600kHz/1.25MHz Step-Up PWM DC-DC Switching Converter

Preliminary Technical Data

ADP1612

FEATURES

Fully integrated 1.5 A , 0.15 Ω power switch
Pin-selectable 600 kHz or 1.25 MHz PWM frequency
1.8 V minimum input voltage
Adjustable output voltage up to 20 V
Adjustable soft start
Input undervoltage lockout
Thermal shutdown
MSOP 8-lead package

APPLICATIONS

TFT LCD bias supplies

Portable applications

Industrial/instrumentation equipment

GENERAL DESCRIPTION

The ADP1612 is a step-up dc-to-dc switching converter with an integrated 1.5 A, 0.15 Ω power switch capable of providing an output voltage as high as 20 V. With a package height of less than 1.1 mm, the ADP1612 is optimal for space-constrained applications such as portable devices or thin film transistor (TFT) liquid crystal displays (LCDs).

The ADP1612 operates in pulse-width modulation (PWM) current mode with up to 90% efficiency. Adjustable soft start prevents inrush currents at startup. The pin-selectable switching frequency and PWM current-mode architecture allow for excellent transient response, easy noise filtering, and the use of small, cost-saving external inductors and capacitors.

The ADP1612 is offered in the lead-free 8-lead MSOP and operates over the temperature range of −40 °C to +85 °C.

FUNCTIONAL BLOCK DIAGRAM

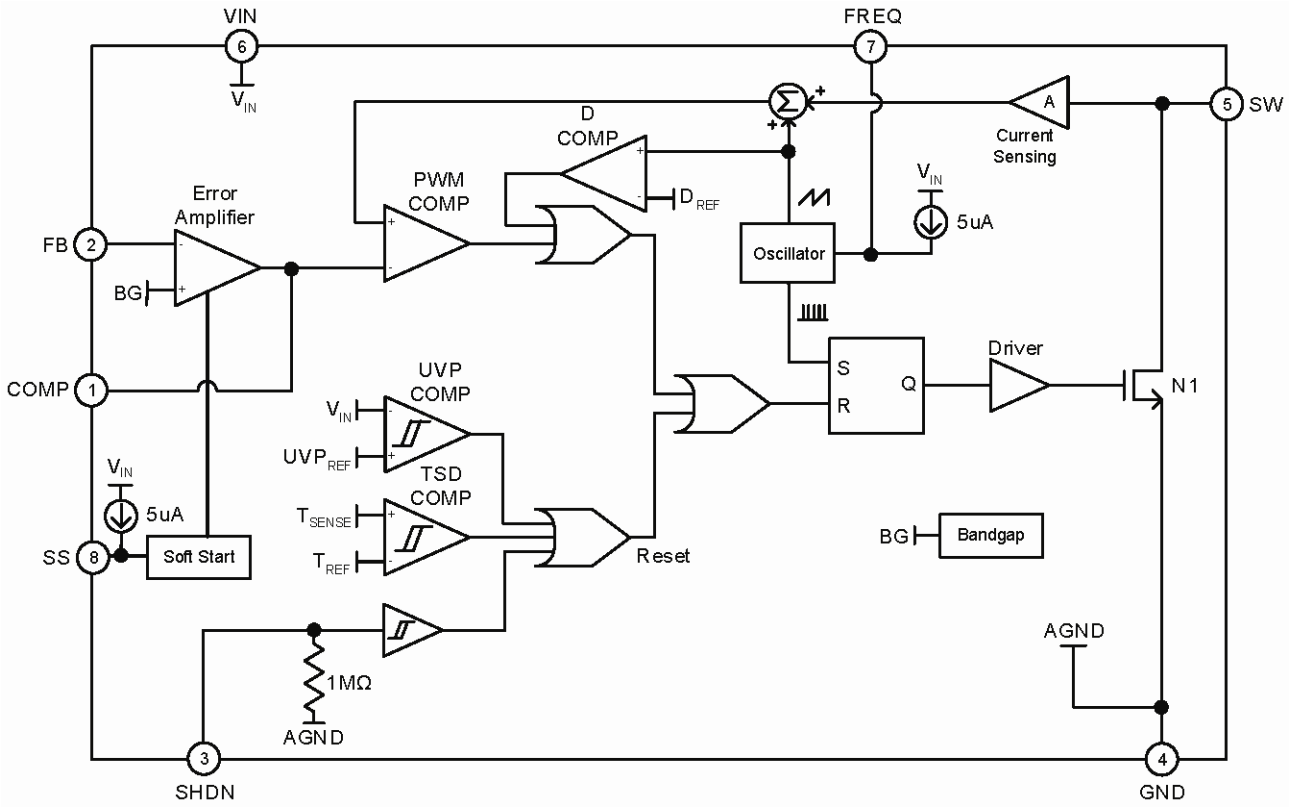

Figure 1.Functional Block Diagram

Rev. PrA

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REVISION HISTORY

6/08—Rev. PrA

SPECIFICATIONS

Specifications with standard typeface are for T_J = 25 °C, and those in **bold face type** apply over the full operating temperature range (T_J = -40 °C to + 125 °C). Unless otherwise specified, V_{IN} = 3.6 V. All limits at temperature extremes are guaranteed by correlation and characterization using standard statistical quality control (SQC), unless otherwise noted.

Table 1.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
SUPPLY						
Input Voltage	V_{IN}		**1.8**		**6**	V
Quiescent Current						
Non-switching State	I_Q	V_{FB} = 1.5 V, FREQ = V_{IN}		900	TBD	µA
Non-switching State	I_Q	V_{FB} = 1.5 V, FREQ = GND		900	TBD	
Shutdown	I_{QSHDN}	V_{SHDN} = 0 V		0.01	2	µA
Switching State[1]	I_{QSW}	f_{SW} = 600 kHz, no load		2	TBD	mA
Switching State[2]	I_{QSW}	f_{SW} = 1.23 MHz, no load		4	TBD	mA
OUTPUT						
Output Voltage	V_{OUT}		V_{IN}		**20**	V
Load Regulation		I_{LOAD} = 10 mA to 150 mA, V_{OUT} = 8 V		TBD		mV/mA
Overall Regulation		Line, load, temperature		TBD		%
REFERENCE						
Feedback Voltage	V_{FB}		TBD	TBD	TBD	V
Line Regulation		V_{IN} = 2.5 V to 5.5 V	TBD		TBD	%/V
ERROR AMPLIFIER						
Transconductance	G_{MEA}	ΔI = 5 µA		160		µA/V
Voltage Gain	A_V			60		dB
FB Input Bias Current		V_{FB} = TBD V		10	TBD	nA
SWITCH						
SW On Resistance	R_{DSON}	I_{SW} = 1.0 A		150	TBD	mΩ
SW Leakage Current		V_{SW} = 20 V		0.01	10	µA
Peak Current Limit[3]	I_{CL}	V_{OUT} = 8 V	TBD	1.5	TBD	A
OSCILLATOR						
Oscillator Frequency	f_{SW}	FREQ = GND	TBD	600	TBD	kHz
		FREQ = V_{IN}	TBD	1.25	TBD	MHz
Maximum Duty Cycle	D_{MAX}	COMP = open, V_{FB} = 1 V, FREQ = V_{IN}	TBD	90	TBD	%
FREQ Pin Current	I_{FREQ}	FREQ = GND	TBD	5	TBD	uA
SHUTDOWN						
Shutdown Input Voltage Low	V_{IL}	Non-switching state, V_{IN} = 1.8 V to 6 V		0.95	0.3	V
Shutdown Input Voltage High	V_{IH}	Switching state, V_{IN} = 1.8 V to 6 V	1.6	0.95		V
Shutdown Input Bias Current	I_{SDHN}	V_{SHDN} = 1.6 V		1	TBD	µA
SOFT START						
SS Charging Current		V_{SS} = 0 V	TBD	5	TBD	µA
UNDERVOLTAGE LOCKOUT[4]						
UVLO Threshold Rising		V_{IN} rising		1.7	**1.8**	V
UVLO Threshold Falling		V_{IN} falling	TBD	1.65		V

[1] This parameter specifies the average current while switching internally and with SW (Pin 5) floating.
[2] This parameter specifies the average current while switching internally and with SW (Pin 5) floating.
[3] Current limit is a function of duty cycle. See *Typical Performance Characteristics* section for typical values over operating ranges.
[4] UVLO

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
V_{IN}, SHDN, FB to GND	−0.3 V to 6.5 V
FREQ to GND	-0.3 V to V_{IN}+ 0.3 V
COMP to GND	1.0 V to 1.6 V
SS to GND	-0.3 V to 1.3 V
SW to GND	21 V
RMS SW Pin Current	1.2 A
Operating Ambient Temperature Range	−40 °C to + 85 °C
Operating Junction Temperature Range	−40 °C to + 125 °C
Storage Temperature Range	−65 °C to + 150 °C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 3. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
8 Lead MSOP			
2-Layer Board	TBD	TBD	°C/W
4-Layer Board	TBD	TBD	°C/W
Maximum Power Dissipation	TBD	TBD	mW

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

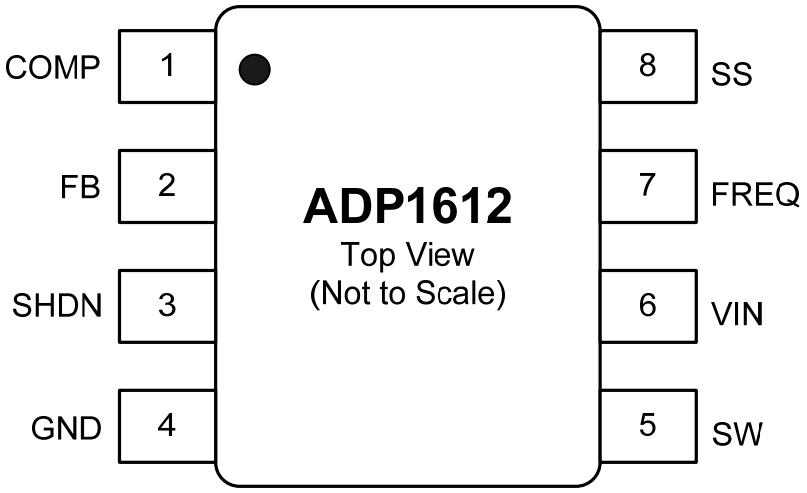


Figure 2.Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	COMP	Compensation input. Connect a series resistor-capacitor network from COMP to GND to compensate the regulator.
2	FB	Output voltage feedback input. Connect a resistive voltage divider from the output voltage to FB to set the regulator output voltage.
3	SHDN	Shutdown input. Drive SHDN low to shut down the regulator; drive SHDN high to turn it on.
4	GND	Ground.
5	SW	Switching output. Connect the power inductor from the input voltage to SW and connect the external rectifier from SW to the output voltage to complete the step-up converter.
6	VIN	Main power supply input. VIN powers the ADP1612 internal circuitry. Connect VIN to the input source voltage. Bypass VIN to GND with a 10 µF or greater capacitor as close to the ADP1612 as possible.
7	FREQ	Frequency Setting Input. FREQ controls the switching frequency. Connect FREQ to GND to program the oscillator to 600 kHz, or connect FREQ to VIN to program it to 1.25 MHz. If FREQ is left floating, the part will default to 600kHz.
8	SS	Soft start timing capacitor input. Connect a capacitor from SS to GND brings up the output slowly at power-up and reduce in-rush current.

TYPICAL PERFORMANCE CHARACTERISTICS

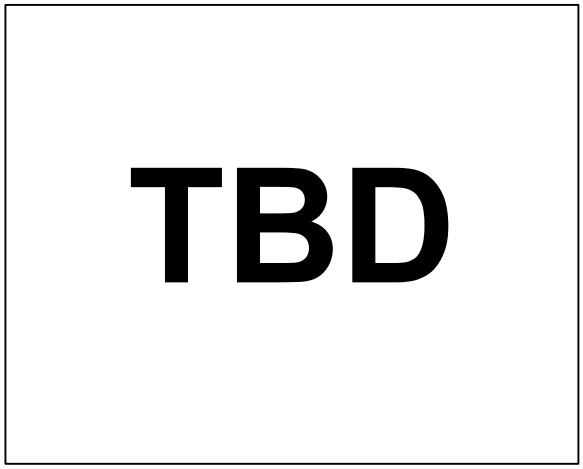


Figure 3

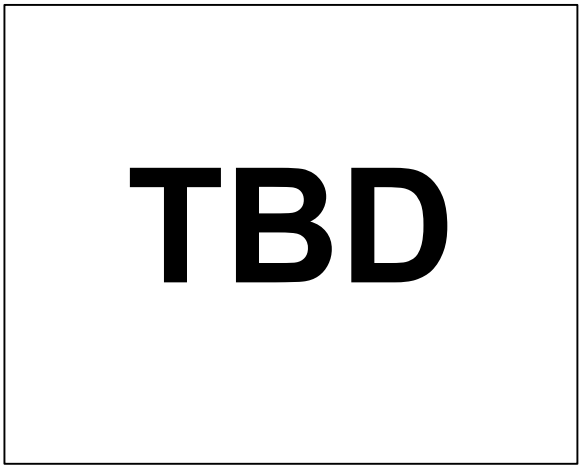
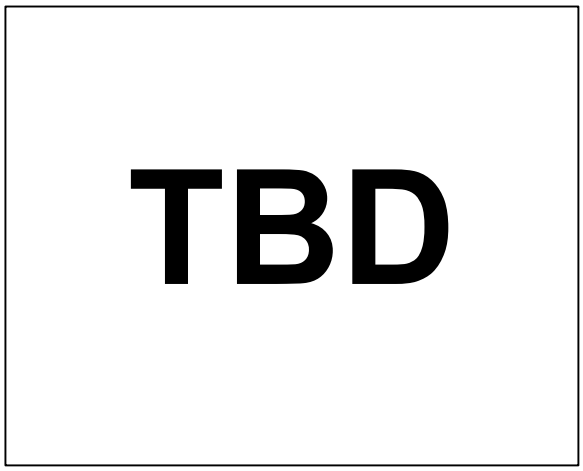


Figure 6



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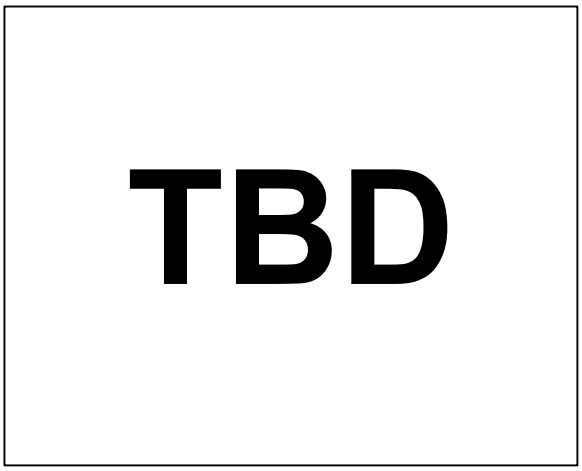

Figure 7

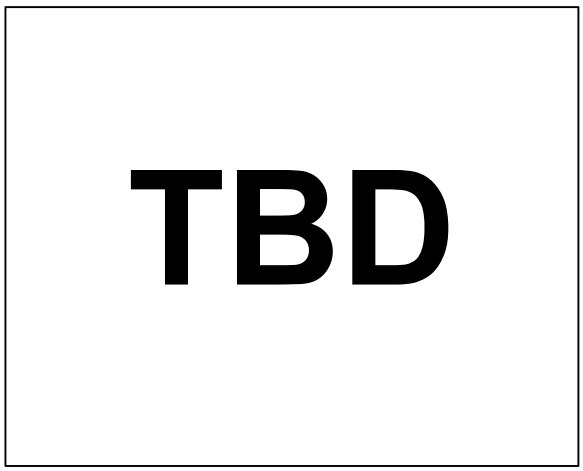

Figure 5

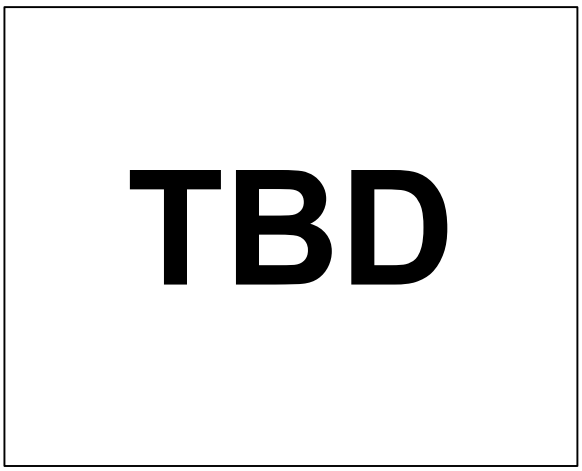

Figure 7

THEORY OF OPERATION

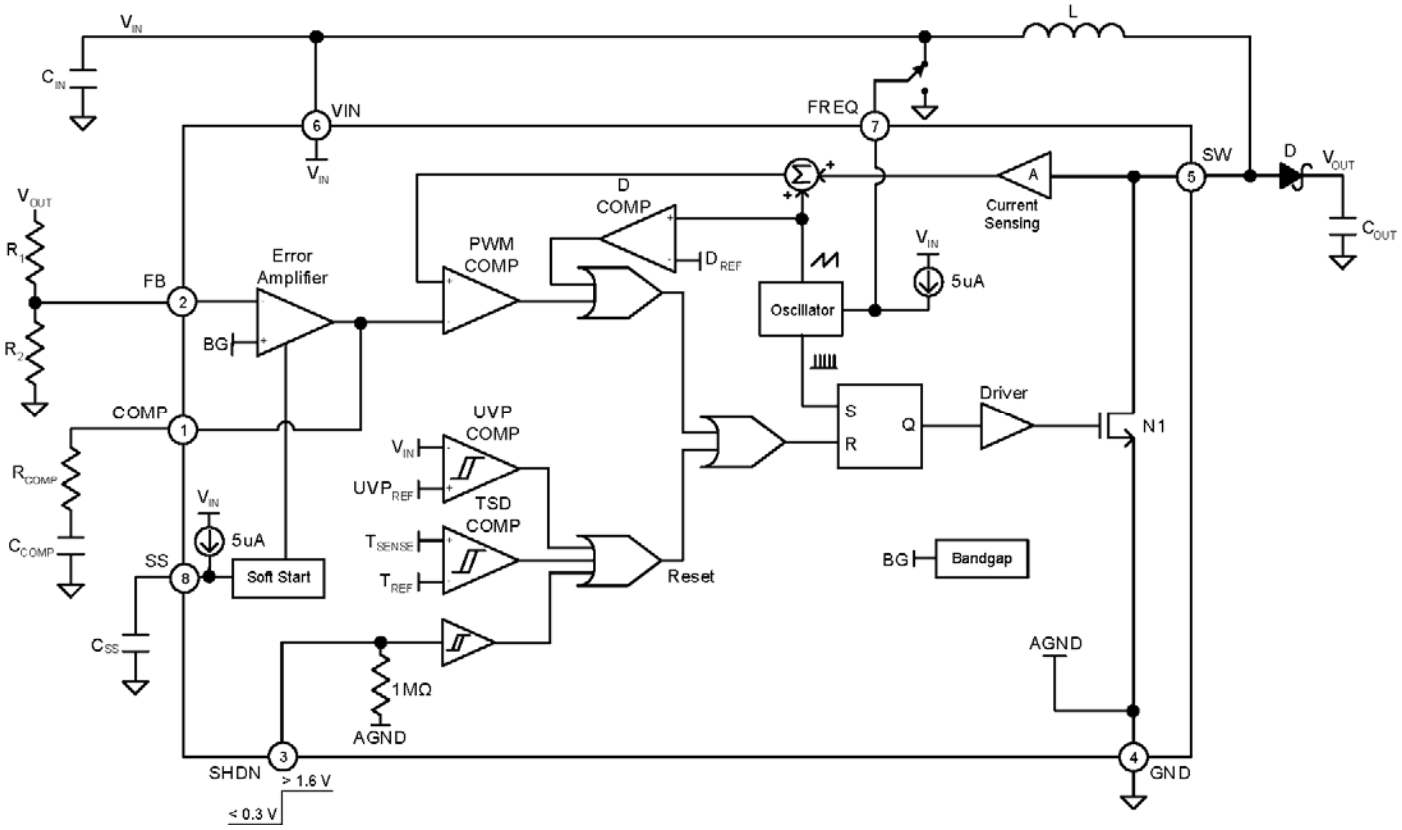

Figure 8. Block Diagram with Application Circuit

The ADP1612 current-mode step-up switching converter converts a 1.8 V to 6 V input voltage up to an output voltage as high as 20 V. The 1.5 A internal switch allows a high output current, and the high 600 kHz/1.25 MHz switching frequency allows tiny external components. The switch current is monitored on a pulse-by-pulse basis to limit it to 1.5 A, typical.

CURRENT-MODE PWM OPERATION

The ADP1612 utilizes a current mode PWM control scheme to regulate the output voltage over all load conditions. The output voltage is monitored at FB through a resistive voltage divider. The voltage at FB is compared to the internal TBD V reference by the internal transconductance error amplifier to create an error voltage at COMP. The switch current is internally measured and added to the stabilizing ramp, and the resulting sum is compared to the error voltage at COMP to control the PWM modulator. This current-mode regulation system allows fast transient response, while maintaining a stable output voltage. By selecting the proper resistor-capacitor network from COMP to GND, the regulator response is optimized for a wide range of input voltages, output voltages, and load conditions.

FREQUENCY SELECTION

The ADP1612's frequency is user-selectable to operate at either 600 kHz to optimize the regulator for high efficiency or to 1.25 MHz for small external components. Connect FREQ to Vin for 1.25 MHz operation, or connect FREQ to GND for 600 kHz operation. If FREQ is left floating, the part will default to 600 kHz.

SOFT START

To prevent input inrush current at startup, connect a capacitor from SS to GND to set the soft start period. When the ADP1612 is in shutdown (SHDN is at GND) or the input voltage is below the 1.65V undervoltage lockout voltage, SS is internally shorted to GND to discharge the soft start capacitor. Once the ADP1612 is turned on, SS sources 5µA, typical, to the soft start capacitor at startup. As the soft start capacitor charges, it limits the voltage at COMP. Because of the current-mode regulator, the voltage at COMP is proportional to the switch peak current, and, therefore, the input current. By slowly charging the soft start capacitor, the input current ramps slowly to prevent it from overshooting excessively at startup.

THERMAL SHUTDOWN

The ADP1612 includes thermal shutdown protection. If the die temperature exceeds 150 ºC, typical, the thermal shutdown will turn off the NMOS power device, significantly reducing power dissipation in the device, and preventing output voltage regulation. The NMOS power device will remain off until the die temperature reduces to 120 ºC, typical. The soft-start capacitor will be discharged during thermal shutdown to ensure low output voltage overshoot and inrush currents when regulation resumes.

ON/OFF CONTROL

The SHDN input turns the ADP1612 regulator on or off. Drive SHDN low to turn off the regulator and reduce the input current to 0.1uA, typical. Drive SHDN high to turn on the regulator.

When the step-up dc–dc switching converter is turned off, there is a dc path from the input to the output through the inductor and output rectifier. This causes the output voltage to remain slightly below the input voltage by the forward voltage of the rectifier, preventing the output voltage from dropping to zero when the regulator is shut down. Figure 11 in the *Application Circuit* section shows the application circuit to disconnect the output voltage from the input voltage at shutdown.

APPLICATIONS INFORMATION

SETTING THE OUTPUT VOLTAGE

The ADP1612 features an adjustable output voltage range of V_{IN} to 20 V. The output voltage is set by the resistor voltage divider (R1 and R2, Figure 8.) from the output voltage (V_{OUT}) to the TBD V feedback input at FB. Use the following formula to determine the output voltage:

$$V_{OUT} = TBD \times (1 + R1/R2) \quad (1)$$

Use an R2 resistance of 10 kΩ or less to prevent output voltage errors due to the 0.1uA FB input bias current. Choose R1 based on the following formula:

$$R1 = R2 \times \left(\frac{V_{OUT} - TBD}{TBD} \right) \quad (2)$$

INDUCTOR SELECTION

The inductor is an essential part of the step-up switching converter. It stores energy during the on-time, and transfers that energy to the output through the output rectifier during the off-time. Use inductance in the range of 4.7 µH to 22 µH. In general, lower inductance values have higher saturation current and lower series resistance for a given physical size. However, lower inductance results in higher peak current that can lead to reduced efficiency and greater input and/or output ripple and noise. A peak-to-peak inductor ripple current close to 30% of the maximum dc input current typically yields an optimal compromise.

For determining the inductor ripple current in continuous operation, the input (V_{IN}) and output (V_{OUT}) voltages determine the switch duty cycle (D) by the following equation:

$$D = \frac{V_{OUT} - V_{IN}}{V_{OUT}} \quad (3)$$

Using the duty cycle and switching frequency, f_{SW}, determine the on-time by the following equation:

$$t_{ON} = \frac{D}{f_{SW}} \quad (4)$$

The inductor ripple current (ΔI_L) in steady state is

$$\Delta I_L = \frac{V_{IN} \times t_{ON}}{L} \quad (5)$$

Solving for the inductance value, L,

$$L = \frac{V_{IN} \times t_{ON}}{\Delta I_L} \quad (6)$$

Make sure that the peak inductor current (the maximum input current plus half the inductor ripple current) is below the rated saturation current of the inductor. Likewise, make sure that the maximum rated rms current of the inductor is greater than the maximum dc input current to the regulator.

For duty cycles greater than 50%, which occur with input voltages greater than one-half the output voltage, slope compensation is required to maintain stability of the current-mode regulator. For stable current-mode operation, ensure that the selected inductance is equal to or greater than L_{MIN}:

$$L > L_{MIN} = \frac{R_{DSON}(V_{OUT} - 2xV_{IN})}{0.55\,\text{V} \times f_{SW}} \quad (7)$$

$$D > 0.5$$

Table 5. Inductor Manufacturers

Vendor	Part	L (µH)	Max DC Current	Max DCR (mΩ)	Height (mm)
Sumida 847-956-0666 www.sumida.com	CMD4D11-4R7MC	4.7	0.75	216	1.2
	CDRH4D28-100	10	1.00	128	3.0
	CDRH5D18-220	22	0.80	290	2.0
	CR43-4R7	4.7	1.15	109	3.5
	CR43-100	10	1.04	182	3.5
Coilcraft 847-639-6400 www.coilcraft.com	DS1608-472	4.7	1.40	60	2.9
	DS1608-103	10	1.00	75	2.9
Toko 847-297-0070 www.tokoam.com	D52LC-4R7M	4.7	1.14	87	2.0
	D52LC-100M	10	0.76	150	2.0

CHOOSING THE INPUT AND OUTPUT CAPACITORS

The ADP1612 requires input and output bypass capacitors to supply transient currents while maintaining constant input and output voltage. Use a low ESR (equivalent series resistance), 10 µF or greater input capacitor to prevent noise at the ADP1612 input. Place the capacitor between V_{IN} and GND as close to the ADP1612 as possible. Ceramic capacitors are preferred because of their low ESR characteristics. Alternatively, use a high value, medium ESR capacitor in parallel with a 0.1 µF low ESR capacitor as close to the ADP1612 as possible.

The output capacitor maintains the output voltage and supplies current to the load while the ADP1612 switch is on. The value and characteristics of the output capacitor greatly affect the output voltage ripple and stability of the regulator. Use a low ESR output capacitor; ceramic dielectric capacitors are preferred.

For very low ESR capacitors such as ceramic capacitors, the ripple current due to the capacitance is calculated as follows. In continuous mode, because the capacitor discharges during the on-time, t_{ON}, the charge removed from the capacitor, Q_C, is the load current multiplied by the on-time. Therefore, the output voltage ripple (ΔV_{OUT}) is

$$\Delta V_{OUT} = \frac{Q_C}{C_{OUT}} = \frac{I_L \times t_{ON}}{C_{OUT}} \quad (8)$$

where:

C_{OUT} is the output capacitance,
I_L is the average inductor current,

$$t_{ON} = \frac{D}{f_{SW}} \quad (9)$$

and

$$D = \frac{V_{OUT} - V_{IN}}{V_{OUT}} \quad (10)$$

Choose the output capacitor based on the following equation:

$$C_{OUT} \geq \frac{I_L \times (V_{OUT} - V_{IN})}{f_{SW} \times V_{OUT} \times \Delta V_{OUT}} \quad (11)$$

Table 6. Capacitor Manufacturers

Vendor	Phone No.	Web Address
AVX	408-573-4150	www.avxcorp.com
Murata	714-852-2001	www.murata.com
Sanyo	408-749-9714	www.sanyovideo.com
Taiyo–Yuden	408-573-4150	www.t-yuden.com

DIODE SELECTION

The output rectifier conducts the inductor current to the output capacitor and load while the switch is off. For high efficiency, minimize the forward voltage drop of the diode. For this reason, Schottky rectifiers are recommended. However, for high voltage, high temperature applications, where the Schottky rectifier reverse leakage current becomes significant and can degrade efficiency, use an ultrafast junction diode.

Make sure that the diode is rated to handle the average output load current. Many diode manufacturers derate the current capability of the diode as a function of the duty cycle. Verify that the output diode is rated to handle the average output load current with the minimum duty cycle. The minimum duty cycle of the ADP1612 is

$$D_{MIN} = \frac{V_{OUT} - V_{IN(MAX)}}{V_{OUT}} \quad (12)$$

where $V_{IN(MAX)}$ is the maximum input voltage.

Table 7. Schottky Diode Manufacturers

Vendor	Phone No.	Web Address
Motorola	602-244-3576	www.mot.com
Diodes, Inc.	805-446-4800	www.diodes.com
Sanyo	310-322-3331	www.irf.com

LOOP COMPENSATION

The ADP1612 uses external components to compensate the regulator loop, allowing optimization of the loop dynamics for a given application.

The step-up converter produces an undesirable right-half plane zero in the regulation feedback loop. This requires compensating the regulator such that the crossover frequency occurs well below the frequency of the right-half plane zero. The right-half plane zero is determined by the following equation:

$$F_Z(RHP) = \left(\frac{V_{IN}}{V_{OUT}}\right)^2 \times \frac{R_{LOAD}}{2\pi \times L} \quad (13)$$

where:

$F_Z(RHP)$ is the right-half plane zero.

R_{LOAD} is the equivalent load resistance or the output voltage divided by the load current.

To stabilize the regulator, make sure that the regulator crossover frequency is less than or equal to one-fifth of the right-half plane zero and less than or equal to one-fifteenth of the switching frequency.

The regulator loop gain is

$$A_{VL} = \frac{V_{FB}}{V_{OUT}} \times \frac{V_{IN}}{V_{OUT}} \times G_{MEA} \times \left|Z_{COMP}\right| \times G_{CS} \times \left|Z_{OUT}\right| \quad (14)$$

where:

A_{VL} is the loop gain.

V_{FB} is the feedback regulation voltage, TBD V.

V_{OUT} is the regulated output voltage.

V_{IN} is the input voltage.

G_{MEA} is the error amplifier transconductance gain.

Z_{COMP} is the impedance of the series RC network from COMP to GND.

G_{CS} is the current sense transconductance gain (the inductor current divided by the voltage at COMP), which is internally set by the ADP1612.

Z_{OUT} is the impedance of the load and output capacitor.

To determine the crossover frequency, it is important to note that, at that frequency, the compensation impedance (Z_{COMP}) is dominated by the resistor, and the output impedance (Z_{OUT}) is dominated by the impedance of the output capacitor. So, when solving for the crossover frequency, the equation (by definition of the crossover frequency) is simplified to

$$|A_{VL}| = \frac{V_{FB}}{V_{OUT}} \times \frac{V_{IN}}{V_{OUT}} \times G_{MEA} \times R_{COMP} \times G_{CS} \times \frac{1}{2\pi \times f_C \times C_{OUT}} = 1 \quad (15)$$

where:

f_C is the crossover frequency.

R_{COMP} is the compensation resistor.

Solving for R_{COMP},

$$R_{COMP} = \frac{2\pi \times f_C \times C_{OUT} \times V_{OUT} \times V_{OUT}}{V_{FB} \times V_{IN} \times G_{MEA} \times G_{CS}} \quad (16)$$

For V_{FB} = TBD, G_{MEA} = 160 µS, and G_{CS} = TBD S,

$$R_{COMP} = \frac{TBD \times f_C \times C_{OUT} \times V_{OUT} \times V_{OUT}}{V_{IN}} \quad (17)$$

Once the compensation resistor is known, set the zero formed by the compensation capacitor and resistor to one-fourth of the crossover frequency, or

$$C_{COMP} = \frac{2}{\pi \times f_C \times R_{COMP}} \quad (18)$$

where C_{COMP} is the compensation capacitor.

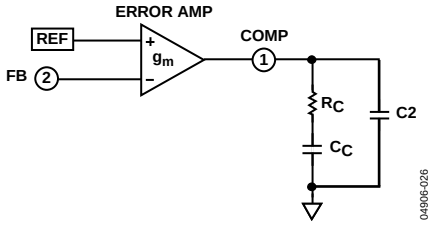

Figure 9. Compensation Components

The capacitor, C2, is chosen to cancel the zero introduced by output capacitance ESR.

Solving for C2,

$$C2 = \frac{ESR \times C_{OUT}}{R_{COMP}} \quad (19)$$

For low ESR output capacitance such as with a ceramic capacitor, C2 is optional. For optimal transient performance, the R_{COMP} and C_{COMP} might need to be adjusted by observing the load transient response of the ADP1612. For most applications, the compensation resistor should be in the range of 10 kΩ to 400 kΩ, and the compensation capacitor should be in the range of 100 pF to 2 nF.

SOFT START CAPACITOR

The voltage at SS ramps up slowly by charging the soft start capacitor (C_{SS}) with an internal 5 µA current source.

The soft start capacitor limits the rate of voltage rise on the COMP pin, which in turn limits the peak switch current at startup.

A 47 nF soft start capacitor results in negligible input current overshoot at startup, and so is suitable for most applications. However, if an unusually large output capacitor is used, a longer soft start period is required to prevent input inrush current.

Conversely, if fast startup is a requirement, the soft start capacitor can be reduced or even removed, allowing the ADP1612 to start quickly, but allowing greater peak switch current.

TYPICAL APPLICATION CIRCUITS

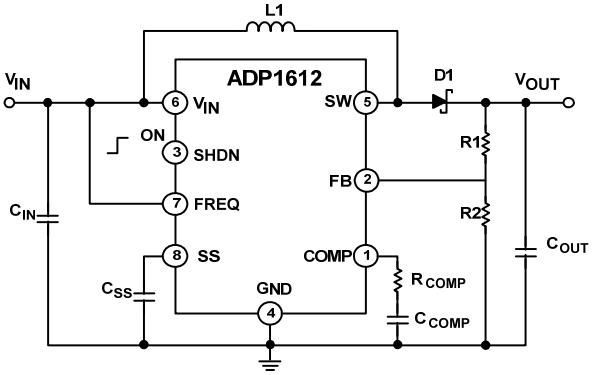

Figure 10. Step Up Regulator

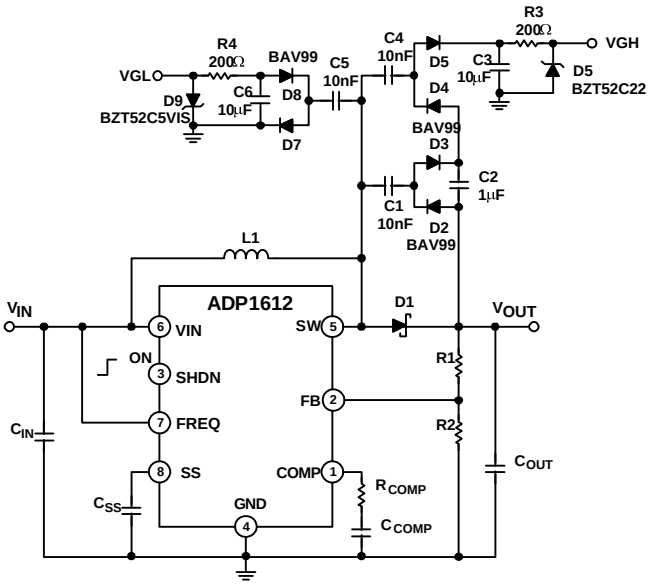

Figure 12. TFT LCD Bias Supply

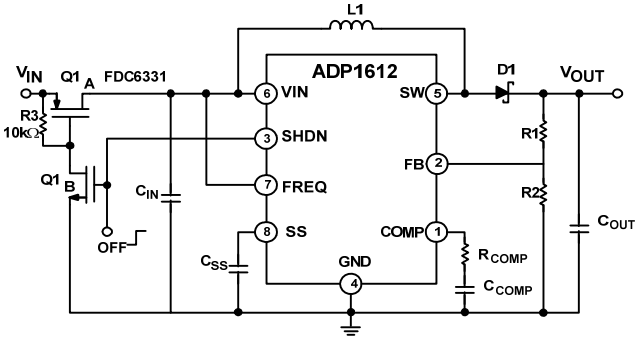

Figure 11. Step-Up Regulator with True Shutdown

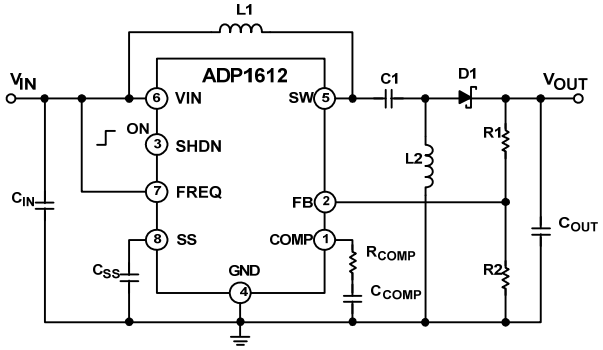

Figure 13. SEPIC Converter

LAYOUT GUIDELINES

For high efficiency, good regulation, and stability, a well-designed printed circuit board layout is required.

Follow these guidelines when designing printed circuit boards (see Figure 8):

- Keep the low ESR input capacitor, C_{IN}, close to V_{IN} and GND.
- Keep the high current path from C_{IN} through the inductor, L1, to SW and PGND as short as possible.
- Keep the high current path from C_{IN} through L1, the rectifier, D1, and the output capacitor, C_{OUT}, as short as possible.
- Keep high current traces as short and as wide as possible.
- Place the feedback resistors as close to FB as possible to prevent noise pickup. Connect the ground of the feedback network directly to an AGND plane that makes a Kelvin connection to the GND pin.
- Place the compensation components as close as possible to COMP. Connect the ground of the compensation network directly to an AGND plane that makes a Kelvin connection to the GND pin.
- Connect the SS capacitor as close to the device as possible. Connect the ground of the SS capacitor to an AGND plane that makes a Kelvin connection to the GND pin.
- Avoid routing high impedance traces near any node connected to SW or near the inductor to prevent radiated noise injection.

OUTLINE DIMENSIONS

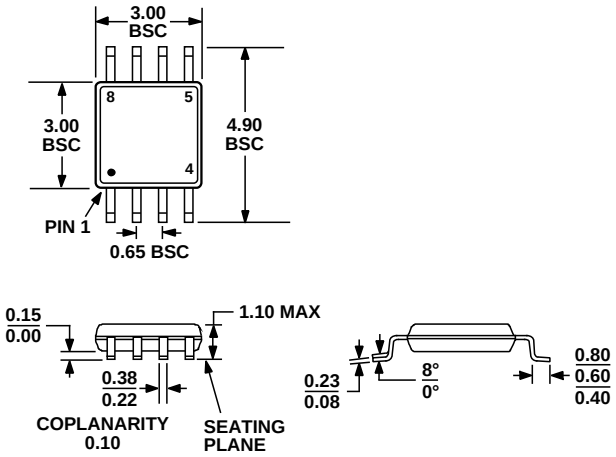

Figure 14. 8-Lead Mini Small Outline Package [MSOP]
(RM-8)
Dimensions shown in millimeters

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option	Branding
ADP1612ARMZ-R7[1]	–40°C to +85°C	8-Lead Mini Small Outline Package [MSOP]	RM-8	P11

[1] Z = Pb-free part.

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