AN983/D

A Simplified Power Supply Design Using the TL494 Control Circuit

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APPLICATION NOTE

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This bulletin describes the operation and characteristics of the TL494 SWITCHMODE™ Voltage Regulator and shows its application in a 400–watt off–line power supply.

The TL494 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 oscillator frequency is determined by:

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

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 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 dead–time control (Figure 1, Pin 4), the error amplifier inputs (Pins 1, 2, 15, 16), or the feedback input (Pin 3). The dead–time control comparator has an effective 120 mV input offset which limits the minimum output dead time to approximately the first 4% of the sawtooth–cycle time. This would result in a maximum duty cycle of 96% with the output mode control (Pin 13) grounded, and 48% with it connected to the reference line. Additional dead time may be imposed on the output by setting the dead–time control input to a fixed voltage, ranging between 0 to 3.3 V.

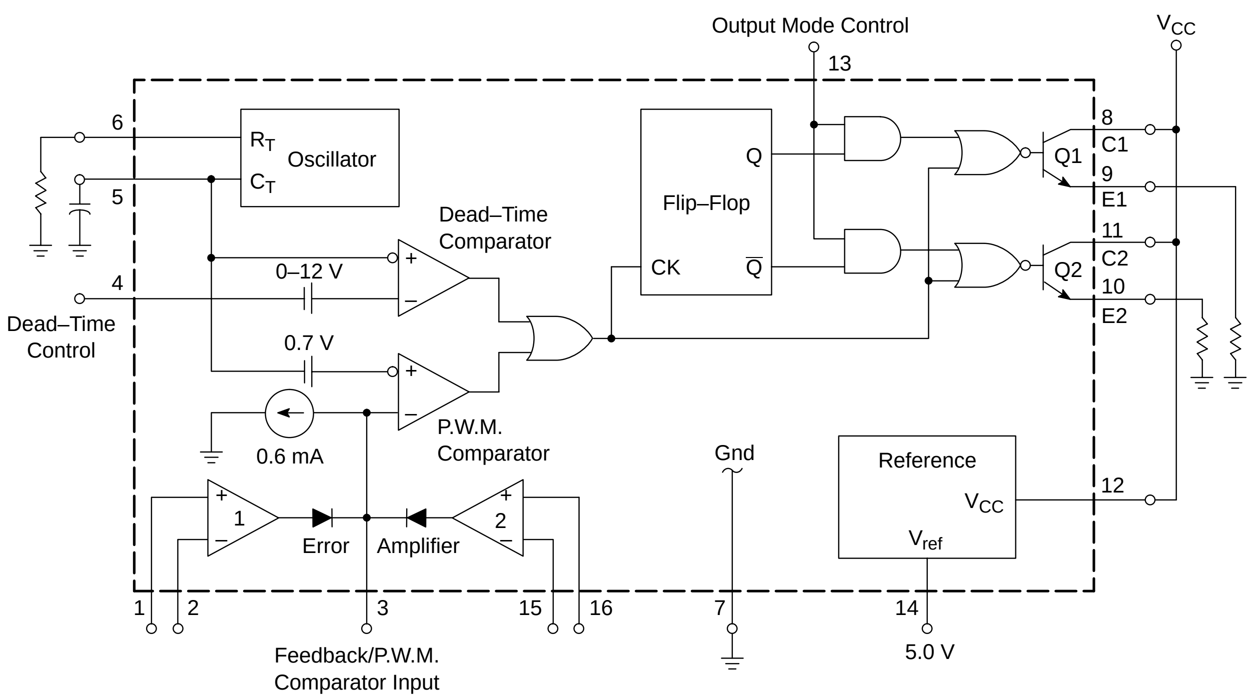

Figure 1. TL494 Block Diagram

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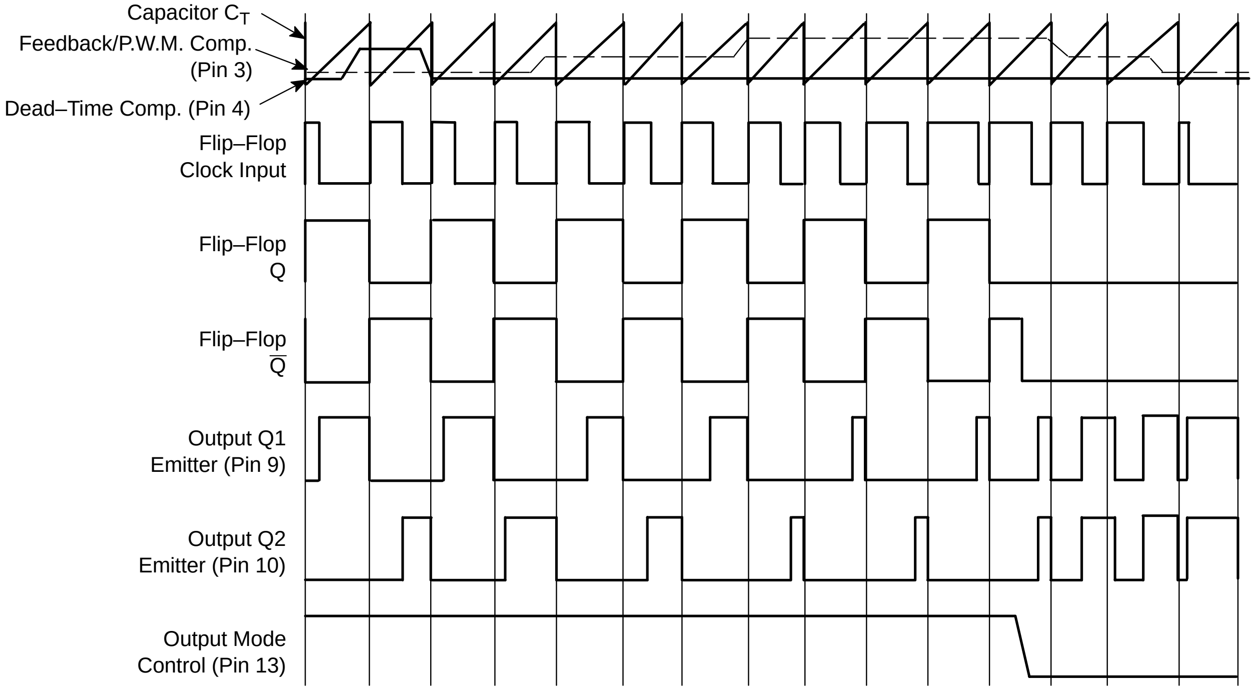

Figure 2. TL494 Timing Diagram

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 dead–time control input, down to zero, as the voltage at the feedback pin varies from 0.5 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 inverting 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 dead–time comparator, which clocks the pulse steering flip–flop and inhibits the output transistors, Q1 and Q2. With the output mode 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 control pin must be tied to ground to disable the flip–flop. The output frequency will now be equal to that of the oscillator.

The TL494 has an internal 5 V reference capable of sourcing up to 10 mA of load currents for external bias circuits. The reference has an internal accuracy of ±5% with a thermal drift of less than 50 mV over an operating temperature range of 0 to 70°C.

APPLICATION OF THE TL494 IN A 400 OFF–LINE POWER SUPPLY

A 5 V, 80 A line operated 25 kHz switching power supply, designed around the TL494, is shown in Figure 3, and the performance data is shown in Table 1. A brief explanation of each section of the power supply is as follows:

AC Input Section

The operating ac line voltage is selectable for nominal of 115 or 230 volts by moving the jumper links to their appropriate positions. The input circuit is a full wave voltage doubler when connected for 115 VAC operation with both halves of the bridge connected in parallel for added line–surge capability. When connected for 230 VAC operation, the input circuit forms a standard full wave bridge.

The line voltage tolerance for proper operation is –10, +20% of nominal. The ac line inrush current, during power up, is limited by resistor R1. It is shorted out of the circuit by triac Q1, only after capacitors C1 and C2 are fully charged, and the high frequency output transformer T1, commences operation.

Power Section

The high frequency output transformer is driven in a half–bridge configuration by transistors Q3 and Q5. Each transistor is protected from inductive turn–off voltage transients by an R–C snubber and a fast recovery clamp rectifier. Transistors Q2 and Q4 provide turn–off drive to Q3 and Q5, respectively. In order to describe the operation of Q2, consider that Q6 and Q3 are turned on. Energy is coupled from the primary to the secondary of T3, forward biasing the base–emitter of Q3, and charging C3 through CR1. Resistor R3 provides a dc path for the 'on' drive after C3 is fully charged. Note that the emitter–base of Q2 is reverse biased during this time. Turn–off drive to Q3 commences during the dead–time period, when both Q6 and Q7 are off. During this time, capacitor C3 will forward bias the base–emitter of Q2 through R3 and R2 causing it to turn on. The base–emitter of Q3 will now be reverse biased by the charge stored in C3 coupled through the collector–emitter of Q2.

Output Section

The ac voltage present at the secondaries of T1 is rectified by four MBR 6035 Schottky devices connected in a full wave center tapped configuration. Each device is protected from excessive switching voltage spikes by an R–C snubber, and output current sharing is aided by having separate secondary windings. Output current limit protection is achieved by incorporating a current sense transformer T4. The out–of–phase secondary halves of T1 are cross connected through the core of T4, forming a 1–turn primary. The 50 kHz output is filtered by inductor L1, and capacitor C4. Resistor R4 is used to guarantee that the power supply will have a minimum output load current of 1 ampere. This prevents the output transistors Q3 and/or Q5 from cycle skipping, as the required on–time to maintain regulation into an open circuit load is less than that of the devices storage time. Transformer T5 is used to reduce output switching spikes by providing common mode noise rejection, and its use is optional.

The MC3423, U1, is used to sense an overvoltage condition at the output, and will trigger the crowbar SCR, Q8. The trip voltage is centered at 6.4 V with a programmed delay of 40 μs. In the event that a fault condition has caused the crowbar to fire, a signal is sent to the control section via jumper 'A' or 'B.' This signal is needed to shut down the output, which will prevent the crowbar SCR from destruction due to over dissipation. Automatic over voltage reset is achieved by connecting jumper 'A'. The control section will cycle the power supply output every 2 seconds until the fault has cleared. If jumper 'B' is connected, SCR Q12 will inhibit the output until the ac line is disconnected.

Low Voltage Supply Section

A low current internal power supply is used to keep the control circuitry active and independent from external loading of the output section. Transformer T2, Q9 and CR2 form a simple 14.3 V series pass regulator.

Control Section

The TL494 provides the pulse width modulation control for the power supply. The minimum output dead–time is set to approximately 4% by grounding Pin 4 through R5. The soft start is controlled by C5 and R5. Transistor Q11 is used to discharge C5 and to inhibit the operation of the power supply if a low ac line voltage condition is sensed indirectly by Q10, or the output inhibit line is grounded.

Error amplifier 1 and 2 are used for output voltage and current–level sensing, respectively. The inverting inputs of both amplifiers are connected together to a 2.5 V reference derived from Pin 14. By connecting the two inputs together, only one R–C feedback network is needed to set the voltage gain and roll off characteristics for both amplifiers. Remote output voltage sensing capability is provided, and the supply will compensate for a combined total of 0.5 V drop in the power busses to the load. The secondary of the output current sense transformer T4, is terminated into 36 Ω and peak detected by BR1 and C6. The current limit adjust is set for a maximum output current of 85 amperes.

The oscillator frequency is set to 50 kHz by the timing components R_T and C_T. This results in a 25 kHz two phase output drive signal, when the output mode (Pin 13) is connected to the reference output (Pin 14).

Table 1. 400 Watt Switcher Performance Data

Test	Conditions		Results
	Input	Output	
Line Regulation	103.5 to 138 Vac	5 Volts and 80 Amps	8 mV 0.16%
Load Regulation	115 Vac	5 Volts, 0 to 80 Amps	20 mV 0.4%
Output Ripple	115 Vac	5 Volts and 80 Amps	P.A.R.D. 50 mV P–P
Efficiency	115 Vac	5 Volts and 80 Amps	73%
Line Inrush Current	115 Vac	5 Volts and 80 Amps	24 Amps Peak

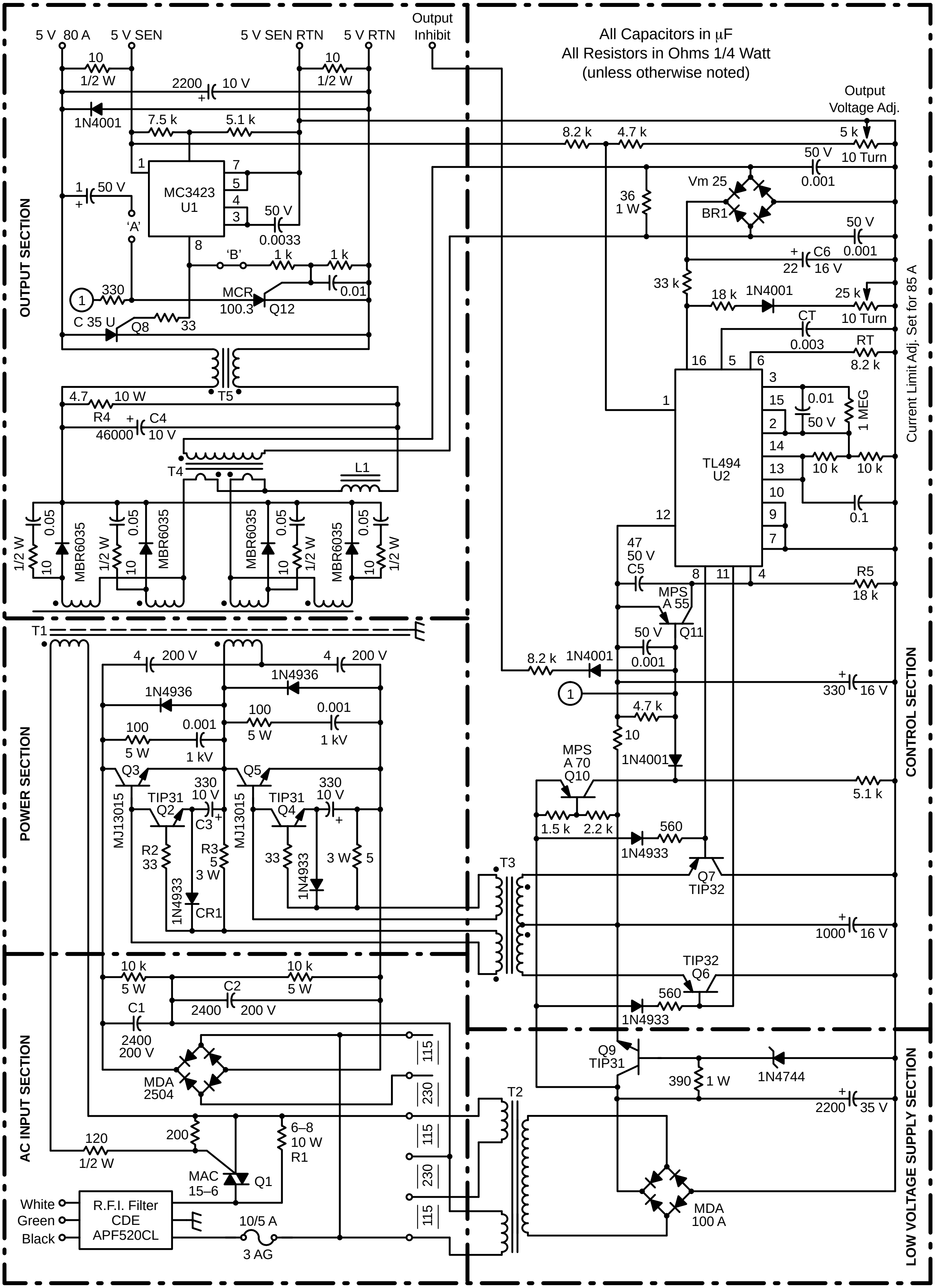

Figure 3. 400 Watt Switchmode Power Supply

Transformer Data

T1	Core:	Ferroxcube EC 70–3C8, 0.002″ gap in each leg	
	Bobbin:	Ferroxcube 70PTB	
	Windings:	Primary (Q3, Q5):	50 turns total, #17 AWG Split wound about secondary.
		Primary (Q1):	4 turns, #17 AWG.
		Secondary, 4 each:	3 turns, #14 AWG Quad Filar wound.
		Shield, 2 each:	Made from soft alloy copper 0.002″ thick.
T2	Core:	Allegheny Ludlum EI–75–M6, 29 gauge	
	Bobbin:	Bobbin Cosmo EI 75	
	Windings:	Primary, 2 each:	1000 turns, #36 AWG.
		Secondary:	200 turns, #24 AWG.
T3	Core:	Ferroxcube 846 T250–3C8	
	Windings:	Primary, 2 each:	30 turns, #30 AWG Bifilar wound.
		Secondary, 2 each:	12 turns, #20 AWG Bifilar wound.
T4	Core:	Magnetics Inc. 55059–A2	
	Windings:	Primary, 2 each:	1 turn, #14 AWG Quad Filar wound. Taken from secondary to T1.
		Secondary:	500 turns, #30 AWG.
T5	Core:	Magnetics Inc. 55071–A2	
	Windings:	Primary:	4 turns, #16 AWG Hex Filar wound.
		Secondary:	4 turns, #16 AWG Hex Filar wound.
L1	Core:	TDK H7C2 DR 56 x 35	
	Windings:	5 turns, soft alloy copper strap, 0.9″ wide x 0.020″ thick, 6 μH.	

Notes

Notes

SWITCHMODE is a trademark of Semiconductor Components Industries, LLC.

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