

## LM2735

# 520kHz/1.6MHz – Space-Efficient Boost and SEPIC DC-DC Regulator

### General Description

The LM2735 is an easy-to-use, space-efficient 2.1A low-side switch regulator ideal for Boost and SEPIC DC-DC regulation. It provides all the active functions to provide local DC/DC conversion with fast-transient response and accurate regulation in the smallest PCB area. Switching frequency is internally set to either 520kHz or 1.6MHz, allowing the use of extremely small surface mount inductor and chip capacitors while providing efficiencies up to 90%. Current-mode control and internal compensation provide ease-of-use, minimal component count, and high-performance regulation over a wide range of operating conditions. External shutdown features an ultra-low standby current of 80 nA ideal for portable applications. Tiny SOT23-5, LLP-6, and eMSOP-8 packages provide space-savings. Additional features include internal soft-start, circuitry to reduce inrush current, pulse-by-pulse current limit, and thermal shutdown.

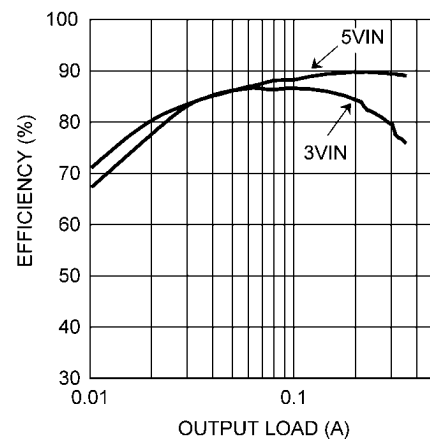
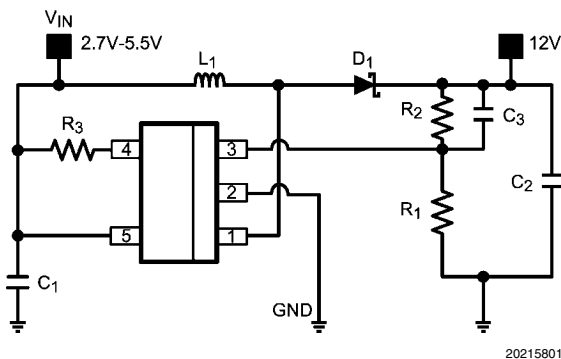
### Features

- Input voltage range 2.7V to 5.5V
  - Output voltage range 3V to 24V
  - 2.1A switch current over full temperature range
  - Current-Mode control
  - Logic high enable pin
  - Ultra low standby current of 80 nA in shutdown
  - 170 mΩ NMOS switch
  - $\pm 2\%$  feedback voltage accuracy
  - Ease-of-use, small total solution size
    - Internal soft-start
    - Internal compensation
    - Two switching frequencies
    - 520 kHz (LM2735-Y)
    - 1.6 MHz (LM2735-X)
- Uses small surface mount inductors and chip capacitors  
Tiny SOT23-5, LLP-6, and eMSOP-8 packages

### Applications

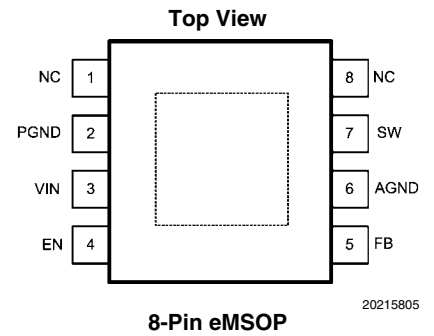
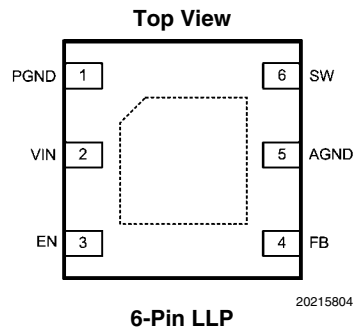
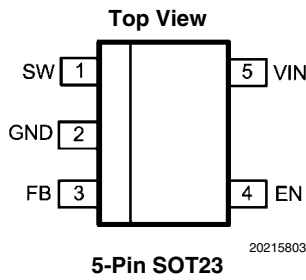
- LCD Display Backlighting For Portable Applications
- OLED Panel Power Supply
- USB Powered Devices
- Digital Still and Video Cameras
- White LED Current Source
- Automotive

### Typical Boost Application Circuit



Efficiency vs Load Current  $V_O = 12V$

## Connection Diagrams



## Ordering Information

| Order Number | Description | Package Type | Package Drawing | Supplied As            | Features                                                      |
|--------------|-------------|--------------|-----------------|------------------------|---------------------------------------------------------------|
| LM2735YMF    | 520kHz      | SOT23-5      | MF05A           | 1000 units tape & reel |                                                               |
| LM2735YMFx   |             |              |                 | 3000 units tape & reel |                                                               |
| LM2735YSD    |             | LLP-6        | SDE06A          | 1000 units tape & reel |                                                               |
| LM2735YSDx   |             |              |                 | 4500 units tape & reel |                                                               |
| LM2735YMY    |             | eMSOP-8      | MUY08A          | 1000 units tape & reel |                                                               |
| LM2735MYx    |             |              |                 | 3500 units tape & reel |                                                               |
| LM2735XMF    | 1.6MHz      | SOT23-5      | MF05A           | 1000 units tape & reel |                                                               |
| LM2735XMFx   |             |              |                 | 3000 units tape & reel |                                                               |
| LM2735XQMF   |             |              |                 | 1000 units tape & reel | AEC-Q100 Grade 1 qualified. Automotive Grade Production Flow* |
| LM2735XQMFx  |             |              |                 | 3000 units tape & reel |                                                               |
| LM2735XSD    |             | LLP-6        | SDE06A          | 1000 units tape & reel |                                                               |
| LM2735XSDx   |             |              |                 | 4500 units tape & reel |                                                               |
| LM2735XMY    |             | eMSOP-8      | MUY08A          | 1000 units tape & reel |                                                               |
| LM2735MYx    |             |              |                 | 3500 units tape & reel |                                                               |

\*Automotive Grade (Q) product incorporates enhanced manufacturing and support processes for the automotive market, including defect detection methodologies. Reliability qualification is compliant with the requirements and temperature grades defined in the AEC-Q100 standard. Automotive grade products are identified with the letter Q. For more information go to <http://www.national.com/automotive>.

## Pin Descriptions - 5-Pin SOT23

| Pin | Name | Function                                                                                                            |
|-----|------|---------------------------------------------------------------------------------------------------------------------|
| 1   | SW   | Output switch. Connect to the inductor, output diode.                                                               |
| 2   | GND  | Signal and power ground pin. Place the bottom resistor of the feedback network as close as possible to this pin.    |
| 3   | FB   | Feedback pin. Connect FB to external resistor divider to set output voltage.                                        |
| 4   | EN   | Shutdown control input. Logic high enables operation. Do not allow this pin to float or be greater than VIN + 0.3V. |
| 5   | VIN  | Supply voltage for power stage, and input supply voltage.                                                           |

## Pin Descriptions - 6-Pin LLP

| Pin | Name | Function                                                                                                            |
|-----|------|---------------------------------------------------------------------------------------------------------------------|
| 1   | PGND | Power ground pin. Place PGND and output capacitor GND close together.                                               |
| 2   | VIN  | Supply voltage for power stage, and input supply voltage.                                                           |
| 3   | EN   | Shutdown control input. Logic high enables operation. Do not allow this pin to float or be greater than VIN + 0.3V. |
| 4   | FB   | Feedback pin. Connect FB to external resistor divider to set output voltage.                                        |
| 5   | AGND | Signal ground pin. Place the bottom resistor of the feedback network as close as possible to this pin & pin 4.      |
| 6   | SW   | Output switch. Connect to the inductor, output diode.                                                               |
| DAP | GND  | Signal & Power ground. Connect to pin 1 & pin 5 on top layer. Place 4-6 vias from DAP to bottom layer GND plane.    |

## Pin Descriptions - 8-Pin eMSOP

| Pin | Name | Function                                                                                                            |
|-----|------|---------------------------------------------------------------------------------------------------------------------|
| 1   |      | No Connect                                                                                                          |
| 2   | PGND | Power ground pin. Place PGND and output capacitor GND close together.                                               |
| 3   | VIN  | Supply voltage for power stage, and input supply voltage.                                                           |
| 4   | EN   | Shutdown control input. Logic high enables operation. Do not allow this pin to float or be greater than VIN + 0.3V. |
| 5   | FB   | Feedback pin. Connect FB to external resistor divider to set output voltage.                                        |
| 6   | AGND | Signal ground pin. Place the bottom resistor of the feedback network as close as possible to this pin & pin 5       |
| 7   | SW   | Output switch. Connect to the inductor, output diode.                                                               |
| 8   |      | No Connect                                                                                                          |
| DAP | GND  | Signal & Power ground. Connect to pin 2 & pin 6 on top layer. Place 4-6 vias from DAP to bottom layer GND plane.    |

**Absolute Maximum Ratings** (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

|                               |                |
|-------------------------------|----------------|
| $V_{IN}$                      | -0.5V to 7V    |
| SW Voltage                    | -0.5V to 26.5V |
| FB Voltage                    | -0.5V to 3.0V  |
| EN Voltage                    | -0.5V to 7.0V  |
| ESD Susceptibility (Note 4)   | 2kV            |
| Junction Temperature (Note 2) | 150°C          |
| Storage Temp. Range           | -65°C to 150°C |

## Soldering Information

Infrared/Convection Reflow (15sec)

220°C

**Operating Ratings** (Note 1)

|                                         |                 |
|-----------------------------------------|-----------------|
| $V_{IN}$                                | 2.7V to 5.5V    |
| $V_{SW}$                                | 3V to 24V       |
| $V_{EN}$ (Note 5)                       | 0V to $V_{IN}$  |
| Junction Temperature Range              | -40°C to +125°C |
| Power Dissipation<br>(Internal) SOT23-5 | 400 mW          |

**Electrical Characteristics**

Limits in standard type are for  $T_J = 25^\circ\text{C}$  only; limits in **boldface type** apply over the junction temperature range of ( $T_J = -40^\circ\text{C}$  to  $125^\circ\text{C}$ ). Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at  $T_J = 25^\circ\text{C}$ , and are provided for reference purposes only.  $V_{IN} = 5\text{V}$  unless otherwise indicated under the Conditions column.

| Symbol                 | Parameter                        | Conditions                                                     | Min          | Typ   | Max          | Units            |
|------------------------|----------------------------------|----------------------------------------------------------------|--------------|-------|--------------|------------------|
| $V_{FB}$               | Feedback Voltage                 | $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (SOT23-5) | <b>1.230</b> | 1.255 | <b>1.280</b> | V                |
|                        |                                  | $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (SOT23-5)   | <b>1.236</b> | 1.255 | <b>1.274</b> |                  |
|                        |                                  | $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (LLP-6)   | <b>1.225</b> | 1.255 | <b>1.285</b> |                  |
|                        |                                  | $-0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (LLP-6)    | <b>1.229</b> | 1.255 | <b>1.281</b> |                  |
|                        |                                  | $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (eMSOP-8) | <b>1.220</b> | 1.255 | <b>1.290</b> |                  |
|                        |                                  | $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (eMSOP-8)   | <b>1.230</b> | 1.255 | <b>1.280</b> |                  |
| $\Delta V_{FB}/V_{IN}$ | Feedback Voltage Line Regulation | $V_{IN} = 2.7\text{V}$ to $5.5\text{V}$                        |              | 0.06  |              | %/V              |
| $I_{FB}$               | Feedback Input Bias Current      |                                                                |              | 0.1   | <b>1</b>     | $\mu\text{A}$    |
| $F_{SW}$               | Switching Frequency              | LM2735-X                                                       | <b>1200</b>  | 1600  | <b>2000</b>  | kHz              |
|                        |                                  | LM2735-Y                                                       | <b>360</b>   | 520   | <b>680</b>   |                  |
| $D_{MAX}$              | Maximum Duty Cycle               | LM2735-X                                                       | <b>88</b>    | 96    |              | %                |
|                        |                                  | LM2735-Y                                                       | <b>91</b>    | 99    |              |                  |
| $D_{MIN}$              | Minimum Duty Cycle               | LM2735-X                                                       |              | 5     |              | %                |
|                        |                                  | LM2735-Y                                                       |              | 2     |              |                  |
| $R_{DS(ON)}$           | Switch On Resistance             | SOT23-5 and eMSOP-8                                            |              | 170   | <b>330</b>   | $\text{m}\Omega$ |
|                        |                                  | LLP-6                                                          |              | 190   | <b>350</b>   |                  |
| $I_{CL}$               | Switch Current Limit             |                                                                | <b>2.1</b>   | 3     |              | A                |
| SS                     | Soft Start                       |                                                                |              | 4     |              | ms               |
| $I_Q$                  | Quiescent Current (switching)    | LM2735-X                                                       |              | 7.0   | <b>11</b>    | mA               |
|                        |                                  | LM2735-Y                                                       |              | 3.4   | <b>7</b>     |                  |
|                        | Quiescent Current (shutdown)     | All Options $V_{EN} = 0\text{V}$                               |              | 80    |              | nA               |
| UVLO                   | Undervoltage Lockout             | VIN Rising                                                     |              | 2.3   | <b>2.65</b>  | V                |
|                        |                                  | VIN Falling                                                    | <b>1.7</b>   | 1.9   |              |                  |
| $V_{EN\_TH}$           | Shutdown Threshold Voltage       | (Note 5)                                                       |              |       | <b>0.4</b>   | V                |
|                        | Enable Threshold Voltage         | (Note 5)                                                       | <b>1.8</b>   |       |              |                  |
| $I_{SW}$               | Switch Leakage                   | $V_{SW} = 24\text{V}$                                          |              | 1.0   |              | $\mu\text{A}$    |
| $I_{EN}$               | Enable Pin Current               | Sink/Source                                                    |              | 100   |              | nA               |

| Symbol        | Parameter                                       | Conditions                | Min | Typ | Max | Units |
|---------------|-------------------------------------------------|---------------------------|-----|-----|-----|-------|
| $\theta_{JA}$ | Junction to Ambient<br>0 LFPM Air Flow (Note 3) | LLP-6 and eMSOP-8 Package |     | 80  |     | °C/W  |
|               |                                                 | SOT23-5 Package           |     | 118 |     |       |
| $\theta_{JC}$ | Junction to Case (Note 3)                       | LLP-6 and eMSOP-8 Package |     | 18  |     | °C/W  |
|               |                                                 | SOT23-5 Package           |     | 60  |     |       |
| $T_{SD}$      | Thermal Shutdown Temperature (Note 2)           |                           |     | 160 |     | °C    |
|               | Thermal Shutdown Hysteresis                     |                           |     | 10  |     |       |

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see Electrical Characteristics.

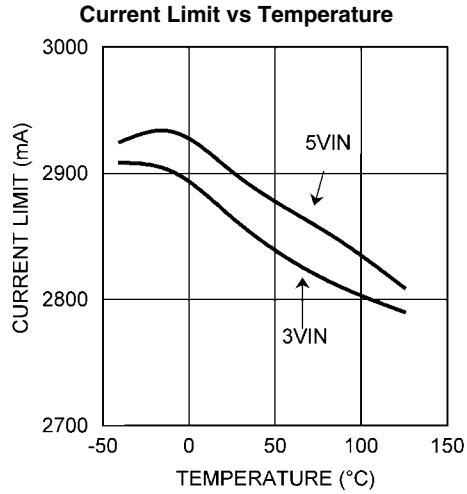
**Note 2:** Thermal shutdown will occur if the junction temperature exceeds the maximum junction temperature of the device

**Note 3:** Applies for packages soldered directly onto a 3" x 3" PC board with 2oz. copper on 4 layers in still air.

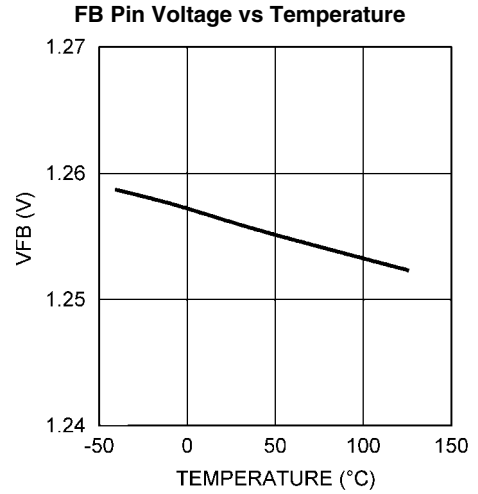
**Note 4:** The human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin.

**Note 5:** Do not allow this pin to float or be greater than  $V_{IN} + 0.3V$ .

## Typical Performance Characteristics

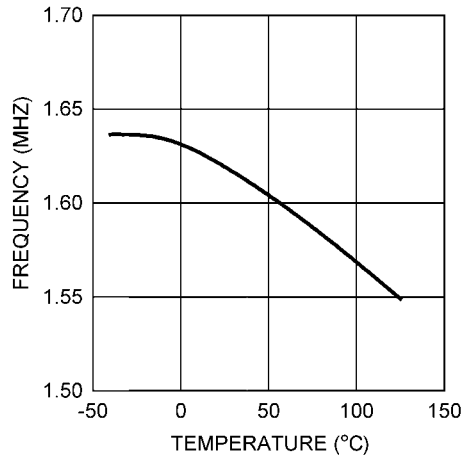


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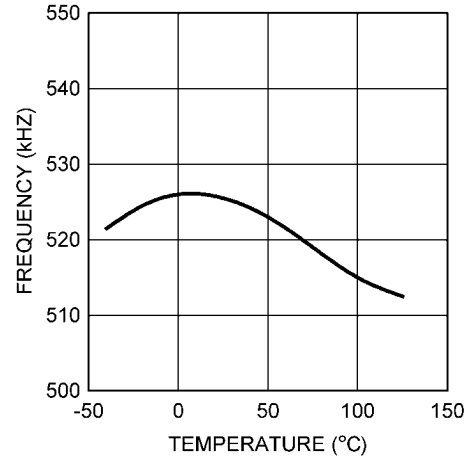
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**Oscillator Frequency vs Temperature - "X"**



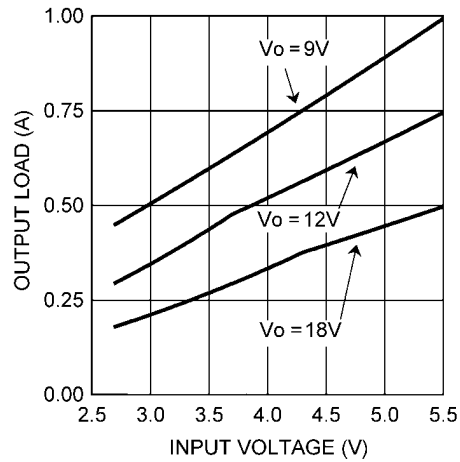
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**Oscillator Frequency vs Temperature - "Y"**



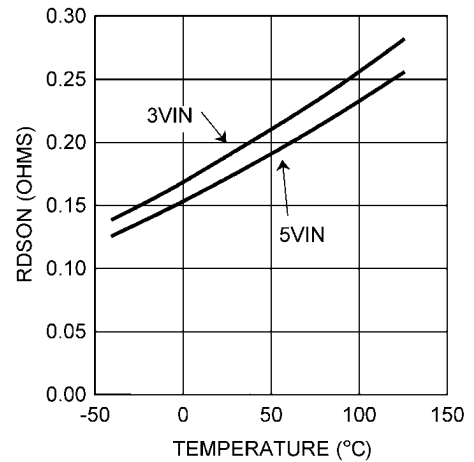
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**Typical Maximum Output Current vs  $V_{IN}$**

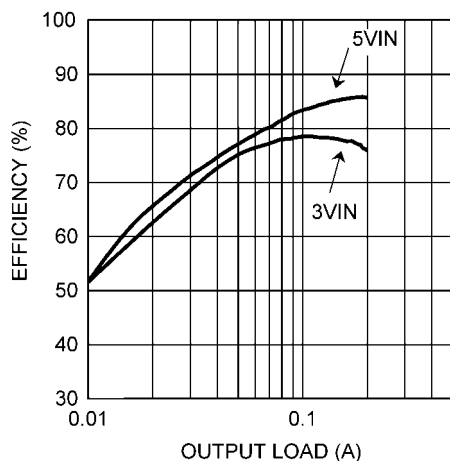


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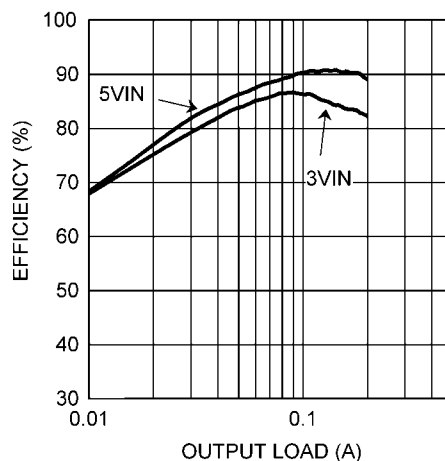
**$R_{DS(on)}$  vs Temperature**



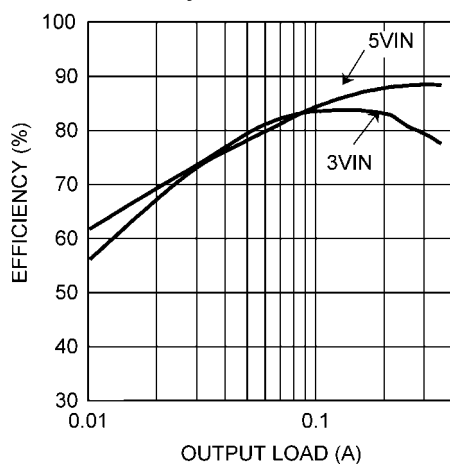
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LM2735X Efficiency vs Load Current,  $V_o = 20V$ 

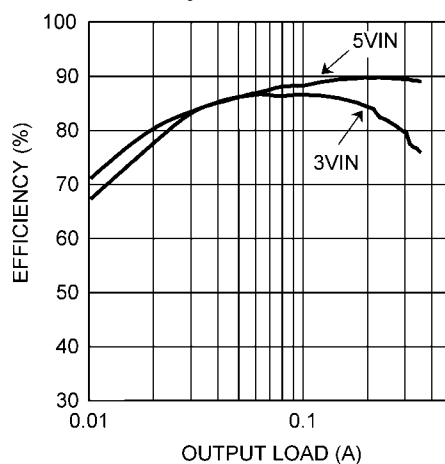
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LM2735Y Efficiency vs Load Current,  $V_o = 20V$ 

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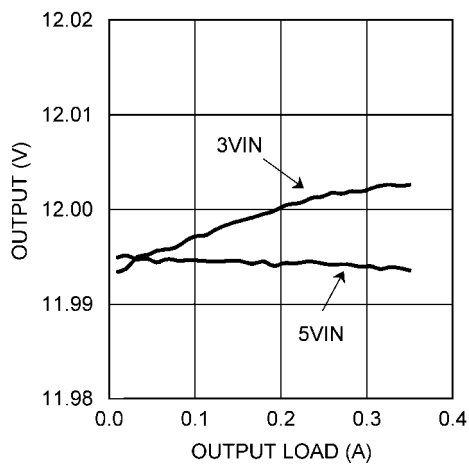
LM2735X Efficiency vs Load Current,  $V_o = 12V$ 

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LM2735Y Efficiency vs Load Current,  $V_o = 12V$ 

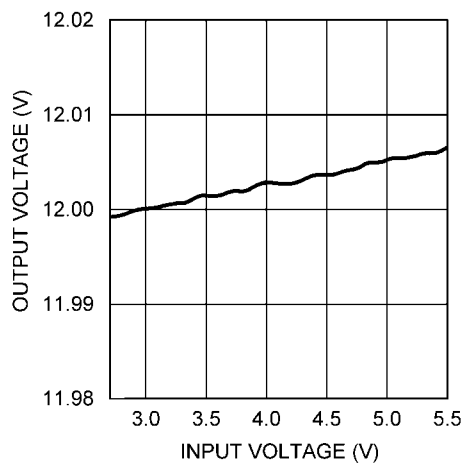
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Output Voltage Load Regulation



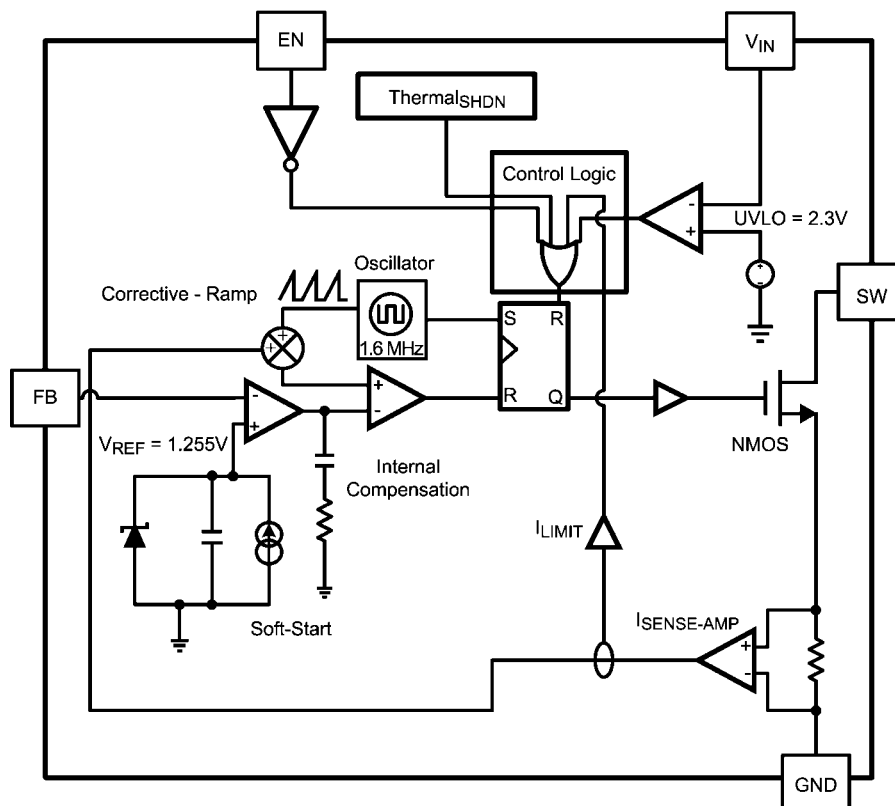
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Output Voltage Line Regulation



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## Simplified Internal Block Diagram



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FIGURE 1. Simplified Block Diagram

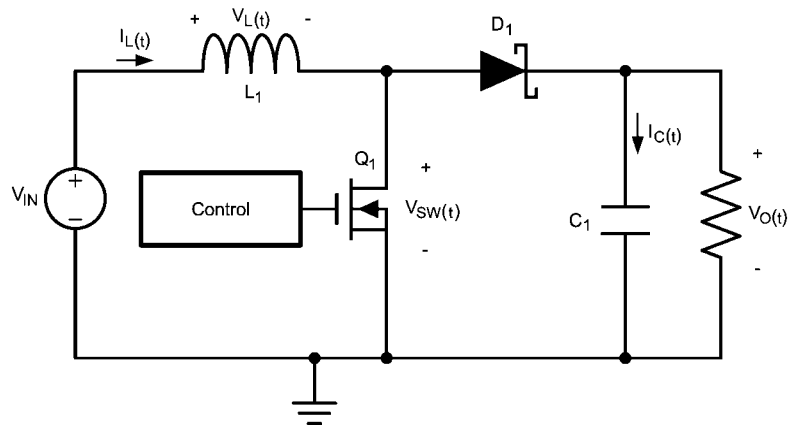
## Application Information

### THEORY OF OPERATION

The LM2735 is a constant frequency PWM boost regulator IC that delivers a minimum of 2.1A peak switch current. The regulator has a preset switching frequency of either 520 kHz or 1.60 MHz. This high frequency allows the LM2735 to operate with small surface mount capacitors and inductors, resulting in a DC/DC converter that requires a minimum amount of board space. The LM2735 is internally compensated, so it is simple to use, and requires few external components. The LM2735 uses current-mode control to regulate the output voltage. The following operating description of the LM2735 will refer to the Simplified Block Diagram (Figure 1) the simplified schematic (Figure 2), and its associated waveforms (Figure 3). The LM2735 supplies a regulated output voltage by switching the internal NMOS control switch at constant frequency and variable duty cycle. A switching cycle begins

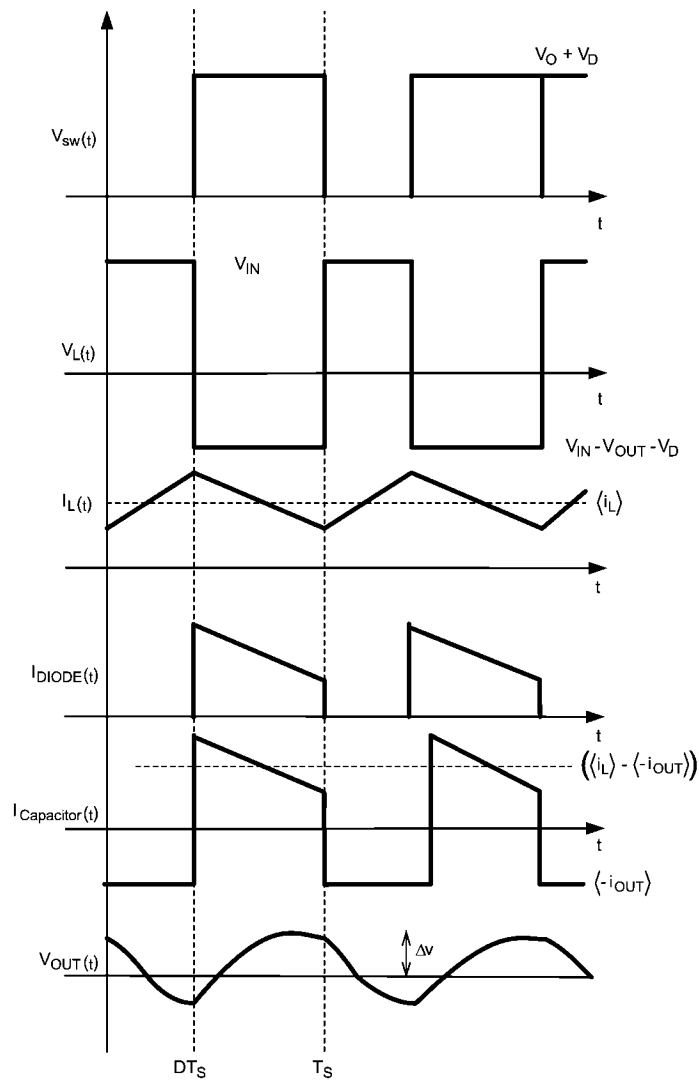
at the falling edge of the reset pulse generated by the internal oscillator. When this pulse goes low, the output control logic turns on the internal NMOS control switch. During this on-time, the SW pin voltage ( $V_{SW}$ ) decreases to approximately GND, and the inductor current ( $I_L$ ) increases with a linear slope.  $I_L$  is measured by the current sense amplifier, which generates an output proportional to the switch current. The sensed signal is summed with the regulator's corrective ramp and compared to the error amplifier's output, which is proportional to the difference between the feedback voltage and  $V_{REF}$ . When the PWM comparator output goes high, the output switch turns off until the next switching cycle begins. During the switch off-time, inductor current discharges through diode D1, which forces the SW pin to swing to the output voltage plus the forward voltage ( $V_D$ ) of the diode. The regulator loop adjusts the duty cycle (D) to maintain a constant output voltage.





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FIGURE 2. Simplified Schematic



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FIGURE 3. Typical Waveforms

## CURRENT LIMIT

The LM2735 uses cycle-by-cycle current limiting to protect the internal NMOS switch. It is important to note that this current limit will not protect the output from excessive current during an output short circuit. The input supply is connected to the output by the series connection of an inductor and a diode. If a short circuit is placed on the output, excessive current can damage both the inductor and diode.

## Design Guide

### ENABLE PIN / SHUTDOWN MODE

The LM2735 has a shutdown mode that is controlled by the Enable pin (EN). When a logic low voltage is applied to EN, the part is in shutdown mode and its quiescent current drops to typically 80 nA. Switch leakage adds up to another 1  $\mu$ A from the input supply. The voltage at this pin should never exceed  $V_{IN} + 0.3V$ .

### THERMAL SHUTDOWN

Thermal shutdown limits total power dissipation by turning off the output switch when the IC junction temperature exceeds 160°C. After thermal shutdown occurs, the output switch doesn't turn on until the junction temperature drops to approximately 150°C.

### SOFT-START

This function forces  $V_{OUT}$  to increase at a controlled rate during start up. During soft-start, the error amplifier's reference voltage ramps to its nominal value of 1.255V in approximately 4.0ms. This forces the regulator output to ramp up in a more linear and controlled fashion, which helps reduce inrush current.

### INDUCTOR SELECTION

The Duty Cycle (D) can be approximated quickly using the ratio of output voltage ( $V_O$ ) to input voltage ( $V_{IN}$ ):

$$\frac{V_{OUT}}{V_{IN}} = \left( \frac{1}{1-D} \right) = \frac{1}{D'}$$

Therefore:

$$D = \frac{V_{OUT} - V_{IN}}{V_{OUT}}$$

Power losses due to the diode (D1) forward voltage drop, the voltage drop across the internal NMOS switch, the voltage drop across the inductor resistance ( $R_{DCR}$ ) and switching losses must be included to calculate a more accurate duty cycle (See Calculating Efficiency and Junction Temperature for a detailed explanation). A more accurate formula for calculating the conversion ratio is:

$$\frac{V_{OUT}}{V_{IN}} = \frac{\eta}{D}$$

Where  $\eta$  equals the efficiency of the LM2735 application.

The inductor value determines the input ripple current. Lower inductor values decrease the size of the inductor, but increase the input ripple current. An increase in the inductor value will decrease the input ripple current.

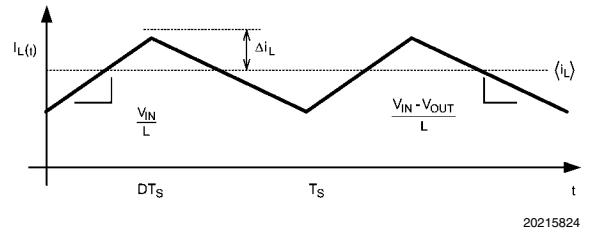


FIGURE 4. Inductor Current

$$\frac{2\Delta i_L}{DT_S} = \left( \frac{V_{IN}}{L} \right)$$

$$\Delta i_L = \left( \frac{V_{IN}}{2L} \right) \times DT_S$$

A good design practice is to design the inductor to produce 10% to 30% ripple of maximum load. From the previous equations, the inductor value is then obtained.

$$L = \left( \frac{V_{IN}}{2 \times \Delta i_L} \right) \times DT_S$$

Where:  $1/T_S = F_{SW}$  = switching frequency

One must also ensure that the minimum current limit (2.1A) is not exceeded, so the peak current in the inductor must be calculated. The peak current ( $I_{LPK}$ ) in the inductor is calculated by:

$$I_{LPK} = I_{IN} + \Delta i_L$$

or

$$I_{LPK} = I_{OUT} / D' + \Delta i_L$$

When selecting an inductor, make sure that it is capable of supporting the peak input current without saturating. Inductor saturation will result in a sudden reduction in inductance and prevent the regulator from operating correctly. Because of the speed of the internal current limit, the peak current of the inductor need only be specified for the required maximum input current. For example, if the designed maximum input current is 1.5A and the peak current is 1.75A, then the inductor should be specified with a saturation current limit of >1.75A. There is no need to specify the saturation or peak current of the inductor at the 3A typical switch current limit.

Because of the operating frequency of the LM2735, ferrite based inductors are preferred to minimize core losses. This presents little restriction since the variety of ferrite-based inductors is huge. Lastly, inductors with lower series resistance (DCR) will provide better operating efficiency. For recommended inductors see Example Circuits.

### INPUT CAPACITOR

An input capacitor is necessary to ensure that  $V_{IN}$  does not drop excessively during switching transients. The primary specifications of the input capacitor are capacitance, voltage, RMS current rating, and ESL (Equivalent Series Inductance). The recommended input capacitance is 10  $\mu$ F to 44  $\mu$ F depending on the application. The capacitor manufacturer specifically states the input voltage rating. Make sure to check any recommended deratings and also verify if there is any

significant change in capacitance at the operating input voltage and the operating temperature. The ESL of an input capacitor is usually determined by the effective cross sectional area of the current path. At the operating frequencies of the LM2735, certain capacitors may have an ESL so large that the resulting impedance ( $2\pi fL$ ) will be higher than that required to provide stable operation. As a result, surface mount capacitors are strongly recommended. Multilayer ceramic capacitors (MLCC) are good choices for both input and output capacitors and have very low ESL. For MLCCs it is recommended to use X7R or X5R dielectrics. Consult capacitor manufacturer datasheet to see how rated capacitance varies over operating conditions.

### OUTPUT CAPACITOR

The LM2735 operates at frequencies allowing the use of ceramic output capacitors without compromising transient response. Ceramic capacitors allow higher inductor ripple without significantly increasing output ripple. The output capacitor is selected based upon the desired output ripple and transient response. The initial current of a load transient is provided mainly by the output capacitor. The output impedance will therefore determine the maximum voltage perturbation. The output ripple of the converter is a function of the capacitor's reactance and its equivalent series resistance (ESR):

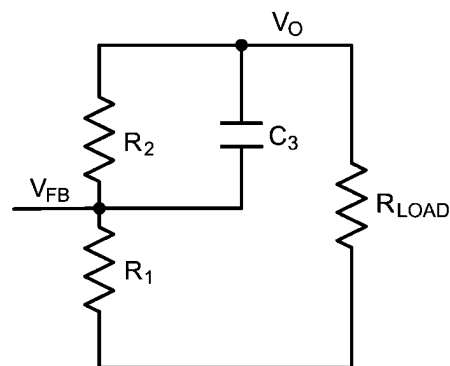
$$\Delta V_{OUT} = \Delta I_L \times R_{ESR} + \left( \frac{V_{OUT} \times D}{2 \times f_{SW} \times R_{LOAD} \times C_{OUT}} \right)$$

When using MLCCs, the ESR is typically so low that the capacitive ripple may dominate. When this occurs, the output ripple will be approximately sinusoidal and 90° phase shifted from the switching action.

Given the availability and quality of MLCCs and the expected output voltage of designs using the LM2735, there is really no need to review any other capacitor technologies. Another benefit of ceramic capacitors is their ability to bypass high frequency noise. A certain amount of switching edge noise will couple through parasitic capacitances in the inductor to the output. A ceramic capacitor will bypass this noise while a tantalum will not. Since the output capacitor is one of the two external components that control the stability of the regulator control loop, most applications will require a minimum at 4.7  $\mu F$  of output capacitance. Like the input capacitor, recommended multilayer ceramic capacitors are X7R or X5R. Again, verify actual capacitance at the desired operating voltage and temperature.

### SETTING THE OUTPUT VOLTAGE

The output voltage is set using the following equation where R1 is connected between the FB pin and GND, and R2 is connected between  $V_{OUT}$  and the FB pin.



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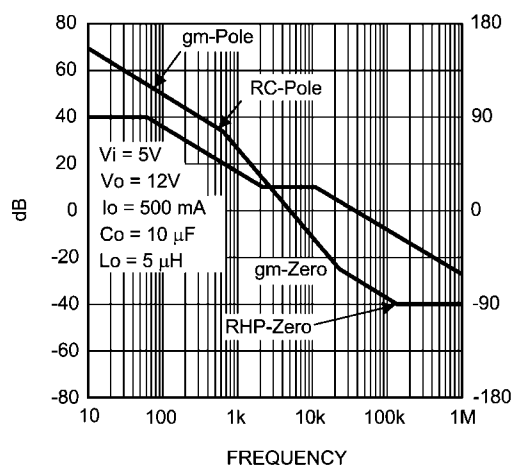
FIGURE 5. Setting Vout

A good value for R1 is 10k $\Omega$ .

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

### COMPENSATION

The LM2735 uses constant frequency peak current mode control. This mode of control allows for a simple external compensation scheme that can be optimized for each application. A complicated mathematical analysis can be completed to fully explain the LM2735's internal & external compensation, but for simplicity, a graphical approach with simple equations will be used. Below is a Gain & Phase plot of a LM2735 that produces a 12V output from a 5V input voltage. The Bode plot shows the total loop Gain & Phase without external compensation.



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FIGURE 6. LM2735 Without External Compensation

One can see that the Crossover frequency is fine, but the phase margin at 0dB is very low (22°). A zero can be placed just above the crossover frequency so that the phase margin will be bumped up to a minimum of 45°. Below is the same application with a zero added at 8 kHz.

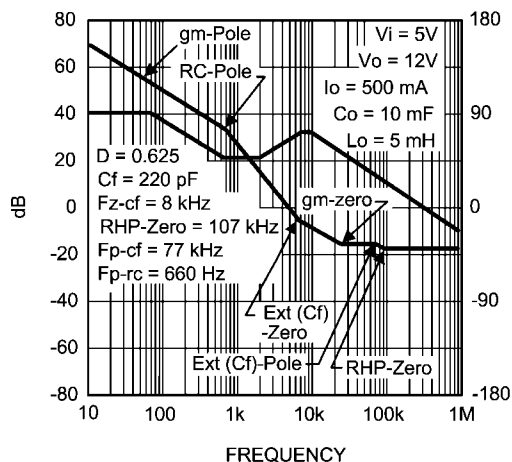


FIGURE 7. LM2735 With External Compensation

The simplest method to determine the compensation component value is as follows.

Set the output voltage with the following equation.

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

Where R1 is the bottom resistor and R2 is the resistor tied to the output voltage. The next step is to calculate the value of C3. The internal compensation has been designed so that when a zero is added between 5 kHz & 10 kHz the converter will have good transient response with plenty of phase margin for all input & output voltage combinations.

$$F_{ZERO-CF} = \frac{1}{2\pi(R_2 \times C_f)} = 5 \text{ kHz} \rightarrow 10 \text{ kHz}$$

Lower output voltages will have the zero set closer to 10 kHz, and higher output voltages will usually have the zero set closer to 5 kHz. It is always recommended to obtain a Gain/Phase plot for your actual application. One could refer to the Typical applications section to obtain examples of working applications and the associated component values.

Pole @ origin due to internal gm amplifier:

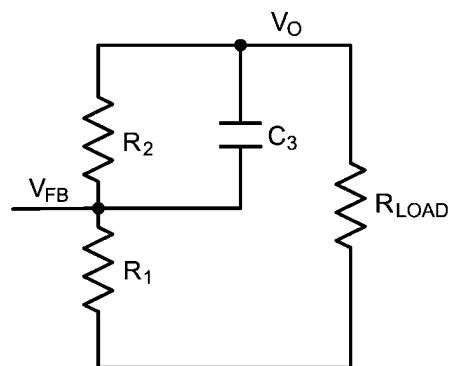
$$F_{P-ORIGIN}$$

Pole due to output load and capacitor:

$$F_{P-RC} = \frac{1}{2\pi(R_{LOAD}C_{OUT})}$$

This equation only determines the frequency of the pole for perfect current mode control (CMC). I.e., it doesn't take into account the additional internal artificial ramp that is added to the current signal for stability reasons. By adding artificial ramp, you begin to move away from CMC to voltage mode control (VMC). The artifact is that the pole due to the output load and output capacitor will actually be slightly higher in frequency than calculated. In this example it is calculated at 650 Hz, but in reality it is around 1 kHz.

The zero created with capacitor C3 & resistor R2:



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FIGURE 8. Setting External Pole-Zero

$$F_{ZERO-CF} = \frac{1}{2\pi(R_2 \times C_3)}$$

There is an associated pole with the zero that was created in the above equation.

$$F_{POLE-CF} = \frac{1}{2\pi((R_1 \parallel R_2) \times C_3)}$$

It is always higher in frequency than the zero.

A right-half plane zero (RHPZ) is inherent to all boost converters. One must remember that the gain associated with a right-half plane zero increases at 20dB per decade, but the phase decreases by 45° per decade. For most applications there is little concern with the RHPZ due to the fact that the frequency at which it shows up is well beyond crossover, and has little to no effect on loop stability. One must be concerned with this condition for large inductor values and high output currents.

$$RHP_{ZERO} = \frac{(D')^2 R_{LOAD}}{2\pi \times L}$$

There are miscellaneous poles and zeros associated with parasitics internal to the LM2735, external components, and the PCB. They are located well over the crossover frequency, and for simplicity are not discussed.

## PCB Layout Considerations

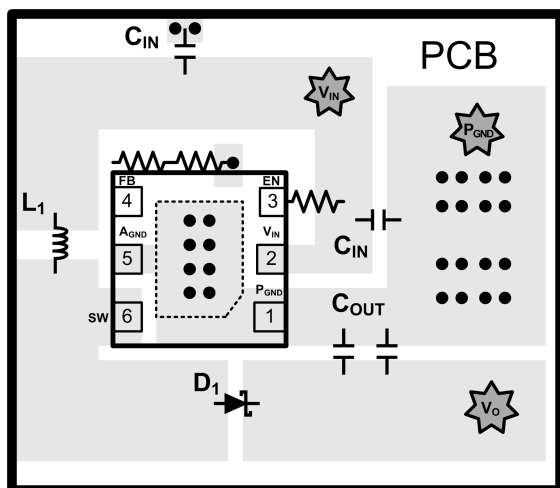
When planning layout there are a few things to consider when trying to achieve a clean, regulated output. The most important consideration when completing a Boost Converter layout is the close coupling of the GND connections of the C<sub>OUT</sub> capacitor and the LM2735 PGND pin. The GND ends should be close to one another and be connected to the GND plane with at least two through-holes. There should be a continuous ground plane on the bottom layer of a two-layer board except under the switching node island. The FB pin is a high impedance node and care should be taken to make the FB trace short to avoid noise pickup and inaccurate regulation. The feedback resistors should be placed as close as possible to the IC, with the AGND of R1 placed as close as possible to the GND (pin 5 for the LLP) of the IC. The V<sub>OUT</sub> trace to R2 should be routed away from the inductor and any other traces that are switching. High AC currents flow through the V<sub>IN</sub>, SW

and  $V_{OUT}$  traces, so they should be as short and wide as possible. However, making the traces wide increases radiated noise, so the designer must make this trade-off. Radiated noise can be decreased by choosing a shielded inductor. The remaining components should also be placed as close as possible to the IC. Please see Application Note AN-1229 for further considerations and the LM2735 demo board as an example of a four-layer layout.

Below is an example of a good thermal & electrical PCB design. This is very similar to our LM2735 demonstration boards

that are obtainable via the National Semiconductor website. The demonstration board consists of a two layer PCB with a common input and output voltage application. Most of the routing is on the top layer, with the bottom layer consisting of a large ground plane. The placement of the external components satisfies the electrical considerations, and the thermal performance has been improved by adding thermal vias and a top layer "Dog-Bone".

Example of Proper PCB Layout



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FIGURE 9. Boost PCB Layout Guidelines

## Thermal Design

When designing for thermal performance, one must consider many variables:

**Ambient Temperature:** The surrounding maximum air temperature is fairly explanatory. As the temperature increases, the junction temperature will increase. This may not be linear though. As the surrounding air temperature increases, resistances of semiconductors, wires and traces increase. This will decrease the efficiency of the application, and more power will be converted into heat, and will increase the silicon junction temperatures further.

**Forced Airflow:** Forced air can drastically reduce the device junction temperature. Air flow reduces the hot spots within a design. Warm airflow is often much better than a lower ambient temperature with no airflow.

**External Components:** Choose components that are efficient, and you can reduce the mutual heating between devices.

### PCB design with thermal performance in mind:

The PCB design is a very important step in the thermal design procedure. The LM2735 is available in three package options (5 pin SOT23, 8 pin eMSOP & 6 pin LLP). The options are electrically the same, but difference between the packages is size and thermal performance. The LLP and eMSOP have thermal Die Attach Pads (DAP) attached to the bottom of the packages, and are therefore capable of dissipating more heat than the SOT23 package. It is important that the customer choose the correct package for the application. A detailed thermal design procedure has been included in this data sheet. This procedure will help determine which package is correct, and common applications will be analyzed.

There is one significant thermal PCB layout design consideration that contradicts a proper electrical PCB layout design consideration. This contradiction is the placement of external components that dissipate heat. The greatest external heat contributor is the external Schottky diode. It would be nice if you were able to separate by distance the LM2735 from the Schottky diode, and thereby reducing the mutual heating effect. This will however create electrical performance issues. It is important to keep the LM2735, the output capacitor, and Schottky diode physically close to each other (see PCB layout

guidelines). The electrical design considerations outweigh the thermal considerations. Other factors that influence thermal performance are thermal vias, copper weight, and number of board layers.

## Definitions

Heat energy is transferred from regions of high temperature to regions of low temperature via three basic mechanisms: radiation, conduction and convection.

**Radiation:** Electromagnetic transfer of heat between masses at different temperatures.

**Conduction:** Transfer of heat through a solid medium.

**Convection:** Transfer of heat through the medium of a fluid; typically air.

*Conduction & Convection will be the dominant heat transfer mechanism in most applications.*

$R_{\theta JA}$ : Thermal impedance from silicon junction to ambient air temperature.

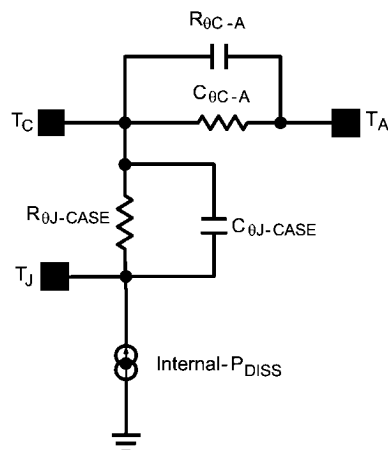
$R_{\theta JC}$ : Thermal impedance from silicon junction to device case temperature.

$C_{\theta JC}$ : Thermal Delay from silicon junction to device case temperature.

$C_{\theta CA}$ : Thermal Delay from device case to ambient air temperature.

$R_{\theta JA}$  &  $R_{\theta JC}$ : These two symbols represent thermal impedances, and most data sheets contain associated values for these two symbols. The units of measurement are  $^{\circ}\text{C}/\text{Watt}$ .

$R_{\theta JA}$  is the sum of smaller thermal impedances (see simplified thermal model below). The capacitors represent delays that are present from the time that power and its associated heat is increased or decreased from steady state in one medium until the time that the heat increase or decrease reaches steady state on the another medium.



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FIGURE 10. Simplified Thermal Impedance Model

The datasheet values for these symbols are given so that one might compare the thermal performance of one package against another. In order to achieve a comparison between packages, all other variables must be held constant in the comparison (PCB size, copper weight, thermal vias, power dissipation,  $V_{IN}$ ,  $V_{OUT}$ , Load Current etc). This does shed light on the package performance, but it would be a mistake to use these values to calculate the actual junction temperature in your application.

$$R_{\theta JA} = \frac{T_J - T_A}{P_{Dissipation}}$$

We will talk more about calculating the variables of this equation later, and how to eventually calculate a proper junction temperature with relative certainty. For now we need to define the process of calculating the junction temperature and clarify some common misconceptions.

$R_{\theta JA}$  [Variables]:

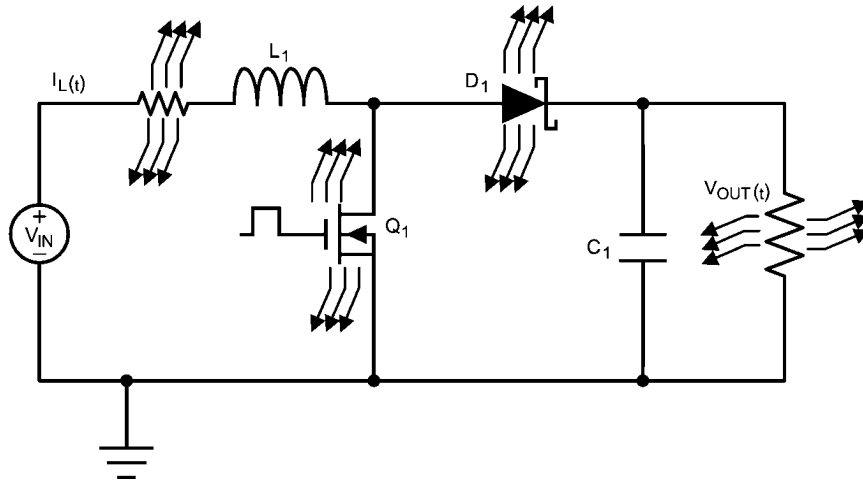
- Input Voltage, Output Voltage, Output Current,  $R_{DS(on)}$ .
- Ambient temperature & air flow.
- Internal & External components power dissipation.
- Package thermal limitations.
- PCB variables (copper weight, thermal via's, layers component placement).

It would be wrong to assume that the top case temperature is the proper temperature when calculating  $R_{\theta JC}$  value. The  $R_{\theta JC}$  value represents the thermal impedance of all six sides of a package, not just the top side. This document will refer to a thermal impedance called  $R_{\Psi JC}$ .  $R_{\Psi JC}$  represents a thermal impedance associated with just the top case temperature. This will allow one to calculate the junction temperature with a thermal sensor connected to the top case.

## LM2735 Thermal Models

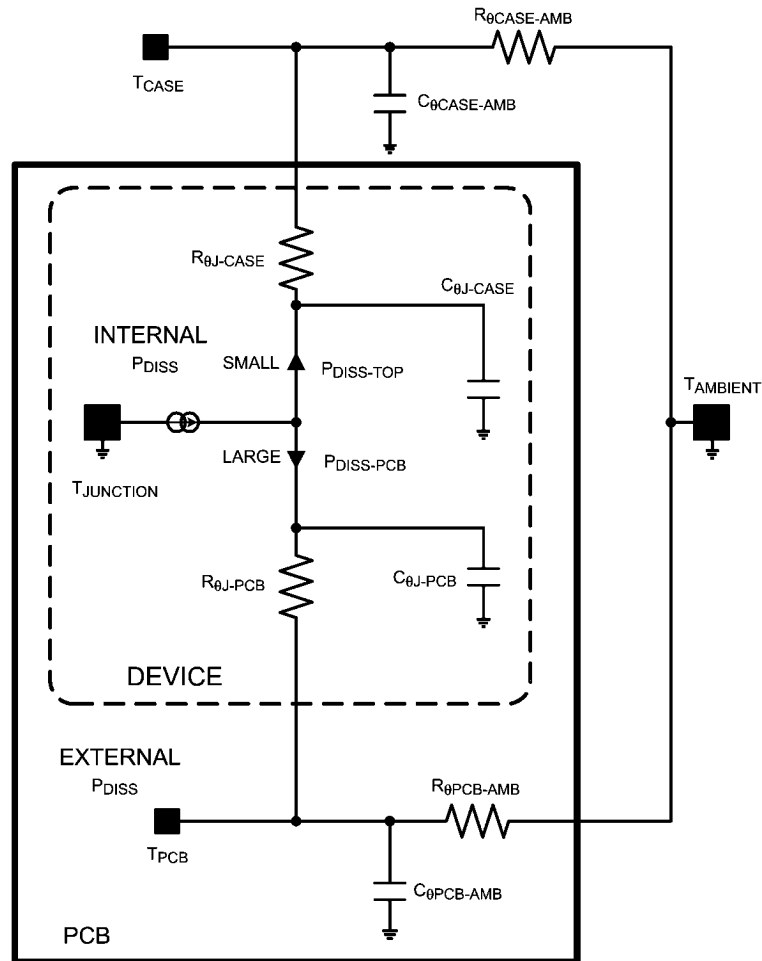
Heat is dissipated from the LM2735 and other devices. The external loss elements include the Schottky diode, inductor,

and loads. All loss elements will mutually increase the heat on the PCB, and therefore increase each other's temperatures.



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FIGURE 11. Thermal Schematic



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FIGURE 12. Associated Thermal Model



## Calculating Efficiency, and Junction Temperature

The complete LM2735 DC/DC converter efficiency ( $\eta$ ) can be calculated in the following manner.

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

or

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Power loss ( $P_{LOSS}$ ) is the sum of two types of losses in the converter, switching and conduction. Conduction losses usually dominate at higher output loads, where as switching losses remain relatively fixed and dominate at lower output loads.

Losses in the LM2735 Device:  $P_{LOSS} = P_{COND} + P_{SW} + P_Q$   
Conversion ratio of the Boost Converter with conduction loss elements inserted:

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{D'} \left( 1 - \frac{D' \times V_D}{V_{IN}} \right) \left( \frac{1}{1 + \frac{R_{DCR} + (D \times R_{DS(on)})}{D'^2 R_{OUT}}} \right)$$

One can see that if the loss elements are reduced to zero, the conversion ratio simplifies to:

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{D'}$$

And we know:

$$\frac{V_{OUT}}{V_{IN}} = \frac{\eta}{D'}$$

Therefore:

$$\eta = D' \frac{V_{OUT}}{V_{IN}} = \left( \frac{1 - \frac{D' \times V_D}{V_{IN}}}{1 + \frac{R_{DCR} + (D \times R_{DS(on)})}{D'^2 R_{OUT}}} \right)$$

Calculations for determining the most significant power losses are discussed below. Other losses totaling less than 2% are not discussed.

A simple efficiency calculation that takes into account the conduction losses is shown below:

$$\eta \approx \left( \frac{1 - \frac{D' \times V_D}{V_{IN}}}{1 + \frac{R_{DCR} + (D \times R_{DS(on)})}{D'^2 R_{OUT}}} \right)$$

The diode, NMOS switch, and inductor DCR losses are included in this calculation. Setting any loss element to zero will simplify the equation.

$V_D$  is the forward voltage drop across the Schottky diode. It can be obtained from the manufacturer's Electrical Characteristics section of the data sheet.

The conduction losses in the diode are calculated as follows:

$$P_{DIODE} = V_D \times I_O$$

Depending on the duty cycle, this can be the single most significant power loss in the circuit. Care should be taken to choose a diode that has a low forward voltage drop. Another concern with diode selection is reverse leakage current. Depending on the ambient temperature and the reverse voltage across the diode, the current being drawn from the output to the NMOS switch during time  $D$  could be significant, this may increase losses internal to the LM2735 and reduce the overall efficiency of the application. Refer to Schottky diode manufacturer's data sheets for reverse leakage specifications, and typical applications within this data sheet for diode selections.

Another significant external power loss is the conduction loss in the input inductor. The power loss within the inductor can be simplified to:

$$P_{IND} = I_{IN}^2 R_{DCR}$$

$$P_{IND} = \left( \frac{I_O^2 R_{DCR}}{D'} \right)$$

The LM2735 conduction loss is mainly associated with the internal NFET:

$$P_{COND-NFET} = I_{SW-rms}^2 \times R_{DS(on)} \times D$$

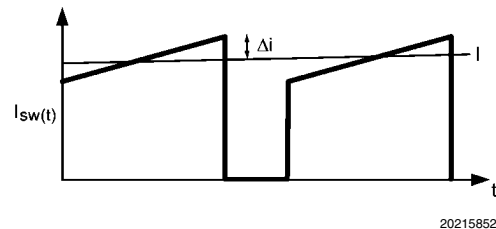


FIGURE 13. LM2735 Switch Current

$$I_{SW-rms} = I_{IND} \sqrt{D} \times \sqrt{1 + \frac{1}{3} \left( \frac{\Delta i}{I_{IND}} \right)^2} \approx I_{IND} \sqrt{D}$$

$$P_{IND} = I_{IN}^2 \times R_{IND-DCR}$$

(small ripple approximation)

$$P_{COND-NFET} = I_{IN}^2 \times R_{DS(on)} \times D$$

$$P_{\text{COND-NFET}} = \left( \frac{I_Q}{D} \right)^2 \times R_{\text{DS(on)}} \times D$$

The value for  $D$  should be equal to the resistance at the junction temperature you wish to analyze. As an example, at 125°C and  $V_{\text{IN}} = 5\text{V}$ ,  $R_{\text{DS(on)}} = 250\text{ m}\Omega$  (See typical graphs for value).

Switching losses are also associated with the internal NMOS switch. They occur during the switch on and off transition periods, where voltages and currents overlap resulting in power loss.

The simplest means to determine this loss is to empirically measuring the rise and fall times (10% to 90%) of the switch at the switch node:

$$P_{\text{SWR}} = 1/2(V_{\text{OUT}} \times I_{\text{IN}} \times F_{\text{SW}} \times T_{\text{RISE}})$$

$$P_{\text{SWF}} = 1/2(V_{\text{OUT}} \times I_{\text{IN}} \times F_{\text{SW}} \times T_{\text{FALL}})$$

$$P_{\text{SW}} = P_{\text{SWR}} + P_{\text{SWF}}$$

**Typical Switch-Node Rise and Fall Times**

| $V_{\text{IN}}$ | $V_{\text{OUT}}$ | $T_{\text{RISE}}$ | $T_{\text{FALL}}$ |
|-----------------|------------------|-------------------|-------------------|
| 3V              | 5V               | 6nS               | 4nS               |
| 5V              | 12V              | 6nS               | 5nS               |
| 3V              | 12V              | 7nS               | 5nS               |
| 5V              | 18V              | 7nS               | 5nS               |

#### Quiescent Power Losses

$I_Q$  is the quiescent operating current, and is typically around 4mA.

$$P_Q = I_Q \times V_{\text{IN}}$$

### Example Efficiency Calculation:

**TABLE 1. Operating Conditions**

|                     |               |
|---------------------|---------------|
| $V_{\text{IN}}$     | 5V            |
| $V_{\text{OUT}}$    | 12V           |
| $I_{\text{OUT}}$    | 500mA         |
| $V_D$               | 0.4V          |
| $F_{\text{SW}}$     | 1.60MHz       |
| $I_Q$               | 4mA           |
| $T_{\text{RISE}}$   | 6nS           |
| $T_{\text{FALL}}$   | 5nS           |
| $R_{\text{DS(on)}}$ | 250m $\Omega$ |
| $R_{\text{DCR}}$    | 50m $\Omega$  |
| $D$                 | 0.64          |
| $I_{\text{IN}}$     | 1.4A          |

$$\Sigma P_{\text{COND}} + P_{\text{SW}} + P_{\text{DIODE}} + P_{\text{IND}} + P_Q = P_{\text{LOSS}}$$

#### Quiescent Power Losses

$$P_Q = I_Q \times V_{\text{IN}} = 20\text{ mW}$$

#### Switching Power Losses

$$P_{\text{SWR}} = 1/2(V_{\text{OUT}} \times I_{\text{IN}} \times F_{\text{SW}} \times T_{\text{RISE}}) \approx 6\text{ ns} \approx 80\text{ mW}$$

$$P_{\text{SWF}} = 1/2(V_{\text{OUT}} \times I_{\text{IN}} \times F_{\text{SW}} \times T_{\text{FALL}}) \approx 5\text{ ns} \approx 70\text{ mW}$$

$$P_{\text{SW}} = P_{\text{SWR}} + P_{\text{SWF}} = 150\text{ mW}$$

#### Internal NFET Power Losses

$$R_{\text{DS(on)}} = 250\text{ m}\Omega$$

$$P_{\text{CONDUCTION}} = I_{\text{IN}}^2 \times D \times R_{\text{DS(on)}} \times 305\text{ mW}$$

#### Diode Losses

$$V_D = 0.45\text{V}$$

$$P_{\text{DIODE}} = V_D \times I_{\text{IN}}(1-D) = 236\text{ mW}$$

#### Inductor Power Losses

$$R_{\text{DCR}} = 75\text{ m}\Omega$$

$$P_{\text{IND}} = I_{\text{IN}}^2 \times R_{\text{DCR}} = 145\text{ mW}$$

#### Total Power Losses are:

**TABLE 2. Power Loss Tabulation**

|                     |               |               |       |
|---------------------|---------------|---------------|-------|
| $V_{\text{IN}}$     | 5V            |               |       |
| $V_{\text{OUT}}$    | 12V           |               |       |
| $I_{\text{OUT}}$    | 500mA         | <b>POUT</b>   | 6W    |
| $V_D$               | 0.4V          | <b>PDIODE</b> | 236mW |
| $F_{\text{SW}}$     | 1.6MHz        |               |       |
| $T_{\text{RISE}}$   | 6nS           | <b>PSWR</b>   | 80mW  |
| $T_{\text{FALL}}$   | 5nS           | <b>PSWF</b>   | 70mW  |
| $I_Q$               | 4mA           | <b>PQ</b>     | 20mW  |
| $R_{\text{DS(on)}}$ | 250m $\Omega$ | <b>PCOND</b>  | 305mW |
| $R_{\text{DCR}}$    | 75m $\Omega$  | <b>PIND</b>   | 145mW |
| $D$                 | 0.623         |               |       |
| $\eta$              | 86%           | <b>PLOSS</b>  | 856mW |

$$P_{\text{INTERNAL}} = P_{\text{COND}} + P_{\text{SW}} = 475\text{ mW}$$

### Calculating $R_{\theta\text{JA}}$ and $R_{\psi\text{JC}}$

$$R_{\theta\text{JA}} = \frac{T_J - T_A}{P_{\text{Dissipation}}}$$

and

$$R_{\psi\text{JC}} = \frac{T_J - T_{\text{CASE}}}{P_{\text{Dissipation}}}$$

We now know the internal power dissipation, and we are trying to keep the junction temperature at or below 125°C. The next step is to calculate the value for  $R_{\theta\text{JA}}$  and/or  $R_{\psi\text{JC}}$ . This is actually very simple to accomplish, and necessary if you think you may be marginal with regards to thermals or determining what package option is correct.

The LM2735 has a thermal shutdown comparator. When the silicon reaches a temperature of 160°C, the device shuts down until the temperature reduces to 150°C. Knowing this, one can calculate the  $R_{\theta\text{JA}}$  or the  $R_{\psi\text{JC}}$  of a specific application. Because the junction to top case thermal impedance is much lower than the thermal impedance of junction to ambient air, the error in calculating  $R_{\psi\text{JC}}$  is lower than for  $R_{\theta\text{JA}}$ . However, you will need to attach a small thermocouple onto the top case of the LM2735 to obtain the  $R_{\psi\text{JC}}$  value.

Knowing the temperature of the silicon when the device shuts down allows us to know three of the four variables. Once we calculate the thermal impedance, we then can work backwards with the junction temperature set to 125°C to see what

maximum ambient air temperature keeps the silicon below the 125°C temperature.

#### Procedure:

Place your application into a thermal chamber. You will need to dissipate enough power in the device so you can obtain a good thermal impedance value.

Raise the ambient air temperature until the device goes into thermal shutdown. Record the temperatures of the ambient air and/or the top case temperature of the LM2735. Calculate the thermal impedances.

Example from previous calculations:

$P_{\text{diss}} = 475 \text{ mW}$

$T_a \text{ @ Shutdown} = 139^\circ\text{C}$

$T_c \text{ @ Shutdown} = 155^\circ\text{C}$

$$R_{\theta JA} = \frac{T_J - T_A}{P_{\text{Dissipation}}} : R_{\Psi JC} = \frac{T_J - T_{\text{Case-Top}}}{P_{\text{Dissipation}}}$$

$R_{\theta JA} \text{ LLP} = 55^\circ\text{C/W}$

$R_{\Psi JC} \text{ LLP} = 21^\circ\text{C/W}$

LLP & eMSOP typical applications will produce  $R_{\theta JA}$  numbers in the range of  $50^\circ\text{C/W}$  to  $65^\circ\text{C/W}$ , and  $R_{\Psi JC}$  will vary between  $18^\circ\text{C/W}$  and  $28^\circ\text{C/W}$ . These values are for PCB's with two and four layer boards with 0.5 oz copper, and four to six thermal vias to bottom side ground plane under the DAP.

For 5-pin SOT23 package typical applications,  $R_{\theta JA}$  numbers will range from  $80^\circ\text{C/W}$  to  $110^\circ\text{C/W}$ , and  $R_{\Psi JC}$  will vary between  $50^\circ\text{C/W}$  and  $65^\circ\text{C/W}$ . These values are for PCB's with two & four layer boards with 0.5 oz copper, with two to four thermal vias from GND pin to bottom layer.

Here is a good rule of thumb for typical thermal impedances, and an ambient temperature maximum of  $75^\circ\text{C}$ : If your design requires that you dissipate more than 400mW internal to the LM2735, or there is 750mW of total power loss in the application, it is recommended that you use the 6 pin LLP or the 8 pin eMSOP package.

**Note:** To use these procedures it is important to dissipate an amount of power within the device that will indicate a true thermal impedance value. If one uses a very small internal dissipated value, one can see that the thermal impedance calculated is abnormally high, and subject to error. The graph below shows the nonlinear relationship of internal power dissipation vs.  $R_{\theta JA}$ .

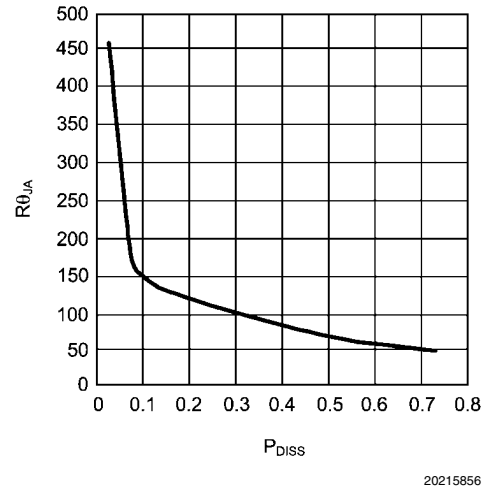


FIGURE 14.  $R_{\theta JA}$  vs Internal Dissipation for the LLP-6 and eMSOP-8 Package

## SEPIC Converter

The LM2735 can easily be converted into a SEPIC converter. A SEPIC converter has the ability to regulate an output voltage that is either larger or smaller in magnitude than the input voltage. Other converters have this ability as well (CUK and Buck-Boost), but usually create an output voltage that is opposite in polarity to the input voltage. This topology is a perfect fit for Lithium Ion battery applications where the input voltage for a single cell Li-Ion battery will vary between 3V & 4.5V and the output voltage is somewhere in between. Most of the analysis of the LM2735 Boost Converter is applicable to the LM2735 SEPIC Converter.

#### SEPIC Design Guide:

SEPIC Conversion ratio without loss elements:

$$\frac{V_o}{V_{IN}} = \frac{D}{D'}$$

Therefore:

$$D = \frac{V_o}{V_o + V_{IN}}$$

#### Small ripple approximation:

In a well-designed SEPIC converter, the output voltage, and input voltage ripple, the inductor ripple and is small in comparison to the DC magnitude. Therefore it is a safe approximation to assume a DC value for these components. The main objective of the Steady State Analysis is to determine the steady state duty-cycle, voltage and current stresses on all components, and proper values for all components.

In a steady-state converter, the net volt-seconds across an inductor after one cycle will equal zero. Also, the charge into a capacitor will equal the charge out of a capacitor in one cycle.

Therefore:

$$I_{L2} = \left( \frac{D}{D'} \right) \times I_{L1}$$

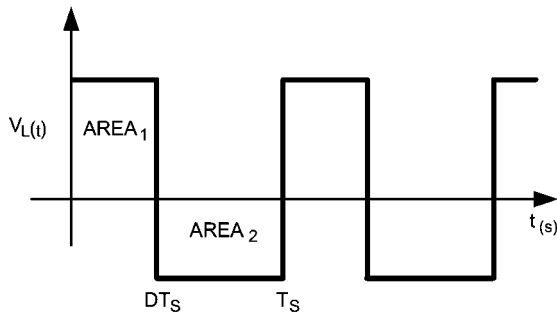
and

$$I_{L1} = \left( \frac{D}{D'} \right) \times \left( \frac{V_O}{R} \right)$$

Substituting  $I_{L1}$  into  $I_{L2}$

$$I_{L2} = \frac{V_O}{R}$$

The average inductor current of L2 is the average output load.



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FIGURE 15. Inductor Volt-Sec Balance Waveform

Applying Charge balance on C1:

$$V_{C1} = \frac{D'(V_O)}{D}$$

Since there are no DC voltages across either inductor, and capacitor C6 is connected to  $V_{IN}$  through L1 at one end, or to ground through L2 on the other end, we can say that

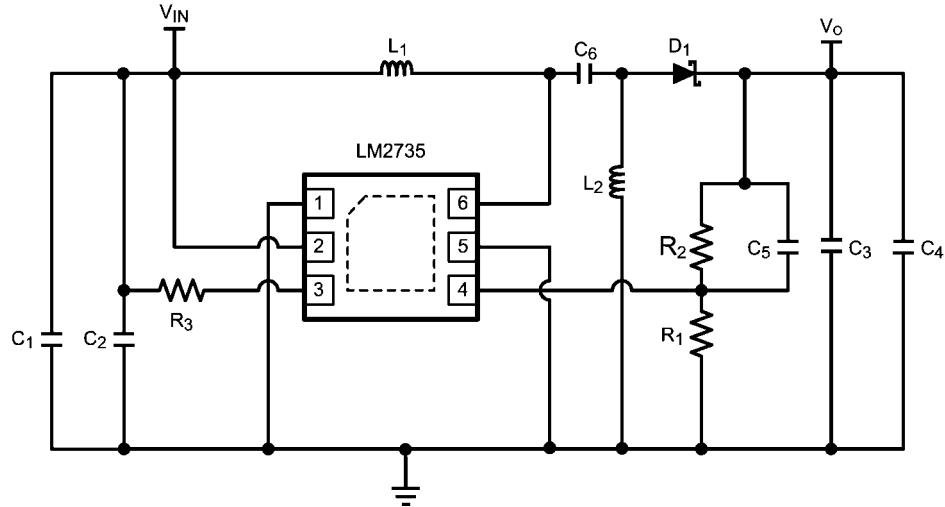
$$V_{C1} = V_{IN}$$

Therefore:

$$V_{IN} = \frac{D'(V_O)}{D}$$

This verifies the original conversion ratio equation.

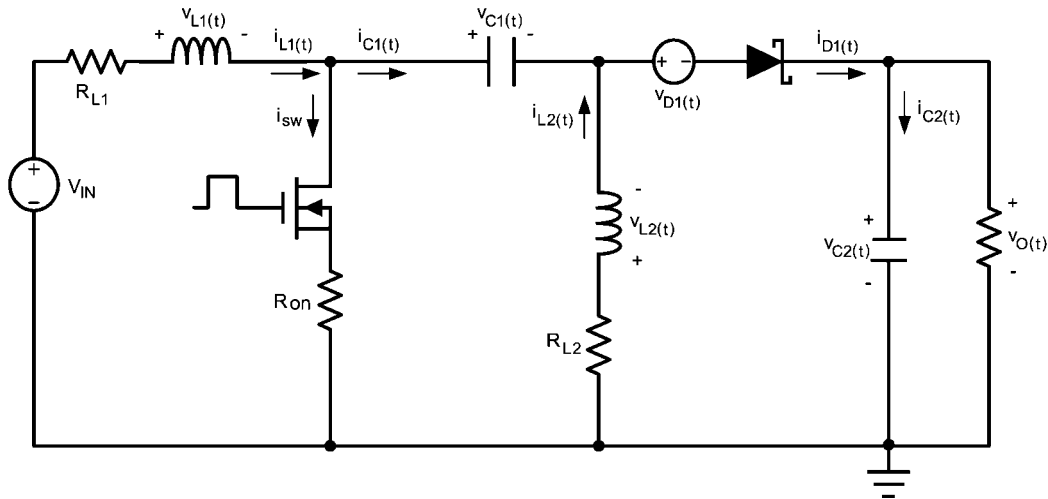
It is important to remember that the internal switch current is equal to  $I_{L1}$  and  $I_{L2}$ . During the D interval. Design the converter so that the minimum guaranteed peak switch current limit (2.1A) is not exceeded.



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FIGURE 16. SEPIC CONVERTER Schematic

## Steady State Analysis with Loss Elements



Using inductor volt-second balance & capacitor charge balance, the following equations are derived:

$$I_{L2} = \left( \frac{V_O}{R} \right)$$

and

$$I_{L1} = \left( \frac{V_O}{R} \right) \times \left( \frac{D}{D'} \right)$$

$$\frac{V_O}{V_{IN}} = \left( \frac{D}{D'} \right) \left( \frac{1}{\left( 1 + \frac{V_D}{V_O} + \frac{R_{L2}}{R} \right) + \left( \frac{D}{D'} \right) \left( \frac{R_{ON}}{R} \right) + \left( \frac{D^2}{D'^2} \right) \left( \frac{R_{L1}}{R} \right)} \right)$$

Therefore:

$$\eta = \left( \frac{1}{\left( 1 + \frac{V_D}{V_O} + \frac{R_{L2}}{R} \right) + \left( \frac{D}{D'} \right) \left( \frac{R_{ON}}{R} \right) + \left( \frac{D^2}{D'^2} \right) \left( \frac{R_{L1}}{R} \right)} \right)$$

One can see that all variables are known except for the duty cycle (D). A quadratic equation is needed to solve for D. A less accurate method of determining the duty cycle is to assume efficiency, and calculate the duty cycle.

$$\frac{V_O}{V_{IN}} = \left( \frac{D}{1 - D} \right) \times \eta$$

$$D = \left( \frac{V_O}{(V_{IN} \times \eta) + V_O} \right)$$

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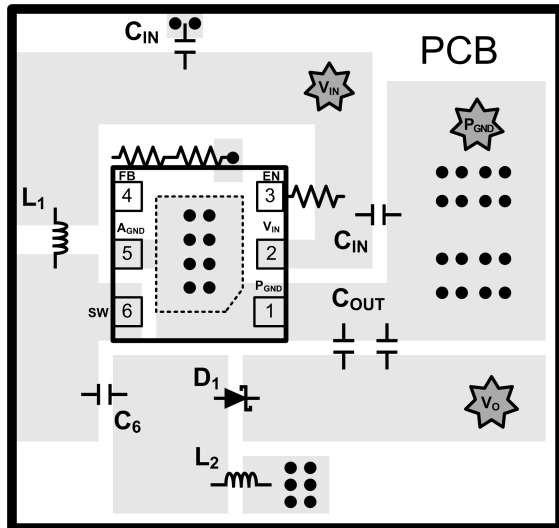
|                 |        |                 |        |                 |        |
|-----------------|--------|-----------------|--------|-----------------|--------|
| V <sub>in</sub> | 2.7V   | V <sub>in</sub> | 3.3V   | V <sub>in</sub> | 5V     |
| V <sub>o</sub>  | 3.1V   | V <sub>o</sub>  | 3.1V   | V <sub>o</sub>  | 3.1V   |
| I <sub>in</sub> | 770 mA | I <sub>in</sub> | 600 mA | I <sub>in</sub> | 375 mA |
| I <sub>o</sub>  | 500 mA | I <sub>o</sub>  | 500 mA | I <sub>o</sub>  | 500 mA |
| η               | 75%    | η               | 80%    | η               | 83%    |

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Efficiencies for Typical SEPIC Application

## SEPIC Converter PCB Layout

The layout guidelines described for the LM2735 Boost-Converter are applicable to the SEPIC Converter. Below is a proper PCB layout for a SEPIC Converter.

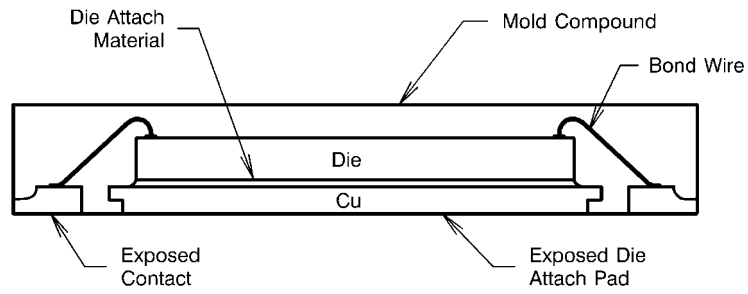


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FIGURE 17. SEPIC PCB Layout

## LLP Package

The LM2735 packaged in the 6-pin LLP:

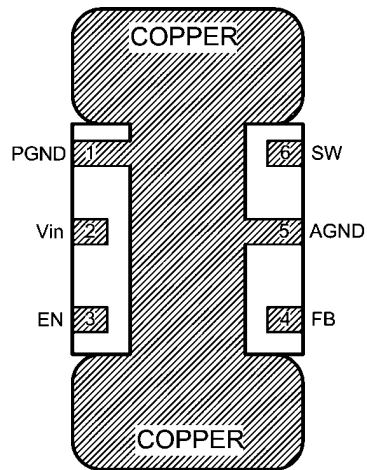


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**FIGURE 18. Internal LLP Connection**

For certain high power applications, the PCB land may be modified to a "dog bone" shape (see Figure 19). Increasing

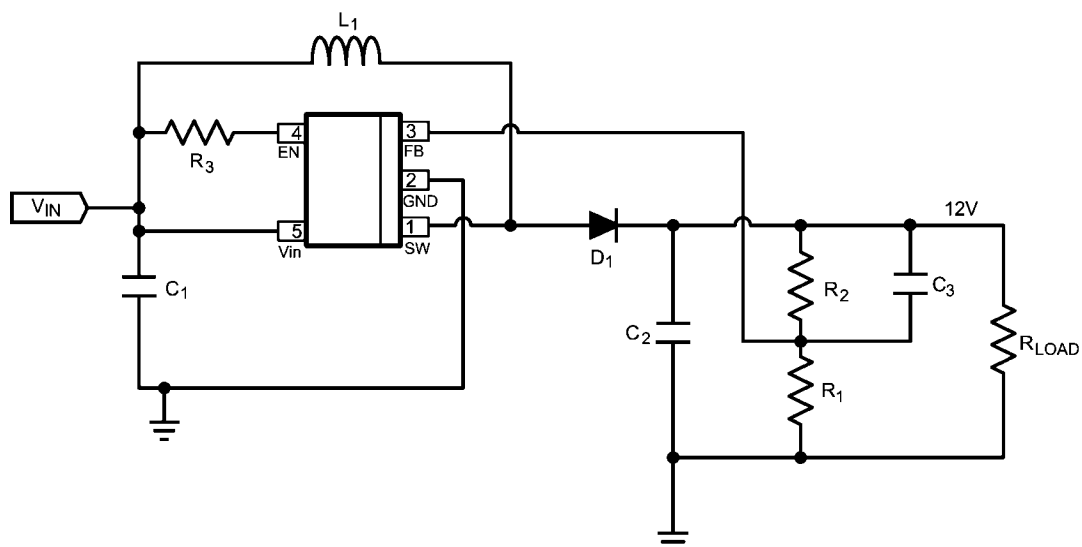
the size of ground plane, and adding thermal vias can reduce the  $R_{\theta JA}$  for the application.



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**FIGURE 19. PCB Dog Bone Layout**

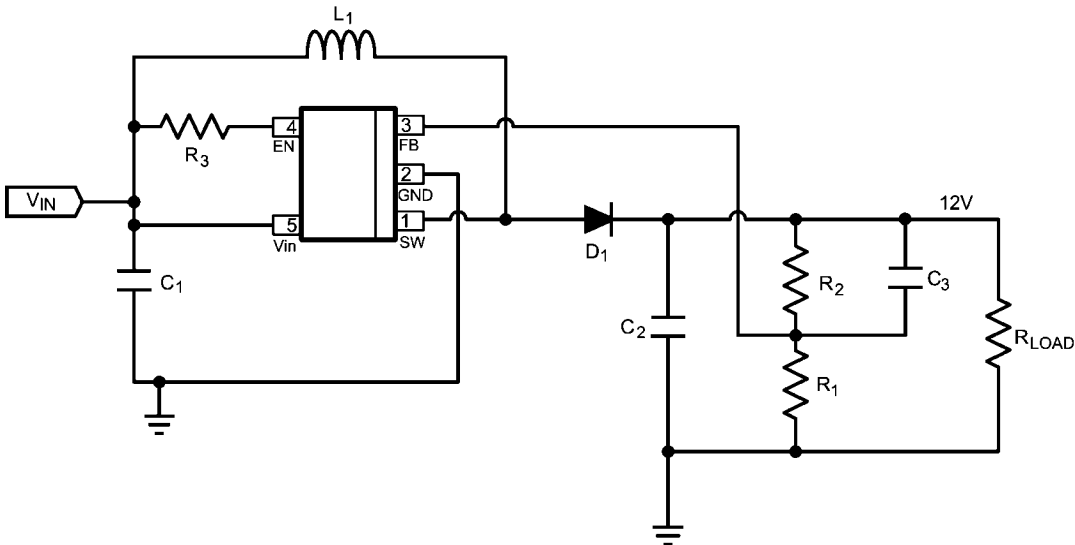
## LM2735X SOT23-5 Design Example 1

LM2735X (1.6MHz):  $V_{in} = 5V$ ,  $V_{out} = 12V @ 350mA$ 

20215875

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735XMF      |
| C1, Input Cap   | 22 $\mu$ F, 6.3V, X5R                           | TDK          | C2012X5R0J226M |
| C2 Output Cap   | 10 $\mu$ F, 25V, X5R                            | TDK          | C3216X5R1E106M |
| C3 Comp Cap     | 330pF                                           | TDK          | C1608X5R1H331K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 15 $\mu$ H 1.5A                                 | Coilcraft    | MSS5131-153ML  |
| R1              | 10.2k $\Omega$ , 1%                             | Vishay       | CRCW06031022F  |
| R2              | 86.6k $\Omega$ , 1%                             | Vishay       | CRCW06038662F  |
| R3              | 100k $\Omega$ , 1%                              | Vishay       | CRCW06031003F  |

LM2735Y SOT23-5 Design Example 2



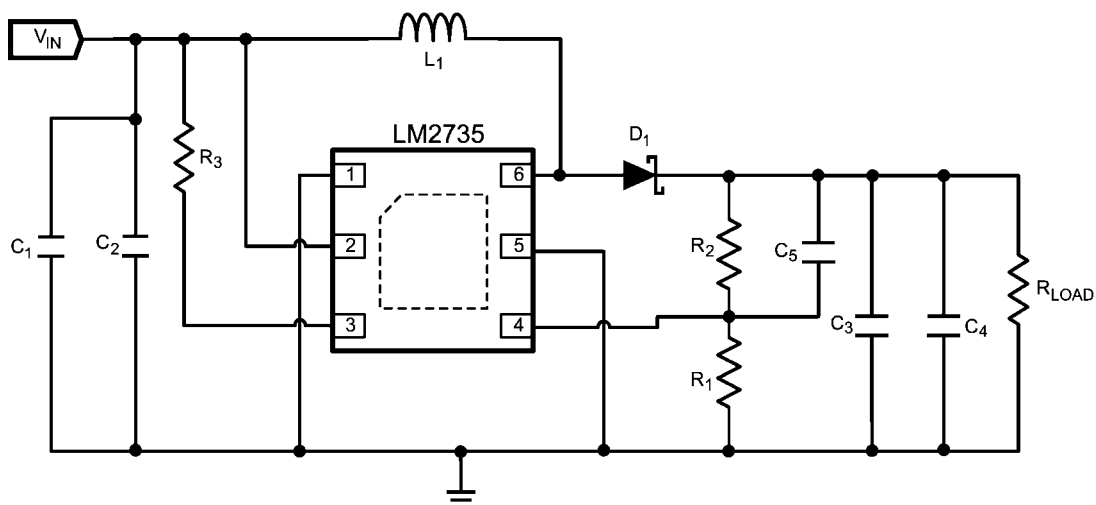
LM2735Y (520kHz): Vin = 5V, Vout = 12V @ 350mA

20215875

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735YMF      |
| C1, Input Cap   | 22μF, 6.3V, X5R                                 | TDK          | C2012X5R0J226M |
| C2 Output Cap   | 10μF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C3 Comp Cap     | 330pF                                           | TDK          | C1608X5R1H331K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 33μH 1.5A                                       | Coilcraft    | DS3316P-333ML  |
| R1              | 10.2kΩ, 1%                                      | Vishay       | CRCW06031022F  |
| R2              | 86.6kΩ, 1%                                      | Vishay       | CRCW06038662F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |



## LM2735X LLP-6 Design Example 3

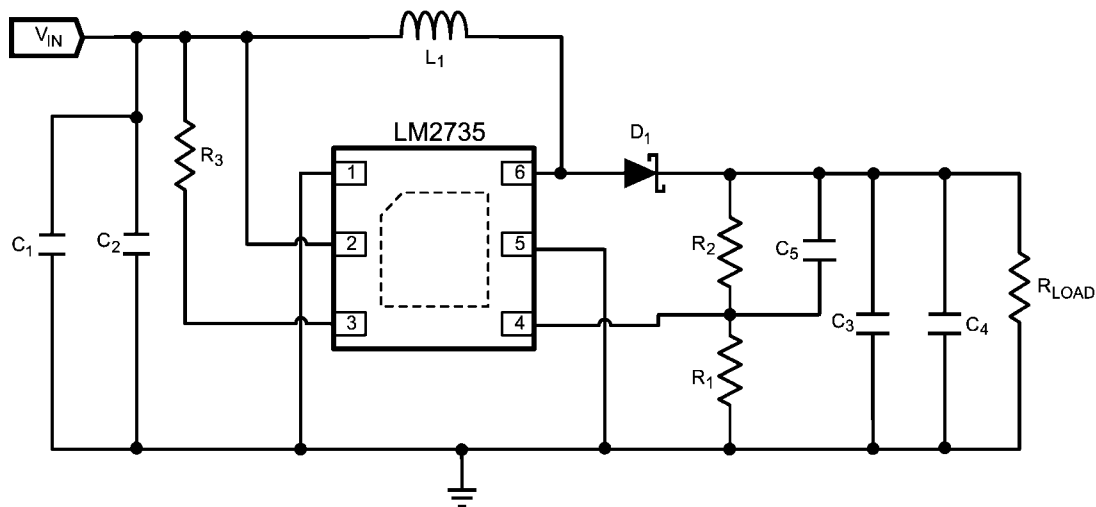


LM2735X (1.6MHz):  $V_{in} = 3.3V$ ,  $V_{out} = 12V @ 350mA$

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| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735XSD      |
| C1 Input Cap    | 22 $\mu$ F, 6.3V, X5R                           | TDK          | C2012X5R0J226M |
| C2 Input Cap    | No Load                                         |              |                |
| C3 Output Cap   | 10 $\mu$ F, 25V, X5R                            | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                         |              |                |
| C5 Comp Cap     | 330pF                                           | TDK          | C1608X5R1H331K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 6.8 $\mu$ H 2A                                  | Coilcraft    | DO1813H-682ML  |
| R1              | 10.2k $\Omega$ , 1%                             | Vishay       | CRCW06031022F  |
| R2              | 86.6k $\Omega$ , 1%                             | Vishay       | CRCW06038662F  |
| R3              | 100k $\Omega$ , 1%                              | Vishay       | CRCW06031003F  |

LM2735Y LLP-6 Design Example 4

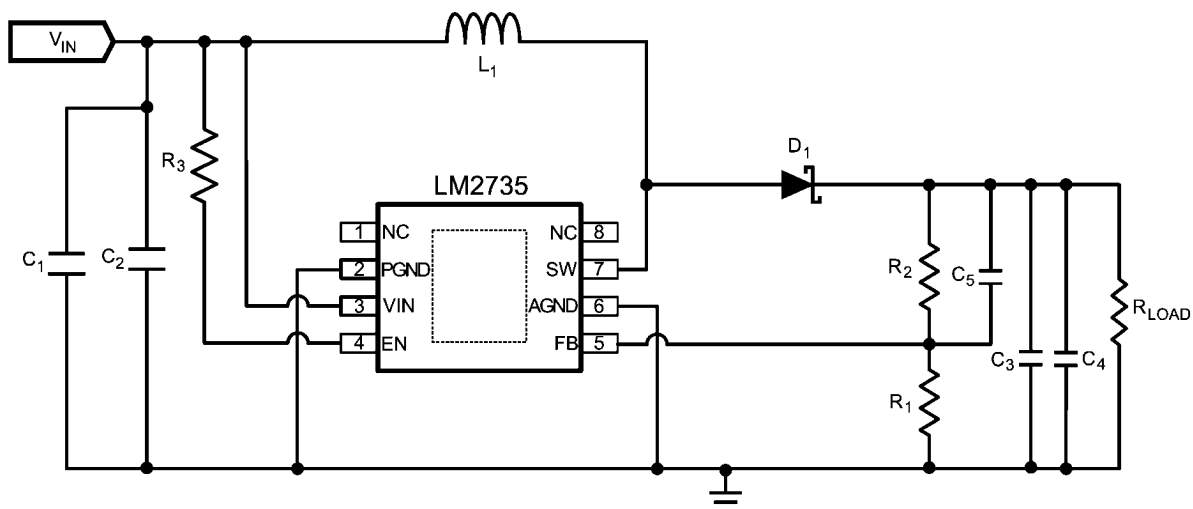


LM2735Y (520kHz): Vin = 3.3V, Vout = 12V @ 350mA

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| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735YSD      |
| C1 Input Cap    | 22μF, 6.3V, X5R                                 | TDK          | C2012X5R0J226M |
| C2 Input Cap    | No Load                                         |              |                |
| C3 Output Cap   | 10μF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                         |              |                |
| C5 Comp Cap     | 330pF                                           | TDK          | C1608X5R1H331K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 15μH 2A                                         | Coilcraft    | MSS5131-153ML  |
| R1              | 10.2kΩ, 1%                                      | Vishay       | CRCW06031022F  |
| R2              | 86.6kΩ, 1%                                      | Vishay       | CRCW06038662F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |

## LM2735Y eMSOP-8 Design Example 5

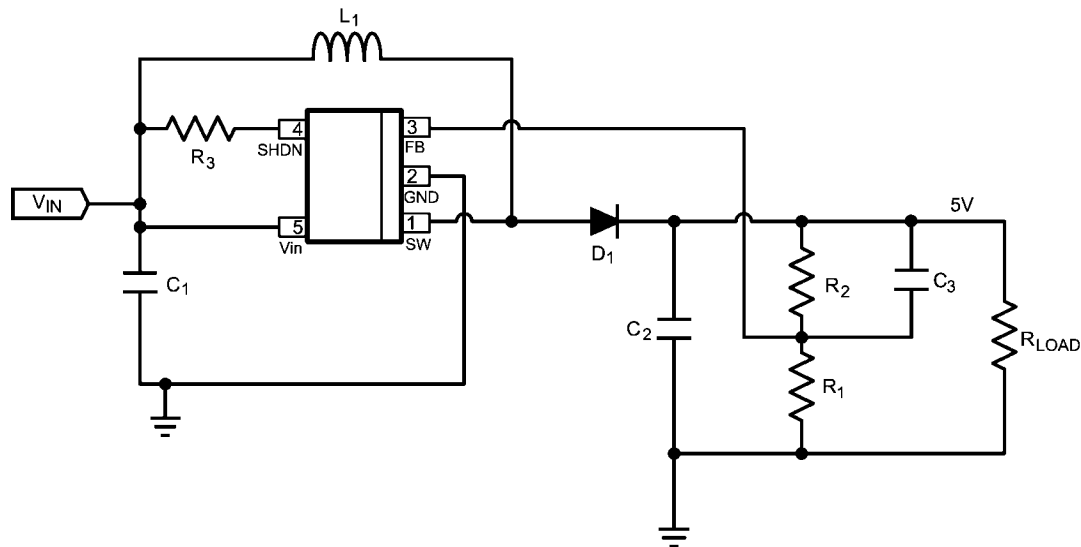


LM2735Y (520kHz):  $V_{in} = 3.3V$ ,  $V_{out} = 12V @ 350mA$

20215877

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735YMY      |
| C1 Input Cap    | 22µF, 6.3V, X5R                                 | TDK          | C2012X5R0J226M |
| C2 Input Cap    | No Load                                         |              |                |
| C3 Output Cap   | 10µF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                         |              |                |
| C5 Comp Cap     | 330pF                                           | TDK          | C1608X5R1H331K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 15µH 1.5A                                       | Coilcraft    | MSS5131-153ML  |
| R1              | 10.2kΩ, 1%                                      | Vishay       | CRCW06031022F  |
| R2              | 86.6kΩ, 1%                                      | Vishay       | CRCW06038662F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |

LM2735X SOT23-5 Design Example 6

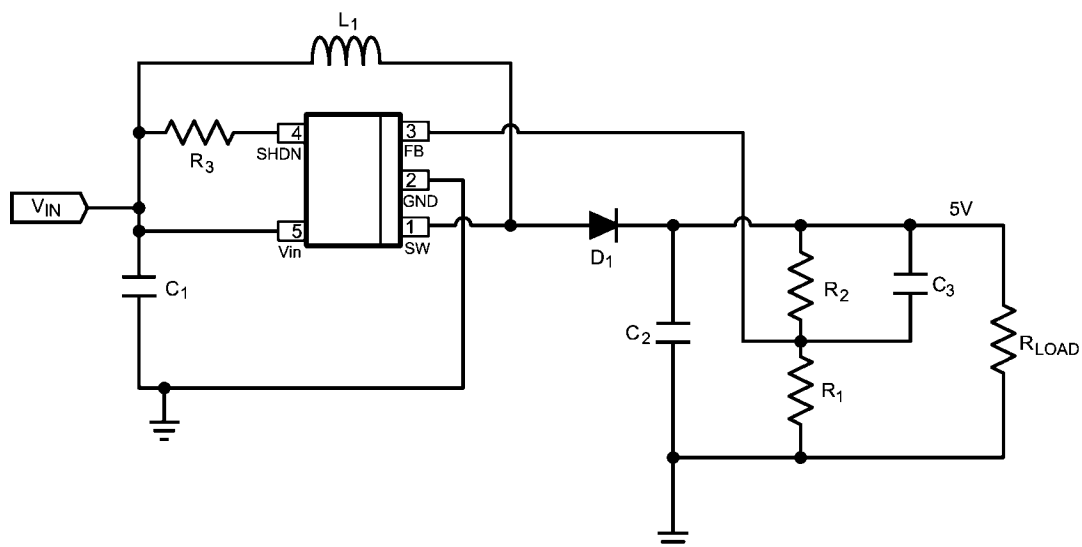


LM2735X (1.6MHz): Vin = 3V, Vout = 5V @ 500mA

20215878

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735XMF      |
| C1, Input Cap   | 10μF, 6.3V, X5R                                 | TDK          | C2012X5R0J106K |
| C2, Output Cap  | 10μF, 6.3V, X5R                                 | TDK          | C2012X5R0J106K |
| C3 Comp Cap     | 1000pF                                          | TDK          | C1608X5R1H102K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 10μH 1.2A                                       | Coilcraft    | DO1608C-103ML  |
| R1              | 10.0kΩ, 1%                                      | Vishay       | CRCW08051002F  |
| R2              | 30.1kΩ, 1%                                      | Vishay       | CRCW08053012F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |

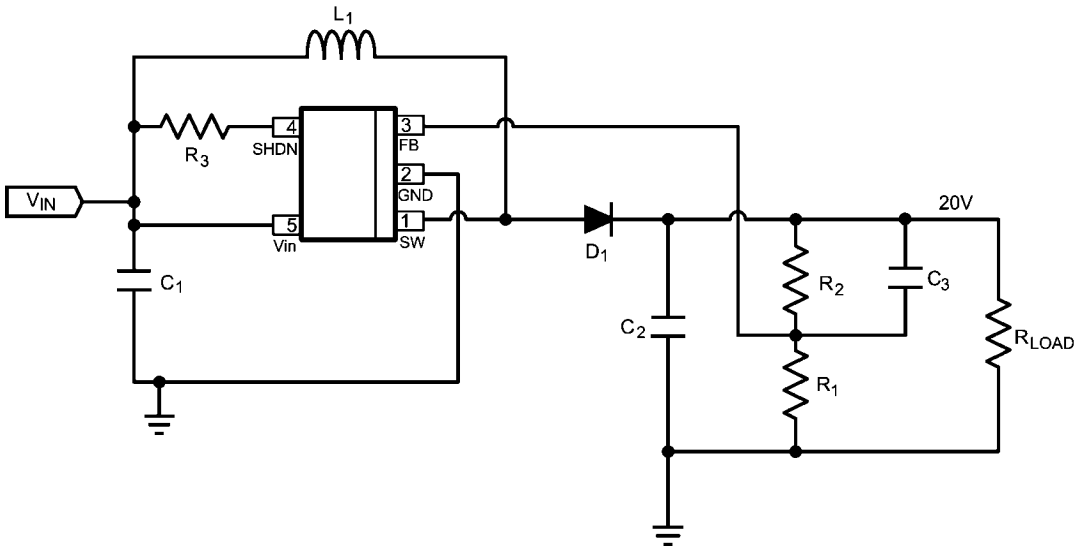
## LM2735Y SOT23-5 Design Example 7

LM2735Y (520kHz):  $V_{in} = 3V$ ,  $V_{out} = 5V @ 750mA$ 

20215878

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735YMF      |
| C1 Input Cap    | 22 $\mu$ F, 6.3V, X5R                           | TDK          | C2012X5R0J226M |
| C2 Output Cap   | 22 $\mu$ F, 6.3V, X5R                           | TDK          | C2012X5R0J226M |
| C3 Comp Cap     | 1000pF                                          | TDK          | C1608X5R1H102K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 22 $\mu$ H 1.2A                                 | Coilcraft    | MSS5131-223ML  |
| R1              | 10.0k $\Omega$ , 1%                             | Vishay       | CRCW08051002F  |
| R2              | 30.1k $\Omega$ , 1%                             | Vishay       | CRCW08053012F  |
| R3              | 100k $\Omega$ , 1%                              | Vishay       | CRCW06031003F  |

LM2735X SOT23-5 Design Example 8

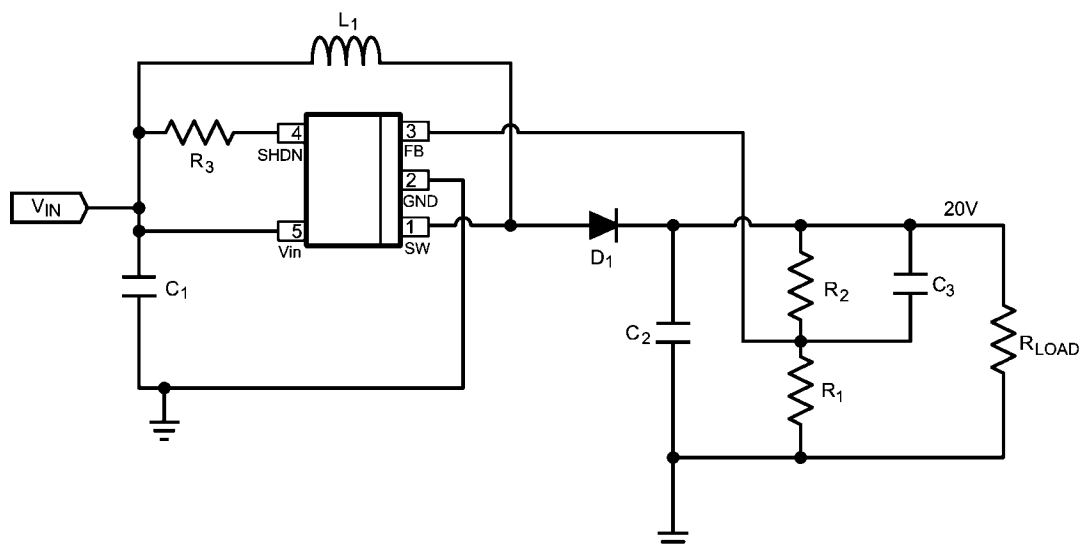


LM2735X (1.6MHz): Vin = 3.3V, Vout = 20V @ 100mA

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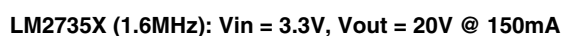
| Part ID         | Part Value                                         | Manufacturer | Part Number    |
|-----------------|----------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                               | NSC          | LM2735XMF      |
| C1, Input Cap   | 22μF, 6.3V, X5R                                    | TDK          | C2012X5R0J226M |
| C2, Output Cap  | 4.7μF, 25V, X5R                                    | TDK          | C3216X5R1E475K |
| C3 Comp Cap     | 470pF                                              | TDK          | C1608X5R1H471K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| L1              | 10μH 1.2A                                          | Coilcraft    | DO1608C-103ML  |
| R1              | 10.0kΩ, 1%                                         | Vishay       | CRCW06031002F  |
| R2              | 150kΩ, 1%                                          | Vishay       | CRCW06031503F  |
| R3              | 100kΩ, 1%                                          | Vishay       | CRCW06031003F  |

## LM2735Y SOT23-5 Design Example 9

LM2735Y (520kHz):  $V_{in} = 3.3V$ ,  $V_{out} = 20V @ 100mA$ 

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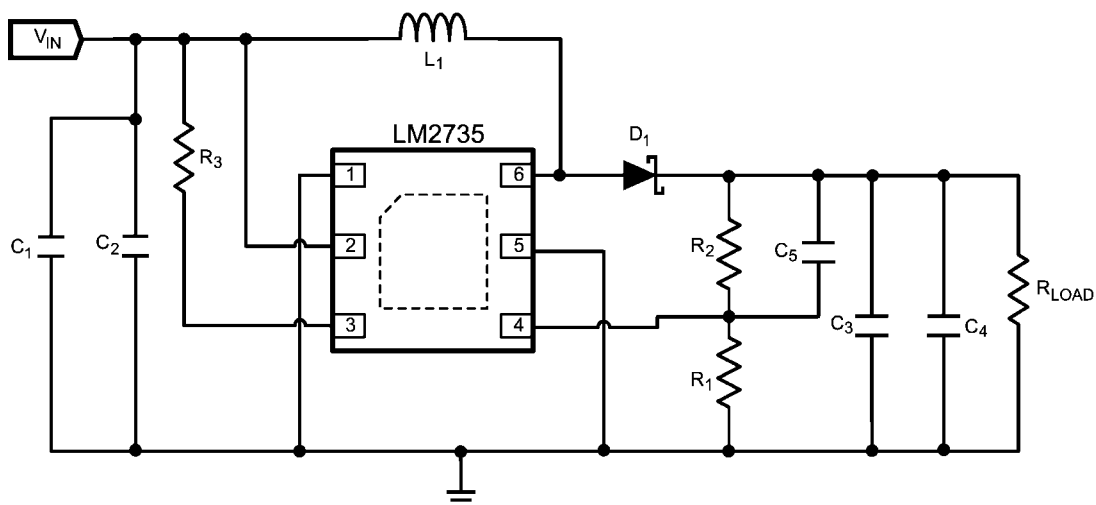
| Part ID         | Part Value                                         | Manufacturer | Part Number    |
|-----------------|----------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                               | NSC          | LM2735YMF      |
| C1 Input Cap    | 22 $\mu$ F, 6.3V, X5R                              | TDK          | C2012X5R0J226M |
| C2 Output Cap   | 10 $\mu$ F, 25V, X5R                               | TDK          | C3216X5R1E106M |
| C3 Comp Cap     | 470pF                                              | TDK          | C1608X5R1H471K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| L1              | 33 $\mu$ H 1.5A                                    | Coilcraft    | DS3316P-333ML  |
| R1              | 10.0k $\Omega$ , 1%                                | Vishay       | CRCW06031002F  |
| R2              | 150.0k $\Omega$ , 1%                               | Vishay       | CRCW06031503F  |
| R3              | 100k $\Omega$ , 1%                                 | Vishay       | CRCW06031003F  |



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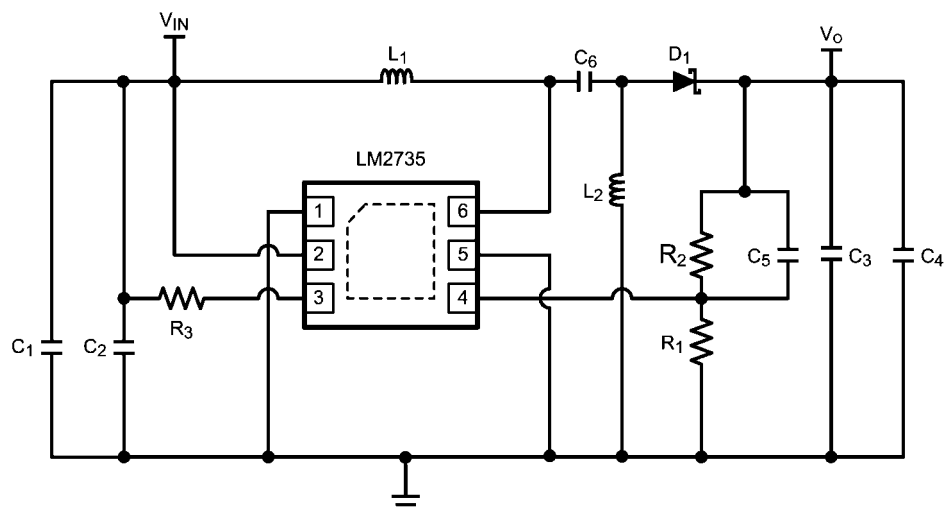
| Part ID         | Part Value                                         | Manufacturer | Part Number    |
|-----------------|----------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                               | NSC          | LM2735XSD      |
| C1 Input Cap    | 22μF, 6.3V, X5R                                    | TDK          | C2012X5R0J226M |
| C2 Input Cap    | 22μF, 6.3V, X5R                                    | TDK          | C2012X5R0J226M |
| C3 Output Cap   | 10μF, 25V, X5R                                     | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                            |              |                |
| C5 Comp Cap     | 470pF                                              | TDK          | C1608X5R1H471K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| L1              | 8.2μH 2A                                           | Coilcraft    | DO1813H-822ML  |
| R1              | 10.0kΩ, 1%                                         | Vishay       | CRCW06031002F  |
| R2              | 150kΩ, 1%                                          | Vishay       | CRCW06031503F  |
| R3              | 100kΩ, 1%                                          | Vishay       | CRCW06031003F  |





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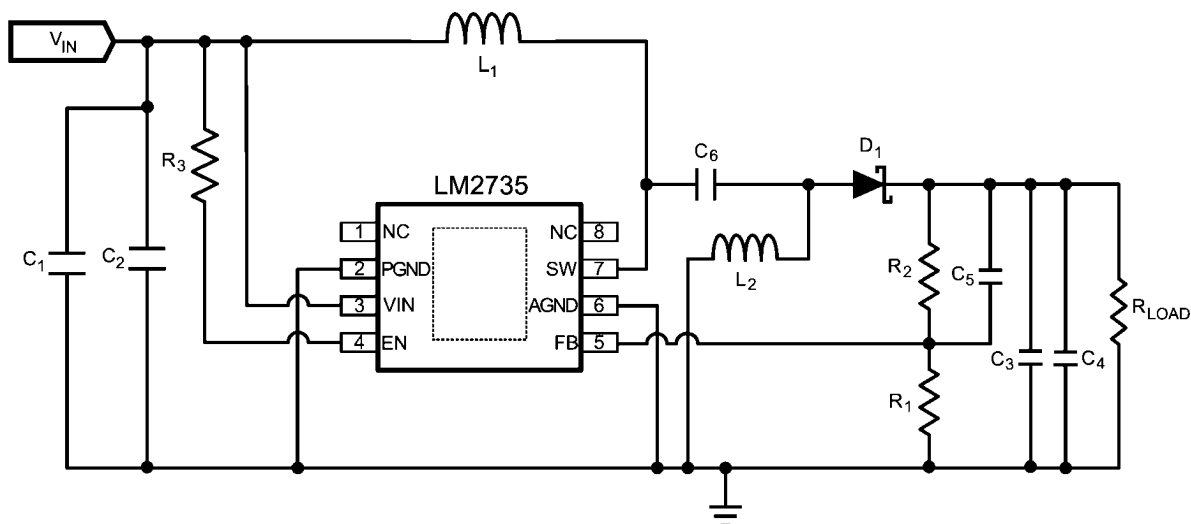
| Part ID         | Part Value                                         | Manufacturer | Part Number    |
|-----------------|----------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                               | NSC          | LM2735YSD      |
| C1 Input Cap    | 10μF, 6.3V, X5R                                    | TDK          | C2012X5R0J106K |
| C2 Input Cap    | 10μF, 6.3V, X5R                                    | TDK          | C2012X5R0J106K |
| C3 Output Cap   | 10μF, 25V, X5R                                     | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                            |              |                |
| C5 Comp Cap     | 470pF                                              | TDK          | C1608X5R1H471K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| L1              | 22μH 1.5A                                          | Coilcraft    | DS3316P-223ML  |
| R1              | 10.0kΩ, 1%                                         | Vishay       | CRCW06031002F  |
| R2              | 150kΩ, 1%                                          | Vishay       | CRCW06031503F  |
| R3              | 100kΩ, 1%                                          | Vishay       | CRCW06031003F  |



**LM2735X (1.6MHz):  $V_{in} = 2.7V - 5V$ ,  $V_{out} = 3.3V @ 500mA$**

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735XSD      |
| C1 Input Cap    | 22μF, 6.3V, X5R                                 | TDK          | C2012X5R0J226M |
| C2 Input Cap    | No Load                                         |              |                |
| C3 Output Cap   | 10μF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                         |              |                |
| C5 Comp Cap     | 2200pF                                          | TDK          | C1608X5R1H222K |
| C6              | 2.2μF 16V                                       | TDK          | C2012X5R1C225K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 6.8μH                                           | Coilcraft    | DO1608C-682ML  |
| L2              | 6.8μH                                           | Coilcraft    | DO1608C-682ML  |
| R1              | 10.2kΩ, 1%                                      | Vishay       | CRCW06031002F  |
| R2              | 16.5kΩ, 1%                                      | Vishay       | CRCW06031652F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |

# LM2735Y eMSOP-8 SEPIC Design Example 13

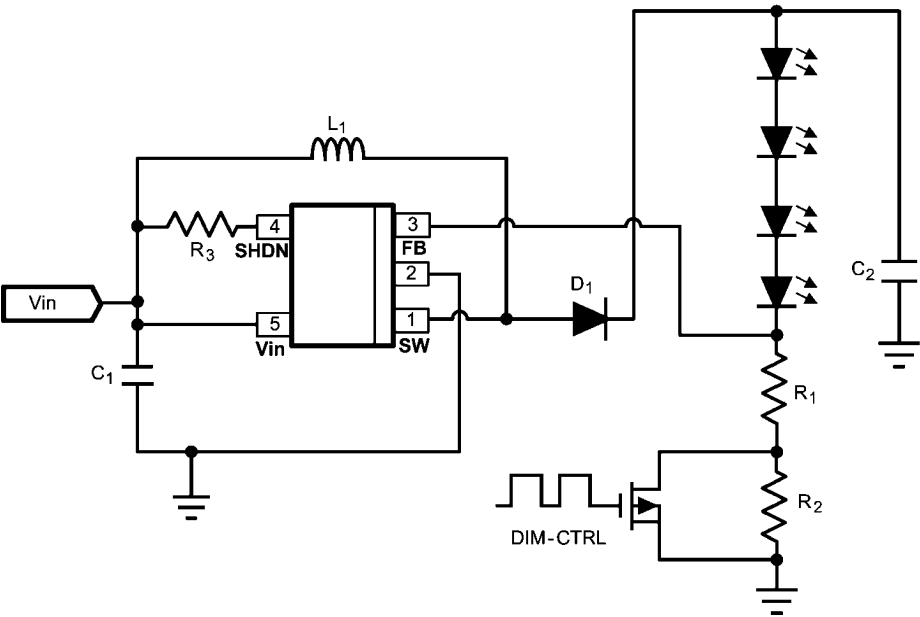


LM2735Y (520kHz):  $V_{in} = 2.7V - 5V$ ,  $V_{out} = 3.3V @ 500mA$

20215881

| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735YMY      |
| C1 Input Cap    | 22 $\mu$ F, 6.3V, X5R                           | TDK          | C2012X5R0J226M |
| C2 Input Cap    | No Load                                         |              |                |
| C3 Output Cap   | 10 $\mu$ F, 25V, X5R                            | TDK          | C3216X5R1E106M |
| C4 Output Cap   | No Load                                         |              |                |
| C5 Comp Cap     | 2200pF                                          | TDK          | C1608X5R1H222K |
| C6              | 2.2 $\mu$ F 16V                                 | TDK          | C2012X5R1C225K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1              | 15 $\mu$ H 1.5A                                 | Coilcraft    | MSS5131-153ML  |
| L2              | 15 $\mu$ H 1.5A                                 | Coilcraft    | MSS5131-153ML  |
| R1              | 10.2k $\Omega$ , 1%                             | Vishay       | CRCW06031002F  |
| R2              | 16.5k $\Omega$ , 1%                             | Vishay       | CRCW06031652F  |
| R3              | 100k $\Omega$ , 1%                              | Vishay       | CRCW06031003F  |

LM2735X SOT23-5 LED Design Example 14

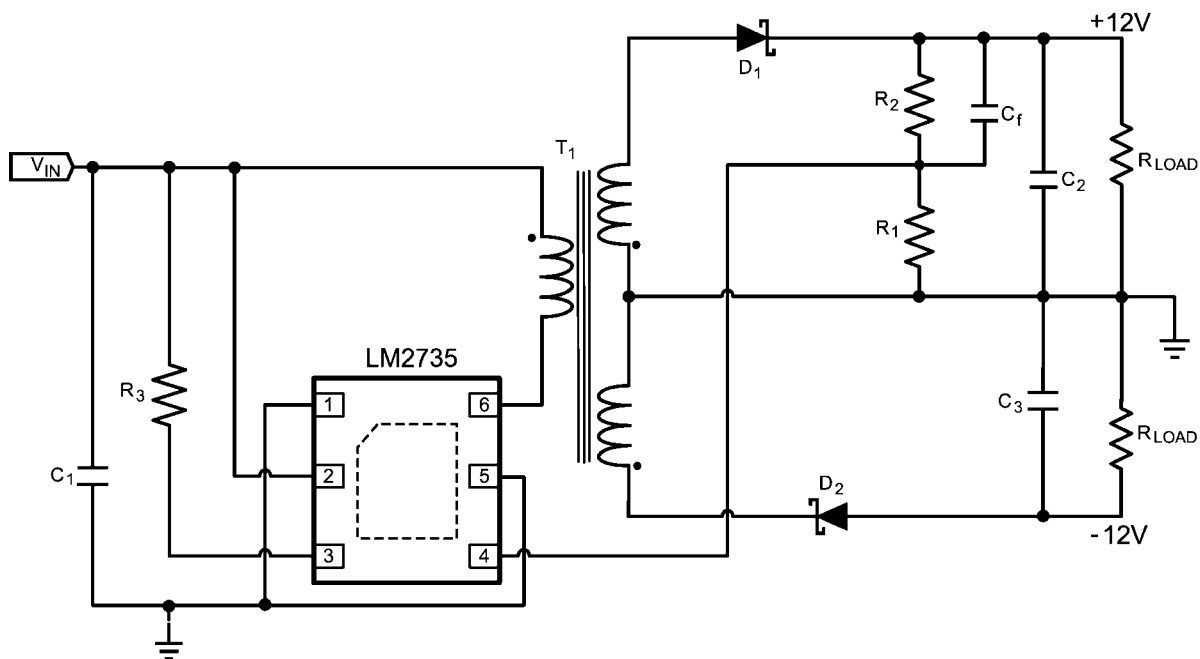


LM2735X (1.6MHz): Vin = 2.7V - 5V, Vout = 20V @ 50mA

20215882

| Part ID         | Part Value                                         | Manufacturer | Part Number    |
|-----------------|----------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                               | NSC          | LM2735XMF      |
| C1 Input Cap    | 22μF, 6.3V, X5R                                    | TDK          | C2012X5R0J226M |
| C2 Output Cap   | 4.7μF, 25V, X5R                                    | TDK          | C3216JB1E475K  |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| L1              | 15μH 1.5A                                          | Coilcraft    | MSS5131-153ML  |
| R1              | 25.5Ω, 1%                                          | Vishay       | CRCW080525R5F  |
| R2              | 100Ω, 1%                                           | Vishay       | CRCW08051000F  |
| R3              | 100kΩ, 1%                                          | Vishay       | CRCW06031003F  |

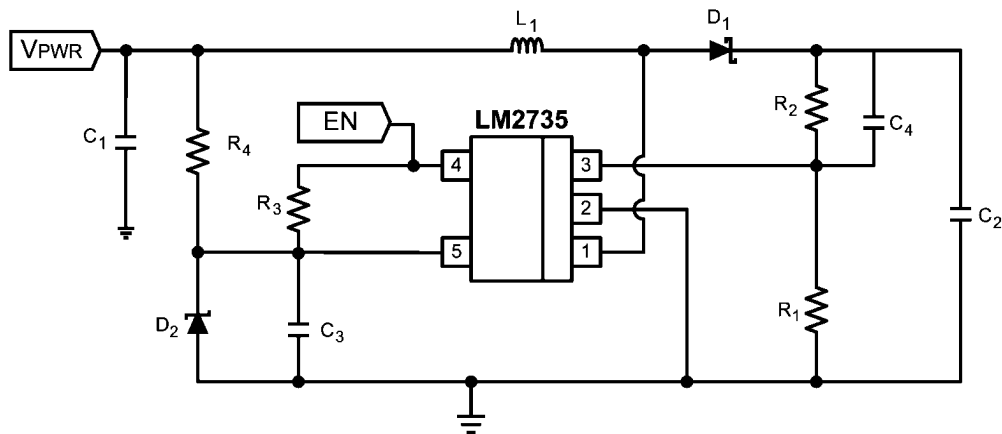
## LM2735Y LLP-6 FlyBack Design Example 15

LM2735Y (520kHz):  $V_{in} = 5V$ ,  $V_{out} = \pm 12V$  150mA

20215883

| Part ID            | Part Value                                         | Manufacturer | Part Number    |
|--------------------|----------------------------------------------------|--------------|----------------|
| U1                 | 2.1A Boost Regulator                               | NSC          | LM2735YSD      |
| C1 Input Cap       | 22 $\mu$ F, 6.3V, X5R                              | TDK          | C2012X5R0J226M |
| C2 Output Cap      | 10 $\mu$ F, 25V, X5R                               | TDK          | C3216X5R1E106M |
| C3 Output Cap      | 10 $\mu$ F, 25V, X5R                               | TDK          | C3216X5R1E106M |
| Cf Comp Cap        | 330pF                                              | TDK          | C1608X5R1H331K |
| D1, D2 Catch Diode | 0.4V <sub>f</sub> Schottky 500mA, 30V <sub>R</sub> | Vishay       | MBR0530        |
| T1                 |                                                    |              |                |
| R1                 | 10.0k $\Omega$ , 1%                                | Vishay       | CRCW06031002F  |
| R2                 | 86.6k $\Omega$ , 1%                                | Vishay       | CRCW06038662F  |
| R3                 | 100k $\Omega$ , 1%                                 | Vishay       | CRCW06031003F  |

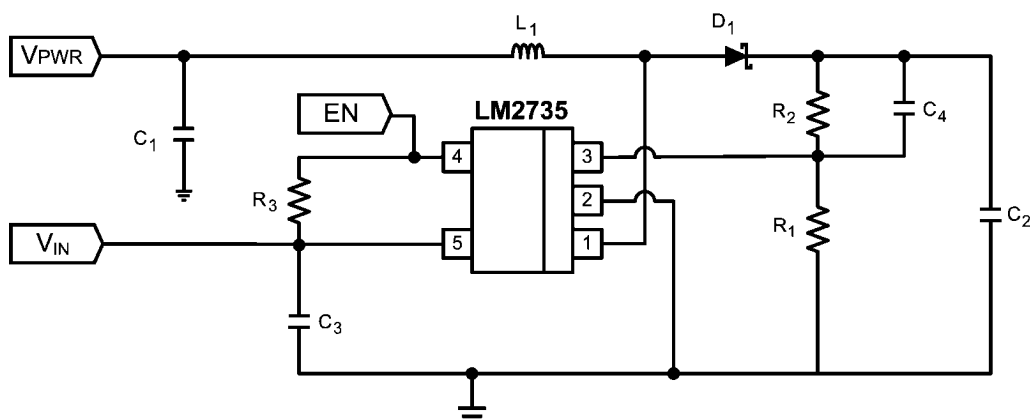
LM2735X SOT23-5 LED Design Example 16  
 $V_{RAIL} > 5.5V$  Application



LM2735X (1.6MHz):  $V_{PWR} = 9V$ ,  $V_{out} = 12V @ 500mA$

202158a3

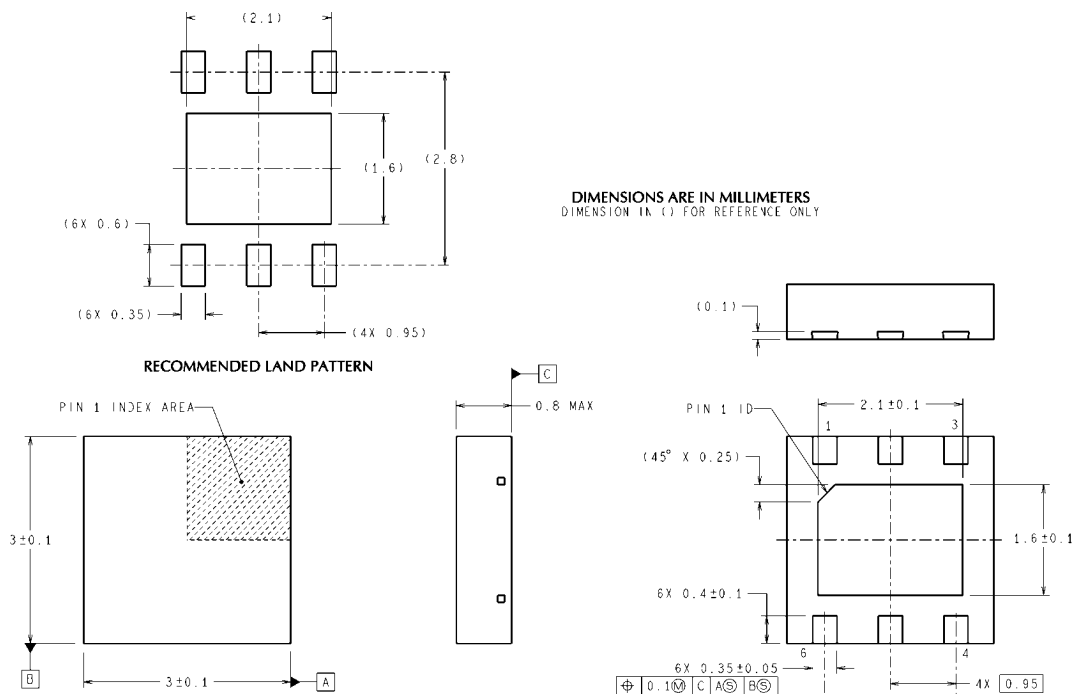
| Part ID         | Part Value                                      | Manufacturer | Part Number    |
|-----------------|-------------------------------------------------|--------------|----------------|
| U1              | 2.1A Boost Regulator                            | NSC          | LM2735XMF      |
| C1, Input Cap   | 10µF, 6.3V, X5R                                 | TDK          | C2012X5R0J106K |
| C2, Output Cap  | 10µF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C3 $V_{IN}$ Cap | 0.1µF, 6.3V, X5R                                | TDK          | C2012X5R0J104K |
| C4 Comp Cap     | 1000pF                                          | TDK          | C1608X5R1H102K |
| D1, Catch Diode | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| D2              | 3.3V Zener, SOT23                               | Diodes Inc   | BZX84C3V3      |
| L1              | 6.8µH 2A                                        | Coilcraft    | DO1813H-682ML  |
| R1              | 10.0kΩ, 1%                                      | Vishay       | CRCW08051002F  |
| R2              | 86.6kΩ, 1%                                      | Vishay       | CRCW08058662F  |
| R3              | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |
| R4              | 499Ω, 1%                                        | Vishay       | CRCW06034991F  |



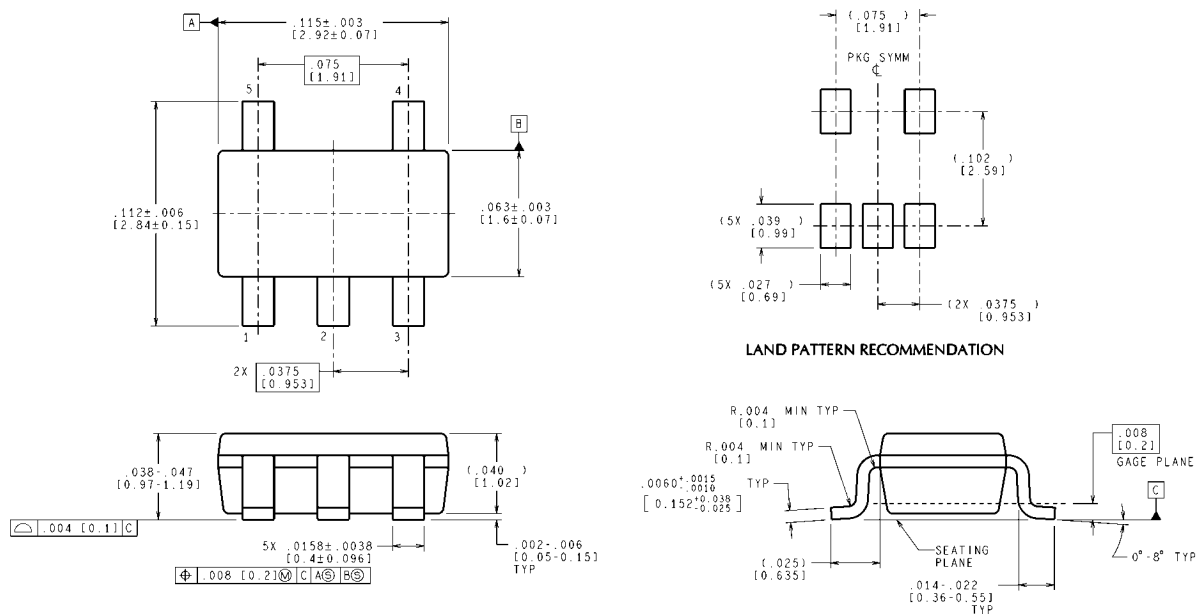
**LM2735X (1.6MHz):**  $V_{PWR} = 9V$  in = 2.7V - 5.5V,  $V_{out} = 12V @ 500mA$

202158a4

| Part ID                | Part Value                                      | Manufacturer | Part Number    |
|------------------------|-------------------------------------------------|--------------|----------------|
| U1                     | 2.1A Boost Regulator                            | NSC          | LM2735XMF      |
| C1, Input Cap          | 10μF, 6.3V, X5R                                 | TDK          | C2012X5R0J106K |
| C2, Output Cap         | 10μF, 25V, X5R                                  | TDK          | C3216X5R1E106M |
| C3 V <sub>IN</sub> Cap | 0.1μF, 6.3V, X5R                                | TDK          | C2012X5R0J104K |
| C4 Comp Cap            | 1000pF                                          | TDK          | C1608X5R1H102K |
| D1, Catch Diode        | 0.4V <sub>f</sub> Schottky 1A, 20V <sub>R</sub> | ST           | STPS120M       |
| L1                     | 6.8μH 2A                                        | Coilcraft    | DO1813H-682ML  |
| R1                     | 10.0kΩ, 1%                                      | Vishay       | CRCW08051002F  |
| R2                     | 86.6kΩ, 1%                                      | Vishay       | CRCW08058662F  |
| R3                     | 100kΩ, 1%                                       | Vishay       | CRCW06031003F  |

**Physical Dimensions** inches (millimeters) unless otherwise noted

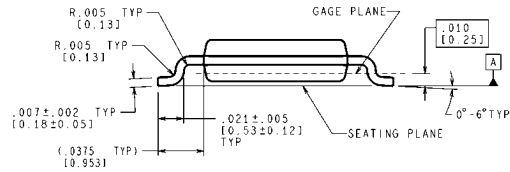
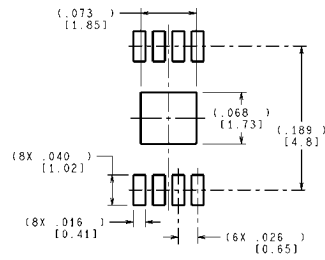
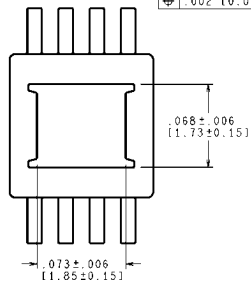
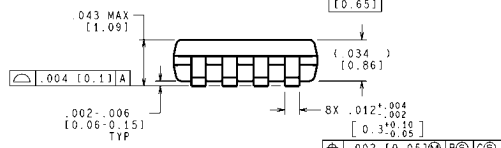
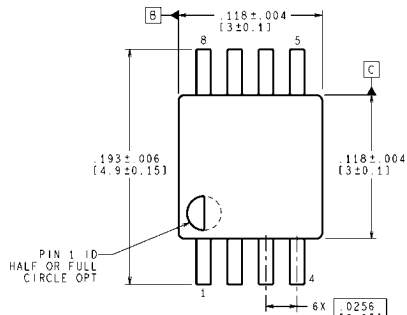
**6-Lead LLP Package**  
**NS Package Number SDE06A**



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DIMENSIONS IN ( ) FOR REFERENCE ONLY

**5-Lead SOT23-5 Package**  
**NS Package Number MF05A**





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### 8-Lead eMSOP Package NS Package Number MUY08A

MUY08A (Rev A)

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