LM25011, LM25011Q, LM25011A, LM25011AQ
42V 2A Constant On-Time Switching Regulator With Adjustable Current Limit

Check for Samples: LM25011, LM25011-Q1

FEATURES

- **LM25011Q is an Automotive Grade Product that is AEC-Q100 Grade 1 Qualified (-40°C to +125°C Operating Junction Temperature)**
- **LM25011A Allows Low Dropout Operation at High Switching Frequency**
- **Input Operating Voltage Range: 6V to 42V**
- **Absolute Maximum Input Rating: 45V**
- **Integrated 2A N-Channel Buck Switch**
- **Adjustable Current Limit Allows for Smaller Inductor**
- **Adjustable Output Voltage from 2.51V**
- **Minimum Ripple Voltage at V_{OUT}**
- **Power Good Output**
- **Switching Frequency Adjustable to 2 MHz**
- **COT Topology Features:**
  - **Switching Frequency Remains Nearly Constant with Load Current and Input Voltage Variations**
  - **Ultra-Fast Transient Response**
  - **No Loop Compensation Required**
  - **Stable Operation with Ceramic Output Capacitors**
  - **Allows for Smaller Output Capacitor and Current Sense Resistor**
- **Adjustable Soft-Start Timing**

- **Thermal Shutdown**
- **Precision 2% Feedback Reference**
- **Package: 10-Pin, VSSOP**

DESCRIPTION

The LM25011 Constant On-time Step-Down Switching Regulator features all the functions needed to implement a low cost, efficient, buck bias regulator capable of supplying up to 2A of load current. This high voltage regulator contains an N-Channel Buck switch, a startup regulator, current limit detection, and internal ripple control. The constant on-time regulation principle requires no loop compensation, results in fast load transient response, and simplifies circuit implementation. The operating frequency remains constant with line and load. The adjustable valley current limit detection results in a smooth transition from constant voltage to constant current mode when current limit is reached, without the use of current limit foldback. The PGD output indicates the output voltage has increased to within 5% of the expected regulation value. Additional features include: Low output ripple, VIN under-voltage lock-out, adjustable soft-start timing, thermal shutdown, gate drive pre-charge, gate drive under-voltage lock-out, and maximum duty cycle limit.

The LM25011A has a shorter minimum off-time than the LM25011, which allows for higher frequency operation at low input voltages.
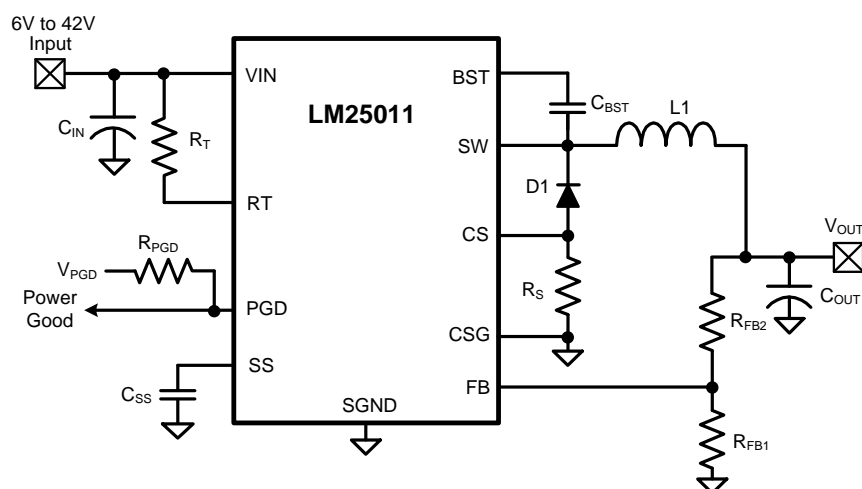
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.
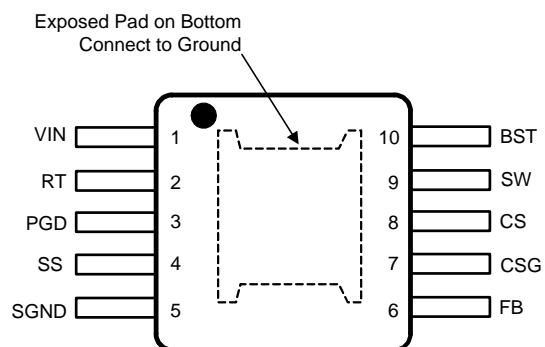All trademarks are the property of their respective owners.

TYPICAL APPLICATION

CONNECTION DIAGRAM

**Figure 1. Top View
10-Lead VSSOP**

Product Folder Links: *LM25011 LM25011-Q1*

PIN DESCRIPTIONS

Pin No.	Name	Description	Application Information
1	VIN	Input supply voltage	Operating input range is 6V to 42V. Transient capability is 45V. A low ESR capacitor must be placed as close as possible to the VIN and SGND pins.
2	RT	On-time Control	An external resistor from VIN to this pin sets the buck switch on-time, and the switching frequency.
3	PGD	Power Good	Logic output indicates when the voltage at the FB pin has increased to above 95% of the internal reference voltage. Hysteresis is provided. An external pull-up resistor to a voltage less than 7V is required.
4	SS	Soft-Start	An internal current source charges an external capacitor to provide the soft-start function.
5	SGND	Signal Ground	Ground for all internal circuitry other than the current limit sense circuit.
6	FB	Feedback	Internally connected to the regulation comparator. The regulation level is 2.51V.
7	CSG	Current Sense Ground	Ground connection for the current limit sensing circuit. Connect to ground and to the current sense resistor.
8	CS	Current sense	Connect to the current sense resistor and the anode of the free-wheeling diode.
9	SW	Switching Node	Internally connected to the buck switch source. Connect to the external inductor, cathode of the free-wheeling diode, and bootstrap capacitor.
10	BST	Bootstrap capacitor connection of the buck switch gate driver.	Connect a 0.1 µF capacitor from SW to this pin. The capacitor is charged during the buck switch off-time via an internal diode.

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.

ABSOLUTE MAXIMUM RATINGS[1]

VIN to SGND (T$_J$ = 25°C)	45V
BST to SGND	52V
SW to SGND (Steady State)	-1.5V to 45V
BST to SW	-0.3V to 7V
CS to CSG	-0.3V to 0.3V
CSG to SGND	-0.3V to 0.3V
PGD to SGND	-0.3V to 7V
SS to SGND	-0.3V to 3V
RT to SGND	-0.3V to 1V
FB to SGND	-0.3V to 7V
ESD Rating, Human Body Model[2]	2kV
Storage Temperature Range	-65°C to +150°C
For soldering specs, see www.ti.com/packaging.	
Junction Temperature	150°C

(1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For guaranteed specifications and test conditions, see the Electrical Characteristics.
(2) The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

OPERATING RATINGS[1]

VIN Voltage	6.0V to 42V
Junction Temperature	−40°C to +125°C

(1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For guaranteed specifications and test conditions, see the Electrical Characteristics.

LM25011, LM25011-Q1

ELECTRICAL CHARACTERISTICS

Specifications with standard type are for T_J = 25°C only; limits in **boldface type** apply over the full Operating Junction Temperature (T_J) range. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T_J = 25°C, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V_{IN} = 12V, R_T = 50 kΩ.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Input (VIN Pin)						
I_{IN}	Input operating current	Non-switching, FB = 3V		1200	**1600**	µA
$UVLO_{VIN}$	VIN under-voltage lock-out threshold	VIN Increasing	**4.6**	5.3	**5.9**	V
	VIN under-voltage lock-out threshold hysteresis			200		mV
Switch Characteristics						
$R_{DS(ON)}$	Buck Switch $R_{DS(ON)}$	I_{TEST} = 200 mA		0.3	**0.6**	Ω
$UVLO_{GD}$	Gate Drive UVLO	BST-SW	**2.4**	3.4	**4.4**	V
	$UVLO_{GD}$ Hysteresis			350		mV
	Pre-charge switch voltage	I_{TEST} = 10 mA into SW pin		1.4		V
	Pre-charge switch on-time			120		ns
Soft-Start Pin						
V_{SS}	Pull-up voltage			2.51		V
I_{SS}	Internal current source			10		µA
V_{SS-SH}	Shutdown Threshold		**70**	140		mV
Current Limit						
V_{ILIM}	Threshold voltage at CS		**-146**	-130	**-115**	mV
	CS bias current	FB = 3V		-120		µA
	CSG bias current	FB = 3V		-35		µA
On Timer, RT Pin						
t_{ON} - 1	On-time	V_{IN} = 12V, R_T = 50 kΩ	**150**	200	**250**	ns
t_{ON} - 2	On-time	V_{IN} = 32V, R_T = 50 kΩ		75		ns
t_{ON} - 3	On-time (current limit) LM25011	V_{IN} = 12V, R_T = 50 kΩ		100		ns
t_{ON} - 3	On-time (current limit) LM25011A	V_{IN} = 12V, R_T = 50 kΩ		200		ns
t_{ON} - 4	On-time	V_{IN} = 12V, R_T = 301 kΩ		1020		ns
t_{ON} - 5	On-time	V_{IN} = 9V, R_T = 30.9 kΩ	**130**	171	**215**	ns
t_{ON} - 6	On-time	V_{IN} = 12V, R_T = 30.9 kΩ	**105**	137	**170**	ns
t_{ON} - 7	On-time	V_{IN} = 16V, R_T = 30.9 kΩ	**79**	109	**142**	ns
Off Timer						
t_{OFF}	Minimum Off-time (LM25011)		**90**	150	**208**	ns
	Minimum Off-time (LM25011A)		**52**	75	**93**	
Regulation Comparator (FB Pin)						
V_{REF}	FB regulation threshold	SS pin = steady state	**2.46**	2.51	**2.56**	V
	FB bias current	FB = 3V		100		nA
Power Good (PGD pin)						
	Threshold at FB, with respect to V_{REF}	FB increasing	**91**	95		%
	Threshold hysteresis			3.3		%
PGD_{VOL}	Low state voltage	I_{PGD} = 1mA, FB = 0V		125	**180**	mV
PGD_{LKG}	Off state leakage	V_{PGD} = 7V, FB = 3V		0.1		µA

Product Folder Links: *LM25011 LM25011-Q1*

ELECTRICAL CHARACTERISTICS (continued)

Specifications with standard type are for T_J = 25°C only; limits in **boldface type** apply over the full Operating Junction Temperature (T_J) range. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T_J = 25°C, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V_{IN} = 12V, R_T = 50 kΩ.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Thermal Shutdown						
T_{SD}	Thermal shutdown	Junction temperature increasing		155		°C
	Thermal shutdown hysteresis			20		°C
Thermal Resistance						
θJA	Junction to Ambient, 0 LFPM Air Flow[1]			48		°C/W
θJC	Junction to Case[1]			10		°C/W

(1)   JEDEC test board description can be found in JESD 51-5 and JESD 51-7.

TYPICAL PERFORMANCE CHARACTERISTICS
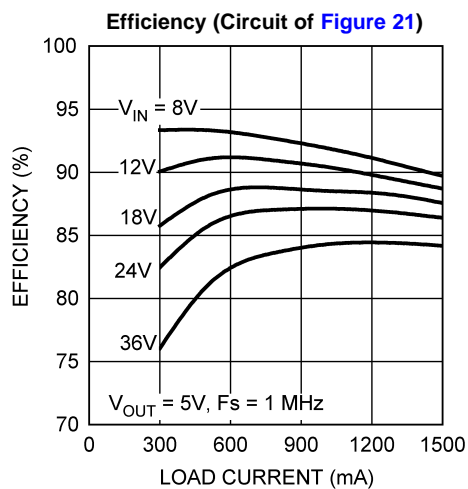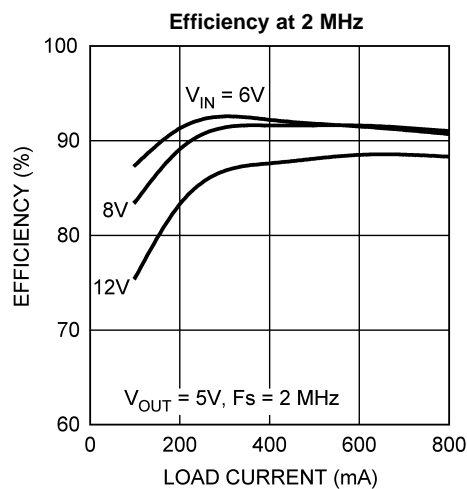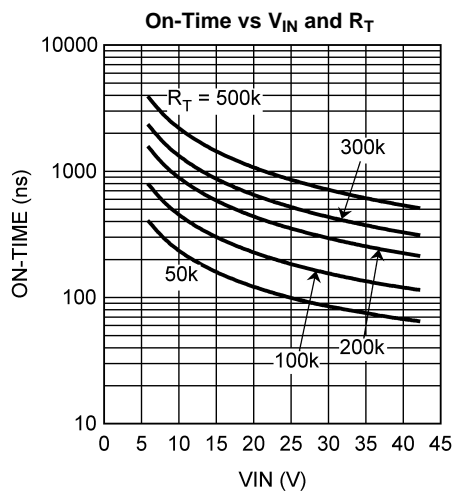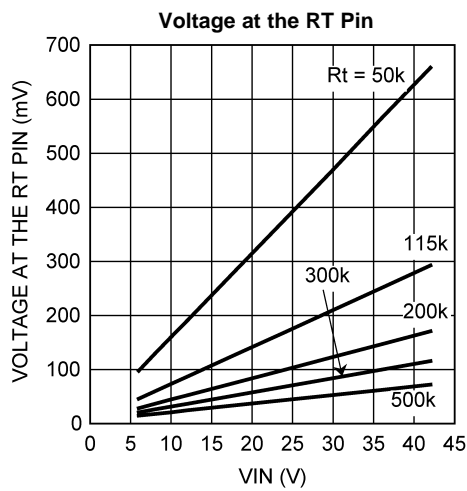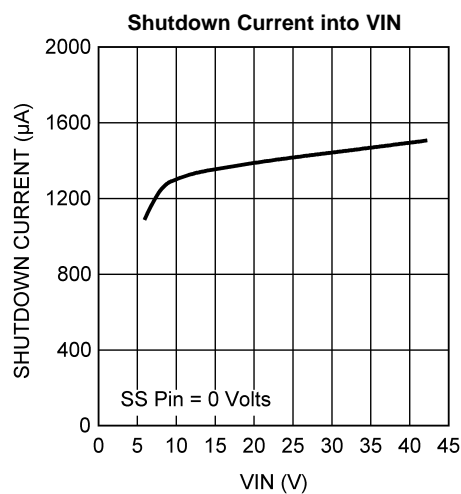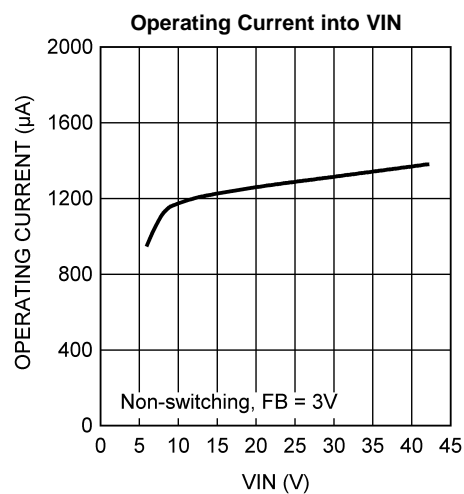
Efficiency (Circuit of Figure 21)

Figure 2.

Efficiency at 2 MHz

Figure 3.

On-Time vs V_{IN} and R_T

Figure 4.

Voltage at the RT Pin

Figure 5.

Shutdown Current into VIN

Figure 6.

Operating Current into VIN

Figure 7.

Product Folder Links: *LM25011 LM25011-Q1*

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

PGD Low Voltage vs. Sink Current

Figure 8.

Reference Voltage vs. Temperature

Figure 9.

Current Limit Threshold vs. Temperature

Figure 10.

Operating Current vs. Temperature

Figure 11.

VIN UVLO vs. Temperature

Figure 12.

SS Pin ShutdownThreshold vs. Temperature

Figure 13.

Product Folder Links: *LM25011 LM25011-Q1*
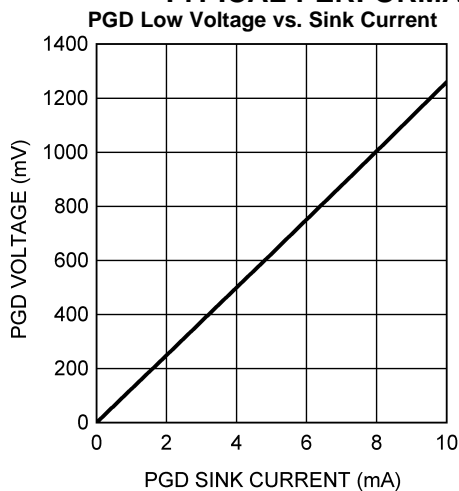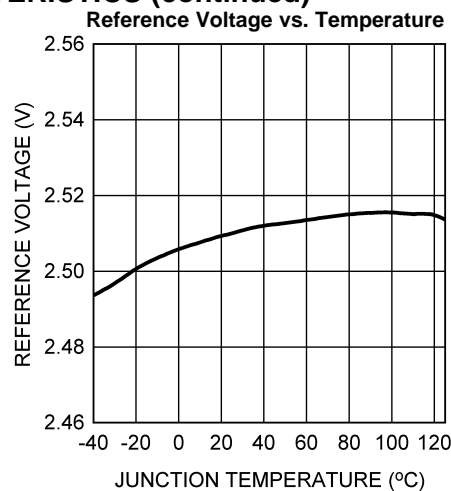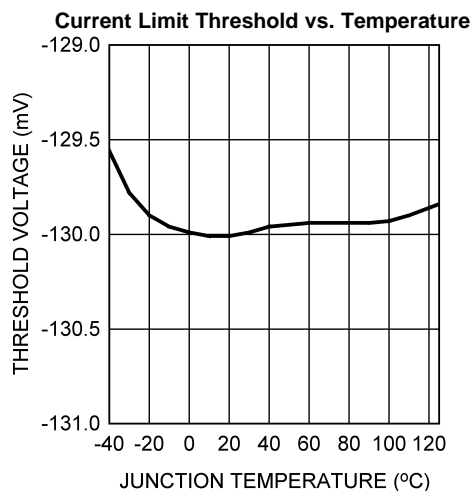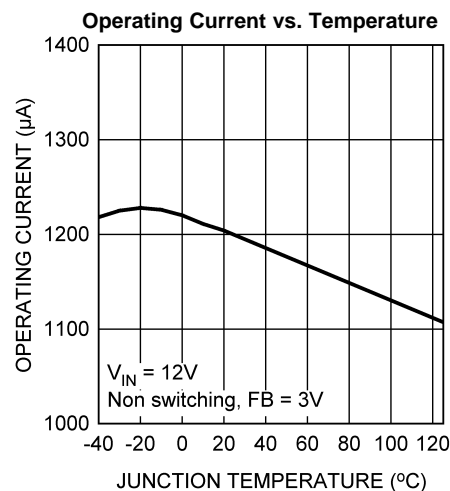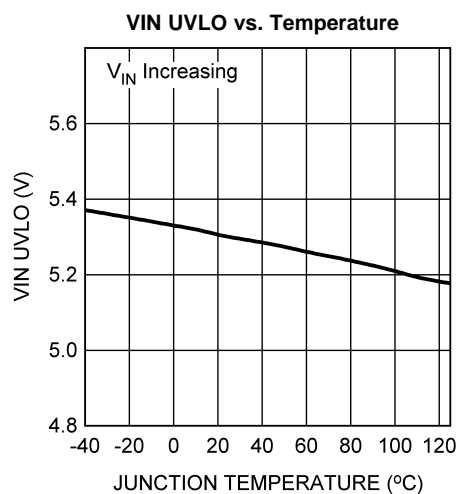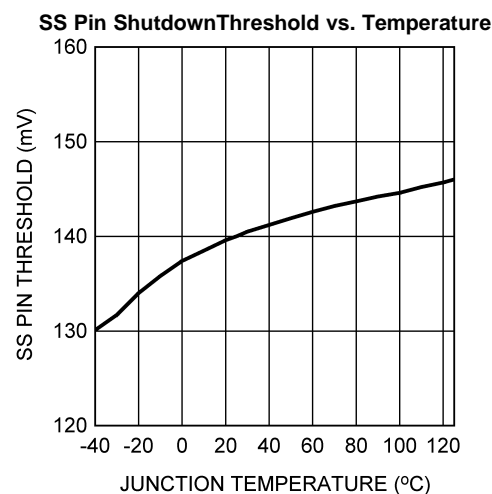
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

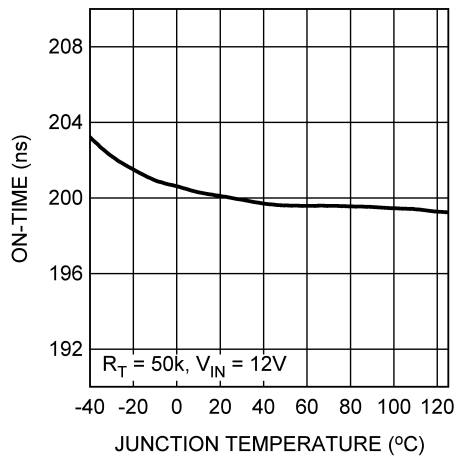**On-Time vs. Temperature**

Figure 14.

Minimum Off-Time vs. Temperature
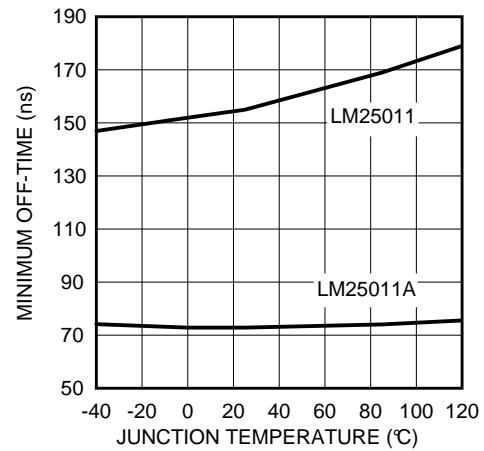
Figure 15.

BLOCK DIAGRAM

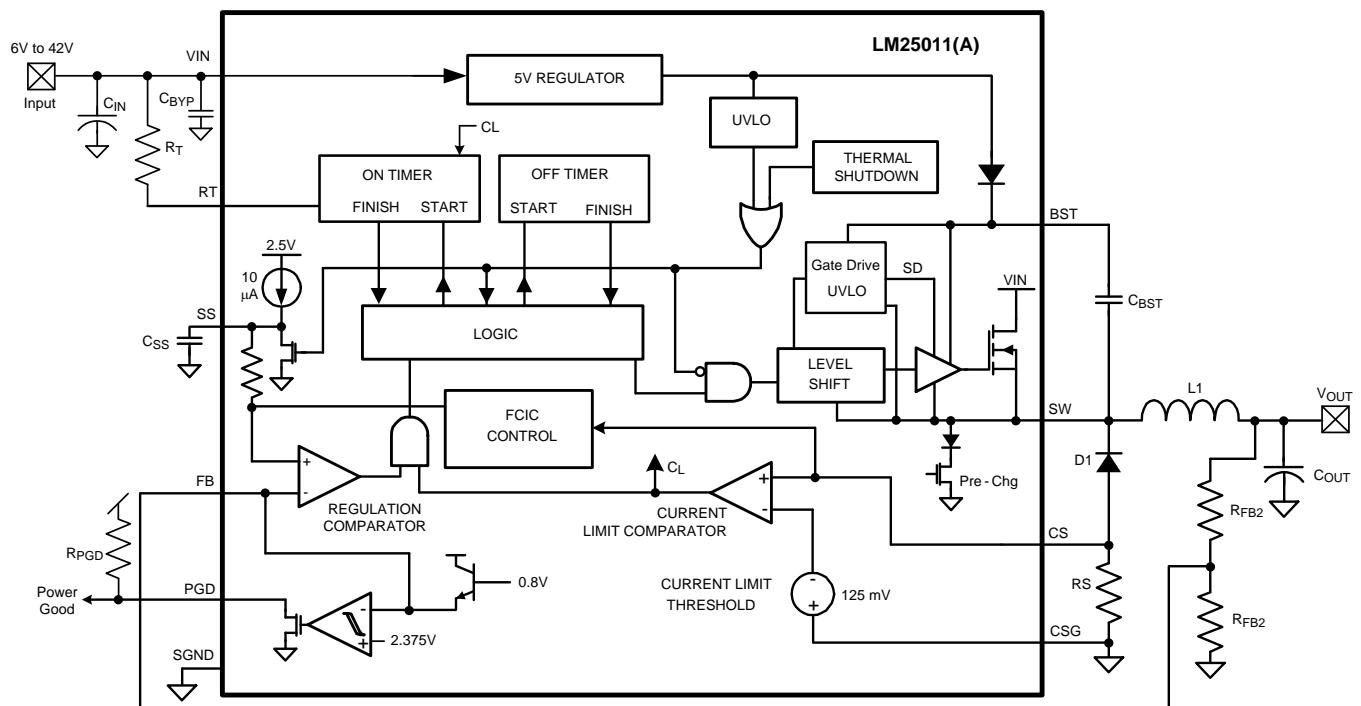**Figure 16. Block Diagram**

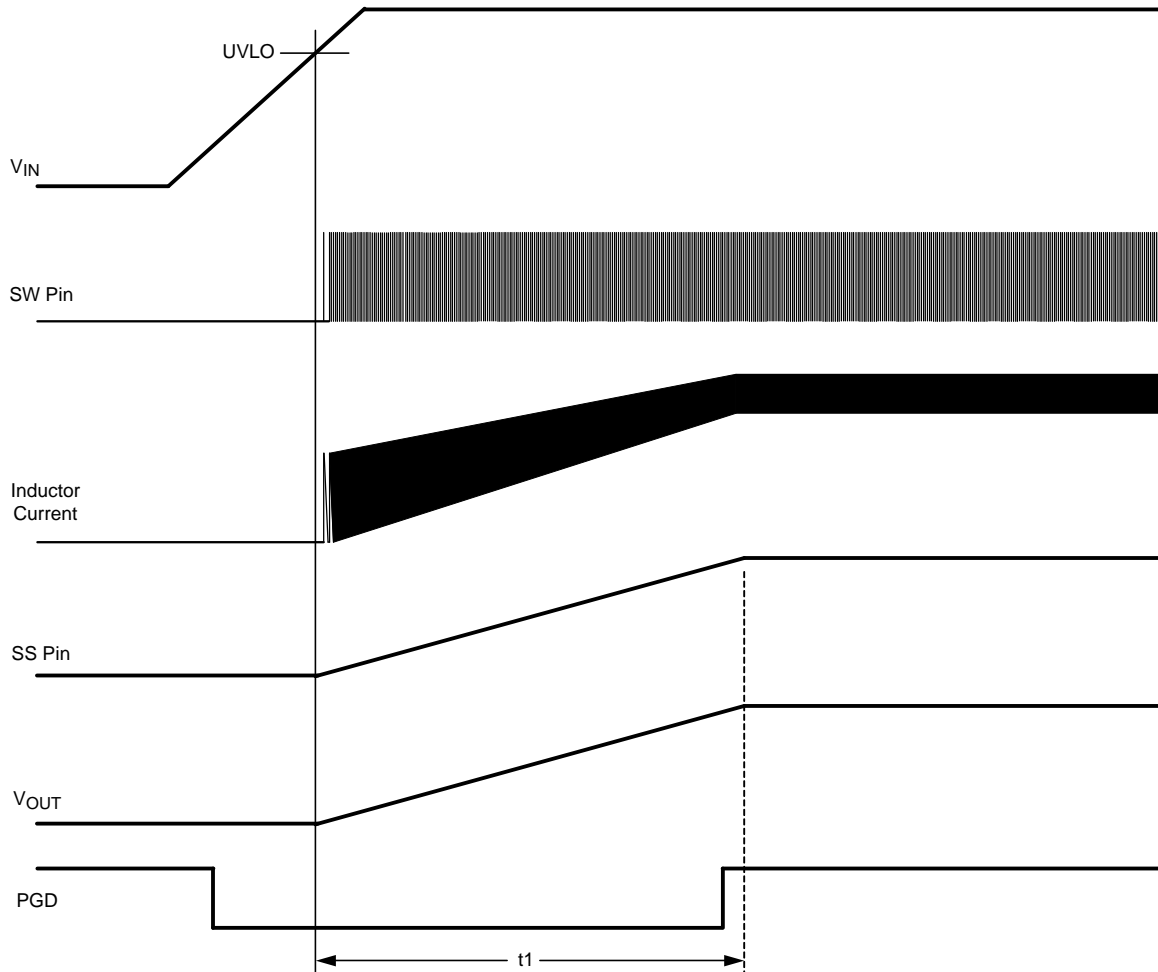Product Folder Links: *LM25011 LM25011-Q1*

Figure 17. Startup Sequence

FUNCTIONAL DESCRIPTION

The LM25011 Constant On-time Step-down Switching Regulator features all the functions needed to implement a low cost, efficient buck bias power converter capable of supplying up to 2.0A to the load. This high voltage regulator contains an N-Channel buck switch, is easy to implement, and is available in a 10-pin VSSOP, PowerPAD power enhanced package. The regulator's operation is based on a constant on-time control principle with the on-time inversely proportional to the input voltage. This feature results in the operating frequency remaining relatively constant with load and input voltage variations. The constant on-time feedback control principle requires no loop compensation resulting in very fast load transient response. The adjustable valley current limit detection results in a smooth transition from constant voltage to constant current when current limit is reached. To aid in controlling excessive switch current due to a possible saturating inductor the on-time is reduced by approximately 40% when current limit is detected. The Power Good output (PGD pin) indicates when the output voltage is within 5% of the expected regulation voltage.

The LM25011 can be implemented to efficiently step-down higher voltages in non-isolated applications. Additional features include: Low output ripple, VIN under-voltage lock-out, adjustable soft-start timing, thermal shutdown, gate drive pre-charge, gate drive under-voltage lock-out, and maximum duty cycle limit.

CONTROL CIRCUIT OVERVIEW

The LM25011 buck regulator employs a control principle based on a comparator and a one-shot on-timer, with the output voltage feedback (FB) compared to an internal reference (2.51V). If the FB voltage is below the reference the internal buck switch is switched on for the one-shot timer period, which is a function of the input voltage and the programming resistor (R_T). Following the on-time the switch remains off until the FB voltage falls below the reference, but never less than the minimum off-time forced by the off-time one-shot timer. When the FB pin voltage falls below the reference and the off-time one-shot period expires, the buck switch is then turned on for another on-time one-shot period.

When in regulation, the LM25011 operates in continuous conduction mode at heavy load currents and discontinuous conduction mode at light load currents. In continuous conduction mode the inductor's current is always greater than zero, and the operating frequency remains relatively constant with load and line variations. The minimum load current for continuous conduction mode is one-half the inductor's ripple current amplitude. The approximate operating frequency is calculated as follows:

$$F_S = \frac{V_{OUT}}{(4.1 \times 10^{-11} \times (R_T + 0.5k)) + (V_{IN} \times 15 \text{ ns})} \tag{1}$$

The buck switch duty cycle is approximately equal to:

$$DC = \frac{t_{ON}}{t_{ON} + t_{OFF}} = t_{ON} \times F_S = \frac{V_{OUT}}{V_{IN}} \tag{2}$$

When the load current is less than one half the inductor's ripple current amplitude the circuit operates in discontinuous conduction mode. The off-time is longer than in continuous conduction mode while the inductor current is zero, causing the switching frequency to reduce as the load current is reduced. Conversion efficiency is maintained at light loads since the switching losses are reduced with the reduction in load and frequency. The approximate discontinuous operating frequency can be calculated as follows:

$$F_S = \frac{V_{OUT}^2 \times L1 \times 1.19 \times 10^{21}}{R_L \times R_T^2} \tag{3}$$

where R_L = the load resistance, and L1 is the circuit's inductor.

The output voltage is set by the two feedback resistors (R_{FB1}, R_{FB2} in the Block Diagram). The regulated output voltage is calculated as follows:

$$V_{OUT} = 2.51V \times (R_{FB1} + R_{FB2}) / R_{FB1} \tag{4}$$

Ripple voltage, which is required at the input of the regulation comparator for proper output regulation, is generated internally in the LM25011, and externally when the LM25011A is used. In the LM25011 the ERM (Emulated Ripple Mode) control circuit generates the required internal ripple voltage from the ripple waveform at the CS pin. The LM25011A, which is designed for higher frequency operation, requires additional ripple voltage, which must be generated externally and provided to the FB pin. This is described in the Applications Information section.

ON-TIME TIMER

The on-time for the LM25011/LM25011A is determined by the R_T resistor and the input voltage (V_{IN}), calculated from:

$$t_{ON} = \frac{4.1 \times 10^{-11} \times (R_T + 500\Omega)}{(V_{IN})} + 15 \text{ ns}$$

(5)

The inverse relationship with V_{IN} results in a nearly constant frequency as V_{IN} is varied. To set a specific continuous conduction mode switching frequency (F_S), the R_T resistor is determined from the following:

$$R_T = \frac{V_{OUT} - (V_{IN} \times F_S \times 15 \text{ ns})}{F_S \times 4.1 \times 10^{-11}} - 500\Omega$$

(6)

The on-time must be chosen greater than 90 ns for proper operation. Equation 1, Equation 5, and Equation 6 are valid only during normal operation; that is, the circuit is not in current limit. When the LM25011 operates in current limit, the on-time is reduced by approximately 40% (this feature is not present in LM25011A). This feature reduces the peak inductor current which may be excessively high if the load current and the input voltage are simultaneously high. This feature operates on a cycle-by-cycle basis until the load current is reduced and the output voltage resumes its normal regulated value. The maximum continuous current into the RT pin must be less than 2 mA. For high frequency applications, the maximum switching frequency is limited at the maximum input voltage by the minimum on-time one-shot period (90 ns). At minimum input voltage the maximum switching frequency is limited by the minimum off-time one-shot period, which, if reached, prevents achievement of the proper duty cycle.

CURRENT LIMIT

Current limit detection occurs during the off-time by monitoring the voltage across the external current sense resistor R_S. Referring to the Block Diagram, during the off-time the recirculating current flows through the inductor, through the load, through the sense resistor, and through D1 to the inductor. If the voltage across the sense resistor exceeds the threshold (V_{ILIM}) the current limit comparator output switches to delay the start of the next on-time period. The next on-time starts when the recirculating current decreases such that the voltage across R_S reduces to the threshold and the voltage at FB is below 2.51V. The operating frequency is typically lower due to longer-than-normal off-times. When current limit is detected, the on-time is reduced by approximately 40% (only in LM25011) if the voltage at the FB pin is below its threshold when the voltage across R_S reduces to its threshold (V_{OUT} is low due to current limiting).

Figure 18 illustrates the inductor current waveform during normal operation and in current limit. During the first "Normal Operation" the load current is I_{01}, the average of the inductor current waveform. As the load resistance is reduced, the inductor current increases until the lower peak of the inductor ripple current exceeds the threshold. During the "Current Limited" portion of Figure 18, each on-time is reduced by approximately 40%, resulting in lower ripple amplitude for the inductor's current. During this time the LM25011 is in a constant current mode with an average load current equal to the current limit threshold plus half the ripple amplitude (I_{OCL}), and the output voltage is below the normal regulated value. Normal operation resumes when the load current is reduced (to I_{O2}), allowing V_{OUT} and the on-time to return to their normal values. Note that in the second period of "Normal Operation", even though the inductor's peak current exceeds the current limit threshold during part of each cycle, the circuit is not in current limit since the inductor current falls below the current limit threshold during each off time. The peak current allowed through the buck switch is 3.5A, and the maximum allowed average current is 2.0A.
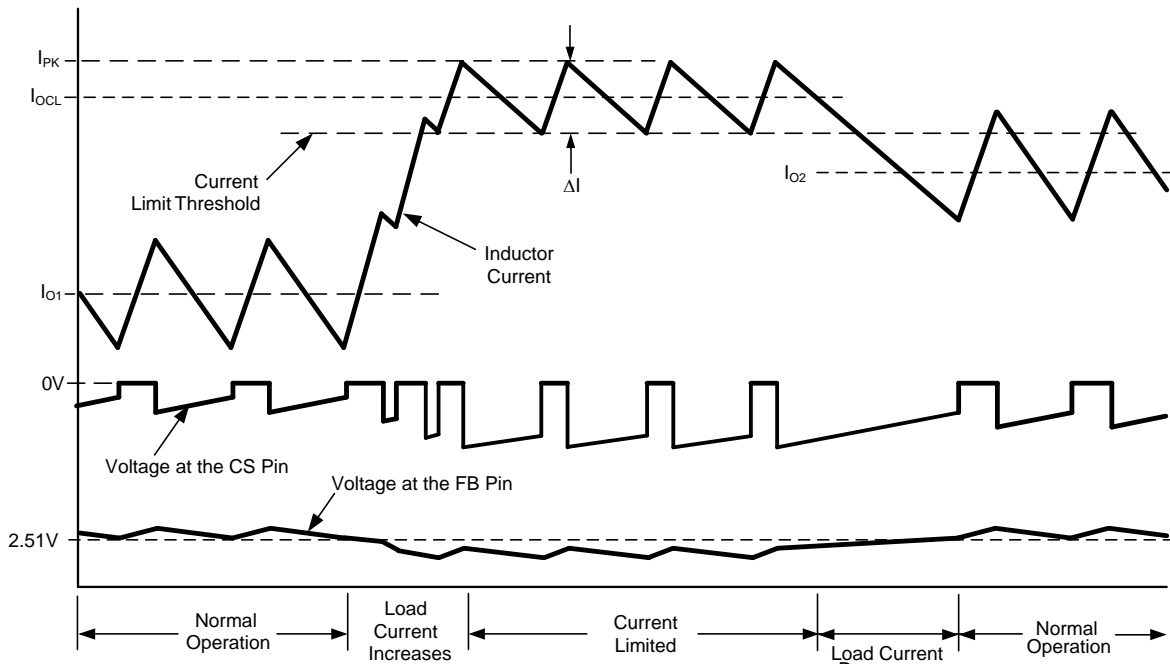
Figure 18. Normal and Current Limit Operation

RIPPLE REQUIREMENTS

The LM25011 requires about 25mVp-p of ripple voltage at the CS pin. Higher switching frequency may require more ripple. That ripple voltage is generated by the decreasing recirculating current (the inductor's ripple current) through R_S during the off-time. See Figure 19.
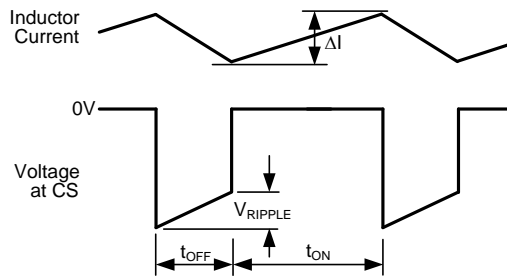

Figure 19. CS Pin Waveform

The ripple voltage is equal to:

$$V_{RIPPLE} = \Delta I \times R_S \qquad (7)$$

where ΔI is the inductor current ripple amplitude, and R_S is the current sense resistor at the CS pin.

More ripple can be achieved by decreasing the inductor value.

The LM25011A, with its shorter minimum off-time, typically will require more ripple than the LM25011. An external circuit to increase the effective ripple voltage may be needed. Different methods of generating this ripple are explained in the "Application Information" section.

Product Folder Links: *LM25011 LM25011-Q1*

N-CHANNEL BUCK SWITCH AND DRIVER

The LM25011 integrates an N-Channel buck switch and associated floating high voltage gate driver. The gate driver circuit works in conjunction with an external bootstrap capacitor (C_{BST}) and an internal high voltage diode. A 0.1 µF capacitor connected between BST and SW provides the supply voltage for the driver during the on-time. During each off-time, the SW pin is at approximately -1V, and C_{BST} is recharged from the internal 5V regulator for the next on-time. The minimum off-time ensures a sufficient time each cycle to recharge the bootstrap capacitor.

SOFT-START

The soft-start feature allows the converter to gradually reach a steady state operating point, thereby reducing startup stresses and current surges. Upon turn-on, when V_{IN} reaches its under-voltage lock-out threshold an internal 10 µA current source charges the external capacitor at the SS pin to 2.51V (t1 in Figure 17). The ramping voltage at SS ramps the non-inverting input of the regulation comparator, and the output voltage, in a controlled manner. For proper operation, the soft-start capacitor should be no smaller than 1000 pF.

The LM25011 can be employed as a tracking regulator by applying the controlling voltage to the SS pin. The regulator's output voltage tracks the applied voltage, gained up by the ratio of the feedback resistors. The applied voltage at the SS pin must be within the range of 0.5V to 2.6V. The absolute maximum rating for the SS pin is 3.0V. If the tracking function causes the voltage at the FB pin to go below the thresholds for the PGD pin, the PGD pin will switch low (see POWER GOOD OUTPUT (PGD)). An internal switch grounds the SS pin if the input voltage at VIN is below its under-voltage lock-out threshold or if the Thermal Shutdown activates. If the tracking function (described above) is used, the tracking voltage applied to the SS pin must be current limited to a maximum of 1 mA.

SHUTDOWN FUNCTION

The SS pin can be used to shutdown the LM25011 by grounding the SS pin as shown in Figure 20. Releasing the pin allows normal operation to resume.
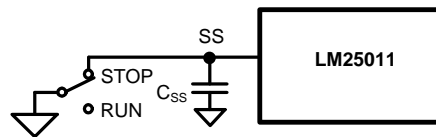

Figure 20. Shutdown Implementation

POWER GOOD OUTPUT (PGD)

The Power Good output (PGD) indicates when the voltage at the FB pin is close to the internal 2.51V reference voltage. The rising threshold at the FB pin for the PGD output to switch high is 95% of the internal reference. The falling threshold for the PGD output to switch low is approximately 3.3% below the rising threshold.

The PGD pin is internally connected to the drain of an N-channel MOSFET switch. An external pull-up resistor (R_{PGD}), connected to an appropriate voltage not exceeding 7V, is required at PGD to indicate the LM25011's status to other circuitry. When PGD is low, the pin's voltage is determined by the current into the pin. See the graph "PGD Low Voltage vs. Sink Current".

Upon powering up the LM25011, the PGD pin is high until the voltage at V_{IN} reaches 2V, at which time PGD switches low. As V_{IN} is increased PGD stays low until the output voltage takes the voltage at the FB pin above 95% of the internal reference voltage, at which time PGD switches high. As V_{IN} is decreased (during shutdown) PGD remains high until either the voltage at the FB pin falls below approximately 92% of the internal reference, or when V_{IN} falls below its lower UVLO threshold, whichever occurs first. PGD then switches low, and remains low until V_{IN} falls below 2V, at which time PGD switches high. If the LM25011 is used as a tracking regulator (see SOFT-START), the PGD output is high as long as the voltage at the FB pin is above the thresholds mentioned above.

Submit Documentation Feedback   13

Product Folder Links: LM25011 LM25011-Q1

THERMAL SHUTDOWN

The LM25011 should be operated so the junction temperature does not exceed 125°C. If the junction temperature increases above that, an internal Thermal Shutdown circuit activates (typically) at 155°C, taking the controller to a low power reset state by disabling the buck switch and taking the SS pin to ground. This feature helps prevent catastrophic failures from accidental device overheating. When the junction temperature reduces below 135°C (typical hysteresis = 20°C) normal operation resumes.

Product Folder Links: *LM25011 LM25011-Q1*

APPLICATIONS INFORMATION

EXTERNAL COMPONENTS

The procedure for calculating the external components is illustrated with a design example using the LM25011. Referring to the Block Diagram, the circuit is to be configured for the following specifications:

- V_{OUT} = 5V
- V_{IN} = 8V to 36V
- Minimum load current for continuous conduction mode ($I_{OUT(min)}$ = 300 mA
- Maximum load current ($I_{OUT(max)}$ = 1.5 A
- Switching frequency (F_S) = 1.0 MHz
- Soft-start time = 5 ms

R_{FB2} **and** R_{FB1}: These resistors set the output voltage, and their ratio is calculated from:

$$R_{FB2}/R_{FB1} = (V_{OUT}/2.51V) - 1 \tag{8}$$

For this example, R_{FB2}/R_{FB1} = 0.992. R_{FB1} and R_{FB2} should be chosen from standard value resistors in the range of 1.0 kΩ – 10 kΩ which satisfy the above ratio. For this example, 4.99 kΩ is chosen for both resistors, providing a 5.02V output.

R_T: This resistor sets the on-time, and (by default) the switching frequency. First check that the desired frequency does not require an on-time or off-time shorter than the minimum allowed values (90 ns and 150, respectively). The minimum on-time occurs at the maximum input voltage. For this example:

$$t_{ON(min)} = \frac{V_{OUT}}{V_{IN(max)} \times F_S} = \frac{5V}{36V \times 1\ MHz} = 139\ ns \tag{9}$$

The minimum off-time occurs at the minimum input voltage. For this example:

$$t_{OFF(min)} = \frac{V_{IN(min)} - V_{OUT}}{V_{IN(min)} \times F_S} = \frac{8V - 5V}{8V \times 1\ MHz} = 375\ ns \tag{10}$$

Both the on-time and off-time are acceptable since they are significantly greater than the minimum value for each. The R_T resistor is calculated from Equation 6 using the minimum input voltage:

$$R_T = \frac{5 - (8V \times 1MHz \times 15\ ns)}{1MHz \times 4.1 \times 10^{-11}} - 500\Omega = 118.5\ k\Omega \tag{11}$$

A standard value 118 kΩ resistor is selected. The minimum on-time calculates to 152 ns at V_{IN} = 36V, and the maximum on-time calculates to 672 ns at Vin = 8V

L1: The parameters controlled by the inductor are the inductor current ripple amplitude (I_{OR}), and the ripple voltage amplitude across the current sense resistor R_S. The minimum load current is used to determine the maximum allowable ripple in order to maintain continuous conduction mode (the lower peak does not reach 0 mA). This is not a requirement of the LM25011, but serves as a guideline for selecting L1. For this example, the maximum ripple current should be less than:

$$I_{OR(max)} = 2 \times I_{OUT(min)} = 600\ mA\ p\text{-}p \tag{12}$$

For applications where the minimum load current is zero, a good starting point for allowable ripple is 20% of the maximum load current. In this case substitute 20% of $I_{OUT(max)}$ for $I_{OUT(min)}$ in Equation 12. The ripple amplitude calculated in Equation 12 is then used in Equation 13:

$$L1_{(min)} = \frac{t_{ON(min)} \times (V_{IN(max)} - V_{OUT})}{I_{OR(max)}} = 7.85\ \mu H \tag{13}$$

A standard value 10 µH inductor is chosen. Using this inductor value, the maximum ripple current amplitude, which occurs at maximum V_{IN}, calculates to 472 mAp-p, and the peak current is 1736 mA at maximum load current. Ensure the selected inductor is rated for this peak current. The minimum ripple current, which occurs at minimum V_{IN}, calculates to 200 mAp-p.

R_S**:** The minimum current limit threshold is calculated at maximum load current, using the minimum ripple current calculated above. The current limit threshold is the lower peak of the inductor current waveform when in current limit (see Figure 18).

$$I_{LIM} = 1.5A - (0.2\,A/2) = 1.4A \tag{14}$$

Current limit detection occurs when the voltage across the sense resistor (R_S) reaches the current limit threshold. To allow for tolerances, the sense resistor value is calculated using the minimum threshold specification:

$$R_S = 115\,mV/1.4A = 82\,m\Omega \tag{15}$$

The next smaller standard value, 80 mΩ, is selected. The next step is to ensure that sufficient ripple voltage occurs across R_S with this value sense resistor. As mentioned in the Ripple Requirements section, a minimum of 15 mVp-p voltage ripple is required across the R_S sense resistor during the off-time to ensure the regulation circuit operates properly. The ripple voltage is the product of the inductor ripple current amplitude and the sense resistor value. In this case, the minimum ripple voltage calculates to:

$$V_{RIPPLE} = \Delta I \times R_S = 200\,mA \times 0.080\Omega = 16\,mV \tag{16}$$

If the ripple voltage had calculated to less than 15 mVp-p the inductor value would have to be reduced to increase the ripple current amplitude. This would have required a recalculation of I_{LIM} and R_S in the above equations. Since the minimum requirement is satisfied in this case no change is necessary.

The nominal current limit threshold calculates to 1.63A. The minimum and maximum thresholds calculate to 1.44A and 1.83A respectively, using the minimum and maximum limits for the current limit threshold specification. The load current is equal to the threshold current plus one half the ripple current. Under normal load conditions, the maximum power dissipation in R_S occurs at maximum load current, and at maximum input voltage where the on-time duty cycle is minimum. In this design example, the minimum on-time duty cycle is:

$$\text{Duty Cycle} = D = \frac{V_{OUT}}{V_{IN}} = \frac{5V}{36V} = 13.9\% \tag{17}$$

At maximum load current, the power dissipation in R_S is equal to:

$$P_{(RS)} = (1.5A)^2 \times 0.080\Omega \times (1 - 0.139) = 155\,mW \tag{18}$$

When in current limit the maximum power dissipation in R_S calculates to

$$P_{(RS)} = (1.83A + 0.472A/4)^2 \times 0.080\Omega = 304\,mW \tag{19}$$

Duty cycle is not included in this power calculation since the on-time duty cycle is typically <5% when in current limit.

C_{OUT}**:** The output capacitor should typically be no smaller than 3.3 μF, although that is dependent on the frequency and the desired output characteristics. C_{OUT} should be a low ESR good quality ceramic capacitor. Experimentation is usually necessary to determine the minimum value for C_{OUT}, as the nature of the load may require a larger value. A load which creates significant transients requires a larger value for C_{OUT} than a non-varying load.

C_{IN} **and** C_{BYP}**:** The purpose of C_{IN} is to supply most of the switch current during the on-time, and limit the voltage ripple at V_{IN}, since it is assumed the voltage source feeding V_{IN} has some amount of source impedance. When the buck switch turns on, the current into V_{IN} suddenly increases to the lower peak of the inductor's ripple current, then ramps up to the upper peak, then drops to zero at turn-off. The average current during the on-time is the average load current. For a worst case calculation, C_{IN} must supply this average load current during the maximum on-time, without letting the voltage at the VIN pin drop below a minimum operating level of 5.5V. For this exercise 0.5V is chosen as the maximum allowed input ripple voltage. Using the maximum load current, the minimum value for C_{IN} is calculated from:

$$C_{IN} = \frac{I_{OUT(max)} \times t_{ON(max)}}{\Delta V} = \frac{1.5A \times 672\,ns}{0.5V} = 2.02\,\mu F \tag{20}$$

where t_{ON} is the maximum on-time, and ΔV is the allowable ripple voltage at V_{IN}. The purpose of C_{BYP} is to minimize transients and ringing due to long lead inductance leading to the VIN pin. A low ESR 0.1 μF ceramic chip capacitor is recommended, and C_{BYP} must be located close to the VIN and SGND pins.

C_{BST}**:** The recommended value for C_{BST} is 0.1 μF. A high quality ceramic capacitor with low ESR is recommended as C_{BST} supplies a surge current to charge the buck switch gate at each turn-on. A low ESR also helps ensure a complete recharge during each off-time.

C_{SS}: The capacitor at the SS pin determines the soft-start time, i.e. the time for the output voltage to reach its final value (t1 in Figure 17). For a soft-start time of 5 ms, the capacitor value is determined from the following:

$$C_{SS} = \frac{5 \text{ ms x } 10\ \mu A}{2.51 V} = 0.02\ \mu F$$

(21)

D1: A Schottky diode is recommended. Ultra-fast recovery diodes are not recommended as the high speed transitions at the SW pin may affect the regulator's operation due to the diode's reverse recovery transients. The diode must be rated for the maximum input voltage, the maximum load current, and the peak current which occurs when the current limit and maximum ripple current are reached simultaneously. The diode's average power dissipation is calculated from:

$$P_{D1} = V_F \text{ x } I_{OUT} \text{ x } (1 - D)$$

(22)

where V_F is the diode's forward voltage drop, and D is the on-time duty cycle.

FINAL CIRCUIT

The final circuit is shown in Figure 21, and its performance is shown in Figure 22 and Figure 23. The current limit measured approximately 1.62A at Vin = 8V, and 1.69A at Vin = 36V.
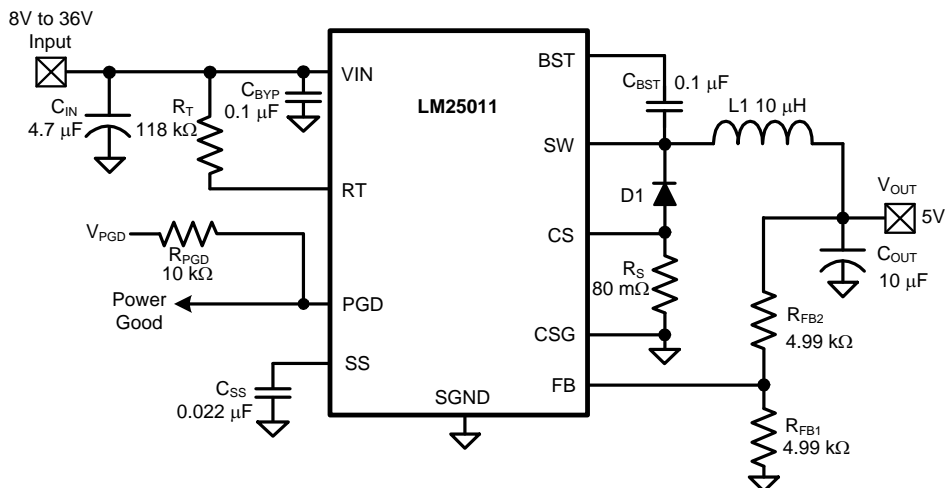
Figure 21. Example Circuit
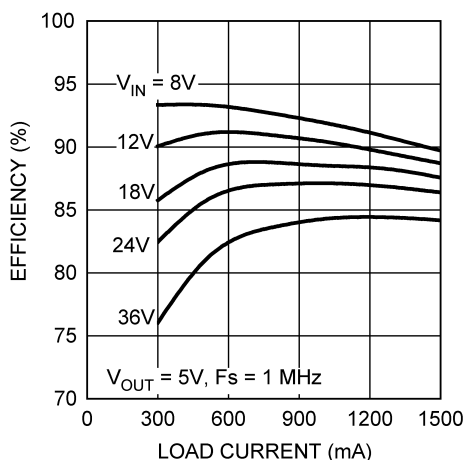
Figure 22. Efficiency (Circuit of Figure 21)
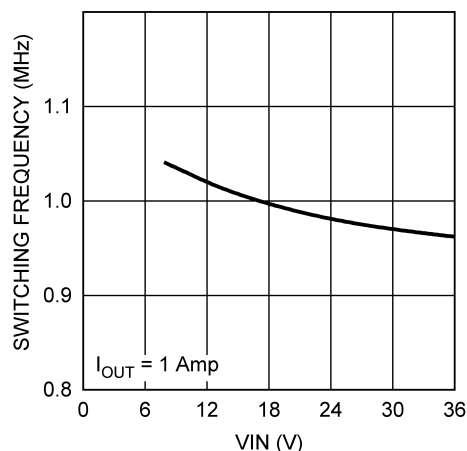
Figure 23. Frequency vs V_{IN} (Circuit of Figure 21)

OUTPUT RIPPLE CONTROL (LM25011A)

The LM25011A most likely will require more ripple voltage than is generated across the RS resistor. Additional ripple can be supplied to the FB pin, in phase with the switching waveform at the SW pin, for proper operation. The required ripple can be supplied from ripple generated at V_{OUT}, through the feedback resistors, as described in Option A below. Options B and C provide for lower output ripple with one or two additional components.

The amount of additional ripple voltage needed at the FB pin is typically in the range of 30-150mV. Higher switching frequencies or higher inductor values (less ripple current) require more ripple voltage injected on FB. Insufficient ripple voltage will result in frequency jitter. For a particular application, add only as much ripple as needed to stabilize the switching frequency over the required input voltage.

Option A) Lowest Cost Configuration: In this configuration R1 is installed in series with the output capacitor (C_{OUT}) as shown in Figure 24. The inductor's ripple current passes through R1, generating a ripple voltage at V_{OUT}. The minimum value for R1 is:

$$R1 = \frac{V_{RIPPLE} \times (R_{FB2} + R_{FB1})}{\Delta I \times R_{FB1}}$$

(23)

where ΔI is the minimum ripple current amplitude, which occurs at minimum Vin.
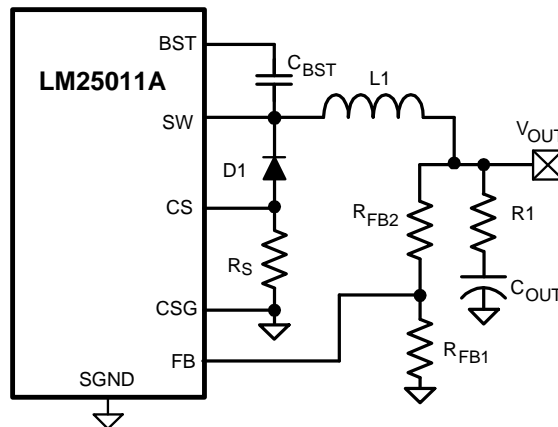
Figure 24. Option A – Lowest Cost Ripple Configuration

Option B) Intermediate Ripple Configuration: This configuration generates less ripple at V_{OUT} than Option A above by the addition of one capacitor (Cff), as shown in Figure 25.
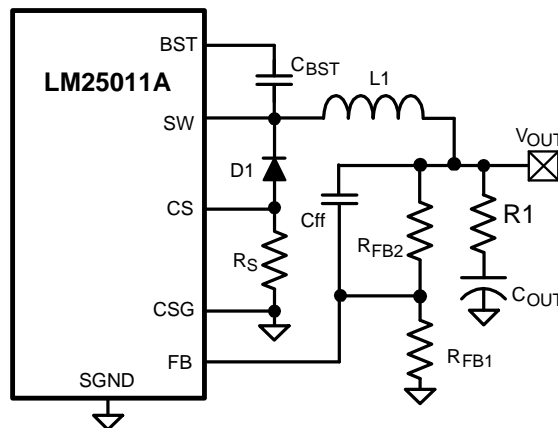

Figure 25. Option B – Intermediate Ripple Configuration

Since the output ripple is passed by Cff to the FB pin with little or no attenuation, R1's value can be chosen so the minimum ripple at V_{OUT} is approximately 150 mVp-p. The minimum value for R1 is calculated from:

Product Folder Links: *LM25011 LM25011-Q1*

$$R1 = \frac{V_{RIPPLE}}{\Delta I}$$

(24)

where ΔI is the minimum ripple current amplitude, which occurs at minimum Vin. The minimum value for Cff is calculated from:

$$Cff > \frac{3 \times t_{ON(max)}}{R_{FB1}//R_{FB2}}$$

(25)

where $t_{ON(max)}$ is the maximum on-time (at minimum V_{IN}), and $R_{FB1}//R_{FB2}$ is the parallel equivalent of the feedback resistors.
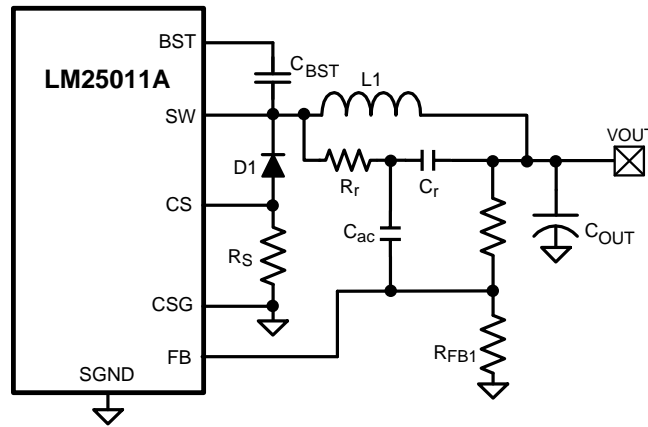
Option C) Minimum Ripple Configuration:

Figure 26. Option C: Minimum Output Ripple Configuration

In some applications, the ripple induced by series resistor R1 may not be acceptable. An external ripple circuit, as shown in Figure 26, can be used to provide the required ripple to the FB pin.

1. The time constant τ=Rr*Cr should be greater than 8-10 times the switching period to generate a triangular ramp at FB pin.
2. The smallest ripple at feedback ΔVFB = (VIN(min)-VOUT)*TON(max)/τ.
3. The ramp capacitor Cr should much smaller than the ac coupling capacitor Cac. Usually Cac=100nF, Cr=1nF, and Rr is chosen to satisfy conditions 1 and 2 above.

PC BOARD LAYOUT

The LM25011 regulation and current limit comparators are very fast, and respond to short duration noise pulses. Layout considerations are therefore critical for optimum performance. The layout must be as neat and compact as possible, and all of the components must be as close as possible to their associated pins. The two major current loops conduct currents which switch very fast, and therefore those loops must be as small as possible to minimize conducted and radiated EMI. The first loop is formed by C_{IN}, through the VIN to SW pins, L1, C_{OUT}, and back to C_{IN}. The second current loop is formed by R_S, D1, L1, C_{OUT} and back to R_S. The ground connection from CSG to the ground end of C_{IN} should be as short and direct as possible.

The power dissipation within the LM25011 can be approximated by determining the circuit's total conversion loss (P_{IN} - P_{OUT}), and then subtracting the power losses in the free-wheeling diode, the sense resistor, and the inductor. The power loss in the diode is approximately:

$$P_{D1} = I_{OUT} \times V_F \times (1\text{-}D)$$

(26)

where Iout is the load current, V_F is the diode's forward voltage drop, and D is the on-time duty cycle. The power loss in the sense resistor is:

$$P_{RS} = (I_{OUT})^2 \times R_S \times (1 - D)$$

(27)

The power loss in the inductor is approximately:

$$P_{L1} = I_{OUT}^2 \times R_L \times 1.1$$

(28)

Product Folder Links: *LM25011 LM25011-Q1*

where R_L is the inductor's DC resistance, and the 1.1 factor is an approximation for the AC losses. If it is expected that the internal dissipation of the LM25011 will produce excessive junction temperatures during normal operation, good use of the PC board's ground plane can help to dissipate heat. Additionally the use of wide PC board traces, where possible, can help conduct heat away from the IC pins. Judicious positioning of the PC board within the end product, along with the use of any available air flow (forced or natural convection) can help reduce the junction temperature.

Product Folder Links: *LM25011 LM25011-Q1*

REVISION HISTORY

Changes from Revision F (February 2013) to Revision G   **Page**

- Changed layout of National Data Sheet to TI format 20

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
LM25011AMY	PREVIEW	MSOP-PowerPAD	DGQ	10	1000	TBD	Call TI	Call TI	-40 to 125		
LM25011AMYX	PREVIEW	MSOP-PowerPAD	DGQ	10	3000	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SN9B	
LM25011AQ1MY/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	1000	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SZZA	Samples
LM25011AQ1MYX/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	3500	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SZZA	Samples
LM25011MY/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	1000	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SVUB	Samples
LM25011MYX/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	3500	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SVUB	Samples
LM25011Q1MY/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	1000	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SZFB	Samples
LM25011Q1MYX/NOPB	ACTIVE	MSOP-PowerPAD	DGQ	10	3500	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	SZFB	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) Only one of markings shown within the brackets will appear on the physical device.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF LM25011, LM25011-Q1 :

● Catalog: LM25011

● Automotive: LM25011-Q1

NOTE: Qualified Version Definitions:

  ● Catalog - TI's standard catalog product

  ● Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

REEL DIMENSIONS

TAPE DIMENSIONS

A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM25011AQ1MY/NOPB	MSOP-Power PAD	DGQ	10	1000	178.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM25011AQ1MYX/NOPB	MSOP-Power PAD	DGQ	10	3500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM25011MY/NOPB	MSOP-Power PAD	DGQ	10	1000	178.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM25011MYX/NOPB	MSOP-Power PAD	DGQ	10	3500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM25011Q1MY/NOPB	MSOP-Power PAD	DGQ	10	1000	178.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM25011Q1MYX/NOPB	MSOP-Power PAD	DGQ	10	3500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM25011AQ1MY/NOPB	MSOP-PowerPAD	DGQ	10	1000	213.0	191.0	55.0
LM25011AQ1MYX/NOPB	MSOP-PowerPAD	DGQ	10	3500	367.0	367.0	35.0
LM25011MY/NOPB	MSOP-PowerPAD	DGQ	10	1000	213.0	191.0	55.0
LM25011MYX/NOPB	MSOP-PowerPAD	DGQ	10	3500	367.0	367.0	35.0
LM25011Q1MY/NOPB	MSOP-PowerPAD	DGQ	10	1000	213.0	191.0	55.0
LM25011Q1MYX/NOPB	MSOP-PowerPAD	DGQ	10	3500	367.0	367.0	35.0

DGQ0010A

.118±.004
[3±0.1]
NOT INCLUDING MOLD FLASH
.006[0.15] MAX PER END

.118±.004
[3±0.1]
NOT INCLUDING
MOLD FLASH

.193±.006
[4.9±0.15]

PIN 1 ID

8X .0197
[0.5]

.043 MAX
[1.09]

(.034)
[0.86]

.004 [0.1] A

.002-.006
[0.06-0.15]
TYP

10X .009⁺·⁰⁰⁴₋·⁰⁰²
[0.23⁺⁰·¹⁰₋₀.₀₅]

.002 [0.05] M B S C S

.068±.006
[1.73±0.15]

.075±.006
[1.9±0.15]

BOTTOM VIEW

(.075)
[1.9]

(.068)
[1.73]

(.189)
[4.8]

(10X .040)
[1.02]

(10X .012)
[0.3]

(8X .0197)
[0.5]

RECOMMENDED LAND PATTERN

GAGE PLANE

R.005 TYP
[0.13]

R.005 TYP
[0.13]

.010
[0.25]

A

.007±.002 TYP
[0.18±0.05]

.021±.005
[0.53±0.12]
TYP

SEATING PLANE

0°-6° TYP

(.0375 TYP)
[0.953]

CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS

MUC10A (Rev A)

Texas
Instruments
www.ti.com

IMPORTANT NOTICE

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Компания «ЭлектроПласт» предлагает заключение долгосрочных отношений при поставках импортных электронных компонентов на взаимовыгодных условиях!

Наши преимущества:
- Оперативные поставки широкого спектра электронных компонентов отечественного и импортного производства напрямую от производителей и с крупнейших мировых складов;
- Поставка более 17-ти миллионов наименований электронных компонентов;
- Поставка сложных, дефицитных, либо снятых с производства позиций;
- Оперативные сроки поставки под заказ (от 5 рабочих дней);
- Экспресс доставка в любую точку России;
- Техническая поддержка проекта, помощь в подборе аналогов, поставка прототипов;
- Система менеджмента качества сертифицирована по Международному стандарту ISO 9001;
- Лицензия ФСБ на осуществление работ с использованием сведений, составляющих государственную тайну;
- Поставка специализированных компонентов (Xilinx, Altera, Analog Devices, Intersil, Interpoint, Microsemi, Aeroflex, Peregrine, Syfer, Eurofarad, Texas Instrument, Miteq, Cobham, E2V, MA-COM, Hittite, Mini-Circuits,General Dynamics и др.);

Помимо этого, одним из направлений компании «ЭлектроПласт» является направление «Источники питания». Мы предлагаем Вам помощь Конструкторского отдела:
- Подбор оптимального решения, техническое обоснование при выборе компонента;
- Подбор аналогов;
- Консультации по применению компонента;
- Поставка образцов и прототипов;
- Техническая поддержка проекта;
- Защита от снятия компонента с производства.

Как с нами связаться

Телефон: 8 (812) 309 58 32 (многоканальный)
Факс: 8 (812) 320-02-42
Электронная почта: org@eplast1.ru
Адрес: 198099, г. Санкт-Петербург, ул. Калинина, дом 2, корпус 4, литера А.