



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

General Description

The MAX5033 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 MAX5033 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 MAX5033 delivers up to 500mA 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 MAX5033A/B/C versions have fixed output voltages of 3.3V, 5V, and 12V, respectively, while the MAX5033D features an adjustable output voltage, from 1.25V to 13.2V.

The MAX5033 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

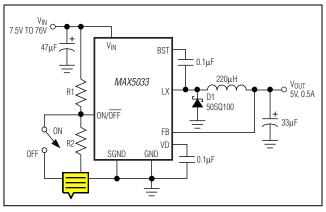
Automotive

Consumer Electronics

Industrial

Distributed Power

Typical Operating Circuit



Features

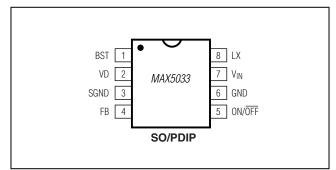
- ♦ Wide 7.5V to 76V Input Voltage Range
- ♦ Fixed (3.3V, 5V, 12V) and Adjustable (1.25V to 13.2V) Voltage Versions
- ♦ 500mA Output Current
- ♦ Efficiency Up to 94%
- ♦ Internal 0.4Ω High-Side DMOS FET
- ♦ 270µA Quiescent Current at No Load, 10µA Shutdown Current
- **♦ Internal Frequency Compensation**
- ♦ 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)
MAX5033AUSA	0°C to +85°C	8 SO	
MAX5033AUPA	0°C to +85°C	8 PDIP	3.3
MAX5033AASA	-40°C to +125°C	8 SO	
MAX5033BUSA	0°C to +85°C	8 SO	
MAX5033BUPA	0°C to +85°C	8 PDIP	5.0
MAX5033BASA	-40°C to +125°C	8 SO	
MAX5033CUSA	0°C to +85°C	8 SO	
MAX5033CUPA	0°C to +85°C	8 PDIP	12
MAX5033CASA	-40°C to +125°C	8 SO	
MAX5033DUSA	0°C to +85°C	8 SO	
MAX5033DUPA	0°C to +85°C	8 PDIP	ADJ
MAX5033DASA	-40°C to +125°C	8 SO	

This product is available in both leaded(Pb) and lead(Pb)-free packages. To order the lead(Pb)-free package, add a + after the part number.

Pin Configuration



For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maximintegrated.com.

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ABSOLUTE MAXIMUM RATINGS

(Voltages referenced to GND, unless otherwise specified.)	VD Short-Circuit DurationIndefinite
V _{IN} 0.3V to +80V SGND0.3V to +0.3V LX0.8V to (V _{IN} + 0.3V)	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
BST0.3V to (V _{IN} + 10V) BST (transient < 100ns)0.3V to (V _{IN} + 15V) BST to LX0.3V to +10V BST to LX (transient < 100ns)0.3V to +15V ON/OFF0.3V to +80V VD0.3V to +12V	Operating Temperature Range MAX5033_U 0°C to +85°C MAX5033_A_ -40°C to +125°C Storage Temperature Range -65°C to +150°C Junction Temperature +150°C Lead Temperature (soldering, 10s) +300°C
FB MAX5033A/MAX5033B/MAX5033C0.3V to +15V MAX5033D0.3V to +12V V _{OUT} Short-Circuit Duration (V _{IN} ≤ 40V)Indefinite	Soldering Temperature (reflow) SO, PDIP Lead(Pb)-free+260°C SO, PDIP Containing lead (Pb)+240°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 (MAX5033_U__)

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
		MAX5033A	7.5		76.0		
Input Voltage Dange	\/	MAX5033B	7.5		76.0	V	
Input Voltage Range	VIN	MAX5033C	15		76		
		MAX5033D	7.5		76.0		
Undervoltage Lockout	UVLO			5.2		V	
		MAX5033A, V _{IN} = 7.5V to 76V, I _{OUT} = 20mA to 500mA	3.185	3.3	3.415		
Output Voltage	Vout	MAX5033B, V _{IN} = 7.5V to 76V, I _{OUT} = 20mA to 500mA	4.85	5.0	5.15	V	
		MAX5033C, V _{IN} = 15V to 76V, I _{OUT} = 20mA to 500mA	11.64	12	12.36		
Feedback Voltage	V _{FB}	V _{IN} = 7.5V to 76V, MAX5033D		1.221	1.250	V	
		V _{IN} = 12V, I _{LOAD} = 500mA, MAX5033A	86 90			%	
		V _{IN} = 12V, I _{LOAD} = 500mA, MAX5033B					
Efficiency	η	V _{IN} = 24V, I _{LOAD} = 500mA, MAX5033C	94				
		V _{IN} = 12V, V _{OUT} = 5V, I _{LOAD} = 500mA, MAX5033D	90				
		V _{FB} = 3.5V, V _{IN} = 7.5V to 76V, MAX5033A		270	440		
Quiescent Supply Current		V _{FB} = 5.5V, V _{IN} = 7.5V to 76V, MAX5033B		270	440		
	lQ	V _{FB} = 13V, V _{IN} = 15V to 76V, MAX5033C		270	440	μΑ	
		V _{FB} = 1.3V, MAX5033D		270	440		
Shutdown Current	ISHDN	$V_{ON/\overline{OFF}} = 0V$, $V_{IN} = 7.5V$ to $76V$		10	45	μΑ	
Peak Swito rent Limit	I _{LIM}	(Note 1) 0.95 1.5 2.		2.1	Α		
Switch Leakage Current	l _{OL}	$V_{IN} = 76V$, $V_{ON/\overline{OFF}} = 0V$, $V_{LX} = 0V$		1		μΑ	

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ELECTRICAL CHARACTERISTICS (MAX5033_U__) (continued)

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
Switch On-Resistance	R _{DS} (ON)	ISWITCH = 500mA		0.4	0.80	Ω	
PFM Threshold	I _{PFM}	Minimum switch current in any cycle	35	65	95	mA	
FB Input Bias Current	ΙΒ	MAX5033D	-150	+0.01	+150	nA	
ON/OFF CONTROL INPUT							
ON/OFF Input-Voltage Threshold	V _{ON/OFF}	Rising trip point	1.53	1.69	1.85	V	
ON/OFF Input-Voltage Hysteresis	V _{HYST}			100		mV	
ON/OFF Input Current	ION/OFF	V _{ON/OFF} = 0V to V _{IN}		10	150	nA	
ON/OFF Operating Voltage Range	V _{ON/OFF}				76	V	
OSCILLATOR							
Oscillator Frequency	fosc		109	125	135	kHz	
Maximum Duty Cycle	D _{MAX}	MAX5033D		95		%	
VOLTAGE REGULATOR							
Regulator Output Voltage	VD	$V_{IN} = 8.5V$ to 76V, $I_L = 0$ mA	6.9	7.8	8.8	V	
Dropout Voltage		$7.5V \le V_{IN} \le 8.5V$, $I_L = 1mA$		2.0		V	
Load Regulation	ΔVD/ΔI _{VD}	0 to 5mA		150		Ω	
PACKAGE THERMAL CHARACT	ERISTICS						
Thermal Resistance	0	SO package (JEDEC 51)		170		0000	
(Junction to Ambient) θ_{JA}		DIP package (JEDEC 51)	110			°C/W	
THERMAL SHUTDOWN							
Thermal-Shutdown Junction Temperature	T _{SH}			+160		°C	
Thermal-Shutdown Hysteresis	THYST			20		°C	

ELECTRICAL CHARACTERISTICS (MAX5033_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 Operating Circuit.*) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
		MAX5033A	7.5		76.0	
Land Valtage Dange		MAX5033B	7.5		76.0	
Input Voltage Range	VIN	MAX5033C	15		76	V
		MAX5033D	7.5		76.0	1
Undervoltage Lockout	UVLO			5.2		V
		MAX5033A, V _{IN} = 7.5V to 76V, I _{OUT} = 20mA to 500mA	3.185	3.3	3.415	
Output Voltage	Vout	MAX5033B, V _{IN} = 7.5V to 76V, I _{OUT} = 20mA to 500mA	4.825	5.0	5.175	V
		MAX5033C, V _{IN} = 15V to 76V, I _{OUT} = 20mA to 500mA	11.58	12	12.42	

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ELECTRICAL CHARACTERISTICS (MAX5033_A__) (continued)

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Feedback Voltage	V _{FB}	V _{IN} = 7.5V to 76V, MAX5033D	1.192	1.221	1.250	V
		V _{IN} = 12V, I _{LOAD} = 500mA, MAX5033A		86		
		V _{IN} = 12V, I _{LOAD} = 500mA, MAX5033B		90		
Efficiency	η	V _{IN} = 24V, I _{LOAD} = 500mA, MAX5033C		94		%
		V _{IN} = 12V, V _{OUT} = 5V, I _{LOAD} = 500mA, MAX5033D		90		
		$V_{FB} = 3.5V$, $V_{IN} = 7.5V$ to 76V, MAX5033A		270	440	
		V _{FB} = 5.5V, V _{IN} = 7.5V to 76V, MAX5033B		270	440	j .
Quiescent Supply Current	IQ	V _{FB} = 13V, V _{IN} = 15V to 76V, MAX5033C		270	440	μΑ
		V _{FB} = 1.3V, MAX5033D		270	440	
Shutdown Current	ISHDN	V _{ON/OFF} = 0V, V _{IN} = 7.5V to 76V		10	45	μΑ
Peak Switch Current Limit	ILIM	(Note 1)	0.95	1.5	2.20	Α
Switch Leakage Current	loL	$V_{IN} = 76V$, $V_{ON/\overline{OFF}} = 0V$, $V_{LX} = 0V$		1		μΑ
Switch On-Resistance	R _{DS(ON)}	Iswitch = 500mA		0.4	0.80	Ω
PFM Threshold	IPFM	Minimum switch current in any cycle	35	65	110	mA
FB Input Bias Current	ΙΒ	MAX5033D	-150	+0.01	+150	nA
ON/OFF CONTROL INPUT	L	·				
ON/OFF Input-Voltage Threshold	V _{ON/OFF}	Rising trip point	1.50	1.69	1.85	V
ON/OFF Input-Voltage Hysteresis	V _{HYST}			100		mV
ON/OFF Input Current	ION/OFF	V _{ON/OFF} = 0V to V _{IN}		10	150	nA
ON/OFF Operating Voltage Range	V _{ON/OFF}				76	V
OSCILLATOR	•		•			
Oscillator Frequency	fosc		105	125	137	kHz
Maximum Duty Cycle	D _{MAX}	MAX5033D		95		%
VOLTAGE REGULATOR						
Regulator Output Voltage	VD	$V_{IN} = 8.5V$ to 76V, $I_L = 0$ mA	6.5	7.8	9.0	V
Dropout Voltage		7.5V ≤ V _{IN} ≤ 8.5V, I _L = 1mA		2.0		V
Load Regulation	ΔVD/ΔI _{VD}	0 to 5mA		150		Ω
PACKAGE THERMAL CHARACT	ERISTICS					
Thermal Resistance	0	SO package (JEDEC 51)		170		0000
(Junction to Ambient)	θJA	DIP package (JEDEC 51)		110		°C/W
THERMAL SHUTDOWN						
Thermal-Shutdown Junction Temperature	T _{SH}			+160		°C
Thermal-Shutdown Hysteresis	THYST			20		°C

Note 1: Switch current at which the current limit is activated.

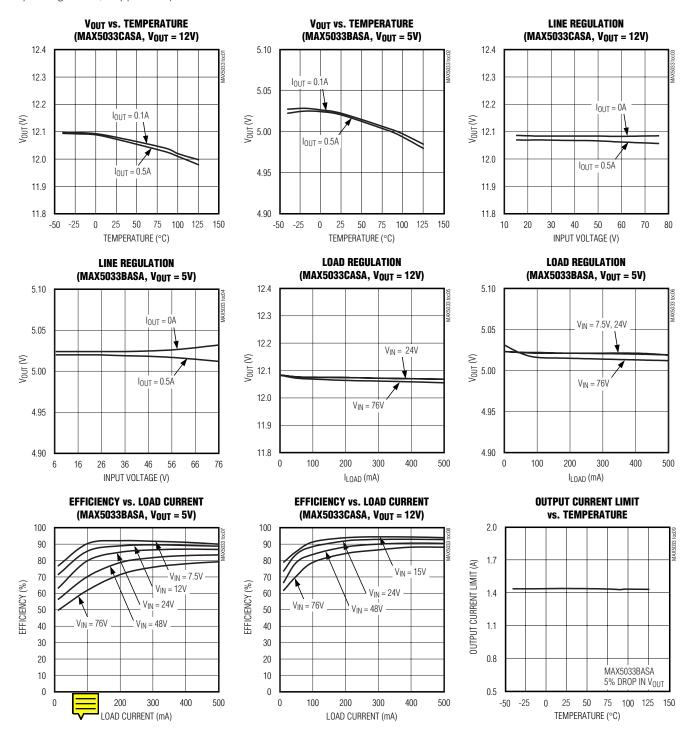
Note 2: All limits at -40°C are guaranteed by design, not production tested.



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Typical Operating Characteristics

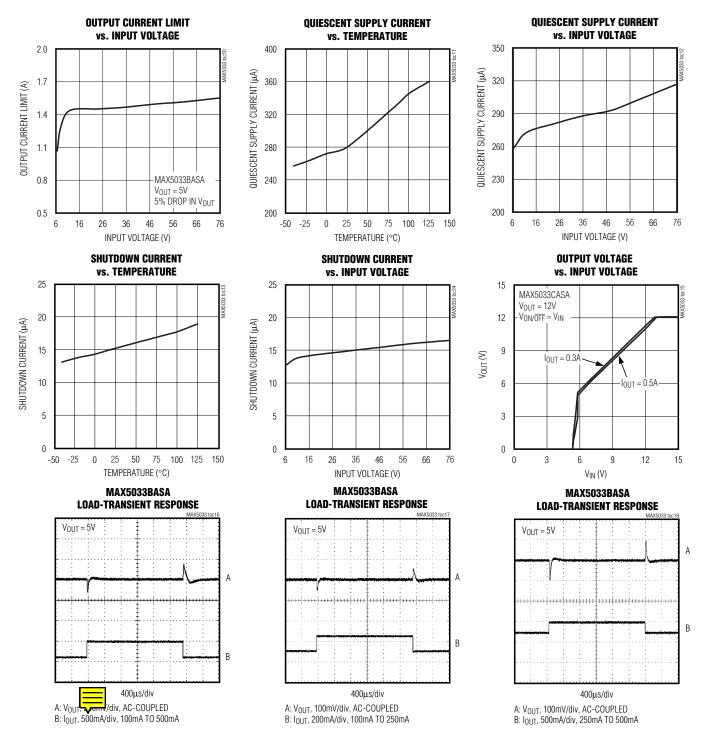
 $(V_{IN} = 12V, V_{ON/\overline{OFF}} = 12V, T_A = -40^{\circ}C$ to +125°C, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$. See the *Typical Operating Circuit*, if applicable.)



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_Typical Operating Characteristics (continued)

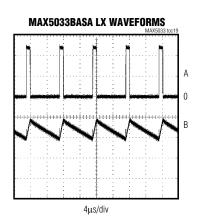
 $(V_{IN} = 12V, V_{ON/\overline{OFF}} = 12V, T_A = -40^{\circ}C$ to +125°C, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$. See the *Typical Operating Circuit*, if applicable.)



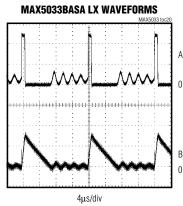
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Typical Operating Characteristics (continued)

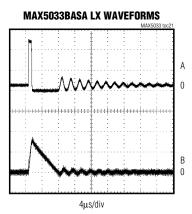
 $(V_{IN} = 12V, V_{ON/\overline{OFF}} = 12V, T_A = -40^{\circ}C$ to +125°C, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$. See the *Typical Operating Circuit*, if applicable.)



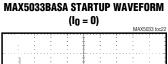
A: SWITCH VOLTAGE (LX PIN) 20V/div, V_{IN} = 48V B: INDUCTOR CURRENT, 200mA/div, (I_{OUT} = 500mA)

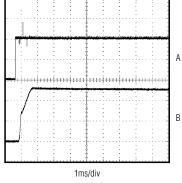


A: SWITCH VOLTAGE, 20V/div, $V_{IN} = 48V$ B: INDUCTOR CURRENT, 100mA/div ($I_{OUT} = 30$ mA)



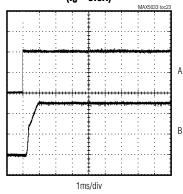
A: SWITCH VOLTAGE (LX PIN), 20V/div, $V_{IN}=48V$ B: INDUCTOR CURRENT, 100mA/div ($I_{OUT}=0$)





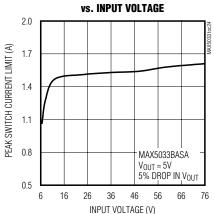
A: V_{ON/OFF}, 2V/div B: V_{OUT}, 2V/div

MAX5033BASA STARTUP WAVEFORM $(I_0 = 0.5A)$



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

PEAK SWITCH CURRENT LIMIT



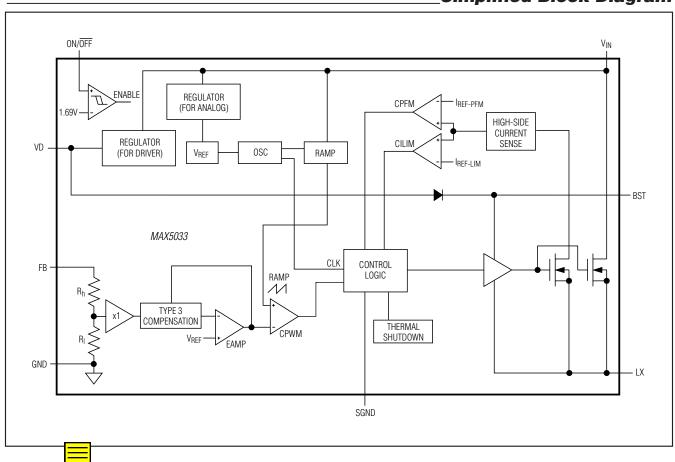


500mA, 76V, High-Efficiency, MAXPower Step-Down DC-DC Converter

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 (MAX5033A, MAX5033B, MAX5033C), connect FB to V _{OUT} . For adjustable output voltage (MAX5033D), use an external resistive voltage-divider to set V _{OUT} . V _{FB} regulating set point is 1.22V.
5	ON/OFF	Shutdown Control Input. Pull ON/OFF low to put the device in shutdown mode. Drive ON/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

Simplified Block Diagram



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

Detailed Description

The MAX5033 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 MAX5033 consumes only 270μA, and in shutdown mode, consumes only 10μA. The MAX5033 also features undervoltage lockout, hiccup-mode output short-circuit protection, and thermal shutdown.

Shutdown Mode

Drive ON/OFF to ground to shut down the MAX5033. Shutdown forces the internal power MOSFET off, turns off all internal circuitry, and reduces the V_{IN} supply current to $10\mu A$ (typ). The ON/OFF rising threshold is 1.69V (typ). Before any operation begins, the voltage at ON/OFF must exceed 1.69V (typ). The ON/OFF input has 100mV hysteresis.

Undervoltage Lockout (UVLO)

Use the ON/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/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 VUVLO(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 $1M\Omega$.

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{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, 16 ramic 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 MAX5033 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 MAX5033A/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 MAX5033D 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 $15k\Omega$, then calculate R3 as follows:

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

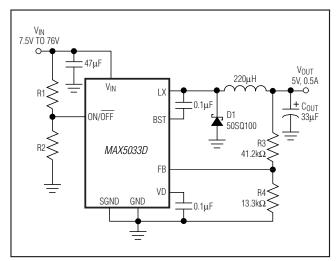


Figure 1. Adjustable Output Voltage

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The MAX5033 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 = VOUT/VIN, IOUTMAX is the maximum output current required, and fsw 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 MAX5033 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

Table 1. Diode Selection

V _{IN} (V)	DIODE PART NUMBER	MANUFACTURER	
	15MQ040N	IR	
7.5 to 00	B240A	Diodes Incorporated	
7.5 to 36	B240	Central Semiconductor	
	MBRS240, MBRS1540	ON Semiconductor	
	30BQ060	IR	
7.5 to 56	B360A	Diodes Incorporated	
7.5 10 56	CMSH3-60	Central Semiconductor	
	MBRD360, MBR3060	ON Semiconductor	
7 F to 76	50SQ100, 50SQ80	IR	
7.5 to 76	MBRM5100	Diodes Incorporated	



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.

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 MAX5033 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 $\Delta V_{\rm ESR}$ (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 fsW is the oscillator switching frequency (125kHz). For example, at $V_{IN} = 48V$ and $V_{OUT} = 3.3V$, 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 130m Ω and 27µF, 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.

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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:

$$\begin{split} I_{PRMS} &= \sqrt{\left(I_{PK}^2 + I_{DC}^2 + \left(I_{PK} \times I_{DC}\right)\right) \times \frac{D}{3}} \\ I_{AVGIN} &= \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} \\ I_{PK} &= I_{OUT} + \frac{\Delta I_{L}}{2}, I_{DC} = I_{OUT} - \frac{\Delta I_{L}}{2} \\ and D &= \frac{V_{OUT}}{V_{IN}} \end{split}$$

IPRMS is the input switch RMS current, IAVGIN 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 (fz) occurs between 20kHz to 40kHz. Use the following equation to verify the value of fz. Capacitors with $100 \text{m}\Omega$ to $250 \text{m}\Omega$ 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:

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

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

The MAX5033 has an internal soft-start time (tss) of 400 μ s. It is important to keep the output rise time at startup below tss to avoid output overshoot. The output rise time is directly proportional to the output capacitor. Use 68 μ F 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 (tRESPONSE) depends on the closedloop 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 from the output capacitance discharge and the ESR drop, use the following equations to calculate the required ESR and capacitance value:

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

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

where ISTEP is the load step and tRESPONSE 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 (typ).

PCB Layout Considerations

Proper PCB 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-

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Application Circuit

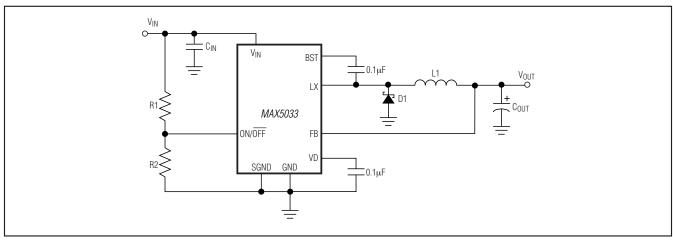


Figure 2. Fixed Output Voltages

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	$C_{IN} = 47\mu F$, Panasonic, EEVFK2A470Q $C_{OUT} = 47\mu F$, Vishay Sprague, 594D476X_016C2T $C_{BST} = 0.1\mu F$, 0805 $R1 = 1M\Omega \pm 1\%$, 0805 $R2 = 384k\Omega \pm 1\%$, 0805 $D1 = 50SQ100$, IR $L1 = 150\mu H$, Coilcraft Inc., DO5022P-154
7.5 to 76	5	0.5	$C_{IN} = 47μ$ F, Panasonic, EEVFK2A470Q $C_{OUT} = 33μ$ F, Vishay Sprague, 594D336X_016C2T $C_{BST} = 0.1μ$ F, 0805 R1 = $1MΩ \pm 1\%$, 0805 R2 = $384kΩ \pm 1\%$, 0805 D1 = $50SQ100$, IR L1 = $220μ$ H, Coilcraft Inc., DO5022P-224
15 to 76	12	0.5	$C_{IN} = 47 \mu F$, Panasonic, EEVFK2A470Q $C_{OUT} = 15 \mu F$, Vishay Sprague, 594D156X_025C2T $C_{BST} = 0.1 \mu F$, 0805 R1 = 1MΩ ±1%, 0805 R2 = 384kΩ ±1%, 0805 D1 = 50SQ100, IR L1 = 330 μH, Coilcraft Inc., DO5022P-334

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 PCB copper plane connecting to V_{IN} and LX for heatsinking.

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

V _{IN} (V)	V _{OUT} (V)	I _{OUT} (A)	EXTERNAL COMPONENTS
3.3 0.5		0.5	C_{IN} = 100μF, Panasonic, EEVFK1E101P C_{OUT} = 47μF, Vishay Sprague, 594D476X_016C2T C_{BST} = 0.1μF, 0805 R1 = 1M Ω ±1%, 0805 R2 = 274k Ω ±1%, 0805 D1 = B220/A, Diodes Incorporated L1 = 150μH, Coilcraft Inc., DO5022P-154
9 to 14	5	0.5	C_{IN} = 100μF, Panasonic, EEVFK1E101P C_{OUT} = 33μF, Vishay Sprague, 594D336X_016C2T C_{BST} = 0.1μF, 0805 R1 = 1M Ω ±1%, 0805 R2 = 274k Ω ±1%, 0805 D1 = B220/A, Diodes Incorporated L1 = 220μH, Coilcraft Inc., DO5022P-224
	3.3	0.5	C_{IN} = 100μF, Panasonic, EEVFK1H101P C_{OUT} = 47μF, Vishay Sprague, 594D476X_016C2T C_{BST} = 0.1μF, 0805 R1 = 1M Ω ±1%, 0805 R2 = 130k Ω ±1%, 0805 D1 = B240/A, Diodes Incorporated L1 = 150μH, Coilcraft Inc., DO5022P-154
18 to 36	5	0.5	C_{IN} = 100μF, Panasonic, EEVFK1H101P C_{OUT} = 33μF, Vishay Sprague, 594D336X_016C2T C_{BST} = 0.1μF, 0805 R1 = 1M Ω ±1%, 0805 R2 = 130k Ω ±1%, 0805 D1 = B240/A, Diodes Incorporated L1 = 220μH, Coilcraft Inc., DO5022P-224
	12	0.5	C_{IN} = 100μF, Panasonic, EEVFK1H101P C_{OUT} = 15μF, Vishay Sprague, 594D156X_025C2T C_{BST} = 0.1μF, 0805 R1 = 1M Ω ±1%, 0805 R2 = 130k Ω ±1%, 0805 D1 = B240/A, Diodes Incorporated L1 = 330μH, Coilcraft Inc., DO5022P-334



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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
Nichicon	858-824-1515	858-824-1525	www.nichicon.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

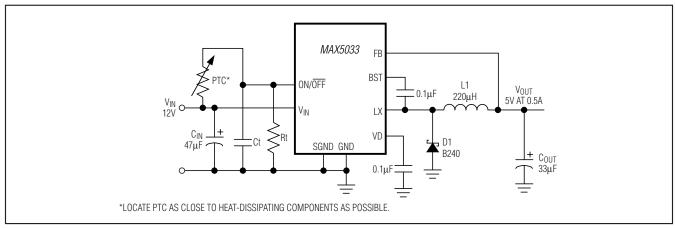


Figure 3. Load Temperature Monitoring with ON/OFF (Requires Accurate VIN)



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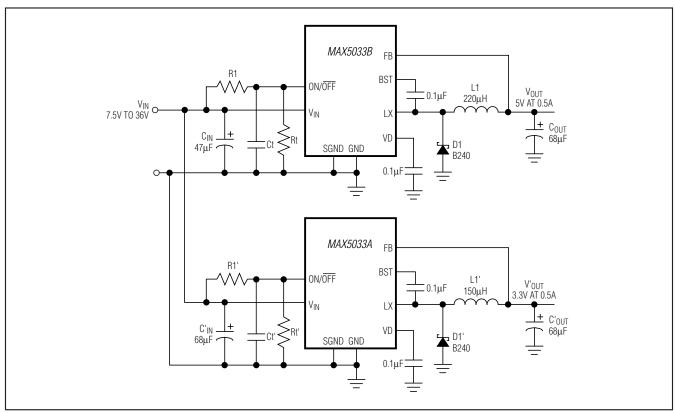


Figure 4. Dual-Sequenced DC-DC Converters (Startup Delay Determined by R1/R1', Ct/Ct' and Rt/Rt')

_____Chip Information

PROCESS: BiCMOS



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Package Information

For the latest package outline information and land patterns, go to www.maxim-ic.com/packages. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 SO/PDIP	S8+5	<u>21-0041</u>	90-0096



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Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	9/03	Initial release	_
1	5/04	New product update	1–7, 10
2	6/04	Removed future product asterisk and made specification changes	1, 2, 3
3	1/07	Modified Absolute Maximum Ratings specifications	2
4	4/10	Corrected inconsistencies in <i>Absolute Maximum Ratings</i> and <i>Electrical Characteristics</i> table	1, 2, 3, 4, 17



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