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DATE: August 29, 2022

Nathaniel E Frank-White

EXHIBIT A

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Application Notes by Category

BY CATEGORY **BY PART NUMBER** GO **NEWEST APPNOTES**

Enter any portion of part number(s)

POWER-SUPPLY CIRCUITS

Application Notes for:

- Automotive
- Cable Modem / Satellite TV
- Cell Phone
- Desktop PC / Server
- Digital Camera
- Fiber Module
- LCD / Flat Panel / Backlight / Display
- Network / Telecom / WLAN
- Notebook Computer
- Other
- PDA / Hand Terminal
- Printer / Fax
- RAID

Application Notes by Topology:

- Boost / Step-Up
- Buck / Step-Down
- Buck-Boost / Step Up-Down
- Charge Pump
- Current Sensing
- Flyback / Isolated / Transformer
- Inverter / Negative Output
- Linear Regulator / LDO
- MOSFET Driver
- USB / Hot-Swap / Load Switching
- White-LED Power

ALSO SEE: Power-Supply Cookbook — Tested designs, with bill of materials, to meet your specs.

TOPOLOGY: Buck / Step-Down

App Note 3740
How to Generate Auxiliary Supplies from a Positive Buck DC-DC Converter

App Note 3767
Meeting the Challenges of Power-Supply Design for Modern, High-Current CPUs

App Note 3753
Thermistor Linearizes Current Limit

App Note 3672
Noise Reduction for the MAX1864 Auxiliary Regulator

App Note 3668
High-Efficiency Current Drive for High-Brightness LEDs

App Note 3638
2.2MHz Buck or Boost Power Supply for ADSL2+ Chipset

App Note 3626
Adding a Watchdog to a Dual-Output Power Supply

App Note 3603
Buck Converters Proliferate in Handhelds as Features and Processing Power Increase

App Note 3581
MAX5074 5V, 3A Reference Design

App Note 3560
High-Efficiency DC-DC Converter Fits LDO Footprint

App Note 3519
Integrated DC-DC Converters Save Space and Design Time in Distributed-Power Systems

App Note 3499
Compact-Footprint, 60A, Two-Phase Power Supply for AMD K8 Motherboards

App Note 3434
RF Power Reduction for CDMA/W-CDMA Cellular Phones

App Note 3442
Simple PSPICE Model Predicts MAX8546 Stability and Transient Response

App Note 3244
3mm-Tall, Dual-Phase, Step-Down, DC-DC Converter Delivers 1.6V at 20A from 12V for Mobile Processor Cores

App Note 3440
An Accurate Control Loop Model for Current-Mode Step-Down Controllers

App Note 3356
MAX1917 Provides Pre-Bias Soft Start for Redundant Supply

App Note 3324
Buck Regulator Forms High-Power Inverting -5V Supply

App Note 3247
RF Power Amplifier Efficiency Improves with Varied Vcc, from DC-DC Supply

App Note 3174
Selecting Power Management for Cellular Handsets

App Note 2997
Basic Switching-Regulator-Layout Techniques

App Note 2767
DAC Makes Controller Programmable

App Note 1901
Convert the MAX1937/8/9 from Latch Off Mode to Hiccup Mode Under Short Circuit Condition

App Note 1897
Building a Power Supply That Works

App Note 1882
Increase the Power of a Buck (Step-Down) Switching Power Supply IC

App Note 1857
DDR Memory-Termination Supply

App Note 1845
Choosing the Right DC-DC Converter for Automotive Applications

App Note 1832
Power Supply Engineer's Guide to Calculate Dissipation for MOSFETs in High-Power Supplies

App Note 225
Using Digital Potentiometers in Adjustable Step-Down DC-DC Converter Designs

App Note 1782
Small Footprint, 10us Response Time, 10mV Output Ripple, 1MHz, 6A Step-Down Regulator

App Note 1775
Power Supply for DDR-SDRAM Termination Operates From 3V to 5.5V Input

App Note 1157
Parallel-Port Interface Powers Low Voltage Systems

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Negative Buck Regulator Produces Positive Output
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Flyback Winding Adds 12V Output To 5V Buck Regulator
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Negative Buck Regulator Employs Step-Up Controller

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APP 3740: Jan 10, 2006
Keywords: step-down, buck, transformer, flyback, SEPIC
Related Parts
Download, PDF Format (219kB)

APPLICATION NOTE 3740

How to Generate Auxiliary Supplies from a Positive Buck DC-DC Converter

Abstract: Many applications require a low-power supply in addition to the main supply. For reasons of cost, inventory management, or electromagnetic compatibility (EMC), a separate converter may not be appropriate. Consequently, another means of providing extra power rails from the main supply is needed. This application note shows how to use a step-down IC converter's switching action to derive one or more outputs, isolated or non-isolated, quasi-regulated or unregulated.

Introduction

Many applications require a low-power supply in addition to the main supply. A typical example is when an analog front-end amplifier needs ±5V, while the main digital circuitry requires +5V only. For reasons of cost, inventory management, or EMC, a separate -5V converter may not be appropriate. Consequently, another means of providing extra power rails from the main supply is needed.

As a solution to this problem, a step-down IC converter's switching action can be used to derive one or more outputs, isolated or non-isolated, quasi-regulated or unregulated. Auxiliary output currents of 10% to 30% of the main output are perfectly possible. This application note will illustrate this technique using the MAX5035 DC-DC converter.

Step-Down Waveforms

A review of the waveforms found in a working step-down converter will identify the voltage and currents that can be used to generate additional outputs. See **Figure 1** below and Example 1 waveforms at the end of this article.

Figure 1. The MAX5035 schematic illustrates step-down converter operation.
Figure 1. The MAX5035 schematic illustrates step-down converter operation.

There is a switching voltage waveform of amplitude at the LX pin:

V_{LX} = [V_{IN} (max) to -V(diode)] < V_{LX} < V_{IN}(min) -V(diode)]

The voltage across the main inductor during the power cycle (LX connected to V_{IN}) is:

$V_{IN}D$ = [V_{IN} (max) - V_{OUT}] < $V_{IN}D$ < [V_{IN}(min) - V_{OUT}]

Continuous Inductor Current Operation

When the power switch is off, the voltage at the LX connection flies negative, turning on the diode, D1, to ensure that the inductor current continues to circulate. Operation is said to be continuous when the power cycle begins before the circulating current in D1 falls to zero (**Figure 2**).

Figure 2. Continuous inductor current waveforms. TS = switching period; D = duty cycle.
Figure 2. Continuous inductor current waveforms. TS = switching period; D = duty cycle.

Knowing the various RMS currents and voltages associated with the key components, power dissipation can be calculated as follows:

Definitions

RON_SW—Data sheet on-resistance of the internal power switch (V_{IN} to LX)
RLOAD—Effective resistance connected at the power-supply output.
IQUIESCENT—Quiescent current of the control IC with no switching action.
IDIODE_RMS—Schottky diode (D1) forward RMS current.
VFORWARD—Forward voltage drop across Schottky diode, D1, at rated current.
ILOAD_RMS—RMS load current.

Auxiliary Outputs

Auxiliary outputs can be added to the main step-down by an additional winding on its inductor. The additional output relies on flyback action in the main inductor during the time that the 'catch' Schottky diode (D1 in Fig1) is conducting. Because the diode voltage drop is relatively constant (300mV to 500mV, typically, depending on current), and because the controller regulates the output voltage, the inductor's voltage drop is also relatively constant during the OFF time of the power switch. For the voltage drop to remain consistent, the main inductor should be in continuous conduction throughout the main step-down load range.

The LX pin can also be used to provide a switching input to a discrete charge-pump circuit. For this to remain consistent, the LX pin must be active whenever the additional output is required. You can keep the LX pin active by ensuring that the main step-down output supports a minimum load.

Inductor Selection

Three functions are needed to set the value of the main inductor: the voltage across the inductor, the operating frequency, and the inductor's current ripple. Together, these functions will ensure that adequate energy is stored in the inductor. The inductor's minimum value is determined by the maximum duty cycle and minimum input voltage, and is given by:

Ripple current is a percentage of output current, and defined as 30% for the MAX5035. Note that the ripple current sets the minimum load current before the onset of discontinuous operation. Because an auxiliary supply increases the peak-current requirements of the power switch, care must be taken to limit the auxiliary power drawn.

For many applications, the Evaluation (EV) kit's standard setup of 100µH and 68µF output filter values will be suitable. These values are retained for the additional supplies. The MAX5035 features fixed, internal type-3 compensation which imposes limitations on the choice of output capacitor. Chose the ESR so that the zero frequency occurs between 20kHz and 40kHz. See the application section of the MAX5035 data sheet for more information.

Auxiliary Output Derived from the Main Inductor's Transformer

The inductor's voltage drop is relatively constant during the power switch's OFF time, because the primary Schottky diode voltage drop is relatively constant (300mV to 500mV, typically, depending on current), and the controller regulates the output voltage. Connecting the secondary rectifier and capacitor so that conduction occurs during the flyback period (diode ON), allows some energy to be tapped off the main inductor. **Figures 3a** and **3b** show two versions of this arrangement. Isolating the auxiliary winding from the main step-down allows flexible connection arrangements. Figure 3a shows the auxiliary output referred to zero volts, and Figure 3b shows the auxiliary output referred to the main positive output. See also waveforms in **Examples 2a** and **2b**.

Figure 3a. Transformer serves as the main inductor (auxiliary output referenced to zero volts. T1 = Cooper

Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)
Figure 3a. Transformer serves as the main inductor (auxiliary output referenced to zero volts. T1 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Figure 3b. Transformer as main inductor (+ve auxiliary output referenced to main output). T1 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)
Figure 3b. Transformer as main inductor (+ve auxiliary output referenced to main output). T1 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Auxiliary output voltage is given by:

$V_{AUX} = N2/N1\ (V_{OUT} + V_{DIODE1}) - V_{DIODE2}$

N1 = primary turns and N2 = secondary turns.

This output in Figure 3 is independent of input-voltage changes, as D2 is ON when the internal LX power switch is OFF. Capacitor C7 should be chosen to support the output during the maximum on-time of the power switch. The secondary output suffers a 2% to 3% output variation as the forward voltage drop of D1 varies with temperature and load current. Since N1 and N2 of the transformer are DC-isolated from each another, the extra output may be referenced to any DC voltage.

For a given inductor value, secondary power at the auxiliary output is limited by the onset of discontinuous current in the main primary loop. Restated simply, D1 must remain in conduction at the end of the flyback period. At the onset of discontinuous operation, conduction through D1 becomes zero, and the voltage at LX will show the characteristic decaying 'ring' at a frequency determined by the output inductance and the total stray capacitance at the LX node.

Secondary loading causes a change of primary current at the point of transition when the internal LX switches from on to off. This current step shown in **Figure 4** is given by:

$I_{XTRA} = P_{SEC}\ (D \times V_{LX})$
D = duty cycle
P_{SEC} = secondary power
V_{LX} = peak voltage excursion at LX

In principle, there is much flexibility in the choice of turns ratio. However, in practice, the availability of standard 1:1 transformers with suitable inductance and peak-current values makes this the most popular choice of turns ratio.

Figure 4. Primary inductor current due to secondary loading.
Figure 4. Primary inductor current due to secondary loading.

Note how the additional loading produces changed primary ripple current. Bold lines identify simplified changes to the main-inductor current shape with active auxiliary output.

Relative Advantages of this Approach

1. Positive or negative auxiliary output
2. Quasiregulated auxiliary output
3. Isolated; can be referenced to ground or main positive output
4. Inductance value set by main step-down
5. Off-the-shelf magnetics (1:1 transformer ratio)

Relative Disadvantages of this Approach

1. Increased primary ripple current increases onset of discontinuous current
2. Minimum load required on aux output
3. Minimum load required on main positive output to maintain switching action at LX

Negative Auxiliary Output Derived from a Charge Pump

The LX terminal voltage excursion can be used as a source for a charge pump to generate an unregulated auxiliary negative output. The additional output is unregulated because the voltage at LX is not isolated from changes of V_{IN}. The additional charge-pump components are shown in **Figure 5**. See also waveforms in **Example 3**.

When the power switch closes at the start of the power cycle, current flows into C7 through D2 and R6 and begins to ramp in the inductor, L1. On the flyback cycle when D1 conducts, the charge on C7 is transferred to C8 and the load. R6 is an important addition, as it limits the peak current into C7. Without R6, the current limit of the power switch will be exceeded, causing premature termination of the power cycle and even shutdown on protected step-down converters like the MAX5035. See **Figure 6**.

Figure 5. Schematic for an auxiliary negative output derived from a charge pump.
Figure 5. Schematic for an auxiliary negative output derived from a charge pump.

Figure 6. Current waveform from an inductor and charge pump.
Figure 6. Current waveform from an inductor and charge pump.

The source impedance of the unregulated charge pump due to R6 and C7 is given by:

Identifying the source impedance of the unregulated charge pump allows the designer to estimate the charge-pump output voltage under variable load conditions.

The open-circuit, charge-pump auxiliary output voltage is given approximately by:

The loaded charge-pump auxiliary output voltage is given by:

With capacitor values in the 1µF to 10µF range, R1 will dominate the source impedance. Output ripple is due almost entirely to ESR of C8 (output capacitor in Figure 4). As the charge pump is unregulated, a linear regulator can be connected at the output to provide a regulated negative output.

Relative Advantages of this Approach

1. Small components
2. Lower cost than 1:1 transformer architecture

Relative Disadvantages of this Approach

1. Unregulated output; an additional regulator may be needed at output if the input voltage has a wide range.
2. High peak currents for modest auxiliary load currents (approx 4 x I_{OUT_AVE})
3. Negative auxiliary output only; the output can be referenced to ground or the main regulated output, provided that enough voltage difference is available to charge the pump capacitor (C7 in Figure 5).
4. Minimum load required on auxiliary output to prevent spike storage overvoltage
5. Minimum load required on main positive output to maintain switching action at LX

SEPIC Auxiliary Supply

A negative output can be obtained from the LX pin by employing a second inductor, L2, which shares the same core and, therefore, the same value as the main step-down inductor. **Figure 7** shows how C5, D2, C6, and L2 form a SEPIC topology. See also waveforms in **Example 4**. The switching signal at LX driving the positive-output step-down is also the same level for driving the negative output. During the switch ON period, the voltage across L1 is $V_{LX} - V_{OUT}$, and during the OFF period is $V_{OUT} + V_{DIODE\_1}$). By transformer action (1:1) this voltage is also impressed across L2 and generates $-V_{OUT}$ with D2 and C5. Because of the less-than-perfect coupling of the two windings L1 and L2, C5 creates the SEPIC connection and improves regulation of what would be a normal flyback auxiliary output with very modest regulation.

The coupling capacitor, C5, is chosen to produce a low-voltage ripple across it as a function of auxiliary load-current duty cycle and clock period.

Relative Advantages of this Approach

1. Quasiregulated output
2. 'Clean' inductor current waveform; less noise generation
3. Ripple reduction due to coupled inductors
4. Single magnetic component (off-the-shelf 1:1 transformer)

Relative Disadvantages of this Approach

1. -V_{OUT} only available
2. Ground referenced output

Figure 7. Coupled inductor SEPIC auxiliary supply. L1, L2 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Figure 7. Coupled inductor SEPIC auxiliary supply. L1, L2 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Conclusions

A number of auxiliary output topologies can be added to an integrated, positive step-down converter. The MAX5035 was chosen for the examples, but the lower output MAX5033 can employ the same circuits, but at reduced outputs.

Flyback Auxiliary
For complete independence from auxiliary output reference, the flyback circuit adds a winding to the main step-down inductor, a Schottky diode, and a capacitor. This design is very appealing and comes with modest regulation. With a 1:1 transformer (Cooper Bussmann DRQ125-101 for the MAX5035), the auxiliary output can be ±V_{OUT} with respect to ground or the main V_{OUT}. Auxiliary output current can be up to 20% of the main output, although some distortion of the main inductor current is to be expected.

Coupled Inductor SEPIC Auxiliary
Not as versatile in grounding arrangements, the coupled inductor SEPIC topology provides a regulated -V_{OUT} referenced to ground only. Regulation is better than the flyback approach, and inductor current waveform distortion is small. Auxiliary output current can be up to 20% of the main output. The coupled inductor aids ripple reduction in the auxiliary output.

Charge Pump Inverter
The charge pump is the lowest cost option with no additional inductor winding. This design is suitable for low-power outputs only because of the high peak currents and voltages associated with the topology. Open-circuit output is approximately V_{IN}, reducing as the loading is increased on the auxiliary output. Suggested maximum loading is 5% or less of the main positive output.

With this approach the main positive output must remain active at all times, and the main step-down inductor current must remain continuous at all times. Extra peak current will be demanded by the auxiliary output, and this must be taken into account when minimum loading of the main output and maximum loading of the auxiliary output are considered.

Suggested Component Suppliers

Supplier	Component	Website
AVX Ceramic	capacitors	www.avxcorp.com
Coilcraft	Power inductors	www.coilcraft.com
Coiltronics	Power inductors	www.cooperET.com
Diodes Incorporated	Schottky diodes	www.diodes.com
Panasonic	Ceramic/Al capacitors	www.panasonic.com
Sanyo	Ceramic/Al capacitors	www.sanyo.com
TDK	Ceramic capacitors	www.component.tdk.com
Vishay	Diodes, resistors, capacitors	www.vishay.com
On-Semiconductor	Schottky diodes	www.onsemi.com

Example 1 Waveforms: Step-down converter, MAX5035 EV Kit No Auxiliary (Fig 1):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω ±5%)

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT} (Violet)

I_{LX_PEAK} = 550mA
V_{LX_PEAK} = 15V
Period = 8µs

Example 2a Waveforms: Transformer as Main Inductor, Flyback Auxiliary Output (Fig 3):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = 5.02V
-I_{OUT_AUX} = -152mA (R_{LOAD} = 33Ω)
C3 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)

ILX_PEAK = 0.63A

Note: The LX waveform distortion is caused by additional loading during the flyback (D1 ON) period.

Example 2b Waveforms: Transformer as Main Inductor, Flyback Auxiliary Output (Fig 3):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = 5.3V
-I_{OUT_AUX} = -104mA (R_{LOAD} = 51Ω)
C3 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)

I_{LX_PEAK} = 0.6A

Note: the reduced LX waveform distortion is caused by reduced loading on flyback (D1 ON) period. Compare this to Example 2a above.

Example 3 Waveforms: Charge Pump Negative Auxiliary Output (Figure 5).

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = -12.3V
-I_{OUT_AUX} = 82mA (R_{LOAD} = 150Ω
D2, 3 = 1N5817MDICT
C7 = 1µ
C8 = 10µF
R6 = 5.6Ω

Waveforms:

1. LX + Charge Pump current ramp (Yellow, 0.2A / sq)
2. LX voltage (Green)
3. -V_{OUT_AUX} (violet, 500mV / sq), AC-coupled.

Lx current waveform = 750mA pk. Contrast with 550mA peak of the basic step down.

Note: the dV/dT spikes at auxiliary output. Post filter with small LC. L may be formed from pc copper track.

Example 4 Waveform: SEPIC Auxiliary Supply (Fig 7):

L1 = L2 = 100µH coupled (1:1) inductor
V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = -5.02V
-I_{OUT_AUX} = 228mA (R_{LOAD} = 22Ω)
C5 = 10µF
C6 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX current ramp (Yellow, 0.2A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)

I_{LX_PEAK} = 1.15A
V_{OUT_AUX} Ripple = 100mV pk-pk excluding narrow dV/dT pulses.

Note: dV/dT spikes at auxiliary output. Post filter with small LC. L may be formed from pc copper track.

More Information APP 3740: Jan 10, 2006

MAX5035	1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter	Full Data Sheet (PDF, 360kB)	Free Samples

Download, PDF Format (219kB)
AN3740, AN 3740, APP3740, Appnote3740, Appnote 3740

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MAX5035

1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter

DESCRIPTION

The MAX5035 easy-to-use, high-efficiency, high-voltage, step-down DC-DC converter operates from an input voltage up to 76V and consumes only 350µA quiescent current at no load. This pulse-width modulated (PWM) converter operates at a fixed 125kHz switching frequency at heavy loads, and automatically switches to pulse-skipping mode to provide low quiescent current and high efficiency at light loads. The MAX5035 includes internal frequency compensation simplifying circuit implementation. The device uses an internal low-on-resistance, high-voltage, DMOS transistor to obtain high efficiency and reduce overall system cost. This device includes undervoltage lockout, cycle-by-cycle current limit, hiccup mode output short-circuit protection, and thermal shutdown.

The MAX5035 delivers up to 1A output current. External shutdown is included, featuring 10µA (typ) shutdown current. The MAX5035A/B/C versions have fixed output voltages of 3.3V, 5V, and 12V, respectively, while the MAX5035D features an adjustable output voltage from 1.25V to 13.2V.

The MAX5035 is available in space-saving 8-pin SO and 8-pin plastic DIP packages and operates over the industrial (0°C to +85°C) temperature range.

KEY FEATURES

- Wide 7.5V to 76V Input Voltage Range
- Fixed (3.3V, 5V, 12V) and Adjustable (1.25V to 13.2V) Versions
- 1A Output Current
- Efficiency Up to 94%
- Internal 0.4 High-Side DMOS FET
- 350µA Quiescent Current at No Load, 10µA Shutdown Current
- Internal Frequency Compensation
- Fixed 125kHz Switching Frequency
- Thermal Shutdown and Short-Circuit Current Limit
- 8-Pin SO and PDIP Packages

APPLICATIONS

- Consumer Electronics
- Distributed Power
- Industrial

KEY SPECIFICATIONS: Switchmode DC-DC Power Supplies

Part Number	Min. V_{IN} (V)	Max. V_{IN} (V)	Max. I_{CC} (mA)	Preset V_{OUT} (V)	Min. Adj. V_{OUT} (V)	Max. Adj. V_{OUT} (V)	Typ. I_{OUT} (A)	Outputs	Op. Freq. (kHz)	Package	Op. Range (°C)	Inductor Based	Current Regulator	Price @ 1k
MAX5035	6.5	76	0.5	3.3 5 12	1.25	13.2	1	• +/-3% • Hiccup mode short-circuit protection	125	8/PDIP.300 8/SO.150	0 to +85	Yes	Pulse-by-pulse	$1.90

LINKS TO MORE INFORMATION

- Printed Data Sheet: (19-2988; Rev 0; Rev 2003-11-05)
- Complete Data Sheet: (PDF 392k): Download or or E-MAIL
- Evaluation Kit: MAX5035EVKIT
- Request Samples: MAX5035 Samples Cart
- Price and Availability
- MAX5035 At-A-Glance

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RELATED PRODUCTS

MAX5033 500mA, 76V, High-Efficiency, MAXPower Step-Down DC-DC Converter - DESCRIPTION

EXHIBIT B

Keywords: step-down, buck, transformer, flyback, SEPIC Jan 10, 2006

APPLICATION NOTE 3740

How to Generate Auxiliary Supplies from a Positive Buck DC-DC Converter

Many applications require a low-power supply in addition to the main supply. For reasons of cost, inventory management, or electromagnetic compatibility (EMC), a separate converter may not be appropriate. Consequently, another means of providing extra power rails from the main supply is needed. This application note shows how to use a step-down IC converter's switching action to derive one or more outputs, isolated or non-isolated, quasi-regulated or unregulated.

Introduction

Many applications require a low-power supply in addition to the main supply. A typical example is when an analog front-end amplifier needs ±5V, while the main digital circuitry requires +5V only. For reasons of cost, inventory management, or EMC, a separate -5V converter may not be appropriate. Consequently, another means of providing extra power rails from the main supply is needed.

As a solution to this problem, a step-down IC converter's switching action can be used to derive one or more outputs, isolated or non-isolated, quasi-regulated or unregulated. Auxiliary output currents of 10% to 30% of the main output are perfectly possible. This application note will illustrate this technique using the MAX5035 DC-DC converter.

Step-Down Waveforms

A review of the waveforms found in a working step-down converter will identify the voltage and currents that can be used to generate additional outputs. See Figure 1 below and Example 1 waveforms at the end of this article.

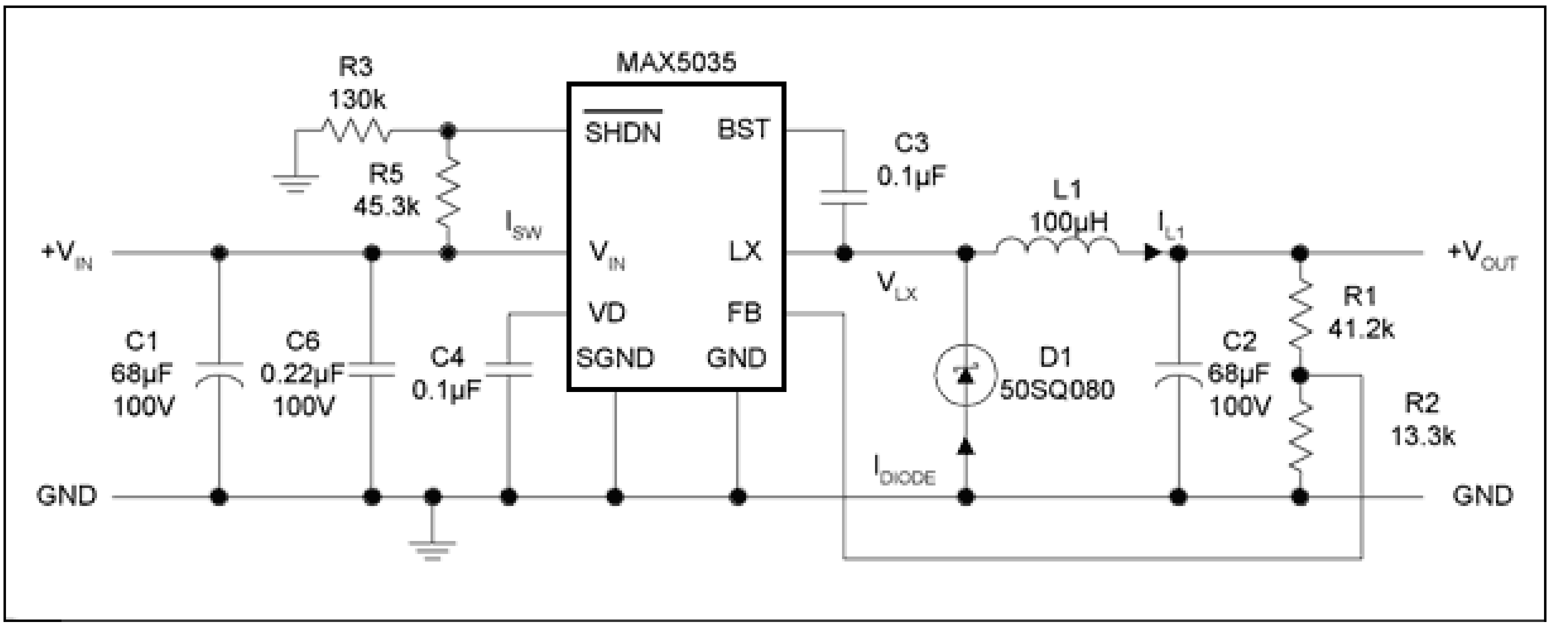


Figure 1. The MAX5035 schematic illustrates step-down converter operation.

There is a switching voltage waveform of amplitude at the LX pin:

V_{LX} = [V_{IN} (max) to -V(diode)] < V_{LX} < V_{IN}(min) -V(diode)]

The voltage across the main inductor during the power cycle (LX connected to V_{IN}) is:

$V_{IN}D$ = [V_{IN} (max) - V_{OUT}] < $V_{IN}D$ < [V_{IN}(min) - V_{OUT}]

Continuous Inductor Current Operation

When the power switch is off, the voltage at the LX connection flies negative, turning on the diode, D1, to ensure that the inductor current continues to circulate. Operation is said to be continuous when the power cycle begins before the circulating current in D1 falls to zero (**Figure 2**).

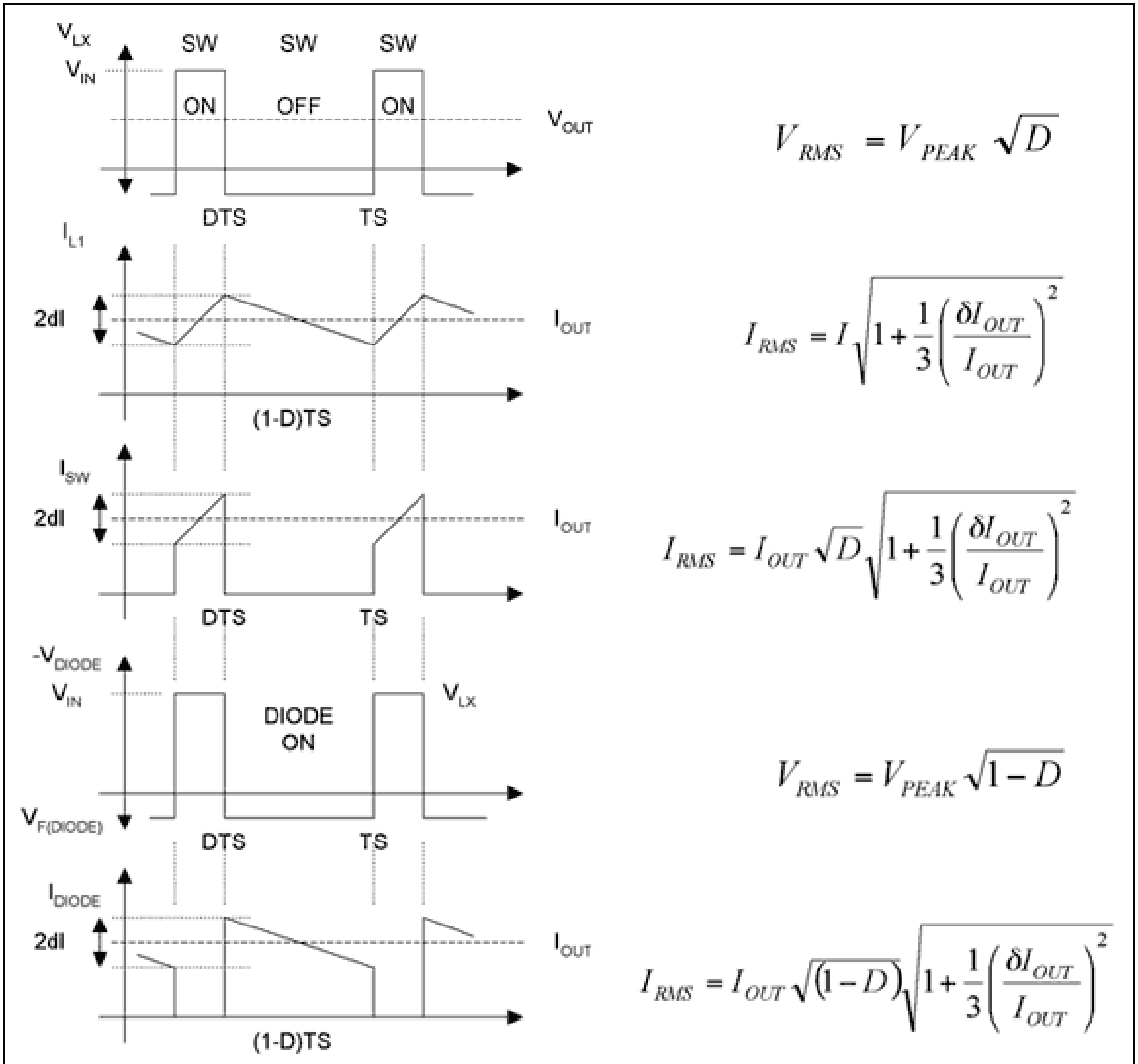


Figure 2. Continuous inductor current waveforms. TS = switching period; D = duty cycle.

Knowing the various RMS currents and voltages associated with the key components, power dissipation can be calculated as follows:

[1] Internal LX switch power dissipation: $P_{SW} = (I_{SW\_RMS})^2 R_{ON\_SW}$

[2] IC quiescent power dissipation: $P_{I\_QUIESCENT} = V_{IN} I_{QUIESCENT}$

[3] Schottky diode (D1) power dissipation: $P_{DIODE} = I_{DIODE\_RMS} V_{DIODE\_FORWARD}$

[4] Load power dissipation: $P_{LOAD} = R_{LOAD}(I_{LOAD\_RMS})^2$

Definitions

RON_SW—Data sheet on-resistance of the internal power switch (V_{IN} to LX)

RLOAD—Effective resistance connected at the power-supply output.
IQUIESCENT—Quiescent current of the control IC with no switching action.
IDIODE_RMS—Schottky diode (D1) forward RMS current.
VFORWARD—Forward voltage drop across Schottky diode, D1, at rated current.
ILOAD_RMS—RMS load current.

Auxiliary Outputs

Auxiliary outputs can be added to the main step-down by an additional winding on its inductor. The additional output relies on flyback action in the main inductor during the time that the 'catch' Schottky diode (D1 in Fig1) is conducting. Because the diode voltage drop is relatively constant (300mV to 500mV, typically, depending on current), and because the controller regulates the output voltage, the inductor's voltage drop is also relatively constant during the OFF time of the power switch. For the voltage drop to remain consistent, the main inductor should be in continuous conduction throughout the main step-down load range.

The LX pin can also be used to provide a switching input to a discrete charge-pump circuit. For this to remain consistent, the LX pin must be active whenever the additional output is required. You can keep the LX pin active by ensuring that the main step-down output supports a minimum load.

Inductor Selection

Three functions are needed to set the value of the main inductor: the voltage across the inductor, the operating frequency, and the inductor's current ripple. Together, these functions will ensure that adequate energy is stored in the inductor. The inductor's minimum value is determined by the maximum duty cycle and minimum input voltage, and is given by:

$$L_{MIN} = \frac{D_{MAX}(V_{IN\_MIN} - V_{OUT})}{I_{RIPPLE} F_{CLOCK}}$$

$$D_{MAX} = \frac{V_{IN\_MIN}}{V_{OUT}} \qquad I_{RIPPLE} = \% I_{LOAD} \qquad \text{(Continuous operation)}$$

Ripple current is a percentage of output current, and defined as 30% for the MAX5035. Note that the ripple current sets the minimum load current before the onset of discontinuous operation. Because an auxiliary supply increases the peak-current requirements of the power switch, care must be taken to limit the auxiliary power drawn.

For many applications, the Evaluation (EV) kit's standard setup of 100µH and 68µF output filter values will be suitable. These values are retained for the additional supplies. The MAX5035 features fixed, internal type-3 compensation which imposes limitations on the choice of output capacitor. Chose the ESR so that the zero frequency occurs between 20kHz and 40kHz. See the application section of the MAX5035 data sheet for more information.

Auxiliary Output Derived from the Main Inductor's Transformer

The inductor's voltage drop is relatively constant during the power switch's OFF time, because the primary Schottky diode voltage drop is relatively constant (300mV to 500mV, typically, depending on current), and the controller regulates the output voltage. Connecting the secondary rectifier and capacitor so that conduction occurs during the flyback period (diode ON), allows some energy to be tapped off the main inductor. **Figures 3a** and **3b** show two versions of this arrangement. Isolating the auxiliary winding from the main step-down allows flexible connection arrangements. Figure 3a shows the auxiliary output referred to zero volts, and Figure 3b shows the auxiliary output referred to the main positive output. See also waveforms in **Examples 2a** and **2b**.

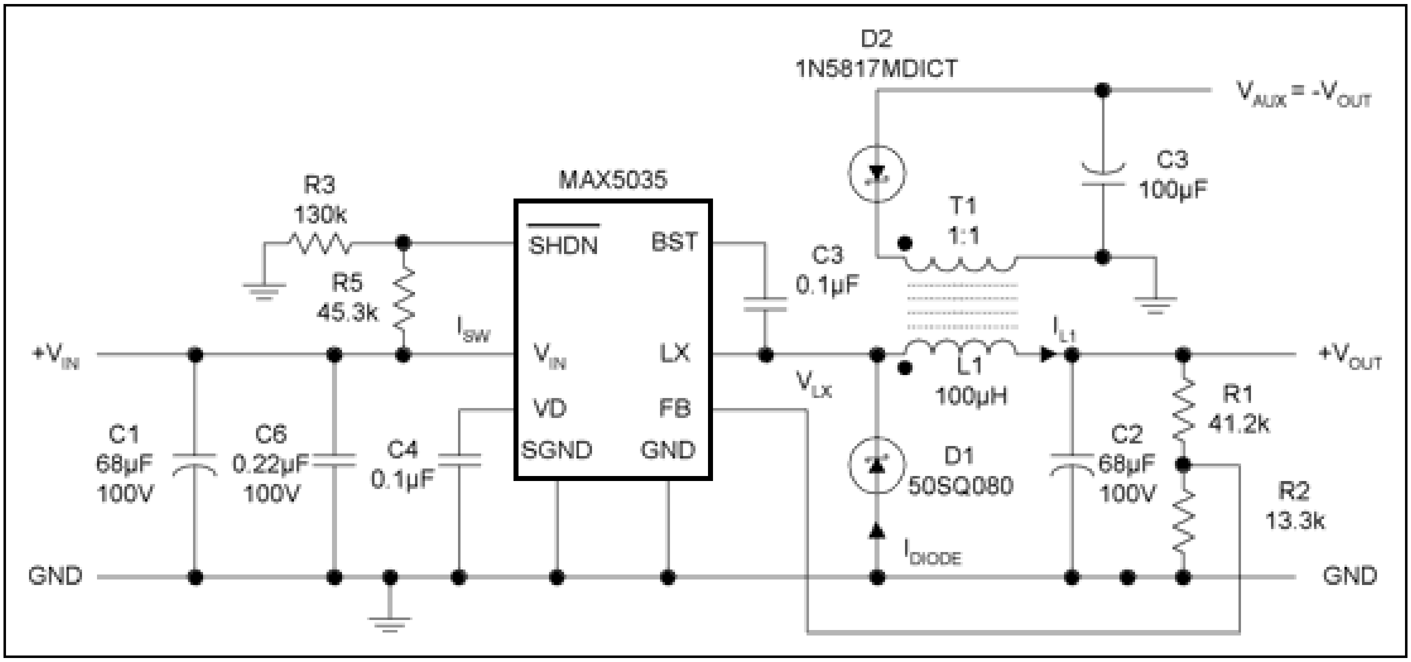


Figure 3a. Transformer serves as the main inductor (auxiliary output referenced to zero volts. T1 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

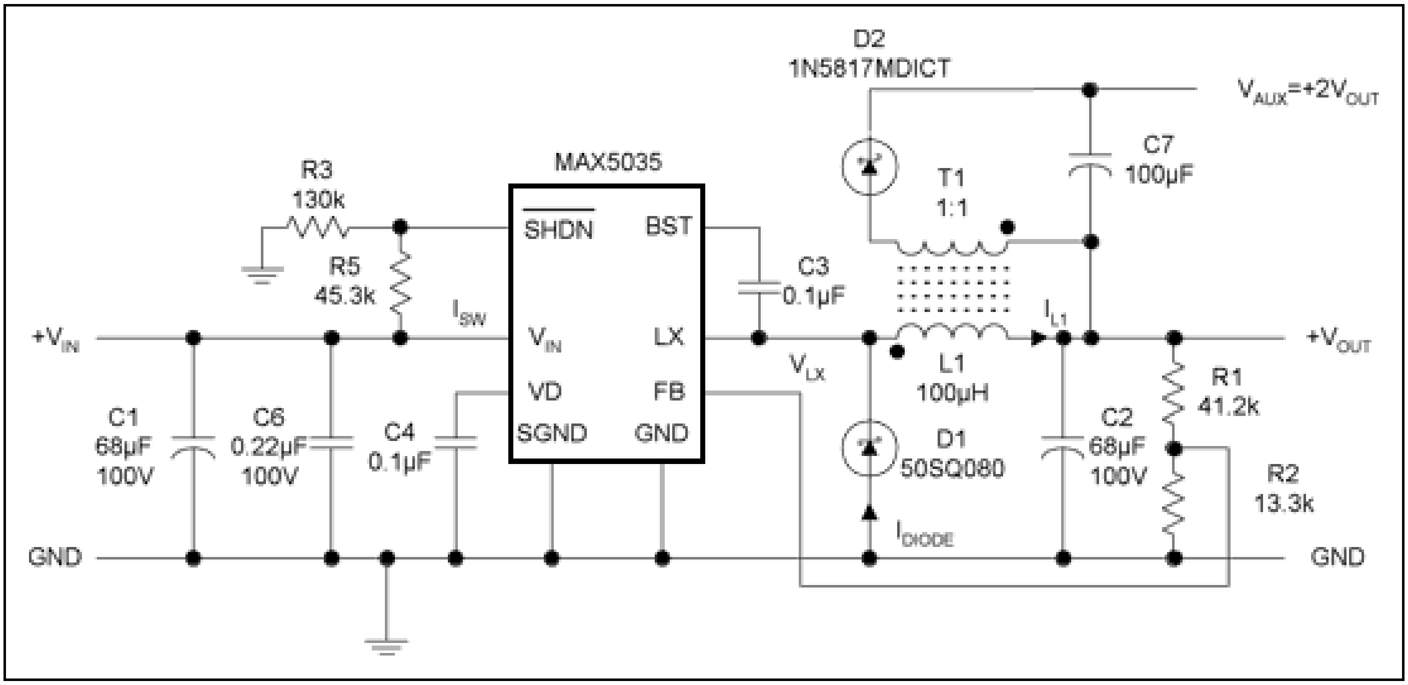


Figure 3b. Transformer as main inductor (+ve auxiliary output referenced to main output). T1 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Auxiliary output voltage is given by:

$V_{AUX} = N2/N1 (V_{OUT} + V_{DIODE1}) - V_{DIODE2}$

N1 = primary turns and N2 = secondary turns.

This output in Figure 3 is independent of input-voltage changes, as D2 is ON when the internal LX power switch is OFF. Capacitor C7 should be chosen to support the output during the maximum on-time of the power switch. The secondary output suffers a 2% to 3% output variation as the forward voltage drop of D1 varies with temperature and load current. Since N1 and N2 of the transformer are DC-isolated from each other, the extra output may be referenced to any DC voltage.

For a given inductor value, secondary power at the auxiliary output is limited by the onset of discontinuous current in the main primary loop. Restated simply, D1 must remain in conduction at the end of the flyback period. At the onset of discontinuous operation, conduction through D1 becomes zero, and the voltage at LX will show the characteristic decaying 'ring' at a frequency determined by the output inductance and the total stray capacitance at the LX node.

Secondary loading causes a change of primary current at the point of transition when the internal LX switches from on to off. This current step shown in **Figure 4** is given by:

$I_{XTRA} = P_{SEC} (D \times V_{LX})$
D = duty cycle
P_{SEC} = secondary power
V_{LX} = peak voltage excursion at LX

In principle, there is much flexibility in the choice of turns ratio. However, in practice, the availability of standard 1:1 transformers with suitable inductance and peak-current values makes this the most popular choice of turns ratio.

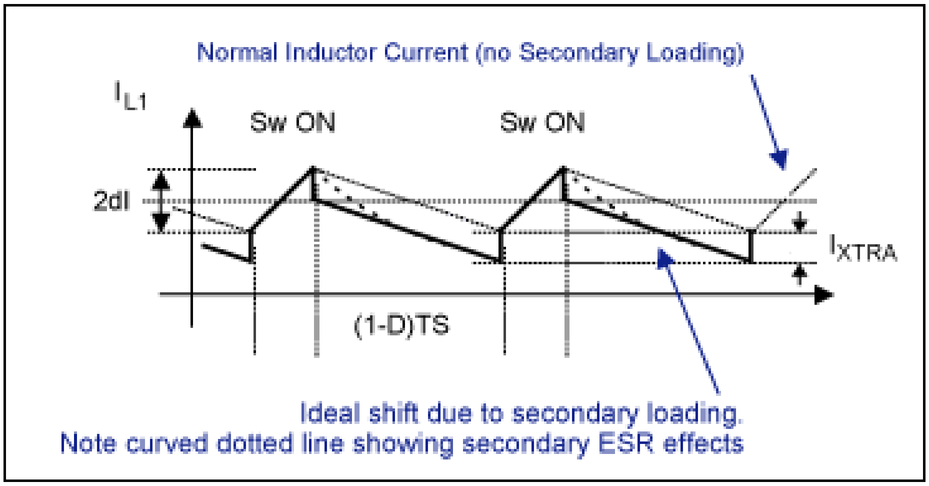


Figure 4. Primary inductor current due to secondary loading.

Note how the additional loading produces changed primary ripple current. Bold lines identify simplified changes to the main-inductor current shape with active auxiliary output.

Relative Advantages of this Approach

1. Positive or negative auxiliary output
2. Quasiregulated auxiliary output
3. Isolated; can be referenced to ground or main positive output
4. Inductance value set by main step-down
5. Off-the-shelf magnetics (1:1 transformer ratio)

Relative Disadvantages of this Approach

1. Increased primary ripple current increases onset of discontinuous current
2. Minimum load required on aux output
3. Minimum load required on main positive output to maintain switching action at LX

Negative Auxiliary Output Derived from a Charge Pump

The LX terminal voltage excursion can be used as a source for a charge pump to generate an unregulated auxiliary negative output. The additional output is unregulated because the voltage at LX is not isolated from changes of V_{IN}. The additional charge-pump components are shown in **Figure 5**. See also waveforms in **Example 3**.

When the power switch closes at the start of the power cycle, current flows into C7 through D2 and R6 and begins to ramp in the inductor, L1. On the flyback cycle when D1 conducts, the charge on C7 is transferred to C8 and the load. R6 is an important addition, as it limits the peak current into C7. Without R6, the current limit of the power switch will be exceeded, causing premature termination of the power cycle and even shutdown on protected step-down converters like the MAX5035. See **Figure 6**.

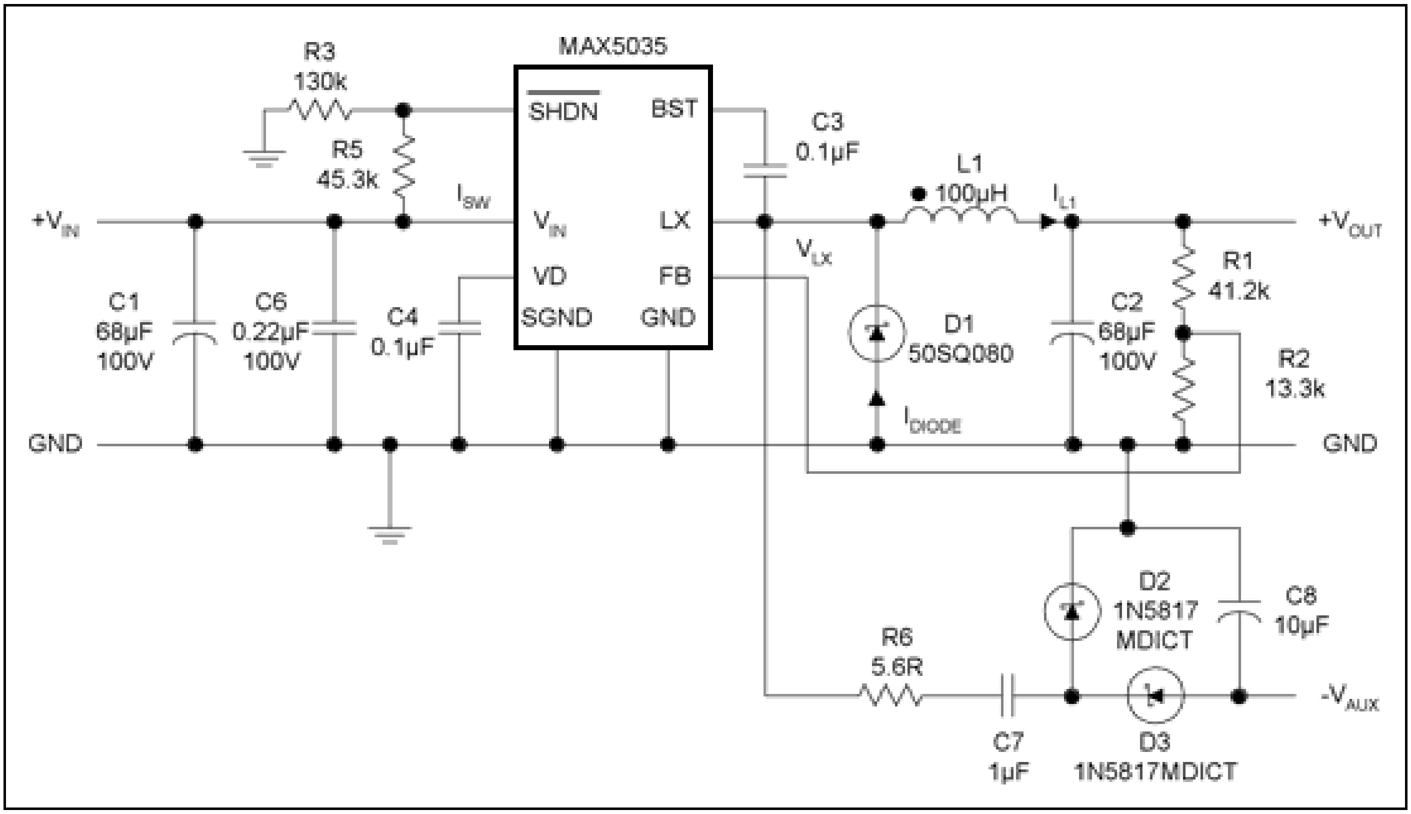


Figure 5. Schematic for an auxiliary negative output derived from a charge pump.

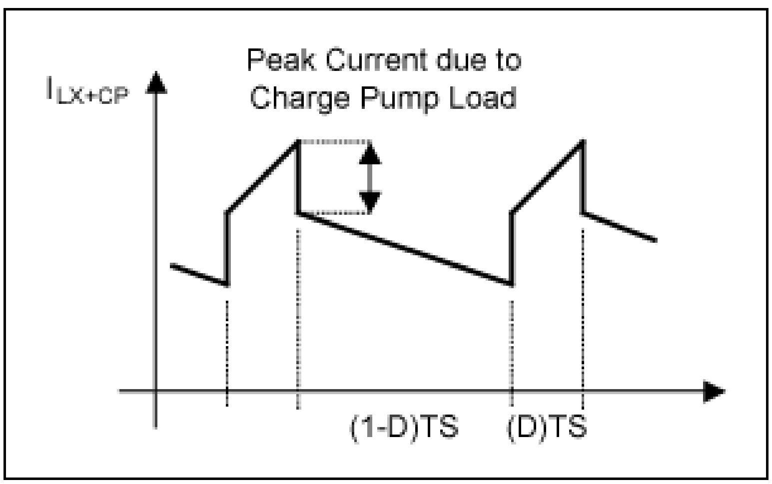


Figure 6. Current waveform from an inductor and charge pump.

The source impedance of the unregulated charge pump due to R6 and C7 is given by:

$$R_{SOURCE\_CP} = \frac{R6}{D} + \frac{DT}{C7} \qquad D = \frac{V_{OUT\_MAIN}}{V_{IN}} \qquad V_{OUT\_MAIN} = \text{Main step-down output.}$$

$$R_{SOURCE\_CP} = \frac{R6 \times V_{IN}}{V_{OUT\_MAIN}} + \frac{V_{OUT\_MAIN}T}{V_{IN}C7} \qquad D = \text{Duty cycle}$$

Identifying the source impedance of the unregulated charge pump allows the designer to estimate the charge-pump output voltage under variable load conditions.

The open-circuit, charge-pump auxiliary output voltage is given approximately by:

$$-V_{AUX\_O/C} = V_{LX} + V_{DIODE\_1} - V_{DIODE\_2} - V_{DIODE\_3} \quad \text{Assumes no spike storage on C8 (+20\%)}$$

The loaded charge-pump auxiliary output voltage is given by:

$$-V_{AUX\_LOADED} = -V_{AUX\_O/C}\left(\frac{R_{LOAD}}{R_{SOURCE\_CP} + R_{LOAD}}\right) \quad \text{Output voltage with load resistor}$$

With capacitor values in the 1µF to 10µF range, R1 will dominate the source impedance. Output ripple is due almost entirely to ESR of C8 (output capacitor in Figure 4). As the charge pump is unregulated, a linear regulator can be connected at the output to provide a regulated negative output.

Relative Advantages of this Approach

1. Small components
2. Lower cost than 1:1 transformer architecture

Relative Disadvantages of this Approach

1. Unregulated output; an additional regulator may be needed at output if the input voltage has a wide range.
2. High peak currents for modest auxiliary load currents (approx 4 x I_{OUT_AVE})
3. Negative auxiliary output only; the output can be referenced to ground or the main regulated output, provided that enough voltage difference is available to charge the pump capacitor (C7 in Figure 5).
4. Minimum load required on auxiliary output to prevent spike storage overvoltage
5. Minimum load required on main positive output to maintain switching action at LX

SEPIC Auxiliary Supply

A negative output can be obtained from the LX pin by employing a second inductor, L2, which shares the same core and, therefore, the same value as the main step-down inductor. **Figure 7** shows how C5, D2, C6, and L2 form a SEPIC topology. See also waveforms in **Example 4**. The switching signal at LX driving the positive-output step-down is also the same level for driving the negative output. During the switch ON period, the voltage across L1 is V_{LX} - V_{OUT}, and during the OFF period is V_{OUT} + V_{DIODE_1}). By transformer action (1:1) this voltage is also impressed across L2 and generates -V_{OUT} with D2 and C5. Because of the less-than-perfect coupling of the two windings L1 and L2, C5 creates the SEPIC connection and improves regulation of what would be a normal flyback auxiliary output with very modest regulation.

The coupling capacitor, C5, is chosen to produce a low-voltage ripple across it as a function of auxiliary load-current duty cycle and clock period.

$$C5_{MIN} = \frac{I_{OUT\_AUX} D_{MIN} T}{V_{IN}(\% Ripple)}$$

Relative Advantages of this Approach

1. Quasiregulated output
2. 'Clean' inductor current waveform; less noise generation

3. Ripple reduction due to coupled inductors
4. Single magnetic component (off-the-shelf 1:1 transformer)

Relative Disadvantages of this Approach

1. $-V_{OUT}$ only available
2. Ground referenced output

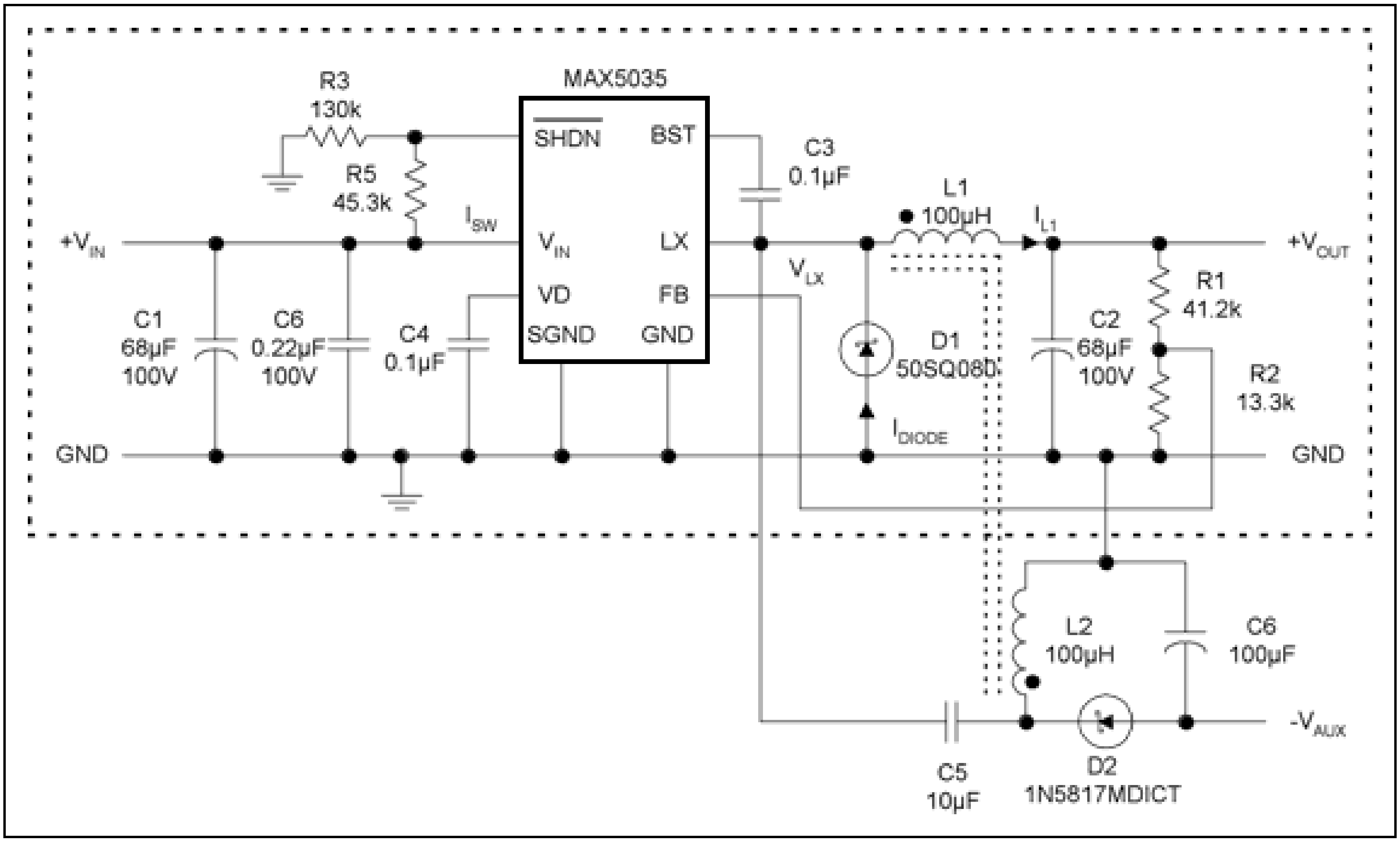


Figure 7. Coupled inductor SEPIC auxiliary supply. L1, L2 = Cooper Bussmann DRQ125-101. (Note the DOT convention for the start of windings.)

Conclusions

A number of auxiliary output topologies can be added to an integrated, positive step-down converter. The MAX5035 was chosen for the examples, but the lower output MAX5033 can employ the same circuits, but at reduced outputs.

Flyback Auxiliary
For complete independence from auxiliary output reference, the flyback circuit adds a winding to the main step-down inductor, a Schottky diode, and a capacitor. This design is very appealing and comes with modest regulation. With a 1:1 transformer (Cooper Bussmann DRQ125-101 for the MAX5035), the auxiliary output can be $\pm V_{OUT}$ with respect to ground or the main V_{OUT}. Auxiliary output current can be up to 20% of the main output, although some distortion of the main inductor current is to be expected.

Coupled Inductor SEPIC Auxiliary
Not as versatile in grounding arrangements, the coupled inductor SEPIC topology provides a regulated $-V_{OUT}$ referenced to ground only. Regulation is better than the flyback approach, and inductor current waveform distortion is small. Auxiliary output current can be up to 20% of the main output. The coupled inductor aids ripple reduction in the auxiliary output.

Charge Pump Inverter
The charge pump is the lowest cost option with no additional inductor winding. This design is suitable for low-power outputs only because of the high peak currents and voltages associated with the topology. Open-circuit output is approximately V_{IN}, reducing as the loading is increased on the auxiliary output. Suggested maximum loading is 5% or less of the main positive output.

With this approach the main positive output must remain active at all times, and the main step-down inductor current must remain continuous at all times. Extra peak current will be demanded by the auxiliary output, and this must be taken into account when minimum loading of the main output and maximum loading of the auxiliary output are considered.

Suggested Component Suppliers

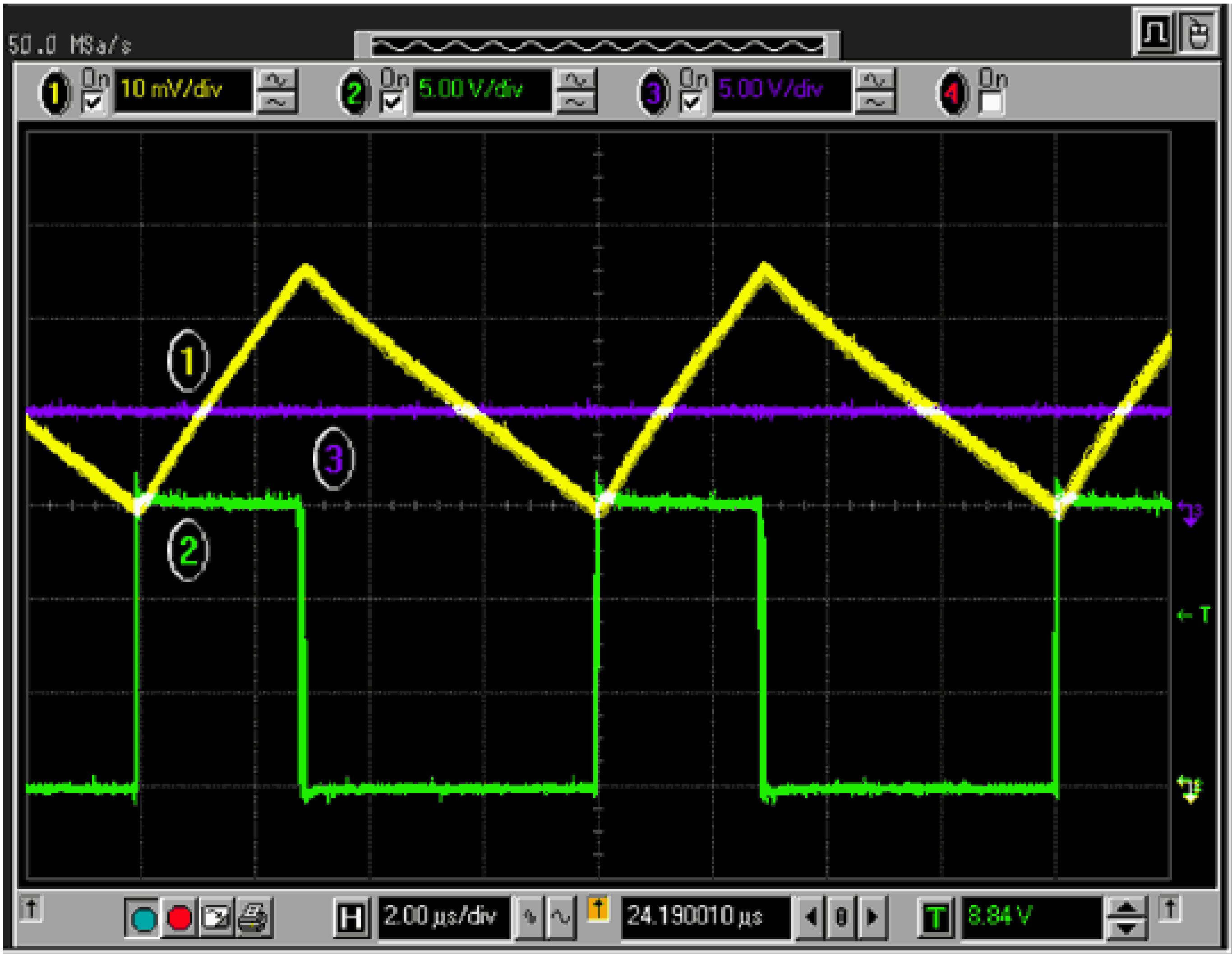
Supplier	Component	Website
AVX Ceramic	capacitors	www.avxcorp.com
Coilcraft	Power inductors	www.coilcraft.com
Coiltronics	Power inductors	www.cooperET.com
Diodes Incorporated	Schottky diodes	www.diodes.com
Panasonic	Ceramic/Al capacitors	www.panasonic.com
Sanyo	Ceramic/Al capacitors	www.sanyo.com
TDK	Ceramic capacitors	www.component.tdk.com
Vishay	Diodes, resistors, capacitors	www.vishay.com
On-Semiconductor	Schottky diodes	www.onsemi.com

Example 1 Waveforms: Step-down converter, MAX5035 EV Kit No Auxiliary (Fig 1):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω ±5%)

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT} (Violet)



I_{LX_PEAK} = 550mA
V_{LX_PEAK} = 15V
Period = 8µs

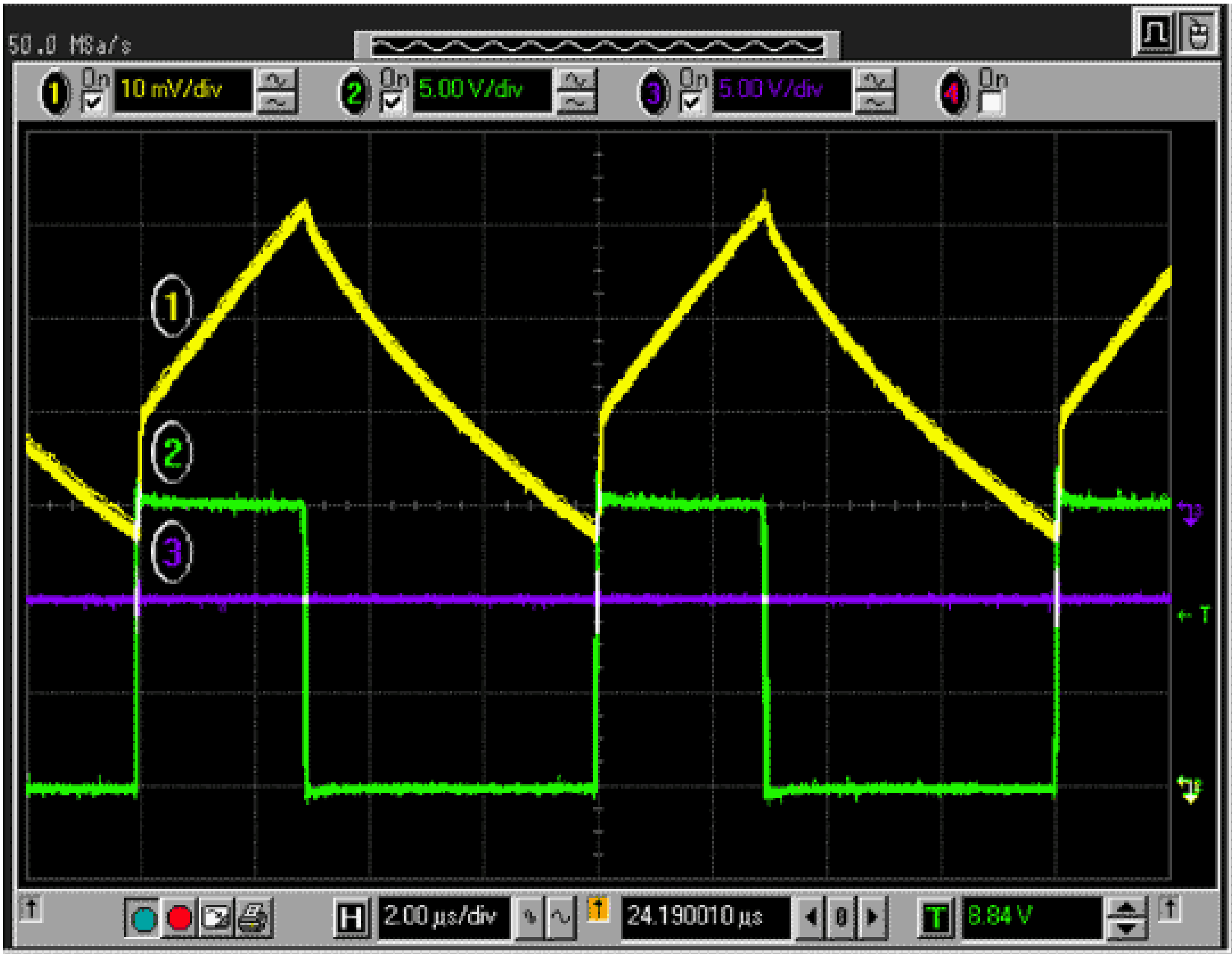
Example 2a Waveforms: Transformer as Main Inductor, Flyback Auxiliary Output (Fig 3):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

$-V_{OUT}$ = 5.02V
$-I_{OUT\_AUX}$ = -152mA (R_{LOAD} = 33Ω)
C3 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)



ILX_PEAK = 0.63A

Note: The LX waveform distortion is caused by additional loading during the flyback (D1 ON) period.

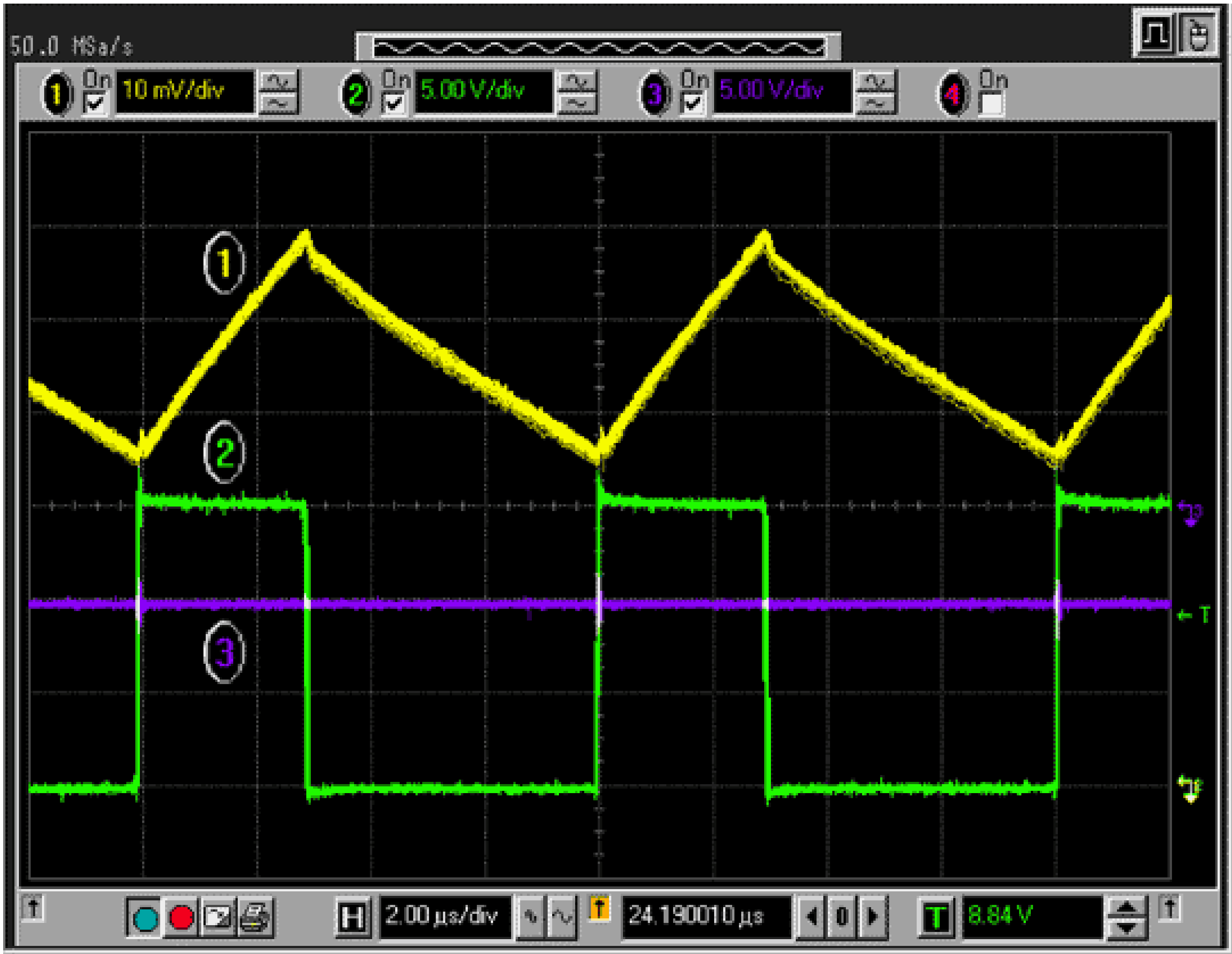
Example 2b Waveforms: Transformer as Main Inductor, Flyback Auxiliary Output (Fig 3):

V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = 5.3V
-I_{OUT_AUX} = -104mA (R_{LOAD} = 51Ω)
C3 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX inductor current ramp (Yellow, 0.1A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)



I_{LX_PEAK} = 0.6A

Note: the reduced LX waveform distortion is caused by reduced loading on flyback (D1 ON) period. Compare this to Example 2a above.

Example 3 Waveforms: Charge Pump Negative Auxiliary Output (Figure 5).

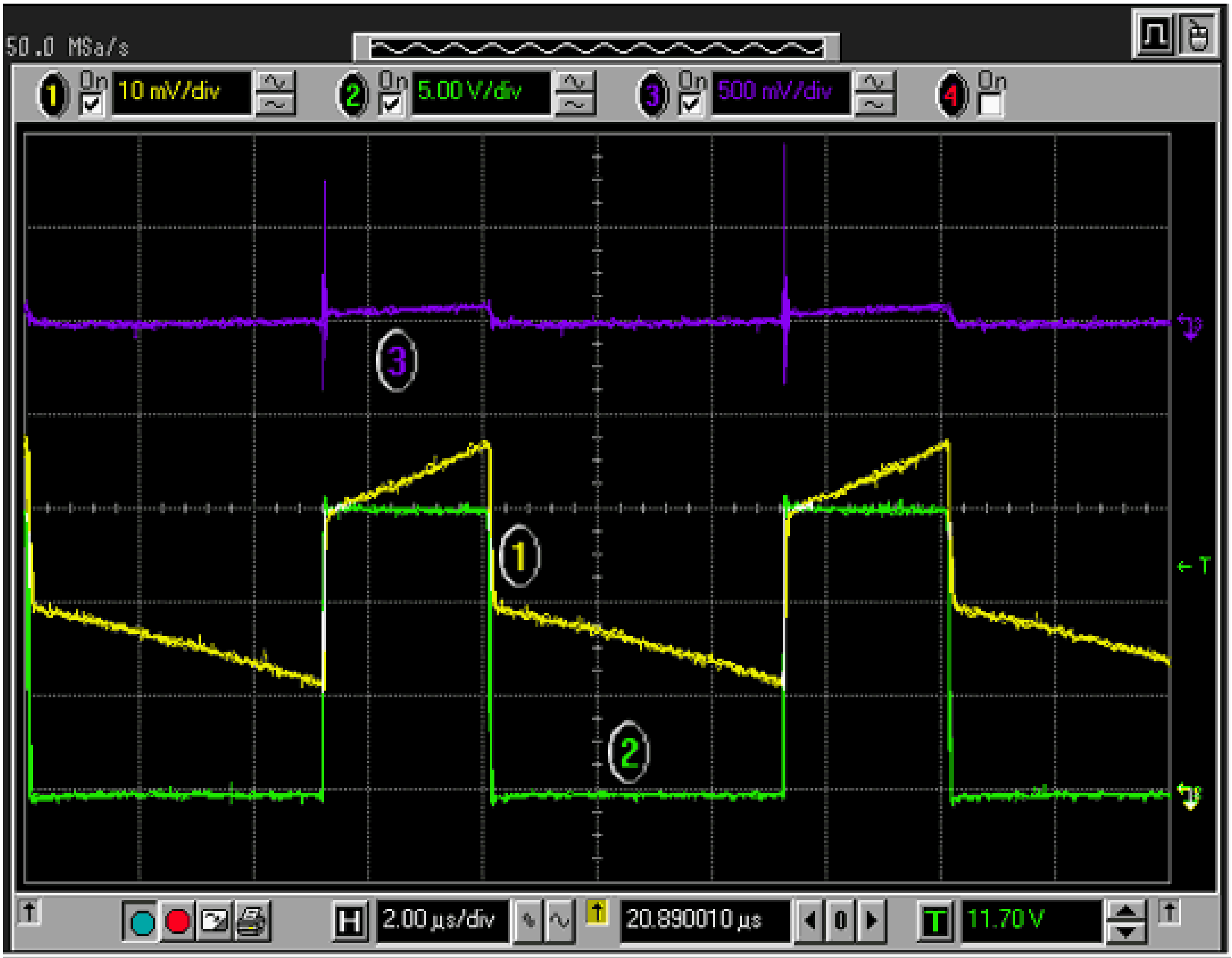
V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

-V_{OUT} = -12.3V
-I_{OUT_AUX} = 82mA (R_{LOAD} = 150Ω
D2, 3 = 1N5817MDICT
C7 = 1µ
C8 = 10µF
R6 = 5.6Ω

Waveforms:

1. LX + Charge Pump current ramp (Yellow, 0.2A / sq)
2. LX voltage (Green)

3. $-V_{OUT\_AUX}$ (violet, 500mV / sq), AC-coupled.



Lx current waveform = 750mA pk. Contrast with 550mA peak of the basic step down.

Note: the dV/dT spikes at auxiliary output. Post filter with small LC. L may be formed from pc copper track.

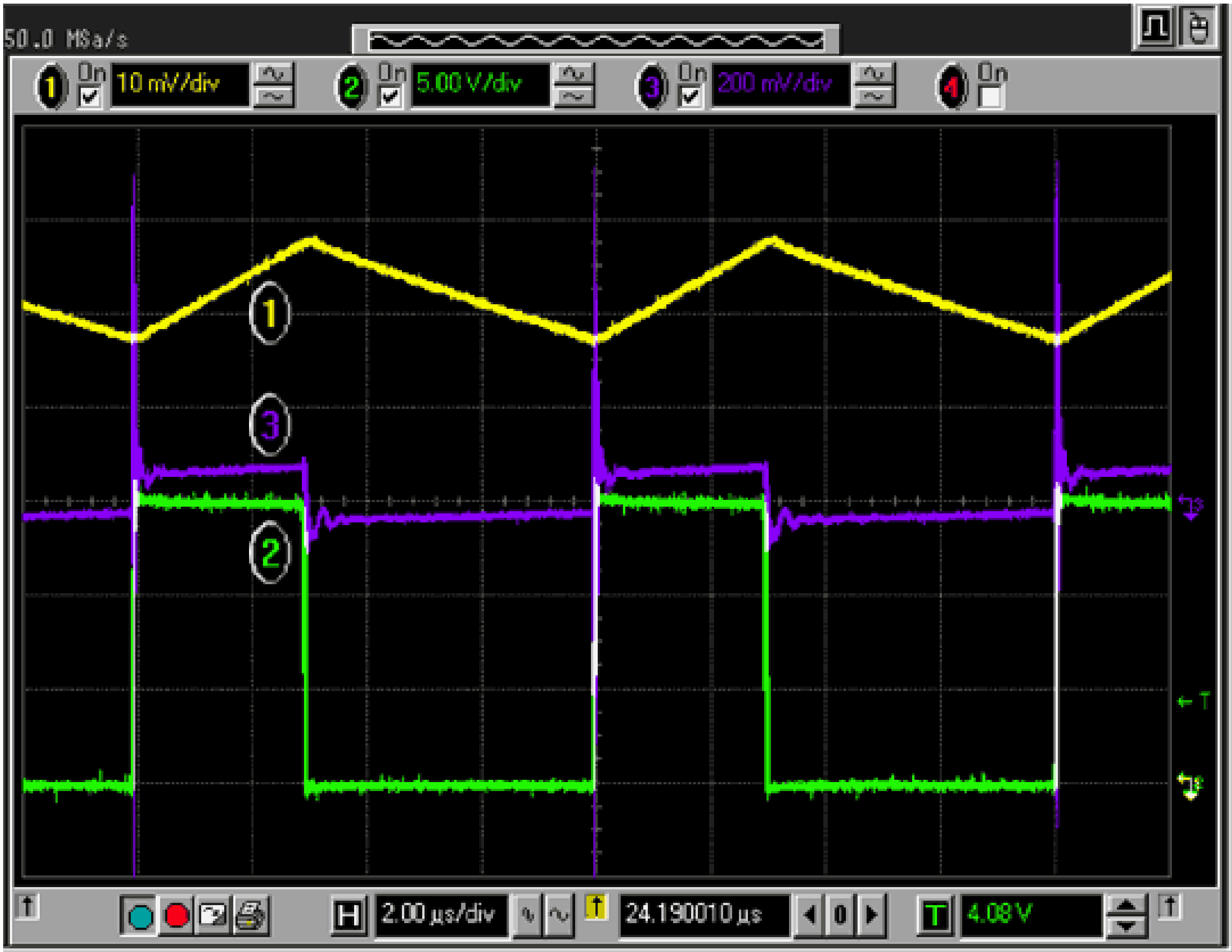
Example 4 Waveform: SEPIC Auxiliary Supply (Fig 7):

L1 = L2 = 100µH coupled (1:1) inductor
V_{IN} = +15V
V_{OUT} = +5V
I_{OUT} = 465mA (R_{LOAD} = 10Ω µ5%)

$-V_{OUT}$ = -5.02V
$-I_{OUT\_AUX}$ = 228mA (R_{LOAD} = 22Ω)
C5 = 10µF
C6 = 100µF
D2 = 1N5817MDICT

Waveforms:

1. LX current ramp (Yellow, 0.2A / sq)
2. LX voltage (Green)
3. V_{OUT_AUX} (Violet)



I_{LX_PEAK} = 1.15A

V_{OUT_AUX} Ripple = 100mV pk-pk excluding narrow dV/dT pulses.

Note: dV/dT spikes at auxiliary output. Post filter with small LC. L may be formed from pc copper track.

Application Note 3740: http://www.maxim-ic.com/an3740

More Information
For technical questions and support: http://www.maxim-ic.com/support
For samples: http://www.maxim-ic.com/samples
Other questions and comments: http://www.maxim-ic.com/contact

Related Parts
MAX5035: QuickView -- Full (PDF) Data Sheet -- Free Samples

AN3740, AN 3740, APP3740, Appnote3740, Appnote 3740

19-2988; Rev 2; 5/04

1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter

General Description

The MAX5035 easy-to-use, high-efficiency, high-voltage, step-down DC-DC converter operates from an input voltage up to 76V and consumes only 270µA quiescent current at no load. This pulse-width modulated (PWM) converter operates at a fixed 125kHz switching frequency at heavy loads, and automatically switches to pulse-skipping mode to provide low quiescent current and high efficiency at light loads. The MAX5035 includes internal frequency compensation simplifying circuit implementation. The device uses an internal low-on-resistance, high-voltage, DMOS transistor to obtain high efficiency and reduce overall system cost. This device includes undervoltage lockout, cycle-by-cycle current limit, hiccup mode output short-circuit protection, and thermal shutdown.

The MAX5035 delivers up to 1A output current. The output current may be limited by the maximum power dissipation capability of the package. External shutdown is included, featuring 10µA (typ) shutdown current. The MAX5035A/B/C versions have fixed output voltages of 3.3V, 5V, and 12V, respectively, while the MAX5035D features an adjustable output voltage from 1.25V to 13.2V.

The MAX5035 is available in space-saving 8-pin SO and 8-pin plastic DIP packages and operates over the automotive (-40°C to +125°C) temperature range.

Applications

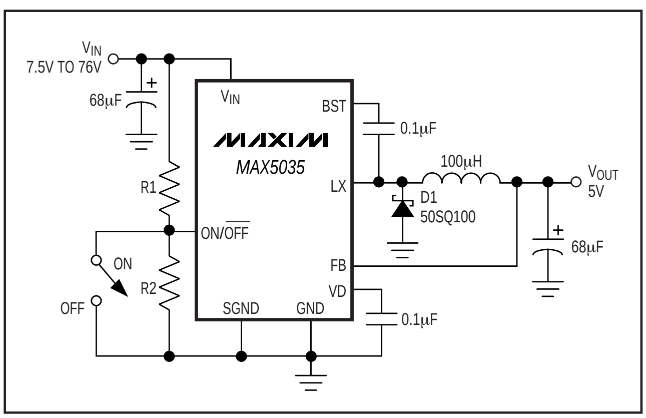
Automotive

Consumer Electronics

Industrial

Distributed Power

Typical Operating Circuit



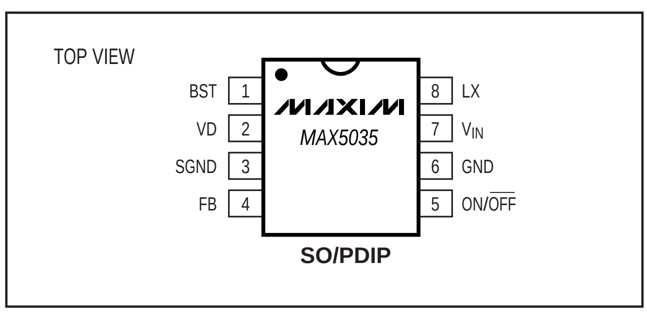
Features

- ♦ **Wide 7.5V to 76V Input Voltage Range**
- ♦ **Fixed (3.3V, 5V, 12V) and Adjustable (1.25V to 13.2V) Versions**
- ♦ **1A Output Current**
- ♦ **Efficiency Up to 94%**
- ♦ **Internal 0.4Ω High-Side DMOS FET**
- ♦ **270µA Quiescent Current at No Load, 10µA Shutdown Current**
- ♦ **Internal Frequency Compensation**
- ♦ **Fixed 125kHz Switching Frequency**
- ♦ **Thermal Shutdown and Short-Circuit Current Limit**
- ♦ **8-Pin SO and PDIP Packages**

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	OUTPUT VOLTAGE (V)
MAX5035AUSA	0°C to +85°C	8 SO	3.3
MAX5035AUPA	0°C to +85°C	8 PDIP	
MAX5035AASA	-40°C to +125°C	8 SO	
MAX5035BUSA	0°C to +85°C	8 SO	5.0
MAX5035BUPA	0°C to +85°C	8 PDIP	
MAX5035BASA	-40°C to +125°C	8 SO	
MAX5035CUSA	0°C to +85°C	8 SO	12
MAX5035CUPA	0°C to +85°C	8 PDIP	
MAX5035CASA	-40°C to +125°C	8 SO	
MAX5035DUSA	0°C to +85°C	8 SO	ADJ
MAX5035DUPA	0°C to +85°C	8 PDIP	
MAX5035DASA	-40°C to +125°C	8 SO	

Pin Configuration



ABSOLUTE MAXIMUM RATINGS

(Voltages referenced to GND, unless otherwise specified.)
V_{IN} ....-0.3V to +80V
SGND ....-0.3V to +0.3V
LX..-0.8V to (V_{IN} + 0.3V)
BST ....-0.3V to (V_{IN} + 10V)
BST (transient < 100ns)........................-0.3V to (V_{IN} + 15V)
BST to LX..-0.3V to +10V
BST to LX (transient < 100ns) ....-0.3V to +15V
ON/$\overline{OFF}$..-0.3V to (V_{IN} + 0.3V)
VD..-0.3V to +12V
FB
MAX5035A/MAX5035B/MAX5035C ....-0.3V to +15V
MAX5035D ....-0.3V to +12V
V_{OUT} Short-Circuit Duration..Indefinite
VD Short-Circuit Duration ....Indefinite
Continuous Power Dissipation (T_A = +70°C)
8-Pin PDIP (derate 9.1mW/°C above +70°C)..............727mW
8-Pin SO (derate 5.9mW/°C above +70°C).................471mW
Operating Temperature Range
MAX5035_U_ _ ....0°C to +85°C
MAX5035_A_ _ ....-40°C to +125°C
Storage Temperature Range ....-65°C to +150°C
Junction Temperature..+150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS (MAX5035_U_ _)

(V_{IN} = +12V, $V_{ON/\overline{OFF}}$ = +12V, I_{OUT} = 0, **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit.*)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Input Voltage Range	V_{IN}	MAX5035A		7.5		76.0	V
		MAX5035B		7.5		76.0	
		MAX5035C		15		76	
		MAX5035D		7.5		76.0	
Undervoltage Lockout	UVLO				5.2		V
Output Voltage	V_{OUT}	MAX5035A	V_{IN} = 7.5V to 76V, I_{OUT} = 20mA to 1A	3.185	3.3	3.415	V
		MAX5035B	V_{IN} = 7.5V to 76V, I_{OUT} = 20mA to 1A	4.85	5.0	5.15	
		MAX5035C	V_{IN} = 15V to 76V, I_{OUT} = 20mA to 1A	11.64	12	12.36	
Feedback Voltage	V_{FB}	V_{IN} = 7.5V to 76V, MAX5035D		1.192	1.221	1.250	V
Efficiency	η	V_{IN} = 12V, I_{LOAD} = 0.5A, MAX5035A			86		%
		V_{IN} = 12V, I_{LOAD} = 0.5A, MAX5035B			90		
		V_{IN} = 24V, I_{LOAD} = 0.5A, MAX5035C			94		
		V_{IN} = 12V, V_{OUT} = 5V, I_{LOAD} = 0.5A, MAX5035D			90		
Quiescent Supply Current	I_Q	V_{FB} = 3.5V, V_{IN} = 7.5V to 76V, MAX5035A			270	440	µA
		V_{FB} = 5.5V, V_{IN} = 7.5V to 76V, MAX5035B			270	440	
		V_{FB} = 13V, V_{IN} = 15V to 76V, MAX5035C			270	440	
		V_{FB} = 1.3V, MAX5035D			270	440	
Shutdown Current	I_{SHDN}	$V_{ON/\overline{OFF}}$ = 0V, V_{IN} = 7.5V to 76V			10	45	µA
Peak Switch Current Limit	I_{LIM}	(Note 1)		1.30	1.80	2.50	A
Switch Leakage Current	I_{OL}	V_{IN} = 76V, $V_{ON/\overline{OFF}}$ = 0V, V_{LX} = 0V			1		µA
Switch On-Resistance	$R_{DS(ON)}$	I_{SWITCH} = 1A			0.40	0.80	Ω

ELECTRICAL CHARACTERISTICS (continued) (MAX5035_U_ _)

(V_{IN} = +12V, $V_{ON/\overline{OFF}}$ = +12V, I_{OUT} = 0, **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit.*)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
PFM Threshold	I_{PFM}	Minimum switch current in any cycle	55	85	130	mA
FB Input Bias Current	I_B	MAX5035D	-150	+0.01	+150	nA
ON/$\overline{OFF}$ CONTROL INPUT						
ON/$\overline{OFF}$ Input-Voltage Threshold	$V_{ON/\overline{OFF}}$	Rising trip point	1.53	1.69	1.85	V
ON/$\overline{OFF}$ Input-Voltage Hysteresis	V_{HYST}			100		mV
ON/$\overline{OFF}$ Input Current	$I_{ON/\overline{OFF}}$	$V_{ON/\overline{OFF}}$ = 0V to V_{IN}		10	150	nA
OSCILLATOR						
Oscillator Frequency	f_{OSC}		109	125	135	kHz
Maximum Duty Cycle	D_{MAX}	MAX5035D		95		%
VOLTAGE REGULATOR						
Regulator Output Voltage	VD	V_{IN} = 8.5V to 76V, I_L = 0	6.9	7.8	8.8	V
Dropout Voltage		7.5V ≤ V_{IN} ≤ 8.5V, I_L = 1mA		2.0		V
Load Regulation	$\Delta VD/\Delta I_{VD}$	0 to 5mA		150		Ω
PACKAGE THERMAL CHARACTERISTICS						
Thermal Resistance (Junction to Ambient)	θ_{JA}	SO package (JEDEC 51)		170		°C/W
		DIP package (JEDEC 51)		110		
THERMAL SHUTDOWN						
Thermal-Shutdown Junction Temperature	T_{SH}			+160		°C
Thermal-Shutdown Hysteresis	T_{HYST}			20		°C

ELECTRICAL CHARACTERISTICS (MAX5035_A_ _)

(V_{IN} = +12V, $V_{ON/\overline{OFF}}$ = +12V, I_{OUT} = 0, **T_A = T_J = -40°C to +125°C**, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit.*) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Input Voltage Range	V_{IN}	MAX5035A		7.5		76.0	V
		MAX5035B		7.5		76.0	
		MAX5035C		15		76	
		MAX5035D		7.5		76.0	
Undervoltage Lockout	UVLO				5.2		V
Output Voltage	V_{OUT}	MAX5035A	V_{IN} = 7.5V to 76V, I_{OUT} = 20mA to 1A	3.185	3.3	3.415	V
		MAX5035B	V_{IN} = 7.5V to 76V, I_{OUT} = 20mA to 1A	4.825	5.0	5.175	
		MAX5035C	V_{IN} = 15V to 76V, I_{OUT} = 20mA to 1A	11.58	12	12.42	
Feedback Voltage	V_{FB}	V_{IN} = 7.5V to 76V, MAX5035D		1.192	1.221	1.250	V

ELECTRICAL CHARACTERISTICS (MAX5035_A_ _)

(V_{IN} = +12V, $V_{ON/\overline{OFF}}$ = +12V, I_{OUT} = 0, **T_A = T_J = -40°C to +125°C**, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit.*) (Note 2)

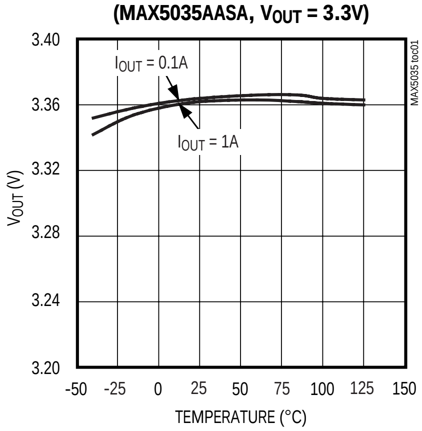
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Efficiency	η	V_{IN} = 12V, I_{LOAD} = 0.5A, MAX5035A		86		%
		V_{IN} = 12V, I_{LOAD} = 0.5A, MAX5035B		90		
		V_{IN} = 24V, I_{LOAD} = 0.5A, MAX5035C		94		
		V_{IN} = 12V, V_{OUT} = 5V, I_{LOAD} = 0.5A, MAX5035D		90		
Quiescent Supply Current	I_Q	V_{FB} = 3.5V, V_{IN} = 7.5V to 76V, MAX5035A		270	440	µA
		V_{FB} = 5.5V, V_{IN} = 7.5V to 76V, MAX5035B		270	440	
		V_{FB} = 13V, V_{IN} = 15V to 76V, MAX5035C		270	440	
		V_{FB} = 1.3V, MAX5035D		270	440	
Shutdown Current	I_{SHDN}	$V_{ON/\overline{OFF}}$ = 0V, V_{IN} = 7.5V to 76V		10	45	µA
Peak Switch Current Limit	I_{LIM}	(Note 1)	1.30	1.80	2.50	A
Switch Leakage Current	I_{OL}	V_{IN} = 76V, $V_{ON/\overline{OFF}}$ = 0V, V_{LX} = 0V		1		µA
Switch On-Resistance	$R_{DS(ON)}$	I_{SWITCH} = 1A		0.40	0.80	Ω
PFM Threshold	I_{PFM}	Minimum switch current in any cycle	55	85	130	mA
FB Input Bias Current	I_B	MAX5035D	-150	+0.01	+150	nA
ON/$\overline{\text{OFF}}$ CONTROL INPUT						
ON/$\overline{\text{OFF}}$ Input-Voltage Threshold	$V_{ON/\overline{OFF}}$	Rising trip point	1.50	1.69	1.85	V
ON/$\overline{\text{OFF}}$ Input-Voltage Hysteresis	V_{HYST}			100		mV
ON/$\overline{\text{OFF}}$ Input Current	$I_{ON/\overline{OFF}}$	$V_{ON/\overline{OFF}}$ = 0V to V_{IN}		10	150	nA
OSCILLATOR						
Oscillator Frequency	f_{OSC}		105	125	137	kHz
Maximum Duty Cycle	D_{MAX}	MAX5035D		95		%
VOLTAGE REGULATOR						
Regulator Output Voltage	VD	V_{IN} = 8.5V to 76V, I_L = 0	6.5	7.8	9.0	V
Dropout Voltage		7.5V ≤ V_{IN} ≤ 8.5V, I_L = 1mA		2.0		V
Load Regulation	$\Delta VD/\Delta I_{VD}$	0 to 5mA		150		Ω
PACKAGE THERMAL CHARACTERISTICS						
Thermal Resistance (Junction to Ambient)	θ_{JA}	SO package (JEDEC 51)		170		°C/W
		DIP package (JEDEC 51)		110		
THERMAL SHUTDOWN						
Thermal-Shutdown Junction Temperature	T_{SH}			+160		°C
Thermal-Shutdown Hysteresis	T_{HYST}			20		°C

Note 1: Switch current at which current limit is activated.
Note 2: All limits at -40°C are guaranteed by design, not production tested.

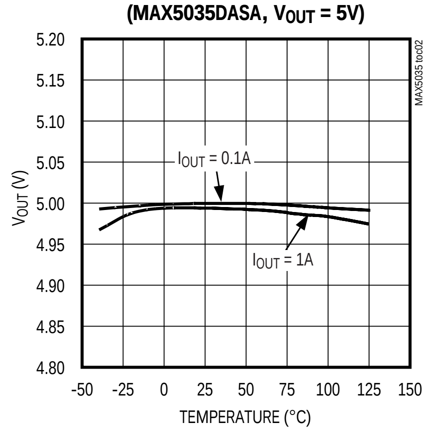
Typical Operating Characteristics

(V_{IN} = 12V, $V_{ON/\overline{OFF}}$ = 12V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit*, if applicable.)

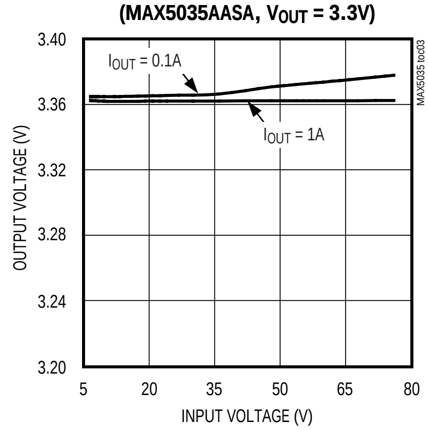
V_{OUT} vs. TEMPERATURE (MAX5035AASA, V_{OUT} = 3.3V)



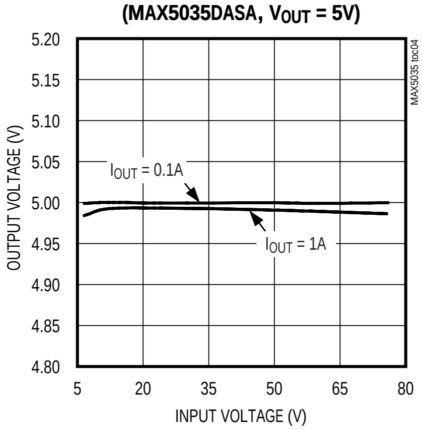
V_{OUT} vs. TEMPERATURE (MAX5035DASA, V_{OUT} = 5V)



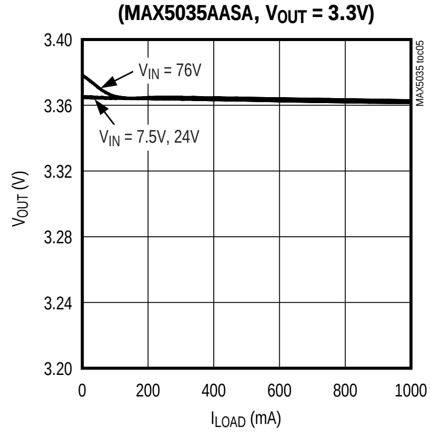
LINE REGULATION (MAX5035AASA, V_{OUT} = 3.3V)



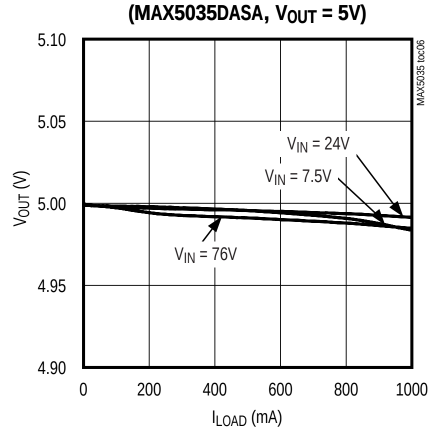
LINE REGULATION (MAX5035DASA, V_{OUT} = 5V)



LOAD REGULATION (MAX5035AASA, V_{OUT} = 3.3V)



LOAD REGULATION (MAX5035DASA, V_{OUT} = 5V)

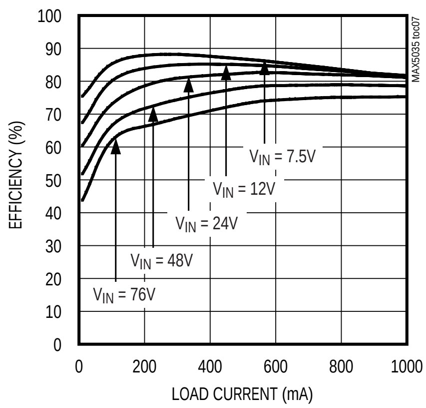


1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter

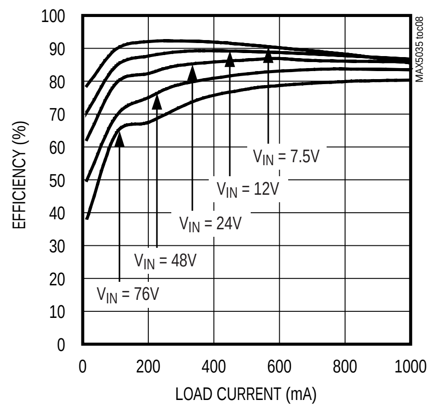
Typical Operating Characteristics (continued)

(V_{IN} = 12V, $V_{ON/\overline{OFF}}$ = 12V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit*, if applicable.)

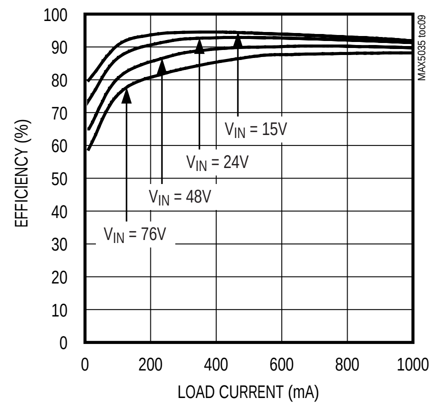
EFFICIENCY vs. LOAD CURRENT (MAX5035AASA, V_{OUT} = 3.3V)



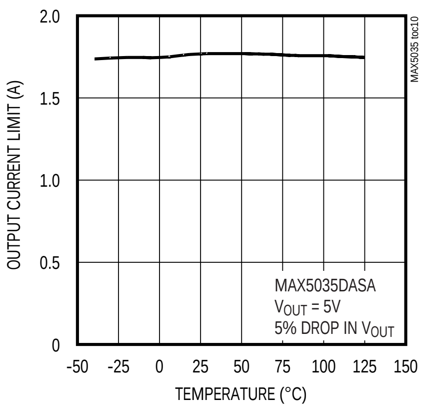
EFFICIENCY vs. LOAD CURRENT (MAX5035DASA, V_{OUT} = 5V)



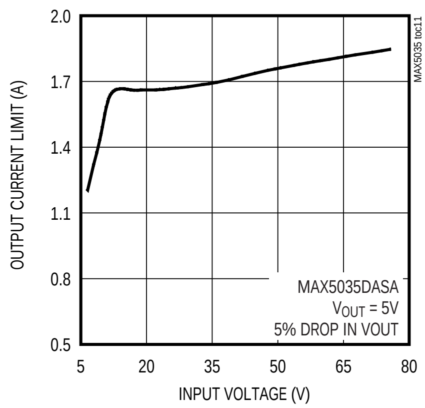
EFFICIENCY vs. LOAD CURRENT (MAX5035DASA, V_{OUT} = 12V)



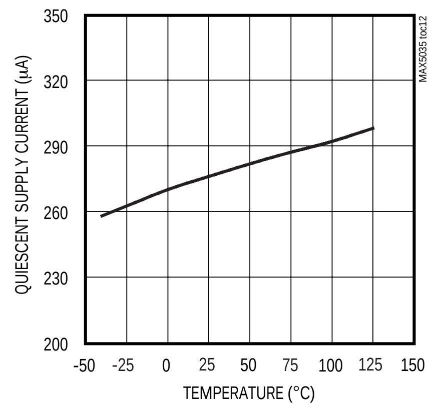
OUTPUT CURRENT LIMIT vs. TEMPERATURE



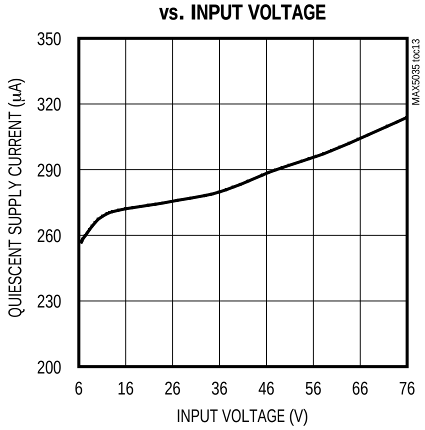
OUTPUT CURRENT LIMIT vs. INPUT VOLTAGE



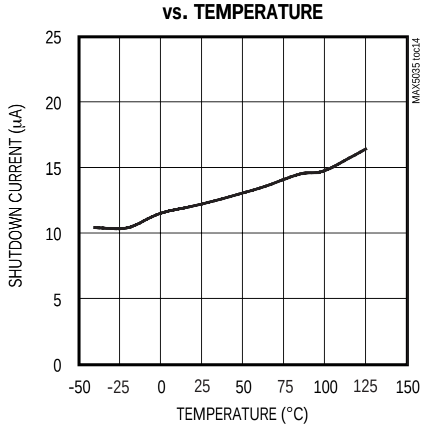
QUIESCENT SUPPLY CURRENT vs. TEMPERATURE



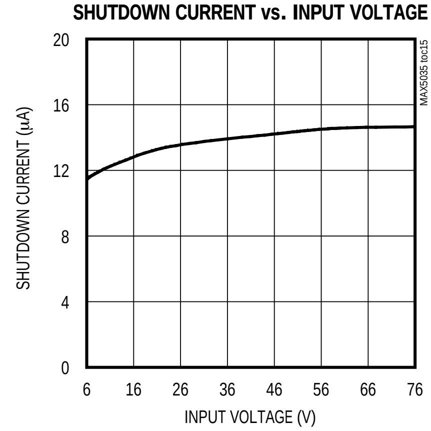
QUIESCENT SUPPLY CURRENT vs. INPUT VOLTAGE



SHUTDOWN CURRENT vs. TEMPERATURE



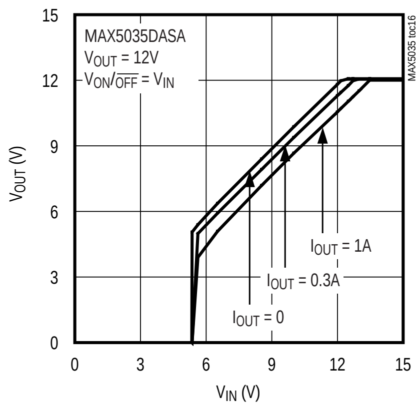
SHUTDOWN CURRENT vs. INPUT VOLTAGE



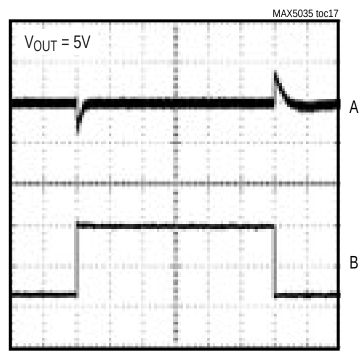
Typical Operating Characteristics (continued)

(V_{IN} = 12V, $V_{ON/\overline{OFF}}$ = 12V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit*, if applicable.)

OUTPUT VOLTAGE vs. INPUT VOLTAGE



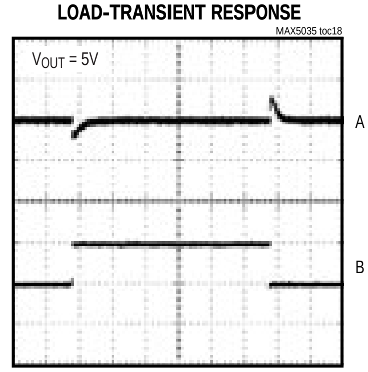
MAX5035DASA LOAD-TRANSIENT RESPONSE



400µs/div

A: V_{OUT}, 200mV/div, AC-COUPLED
B: I_{OUT}, 500mA/div, 0.1A TO 1A

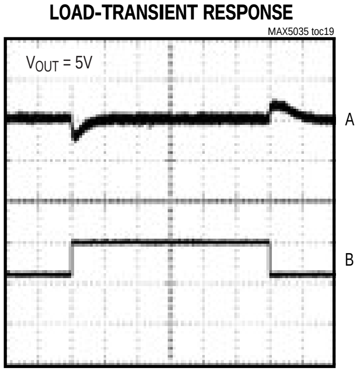
MAX5035DASA LOAD-TRANSIENT RESPONSE



400µs/div

A: V_{OUT}, 200mV/div, AC-COUPLED
B: I_{OUT}, 500mA/div, 0.5A TO 1A

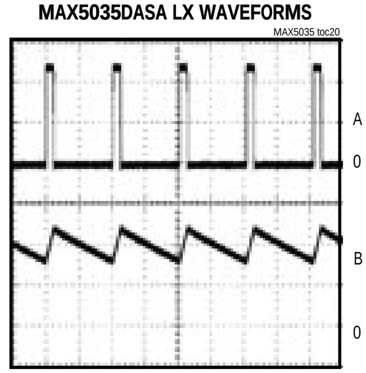
MAX5035DASA LOAD-TRANSIENT RESPONSE



400µs/div

A: V_{OUT}, 200mV/div, AC-COUPLED
B: I_{OUT}, 500mA/div, 0.1A TO 0.5A

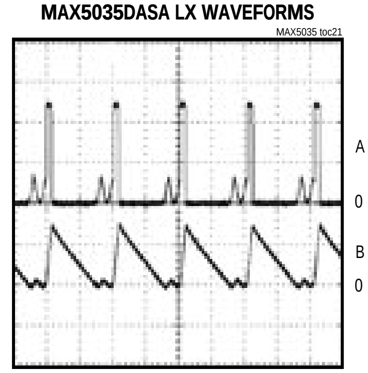
MAX5035DASA LX WAVEFORMS



4µs/div

A: SWITCH VOLTAGE (LX PIN), 20V/div (V_{IN} = 48V)
B: INDUCTOR CURRENT, 500mA/div (I_{OUT} = 1A)

MAX5035DASA LX WAVEFORMS



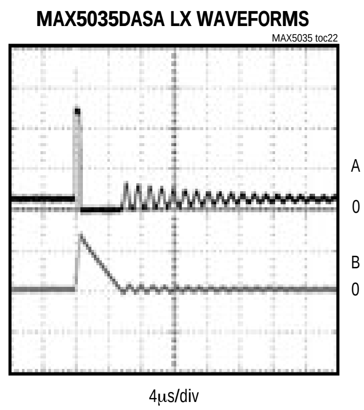
4µs/div

A: SWITCH VOLTAGE (LX PIN), 20V/div (V_{IN} = 48V)
B: INDUCTOR CURRENT, 200mA/div (I_{OUT} = 100mA)

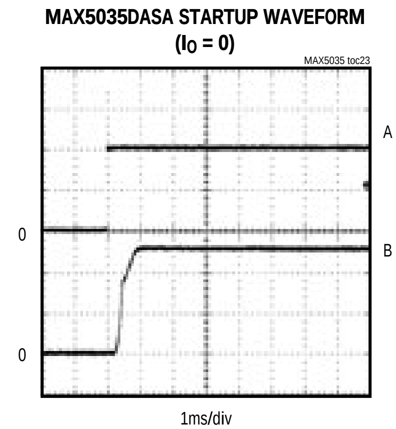
1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter

Typical Operating Characteristics (continued)

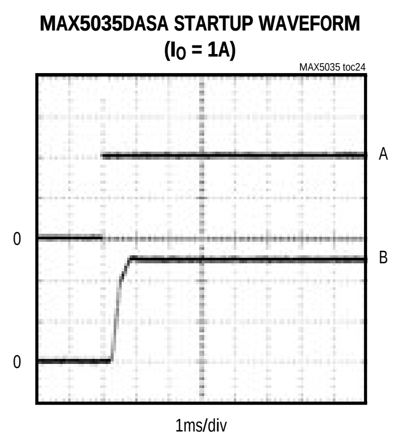
(V_{IN} = 12V, $V_{ON/\overline{OFF}}$ = 12V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C. See the *Typical Application Circuit*, if applicable.)



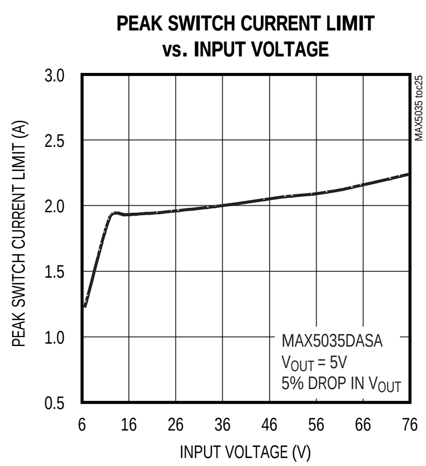
A: SWITCH VOLTAGE (LX PIN), 20V/div (V_{IN} = 48V)
B: INDUCTOR CURRENT, 200mA/div (I_{OUT} = 0)



A: $V_{ON/\overline{OFF}}$, 2V/div
B: V_{OUT}, 2V/div



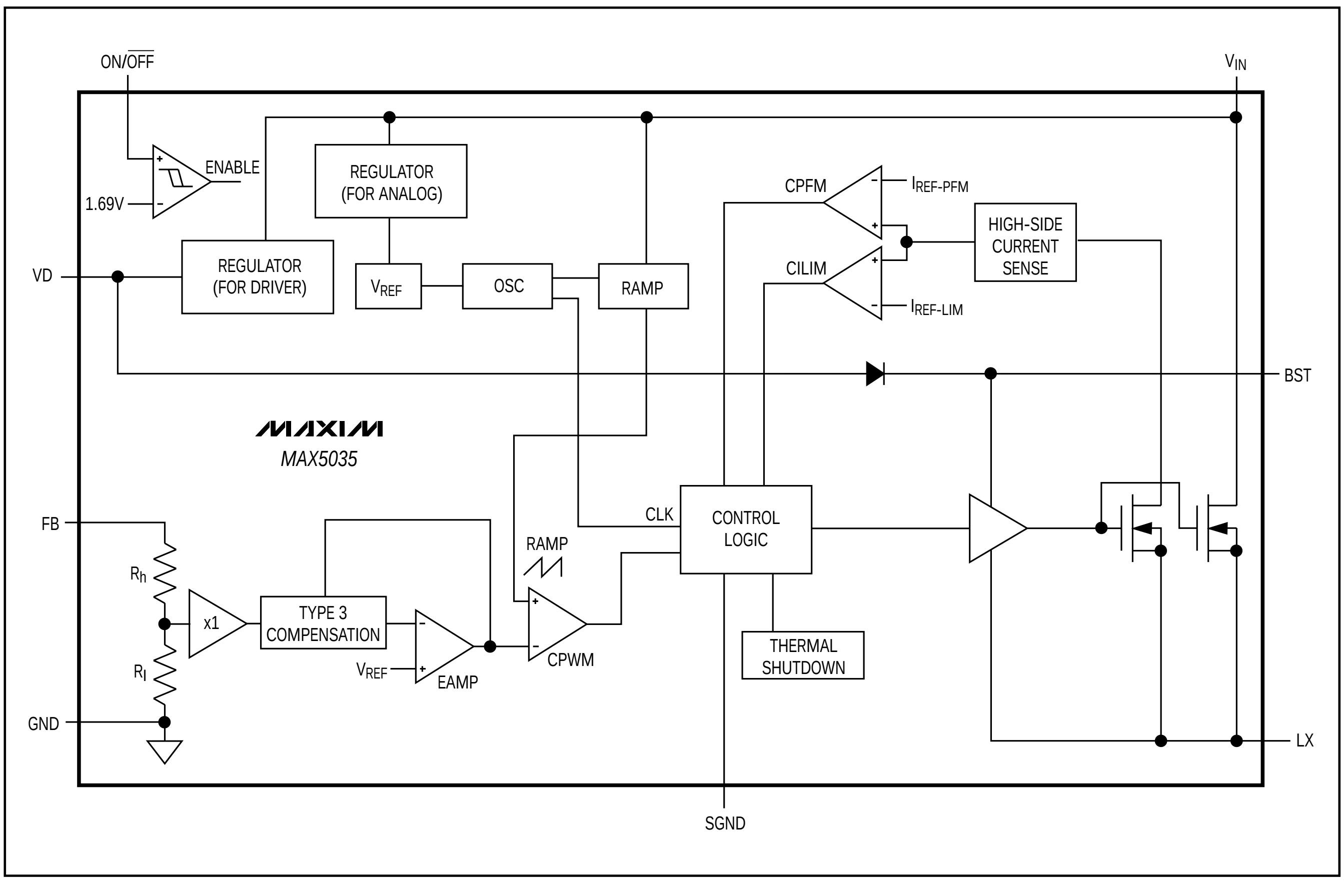
A: $V_{ON/\overline{OFF}}$, 2V/div
B: V_{OUT}, 2V/div



Pin Description

PIN	NAME	FUNCTION
1	BST	Boost Capacitor Connection. Connect a 0.1µF ceramic capacitor from BST to LX.
2	VD	Internal Regulator Output. Bypass VD to GND with a 0.1µF ceramic capacitor.
3	SGND	Internal Connection. SGND must be connected to GND.
4	FB	Output Sense Feedback Connection. For fixed output voltage (MAX5035A, MAX5035B, MAX5035C), connect FB to V_{OUT}. For adjustable output voltage (MAX5035D), use an external resistive voltage-divider to set V_{OUT}. V_{FB} regulating set point is 1.22V.
5	ON/$\overline{OFF}$	Shutdown Control Input. Pull ON/$\overline{OFF}$ low to put the device in shutdown mode. Drive ON/$\overline{OFF}$ high for normal operation.
6	GND	Ground
7	V_{IN}	Input Voltage. Bypass V_{IN} to GND with a low ESR capacitor as close to the device as possible.
8	LX	Source Connection of Internal High-Side Switch

Block Diagram



Detailed Description

The MAX5035 step-down DC-DC converter operates from a 7.5V to 76V input voltage range. A unique voltage-mode control scheme with voltage feed-forward and an internal switching DMOS FET provides high efficiency over a wide input voltage range. This pulse-width modulated converter operates at a fixed 125kHz switching frequency. The device also features automatic pulse-skipping mode to provide low quiescent current and high efficiency at light loads. Under no load, the MAX5035 consumes only 270µA, and in shutdown mode, consumes only 10µA. The MAX5035 also features undervoltage lockout, hiccup mode output short-circuit protection, and thermal shutdown.

Shutdown Mode

Drive ON/$\overline{\text{OFF}}$ to ground to shut down the MAX5035. Shutdown forces the internal power MOSFET off, turns off all internal circuitry, and reduces the V_{IN} supply current to 10µA (typ). The ON/$\overline{\text{OFF}}$ rising threshold is 1.69V (typ). Before any operation begins, the voltage at ON/$\overline{\text{OFF}}$ must exceed 1.69V (typ). The ON/$\overline{\text{OFF}}$ input has 100mV hysteresis.

Undervoltage Lockout (UVLO)

Use the ON/$\overline{\text{OFF}}$ function to program the UVLO threshold at the input. Connect a resistive voltage-divider from V_{IN} to GND with the center node to ON/$\overline{\text{OFF}}$ as shown in Figure 1. Calculate the threshold value by using the following formula:

$$V_{UVLO(TH)} = \left(1 + \frac{R1}{R2}\right) \times 1.85V$$

The minimum recommended $V_{UVLO(TH)}$ is 6.5V, 7.5V, and 13V for the output voltages of 3.3V, 5V, and 12V, respectively. The recommended value for R2 is less than 1MΩ.

If the external UVLO threshold-setting divider is not used, an internal undervoltage-lockout feature monitors the supply voltage at V_{IN} and allows operation to start when V_{IN} rises above 5.2V (typ). This feature can be used only when V_{IN} rise time is faster than 2ms. For slower V_{IN} rise time, use the resistive-divider at ON/$\overline{\text{OFF}}$.

Boost High-Side Gate Drive (BST)

Connect a flying bootstrap capacitor between LX and BST to provide the gate-drive voltage to the high-side N-channel DMOS switch. The capacitor is alternately charged from the internally regulated output voltage VD and placed across the high-side DMOS driver. Use a 0.1µF, 16V ceramic capacitor located as close to the device as possible.

On startup, an internal low-side switch connects LX to ground and charges the BST capacitor to VD. Once the BST capacitor is charged, the internal low-side switch is turned off and the BST capacitor voltage provides the necessary enhancement voltage to turn on the high-side switch.

Thermal-Overload Protection

The MAX5035 features integrated thermal overload protection. Thermal overload protection limits total power dissipation in the device, and protects the device in the event of a fault condition. When the die temperature exceeds +160°C, an internal thermal sensor signals the shutdown logic, turning off the internal power MOSFET and allowing the IC to cool. The thermal sensor turns the internal power MOSFET back on after the IC's die temperature cools down to +140°C, resulting in a pulsed output under continuous thermal overload conditions.

Applications Information

Setting the Output Voltage

The MAX5035A/B/C have preset output voltages of 3.3V, 5.0V, and 12V, respectively. Connect FB to the preset output voltage (see the *Typical Operating Circuit*).

The MAX5035D offers an adjustable output voltage. Set the output voltage with a resistive voltage-divider connected from the circuit's output to ground (Figure 1). Connect the center node of the divider to FB. Choose R4 less than 15kΩ, then calculate R3 as follows:

$$R3 = \frac{(V_{OUT} - 1.22)}{1.22} \times R4$$

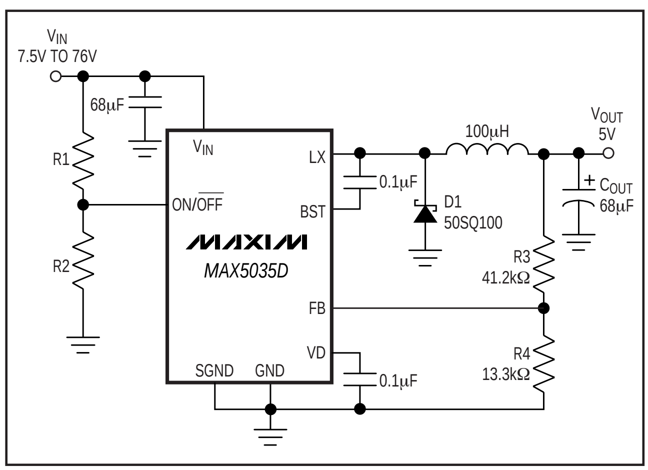


Figure 1. Adjustable Output Voltage

The MAX5035 features internal compensation for optimum closed-loop bandwidth and phase margin. With the preset compensation, it is strongly advised to sense the output immediately after the primary LC.

Inductor Selection

The choice of an inductor is guided by the voltage difference between V_{IN} and V_{OUT}, the required output current, and the operating frequency of the circuit. Use an inductor with a minimum value given by:

$$L = \frac{(V_{IN} - V_{OUT}) \times D}{0.3 \times I_{OUTMAX} \times f_{SW}}$$

where:

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

I_{OUTMAX} is the maximum output current required, and f_{SW} is the operating frequency of 125kHz. Use an inductor with a maximum saturation current rating equal to at least the peak switch current limit (I_{LIM}). Use inductors with low DC resistance for higher efficiency.

Selecting a Rectifier

The MAX5035 requires an external Schottky rectifier as a freewheeling diode. Connect this rectifier close to the device using short leads and short PC board traces. Choose a rectifier with a continuous current rating greater than the highest expected output current. Use a rectifier with a voltage rating greater than the maximum expected input voltage, V_{IN}. Use a low forward-voltage Schottky rectifier for proper operation and high efficiency. Avoid higher than necessary reverse-voltage Schottky rectifiers that have higher forward-voltage drops. Use a Schottky rectifier with forward-voltage drop (V_{FB}) less than 0.45V at +25°C and maximum load current to avoid forward biasing of the internal body diode (LX to ground). Internal body diode conduction may cause excessive junction temperature rise and thermal shutdown. Use Table 1 to choose the proper rectifier at different input voltages and output current.

Table 1. Diode Selection

V_{IN} (V)	DIODE PART NUMBER	MANUFACTURER
7.5 to 36	15MQ040N	IR
	B240A	Diodes, Inc.
	B240	Central Semiconductor
	MBRS240, MBRS1540	ON Semiconductor
7.5 to 56	30BQ060	IR
	B360A	Diodes, Inc.
	CMSH3-60	Central Semiconductor
	MBRD360, MBR3060	ON Semiconductor
7.5 to 76	50SQ100, 50SQ80	IR
	MBRM5100	Diodes, Inc.

Input Bypass Capacitor

The discontinuous input-current waveform of the buck converter causes large ripple currents in the input capacitor. The switching frequency, peak inductor current, and the allowable peak-to-peak voltage ripple that reflects back to the source dictate the capacitance requirement. The MAX5035 high switching frequency allows the use of smaller-value input capacitors.

The input ripple is comprised of ΔV_Q (caused by the capacitor discharge) and ΔV_{ESR} (caused by the ESR of the capacitor). Use low-ESR aluminum electrolytic capacitors with high ripple-current capability at the input. Assuming that the contribution from the ESR and capacitor discharge is equal to 90% and 10%, respectively, calculate the input capacitance and the ESR required for a specified ripple using the following equations:

$$ESR_{IN} = \frac{\Delta V_{ESR}}{\left(I_{OUT} + \frac{\Delta I_L}{2}\right)}$$

$$C_{IN} = \frac{I_{OUT} \times D(1-D)}{\Delta V_Q \times f_{SW}}$$

where

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

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

I_{OUT} is the maximum output current of the converter and f_{SW} is the oscillator switching frequency (125kHz). For example, at V_{IN} = 48V, V_{OUT} = 3.3V, the ESR and input capacitance are calculated for the input peak-to-peak ripple of 100mV or less yielding an ESR and capacitance value of 80mΩ and 51µF, respectively.

Low-ESR, ceramic, multilayer chip capacitors are recommended for size-optimized application. For ceramic capacitors, assume the contribution from ESR and capacitor discharge is equal to 10% and 90%, respectively.

The input capacitor must handle the RMS ripple current without significant rise in temperature. The maximum capacitor RMS current occurs at about 50% duty cycle.

Ensure that the ripple specification of the input capacitor exceeds the worst-case capacitor RMS ripple current. Use the following equations to calculate the input capacitor RMS current:

$$I_{CRMS} = \sqrt{I_{PRMS}^2 - I_{AVGIN}^2}$$

where

$$I_{PRMS} = \sqrt{\left(I_{PK}^2 + I_{DC}^2 + \left(I_{PK} \times I_{DC}\right)\right) \times \frac{D}{3}}$$

$$I_{AVGIN} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta}$$

$$I_{PK} = I_{OUT} + \frac{\Delta I_L}{2}, \; I_{DC} = I_{OUT} - \frac{\Delta I_L}{2}$$

$$\text{and } D = \frac{V_{OUT}}{V_{IN}}$$

I_{PRMS} is the input switch RMS current, I_{AVGIN} is the input average current, and η is the converter efficiency.

The ESR of aluminum electrolytic capacitors increases significantly at cold temperatures. Use a 1µF or greater value ceramic capacitor in parallel with the aluminum electrolytic input capacitor, especially for input voltages below 8V.

Output Filter Capacitor

The worst-case peak-to-peak and RMS capacitor ripple current, allowable peak-to-peak output ripple voltage, and the maximum deviation of the output voltage during load steps determine the capacitance and the ESR requirements for the output capacitors.

The output capacitance and its ESR form a zero, which improves the closed-loop stability of the buck regulator. Choose the output capacitor so the ESR zero frequency (f_Z) occurs between 20kHz to 40kHz. Use the following equation to verify the value of f_Z. Capacitors with 100mΩ to 250mΩ ESR are recommended to ensure the closed-loop stability, while keeping the output ripple low.

$$f_Z = \frac{1}{2 \times \pi \times C_{OUT} \times ESR_{OUT}}$$

The output ripple is comprised of ΔV_{OQ} (caused by the capacitor discharge) and ΔV_{OESR} (caused by the ESR of the capacitor). Use low-ESR tantalum or aluminum electrolytic capacitors at the output. Assuming that the contributions from the ESR and capacitor discharge equal 80% and 20% respectively, calculate the output capacitance and the ESR required for a specified ripple using the following equations:

$$ESR_{OUT} = \frac{\Delta V_{OESR}}{\Delta I_L}$$

$$C_{OUT} \approx \frac{\Delta I_L}{2.2 \times \Delta V_{OQ} \times f_{SW}}$$

The MAX5035 has an internal soft-start time (t_{SS}) of 400µs. It is important to keep the output rise time at startup below t_{SS} to avoid output overshoot. The output rise time is directly proportional to the output capacitor. Use 68µF or lower capacitance at the output to control the overshoot below 5%.

In a dynamic load application, the allowable deviation of the output voltage during the fast-transient load dictates the output capacitance value and the ESR. The output capacitors supply the step load current until the controller responds with a greater duty cycle. The response time ($t_{RESPONSE}$) depends on the closed-loop bandwidth of the converter. The resistive drop across the capacitor ESR and capacitor discharge cause a voltage droop during a step load. Use a combination of low-ESR tantalum and ceramic capacitors for better transient load and ripple/noise performance. Keep the maximum output-voltage deviation above the tolerable limits of the electronics being powered. Assuming a 50% contribution each from the output capacitance discharge and the ESR drop, use the following equations to calculate the required ESR and capacitance value:

$$ESR_{OUT} = \frac{\Delta V_{OESR}}{I_{STEP}}$$

$$C_{OUT} = \frac{I_{STEP} \times t_{RESPONSE}}{\Delta V_{OQ}}$$

where I_{STEP} is the load step and $t_{RESPONSE}$ is the response time of the controller. Controller response time is approximately one-third of the reciprocal of the closed-loop unity-gain bandwidth, 20kHz typically.

PC Board Layout Considerations

Proper PC board layout is essential. Minimize ground noise by connecting the anode of the Schottky rectifier, the input bypass capacitor ground lead, and the output filter capacitor ground lead to a single point ("star" ground configuration). A ground plane is required. Minimize lead lengths to reduce stray capacitance, trace resistance, and radiated noise. In particular, place the Schottky rectifier diode right next to the device. Also, place BST and VD bypass capacitors very close to the device. Use the PC board copper plane connecting to V_{IN} and LX for heatsinking.

Application Circuits

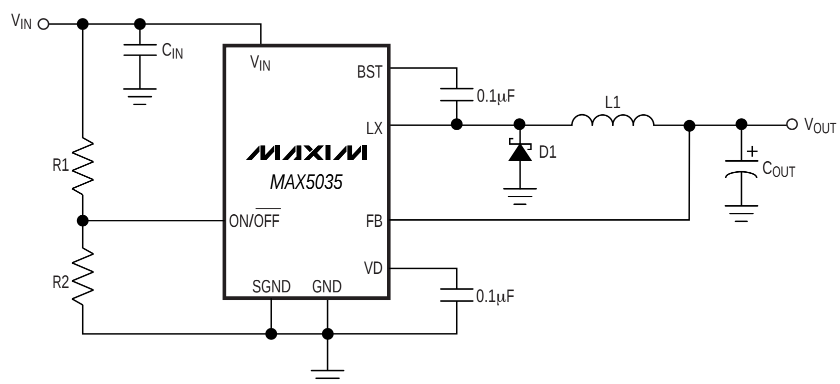


Figure 2. Fixed Output Voltages

Table 2. Typical External Components Selection (Circuit of Figure 2)

V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)	EXTERNAL COMPONENTS
7.5 to 76	3.3	0.5	C_{IN} = 68µF, Panasonic, EEVFK2A680Q C_{OUT} = 68µF, Vishay Sprague, 594D686X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 384kΩ ±1%, 0805 D1 = 50SQ100, IR L1 = 100µH, Coilcraft Inc., DO5022P-104
7.5 to 76	3.3	1	
7.5 to 76	5	0.5	C_{IN} = 68µF, Panasonic, EEVFK2A680Q C_{OUT} = 68µF, Vishay Sprague, 594D68X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 384kΩ ±1%, 0805 D1 = 50SQ100, IR L1 = 100µH, Coilcraft Inc., DO5022P-104
7.5 to 76	5	1	
15 to 76	12	1	C_{IN} = 68µF, Panasonic, EEVFK2A680Q C_{OUT} = 15µF, Vishay Sprague, 594D156X0025C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 139kΩ ±1%, 0805 D1 = 50SQ100, IR L1 = 220µH, Coilcraft Inc., DO5022P-224

Table 2. Typical External Components Selection (Circuit of Figure 2) (continued)

V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)	EXTERNAL COMPONENTS
9 to 14	3.3	1	C_{IN} = 220µF, Panasonic, EEVFK1E221P C_{OUT} = 68µF, Vishay Sprague, 594D686X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 274kΩ ±1%, 0805 D1 = B220, Diodes Inc. L1 = 100µH, Coilcraft Inc., DO5022P-104
	5	1	C_{IN} = 220µF, Panasonic, EEVFK1E221P C_{OUT} = 68µF, Vishay Sprague, 594D686X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 274kΩ ±1%, 0805 D1 = B220, Diodes Inc. L1 = 100µH, Coilcraft Inc., DO5022P-104
18 to 36	3.3	1	C_{IN} = 220µF, Panasonic, EEVFK1H221P C_{OUT} = 68µF, Vishay Sprague, 594D686X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 130kΩ ±1%, 0805 D1 = MBRS2040, ON Semiconductor L1 = 100µH, Coilcraft Inc., DO5022P-104
	5	1	C_{IN} = 220µF, Panasonic, EEVFK1H221P C_{OUT} = 68µF, Vishay Sprague, 594D686X_010C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 130kΩ ±1%, 0805 D1 = MBRS2040, ON Semiconductor L1 = 100µH, Coilcraft Inc., DO5022P-104
	12	1	C_{IN} = 220µF, Panasonic, EEVFK1H221P C_{OUT} = 15µF, Vishay Sprague, 594D156X_0025C2T C_{BST} = 0.1µF, 0805 R1 = 1MΩ ±1%, 0805 R2 = 130kΩ ±1%, 0805 D1 = MBRS2040, ON Semiconductor L1 = 220µH, Coilcraft Inc., DO5022P-224

Table 3. Component Suppliers

SUPPLIER	PHONE	FAX	WEBSITE
AVX	843-946-0238	843-626-3123	www.avxcorp.com
Coilcraft	847-639-6400	847-639-1469	www.coilcraft.com
Diodes Incorporated	805-446-4800	805-446-4850	www.diodes.com
Panasonic	714-373-7366	714-737-7323	www.panasonic.com
Sanyo	619-661-6835	619-661-1055	www.sanyo.com
TDK	847-803-6100	847-390-4405	www.component.tdk.com
Vishay	402-563-6866	402-563-6296	www.vishay.com

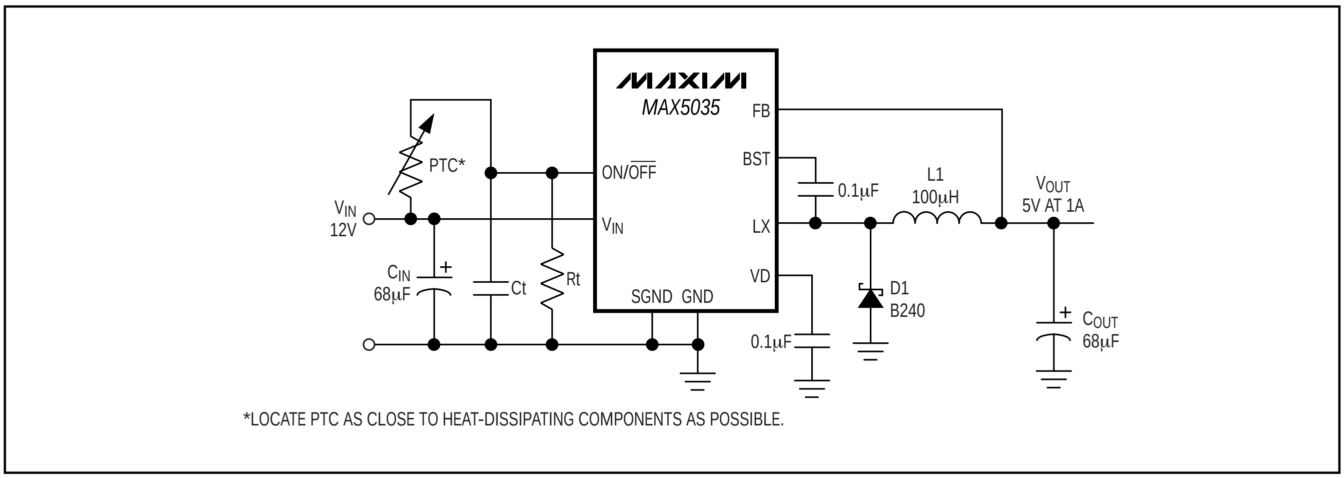


Figure 3. Load Temperature Monitoring with ON/$\overline{OFF}$ (Requires Accurate V_{IN})

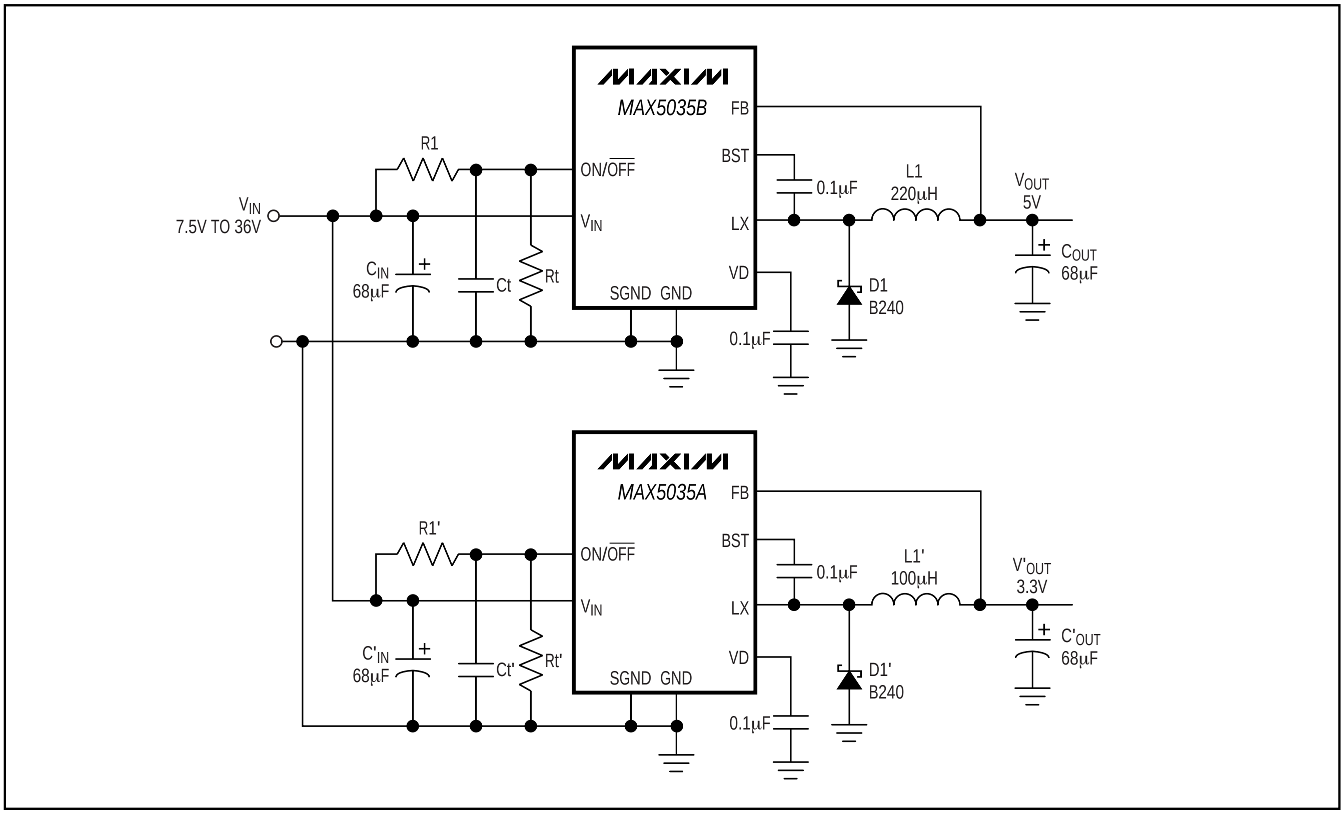


Figure 4. Dual-Sequenced DC-DC Converters (Startup Delay Determined by R1/R1', Ct/Ct' and Rt/Rt')

Chip Information

TRANSISTOR COUNT: 4344

PROCESS: BiCMOS

Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

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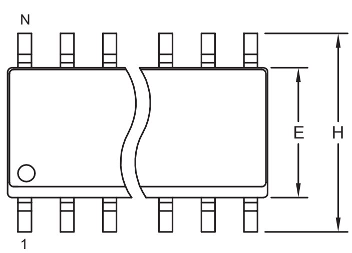
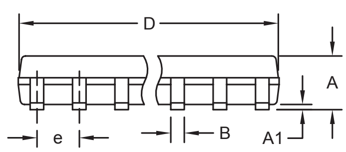


TOP VIEW

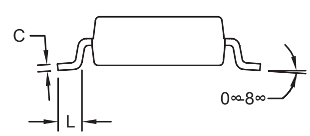
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050 BSC		1.27 BSC	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
L	0.016	0.050	0.40	1.27

VARIATIONS:

	INCHES		MILLIMETERS			
DIM	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	AA
D	0.337	0.344	8.55	8.75	14	AB
D	0.386	0.394	9.80	10.00	16	AC



FRONT VIEW



SIDE VIEW

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15mm (.006").
3. LEADS TO BE COPLANAR WITHIN 0.10mm (.004").
4. CONTROLLING DIMENSION: MILLIMETERS.
5. MEETS JEDEC MS012.
6. N = NUMBER OF PINS.

DALLAS SEMICONDUCTOR MAXIM

PROPRIETARY INFORMATION

TITLE: PACKAGE OUTLINE, .150" SOIC

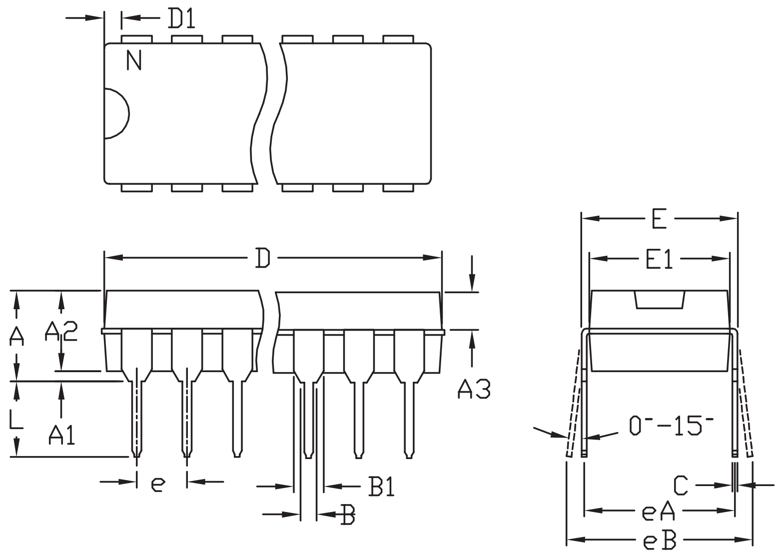
APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21-0041	B	1/1

1A, 76V, High-Efficiency MAXPower Step-Down DC-DC Converter

Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

PDIPN.EPS



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	---	0.180	---	4.572
A1	0.015	---	0.38	---
A2	0.125	0.175	3.18	4.45
A3	0.055	0.080	1.40	2.03
B	0.015	0.022	0.381	0.56
B1	0.045	0.065	1.14	1.65
C	0.008	0.014	0.2	0.355
D1	0.005	0.080	0.13	2.03
E	0.300	0.325	7.62	8.26
E1	0.240	0.310	6.10	7.87
e	0.100 BSC.		2.54 BSC.	
eA	0.300 BSC.		7.62 BSC.	
eB	0.400 BSC.		10.16 BSC.	
L	0.115	0.150	2.921	3.81

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS001
D	0.348	0.390	8.84	9.91	8	AB
D	0.735	0.765	18.67	19.43	14	AC
D	0.745	0.765	18.92	19.43	16	AA
D	0.885	0.915	22.48	23.24	18	AD
D	1.015	1.045	25.78	26.54	20	AE
D	1.14	1.265	28.96	32.13	24	AF
D	1.360	1.380	34.54	35.05	28	*5

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. CONTROLLING DIMENSION: MILLIMETER
4. MEETS JEDEC MS001-XX AS SHOWN IN ABOVE TABLE
5. SIMILIAR TO JEDEC MO-058AB
6. N = NUMBER OF PINS

MAXIM 120 SAN GABRIEL DR SUNNYVALE CA 94086 FAX (408) 737 7194
PROPRIETARY INFORMATION
TITLE: PACKAGE FAMILY OUTLINE: PDIP .300"
1/1
DOCUMENT CONTROL NUMBER: 21-0043 REV: D

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