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



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WL, L	= Wafer Lot	
Y	= Year	

VWV, W = Work Week

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 @ $T_A \le 45^{\circ}C$	PD	1000	mW
Thermal Resistance Junction-to-Ambient (PDIP) Junction-to-Air (TSSOP) Junction-to-Ambient (SOIC)	R _{θJA}	80 140 135	°C/W
Operating Junction Temperature	TJ	125	°C
Storage Temperature Range	T _{stg}	–55 to +125	°C
Operating Ambient Temperature Range TL594CD, CN, CDTB	T _A	–25 to 85	°C
Derating Ambient Temperature	T _A	45	°C

1. Maximum thermal limits must be observed.

PIN CONNECTIONS



ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 1737 of this data sheet.

RECOMMENDED OPERATING CONDITIONS

Characteristics	Symbol	Min	Тур	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	kΩ
Timing Capacitor	CT	0.0047	0.001	10	μF
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 μ F, R_T = 12 k Ω , unless otherwise noted.)

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

Characteristics	Symbol	Min	Тур	Max	Unit
REFERENCE SECTION					
Reference Voltage $(I_O = 1.0 \text{ mA}, T_A = 25^{\circ}\text{C})$ $(I_O = 1.0 \text{ mA})$	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	μΑ
Emitter Off-State Current (V _{CC} = 40 V, V _C = 40 V, V _E = 0 V)	I _{E(off)}	-	-	-100	μA
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
$ \begin{array}{l} \mbox{Output Control Pin Current} \\ \mbox{Low State } (V_{OC} \leq 0.4 \ V) \\ \mbox{High State } (V_{OC} = V_{ref}) \end{array} $	I _{OCL} I _{OCH}		0.1 2.0	- 20	μA
Output Voltage Rise Time Common–Emitter (See Figure 13) Emitter–Follower (See Figure 14)	tr		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	μA
Input Common Mode Voltage Range (V _{CC} = 40 V, T _A = 25° 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 (ΔV_O = 3.0 V, V_O = 0.5 V to 3.5 V, R_L = 2.0 k Ω)	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)	φm	-	65	-	deg.
Common Mode Rejection Ratio (V _{CC} = 40 V)	CMRR	65	90	-	dB
Power Supply Rejection Ratio (ΔV_{CC} = 33 V, V _O = 2.5 V, R _L = 2.0 k Ω)	PSRR		100	_	dB
Output Sink Current (V _{O (Pin 3)} = 0.7 V)	I ₀ -	0.3	0.7	_	mA
Output Source Current (V _{O (Pin 3)} = 3.5 V)	I ₀ +	-2.0	-4.0	-	mA

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

ELECTRICAL CHARACTERISTICS (V_{CC} = 15 V, C_T = 0.01 μ F, R_T = 12 k Ω , unless otherwise noted.) For typical values T_A = 25°C, for min/max values T_A is the operating ambient temperature range that applies, unless otherwise noted.

Characteristics	Symbol	Min	Тур	Max	Unit
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 V)	I _{I-}	0.3	0.7	-	mA
DEADTIME CONTROL SECTION (Test Circuit Figure 11)					
Input Bias Current (Pin 4) (V _{Pin 4} = 0 V to 5.25 V)	I _{IB (DT)}	-	-2.0	-10	μΑ
	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 ($C_T = 0.001 \ \mu\text{F}, R_T = 30 \ \text{k}\Omega$) ($C_T = 0.01 \ \mu\text{F}, R_T = 12 \ \text{k}\Omega, T_A = 25^\circ\text{C}$) ($C_T = 0.01 \ \mu\text{F}, R_T = 12 \ \text{k}\Omega, T_A = T_{low} \text{ to } T_{high}$)	f _{osc}	- 9.2 9.0	40 10 -	- 10.8 12	kHz
Standard Deviation of Frequency* (C _T = 0.001 μ F, R _T = 30 k Ω)	ofosc	-	1.5	-	%
Frequency Change with Voltage (V _{CC} = 7.0 V to 40 V, T _A = 25°C)	$\Delta f_{OSC} (\Delta V)$	_	0.2	1.0	%
Frequency Change with Temperature $(\Delta T_A = T_{low} \text{ to } T_{high}, C_T = 0.01 \ \mu\text{F}, R_T = 12 \ \text{k}\Omega)$	$\Delta f_{OSC} (\Delta T)$	-	4.0	1.9	%
UNDERVOLTAGE LOCKOUT SECTION	· · ·			•	
Turn–On Threshold (V _{CC} Increasing, I _{ref} = 1.0 mA) $T_A = 25^{\circ}C$ $T_A = T_{low}$ 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 V) (V_{CC} = 40 V)	Icc	Ę	8.0 8.0	15 18	mA
Average Supply Current (V _{Pin 4} = 2.0 V, C _T = 0.01 μ F, R _T = 12 k Ω , V _{CC} = 15 V, See Figure 11)		_	11	_	mA

*Standard deviation is a measure of the statistical distribution about the mean as derived from the formula, σ_{--}

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









Figure 2. Timing Diagram

APPLICATIONS INFORMATION

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:

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

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 common–mode input range from -0.3 V to (V_{CC} – 2 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.

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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

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 11. Error–Amplifier Characteristics



Figure 13. Common–Emitter Configuration Test Circuit and Waveform



Figure 12. Deadtime and Feedback Control Circuit



Figure 14. Emitter–Follower Configuration Test Circuit and Waveform







Figure 16. Deadtime Control Circuit



Figure 17. Soft-Start Circuit



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



Figure 19. Slaving Two or More Control Circuits



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



Test	Conditions	Results	
Line Regulation	V _{in} = 10 V to 40 V	14 mV 0.28%	L1 – 3.5 mH @ 0.3 A T1 – Primary: 20T C.T. #28 AWG
Load Regulation	V _{in} = 28 V, I _O = 1.0 mA to 1.0 A	3.0 mV 0.06%	Secondary: 12OT C.T. #36 AWG
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 Ω	1.6 A	
Efficiency	V _{in} = 28 V, I _O = 1.0 A	71%	





Test	Conditions	Results
Line Regulation	V _{in} = 8.0 V to 40 V	3.0 mV 0.01%
Load Regulation	V_{in} = 12.6 V, I _O = 0.2 mA to 200 mA	5.0 mV 0.02%
Output Ripple	V _{in} = 12.6 V, I _O = 200 mA	40 mVpp P.A.R.D.
Short Circuit Current	V _{in} = 12.6 V, R _L = 0.1 Ω	250 mA
Efficiency	V _{in} = 12.6 V, I _O = 200 mA	72%

Figure 22. Pulse Width Modulated Step-Down Converter

ORDERING INFORMATION

Device	Operating Temperature Range	Package	Shipping
TL594CD	–25 to 85°C	SOIC-16	48 Units/Rail
TL594CDR2	–25 to 85°C	SOIC-16	2400 Tape & Reel
TL594CN	–25 to 85°C	PDIP-16	25 Units/Rail
TL594CDTB	–25 to 85°C	TSSOP-16	96 Units/Rail
TL594CDTBR2	–25 to 85°C	TSSOP-16	2500 Tape & Reel