LM2694 Evaluation Board

National Semiconductor
Application Note 1472
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Introduction

The LM2694EVAL evaluation board provides the design engineer with a fully functional buck regulator, employing the constant on-time (COT) operating principle. This evaluation board provides a 5V output over an input range of 8V - 30V. The circuit delivers load currents to 0.5A, with current limit set at ≊0.65A. The board is populated with all external components except R4, C6, C9 and C12. These components provide options for managing the output ripple voltage as described later in this document.

The board's specification are:

- Input Voltage: 8V to 30V
- Output Voltage: 5V
- Maximum load current: 0.5A
- Minimum load current: 0A
- Current Limit: 0.65A
- Measured Efficiency: 93.4% (V_{IN} = 8V, I_{OUT} = 200 mA)
- Nominal Switching Frequency: 250 kHz
- Size: 2.25 in. x 0.88 in. x 0.55 in

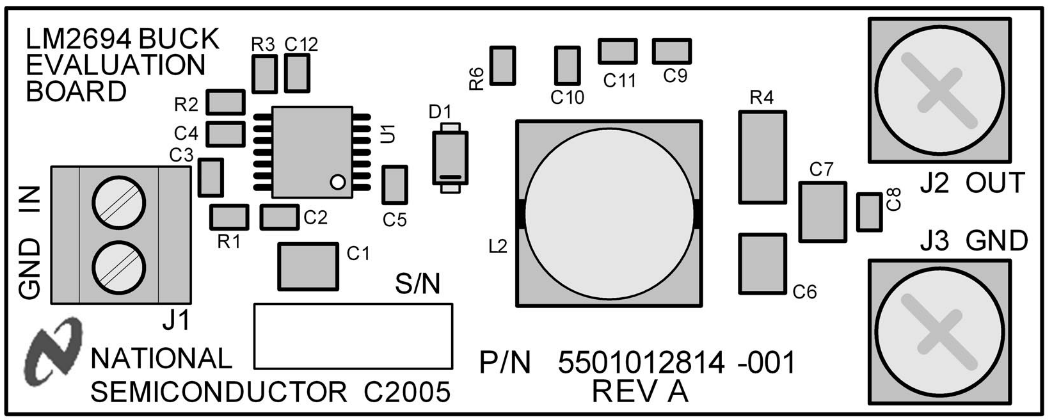

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FIGURE 1. Evaluation Board - Top Side

Theory of Operation

Refer to the evaluation board schematic in Figure 5. When the circuit is in regulation, the buck switch is on each cycle for a time determined by R1 and V_{IN} according to the equation:

$$t_{ON} = \frac{1.14 \times 10^{-10} \times (R1 + 1.4k)}{(V_{IN} - 1.5V)} + 95 \text{ ns}$$

The on-time of this evaluation board ranges from ≊2600 ns at V_{IN} = 8V, to ≊660 ns at V_{IN} = 30V. The on-time varies inversely with V_{IN} to maintain a nearly constant switching frequency. At the end of each on-time the Minimum Off-Timer ensures the buck switch is off for at least 265 ns. In normal operation, the off-time is much longer. During the off-time, the output capacitor (C7) is discharged by the load current. When the output voltage falls sufficiently that the voltage at FB is below 2.5V, the regulation comparator initiates a new on-time period. For stable, fixed frequency operation, ≊25 mV of ripple is required at FB to switch the regulation comparator. Refer to the LM2694 data sheet for a detailed block diagram, and a complete description of the various functional blocks.

Board Layout and Probing

The pictorial in Figure 1 shows the placement of the circuit components. The following should be kept in mind when the board is powered:

1) When operating at high input voltage and high load current, forced air flow is recommended.

2) The LM2694, and diode D1 may be hot to the touch when operating at high input voltage and high load current.

3) Use CAUTION when probing the circuit at high input voltages to prevent injury, as well as possible damage to the circuit.

4) At maximum load current (0.5A), the wire size and length used to connect the load becomes important. Ensure there is not a significant drop in the wires between this evaluation board and the load.

Board Connection/Start-up

The input connections are made to the J1 connector. The load is connected to the OUT and GND terminals. Ensure the wires are adequately sized for the intended load current. Before start-up a voltmeter should be connected to the input terminals, and to the output terminals. The load current should be monitored with an ammeter or a current probe. It is recommended that the input voltage be increased gradually to 8V, at which time the output voltage should be 5V. If the output voltage is correct with 8V at V_{IN}, then increase the input voltage as desired and proceed with evaluating the circuit.

Output Ripple Control

The LM2694 requires a minimum of 25 mVp-p ripple at the FB pin, in phase with the switching waveform at the SW pin, for proper operation. In the simplest configuration (Figure 4) that ripple is derived from the ripple at the output, generated by the inductor's ripple current flowing through R4. That ripple voltage is attenuated by the feedback resistors, requiring that the ripple amplitude at OUT be higher than the minimum of 25 mVp-p by the gain factor. Options for reducing the output ripple are discussed below, and the results are shown in the graph of Figure 8.

A) **Minimum Output Ripple:** This evaluation board is supplied configured for minimum ripple at OUT. The output ripple, which ranges from 2mVp-p at V_{IN} = 8V to 3 mVp-p at V_{IN} = 30V, is determined primarily by the ESR of output capacitor (C7), and the inductor's ripple current, which ranges from 60 mAp-p to 100 mAp-p over the input voltage range. The ripple voltage required by the FB pin is generated by R6, C10 and C11 since the SW pin switches from -1V to V_{IN}, and the right end of C10 is a virtual ground. The values for R6 and C10 are chosen to generate a 30-40 mVp-p triangle waveform at their junction. That triangle wave is then coupled to the FB pin through C11. The following procedure is used to calculate values for R6, C10 and C11:

1) Calculate the voltage V_A:

$$V_A = V_{OUT} - (V_{SW} \times (1 - (V_{OUT}/V_{IN})))$$

where V_{SW} is the absolute value of the voltage at the SW pin during the off-time (typically 1V), and V_{IN} is the minimum input voltage. For this circuit V_A calculates to 4.63V. This is the DC voltage at the R6/C10 junction, and is used in the next equation.

2) Calculate the R6 x C10 product:

$$R6 \times C10 = \frac{(V_{IN} - V_A) \times t_{ON}}{\Delta V}$$

where t_{ON} is the maximum on-time (≊2600 ns), V_{IN} is the minimum input voltage, and ΔV is the desired ripple amplitude at the R6/C10 junction, 30 mVp-p for this example.

$$R6 \times C10 = \frac{(8V - 4.63V) \times 2600\ ns}{0.03V} = 2.9 \times 10^{-4}$$

R6 and C10 are then chosen from standard value components to satisfy the above product. For example, C10 can be 2700 pF requiring R6 to be 110 kΩ. C11 is chosen to be 0.01 µF, large compared to C10. The circuit as supplied on this EVB is shown in Figure 2.

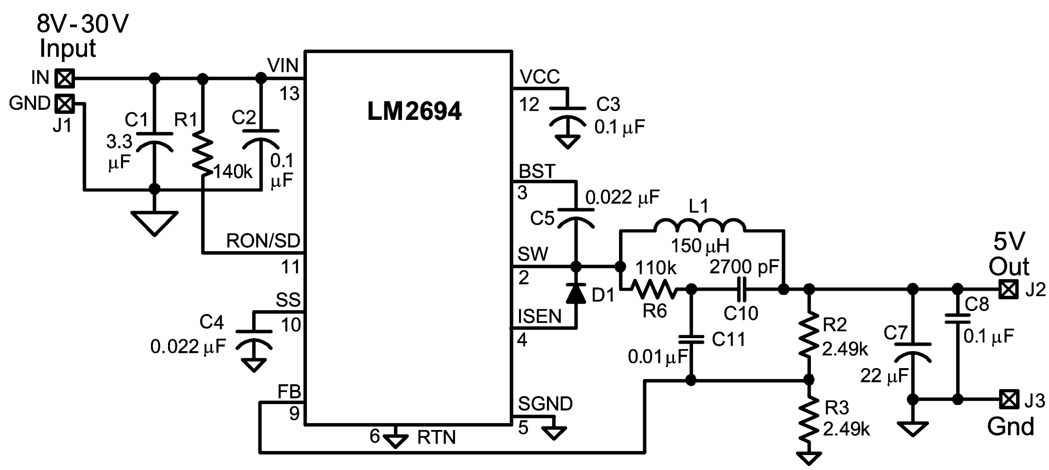

FIGURE 2. Minimum Output Ripple Configuration

B) **Intermediate Ripple Level Configuration:** This configuration generates more ripple at the output than the above configuration, but uses one less capacitor. If some ripple can be tolerated in the application, this configuration is slightly more economical, and simpler. R4 and C6 and C9 are used instead of R6, C7, C8, C10 and C11, as shown in Figure 3.

Output Ripple Control (Continued)

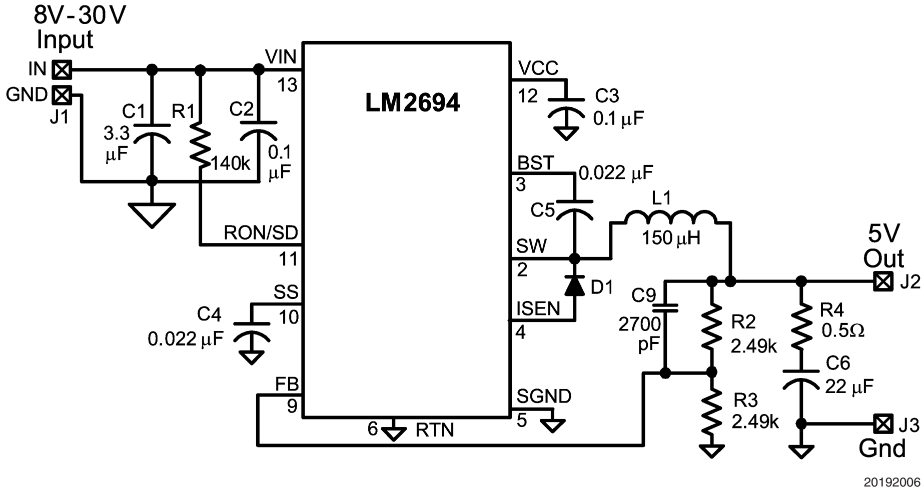

FIGURE 3. Intermediate Ripple Configuration

R4 is chosen to generate ≥25 mV - 30 mVp-p at the output, knowing that the minimum ripple current in this circuit is 60 mAp-p at minimum V_{IN}. C9 couples that ripple to the FB pin without the attenuation of the feedback resistors. C9's minimum value is calculated from:

$$C9 = \frac{t_{ON(max)}}{(R2//R3)}$$

where $t_{ON(max)}$ is the maximum on-time (at minimum V_{IN}), and R2//R3 is the equivalent parallel value of the feedback resistors. For this evaluation board $t_{ON(max)}$ is approximately 2600 ns, and R2//R3 = 1.25 kΩ, and C9 calculates to a minimum of 2080 pF. The resulting ripple at the output ranges from 30 mVp-p to 50 mVp-p over the input voltage range.

C) **Lowest Cost Configuration:** This configuration is the same as option B above, but without C9. Since 25 mVp-p are required at the FB pin, R4 is chosen to generate 50 mV at OUT, knowing that the minimum ripple current in this circuit is 60 mAp-p at minimum V_{IN}. To allow for tolerances, 1.0Ω is used for R4. The resulting ripple at OUT ranges from ≅60 mVp-p to ≅100 mVp-p over the input voltage range. If the application can tolerate this ripple level, this is the most economical solution. The circuit is shown in Figure 4. An alternative to this circuit is to eliminate R4 if C6 has sufficient ESR.

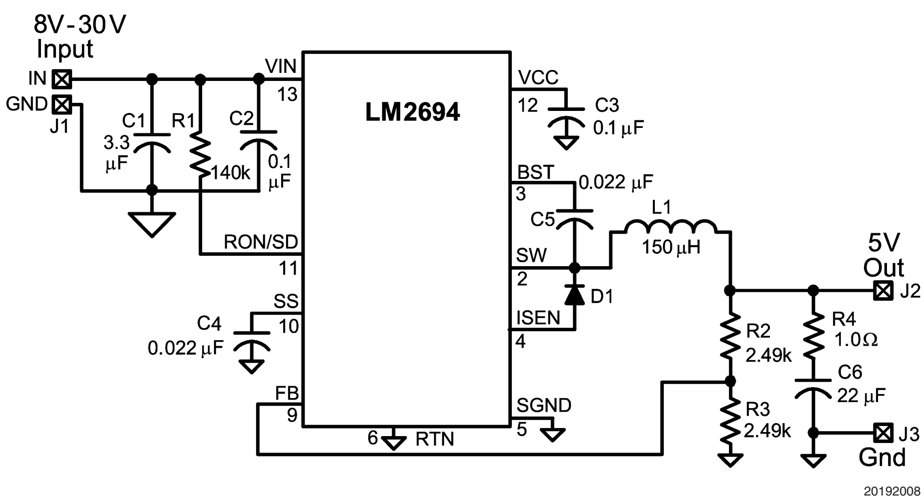

FIGURE 4. Lowest Cost Configuration

Minimum Load Current

The LM2694 requires a minimum load current of ≅500 µA to ensure the boost capacitor (C5) is recharged sufficiently during each off-time. In this evaluation board, the minimum load current is provided by the feedback resistor (R2, R3), allowing the board's minimum load current to be specified at zero.

Circuit Performance

Figures 6 through 9 indicate the performance of this evaluation board. Figure 10 indicates waveforms at various points within the circuit, and Figure 11 indicates how the output responds to the load current changing between 200 mA and 400 mA. Figure 12 indicates the preferred method for using a scope probe to measure output ripple and transient waveforms. The probe's ground ring touches the output ground terminal (J3) and the probe's tip touches the 5V output terminal (J2). This method eliminates noise and switching spikes which the probe's ground lead would pick up if it were used.

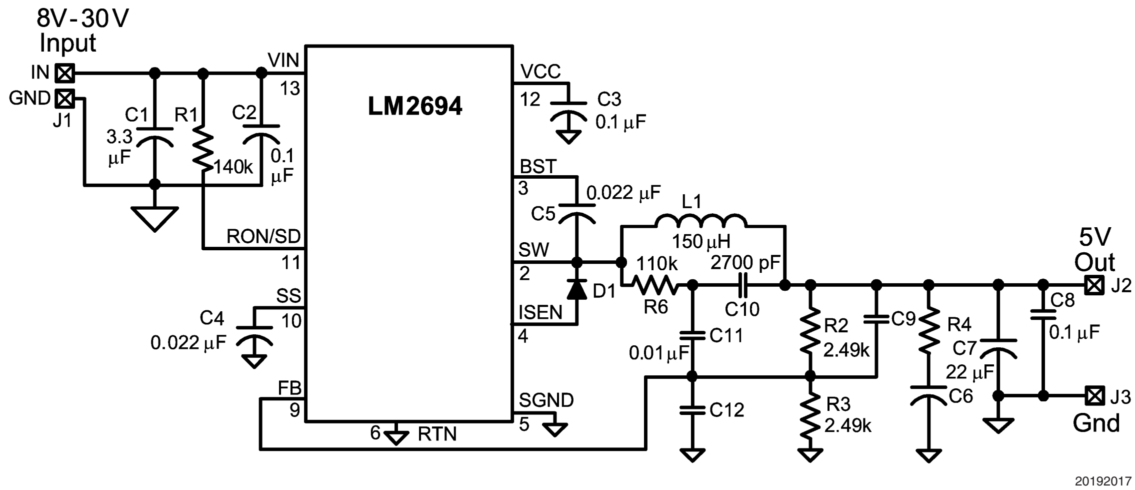

FIGURE 5. Evaluation Board Schematic

Item	Description	Mfg., Part Number	Package	Value
C1	Ceramic Capacitor	TDK C3225X7R1H335M	1210	3.3 µF, 50V
C2, 3, 8	Ceramic Capacitor	TDK C2012X7R2A104M	0805	0.1 µF, 100V
C4, 5	Ceramic Capacitor	TDK C2012X7R2A223M	0805	0.022 µF, 100V
C6		Unpopulated	1210	
C7	Ceramic Capacitor	TDK C3225X7R1C226M	1210	22 µF, 16V
C9		Unpopulated	0805	
C10	Ceramic Capacitor	TDK C2012X7R2A272M	0805	2700 pF, 100V
C11	Ceramic Capacitor	TDK C2012X7R2A103M	0805	0.01 µF, 100V
C12	Ceramic Capacitor	Unpopulated	0805	
D1	Schottky Diode	Diodes Inc. DFLS160	Power DI 123	60V, 1A
L1	Inductor	TDK SLF10145-151MR79, or Cooper Bussman DR74-151	10 mm x 10 mm	150 µH, 0.8A
R1	Resistor	Vishay CRCW08051413F	0805	140kΩ
R2, R3	Resistor	Vishay CRCW08052491F	0805	2.49kΩ
R4	Resistor	Unpopulated	2010	
R6	Resistor	Vishay CRCW08051103F	0805	110kΩ
U1	Switching Regulator	National Semiconductor LM2694MT	TSSOP-14	

Circuit Performance

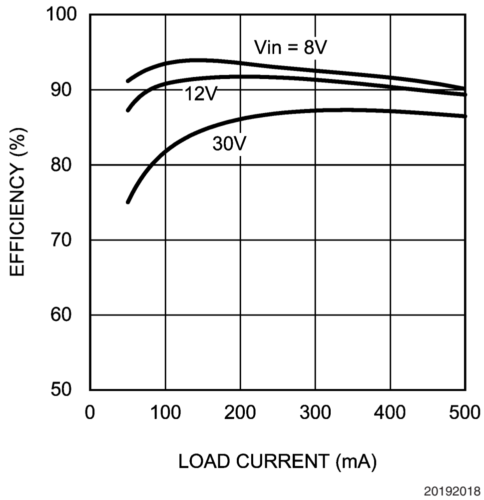

FIGURE 6. Efficiency vs Load Current

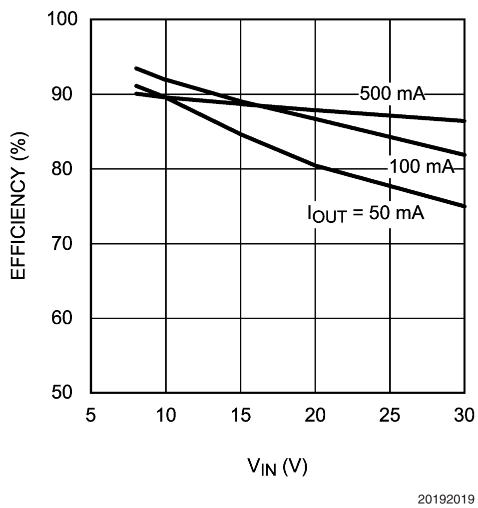

FIGURE 7. Efficiency vs Input Voltage

Circuit Performance (Continued)

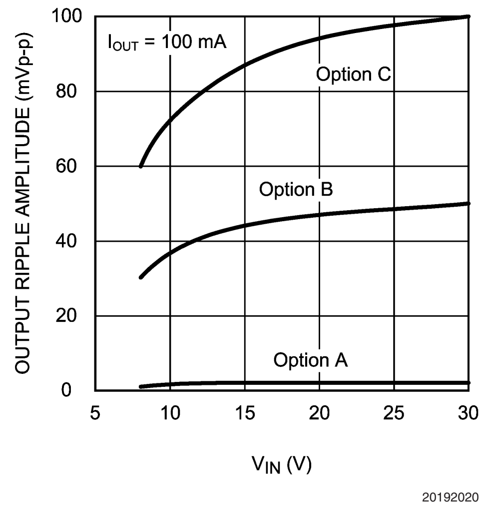

FIGURE 8. Output Voltage Ripple

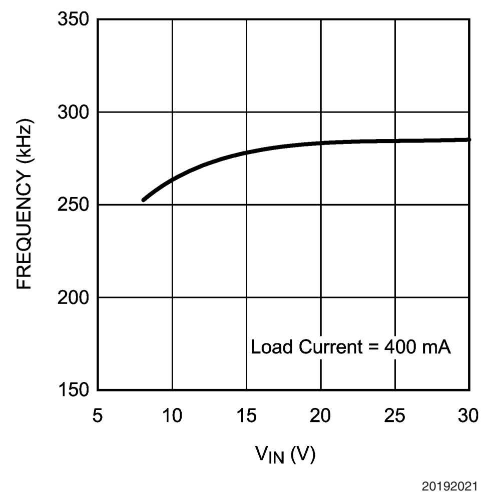

FIGURE 9. Switching Frequency vs. Input Voltage

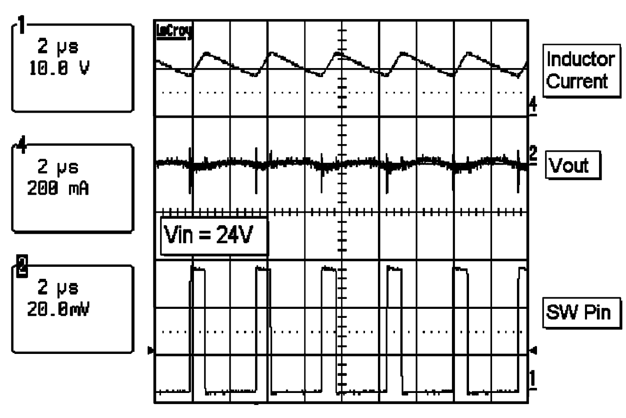

FIGURE 10. Circuit Waveforms

Circuit Performance (Continued)

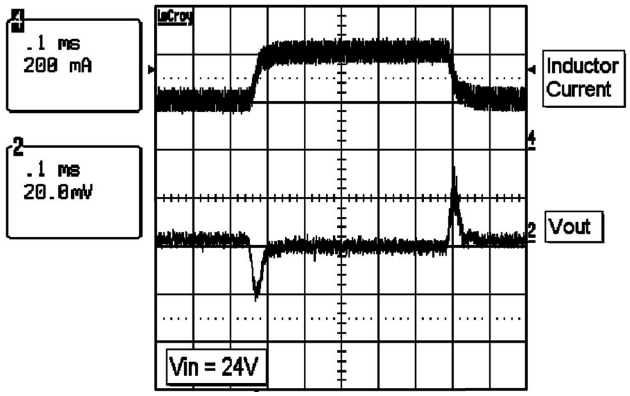

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FIGURE 11. Transient Response

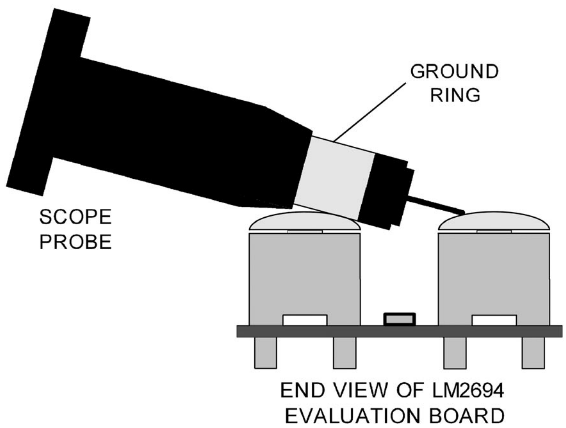

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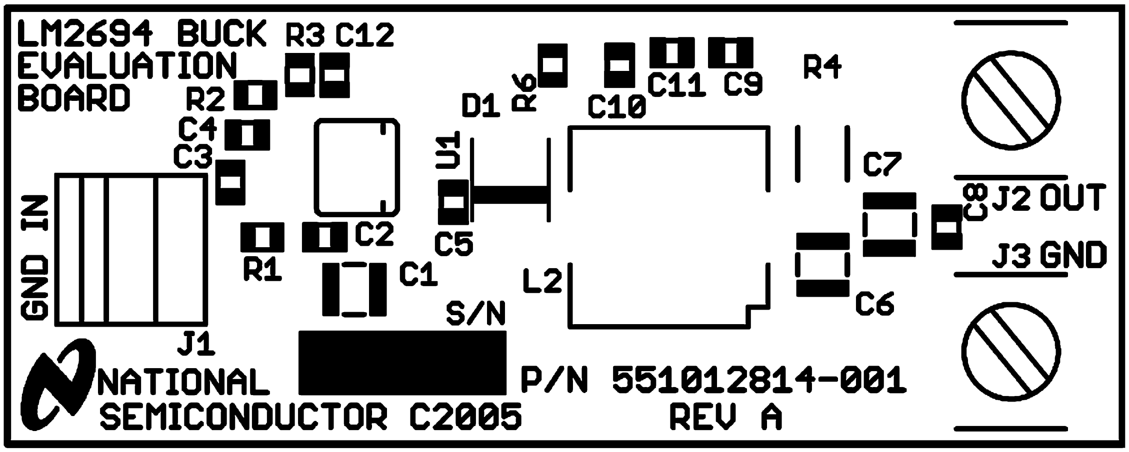
FIGURE 12. Preferred Method for Measuring Output Waveforms

PCB Layout



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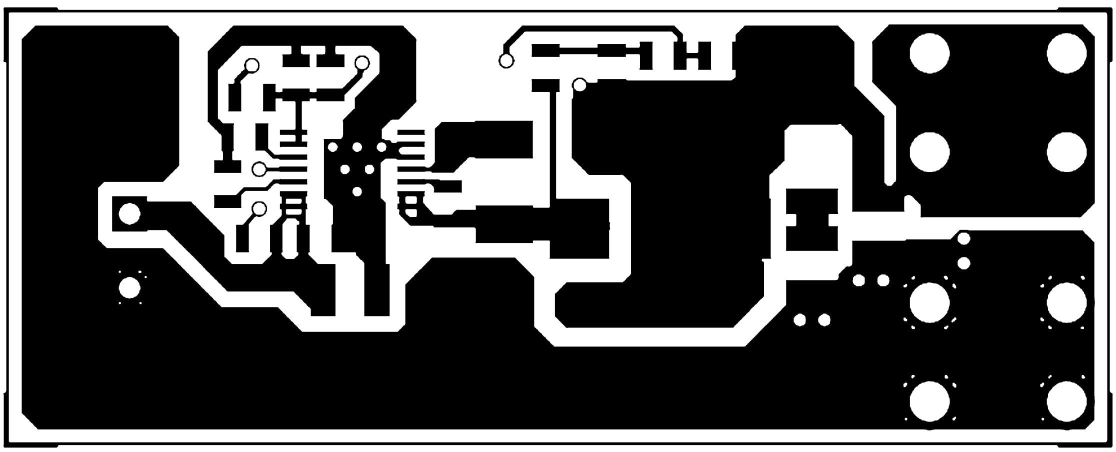
Board Silkscreen



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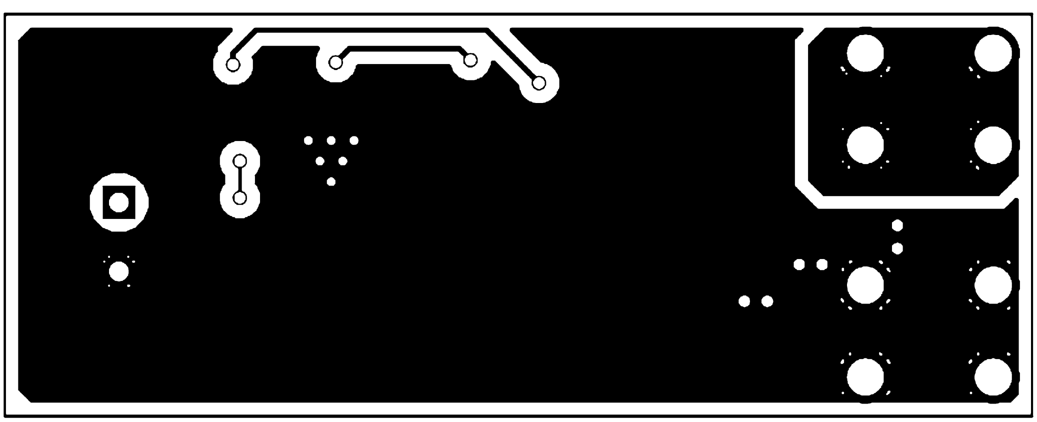
Board Top Layer



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Board Bottom Layer (viewed from top)

Notes

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