PWM Control IC with Power-Saving Function for Light Loads

Hiroshi Maruyama
Hironobu Shiroyama

1. Introduction

In recent years, the conservation of energy has been regarded as an important measure for global environmental problems. Therefore, efforts are focused on raising the efficiency and lowering the power consumption of switching power supplies, which are widely used in electrical and electronic devices, and especially in devices such as televisions, VCRs and OA devices that are always connected to a power supply. Power supplies designed to have a standby (low power consumption) mode are also becoming more widespread.

Fuji Electric had developed products, mainly for the bipolar FA531X series, as the control ICs for AC-DC converters, which convert a commercial AC supply (100V, 230V, etc.) to a DC power supply. Recently, the power consumed by the control IC of the power supply itself during standby mode with a minimum load has come to be regarded as a problem. Therefore, a transition from conventional bipolar products to low power consuming products that use high voltage

Table 1 IC product series for AC-DC converter

Model Process (pins)	Operating voltage Standard supply current	Maximum switching frequency Maximum duty cycle	Peak output current	Error amplifier	Reference voltage	Function	Application
FA5304AP/AS Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 46%	±1.5 A	2.0 V ±5%	—	Overload/overvoltage/ overcurrent (positive voltage sensing)	General-purpose power supply
FA5305AP/AS Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 46%	±1.5 A	2.0 V ±5%	—	Overload/overvoltage/ overcurrent (negative voltage sensing)	General-purpose power supply
FA5310BP/BS Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 46%	±1.5 A	—	—	Overload/overvoltage/ overcurrent (positive voltage sensing)	General-purpose power supply Forward converter
FA5311BP/BS Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 70%	±1.5 A	—	—	Overload/overvoltage/ overcurrent (positive voltage sensing)	General-purpose power supply Flyback converter
FA5314P/S Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 46%	±1.5 A	—	—	Overload/overvoltage/ overcurrent (negative voltage sensing)	General-purpose power supply Forward converter
FA5315P/S Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 70%	±1.5 A	—	—	Overload/overvoltage/ overcurrent (negative voltage sensing)	General-purpose power supply Flyback converter
FA5316P/S Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 46%	±1.0 A	—	—	Overload/overvoltage/ overcurrent (positive voltage sensing)	General-purpose power supply Forward converter
FA5317P/S Bipolar (8-pin)	10 to 30 V 9 mA	600 kHz 70%	±1.0 A	—	—	Overload/overvoltage/ overcurrent (positive voltage sensing)	General-purpose power supply Flyback converter
FA5332P/M Bipolar (16-pin)	10 to 28 V 10 mA	150 kHz 92%	±1.5 A	1.55 V ±2%	5 V ±4%	External synchronization/ overvoltage/overcurrent	Power factor controller
FA13842P/N CMOS (8-pin)	10 to 28 V 3 mA	500 kHz 96%	–0.4 A +1.0 A	2.5 V ±4%	5 V ±5%	Current mode	General-purpose power supply Flyback converter
FA13844P/N CMOS (8-pin)	10 to 28 V 3 mA	500 kHz 48%	–0.4 A +1.0 A	2.5 V ±4%	5 V ±5%	Current mode	General-purpose power supply Forward converter

CMOS (complementary MOS) is being promoted.

As related products, Fuji Electric has developed 8-pin CMOS PWM (pulse width modulation) control ICs FA3641 and FA3647 that have a power-saving function for light loads. This paper will present a summary of these ICs.

2. Product Summary

2.1 Features

Fuji Electric has already created a product series of control ICs for AC-DC converters as shown in Table 1. These ICs use a bipolar process. The newly developed FA3641/47, made by a CMOS process, were designed as PWM control ICs and incorporate a power-saving function for light loads in addition to the same functions as the bipolar FA531X series.

These control ICs are designed to have low power consumption due to adoption of a high-voltage CMOS process, and have a built-in function to reduce oscillation frequency at light loads, thereby reducing switching loss. Therefore, these control ICs can improve efficiency at light loads and satisfy demands for low power consumption and a small number of parts.

The pin assignment is designed to be pin compatible with the FA531X series, and various protection functions are configured with the CMOS circuitry to be the same as in the FA531X series. In addition, overvoltage protection for the VCC terminal is integrated as a built-in function. Two types of packages are provided, DIP (dual in-line package) and SOP (small out-line package).

Figure 1 shows the external view.

The main features of the ICs are as follows.

(1) Low supply current is realized by adopting a high-voltage CMOS process.
Latch-cutoff state: 50μA, during operation: 1.9mA (no load)

(2) Light loads are automatically evaluated with the FB terminal voltage (switching duty cycle). During light load operation, the frequency is decreased, thereby improving the switching loss.

(3) The oscillator frequency is decreased when the FB terminal voltage is 1.18V or less (10% or less of the output duty). To prevent the generation of noise at changeover, the frequency is continuously changed corresponding to the FB terminal voltage. Further, the rate of reduction of the oscillation frequency corresponding to the FB terminal voltage can be changed with an external resistor.

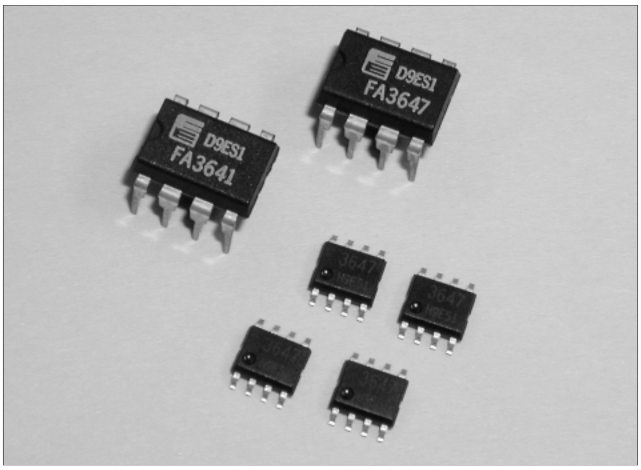
(4) A built-in circuit prevents low-voltage malfunction of the VCC terminal that has hysteresis characteristics (UVLO: under voltage lock-out).
16.5V ON/9V OFF

(5) The IS terminal has an overcurrent limiting function, and positive voltage sensing and negative voltage sensing products are arranged in a product series.
○ FA3641P/N: IS + positive voltage sensing 235mV
○ FA3647P/N: IS – negative voltage sensing –170mV

(6) Various protection functions such as overcurrent, overload, overvoltage of the VCC terminal, latch-cutoff and soft-start are built-in.

Main characteristics of the FA3641/3647 ICs are listed in Table 2, and a magnified chip view is shown in Fig. 2.

Fig.1 FA3641/3647 external view



2.2 Circuit configuration and devices

The block diagram of the developed FA3641 is shown in Fig. 3.

The IC is constructed from a high-voltage block containing a reference voltage generator connected to the VCC terminal, a UVLO circuit, an output drive circuit, a CS terminal voltage detection circuit, etc., and a low-voltage block containing an oscillator connected to the reference voltage generator circuit, a PWM comparator, an overload detection circuit, an overcurrent detection circuit, a variable frequency circuit for light loads, etc.

2.2.1 Devices

The processes used for devices are classified into 30V high-voltage MOS devices and 5V low-voltage MOS devices, and CMOS circuits can be configured for either high- or low-voltage.

Further, bipolar devices such as the npn transistor, pnp transistor and zener diode can be constructed by combining heavily doped regions, which form the source and drain used for the conventional CMOS process, and lightly doped regions used for high-voltage. This npn transistor is used in a band gap reference voltage circuit that is utilized in the reference voltage generator.

2.2.2 Oscillator

A variable frequency function for light loads is integrated into this newly developed product, and an explanation of its operation will follow. Since the oscillator contains an internal timing capacitor (CT) and the REF terminal is output at the 7th pin instead of the conventional CT terminal, the oscillation frequency during normal operation is adjusted with the value of a timing resistor (RT) connected to the RT terminal. Figure 4 shows the circuit configuration of the oscillator unit.

The RT control circuit (RT amplifier) controls the voltage of the positive input terminal so as to be equal to the RT terminal voltage. Consequently, the RT terminal voltage becomes constant, and constant current flows, the value of which is determined by the value of the externally connected RT. This current is supplied from p-channel MOS MP1, and a current whose value is 1/4 of this current flows through MP2. A current of the same value as the current flow from MP2 to MN1 is supplied from MP4 through MP5 to CT as a charging current, and is extracted from MN3 through MN5 as a discharging current. At this time, since identical gate signals are input into MP5 and MN5, one of the transistors is turned on and the other transistor is turned off. By means of this on/off changeover, CT is charged and discharged with a constant current to create an oscillation waveform. Since comparators detecting 3V and 1V levels are connected to CT, CT is discharged when the voltage exceeds 3V and charged when the voltage becomes less than 1V. Thus, by changing the RS flipflop states and the on/off of the MP5 and MN5 gates, oscillation between 3V and 1V continues.

Table 2 FA3641/3647 main characteristics

(a) Absolute maximum ratings

Item		Characteristic
Supply voltage		10 to 30V
Peak output current	Source current	–0.5A
	Sink current	+1.0A
Oscillation frequency		30 to 500kHz
Ambient temperature		–30 to 85°C
Junction temperature		125°C

(b) Electrical characteristics (main characteristics)

Item	Characteristic
Startup current	12μA (standard)
Standby current (VCC terminal =14V)	2μA (maximum)
Operating state supply current	1.9mA (standard)
Latch-cutoff state	100μA (maximum)
Reference voltage	5V±5%
IS terminal current limiting voltage	235mV (FA3641) –170mV (FA3647)
FB terminal overload voltage	3.0V (standard)
VCC terminal UVLO circuit voltage	16.5V/9.0V
VCC terminal overvoltage protection threshold voltage	32V±2V
CS terminal latch-cutoff voltage	8.5/7.9V
CS terminal ON/OFF voltage	0.82V/0.68V
FB variable frequency start voltage	1.18V (standard)
Maximum duty cycle	70%±4%
Output rising time (C_L = 1,000pF)	50ns (standard)
Output falling time (C_L = 1,000pF)	40ns (standard)

Fig.2 Magnified view of chip (FA3647)

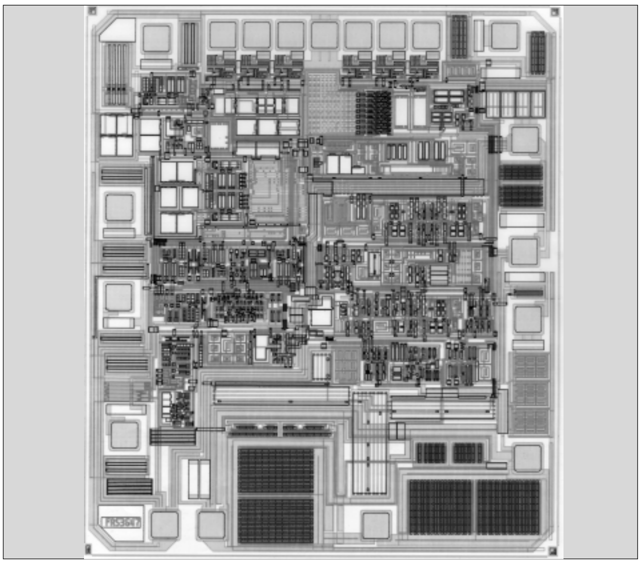


Fig.3 FA3641 circuit block diagram

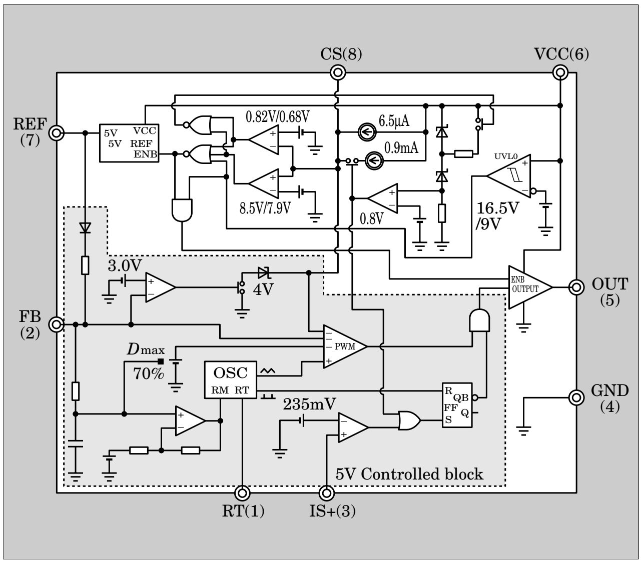
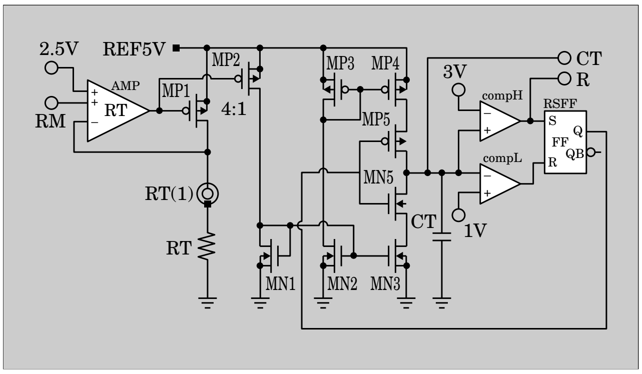


Fig.4 Oscillation circuit (OSC)



The variable oscillation frequency unit has two systems of positive input terminals to the RT amplifier, one system inputs 2.5V for normal operation and the other system has a function to effectively select the lower system voltage for light loads (RM). When RM voltage decreases to less than 2.5V, the RT terminal voltage is lowered from 2.5V to RM voltage, consequently the charge and discharge current decreases and the oscillation frequency is reduced.

2.2.3 Variable oscillation frequency circuit for light loads

Next, the relation between RM voltage that is input to the RT amplifier and FB terminal voltage shall be described. Figure 5 shows the circuit configuration of this unit.

Light loads are detected by the FB terminal voltage. When the FB terminal voltage decreases to 1.18V or less (corresponding to a switching duty cycle of approximately 10%), the voltage RM, which is input to the oscillator after being converted with an operational amplifier, becomes 2.5V or less, and the circuit transitions to light load operation. Decreasing the RT terminal voltage below 2.5V reduces the oscillation frequency.

When the FB terminal voltage changes from 1.18V to 1V, the oscillation frequency will continuously change up to a frequency approximately 1/2 that of normal state. Even in this reduced frequency state, control of the duty cycle is the same as for normal operation, and the duty changes corresponding to the FB terminal voltage. To stabilize the operation, the circuit for light loads is controlled by a voltage that passes through an RC filter after leaving the FB terminal. Therefore, a delayed response may occur and the pulse width may be abnormally wide. To prevent this, a limiting circuit is added. Specifically, another operational amplifier inputs voltage, which has been converted from the FB terminal voltage, into the PWM comparator. Even if the FB terminal voltage rapidly rises, the pulse width is limited so as not to exceed the maximum value, which is set at a maximum duty of 70% for normal operation.

Furthermore, connecting a resistor between the REF terminal and RT terminal can increase the rate at which the oscillation frequency is reduced corresponding to changes in the FB terminal voltage for light loads.

Fig.5 Variable oscillation frequency circuit for light loads

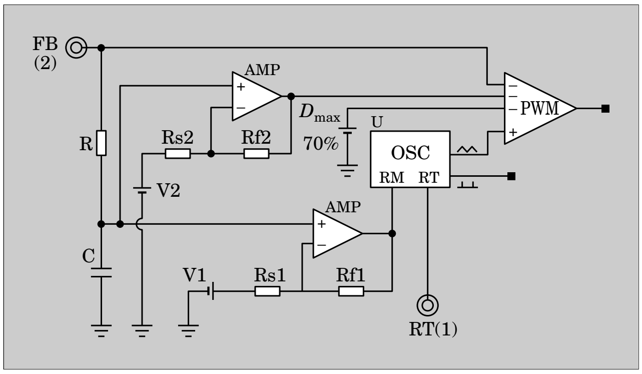
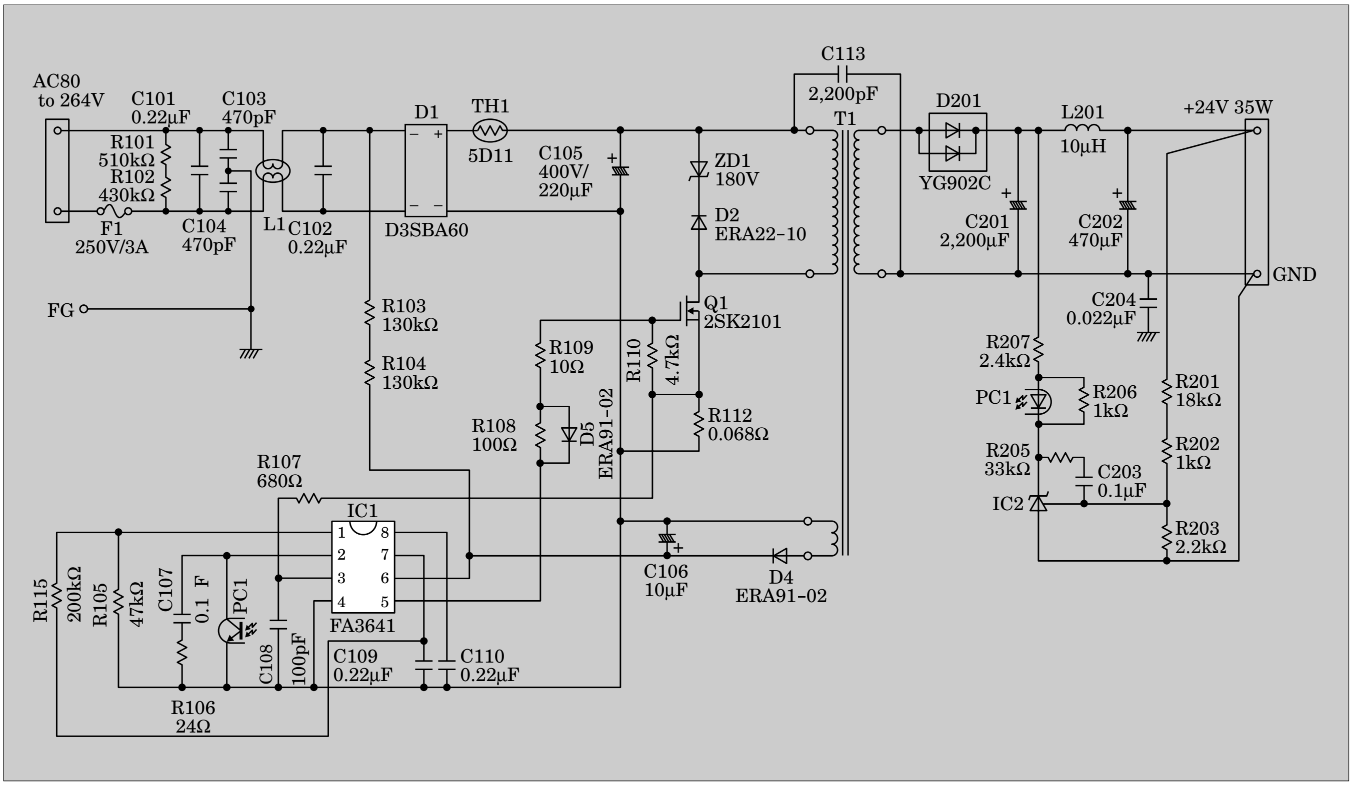


Fig.6 Circuit diagram of power supply for evaluation (FA3641)



3. Application as a Power Supply

3.1 Specification of evaluation circuit

To evaluate the characteristics under conditions more similar to those of user applications, this IC was inserted in an actual power supply circuit and evaluated.

The main specifications of this power supply were as follows.

- ○ Input: 80 to 264V AC, 50/60Hz
- ○ Output: 24V DC, 35W
- ○ Protection functions:
  Overload shutdown, overvoltage shutdown and overcurrent limiting
- ○ Oscillation frequency:
  75 kHz (at rated load)
  15 kHz (unloaded)

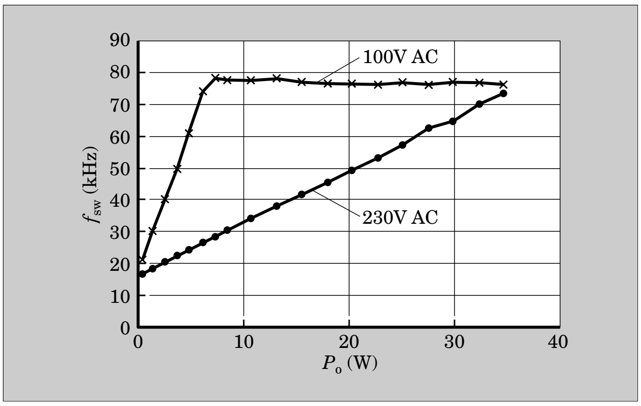
The circuit diagram is shown in Fig. 6.

3.2 Reducing oscillation frequency function for light loads

An important feature of this IC is the reducing oscillation frequency function for light loads, and results of its evaluation using this evaluation circuit are shown in Fig. 7. From Fig. 7, it is seen that the frequency continuously decreases when the load is light.

Since this IC judges light loads by the FB terminal voltage, the higher the input power supply voltage, the higher the output power at which the frequency starts to decrease. In this evaluation circuit, when the input is 100V AC, the frequency begins to decrease at an output of approximately 7W. On the other hand, when the input is 230V AC, the frequency begins to decrease when the power is approximately 35W, that is the rated output.

Fig.7 Oscillation frequency



3.3 Improved efficiency during light loads

To verify the improvement in efficiency during light load operation, this efficiency is compared to the efficiency of a conventional type IC operating in the same evaluation circuit. The conventional type IC used for the comparison is FA5311BP, and its functions are nearly equal to those of the new IC except for the reducing oscillation frequency function. The conventional type IC is manufactured with a bipolar process and consumes more power than the CMOS FA3641/47.

Figure 8 compares the results of power supply efficiencies under the condition of 230V AC input voltage. When the output is near the rated value, both ICs operate with the same frequency, the difference in power consumption is very small compared with the output power, and differences in efficiency are scarcely recognized. However, when the output power becomes small, the improved efficiency of the FA3641/47 becomes noticeable. In this evaluation of the power supply, the efficiency is improved up to approximately 30% at 230V AC.

AC adapters frequently remain connected to an electrical outlet even when the device (such as a notebook computer) connected to the AC adapter is not being used. At such a time, the power supply in the AC adapter is operating under unloaded conditions, and all input power becomes a loss. Therefore, for energy conservation purposes, it is important to reduce the input power when there is no load. Figure 9 compares the results of input power characteristics under the condition of no load.

The input power is reduced by 0.2W at 100V AC and by 0.9W at 230V AC. Over the entire input

Fig.8 Efficiency (input 230V AC)

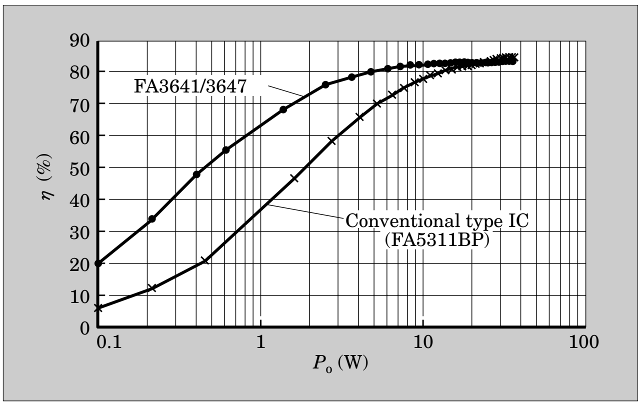


Fig.9 Input power under condition of no load

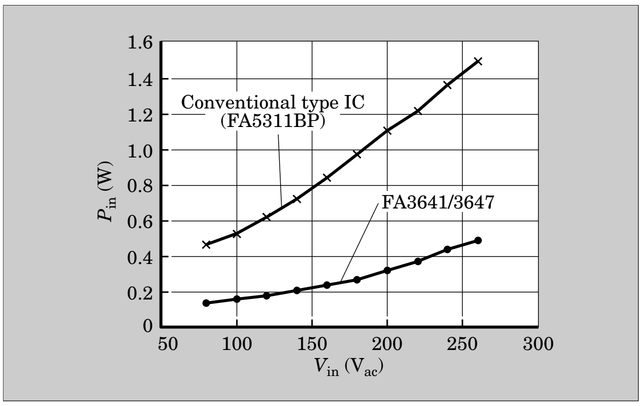


Table 3 Improved loss characteristics

Item	Loss (mW)		Improvement (mW)
	FA3641/3647	FA5311	
IC operating loss	20	100	80
Startup resistor loss	100	280	180
Switching loss	120	600	480

voltage range, input power of 0.5W or less is achieved under the condition of no load.

The main factors responsible for reduced loss and improved efficiency under the conditions of light load and no load can be cited as follows.

(1) Reduced IC operating loss by means of a low operating current

(2) Reduced start-up resistor loss by means of a low start-up current

(3) Reduced switching current by means of a function that lowers the oscillation frequency during light loads

The results of these improvements are listed in Table 3 for the case of a 230V AC input and no load.

The only difference between the two power supplies compared above is that they use different ICs. Therefore, by simply changing the IC, it is possible to improve the efficiency for light loads, as is seen in this example.

4. Conclusion

We presented a summary of the PWM controlled IC with power-saving function for light loads. Compared to the bipolar control IC, the CMOS control IC has favorable low power consumption characteristics. Moreover, the CMOS structure facilitates the integration of logic circuits, enabling the construction of higher function ICs. Fuji Electric is determined to respond to market needs, develop unique products, and in addition to the ICs developed this time, promote the use of CMOS processes in other control ICs for switching power supplies.

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