Application Report

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Designing Switching Voltage Regulators With the TL499A

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ABSTRACT

In this application report, the TL499A wide-range power-supply controller is discussed in detail. A general overview of TL499A architecture presents the primary functions of the device and its features. An in-depth study of the device, used with several external components, showcases the versatility and limitations of the device and provides a thorough understanding of the criteria required to select appropriate values for these components. Applying the device to several basic applications demonstrates its usefulness and versatility. A dc-to-dc converter design example is given, using the TL499A as a series regulator that converts to a step-up switching regulator during a primary power-source interruption and subsequent restoration.

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1 Introduction

The TL499A is an integrated circuit designed to provide a wide range of adjustable regulated supply voltages. The regulated output voltage can be set from 2.9 V to 30 V by adjusting two external resistors. When the TL499A is coupled to ac-line power through a step-down transformer, it operates as a series dc-voltage regulator to maintain the regulated output voltage. With the addition of a battery from 1.1 V to 10 V, an inductor, a filter capacitor, and two resistors, the TL499A operates as a step-up switching regulator during an ac-line power failure. The main function blocks of the internal composition are a series regulator and a switching regulator, which can be used independently. However, the TL499A is best suited for use in a battery backup system after a power failure. Optimal conversion efficiency can be obtained by inserting a suitable resistor between the switching-current control terminal and ground, thereby restricting switching current.

2 TL499A Principles of Operation

The block diagram of the TL499A is shown in Figure 1. The TL499A consists of a series regulator, a switching regulator, and a voltage-control circuit. The TL499A can be configured to regulate an output voltage between a minimum of 2.9 V and maximum of 30 V by choosing appropriate values of external resistors, R_{E1} and R_{E2} (see Figure 2). In addition, the input voltage range during step-up switching-regulator mode is between 1.1 V and 10 V.

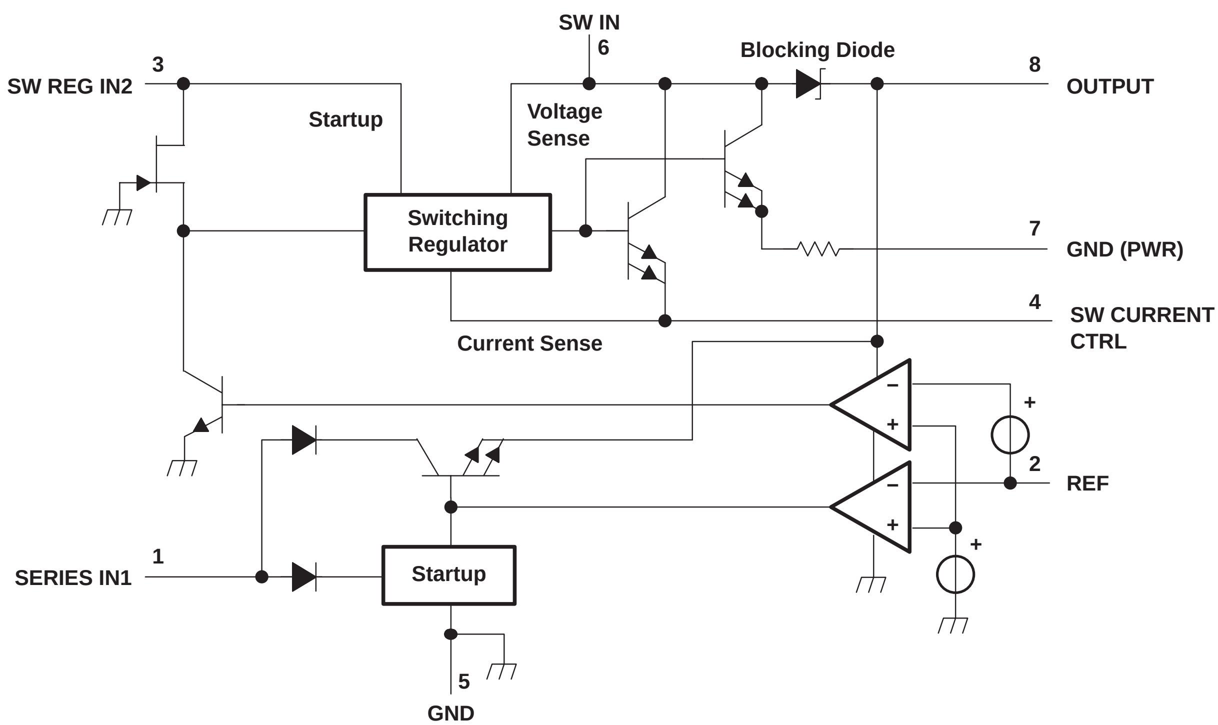

Figure 1. TL499A Block Diagram

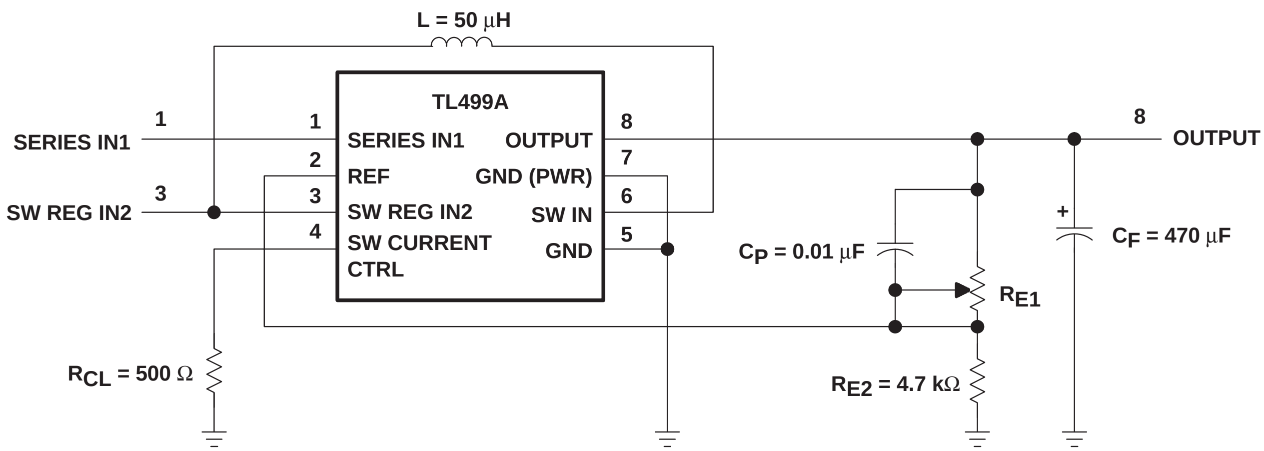

Figure 2. TL499A Basic Configuration

2.1 Series Regulator

The basic block diagram of a series regulator is shown in Figure 3. The name series regulator originates in the control element used for regulation. Modulating the series element regulates the output voltage. Generally, this series element is a transistor, and it operates like a variable resistance. Any change of input voltage changes the equivalent conductance of the series element. The product of this equivalent conductance and load current produces a potential voltage drop to compensate for the change of input voltage.

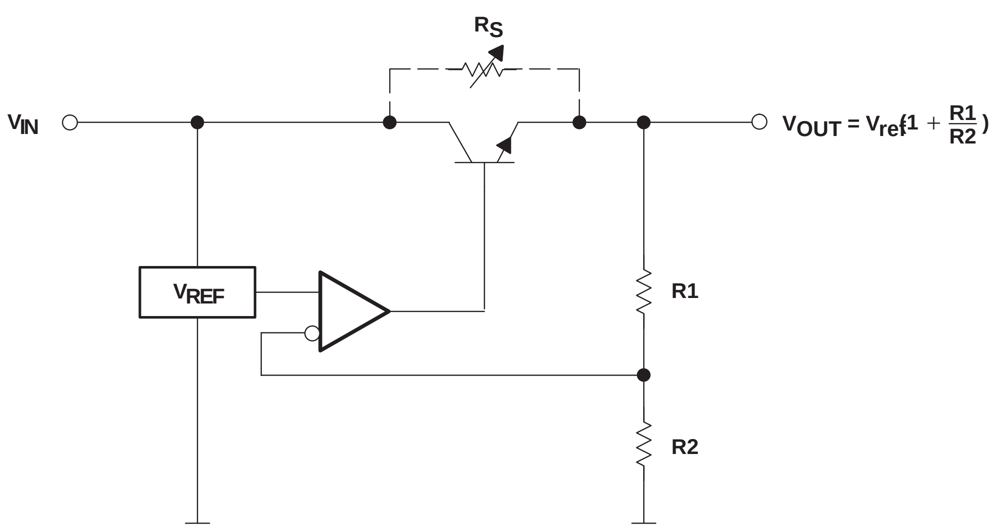

Figure 3. Basic Composition of Series Regulator

When considering the basic configuration of a series regulator, the equivalent series resistance (R_S) is derived in the following equations.

Output voltage (V_{OUT}) is given by:

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

$$V_{DIFF} = I_{LOAD} \times R_S \tag{2}$$

$$V_{OUT} = V_{IN} - I_{LOAD} \times R_S \tag{3}$$

Change in series resistance (ΔR_S), in terms of change of input voltage, is given by:

$$\Delta R_S = \frac{\Delta V_{IN}}{I_{LOAD}} \tag{4}$$

Change in series resistance (ΔR_S), in terms of change of load current, is given by:

$$\Delta R_S = \frac{\Delta I_{LOAD} \times R_S}{I_{LOAD} + \Delta I_{LOAD}} \tag{5}$$

The regulation characteristic over series input voltage is shown in Figure 4.

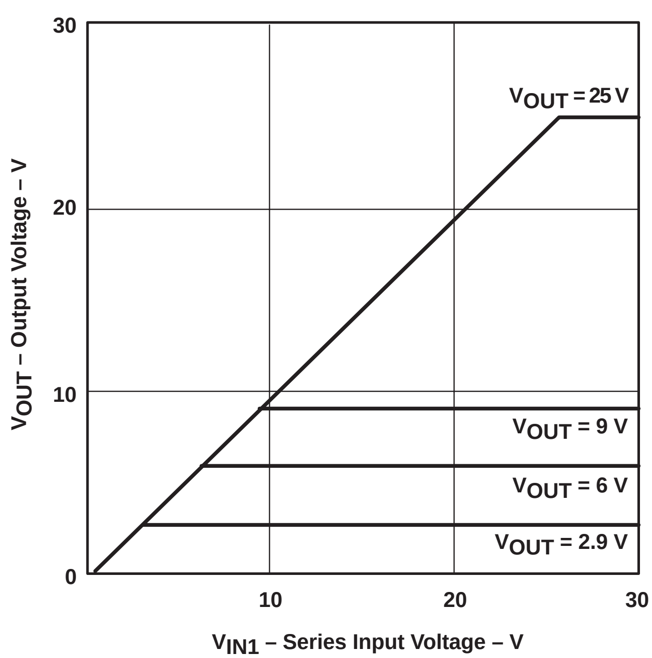

Figure 4. Series-Regulation Characteristic

The internal equivalent circuit of the series-regulator block of the TL499A is shown in Figure 5. The series regulator of TL499A operates exactly the same as the basic series regulator shown in Figure 3. The internal reference voltage is 1.26 V (typical). The external resistor divider (R_{E1} and R_{E2}) sets the output voltage level. The output voltage of the series regulator can be set between 2.9 V and 30 V, and regulation is possible for output currents up to 100 mA within the allowable total power-dissipation range. It is recommended that a value of 4.7 kΩ for resistor R_{E2} be used.

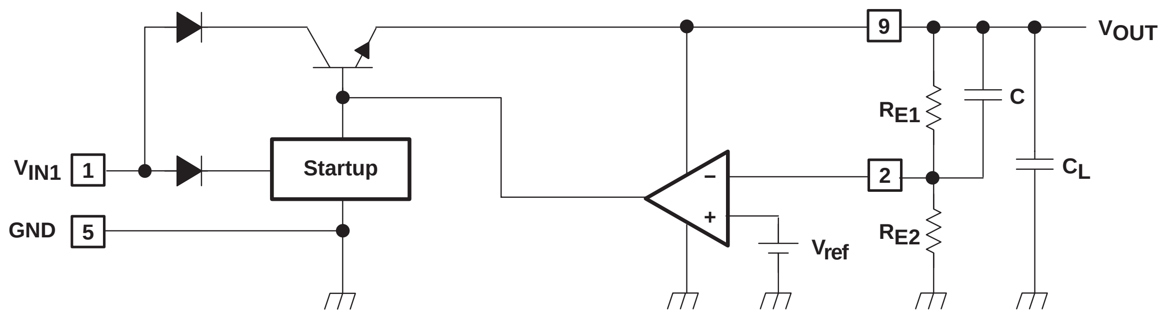

Figure 5. Internal Equivalent Circuit of Series Regulator

2.2 Step-Up Switching Regulator

The operating principle of a switching voltage regulator with high conversion efficiency can be understood by analyzing the basic configuration of the step-up switching regulator shown in Figure 6.

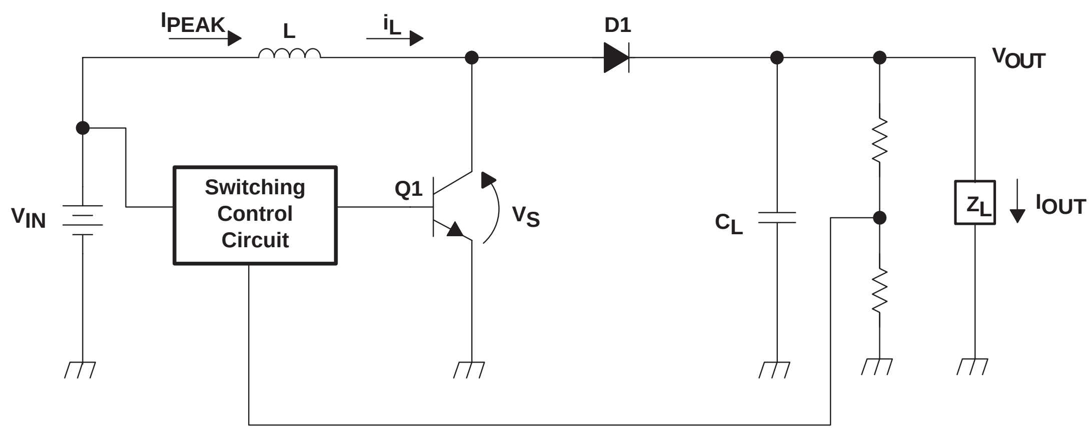

Figure 6. Basic Composition of Step-Up Switching Regulator

The duty cycle of the switching transistor (Q_1) is controlled by the switching frequency of the control circuit. Q_1 alternates between on and off states during operation.

To obtain a stable output voltage in a series regulator, the pass transistor, which is the control element of a series regulator, operates continuously. In a switching regulator, the switching transistor alternates between on and off states. Because this transistor always is saturated in the on state and is completely off at other times, the voltage loss associated with the switching transistor is very small compared to the voltage loss attributed to the pass transistor of the series regulator.

When Q_1 is turned on at the beginning of the charge cycle, the voltage of $V_{IN} - V_S$ (V_{IN} is the input voltage and V_S is the saturation voltage of the switching transistor) is developed across both ends of inductor L, as the inductor current increases linearly. At the end of the charge cycle, the current through the inductor is at its peak value. Peak current is expressed as:

$$I_{PEAK} = \frac{V_{IN} - V_S}{L} \times t_{ON} \quad (6)$$

At the end of the charge cycle, the switching transistor (Q_1) is turned off, and the regulator goes into discharge mode. The diode (D_1) acts as a flywheel diode and provides a current path from the inductor (L) to the output. The inductor current is reduced linearly as it is discharged. The ratio of the charge/discharge time is proportional to the input-to-output voltage difference divided by the input voltage.

$$\frac{t_{CHARGE}}{t_{DISCHARGE}} = \frac{\Delta V}{V_{IN}} \quad (7)$$

$$\Delta V = V_{OUT} - V_{IN} \quad (8)$$

As the voltage difference increases, the discharge time decreases and becomes smaller than the charge time.

$$t_{DISCHARGE} = \frac{I_{PEAK}}{V_{OUT} - V_{IN}} \times L \quad (9)$$

If switching losses are considered negligible, the conversion efficiency of an ideal step-up switching regulator is:

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% \quad (10)$$

$$P_{OUT} = V_{OUT} \times I_{OUT} \quad (11)$$

$$P_{IN} = V_{IN} \times I_{IN} \quad (12)$$

$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}} \times 100\% \quad (13)$$

The conversion efficiency of the TL499A during switching-regulator operation can be maximized by changing the value of the current-limiting resistance, R_C. An example of the characteristic curve of the conversion efficiency (η) versus R_C is shown in Figure 7.

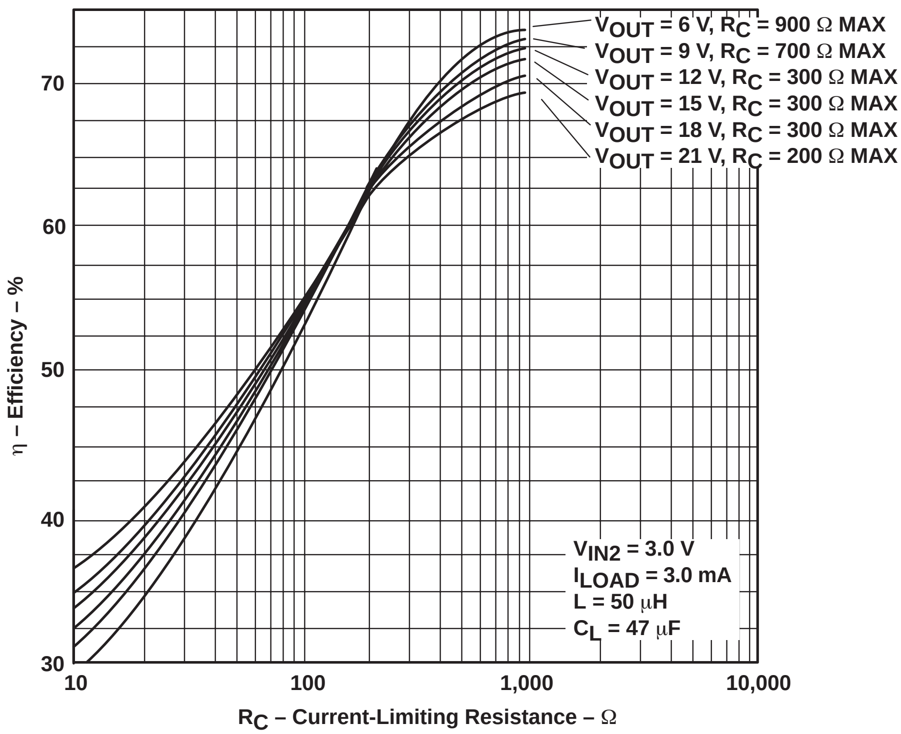

Figure 7. Step-Up Switching-Regulator Efficiency vs R_C

2.3 Switching-Current-Limiting Resistor

The switching current of the TL499A can be restricted by inserting a resistor (R_C) of 150 Ω to 1 kΩ between the switching-current control terminal (pin 4) and GND (pin 5) (see Figure 2). The exact value of R_C depends on the desired conversion efficiency and the requirements (V_{IN}, V_{OUT}, I_{OUT}, L, etc.) of the application circuit. Graphs of the maximum peak switching current versus R_C are shown in Figure 8 (at I_{OUT} = 25 mA) and Figure 9 (at I_{OUT} = 10 mA). The TL499A has internal current-limiting and thermal-shutdown circuitry that turns off the switching transistor if the junction temperature becomes too high.

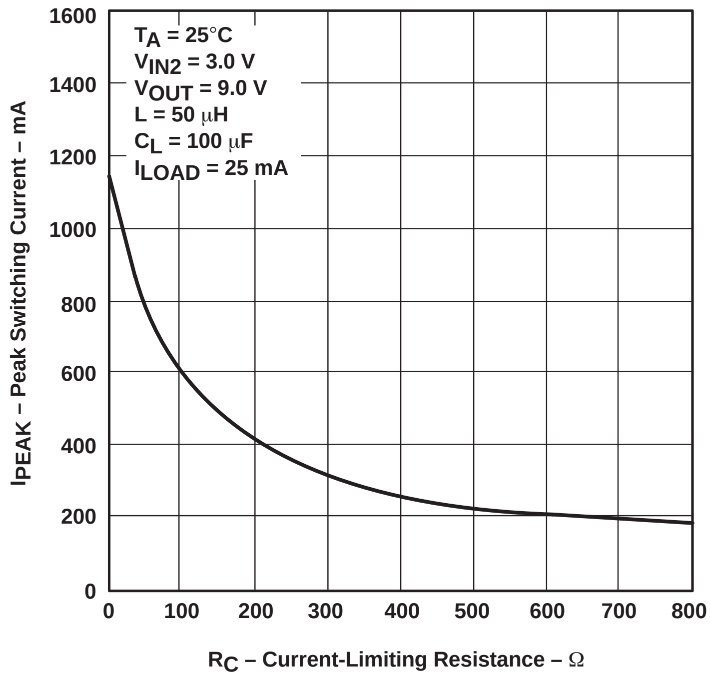

Figure 8. Peak Switching Current (I_{PEAK}) vs Current-Limiting Resistance (R_C), I_{OUT} = 25 mA

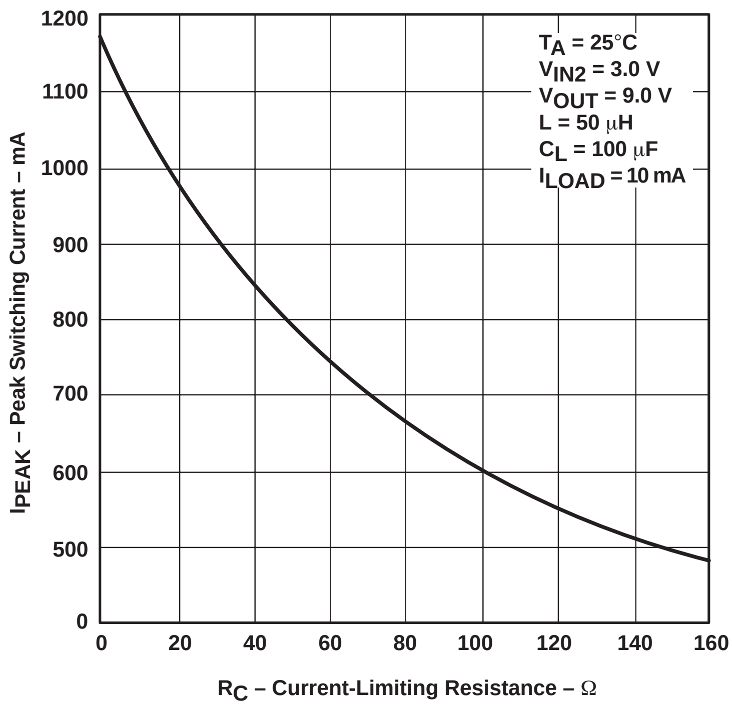

Figure 9. Peak Switching Current (I_{PEAK}) vs Current-Limiting Resistance (R_C), I_{OUT} = 10 mA

2.4 Setting the Output Voltage

The basic configuration circuit of the TL499A is shown in Figure 2. The output voltage is set by the negative-feedback circuit shown in Figure 10. The TL499A has an internal reference voltage of 1.26 V (typical). Using this internal reference voltage and the external resistors R_{E1} and R_{E2}, it is possible to set the desired output voltage. It is recommended that a value of 4.7 kΩ for R_{E2} be used. Figure 11 can be used as an aid to select an appropriate value for R_{E1} to provide the desired output voltage. The error amplifier controls the output voltage by detecting changes in the load and feeding back the information to either the series regulator or the bias circuit of the switching regulator, depending on the mode in which the TL499A is operating.

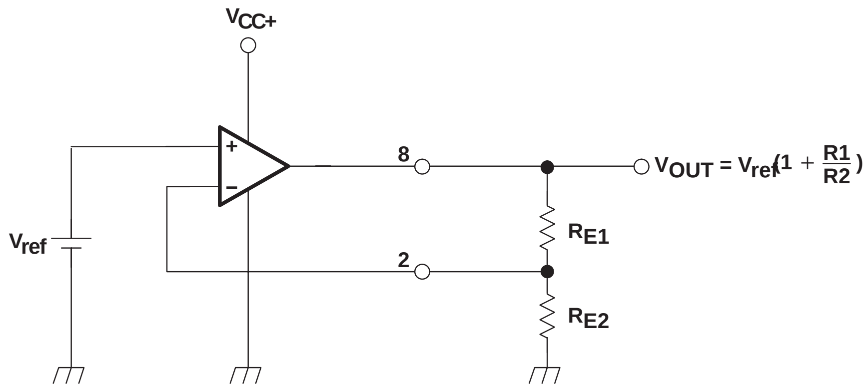

Figure 10. Negative-Feedback Circuit

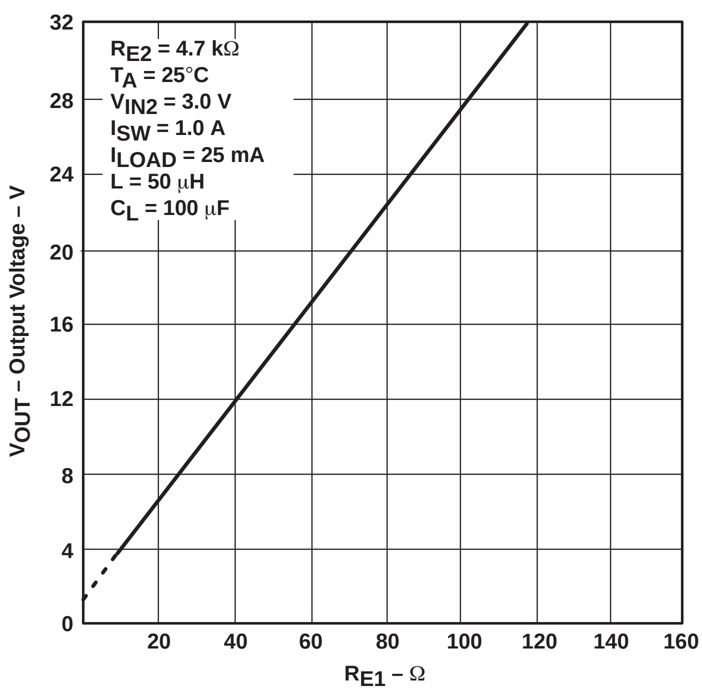

Figure 11. Output Voltage vs R_{E1}

3 Switching-Regulator Circuit Design

3.1 Operation on Battery Power

The design procedure for acquiring optimal efficiency is shown in Figure 32. When the TL499A is operating in switching-regulator mode, the battery supplies power to the load through the inductor. Over time, the battery voltage begins to decay and, as a result, the magnitude of switching current through the inductor increases with time. As the inductor current increases, the battery discharges more rapidly.

The standard characteristics of a typical nickel-cadmium storage battery are shown in Table 1 and Figure 13. The standard characteristics of a typical manganese dry-cell storage battery are shown in Table 2 and Figure 14. To make the TL499A supply continuous output power for a reasonable amount of time during switching-mode operation on battery power, it is necessary to select an appropriate value for R_C by taking into consideration the discharge characteristic of the battery and the load of the regulator. The recommended value of R_C is between 150 Ω and 1 kΩ.

3.2 Load-Current Limitations During Switching-Regulator Operation

Just as the TL499A can be used with a broad combination of input and output voltages that affect the maximum-value output current, the output current changes with the values of R_C. Although the value of R_C must be within the range of 150 Ω to 1 kΩ, the TL499A still can achieve stable and efficient operation with little output voltage ripple. Maximum load currents, as a function of R_C for different input and output voltage combinations, are shown in Tables 3 through 12. The current value indicated in the tables is the value of the load current when a 10-mV decrease in the reference voltage (pin 2) is measured, and the load current is increased gradually from a starting value of 10 mA.

If the load current is increased beyond the specification, the load regulation worsens, and the expected output voltage no longer is achieved.

When the battery cannot supply the peak switching current set up by R_C (see Figures 8 and 9), the TL499A cannot start the switching operation. Also, the TL499A must be connected to a battery capable of supplying sufficient current when the TL499A is used in applications other than changing between series- and switching-regulator operation (battery backup operation), such as when using the TL499A only in switching-mode operation.

Table 1. Sealed-Type Nickel-Cadmium Storage Batteries (SANYO Electric Co., Ltd.)

Model	Nominal Voltage (V)	Nominal Capacity (mAh)	Standard Charge		Rapid Charge		Internal Resistance (mΩ)	Outside Size				Approx. Weight (g)
								With Tube		Base Battery		
			Current (mA)	Time (hour)	Current (mA)	Time (hour)		Diameter (mm)	Height (mm)	Diameter (mm)	Height (mm)	
N−50AAA	1.2	50	5	14~16	15	4~6	55.0	$10.5^{0}_{-0.5}$	16.0^{0}_{-1}	$10.0^{0.2}_{-0.2}$	$15.0^{0.2}_{-0.2}$	4
N−75P	1.2	75	4.5		23		45.0	$13.0^{0}_{-0.5}$	14.5^{0}_{-1}	$12.5^{0.2}_{-0.2}$	$14.0^{0.3}_{-0.3}$	6
N−110AA	1.2	110	11		33		30.0	$14.5^{0}_{-0.5}$	17.0^{0}_{-1}	$14.0^{0.2}_{-0.2}$	$16.7^{0.3}_{-0.3}$	8
N−120TA	1.2	120	12		36		34.0	$7.8^{0}_{-0.5}$	42.5^{0}_{-1}	$7.5^{0.2}_{-0.2}$	$41.8^{0.3}_{-0.3}$	7
N−150N	1.2	150	15		45		27.0	$12.0^{0}_{-0.5}$	29.5^{0}_{-1}	$11.5^{0.2}_{-0.2}$	$28.5^{0.3}_{-0.3}$	9
N−200AAA	1.2	200	20		60		21.0	$10.5^{0}_{-0.5}$	44.5^{0}_{-1}	$10.0^{0.2}_{-0.2}$	$43.7^{0.3}_{-0.3}$	10
N−200A	1.2	200	20		60		20.0	$17.0^{0}_{-0.5}$	17.0^{0}_{-1}	$16.5^{0.2}_{-0.2}$	$16.3^{0.3}_{-0.3}$	11
N−270AA	1.2	270	27		81		15.0	$14.5^{0}_{-0.5}$	30.0^{0}_{-1}	$14.0^{0.2}_{-0.2}$	$29.5^{0.3}_{-0.3}$	14
N−500A	1.2	500	50		150		9.0	$17.0^{0}_{-0.5}$	28.0^{0}_{-1}	$16.5^{0.2}_{-0.2}$	$27.8^{0.2}_{-0.2}$	20
N−600AA	1.2	600	60		180		12.0	$14.2^{0}_{-0.5}$	50.0^{0}_{-1}	$13.8^{0.2}_{-0.2}$	$49.5^{0.3}_{-0.3}$	24
N−600AAL	1.2	600	60		180		12.0	$14.2^{0}_{-0.5}$	48.7^{0}_{-1}	$13.8^{0.2}_{-0.2}$	$48.2^{0.3}_{-0.3}$	24
N−650SC	1.2	650	65		–		6.0	23^{0}_{-1}	26.0^{0}_{-1}	$22.0^{0.3}_{-0.3}$	$25.8^{0.2}_{-0.2}$	29
N−1000SC	1.2	1000	100		–		4.8	23^{0}_{-1}	34.0^{0}_{-1}	$22.0^{0.3}_{-0.3}$	$33.0^{0.3}_{-0.3}$	42
N−1100C	1.2	1100	110		–		4.6	26^{0}_{-1}	30.0^{0}_{-1}	$25.2^{0.3}_{-0.3}$	$29.8^{0.2}_{-0.2}$	44
N−1300SC	1.2	1300	130		–		4.2	23^{0}_{-1}	43.0^{0}_{-1}	$22.0^{0.3}_{-0.3}$	$42.0^{0.3}_{-0.3}$	50
N−2000C	1.2	2000	200		–		4.1	26^{0}_{-1}	50.0^{0}_{-2}	$25.2^{0.3}_{-0.3}$	$49.0^{0.3}_{-0.3}$	80
N−4000D	1.2	4000	400		–		3.3	34^{0}_{-2}	61.0^{0}_{-2}	$32.3^{0.3}_{-0.3}$	$60.0^{0.4}_{-0.4}$	160
N−6PT	7.2	120	12		24	7~8	210.0	17.0 (W) × 26.0 (L) × 48.5 (H)		–	–	42

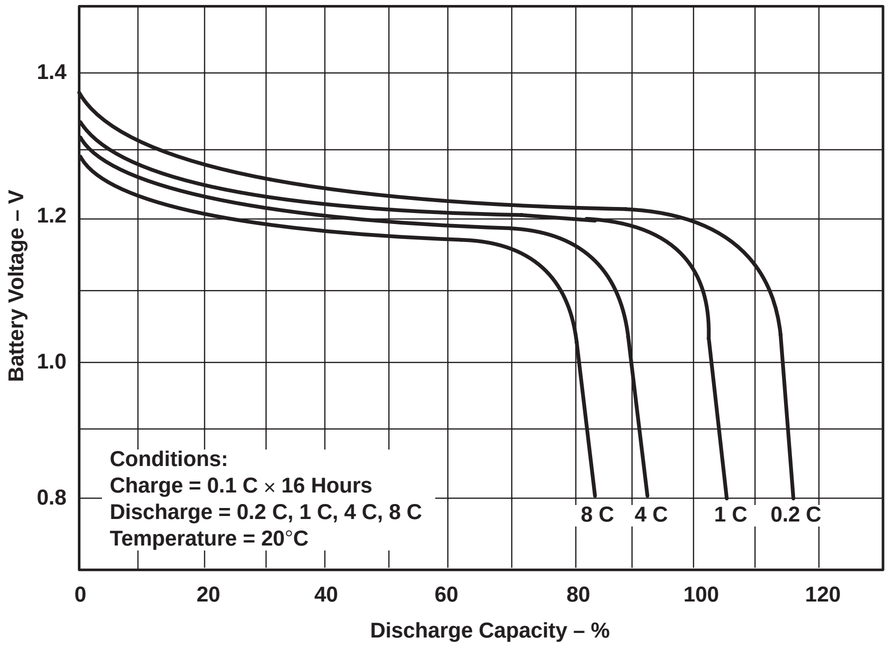

Figure 12. Discharge Characteristics of Nickel-Cadmium Batteries

Table 2. Compensated-Type Manganese Dry-Cell Batteries (Matsushita Battery Industrial Co., Ltd.)

MODEL NUMBER	OUTSIDE SIZE (mm)	WEIGHT (g)	NOMINAL VOLTAGE (V)	NOMINAL CAPACITY
SUM-1 (NG)	34.0∅ × 61.5	106	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V): typical 56.5 hours
				20 Ω, 4 hours per day, intermittent electrical discharge (up to 0.9 V): typical 123 hours
SUM-2 (NG)	26.0∅ × 50.0	51	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V): typical 23.5 hours
				40 Ω, 4 hours per day, intermittent electrical discharge (up to 0.9 V): typical 108 hours
SUM-3 (NG)	14.5∅ × 50.5	20	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V): typical 6.7 hours
				75 Ω, 4 hours per day, intermittent electrical discharge (up to 0.9 V): typical 68 hours
SUM-1 (DG)	34.0∅ × 61.5	99	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V): typical 42 hours
				20 Ω, 4 hours per day, intermittent electrical discharge (up to 0.9 V): typical 98 hours
SUM-2 (DG)	26.0∅ × 50.0	47	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V) typical 18.2 hours
				40 Ω, 4 hours per day, intermittent electrical discharge (up to 0.9 V): typical 87 hours
SUM-3 (DG)	14.5∅ × 50.5	19	1.5	10 Ω, 4 hours per day, intermittent electrical discharge (up to 1.0 V): typical 5.2 hours
				75 Ω, 4 hours per day, intermittent electrical discharge (up to 0. 9 V): typical 58 hours

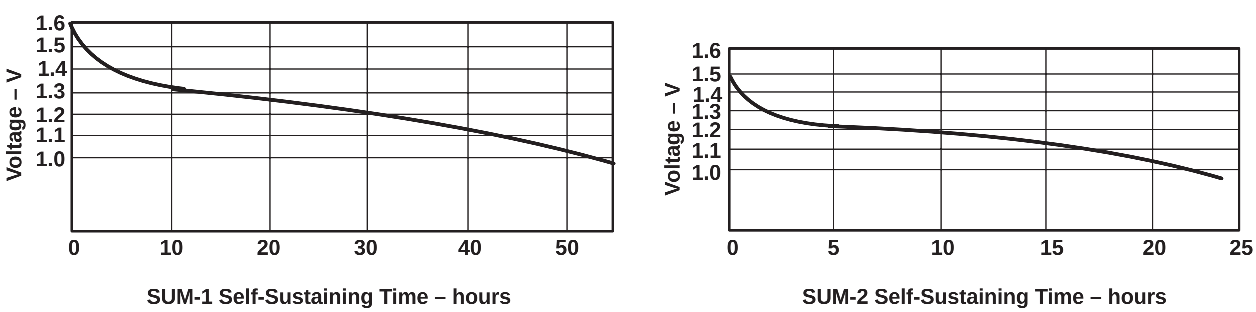

Figure 13. Discharge Characteristics of Dry-Cell Batteries

4 Recommended Load-Current Tables

4.1 Recommended Load-Current Table for Switching-Regulator Operation (TL499ACP DIP Package)

The maximum output current values for various combinations of input and output voltages for the TL499ACP are shown in Tables 3−7.

Table 3. TL499ACP Recommended Load Current During Switching Operation (R_C = 150 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										65	90	90
25									50	80	100	100
20						20	25	30	80	100	100	100
15				15	20	30	45	55	100	100	100	100
12	10	15	20	25	30	40	55	70	100	100	100	100
10	15	20	25	30	35	45	65	80	100	100		
9.0	20	25	25	35	40	50	70	90	100	100		
6.0	30	35	40	45	55	75	95	100	R_{E2} = 4.7 kΩ C_L = 330 µF L = 50 µH (r_{in} ≤ 0.1 Ω) C = 0.1 µF T_A = 25°C			
5.0	30	40	45	55	70	85	100	100				
4.5	35	45	50	60	75	95	100	100†				
3.0	55	65†	75†	95†	100†							
2.9	60†	70†	75†	100†	100†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 4. TL499ACP Recommended Load Current During Switching Operation (R_C = 200 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										50	100	100
25									50	70	100	100
20						15	25	30	70	90	100	100
15				10	15	25	35	45	90	100	100	100
12	10	10	15	20	25	35	45	60	100	100	100	100
10	15	20	20	25	30	40	55	70	100	100		
9.0	20	20	25	30	35	45	60	80	100			
6.0	25	30	35	45	50	65	90	100	R_{E2} = 4.7 kΩ C_L = 330 µF L = 50 µH (r_{in} ≤ 0.1 Ω) C = 0.1 µF T_A = 25°C			
5.0	30	35	40	55	60	75	100	100				
4.5	35	40	45	55	65	85	100	100†				
3.0	50	55†	65†	80†	90†							
2.9	50†	60†	65†	85†	100†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.

NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 5. TL499ACP Recommended Load Current During Switching Operation (R_C = 300 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										40	70	70
25									40	55	100	100
20						10	15	20	55	70	100	100
15				10	10	20	30	35	75	95	100	100
12	10	10	10	15	20	25	35	45	95	100	100	100
10	15	15	15	20	25	30	45	55	100	100		
9.0	15	15	20	25	30	35	50	60	100	100		
6.0	25	25	30	35	45	55	70	90	R_{E2} = 4.7 kΩ C_L = 330 µF L = 50 µH (r_{in} ≤ 0.1 Ω) C = 0.1 µF T_A = 25°C			
5.0	30	30	35	45	50	65	85	100				
4.5	30	35	40	45	55	70	95	100†				
3.0	45	50†	55†	70†	90†							
2.9	45†	50†	60†	75†	95†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.

NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 6. TL499ACP Recommended Load Current During Switching Operation (R_C = 510 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										30	50	50
25									25	40	75	75
20									40	55	90	90
15							15	20	55	70	100	100
12					10	15	25	35	65	80	100	100
10				10	20	25	30	40	70	85		
9.0	10	10	10	15	20	25	35	45	75	100		
6.0	15	20	20	25	30	35	50	60	R_{E2} = 4.7 kΩ C_L = 330 µF L = 50 µH (r_{in} ≤ 0.1 Ω) C = 0.1 µF T_A = 25°C			
5.0	20	20	25	30	35	45	55	70				
4.5	20	25	30	35	40	50	65	90†				
3.0	35	35†	40†	50†	75†							
2.9	35†	35†	40†	55†	80†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 7. TL499ACP Recommended Load Current During Switching Operation (R_C = 1 kΩ)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30											35	35
25										35	50	50
20										35	60	60
15								10	30	45	65	65
12								20	40	45	85	85
10							15	25	40	55		
9.0				10	10	15	25	30	45	60		
6.0	10	10	10	15	20	20	30	35	R_{E2} = 4.7 kΩ C_L = 330 µF L = 50 µH (r_{in} ≤ 0.1 Ω) C = 0.1 µF T_A = 25°C			
5.0	10	10	15	20	20	25	35	40				
4.5	15	15	15	20	25	30	40	45†				
3.0	20	25†	25†	30†	35†							
2.9	20†	25†	25†	30†	45†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

4.2 Recommended Load-Current Table for Switching-Regulator Operation (TL499ACPS SOP Package)

The maximum output current values for various combinations of input and output voltages for the TL499ACPS are shown in Tables 8−12.

Table 8. TL499ACPS Recommended Load Current During Switching Operation (R_C = 150 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										45	55	60
25									50	60	70	75
20						20	25	30	75	80	95	100
15				15	20	30	40	55	100	100	100	100
12	10	15	20	25	30	40	55	70	100	100	100	100
10	15	20	25	30	35	45	65	80	100	100		
9.0	20	25	25	35	40	50	70	90	100	100		
6.0	30	35	40	45	55	75	95	100	R_{E2} = 4.7 kΩ C_L = 330 μF L = 50 μH (r_{in} ≤ 0.1 Ω) C = 0.1 μF T_A = 25°C			
5.0	35	40	45	55	70	85	100	100				
4.5	35	45	50	60	75	95	100	100†				
3.0	55	65†	75†	95†	100†							
2.9	60†	70†	75†	95†	100†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 9. TL499ACPS Recommended Load Current During Switching Operation (R_C = 200 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										45	85	85
25									50	60	100	100
20						15	25	30	70	85	100	100
15				10	15	25	35	45	90	100	100	100
12	10	10	15	20	25	35	45	55	100	100	100	100
10	15	20	20	25	30	40	55	70	100	100		
9.0	20	20	25	30	35	45	60	75	100	100		
6.0	25	30	35	45	50	65	90	100	R_{E2} = 4.7 kΩ C_L = 330 μF L = 50 μH (r_{in} ≤ 0.1 Ω) C = 0.1 μF T_A = 25°C			
5.0	30	35	40	55	60	75	100	100				
4.5	35	40	45	55	65	85	100	100†				
3.0	45	45†	50†	60†	70†							
2.9	45†	45†	50†	60†	70†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 10. TL499ACPS Recommended Load Current During Switching Operation (R_C = 300 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										30	65	70
25									35	45	85	95
20						10	15	20	45	60	100	100
15				10	10	20	25	35	70	90	100	100
12	10	10	10	15	20	25	35	45	90	100	100	100
10	10	15	15	20	25	30	40	50	100	100		
9.0	15	15	20	20	25	35	45	60	100	100		
6.0	20	25	25	35	40	50	70	85	R_{E2} = 4.7 kΩ C_L = 330 μF L = 50 μH (r_{in} ≤ 0.1 Ω) C = 0.1 μF T_A = 25°C			
5.0	25	30	35	40	50	60	80	100				
4.5	30	35	40	45	50	65	80	100†				
3.0	45	45†	50†	55†	60†							
2.9	45†	50†	50†	55†	60†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 11. TL499ACPS Recommended Load Current During Switching Operation (R_C = 510 Ω)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30										15	35	50
25									15	25	50	65
20									25	35	70	85
15							15	20	40	55	100	100
12					10	15	20	25	55	70	100	100
10				10	15	20	25	35	65	85		
9.0	10	10	10	15	20	20	30	35	75	100		
6.0	15	15	20	25	25	35	45	55	R_{E2} = 4.7 kΩ C_L = 330 μF L = 50 μH (r_{in} ≤ 0.1 Ω) C = 0.1 μF T_A = 25°C			
5.0	20	20	25	30	35	40	55	70				
4.5	20	20	25	30	35	45	55	70†				
3.0	30	30†	35†	40†	40†							
2.9	30†	30†	35†	40†	40†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: $\Delta V = V_{OUT} - V_{IN2}$

Table 12. TL499ACPS Recommended Load Current During Switching Operation (R_C = 1 kΩ)

V_{OUT} OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)											
30											5	10
25										5	15	20
20										10	30	35
15								5	15	20	50	65
12								10	20	25	65	80
10							10	15	30	45		
9.0				5	5	10	10	15	35	50		
6.0	5	5	10	10	10	15	20	25	R_{E2} = 4.7 kΩ C_L = 330 μF L = 50 μH (r_{in} ≤ 0.1 Ω) C = 0.1 μF T_A = 25°C			
5.0	10	10	10	10	15	20	25	35				
4.5	10	10	10	15	15	20	30	35†				
3.0	15	15†	20†	20†	25†							
2.9	15†	15†	20†	20†	25†							
	1.1	1.2	1.3	1.5	1.7	2.0	2.5	3.0	5.0	6.0	9.0	10
	V_{IN2} INPUT VOLTAGE (V)											

† ΔV should satisfy the following conditions: ΔV ≥ 1.2 V at T_A ≤ 70°C, and ΔV ≥ 1.9 V at T_A ≤ 85°C.
NOTE: ΔV = $V_{OUT} - V_{IN2}$

5 Application-Circuit Example

5.1 Battery-Backup Circuit

The TL499A operates as a series regulator when a dc input voltage of V_{IN1} = 4.5 V to 32.0 V is present at pin 1. The output voltage in the series mode is slightly higher than in the switching mode. This is because the feedback voltage of a series-regulator circuit is higher than the feedback voltage of a switching circuit. This output voltage difference (V_{FL}), or change voltage, typically is 2% of the output voltage, but it can be as high as 3%. The change voltage gives priority to series operation over switching operation to conserve battery power while line power is available. While the series-regulator circuit is operating, the switching circuit is in the OFF state, and battery power is not used. The characteristics of change voltage versus output voltage are shown in Figure 14. The battery-backup circuit diagram, which is used with a power-supply transformer, is shown in Figure 15.

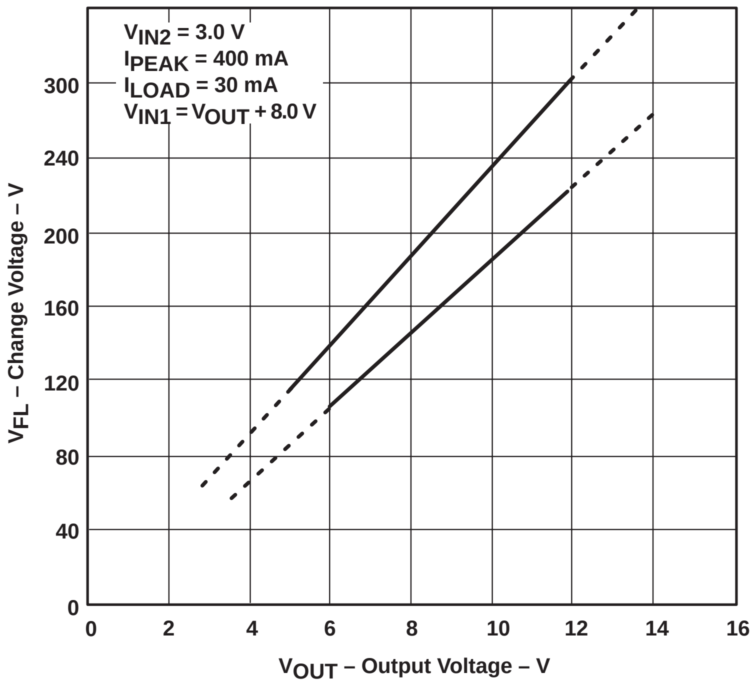

Figure 14. Change Voltage (V_{FL}) vs Output Voltage

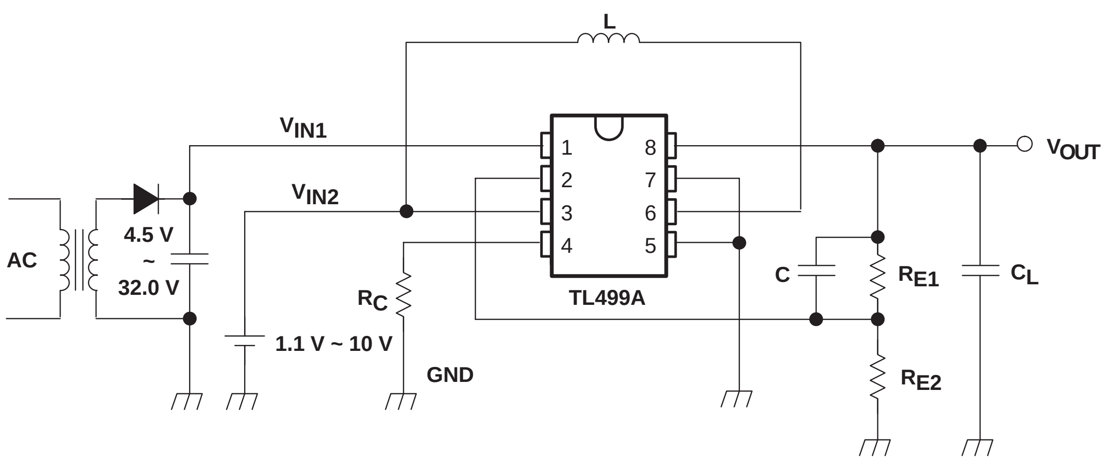

Figure 15. Battery-Backup Circuit

5.2 Charge-Protection Circuit

Because voltages in excess of the recommended maximum may appear at the input of the TL499A when fault conditions occur on the ac line or when the battery is removed, inserting a Zener diode for protection (see Figure 16) is recommended. The standby current required in this circuit is shown in Figure 17.

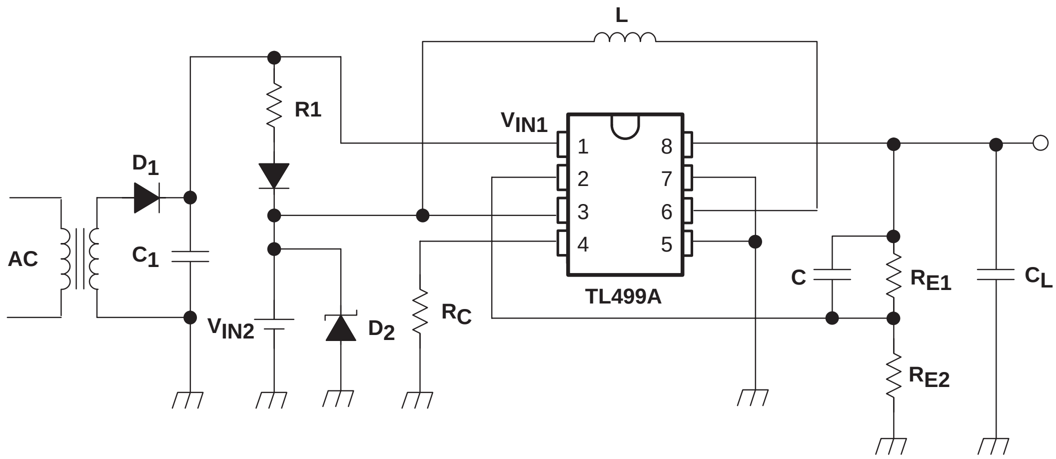

Figure 16. Charge-Protection Circuit

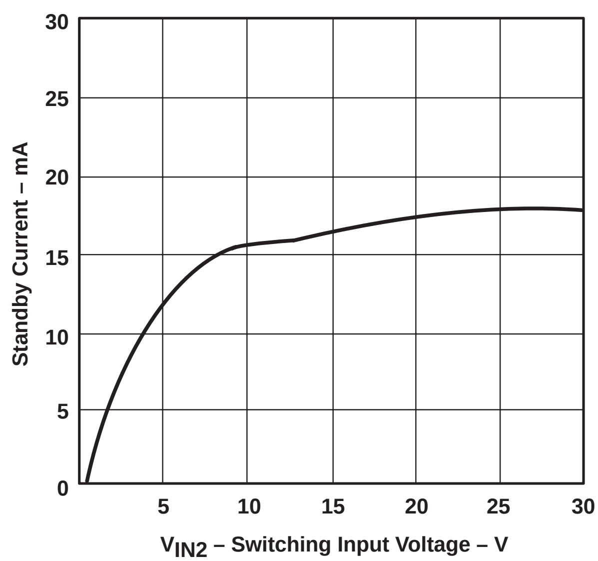

Figure 17. Standby-Current Characteristics

5.3 Switching-Inhibit Circuit

As shown in Figure 18, the switching circuit of the TL499A can be turned off by applying an external dc voltage approximately 1.0 V higher than the switching output voltage at pin 8. However, this method causes a heavy current load on the external voltage source and results in a reduction in voltage under the heavy load. An external power supply with a current capacity greater than the load current is needed, and this may not be practical in the application. Another method is shown in Figure 19. The circuit of Figure 19 turns off the switching circuit by applying a voltage above the typical 1.26-V internal reference voltage to pin 2. The current that flows into pin 2 is independent of the load. The recommended voltage range is from (V_{REF} + 0.2 V) to (V_{IN1} − 2.0 V). The characteristic graph of the pin-2 sink current versus the externally applied shutdown voltage is shown in Figure 20.

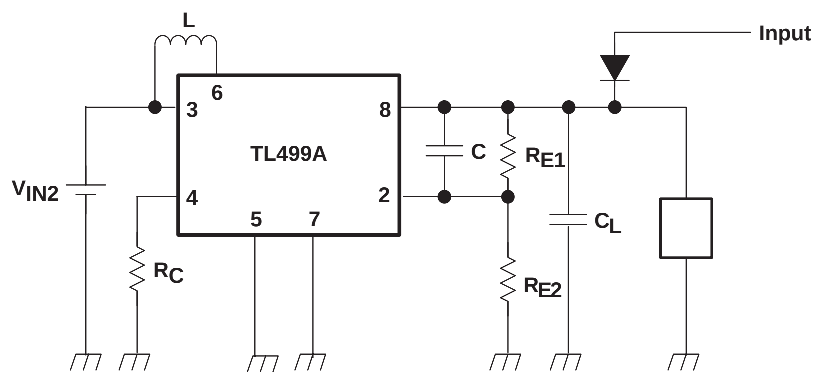

Figure 18. Switching-Inhibit Circuit Using Pin 8

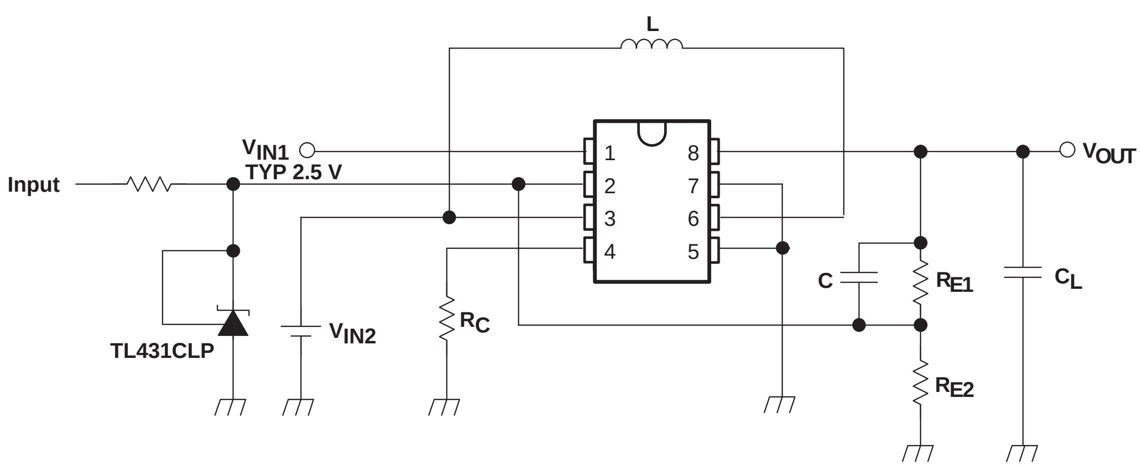

Figure 19. Switching-Inhibit Circuit Using Pin 2

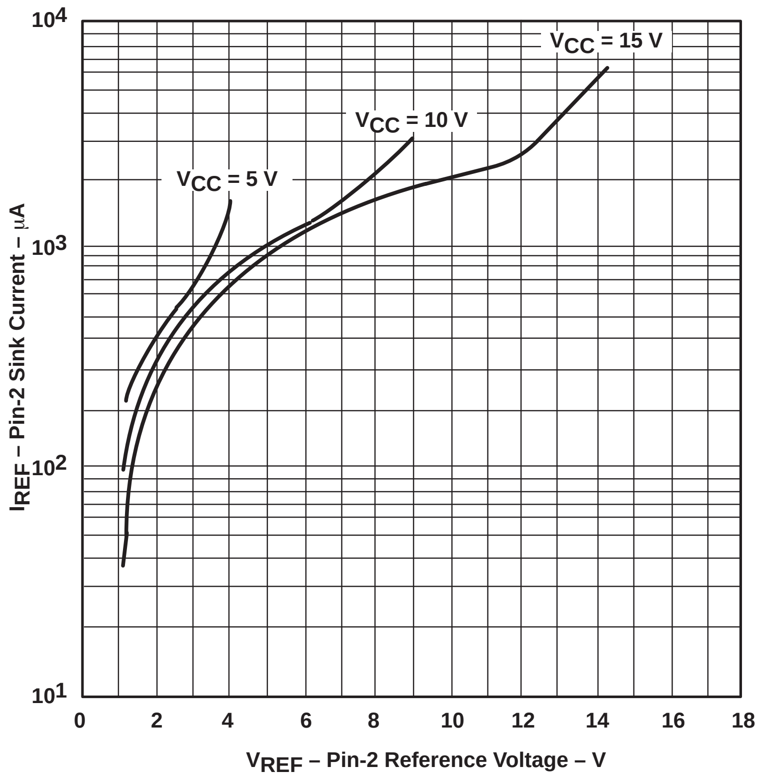

Figure 20. Pin-2 Sink Current vs Pin-2 Reference Voltage

6 Switching-Regulator Design Notes

6.1 Inductor-Coil Selection

The designer must ensure that the inductor used with the TL499A is not saturated by a peak switching current of about 1.0 A and that it has a good frequency characteristic. If the Q of the inductor is too high, it produces ringing in the switching waveform, and the efficiency decreases. In addition, the designer should choose an inductor with a relatively low internal series resistance. Although it is beneficial to increase the internal resistance of the coil when the ripple noise is excessive, the switching efficiency will not be optimal. Some inexpensive drum-core coils are available with low resistance and a good frequency characteristic. Other types of coils, such as the ring core, have low internal resistance characteristics, but they are comparatively expensive. The characteristics of some standard drum-core coils are shown in Table 13. A dimensional diagram of these drum coils is given in Figure 21.

Table 13. Standard Drum-Core-Type Coil Characteristics

CHARACTERISTIC	MODEL NUMBER				
	DR4-500K	K-500K	K-800K	K-101K	K-141K
Number of turns	(1–2) 43½	(1–2) 45½	(1–2) 55½	(1–2) 53½	(1–2) 62½
Set inductance	50 µH (± <10%)	50 µH (± <10%)	80 µH (± <10%)	100 µH (± <10%)	140 µH (± <10%)
Q at no load	≥20	≥20	≥20	≥20	≥20
Measurement frequency	2.52 MHz	2.52 MHz	2.52 MHz	796 kHz	796 kHz
Core	Drum core 4 × 6 4B4	Drum core 6 × 8.5 L4	Drum core 6 × 8.5 L4	Drum core 8 × 10 L5	Drum core 8 × 10 L5
Wire	0.12 2-UEW	0.4 UEW	0.35 UEW	0.4 UEW	0.35 UEW
Coil processing	High-frequency varnish	High-frequency varnish	High-frequency varnish	High-frequency varnish	High-frequency varnish
Direct current resistance	≤1.0 Ω	≤0.092 Ω	≤0.142 Ω	≤0.135 Ω	≤0.21 Ω
Form size					
Core diameter, A	4 mm	6 mm	6 mm	8 mm	8 mm
Core height, B	6 mm	8.5 mm	8.5 mm	10 mm	10 mm
Lead 1, C	33 ±2 mm	20 ±2 mm	20 ±2 mm	33 ±2 mm	33 ±2 mm
Lead 2, D	38 ±2 mm	20 ±2 mm	20 ±2 mm	33 ±2 mm	33 ±2 mm
Lead pitch, E	2 ±0.5 mm	3.5 ±1 mm	3.5 ±1 mm	4.5 ±1 mm	4.5 ±1 mm
Lead diameter, F	0.6 mm	0.6 mm	0.6 mm	0.6 mm	0.6 mm

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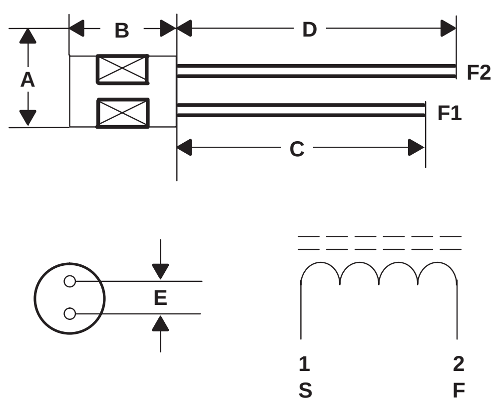


Figure 21. Inductor Dimensions

6.2 Oscillation Frequency and Pulse Width of the Switching Transistor

The waveform of the switching transistor of the TL499A is shown in Figure 22. The upper waveform is the switching transistor collector voltage, and the lower waveform is the inductor peak switching current. The waveforms are divided roughly into three portions:

- Transistor on time for charging energy into the inductor: t_{ON}
- Transistor off time for discharging energy into the output load: t_{OFF}
- Transistor quiescent time for stopping energy change: t_{QUI}

Note the following switching characteristics of the TL499A:

- If the load current (I_{LOAD}) is increased, the duration of the pulse sequence (the number of pulses between quiescent time periods) increases. Therefore, the duration of the quiescent time decreases. And, if the load current is increased further, the peak voltage of the pulse sequence is decreased, and it becomes impossible to maintain the specified output voltage.
- The collector voltage of the switching transistor during quiescent time is equal to the switching input voltage.
- The error amplifier determines the duration of the quiescent time (t_{QUI}) of the switching transistor.
- If output voltage is increased, the duration of the pulse sequence also increases.
- If the switching input voltage is lowered, the duration of the pulse sequence increases.

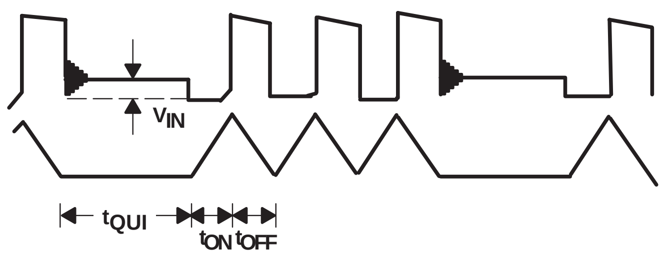
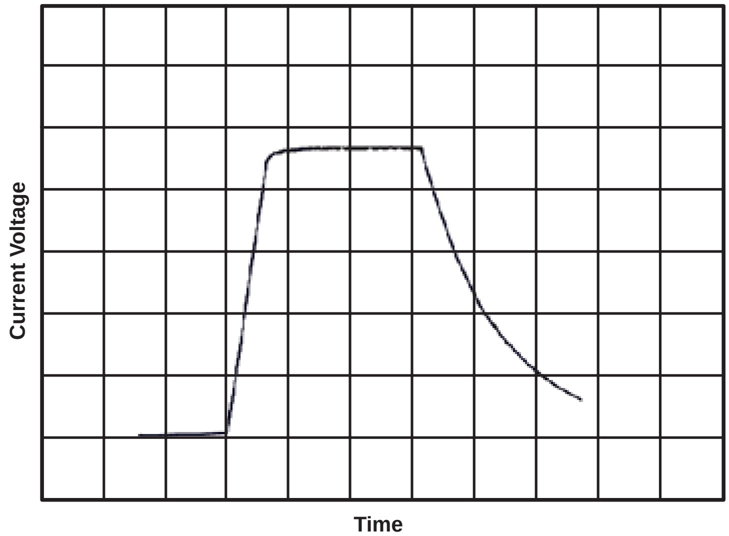


Figure 22. TL499A Switching Waveforms

7 Switching Waveforms

Some switching transistor collector voltage and inductor peak switching-current waveforms are shown in Figures 23–31 for various input and output conditions.

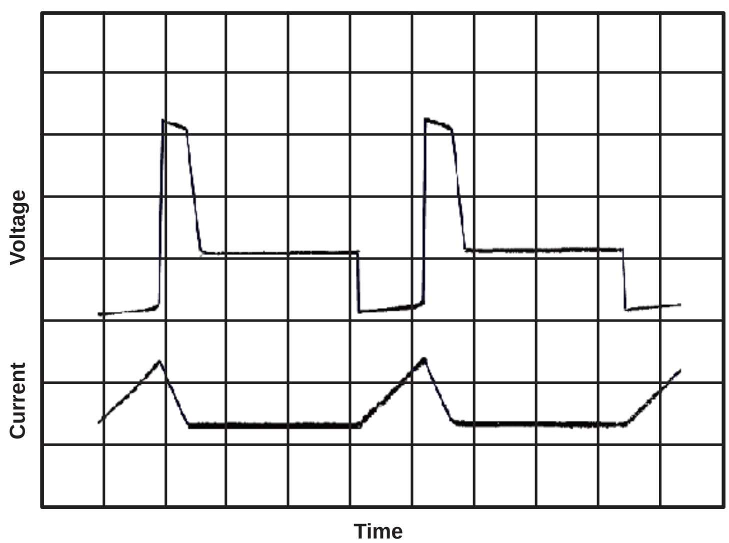
7.1 Switching Voltage/Current Waveforms With V_{IN2} = 5 V, V_{OUT} = 10 V



V_{IN2} = 5.0 V
V_{OUT} = 10.0 V
L = 50 µH
C_L = 220 µF/35 V
C = 0.1 µF
R_C = 150 Ω
I_{LOAD} = 100 mA
Y-axis scale: 2 V/div
X-axis scale: 2 ms/div

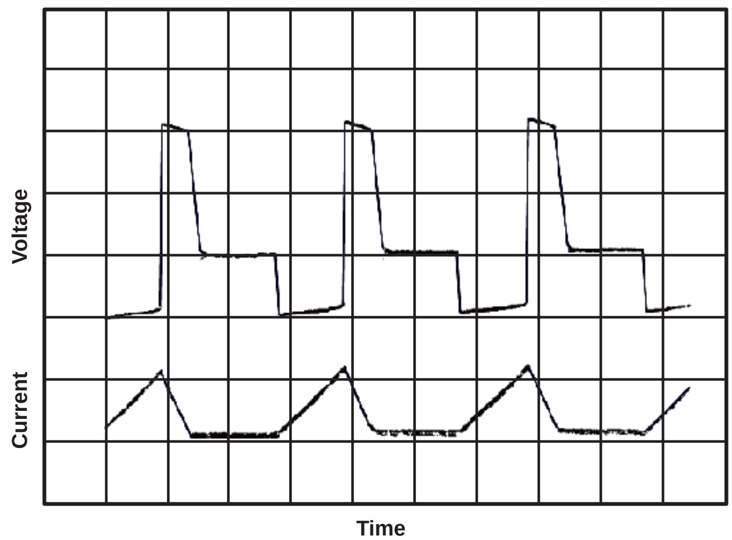
Figure 23. Switching Output-Voltage Waveform

7.2 Switching Voltage/Current Waveforms With V_{IN2} = 5 V, V_{OUT} = 15 V



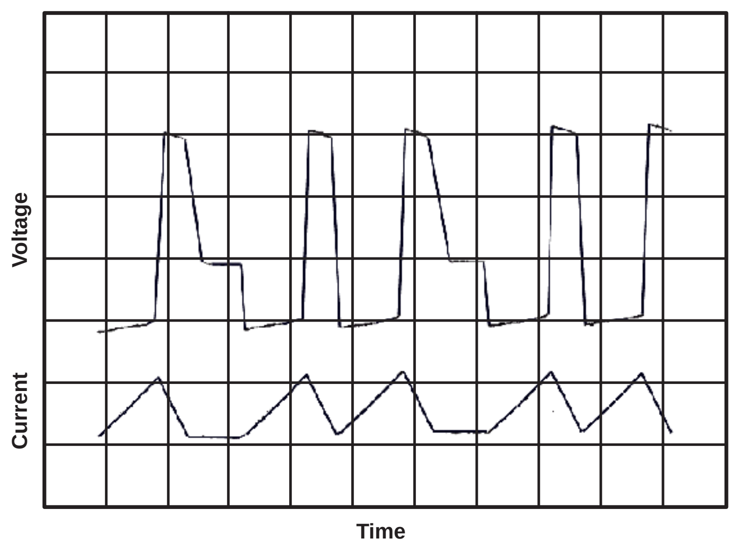
V_{IN2} = 5.0 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 µH
C_L = 220 µF/35 V
C = 0.1 µF
I_{LOAD} = 50 mA
X-axis scale: 10 µs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

Figure 24. TL499A Switching Voltage/Current Waveform, I_{LOAD} = 50 mA



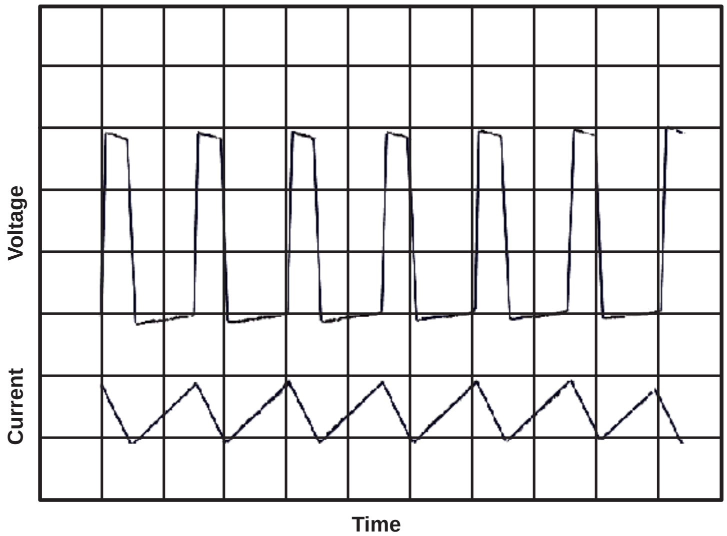
V_{IN2} = 5.0 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 µH
C_L = 220 µF/35 V
C = 0.1 µF
I_{LOAD} = 70 mA
X-axis scale: 10 µs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

Figure 25. TL499A Switching Voltage/Current Waveform, I_{LOAD} = 70 mA



V_{IN2} = 5.0 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 µH
C_L = 220 µF/35 V
C = 0.1 µF
I_{LOAD} = 100 mA
X-axis scale: 10 µs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

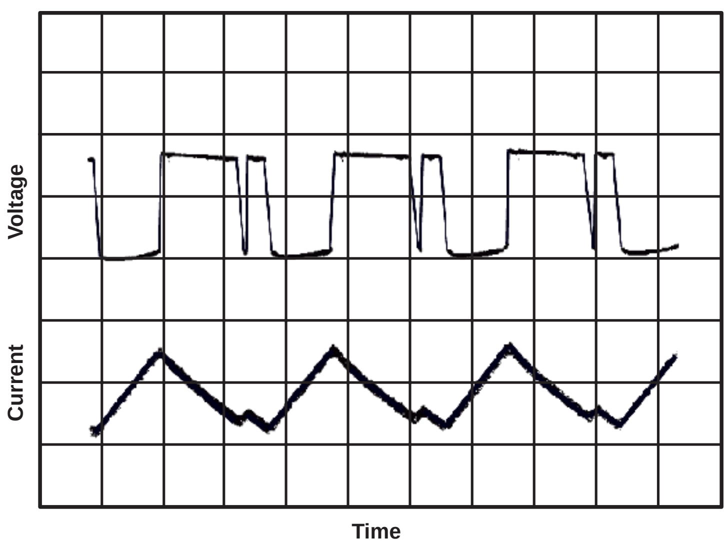
Figure 26. TL499A Switching Voltage/Current Waveform, I_{LOAD} = 100 mA



V_{IN2} = 5.0 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 μH
C_L = 220 μF/35 V
C = 0.1 μF
I_{LOAD} = 120 mA
X-axis scale: 10 μs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

NOTE: Use under these conditions is not recommended.

Figure 27. TL499A Switching Voltage/Current Waveform (Maximum Load)

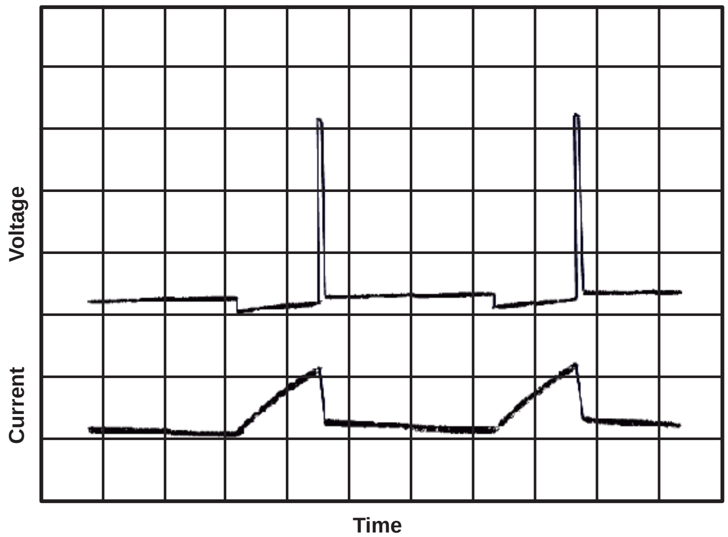


V_{IN2} = 5.0 V
V_{OUT} = 7.80 V
(Target V_{OUT} = 15.0 V)
R_C = 150 Ω
L = 50 μH
C_L = 220 μF/35 V
C = 0.1 μF
I_{LOAD} = 290 mA
X-axis scale: 5 μs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 0.4 A/div

NOTE: Use under these conditions is not recommended.

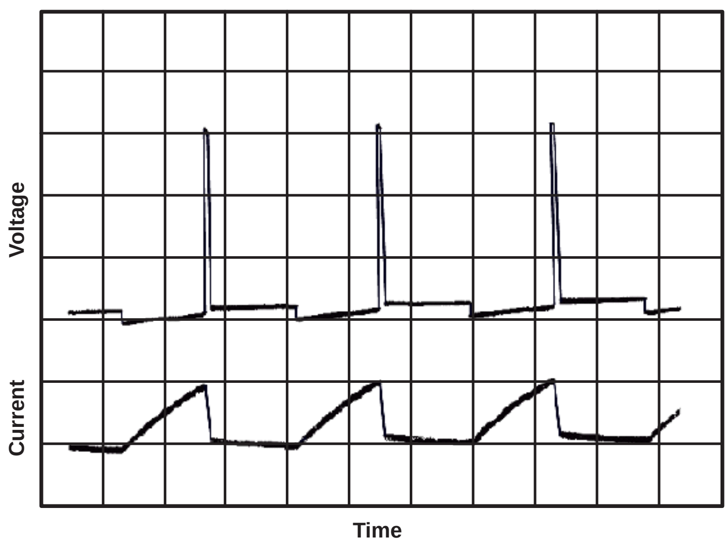
Figure 28. TL499A Switching Voltage/Current Waveform (Excessive Load)

7.3 Switching Waveforms With V_{IN2} = 1.1 V, V_{OUT} = 15 V



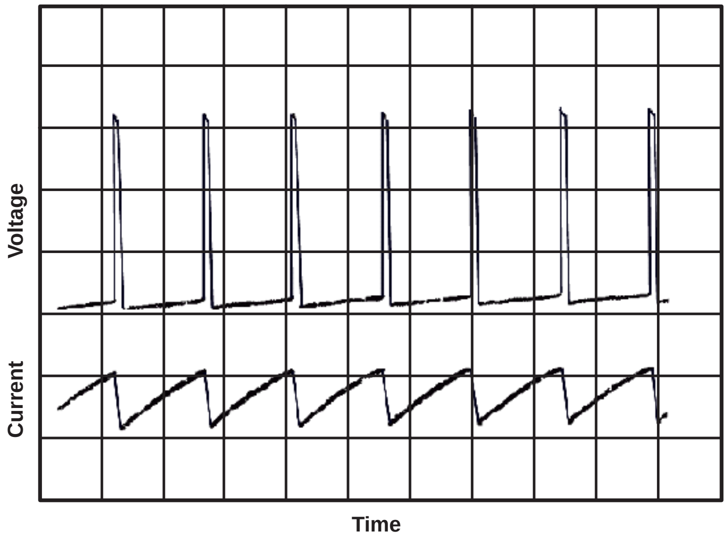
V_{IN2} = 1.1 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 μH
C_L = 220 μF/35 V
C = 0.1 μF
I_{LOAD} = 0.5 mA
X-axis scale: 50 μs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

Figure 29. TL499A Switching Voltage/Current Waveform, I_{LOAD} = 0.5 mA



V_{IN2} = 1.1 V
V_{OUT} = 15.0 V
R_C = 150 Ω
L = 50 μH
C_L = 220 μF/35 V
C = 0.1 μF
I_{LOAD} = 7.5 mA
X-axis scale: 50 μs/div
Upper Y-axis scale: 5 V/div
Lower Y-axis scale: 1 A/div

Figure 30. TL499A Switching Voltage/Current Waveform, I_{LOAD} = 7.5 mA



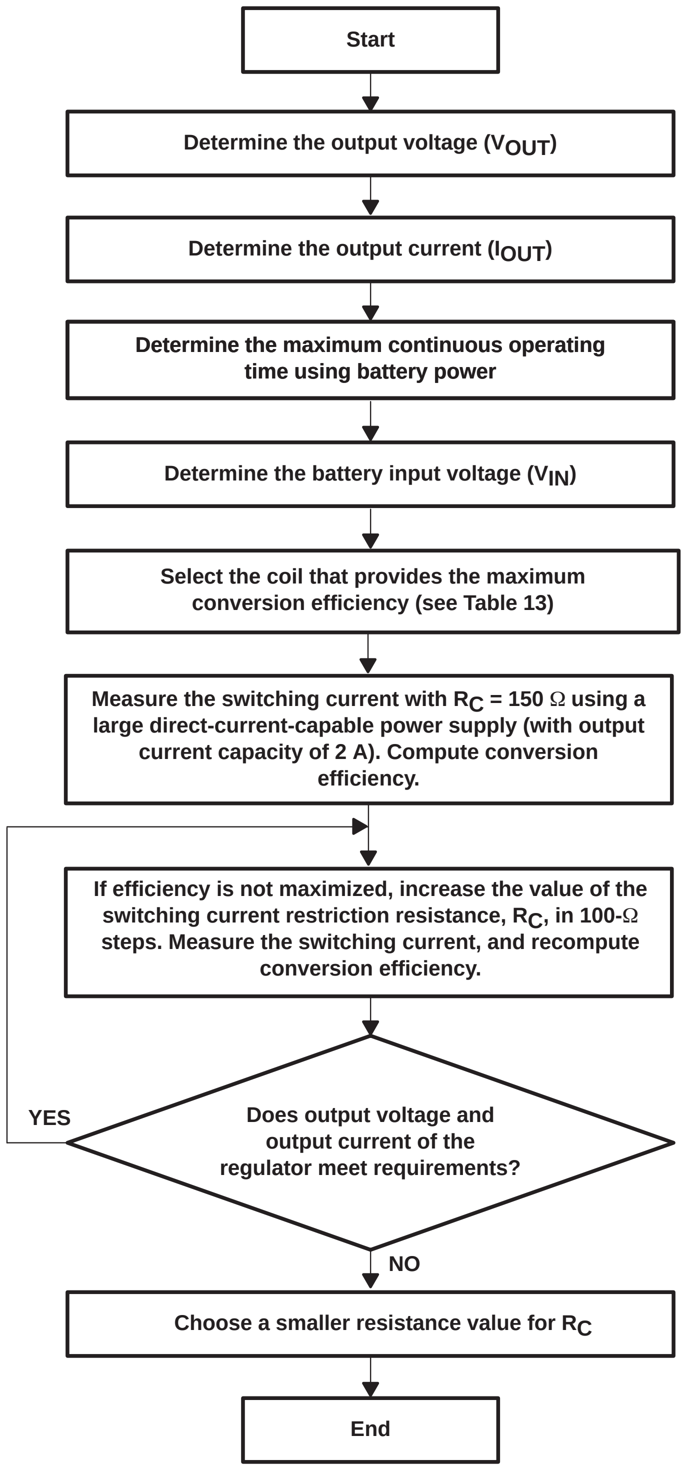
V_{IN2} = 1.1 V	**C = 0.1 μF**
V_{OUT} = 15.0 V	**I_{LOAD} = 15.0 mA**
R_C = 150 Ω	**X-axis scale: 5 μs/div**
L = 50 μH	**Upper Y-axis scale: 5 V/div**
C_L = 220 μF/35 V	**Lower Y-axis scale: 1 A/div**

NOTE: Use under these conditions is not recommended.

Figure 31. TL499A Switching Voltage/Current Waveform (Maximum Load)

8 Switching-Regulator Design-Procedure Flowchart

A flowchart to assist with the circuit design using the TL499A is shown in Figure 32.



Notes

V_{OUT} = CONSTANT

I_{OUT} = CONSTANT

The appropriate battery is selected.

V_{IN} = CONSTANT

For the inductor (L), a value between 50 µH and 150 µH is recommended. For the filter capacitor (C_L), a value of 470 µF is recommended.

The conversion efficiency is about 55% when using a value of R_C between 150 Ω and 1 kΩ. When input and output voltage and values of external surrounding parts are set constant, limit the maximum output current to a value where the quiescent time period (t_{QUI}) exists in the switching waveform, as shown in Figure 22.

See the circuit of Figure 2.
Conversion efficiency:

$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}} \times 100\%$$

After taking the electric discharge characteristic of the battery into consideration, it is necessary to determine the value of R_C. Use a small value between 100 Ω and 300 Ω.

Figure 32. Switching-Regulator Design-Procedure Flowchart

9 Precautions on TL499A Design and Use

To take full advantage of the features of the TL499A, consider the following sections.

9.1 Circuit Pattern and Layout

Because high-frequency peak current flows during the switching operation, the external surrounding parts (C, R_{E1}, R_{E2}, etc.) (see Figure 2) must be arranged as close to the IC as possible and mounted to a circuit with a large ground pattern and thick lead width (see Figure 33). Use a large ground plane to provide good heat dissipation.

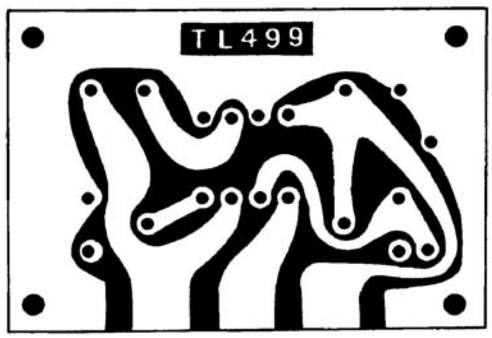


Figure 33. Recommended Board-Pattern Layout

9.2 External Surrounding Parts

- Coil [L (50 µH to 150 µH)]. Coils have the most influence on the efficiency and performance of the switching regulator. If the dc series resistance of the coil is not ideal (0.1 Ω or less), this large direct-current resistance may not allow switching operation to start up, and it will create problems.
- Decoupling capacitor (C_L). Although a large capacitor value greatly enhances output voltage ripple removal, if it is too large, the inrush current at the time of switching start-up may become excessive and cause the TL499 to not start up during the switching operation. Increasing the value of the decoupling capacitor (C_L) between 100 µF and 470 µF may be necessary, depending on the case.
- Path capacitor [C (0.05 µF to 0.1 µF)]. This capacitor is inserted between pins 2 and 8 to reduce output ripple voltage as much as possible.
- Switching-current-limiting resistance (R_C). Use this resistor within the limits of 150 Ω to 1 kΩ. If this value is too small, switching current increases greatly and efficiency worsens. If this value is too large, a stabilized output voltage will not be achieved.
- Input capacitor (C_{IN}). When the change of power-supply voltage from series mode to switching mode is large, or if the distance between the IC and the battery power supply is separated by a large distance, use of an input surge capacitor between pin 3 and ground is recommended to prevent a large, sudden inrush of current to the IC.
- Line-voltage sensing switch (S). When using a line-voltage sensing switch, use one in which the contact resistance is very small. The switching regulator may not start if the contact resistance is large.

9.3 High-Frequency Noise

If the TL499A has fixed values for input and output voltage, the oscillation frequency of the switching transistor increases with increasing load current. Because the frequency range of switching noise is broad, noise may be induced in the surrounding components. To help reduce the effects of switching noise:

- Keep the IC, coil, and capacitor wires as short as possible, and use a large ground pattern (use the recommended pattern in Figure 33).
- Keep the IC away from nodes with high input impedance or antennas.
- Try to reduce the load current and change the component values of external surrounding parts, if needed.
- Ensure that the path capacitor (C) between pins 2 and 8 is securely inserted and, also, insert a capacitor on the switching input side (pin 3).
- Consider the direction of the magnetic field generated by the coil, and shield it by using a screen, plate, etc.

9.4 Output Overload and Short Circuiting of the Output

When the output is overloaded, switching operation stops and the input current flows to ground through the switching transistor. This generates heat inside the IC in proportion to $V_{CESAT} \times I_{IN}$. Because the short-circuit current during overload time may not be restricted by R_C, the IC can be destroyed. Therefore, avoid overloading and/or short-circuiting the output.

10 References

1. TI Semiconductor Technical Data No. 51, Revision 3: *Series/Switching Regulator With Variable Output TL499A* (SPRS039)