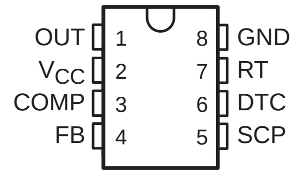
- **Complete PWM Power Control**
- **3.6-V to 40-V Operation**
- **Internal Undervoltage-Lockout Circuit**
- **Internal Short-Circuit Protection**
- **Oscillator Frequency . . . 20 kHz to 500 kHz**
- **Variable Dead Time Provides Control Over Total Range**
- **±3% Tolerance on Reference Voltage (TL5001A)**

D OR P PACKAGE
(TOP VIEW)



description

The TL5001 and TL5001A incorporates on a single monolithic chip all the functions required for a pulse-width-modulation (PWM) control circuit. Designed primarily for power-supply control, the TL5001/A contains an error amplifier, a regulator, an oscillator, a PWM comparator with a dead-time-control input, undervoltage lockout (UVLO), short-circuit protection (SCP), and an open-collector output transistor. The TL5001A has a reference voltage tolerance of ±3% compared to ±5% for the TL5001.

The error-amplifier common-mode voltage ranges from 0 V to 1.5 V. The noninverting input of the error amplifier is connected to a 1-V reference. Dead-time control (DTC) can be set to provide 0% to 100% dead time by connecting an external resistor between DTC and GND. The oscillator frequency is set by terminating RT with an external resistor to GND. During low V_{CC} conditions, the UVLO circuit turns the output off until V_{CC} recovers to its normal operating range.

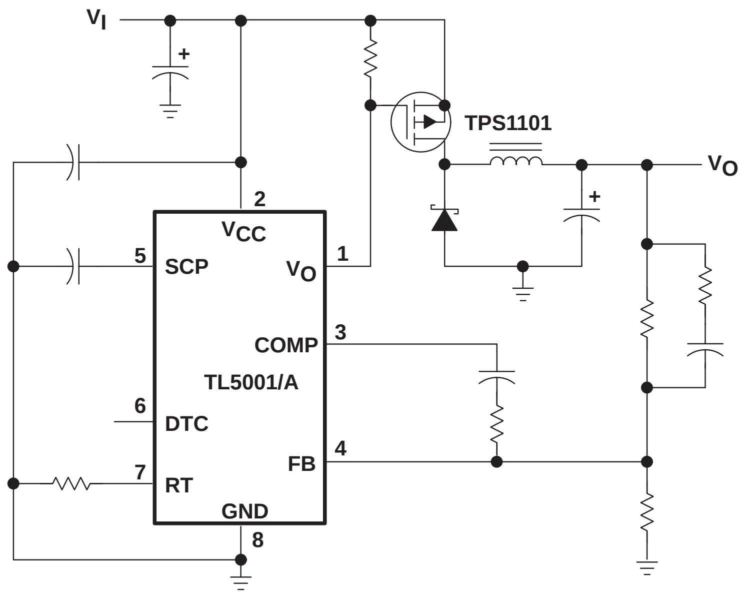
The TL5001C and TL5001AC are characterized for operation from –20°C to 85°C. The TL5001I and TL5001AI are characterized for operation from –40°C to 85°C.

AVAILABLE OPTIONS

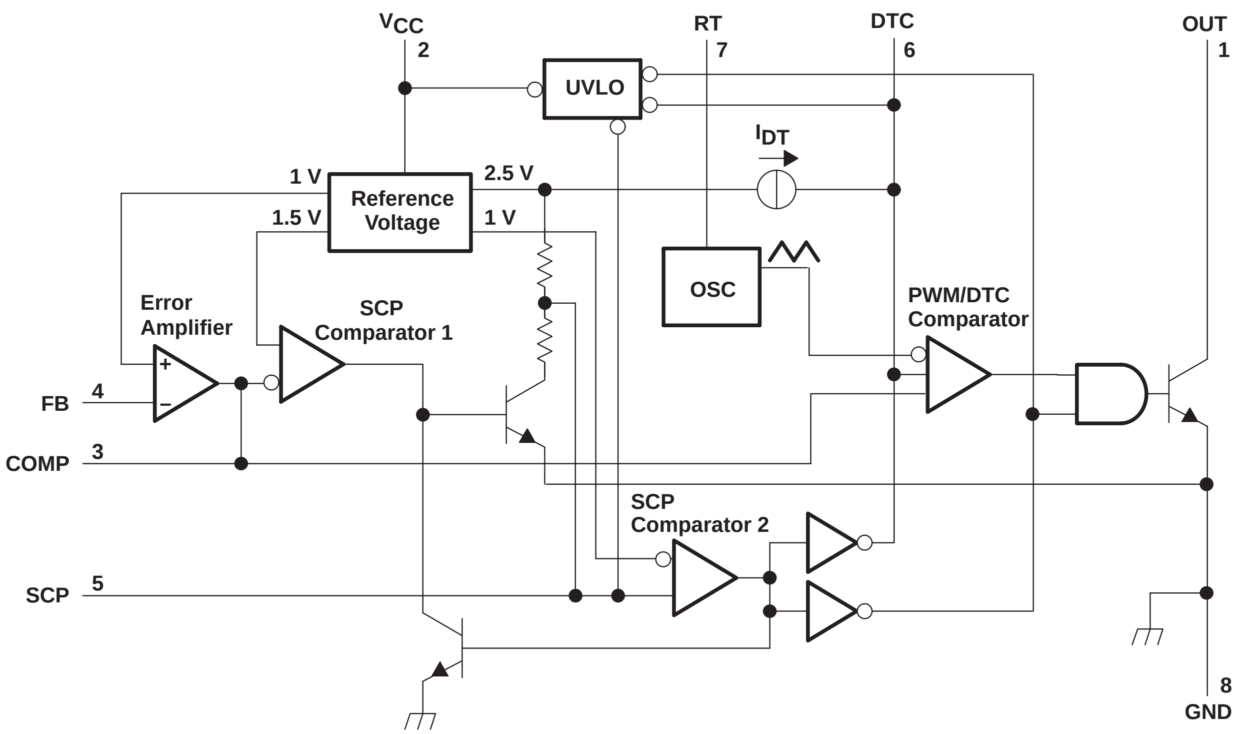
T_A	PACKAGED DEVICES		
	SMALL OUTLINE (D)	PLASTIC DIP (P)	CHIP FORM (Y)
–20°C to 85°C	TL5001CD	TL5001CP	TL5001Y
	TL5001ACD	TL5001ACP	—
–40°C to 85°C	TL5001ID	TL5001IP	—
	TL5001AID	TL5001AIP	—

The D package is available taped and reeled. Add the suffix R to the device type (e.g., TL5001CDR). Chip forms are tested at T_A = 25°C.

schematic for typical application



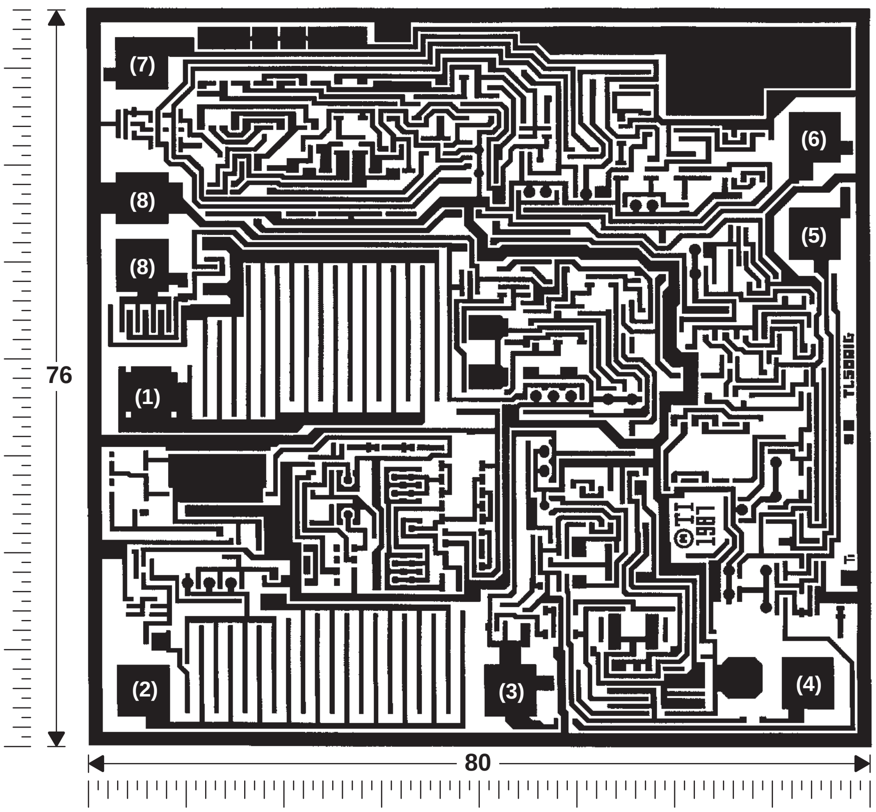
functional block diagram

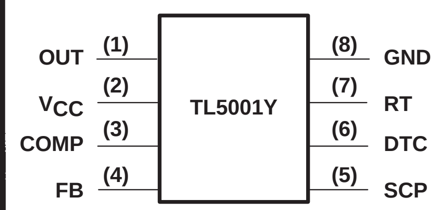


TL5001Y chip information

This chip, when properly assembled, displays characteristics similar to the TL5001C. Thermal compression or ultrasonic bonding may be used on the doped aluminum bonding pads. The chips may be mounted with conductive epoxy or a gold-silicon preform.

BONDING PAD ASSIGNMENTS





CHIP THICKNESS:
11 MILS TYPICAL

BONDING PADS:
7 X 7 MILS MINIMUM

T_J max = 150°C

TOLERANCES ARE ±10%.

ALL DIMENSIONS ARE IN MILS.

detailed description

voltage reference

A 2.5-V regulator operating from V_{CC} is used to power the internal circuitry of the TL5001 and TL5001A and as a reference for the error amplifier and SCP circuits. A resistive divider provides a 1-V reference for the error amplifier noninverting input. The TL5001 1-V reference remains within 5% of nominal over the operating temperature range. In the TL5001A, the 1-V reference remains within 3% of nominal.

error amplifier

The error amplifier compares a sample of the dc-to-dc converter output voltage to the 1-V reference and generates an error signal for the PWM comparator. The dc-to-dc converter output voltage is set by selecting the error-amplifier gain (see Figure 1), using the following expression:

$$V_O = (1 + R1/R2)\ (1\ V)$$

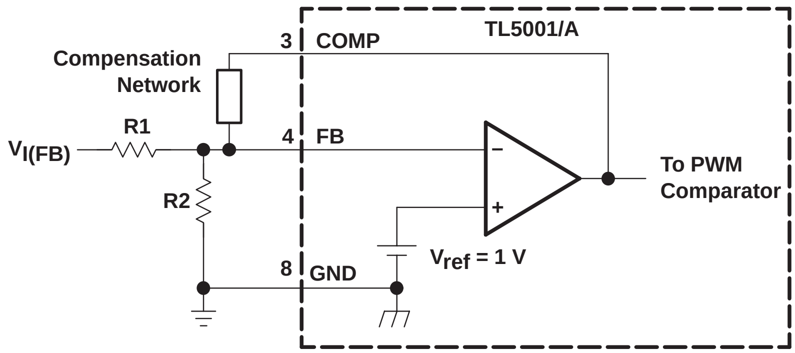


Figure 1. Error-Amplifier Gain Setting

The error-amplifier output is brought out as COMP for use in compensating the dc-to-dc converter control loop for stability. Because the amplifier can only source 45 µA, the total dc load resistance should be 100 kΩ or more.

oscillator/PWM

The oscillator frequency (f_{osc}) can be set between 20 kHz and 500 kHz by connecting a resistor between RT and GND. Acceptable resistor values range from 15 kΩ to 250 kΩ. The oscillator frequency can be determined by using the graph shown in Figure 5.

The oscillator output is a triangular wave with a minimum value of approximately 0.7 V and a maximum value of approximately 1.3 V. The PWM comparator compares the error-amplifier output voltage and the DTC input voltage to the triangular wave and turns the output transistor off whenever the triangular wave is greater than the lesser of the two inputs.

dead-time control (DTC)

DTC provides a means of limiting the output-switch duty cycle to a value less than 100%, which is critical for boost and flyback converters. A current source generates a reference current (I_{DT}) at DTC that is nominally equal to the current at the oscillator timing terminal, RT. Connecting a resistor between DTC and GND generates a dead-time reference voltage (V_{DT}), which the PWM/DTC comparator compares to the oscillator triangle wave as described in the previous section. Nominally, the maximum duty cycle is 0% when V_{DT} is 0.7 V or less and 100% when V_{DT} is 1.3 V or greater. Because the triangle wave amplitude is a function of frequency and the source impedance of RT is relatively high (1250 Ω), choosing R_{DT} for a specific maximum duty cycle, D, is accomplished using the following equation and the voltage limits for the frequency in question as found in Figure 11 (V_{osc}max and V_{osc}min are the maximum and minimum oscillator levels):

dead-time control (DTC) (continued)

$$R_{DT} = \left(R_t + 1250\right)\left[D\left(V_{osc}max - V_{osc}min\right) + V_{osc}min\right]$$

where

R_{DT} and R_t are in ohms, D in decimal

Soft start can be implemented by paralleling the DTC resistor with a capacitor (C_{DT}) as shown in Figure 2. During soft start, the voltage at DTC is derived by the following equation:

$$V_{DT} \approx I_{DT}R_{DT}\left(1 - e^{\left(-t/R_{DT}C_{DT}\right)}\right)$$

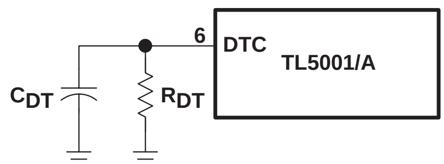


Figure 2. Soft-Start Circuit

If the dc-to-dc converter must be in regulation within a specified period of time, the time constant, $R_{DT}C_{DT}$, should be $t_0/3$ to $t_0/5$. The TL5001/A remains off until $V_{DT} \approx 0.7$ V, the minimum ramp value. C_{DT} is discharged every time UVLO or SCP becomes active.

undervoltage-lockout (UVLO) protection

The undervoltage-lockout circuit turns the output transistor off and resets the SCP latch whenever the supply voltage drops too low (approximately 3 V) for proper operation. A hysteresis voltage of 200 mV eliminates false triggering on noise and chattering.

short-circuit protection (SCP)

The TL5001/A includes short-circuit protection (see Figure 3), which turns the power switch off to prevent damage when the converter output is shorted. When activated, the SCP prevents the switch from being turned on until the internal latching circuit is reset. The circuit is reset by reducing the input voltage until UVLO becomes active or until the SCP terminal is pulled to ground externally.

When a short circuit occurs, the error-amplifier output at COMP rises to increase the power-switch duty cycle in an attempt to maintain the output voltage. SCP comparator 1 starts an RC timing circuit when COMP exceeds 1.5 V. If the short is removed and the error-amplifier output drops below 1.5 V before time out, normal converter operation continues. If the fault is still present at the end of the time-out period, the timer sets the latching circuit and turns off the TL5001/A output transistor.

short-circuit protection (SCP) (continued)

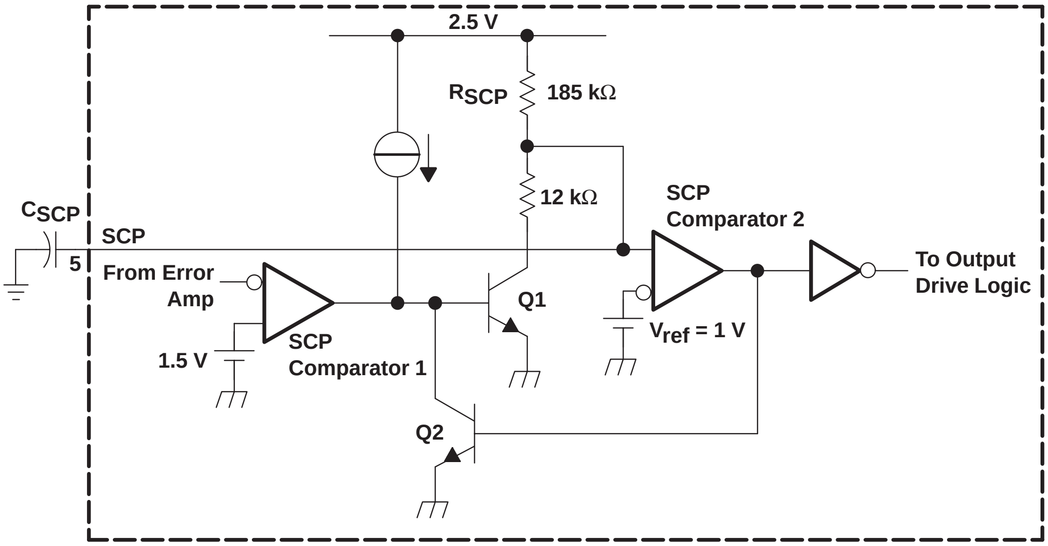


Figure 3. SCP Circuit

The timer operates by charging an external capacitor (C_{SCP}), connected between the SCP terminal and ground, towards 2.5 V through a 185-kΩ resistor (R_{SCP}). The circuit begins charging from an initial voltage of approximately 185 mV and times out when the capacitor voltage reaches 1 V. The output of SCP comparator 2 then goes high, turns on Q2, and latches the timer circuit. The expression for setting the SCP time period is derived from the following equation:

$$V_{SCP} = (2.5 - 0.185)\left(1 - e^{-t/\tau}\right) + 0.185$$

where

$$\tau = R_{SCP}C_{SCP}$$

The end of the time-out period, t_{SCP}, occurs when V_{SCP} = 1 V. Solving for C_{SCP} yields:

$$C_{SCP} = 12.46 \times t_{SCP}$$

where

t is in seconds, C in μF.

t_{SCP} must be much longer (generally 10 to 15 times) than the converter start-up period or the converter will not start.

output transistor

The output of the TL5001/A is an open-collector transistor with a maximum collector current rating of 21 mA and a voltage rating of 51 V. The output is turned on under the following conditions: the oscillator triangle wave is lower than both the DTC voltage and the error-amplifier output voltage, the UVLO circuit is inactive, and the short-circuit protection circuit is inactive.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{CC} (see Note 1)		41 V
Amplifier input voltage, $V_{I(FB)}$		20 V
Output voltage, V_O, OUT		51 V
Output current, I_O, OUT		21 mA
Output peak current, $I_{O(peak)}$, OUT		100 mA
Continuous total power dissipation		See Dissipation Rating Table
Operating ambient temperature range, T_A:	TL5001C, TL5001AC	–20°C to 85°C
	TL5001I, TL5001AI	–40°C to 85°C
Storage temperature range, T_{stg}		–65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds		260°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 under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.

DISSIPATION RATING TABLE

PACKAGE	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING
D	725 mW	5.8 mW/°C	464 mW	377 mW
P	1000 mW	8.0 mW/°C	640 mW	520 mW

recommended operating conditions

		MIN	MAX	UNIT
Supply voltage, V_{CC}		3.6	40	V
Amplifier input voltage, $V_{I(FB)}$		0	1.5	V
Output voltage, V_O, OUT			50	V
Output current, I_O, OUT			20	mA
COMP source current			45	µA
COMP dc load resistance		100		kΩ
Oscillator timing resistor, R_t		15	250	kΩ
Oscillator frequency, f_{osc}		20	500	kHz
Operating ambient temperature, T_A	TL5001C, TL5001AC	–20	85	°C
	TL5001I, TL5001AI	–40	85	

electrical characteristics over recommended operating free-air temperature range, V_{CC} = 6 V, f_{osc} = 100 kHz (unless otherwise noted)

reference

PARAMETER	TEST CONDITIONS	TL5001			TL5001A			UNIT
		MIN	TYP†	MAX	MIN	TYP†	MAX	
Output voltage	COMP connected to FB	0.95	1	1.05	0.97	1	1.03	V
Input regulation	V_{CC} = 3.6 V to 40 V		2	12.5		2	12.5	mV
Output voltage change with temperature	T_A = –20°C to 25°C (C suffix)	–10	–1	10	–10	–1	10	mV/V
	T_A = –40°C to 25°C (I suffix)	–10	–1	10	–10	–1	10	
	T_A = 25°C to 85°C	–10	–2	10	–10	–2	10	

† All typical values are at T_A = 25°C.

electrical characteristics over recommended operating free-air temperature range, V_{CC} = 6 V, f_{osc} = 100 kHz (unless otherwise noted) (continued)

undervoltage lockout

PARAMETER	TEST CONDITIONS	TL5001			TL5001A			UNIT
		MIN	TYP†	MAX	MIN	TYP†	MAX	
Upper threshold voltage	T_A = 25°C		3			3		V
Lower threshold voltage	T_A = 25°C		2.8			2.8		V
Hysteresis	T_A = 25°C	100	200		100	200		mV
Reset threshold voltage	T_A = 25°C	2.1	2.55		2.1	2.55		V

† All typical values are at T_A = 25°C.

short-circuit protection

PARAMETER	TEST CONDITIONS	TL5001			TL5001A			UNIT
		MIN	TYP†	MAX	MIN	TYP†	MAX	
SCP threshold voltage	T_A = 25°C	0.95	1.00	1.05	0.97	1.00	1.03	V
SCP voltage, latched	No pullup	140	185	230	140	185	230	mV
SCP voltage, UVLO standby	No pullup		60	120		60	120	mV
Input source current	T_A = 25°C	–10	–15	–20	–10	–15	–20	μA
SCP comparator 1 threshold voltage			1.5			1.5		V

† All typical values are at T_A = 25°C.

oscillator

PARAMETER	TEST CONDITIONS	TL5001			TL5001A			UNIT
		MIN	TYP†	MAX	MIN	TYP†	MAX	
Frequency	R_t = 100 kΩ		100			100		kHz
Standard deviation of frequency			15			15		kHz
Frequency change with voltage	V_{CC} = 3.6 V to 40 V		1			1		kHz
Frequency change with temperature	T_A = –40°C to 25°C	–4	–0.4	4	–4	–0.4	4	kHz
	T_A = –20°C to 25°C	–4	–0.4	4	–4	–0.4	4	kHz
	T_A = 25°C to 85°C	–4	–0.2	4	–4	–0.2	4	kHz
Voltage at RT			1			1		V

† All typical values are at T_A = 25°C.

dead-time control

PARAMETER		TEST CONDITIONS	TL5001			TL5001A			UNIT
			MIN	TYP†	MAX	MIN	TYP†	MAX	
Output (source) current	TL5001C	$V_{(DT)}$ = 1.5 V	$0.9 \times I_{RT}$‡		$1.1 \times I_{RT}$	$0.9 \times I_{RT}$‡		$1.1 \times I_{RT}$	μA
	TL5001I	$V_{(DT)}$ = 1.5 V	$0.9 \times I_{RT}$‡		$1.2 \times I_{RT}$	$0.9 \times I_{RT}$‡		$1.2 \times I_{RT}$	
Input threshold voltage		Duty cycle = 0%	0.5	0.7		0.5	0.7		V
		Duty cycle = 100%		1.3	1.5		1.3	1.5	

† All typical values are at T_A = 25°C.
‡ Output source current at RT

electrical characteristics over recommended operating free-air temperature range, V_{CC} = 6 V, f_{osc} = 100 kHz (unless otherwise noted) (continued)

error amplifier

PARAMETER		TEST CONDITIONS	TL5001			TL5001A			UNIT
			MIN	TYP†	MAX	MIN	TYP†	MAX	
Input voltage		V_{CC} = 3.6 V to 40 V	0		1.5	0		1.5	V
Input bias current				–160	–500		–160	–500	nA
Output voltage swing	Positive		1.5	2.3		1.5	2.3		V
	Negative			0.3	0.4		0.3	0.4	V
Open-loop voltage amplification				80			80		dB
Unity-gain bandwidth				1.5			1.5		MHz
Output (sink) current		$V_{I(FB)}$ = 1.2 V, COMP = 1 V	100	600		100	600		µA
Output (source) current		$V_{I(FB)}$ = 0.8 V, COMP = 1 V	–45	–70		–45	–70		µA

† All typical values are at T_A = 25°C.

output

PARAMETER	TEST CONDITIONS	TL5001			TL5001A			UNIT
		MIN	TYP†	MAX	MIN	TYP†	MAX	
Output saturation voltage	I_O = 10 mA		1.5	2		1.5	2	V
Off-state current	V_O = 50 V, V_{CC} = 0			10			10	µA
	V_O = 50 V			10			10	
Short-circuit output current	V_O = 6 V		40			40		mA

† All typical values are at T_A = 25°C.

total device

PARAMETER		TEST CONDITIONS	TL5001			TL5001A			UNIT
			MIN	TYP†	MAX	MIN	TYP†	MAX	
Standby supply current	Off state			1	1.5		1	1.5	mA
Average supply current		R_t = 100 kΩ		1.4	2.1		1.4	2.1	mA

† All typical values are at T_A = 25°C.

electrical characteristics, V_{CC} = 6 V, f_{osc} = 100 kHz, T_A = 25°C (unless otherwise noted)

reference

PARAMETER	TEST CONDITIONS	TL5001Y MIN	TL5001Y TYP	TL5001Y MAX	UNIT
Output voltage	COMP connected to FB		1		V
Input regulation	V_{CC} = 3.6 V to 40 V		2		mV
Output voltage change with temperature			–2		mV/V

undervoltage lockout

PARAMETER	TL5001Y MIN	TL5001Y TYP	TL5001Y MAX	UNIT
Upper threshold voltage		3		V
Lower threshold voltage		2.8		V
Hysteresis		200		mV
Reset threshold voltage		2.55		V

short-circuit protection

PARAMETER	TEST CONDITIONS	TL5001Y MIN	TL5001Y TYP	TL5001Y MAX	UNIT
SCP threshold voltage			1		V
SCP voltage, latched	No pullup		185		mV
SCP voltage, UVLO standby	No pullup		60		mV
Input source current			–15		µA
SCP comparator 1 threshold voltage			1.5		V

oscillator

PARAMETER	TEST CONDITIONS	TL5001Y MIN	TL5001Y TYP	TL5001Y MAX	UNIT
Frequency	R_t = 100 kΩ		100		kHz
Standard deviation of frequency			15		kHz
Frequency change with voltage	V_{CC} = 3.6 V to 40 V		1		kHz
Frequency change with temperature			–0.4		kHz
			–0.2		
Voltage at RT			1		V

dead-time control

PARAMETER	TEST CONDITIONS	TL5001Y MIN	TL5001Y TYP	TL5001Y MAX	UNIT
Input threshold voltage	Duty cycle = 0%		0.7		V
	Duty cycle = 100%		1.3		

electrical characteristics, V_{CC} = 6 V, f_{osc} = 100 kHz, T_A = 25°C (unless otherwise noted) (continued)

error amplifier

PARAMETER		TEST CONDITIONS	TL5001Y			UNIT
			MIN	TYP	MAX	
Input bias current				–160		nA
Output voltage swing	Positive			2.3		V
	Negative			0.3		V
Open-loop voltage amplification				80		dB
Unity-gain bandwidth				1.5		MHz
Output (sink) current		$V_{I(FB)}$ = 1.2 V, COMP = 1 V		600		µA
Output (source) current		$V_{I(FB)}$ = 0.8 V, COMP = 1 V		–70		µA

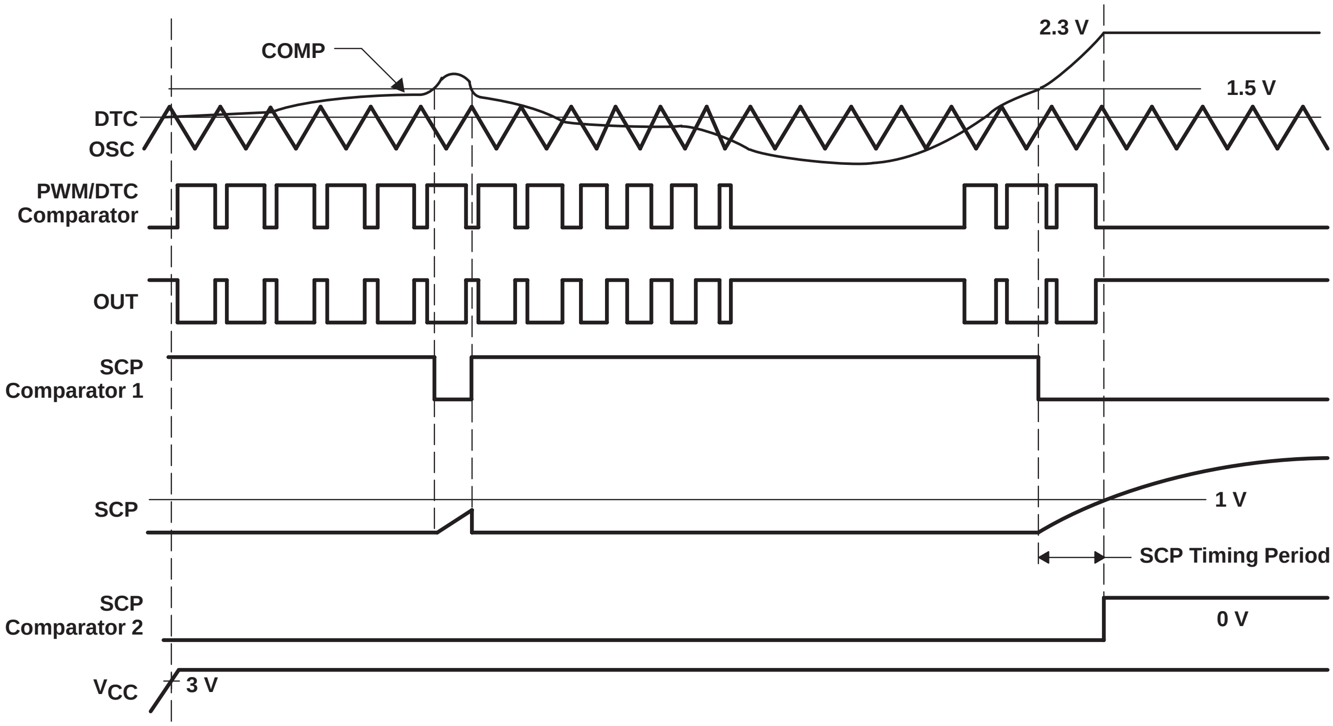
output

PARAMETER	TEST CONDITIONS	TL5001Y			UNIT
		MIN	TYP	MAX	
Output saturation voltage	I_O = 10 mA		1.5		V
Short-circuit output current	V_O = 6 V		40		mA

total device

PARAMETER		TEST CONDITIONS	TL5001Y			UNIT
			MIN	TYP	MAX	
Standby supply current	Off state			1		mA
Average supply current		R_t = 100 kΩ		1.4		mA

PARAMETER MEASUREMENT INFORMATION



NOTE A: The waveforms show timing characteristics for an intermittent short circuit and a longer short circuit that is sufficient to activate SCP.

Figure 4. PWM Timing Diagram

TYPICAL CHARACTERISTICS

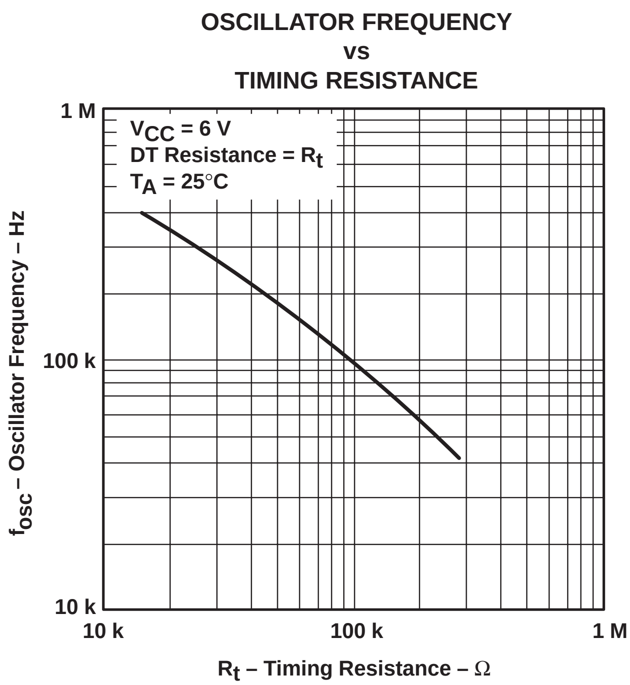


Figure 5

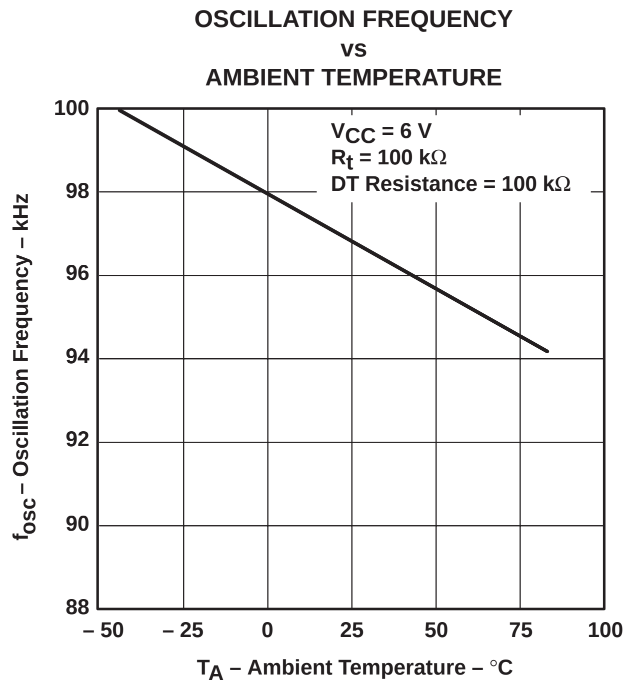


Figure 6

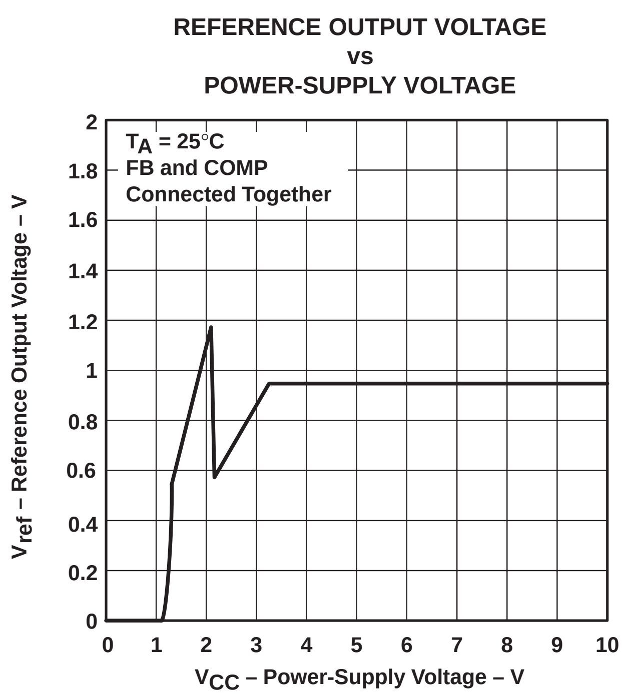


Figure 7

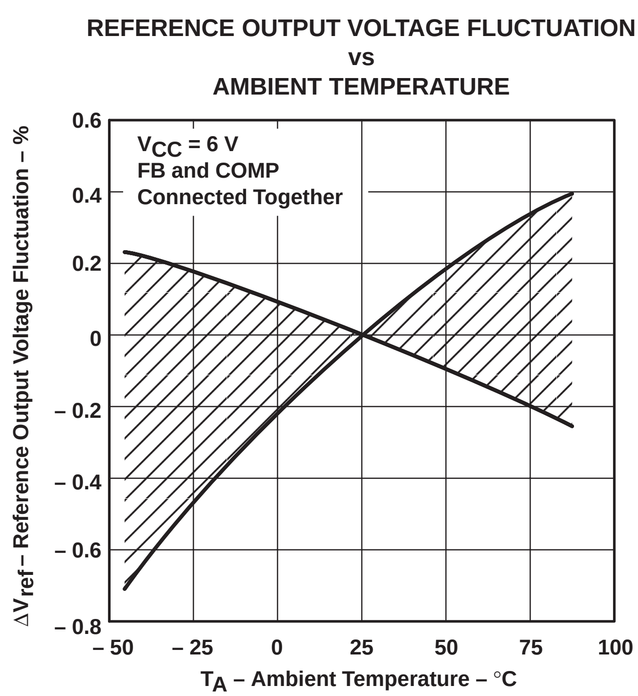


Figure 8

TYPICAL CHARACTERISTICS

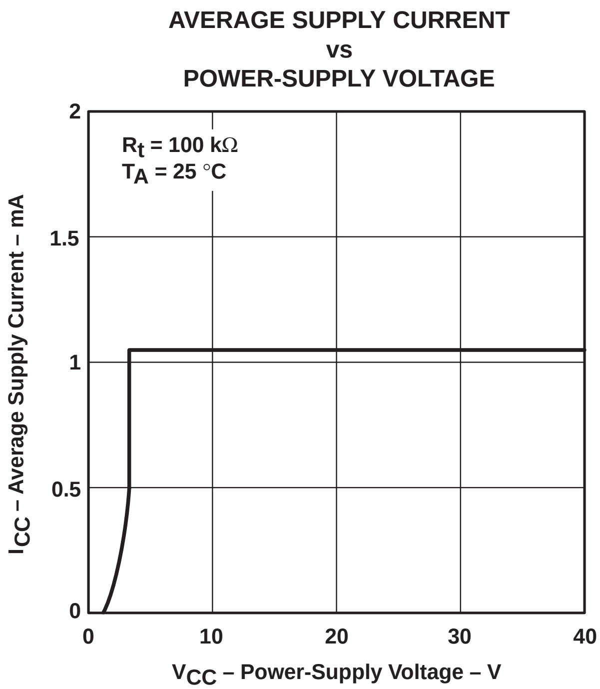


Figure 9

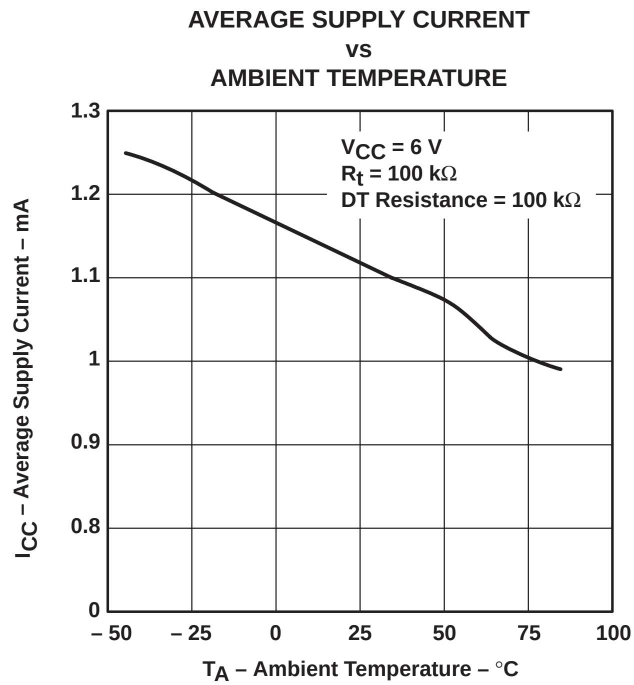


Figure 10

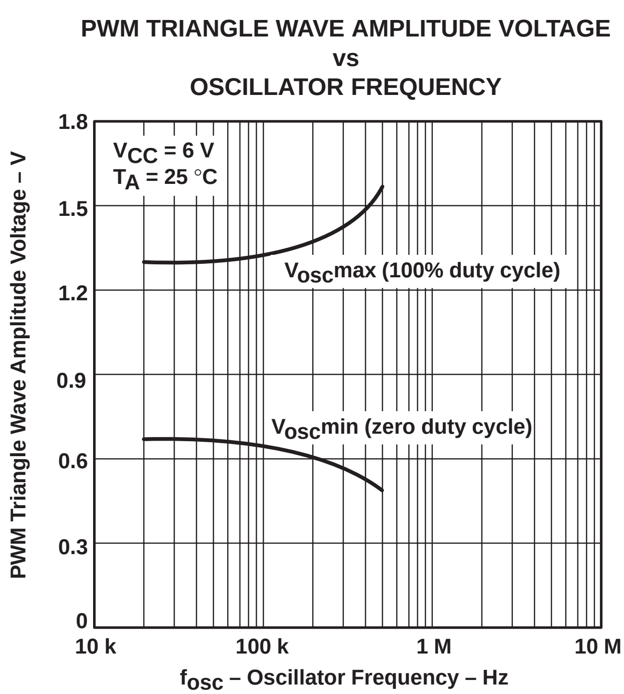


Figure 11

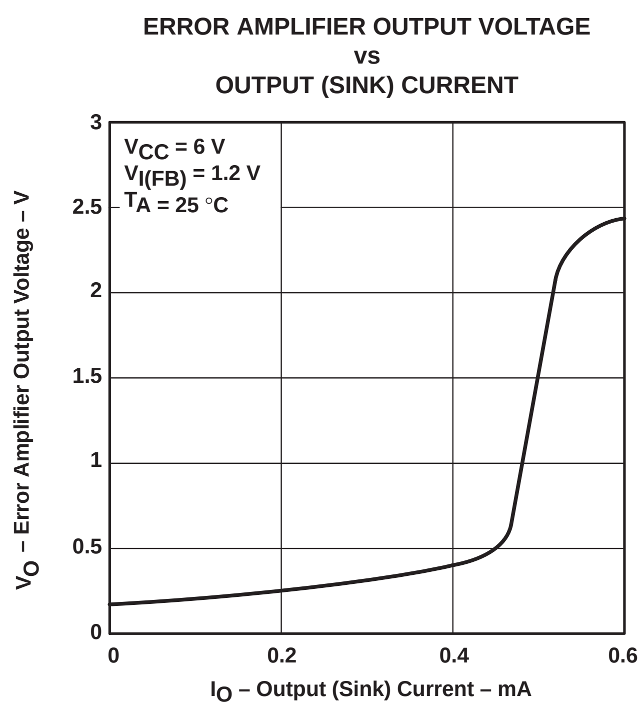


Figure 12

TYPICAL CHARACTERISTICS

ERROR AMPLIFIER OUTPUT VOLTAGE
vs
OUTPUT (SOURCE) CURRENT

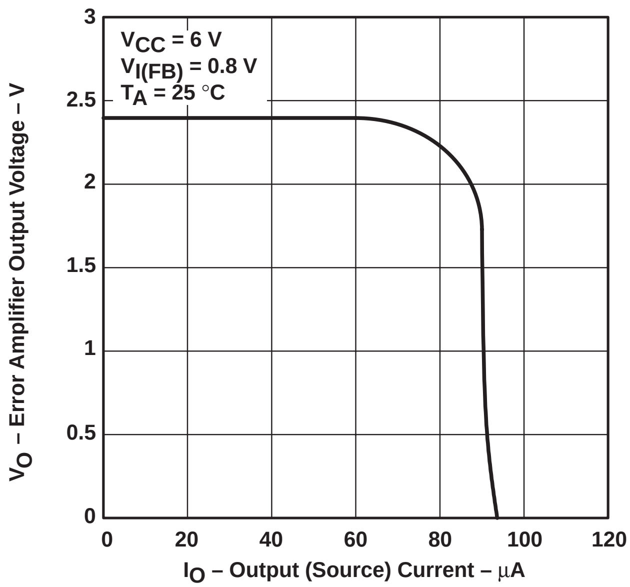


Figure 13

ERROR AMPLIFIER OUTPUT VOLTAGE
vs
AMBIENT TEMPERATURE

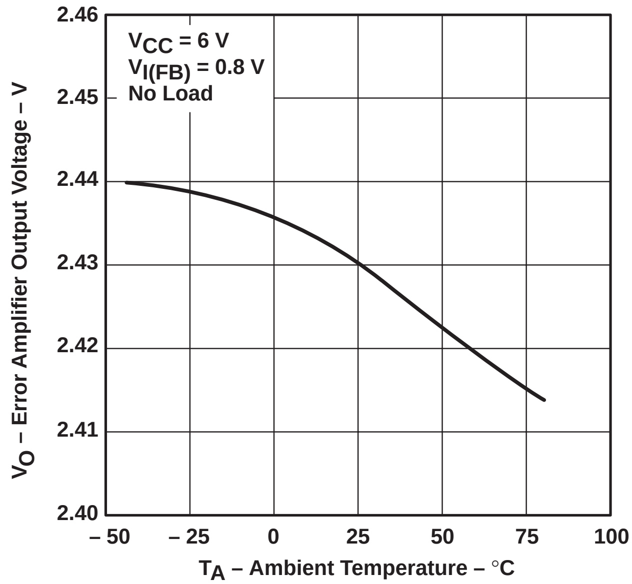


Figure 14

ERROR AMPLIFIER OUTPUT VOLTAGE
vs
AMBIENT TEMPERATURE

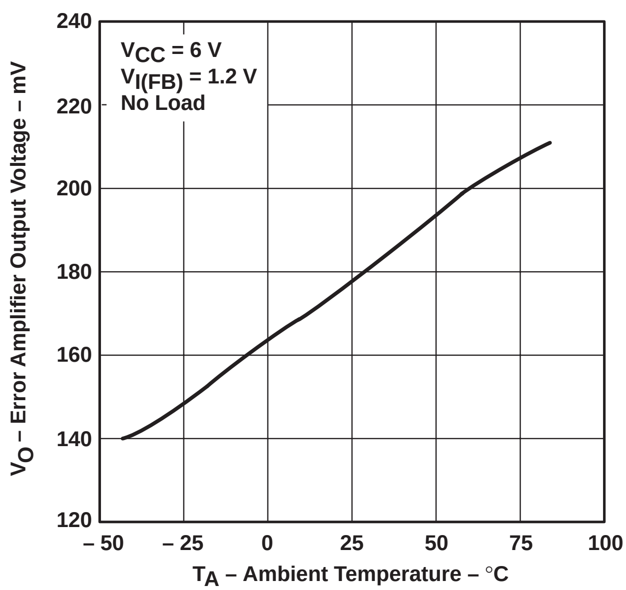


Figure 15

ERROR AMPLIFIER CLOSED-LOOP GAIN AND
PHASE SHIFT
vs
OSCILLATOR FREQUENCY

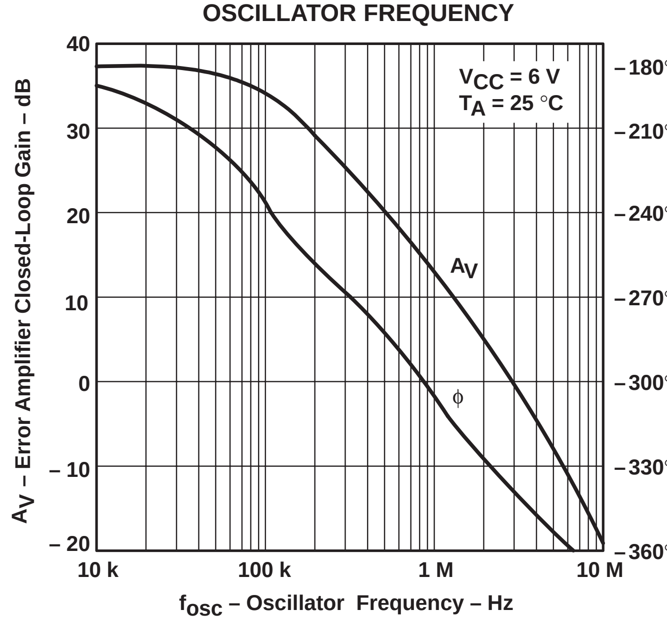


Figure 16

TYPICAL CHARACTERISTICS

OUTPUT DUTY CYCLE vs DTC VOLTAGE

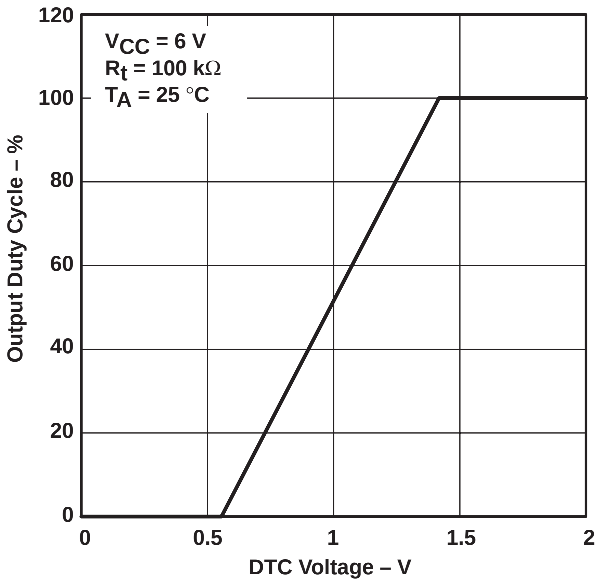


Figure 17

SCP TIME-OUT PERIOD vs SCP CAPACITANCE

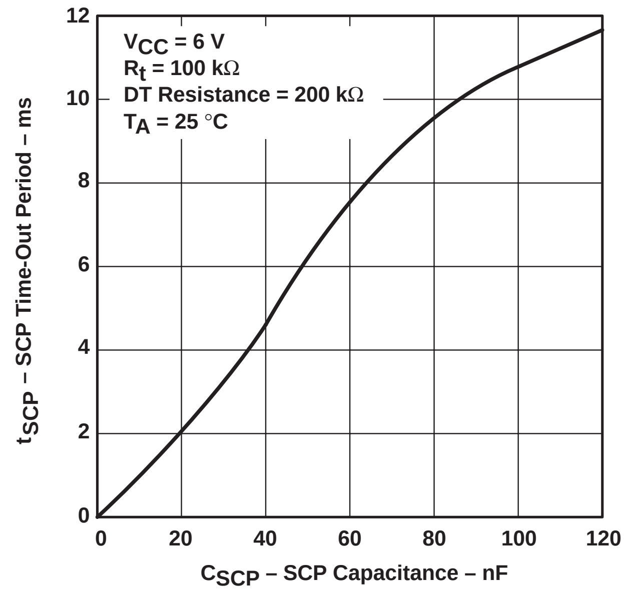


Figure 18

DTC OUTPUT CURRENT vs RT OUTPUT CURRENT

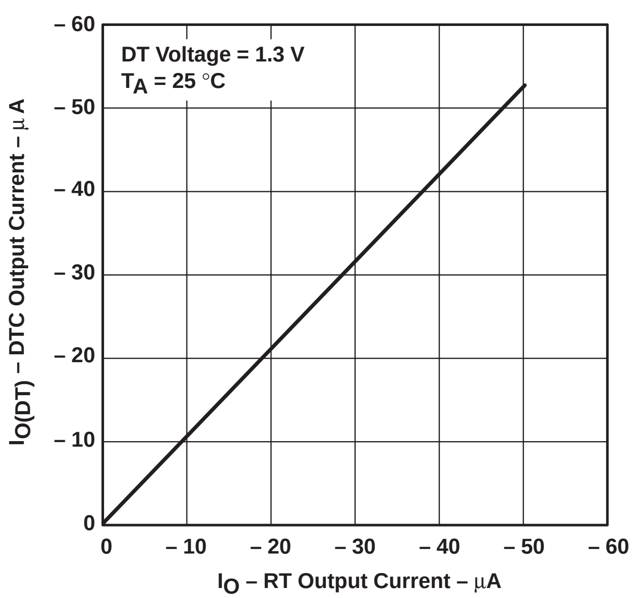


Figure 19

OUTPUT SATURATION VOLTAGE vs OUTPUT (SINK) CURRENT

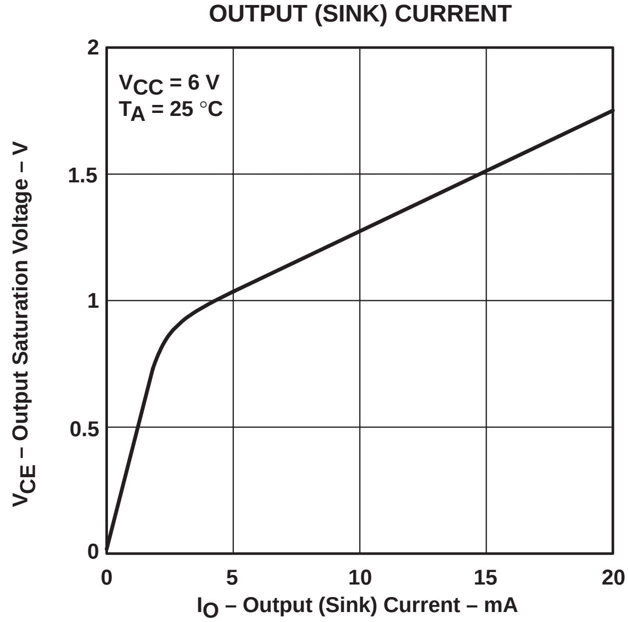
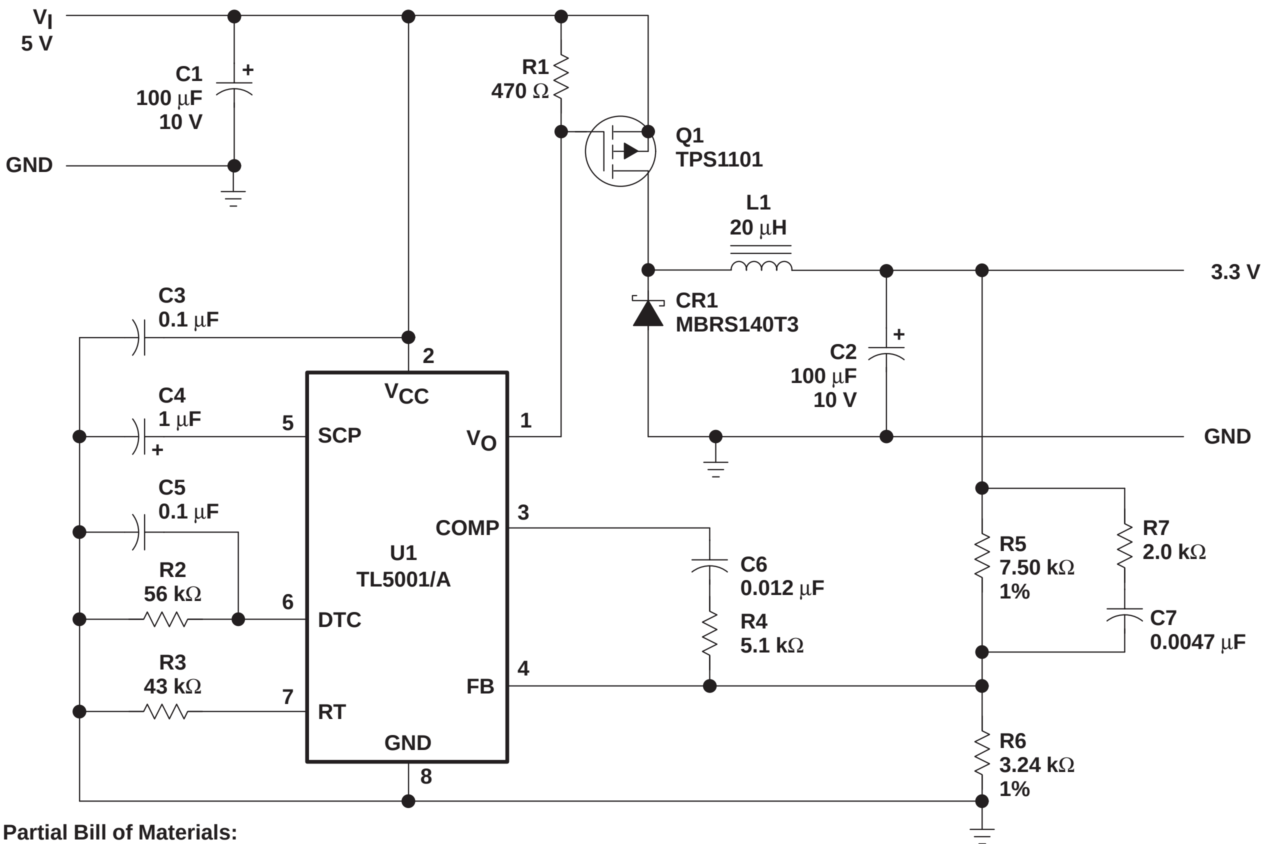


Figure 20

APPLICATION INFORMATION



Partial Bill of Materials:

U1	TL5001/A	Texas Instruments
Q1	TPS1101	Texas Instruments
LI	CTX20-1 or 23 turns of #28 wire on Micrometals No. T50-26B core	Coiltronics
C1	TPSD107M010R0100	AVX
C2	TPSD107M010R0100	AVX
CR1	MBRS140T3	Motorola

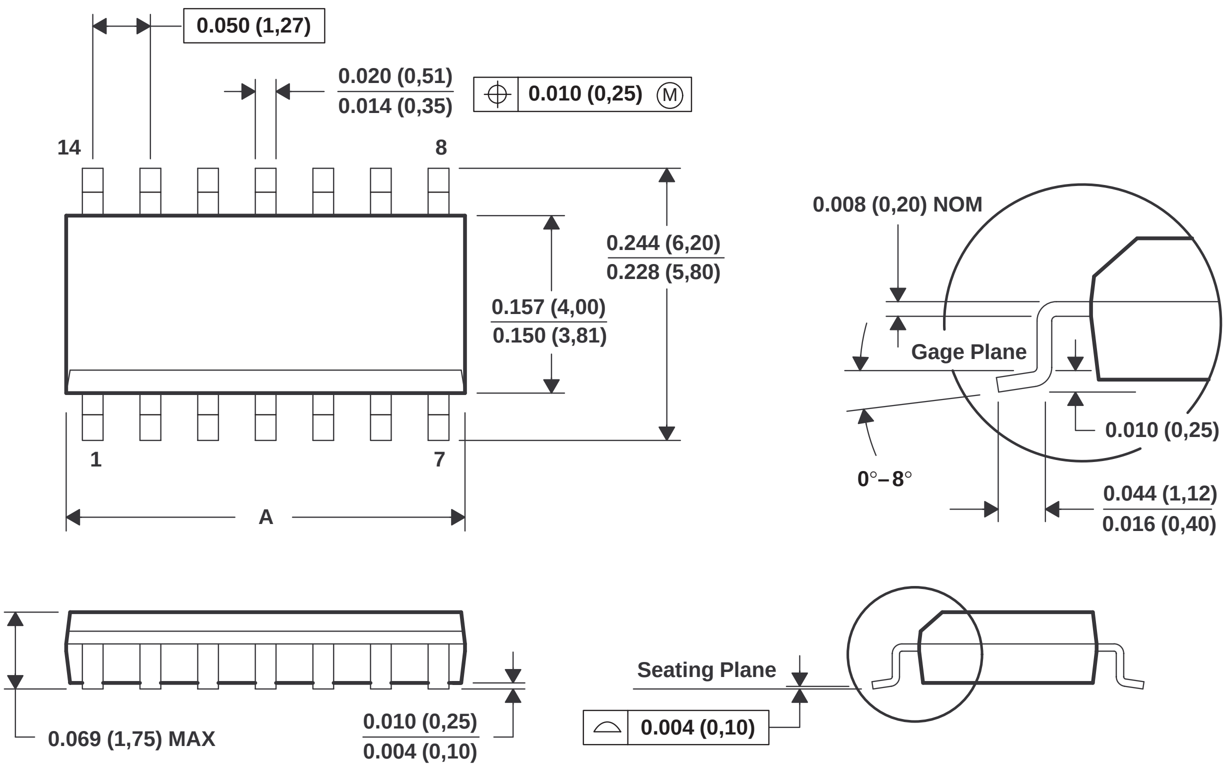
NOTES: A. Frequency = 200 kHz
B. Duty cycle = 90% max
C. Soft-start time constant (TC) = 5.6 ms
D. SCP TC = 70 msA

Figure 21. Step-Down Converter

MECHANICAL DATA

D (R-PDSO-G)** **PLASTIC SMALL-OUTLINE PACKAGE**

14 PIN SHOWN



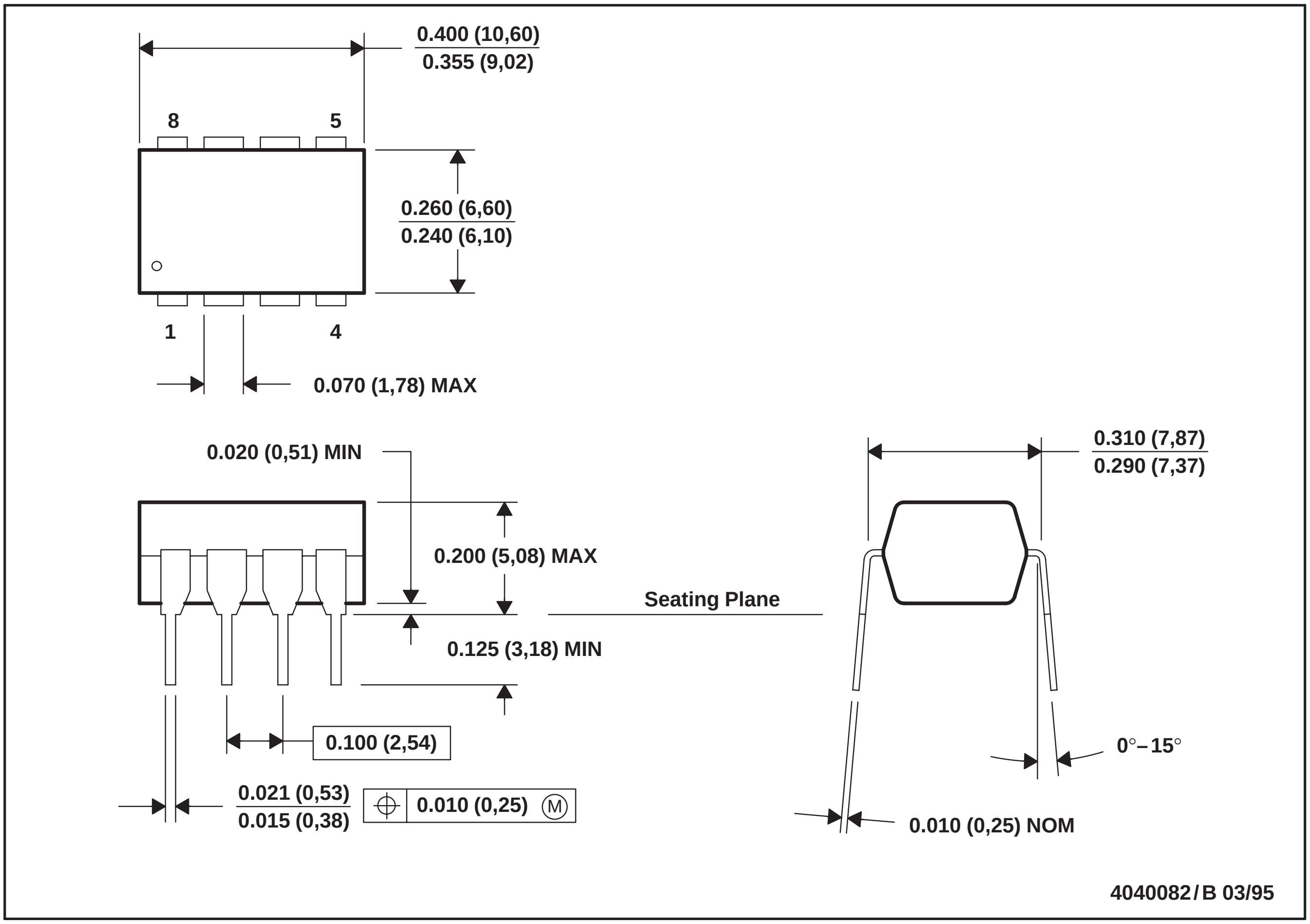
PINS ** / DIM	8	14	16
A MAX	0.197 (5,00)	0.344 (8,75)	0.394 (10,00)
A MIN	0.189 (4,80)	0.337 (8,55)	0.386 (9,80)

4040047 / D 10/96

NOTES: B. All linear dimensions are in inches (millimeters).
C. This drawing is subject to change without notice.
D. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
E. Falls within JEDEC MS-012

MECHANICAL INFORMATION

P (R-PDIP-T8) **PLASTIC DUAL-IN-LINE PACKAGE**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

IMPORTANT NOTICE