1 Introduction

The LM25007EVAL 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 9V - 42V. The circuit delivers load currents to 450 mA, with current limit at 670 mA. The board is populated with all external components except C6 and C9. These components provide options for managing the output ripple as described later in this document.

The board’s specification are:

- Input Voltage: 9V to 42V
- Output Voltage: 5V
- Maximum load current: 450 mA
- Minimum load current: 0 mA
- Current Limit: 670 mA
- Measured Efficiency: 92.6% (V_in = 9V, I_out = 150 mA)
- Nominal Switching Frequency: 306 kHz
- Size: 1.6 in. x 1.0 in. x 0.5 in

2 Theory of Operation

Figure 5 contains a simplified block diagram of the LM25007. When the circuit is in regulation, the buck switch is on each cycle for a time determined by R1 and the input voltage according to Equation 1:

\[ t_{ON} = \frac{1.42 \times 10^{-10} \times R1}{V_{IN}} \]

(1)

The nominal switching frequency is calculated from Equation 2:

\[ F_S = \frac{V_{OUT}}{1.42 \times 10^{-10} \times R1} \]

(2)
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:

1) When operating at high input voltage and high load current, forced air flow is recommended.
2) The LM25007 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) Ensure the wires connecting this board to the load are sized appropriately for the load current. 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 V1 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 9V, at which time the output voltage should be 5V. If the output voltage is correct with 9V at Vin, then increase the input voltage as desired and proceed with evaluating the circuit.

5 Output Ripple Control

The LM25007 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 that ripple is derived from the ripple at VOUT, 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 VOUT 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.

5.1 Minimum Output Ripple

This evaluation board is supplied configured for minimum ripple at VOUT by setting R4 to zero ohms, and including components R6, C7 and C8. The output ripple that ranges from 2 mVp-p at Vin = 9V to 7 mVp-p at Vin = 42V, is determined primarily by the ESR of output capacitor (C2), and the inductor’s ripple current that ranges from 75 mAp-p to 144 mAp-p over the input voltage range. This performance applies only to continuous conduction mode as the ripple amplitude is higher in discontinuous conduction mode. The ripple voltage required by the FB pin is generated by R6, C7 and C8 since the SW pin switches from -1V to Vin, and the right end of C7 is a virtual ground. The values for R6 and C7 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 C8. The following procedure is used to calculate values for R6, C7 and C8:

- Calculate the voltage VA:
  \[ V_A = V_{OUT} \times (1 - (V_{SW}/V_{IN})) \]  
  where, VSW is the absolute value of the voltage at the SW pin during the off-time (typically 1V), and VIN is the minimum input voltage. For this circuit VA calculates to 4.55V. This is the DC voltage at the R6/C7 junction, and is used in Equation 4.
• Calculate the $R_6 \times C_7$ product:

$$R_6 \times C_7 = \frac{(V_{IN} - V_A) \times t_{ON}}{\Delta V}$$

(4)

where, $t_{ON}$ is the maximum on-time ($\approx 1800$ ns), $V_{IN}$ is the minimum input voltage, and $\Delta V$ is the desired ripple amplitude at the $R_6/C_7$ junction, 30 mVp-p for this example.

$$R_6 \times C_7 = \frac{(9V - 4.55V) \times 1800 \text{ ns}}{0.03V} = 2.67 \times 10^{-4}$$

(5)

$R_6$ and $C_7$ are then chosen from standard value components to satisfy the above product. For example, $C_7$ can be 2200 pF requiring $R_6$ to be 121 kΩ. $C_8$ is chosen to be 0.01 µF, large compared to $C_7$. This portion of the circuit, as supplied on this EVB, is shown in Figure 2.

![Figure 2. Minimum Ripple Using R6, C7, C8](image)

### 5.2 Intermediate Ripple Level Configuration

This configuration generates more ripple at $V_{OUT1}$ 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. $R_4$ and $C_6$ are used instead of $R_6$, $C_7$, and $C_8$, as shown in Figure 3.

![Figure 3. Intermediate Ripple Level Configuration Using C6 and R4](image)
R4 is chosen to generate ≥25 mV at \( V_{OUT1} \), knowing that the minimum ripple current in this circuit is 75 mAP-p at minimum \( V_{IN} \). C6 couples that ripple to the FB pin without the attenuation of the feedback resistors. C6’s minimum value is calculated from:

\[
C6 = \frac{t_{ON(max)}}{(R2//R3)}
\]

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 1800 ns, and R2//R3 = 1.5 kΩ, and C6 calculates to a minimum of 1200 pF. The resulting ripple at \( V_{OUT1} \) ranges from ≊ 25 mVP-p to 50 mVP-p over the input voltage range with the circuit in continuous conduction mode. The ripple amplitude is higher if the load current is low enough to force the circuit into discontinuous conduction mode.

### 5.3 Minimum Cost Configuration

This configuration is the same as Section 5.2, but without C6. Since 25 mVP-p are required at the FB pin, R4 is chosen to generate 50 mVP-p at \( V_{OUT1} \), knowing that the minimum ripple current in this circuit is 75 mAP-p at minimum \( V_{IN} \). To allow for tolerances, 0.68Ω is used for R4. The resulting ripple at \( V_{OUT1} \) ranges from ≊ 50 mVP-p to ≊ 100 mVP-p over the input voltage range. If the application can accept this ripple level, this is the most economical solution. The circuit is shown in Figure 4.

![Figure 4. Minimum Cost Configuration](image)

### 5.4 Alternate Low Ripple Configuration

A low ripple output can be obtained by connecting the load to \( V_{OUT2} \) in the circuits of Section 5.2 or Section 5.3. Since R4 degrades load regulation, this alternative may be viable for applications where the load current is relatively constant. If this method is used, ensure R4’s power rating is appropriate for the load current.

### 6 Current Limit

The LM25007 contains an intelligent current limit off-timer. The current limit threshold is 725 mA, ±25%. If the current in the buck switch (the peak of the inductor’s current waveform) reaches the threshold the present on-time cycle is immediately terminated, and a non-resetable off-time is initiated. The length of the off-time is controlled by an external resistor (R5) and the voltage at the FB pin. If FB = 0V (output is shorted to ground) the off-time is the preset maximum of 17 µs. This off-time ensures safe short circuit operation to the maximum input voltage of 42V. In cases of less severe overload where the output voltage, and the voltage at FB, is above ground the current limit off-time is less than 17 µs. The shorter off-times reduces the amount of foldback, recovery time, and also reduces the startup time.
The current limit off-time is calculated from Equation 7:

\[
t_{\text{OFF}} = \frac{10^{-5}}{0.59 + \frac{V_{\text{FB}}}{7.22 \times 10^{-6} \times R_5}}
\]

(7)

The current limit off-time ranges from 4.3 µs to 17 µs as \( V_{\text{FB}} \) varies from 2.5V to 0V, with \( R_5 = 200 \, \Omega \). The guideline for selecting \( R_5 \)'s value is that the current limit off-time (at \( V_{\text{FB}} = 2.5V \)) should be slightly longer than the maximum off-time encountered in normal operation. Setting a shorter off-time could result in inadequate overload protection, and setting a much longer off-time can affect the startup operation.

7 Minimum Load Current

The LM25007 requires a minimum load current of \( \approx 500 \, \mu A \) 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 resistors (R2, R3), allowing the board’s minimum load current to be specified at zero.

![Figure 5. Complete Evaluation Board Schematic](image)

Table 1. Bill of Materials (BOM)

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Mfg., Part Number</th>
<th>Package</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Ceramic Capacitor</td>
<td>TDK C3225X7R2A105M</td>
<td>1210</td>
<td>1.0 µF, 100V</td>
</tr>
<tr>
<td>C2</td>
<td>Ceramic Capacitor</td>
<td>TDK C3225X7R1C226M</td>
<td>1210</td>
<td>22 µF, 16V</td>
</tr>
<tr>
<td>C3, 4</td>
<td>Ceramic Capacitor</td>
<td>TDK C2012X7R2A104M</td>
<td>0805</td>
<td>0.1 µF, 100V</td>
</tr>
<tr>
<td>C5, 8</td>
<td>Ceramic Capacitor</td>
<td>TDK C2012X7R2A103M</td>
<td>0805</td>
<td>0.01 µF, 100V</td>
</tr>
<tr>
<td>C6</td>
<td>Unpopulated</td>
<td></td>
<td>0805</td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>Ceramic Capacitor</td>
<td>TDK C2012X7R2A222M</td>
<td>0805</td>
<td>2200 pF</td>
</tr>
<tr>
<td>C9</td>
<td>Unpopulated</td>
<td></td>
<td>0805</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Schottky Diode</td>
<td>Diodes Inc. DFLS160</td>
<td>Power Di 123</td>
<td>60V, 1A</td>
</tr>
<tr>
<td>L1</td>
<td>Power Inductor</td>
<td>TDK SLF7045T-101MR50</td>
<td>7 mm x 7 mm</td>
<td>100 µH</td>
</tr>
<tr>
<td>R1</td>
<td>Resistor</td>
<td>Vishay CRCW08051153F</td>
<td>0805</td>
<td>115 kΩ</td>
</tr>
<tr>
<td>R2, 3</td>
<td>Resistor</td>
<td>Vishay CRCW08053011F</td>
<td>0805</td>
<td>3.01 kΩ</td>
</tr>
<tr>
<td>R4</td>
<td>Resistor</td>
<td>Vishay CRCW2010000Z</td>
<td>2010</td>
<td>0 Ω</td>
</tr>
<tr>
<td>R5</td>
<td>Resistor</td>
<td>Vishay CRCW08052003F</td>
<td>0805</td>
<td>200 kΩ</td>
</tr>
<tr>
<td>R6</td>
<td>Resistor</td>
<td>Vishay CRCW08051213F</td>
<td>0805</td>
<td>121 kΩ</td>
</tr>
<tr>
<td>U1</td>
<td>Switching Regulator</td>
<td>LM25007</td>
<td>VSSOP-8</td>
<td></td>
</tr>
</tbody>
</table>
8  Circuit Performance

![Figure 6. Efficiency vs Load Current](image1)

![Figure 7. Efficiency vs Input Voltage](image2)
Figure 8. Output Voltage Ripple

Figure 9. Switching Frequency vs. Load Current
Figure 10. Board Silkscreen

Figure 11. Board Top Layer
Figure 12. Board Bottom Layer (viewed from top)
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio
Amplifiers
Data Converters
DLP® Products
DSP
Clocks and Timers
Interface
Logic
Power Mgmt
Microcontrollers
RFID
OMAP Applications Processors
Wireless Connectivity

Applications

Automotive and Transportation
Communications and Telecom
Computers and Peripherals
Consumer Electronics
Energy and Lighting
Industrial
Medical
Security
Space, Avionics and Defense
Video and Imaging
TI E2E Community

www.ti.com/audio
amplifier.ti.com
dataconverter.ti.com
www.dlp.com
dsp.ti.com
www.ti.com/clocks
interface.ti.com
logic.ti.com
power.ti.com
microcontroller.ti.com
www.ti-rfid.com
www.ti.com/omap
www.ti.com/wirelessconnectivity

www.ti.com/automotive
www.ti.com/communications
www.ti.com/computers
www.ti.com/consumer-apps
www.ti.com/energy
www.ti.com/industrial
www.ti.com/medical
www.ti.com/security
www.ti.com/space-avionics-defense
www.ti.com/video
www.ti-rfid.com
e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2013, Texas Instruments Incorporated