

# LM2696 Demonstration Board

National Semiconductor  
Application Note 1410  
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## Introduction

The LM2696 is a constant on-time, buck regulator capable of delivering up to 3A into a load.

The LM2696 is capable of switching frequencies in the range of 100 kHz to 500 kHz and accepts input voltages from 4.5V to 24V. An internal soft-start and power-good flag are also provided to allow for simple sequencing between multiple regulators.

The operating conditions for the evaluation board are the following:

$$V_{IN} = 6V \text{ to } 24V$$

$$V_{OUT} = 2.5V$$

$$I_{OUT} = 0A \text{ to } 3A$$

$$f_{SW} = 250 \text{ kHz}$$

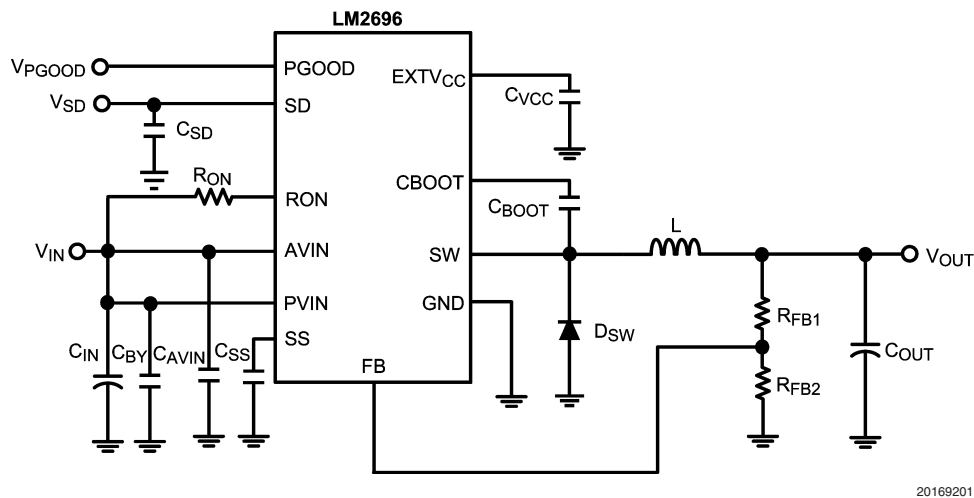


FIGURE 1. Evaluation Board Schematic

TABLE 1. Bill of Materials

ID	Part Number	Type	Size	Parameters	Qty	Vendor
U1	LM2696	3A Constant on-time Regulator	eTSSOP-16		1	NSC
L	MSS1260-682MX	Inductor	MSS1260	6.8 $\mu$ H, 4.9A ISAT	1	Coilcraft
C <sub>IN</sub>	EEUFC1V181	Capacitor	8 x 11.5	180 $\mu$ F, 35V	1	Sanyo
C <sub>BY</sub>	VJ0805Y104KXAM	Capacitor	0805	0.1 $\mu$ F	1	Vishay
C <sub>SS</sub>	VJ080JY103KXX	Capacitor	0805	0.01 $\mu$ F	1	Vishay
C <sub>VCC</sub>	VJ0805Y105JXACW1BC	Capacitor	0805	1 $\mu$ F	1	Vishay
C <sub>BOOT</sub>	VJ0805Y104KXAM	Capacitor	0805	0.1 $\mu$ F	1	Vishay
C <sub>AVIN</sub>	VJ0805Y105JXACW1BC	Capacitor	0805	1 $\mu$ F	1	Vishay
C <sub>OUT</sub>	TPSW476M010R0150	Capacitor	W	47 $\mu$ F, 10V, 150 m $\Omega$	1	AVX
C <sub>SD</sub>	VJ0805Y102KXXA	Capacitor	0805	1 nF	1	Vishay
R <sub>FB1</sub>	CRCW08051001F	Resistor	0805	1 k $\Omega$	1	Vishay
R <sub>FB2</sub>	CRCW08051001F	Resistor	0805	1 k $\Omega$	1	Vishay
R <sub>ON</sub>	CRCW08051433F	Resistor	0805	143 k $\Omega$	1	Vishay
D <sub>SW</sub>	CMSH3-40M-NST	Schottky Diode	SMB	40V@3A diode, V <sub>F</sub> = 0.55V	1	Central Semiconductor

## Introduction (Continued)

TABLE 1. Bill of Materials (Continued)

ID	Part Number	Type	Size	Parameters	Qty	Vendor
160-1026-02 -05-00	Solder Terminals		Terminals for $V_{IN}$ , GND and $V_{OUT}$		7	Wearnes

## Performance

Benchmark data has been taken from the evaluation board using the LM2696. Figure 2 shows an efficiency measurement taken with  $V_{IN}$  at 12V.

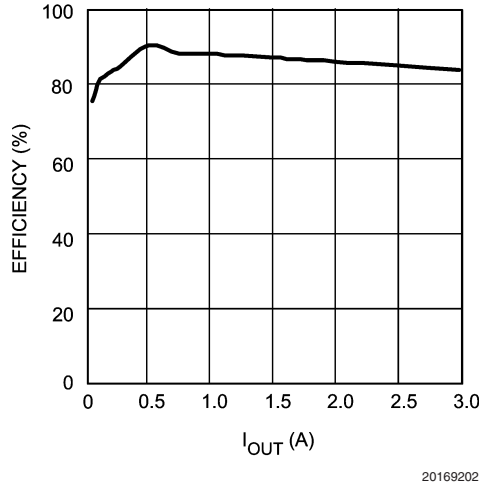


FIGURE 2. Efficiency with  $V_{IN} = 12V$

The advantage of the evaluation board is the ability to examine performance tradeoffs through substitution of parts. By careful selection of the components used, it is possible to optimize the application circuit for a given parameter. For instance, the inductor footprint has been designed to accommodate DO-3316 and MSS-1278 packages. The inductor selection would then be determined by the design constraints.

## Frequency Selection

The resistor connected to the  $R_{ON}$  pin sets the switching frequency of the LM2696. This resistor controls the current flowing into the  $R_{ON}$  pin and is directly related to the on-time pulse. Connecting a resistor from this pin to PVIN allows the switching frequency to remain constant as the input voltage changes. In normal operation this pin is approximately 0.65V above GND. In shutdown, this pin becomes a high impedance node to prevent current flow.

The value of  $R_{ON}$  may be expressed as:

$$R_{ON} = \frac{(V_{IN} - V_D) \times V_{OUT}}{k_{ON} \times f_{SW} \times V_{IN}} \times 10^6$$

Where  $R_{ON}$  is in k $\Omega$ ,  $f_{SW}$  is in kHz, and  $k_{ON}$  is in  $\mu A \cdot \mu s$

Under no condition should a bypass capacitor be connected to the  $R_{ON}$  pin. Doing so couples any AC perturbations into the pin and prevents proper operation.

For this demo board,  $R_{ON}$  is calculated as:

$$R_{ON} = \frac{(12V - 0.65V) \times 2.5V}{66 \mu A \times \mu s \times 250 \text{ kHz} \times 12V} \times 10^6 = 143 \text{ k}\Omega$$

## Inductor Selection

Typically an inductor is selected such that the maximum peak-to-peak ripple current is less than 30% of the maximum load current. The inductor current ripple ( $\Delta I_L$ ) may be expressed as:

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \cdot D}{L \cdot f_{SW}}$$

The inductor for this demo board was calculated as the following:

$$L = \frac{(12V - 2.5V) \times 0.21V}{(40\% \times 3A) \times 250 \text{ kHz}} \times 10^3 = 6.8 \mu H$$

A standard value of 10  $\mu H$  may be chosen.

The other characteristics of the inductor that should be taken into account are saturation current and core material. A shielded inductor or low profile unshielded inductor is recommended to reduce EMI.

Physical orientation of the inductor effects the parts stability. The inductor should be oriented such that the magnetic flux flows down through the center of the inductor and returns through the ground plane. Simply put, the inductor should be oriented such that terminal associated with the dot or label is connected to the switchnode.

## Output Capacitor

The output capacitor size and ESR have a direct affect on the stability of the loop. This is because the constant on-time control scheme works by sensing the output voltage ripple and switching appropriately.

The ripple voltage necessary at the feedback pin may be estimated using the following relationship:

$$\Delta V_{FB} \geq 0.057 \times f_{SW} + 35$$

Where  $f_{SW}$  is in kHz and  $\Delta V_{FB}$  is in mV.

## Output Capacitor (Continued)

This minimum ripple voltage is necessary in order for the comparator to initiate switching.

The ripple at the output may be calculated by multiplying the feedback ripple voltage by the gain seen through the feedback resistors. This gain H may be expressed as:

$$H = \frac{V_{OUT}}{V_{FB}} = \frac{V_{OUT}}{1.25V}$$

For this demo board, the ripple necessary at the feedback pin is calculated as:

$$\Delta V_{FB} \geq 21 \text{ mV} \geq 0.057 \times 250 \text{ kHz} + 35$$

Therefore, the ripple at the output is:

$$\Delta V_{OUT} = 42 \text{ mV} = 21 \text{ mV} \times \frac{2.5V}{1.25V}$$

Since the ripple current is calculated as 798 mA, the output capacitor must have an ESR not less than:

$$ESR = 36 \text{ m}\Omega = \frac{\text{Ripple\_Voltage}}{\text{Ripple\_Current}} = \frac{42 \text{ mV}}{1200 \text{ mA}}$$

Typically the best performance is obtained using POSCAPs, SP CAPs, tantalum, Niobium Oxide, or similar chemistry type capacitors. Low ESR ceramic capacitors may be used in conjunction with the RC feed forward scheme; however, the feed forward voltage at the feedback pin must be greater than 30mV. See the 'Ripple Feed Forward' section for more information.

## Ripple Feed Forward

An RC network may be used to eliminate the need for high ESR capacitors. Such a network is connected as shown in Figure 3.

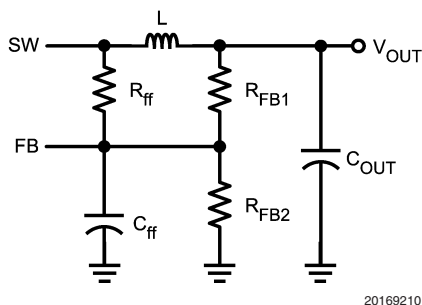


FIGURE 3. RC Feed Forward Network

The value of  $R_{ff}$  should be large in order to prevent any potential offset in  $V_{OUT}$ . Typically the value of  $R_{ff}$  is on the order of  $1M\Omega$  and the value of  $R_{FB1}$  should be less than

$10k\Omega$ . The large difference in resistor values minimizes output voltage offset errors in DCM. The value of the capacitor may be selected using the following relationship:

$$C_{ff\_MAX} = \frac{(V_{IN\_MIN} - V_{FB}) \cdot T_{ON\_MIN}}{0.03V \cdot R_{ff}}$$

Where the on-time ( $T_{ON\_MIN}$ ) is in  $\mu s$ , and the resistance ( $R_{ff}$ ) is in  $M\Omega$ .

If a ceramic output capacitor is used with this demo board,  $C_{ff\_MAX}$  is calculated as:

$$C_{ff\_MAX} = \frac{(6V - 1.25V) \times 0.42 \mu s}{0.03V \times 1 M\Omega} = 67 \text{ pF}$$

A standard value of 270 pF may be chosen.

## Feedback Resistors

In order to reduce noise at the feedback pin,  $R_{FB2}$  is typically on the order of  $1k\Omega$ . To calculate the value of  $R_{FB1}$ , one may use the relationship:

$$R_{FB1} = R_{FB2} \left( \frac{V_{OUT}}{V_{FB}} - 1 \right)$$

Where  $V_{FB}$  is the internal reference voltage (1.255V typical). The output voltage value can be set in a precise manner by taking into account the fact that the reference voltage is regulating the bottom of the output ripple as opposed to the average value. This relationship is shown in Figure 4.

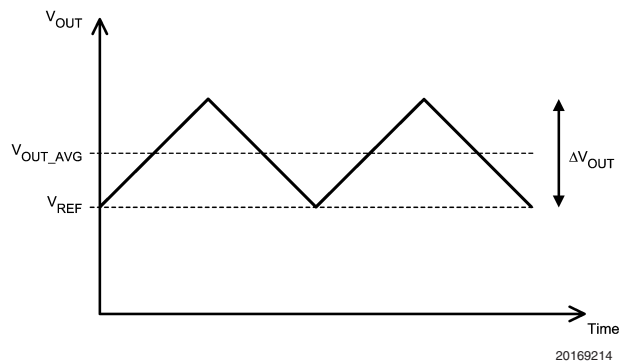


FIGURE 4. Average and Ripple Output Voltages

One should note that for high output voltages ( $>5V$ ), a load of approximately 15mA may be required for the output voltage to reach the desired value.

The resistors for this demo board were selected as:  $R_{FB2} = 1k\Omega$

$$R_{FB1} = 1 \text{ k}\Omega \left( \frac{2.5\text{V}}{1.25\text{V}} - 1 \right) = 1 \text{ k}\Omega$$

## Soft-Start Capacitor

The SS capacitor is used to slowly ramp the reference from 0V to its final value of 1.25V. The startup time may be calculated using the following relationship:

$$t_{SS} = \frac{1.25\text{V} \times C_{SS}}{I_{SS}} \times 10^3$$

or conversely, capacitance as a function of startup time:

$$C_{SS} = I_{SS} \frac{t_{SS}}{1.25\text{V}} \times 10^{-3}$$

Where  $I_{SS}$  is the soft-start pin source current (1  $\mu\text{A}$  typical) in  $\mu\text{A}$ ,  $C_{SS}$  is in  $\mu\text{F}$ , and  $t_{SS}$  is in ms.

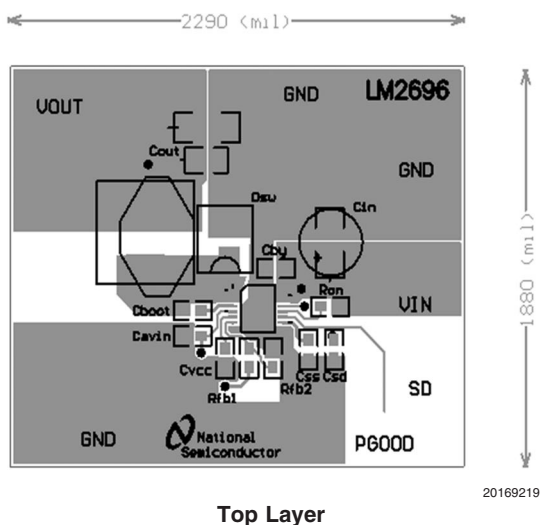
The soft-start capacitor was selected such that the soft start time would be approximately 12.5 ms. The capacitor value was calculated as:

$$C_{SS} = 0.01 \mu\text{F} = 1 \mu\text{A} \frac{12.5 \text{ ms}}{1.25\text{V}} \times 10^{-3}$$

## Shutdown

The state of the shutdown pin enables the device or places it in a sleep state. This pin has an internal pull-up and may be left floating or connected to a high logic level. Connecting this pin to GND will shutdown the part. This pin must be bypassed with a 1nF ceramic capacitor to ensure proper logic thresholds.

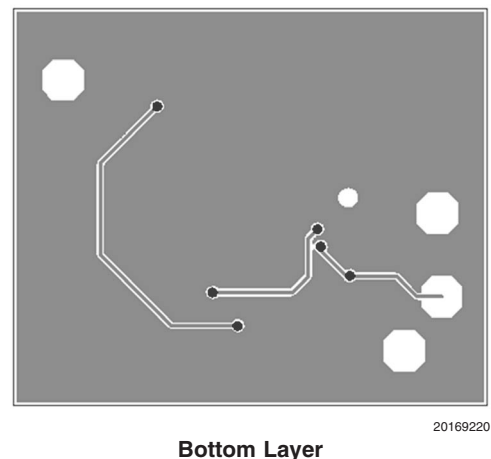
## PCB Layouts



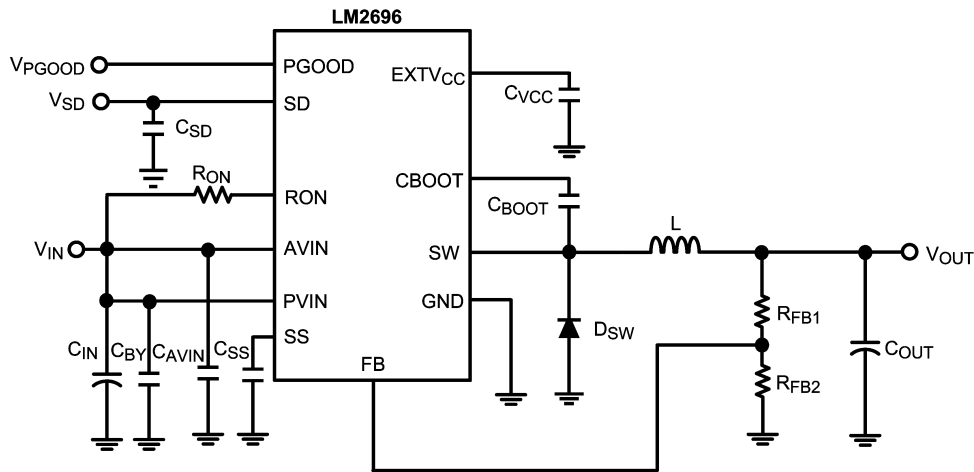
## Layout Guidelines

Good layout for DC-DC converters can be implemented by following a few simple design guidelines:

1. Place the power components (catch diode, inductor, and filter capacitors) close together. Make the traces between them as short and wide as possible.
2. Use wide traces between the power components and for power connections to the DC-DC converter circuit.
3. Connect the ground pins of the input and output filter capacitors and catch diode as close as possible using generous component-side copper fill as a pseudoground plane. Then, connect this to the ground plane through several vias.
4. Arrange the power components so that the switching loops curl in the same direction.
5. Separate noise sensitive traces, such as the voltage feedback path, from noisy traces associated with the power components.
6. Ensure a low-impedance ground for the converter IC.
7. Place the supporting components for the converter IC, including frequency selection components as close to the converter IC as possible, but away from noisy traces and the power components. Make their connections to the converter IC and its pseudoground plane as short as possible.
8. Place noise sensitive circuitry such as radio or modem blocks away from the DC-DC converter.



## Alternate Application Circuit



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5V to 2.5V Voltage Applications Circuit

TABLE 2.

ID	Part Number	Type	Size	Parameters	Qty	Vendor
U1	LM2696	3A Constant on-time Regulator	eTSSOP-16		1	NSC
L	MSS1260-103MX	Inductor	MSS1260	10 $\mu$ H, 4.0A ISAT	1	Coilcraft
C <sub>IN</sub>	EEUFC1V181	Capacitor	10 x 12.5	180 $\mu$ F, 35V, 90 m $\Omega$	1	Panasonic
C <sub>BY</sub>	VJ0805Y104KXAM	Capacitor	0805	0.1 $\mu$ F	1	Vishay
C <sub>SS</sub>	VJ080JY103KXX	Capacitor	0805	0.01 $\mu$ F	1	Vishay
C <sub>VCC</sub>	VJ0805Y105JXACW1BC	Capacitor	0805	1 $\mu$ F	1	Vishay
C <sub>BOOT</sub>	VJ0805Y104KXAM	Capacitor	0805	0.1 $\mu$ F	1	Vishay
C <sub>AVIN</sub>	VJ0805Y105JXACW1BC	Capacitor	0805	1 $\mu$ F	1	Vishay
C <sub>OUT</sub>	TPSC107M006R0075	Capacitor	C	100 $\mu$ F, 6V, 75 m $\Omega$	1	AVX
C <sub>SD</sub>	VJ0805Y102KXXA	Capacitor	0805	1 nF	1	Vishay
R <sub>FB1</sub>	CRCW08051651F	Resistor	0805	1.65 k $\Omega$	1	Vishay
R <sub>FB2</sub>	CRCW08051001F	Resistor	0805	1 k $\Omega$	1	Vishay
R <sub>ON</sub>	CRCW08051543F	Resistor	0805	154 k $\Omega$	1	Vishay
D <sub>SW</sub>	CMSH3-40M-NST	Schottky Diode	SMB	40V@3A diode, VF = 0.55V	1	Central Semiconductor
160-1026-02-05-00	Solder Terminals		Terminals for V <sub>IN</sub> , GND and V <sub>OUT</sub>		7	Wearnes

## Notes

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