Micro DC-DC Converter

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1. Introduction

Portable electronic equipment is increasingly requested to provide the apparently conflicting properties of smaller size and greater multi-functionality. Moreover, operation at lower current is also requested in order to reduce power consumption and to extend the duration of continuous battery-powered operation.

The LSI (large scale integrated) circuits used in portable electronic equipment are fabricated with miniaturization processes to run on lower supply voltages, and the power supplies of equipment having just a single Li-ion battery cell (3.6 V) as well as equipment containing two cells (7.2 V) are transitioning from a configuration of a conventional LDO (low drop out regulator) entity toward a configuration based on a DC-DC converter.

So that the battery operation time may be extended as much as possible, power management for the power supply system is needed to turn the power on and off accurately for each LSI circuit acting as a load. For this purpose, a DC-DC converter is required for each power supply to be turned on and off. However, the attachment of a large-size inductor to each DC-DC converter prevents the set from being made smaller and thinner. Moreover, the use of a small-size inductor requires a control IC that operates at high switching frequencies.

This paper describes Fuji Electric's FB6800 series of micro DC-DC converters that integrate a control IC and an inductor, having been developed and commercialized in response to the above-described marketplace requirements of portable electronic equipment.

2. Features

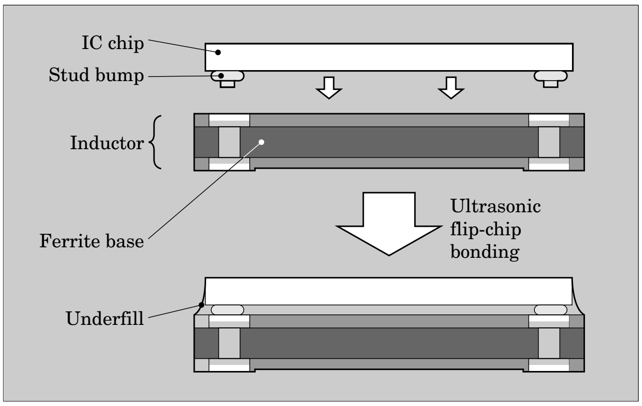
As can be seen in Table 1, the FB6800 series consists of seven types of micro DC-DC converter products that combine an inductor and a control IC which implements buck, boost, or inverted boost voltage conversions.

As shown in Fig. 1, the inductor area of the micro DC-DC converter is fabricated by plating wiring on a ferrite base, and at the same time, pad electrodes necessary for mounting are also formed. The electrode area of the control IC is ultrasonically flip-chip bonded to an inductor.

Table 1 FB6800 series of micro DC-DC converters

Model	Conversion method	Output voltage	Maximum output current	Synchronous/asynchronous	Example applications
FB6813Q	Buck	1.05 to 2.025 V	300 mA	Synchronous rectification	CPU
FB6804Q	Buck	2.5 to 5.15 V	300 mA	Synchronous rectification	I/O
FB6824Q	Buck	2.5 to 5.15 V	300 mA	Asynchronous	I/O
FB6805Q	Buck	3.0 to 3.45 V	600 mA	Synchronous rectification	Motor
FB6825Q	Buck	3.0 to 3.45 V	600 mA	Asynchronous	Motor
FB6806Q	Boost	15.5 to 16.25 V	40 mA	Asynchronous	CCD
FB6807Q	Inverted boost	– 27.0 V input voltage	20 mA	Asynchronous	White LED

Fig.1 Ultrasonic flip-chip bonding



Main features are described below.

(1) External shape

The dimensions of the micro DC-DC converter shown in Fig. 2 are 3.5 mm × 3.5 mm, with a maximum thickness of 1 mm.

(2) Package

As shown in Fig. 3, the use of a 12-pin CSM (chip size module) enables the micro DC-DC converter module to be realized at nearly the same size as the chip itself.

(3) Terminal configuration

The terminal area is configured with an LGA (land grid array) that is not exposed to the package exterior, and which enables the smaller required mounting area.

(4) Inductor: L = 1.64 μH (300 mA), R_{dc} = 0.2 Ω

Ferrite was selected as the base material in order to reduce core loss, and the design was optimized to impede magnetic saturation.

(5) Input voltage

In order to realize high efficiency with a relatively high voltage of 4 to 8.4 V (corresponding to two Li-ion battery cells), an LDD (lightly doped drain) CMOS (complementary metal oxide semiconductor) structure was used and the LDD ion implantation density and dimensions were optimized.

(6) Protection circuit

A protection circuit is built-in to protect against such abnormal conditions as an output short to ground, chip overheating, and UVLO (under voltage lock out), etc. If an abnormal condition is detected, operation is stopped. Setting of the ALERT pin to Low-level releases the protection state, and setting it to High-level restores the protection state.

(7) Switching frequency: 2 MHz

High-speed operation is realized with a design in which the dead time control, driver circuits, high-speed comparator and oscillation circuit were optimized.

(8) Serial interface

A serial interface with the CPU enables the implementation of various settings such as ON/OFF of the power supply operation, output voltage settings, and the like.

(9) Soft-start operation with no time lag

By providing an offset voltage at the input to the comparator for soft-start, the time delay from the receipt of an ON-signal until the start of switching has been reduced.

(10) Low current consumption: 1 μA during standby, 800 μA during operation

Each circuit block has been designed to consume less current so that the portable electronic equipment can realize the necessary lower current consumption.

Main electrical characteristics of the FB6813Q are listed in Table 2.

Fig.2 Appearance of micro DC-DC converter (1)

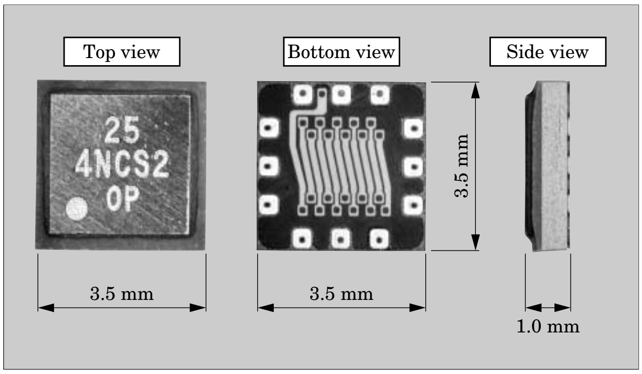


Fig.3 Appearance of micro DC-DC converter (2)

3. Micro DC-DC Converter Module Technology

The micro DC-DC converter assembly utilizes flip-chip bonding.

With an assembly that uses conventional wire bonding, wires extend from the chip to the wire-connecting base, and as a result the inductor becomes larger in size and impedes efforts to save space.

With flip-chip bonding, instead of using wires, stud electrodes known as bumps are fabricated on the IC chip surface for the purpose of forming connections, and are directly mounted to the inductor base.

Bumps are fabricated using wire bonding to form stud bumps as shown in Fig. 4. To fabricate a bump, a gold ball is formed at the tip of a gold wire, that gold

Fig.4 Stud bump photograph

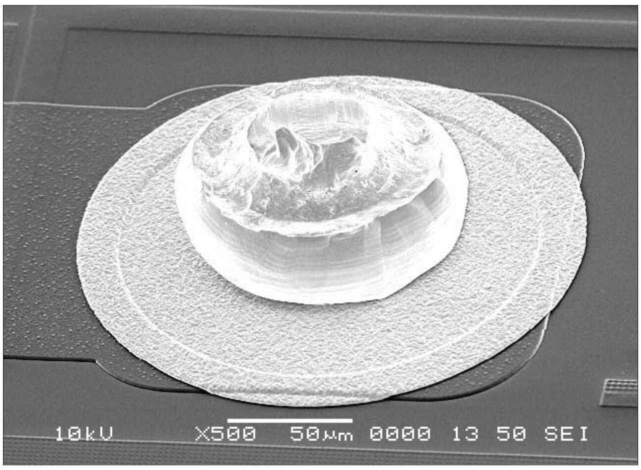


Table 2 Main electrical characteristics of the FB6813Q

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Power supply voltage	V_{IN}	—	3.0	—	8.4	V
Control power supply voltage	V_{DD}	—	2.93	3.0	3.07	V
Output voltage	V_{OUT}	SEL = H, SD = 0010, No load	1.029	1.05	1.071	V
		SEL = H, SD = 0000, No load	1.078	1.10	1.122	V
		SEL = H, SD = 0001, No load	1.127	1.15	1.173	V
		SEL = H, SD = 1000, No load	1.176	1.20	1.224	V
		SEL = H, SD = 1001, No load	1.225	1.25	1.275	V
		SEL = H, SD = 1010, No load	1.274	1.30	1.326	V
		SEL = H, SD = 1011, No load	1.323	1.35	1.377	V
		SEL = H, SD = 0100, No load	1.47	1.50	1.53	V
		SEL = H, SD = 0101, No load	1.519	1.55	1.581	V
		SEL = H, SD = 0110, No load	1.568	1.60	1.632	V
		SEL = H, SD = 0111, No load	1.617	1.65	1.683	V
		SEL = H, SD = 0011, No load	1.666	1.70	1.734	V
		SEL = H, SD = 1100, No load	1.764	1.80	1.836	V
		SEL = H, SD = 1101, No load	1.837	1.875	1.913	V
		SEL = H, SD = 1110, No load	1.911	1.95	1.989	V
		SEL = H, SD = 1111, No load	1.984	2.025	2.066	V
Efficiency	η	V_{IN} = 3.6 V, V_{OUT} = 1.8 V, I_{OUT} = 0.2 A	85	89	—	%
Line regulation	$\Delta V_{OUT}/V_{IN}$	V_{IN} = 4 to 8.4 V, V_{OUT} = 1.5 V, I_{OUT} = 0.3 A	0	—	±1	%
Load regulation	$\Delta V_{OUT}/I_{OUT}$	V_{OUT} = 1.5 V, I_{OUT} = 0 to 0.3 A	0	—	±0.04	mV/mA
Open loop voltage gain	A_V	—	60	—	—	dB
Unity gain bandwidth	f_T	—	1	—	—	MHz
Overheat protection temperature	T_{SD}	—	125	—	150	°C
Oscillation frequency	f_{osc}	—	1.8	2.0	2.2	MHz
Current consumption	I_{VDD}	VDD pin, when off	—	—	1.0	μA
		VDD pin, during operation	—	—	800	μA
	I_{PVDD}	PVDD pin, when off	—	—	1.0	μA

ball is then bonded to an electrode on the IC chip, leveling is performed to align the bump height, and then the wire is cut.

Gold plated electrodes are also fabricated on the surface of the inductor base, and are bonded to the control IC with ultrasonic Au-Au bonding.

Next, the gap between the flip-chip bonded inductor and control IC is coated and filled with underfill material to ensure the bonding strength, and finally the inductor base is diced to form individual micro DC-DC converter chips.

4. Application Circuit

Figure 5 shows a block diagram and Fig. 6 shows an example application circuit of the FB6813Q. This product contains a built-in inductor and output MOS (metal oxide semiconductor), and therefore enables a buck switching power supply to be configured simply with input and output capacitors, and a phase compensation capacitance and resistance as the only external components, thus contributing to space savings of the set.

The following improvements were implemented to realize high efficiency in the FB6813Q.

(1) Control circuit: Dead time control, and lower current consumption and optimization of the oscillation frequency for each block
(2) Output MOS: Optimized high-voltage design for low on-resistance and low gate charge
(3) Inductor: Selection of base material that reduces core loss

After implementing the abovementioned improvements, efficiency was measured when the load and output voltage are changed, and as shown in the example of Fig. 7, a high efficiency of 90 % was realized with an input voltage (V_{IN}) of 3.6 V, an output voltage (V_{OUT}) of 1.8 V and an output current (I_{OUT}) of 180 mA.

By using the newly developed FB6800 series of products, a micro DC-DC converter can be installed in the vicinity of a device acting as a load and a micro processor can implement serial control to turn the power supply on and off, thus enabling the set to be made smaller, thinner, and a distributed system to be

Fig.5 FB6813Q block diagram

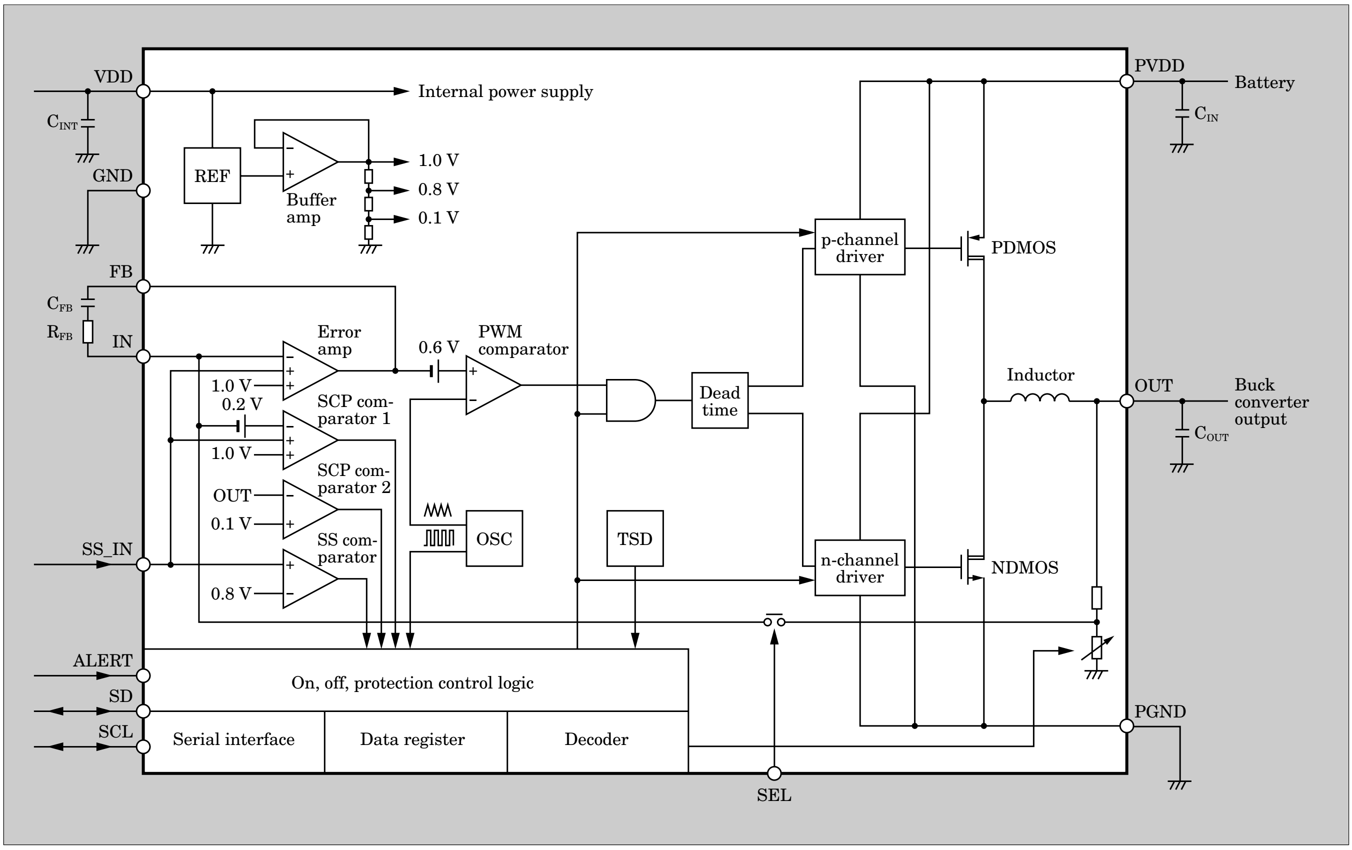


Fig.6 Example of FB6813Q application circuit

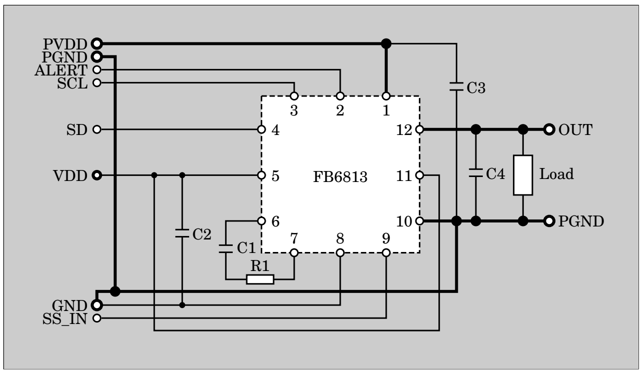
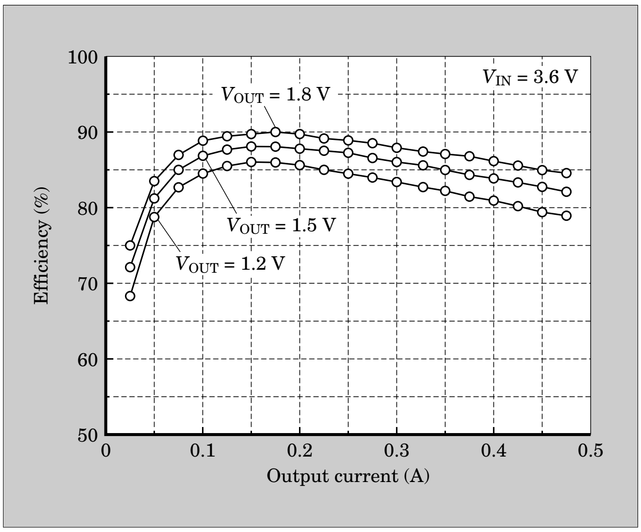


Fig.7 Example of measured efficiency of the FB6813Q



configured that achieves longer battery life.

5. Conclusion

The FB6800 series of micro DC-DC converters developed mainly for applications in DVCs (digital video cameras) and DSCs (digital still cameras) has been introduced.

In the future, Fuji Electric intends to broaden the product line by adding a micro DC-DC converter for a single Li-ion battery cell as used in cellular phones and DSCs, while at the same time, striving to realize higher efficiency and smaller size.

Reference

(1) Hayashi, Z. et al. High-Efficiency DC-DC Converter Chip Size Module with Integrated Soft Ferrite. The 2003 International Magnetics Conference (INTERMAG 2003).