High-Efficiency Synchronous Step-up DC/DC Converter with Selectable Current Limit

FEATURES

- High efficiency (93% with V_{IN}=2.4V, V_{OUT}= 3.3V, I_{OUT}=200mA)
- Output current up to 500mA. (V_{IN}=2.4V, at V_{OUT}=3.3V, CLSEL=OUT)
- Quiescent supply current of 20µA
- Power-saving shutdown mode (0.1µA typical).
- Internal synchronous rectifier (no external diode required).
- Selectable current limit for reduced ripple.
- Low-noise, anti-ringing feature.
- On-chip low-battery detector.
- Low-battery hysteresis.
- Space-saving package: MSOP-10

APPLICATIONS

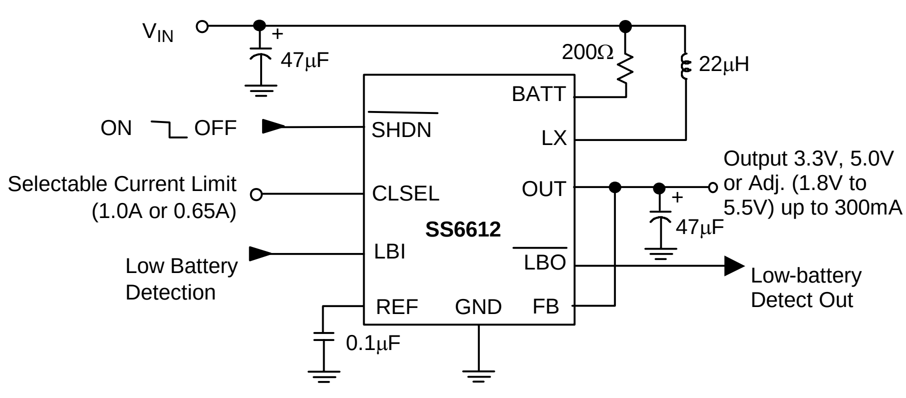
- Palmtop & Notebook Computers.
- PDAs
- Wireless Phones
- Pocket Organizers.
- Digital Cameras.
- Hand-Held Devices with 1 to 3 Cells of NiMH/NiCd Batteries.

DESCRIPTION

The SS6612 is a high-efficiency step-up DC/DC converter, with a start-up voltage as low as 0.8V, and an operating voltage down to 0.7V. Consuming only 20µA of quiescent current, this device includes a built-in synchronous rectifier that reduces size and cost by eliminating the need for an external Schottky diode, and improves overall efficiency by minimizing losses.

The switching frequency can range up to 500KHz depending on the load and input voltage. The output voltage can be easily set; by two external resistors for 1.8V to 5.5V; connecting FB to OUT to get 3.3V; or connecting to GND to get 5.0V. For additional design flexibility, the peak current of the internal switch is selectable (0.65A or 1.0A). The SS6612 also features a circuit that eliminates noise caused by inductor ringing.

TYPICAL APPLICATION CIRCUIT



ORDERING INFORMATION

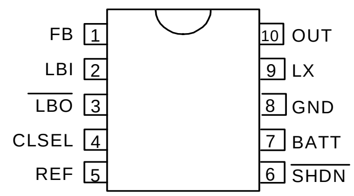
SS6612CXXX

- Packing
  - TR: Tape and reel
- Package type
  - O: MSOP-10

Example: SS6612COTR
→ in MSOP-10 package supplied on tape and reel.

PIN CONFIGURATION

MSOP-10 TOP VIEW



ABSOLUTE MAXIMUM RATINGS

Supply Voltage (OUT to GND)	8.0V
Switch Voltage (LX to GND)	V_{OUT}+ 0.3V
Battery Voltage (BATT to GND)	6.0V
$\overline{\text{SHDN}}$, LBO to GND	6.0V
LBI, REF, FB, CLSEL to GND	V_{OUT}+0.3V
Switch Current (LX)	-1.5A to +1.5A
Output Current (OUT)	-1.5A to +1.5A
Operating Temperature Range	-40°C ~ +85°C
Storage Temperature Range	-65°C ~150°C

TEST CIRCUIT

Refer to the typical application circuit.

ELECTRICAL CHARACTERISTICS

(V_{IN} = 2.0V, V_{OUT} = 3.3V (FB = V_{OUT}), R_L = ∝, T_A = 25°C, unless otherwise specified.)

PARAMETER	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
Minimum Input Voltage				0.7		V
Operating Voltage			1.1		5.5	V
Start-Up Voltage	R_L=3kΩ (Note1)			0.8	1.1	V
Start-Up Voltage Temp. Coeff.				-2		mV/°C
Output Voltage Range	V_{IN}<V_{OUT}		1.8		5.5	
Output Voltage	FB = V_{OUT}		3.17	3.3	3.43	V
Steady State Output Current (Note 2)	FB=OUT (V_{OUT} =3.3V)	CLSEL=OUT	300	350		mA
		CLSEL=GND	150	300		
	FB=GND (V_{OUT} =5.0V)	CLSEL=OUT	180	230		
		CLSEL=GND	90	160		
Reference Voltage	I_{REF}= 0		1.199	1.23	1.261	V
Reference Voltage Temp. Coeff.				0.024		mV/°C
Reference Load Regulation	I_{REF} = 0 to 100μA			10	30	mV
Reference Line Regulation	V_{OUT} = 1.8V to 5.5V			5	10	mV/V
FB, LBI Input Threshold			1.199	1.23	1.261	V
Internal switch On-Resistance	I_{LX} = 100mA			0.3	0.6	Ω
LX Switch Current Limit	CLSEL=OUT		0.80	1.0	1.25	A
	CLSEL=GND		0.50	0.65	0.85	
LX Leakage Current	V_{LX}=0V~4V; V_{OUT}=4V			0.05	1	μA
Operating Current into OUT (Note 3)	V_{FB} = 1.4V , V_{OUT} = 3.3V			20	35	μA
Shutdown Current into OUT	$\overline{SHDN}$ = GND			0.1	1	μA
Efficiency	V_{OUT}= 3.3V ,I_{LOAD} = 200mA			90		%
	V_{OUT} = 2V ,I_{LOAD} = 1mA			85		

ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	TEST CONDITIONS	MIN.	TYP.	MAX.	UNIT
LX Switch On-Time	V_{FB} =1V , V_{OUT} = 3.3V	2	4	7	µs
LX Switch Off-Time	V_{FB} =1V , V_{OUT} = 3.3V	0.6	0.9	1.4	µs
FB Input Current	V_{FB} = 1.4V		0.03	50	nA
LBI Input Current	V_{LBI} = 1.4V		1	50	nA
CLSEL Input Current	CLSEL = OUT		1.4	3	µA
$\overline{SHDN}$ Input Current	$V_{\overline{SHDN}}$ = 0 or V_{OUT}		0.07	50	nA
$\overline{LBO}$ Low Output Voltage	V_{LBI} = 0, I_{SINK} = 1mA		0.2	0.4	µA
$\overline{LBO}$ Off Leakage Current	$V_{\overline{LBO}}$ = 5.5V, V_{LBI} = 5.5V		0.07	1	
LBI Hystereisis			50		mV
Damping Switch Resistance	V_{BATT} = 2V		50	100	Ω
$\overline{SHDN}$ Input Voltage	V_{IL}			$0.2V_{OUT}$	V
	V_{IH}	$0.8V_{OUT}$			
CLSEL Input Voltage	V_{IL}			$0.2V_{OUT}$	V
	V_{IH}	$0.8V_{OUT}$			

Note 1: Start-up voltage operation is guaranteed without the addition of an external Schottky diode between the input and output.
Note 2: Steady-state output current indicates that the device maintains output voltage regulation under load.
Note 3: Device is bootstrapped (power to the IC comes from OUT). This correlates directly with the actual battery supply.

TYPICAL PERFORMANCE CHARACTERISTICS

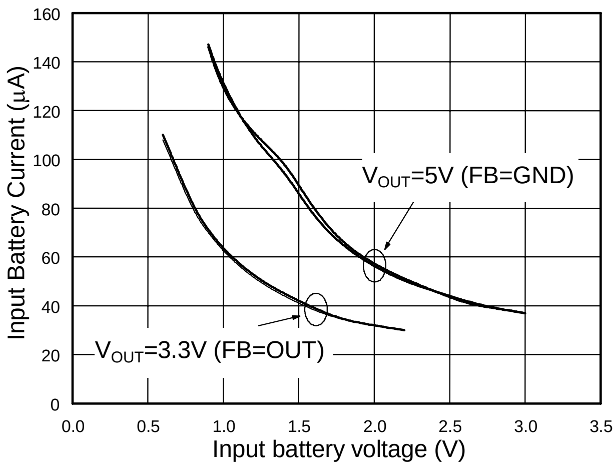


Fig. 1 No-Load Battery Current vs. Input Battery

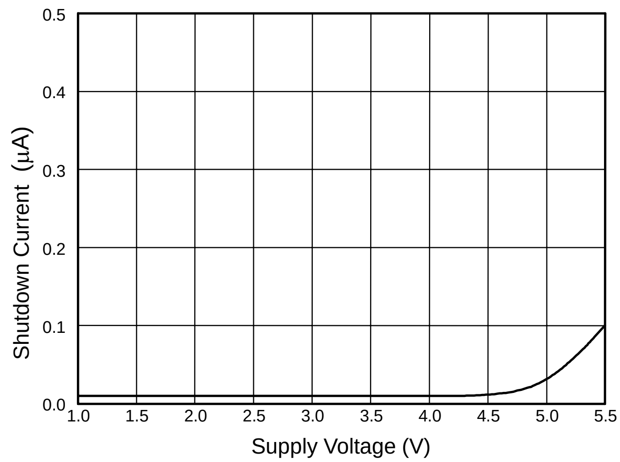


Fig. 2 Shutdown Current vs. Supply Voltage

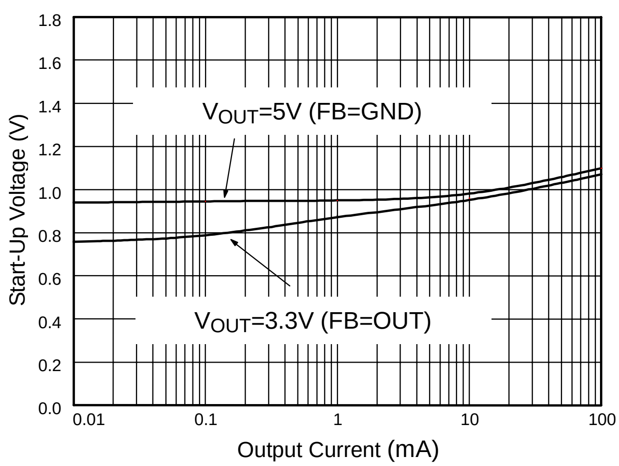


Fig. 3 Start-Up Voltage vs. Output Current

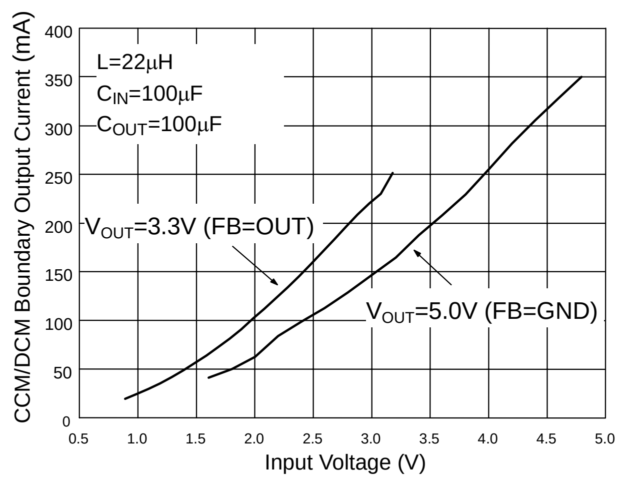


Fig. 4 Turning Point between CCM & DCM

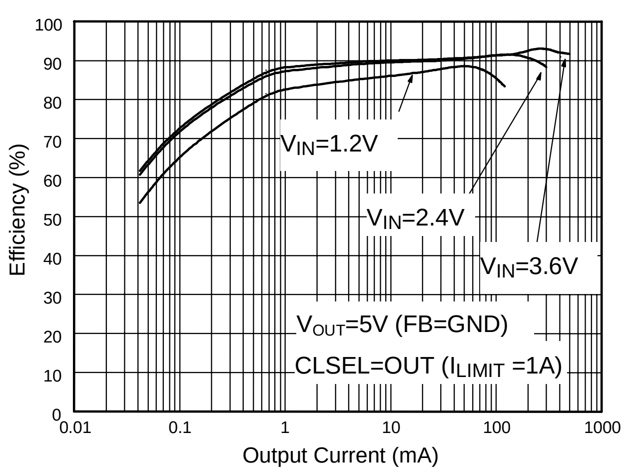


Fig. 5 Efficiency vs. Output Current (ref. to Fig.35)

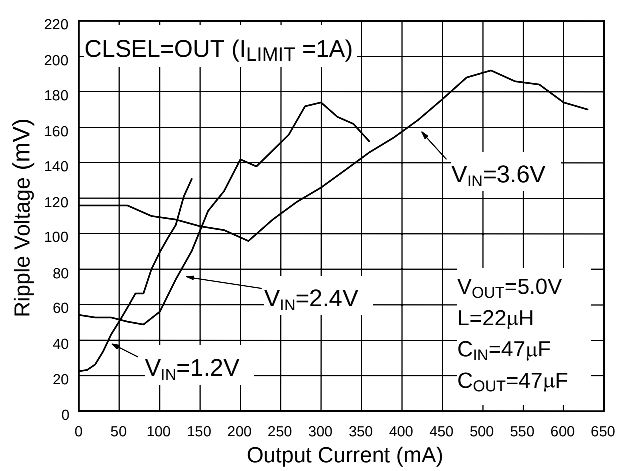


Fig. 6 Ripple Voltage (ref. to Fig.35)

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

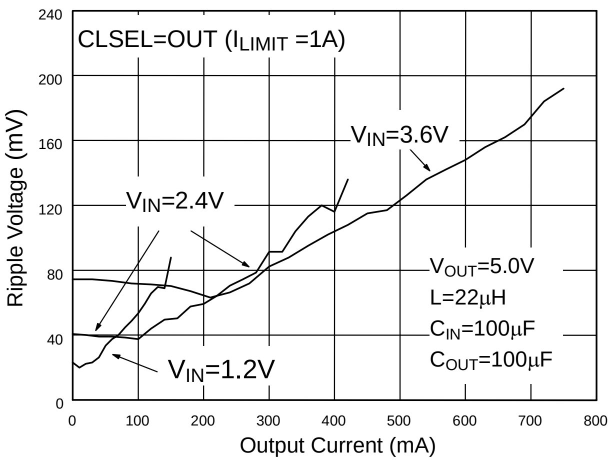


Fig. 7 Ripple Voltage (ref. to Fig.35)

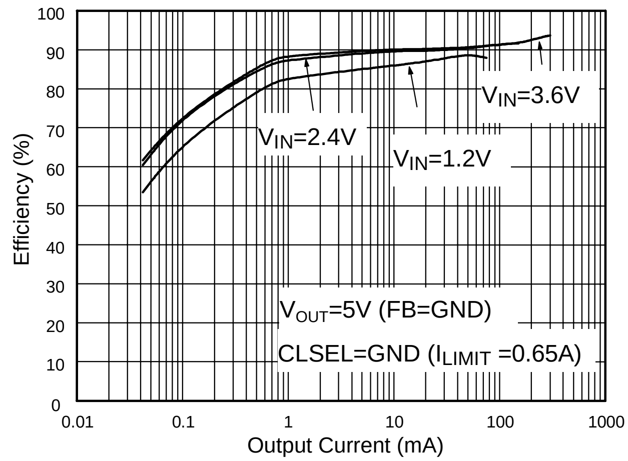


Fig. 8 Efficiency vs. Output Current (ref. to Fig.35)

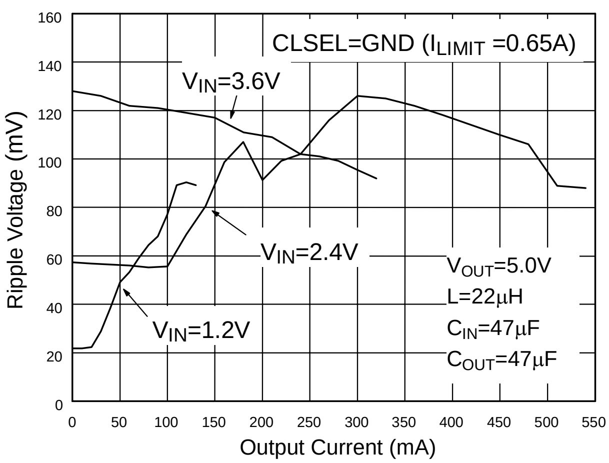


Fig. 9 Ripple Voltage (ref. to Fig.35)

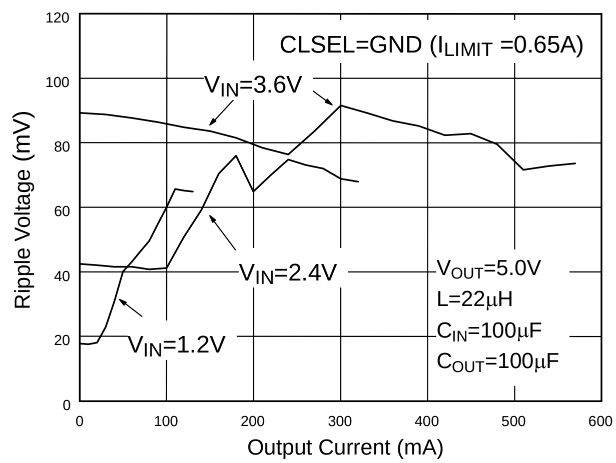


Fig. 10 Ripple Voltage (ref. to Fig.35)

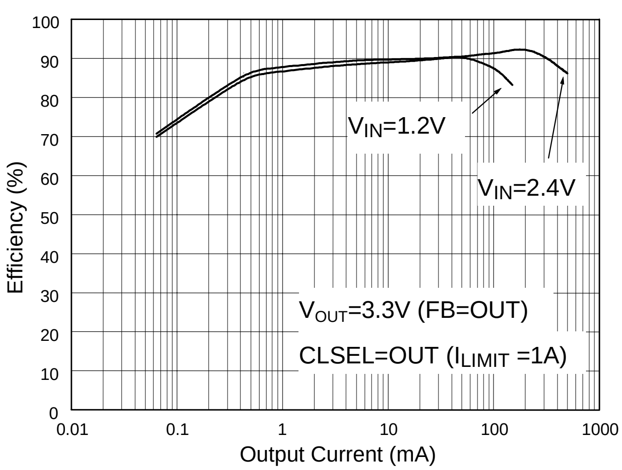


Fig. 11 Efficiency vs. Output Current (ref. to Fig.34)

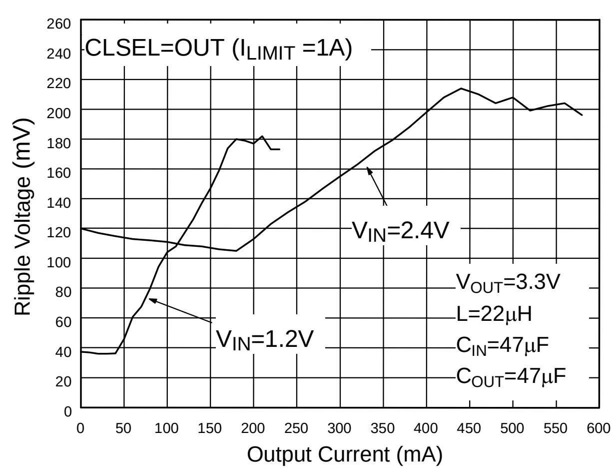


Fig. 12 Ripple Voltage (ref. to Fig.34)

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

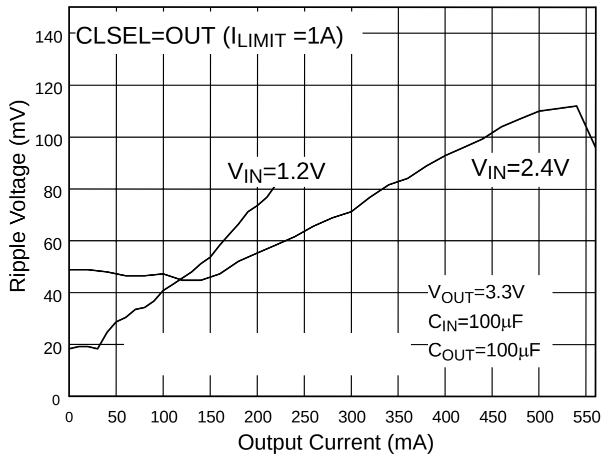


Fig. 13 Ripple Voltage (ref. to Fig.34)

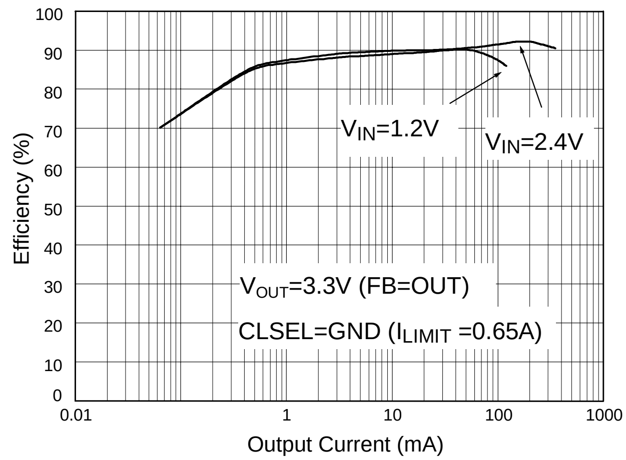


Fig. 14 Efficiency vs. Output Current (ref. to Fig.34)

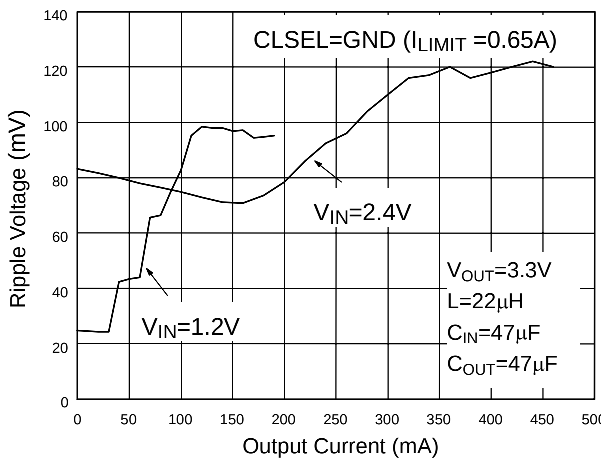


Fig. 15 Ripple Voltage (ref. to Fig.34)

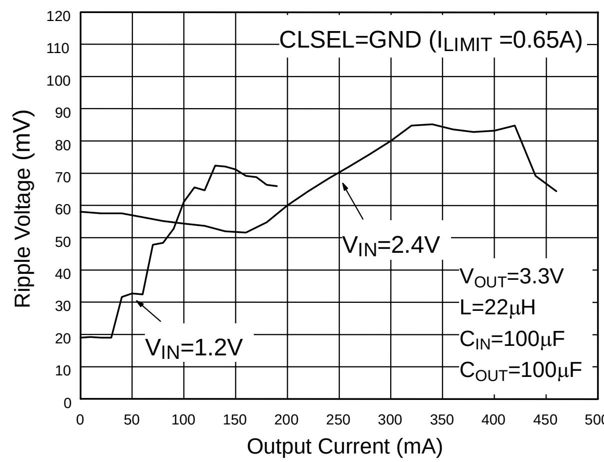


Fig. 16 Ripple Voltage (ref. to Fig.34)

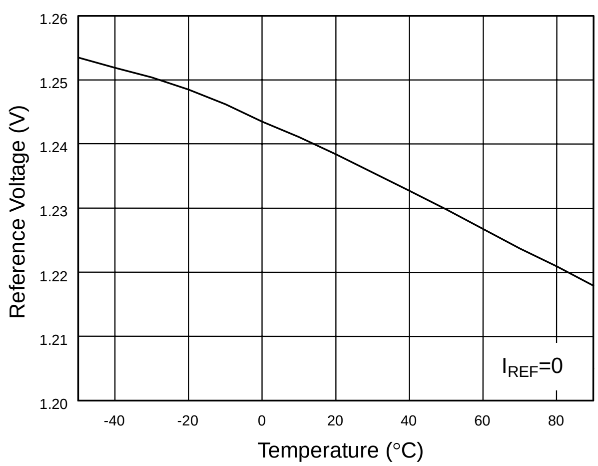


Fig. 17 Reference Voltage vs. Temperature

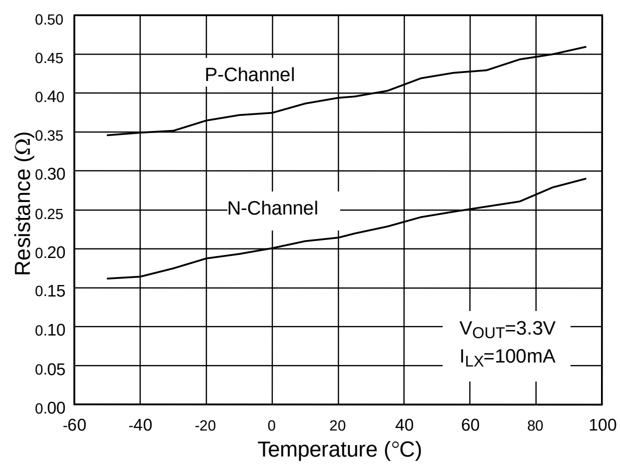


Fig. 18 Switch Resistance vs. Temperature

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

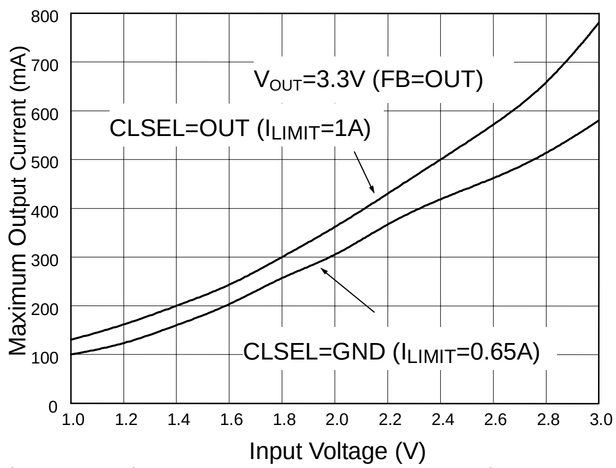


Fig 19 Maximum Output Current vs. Input Voltage

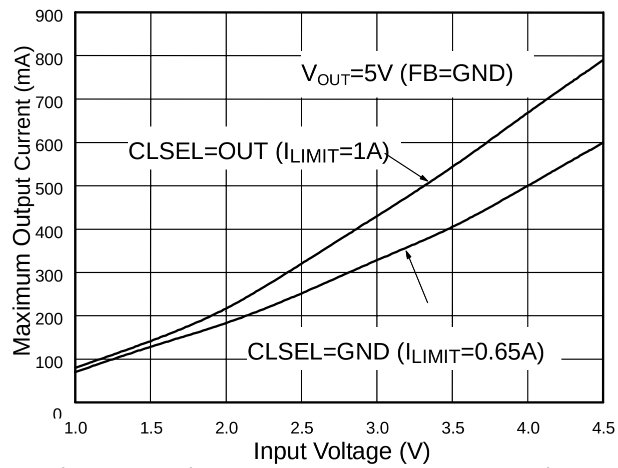


Fig. 20 Maximum Output Current vs. Input Voltage

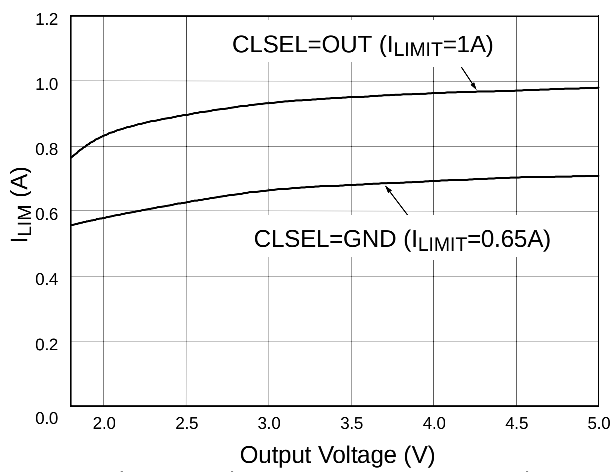


Fig. 21 Inductor Current vs. Output Voltage

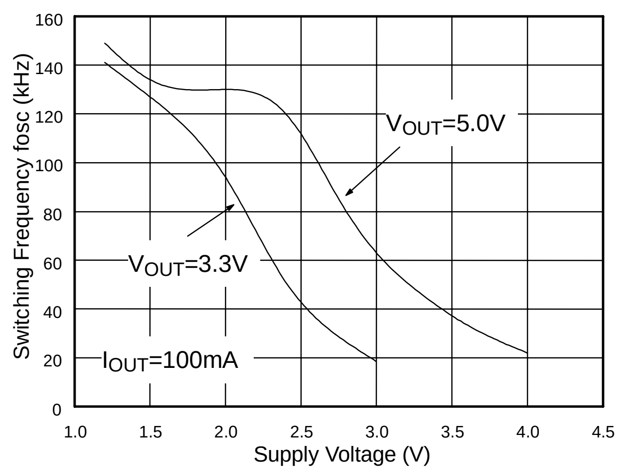


Fig. 22 Switching Frequency vs. Supply Voltage

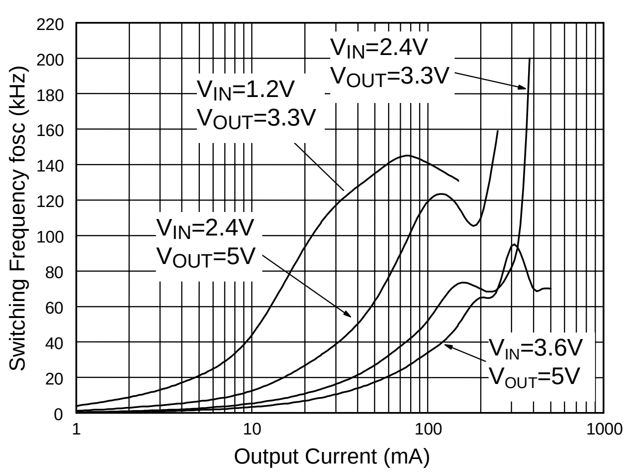


Fig. 23 Switching Frequency vs. Output Current

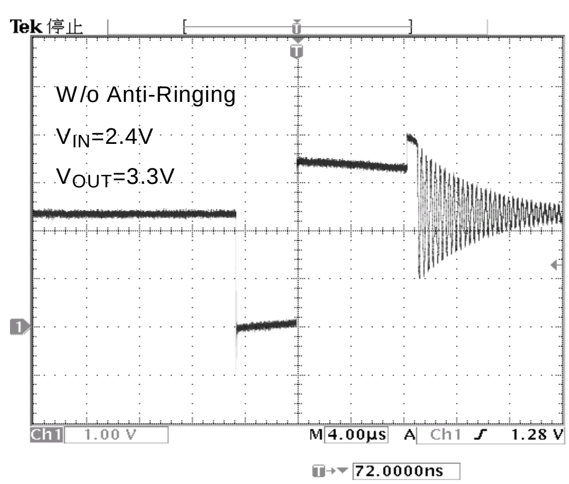


Fig. 24 Without Anti-Ringing Function

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

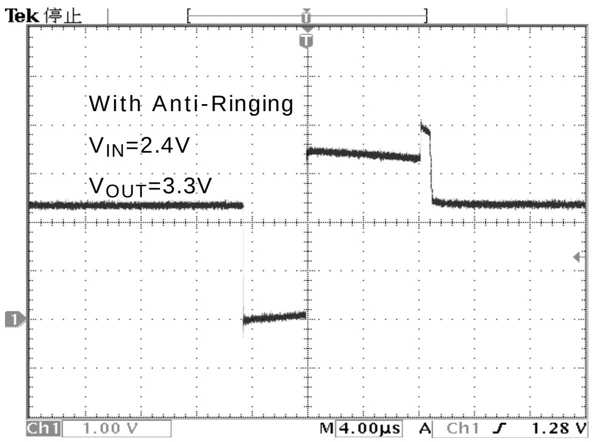


Fig. 25 With Anti-Ringing Function

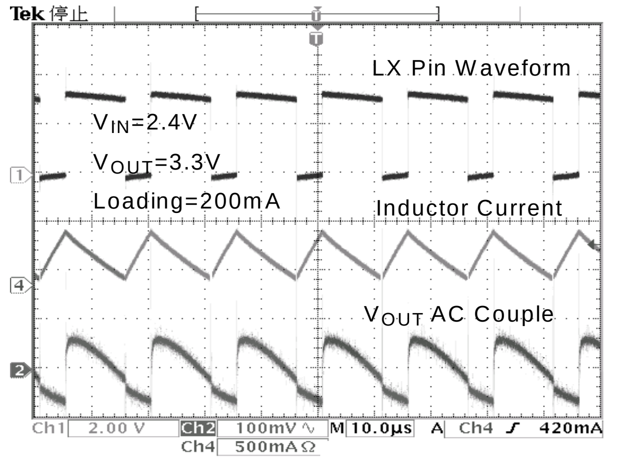


Fig. 26 Heavy Load Waveform

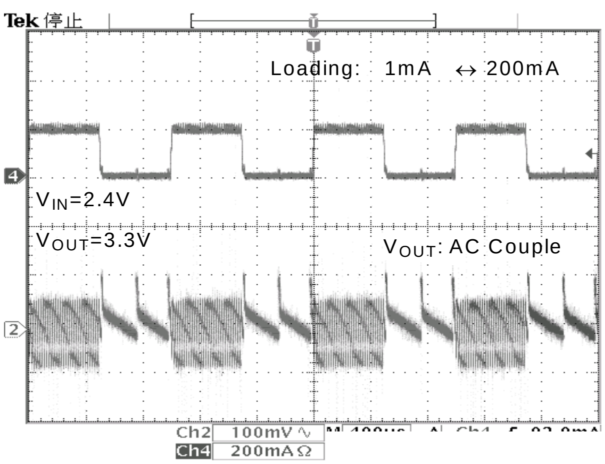


Fig. 27 Load Transient Response

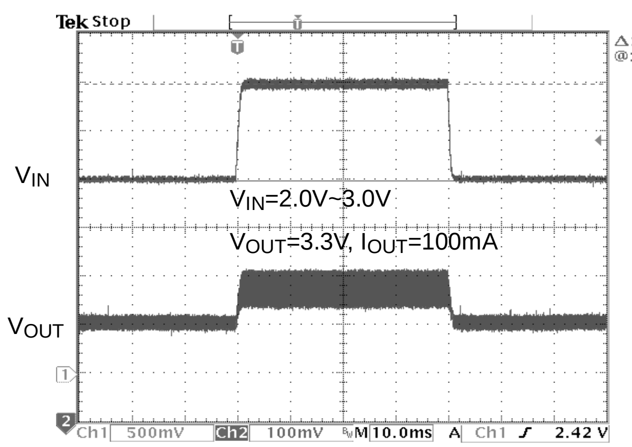


Fig. 28 Line Transient Response

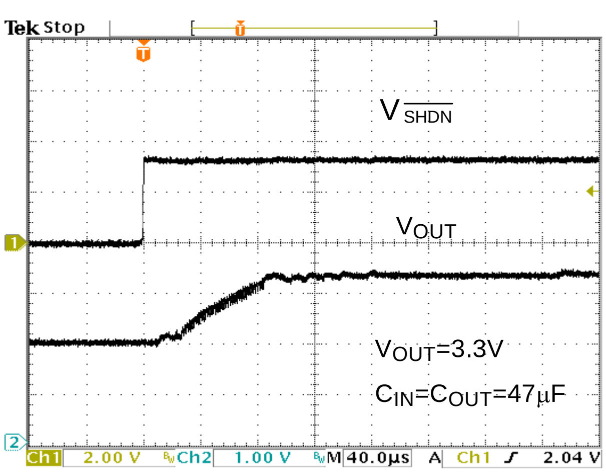


Fig. 29 Exiting Shutdown

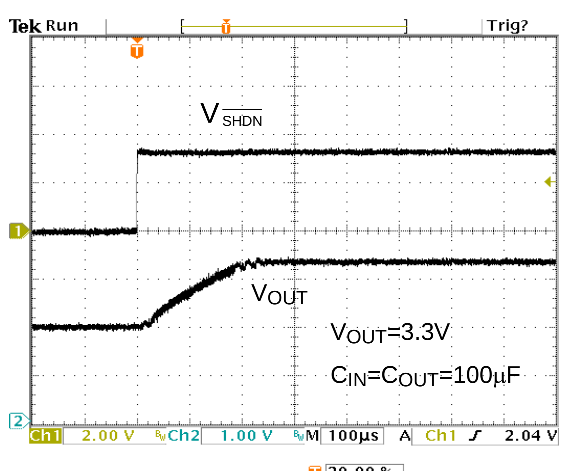


Fig. 30 Exiting Shutdown

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

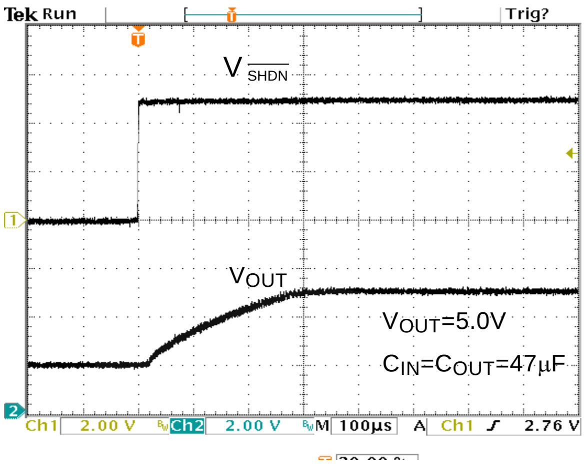


Fig. 31 Exiting Shutdown

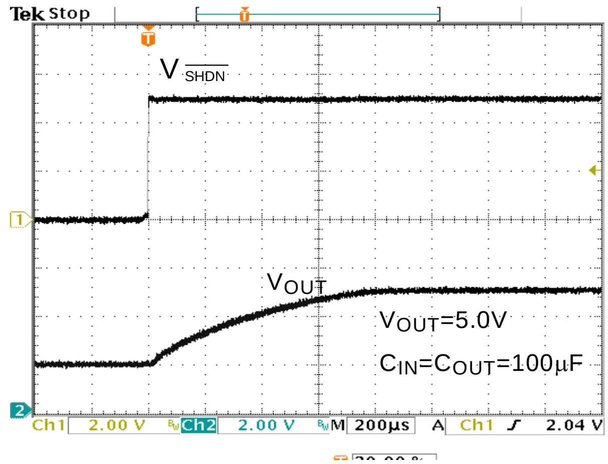
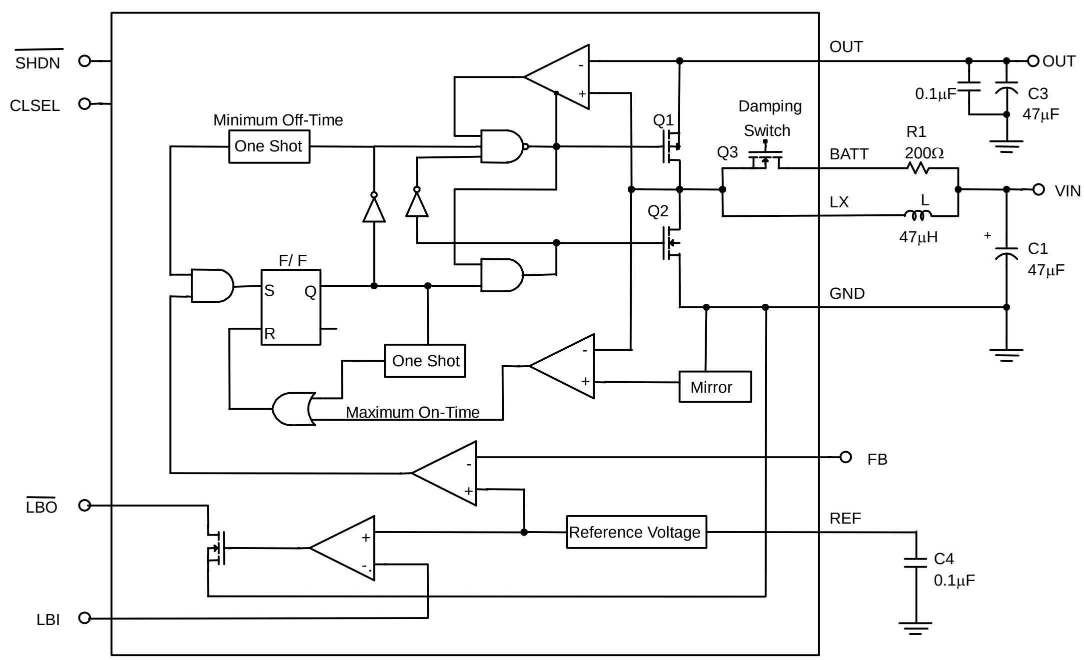


Fig. 32 Exiting Shutdown

BLOCK DIAGRAM



PIN DESCRIPTIONS

PIN 1: FB- Connected to OUT to get +3.3V output, connected to GND to get +5.0V output, or using a resistor network to set output voltage ranging from +1.8V to +5.5V.

PIN 2: LBI- Low-battery comparator input internally set at +1.23V to trip.

PIN 3: $\overline{\text{LBO}}$- Open-drain low battery comparator output. Output is low when VLBI is <1.23V. LBO is high impedance during shutdown.

PIN 4: CLSEL- Current-limit select input. CLSEL= OUT sets the current limit to 1.0A. CLSEL=GND sets the current limit to 0.65A.

PIN 5: REF- 1.23V reference voltage. Bypass with a 0.1μF capacitor.

PIN 6: $\overline{\text{SHDN}}$- Shutdown input. High=operating, low=shutdown.

PIN 7: BATT- Battery input and damping switch connection. If damping switch is unused, leave BATT unconnected.

PIN 8: GND- Ground.

PIN 9: LX- N-channel and P-channel power MOSFET drain.

PIN 10: OUT- Power output. OUT provides bootstrap power to the IC.

APPLICATION INFORMATION

Overview

The SS6612 is a high-efficiency, step-up DC/DC converter, featuring a built-in synchronous rectifier, which reduces size and cost by eliminating the need for an external Schottky diode. The start-up voltage of the SS6612 is as low as 0.8V and it operates with an input voltage down to 0.7V. Quiescent supply current is only 20μA. In addition, the SS6612 features a circuit that eliminates inductor ringing to reduce noise. The internal P-MOSFET on-resistance is typically 0.3Ω to improve overall efficiency by minimizing AC losses. The output voltage can be easily set; by two external resistors for 1.8V to 5.5V; connecting FB to OUT to get 3.3V; or connecting to GND to get 5.0V. The CLSEL pin offers a selectable current limit (1.0A or 0.65A). The lower current limit allows the use of a physically smaller inductor in space-sensitive applications.

PFM Control Scheme

A key feature of the SS6612 is a unique minimum-off-time, constant-on-time, current-limited, pulse-frequency-modulation (PFM) control scheme (see BLOCK DIAGRAM) with ultra-low quiescent current. The peak current of the internal N-MOSFET power switch is selectable. The switch frequency depends on either loading conditions or input voltage, and can range up to 500KHz. It is governed by a pair of one-shots that set a minimum off-time (1μs) and a maximum on-time (4μs).

Synchronous Rectification

Using the internal synchronous rectifier eliminates the need for an external Schottky diode, reducing the cost and board space. During the cycle of off-time, the P-MOSFET turns on and shuts the N-MOSFET off. Due to the low turn-on resistance of the MOSFET, the synchronous rectifier significantly improves efficiency without an additional external Schottky diode. Thus, the conversion efficiency can be as high as 93%.

Reference Voltage

The reference voltage (REF) is nominally 1.23V for excellent T.C. performance. In addition, the REF pin can source up to 100μA to an external circuit with good load regulation (<10mV). A bypass capacitor of 0.1µF is required for proper operation and good performance.

Shutdown

The whole circuit is shutdown when $V_{\overline{SHDN}}$ is low. In shutdown mode, the current can flow from the battery to the output due to the body diode of the P-MOSFET. VOUT falls to approximately (Vin - 0.6V) and LX remains high impedance. The capacitance and load at OUT determine the rate at which V_{OUT} decays. Shutdown can be pulled as high as 6V, regardless of the voltage at OUT.

Current Limit Select Pin

The SS6612 allows a selectable inductor current limit of either 1.0A or 0.65A, allowing the flexibility to design for higher current or smaller applications. CLSEL draws 1.4µA when connecting to OUT.

BATT/Damping Switch

The SS6612 is designed with an internal damping switch (Fig.33) to reduce ringing at LX. The damping switch supplies a path to quickly dissipate the energy stored in the inductor and reduces the ringing at LX. Damping LX ringing does not reduce V_{OUT} ripple, but does reduce EMI. R1=200Ω works well for most applications while reducing efficiency by only 1%. Larger R1 values provide less damping, but less impact on efficiency. In principle, a lower value of R1 is needed to fully damp LX when V_{OUT} /V_{IN} ratio is high.

Selecting the Output Voltage

V_{OUT} can be simply set to 3.3V/5.0V by connecting the FB pin to OUT/GND due to the use of an internal resistor divider in the IC (Fig.34 and Fig.35). In order to adjust the output voltage, a resistor divider is connected to V_{OUT}, FB, GND (Fig.36). Vout can be calculated by the following equation:

$$R5 = R6\left[\left(V_{OUT} / V_{REF}\right) - 1\right] \quad \text{.....................................(1)}$$

where V_{REF} =1.23V and V_{OUT} ranges from 1.8V to 5.5V. The recommended R6 is 240kΩ.

Low-Battery Detection

The SS6612 contains an on-chip comparator with 50mV internal hysteresis (REF, REF+50mV) for low battery detection. If the voltage at LBI falls below the internal reference voltage, LBO (an open-drain output) sinks current to GND.

Component Selection

1. Inductor Selection

An inductor value of 22µH performs well in most applications. The SS6612 also works with inductors in the 10µH to 47µH range. An inductor with higher peak inductor current creates a higher output voltage ripple (I_{PEAK}×output filter capacitor ESR). The inductor's DC resistance significantly affects efficiency. We can calculate the maximum output current as follows:

$$I_{OUT(MAX)} = \frac{V_{IN}}{V_{OUT}}\left[I_{LIM} - t_{OFF}\left(\frac{V_{OUT} - V_{IN}}{2 \times L}\right)\right]\eta$$

....(2)

where $I_{OUT(MAX)}$=maximum output current in amps

V_{IN}=input voltage

L=inductor value in µH

η =efficiency (typically 0.9)

t_{OFF}=LX switch' off-time in µs

I_{LIM}=1.0A or 0.65A

2. Capacitor Selection

The output ripple voltage is related to the peak inductor current and the output capacitor ESR. Besides output ripple voltage, the output ripple current may also be of concern. A filter capacitor with low ESR is helpful to the efficiency and the steady state output current of the SS6612. Therefore a NIPPON MCM series tantalum capacitor of 100µF/6V is recommended. A smaller capacitor (down to 47µF with higher ESR) is acceptable for light loads or in applications that can tolerate higher output ripple.

3. PCB Layout and Grounding

Since the SS6612's switching frequency can range up to 500kHz, the SS6612 can be very sensitive. Careful printed circuit layout is important for minimizing ground bounce and noise. The OUT pin should be as clear as possible, and the GND pin should be placed close to the ground plane. Keep the IC's GND pin and the ground leads of the input and output filter capacitors less than 0.2in (5mm) apart. In addition, keep all connections to the FB and LX pins as short as possible. In particular, when using external feedback resistors, locate them as close to the FB as possible. To maximize output power and efficiency, and minimize output ripple voltage, use a ground plane and solder the IC's GND directly to the ground plane. Fig.37 to 39 are the recommended layout diagrams.

Ripple Voltage Reduction

Two or three parallel output capacitors can significantly improve the output ripple voltage of the SS6612. The addition of an extra input capacitor results in a stable output voltage. Fig.40 shows the application circuit with the above features. Fig. 41 to 48 show the performance of Fig.40.

APPLICATION EXAMPLES

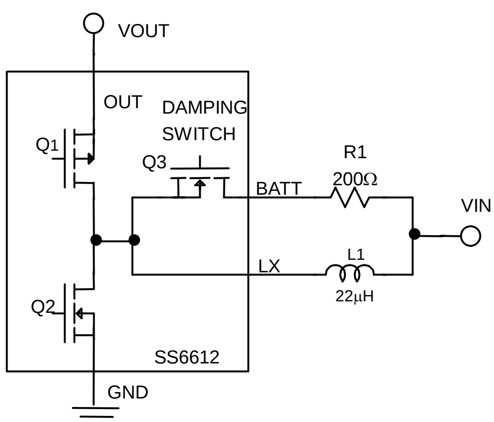
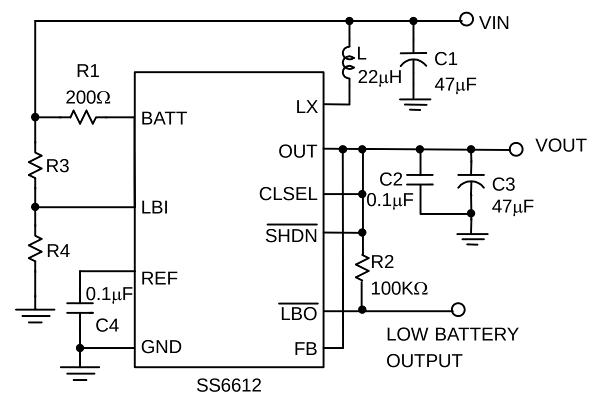
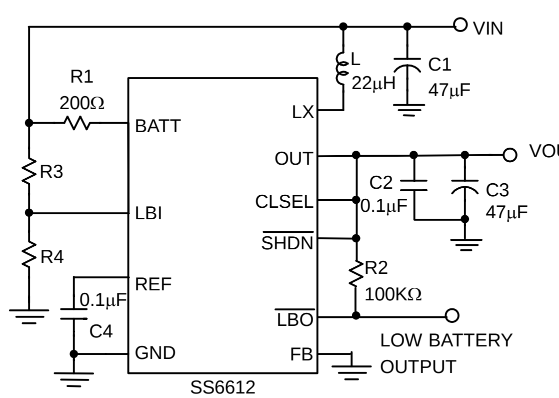


Fig.33 Simplified Damping Switch Diagram



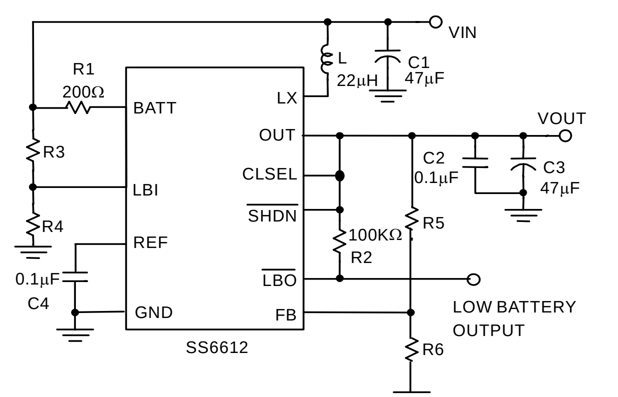
L: TDK SLF7045T-22OMR90
C1, C3: NIPPON Tantalum Capacitor 6MCM476MB2TER

Fig.34 V_{OUT} = 3.3V Application Circuit.



L: TDK SLF7045T-22OMR90
C1, C3: NIPPON Tantalum Capacitor 6MCM476MB2TER

Fig.35 V_{OUT} = 5.0V Application Circuit.



L: TDK SLF7045T-22OMR90
C1, C3: NIPPON Tantalum Capacitor 6MCM476MB2TER
$V_{OUT}=V_{REF}*(1+R5/R6)$

Fig.36 An Adjustable Output Application Circuit

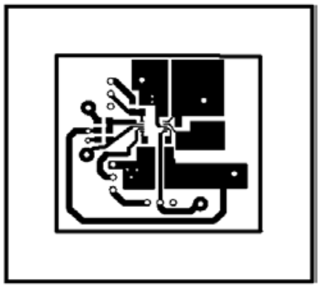


Fig.37 Top layer

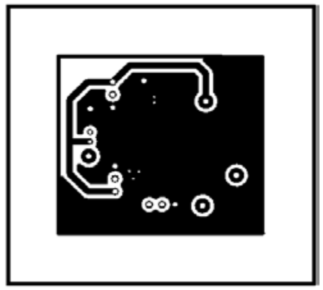


Fig.38 Bottom layer

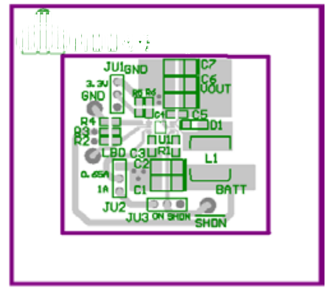
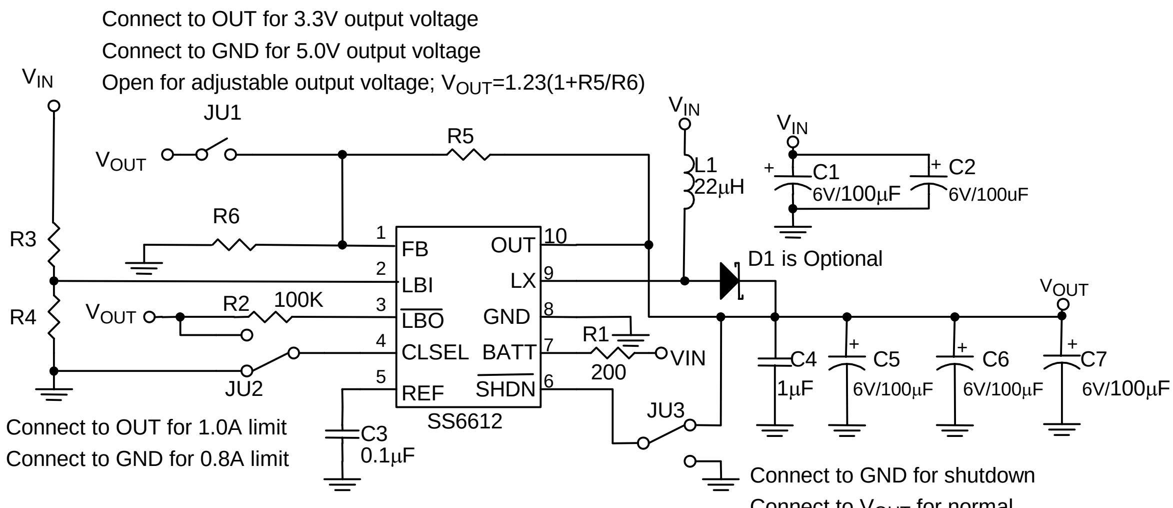


Fig.39 Placement



L1: TDK SLF7045T-22OMR90

C1~C2, C5~7: NIPPON Tantalum Capacitor 6MCM107MCTER

Fig.40 SS6612 application circuit with small ripple voltage

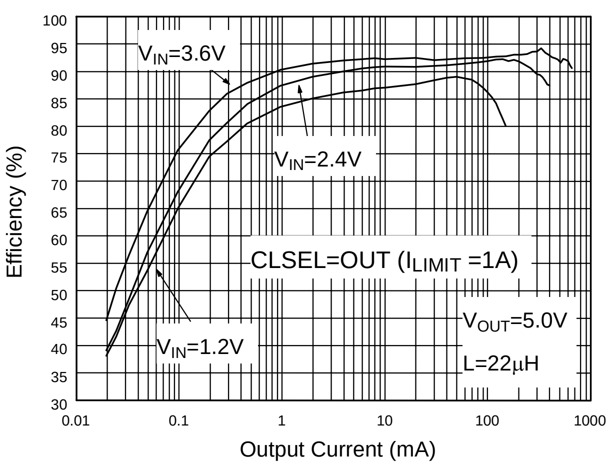


Fig. 41 Efficiency (ref. to Fig.40)

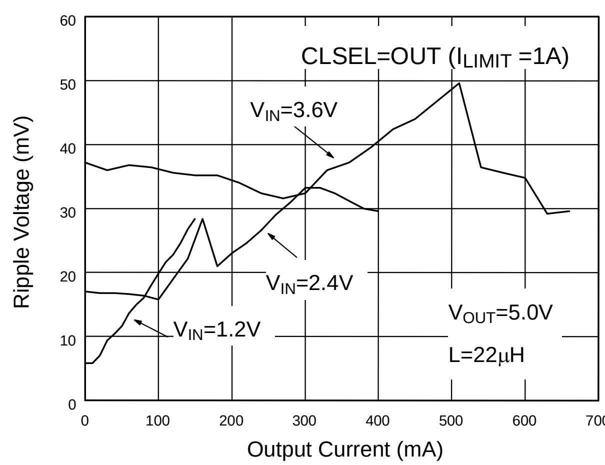


Fig. 42 Ripple Voltage (ref. to Fig.40)

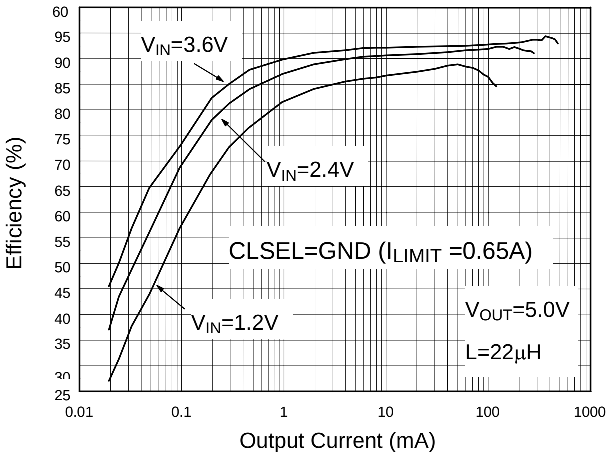


Fig. 43 Efficiency (ref. to Fig.40)

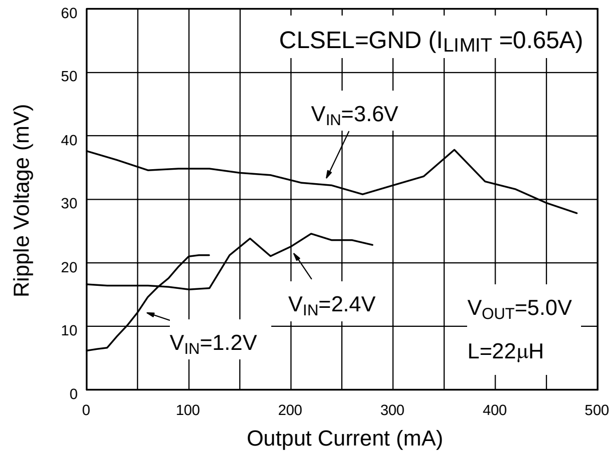


Fig. 44 Ripple Voltage (ref. to Fig.40)

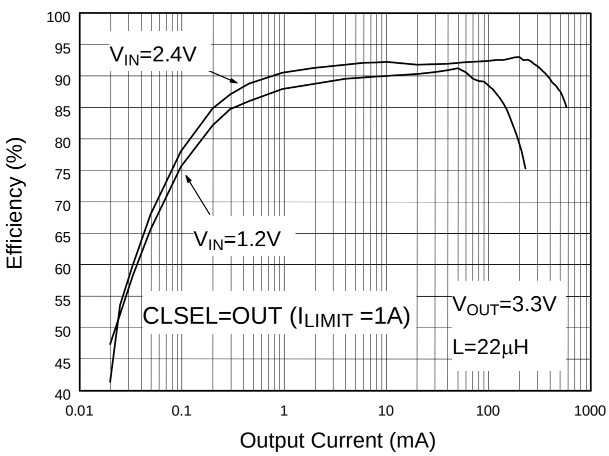


Fig. 45 Efficiency (ref. to Fig.40)

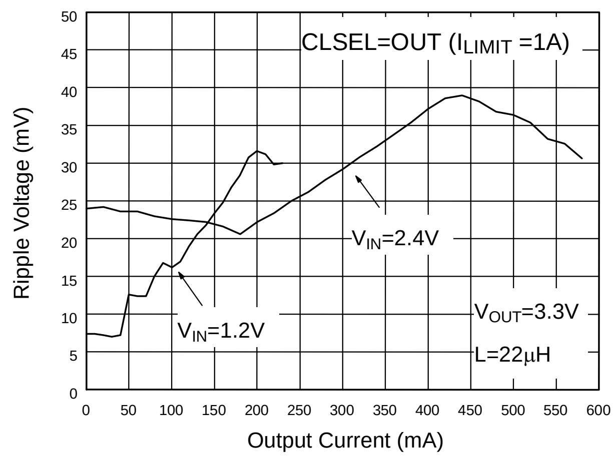


Fig. 46 Ripple Voltage (ref. to Fig.40)

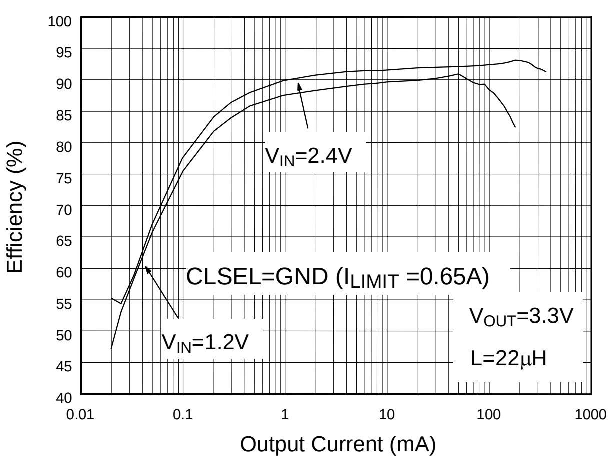


Fig. 47 Efficiency (ref. to Fig.40)

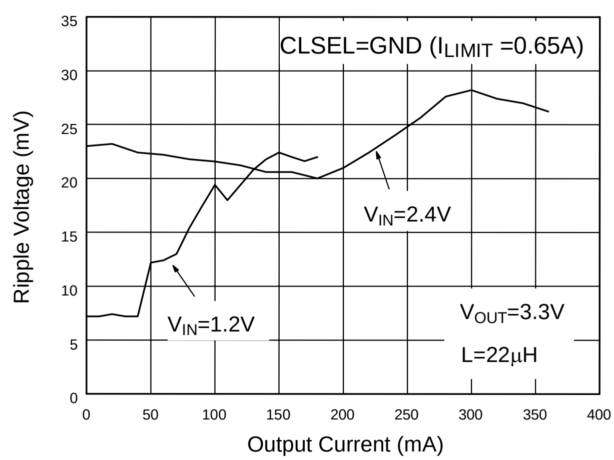
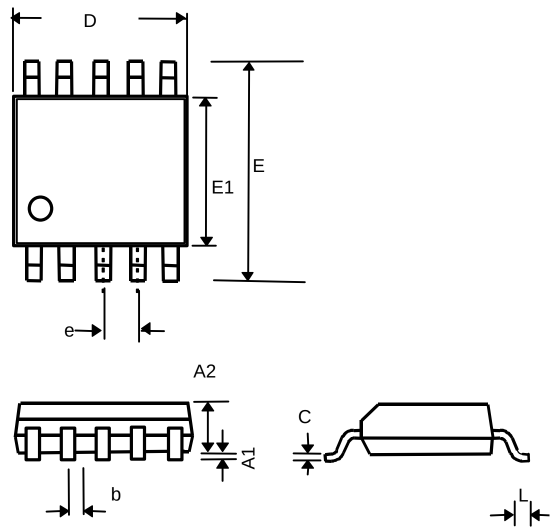


Fig. 48 Ripple Voltage (ref. to Fig.40)

■ PHYSICAL DIMENSIONS

10 LEAD MSOP (unit: mm)



SYMBOL	MIN	MAX
A1	--	0.20
A2	0.76	0.97
b	0.15	0.30
C	0.13	0.23
D	2.90	3.10
E	4.80	5.00
E1	2.90	3.10
e	0.50	
L	0.40	0.66