NB648

High Effeciency 8A, 25V, 580kHz Synchronous Step-down Converter

The Future of Analog IC Technology

DESCRIPTION

The NB648 is a high frequency synchronous rectified step-down switch mode converter with built in internal power MOSFETs. It offers a very compact solution to achieve 8A continuous output current over a wide input supply range with excellent load and line regulation. The NB648 operates at high efficiency over a wide output current load range.

Current mode operation provides fast transient response and eases loop stabilization.

Full protection features include OCP and thermal shut down.

The NB648 requires a minimum number of readily available standard external components and is available in a space saving 5mx6mm 30-pin QFN package.

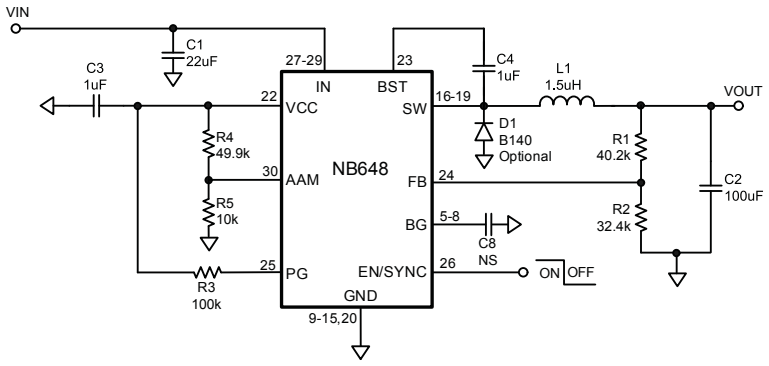
FEATURES

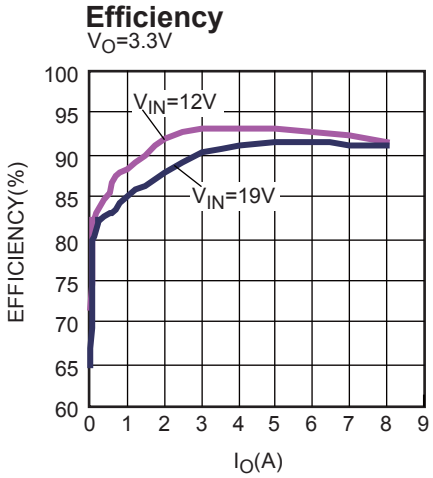
- Wide 4.5V to 25V Operating Input Range
- 8A Output Current
- Low R_{DS}(ON) Internal Power MOSFETs
- Proprietary Switching Loss Reduction Technique
- Fixed 580kHz Switching Frequency
- Sync from 300kHz to 2MHz External Clock
- Internal Compensation
- OCP Protection and Thermal Shutdown
- Output Adjustable from 0.8V to 15V
- Available in 30-pin QFN 5x6mm Package

APPLICATIONS

- Notebook Systems and I/O Power
- Networking Systems
- Digital Set Top Boxes
- Personal Video Recorders
- Flat Panel Television and Monitors
- Distributed Power Systems

TYPICAL APPLICATION



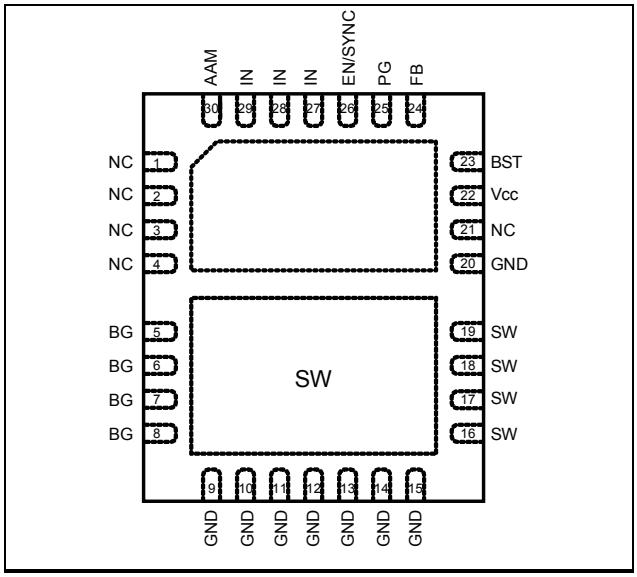


ORDERING INFORMATION

Part Number*	Package	Top Marking	Free Air Temperature (T_A)
NB648EQJ	(5x6mm) QFN30	N648EQJ	–20°C to +85°C

For Tape & Reel, add suffix –Z (eg. NB648EQJ–Z).
For RoHS compliant packaging, add suffix –LF (eg.NB648EQJ–LF–Z)

PACKAGE REFERENCE



ABSOLUTE MAXIMUM RATINGS (1)

Supply Voltage V_{IN} 28V
V_{SW} ..... –0.3V to V_{IN} + 0.3V
V_{BS} ..... V_{SW} + 6V
All Other Pins..... –0.3V to +6V
Continuous Power Dissipation (T_A = +25°C) (2)
..... 3.79W
Junction Temperature..... 150°C
Lead Temperature ..... 260°C
Storage Temperature..... –65°C to +150°C

Recommended Operating Conditions (3)

Supply Voltage V_{IN} ..... 4.5V to 25V
Output Voltage V_{OUT}..... 0.8V to 15V
Operating Junct. Temp (T_J)..... –20°C to +125°C

Thermal Resistance (4) θ_{JA} θ_{JC}

5x6mm QFN30	33	7	°C/W

Notes:

1) Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature T_J (MAX), the junction-to-ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX)-T_A)/θ_{JA}. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
3) The device is not guaranteed to function outside of its operating conditions.
4) Measured on JESD51-7, 4-layer PCB.

ELECTRICAL CHARACTERISTICS

V_{IN} = 12V, T_A = +25°C, unless otherwise noted.

Parameters	Symbol	Condition	Min	Typ	Max	Units
Supply Current (Shutdown)	I_{IN}	V_{EN} = 0V		0	1	μA
Supply Current (Quiescent)	I_{IN}	V_{EN} = 2V, V_{FB} = 1V		0.7	1	mA
HS Switch On Resistance (5)	HS_{RDS-ON}			50		mΩ
LS Switch On Resistance (5)	LS_{RDS-ON}			8		mΩ
Switch Leakage	SW_{LKG}	V_{EN} = 0V, V_{SW} = 0V or 12V		10	200	nA
Current Limit (5)	I_{LIMIT}		9.5			A
Oscillator Frequency	F_{SW}	V_{FB} = 0.75V	450	580	730	kHz
Maximum Duty Cycle	D_{MAX}	V_{FB} = 700mV	85	90		%
Sync Frequency Range	F_{SYNC}		0.3		2	MHz
Feedback Voltage	V_{FB}		788	808	828	mV
Feedback Current	I_{FB}	V_{FB} = 800mV		10	100	nA
EN/SYNC Input Low Voltage	VIL_{EN}				0.4	V
EN/SYNC Input High Voltage	VIH_{EN}		2			V
EN Input Current	I_{EN}	V_{EN} = 2V		2		μA
		V_{EN} = 0V		0.1		
EN Turn Off Delay	EN_{Td-Off}			15		μsec
Power Good Rising Threshold	PG_{Vth-Hi}			0.71		V
Power Good Falling Threshold	PG_{Vth-Lo}			0.53		V
Power Good Delay	PG_{Td}			25		μs
Power Good Sink Current Capability	V_{PG}	Sink 4mA			0.4	V
Power Good Leakage Current	I_{PG_LEAK}	V_{PG} = 3.3V		1	100	nA
V_{IN} Under Voltage Lockout Threshold Rising	$INUV_{Vth}$		3.8	4.0	4.2	V
V_{IN} Under Voltage Lockout Threshold Hysteresis	$INUV_{HYS}$			880		mV
VCC Regulator	V_{CC}		4.5	5.5		
VCC Load Regulation		Icc=5mA		5		%
Thermal Shutdown	T_{SD}			150		°C

Note:

5) Guaranteed by design.

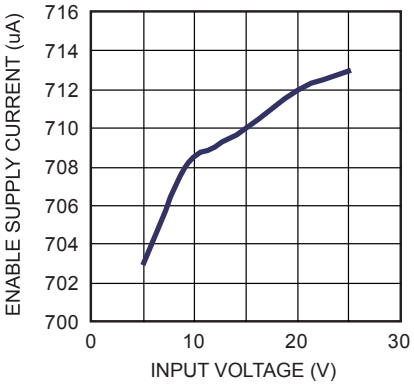
PIN FUNCTIONS

Pin #	Name	Description
1—4	NC	No Connect.
5—8	BG	Low Side Gate Drive
9—15, 21	GND	System Ground. This pin is the reference ground of the regulated output voltage. For this reason care must be taken in PCB layout.
16—19 Exposed Pad	SW	Switch Output. Use wide PCB traces and multiple vias to make the connection.
22	VCC	Bias Supply. Decouple with 1μF capacitor.
23	BST	Bootstrap. A capacitor connected between SW and BS pins is required to form a floating supply across the high-side switch driver.
24	FB	Feedback. An external resistor divider from the output to GND, tapped to the FB pin, sets the output voltage.
25	PG	Power Good Output, the output of this pin is open drain. Power good threshold is 90% low to high and 70% high to low of regulation value. There is a 20μs delay to pull PG if the output voltage is lower than 10% of regulation value.
26	EN/SYNC	EN=1 to enable the NB648. External clock can be applied to EN pin for changing switching frequency. For automatic start-up, connect EN pin to VIN with 100kΩ resistor.
27—29	IN	Supply Voltage. The NB648 operates from a +4.5V to +25V input rail. C1 is needed to decouple the input rail. Use wide PCB traces and multiple vias to make the connection.
30	AAM	Connects to a voltage set by 2 resistor dividers forces NB648 into non-synchronous mode when load is small.

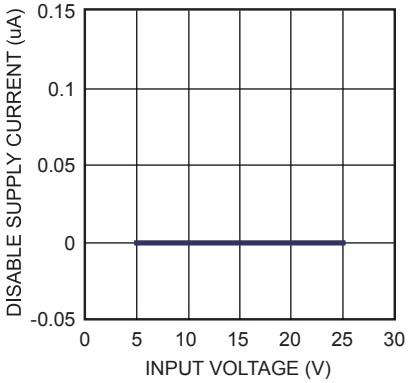
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 12.6V, V_{OUT} = 3.3V, L = 1.5µH, T_A = +25ºC, unless otherwise noted.

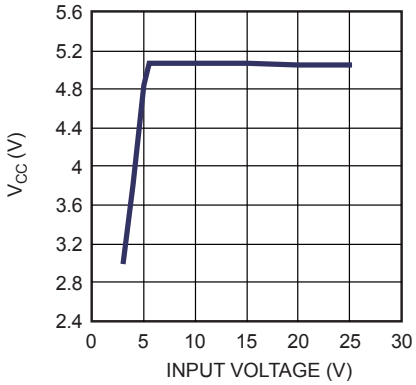
Enable Supply Current vs. Input Voltage



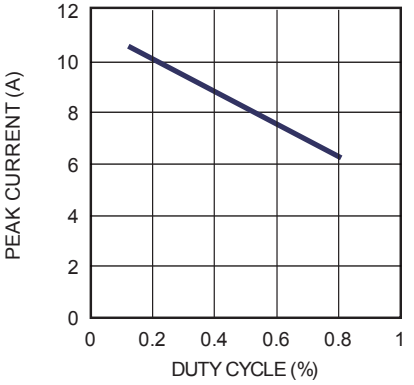
Disable Supply Current vs. Input Voltage



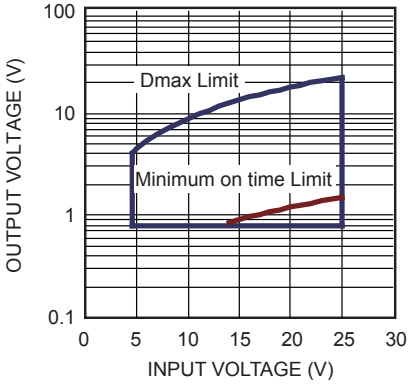
VCC Regulator Line Regulation



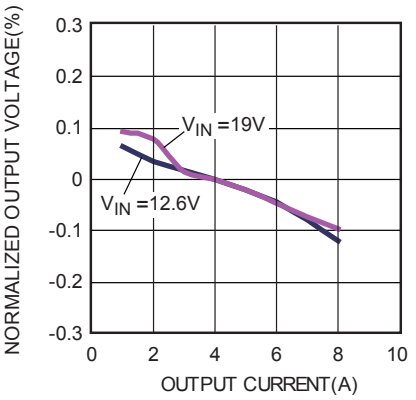
Peak Current vs. Duty Cycle



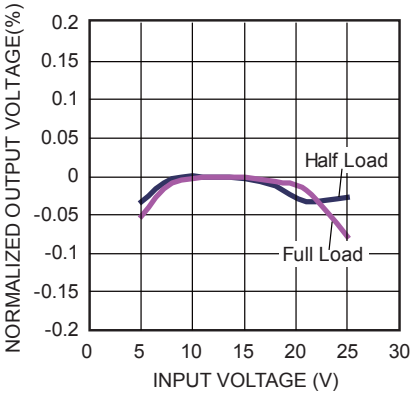
Operating Range



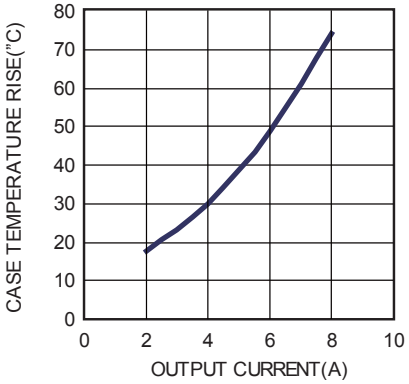
Load Regulation



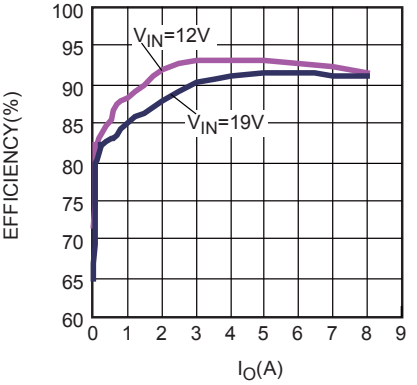
Line Regulation



Case Temperature vs. Output Current



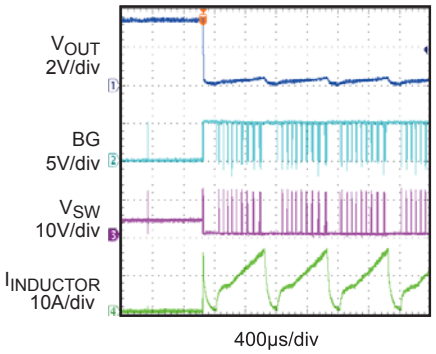
Efficiency



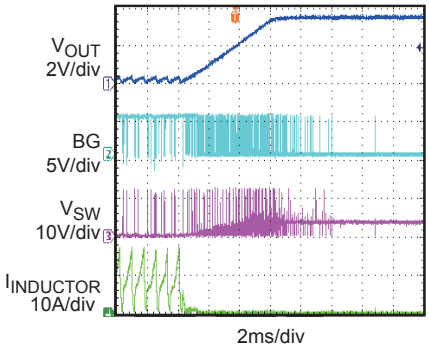
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12.6V, V_{OUT} = 3.3V, L = 1.5µH, T_A = +25ºC, unless otherwise noted.

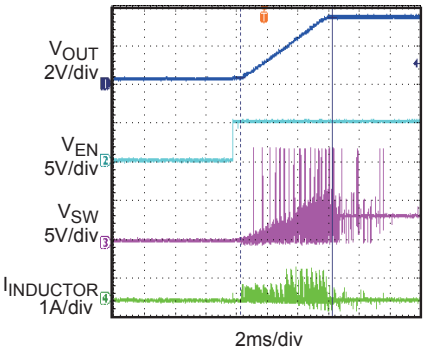
Short Entry



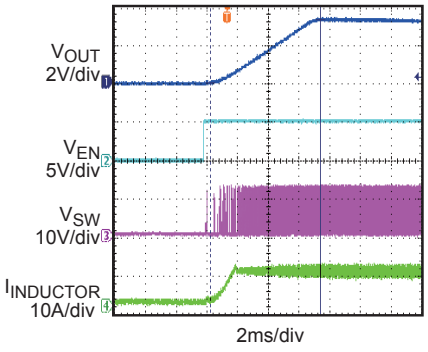
Short Recovery



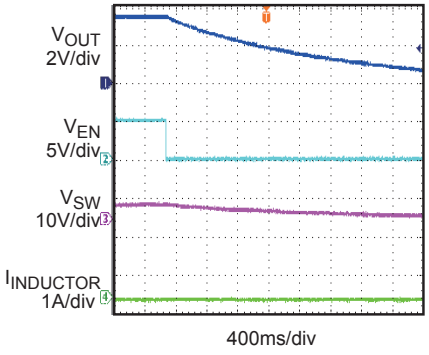
Enable Startup without Load



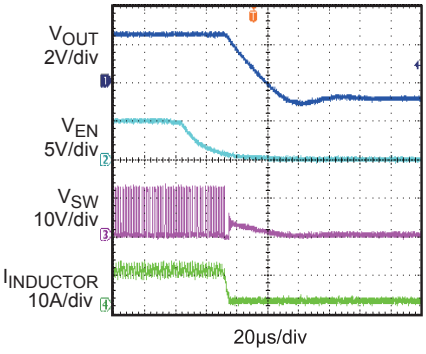
Enable Startup with 8A Load



Enable Shutdown without Load

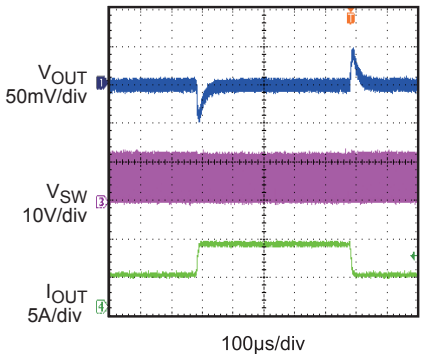


Enable Shutdown with 8A Load



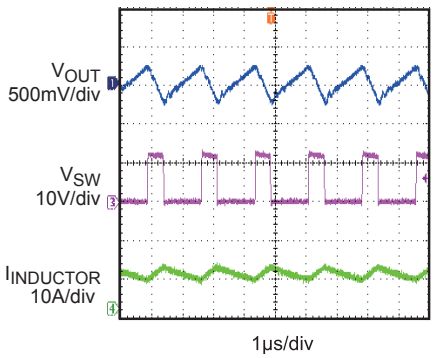
Load Transient Response

I_{OUT}=4A-8A, 1A/us



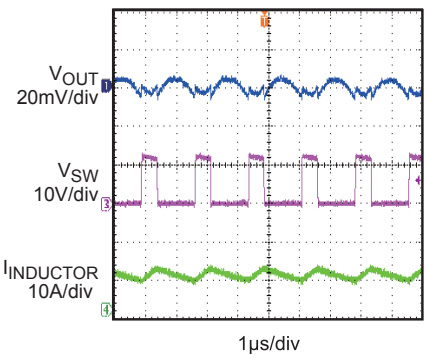
Input Ripple Voltage

I_{OUT}=8A



Output Ripple Voltage

I_{OUT}=8A



BLOCK DIAGRAM

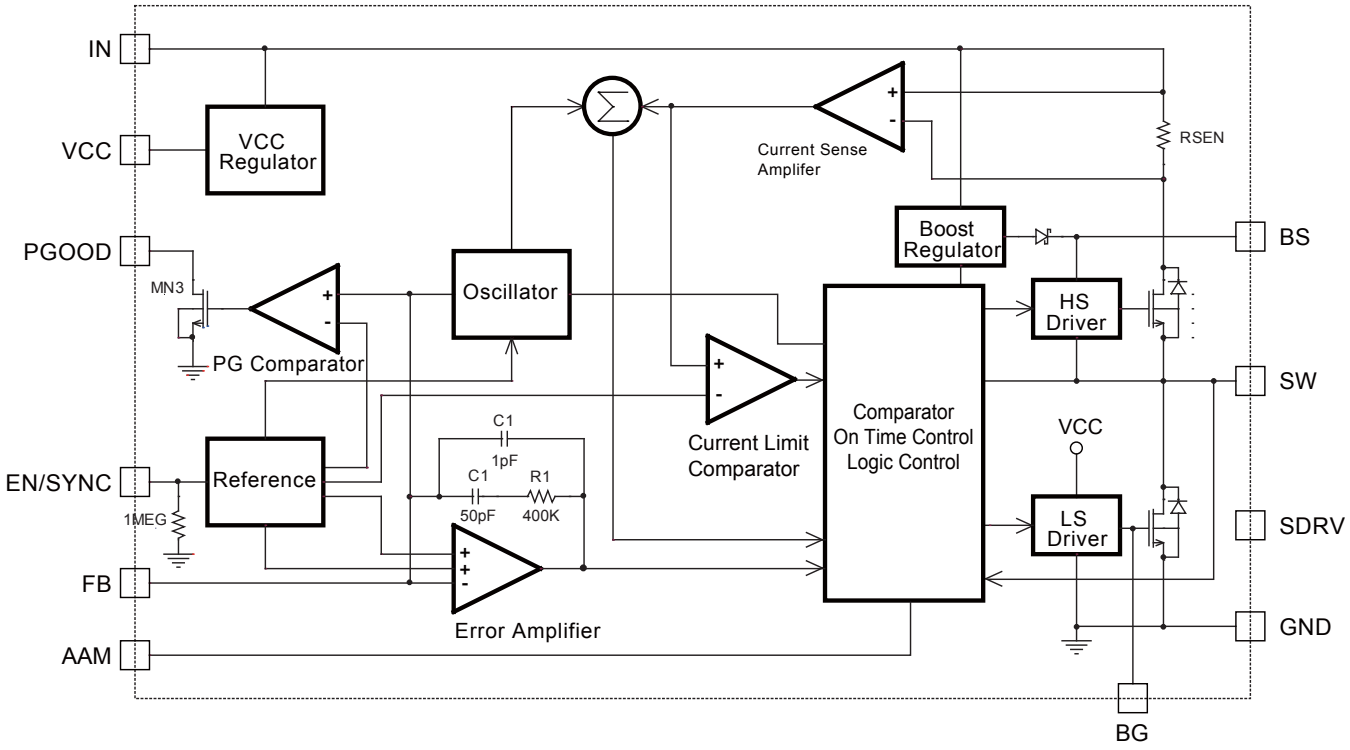


Figure 2—Function Block Diagram

OPERATION

The NB648 is a high frequency synchronous rectified step-down switch mode converter with built in internal power MOSFETs. It offers a very compact solution to achieve 8A continuous output current over a wide input supply range with excellent load and line regulation.

The NB648 operates in a fixed frequency, peak current control mode to regulate the output voltage. A PWM cycle is initiated by the internal clock. The high-side power MOSFET is turned on and remains on until its current reaches the value set by the COMP voltage. When the power switch is off, it remains off until the next clock cycle starts. If, in 90% of one PWM period, the current in the power MOSFET does not reach the COMP set current value, the power MOSFET will be forced to turn off.

Error Amplifier

The error amplifier compares the FB pin voltage with the internal 0.808V reference (REF) and outputs a current proportional to the difference between the two. This output current is then used to charge or discharge the internal compensation network to form the COMP voltage, which is used to control the power MOSFET current. The optimized internal compensation network minimizes the external component counts and simplifies the control loop design.

Internal Regulator

Most of the internal circuitries are powered from the 5V internal regulator. This regulator takes the VIN input and operates in the full VIN range. When VIN is greater than 5.0V, the output of the regulator is in full regulation. When VIN is lower than 5.0V, the output decreases. Since this internal regulator provides the bias current for the bottom gate driver that requires significant amount of current depending upon the external MOSFET selection, a 1uF ceramic capacitor for decoupling purpose is required.

Enable/Sync Control

The NB648 has a dedicated Enable/Sync control pin (EN/SYNC). By pulling it high or low, the IC can be enabled and disabled by EN. Tie EN to VIN for automatic start up. To disable the part, EN must be pulled low for at least 5μs.

The NB648 can be synchronized to external clock range from 300kHz up to 2MHz through the EN/SYNC pin. The internal clock rising edge is synchronized to the external clock rising edge.

Under-Voltage Lockout (UVLO)

Under-voltage lockout (UVLO) is implemented to protect the chip from operating at insufficient supply voltage. The NB648 UVLO comparator monitors the output voltage of the internal regulator, VCC. The UVLO rising threshold is about 4.0V while its falling threshold is a consistent 3.2V.

Internal Soft-Start

The soft-start is implemented to prevent the converter output voltage from overshooting during startup. When the chip starts, the internal circuitry generates a soft-start voltage (SS) ramping up from 0V to 1.2V. When it is lower than the internal reference (REF), SS overrides REF so the error amplifier uses SS as the reference. When SS is higher than REF, REF regains control.

Over-Current-Protection and Hiccup

The NB648 has cycle-by-cycle over current limit when the inductor current peak value exceeds the set current limit threshold. Meanwhile, output voltage starts to drop until FB is below the Under-Voltage (UV) threshold, typically 30% below the reference. Once a UV is triggered, the NB648 enters hiccup mode to periodically restart the part. This protection mode is especially useful when the output is dead-short to ground. The average short circuit current is greatly reduced to alleviate the thermal issue and to protect the regulator. The NB648 exits the hiccup mode once the over current condition is removed.

Thermal Shutdown

Thermal shutdown is implemented to prevent the chip from operating at exceedingly high temperatures. When the silicon die temperature is higher than 150°C, it shuts down the whole chip. When the temperature is lower than its lower threshold, typically 140°C, the chip is enabled again.

Floating Driver and Bootstrap Charging

The floating power MOSFET driver is powered by an external bootstrap capacitor. This floating driver has its own UVLO protection. This UVLO's rising threshold is 2.2V with a hysteresis of 150mV. The bootstrap capacitor voltage is regulated internally by VIN through D1, M3, C4, L1 and C2 (Figure 2). If (VIN-VSW) is more than 5V, U2 will regulate M1 to maintain a 5V BST voltage across C4.

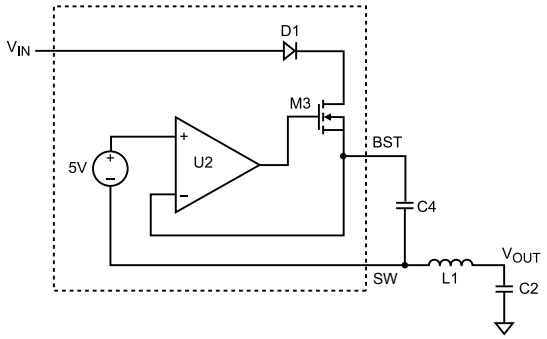


Figure 2—Internal Bootstrap Charging Circuit

Startup and Shutdown

If both VIN and EN are higher than their appropriate thresholds, the chip starts. The reference block starts first, generating stable reference voltage and currents, and then the internal regulator is enabled. The regulator provides stable supply for the remaining circuitries.

Three events can shut down the chip: EN low, VIN low and thermal shutdown. In the shutdown procedure, the signaling path is first blocked to avoid any fault triggering. The COMP voltage and the internal supply rail are then pulled down. The floating driver is not subject to this shutdown command.

Setting the Output Voltage

The external resistor divider is used to set the output voltage (see the schematic on front page). The feedback resistor R1 also sets the feedback loop bandwidth with the internal compensation capacitor (see Figure 1). Choose R1 to be around 31.6kΩ for optimal transient response. R2 is then given by:

$$R2 = \frac{R1}{\frac{V_{OUT}}{0.808V} - 1}$$

Table 1—Resistor Selection for Common Output Voltages

V_{OUT} (V)	R1 (kΩ)	R2 (kΩ)
1.8	31.6 (1%)	25.5 (1%)
2.5	31.6 (1%)	14.7(1%)
3.3	31.6 (1%)	10(1%)
5	31.6 (1%)	6.04 (1%)

Selecting the Inductor

A 1μH to 10μH inductor with a DC current rating of at least 25% percent higher than the maximum load current is recommended for most applications. For highest efficiency, the inductor DC resistance should be less than 15mΩ. For most designs, the inductance value can be derived from the following equation.

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

Where ΔI_L is the inductor ripple current.

Choose inductor current to be approximately 30% if the maximum load current, 8A. The maximum inductor peak current is:

$$I_{L(MAX)} = I_{LOAD} + \frac{\Delta I_L}{2}$$

Under light load conditions below 100mA, larger inductance is recommended for improved efficiency.

Selecting the Input Capacitor

The input current to the step-down converter is discontinuous, therefore a capacitor is required to supply the AC current to the step-down converter while maintaining the DC input voltage. Use low ESR capacitors for the best performance. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. For most applications, a 22μF capacitor is sufficient.

Since the input capacitor (C1) absorbs the input switching current it requires an adequate ripple current rating. The RMS current in the input capacitor can be estimated by:

$$I_{C1} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worse case condition occurs at VIN =2VOUT, where:

$$I_{C1} = \frac{I_{LOAD}}{2}$$

For simplification, choose the input capacitor whose RMS current rating greater than half of the maximum load current. The input capacitor can be electrolytic, tantalum or ceramic. When using electrolytic or tantalum capacitors, a small, high quality ceramic capacitor, i.e. 0.1μF, should be placed as close to the IC as possible. When using ceramic capacitors, make sure that they have enough capacitance to provide sufficient charge to prevent excessive voltage ripple at input. The input voltage ripple caused by capacitance can be estimated by:

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_S \times C1} \times \frac{V_{OUT}}{VIN} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Selecting the Output Capacitor

The output capacitor (C2) is required to maintain the DC output voltage. Ceramic, tantalum, or low ESR electrolytic capacitors are recommended. Low ESR capacitors are preferred to keep the output voltage ripple low. The output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_S \times C2}\right)$$

Where L is the inductor value and RESR is the equivalent series resistance (ESR) value of the output capacitor.

In the case of ceramic capacitors, the impedance at the switching frequency is dominated by the capacitance. The output voltage ripple is mainly caused by the capacitance. For simplification, the output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_S^2 \times L \times C2} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

In the case of tantalum or electrolytic capacitors, the ESR dominates the impedance at the switching frequency. For simplification, the output ripple can be approximated to:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times R_{ESR}$$

The characteristics of the output capacitor also affect the stability of the regulation system. The NB648 can be optimized for a wide range of capacitance and ESR values.

External Bootstrap Diode

An external bootstrap diode may enhance the efficiency of the regulator, the applicable conditions of external BST diode are:

- V_{OUT} is 5V or 3.3V; and
- Duty cycle is high: D= $\frac{V_{OUT}}{V_{IN}}$ >65%

In these cases, an external BST diode is recommended from the output of the voltage regulator to BST pin, as shown in Fig.3

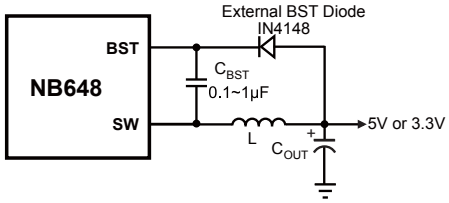


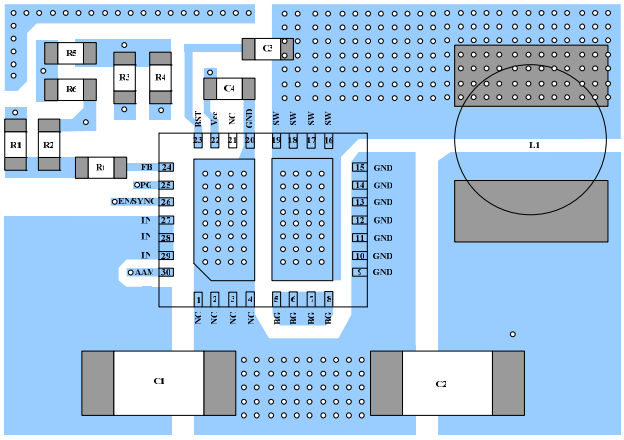
Figure 3—Add Optional External Bootstrap Diode to Enhance Efficiency

The recommended external BST diode is IN4148, and the BST cap is 0.1~1μF.

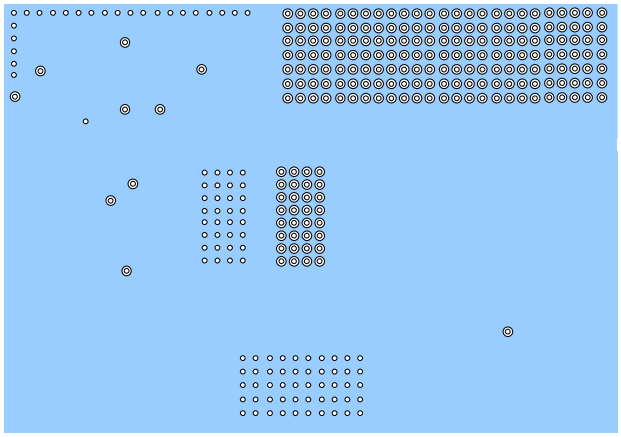
PCB Layout

PCB layout is very important to achieve stable operation. Please follow these guidelines and take Figure 4 for references.

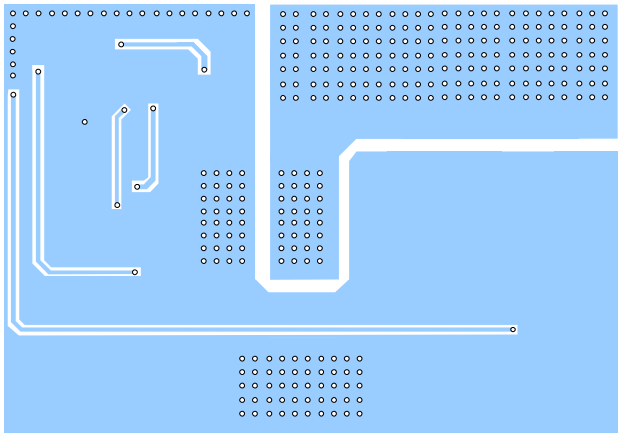
The high current paths (GND, IN and SW) should be placed very close to the device with short, direct and wide traces. The input capacitor needs to be as close as possible to the IN and GND pins. The external feedback resistors should be placed next to the FB pin. Keep the switching node SW short and away from the feedback network.



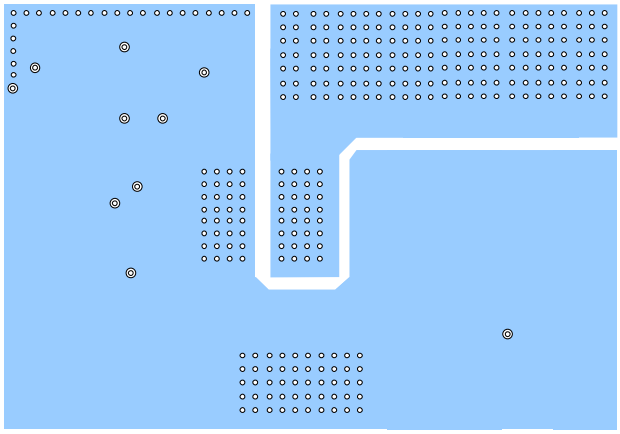
Top Layer



Inner 1



Inner 2

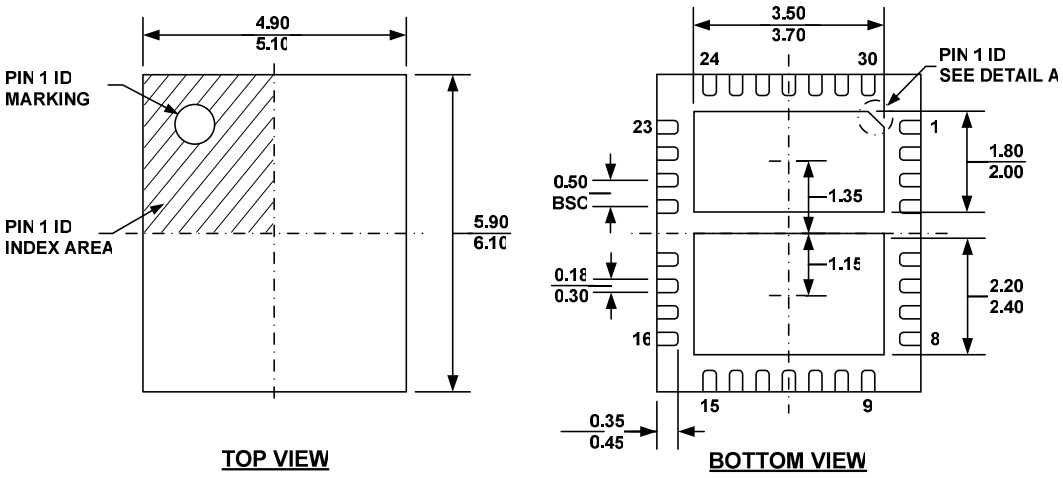


Bottom Layer

Figure 4—PCB Layout

PACKAGE INFORMATION

5x6mm QFN30



NOTE:

1) ALL DIMENSIONS ARE IN MILLIMETERS.
2) EXPOSED PADDLE SIZE DOES NOT INCLUDE MOLD FLASH.
3) LEAD COPLANARITY SHALL BE 0.10 MILLIMETER MAX.
4) JEDEC REFERENCE IS MO-220, VARIATION VHJD.
5) DRAWING IS NOT TO SCALE.