800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

ABSOLUTE MAXIMUM RATINGS

ONA, $\overline{ONB}$, ONL, TRACK, OUT, INL to GND .....-0.3V, +6V
PGND to GND .....±0.3V
LX to GND .....-0.3V to (POUT + 0.3V)
OUTL to GND .....-0.3V to (INL + 0.3V)
CLK/SEL, REF, FB, FBL, ISET, POUT to GND .....-0.3V to (OUT + 0.3V)
OUTL Short Circuit .....Continuous
Continuous Power Dissipation (T_A = +70°C)
16-Pin QSOP (derate 8.3mW/°C above +70°C).....667mW
16-Pin TSSOP-EP (derate 19mW/°C above +70°C) 1500mW
Operating Temperature Range .....-40°C to +85°C
Junction Temperature .....+150°C
Storage Temperature Range .....-65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C
Soldering Temperature (reflow) .....+260°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

(V_{OUT} = V_{POUT} = V_{INL} = V_{ONA} = V_{ONL} = 3.6V, CLK/SEL = FBL = $\overline{ONB}$ = TRACK = PGND = GND, ISET = REF (bypassed with 0.22µF), LX = open, OUTL = open (bypassed with 4.7µF), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
DC-DC CONVERTER							
Input Voltage Range		(Note 1)			0.7	5.5	V
INL Voltage Range		(Note 1)			2.3	5.5	V
Minimum Startup Voltage		I_{LOAD} < 1mA, T_A = +25°C, Figure 2			0.9	1.1	V
Temperature Coefficient of Startup Voltage		I_{LOAD} < 1mA			-2		mV/°C
FB Regulation Voltage	V_{FB}	CLK/SEL = OUT, 0 < I_{LX} < 0.55A		1.215	1.250	1.275	V
FB Input Leakage Current		V_{FB} = 1.35V			0.01	100	nA
Output Voltage Adjust Range				2.5		5.5	V
Load Regulation		CLK/SEL = OUT, 0 < I_{LOAD} < 800mA			-1		%
OUT Voltage in Track Mode		V_{OUTL} > 2.0V, INL = POUT		V_{OUTL} + 0.4	V_{OUTL} + 0.5	V_{OUTL} + 0.6	V
Frequency in Startup Mode	f_{LX}	V_{OUT} = 1.5V		125		1000	kHz
Startup to Normal Mode Transition Voltage		Rising edge only (Note 2)		2.00	2.15	2.30	V
ISET Input Leakage Current		V_{ISET} = 1.25V			0.01	50	nA
Supply Current in Normal Mode (Note 3)		CLK/SEL = ONL = GND, no load			100	200	µA
Supply Current in Low-Noise PWM Mode (Note 3)		CLK/SEL = OUT, no load	V_{FB} = 1.5V		130	200	µA
			FB = GND (LX switching)		2.5		mA
Supply Current in Shutdown		ONA = ONL = GND, $\overline{ONB}$ = OUT			1	10	µA

ELECTRICAL CHARACTERISTICS (continued)

(V_{OUT} = V_{POUT} = V_{INL} = V_{ONA} = V_{ONL} = 3.6V, CLK/SEL = FBL = $\overline{ONB}$ = TRACK = PGND = GND, ISET = REF (bypassed with 0.22µF), LX = open, OUTL = open (bypassed with 4.7µF), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DC-DC SWITCHES						
POUT Leakage Current		V_{LX} = 0V, V_{OUT} = 5.5V		0.1	10	µA
LX Leakage Current		V_{LX} = V_{OUT} = $V_{\overline{ONB}}$ = 5.5V, ONA = GND		0.1	10	µA
Switch On-Resistance		N-channel		0.17	0.28	Ω
		P-channel		0.22	0.5	
N-Channel Current Limit (Note 4)	I_{LIM}	V_{ISET} = 1.25V, CLK/SEL = GND or OUT	1000	1250	1600	mA
P-Channel Turn-Off Current		CLK/SEL = GND	10	50	120	mA
REFERENCE						
Reference Output Voltage	V_{REF}	I_{REF} = 0A	1.230	1.250	1.270	V
Reference Load Regulation		-1µA < I_{REF} < 50µA		5	15	mV
Reference Supply Regulation		2.5V < V_{OUT} < 5.5V		0.2	5	mV
LINEAR REGULATOR						
INL Voltage Range		(Note 1)		2.3	5.5	V
INL Startup Voltage	V_{INL}	V_{OUT} = 2V, rising edge only	2.15	2.30	2.45	V
Output Voltage in Internal Feedback Mode		FBL = GND, I_{OUTL} = 10mA	2.80	2.85	2.90	V
FBL Dual-Mode Threshold			150	250	350	mV
FBL Regulation Voltage	V_{FBL}	FBL = OUTL, I_{OUTL} = 10mA, I_{REF} = 0A	1.230	1.250	1.270	V
FBL Input Leakage Current		V_{FBL} = 1.5V		0.01	50	nA
OUTL Adjust Range			1.25		5	V
Short-Circuit Current Limit		V_{FBL} = 1V	550		1300	mA
Dropout Resistance		V_{FBL} = 1V, I_{OUTL} = 500mA		0.25	0.5	Ω
Load Regulation		1mA < I_{OUTL} < 500mA, FBL = GND		0.5	1	%
Line Regulation		2.5V < (V_{OUT} = V_{INL} = V_{POUT}) < 5.5V, FBL = OUTL	-0.5		0.5	%
INL Supply Current in Shutdown		OUTL = ONA = ONL = GND		0.1	10	µA
INL No-Load Supply Current		I_{OUTL} = 0A, V_{INL} = 5.5V		90	250	µA
AC Power-Supply Rejection		f = 10kHz		65		dB
Thermal Shutdown		Hysteresis approximately 10°C		160		°C

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

ELECTRICAL CHARACTERISTICS (continued)

(V_{OUT} = V_{POUT} = V_{INL} = V_{ONA} = V_{ONL} = 3.6V, CLK/SEL = FBL = $\overline{ONB}$ = TRACK = PGND = GND, ISET = REF (bypassed with 0.22µF), LX = open, OUTL = open (bypassed with 4.7µF), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A =+25 °C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
CONTROL INPUTS							
Input Low Level		ONA, $\overline{ONB}$, ONL (Note 5)	1.1V < V_{OUT} < 1.8V			0.2	V
			1.8V < V_{OUT} < 5.5V			0.4	
		CLK/SEL	1.2V < V_{OUT} < 5.5V			0.2 × V_{OUT}	
		TRACK	1.2V < V_{INL} < 5.5V			0.2 × V_{INL}	
Input High Level		ONA, $\overline{ONB}$, ONL (Note 5)	1.1V < V_{OUT} < 1.8V	V_{OUT} - 0.2			V
			1.8V < V_{OUT} < 5.5V	1.6			
		CLK/SEL	1.2V < V_{OUT} < 5.5V	0.8 × V_{OUT}			
		TRACK	1.2V < V_{INL} < 5.5V	0.8 × V_{INL}			
Input Leakage Current (CLK/SEL, ONA, $\overline{ONB}$, ONL, TRACK)					0.01	1	µA
Internal Oscillator Frequency		CLK/SEL = OUT		0.8	1	1.2	MHz
External Oscillator Synchronization Range				0.5		1.2	MHz
Oscillator Maximum Duty Cycle				80	86	90	%
Minimum CLK/SEL Pulse					200		ns
Maximum CLK/SEL Rise/Fall Time					100		ns

ELECTRICAL CHARACTERISTICS

(V_{OUT} = V_{POUT} = V_{INL} = V_{ONA} = V_{ONL} = 3.6V, CLK/SEL = FBL = $\overline{ONB}$ = TRACK = PGND = GND, ISET = REF (bypassed with 0.22µF), LX = open, OUTL = open (bypassed with 4.7µF), **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 6)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DC-DC CONVERTER						
FB Regulation Voltage	V_{FB}	CLK/SEL = OUT, 0 < I_{LX} < 0.55A	1.210		1.280	V
OUT Voltage in Track Mode		V_{OUTL} > 2.0V, INL = POUT	V_{OUTL} + 0.4		V_{OUTL} + 0.6	V
Startup to Normal Mode Transition Voltage		Rising edge only (Note 2)	2.00		2.30	V
Supply Current in Normal Mode (Note 3)		CLK/SEL = ONL = GND, no load			200	µA
Supply Current in Low-Noise PWM Mode (Note 3		CLK/SEL = OUT, V_{FB} = 1.5V, no load			200	µA
Supply Current in Shutdown		ONA = ONL = GND, $\overline{ONB}$ = OUT			10	µA
DC-DC SWITCHES						
POUT Leakage Current		V_{LX} = 0V, V_{OUT} = 5.5V			10	µA
LX Leakage Current		V_{LX} = V_{OUT} = $V_{\overline{ONB}}$ = 5.5V, ONA = GND			10	µA
Switch On-Resistance		N-channel			0.28	Ω
		P-channel			0.50	
N-Channel Current Limit (Note 4)	I_{LIM}	V_{ISET} = 1.25V, CLK/SEL = GND or OUT	1000		1600	mA
P-Channel Turn-Off Current		CLK/SEL = GND	5		120	mA
REFERENCE						
Reference Output Voltage		I_{REF} = 0A	1.225		1.275	V
LINEAR REGULATOR						
Output Voltage in Internal Feedback Mode		FBL = GND, I_{OUTL} = 10mA	2.79		2.90	V
FBL Input Threshold			150		350	mV
FBL Regulation Voltage		FBL = OUTL, I_{OUTL} = 10mA, I_{REF} = 0A	1.225		1.275	V
LDO Startup Voltage		V_{OUT} = 2V, rising edge only	2.15		2.45	V
Dropout Resistance		V_{FBL} = 1V, I_{OUTL} = 500mA			0.5	Ω
INL Supply Current in Shutdown		OUTL = ONA = ONL = GND			10	µA
INL No-Load Supply Current		I_{OUTL} = 0A, V_{INL} = 5.5V			250	µA

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

ELECTRICAL CHARACTERISTICS (continued)

(V_{OUT} = V_{POUT} = V_{INL} = V_{ONA} = V_{ONL} = 3.6V, CLK/SEL = FBL = $\overline{ONB}$ = TRACK = PGND = GND, ISET = REF (bypassed with 0.22µF), LX = open, OUTL = open (bypassed with 4.7µF), **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 6)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
CONTROL INPUTS							
Input Low Level		ONA, $\overline{ONB}$, ONL (Note 5)	1.1V < V_{OUT} < 1.8V			0.2	V
			1.8V < V_{OUT} < 5.5V			0.4	
		CLK/SEL	1.2V < V_{OUT} < 5.5V			0.2 × V_{OUT}	
		TRACK	1.2V < V_{INL} < 5.5V			0.2 × V_{INL}	
Input High Level		ONA, $\overline{ONB}$, ONL (Note 5)	1.1V < V_{OUT} < 1.8V	V_{OUT} - 0.2			V
			1.8V < V_{OUT} < 5.5V	1.6			
		CLK/SEL	1.2V < V_{OUT} < 5.5V	0.8 × V_{OUT}			
		TRACK	1.2V < V_{INL} < 5.5V	0.8 × V_{INL}			
Input Leakage Current (CLK/SEL, ONA, $\overline{ONB}$, ONL, TRACK)						1	µA
Internal Oscillator Frequency		CLK/SEL = OUT		0.8		1.2	MHz
Oscillator Maximum Duty Cycle				79		90	%

Note 1: Operating voltage. Since the regulator is bootstrapped to the output, once started it will operate down to 0.7V input.

Note 2: The device is in startup mode when V_{OUT} is below this value (see *Low-Voltage Startup Oscillator* section). Do not apply full load current.

Note 3: Supply current into the OUT and POUT pins. This current correlates directly to the actual battery-supply current, but is reduced in value according to the step-up ratio and efficiency.

Note 4: Minimum recommended ISET voltage in normal mode is 0.625V.

Note 5: ONA, $\overline{ONB}$, ONL have hysteresis of approximately 0.15 × V_{OUT}.

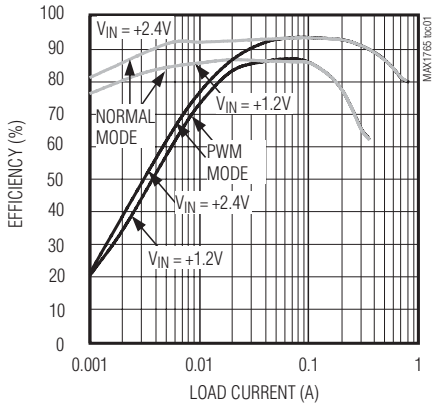
Note 6: Specifications to -40°C are guaranteed by design and not production tested.

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

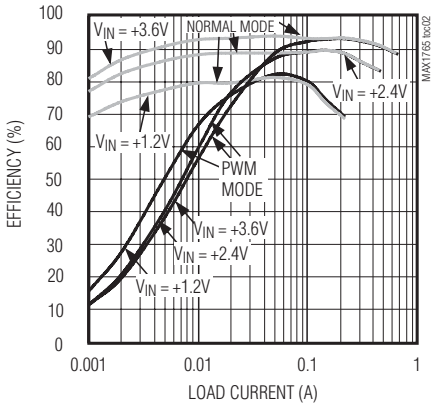
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

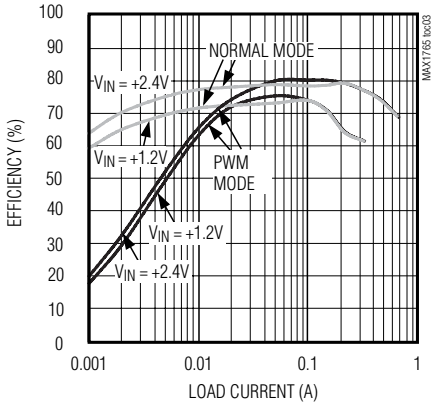
EFFICIENCY vs. LOAD CURRENT (V_{OUT} = +3.3V)



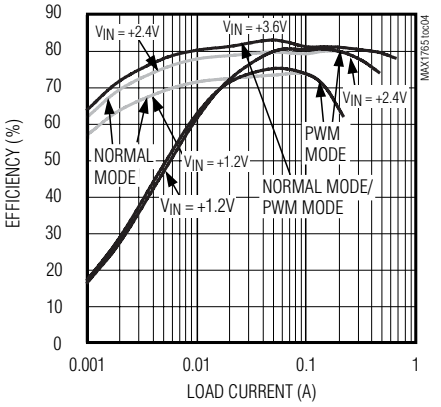
EFFICIENCY vs. LOAD CURRENT (V_{OUT} = +5V)



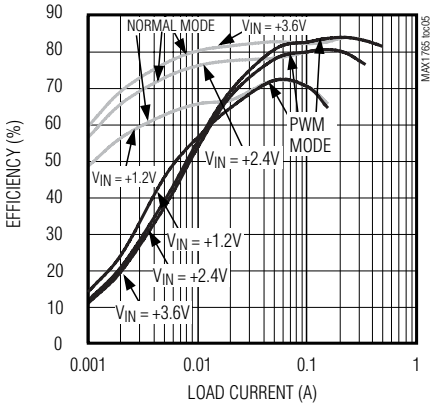
TRACK MODE EFFICIENCY vs. LOAD CURRENT (V_{OUTL} = +2.85V)



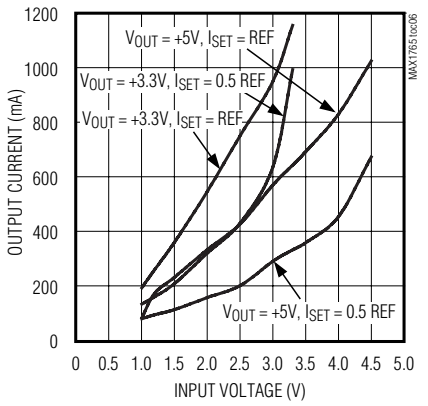
TRACK MODE EFFICIENCY vs. LOAD CURRENT (V_{OUTL} = +3.3V)



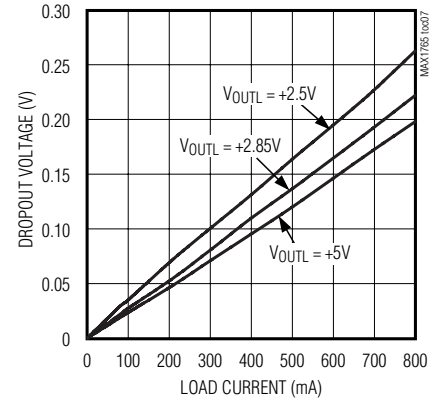
TRACK MODE EFFICIENCY vs. LOAD CURRENT (V_{OUTL} = +5V)



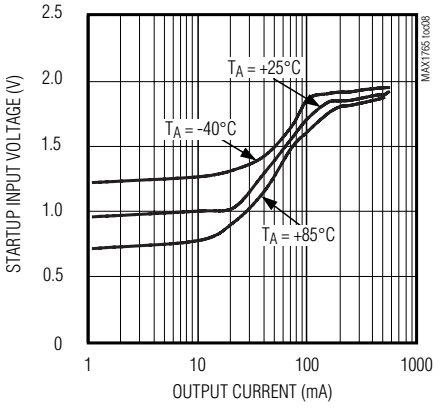
MAXIMUM OUTPUT CURRENT vs. INPUT VOLTAGE



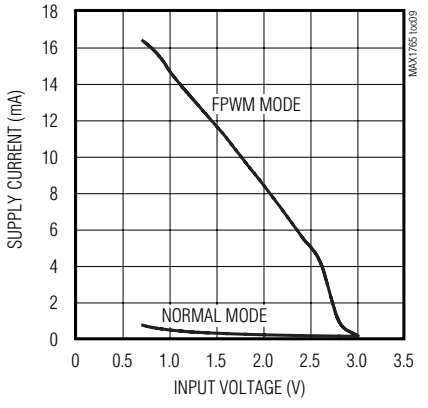
LINEAR REGULATOR DROPOUT VOLTAGE vs. LOAD CURRENT



STARTUP INPUT VOLTAGE vs. OUTPUT CURRENT



NO-LOAD SUPPLY CURRENT vs. INPUT VOLTAGE

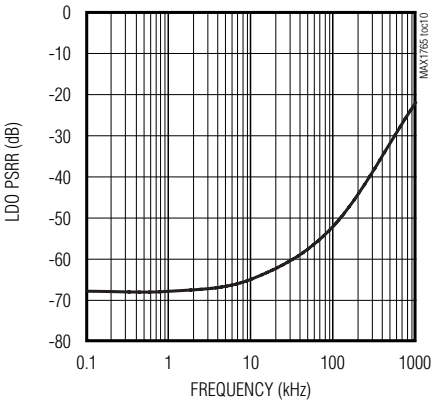


800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

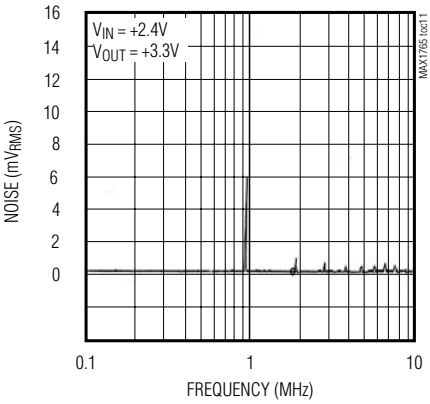
Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

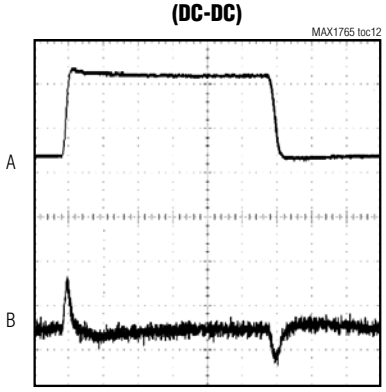
LDO PSRR vs. FREQUENCY (100Hz TO 1MHz)



BOOST FOLLOWED BY LDO OUTPUT NOISE SPECTRUM

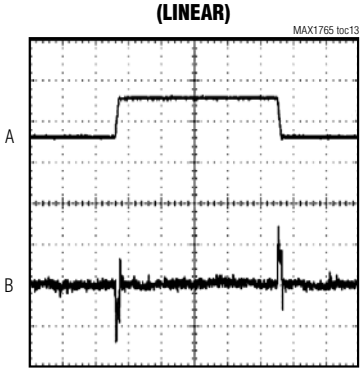


LINE TRANSIENT RESPONSE (DC-DC)



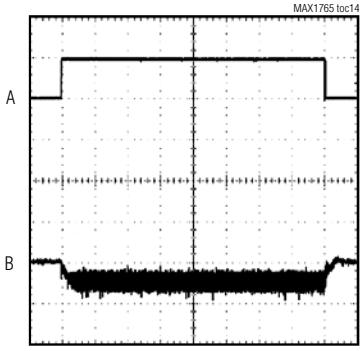
100µs/div
A: V_{IN}, 500mV/div
B: V_{OUT}, 1mV/div, AC-COUPLED
V_{OUT} = +3.3V, I = 0mA
V_{IN} = +1.4V TO +2.4V

LINE TRANSIENT RESPONSE (LINEAR)



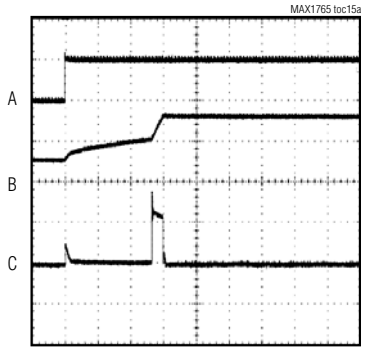
I = 0mA, V_{IN} = +3V TO +5V, V_{OUT} = +3.3V
A: V_{IN}, 2V/div
B: V_{OUT}, 5mV/div, AC-COUPLED

LOAD TRANSIENT RESPONSE



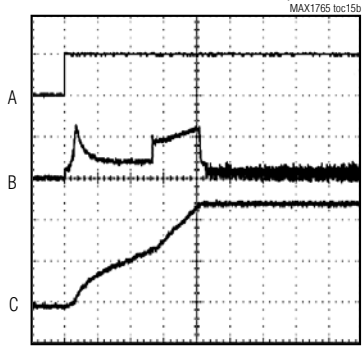
50µs/div
V_{IN} = +2.4V, V_{OUT} = +3.3V, I_{OUT} = 0 TO 500mA
A: I_{OUT}, 500mA/div
B: V_{OUT},100mV/div

TURN-ON WAVEFORMS NO SOFT-START COMPONENTS



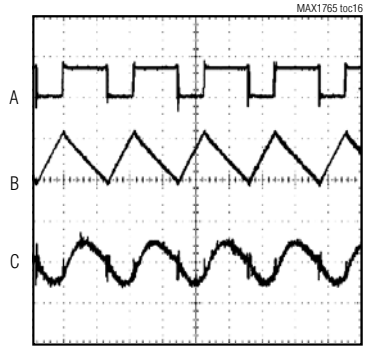
A: 0NA, 5V/div
B: V_{OUT}, 2V/div
C: INPUT CURRENT, 1A/div

SOFT-START WAVEFORMS (R_{SS} = 500kΩ, C_{SS} = 0.1µF)



2.5ms/div
A: 0NA, 5V/div
B: INPUT CURRENT, 100mA/div
C: V_{OUT}, 1V/div

HEAVY-LOAD SWITCHING WAVEFORMS (I_{OUT} = 650mA, V_{IN} = +2.4V, V_{OUT} = 3.3V)



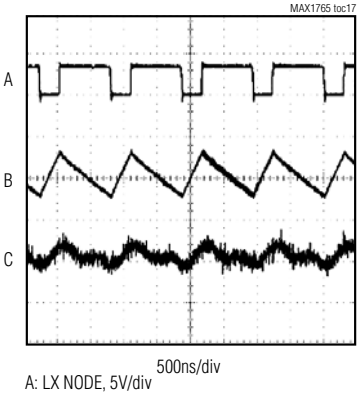
500ns/div
A: LX, 5V/div
B: INDUCTOR CURRENT, 200mA/div
C: OUTPUT RIPPLE, 50mV/div, AC-COUPLED

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

Typical Operating Characteristics (continued)

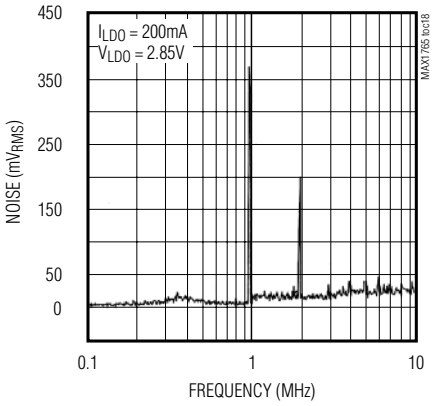
(T_A = +25°C, unless otherwise noted.)

LIGHT-LOAD SWITCHING WAVEFORMS (V_{IN} = +2.4V, V_{OUT} = +3.3V, I_{OUT} = 10mA)

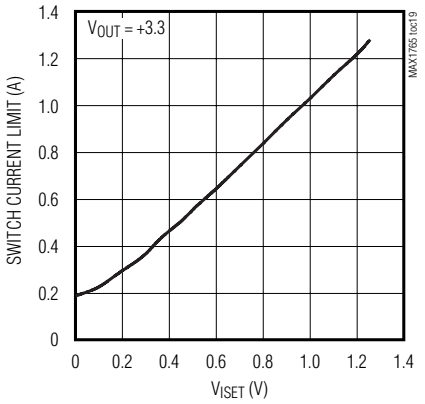


A: LX NODE, 5V/div
B: INDUCTOR CURRENT, 200mA/div, AC-COUPLED
C: OUTPUT RIPPLE, 20mV/div, AC-COUPLED

LINEAR-REGULATOR OUTPUT NOISE



SWITCH CURRENT LIMIT vs. V_{ISET}



Pin Description

PIN	NAME	FUNCTION
1	FBL	Low-Dropout Linear Regulator Dual-Mode Feedback Input. Connect FBL to ground for 2.85V nominal output voltage. Connect FBL to a resistor-divider from OUTL to ground for an adjustable output voltage. FBL regulates to 1.25V.
2	ISET	Set N-Channel Current Limit. For maximum current limit, connect ISET to REF. To reduce current limit, use a resistor-divider from REF to GND. If soft-start is desired, a capacitor can be added from ISET to GND. When ONA = LO and $\overline{ONB}$ = HI or V_{REF} < 80% of nominal value, an on-chip 100kΩ switchable resistor discharges ISET to GND.
3	REF	1.25V Reference Output. Connect a 0.22µF bypass capacitor to GND; 50µA of external load current is allowed. The reference is enabled if ONA = HI, $\overline{ONB}$ = LO, or ONL = HI.
4	GND	Ground. Connect to PGND with short trace.
5	FB	Boost Converter Feedback Input. Connect a resistor-divider between OUT and GND to set the output voltage in the range of 2.5V to 5V. In track mode, FB is disabled after OUTL is in regulation.
6	OUT	Boost Converter IC power is derived from OUT. Connect OUT to POUT through a 4.7Ω resistor and bypass to GND with a 0.68µF capacitor.
7	ONA	ON Input. When high, the DC-DC is operational (Table 2).
8	CLK/SEL	CLOCK Input for the DC-DC Converter. Also serves to program operating mode of switch as follows: **CLK/SEL = LOW:** Normal mode. Operates at a fixed frequency, automatically switching to low-power (SKIP) mode when the load is minimized. **CLK/SEL = HI:** Forced PWM mode. Operates in low-noise, constant-frequency mode at all loads. **CLK/SEL = Clocked:** Synchronized forced PWM mode. The internal oscillator is synchronized to an external clock in the 500kHz to 1200kHz frequency range.

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

Pin Description (continued)

PIN	NAME	FUNCTION
9	$\overline{ONB}$	ON Input. When low, the DC-DC is operational (Table 2).
10	PGND	Power Ground
11	LX	Inductor connection to the drain of P-channel synchronous rectifier and N-channel switch.
12	POUT	Boost Converter Power Output. POUT is the source of the P-channel synchronous-rectifier MOSFET switch. Connect POUT to INL. Bypass POUT to PGND with a 100µF capacitor.
13	INL	Linear Regulator Power Input. Source of PFET pass device connected between INL and OUTL. Connect INL to POUT.
14	OUTL	Linear Regulator Output. OUTL can source up to 500mA. Bypass OUTL to GND with a 4.7µF capacitor.
15	TRACK	Track-Mode Control Input for DC-DC Converter. In track mode, the boost converter output is sensed at OUT and set to 0.5V above OUTL to improve efficiency. Set TRACK to OUT for track mode and to GND for normal operation (Table 2).
16	ONL	Linear Regulator ON Input. Enables the linear regulator output when TRACK = LOW. ONA and $\overline{ONB}$ determine the linear regulator's output state when TRACK = HIGH.
—	EP	Exposed Pad (TSSOP Only). Internally connected to GND and PGND. Connect to a large ground plane.

Detailed Description

The MAX1765 is a highly efficient, low-noise power supply for portable RF hand-held instruments. This boost power supply combines an LDO linear regulator, a low-noise, high-power, step-up switching regulator, an N-channel power MOSFET, a P-channel synchronous rectifier, shutdown control, and a precision voltage reference in a single 16-pin QSOP or a thermally enhanced TSSOP-EP (Figure 1).

The switching DC-DC converter boosts a 1-cell to 3-cell NiMH/NiCd or a single Li+ battery input to an adjustable output voltage between 2.5V and 5.5V. The MAX1765 guarantees startup with voltages as low as 1.1V and will remain operational down to 0.7V (Figure 2). The internal LDO regulator provides linear postregulation for noise-sensitive circuitry, or it can be used as a separate voltage output adjustable from 1.25V up to POUT.

The MAX1765 is optimized for use in cellular phones and other applications requiring low noise during full-power operation, as well as low quiescent current for maximum battery life during standby and shutdown. The device automatically transitions to a low-quiescent-current pulse-skipping control scheme during light loads that reduces the quiescent power consumption to 360µW. The supply current of the device can be further reduced to 1µA when the device is shut down. Figure 2 shows a typical application of the MAX1765 in normal mode.

The switching regulator supports two low-noise modes: fixed-frequency PWM for low noise in all load conditions, and synchronization of the internal oscillator to an external clock driving the CLK input. In TRACK mode, the DC and linear regulator work together to maintain excellent PSRR without excessive efficiency loss.

Additional MAX1765 features include synchronous rectification for high efficiency and increased battery life, dual boost shutdown controls for µP or a pushbutton momentary switch, and a separate shutdown control for the linear regulator.

Step-Up Converter

During DC-DC converter operation, the internal N-channel MOSFET turns on for the first part of each cycle, allowing current to ramp up in the inductor and store energy in a magnetic field. During the second part of each cycle, the MOSFET turns off and inductor current flows through the synchronous rectifier to the output filter capacitor and the load. As the energy stored in the inductor is depleted, the current ramps down and the synchronous rectifier turns off. The CLK/SEL pin determines whether a pulse-skipping or PWM control method is used at light loads (Table 1).

Normal Operation

Pulling CLK/SEL low selects the MAX1765's normal operating mode. In this mode, the device operates in PWM when driving medium to heavy loads and automatically switches to SKIP mode if the load requires less power. SKIP mode allows higher efficiency than PWM under light-load conditions.

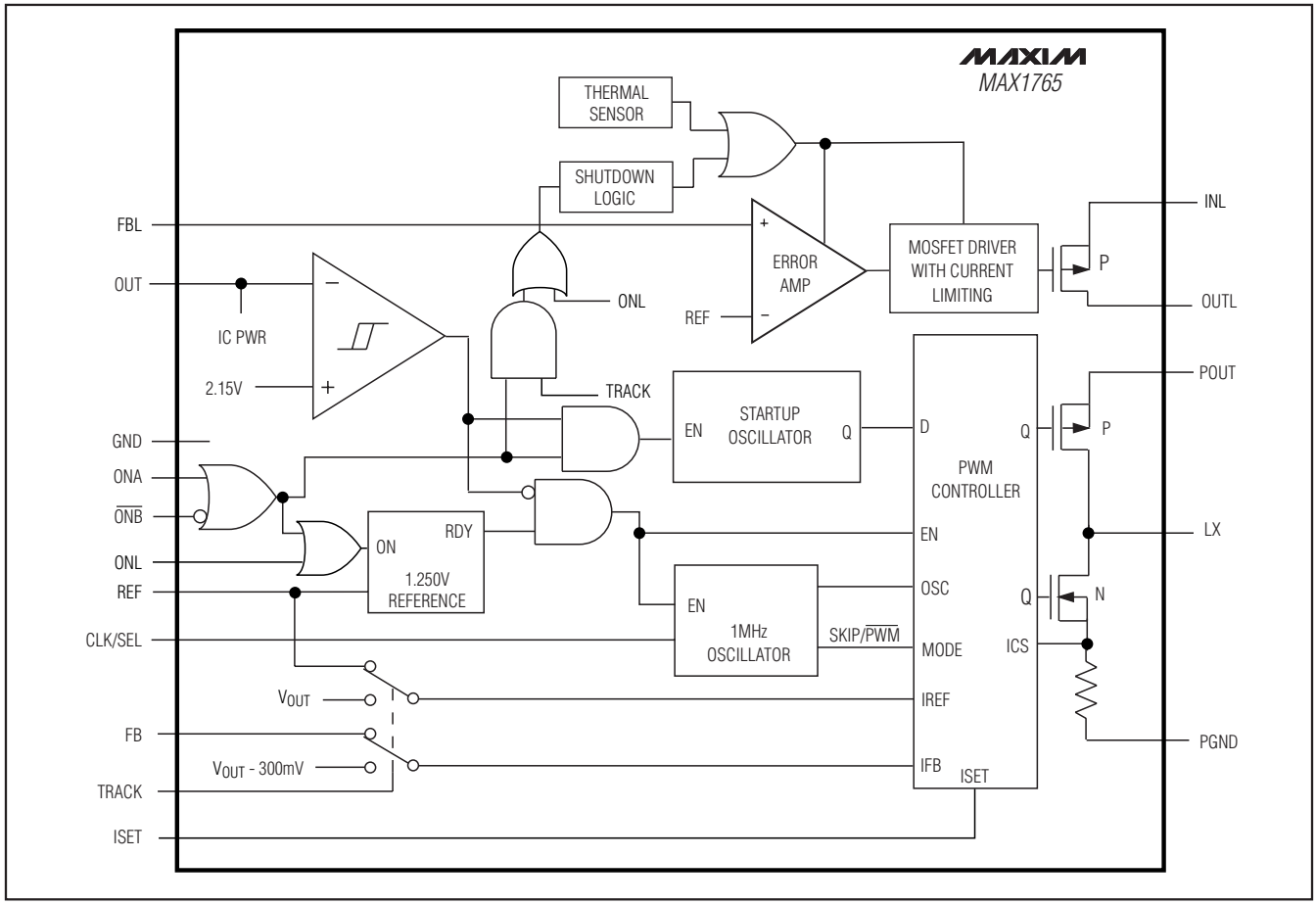


Figure 1. Functional Diagram

Table 1. Selecting the Operating Mode

CLK/SEL	MODE	FEATURES
0	Normal Operation	High-efficiency pulse skipping at light loads, PWM at medium and heavy loads
1	Forced PWM	Low noise, fixed frequency at all loads
External Clock 500kHz to 1.2MHz	Synchronized PWM	Low noise, fixed frequency at all loads

Light-Load Operation in Normal Mode

At light loads, the MAX1765 operates by turning on the DC-DC converter's N-channel field-effect transistor (FET) when $V_{FB} < V_{REF}$, synchronized with the rising edge of the oscillator. The N-channel FET will remain on, ramping up the inductor current past the minimum inductor current, until the internal error amplifier and current mode circuitry determine that the needs of the system have been met or the device hits the ISET current limit. The N-channel is then turned off and the P-channel is turned on until current decays to the P-channel turn-off current level. The N-channel will remain off until V_{FB} is again less than V_{REF}, and a rising edge of the oscillator occurs.

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

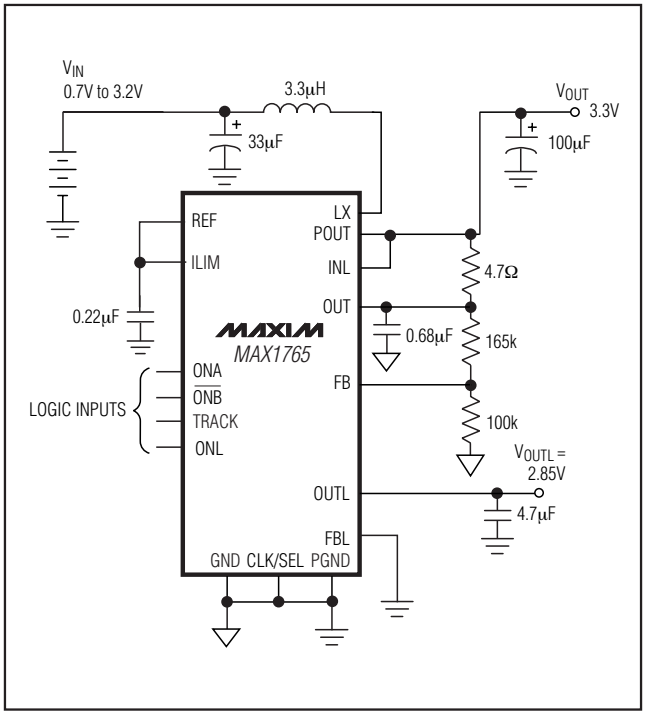


Figure 2. Typical Application Circuit

PWM Operation in Normal Mode

The MAX1765 transitions to fixed-frequency PWM operation under medium and heavy loads. The N-channel FET is engaged when $V_{FB} < V_{REF}$ and is kept on to ramp up the current in the inductor until one of the following conditions occurs: the system needs are met, the next falling edge of the internal oscillator is achieved, or the maximum inductor current (ISET) is reached. The N-channel is turned off, activating the P-channel synchronous rectifier that remains on until the inductor current gets to the P-channel turn-off current level, or $V_{FB} < V_{REF}$ and there is a rising oscillator clock edge. The 1MHz fixed-frequency operation produces an easily filtered fixed-noise spectrum.

Forced PWM Operation

When CLK/SEL is high, the MAX1765 operates in a low-noise PWM-only mode. The N-channel FET is turned on when $V_{FB} < V_{REF}$ and is kept on to ramp up the inductor current until one of the following conditions occurs: the system needs are met, the next falling edge of the internal oscillator is achieved, or the ISET is reached. The N-channel is then turned off, activating the P-channel synchronous rectifier that remains on until the next rising edge of the oscillator, where the N-channel is again turned on under most conditions. The P-channel zero detect circuitry is deactivated in forced PWM mode. This means an N- or P-channel FET is on all the time for most load conditions.

At light loads, the P-channel will remain on so the device can pass current back to the input from the output. The P-channel will only pass current for two cycles before it is disabled. Then, the device remains inactive until $V_{FB} < V_{REF}$.

During forced PWM operation, the MAX1765 switches at a constant frequency (1MHz) and modulates the MOSFET switch pulse width to control the power transferred per cycle in order to regulate the output voltage for most output currents. Switching harmonics generated by fixed-frequency operation are consistent and easily filtered. (See the Boost Followed by LDO Output Noise Spectrum plot in the *Typical Operating Characteristics*.)

Synchronized PWM Operation

The MAX1765 can be synchronized in PWM mode to an external frequency of 500kHz to 1.2MHz by applying an external clock signal to CLK/SEL. This allows interference to be minimized in wireless applications. The synchronous rectifier is active during synchronized PWM operation.

Synchronous Rectifier

The MAX1765 features an internal 250mΩ, P-channel synchronous rectifier to enhance efficiency. Synchronous rectification provides a 5% efficiency improvement over similar nonsynchronous boost regulators. In PWM mode, the synchronous rectifier is turned on during the second portion of each switching cycle. At light loads (in normal mode), an internal comparator turns on the synchronous rectifier when the voltage at LX exceeds the boost regulator output, and turns it off when the inductor current drops below 50mA.

Low-Voltage Startup Oscillator

The MAX1765 uses a low-voltage startup oscillator for a 1.1V guaranteed minimum input startup input voltage. A Schottky diode placed across LX and POUT reduces the startup voltage to 0.9V. At startup, the low-voltage oscillator switches the N-channel MOSFET until the output voltage reaches 2.15V. Above this level, the normal boost-converter feedback and control circuitry takes over. Once the device is in regulation, it can operate down to 0.7V input since internal power for the IC is bootstrapped from the OUT pin. Do not apply full load until the output exceeds 2.3V.

Linear Regulator

The MAX1765 contains an LDO with a fixed 2.85V (or adjustable) output. The MAX1765 linear regulator features a 250mΩ, P-channel MOSFET pass transistor. This provides several advantages, including longer battery life, over similar designs using a PNP pass transistor. The P-channel MOSFET requires no base-drive current. This reduces quiescent current considerably, since PNP-based regulators tend to waste base-drive current in dropout when the pass transistor saturates.

Connect the input of the linear regulator (INL) to POUT. The linear regulator can be used to postfilter the switching regulator or regulate a separate supply voltage. This regulated output is intended to power noise-sensitive analog circuitry, such as low-noise amplifiers and IF stages in cellular phones and other instruments, and can deliver up to 500mA. Use a 4.7µF capacitor with less than a 1Ω equivalent series resistance (ESR) on the output to provide stability. The linear regulator has an internal 1.3A (max) current limit and thermal-overload protection circuitry to protect this output.

Configurations

There are several useful circuit configurations that can be implemented with the MAX1765. The TRACK input divides the circuit configurations into two types, one where the DC-DC converter tracks to the LDO output, and the other where the boost and the LDO regulate independently.

Track Mode

Asserting the TRACK input places the MAX1765 into track mode, where the DC-DC switching regulator's feedback pin (FB) is ignored, and the boost output (POUT) "tracks" to 500mV above the linear regulator output. The primary use of the MAX1765 in TRACK mode is as a simple or very-low-noise step-up/down power supply (see Figures 3 and 4; also see the Maximum Output Current vs. Input Voltage plot in the *Typical Operating Characteristics*.)

This circuit operates as a linear regulator when the input supply (a battery) is greater than V_{LDO}. When the battery discharges below V_{LDO}, the DC-DC converter turns on, boosting POUT to a constant 500mV above the linear regulator output. This configuration also allows for true shutdown (see *True Shutdown*).

Dual-Supply Mode

When the TRACK input is low, the MAX1765 operates two independent power supplies, a DC-DC converter, and a linear regulator. One such application of this configuration is shown in Figure 4. In this mode, the device generates two boosted voltages from a single battery supply. The DC-DC converter could be used to supply the power amplifier (PA) of a cell phone, while the linear regulator powers the baseband functions within the phone. Asserting TRACK switches the device into track mode when the high-voltage supply for the PA is no longer needed, thus improving efficiency in standby-receive mode. When the PA again needs 5V, deassert the TRACK input.

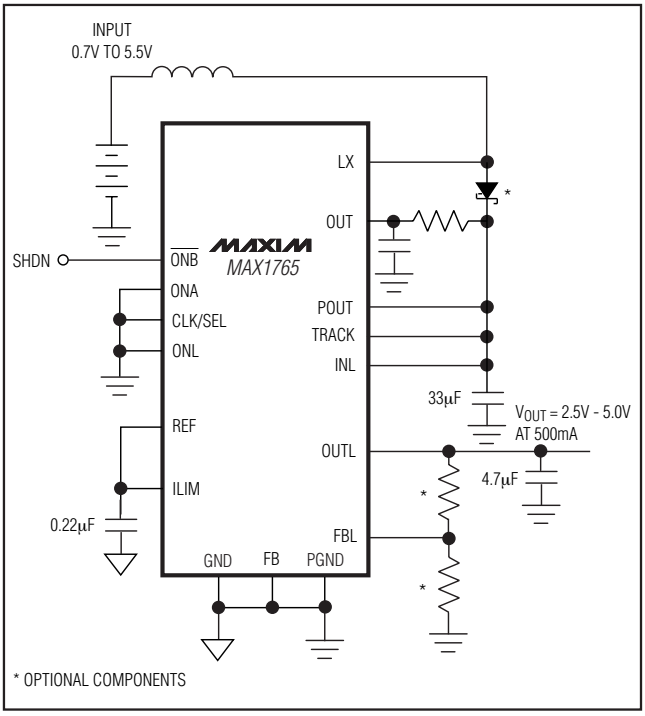


Figure 3. Simple Step-Up/Step-Down Converter

Shutdown

The MAX1765 has a shutdown mode that reduces quiescent current to 1µA. During shutdown, the reference, LDO, DC-DC converter, and all feedback and control circuitry are off. Table 2 shows the MAX1765 shutdown truth table. If ONA, $\overline{ONB}$, and ONL are all deasserted, the device is shut down.

True Shutdown

When a typical boost converter is placed into shutdown, current can flow through the body diode of the synchronous rectifier to the load. The MAX1765 can be configured to allow true shutdown as shown in Figure 5. The shutdown function is active low and is connected to both ONA and ONL. When asserted, both the DC-DC converter and the LDO are shut down simultaneously.

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

Table 2. Operating Mode Truth Table

OPERATING MODE	TRACK	ONA	$\overline{ONB}$	ONL	LINEAR REGULATOR	DC-DC CONVERTER	REF
Shutdown	X	L	H	L	OFF	OFF	OFF
Track	H	H	X	X	ON	ON	ON
	H	X	L	X			
Independent Regulation	L	H	X	H	ON	ON	ON
	L	X	L	H			
DC-DC Only	L	H	X	L	OFF	ON	ON
	L	X	L	L			
LDO Only	X	L	H	H	ON	OFF	ON

The LDO acts like a switch in this situation and disconnects the input from the load. Connect FBL to a resistor-divider from V_{REF} to GND (R3 and R4 in Figure 5) so that V_{FBL} = 0.5V (above the Dual Mode™ threshold) when OUTL is regulated, to ensure that the linear regulator is saturated. Another method to configure the MAX1765 for true shutdown is shown in Figure 6. This shutdown function is active high and connects to the gate of a low-impedance PFET and $\overline{ONB}$. The PFET acts like a switch in this situation and disconnects the input from the load.

Reference

The MAX1765 has an internal 1.25V, 1% reference. Connect a 0.22µF ceramic bypass capacitor to GND within 0.2in (5mm) of the REF pin. REF can source up to 50µA of external load current. Typically connect ISET to REF to give the MAX1765 full inductor current limit.

Design Procedure

Setting DC-DC Converter Voltage

Set the output voltage between +2.5V and +5.5V by connecting a resistor voltage-divider from OUT to FB to GND (Figure 7). Connect the resistor voltage-divider as close to the IC as possible, within 0.2in (5mm) of FB. Choose R2 of 40kΩ or less, then calculate R1 using:

$$R1 = R2 \left(\frac{V_{OUT}}{V_{FB}} - 1 \right)$$

where V_{FB}, the boost-regulator feedback set point, is +1.25V.

For output voltages above 4V, connect a Schottky diode between LX and POUT to prevent voltage transition from exceeding the LX voltage rating.

Setting the Linear Regulator Voltage

The LDO regulation voltage can also be set similarly to the DC-DC converter. Connecting FBL to GND sets the LDO output to 2.85V. To set other output voltages between 1.25V and POUT, connect a resistor-divider from OUTL to FBL to GND (Figure 7). Connect the resistor voltage-divider as close to the IC as possible, within 0.2in (5mm) of FBL. The maximum input bias current for the FBL input is 50nA. Choose R4 of 40kΩ or less, then calculate R3 using:

$$R3 = R4 \left(\frac{V_{OUTL}}{V_{FBL}} - 1 \right)$$

where V_{FBL}, the linear regulator feedback set point, is +1.25V.

Setting the Switch Current Limit and Soft-Start

The ISET pin adjusts the inductor current limit and implements soft-start. With ISET connected to REF, the inductor current limits at 1.25A. With ISET connected to a resistive divider set from REF to GND, the current limit is reduced according to:

$$I_{LIM} = 1.25A \left(\frac{R_{SS2}}{R_{SS1} + R_{SS2}} \right)$$

Dual Mode is a trademark of Maxim Integrated Products

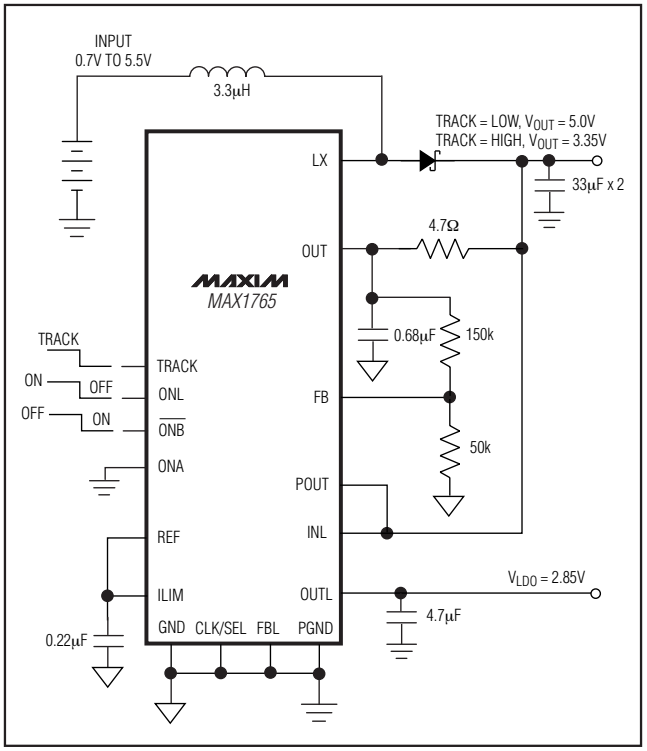


Figure 4. Dual-Output Power Supply

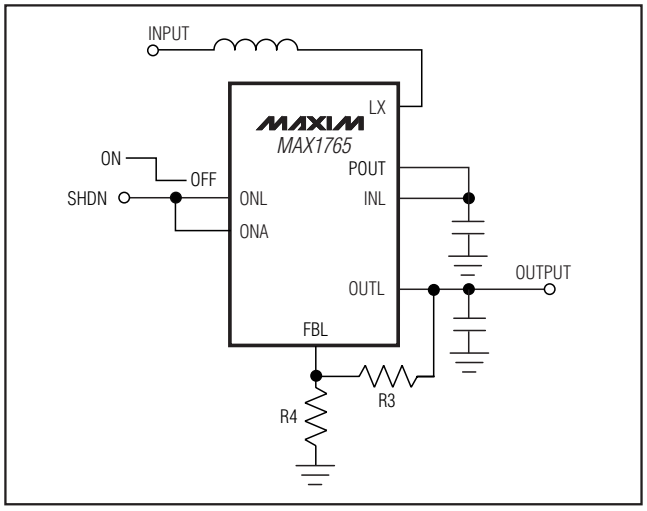


Figure 5. LDO Enable Allows True Boost Shutdown

Implement soft-start by placing a resistor from ISET to REF and a capacitor from ISET to GND (Figure 8). In shutdown, ISET is discharged to GND through an on-chip 100kΩ resistor. At power-up, ISET is 0V and the current limit is zero. As the capacitor voltage rises, the current limit increases and the output voltage rises. The soft-start time constant is:

$$t_{RISE} = R_{SS}C_{SS}$$

Placing a capacitor across the lower resistor of the current-limiting resistive divider provides both features simultaneously (Figure 9).

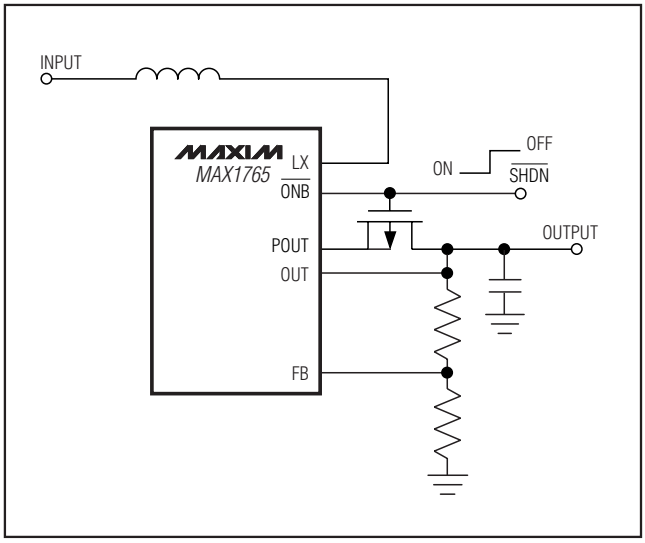


Figure 6. PFET Allows True Boost Shutdown

Package Selection

The MAX1765 is available in two packages, a 16-pin QSOP and a thermally enhanced TSSOP-EP. The QSOP is the less expensive of the two packages, and requires a less complex layout design. This layout allows the designer to route underneath the device. The power dissipation for the QSOP is 0.7W.

The TSSOP-EP comes with an exposed metal pad that is connected to the substrate of the IC. This increases the power dissipation up to 1.5W for the TSSOP-EP. To achieve maximum power capability, the exposed pad of the TSSOP-EP should be reflowed to a pad with low thermal resistance. For convenience, this pad can be connected to AGND or PGND.

Inductor Selection

The MAX1765's high switching frequency allows the use of a small surface-mount inductor. For most applications, a 3.3µH inductor works well. The inductor

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

should have a saturation current rating exceeding the N-channel switch current limit; however, it is acceptable to bias the inductor current into saturation by as much as 20% if a slight reduction in efficiency is acceptable. Lower current-rated inductors may be used if ISET is employed to reduce the peak inductor current (see *Setting the Switch Current Limit and Soft-Start*). For high efficiency, choose an inductor with a high-frequency core material to reduce core losses. To minimize radiated noise, use a toroid or shielded inductor. See Table 3 for suggested components and Table 4 for a list of component suppliers.

Output Diode

To assist startup with input voltages below 1.1V or when V_{OUT} is set for >4V, use a Schottky diode—such as a 1N5817, MBR0520L or equivalent—between LX and POUT (Figure 2). The Schottky diode carries current after the synchronous rectifier turns off. Thus, its current rating only needs to be 500mA. Connect the diode as close to the IC as possible. Do not use ordinary rectifier diodes; their slow switching speeds and long reverse-recovery times render them unacceptable. For input voltages over 1.8V, the Schottky diode may improve light-load efficiency.

Input and Output Filter Capacitors

Choose input and output filter capacitors that will service the input and output peak currents with acceptable voltage ripple. Choose input capacitors with working voltage ratings over the maximum input voltage and output capacitors with working voltage ratings higher than the output. A 100µF, 100mΩ, low equivalent-series-resistance (ESR) tantalum output capacitor is recommended for most applications. At the output of the linear regulator (OUTL), use a 4.7µF ceramic capacitor for stability at loads up to 500mA.

The input filter capacitor reduces peak currents drawn from the input source and also reduces input switching noise. The input voltage source impedance determines the required size of the input capacitor. When operating directly from one or two NiMH cells placed close to the MAX1765, use a single 33µF low-ESR input filter capacitor.

The Sanyo POSCAP, Panasonic SP/CB, and Kemet T510 are good low-ESR capacitors. Low-ESR tantalum capacitors offer a good trade-off between price and performance. Do not exceed the ripple current ratings of tantalum capacitors. Avoid aluminum electrolytic capacitors; their high ESR typically results in higher output ripple voltage.

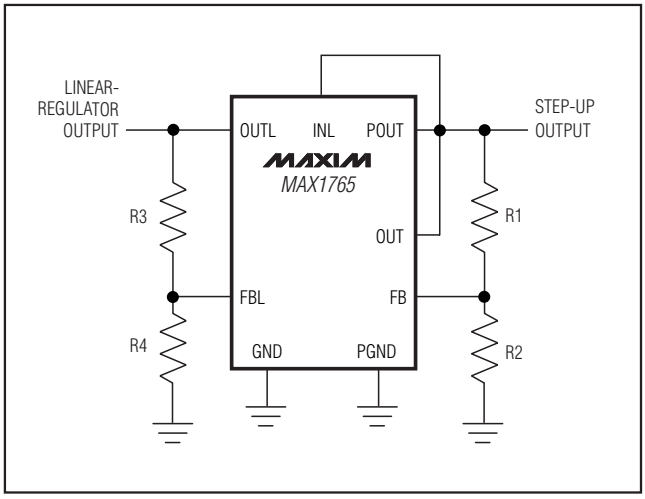


Figure 7. Feedback Connections

Bypass Capacitors

Bypass REF to GND with 0.22µF. Also, bypass OUT to GND with a 0.68µF ceramic capacitor, and connect OUT to POUT with a 4.7Ω resistor. Each of these components should be placed as close to its respective IC pins as possible, within 0.2in (5mm).

Layout Considerations

High switching frequencies and large peak currents make PC board layout a critical part of design. Poor design will cause excessive EMI and ground bounce, both of which can cause instability or regulation errors by corrupting the voltage and current feedback signals.

Power components—such as the inductor, converter IC, filter capacitors, and output diode—should be placed as close together as possible, and their traces should be kept short, direct, and wide. Connect the inductor from the battery to the LX pins as close to the IC as possible.

Keep the voltage feedback network very close to the IC, within 0.2in (5mm) of the FB pins. Keep noisy traces, such as those from the LX pin, away from the voltage feedback networks and guarded from them using grounded copper. Refer to the MAX1765 EV kit for a full PC board example.

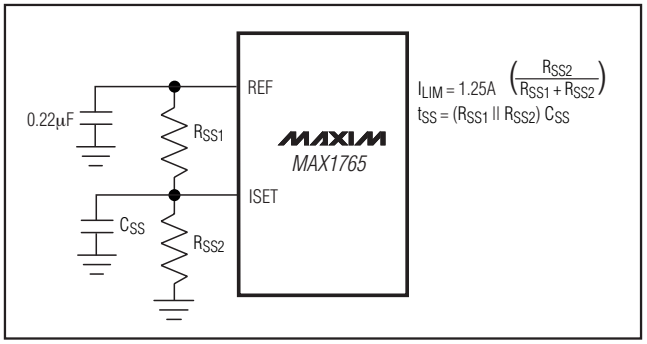


Figure 8. Soft-Start, Reduced Current Limit

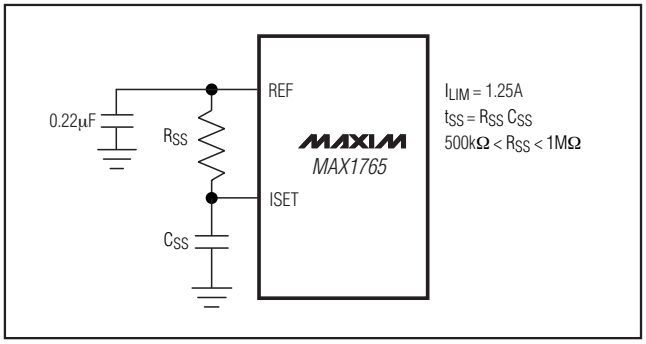


Figure 9. Soft-Start, Maximum Current Limit

Table 3. Component Selection Guide

PRODUCTION	3.3µH INDUCTORS	CAPACITORS	SCHOTTKY DIODES
Surface Mount	Coilcraft DS3316P Coilcraft LPT3305	AVX TPS series Kemet T510 series Sanyo POSCAP series	Motorola MBR0520L Nihon EP10QY03

Applications Information

Use in a Typical Wireless Phone Application

The MAX1765 is ideal for use in digital cordless and PCS phones. The PA is connected directly to the step-up converter output for maximum voltage swing and power efficiency (Figure 10). The internal linear regulator is used for postregulation to generate low-noise power for DSP, control, and RF circuitry. The following equations may be used to estimate the typical available output current under conditions other than those listed here:

$$I_{OUT,MAX} = \left(I_{LIM} - \frac{I_{RIPPLE}}{2}\right)(1 - D)$$

$$I_{RIPPLE} = \frac{1}{f_{SW}} \times \frac{D}{L} \times \left[V_{IN} - I_{LIM} \times (R_{NCH} + L_{ESR})\right]$$

$$D = \frac{V_{OUT} - V_{IN} + I_{LIM} \times (R_{NCH} + L_{ESR})}{V_{OUT} + I_{LIM}(R_{PCH} - R_{NCH})}$$

Table 4. Component Suppliers

SUPPLIER	COUNTRY	PHONE
AVX	USA	843-448-9411
Coilcraft	USA	847-639-6400
Kemet	USA	810-287-2536
Motorola	USA	408-629-4789
	Japan	81-45-474-7030
Sumida	USA	847-956-0666
	Japan	81-3-3607-3302

Note: *Please indicate that you are using the MAX1765 when contacting these component suppliers.*

where I_{LIM} is the peak inductor current limit, f_{SW} is the operating frequency (typically 1.2MHz), L is the inductance of the chosen inductor, L_{RESR} is the resistance of the chosen inductor, R_{NCH} and R_{PCH} are the resistances of the internal N-channel and P-channel, respectively.

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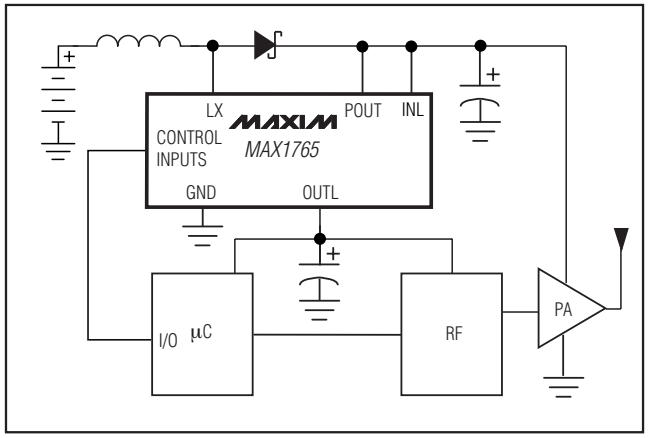

Figure 10. Typical Phone Application

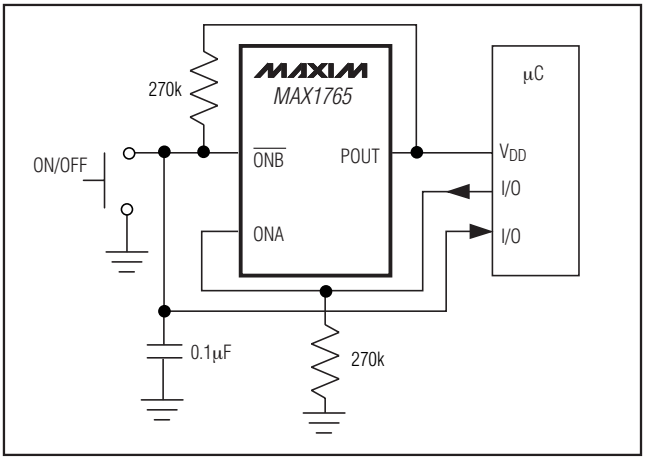

Figure 11. Momentary Pushbutton On/Off Switch

Table 5. Typical Available Output Current

NUMBER OF CELLS	INPUT VOLTAGE (V)	OUTPUT VOLTAGE (V)	OUTPUT CURRENT (mA)
1 NiCd/NiMH	1.2	3.3	330
2 NiCd/NiMH	2.4	3.3	730
	2.4	5.0	460
3 NiCd/NiMH or 1 Li+	3.6	5.0	720

Table 5 lists the typical available output current when operating with one or more NiCd/NiMH cells or one Li+ cell.

Adding a Manual Power Reset

A momentary pushbutton switch can be used to turn the MAX1765 on and off (Figure 11). ONA is pulled low and $\overline{ONB}$ is pulled high to turn the device off. When the momentary switch is pressed, $\overline{ONB}$ is pulled low and the regulator turns on. The switch must be pressed long enough for the microcontroller (µC) to exit reset and drive ONA high. A small capacitor is added to help debounce the switch. The µC issues a logic high to ONA, which holds the device on, regardless of the switch state. To turn the regulator off, press the switch again, allowing the µC to read the switch status and pull ONA low. When the switch is released, $\overline{ONB}$ is pulled high.

Package Information

For the latest package outline information and land patterns (footprints), 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.
16 QSOP	E16+1	21-0055	90-0167
16 QSOP-EP	U16E+3	21-0108	90-0120

800mA, Low-Noise, Step-Up DC-DC Converter with 500mA Linear Regulator

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	12/00	Initial release	—
1	4/11	Added lead-free designation, updated TOCs 1 and 2, and updated *Pin Description* section	1, 7, 10

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