Multiple-Chip Power Device “M-POWER” for Power Supplies

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1. Introduction

Recently, in consideration of the environment, measures to reduce energy dissipation, input current distortion, EMI-noise, etc. have become required in the switching power supplies of telecommunication and home electronic equipment. To address these and the requirements for fail-safe operation, Fuji Electric has developed a power supply that can satisfy these requirements with a one-converter-type supply, and has marketed the M-POWER as application specific multiple-chip power device (Fig. 1).

The power supply that uses M-POWER satisfies energy saving, low-input current distortion and high safety demands while being compact. High efficiency is achieved by applying a novel soft-switching circuit, and low-input current distortion is achieved by using a novel one-converter-type power factor correction (PFC) circuit. Low-dissipation losses while in standby mode are achieved using a standby mode control that operates at a lower switching frequency than that of the normal mode. Fail-safe operation is achieved by various protection functions with latched shutdown.

2. Features

The main features of the Fuji Electric one-converter-type power supply and M-POWER are as follows.
(1) High efficiency by regenerating snubber energy
(2) Standby input power less than 3W (at output power of 1W), Energy 2000 compliant; does not require auxiliary power supply for standby
(3) Input current satisfies the harmonic regulation of IEC 1000-3-2; no active filter circuit required
(4) Low EMI-noise by soft switching operation
(5) Universal input
(6) Various types of protection functions with latched shutdown; a fail-safe power supply can be constructed

3. Power Supply Using M-POWER

3.1 Circuit configuration

Figure 2 shows the circuit configuration of the switching power supply that uses the M-POWER device. This circuit is basically a fly-back converter that operates by constant frequency PWM (pulse width modulation) control and has two notable circuits.

The first circuit is for soft-switching operation. It is comprised of MOSFETs $Q_1$ and $Q_2$, capacitor $C_2$ and winding $N_4$. The main switch $Q_1$ can operate zero-voltage switching using the auxiliary switch $Q_2$. It is a zero-voltage transition type soft-switching circuit (ZVT)[1].

The second circuit is a one-converter-type power factor correction circuit (PFC), and is comprised of reactor $L_1$, diodes $D_1$ and $D_2$, and winding $N_3$ of transformer $Tr$.

Fig.1 External view of M-POWER

Fig.2 Circuit configuration
In Fig. 2, the M-POWER multi-chip power device is comprised of MOSFET Q₁, MOSFET Q₂, and a control IC (the part enclosed with dotted line).

3.2 Soft-switching circuit by zero-voltage-transition method (ZVT)

The soft-switching circuit has three operation modes, which are shown in Fig. 3.

Mode 1 (period T₁ to T₂):
Q₂ is turned on first. The stored electric charge in capacitor C₂ discharges through winding N₄ of transformer Tr. Voltage V_N4 is applied to winding N₄, and voltage V_N₁ is excited in winding N₁. Voltage V_N₁ becomes larger than DC voltage V_C₁, and current iₚ flows through capacitor C₁. A part of the stored electric charge in capacitor C₂ is regenerated in capacitor C₁. Moreover, winding N₄ current i_N₄ becomes the excitation current of Tr. Switch Q₂ operates zero-current switching (ZCS) at turn-on, because the leakage inductance of N₄ causes the Q₂ turn-on current to rise gradually.

Mode 2 (period T₂ to T₃):
After VC₂ becomes 0V, Q₁ turns on. Therefore, Q₁ achieves zero-voltage switching (ZVS). Voltage V_C₁ is applied to winding N₁, and voltage V_N₄ (= V_C₁ × N₄/N₁) is applied to winding N₄. Current i_N₄ is decreased due to the reverse counter voltage V_N₄, and soon becomes 0A. When Q₂ turns off at T₃, Q₂ achieves zero-voltage switching (ZVS).

Mode 3 (period T₄ to T₅):
When Q₁ turns off at T₄, Q₁ achieves zero-voltage switching (ZVS) because C₂, which is connected in parallel to Q₁, is 0V at this time.

The efficiency characteristics are shown in Fig. 4, along with the efficiency characteristic of the RCC, which used capacitor C₂ and the excitation inductance of transformer Tr for resonance. The efficiency of the proposed circuit is 86.4%, and the efficiency of the RCC is 84.3% at an input voltage of 200V, an improvement of 2.1%. Because the RCC ceases to perform ZVS operation when VC₁ becomes larger than the reset voltage of Tr, the turn-on loss increases. Moreover, since the switching frequency of the RCC increases when VC₁ becomes larger, the switching losses increase as well.

3.3 PFC circuit

The PFC circuit is shown in Fig. 5.
(1) The effect of winding N₃
Voltage V_N₃ is generated in winding N₃ when Q₁ is turned off. Current i₃ can flow when the sum of V_N₃ and the rectified input voltage (|V_in| + V_N₃) is larger than 0V.
than $V_{C1}$. As a result, the distortion current of $i_3$ can be lower than that of $i_{inc}$.

(2) The effect of reactor $L_1$

On the other hand, with only winding $N_3$, the PFC effect is reduced when the input voltage $V_{in}$ is higher.

The reactor $L_1$ circuit is added to improve this characteristic. Current $i_3$ can flow through the input supply, through $D_1$, through $L_1$ and to $Q_1$, when $Q_1$ is turned on. Current $i_3$ becomes larger and the PFC effect becomes larger when the input voltage is higher.

The effect of winding $N_2$ is mainly used at lower input voltages and that of reactor $L_1$ is mainly used at higher voltages. As a result, the novel one-converter-type PFC circuit can satisfy the regulations for input current distortion over a wide range of input voltages, such as from 80V to 288V.

The harmonic input currents are shown in Fig. 6, and it can be seen that the input current satisfies the IEC 1000-3-2 regulations.

4. **M-POWER**

4.1 Block diagram and pin functions

The circuit block diagram of the M-POWER device is shown in Fig. 7 and is comprised of MOSFET $Q_1$, MOSFET $Q_2$, and a control IC. Pin functions are shown in Table 1. Through the use of multiple function pins, the M-POWER achieves a compact construction with only 7 pins, a relatively small number of pins.

4.2 Control IC

Features of the control IC are as follows.

(1) Current mode PWM control IC
(2) Contains 2 output stages for driving MOSFETs $Q_1$ and $Q_2$; has a function to turn $Q_2$ on about 300ns faster than $Q_1$.
(3) Low-power dissipation due to C-MOS (Complementary MOS) fabrication process
(4) UVLO (undervoltage lockout) with hysteresis

4.3 Output stages

The output stages of the control IC have a built-in C-MOS inverter construction, thereby enabling the gate voltages of MOSFETs $Q_1$ and $Q_2$ to fully swing to the applied voltage at the $V_{cc}$ pin. Output stages are directly connected to the gates of MOSFETs $Q_1$ and $Q_2$ and the resistance between drain and source of the C-MOS inverter contributes to gate resistance. So both

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Fig.6 Harzmonic currents

Fig.7 M-POWER circuit block diagram
the impedance between the output stage and the MOSFET gate, and the inductance of the wiring are very small. The delay time when driving the MOSFET is very short and IC malfunctions seldom or never occur.

4.4 Power saving standby mode operation

The M-POWER device has a standby mode operation function, which reduces the switching frequency (20kHz) to lower than the normal switching frequency in order to reduce switching losses. Operation at the time of a change from the normal mode to the standby mode is shown in Fig. 8. When Vcc (supply voltage of IC) is set to 15V, the circuit operates in the normal mode. When Vcc is set to 12V, the circuit operates in the standby mode at a lower switching frequency (20kHz).

Figure 9 shows the dissipation losses when output power \( P_0 = 1 \text{W} \), and for the sake of comparison, dissipation losses of the RCC. With ZVT operation, the dissipation losses can be reduced to 1.5W, as compared to 3.5W for the RCC. Recently, it has become common to use an additional power supply that operates only in standby mode. However, the M-POWER system does not use an additional power supply, and as a result is compact and inexpensive.

4.5 Protection functions

Protection functions of the M-POWER device are listed in Table 2. The M-POWER device has four types of protection functions: over current protection (OC), short-circuit protection (SC), Vcc over voltage protection (OV) and over heating protection (OH). Each function is equipped with a latched shutdown function. In the case of OC, the current is limited pulse-by-pulse.

Moreover, the latched shutdown function of OC, OV and OH has a built-in timer of about one-second. If an abnormal operation continues for approximately one-second, the latched shutdown function operates. This function keeps the output voltage of the control IC low and absolutely halts all MOSFET switching.

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**Table 1 Pin functions**

<table>
<thead>
<tr>
<th>Terminal No.</th>
<th>Symbol</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D1</td>
<td>Drain of main MOSFET</td>
<td>Drain of main MOSFET</td>
</tr>
<tr>
<td>2</td>
<td>D2</td>
<td>Drain(sub MOSFET)</td>
<td>Drain(sub MOSFET)</td>
</tr>
<tr>
<td>3</td>
<td>S</td>
<td>Source of main MOSFET</td>
<td>Source of main MOSFET</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source of sub MOSFET</td>
<td>Source of sub MOSFET</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current sensing</td>
<td>Input voltage proportional to inductor current Detection of over-current current</td>
</tr>
<tr>
<td>4</td>
<td>Vcc</td>
<td>Power supply input</td>
<td>Power supply input Setting to 15V normal mode operation Setting to 12V standby mode operation</td>
</tr>
<tr>
<td>5</td>
<td>GND</td>
<td>Ground GND current supply</td>
<td>GND of IC power supply GND of current sensing</td>
</tr>
<tr>
<td>6</td>
<td>Fc</td>
<td>Oscillator control</td>
<td>Setting oscillation frequency with capacitor which is connected between Fc-GND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Synchronized signal input</td>
<td>Synchronized operation is started when Fc terminal voltage has fallen to OV</td>
</tr>
<tr>
<td>7</td>
<td>COMP</td>
<td>Feedback</td>
<td>Input feedback signal from the secondary side</td>
</tr>
</tbody>
</table>

**Table 2 Protection functions of the M-POWER**

<table>
<thead>
<tr>
<th>Protection function</th>
<th>Detecting element</th>
<th>Detection level</th>
<th>Latched shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over current (OC)</td>
<td>Voltage of 3-5pin</td>
<td>Voltage of over current ( V_{OC} ) : 0.90V(typ.)</td>
<td>1 sec Timer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulse-by-pulse current limiting voltage ( V_{PP} ) : 0.95V(typ.)</td>
<td>–</td>
</tr>
<tr>
<td>Short circuit (SC)</td>
<td>Voltage of 3-5pin</td>
<td>Short circuit current limiting voltage ( V_{SC} ) : 1.50V(typ.)</td>
<td>1 time</td>
</tr>
<tr>
<td>Over voltage (OV)</td>
<td>Voltage of 4-5pin</td>
<td>Over voltage threshold voltage ( V_{TH} ) : 22V(typ.)</td>
<td>1 time</td>
</tr>
<tr>
<td>Over heating (OH)</td>
<td>Temperature of control IC</td>
<td>Operating temperature ( T_{J} ) : 150°C(max.)</td>
<td>1 sec Timer</td>
</tr>
</tbody>
</table>
Therefore, a fail-safe power supply can be constructed using the M-POWER device.

4.6 Package
The M-POWER's package is shown in Fig.10. Features of the package are as follows.
(1) Same dimensions as the TO-3PL size.
(2) The heat dissipation of Q1, which generates the most heat, was carefully considered in the design and the construction was devised to move the frame for Q1 to the backside. By construction the frame for Q2 and the control IC, which generate little heat, as a full-molded design, heat dissipation and insulation of each chip is secured.
(3) Without wiring boards, such as a ceramic board, each chip is mounted on a separate frame and is connected with Al-wire. The structure is designed to be both simple and highly reliable.

4.7 Product series
The drain-source breakdown voltage ($V_{DS}$) is designed to be compatible with a universal input. The product series of M-POWER devices, as listed in Table 3, combines drain-source on-state resistance ($R_{DS(on)}$), the voltage of start threshold and the operating temperature of over heating protection ($T_{j(OH)}$).

5. Conclusion
The one-converter-type power supply and the M-POWER device, both developed by Fuji Electric, have been introduced. Through their use, high efficiency, low dissipation loss at standby mode, low input distortion, small size and fail-safe power supplies can be constructed. We are confident that the M-POWER will contribute to the energy savings of power supplies.

In the future, we will develop a series of devices for a wide range of applications, and make the products easier to use.

Reference

<table>
<thead>
<tr>
<th>Type name</th>
<th>Main-MOSFET</th>
<th>Sub-MOSFET</th>
<th>Control IC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_{DS}$</td>
<td>$R_{DS(on)}$</td>
<td>$V_{CC(ON)}$</td>
</tr>
<tr>
<td>F9202LA</td>
<td>700V</td>
<td>1.2Ω</td>
<td>800V</td>
</tr>
<tr>
<td>F9203LA</td>
<td>700V</td>
<td>0.8Ω</td>
<td>800V</td>
</tr>
<tr>
<td>F9206L</td>
<td>700V</td>
<td>1.2Ω</td>
<td>800V</td>
</tr>
<tr>
<td>F9207L</td>
<td>700V</td>
<td>0.8Ω</td>
<td>800V</td>
</tr>
<tr>
<td>F9208L</td>
<td>700V</td>
<td>0.8Ω</td>
<td>800V</td>
</tr>
</tbody>
</table>
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