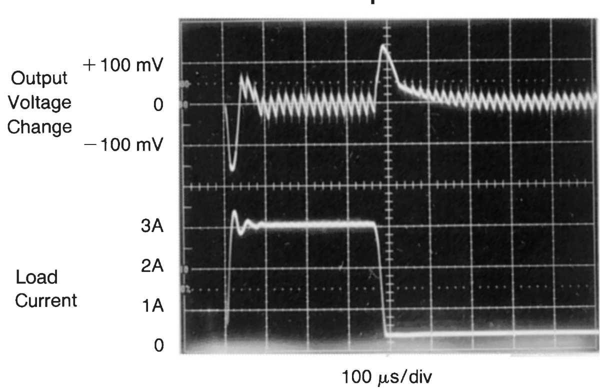
B: Output Pin Current, 2A/div

C: Inductor Current, 2A/div

D: Output Ripple Voltage, 50 mV/div, AC-Coupled

Horizontal Time Base: 5 µs/div

Load Transient Response



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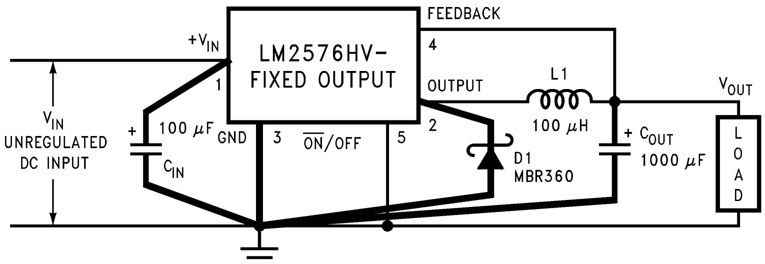
Test Circuit and Layout Guidelines

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible.

Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Fixed Output Voltage Versions



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C_{IN} — 100 µF, 75V, Aluminum Electrolytic

C_{OUT} — 1000 µF, 25V, Aluminum Electrolytic

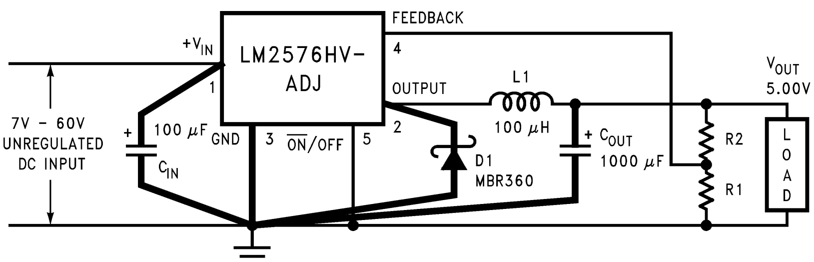
D_1 — Schottky, MBR360

L_1 — 100 µH, Pulse Eng. PE-92108

R_1 — 2k, 0.1%

R_2 — 6.12k, 0.1%

Adjustable Output Voltage Version



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$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where V_{REF} = 1.23V, R1 between 1k and 5k.

FIGURE 2.

LM2576 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(Max) = 15V I_{LOAD}(Max) = 3A
1. Inductor Selection (L1) A. Select the correct Inductor value selection guide from *Figures 3, 4, 5* or *Figure 6*. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by V_{IN}(Max) and I_{LOAD}(Max), and note the inductor code for that region. **C.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 3*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of 1.15 x I_{LOAD}. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1) A.** Use the selection guide shown in *Figure 4*. **B.** From the selection guide, the inductance area intersected by the 15V line and 3A line is L100. **C.** Inductor value required is 100 µH. From the table in *Figure 3*. Choose AIE 415-0930, Pulse Engineering PE92108, or Renco RL2444.
2. Output Capacitor Selection (C_{OUT}) A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 µF and 470 µF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT}) A.** C_{OUT} = 680 µF to 2000 µF standard aluminum electrolytic. **B.**Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1) A.**For this example, a 3A current rating is adequate. **B.** Use a 20V 1N5823 or SR302 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 8*.
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 100 µF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

LM2576 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

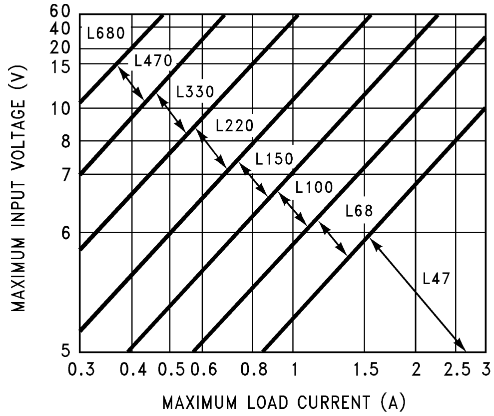

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FIGURE 3. LM2576(HV)-3.3

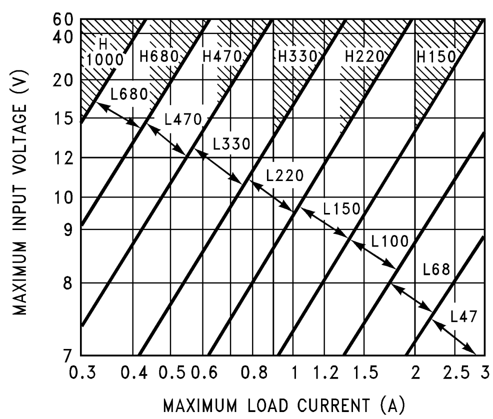

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FIGURE 4. LM2576(HV)-5.0

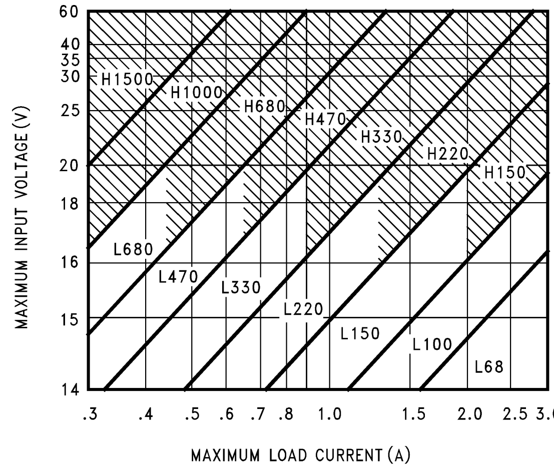

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FIGURE 5. LM2576(HV)-12

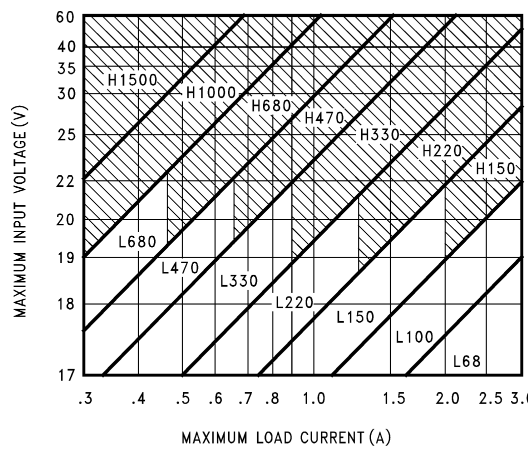

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FIGURE 6. LM2576(HV)-15

LM2576 Series Buck Regulator Design Procedure (Continued)

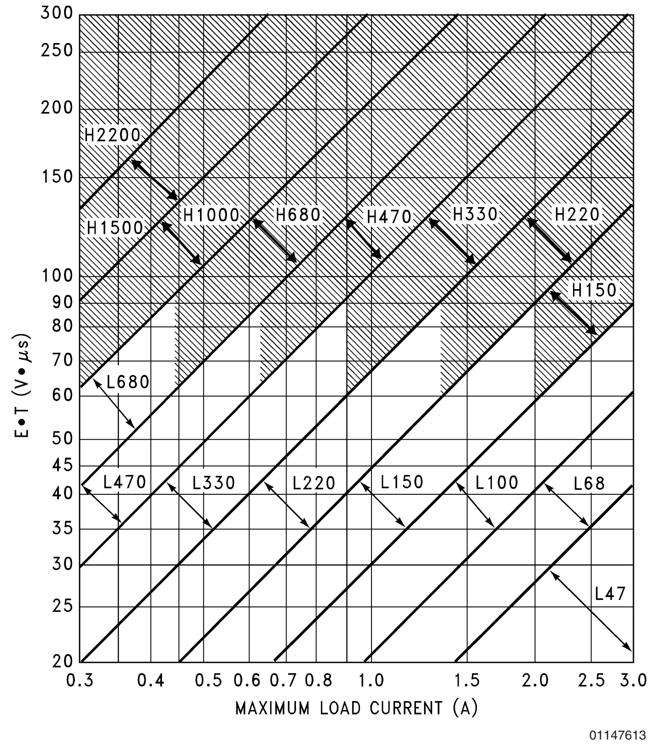


FIGURE 7. LM2576(HV)-ADJ

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current F = Switching Frequency *(Fixed at 52 kHz)*	**Given:** V_{OUT} = 10V V_{IN}(Max) = 25V I_{LOAD}(Max) = 3A F = 52 kHz
1. Programming Output Voltage *(Selecting R1 and R2, as shown in Figure 2)* Use the following formula to select the appropriate resistor values. $$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$ R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)* $$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$	**1. Programming Output Voltage** *(Selecting R1 and R2)* $$V_{OUT} = 1.23\left(1 + \frac{R_2}{R_1}\right) \quad \text{Select } R1 = 1k$$ $$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$$ R_2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
2. Inductor Selection (L1) A. Calculate the inductor Volt • microsecond constant, E • T (V • µs), from the following formula: $$E \bullet T = (V_{IN} - V_{OUT}) \frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (in\ kHz)} (V \bullet \mu s)$$ **B.** Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 7*. **C.** On the horizontal axis, select the maximum load current. **D.** Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor code for that region. **E.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of 1.15 x I_{LOAD}. For additional inductor information, see the inductor section in the application hints section of this data sheet.	**2. Inductor Selection (L1) A.** Calculate E • T (V • µs) $$E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115\ V \bullet \mu s$$ **B.** E • T = 115 V • µs **C.** I_{LOAD}(Max) = 3A **D.** Inductance Region = H150 **E.** Inductor Value = 150 µH *Choose from **AIE** part #415-0936 **Pulse Engineering** part* #PE-531115, or ***Renco part #RL2445.***
3. Output Capacitor Selection (C_{OUT}) A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement: $$C_{OUT} \geq 13{,}300 \frac{V_{IN}(Max)}{V_{OUT} \bullet L(\mu H)} (\mu F)$$ The above formula yields capacitor values between 10 µF and 2200 µF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields. **B.** The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.	**3. Output Capacitor Selection (C_{OUT})** $$C_{OUT} > 13{,}300 \frac{25}{10 \bullet 150} = 22.2\ \mu F$$ However, for acceptable output ripple voltage select C_{OUT} ≥ 680 µF C_{OUT} = 680 µF electrolytic capacitor
4. Catch Diode Selection (D1) A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8*. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1) A.** For this example, a 3.3A current rating is adequate. **B.** Use a 30V 31DQ03 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8*.
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 100 µF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

*To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the SIMPLE SWITCHER line of switching regulators. **Switchers Made Simple** (Version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

V_R	Schottky		Fast Recovery	
	3A	4A–6A	3A	4A–6A
20V	1N5820 MBR320P SR302	1N5823	The following diodes are all rated to 100V 31DF1 HER302	The following diodes are all rated to 100V 50WF10 MUR410 HER602
30V	1N5821 MBR330 31DQ03 SR303	50WQ03 1N5824		
40V	1N5822 MBR340 31DQ04 SR304	MBR340 50WQ04 1N5825		
50V	MBR350 31DQ05 SR305	50WQ05		
60V	MBR360 DQ06 SR306	50WR06 50SQ060		

FIGURE 8. Diode Selection Guide

Inductor Code	**Inductor Value**	**Schott** (Note 12)	**Pulse Eng.** (Note 13)	**Renco** (Note 14)
L47	47 µH	671 26980	PE-53112	RL2442
L68	68 µH	671 26990	PE-92114	RL2443
L100	100 µH	671 27000	PE-92108	RL2444
L150	150 µH	671 27010	PE-53113	RL1954
L220	220 µH	671 27020	PE-52626	RL1953
L330	330 µH	671 27030	PE-52627	RL1952
L470	470 µH	671 27040	PE-53114	RL1951
L680	680 µH	671 27050	PE-52629	RL1950
H150	150 µH	671 27060	PE-53115	RL2445
H220	220 µH	671 27070	PE-53116	RL2446
H330	330 µH	671 27080	PE-53117	RL2447
H470	470 µH	671 27090	PE-53118	RL1961
H680	680 µH	671 27100	PE-53119	RL1960
H1000	1000 µH	671 27110	PE-53120	RL1959
H1500	1500 µH	671 27120	PE-53121	RL1958
H2200	2200 µH	671 27130	PE-53122	RL2448

Note 12: Schott Corporation, (612) 475-1173, 1000 Parkers Lake Road, Wayzata, MN 55391.

Note 13: Pulse Engineering, (619) 674-8100, P.O. Box 12235, San Diego, CA 92112.

Note 14: Renco Electronics Incorporated, (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 100 µF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below –25˚C, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

Application Hints (Continued)

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

where $\frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$ for a buck regulator

and $\frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}}$ for a buck-boost regulator.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2576 (or any of the SIMPLE SWITCHER family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figure 3* through *Figure 7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 300 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toriod, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2576 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 µF–1000 µF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

Output Ripple Voltage = (ΔI_{IND}) (ESR of C_{OUT})

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

Application Hints (Continued)

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2576 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 µH & 100 µF) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 x reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2576 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2576 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$ /OFF INPUT

For normal operation, the $\overline{\text{ON}}$ /OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$ /OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$ /OFF pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the 5-lead TO-220 and TO-263 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, only a small heat sink is required to keep the LM2576 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (125˚C for the LM2576). For a safe, conservative design, a temperature approximately 15˚C cooler than the maximum temperatures should be selected.
4. LM2576 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2576 can be estimated as follows:

$$P_D = (V_{IN})(I_Q) + (V_O/V_{IN})(I_{LOAD})(V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\ (\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\ (\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

Included on the **Switcher Made Simple** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2576-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 700 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

Additional Applications (Continued)

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 µH and 220 µH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}\,(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}\,|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2L_1\,f_{osc}}$$

Where f_{osc} = 52 kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

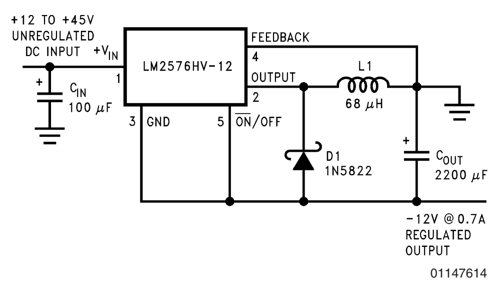


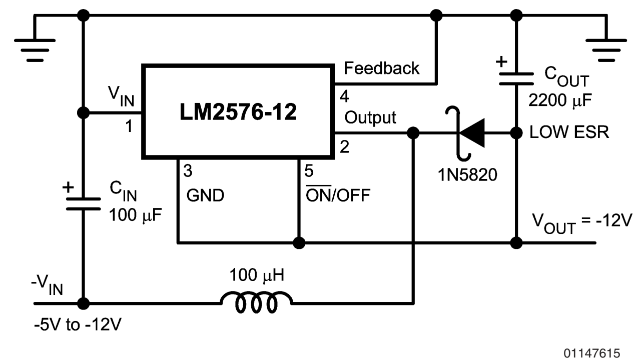
FIGURE 10. Inverting Buck-Boost Develops −12V

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2576 is +28V, or +48V for the LM2576HV.

The ***Switchers Made Simple*** (version 3.0) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.



Typical Load Current

400 mA for V_{IN} = −5.2V

750 mA for V_{IN} = −7V

Note: Heat sink may be required.

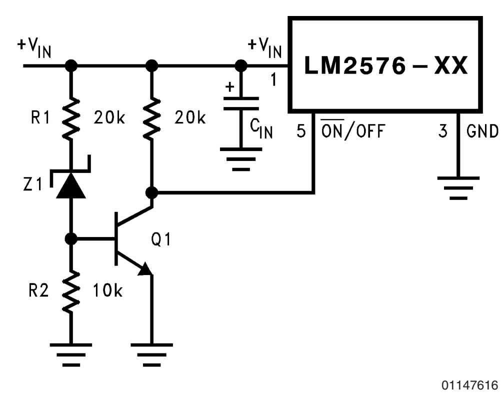
FIGURE 11. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

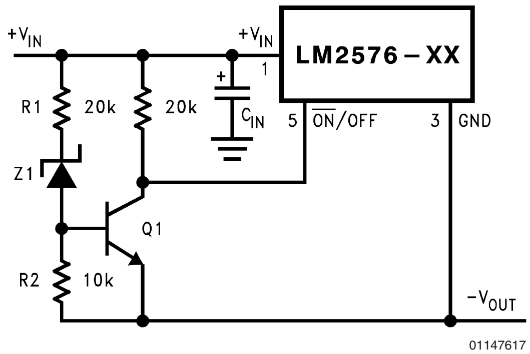
$V_{TH} \approx V_{Z1} + 2V_{BE}(Q1)$



Note: Complete circuit not shown.

FIGURE 12. Undervoltage Lockout for Buck Circuit

Additional Applications (Continued)



Note: Complete circuit not shown (see *Figure 10*).

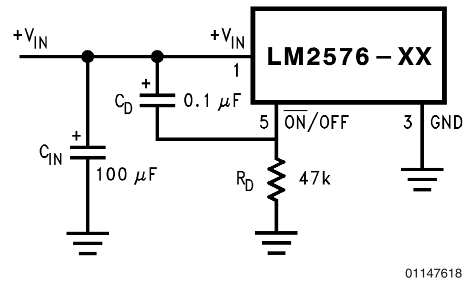
FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit

DELAYED STARTUP

The $\overline{\text{ON}}$ /OFF pin can be used to provide a delayed startup feature as shown in *Figure 14*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{\text{ON}}$ /OFF pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 3A power supply that features an adjustable output voltage is shown in *Figure 15*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



Note: Complete circuit not shown.

FIGURE 14. Delayed Startup

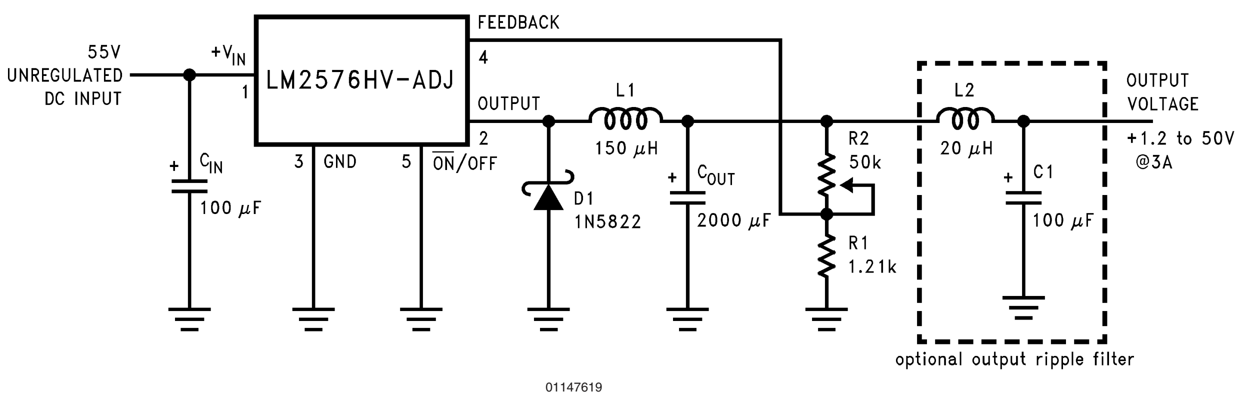


FIGURE 15. 1.2V to 55V Adjustable 3A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator

$$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$$

for buck-boost regulator

$$D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2576 switch is OFF.

EFFICIENCY (η)

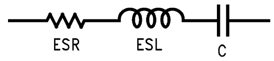
The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Definition of Terms (Continued)

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.



01147620

FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 µF–1000 µF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors (“low-ESR”, “high-frequency”, or “low-inductance”) in the 100 µF–1000 µF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2576 when in the standby mode ($\overline{ON}$ /OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

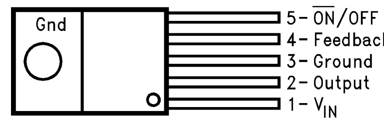
The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

OPERATING VOLT MICROSECOND CONSTANT ($E \bullet T_{op}$)

The product (in Volt•µs) of the voltage applied to the inductor and the time the voltage is applied. This $E \bullet T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams (Note 15)

Straight Leads
5-Lead TO-220 (T)
Top View



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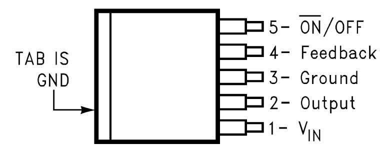
LM2576T-XX or LM2576HVT-XX
NS Package Number T05A

TO-263 (S)
5-Lead Surface-Mount Package
Top View

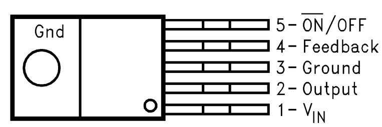


Side View

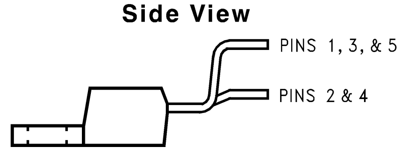
01147625

LM2576S-XX or LM2576HVS-XX
NS Package Number TS5B
LM2576SX-XX or LM2576HVSX-XX
NS Package Number TS5B, Tape and Reel

Bent, Staggered Leads
5-Lead TO-220 (T)
Top View



Side View

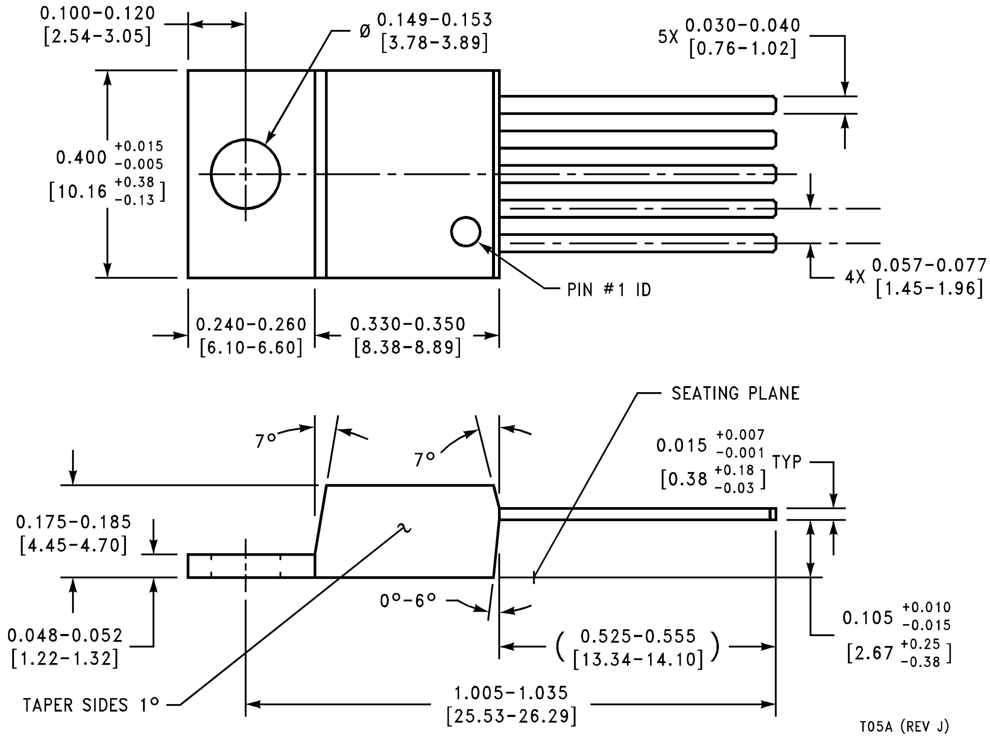


01147622

LM2576T-XX Flow LB03
or LM2576HVT-XX Flow LB03
NS Package Number T05D

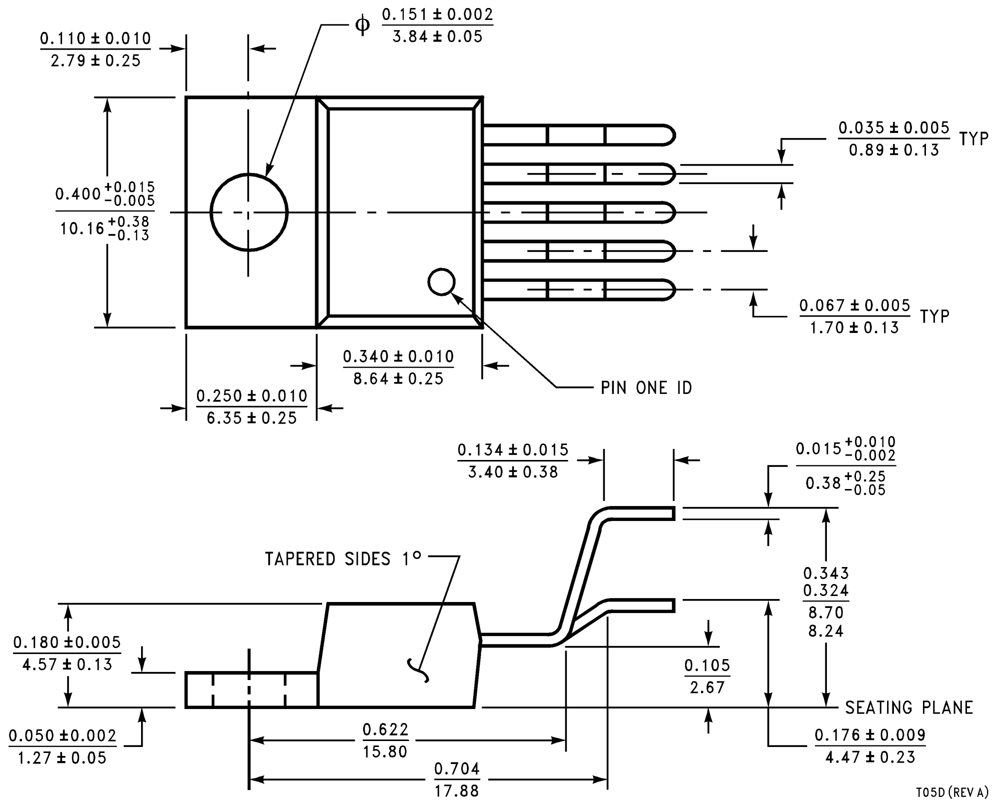
Note 15: (XX indicates output voltage option. See ordering information table for complete part number.)

Physical Dimensions inches (millimeters) unless otherwise noted



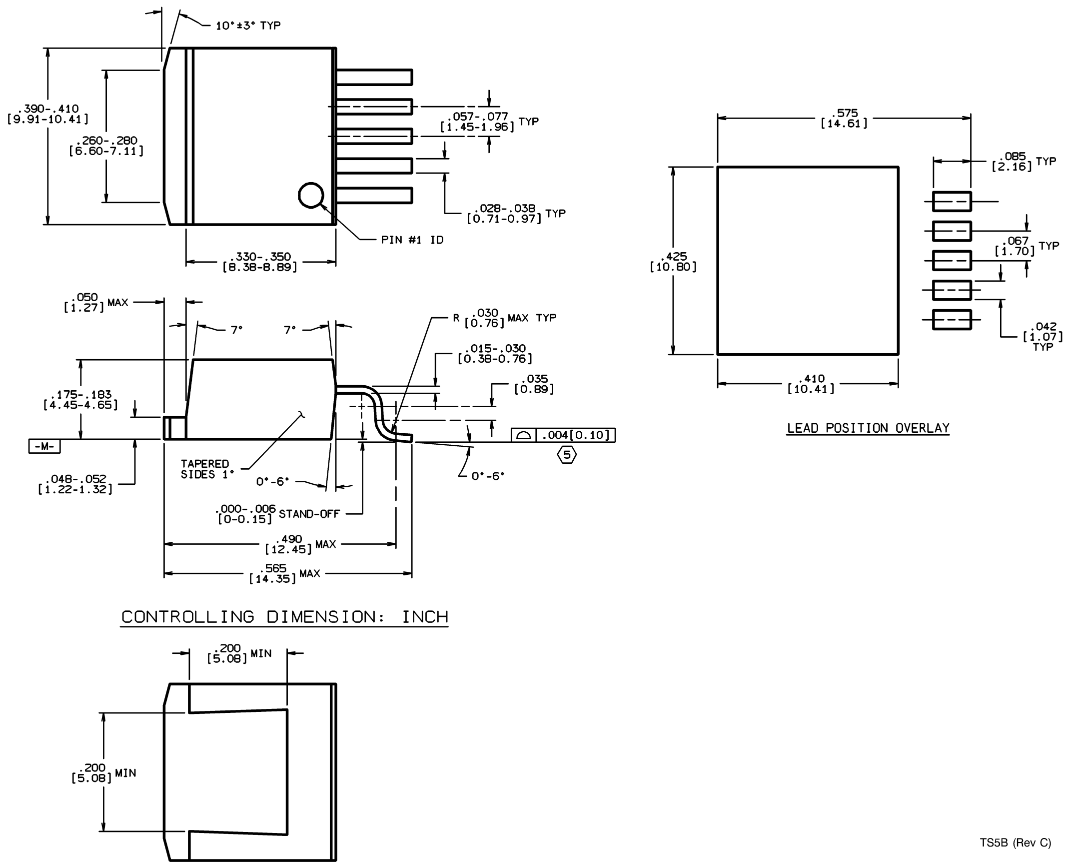
5-Lead TO-220 (T)
Order Number LM2576T-3.3, LM2576HVT-3.3, LM2576T-5.0, LM2576HVT-5.0, LM2576T-12, LM2576HVT-12, LM2576T-15, LM2576HVT-15, LM2576T-ADJ or LM2576HVT-ADJ
NS Package Number T05A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Bent, Staggered 5-Lead TO-220 (T)
Order Number LM2576T-3.3 Flow LB03, LM2576T-XX Flow LB03, LM2576HVT-3.3 Flow LB03,
LM2576T-5.0 Flow LB03, LM2576HVT-5.0 Flow LB03,
LM2576T-12 Flow LB03, LM2576HVT-12 Flow LB03,
LM2576T-15 Flow LB03, LM2576HVT-15 Flow LB03,
LM2576T-ADJ Flow LB03 or LM2576HVT-ADJ Flow LB03
NS Package Number T05D

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TS5B (Rev C)

5-Lead TO-263 (S)
Order Number LM2576S-3.3, LM2576S-5.0,
LM2576S-12,LM2576S-15, LM2576S-ADJ,
LM2576HVS-3.3, LM2576HVS-5.0, LM2576HVS-12,
LM2576HVS-15, or LM2576HVS-ADJ
NS Package Number TS5B
5-Lead TO-263 in Tape & Reel (SX)
Order Number LM2576SX-3.3, LM2576SX-5.0,
LM2576SX-12, LM2576SX-15, LM2576SX-ADJ,
LM2576HVSX-3.3, LM2576HVSX-5.0, LM2576HVSX-12,
LM2576HVSX-15, or LM2576HVSX-ADJ
NS Package Number TS5B

Notes

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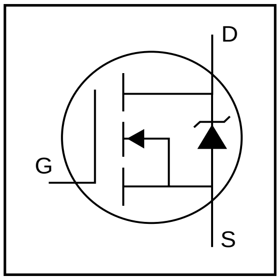
- Fast Switching
- Repetitive Avalanche Allowed up to Tjmax



V_{DSS} = 75V

$R_{DS(on)}$ = 0.0078Ω

I_D = 130A⑥

Description

Specifically designed for Automotive applications, this Stripe Planar design of HEXFET® Power MOSFETs utilizes the lastest processing techniques to achieve extremely low on-resistance per silicon area. Additional features of this HEXFET power MOSFET are a 175°C junction operating temperature, fast switching speed and improved repetitive avalanche rating. These benefits combine to make this design an extremely efficient and reliable device for use in Automotive applications and a wide variety of other applications.

TO-220AB

Absolute Maximum Ratings

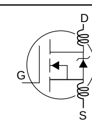
	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	130⑥	
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	92⑥	A
I_{DM}	Pulsed Drain Current ①	520	
P_D @T_C = 25°C	Power Dissipation	330	W
	Linear Derating Factor	2.2	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	390	mJ
I_{AR}	Avalanche Current①	See Fig.12a, 12b, 15, 16	A
E_{AR}	Repetitive Avalanche Energy⑦		mJ
dv/dt	Peak Diode Recovery dv/dt ③	4.6	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting Torque, 6-32 or M3 screw	10 lbf•in (1.1N•m)	

Thermal Resistance

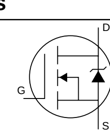
	Parameter	Typ.	Max.	Units
$R_{θJC}$	Junction-to-Case	–––	0.45	
$R_{θCS}$	Case-to-Sink, Flat, Greased Surface	0.50	–––	°C/W
$R_{θJA}$	Junction-to-Ambient	–––	62	

10/11/01

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	75	——	——	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	——	0.09	——	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	——	——	0.0078	Ω	V_{GS} = 10V, I_D = 78A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	——	4.0	V	V_{DS} = 10V, I_D = 250μA
g_{fs}	Forward Transconductance	74	——	——	S	V_{DS} = 25V, I_D = 78A
I_{DSS}	Drain-to-Source Leakage Current	——	——	20	μA	V_{DS} = 75V, V_{GS} = 0V
		——	——	250		V_{DS} = 60V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	——	——	200	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	——	——	-200		V_{GS} = -20V
Q_g	Total Gate Charge	——	160	250	nC	I_D = 78A
Q_{gs}	Gate-to-Source Charge	——	35	52		V_{DS} = 60V
Q_{gd}	Gate-to-Drain ("Miller") Charge	——	54	81		V_{GS} = 10V④
$t_{d(on)}$	Turn-On Delay Time	——	11	——	ns	V_{DD} = 38V
t_r	Rise Time	——	150	——		I_D = 78A
$t_{d(off)}$	Turn-Off Delay Time	——	150	——		R_G = 2.5Ω
t_f	Fall Time	——	140	——		V_{GS} = 10V ④
L_D	Internal Drain Inductance	——	4.5	——	nH	Between lead, 6mm (0.25in.) from package and center of die contact 
L_S	Internal Source Inductance	——	7.5	——		
C_{iss}	Input Capacitance	——	5600	——	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	——	890	——		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	——	190	——		ƒ = 1.0KHz, See Fig. 5
C_{oss}	Output Capacitance	——	5800	——		V_{GS} = 0V, V_{DS} = 1.0V, ƒ = 1.0KHz
C_{oss}	Output Capacitance	——	560	——		V_{GS} = 0V, V_{DS} = 60V, ƒ = 1.0KHz
C_{oss} eff.	Effective Output Capacitance ⑤	——	1100	——		V_{GS} = 0V, V_{DS} = 0V to 60V

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	——	——	130⑥	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①	——	——	520		
V_{SD}	Diode Forward Voltage	——	——	1.3	V	T_J = 25°C, I_S = 78A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	——	110	170	ns	T_J = 25°C, I_F = 78A
Q_{rr}	Reverse RecoveryCharge	——	390	590	nC	di/dt = 100A/μs ④
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11).

② Starting T_J = 25°C, L = 0.13mH R_G = 25Ω, I_{AS} = 78A. (See Figure 12).

③ $I_{SD} \le$ 78A, di/dt ≤ 320A/μs, $V_{DD} \le V_{(BR)DSS}$, $T_J \le$ 175°C

④ Pulse width ≤ 400μs; duty cycle ≤ 2%.

⑤ C_{oss} eff. is a fixed capacitance that gives the same charging time as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS} .

⑥ Calculated continuous current based on maximum allowable junction temperature. Package limitation current is 75A.

⑦ Limited by T_{Jmax} , see Fig.12a, 12b, 15, 16 for typical repetitive avalanche performance.

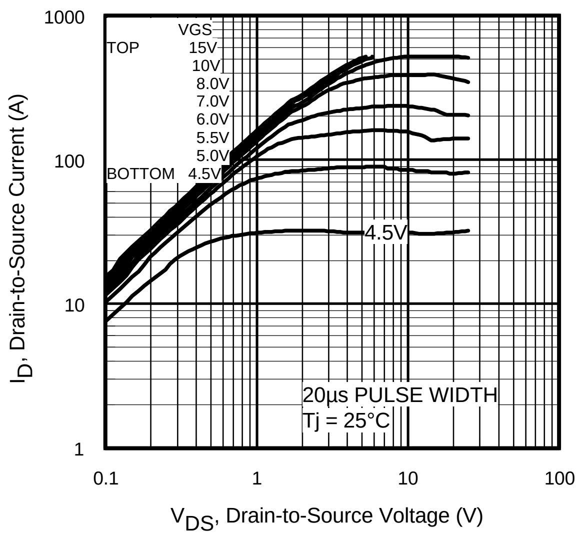


Fig 1. Typical Output Characteristics

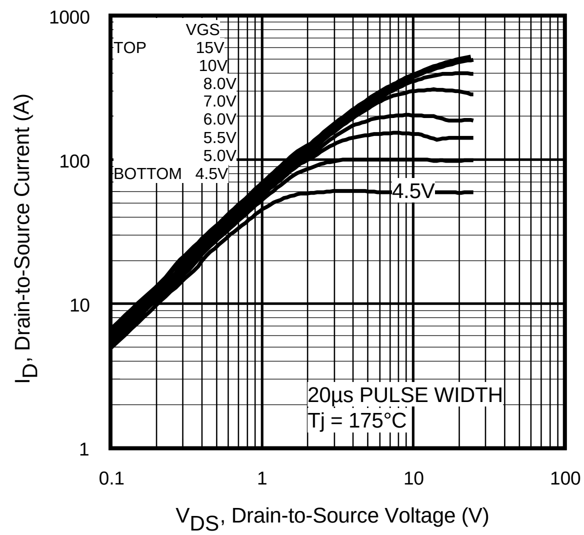


Fig 2. Typical Output Characteristics

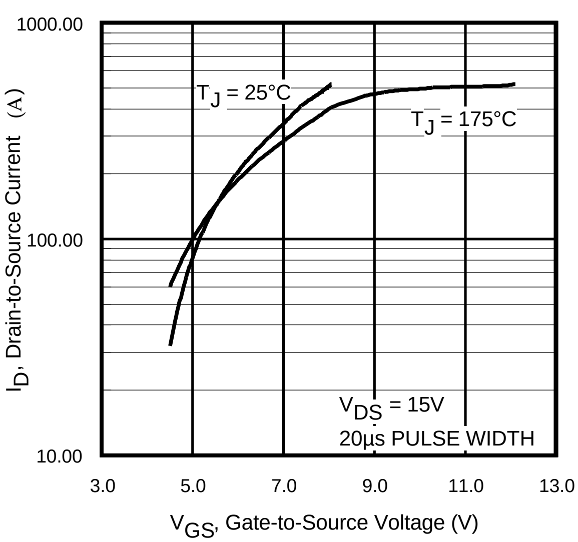


Fig 3. Typical Transfer Characteristics

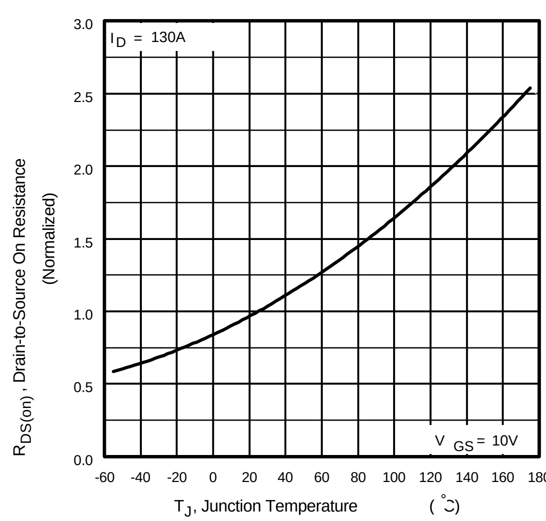


Fig 4. Normalized On-Resistance
vs. Temperature

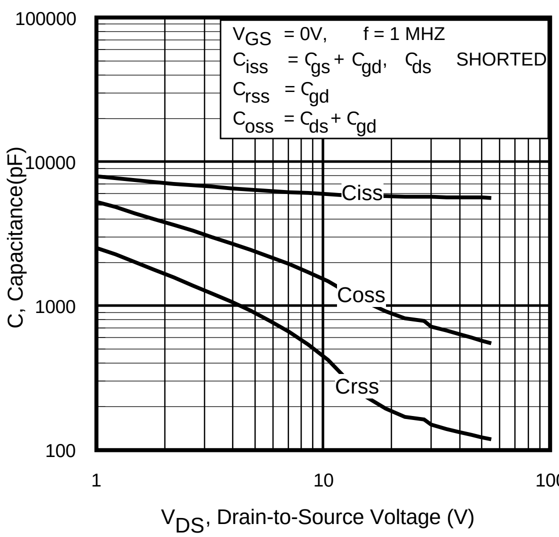


Fig 5. Typical Capacitance vs. Drain-to-Source Voltage

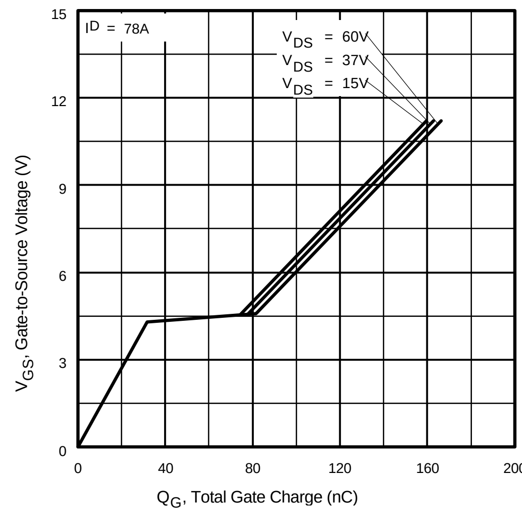


Fig 6. Typical Gate Charge vs. Gate-to-Source Voltage

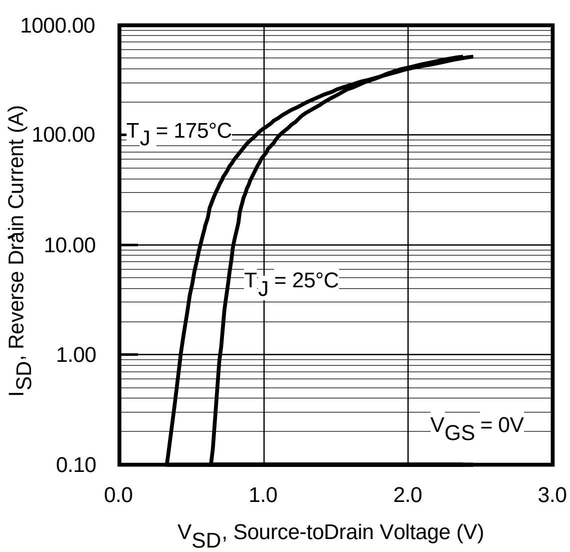


Fig 7. Typical Source-Drain Diode Forward Voltage

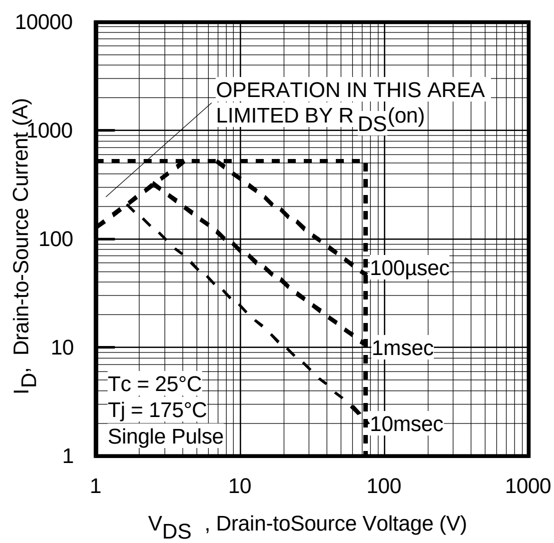


Fig 8. Maximum Safe Operating Area

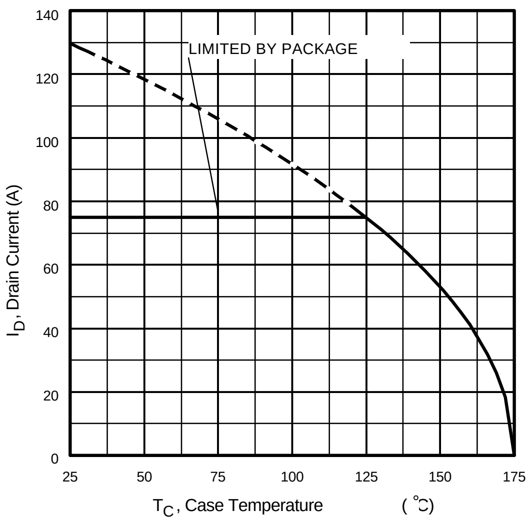


Fig 9. Maximum Drain Current vs. Case Temperature

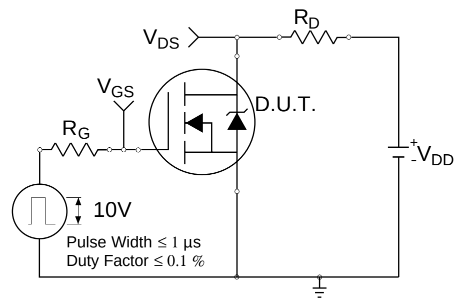


Fig 10a. Switching Time Test Circuit

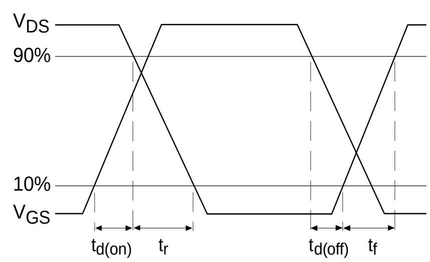


Fig 10b. Switching Time Waveforms

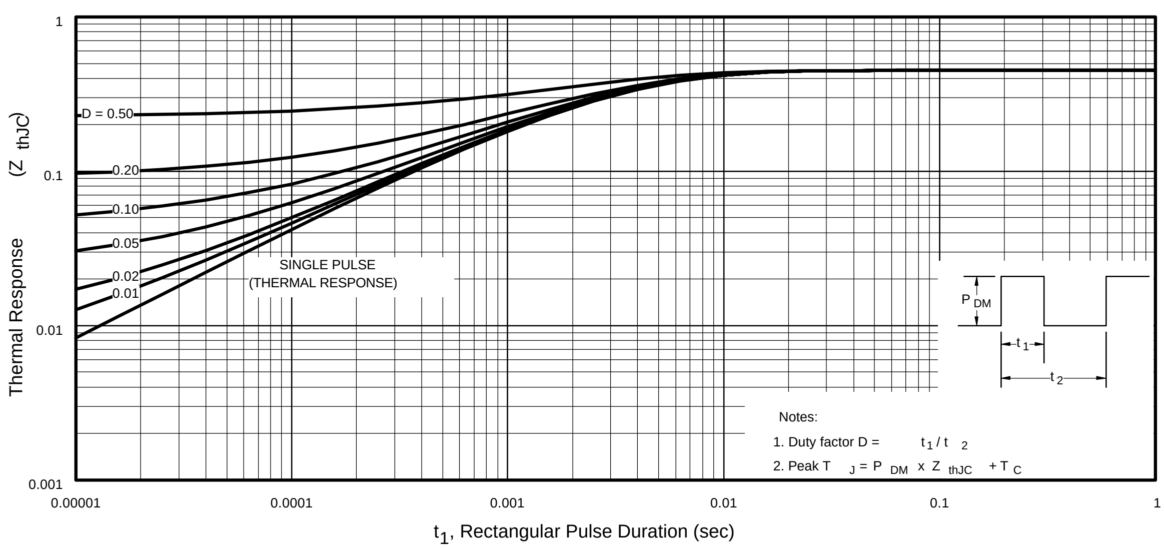


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

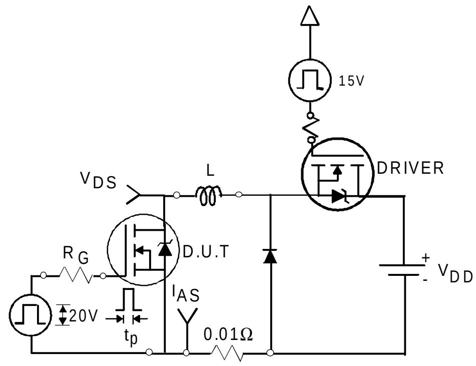


Fig 12a. Unclamped Inductive Test Circuit

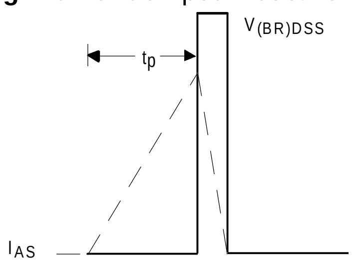


Fig 12b. Unclamped Inductive Waveforms

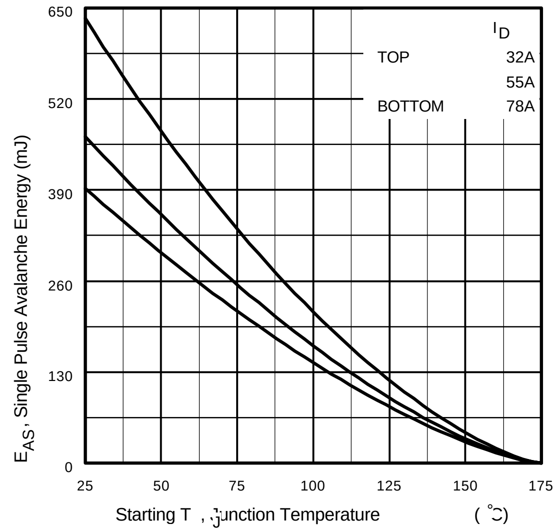


Fig 12c. Maximum Avalanche Energy vs. Drain Current

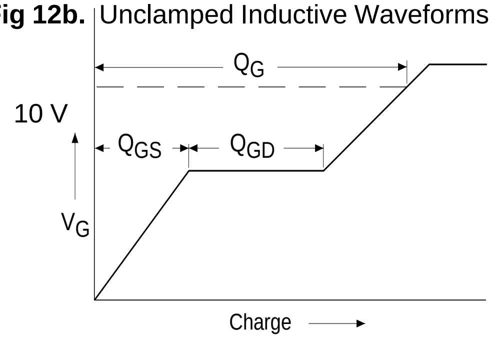


Fig 13a. Basic Gate Charge Waveform

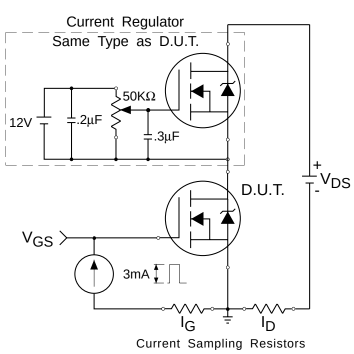


Fig 13b. Gate Charge Test Circuit

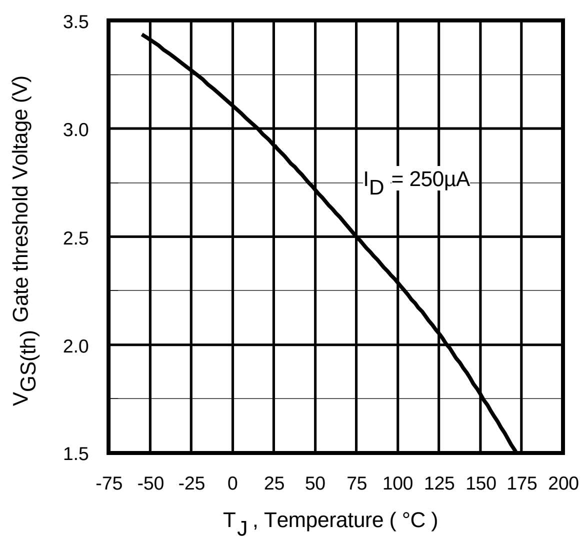


Fig 14. Threshold Voltage vs. Temperature

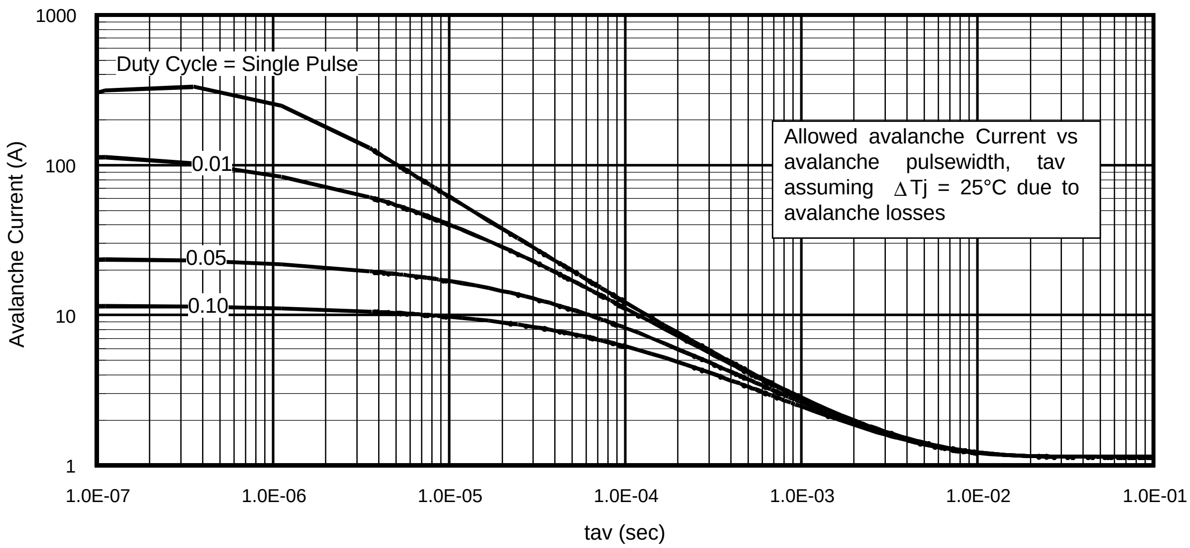


Fig 15. Typical Avalanche Current vs.Pulsewidth

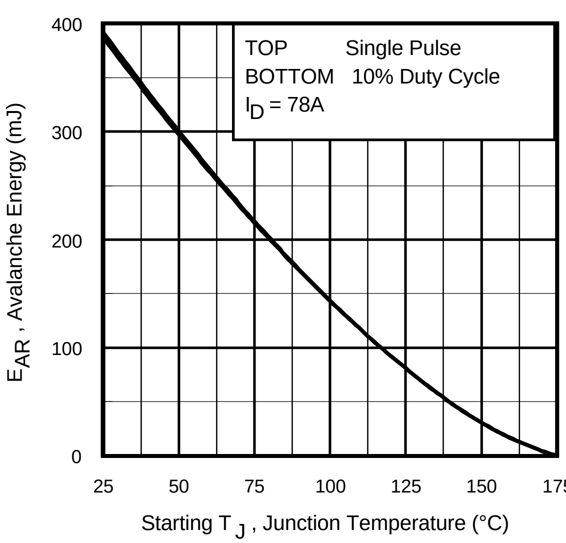


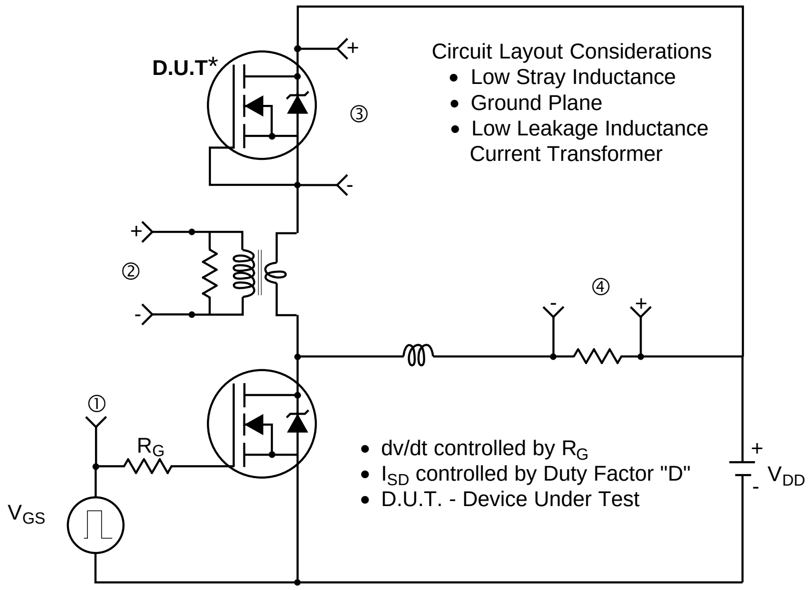
Fig 16. Maximum Avalanche Energy vs. Temperature

Notes on Repetitive Avalanche Curves , Figures 15, 16:
(For further info, see AN-1005 at www.irf.com)

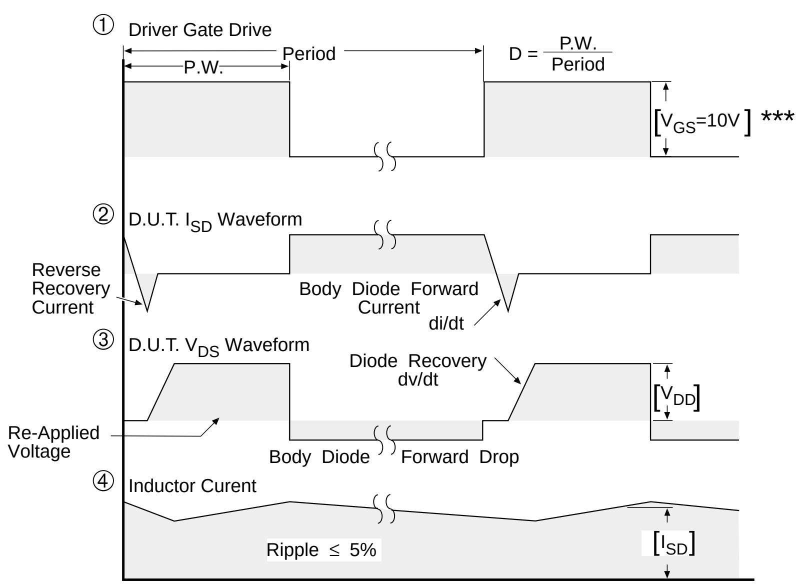
1. Avalanche failures assumption:
   Purely a thermal phenomenon and failure occurs at a temperature far in excess of T_{jmax}. This is validated for every part type.
2. Safe operation in Avalanche is allowed as long as T_{jmax} is not exceeded.
3. Equation below based on circuit and waveforms shown in Figures 12a, 12b.
4. $P_{D\ (ave)}$ = Average power dissipation per single avalanche pulse.
5. BV = Rated breakdown voltage (1.3 factor accounts for voltage increase during avalanche).
6. I_{av} = Allowable avalanche current.
7. ΔT = Allowable rise in junction temperature, not to exceed T_{jmax} (assumed as 25°C in Figure 15, 16).
   t_{av} = Average time in avalanche.
   D = Duty cycle in avalanche = $t_{av} \cdot f$
   $Z_{thJC}(D, t_{av})$ = Transient thermal resistance, see figure 11)

$$P_{D\ (ave)} = 1/2\ (1.3 \cdot BV \cdot I_{av}) = \Delta T / Z_{thJC}$$
$$I_{av} = 2\Delta T / [1.3 \cdot BV \cdot Z_{th}]$$
$$E_{AS\ (AR)} = P_{D\ (ave)} \cdot t_{av}$$

Peak Diode Recovery dv/dt Test Circuit



* Reverse Polarity of D.U.T for P-Channel

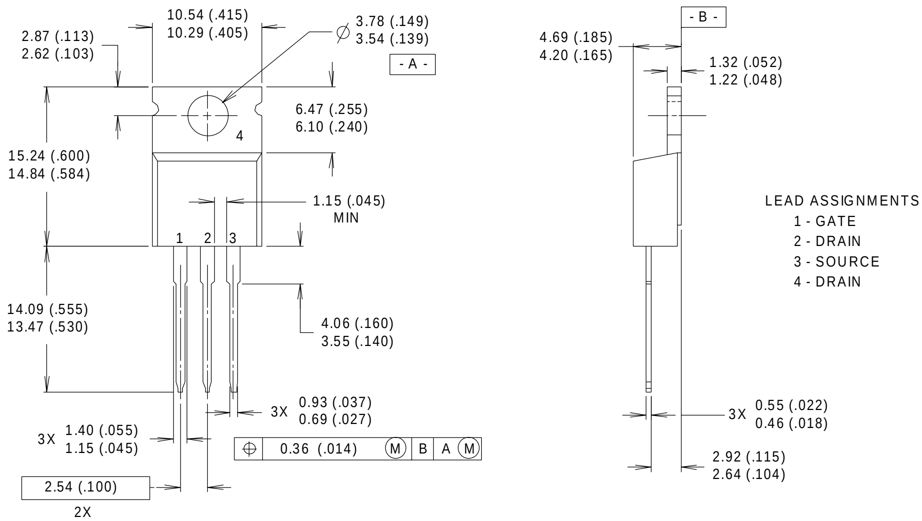


*** V_{GS} = 5.0V for Logic Level and 3V Drive Devices

Fig 17. For N-channel HEXFET® power MOSFETs

TO-220AB Package Outline

Dimensions are shown in millimeters (inches)



NOTES:

1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.

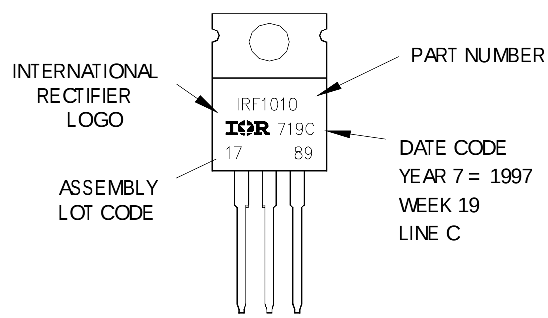
2 CONTROLLING DIMENSION : INCH

3 OUTLINE CONFORMS TO JEDEC OUTLINE TO-220AB.

4 HEATSINK & LEAD MEASUREMENTS DO NOT INCLUDE BURRS.

TO-220AB Part Marking Information

EXAMPLE: THIS IS AN IRF1010
LOT CODE 1789
ASSEMBLED ON WW 19, 1997
IN THE ASSEMBLY LINE "C"



Data and specifications subject to change without notice.
This product has been designed and qualified for the Automotive [Q101] market.
Qualification Standards can be found on IR's Web site.

International
IOR Rectifier

IR WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, USA Tel: (310) 252-7105
TAC Fax: (310) 252-7903
Visit us at www.irf.com for sales contact information.10/01

National Semiconductor

May 2000

LM78XX Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

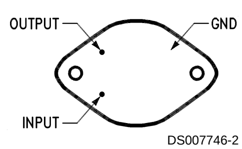
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

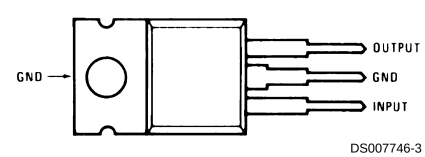
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



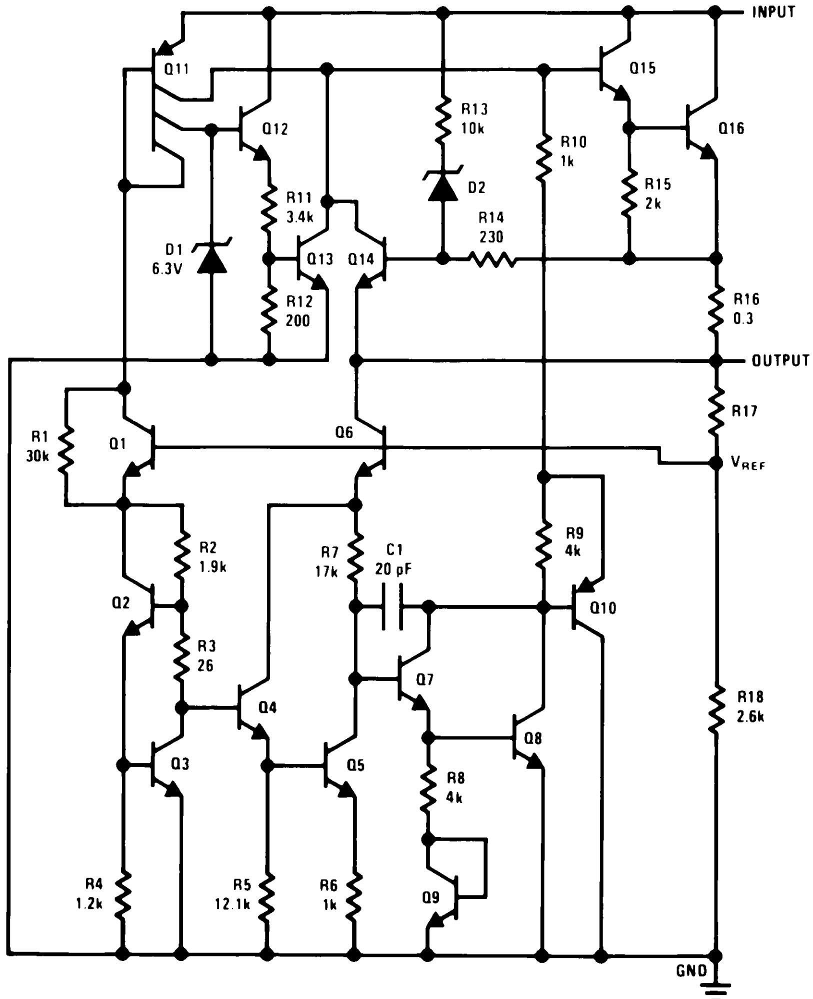
Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Schematic



DS007746-1

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0˚C to +70˚C
Maximum Junction Temperature	
(K Package)	150˚C
(T Package)	150˚C
Storage Temperature Range	−65˚C to +150˚C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300˚C
TO-220 Package T	230˚C

Electrical Characteristics LM78XXC (Note 2)

0˚C ≤ T_J ≤ 125˚C unless otherwise noted.

Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25˚C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25˚C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0˚C ≤ Tj ≤ +125˚C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25˚C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0˚C ≤ Tj ≤ +125˚C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25˚C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0˚C ≤ Tj ≤ +125˚C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25˚C			8			8			8	mA
			0˚C ≤ Tj ≤ +125˚C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25˚C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN}≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0˚C ≤ Tj ≤ +125˚C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN}≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A =25˚C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25˚C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0˚C ≤ Tj ≤ +125˚C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	Tj = 25˚C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

0˚C ≤ T_J ≤ 125˚C unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	Tj = 25˚C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25˚C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0˚C ≤ Tj ≤ +125˚C, I_O = 5 mA		0.6			1.5			1.8		mV/˚C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25˚C, I_O ≤ 1A		7.5		14.6			17.7			V

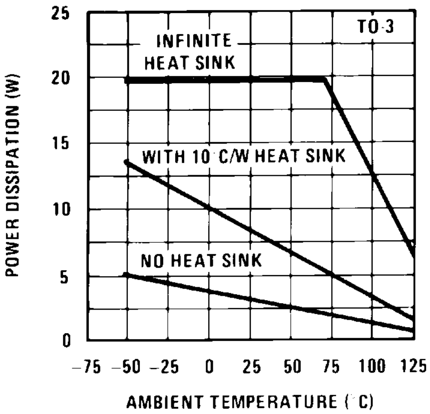
Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4˚C/W junction to case and 35˚C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4˚C/W junction to case and 50˚C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_W ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Typical Performance Characteristics

Maximum Average Power Dissipation



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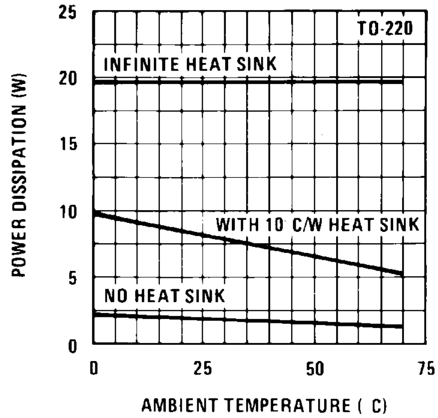
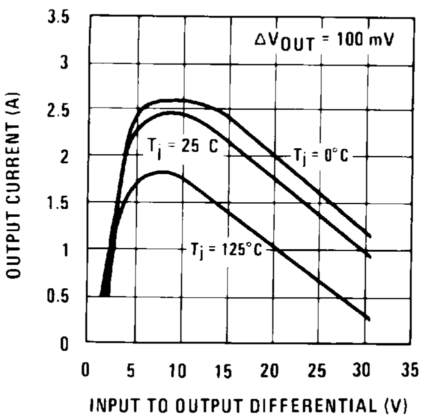
Maximum Average Power Dissipation



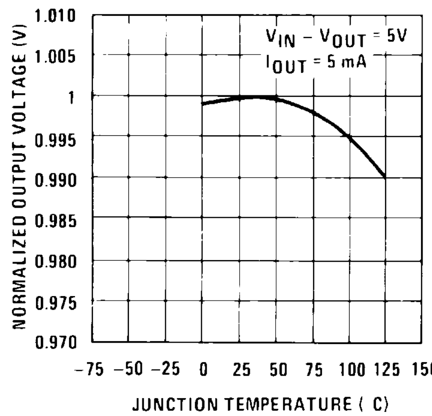
DS007746-6

Peak Output Current



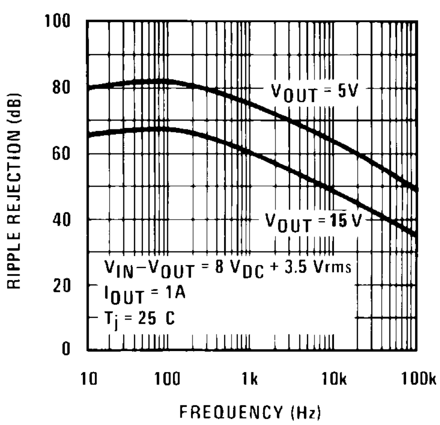
DS007746-7

Output Voltage (Normalized to 1V at T_J = 25˚C)



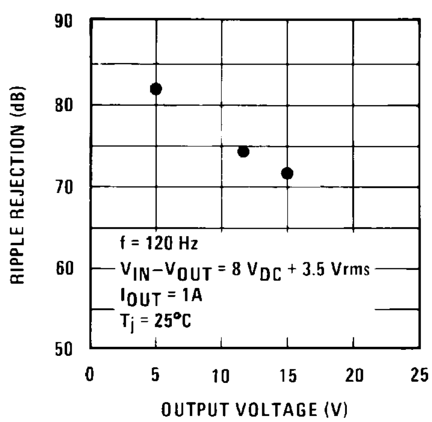
DS007746-8

Ripple Rejection



DS007746-9

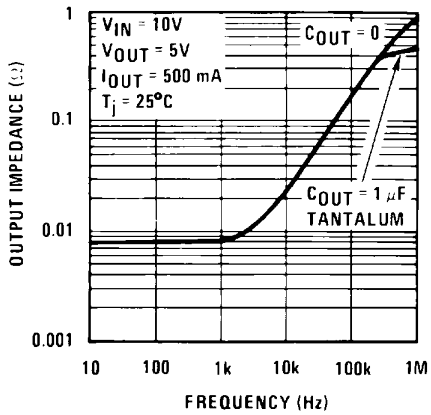
Ripple Rejection



DS007746-10

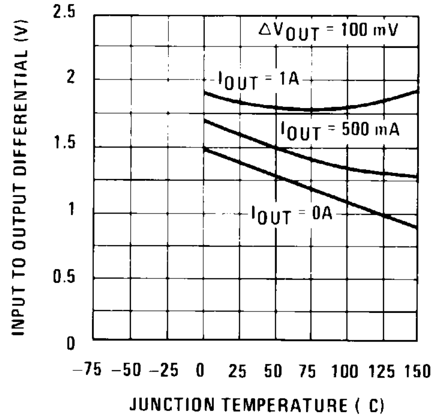
Typical Performance Characteristics (Continued)

Output Impedance



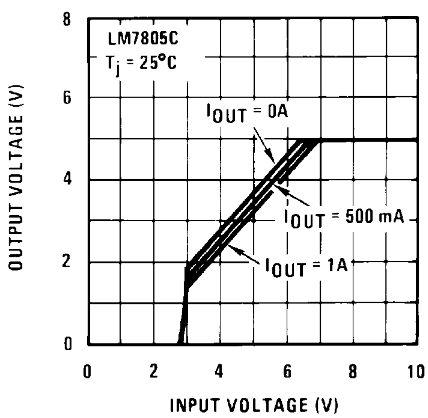
DS007746-11

Dropout Voltage



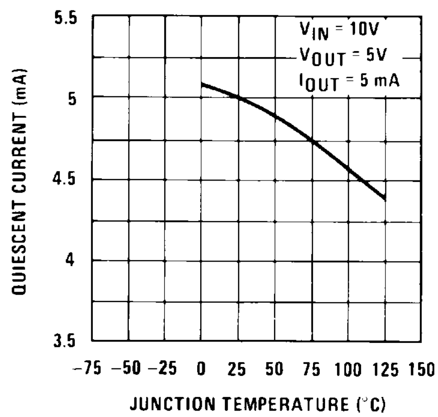
DS007746-12

Dropout Characteristics



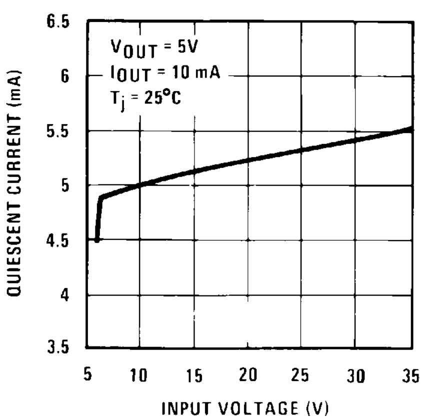
DS007746-13

Quiescent Current



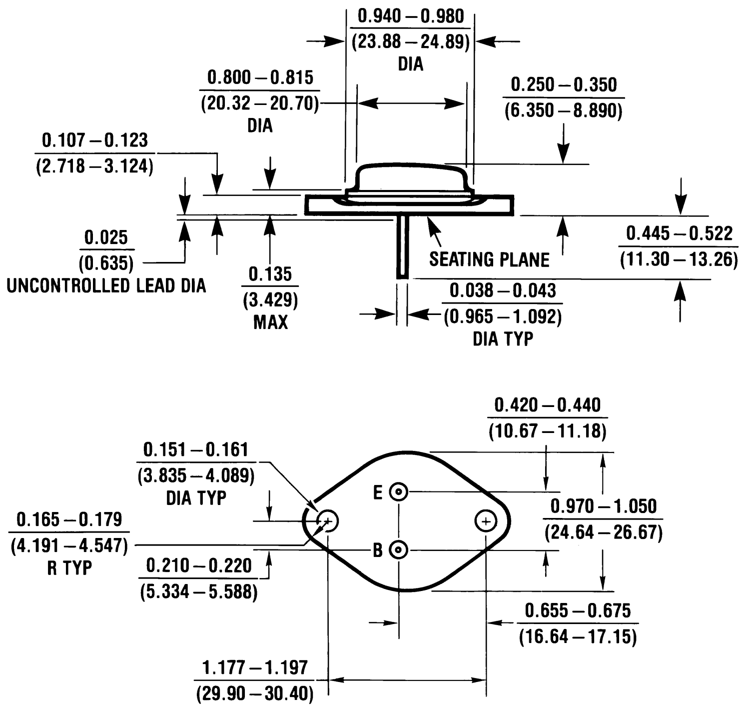
DS007746-14

Quiescent Current



DS007746-15

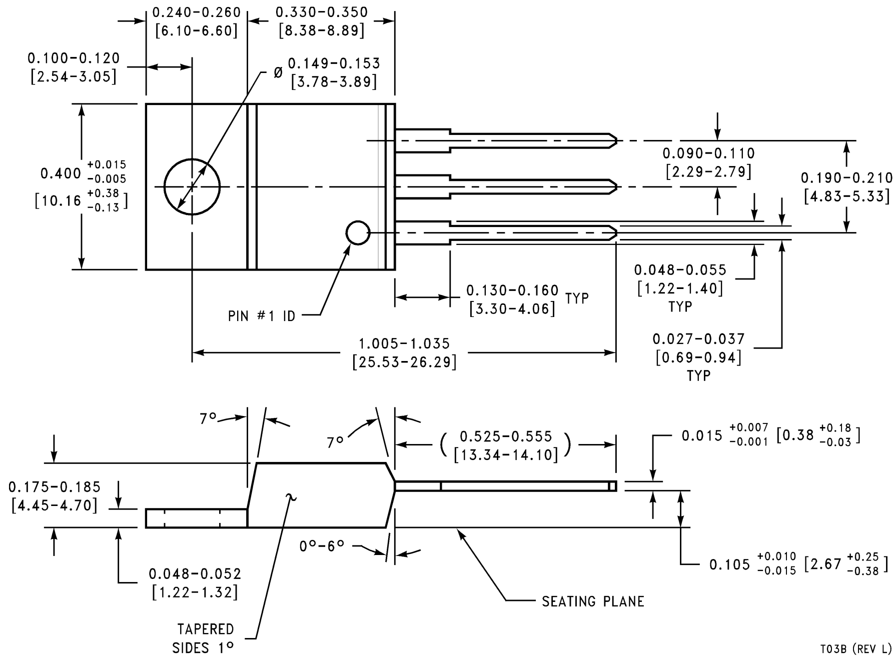
Physical Dimensions inches (millimeters) unless otherwise noted



KC02A (REV C)

Aluminum Metal Can Package (KC)
Order Number LM7805CK, LM7812CK or LM7815CK
NS Package Number KC02A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-220 Package (T)
Order Number LM7805CT, LM7812CT or LM7815CT
NS Package Number T03B

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

INTEGRATED CIRCUITS

DATA SHEET

74HC00; 74HCT00
Quad 2-input NAND gate

Product specification
Supersedes data of 1997 Aug 26

2003 Jun 30

Philips
Semiconductors

PHILIPS

FEATURES

- Complies with JEDEC standard no. 8-1A
- ESD protection:
  HBM EIA/JESD22-A114-A exceeds 2000 V
  MM EIA/JESD22-A115-A exceeds 200 V
- Specified from –40 to +85 °C and –40 to +125 °C.

DESCRIPTION

The 74HC00/74HCT00 are high-speed Si-gate CMOS devices and are pin compatible with low power Schottky TTL (LSTTL). They are specified in compliance with JEDEC standard no. 7A.

The 74HC00/74HCT00 provide the 2-input NAND function.

QUICK REFERENCE DATA

GND = 0 V; T_{amb} = 25 °C; t_r = t_f = 6 ns.

SYMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			74HC00	74HCT00	
t_{PHL}/t_{PLH}	propagation delay nA, nB to nY	C_L = 15 pF; V_{CC} = 5 V	7	10	ns
C_I	input capacitance		3.5	3.5	pF
C_{PD}	power dissipation capacitance per gate	notes 1 and 2	22	22	pF

Notes

1. C_{PD} is used to determine the dynamic power dissipation (P_D in μW).
   $P_D = C_{PD} \times V_{CC}^2 \times f_i \times N + \Sigma(C_L \times V_{CC}^2 \times f_o)$ where:
   f_i = input frequency in MHz;
   f_o = output frequency in MHz;
   C_L = output load capacitance in pF;
   V_{CC} = supply voltage in Volts;
   N = total load switching outputs;
   $\Sigma(C_L \times V_{CC}^2 \times f_o)$ = sum of the outputs.
2. For 74HC00 the condition is V_I = GND to V_{CC}.
   For 74HCT00 the condition is V_I = GND to V_{CC} – 1.5 V.

FUNCTION TABLE

See note 1.

INPUT		OUTPUT
nA	nB	nY
L	L	H
L	H	H
H	L	H
H	H	L

Note

1. H = HIGH voltage level;
   L = LOW voltage level.

ORDERING INFORMATION

TYPE NUMBER	PACKAGE				
	TEMPERATURE RANGE	PINS	PACKAGE	MATERIAL	CODE
74HC00N	–40 to +125 °C	14	DIP14	plastic	SOT27-1
74HCT00N	–40 to +125 °C	14	DIP14	plastic	SOT27-1
74HC00D	–40 to +125 °C	14	SO14	plastic	SOT108-1
74HCT00D	–40 to +125 °C	14	SO14	plastic	SOT108-1
74HC00DB	–40 to +125 °C	14	SSOP14	plastic	SOT337-1
74HCT00DB	–40 to +125 °C	14	SSOP14	plastic	SOT337-1
74HC00PW	–40 to +125 °C	14	TSSOP14	plastic	SOT402-1
74HCT00PW	–40 to +125 °C	14	TSSOP14	plastic	SOT402-1
74HC00BQ	–40 to +125 °C	14	DHVQFN14	plastic	SOT762-1
74HCT00BQ	–40 to +125 °C	14	DHVQFN14	plastic	SOT762-1

PINNING

PIN	SYMBOL	DESCRIPTION
1	1A	data input
2	1B	data input
3	1Y	data output
4	2A	data input
5	2B	data input
6	2Y	data output
7	GND	ground (0 V)
8	3Y	data output
9	3A	data input
10	3B	data input
11	4Y	data output
12	4A	data input
13	4B	data input
14	V_{CC}	supply voltage

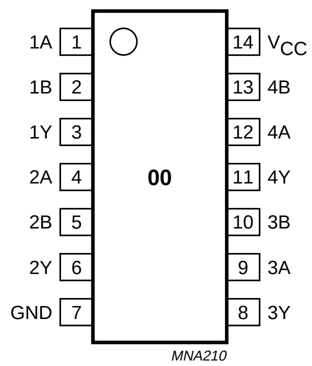
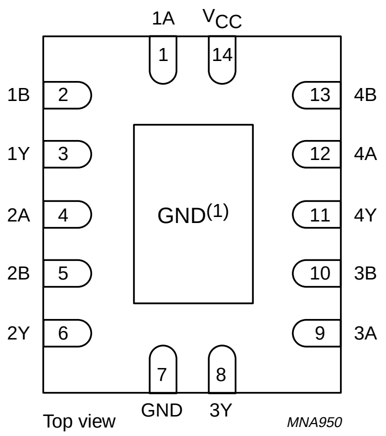


Fig.1 Pin configuration DIP14, SO14 and (T)SSOP14.



(1) The die substrate is attached to this pad using conductive die attach material. It can not be used as a supply pin or input.

Fig.2 Pin configuration DHVQFN14.

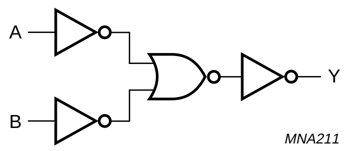


Fig.3 Logic diagram (one gate).

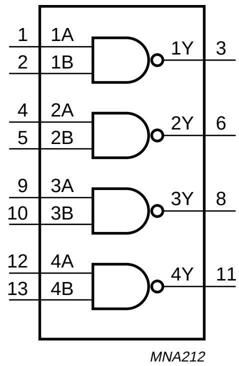


Fig.4 Function diagram.

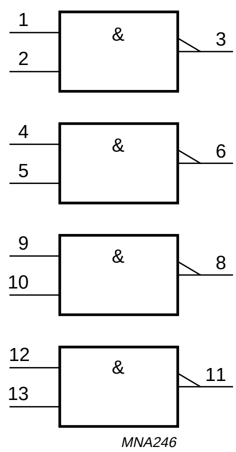


Fig.5 IEC logic symbol.

RECOMMENDED OPERATING CONDITIONS

SYMBOL	PARAMETER	CONDITIONS	74HC00			74HCT00			UNIT
			MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
V_{CC}	supply voltage		2.0	5.0	6.0	4.5	5.0	5.5	V
V_I	input voltage		0	–	V_{CC}	0	–	V_{CC}	V
V_O	output voltage		0	–	V_{CC}	0	–	V_{CC}	V
T_{amb}	operating ambient temperature	see DC and AC characteristics per device	–40	+25	+125	–40	+25	+125	°C
t_r, t_f	input rise and fall times	V_{CC} = 2.0 V	–	–	1000	–	–	–	ns
		V_{CC} = 4.5 V	–	6.0	500	–	6.0	500	ns
		V_{CC} = 6.0 V	–	–	400	–	–	–	ns

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 60134); voltages are referenced to GND (ground = 0 V).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CC}	supply voltage		–0.5	+7.0	V
I_{IK}	input diode current	V_I < –0.5 V or V_I > V_{CC} + 0.5 V	–	±20	mA
I_{OK}	output diode current	V_O < –0.5 V or V_O > V_{CC} + 0.5 V	–	±20	mA
I_O	output source or sink current	–0.5 V < V_O < V_{CC} + 0.5 V	–	±25	mA
I_{CC}, I_{GND}	V_{CC} or GND current		–	±50	mA
T_{stg}	storage temperature		–65	+150	°C
P_{tot}	power dissipation	T_{amb} = –40 to +125 °C; note 1	–	500	mW

Note

1. For DIP14 packages: above 70 °C derate linearly with 12 mW/K.
   For SO14 packages: above 70 °C derate linearly with 8 mW/K.
   For SSOP14 and TSSOP14 packages: above 60 °C derate linearly with 5.5 mW/K.
   For DHVQFN14 packages: above 60 °C derate linearly with 4.5 mW/K.

DC CHARACTERISTICS

Type 74HC00

At recommended operating conditions; voltages are referenced to GND (ground = 0 V).

SYMBOL	PARAMETER	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
		OTHER	V_{CC} (V)				
T_{amb} = –40 to +85 °C; note 1							
V_{IH}	HIGH-level input voltage		2.0	1.5	1.2	–	V
			4.5	3.15	2.4	–	V
			6.0	4.2	3.2	–	V
V_{IL}	LOW-level input voltage		2.0	–	0.8	0.5	V
			4.5	–	2.1	1.35	V
			6.0	–	2.8	1.8	V
V_{OH}	HIGH-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = –20 μA	2.0	1.9	2.0	–	V
		I_O = –20 μA	4.5	4.4	4.5	–	V
		I_O = –20 μA	6.0	5.9	6.0	–	V
		I_O = –4.0 mA	4.5	3.84	4.32	–	V
		I_O = –5.2 mA	6.0	5.34	5.81	–	V
V_{OL}	LOW-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = 20 μA	2.0	–	0	0.1	V
		I_O = 20 μA	4.5	–	0	0.1	V
		I_O = 20 μA	6.0	–	0	0.1	V
		I_O = 4.0 mA	4.5	–	0.15	0.33	V
		I_O = 5.2 mA	6.0	–	0.16	0.33	V
I_{LI}	input leakage current	$V_I = V_{CC}$ or GND	6.0	–	–	±1.0	μA
I_{OZ}	3-state output OFF current	$V_I = V_{IH}$ or V_{IL}; $V_O = V_{CC}$ or GND	6.0	–	–	±.5.0	μA
I_{CC}	quiescent supply current	$V_I = V_{CC}$ or GND; I_O = 0	6.0	–	–	20	μA

SYMBOL	PARAMETER	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
		OTHER	V_{CC} (V)				
T_{amb} = –40 to +125 °C							
V_{IH}	HIGH-level input voltage		2.0	1.5	–	–	V
			4.5	3.15	–	–	V
			6.0	4.2	–	–	V
V_{IL}	LOW-level input voltage		2.0	–	–	0.5	V
			4.5	–	–	1.35	V
			6.0	–	–	1.8	V
V_{OH}	HIGH-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = –20 μA	2.0	1.9	–	–	V
		I_O = –20 μA	4.5	4.4	–	–	V
		I_O = –20 μA	6.0	5.9	–	–	V
		I_O = –4.0 mA	4.5	3.7	–	–	V
		I_O = –5.2 mA	6.0	5.2	–	–	V
V_{OL}	LOW-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = 20 μA	2.0	–	–	0.1	V
		I_O = 20 μA	4.5	–	–	0.1	V
		I_O = 20 μA	6.0	–	–	0.1	V
		I_O = 4.0 mA	4.5	–	–	0.4	V
		I_O = 5.2 mA	6.0	–	–	0.4	V
I_{LI}	input leakage current	$V_I = V_{CC}$ or GND	6.0	–	–	±1.0	μA
I_{OZ}	3-state output OFF current	$V_I = V_{IH}$ or V_{IL}; $V_O = V_{CC}$ or GND	6.0	–	–	±10.0	μA
I_{CC}	quiescent supply current	$V_I = V_{CC}$ or GND; $I_O = 0$	6.0	–	–	40	μA

Note

1. All typical values are measured at T_{amb} = 25 °C.

Type 74HCT00

At recommended operating conditions; voltages are referenced to GND (ground = 0 V).

SYMBOL	PARAMETER	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
		OTHER	V_{CC} (V)				
T_{amb} = –40 to +85 °C; note 1							
V_{IH}	HIGH-level input voltage		4.5 to 5.5	2.0	1.6	–	V
V_{IL}	LOW-level input voltage		4.5 to 5.5	–	1.2	0.8	V
V_{OH}	HIGH-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = –20 μA	4.5	4.4	4.5	–	V
		I_O = –4.0 mA	4.5	3.84	4.32	–	V
V_{OL}	LOW-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = 20 μA	4.5	–	0	0.1	V
		I_O = 4.0 mA	4.5	–	0.15	0.33	V
I_{LI}	input leakage current	$V_I = V_{CC}$ or GND	5.5	–	–	±1.0	μA
I_{OZ}	3-state output OFF current	$V_I = V_{IH}$ or V_{IL}; $V_O = V_{CC}$ or GND; I_O = 0	5.5	–	–	±5.0	μA
I_{CC}	quiescent supply current	$V_I = V_{CC}$ or GND; I_O = 0	5.5	–	–	20	μA
ΔI_{CC}	additional supply current per input	$V_I = V_{CC}$ – 2.1 V; I_O = 0	4.5 to 5.5	–	150	675	μA
T_{amb} = –40 to +125 °C							
V_{IH}	HIGH-level input voltage		4.5 to 5.5	2.0	–	–	V
V_{IL}	LOW-level input voltage		4.5 to 5.5	–	–	0.8	V
V_{OH}	HIGH-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = –20 μA	4.5	4.4	–	–	V
		I_O = –4.0 mA	4.5	3.7	–	–	V
V_{OL}	LOW-level output voltage	$V_I = V_{IH}$ or V_{IL}					
		I_O = 20 μA	4.5	–	–	0.1	V
		I_O = 4.0 mA	4.5	–	–	0.4	V
I_{LI}	input leakage current	$V_I = V_{CC}$ or GND	5.5	–	–	±1.0	μA
I_{OZ}	3-state output OFF current	$V_I = V_{IH}$ or V_{IL}; $V_O = V_{CC}$ or GND; I_O = 0	5.5	–	–	±10	μA
I_{CC}	quiescent supply current	$V_I = V_{CC}$ or GND; I_O = 0	5.5	–	–	40	μA
ΔI_{CC}	additional supply current per input	$V_I = V_{CC}$ – 2.1 V; I_O = 0	4.5 to 5.5	–	–	735	μA

Note

1. All typical values are measured at T_{amb} = 25 °C.

AC CHARACTERISTICS

Type 74HC00

GND = 0 V; t_r = t_f = 6 ns; C_L = 50 pF.

SYMBOL	PARAMETER	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
		WAVEFORMS	V_{CC} (V)				
T_{amb} = –40 to +85 °C; note 1							
t_{PHL}/t_{PLH}	propagation delay nA, nB to nY	see Fig.6	2.0	–	25	115	ns
		see Fig.6	4.5	–	9	23	ns
		see Fig.6	6.0	–	7	20	ns
t_{THL}/t_{TLH}	output transition time		2.0	–	19	95	ns
			4.5	–	7	19	ns
			6.0	–	6	16	ns
T_{amb} = –40 to +125 °C							
t_{PHL}/t_{PLH}	propagation delay nA, nB to nY	see Fig.6	2.0	–	–	135	ns
		see Fig.6	4.5	–	–	27	ns
		see Fig.6	6.0	–	–	23	ns
t_{THL}/t_{TLH}	output transition time		2.0	–	–	110	ns
			4.5	–	–	22	ns
			6.0	–	–	19	ns

Note

1. All typical values are measured at T_{amb} = 25 °C.

Type 74HCT00

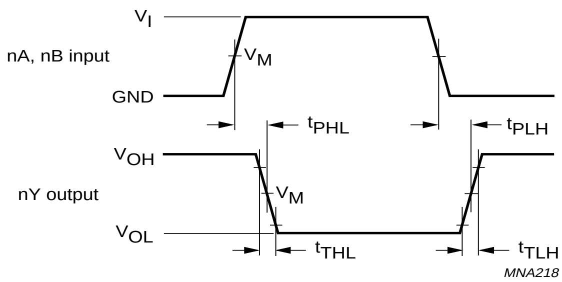
GND = 0 V; t_r = t_f = 6 ns; C_L = 50 pF

SYMBOL	PARAMETER	TEST CONDITIONS		MIN.	TYP	MAX.	UNIT
		WAVEFORMS	V_{CC} (V)				
T_{amb} = –40 to +85 °C; note 1							
t_{PHL}/t_{PLH}	propagation delay nA, nB to nY	see Fig.6	4.5	–	12	24	ns
t_{THL}/t_{TLH}	output transition time		4.5	–	–	29	ns
T_{amb} = –40 to +125 °C							
t_{PHL}/t_{PLH}	propagation delay nA, nB to nY	see Fig.6	4.5	–	–	29	ns
t_{THL}/t_{TLH}	output transition time		4.5	–	–	22	ns

Note

1. All typical values are measured at T_{amb} = 25 °C.

AC WAVEFORMS

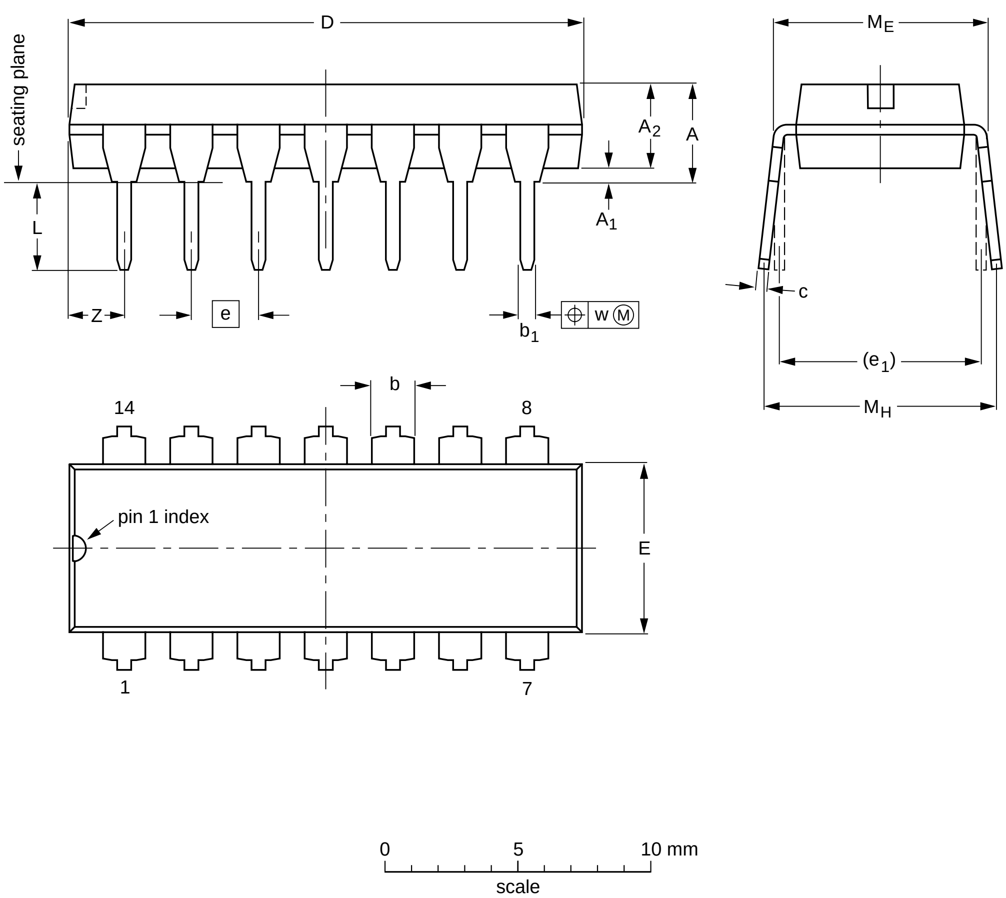


74HC00: V_M = 50%; V_I = GND to V_{CC}.
74HCT00: V_M = 1.3 V; V_I = GND to 3 V.

Fig.6 Waveforms showing the input (nA, nB) to output (nY) propagation delays.

PACKAGE OUTLINES

DIP14: plastic dual in-line package; 14 leads (300 mil) **SOT27-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

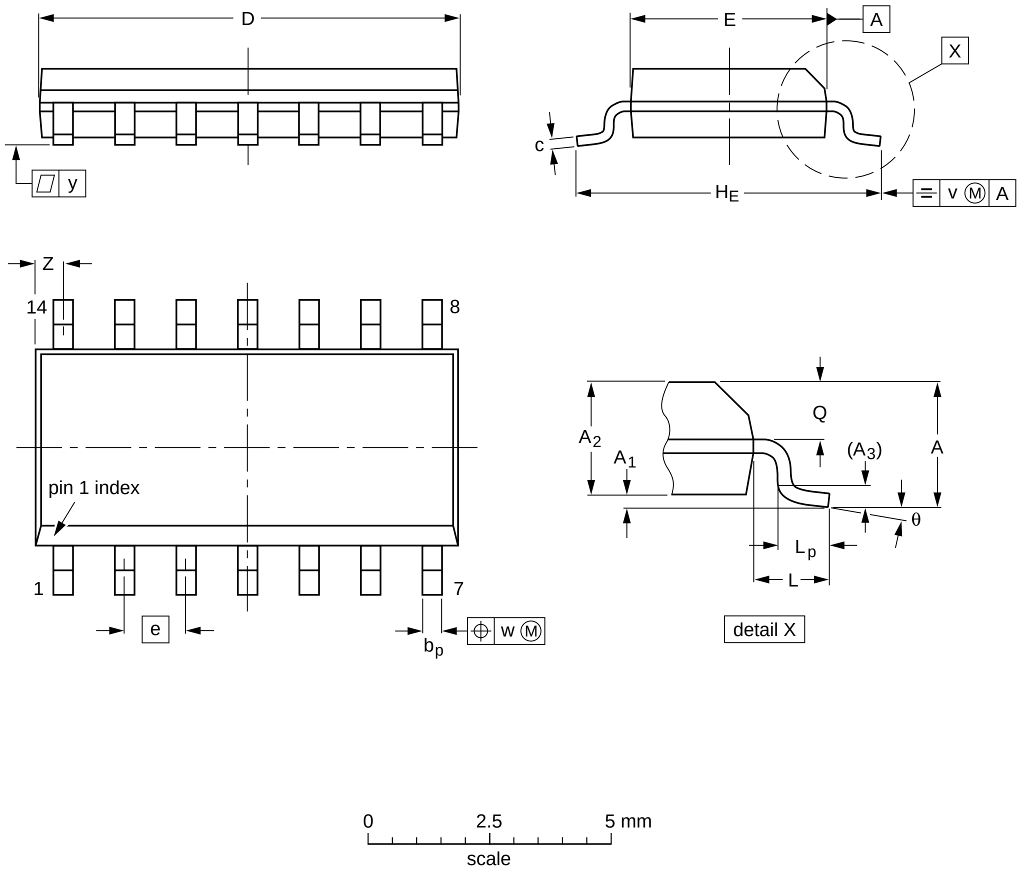
UNIT	A max.	A_1 min.	A_2 max.	b	b_1	c	D (1)	E (1)	e	e_1	L	M_E	M_H	w	Z (1) max.
mm	4.2	0.51	3.2	1.73 1.13	0.53 0.38	0.36 0.23	19.50 18.55	6.48 6.20	2.54	7.62	3.60 3.05	8.25 7.80	10.0 8.3	0.254	2.2
inches	0.17	0.02	0.13	0.068 0.044	0.021 0.015	0.014 0.009	0.77 0.73	0.26 0.24	0.1	0.3	0.14 0.12	0.32 0.31	0.39 0.33	0.01	0.087

Note

1. Plastic or metal protrusions of 0.25 mm (0.01 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT27-1	050G04	MO-001	SC-501-14			~~99-12-27~~ 03-02-13

SO14: plastic small outline package; 14 leads; body width 3.9 mm **SOT108-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

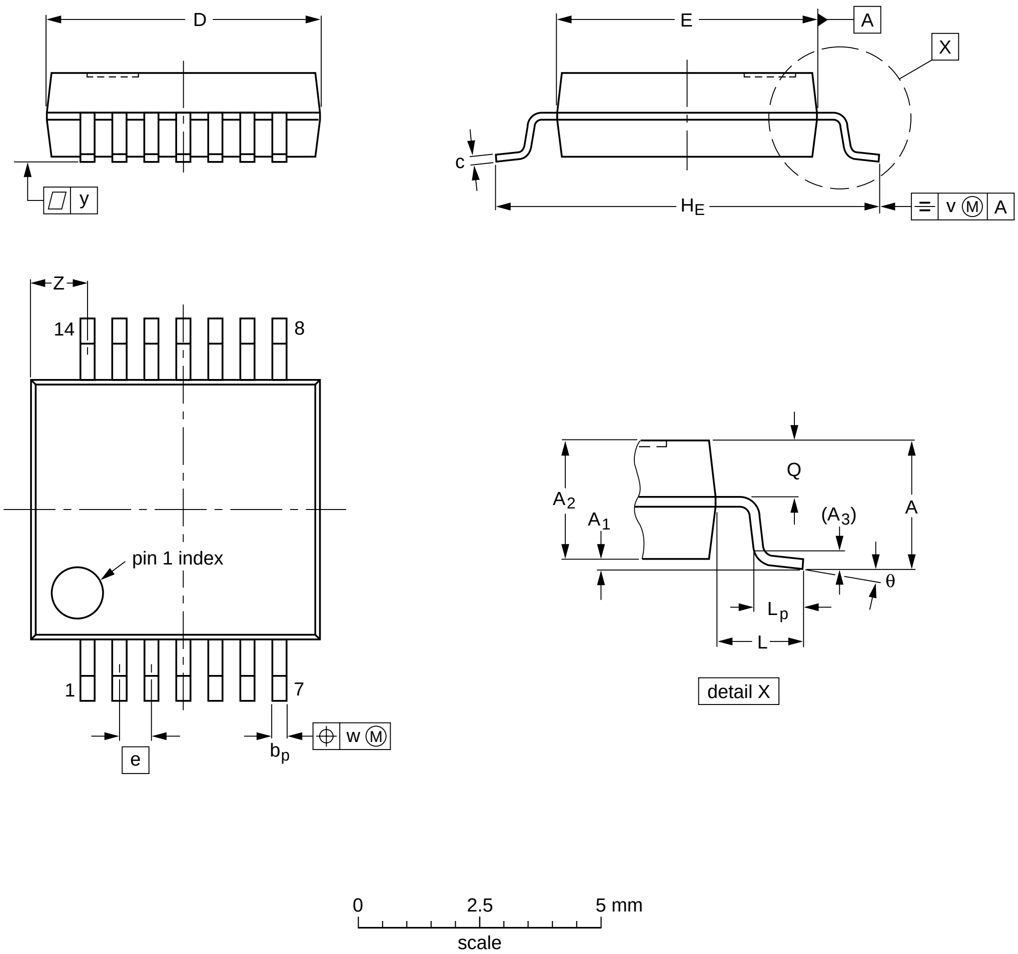
UNIT	A max.	A_1	A_2	A_3	b_p	c	D(1)	E(1)	e	H_E	L	L_p	Q	v	w	y	Z (1)	θ
mm	1.75	0.25 0.10	1.45 1.25	0.25	0.49 0.36	0.25 0.19	8.75 8.55	4.0 3.8	1.27	6.2 5.8	1.05	1.0 0.4	0.7 0.6	0.25	0.25	0.1	0.7 0.3	8° 0°
inches	0.069	0.010 0.004	0.057 0.049	0.01	0.019 0.014	0.0100 0.0075	0.35 0.34	0.16 0.15	0.05	0.244 0.228	0.041	0.039 0.016	0.028 0.024	0.01	0.01	0.004	0.028 0.012	

Note

1. Plastic or metal protrusions of 0.15 mm (0.006 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT108-1	076E06	MS-012				~~99-12-27~~ 03-02-19

SSOP14: plastic shrink small outline package; 14 leads; body width 5.3 mm **SOT337-1**



DIMENSIONS (mm are the original dimensions)

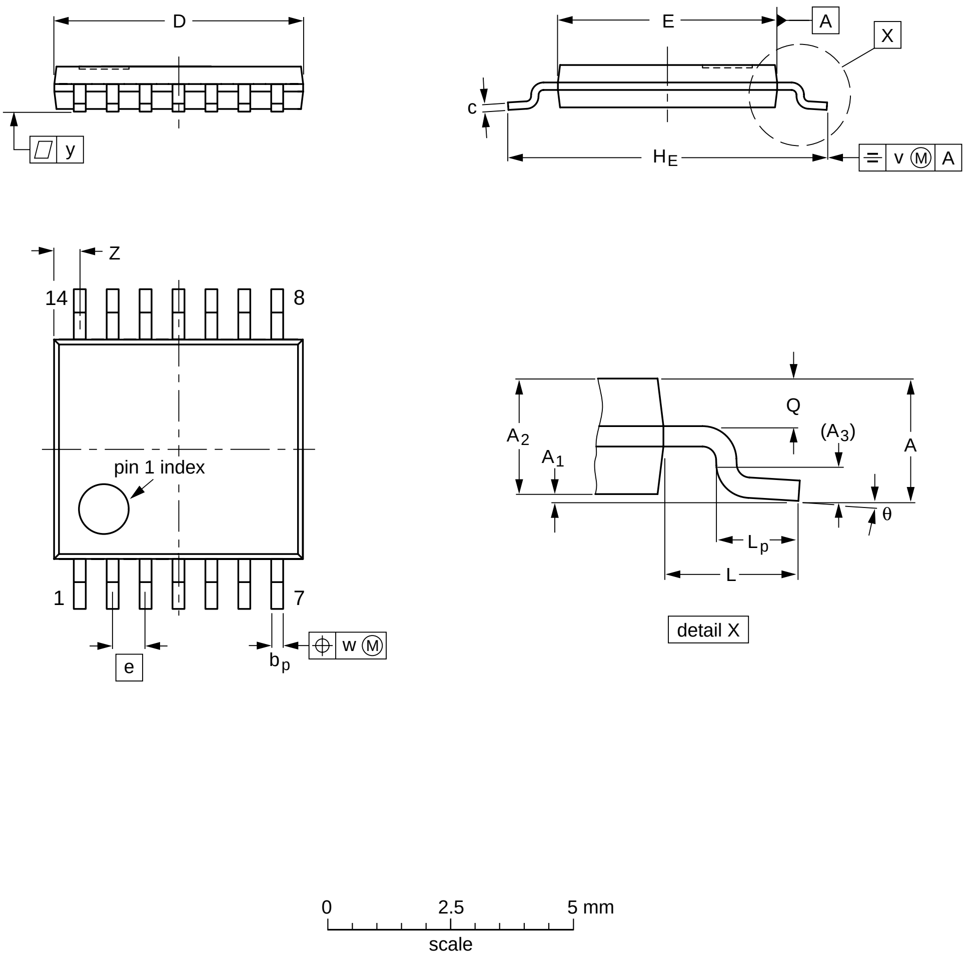
UNIT	A max.	A_1	A_2	A_3	b_p	c	$D^{(1)}$	$E^{(1)}$	e	H_E	L	L_p	Q	v	w	y	$Z^{(1)}$	θ
mm	2	0.21 0.05	1.80 1.65	0.25	0.38 0.25	0.20 0.09	6.4 6.0	5.4 5.2	0.65	7.9 7.6	1.25	1.03 0.63	0.9 0.7	0.2	0.13	0.1	1.4 0.9	8^o 0^o

Note

1. Plastic or metal protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT337-1		MO-150				~~99-12-27~~ 03-02-19

TSSOP14: plastic thin shrink small outline package; 14 leads; body width 4.4 mm **SOT402-1**



DIMENSIONS (mm are the original dimensions)

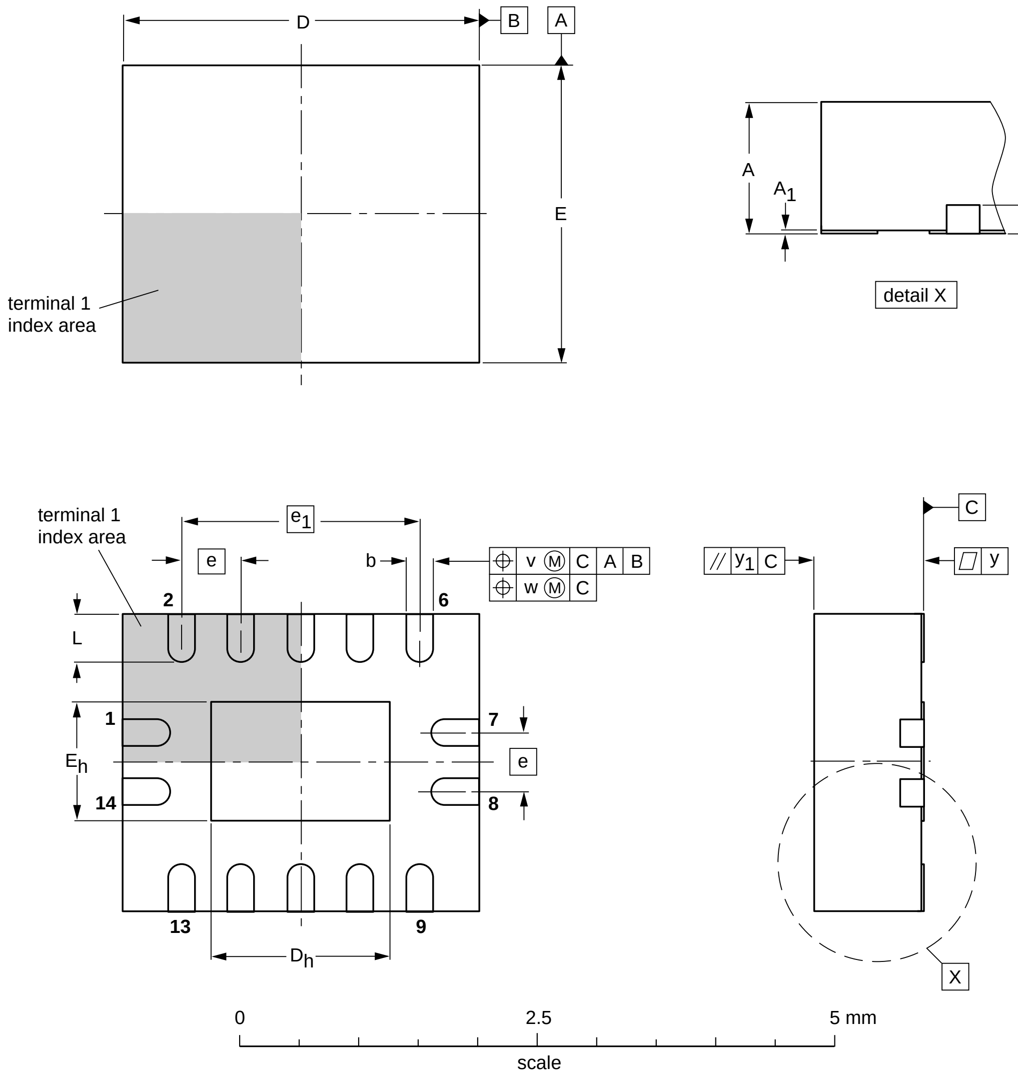
UNIT	A max.	A_1	A_2	A_3	b_p	c	D (1)	E (2)	e	H_E	L	L_p	Q	v	w	y	Z (1)	θ
mm	1.1	0.15 0.05	0.95 0.80	0.25	0.30 0.19	0.2 0.1	5.1 4.9	4.5 4.3	0.65	6.6 6.2	1	0.75 0.50	0.4 0.3	0.2	0.13	0.1	0.72 0.38	8^o 0^o

Notes

1. Plastic or metal protrusions of 0.15 mm maximum per side are not included.
2. Plastic interlead protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT402-1		MO-153				~~99-12-27~~ 03-02-18

DHVQFN14: plastic dual in-line compatible thermal enhanced very thin quad flat package; no leads; 14 terminals; body 2.5 x 3 x 0.85 mm **SOT762-1**



DIMENSIONS (mm are the original dimensions)

UNIT	A(1) max.	A_1	b	c	D(1)	D_h	E(1)	E_h	e	e_1	L	v	w	y	y_1
mm	1	0.05 0.00	0.30 0.18	0.2	3.1 2.9	1.65 1.35	2.6 2.4	1.15 0.85	0.5	2	0.5 0.3	0.1	0.05	0.05	0.1

Note

1. Plastic or metal protrusions of 0.075 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT762-1	- - -	MO-241	- - -			~~02-10-17~~ 03-01-27

DATA SHEET STATUS

LEVEL	DATA SHEET STATUS(1)	PRODUCT STATUS(2)(3)	DEFINITION
I	Objective data	Development	This data sheet contains data from the objective specification for product development. Philips Semiconductors reserves the right to change the specification in any manner without notice.
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1. Please consult the most recently issued data sheet before initiating or completing a design.
2. The product status of the device(s) described in this data sheet may have changed since this data sheet was published. The latest information is available on the Internet at URL http://www.semiconductors.philips.com.
3. For data sheets describing multiple type numbers, the highest-level product status determines the data sheet status.

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Limiting values definition — Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 60134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

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Contact information

For additional information please visit **http://www.semiconductors.philips.com**. Fax: **+31 40 27 24825**
For sales offices addresses send e-mail to: **sales.addresses@www.semiconductors.philips.com**.

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