

# Precision Switchmode Pulse Width Modulation Control Circuit

The TL594 is a fixed frequency, pulse width modulation control circuit designed primarily for Switchmode power supply control.

- Complete Pulse Width Modulation Control Circuitry
- On-Chip Oscillator with Master or Slave Operation
- On-Chip Error Amplifiers
- On-Chip 5.0 V Reference, 1.5% Accuracy
- Adjustable Deadtime Control
- Uncommitted Output Transistors Rated to 500 mA Source or Sink
- Output Control for Push-Pull or Single-Ended Operation
- Undervoltage Lockout

**MAXIMUM RATINGS** (Full operating ambient temperature range applies, unless otherwise noted.)

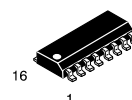
Rating	Symbol	Value	Unit
Power Supply Voltage	$V_{CC}$	42	V
Collector Output Voltage	$V_{C1}, V_{C2}$	42	V
Collector Output Current (each transistor) (Note 1)	$I_{C1}, I_{C2}$	500	mA
Amplifier Input Voltage Range	$V_{IR}$	-0.3 to +42	V
Power Dissipation @ $T_A \leq 45^\circ\text{C}$	$P_D$	1000	mW
Thermal Resistance, Junction-to-Ambient	$R_{\theta JA}$	80	$^\circ\text{C/W}$
Operating Junction Temperature	$T_J$	125	$^\circ\text{C}$
Storage Temperature Range	$T_{stg}$	-55 to +125	$^\circ\text{C}$
Operating Ambient Temperature Range TL594ID, CN TL594CD, IN	$T_A$	0 to +70 -25 to +85	$^\circ\text{C}$
Derating Ambient Temperature	$T_A$	45	$^\circ\text{C}$

**NOTES:** 1. Maximum thermal limits must be observed.

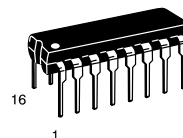
## TL594

### PRECISION SWITCHMODE PULSE WIDTH MODULATION CONTROL CIRCUIT

#### SEMICONDUCTOR TECHNICAL DATA

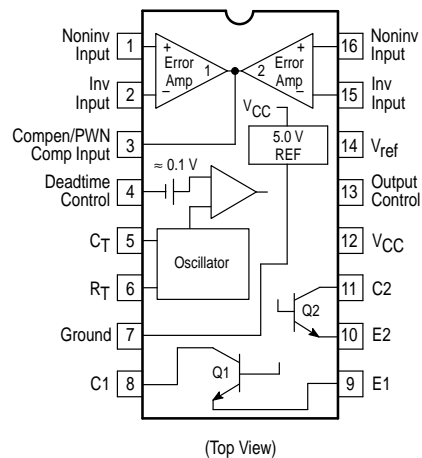


**D SUFFIX**  
PLASTIC PACKAGE  
CASE 751B  
(SO-16)



**N SUFFIX**  
PLASTIC PACKAGE  
CASE 648

#### PIN CONNECTIONS



#### ORDERING INFORMATION

Device	Operating Temperature Range	Package
TL594CD	$T_A = 0^\circ \text{ to } +70^\circ\text{C}$	SO-16
TL594CN		Plastic
TL594IN	$T_A = -25^\circ \text{ to } +85^\circ\text{C}$	Plastic

## RECOMMENDED OPERATING CONDITIONS

Characteristics	Symbol	Min	Typ	Max	Unit
Power Supply Voltage	$V_{CC}$	7.0	15	40	V
Collector Output Voltage	$V_{C1}, V_{C2}$	–	30	40	V
Collector Output Current (Each transistor)	$I_{C1}, I_{C2}$	–	–	200	mA
Amplified Input Voltage	$V_{in}$	0.3	–	$V_{CC} - 2.0$	V
Current Into Feedback Terminal	$I_{fb}$	–	–	0.3	mA
Reference Output Current	$I_{ref}$	–	–	10	mA
Timing Resistor	$R_T$	1.8	30	500	k $\Omega$
Timing Capacitor	$C_T$	0.0047	0.001	10	$\mu$ F
Oscillator Frequency	$f_{osc}$	1.0	40	200	kHz
PWM Input Voltage (Pins 3, 4, 13)	–	0.3	–	5.3	V

**ELECTRICAL CHARACTERISTICS** ( $V_{CC} = 15$  V,  $C_T = 0.01$   $\mu$ F,  $R_T = 12$  k $\Omega$ , unless otherwise noted.)For typical values  $T_A = 25^\circ\text{C}$ , for min/max values  $T_A$  is the operating ambient temperature range that applies, unless otherwise noted.

Characteristics	Symbol	Min	Typ	Max	Unit
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## REFERENCE SECTION

Reference Voltage ( $I_O = 1.0$ mA, $T_A = 25^\circ\text{C}$ ) ( $I_O = 1.0$ mA)	$V_{ref}$	4.925 4.9	5.0 –	5.075 5.1	V
Line Regulation ( $V_{CC} = 7.0$ V to 40 V)	$Reg_{line}$	–	2.0	25	mV
Load Regulation ( $I_O = 1.0$ mA to 10 mA)	$Reg_{load}$	–	2.0	15	mV
Short Circuit Output Current ( $V_{ref} = 0$ V)	$I_{SC}$	15	40	75	mA

## OUTPUT SECTION

Collector Off-State Current ( $V_{CC} = 40$ V, $V_{CE} = 40$ V)	$I_{C(off)}$	–	2.0	100	$\mu$ A
Emitter Off-State Current ( $V_{CC} = 40$ V, $V_C = 40$ V, $V_E = 0$ V)	$I_{E(off)}$	–	–	–100	$\mu$ A
Collector–Emitter Saturation Voltage (Note 2) Common–Emitter ( $V_E = 0$ V, $I_C = 200$ mA) Emitter–Follower ( $V_C = 15$ V, $I_E = -200$ mA)	$V_{SAT(C)}$ $V_{SAT(E)}$	– –	1.1 1.5	1.3 2.5	V
Output Control Pin Current Low State ( $V_{OC} \leq 0.4$ V) High State ( $V_{OC} = V_{ref}$ )	$I_{OCL}$ $I_{OCH}$	– –	0.1 2.0	– 20	$\mu$ A
Output Voltage Rise Time Common–Emitter (See Figure 13) Emitter–Follower (See Figure 14)	$t_r$	– –	100 100	200 200	ns
Output Voltage Fall Time Common–Emitter (See Figure 13) Emitter–Follower (See Figure 14)	$t_f$	– –	40 40	100 100	ns

## ERROR AMPLIFIER SECTION

Input Offset Voltage ( $V_O$ (Pin 3) = 2.5 V)	$V_{IO}$	–	2.0	10	mV
Input Offset Current ( $V_O$ (Pin 3) = 2.5 V)	$I_{IO}$	–	5.0	250	nA
Input Bias Current ( $V_O$ (Pin 3) = 2.5 V)	$I_{IB}$	–	–0.1	–1.0	$\mu$ A
Input Common Mode Voltage Range ( $V_{CC} = 40$ V, $T_A = 25^\circ\text{C}$ )	$V_{ICR}$	0 to $V_{CC} - 2.0$			V
Inverting Input Voltage Range	$V_{IR(INV)}$	–0.3 to $V_{CC} - 2.0$			V
Open Loop Voltage Gain ( $\Delta V_O = 3.0$ V, $V_O = 0.5$ V to 3.5 V, $R_L = 2.0$ k $\Omega$ )	$A_{VOL}$	70	95	–	dB
Unity–Gain Crossover Frequency ( $V_O = 0.5$ V to 3.5 V, $R_L = 2.0$ k $\Omega$ )	$f_C$	–	700	–	kHz
Phase Margin at Unity–Gain ( $V_O = 0.5$ V to 3.5 V, $R_L = 2.0$ k $\Omega$ )	$\phi_m$	–	65	–	deg.
Common Mode Rejection Ratio ( $V_{CC} = 40$ V)	CMRR	65	90	–	dB
Power Supply Rejection Ratio ( $\Delta V_{CC} = 33$ V, $V_O = 2.5$ V, $R_L = 2.0$ k $\Omega$ )	PSRR	–	100	–	dB
Output Sink Current ( $V_O$ (Pin 3) = 0.7 V)	$I_{O-}$	0.3	0.7	–	mA
Output Source Current ( $V_O$ (Pin 3) = 3.5 V)	$I_{O+}$	–2.0	–4.0	–	mA

**NOTE:** 2. Low duty cycle pulse techniques are used during test to maintain junction temperature as close to ambient temperature as possible.

# TL594

## ELECTRICAL CHARACTERISTICS ( $V_{CC} = 15\text{ V}$ , $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ , unless otherwise noted.)

For typical values  $T_A = 25^\circ\text{C}$ , for min/max values  $T_A$  is the operating ambient temperature range that applies, unless otherwise noted.

Characteristics	Symbol	Min	Typ	Max	Unit
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### PWM COMPARATOR SECTION (Test Circuit Figure 11)

Input Threshold Voltage (Zero Duty Cycle)	$V_{TH}$	–	3.6	4.5	V
Input Sink Current ( $V_{Pin\ 3} = 0.7\text{ V}$ )	$I_{I-}$	0.3	0.7	–	mA

### DEADTIME CONTROL SECTION (Test Circuit Figure 11)

Input Bias Current (Pin 4) ( $V_{Pin\ 4} = 0\text{ V to } 5.25\text{ V}$ )	$I_{IB}\text{ (DT)}$	–	–2.0	–10	$\mu\text{A}$
Maximum Duty Cycle, Each Output, Push–Pull Mode ( $V_{Pin\ 4} = 0\text{ V}$ , $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ ) ( $V_{Pin\ 4} = 0\text{ V}$ , $C_T = 0.001\text{ }\mu\text{F}$ , $R_T = 30\text{ k}\Omega$ )	$DC_{max}$	45 –	48 45	50 –	%
Input Threshold Voltage (Pin 4) (Zero Duty Cycle) (Maximum Duty Cycle)	$V_{TH}$	– 0	2.8 –	3.3 –	V

### OSCILLATOR SECTION

Frequency ( $C_T = 0.001\text{ }\mu\text{F}$ , $R_T = 30\text{ k}\Omega$ ) ( $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ , $T_A = 25^\circ\text{C}$ ) ( $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ , $T_A = T_{low}\text{ to } T_{high}$ )	$f_{osc}$	– 9.2 9.0	40 10 –	– 10.8 12	kHz
Standard Deviation of Frequency* ( $C_T = 0.001\text{ }\mu\text{F}$ , $R_T = 30\text{ k}\Omega$ )	$\sigma f_{osc}$	–	1.5	–	%
Frequency Change with Voltage ( $V_{CC} = 7.0\text{ V to } 40\text{ V}$ , $T_A = 25^\circ\text{C}$ )	$\Delta f_{osc}\text{ (}\Delta V\text{)}$	–	0.2	1.0	%
Frequency Change with Temperature ( $\Delta T_A = T_{low}\text{ to } T_{high}$ , $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ )	$\Delta f_{osc}\text{ (}\Delta T\text{)}$	–	4.0	–	%

### UNDERVOLTAGE LOCKOUT SECTION

Turn–On Threshold ( $V_{CC}$ Increasing, $I_{ref} = 1.0\text{ mA}$ ) $T_A = 25^\circ\text{C}$ $T_A = T_{low}\text{ to } T_{high}$	$V_{th}$	4.0 3.5	5.2 –	6.0 6.5	V
Hysteresis TL594C,I TL594M	$V_H$	100 50	150 150	300 300	mV

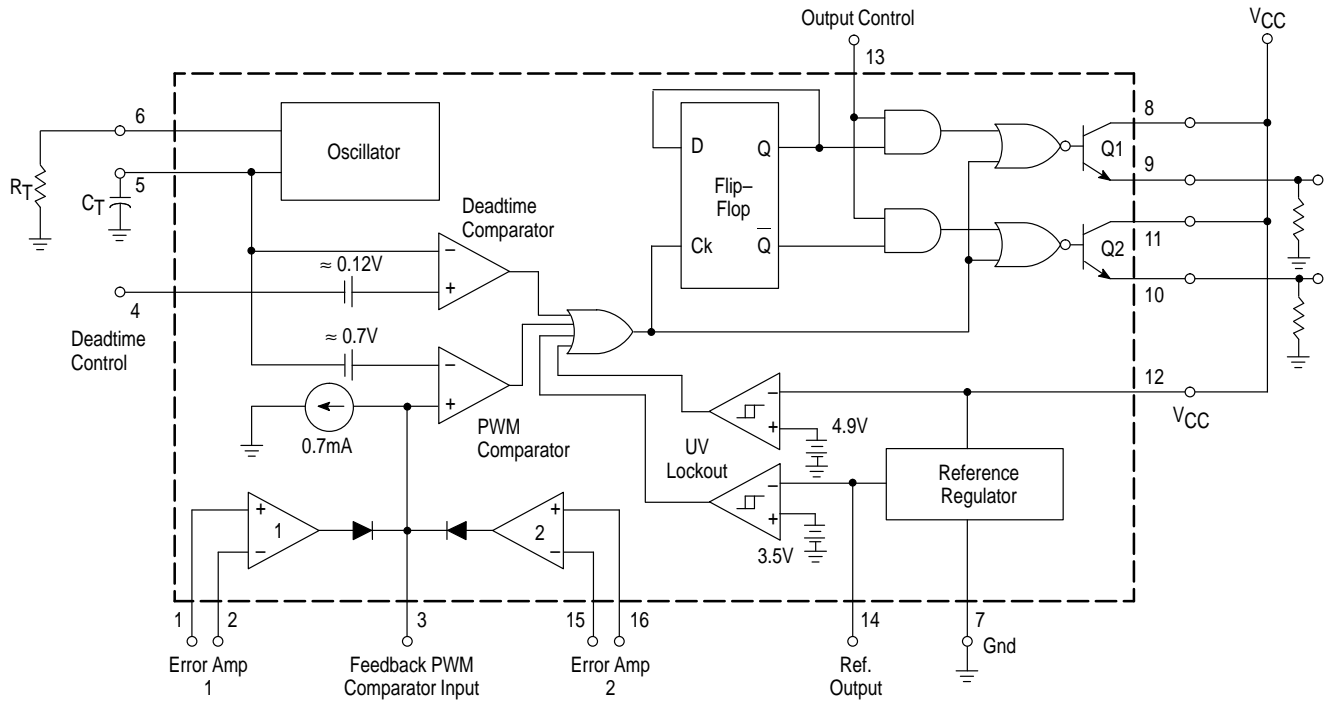
### TOTAL DEVICE

Standby Supply Current (Pin 6 at $V_{ref}$ , All other inputs and outputs open) ( $V_{CC} = 15\text{ V}$ ) ( $V_{CC} = 40\text{ V}$ )	$I_{CC}$	– –	8.0 8.0	15 18	mA
Average Supply Current ( $V_{Pin\ 4} = 2.0\text{ V}$ , $C_T = 0.01\text{ }\mu\text{F}$ , $R_T = 12\text{ k}\Omega$ , $V_{CC} = 15\text{ V}$ , See Figure 11)		–	11	–	mA

\* Standard deviation is a measure of the statistical distribution about the mean as derived from the formula,  $\sigma$

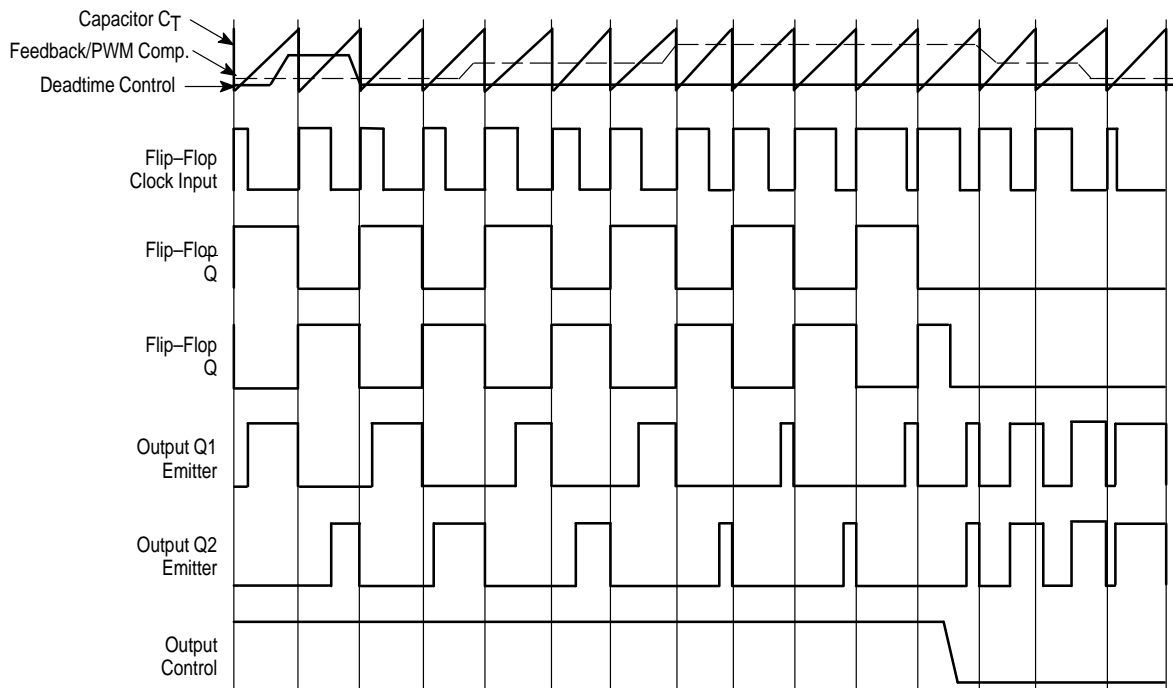
$$\sigma = \sqrt{\frac{\sum_{n=1}^N (X_n - \bar{X})^2}{N - 1}}$$

Figure 1. Representative Block Diagram



This device contains 46 active transistors.

Figure 2. Timing Diagram



### Description

The TL594 is a fixed-frequency pulse width modulation control circuit, incorporating the primary building blocks required for the control of a switching power supply. (See Figure 1.) An internal-linear sawtooth oscillator is frequency-programmable by two external components,  $R_T$  and  $C_T$ . The approximate oscillator frequency is determined by:

$$f_{osc} \approx \frac{1.1}{R_T \cdot C_T}$$

For more information refer to Figure 3.

Output pulse width modulation is accomplished by comparison of the positive sawtooth waveform across capacitor  $C_T$  to either of two control signals. The NOR gates, which drive output transistors Q1 and Q2, are enabled only when the flip-flop clock-input line is in its low state. This happens only during that portion of time when the sawtooth voltage is greater than the control signals. Therefore, an increase in control-signal amplitude causes a corresponding linear decrease of output pulse width. (Refer to the Timing Diagram shown in Figure 2.)

The control signals are external inputs that can be fed into the deadtime control, the error amplifier inputs, or the feedback input. The deadtime control comparator has an effective 120 mV input offset which limits the minimum output deadtime to approximately the first 4% of the sawtooth-cycle time. This would result in a maximum duty cycle on a given output of 96% with the output control grounded, and 48% with it connected to the reference line. Additional deadtime may be imposed on the output by setting the deadtime-control input to a fixed voltage, ranging between 0 V to 3.3 V.

The pulse width modulator comparator provides a means for the error amplifiers to adjust the output pulse width from the maximum percent on-time, established by the deadtime control input, down to zero, as the voltage at the feedback pin varies from 0.5 V to 3.5 V. Both error amplifiers have a

Functional Table

Input/Output Controls	Output Function	$\frac{f_{out}}{f_{osc}} =$
Grounded	Single-ended PWM @ Q1 and Q2	1.0
@ $V_{ref}$	Push-pull Operation	0.5

common-mode input range from -0.3 V to  $(V_{CC} - 2 \text{ V})$ , and may be used to sense power-supply output voltage and current. The error-amplifier outputs are active high and are ORed together at the noninverting input of the pulse-width modulator comparator. With this configuration, the amplifier that demands minimum output on time, dominates control of the loop.

When capacitor  $C_T$  is discharged, a positive pulse is generated on the output of the deadtime comparator, which clocks the pulse-steering flip-flop and inhibits the output transistors, Q1 and Q2. With the output-control connected to the reference line, the pulse-steering flip-flop directs the modulated pulses to each of the two output transistors alternately for push-pull operation. The output frequency is equal to half that of the oscillator. Output drive can also be taken from Q1 or Q2, when single-ended operation with a maximum on-time of less than 50% is required. This is desirable when the output transformer has a ringback winding with a catch diode used for snubbing. When higher output-drive currents are required for single-ended operation, Q1 and Q2 may be connected in parallel, and the output-mode pin must be tied to ground to disable the flip-flop. The output frequency will now be equal to that of the oscillator.

The TL594 has an internal 5.0 V reference capable of sourcing up to 10 mA of load current for external bias circuits. The reference has an internal accuracy of  $\pm 1.5\%$  with a typical thermal drift of less than 50 mV over an operating temperature range of 0° to 70°C.

Figure 3. Oscillator Frequency versus Timing Resistance

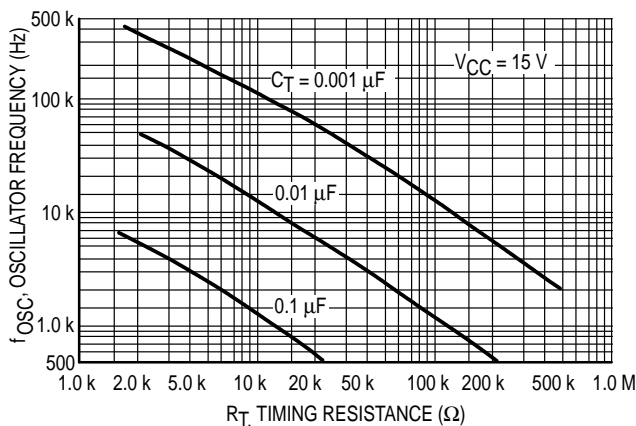
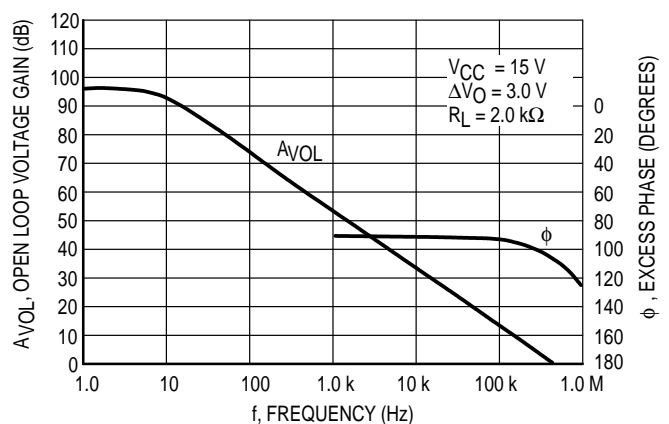
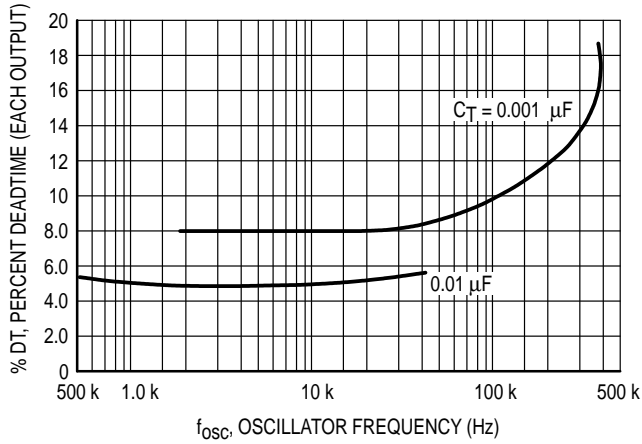


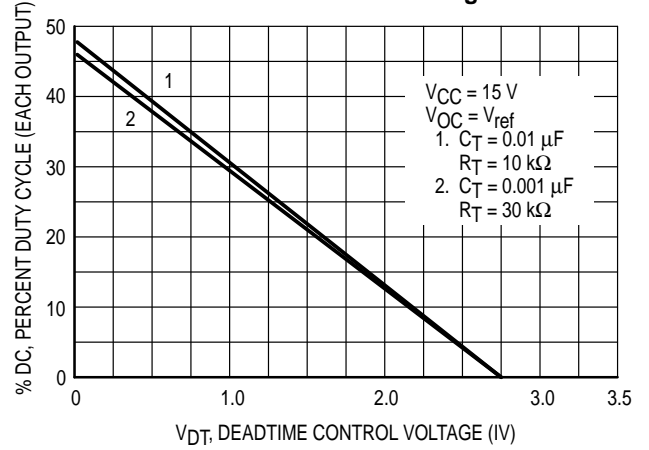
Figure 4. Open Loop Voltage Gain and Phase versus Frequency



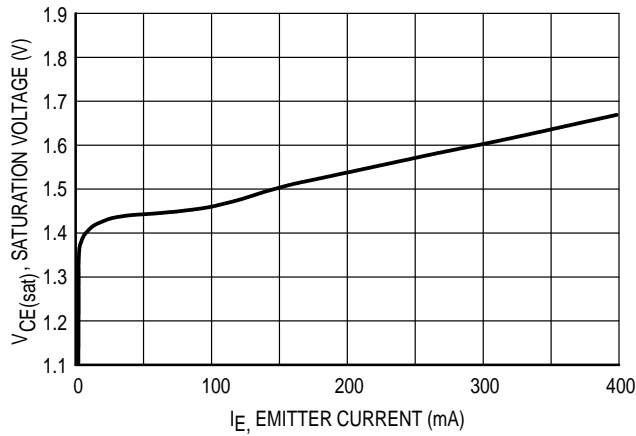
**Figure 5. Percent Deadtime versus Oscillator Frequency**



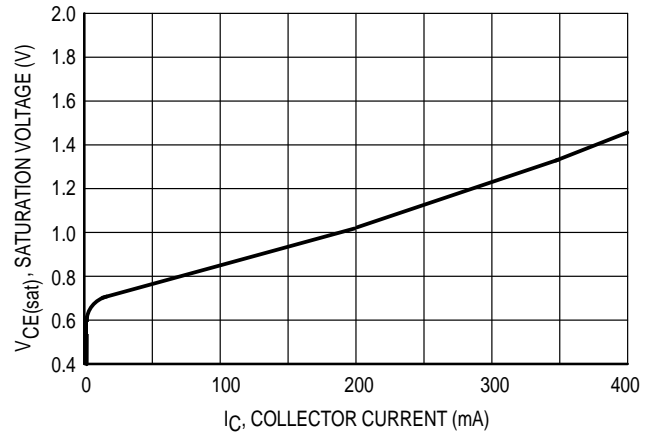
**Figure 6. Percent Duty Cycle versus Deadtime Control Voltage**



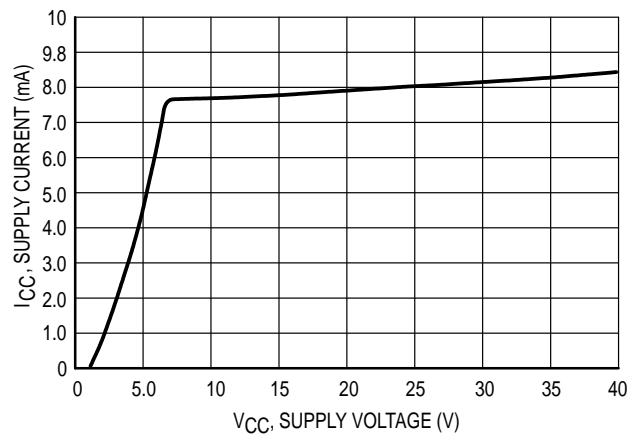
**Figure 7. Emitter-Follower Configuration Output Saturation Voltage versus Emitter Current**



**Figure 8. Common-Emitter Configuration Output Saturation Voltage versus Collector Current**



**Figure 9. Standby Supply Current versus Supply Voltage**



**Figure 10. Undervoltage Lockout Thresholds versus Reference Load Current**

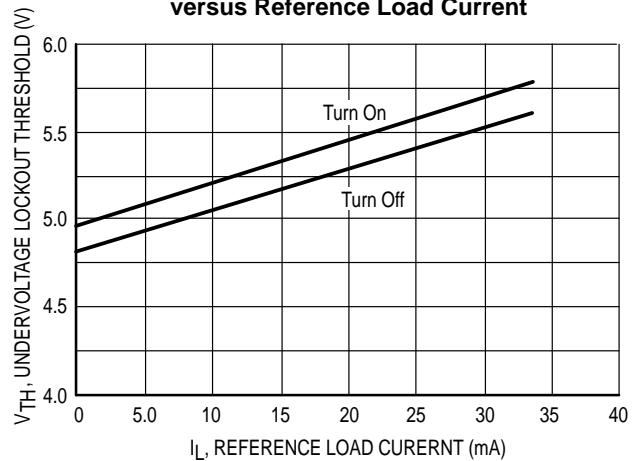


Figure 11. Error-Amplifier Characteristics

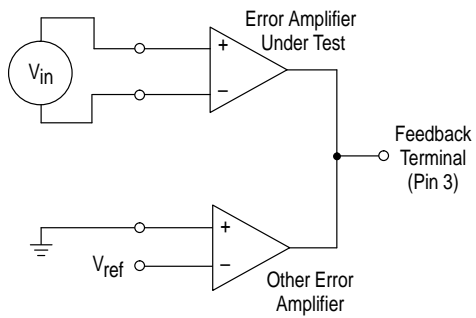


Figure 12. Deadtime and Feedback Control Circuit

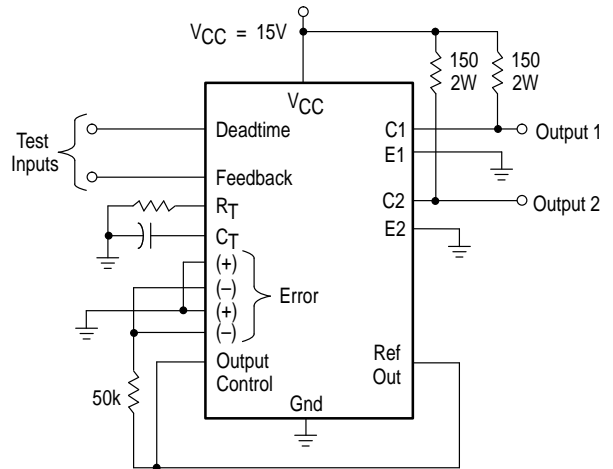


Figure 13. Common-Emitter Configuration Test Circuit and Waveform

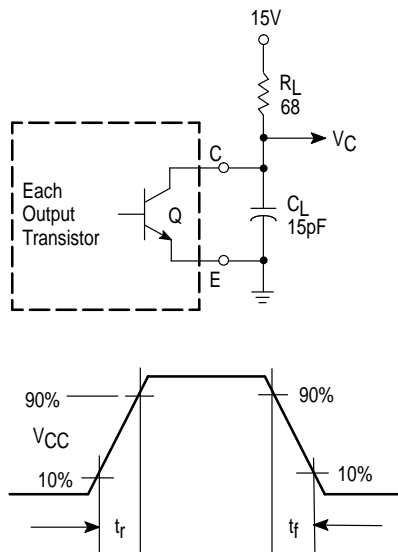
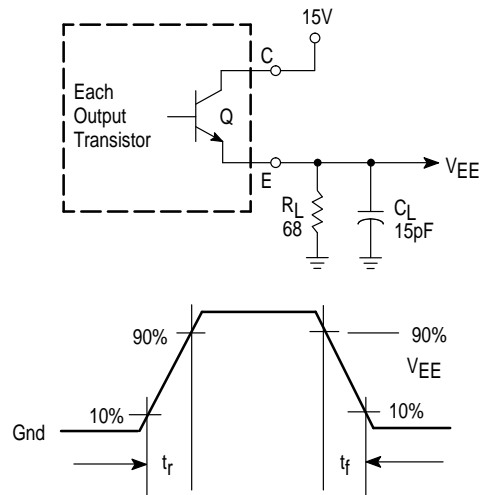
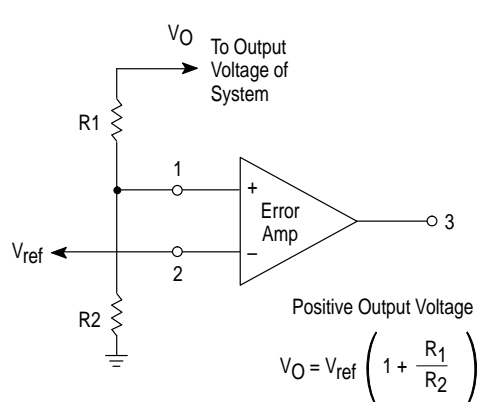


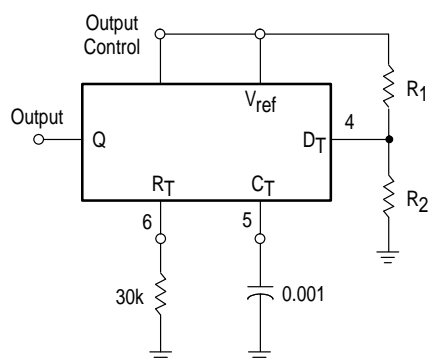
Figure 14. Emitter-Follower Configuration Test Circuit and Waveform



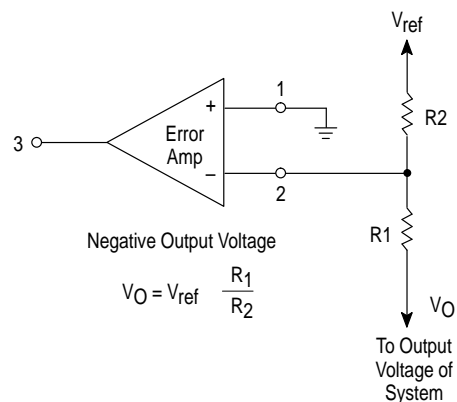
### Figure 15. Error–Amplifier Sensing Techniques



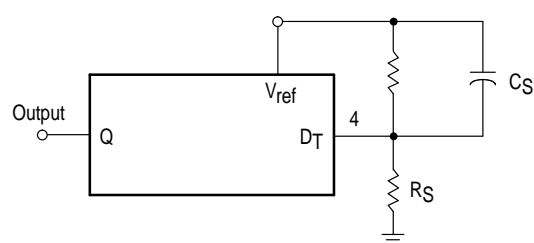
**Figure 16. Deadtime Control Circuit**



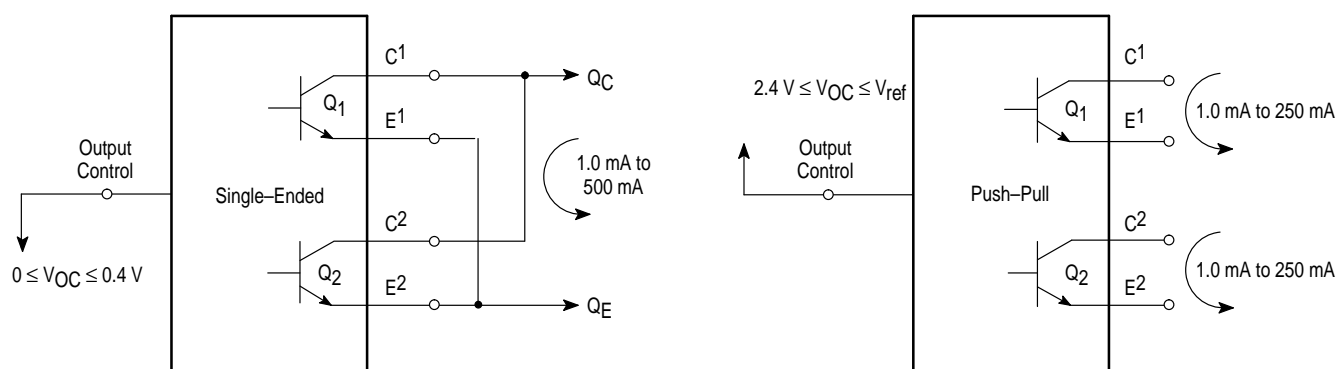
$$\text{Max. \% on Time, each output} \approx 45 - \left( \frac{80}{1 + \frac{R1}{R2}} \right)$$



### Figure 17. Soft-Start Circuit



**Figure 18. Output Connections for Single-Ended and Push-Pull Configurations**





## TL594

Figure 19. Slaving Two or More Control Circuits

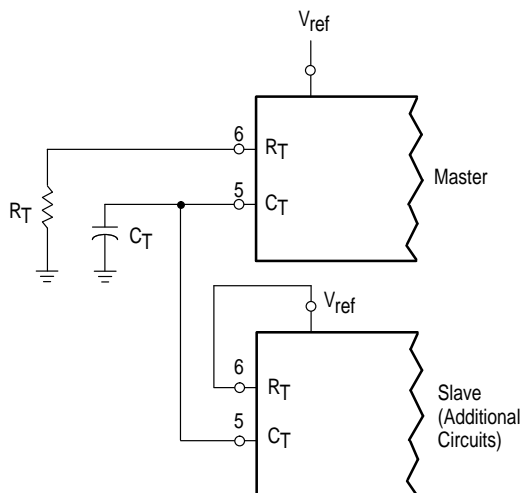


Figure 20. Operation with  $V_{in} > 40$  V Using External Zener

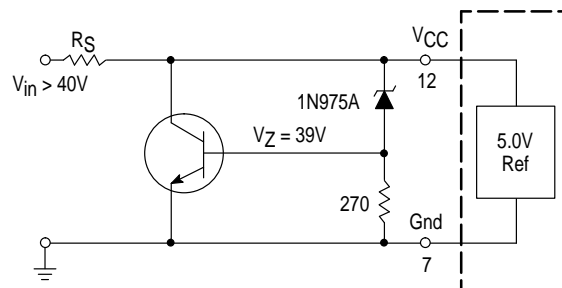
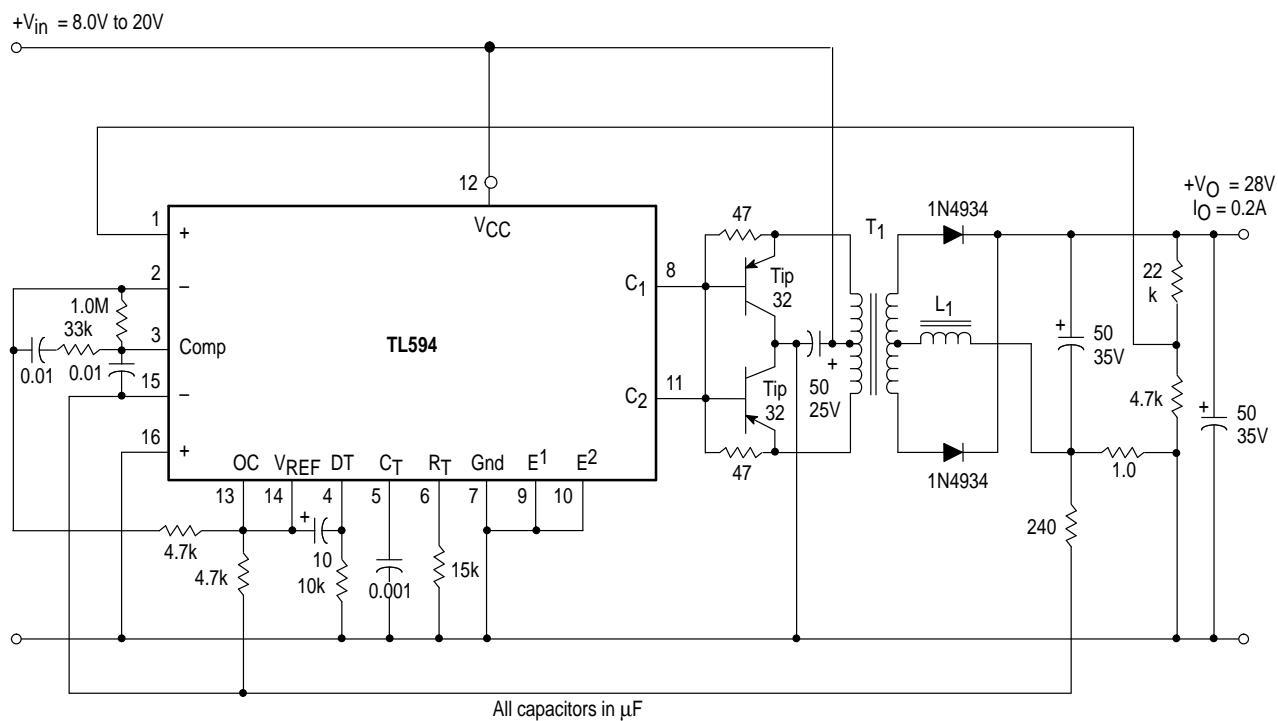


Figure 21. Pulse Width Modulated Push-Pull Converter

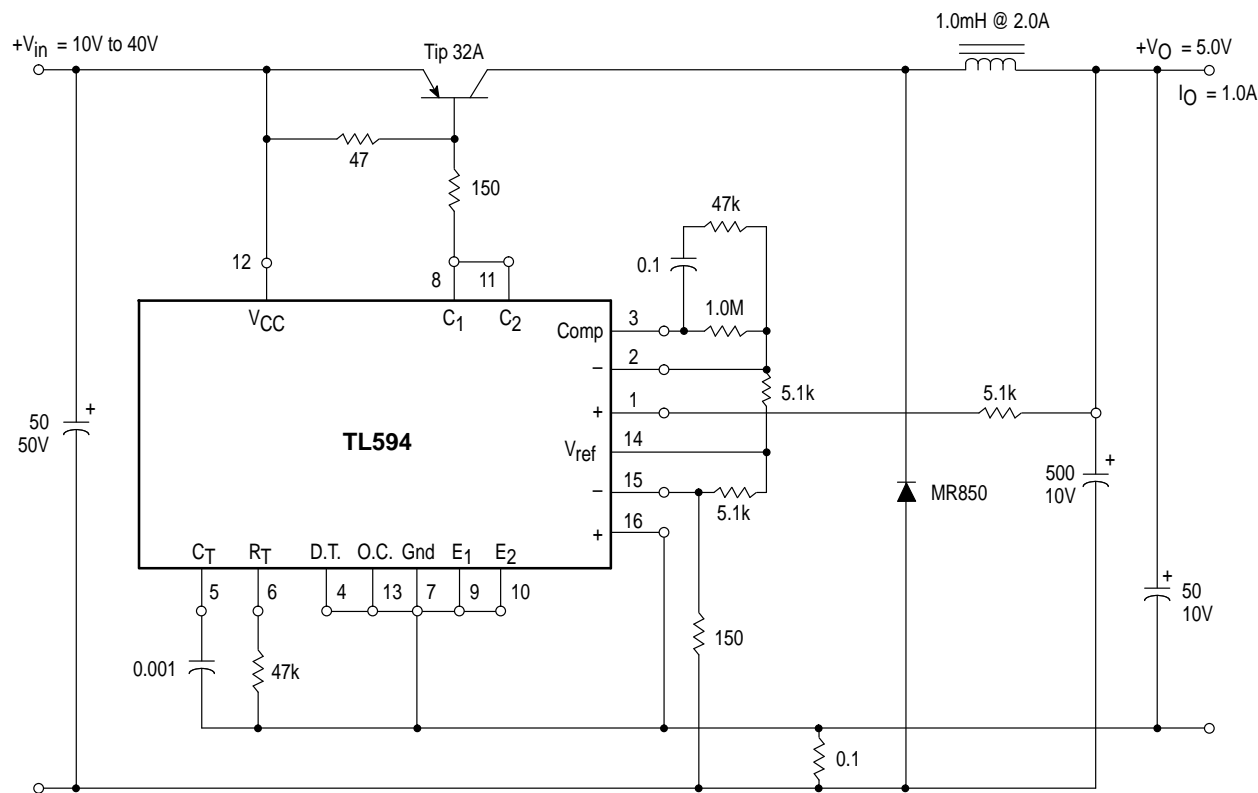


Test	Conditions	Results
Line Regulation	$V_{in} = 10$ V to 40 V	14 mV 0.28%
Load Regulation	$V_{in} = 28$ V, $I_O = 1.0$ mA to 1.0 A	3.0 mV 0.06%
Output Ripple	$V_{in} = 28$ V, $I_O = 1.0$ A	65 mVpp P.A.R.D.
Short Circuit Current	$V_{in} = 28$ V, $R_L = 0.1$ $\Omega$	1.6 A
Efficiency	$V_{in} = 28$ V, $I_O = 1.0$ A	71%

L1 – 3.5 mH @ 0.3 A  
T1 – Primary: 20T C.T. #28 AWG  
Secondary: 120T C.T. #36 AWG  
Core: Ferroxcube 1408P-L00-3CB

TL594

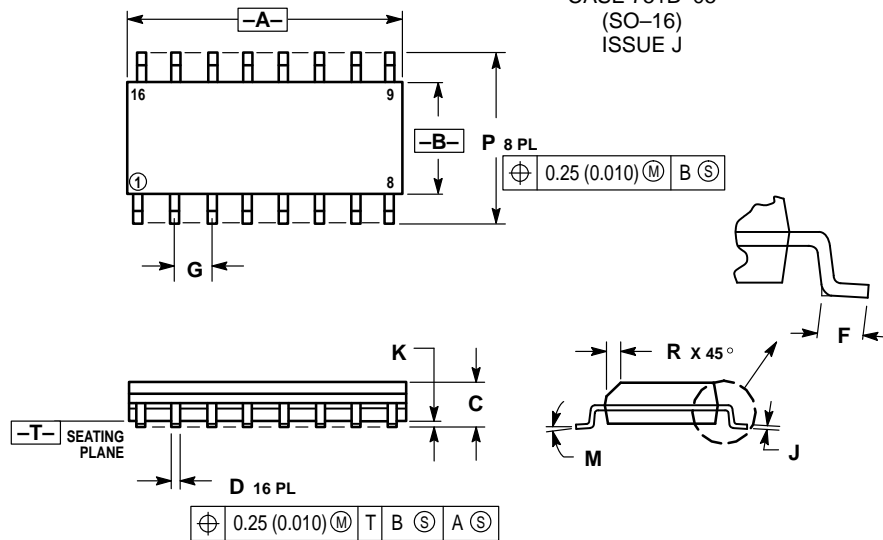
Figure 22. Pulse Width Modulated Step-Down Converter



Test	Conditions	Results
Line Regulation	$V_{in} = 8.0 \text{ V to } 40 \text{ V}$	3.0 mV 0.01%
Load Regulation	$V_{in} = 12.6 \text{ V}, I_O = 0.2 \text{ mA to } 200 \text{ mA}$	5.0 mV 0.02%
Output Ripple	$V_{in} = 12.6 \text{ V}, I_O = 200 \text{ mA}$	40 mVpp P.A.R.D.
Short Circuit Current	$V_{in} = 12.6 \text{ V}, R_L = 0.1 \Omega$	250 mA
Efficiency	$V_{in} = 12.6 \text{ V}, I_O = 200 \text{ mA}$	72%

# TL594 OUTLINE DIMENSIONS

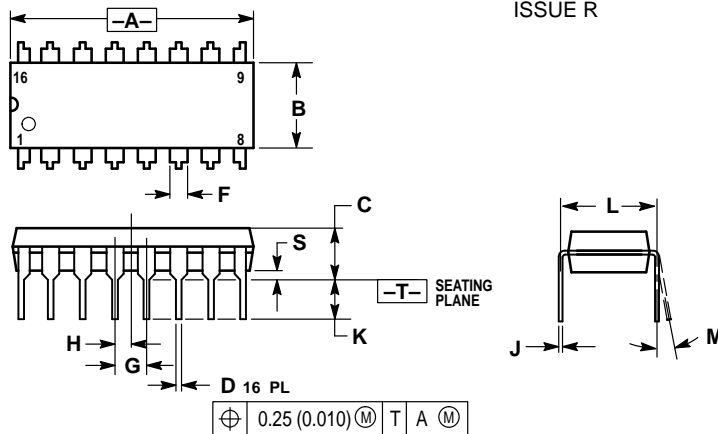
## D SUFFIX PLASTIC PACKAGE CASE 751B-05 (SO-16) ISSUE J



- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: MILLIMETER.
  3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
  4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
  5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.


DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	9.80	10.00	0.386	0.393
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.054	0.068
D	0.35	0.49	0.014	0.019
F	0.40	1.25	0.016	0.049
G	1.27 BSC		0.050 BSC	
J	0.19	0.25	0.008	0.009
K	0.10	0.25	0.004	0.009
M	0°	7°	0°	7°
P	5.80	6.20	0.229	0.244
R	0.25	0.50	0.010	0.019

## N SUFFIX PLASTIC PACKAGE CASE 648-08 ISSUE R



- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: INCH.
  3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
  4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
  5. ROUNDED CORNERS OPTIONAL.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.740	0.770	18.80	19.55
B	0.250	0.270	6.35	6.85
C	0.145	0.175	3.69	4.44
D	0.015	0.021	0.39	0.53
F	0.040	0.70	1.02	1.77
G	0.100 BSC		2.54 BSC	
H	0.050 BSC		1.27 BSC	
J	0.008	0.015	0.21	0.38
K	0.110	0.130	2.80	3.30
L	0.295	0.305	7.50	7.74
M	0°	10°	0°	10°
S	0.020	0.040	0.51	1.01

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