MAX16956

36V, 300mA, Mini Buck Converter with 1.1µA IQ

General Description

The MAX16956 is a small, synchronous buck converter with integrated high-side and low-side switches. The device is designed to deliver up to 300mA with input voltages from 3.5V to 36V, while using only 1.1µA quiescent current at no load (fixed-output versions). Voltage quality can be monitored by observing the RESET signal. The device can operate near dropout by running at 97% duty cycle, making it ideal for automotive applications under cold-crank.

The device offers fixed-output voltages of 5V and 3.3V, as well as an adjustable version. The adjustable version allows the user to program the output voltage between 1V and 10V by using a resistor-divider. Frequency is fixed at 2.1MHz, which allows for small external components, reduced output ripple, and minimized AM radio interference. The device offers both forced-PWM and skip modes of operation, with ultra-low quiescent current of 1.1µA in skip mode. The device can be ordered with spread-spectrum frequency modulation designed to minimize EMI-radiated emissions due to the switching frequency.

The MAX16956 is available in a small (3mm x 3mm) 10-pin μ MAX® package and operates across the full automotive temperature range of -40°C to +125°C. The device is AEC-Q100 qualified.

Applications

- Automotive Body ECUs
- Point-of-Load Applications
- Distributed DC Power Systems

Benefits and Features

- Integration and High-Switching Frequency Saves Space
 - DC-DC Converter Up to 300mA Capability
 - Fixed 5V/3.3V or Programmable Output-Voltage Options (1V to 10V)
 - · Current-Mode-Control Architecture
 - · 2.1MHz Operating Frequency
 - Fixed 5.4ms Internal Soft-Start
- Spread-Spectrum Frequency Modulation Reduces EMI Emissions
- Low I_Q Enables Designers to Meet Stringent OEM Module Power-Consumption Requirements
 - 1.1µA Quiescent Current in Standby Mode (Fixed-Output-Voltage Versions Only)
- Wide Input Voltage Range Supports Automotive Applications
 - Operating V_{IN} Range: 3.5V to 36V (42V Tolerant)
 - 97% (Max) Duty-Cycle Operation with Low Dropout
- Robust Performance Supports Wide Range of Automotive Applications
 - · Short-Circuit. Thermal Protections
 - -40°C to +125°C Automotive Temperature Range
 - · AEC-Q100 Qualified

Typical Application Circuits, Ordering Information, and Selector Guide appear at end of data sheet.

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36V, 300mA, Mini Buck Converter with 1.1µA IQ

Absolute Maximum Ratings

(Voltages Referenced to PGND)	
SUP	0.3V to +42V
EN	0.3V to V _{SUP} + 0.3V
BST to LX	+6V
BST	
MODE, OUT/FB, RESET	0.3V to V _{BIAS} + 0.3V
AGND	0.3V to +0.3V
BIAS	0.3V to +6.0V
OUT/FB Short-Circuit Duration	Continuous

Continuous Power Dissipation ($T_A = +70^{\circ}C$)	
(derate 12.9mW/°C above +70°C)	1031mW
Operating Temperature Range	40°C to +125°C
Junction Temperature	+150°C
Storage Temperature Range	65°C to +150°C
Lead Temperature (soldering, 10s)	300°C
Soldering Temperature (reflow)	+260°C

Package Thermal Characteristics (Note 1)

 μMAX

Junction-to-Ambient Thermal Resistance (θ_{JA})...... 77.6°C/W

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.

Electrical Characteristics

 $(V_{SUP} = V_{EN} = 14V, V_{MODE} = 0V, T_A = T_J = -40^{\circ}C$ to +125°C, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$, unless otherwise noted.) (Note 2)

PARAMETER	SYMBOL	CONDITIO	ONS	MIN	TYP	MAX	UNITS
Supply Voltage	V _{SUP}			3.5		36	V
Supply Voltage	V _{SUP}	T < 500ms (Note 3)				42	V
		V _{EN} = 0V			0.75	3.0	
		No load, fixed 3.3V V _{OUT}	No load, fixed 3.3V V _{OUT}		1.1	3.0	1 .
Supply Current	I _{SUP}	No load, fixed 5V V _{OUT}			1.8	5.0	μA
Cappi, Canoni	130F	No load, adjustable V _{OUT}	-		32	70	
		V _{MODE} = V _{BIAS} , no load switching	, FPWM, no	0.5	1	1.5	mA
LIV/ Lookout		V _{BIAS} rising Hysteresis		3.0	3.2	3.4	
UV Lockout					0.4		- V
BIAS Regulator Voltage	V _{BIAS}	V _{SUP} = 5.5V to 36V (MAX16956C/F only)			5		V
BIAS Current Limit				10			mA
BUCK CONVERTER				•			
Valtage Accuracy	V _{OUT,5V}	V _{OUT} = 5V	6V≤V _{SUP} ≤	4.9	5.0	5.2	V
Voltage Accuracy	V _{OUT,3.3V}	V _{OUT} = 3.3V	36V, I _{LOAD} = 0 to 300mA	3.2	3.3	3.4	v
Output Voltage Range	V _{OUT}	Adjustable output versions		1		10	V
FB Voltage Accuracy	V _{FB}	Adjustable output versions, 6V ≤ V _{SUP} ≤ 36V		0.98	1.0	1.03	V
FB Input Current	I _{FB}	V _{FB} = 1V			0.02		μA
FB Load Regulation	ΔV_{LOAD}	I _{LOAD} = 0.3mA to 300mA			1		%

Electrical Characteristics (continued)

 $(V_{SUP} = V_{EN} = 14V, V_{MODE} = 0V, T_A = T_J = -40^{\circ}C$ to +125°C, unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$, unless otherwise noted.) (Note 2)

FB Line Regulation ΔVLINE 6V ≤ V _{SUP} ≤ 36V 0.02 − %/V High-Side DMOS R _{DSON} RON,HS V _{BIAS} = 5V, I _{LX} = 200mA 1000 2200 mΩ Low-Side DMOS R _{DSON} RON,LS V _{BIAS} = 5V, I _{LX} = 200mA 500 1200 mΩ DMOS High-Side Current-Linit Threshold I _{MAX} V _{BIAS} = 5V, I _{LX} = 200mA 70 100 130 mA DMOS Low-Side Skip-Mode Peak-Current Threshold I _{SKIP} FPWM mode 40 w mA DMOS Low-Side Negative Current-Limit Threshold I _{NEG} FPWM mode -0.320 w mA DMOS Low-Side Negative Current-Limit Threshold I _{NEG} FPWM mode -0.320 w mA DMOS Low-Side Negative Current-Limit Threshold I _{NEG} FPWM mode -0.320 w m DMOS Low-Side Negative Current-Limit Threshold I _{NEG} FPWM mode -0.320 w m Soft-Start Ramp Time I _{NEG} I _N S 0 -0.12 m m Maximum On-Time I _N S V _N S	PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Low-Side DMOS RDSON RONLS VBIAS = 5V. ILX = 200mA 500 1200 mΩ DMOS High-Side Current-Limit Threshold IMAX 0.425 0.5 0.575 A DMOS High-Side Skip-Mode Peak-Current Threshold Iskip 70 100 130 mA DMOS Low-Side Zero-Crossing Threshold Izx 40 40 mA DMOS Low-Side Regative Current-Limit Threshold INEG FPWM mode 5.4 mA DMOS Low-Side Regative Current-Limit Threshold INEG FPWM mode 5.4 mS LX Rise Time INEG KINEG MO 6 mS LX Rise Time Instance KINEG MO 6 mS Maximum Duty Cycle DCMAX 97 % mS PWM Switching Frequency fsw pread-spectrum option only 195 2.1 2.25 MHz Spread-Spectrum Range SS pread-spectrum option only 8 90 92 94 94 94 94 94 94 94 94	FB Line Regulation	ΔV _{LINE}	6V ≤ V _{SUP} ≤ 36V		0.02		%/V
Low-Side DMOS RDSON RONLS VBIAS = 5V. ILX = 200MA 500 1200 mΩ DMOS High-Side Current-Limit Threshold IMAX 1MAX 0.425 0.5 0.575 A DMOS High-Side Skip-Mode Peak-Current Threshold I skiip 70 100 130 mA DMOS Low-Side Negative Current-Limit Threshold I NEG FPWM mode 2-0.320 A DMOS Low-Side Negative Current-Limit Threshold I NEG FPWM mode -0.320 A Soft-Start Ramp Time 1 NEG FPWM mode	High-Side DMOS R _{DSON}	R _{ON,HS}	V _{BIAS} = 5V, I _{LX} = 200mA		1000	2200	mΩ
DMOS High-Side Current-Limit Threshold IMAX IMAX 0.425 0.5 0.575 A DMOS High-Side Skip-Mode Peak-Current Threshold IskiP - 70 100 130 mA DMOS Low-Side Zero-Crossing Threshold Izx - 40 - mA DMOS Low-Side Negative Current-Limit Threshold INEG FPWM mode - -0.320 - - OMOS Low-Side Negative Current-Limit Threshold INEG FPWM mode - -0.320 - </td <td>Low-Side DMOS R_{DSON}</td> <td></td> <td>V_{BIAS} = 5V, I_{LX} = 200mA</td> <td></td> <td>500</td> <td>1200</td> <td>mΩ</td>	Low-Side DMOS R _{DSON}		V _{BIAS} = 5V, I _{LX} = 200mA		500	1200	mΩ
Peak-Current Threshold	_	I _{MAX}		0.425	0.5	0.575	А
Threshold 1ZX Mean of the polyment o		I _{SKIP}		70	100	130	mA
Current-Limit Threshold INEG FFVM mode -0.320	_	I _{ZX}			40		mA
LX Rise Time t _{RISE,LX} (Note 3) 6 ns Minimum On-Time t _{ON_MIN} 60 ns Maximum Duty Cycle DC _{MAX} 97 % PWM Switching Frequency f _{SW} 1.95 2.1 2.25 MHz Spread-Spectrum Range SS Spread-spectrum option only ±6 % RESET OUTPUT (RESET) RESET Threshold VTHR_RES VOUT falling 90 92 94 %VOUT RESET Debounce t _{DEB} 12 µs Nout Falling 88 90 92 94 %VOUT Nout Falling 88 90 92 94 %VOUT Nout Falling Nout Falling <td< td=""><td>_</td><td>I_{NEG}</td><td>FPWM mode</td><td></td><td>-0.320</td><td></td><td>А</td></td<>	_	I _{NEG}	FPWM mode		-0.320		А
Minimum On-Time	Soft-Start Ramp Time	t _{SS}			5.4		ms
Maximum Duty Cycle DC _{MAX} 97 % PWM Switching Frequency f _{SW} 1.95 2.1 2.25 MHz Spread-Spectrum Range SS Spread-spectrum option only ±6 % RESET OUTPUT (RESET) RESET Threshold VTHR_RES VOUT rising 90 92 94 %VOUT RESET Debounce t _{DEB} VOUT falling 88 90 92 µs RESET High Leakage Current ILEAK,RES TA = +25°C 1 µA V RESET Low Level VOUT,RES Sinking 1mA 0.4 V LOGIC LEVELS EN Input High Threshold VIH,EN 2.4 V EN Input Low Threshold VIL,EN 0.4 V EN Input High Threshold VIL,EN 0.4 V EN Input High Threshold VIL,MODE 0.4 V MODE Input High Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 10.4 V THERMAL PROTECTION	LX Rise Time	t _{RISE,LX}	(Note 3)		6		ns
PWM Switching Frequency f _{SW} 1.95 2.1 2.25 MHz Spread-Spectrum Range SS Spread-spectrum option only ±6 % RESET OUTPUT (RESET) RESET Threshold VTHR_RES VOUT rising 90 92 94 %VOUT RESET Debounce tDEB 12 µs RESET High Leakage Current ILEAK,RES TA = +25°C 1 µA V RESET Low Level VOUT,RES Sinking 1mA 0.4 V LOGIC LEVELS EN Input High Threshold VIH,EN 2.4 V EN Input Low Threshold VIL,EN 0.4 V EN Input High Threshold VIH,EN 0.4 V EN Input Low Threshold VIH,EN 0.4 V MODE Input High Threshold VIH,MODE 1.4 V MODE Input Low Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION TSHDN (Note 3) +175 °C	Minimum On-Time	t _{ON_MIN}			60		ns
Spread-Spectrum Range SS Spread-spectrum option only ±6 % RESET OUTPUT (RESET) RESET Threshold VTHR_RES VOUT rising 90 92 94 %VOUT RESET Debounce total VOUT falling 88 90 92 %VOUT RESET Debounce total 12 µs RESET High Leakage Current ILEAK,RES TA = +25°C 1 µA V RESET Low Level VOUT,RES Sinking 1mA 0.4 V V LOGIC LEVELS EN Input High Threshold VIH,EN 2.4 V V EN Input Low Threshold VIL,EN 0.4 V EN Input Current IIN,EN 0.1 µA MODE Input High Threshold VIH,MODE 1.4 V MODE Input Low Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION TSHDN (Note 3) +175 °C	Maximum Duty Cycle	DC _{MAX}			97		%
RESET OUTPUT (RESET) RESET Threshold VTHR_RES VOUT rising 90 92 94 %VOUT %VOUT %VOUT 88 90 92 94 %VOUT %VOUT %VOUT 88 90 92 94 %VOUT %VOUT %VOUT 88 90 92 94 µS %VOUT µS %VOUT \$12 µS µS %VOUT \$12 µS \$12 ¥S \$12 ¥S <td< td=""><td>PWM Switching Frequency</td><td>f_{SW}</td><td></td><td>1.95</td><td>2.1</td><td>2.25</td><td>MHz</td></td<>	PWM Switching Frequency	f _{SW}		1.95	2.1	2.25	MHz
Name	Spread-Spectrum Range	SS	Spread-spectrum option only		±6		%
RESET Threshold	RESET OUTPUT (RESET)						
VTHF_RES VOUT failing 88 90 92	DECET Throubold	V _{THR_RES}	V _{OUT} rising	90	92	94	%V _{OUT}
RESET High Leakage Current $I_{LEAK,RES}$ $T_A = +25^{\circ}C$ 1 μA RESET Low Level $V_{OUT,RES}$ Sinking 1mA0.4 V LOGIC LEVELSEN Input High Threshold $V_{IH,EN}$ 2.4 V EN Input Low Threshold $V_{IL,EN}$ 0.4 V EN Input Current $I_{IN,EN}$ 0.1 μA MODE Input High Threshold $V_{IH,MODE}$ 1.4 V MODE Input Low Threshold $V_{IL,MODE}$ 0.4 V MODE Internal Pulldown $R_{PD,MODE}$ 1000 $k \Omega$ THERMAL PROTECTIONThermal Shutdown T_{SHDN} (Note 3)+175°C	RESET THIESHOLD	V _{THF_RES}	V _{OUT} falling	88	90	92	
RESET Low Level VOUT,RES Sinking 1mA 0.4 V LOGIC LEVELS EN Input High Threshold VIH,EN 2.4 V EN Input Low Threshold VIL,EN 0.4 V EN Input Current I _{IN,EN} 0.1 μA MODE Input High Threshold VIH,MODE 1.4 V MODE Input Low Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION Thermal Shutdown T _{SHDN} (Note 3) +175 °C	RESET Debounce	t _{DEB}			12		μs
LOGIC LEVELS EN Input High Threshold VIH,EN 2.4 V EN Input Low Threshold VIL,EN 0.4 V EN Input Current IIN,EN 0.1 μA MODE Input High Threshold VIH,MODE 1.4 V MODE Input Low Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION Thermal Shutdown TSHDN (Note 3) +175 °C	RESET High Leakage Current	I _{LEAK,RES}	T _A = +25°C			1	μA
EN Input High Threshold VIH,EN 2.4 V EN Input Low Threshold VIL,EN 0.4 V EN Input Current IIN,EN 0.1 μA MODE Input High Threshold VIH,MODE 1.4 V MODE Input Low Threshold VIL,MODE 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION Thermal Shutdown T _{SHDN} (Note 3) +175 °C	RESET Low Level	V _{OUT,RES}	Sinking 1mA			0.4	V
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	LOGIC LEVELS						
EN Input Low Threshold $V_{IL,EN}$ 0.4VEN Input Current $I_{IN,EN}$ 0.1 μ AMODE Input High Threshold $V_{IH,MODE}$ 1.4VMODE Input Low Threshold $V_{IL,MODE}$ 0.4VMODE Internal Pulldown $R_{PD,MODE}$ 1000 $k\Omega$ THERMAL PROTECTIONThermal Shutdown T_{SHDN} (Note 3)+175°C	EN Input High Threshold	V _{IH,EN}		2.4			V
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	EN Input Low Threshold					0.4	V
MODE Input Low Threshold V _{IL,MODE} 0.4 V MODE Internal Pulldown RPD,MODE 1000 kΩ THERMAL PROTECTION Thermal Shutdown T _{SHDN} (Note 3) +175 °C	EN Input Current	I _{IN,EN}			0.1		μA
MODE Internal Pulldown $R_{PD,MODE}$ 1000 $k\Omega$ THERMAL PROTECTION Thermal Shutdown T_{SHDN} (Note 3) +175 °C	MODE Input High Threshold	V _{IH,MODE}		1.4			V
MODE Internal Pulldown $R_{PD,MODE}$ 1000 $k\Omega$ THERMAL PROTECTION Thermal Shutdown T_{SHDN} (Note 3) +175 °C	MODE Input Low Threshold	V _{IL,MODE}				0.4	V
Thermal Shutdown T _{SHDN} (Note 3) +175 °C	MODE Internal Pulldown	R _{PD,MODE}			1000		kΩ
GHEN /	THERMAL PROTECTION	THERMAL PROTECTION					
Thermal-Shutdown Hysteresis T _{SHDN,HYS} (Note 3) +15 °C	Thermal Shutdown	T _{SHDN}	(Note 3)		+175		°C
	Thermal-Shutdown Hysteresis	T _{SHDN,HYS}	(Note 3)		+15		°C

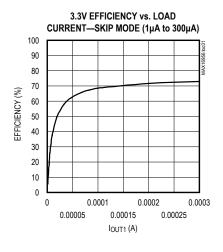
Note 2: Limits are 100% tested at $T_A = +25$ °C (and/or $T_A = +125$ °C). Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization.

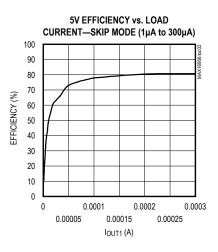
Note 3: Guaranteed by design; not production tested.

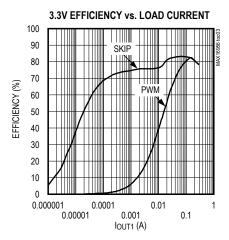
Note 4: When the typical minimum on-time of 80ns is violated, the device skips pulses.

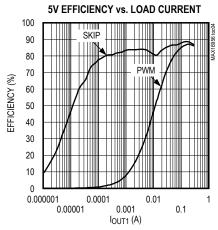
Typical Operating Characteristics

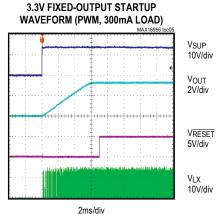
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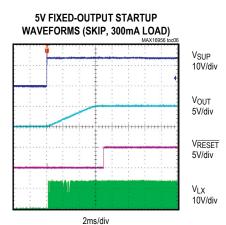


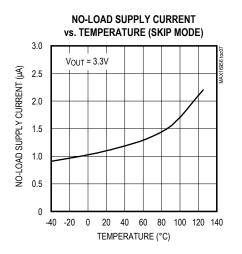






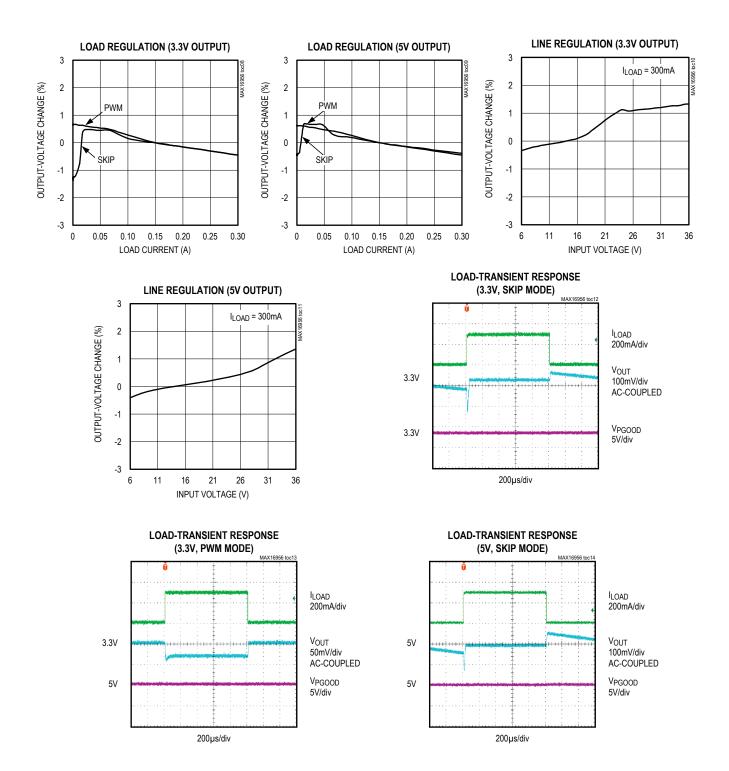






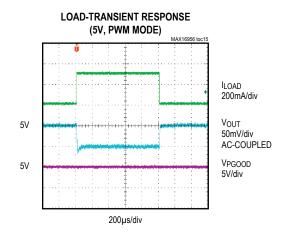
Typical Operating Characteristics (continued)

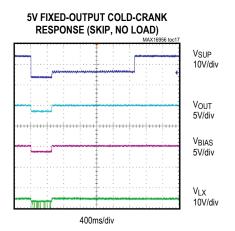
 $(V_{SUP} = V_{EN} = 14V, T_A = +25^{\circ}C, unless otherwise noted.)$

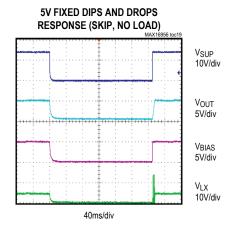


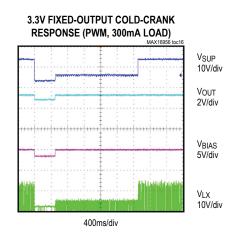
Typical Operating Characteristics (continued)

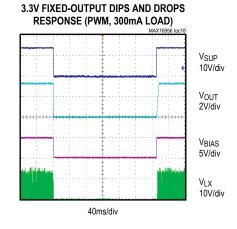
 $(V_{SUP} = V_{EN} = 14V, T_A = +25^{\circ}C, unless otherwise noted.)$

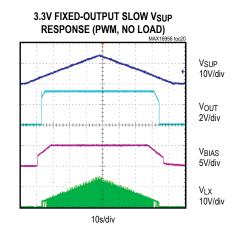






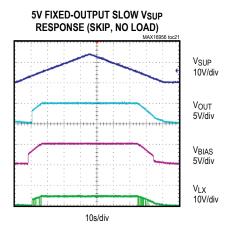


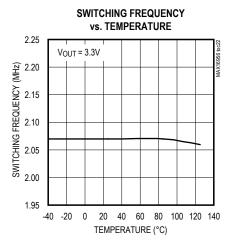


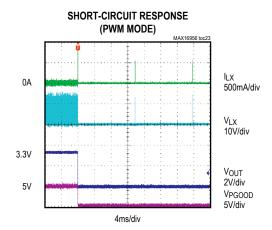


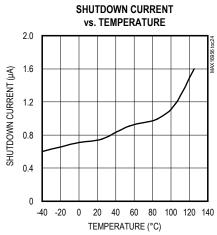
Typical Operating Characteristics (continued)

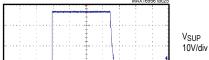
 $(V_{SUP} = V_{EN} = 14V, T_A = +25^{\circ}C, unless otherwise noted.)$



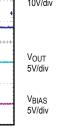








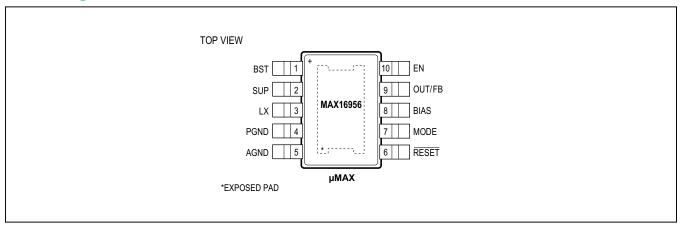
5V FIXED-OUTPUT LOAD-DUMP RESPONSE (SKIP, V_{SUP} = 13.5V TO 42V, NO LOAD)



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100ms/div

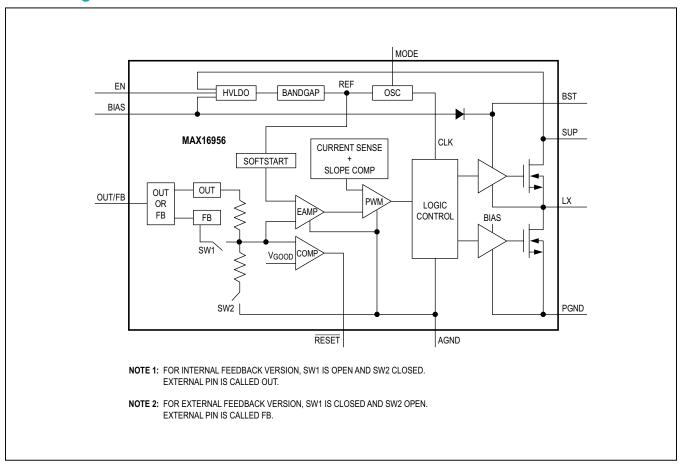
Pin Configuration



Pin Description

PIN	NAME	FUNCTION
1	BST	High-Side Driver Supply. Connect a 0.1µF bootstrap capacitor between LX and BST.
2	SUP	IC Supply Input. Connect a minimum of 4.7μF ceramic capacitor from SUP to PGND.
3	LX	Buck Switching Node. LX is high impedance when the device is off.
4	PGND	Power Ground. Connect to AGND under the device in a star configuration.
5	AGND	Analog Ground. Connect to PGND under the device in a star configuration.
6	RESET	Open-Drain Reset Output. An external pullup resistor is required.
7	MODE	Mode Switch-Control Input. Connect to ground or leave open to enable skip-mode operation under light loads. Connect to BIAS to enable forced-PWM mode. MODE has a 1MΩ internal pulldown.
8	BIAS	5V Internal Logic Supply. Connect a 1μF ceramic capacitor to AGND.
9	OUT/FB	MAX16956A/B/D/E (Fixed Output): Buck Regulator Voltage-Sense Input. Bypass OUT to PGND with a minimum 22μF X7R ceramic capacitor. MAX16956C/F (Adjustable Output): Feedback Input. Connect FB to a resistive divider between the buck output and AGND to set the output voltage.
10	EN	SUP Voltage-Compatible Enable Input. Drive EN low to disable the device. Drive EN high to enable the device.
_	EP	Exposed Pad. Connect EP to a large copper ground plane for effective power dissipation. Do not use EP as the only IC ground connection. EP must be connected to PGND.

Block Diagram



36V, 300mA, Mini Buck Converter with 1.1µA IQ

Detailed Description

The MAX16956 is a small, current-mode buck converter that features synchronous rectification and requires no external compensation network. The device operates from a 3.5V to 36V supply voltage and can deliver up to 300mA output current. Frequency is fixed at 2.1MHz, which allows for small external components, reduced output ripple, and guarantees no AM-band interference.

The device offers fixed output voltages of 5V and 3.3V. The device also offers adjustable output-voltage versions that can be set between 1V and 10V by using an external resistive divider. Voltage quality can be monitored by observing the $\overline{\text{RESET}}$ signal. The device offers both forced-PWM and skip mode, with ultra-low-quiescent current of 1.1 μ A in skip mode.

DC-DC Converter Control Architecture

The device step-down converter uses a PWM peak current-mode control scheme, with a load-line architecture. Peak current-mode control provides several advantages over voltage-mode control, including precise control of the inductor current on a cycle-by-cycle basis, simpler compensation, and inherent compensation for line voltage variation.

An internal transconductance amplifier establishes an integrated error voltage. The heart of the PWM controller is an open-loop comparator: one input is the integrated voltage-feedback signal; the other consists of the amplified current-sense signal plus slope-compensation ramp. Integrated high-side current sensing is used, which reduces component count and layout risk by eliminating the need to carefully route sensitive external signals. Error-amplifier compensation is also integrated, once again simplifying the power-supply designer's task while eliminating external components.

At each rising edge of the internal clock, the high-side MOSFET turns on until the PWM comparator trips, the maximum duty cycle is reached, or the peak current limit is reached (see the *Current Limit/Short-Circuit Protection* section). During this on-time, current ramps up through the inductor, storing energy in a magnetic field and sourcing current to the output. The current-mode feedback system regulates the peak inductor current as a function of the output-voltage error signal. During the second-half of the cycle, the high-side MOSFET turns off and the low-side MOSFET turns on. The inductor releases the stored energy as the current ramps down,

providing current to the output. The output capacitor stores charge when the inductor current exceeds the required load current and discharges when the inductor current is lower, smoothing the voltage across the load.

The device features load-line architecture to reduce the output capacitance needed, potentially saving system cost and size. The output voltage is positioned slightly positive at no load, still within the tolerance window, to take advantage of the fact that any load disturbance is a load step only. This increases the amount of margin available to the undershoot that occurs on a load step, allowing a reduction in the required output capacitance. As the load increases, a small but controlled amount of load regulation ("load-line") error occurs, so that at heavier loads the voltage is positioned slightly below nominal. This takes advantage of the fact that any load disturbance is load released, increasing the amount of margin available to the overshoot that occurs.

The device can operate in either forced-PWM or skip mode. In forced-PWM mode, the converter maintains a constant switching frequency, regardless of load, to allow for easier filtering of the switching noise. The device includes proprietary circuitry that dramatically reduces quiescent current consumption in skip mode, improving light-load efficiency. See the *Forced PWM/Skip Modes* section for further details.

System Enable (EN)

An enable control input (EN) activates the device from its low-power shutdown mode. EN is compatible with inputs from automotive battery level down to 3.5V. The high-voltage compatibility allows EN to be connected to SUP, KEY/KL30, or the inhibit pin (INH) of a CAN transceiver.

Linear Regulator Output (BIAS)

The device includes a 5V linear regulator output (BIAS) that provides power to the internal circuit blocks. Connect a $1\mu F$ ceramic capacitor from BIAS to AGND. Do not load this pin externally.

Undervoltage Lockout

When VBIAS drops below the undervoltage-lockout (UVLO) level of $V_{\rm UVLO}$ = 2.8V (typ), the device assumes that the supply voltage is too low for proper operation, so the UVLO circuitry inhibits switching. When VBIAS rises above the UVLO rising threshold, the controller enters the startup sequence and then resumes normal operation.

Startup and Soft-Start

The device features an internal soft-start timer. The output-voltage soft-start ramp time is 5.4ms (typ). If a short circuit or undervoltage is encountered after the soft-start timer has expired, the device is disabled for 13.4ms (typ) and then reattempts soft-start again. This pattern repeats until the short circuit has been removed.

RESET Output

The device features an open-drain RESET output to monitor the output voltage. The RESET output requires an external pullup resistor. RESET goes high (high impedance) after the regulator output increases above 92% of the nominal regulated voltage. RESET goes low when the regulator output drops to below 90% of the nominal regulated voltage.

Forced PWM/Skip Modes

The device features a logic-level input (MODE) to switch between forced-PWM and skip modes. Connecting MODE to BIAS enables the forced-PWM operation. Connecting MODE to ground, or leaving unconnected, enables skipmode operation with ultra-low-quiescent current of 1.1µA. In skip-mode operation, the converter's switching frequency is load dependent until the output load reaches the skip threshold. At higher load current, the switching frequency does not change and the operating mode is similar to the forced-PWM mode. Skip mode helps improve efficiency in light-load applications by allowing the converter to turn on the high-side switch only when the output voltage falls below a set threshold. As such, the converter does not switch the MOSFETs on and off as often as is the case in the forced-PWM mode. Consequently, the gate charge and switching losses are much lower in skip mode.

Current Limit/Short-Circuit Protection

The device has fault protection designed to protect itself from abnormal conditions. If the output is soft shorted (meaning the output is overloaded but over 50% of regulation), cycle-by-cycle current limit limits how high the inductor current goes for any cycle. If the output is hard shorted to ground and the output falls to less than 50% of regulation, the part goes into a mode where it switches until 15 cycles are ended by current limit, then waits for 13.4ms before trying to soft-start again. This mode of operation limits the amount of power dissipated by the device under these conditions. The device also has overtemperature protection. If the die temperature

exceeds approximately 175°C, the device stops switching until the die temperature drops by approximately 15°C and then resumes operation, including going through soft-start again.

Spread-Spectrum Option

The device has an internal spread-spectrum option to optimize EMI performance. This is factory set on the D, E, and F variants of the device. For spread-spectrum-enabled variants of the device, the operating frequency is varied $\pm 6\%$ centered on 2.1MHz. The modulation signal is a triangular wave with a period of 230µs at 2.1MHz. Therefore, f_{SW} ramps down 6% and back to 2.1MHz in 115µs and also ramps up 6% and back to 2.1MHz in 115µs. The cycle repeats.

Applications Information

Setting the Output Voltage

The device's adjustable output-voltage version (see the *Selector Guide* for more details) allows the user to set the output to any voltage between 1V and 10V. Connect a resistive divider from output (V_{OUT}) to FB to AGND to set the output voltage (Figure 1). Select R2 (FB to AGND resistor) less than or equal to $100k\Omega$. Calculate R1 (V_{OUT} to FB resistor) with the following equation:

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

where V_{FB} = 1V (see the *Electrical Characteristics*).

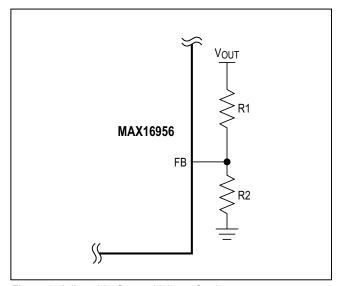


Figure 1. Adjustable Output-Voltage Setting

36V, 300mA, Mini Buck Converter with 1.1µA IQ

Inductor Selection

Three key inductor parameters must be specified for operation with the device: inductance value (L), inductor saturation current (I_{SAT}), and DC resistance (R_{DCR}). To select inductance value, the ratio of inductor peak-to-peak AC current to DC average current (LIR) must be selected first. A good compromise between size and loss is a 30% peak-to-peak ripple current to average current ratio (LIR = 0.3). The switching frequency, input voltage, output voltage, and selected LIR then determines the inductor value as follows:

$$L = \frac{V_{OUT} \times (V_{SUP} - V_{OUT})}{V_{SUP} \times f_{SW} \times I_{OUT} \times LIR}$$

where V_{SUP} , V_{OUT} , and I_{OUT} are typical values (so that efficiency is optimum for typical conditions). The switching frequency is 2.1MHz. Table 1 lists some of the inductor values for 300mA output current and several output voltages.

Input Capacitor

The input filter capacitor reduces peak currents drawn from the power source and reduces noise and voltage ripple on the input caused by the circuit's switching. The input capacitor RMS current requirement (I_{RMS}) is defined by the following equation:

$$I_{RMS} = I_{LOAD(MAX)} \frac{\sqrt{V_{OUT} \times (V_{SUP} - V_{OUT})}}{V_{SUP}}$$

I_{RMS} has a maximum value when the input voltage equals twice the output voltage ($V_{SUP} = 2V_{OUT}$), so $I_{RMS(MAX)} = I_{LOAD(MAX)}/2$.

Choose an input capacitor that exhibits less than +10°C self-heating temperature rise at the RMS input current for optimal long-term reliability.

The input voltage ripple is composed of ΔV_Q (caused by the capacitor discharge) and ΔV_{ESR} (caused by the ESR of the capacitor). Use low-ESR ceramic capacitors with high ripple current capability at the input. Assume

Table 1. Inductor Values for 300mA Output Current

V _{SUP} /V _{OUT} (V)	14V/5V	14V/3.3V
INDUCTOR (μH) I _{LOAD} = 300mA	10μH (typ) 22μH (max)	10μH (typ) 22μH (max)

the contribution from the ESR and capacitor discharge equal to 50%. Calculate the input capacitance and ESR required for a specified input voltage ripple using the following equations:

$$ESR_{IN} = \frac{\Delta V_{ESR}}{I_{OUT} + \frac{\Delta I_{L}}{2}}$$

where:

$$\Delta I_{L} = \frac{(V_{SUP} - V_{OUT}) \times V_{OUT}}{V_{SUP} \times f_{SW} \times L}$$

and:

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

where $I_{\mbox{OUT}}$ is the maximum output current and D is the duty cycle.

Output Capacitor

The output filter capacitor must have low enough ESR to meet output ripple and load transient requirements. The output capacitance must be high enough to absorb the inductor energy while transitioning from full-load to no-load conditions. When using high-capacitance, low-ESR capacitors, the filter capacitor's ESR dominates the output voltage ripple. Therefore, the size of the output capacitor depends on the maximum ESR required to meet the output voltage ripple (V_{RIPPLE(P-P)}) specifications:

$$V_{RIPPLE(P-P)} = ESR \times I_{LOAD(MAX)} \times LIR$$

The actual capacitance value required relates to the physical size needed to achieve low ESR, as well as to the chemistry of the capacitor technology. Therefore, the capacitor is usually selected by ESR and voltage rating rather than by capacitance value.

When using low-capacity filter capacitors, such as ceramic capacitors, size is usually determined by the capacity needed to prevent voltage droop and voltage rise from causing problems during load transients. Generally, once enough capacitance is added to meet the overshoot requirement, undershoot at the rising-load edge is no longer a problem.

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36V, 300mA, Mini Buck Converter with 1.1µA IQ

PCB Layout Guidelines

Careful PCB layout is critical to achieve low-switching power losses and clean, stable operation. Use a multilayer board whenever possible for better noise immunity and power dissipation. Follow these guidelines for good PCB layout:

- The input capacitor (4.7μF, see Figures 3 and 4) should be placed immediately next to the SUP pin of the device. Since the device operates at 2.1MHz switching frequency, this placement is critical for effective decoupling of high-frequency noise from the SUP pin.
- 2) Solder the exposed pad to a large copper plane area under the device. To effectively use this copper area as heat exchanger between the PCB and ambient, expose the copper area on the top and bottom sides. Add a few small vias or one large via on the copper pad for

- efficient heat transfer. Connect the exposed pad to PGND, ideally at the return terminal of the output capacitor.
- Isolate the power components and high-current path from the sensitive analog circuitry. Doing so is essential to prevent any noise coupling into the analog signals.
- 4) Keep the high-current paths short, especially at the ground terminals. This practice is essential for stable, iitter-free operation.
- 5) Connect PGND and AGND together at the return terminal of the output capacitor. Do not connect them anywhere else.
- 6) Keep the power traces and load connections short. This practice is essential for high efficiency.
- 7) Place the BIAS capacitor ground next to the AGND pin and connect with a short and wide trace.

Typical Application Circuits

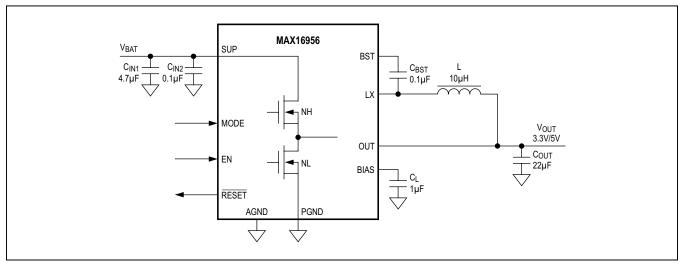


Figure 2. MAX16956AUBA/V+ (5.0V Fixed) and MAX16956AUBB/V+ (3.3V Fixed), 10-Pin μMAX

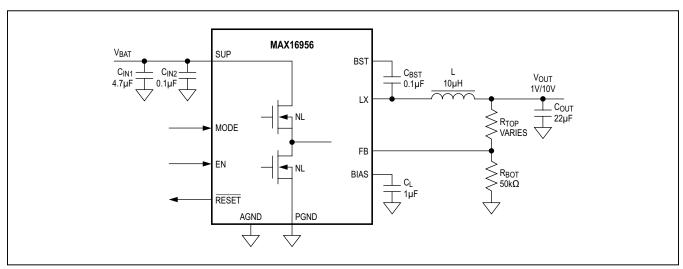


Figure 3. MAX16956AUBC/V+, Variable Output Voltage, 10-Pin μMAX

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX16956AUB_+	-40°C to +125°C	10 μMAX-EP*
MAX16956AUB_/V+	-40°C to +125°C	10 μMAX-EP*

Note: Insert the desired suffix letter (from the Selector Guide) into the blank to indicate the output voltage and spread-spectrum option. /V denotes an automotive qualified part.

Selector Guide

PART	v_{OUT}	RESET TIME (μs)	SPREAD SPECTRUM	PIN-PACKAGE
MAX16956AUBA+	Fixed 5V	10	Off	10 μMAX-EP
MAX16956AUBA/V+	Fixed 5V	10	Off	10 μMAX-EP
MAX16956AUBB+	Fixed 3.3V	10	Off	10 μMAX-EP
MAX16956AUBB/V+	Fixed 3.3V	10	Off	10 μMAX-EP
MAX16956AUBC+	Adjustable	10	Off	10 μMAX-EP
MAX16956AUBC/V+	Adjustable	10	Off	10 μMAX-EP
MAX16956AUBD/V+	Fixed 5V	10	On	10 μMAX-EP
MAX16956AUBE/V+	Fixed 3.3V	10	On	10 μMAX-EP
MAX16956AUBF/V+	Adjustable	10	On	10 μMAX-EP

Package Information

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.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.
10 μMAX	U10E+3	<u>21-0109</u>	<u>90-0148</u>

⁺Denotes a lead(Pb)-free/RoHS-compliant package.

^{*}EP = Exposed pad.

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Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	6/13	Initial release	_
1	2/14	Changed PGND to AGND for pin 8 in the <i>Pin Description</i> section, removed C1 from Figure 1, and added nonautomotive OPNs for MAX16956A, MAX16956B, and MAX16956C versions	8, 11, 15
2	3/14	Removed future product references	15
3	2/15	Updated the Benefits and Features section	1
4	8/15	Updated Block Diagram	9

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

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