LM2611 1.4MHz Cuk Converter

Check for Samples: LM2611

FEATURES

- **1.4MHz switching frequency**
- **Low $R_{DS(ON)}$ DMOS FET**
- **1mVp-p output ripple**
- **−5V at 300mA from 5V input**
- **Better regulation than a charge pump**
- **Uses tiny capacitors and inductors**
- **Wide input range: 2.7V to 14V**
- **Low shutdown current: <1µA**
- **5-lead SOT-23 package**

APPLICATIONS

- **MR Head Bias**
- **Digital camera CCD bias**
- **LCD bias**
- **GaAs FET bias**
- **Positive to negative conversion**

DESCRIPTION

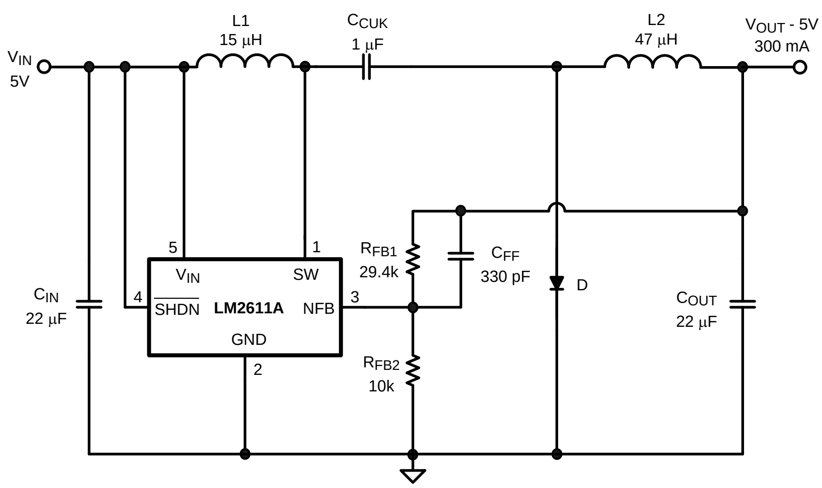
The LM2611 is a current mode, PWM inverting switching regulator. Operating from a 2.7 - 14V supply, it is capable of producing a regulated negative output voltage of up to −(36-$V_{IN(MAX)}$). The LM2611 utilizes an input and output inductor, which enables low voltage ripple and RMS current on both the input and the output. With a switching frequency of 1.4MHz, the inductors and output capacitor can be physically small and low cost. High efficiency is achieved through the use of a low $R_{DS(ON)}$ FET.

The LM2611 features a shutdown pin, which can be activated when the part is not needed to lower the Iq and save battery life. A negative feedback (NFB) pin provides a simple method of setting the output voltage, using just two resistors. Cycle-by-cycle current limiting and internal compensation further simplify the use of the LM2611.

The LM2611 is available is a small SOT23-5 package. It comes in two grades:

	Grade A	Grade B
Current Limit	1.2A	0.9A
$R_{DS(ON)}$	0.5Ω	0.7Ω

Typical Application Circuit



C_{IN}: TAIYO YUDEN X5R JMK325BJ226MM
C_{CUK}: TAIYO YUDEN X5R EMK316BJ105MF
C_{OUT}: TAIYO YUDEN X5R JMK325BJ226MM
D: ON SEMICONDUCTOR MBR0520
L1: SUMIDA CR32-150
L2: SUMIDA CR32-470

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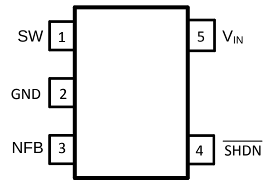
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

5-lead SOT-23 Package
Top View



See Package Number DBV0005A

Pin Description

Pin	Name	Function
1	SW	Drain of internal switch. Connect at the node of the input inductor and Cuk capacitor.
2	GND	Analog and power ground.
3	NFB	Negative feedback. Connect to output via external resistor divider to set output voltage.
4	$\overline{SHDN}$	Shutdown control input. V_{IN} = Device on. Ground = Device in shutdown.
5	V_{IN}	Analog and power input. Filter out high frequency noise with a 0.1 µF ceramic capacitor placed close to the pin.

Absolute Maximum Ratings (1)

V_{IN}	14.5V
SW Voltage	−0. 4V to 36V
NFB Voltage	+0. 4V to −6V
$\overline{SHDN}$ Voltage	−0. 4V to 14.5V
Maximum Junction Temperature	125°C
Power Dissipation (2)	Internally Limited
Lead Temperature	300°C
ESD Susceptibility (3)	
Human Body Model	2kV
Machine Model	200V

(1) Absolute maximum ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions for which the device is intended to be functional, but device parameter specifications may not be ensured. For specifications and test conditions, see the Electrical Characteristics.

(2) The maximum allowable power dissipation is a function of the maximum junction temperature, T_J(MAX), the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. See the Electrical Characteristics table for the thermal resistance of various layouts. The maximum allowable power dissipation at any ambient temperature is calculated using: P_D (MAX) = ($T_{J(MAX)} - T_A$)/θ_{JA}. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown.

(3) The human body model is a 100 pF capacitor discharged through a 1.5kΩ resistor into each pin. The machine model is a 200pF capacitor discharged directly into each pin.

Operating Conditions

Operating Junction Temperature Range	−40°C to +125°C
Storage Temperature	−65°C to +150°C
Supply Voltage	2.7V to 14V
θ_{JA}	256°C/W

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Electrical Characteristics

Specifications in standard type face are for T_J = 25°C and those with **boldface type** apply over the **Temperature Range** T_J = −40°C to +85°C, unless otherwise specified. V_{IN} = 5.0V and I_L = 0A, unless otherwise specified.

Symbol	Parameter	Conditions	Min [1]	Typ [2]	Max [1]	Units
V_{IN}	Input Voltage		**2.7**		**14**	V
I_{SW}	Switch Current Limit	Grade A	**1**	1.2	**2**	A
		Grade B	**0.7**	0.9		
R_{DSON}	Switch ON Resistance	Grade A		0.5	0.65	Ω
		Grade B		0.7	0.9	
$SHDN_{TH}$	Shutdown Threshold	Device enabled	**1.5**			V
		Device disabled			**0.50**	
I_{SHDN}	Shutdown Pin Bias Current	V_{SHDN} = 0V		0.0		µA
		V_{SHDN} = 5V		0.0	**1.0**	
NFB	Negative Feedback Reference	V_{IN} = 3V	**−1.205**	−1.23	**−1.255**	V
I_{NFB}	NFB Pin Bias Current	V_{NFB} =−1.23V	**−2.7**	−4.7	**−6.7**	µA
I_q	Quiescent Current	V_{SHDN} = 5V, Switching		1.8	**3.5**	mA
		V_{SHDN} = 5V, Not Switching		270	**500**	µA
		V_{SHDN} = 0V		0.024	**1**	µA
$\%V_{OUT}/ \Delta V_{IN}$	Reference Line Regulation	2.7V ≤ V_{IN} ≤ 14V		0.02		%/V
f_S	Switching Frequency		**1.0**	1.4	**1.8**	MHz
D_{MAX}	Maximum Duty Cycle		**82**	88		%
I_L	Switch Leakage	Not Switching V_{SW} = 5V			1	µA

(1) All limits are specified at room temperature (standard typeface) and at temperature extremes (bold typeface). All room temperature limits are 100% tested through statistical analysis. All limits at temperature extremes via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the expected value of the parameter.

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Typical Performance Characteristics

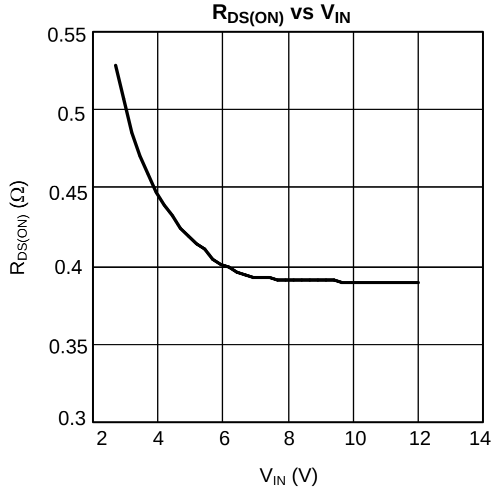
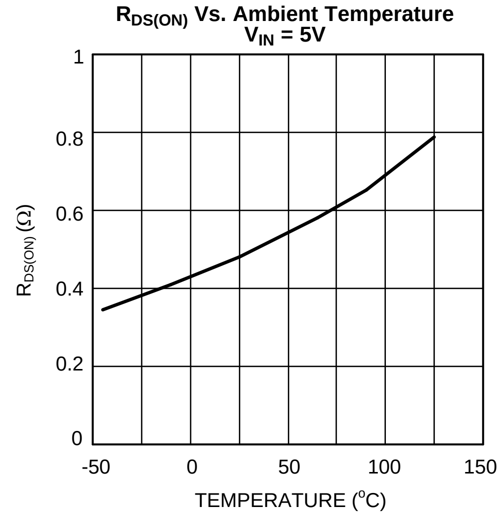


Figure 1.



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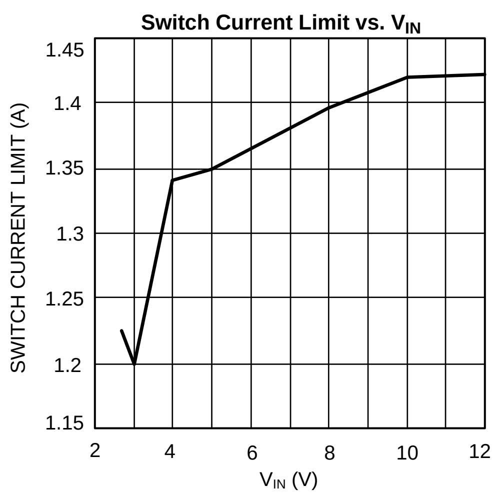

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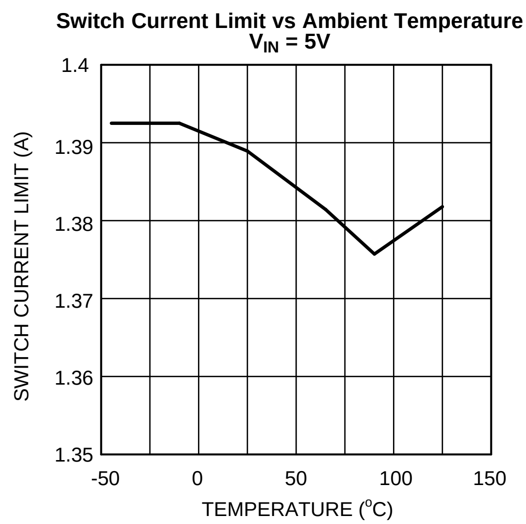

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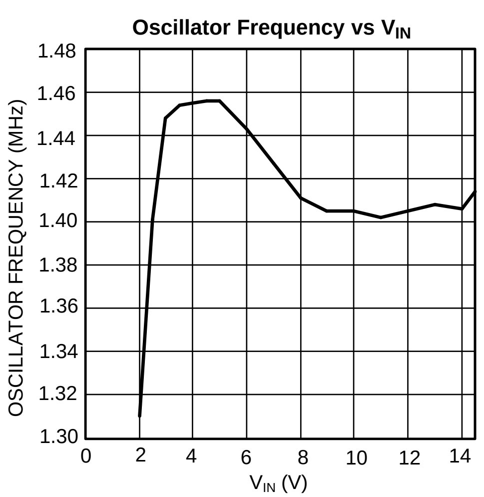

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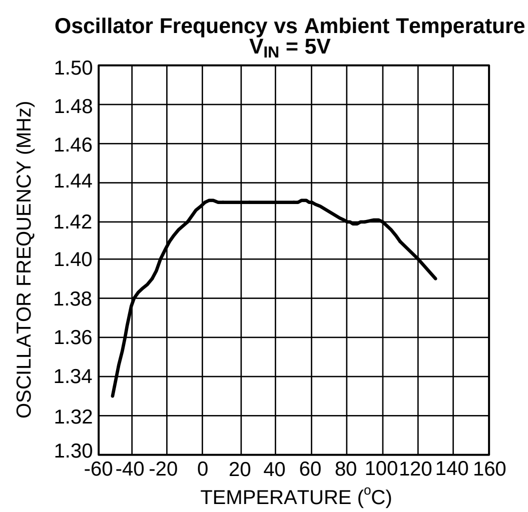

Figure 6.

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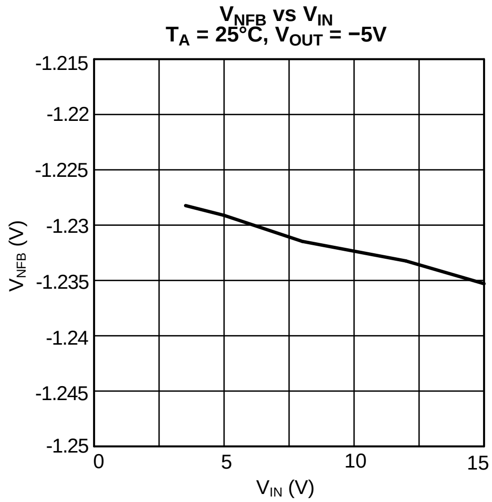
Typical Performance Characteristics (continued)



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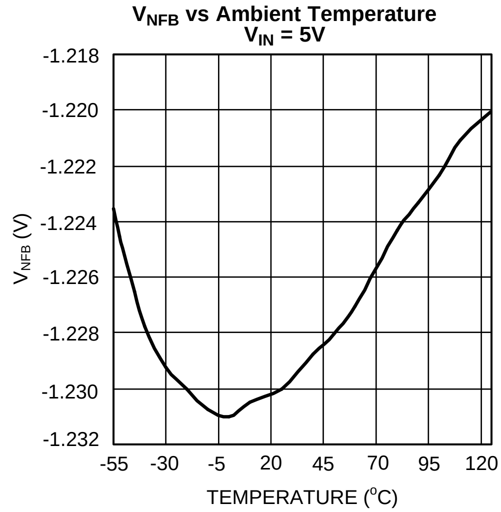

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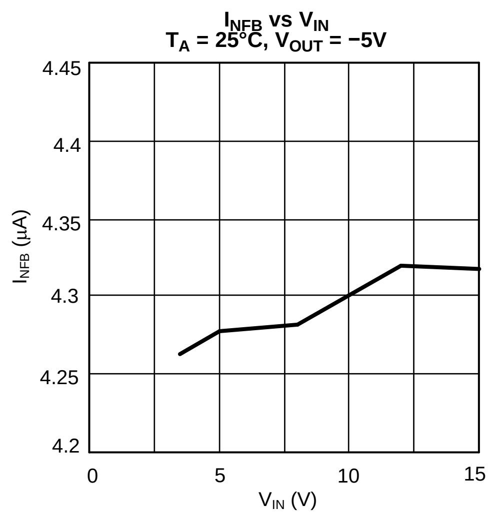

Figure 9.

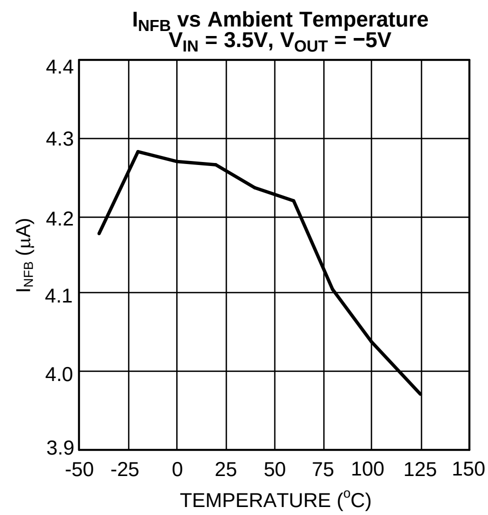

Figure 10.

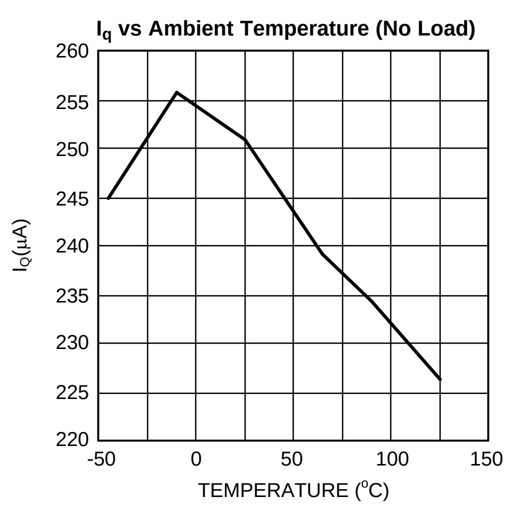

Figure 11.

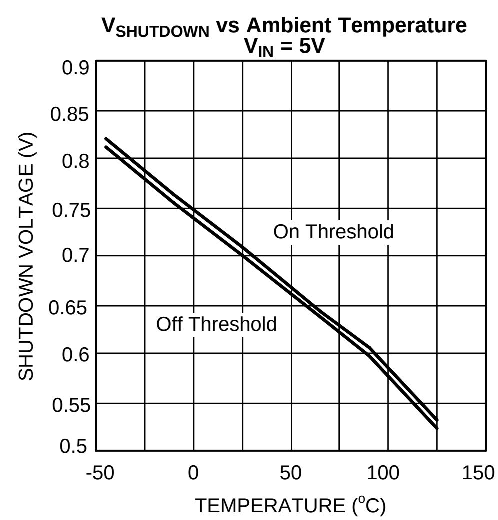

Figure 12.

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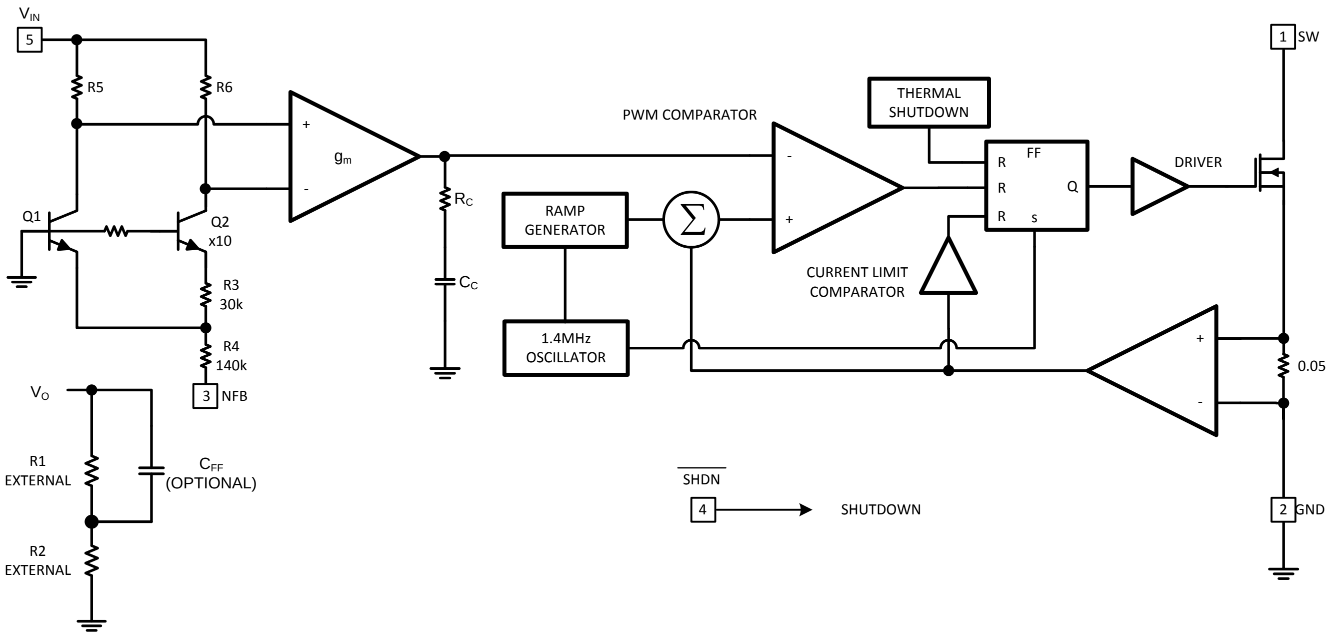
Block Diagram



Operation

Cuk Converter

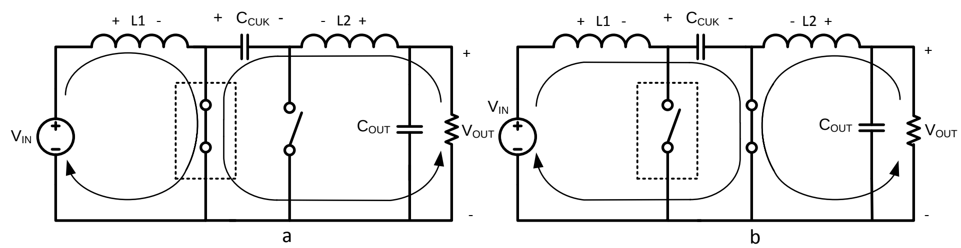


Figure 13. Operating Cycles of a Cuk Converter

The LM2611 is a current mode, fixed frequency PWM switching regulator with a −1.23V reference that makes it ideal for use in a Cuk converter. The Cuk converter inverts the input and can step up or step down the absolute value. Using inductors on both the input and output, the Cuk converter produces very little input and output current ripple. This is a significant advantage over other inverting topologies such as the buck-boost and flyback.

The operating states of the Cuk converter are shown in Figure 13. During the first cycle, the transistor switch is closed and the diode is open. L1 is charged by the source and L2 is charged by C_{CUK}, while the output current is provided by L2. In the second cycle, L1 charges C_{CUK} and L2 discharges through the load. By applying the volt-second balance to either of the inductors, the relationship of V_{OUT} to the duty cycle (D) is found to be:

$$V_{OUT} = -V_{IN} \frac{D}{1-D} \tag{1}$$

The following sections review the steady-state design of the LM2611 Cuk converter.

Output and Input Inductor

Figure 14 and Figure 15 show the steady-state voltage and current waveforms for L1 and L2, respectively. Referring to Figure 13 (a), when the switch is closed, V_{IN} is applied across L1. In the next cycle, the switch opens and the diode becomes forward biased, and V_{OUT} is applied across L1 (the voltage across C_{CUK} is $V_{IN} - V_{OUT}$.

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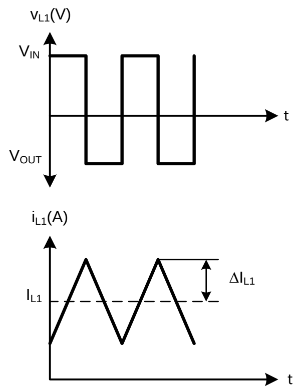

Figure 14. Voltage and Current Waveforms in Inductor L1 of a Cuk Converter

The voltage and current waveforms of inductor L2 are shown in Figure 15. During the first cycle of operation, when the switch is closed, V_{IN} is applied across L2. When the switch opens, V_{OUT} is applied across L2.

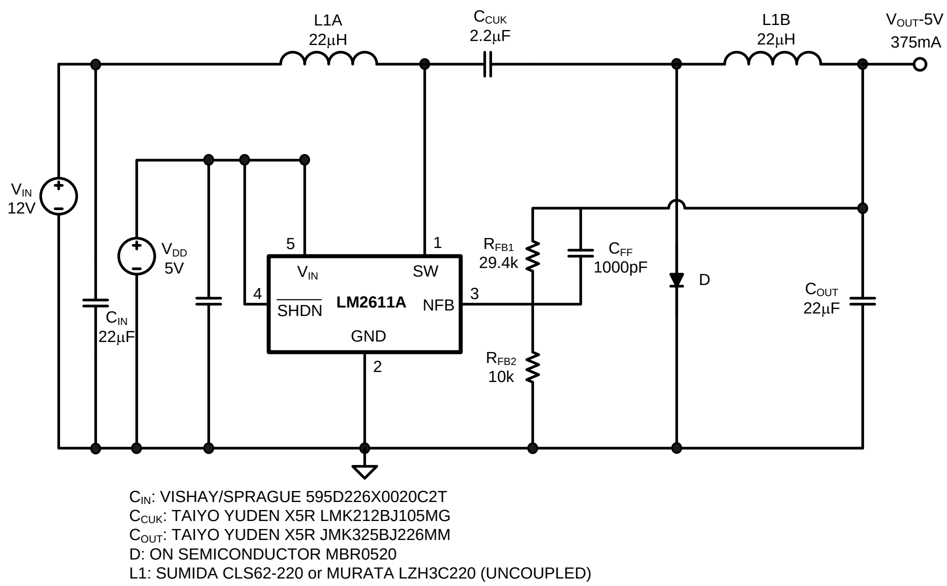

Figure 15. Voltage and Current Waveforms in Inductor L2 of a Cuk Converter

The following equations define values given in Figure 14 and Figure 15:

$$I_{L2} = I_{OUT} \tag{2}$$

$$\Delta i_{L2} = \frac{V_{IN} \times D \times T_S}{2 \times L_2} \tag{3}$$

$$I_{L1} = \frac{D}{1-D} I_{L2} = \frac{D}{1-D} I_{OUT} \tag{4}$$

$$\Delta i_{L1} = \frac{V_{IN} \times D \times T_S}{2 \times L_1} \tag{5}$$

Use these equations to choose correct core sizes for the inductors. The design of the LM2611's internal compensation assumes L1 and L2 are equal to 10 - 22 µH, thus it is recommended to stay within this range.

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Switch Current Limit

The LM2611 incorporates a separate current limit comparator, making current limit independent of any other variables. The current limit comparator measures the switch current versus a reference that represents current limit. If at any time the switch current surpasses the current limit, the switch opens until the next switching period. To determine the maximum load for a given set of conditions, both the input and output inductor currents must be considered. The switch current is equal to $i_{L1} + i_{L2}$, and is drawn in Figure 16. In summary:

$$i_{SW(PEAK)} = i_{L1} + i_{L2} = I_{L1} + I_{L2} + \Delta i_{L1} + \Delta i_{L2}$$
$$= I_{OUT} \times \left(1 + \frac{D}{(1-D)}\right) + \frac{V_{IN} \times D \times T_S}{2} \times \left(\frac{1}{L_1} + \frac{1}{L_2}\right) \quad (6)$$

$I_{SW(PEAK)}$ must be less than the current limit (1.2A typical), but will also be limited by the thermal resistivity of the LM2611's SOT23-5 package (θ_{JA} = 265°C/W).

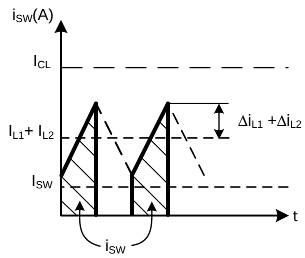

Figure 16. Switch Current Waveform in a Cuk Converter. The peak value is equal to the sum of the average currents through L1 and L2 and the average-to-peak current ripples through L1 and L2.

Input Capacitor

The input current waveform to a Cuk converter is continuous and triangular, as shown in Figure 14. The input inductor insures that the input capacitor sees fairly low ripple currents. However, as the input inductor gets smaller, the input ripple goes up. The RMS current in the input capacitor is given by:

$$I_{CIN(RMS)} = \frac{1}{2\sqrt{3}} \frac{V_{IN}}{f_s L_1 \left(\frac{Vi}{|V_o|} + 1\right)} \quad (7)$$

The input capacitor should be capable of handling the RMS current. Although the input capacitor is not so critical in a Cuk converter, a 10µF or higher value good quality capacitor prevents any impedance interactions with the input supply. A 0.1µF or 1µF ceramic bypass capacitor is also recommended on the V_{IN} pin (pin 5) of the IC. This capacitor must be connected very close to pin 5 (within 0.2 inches).

Output Capacitor

Like the input current, the output current is also continuous, triangular, and has low ripple (see I_{L2} in Figure 15). The output capacitor must be rated to handle its RMS current:

$$I_{COUT(RMS)} = \frac{\Delta i_{L2}}{\sqrt{3}} = \frac{1}{2\sqrt{3}} \frac{V_{IN}}{f_s L_2 \left(\frac{Vi}{|V_o|} + 1\right)} \quad (8)$$

For example, $I_{COUT(RMS)}$ can range from 30mA to 180mA with 10µH ≤ $L_{1,2}$ ≤ 22µH, −10V ≤ V_{OUT} ≤ −3.3V, and 2.7V ≤ V_{IN} ≤ 30V (V_{IN} may be 30V if using separate power and analog supplies, see Split Supply Operation in the APPLICATIONS section). The worst case conditions are with $L_{1,2}$, $V_{OUT(MAX)}$, and $V_{IN(MAX)}$. Many capacitor technologies will provide this level of RMS current, but ceramic capacitors are ideally suited for the LM2611. Ceramic capacitors provide a good combination of capacitance and equivalent series resistance (ESR) to keep the zero formed by the capacitance and ESR at high frequencies. The ESR zero is calculated as:

$$f_{ESR} = \frac{1}{2\pi C_{OUT} ESR} \text{ (Hz)} \quad (9)$$

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A general rule of thumb is to keep f_{ESR} > 80kHz for LM2611 Cuk designs. Low ESR tantalum capacitors will usually be rated for at least 180mA in a voltage rating of 10V or above. However the ESR in a tantalum capacitor (even in a low ESR tantalum capacitor) is much higher than in a ceramic capacitor and could place f_{ESR} low enough to cause the LM2611 to run unstable.

Improving Transient Response/Compensation

The compensator in the LM2611 is internal. However, a zero-pole pair can be added to the open loop frequency response by inserting a feed forward capacitor, C_{FF}, in parallel to the top feedback resistor (R_{FB1}). Phase margin and bandwidth can be improved with the added zero-pole pair. This inturn will improve the transient response to a step load change (see Figure 17 and Figure 18). The position of the zero-pole pair is a function of the feedback resistors and the capacitor value:

$$\omega_Z = \frac{1}{C_{FF}R_{FB1}} \text{ (rad/s)} \tag{10}$$

$$\omega_p = \frac{1}{C_{FF}R_{FB1}}\left(1+\frac{R_{FB1}}{R_{FB2}}\right) \text{ (rad/s)} \tag{11}$$

The optimal position for this zero-pole pair will vary with circuit parameters such as D, I_{OUT}, C_{OUT}, L1, L2, and C_{CUK}. For most cases, the value for the zero frequency is between 5 kHz to 20 kHz. Notice how the pole position, ω_p, is dependant on the feedback resistors R_{FB1} and R_{FB2}, and therefore also dependant on the output voltage. As the output voltage becomes closer to −1.26V, the pole moves towards the zero, tending to cancel it out. If the absolute magnitude of the output voltage is less than 3.3V, adding the zero-pole pair will not have much effect on the response.

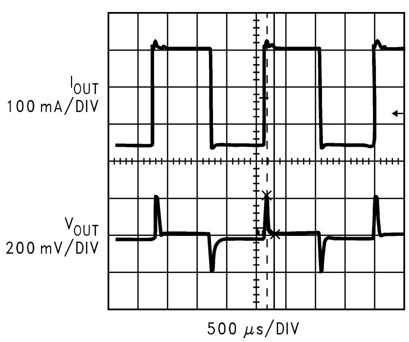

Figure 17. 130mA to 400mA Transient Response of the circuit in 5V to -5V Inverting Converter with C_{FF}= 1nF

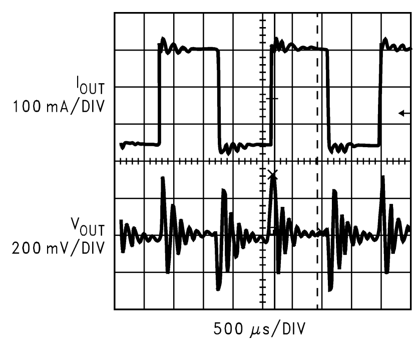

Figure 18. 130mA to 400mA Transient Response of the circuit in 5V to -5V Inverting Converter with C_{FF} disconnected

Hysteretic Mode

As the output current decreases, there will come a point when the energy stored in the Cuk capacitor is more than the energy required by the load. The excess energy is absorbed by the output capacitor, causing the output voltage to increase out of regulation. The LM2611 detects when this happens and enters a pulse skipping, or hysteretic mode. In hysteretic mode, the output voltage ripple will increase, as illustrated in Figure 19 and Figure 20.

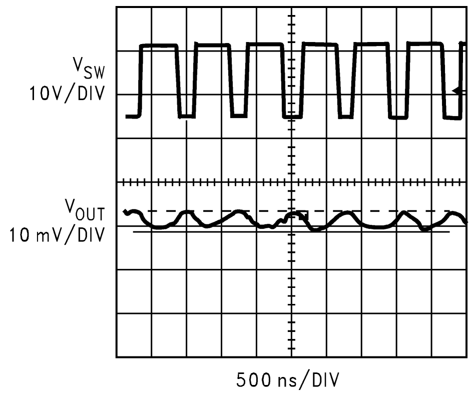

Figure 19. The LM2611 in PWM mode has very low ripple

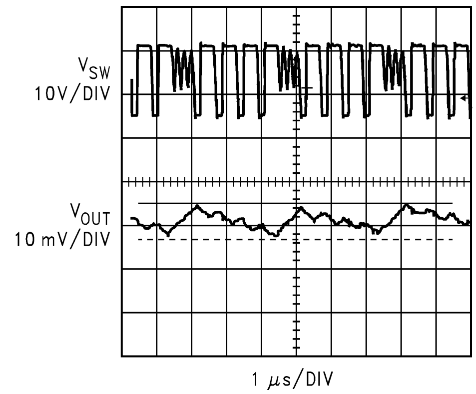

Figure 20. At low loads, the LM2611 enters a pulse-skipping mode. The output ripple slightly increases in this mode.

Thermal Shutdown

If the junction temperature of the LM2611 exceeds 163°C, it will enter thermal shutdown. In thermal shutdown, the part deactivates the driver and the switch turns off. The switch remains off until the junction temperature drops to 155°C, at which point the part begins switching again. It will typically take 10ms for the junction temperature to drop from 163°C to 155°C with the switch off.

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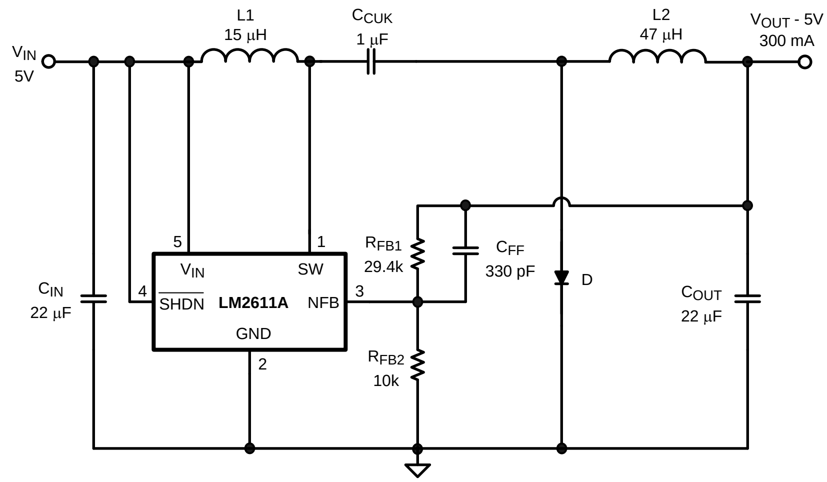
APPLICATION INFORMATION

Application Circuits

5V to -5V Inverting Converter



C_{IN}: TAIYO YUDEN X5R JMK325BJ226MM
C_{CUK}: TAIYO YUDEN X5R EMK316BJ105MF
C_{OUT}: TAIYO YUDEN X5R JMK325BJ226MM
D: ON SEMICONDUCTOR MBR0520
L1: SUMIDA CR32-150
L2: SUMIDA CR32-470

Figure 21. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 5V

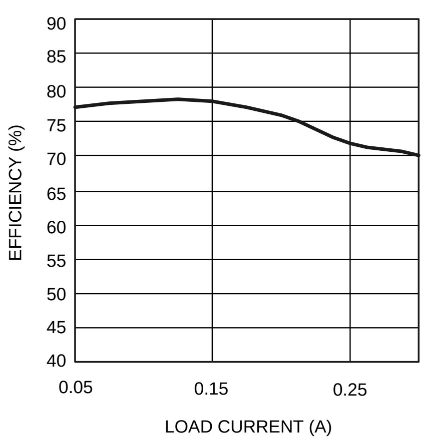


Figure 22. Efficiency vs Load Current

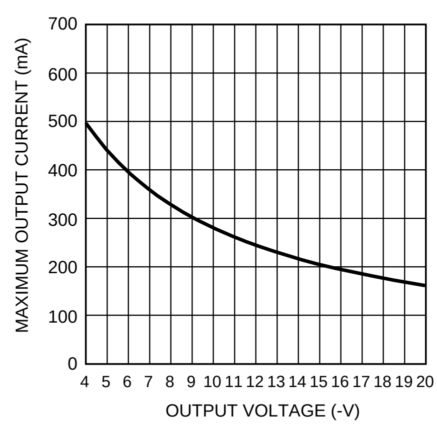


Figure 23. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 5V

9V to -5V Inverting Converter

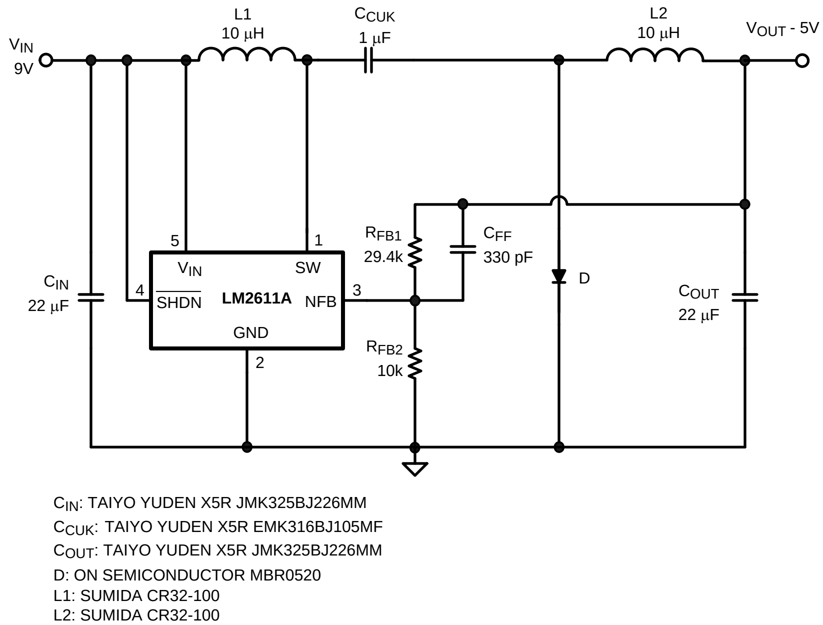


Figure 24. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 9V

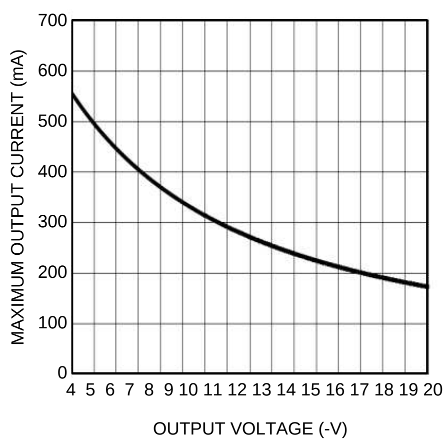


Figure 25. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 9V

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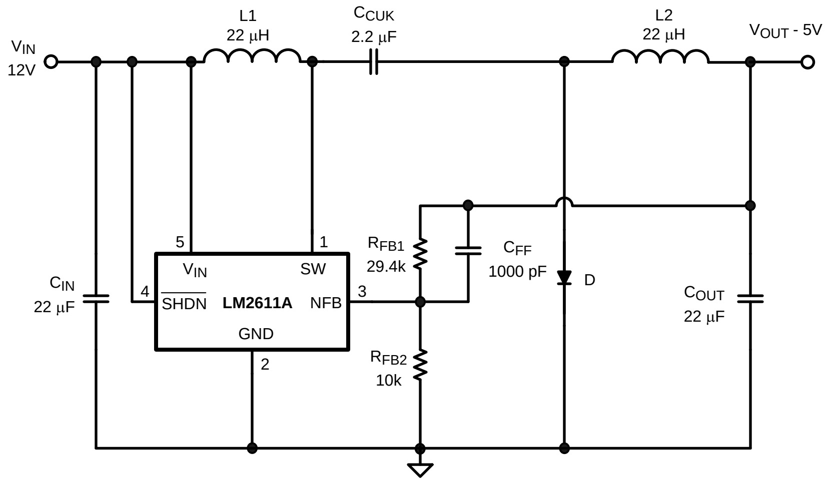
12V to -5V Inverting Converter



C_{IN}: TAIYO YUDEN X5R JMK325BJ226MM
C_{CUK}: TAIYO YUDEN X5R EMK316BJ225ML
C_{OUT}: TAIYO YUDEN X5R JMK325BJ226MM
D: ON SEMICONDUCTOR MBR0520
L1: SUMIDA CR32-220
L2: SUMIDA CR32-220

Figure 26. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 12V

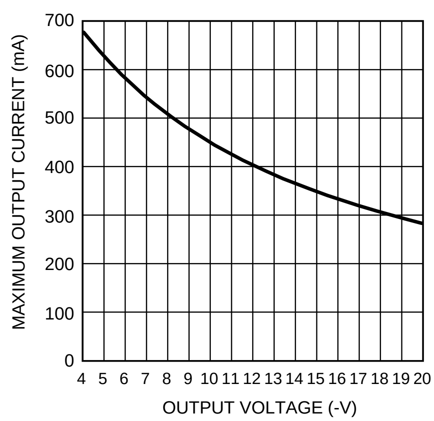


Figure 27. The Maximum Output Current vs Output Voltage (Adjust R_{FB2} to Set a Different Output Voltage) When The Input Voltage is 12V

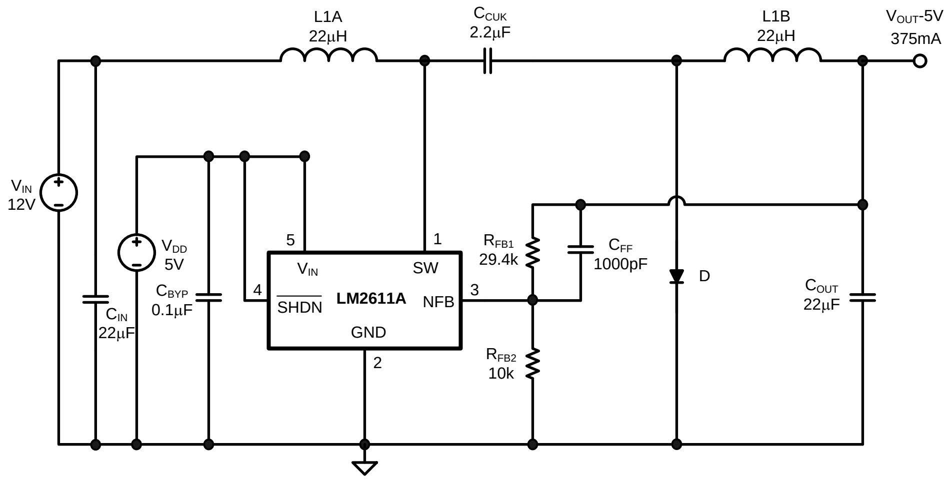


Figure 28. LM2611 Operating with Separate Power and Biasing Supplies

Split Supply Operation

The LM2611 may be operated with separate power and bias supplies. In the circuit shown in Figure 28. V_{IN} is the power supply that the regulated voltage is derived from, and V_{DD} is a low current supply used to bias the LM2611. Conditions for the supplies are:

$$2.7V \leq V_{DD} \leq 14V \tag{12}$$

$$0V \leq V_{IN} \leq (36 - |V_{OUT}|)\ V \tag{13}$$

As the input voltage increases, the maximum output current capacbility increases. Using a separate, higher voltage supply for power conversion enables the LM2611 to provide higher output currents than it would with a single supply that is limited in voltage by $V_{IN(MAX)}$.

Shutdown/Soft Start

A soft start circuit is used in switching power supplies to limit the input inrush current upon start-up. Without a soft-start circuit, the inrush current can be several times the steady-state load current, and thus apply unnecessary stress to the input source. The LM2611 does not have soft-start circuitry, but implementing the circuit in Figure 29 will lower the peak inrush current. The $\overline{SHDN}$ pin is coupled to the output through C_{SS}. The LM2611 is toggled between shutdown and run states while the output slowly decreases to its steady-state value. The energy required to reach steady-state is spread over a longer time and the input current spikes decrease (see Figure 30 and Figure 31).

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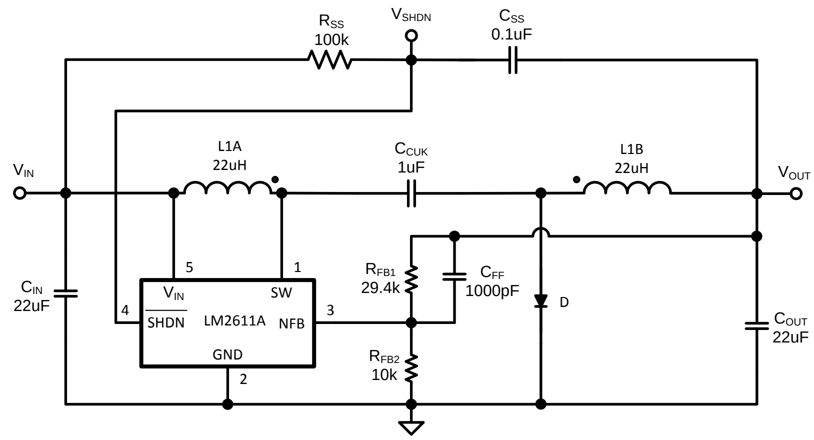


Figure 29. LM2611 Soft Start Circuit

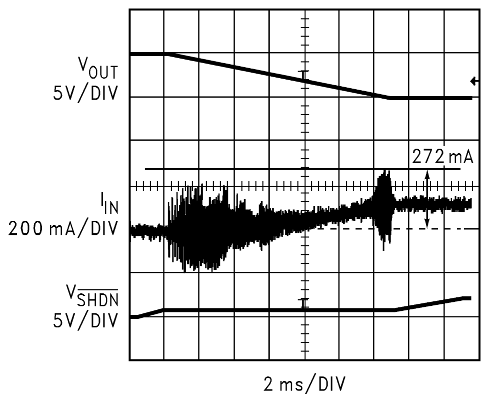


Figure 30. Start-Up Waveforms with Soft Start Circuit

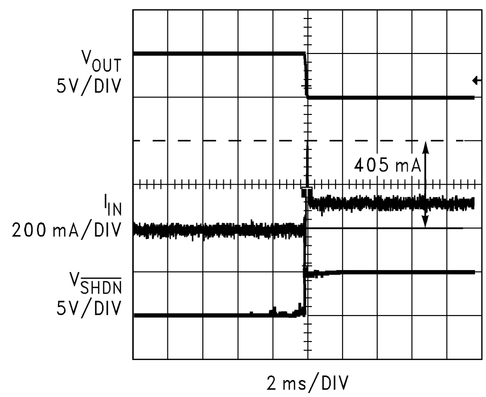
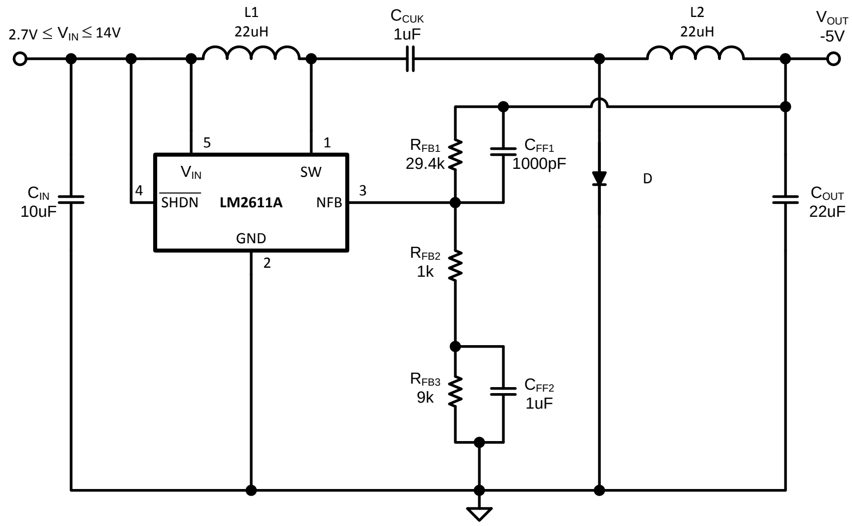


Figure 31. Start-Up Waveforms without Soft Start Circuit

High Duty Cycle/Load Current Operation

The circuit in Figure 32 is used for high duty cycles (D > 0.5) and high load currents. The duty cycle will begin to increase beyond 50% as the input voltage drops below the absolute magnitude of the output voltage. R_{FB3} and C_{FF2} are added to the feedback network to introduce a low frequency lag compensation (pole-zero pair) necessary to stabilize the circuit under the combination of high duty cycle and high load currents.



C_{IN}: TAIYO YUDEN X5R JMK325BJ106MN
C_{CUK}: TAIYO YUDEN X5R TMK316BJ105ML
C_{OUT}: TAIYO YUDEN X5R JMK325BJ226MM
D: ON SEMICONDUCTOR MBR0520
L1, L2: SUMIDA CDRH6D28-220

Figure 32. LM2611 High Current Schematic

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REVISION HISTORY

Changes from Revision H (April 2013) to Revision I	Page
• Changed layout of National Data Sheet to TI format	16

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
LM2611AMF	ACTIVE	SOT-23	DBV	5	1000	TBD	Call TI	Call TI	-40 to 125	S40A	Samples
LM2611AMF/NOPB	ACTIVE	SOT-23	DBV	5	1000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	S40A	Samples
LM2611AMFX	ACTIVE	SOT-23	DBV	5	3000	TBD	Call TI	Call TI	-40 to 125	S40A	Samples
LM2611AMFX/NOPB	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	S40A	Samples
LM2611BMF	ACTIVE	SOT-23	DBV	5	1000	TBD	Call TI	Call TI	-40 to 125	S40B	Samples
LM2611BMF/NOPB	ACTIVE	SOT-23	DBV	5	1000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	S40B	Samples
LM2611BMFX	ACTIVE	SOT-23	DBV	5	3000	TBD	Call TI	Call TI	-40 to 125	S40B	Samples
LM2611BMFX/NOPB	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	S40B	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Top-Side Marking for that device.

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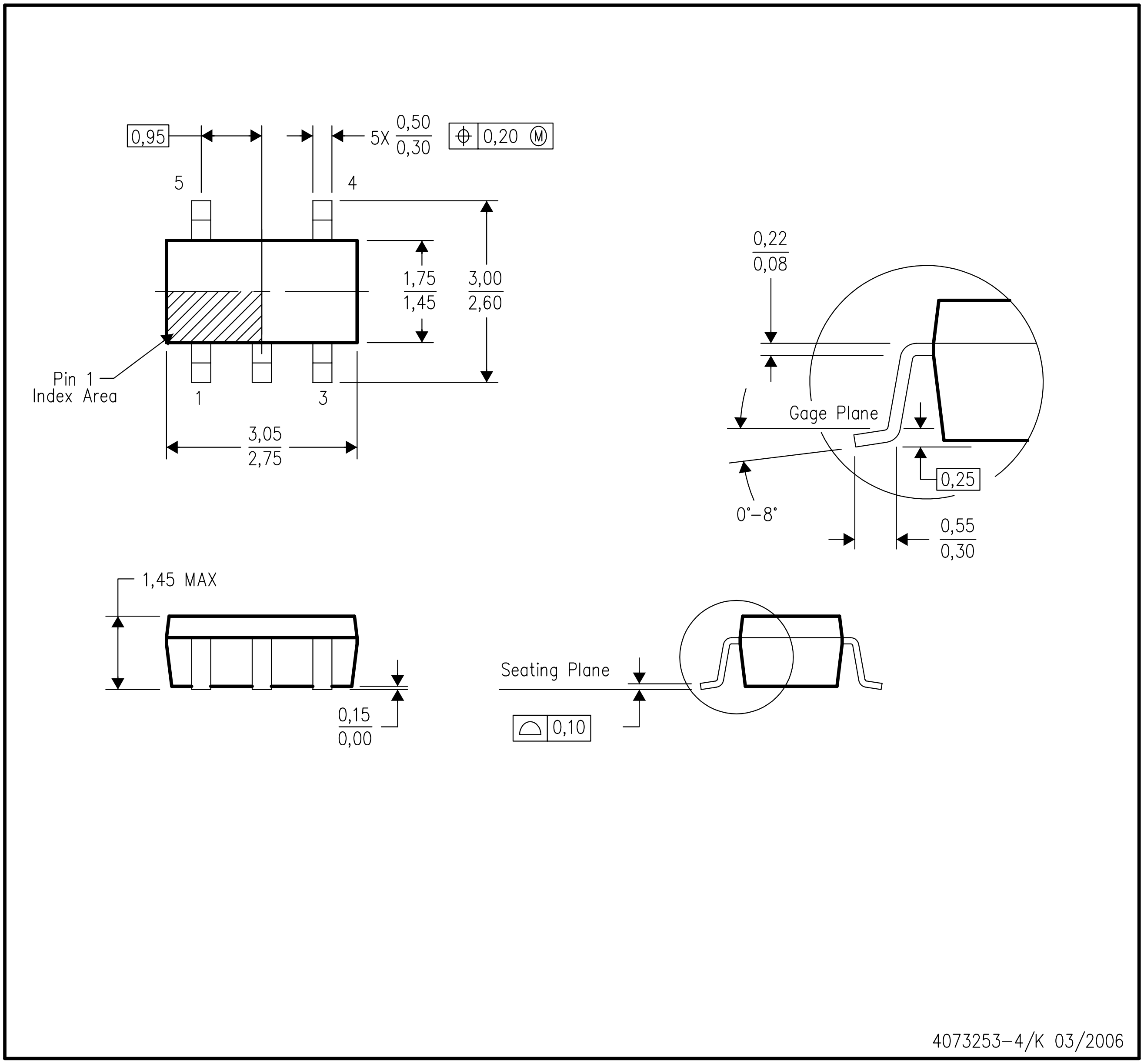
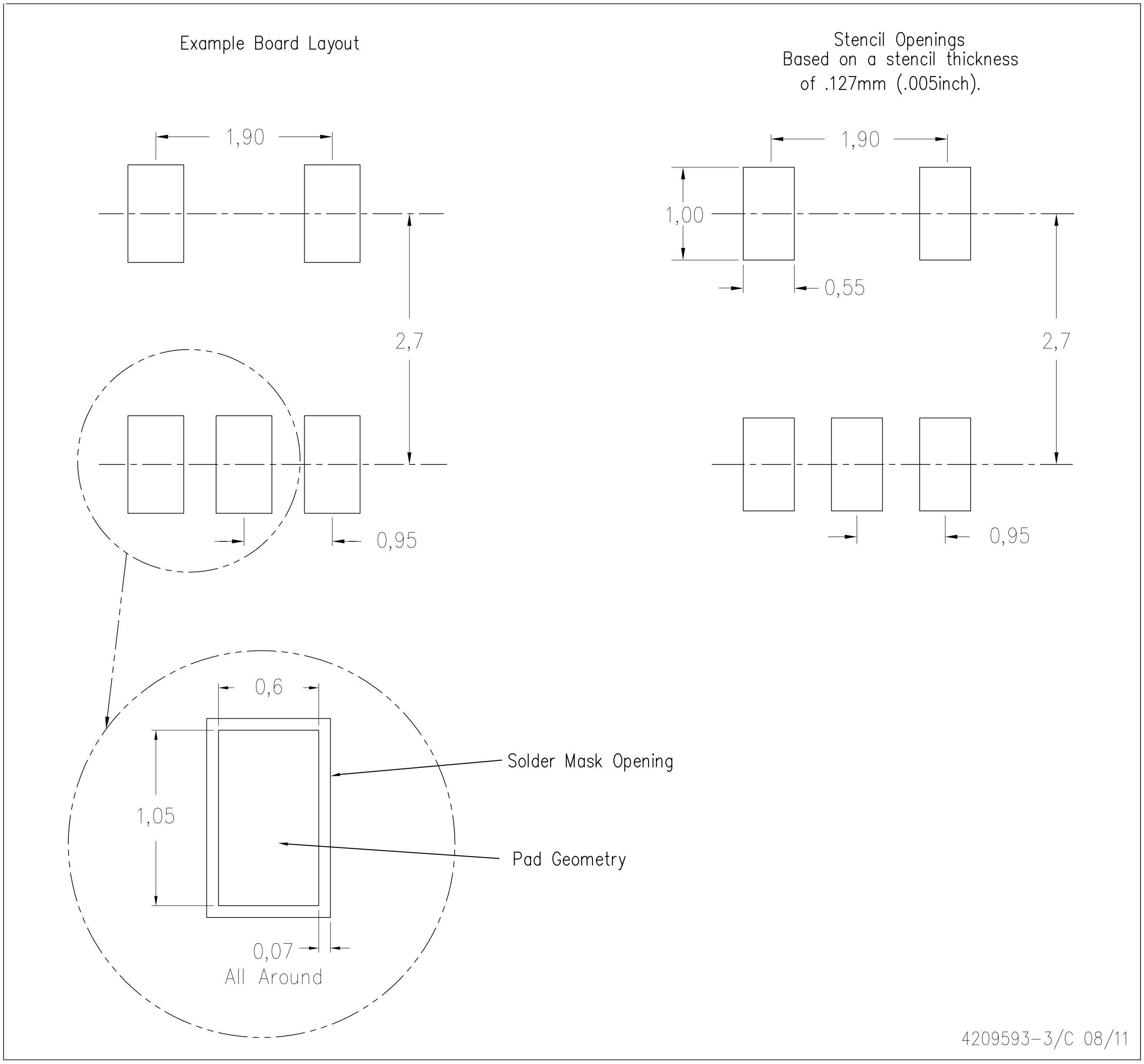


NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO-178 Variation AA.

DBV (R-PDSO-G5) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC-7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

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