“FA6C00 Series” 4th-Generation LLC Current Resonant Control ICs

KOBAYASHI, Yoshinori* TANAKA, Kiminori* MORIMOTO, Toshimitsu*

ABSTRACT

Switching power supplies for electronic devices are being required to improve efficiency and reduce system costs. Fuji Electric has developed the “FA6C00 Series” 4th-generation LLC current resonant control ICs, which improve efficiency at light loads and help reduce the number of power supply components. This series uses high-frequency burst control at light loads, several watts to several tens of watts, thereby improving efficiency by about 10% compared with conventional products. Furthermore, it utilizes resonant current phase ratio control to improve output response characteristics, reducing seven phase compensating parts. Using these ICs allows users to improve the efficiency in 75- to 300-W equipment, such as LED lighting power supplies, standard industrial power supplies, and consumer power supplies for LCD TVs, while reducing their system costs.

1. Introduction

The switching power supplies used in electronic devices need to achieve not only cost savings, but also high efficiency and low noise. Therefore, high-efficiency and low-noise LLC current resonant circuits have been widely utilized in switching power supplies with an output power of 75 to 300 W.

Up until recently, their power consumption in standby mode has been less than a few hundred milliwatts. However, due to the spread of the Internet of Things (IoT), various electronic devices are now connected to the Internet, and this has increased power consumption in standby mode to the extent that it is now considered a light load ranging from several watts to several tens of watts. As a result, it has been necessary to improve the efficiency of power supplies at light loads.

Fuji Electric has launched LLC current resonant control ICs, such as the “FA5760,” which is suitable for a small power supply, supporting a wide range of input voltages of 85 to 264 V AC; the “FA6A00,” which consumes low standby power; and the “FA6B20,” which featurs a built-in funcrion of automatic switchng to the standby mode, contributing to reducing the number of components of a switching power supply.

Recently, we have developed the “FA6C00 Series” as a 4th-generation LLC current resonant control IC capable of further improving power supply efficiency at light loads and reducing the number of power supply components (see Fig. 1).

In this paper, we will provide an overview of the “FA6C00 Series” while also describing its features and application effects.

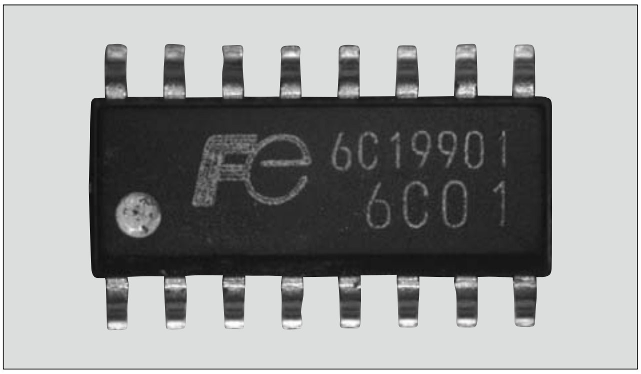

Fig.1 4th-generation LLC current resonant control IC

2. Product Overview and Features

In addition to inheriting the low standby power features of conventional products, this series of ICs utilizes high-frequency burst control to reduce noise at light loads and improve efficiency over a wide range of loads.

Furthermore, by adopting a new method of resonant current phase ratio control and improving output response characteristics, it facilitates cost savings for power management systems by reducing the number of phase compensation components necessary for stable operation.

It also makes it possible to increase efficiency and save system cost for various types of power supplies with 75 to 300 W, such as power supplies for LED lighting, standard power supplies for industrial applications, and consumer power supplies for LCD TVs. Figure 1 shows the external appearance of the “FA6C00 Series,” and Fig. 2 the block diagram, and Table 1 the main specifications.

The FA6C00 Series consists of a control circuit for

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* Electronic Devices Business Group, Fuji Electric Co., Ltd.

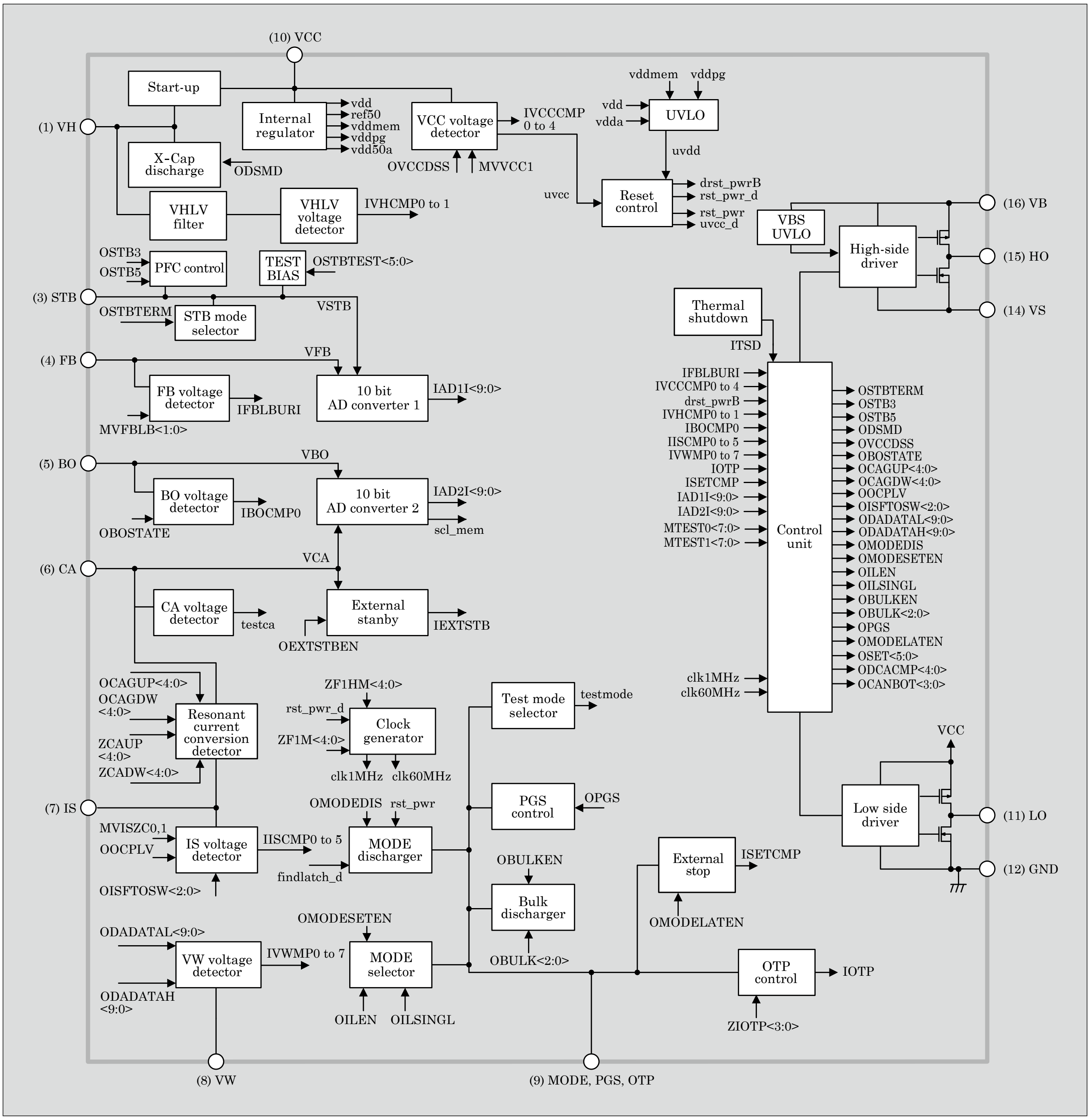


Fig.2 Block diagram of “FA6C00 Series”

Table 1 Main specifications

Item	Rating
High side floating absolute voltage	−0.3 to +780 V
High side floating supply voltage ($V_{BS} = V_B - V_S$)	−0.3 to +30 V
Low-side power supply voltage V_{CC}	−0.3 to +40 V
VH pin input voltage	−0.3 to +650 V
Light-load efficiency ($P_o = 11$ W)	78.9%
Operating junction temperature (Depends on the series)	−40 to +150 °C
	−60 to +150 °C

controlling the LLC current resonant circuit, a drive circuit with a breakdown voltage of 780 V capable of directly operating the metal-oxide-semiconductor field-effect transistor (MOSFET) employed as a high-side switching device for the half-bridge circuit, and a start-up device with a breakdown voltage of 650 V for starting the IC at low power consumption.

The package adopts a JEDEC compliant 16-pin small outline package (SOP).

Both the high-side and low-side outputs operate alternately at a 50% duty ratio, while typically operating at frequencies up to approximately 250 kHz.

The function of pin 9 can be selected from the power good signal output (PGS pin), protection by external-signal input (MODE pin) or thermistor connection (OTP pin).

3. Main Functions and Characteristics

3.1 High-frequency burst control

Conventional types of operation include normal operation for continuous switching control and standby operation for burst control during intentional switching stoppage periods. It also has an automatic standby function for monitoring input current and automatically switching between these two operations. In particular, this function detects the resonant current of the primary-side LLC current resonant circuit using the IS pin and smooths the voltage from the CA pin with a capacitor to detect secondary-side load amounts, thereby switching operations. However, there was also a problem in that efficiency lower due to the excitation current of the transformer when performing continuous switching control at a load range between approximately 5 to 30 W. At the same time, when burst control is performed to improve efficiency, output voltage ripple increases as the resonant current peak value rises. As a result, unstable operation would occur on a load side equipment. Moreover, another problem existed in that the faster burst cycle would generate audible noise from the power supply transformer. Therefore, the FA6C00 Series utilizes a new high-frequency burst control method in between the load regions with continuous switching control and burst control (low-frequency burst control) in order to achieve high efficiency while suppressing output voltage ripple and transformer audible noise at light loads.

Figure 3 shows the operating principle of high-frequency burst control. This control method monitors resonant voltage and resonant current and controls turn-off timing with three pulses. The first pulse (LO) creates a state in which the second pulse (HO) can resonate and turns off at the resonant voltage threshold voltage V_{Pth1}. The second pulse (HO) transmits power and turns off at the resonant voltage threshold voltage V_{Pth2}. The third pulse (LO) turns off at the resonant current threshold voltage I_{Crth3}.

Figure 4 shows the external circuit configuration for detecting resonant voltage and resonant current. The resonant voltage is detected using auxiliary winding wire (VW pin), and the resonant current is detected using a shunt circuit (IS pin). Since this is the same detection method as that of the forced turn-off function, high-frequency burst control can be performed using the existing circuit without needing to add a new external circuit.

Figure 5 shows the operating waveform of high-frequency burst control. Current flows to the secondary diode only when the second pulse is on.

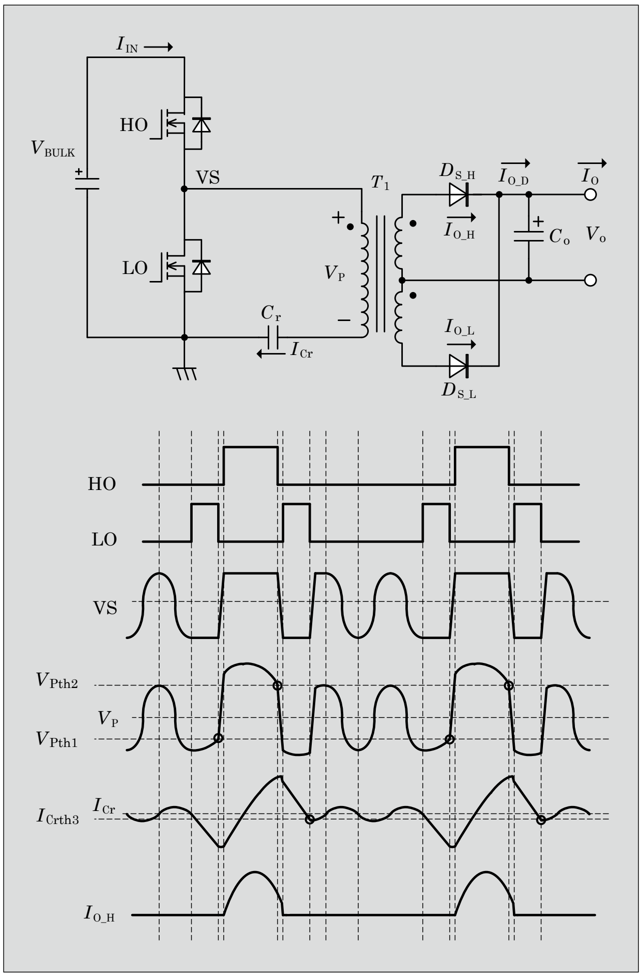


Fig.3 Operating principle of high-frequency burst control

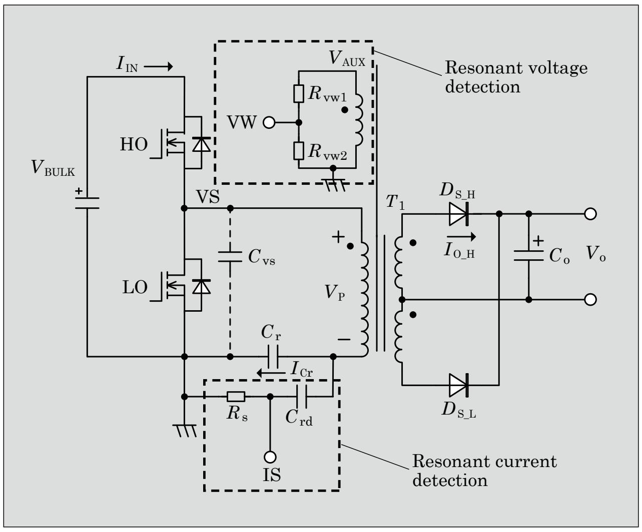


Fig.4 Configuration of external circuit

Controlling the on-width of the second pulse will determine the peak value of the current, thereby controlling the amount of power to be transmitted, and then burst frequency is determined. Since the on-width and burst frequency are controlled optimally based on the load amount, power can be transmitted without waste while also improving efficiency. Fur-

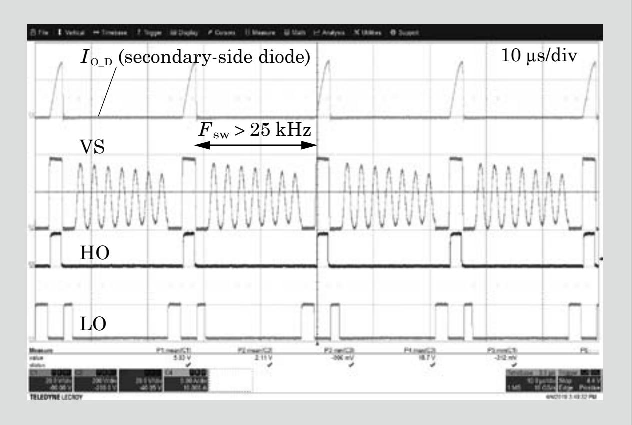


Fig.5 Operating waveform of high-frequency burst control

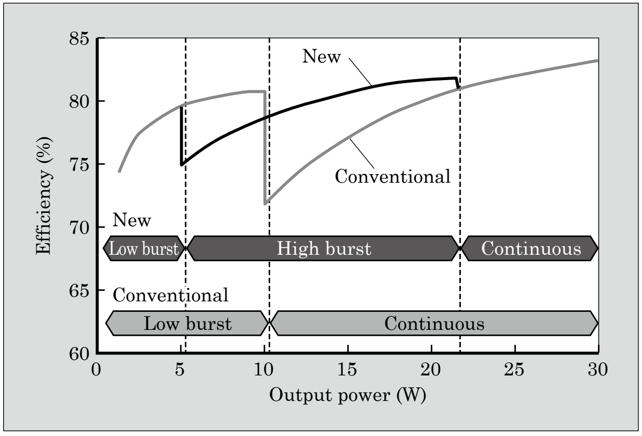


Fig.6 Efficiency and IC control method

thermore, the burst frequency is limited to 25 kHz or higher, thereby exceeding the audible frequency. This suppresses both transformer noise and output voltage ripple.

Figure 6 shows the operation and efficiency of the IC when using high-frequency burst control. Control method at a load range of 10 to 22 W to reduce transformer audible noise was changed from continuous switching control to high-frequency burst control in which switching is performed at 25 kHz or higher, also improving efficiency.

3.2 Resonant current phase ratio control

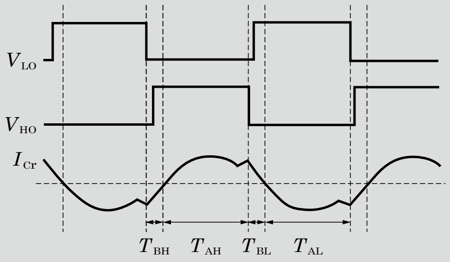
Fuji Electric's LLC current resonant control ICs have conventionally provided feedback control for the output voltage by inputting the secondary-side output voltage of the power supply into the FB pin and modulating the oscillation frequency during normal operation according to the input voltage.

The FA6C00 Series utilizes a new resonant current phase ratio control method. This control reduces phase lag to enable high-speed response by using not only conventional secondary-side output voltage feedback (FB), but also the primary-side resonant current I_{Cr} when performing control, reducing the number of phase compensation circuit components.

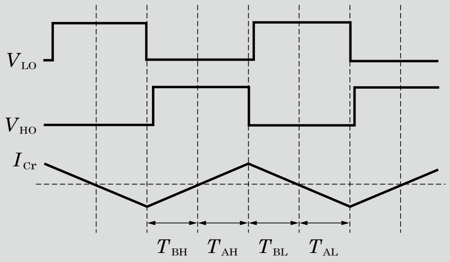
Figure 7 shows the resonant waveform, and Fig. 8 shows the relationship between the resonant phase ratio K_{CPR} and the output power P_o. When the time ratio before and after the polarity of the resonant current I_{Cr} is reversed is defined as the resonant current phase ratio, the resonant phase ratio K_{CPR} at which the polarity of the resonant current is reversed is given by Equation (1).

$$K_{CPR}=\frac{T_{AH}}{T_{BH}}=\frac{T_{AL}}{T_{BL}} \quad \text{......} (1)$$

K_{CPR}: Resonant phase ratio
T_{B*} : The time from when the MOSFET on one side of the bridge is turned off until the resonant current reaches zero
T_{A*} : Time until the MOSFET opposite the bridge turns off
"*" component of the T_{A*}, T_{B*} is as follows:
"H" : High side
"L" : Low side



(a) Heavy-load resonant waveform



(b) Light-load resonant waveform

Fig.7 Resonant waveform

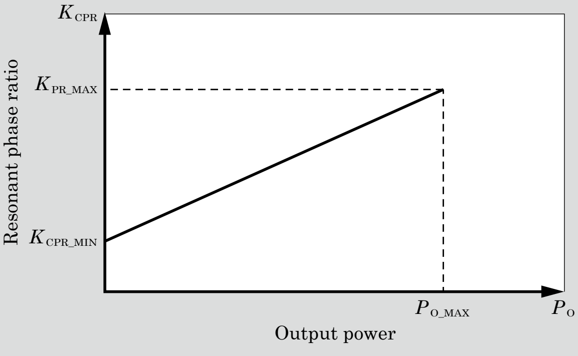


Fig.8 Resonant phase ratio K_{CPR} − output power P_o

There is a linear relationship between the resonant phase ratio K_{CPR} and the output power P_{o}. On the basis of this relationship, the output power P_{o} can be controlled independently of the input voltage and output voltage by controlling the resonant phase ratio K_{CPR}. Resonant current phase ratio control controls the on-width by calculating the resonant phase ratio corresponding to the feedback voltage V_{FB}. The relationship between V_{FB} and the resonant phase ratio K_{CPR} can be determined by Equation (2). From Equations (1) and (2), the time T_{A^*} after the polarity of the resonant current I_{Cr} is reversed can be obtained as shown in Equations (3) and (4). By measuring the time T_{B^*} before resonant current I_{Cr} polarity reversal, the turn-off point can be determined since it is possible to calculate the time T_{A^*} after polarity reversal according to V_{FB} at that time.

$$V_{\mathrm{FB}}=\frac{K_{\mathrm{CPR}}}{A}+B \quad \cdots\cdots (2)$$

V_{FB} : Feedback voltage
K_{CPR} : Resonant phase ratio
A, B : Constant

$$T_{\mathrm{AH}}=(V_{\mathrm{FB}}-B)\cdot A\cdot T_{\mathrm{BH}} \quad \cdots\cdots (3)$$

$$T_{\mathrm{AL}}=(V_{\mathrm{FB}}-B)\cdot A\cdot T_{\mathrm{BL}} \quad \cdots\cdots (4)$$

4. Application Effects on Power Supply Circuits

4.1 Reduction in number of circuit components and faster response

Figure 9 shows an application circuit diagram that uses the FA6C00 Series. This series ICs can be increased in efficiency further by combining Fuji Electric's "FA1B00 Series" critical-mode PFC control ICs.

Table 2 and Fig. 10 show the effect on the reduction of the number of power supply components. The use of resonant current phase ratio control has reduced the number of phase compensation circuit components by 7, and this has helped reduce power management system costs. Moreover, by changing the PFC-LLC interconnection signal, the number of components in the interconnection circuit has been reduced by one.

Figure 11 shows the sudden load change response characteristic. The resonant current phase ratio control described above improves the responsiveness of the power supply and keeps the output voltage ripple ΔV_{o} at sudden load changes to within 5%.

4.2 Improved light-load efficiency

Figure 12 shows the efficiency of the actual power supply. The use of new high-frequency burst operation control has increased the efficiency of light loads

Table 2 Effect on the reduction of power supply components

Function	Component	Component number		Reduction number
		New	Conventional	
Phase compensation circuit	Transistor	0	1	−1
	Capacitor	1	3	−2
	Resistor	0	4	−4
	Total	1	8	−7
PFC-LLC interconnection circuit	Transistor	1	1	0
	Capacitor	3	3	0
	Resistor	3	4	−1
	Total	7	8	−1

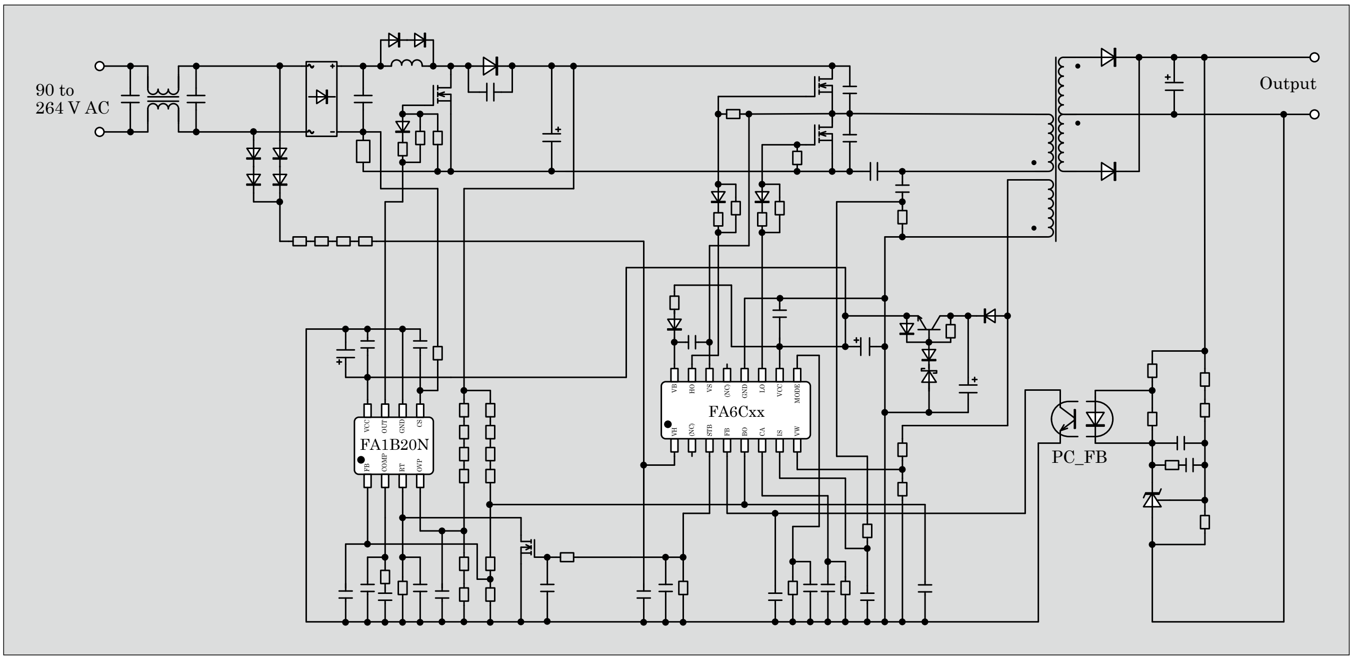
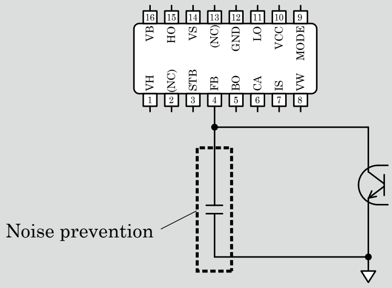
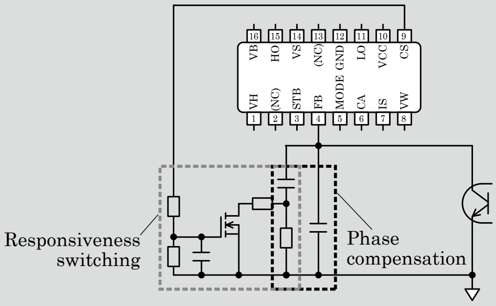


Fig.9 Example of application circuit



(a) New circuit



(b) Conventional circuit

Fig.10 Phase compensation circuit

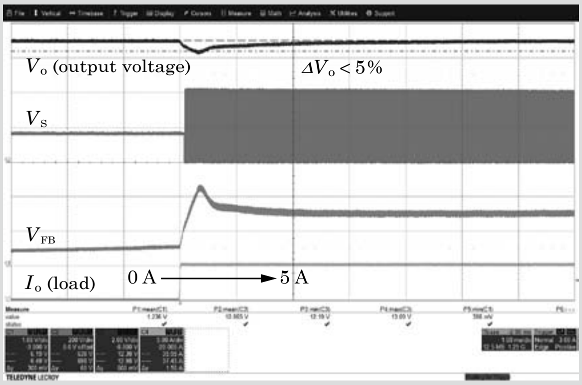


Fig.11 Sudden load change response characteristics

(11-W loads) by approximately 10%. The use of conventional continuous switching control and low frequency burst control lower efficiency at operation mode switching loads, but by providing high-frequency burst control between continuous switching control and low-frequency burst control, efficiency has improved at light loads of approximately 10 to 22 W. Furthermore, transformer audible noise can be reduced when using high-frequency burst control at loads of approximately 6 to 10 W, although efficiency does suffer slightly. High-frequency burst control is effective in improving light load efficiency and reducing audible noise in transformers.

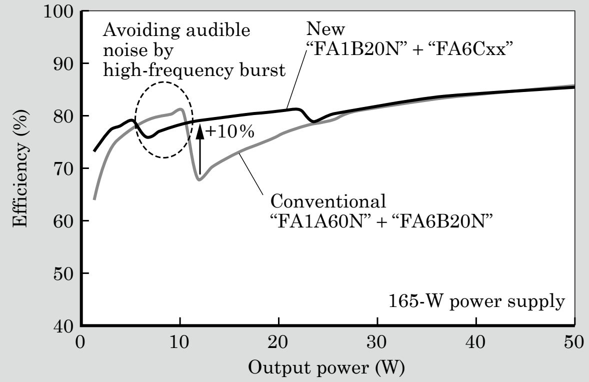


Fig.12 Efficiency

5. Postscript

In this paper, we introduced the "FA6C00 Series" 4th-generation LLC current resonant control ICs. By configuring power supplies with this IC, it is possible to improve light load efficiency and reduce the number of power supply components.

In the future, Fuji Electric plans to continue innovating new technologies that can further improve efficiency and reduce components, while developing products that meet the increasingly strict standards and market requirements that emerge year after year.

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