Two-channel Current Mode Synchronous Buck Regulator Control IC

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1. Introduction

Recently, digital home appliances such as digital televisions, DVD (digital versatile disk) players and DSCs (digital still cameras) have grown in popularity. In particular, in Japan, the transition to digital terrestrial broadcasting which began in 2003 is expected to be complete for all television broadcasts by 2011.

This paper introduces Fuji Electric's FA7731F, a 2-channel current mode synchronous buck regulator control IC developed for use with a CPU as a power supply for the tuner unit in digital televisions, which are rapidly growing in popularity.

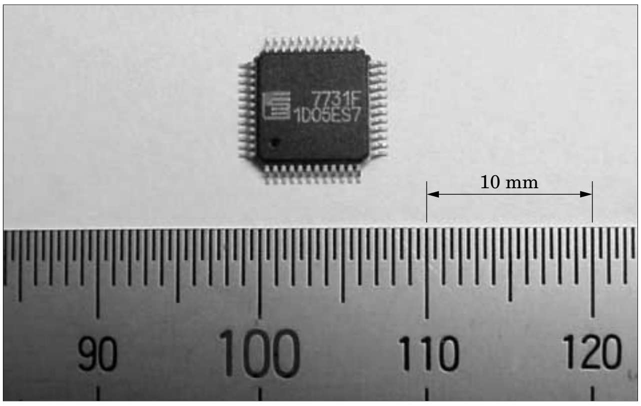
2. Product Overview

Figure 1 shows the appearance of Fuji Electric's newly developed and commercialized power supply control IC.

2.1 IC features

In order to build digital television tuners that are more compact in size and less expensive, even the power supply system is increasingly being required to use fewer parts, dissipate less power, and to be less expensive. In digital television tuner applications, in order to supply a low-voltage and high-current to the CPU (acting as a load) from a relatively high voltage of approximately 7 to 14 V, a synchronous buck regulator control IC that has a large power dissipation capacity and contains a high-voltage low on-resistance output MOSFET (metal oxide semiconductor field-effect transistor) is needed. However, since no IC on the market has specifications that meet such requirements, Fuji Electric took the initiative to lead its competitors and develop such a commercial IC.

Fig.1 Appearance of the FA7731F



The features of this IC are described below. Firstly, it has excellent high-speed response to fluctuations in the load. The CPU, acting as a load, causes large fluctuates in the load, and a current mode control system and a synchronous rectification output system are used to suppress those fluctuations instantaneously. Secondly, it is compact. To realize a more compact size of the power supply, four power MOSFETs for two channels are all integrated into the power supply control IC. Thirdly, it is inexpensive. An output voltage detection resistor and a feedback resistor and capacitor for an error amplifier, which were previously attached externally, have also been integrated into the power supply control IC.

The IC is housed in a compact, thin and high-power dissipating TQFP48 pin (exposed pad) package. Specifications of the power supply control IC are listed in Table 1.

2.2 Operation

Figure 2 shows the circuit block diagram of the FA7731F. The operation of each circuit block is described below.

(1) ON_OFF circuit

The entire power supply can be controlled to turn on or off by switching the ON_OFF pin. When turned off, the current consumption of the power supply control IC is 8 μA, and a standby current can be realized.

(2) Oscillator circuit

The oscillation frequency of the power supply control IC is set to an arbitrary frequency between 100 and 400 kHz by connecting a resistor ranging from 18 to 82 kΩ between the RT pin and ground. The phase difference between the frequencies of channels 1 and 2 is 180 degrees. As a result, the size of the input capacitor can be reduced.

Table 1 Specifications of the FA7731F

Input voltage		7 to 14 V
Output voltage		≥1 V
No. of output channels		2
Switching control system		Current mode
Switching frequency		100 to 400 kHz
Rectification system		Synchronous rectification with internal output power MOSFETs
Phase difference between channels		180 degrees
Slope compensation		Adjusted with external resistor
Operation mode control	ON/OFF control	Switches ON/OFF entire power supply
	CS1 control	Switches ON/OFF channel 1
	CS2 control	Switches ON/OFF channel 2
Compensation parts for error amplifier	Internal	Built-in
	External	Can be attached to FB pin
Voltage detection	Internal	1.5 V (switched by SEL pin)
		1.2 V (switched by SEL pin)
	External	Arbitrary (switched by SEL pin)
Protection function	Soft-start	Adjusted with external capacitor
	Timer latch	Adjusted with external capacitor
	UVLO	6.5 V (on), 6.0 V (off)
	Overcurrent protection	4.5 A
	Overheat protection	145°C
Package		TQFP48 pin (exposed pad) ($\theta_{j\text{-}a}$ = 25.9°C)

Fig.2 Circuit block diagram

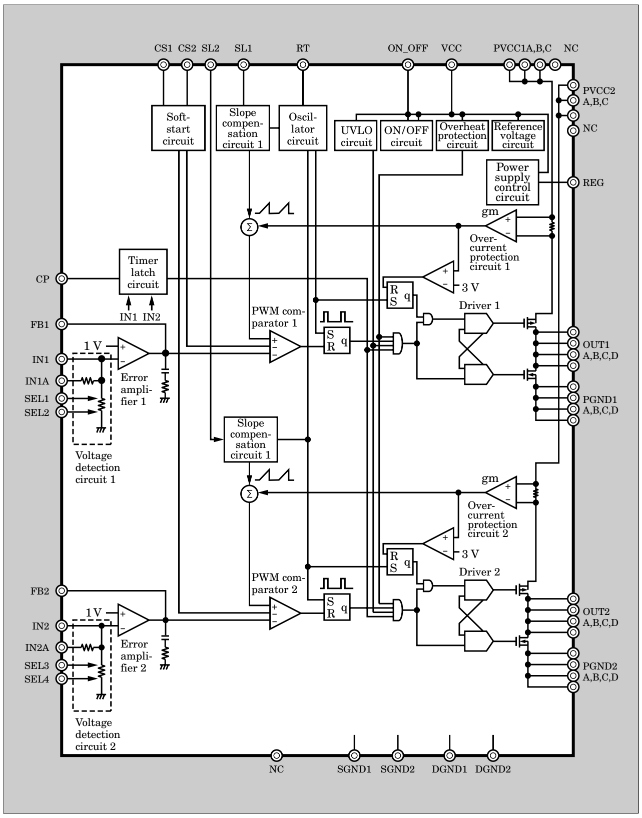


Table 2 SEL pin vs. output voltage

Channel	Output voltage	SEL1	SEL2	SEL3	SEL4
1	Arbitrary	Ground	Open		
	1.5 V	Ground	Ground		
	1.2 V	Open	Ground		
2	Arbitrary			Ground	Open
	1.5 V			Ground	Ground
	1.2 V			Open	Ground

(3) Slope compensation circuit

With peak current mode PWM (pulse width modulation) control, subharmonic oscillation may occur at duty cycles of 50 % or above. In order to avoid this phenomenon, SL pins are provided separately for channel 1 and channel 2. By connecting a resistor of 10 to 50 kΩ between the SL pin and ground, a compensating signal is automatically generated inside the IC and subharmonic oscillation can be avoided.

(4) Soft-start circuit

Each channel is provided with a soft-start circuit. An internal current source is built into the CS pin, enabling the soft-start period of the power supply to be adjusted by changing the value of an external capacitor.

(5) Timer-latch short-circuit protection circuit

This circuit monitors the input voltages to the error amplifier of each channel, and if a state in which the input voltage to either channel is 0.2 V lower than the usual voltage (1.0 V) continues for the duration of time that exceeds the setting period of the timer latch circuit, the driver outputs of both channels are stopped simultaneously. Similar to the CS pin, the CP pin also contains an internal current source and the timer latch setting time can be adjusted to an arbitrary value by changing the value of an external capacitor.

(6) Overheat protection circuit

If the IC temperature is at least 145°C for a duration of time that exceeds the setting period of the timer latch circuit, the overheat protection circuit stops the driver outputs of both channels simultaneously.

(7) Undervoltage lockout (UVLO) protection circuit

If the supply voltage (VCC) drops to 6.0 V or less, this protection circuit stops the driver outputs of both channels simultaneously. If VCC recovers to a voltage of at least 6.5 V, the power supply is automatically restored.

(8) Pulse-by-pulse overcurrent protection circuit

This circuit monitors the current flowing to the main MOSFET in each channel, and if that current increases to 4.5 A or above, turns off the main MOS

FET and provides a pulse-by-pulse overcurrent function.

(9) Output voltage detection circuit

The output voltage detection circuit is capable of switching between three modes by switching the four SEL pins (SEL1 to SEL4). Table 2 lists the correspondence between the SEL pins and output voltage. Detection of the output voltages of 1.2 V and 1.5 V is implemented using the IC's internal detection resistor. A mode for detecting arbitrary voltages is supported with externally attached detection resistors.

(10) Setting pin for feedback resistor and capacitor of error amplifier

Compensation parts for the error amplifier are built-in, thus simplifying the design of the power supply. The compensation provided by these built-in parts can be changed by adding capacitance and resistance in series between the FB pin and ground.

3. Application Circuit

3.1 Circuit configuration

Figure 3 shows an example application circuit for the FA7731F. In this example, the supply voltage is 9 V, the channel 1 output is 1.2 V and the channel 2 output is 1.5 V. There are a total of nine externally connected chip capacitor and chip resistor parts, and since the power MOSFET is integrated inside the IC instead of connected externally as in the past, the circuit configuration is extremely compact and simple.

Fig.3 Application circuit example

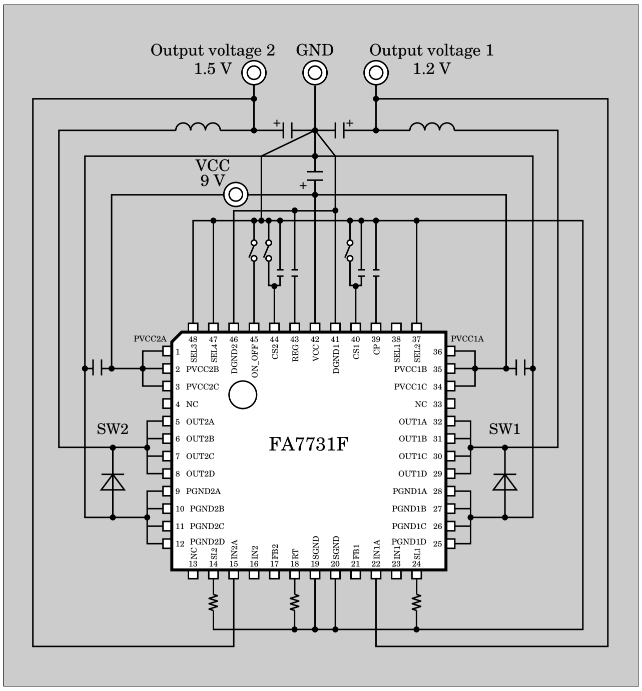


Table 3 ON resistance of internal power MOSFETs

Channel	Device	ON-resistance (Ω)
1	PMOSFET	0.3
	NMOSFET	0.2
2	PMOSFET	0.4
	NMOSFET	0.1

3.2 Efficiency characteristic

The output power MOSFETs of both channels are configured as synchronous rectification systems in order to increase efficiency. Table 3 lists the on-resistance of the internal power MOSFETs of each channel. Figure 4 shows the efficiency characteristic of channel 1 when channel 2 switching has been stopped. Similarly, Fig. 5 shows the efficiency characteristic of channel 2 when channel 1 switching has been stopped. Figures 4 and 5 show that efficiency of greater than 90 % can be obtained when the output voltage is 5 V.

Fig.4 Efficiency of output voltage 1

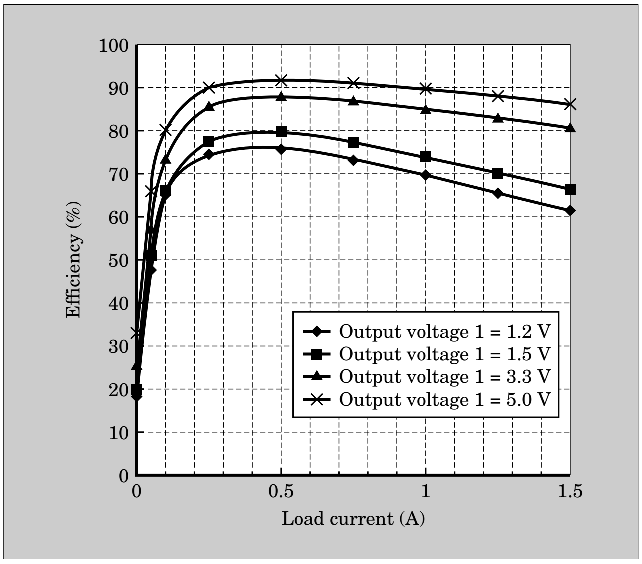


Fig.5 Efficiency of output voltage 2

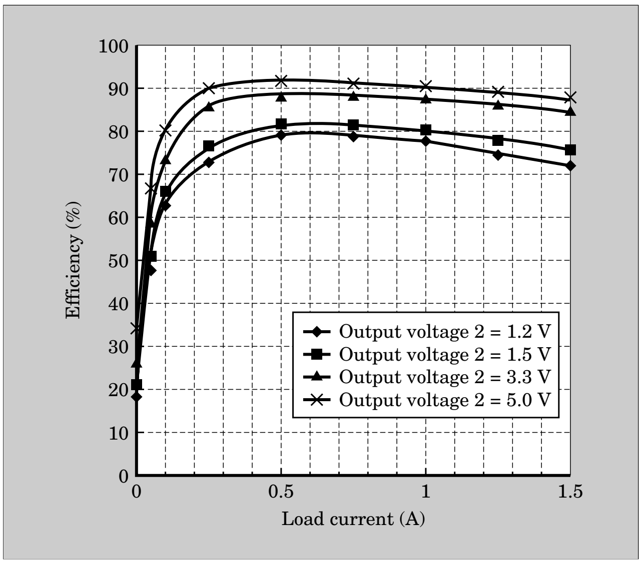


Fig.6 Drain-to-source voltage waveforms of synchronous rectification-side MOSFETs

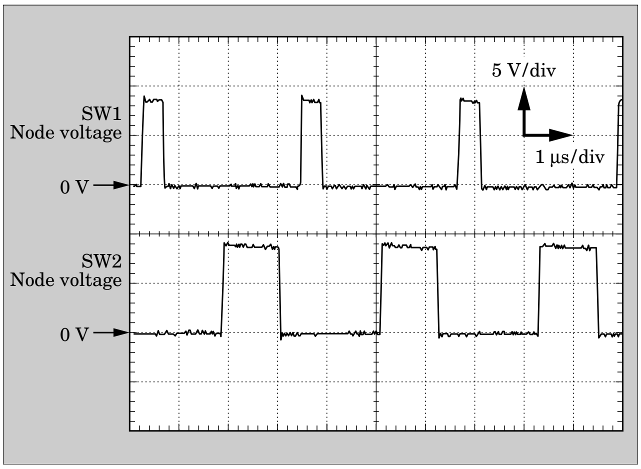
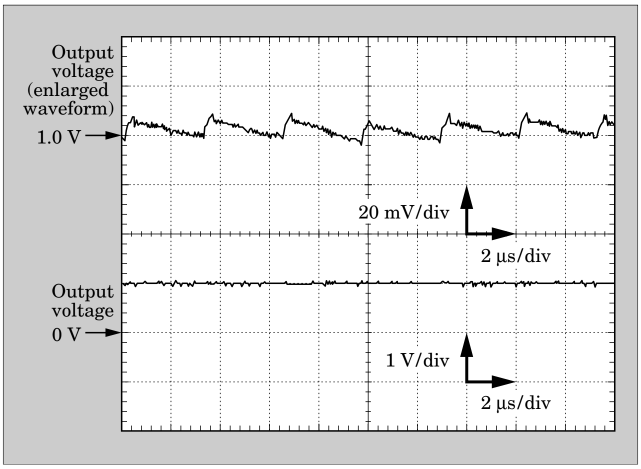


Fig.7 Steady state output voltage waveforms when output voltage is set to 1.0 V



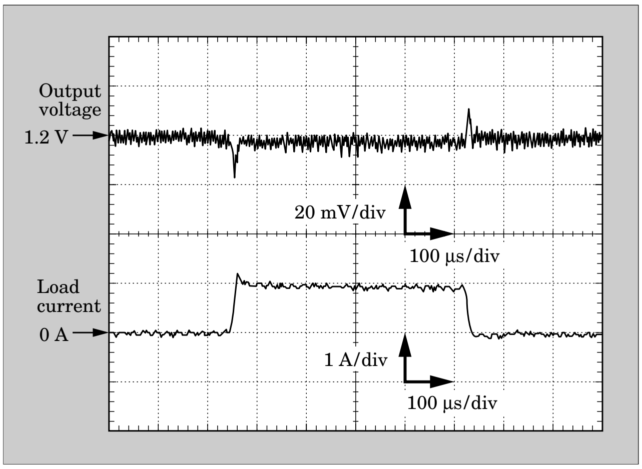
3.3 Two-phase operation

Both channels have the same frequency, but their phases differ by 180 degrees. Figure 6 shows the drain-to-source voltage waveforms of synchronous rectification-side MOSFETs when both channels are operating. From Fig. 6 it can be seen that by shifting the operation of both channels by 180 degrees, the peak input ripple current is reduced to half the value of the peak current during synchronous operation, and the RMS current of the input capacitor is reduced drastically, thereby enabling the size of the input capacitor to be reduced.

3.4 Characteristic of low output voltage

Output voltage detection has two modes, an external mode and an internal mode. In the case of the internal mode, the lowest output voltage is 1.2 V. In the case where use of an even lower voltage is desired, by configuring the SEL pins to set the voltage detection resistor to external mode and setting the externally attached voltage detection resistor to an appropriate value, the output voltage can be adjusted to any arbitrary value of 1.0 V and above. Figure 7 shows the steady state output voltage waveforms when input voltage and output voltage are set to 9.0 V and 1.0 V respectively.

Fig.8 Transient state output voltage waveforms in response to 1 A load fluctuations when output voltage is set to 1.2 V



3.5 Characteristic when load fluctuates

In order to provide stable supply voltage, the DC-DC converter control system employs a current mode system having excellent stability. Figure 8 shows the transient state output voltage waveforms when the output voltage is set to 1.2 V. In response to 1 A step-up and step-down load fluctuations, an excellent transient state characteristic is exhibited with output fluctuations of 20 mV or less and extremely small load fluctuations.

4. Conclusion

This paper has presented an overview of Fuji Electric's 2-channel current mode synchronous buck regulator control IC that contains built-in power MOSFETs.

With the rapid proliferation of digital home appliances, the power supplies in those products are increasingly being required to provide higher performance and smaller size, and to be less expensive.

In response to these marketplace requirements, Fuji Electric remains committed to lowering the on-resistance of power MOSFETs, to reducing the part count by eliminating external Schottky barrier diodes and external capacitors such as used in the soft-start and timer latch circuits, and to raising the quality of and providing more compact and less expensive power supplies.

Reference

(1) Middlebrook, R. D. Topics in Multiple-Loop Regulators and Current-Mode Programming. IEEE Transactions on Power Electronics. vol.PE-2, no.2, 1987-04.