

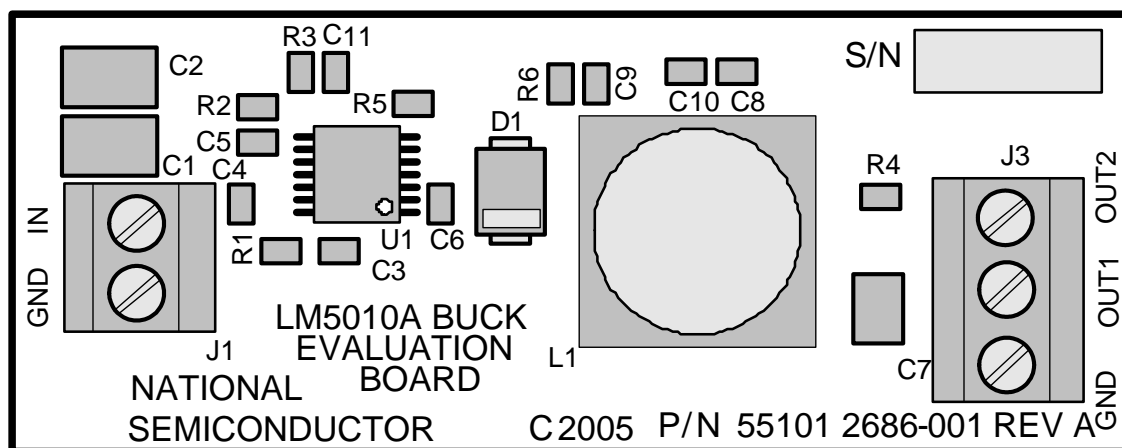
## AN-1423 LM5010A Evaluation Board

### 1 Introduction

The LM5010AEVAL 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 6V - 75V. The circuit delivers load currents to 1A, with current limit set at  $\approx 1.3A$ . The board is populated with all external components except R6 and C9-C11. These components provide options for reducing output ripple as described later in this document.

The board's specification are:

- Input Voltage: 6V to 75V
- Output Voltage: 5V
- Maximum load current: 1.0A
- Minimum load current: 0A
- Current Limit: 1.3A
- Measured Efficiency: 94.75% ( $V_{IN} = 6V$ ,  $I_{OUT} = 200\text{ mA}$ )
- Nominal Switching Frequency: 200 kHz
- Size: 2.25 in. x 0.88 in. x 0.47 in



**Figure 1. Evaluation Board - Top Side**

### 2 Theory of Operation

The evaluation board schematic in [Figure 3](#) contains a simplified block diagram of the LM5010A, *LM5010A-Q1 High-Voltage 1-A Step-Down Switching Regulator Data Sheet* ([SNVS376](#)). When the circuit is in regulation, the buck switch is on each cycle for a time determined by R1 and  $V_{IN}$  according to [Equation 1](#):

$$t_{ON} = \frac{1.18 \times 10^{-10} \times (R1 + 1.4k)}{(V_{IN} - 1.4V)} + 67\text{ ns} \quad (1)$$

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The on-time of this evaluation board ranges from  $\approx 5000$  ns at  $V_{IN} = 6$  V, to  $\approx 380$  ns at  $V_{IN} = 75$  V. 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 260 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 2.5 V, the regulation comparator initiates a new on-time period. For stable, fixed frequency operation,  $\approx 25$  mV of ripple is required at FB to switch the regulation comparator. For a more detailed block diagram and a complete description of the various functional blocks, see the *LM5010A, LM5010A-Q1 High-Voltage 1-A Step-Down Switching Regulator Data Sheet* ([SNVS376](#)).

### 3 Board Layout and Probing

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

- When operating at high input voltage and high load current, forced air flow is necessary.
- The LM5010A, and the diode D1 will be hot to the touch when operating at high input voltage and high load current.
- Use CAUTION when probing the circuit at high input voltages to prevent injury, as well as possible damage to the circuit.
- At maximum load current (1 A), 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.

### 4 Board Connection/Start-up

The input connections are made to the J1 connector. The load is normally connected to the OUT1 and GND terminals of the J3 connector. 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 6 V, at which time the output voltage should be 5 V. If the output voltage is correct with 6 V at  $V_{IN}$ , then increase the input voltage as desired and proceed with evaluating the circuit.

### 5 Reducing Output Ripple

The LM5010A 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 basic application circuit shown in the device-specific data sheet, C8 is not included. The required ripple at FB is derived from the ripple at  $V_{OUT1}$ , which is generated by the inductor's ripple current passing through R4 and the ESR of capacitor C7. Since the ripple voltage at  $V_{OUT1}$  is attenuated by the R2/R3 feedback divider, a minimum of 50 mVp-p is required at  $V_{OUT1}$ . If this ripple level is acceptable for the intended application, C8 can be removed from this evaluation board, and R4 increased to 1.5  $\Omega$ . In that case, the minimum ripple amplitude ( $\approx 55$  mVp-p) occurs at minimum  $V_{IN}$  (6 V), and increases to  $\approx 340$  mVp-p at  $V_{IN} = 75$  V, as shown in **Figure 6**.

If a low ripple output is desired, three alternatives are described in [Section 5.1](#), [Section 5.2](#), and [Section 5.3](#).

#### 5.1 Option A: Ripple Reduction

This EVB is supplied with C8 installed, and  $R4 = 0.68 \Omega$ , providing a relatively low ripple output at  $V_{OUT1}$  since C8 couples the output ripple directly to FB without attenuation. The ripple amplitude at  $V_{OUT1}$  ranges from 30 mVp-p to 170 mVp-p (see **Figure 6**) as  $V_{IN}$  is varied over its range. The minimum value for C8 is calculated from:

$$C8 = \frac{t_{ON(max)}}{(R2//R3)} \quad (2)$$

where,  $t_{ON(max)}$  is the maximum on-time at minimum  $V_{IN}$ , and  $R2//R3$  is the equivalent parallel value of R2 and R3. For this evaluation board,  $t_{ON(max)}$  is approximately 5000 ns, and  $R2//R3 = 500 \Omega$ , resulting in a minimum value of 0.01  $\mu$ F for C8.

## 5.2 Option B: Ripple Reduction

Add R6, C9, C10, replace R4 with zero ohms, and leave C8 and C11 positions open. Since the SW pin switches from -1V to  $V_{IN}$ , and the right end of C9 is a virtual ground, R6 and C9 are chosen to generate a 30-40 mVp-p triangle wave at their junction. That triangle wave is coupled to the FB pin through C10. To calculate the values for R6, C9, and C10, use the following procedure, using the minimum input voltage for  $V_{in}$ :

Calculate the voltage  $V_A$ :

$$V_A = V_{OUT} - (V_{SW} \times (1 - (V_{OUT}/V_{in}))) \quad (3)$$

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 4.83V. This is the DC voltage at the R6/C9 junction, and is used in [Equation 4](#).

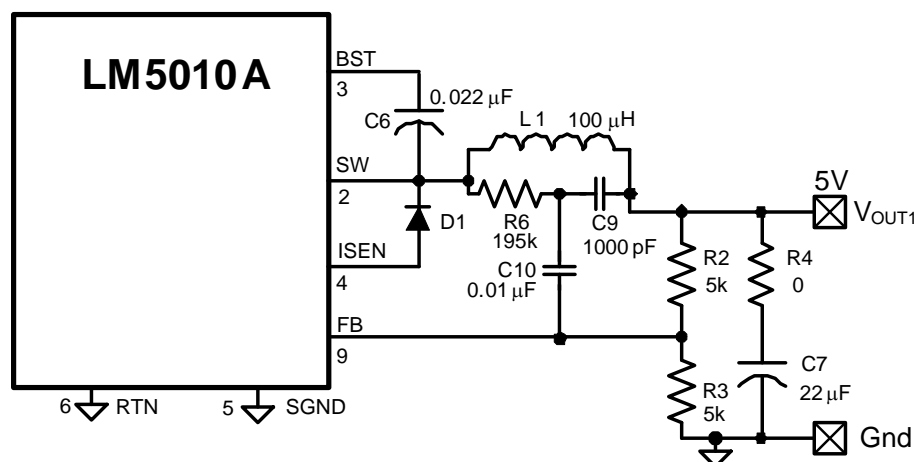
Calculate the R6•C9 product:

$$R6 \bullet C9 = \frac{(V_{in} - V_A) \times t_{ON}}{\Delta V} \quad (4)$$

where,  $t_{ON}$  is the on-time at minimum  $V_{in}$  ( $\approx 5 \mu s$ ), and  $\Delta V$  is the desired ripple amplitude at the R6/C9 junction, 30mV for this example.

$$R6 \cdot C9 = \frac{(5V - 4.05V) \times 5}{0.03V} = 1.95 \times 10^{-4} \quad (5)$$

R6 and C9 are then chosen from standard value components to satisfy the above product. For example, C9 can be 1000 pF, requiring R6 to be 195 k $\Omega$ . C10 is chosen to be 0.01  $\mu$ F, large compared to C9. R2 and R3 are increased to 5 k $\Omega$  each to reduce the loading on the signal provided through C10. The resulting circuit is:



### Figure 2. Low Ripple Output Using R6, C9, C10

The resulting ripple at  $V_{OUT1}$  ranges from 5 mVp-p at  $V_{in} = 6V$ , to 18 mVp-p at  $V_{in} = 75V$ , and varies slightly with load current, see [Figure 6](#). These values are valid only for continuous conduction mode (load current is between 120 mA and 1.3A). If the load current is reduced below 120 mA such that the circuit operates in discontinuous conduction mode the  $V_{OUT1}$  ripple ranges from  $\approx 40$  mVp-p to  $\approx 100$  mVp-p. If the circuit is operated in current limit mode the ripple ranges from  $\approx 100$  mVp-p to  $\approx 300$  mVp-p.

### 5.3 Option C: Ripple Reduction

Connect the load to  $V_{OUT2}$  (leave  $R4$  in). The ripple at this output varies from  $\approx 3$  mVp-p to  $\approx 7.5$  mVp-p over the input voltage range, see [Figure 6](#). However, the load regulation is not as good at  $V_{OUT2}$  as at  $V_{OUT1}$  due to the presence of  $R4$ . This alternative may be preferred for applications where the load current is relatively constant.

## 6 Increasing the Current Limit

The evaluation board current limit activates at a load current of  $\approx 1.3\text{A}$ . If it is desired to increase the current limit for a particular application, R5 must be added to the board. To determine the appropriate value for this resistor, see the *LM5010A, LM5010A-Q1 High-Voltage 1-A Step-Down Switching Regulator Data Sheet* ([SNVS376](#)).

## 7 Minimum Load Current

The LM5010A requires a minimum load current of  $\approx 500\text{ }\mu\text{A}$  to ensure the boost capacitor (C6) 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 at  $V_{\text{OUT1}}$  (or  $V_{\text{OUT2}}$ ) to be specified at zero.

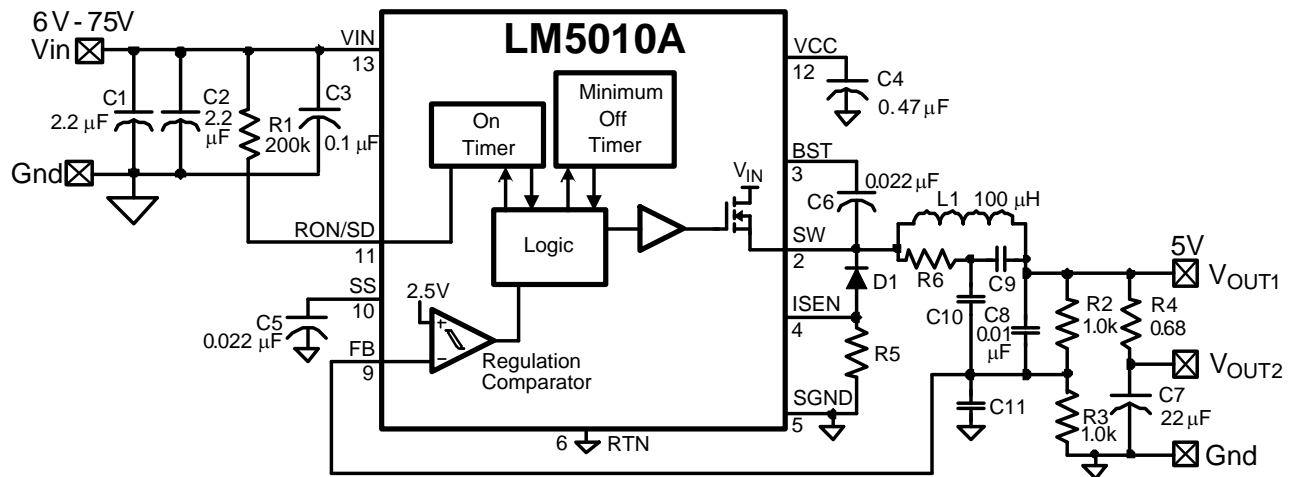
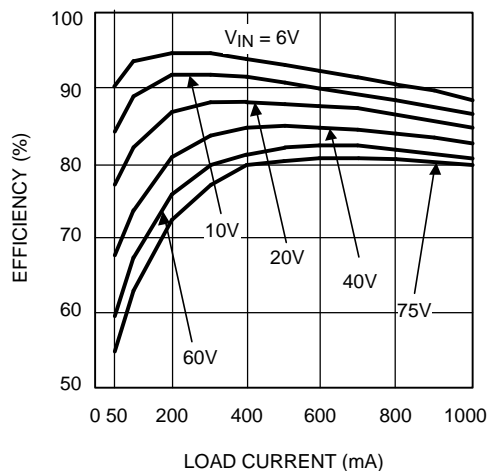


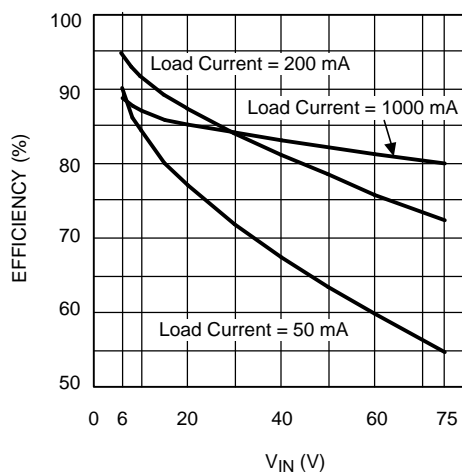
Figure 3. Evaluation Board Schematic

Table 1. Bill of Materials (BOM)

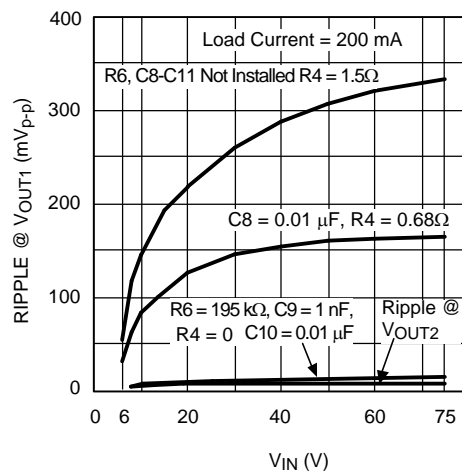
| Item  | Description         | Mfg., Part Number                                      | Package           | Value                     |
|-------|---------------------|--------------------------------------------------------|-------------------|---------------------------|
| C1, 2 | Ceramic Capacitor   | TDK C4532X7R2A225M                                     | 1812              | 2.2 $\mu\text{F}$ , 100V  |
| C3    | Ceramic Capacitor   | TDK C2012X7R2A104M                                     | 0805              | 0.1 $\mu\text{F}$ , 100V  |
| C4    | Ceramic Capacitor   | TDK C2012X7R1C474M                                     | 0805              | 0.47 $\mu\text{F}$ , 16V  |
| C5, 6 | Ceramic Capacitor   | TDK C2012X7R1C223M                                     | 0805              | 0.022 $\mu\text{F}$ , 16V |
| C7    | Ceramic Capacitor   | TDK C4532X7R1E226M                                     | 1812              | 22 $\mu\text{F}$ , 25V    |
| C8    | Ceramic Capacitor   | TDK C2012X7R1C103M                                     | 0805              | 0.01 $\mu\text{F}$ , 16V  |
| C9    |                     | Unpopulated                                            |                   |                           |
| C10   |                     | Unpopulated                                            |                   |                           |
| C11   |                     | Unpopulated                                            |                   |                           |
| D1    | Schottky Diode      | Central Semi CSMH2-100                                 | SMB               | 100V, 2A                  |
| L1    | Power Inductor      | TDK SLF12575T-101M1R9, or<br>Cooper Bussmann DR125-101 | 12.5 mm x 12.5 mm | 100 $\mu\text{H}$ , 1.9A  |
| R1    | Resistor            | CRCW08052003F                                          | 0805              | 200 k $\Omega$            |
| R2, 3 | Resistor            | CRCW08051001F                                          | 0805              | 1.00 k $\Omega$           |
| R4    | Resistor            | ERJ-6RQFR68V (Panasonic)                               | 0805              | 0.68 $\Omega$             |
| R5    |                     | Unpopulated                                            |                   |                           |
| R6    |                     | Unpopulated                                            |                   |                           |
| U1    | Switching Regulator | Texas Instruments LM5010                               | HTSSOP - 14       |                           |



**Figure 4. Efficiency vs Load Current**



**Figure 5. Efficiency vs  $V_{IN}$**



**Figure 6. Voltage Ripple at  $V_{OUT1}$ ,  $V_{OUT2}$**

## 8 PCB Layout

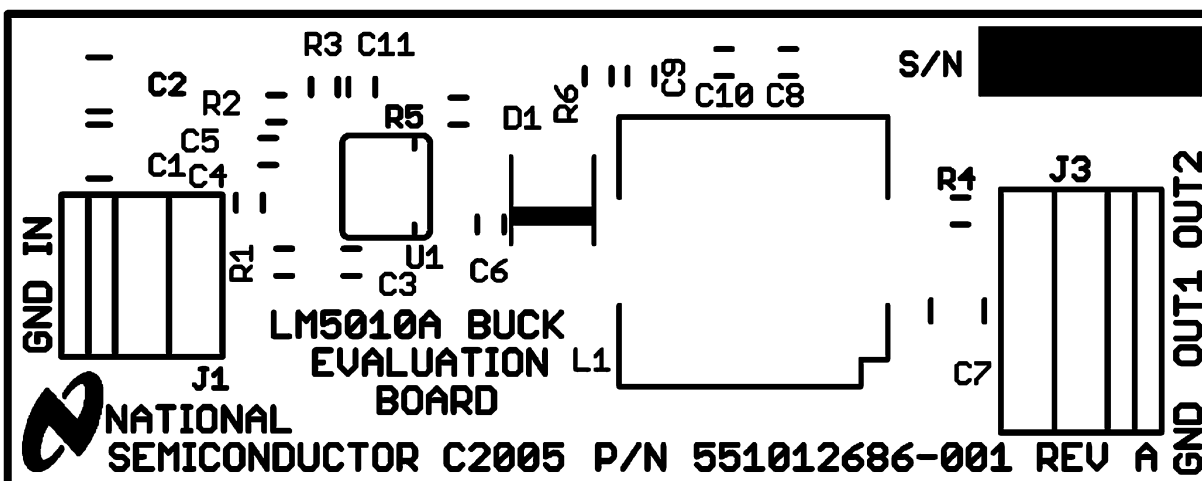


Figure 7. Board Silkscreen

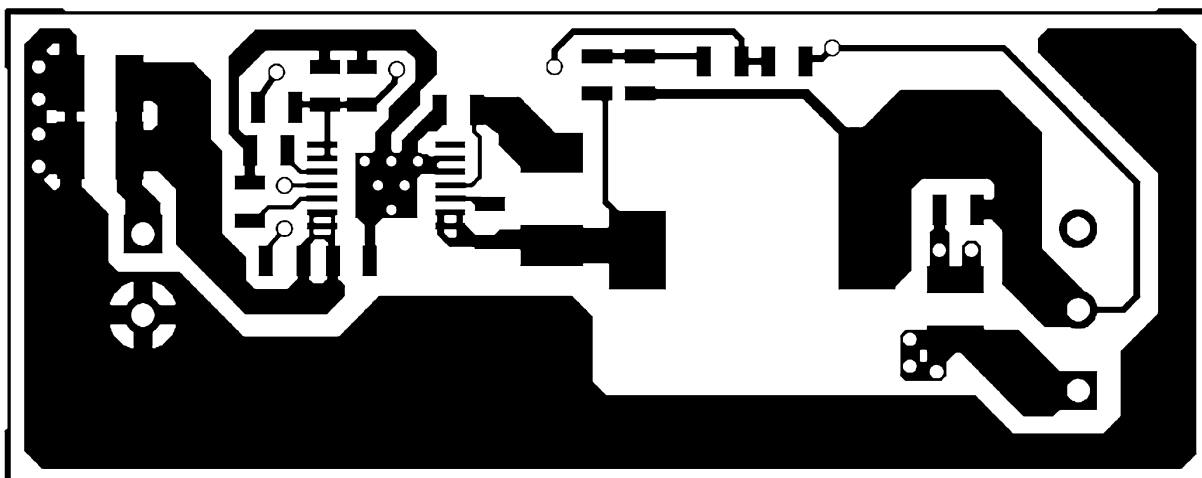


Figure 8. Board Top Layer

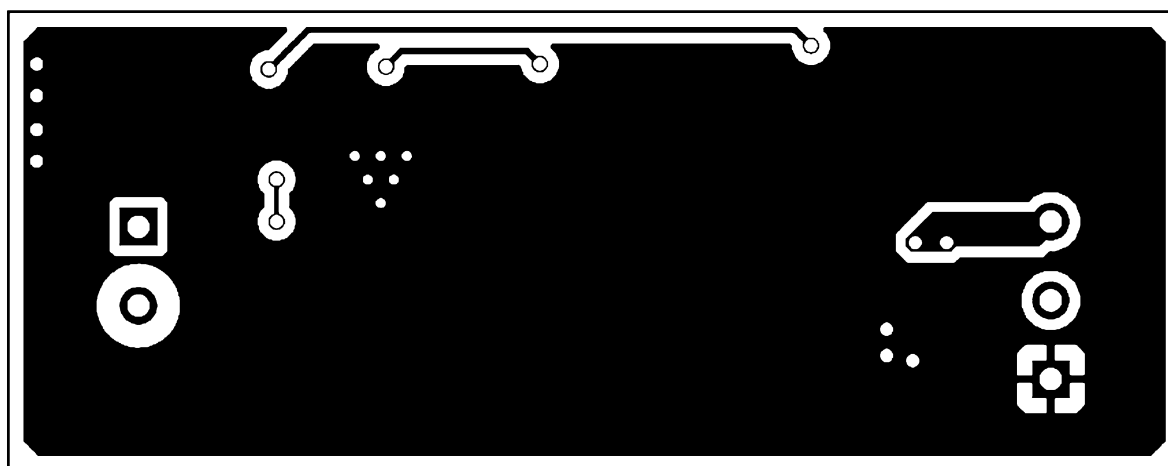


Figure 9. Board Bottom Layer (viewed from top)

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