Power Supply IC Technology Contributes to Smaller Size and Lower Power Consumption of Electronic Equipment

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1. Introduction

Power supply technology is a basic technology that supports all types of electronic equipment. Switching power supplies, in particular, are characterized by small size, light weight and high efficiency and are the mainstream technology used in power supplies at present. In recent years, with the advent of an advanced information and communications-oriented society, trends toward personalization and mobilization have accelerated and demands are increasing for electronic devices that are smaller, lighter in weight and consume less power. Power supply technology is also entering an era of change.

Having a long history of involvement with semiconductor devices for switching power supplies, Fuji Electric is now concentrating on power supply ICs (integrated circuits) as core devices that perform control functions. Fuji Electric's power supply ICs fall into the two categories of AC-DC power supply-use devices that take a commercial AC line input and DC-DC converter-use devices that are mainly used in battery-driven applications. These devices had previously been produced as commercial products using bipolar technology, but in response to market demands for lower power consumption and a combination of functions, a change to high-voltage CMOS (complementary metal oxide semiconductor) analog technology was initiated several years ago and at present, nearly all of Fuji Electric's power supply ICs have completed the transition to CMOS technology.

This paper introduces the technical and product development for power supply ICs and also discusses Fuji Electric's future outlook for this field.

2. High-voltage CMOS Analog Technology of Power Supply ICs

2.1 Process device technology

Table 1 compares the IC process technologies used in power supply ICs. Bipolar technology is commonly used throughout the industry and to date Fuji Electric has commercialized many power supply ICs using this technology. A power supply IC that uses bipolar technology will feature high accuracy of the control circuit (offset voltage of error amplifier, accuracy of reference voltage, and the like) and a low process cost since only a few mask steps are required during the manufacturing process, but since it is a current controlled device, the degree to which power consumption can be decreased will be limited. Moreover, because each transistor is isolated by a p-n junction, the parasitic capacitance with the substrate will be large and since the storage time during transistor switching will be long, a bipolar process is considered to be disadvantageous for high frequency operation. Additionally, the technique of isolation by p-n junction is difficult to miniaturize and is ill-suited for high levels of integration. As a power supply IC process, bipolar technology became unable to satisfy the requirements of the market.

Table 1 Comparison of power supply IC process technology

Item \ Process	Bipolar	Bi-CMOS	CMOS
Power consumption	Poor	Fair	Excellent
Miniaturization	Poor	Fair	Excellent
Circuit accuracy	Excellent	Excellent	Fair → Excellent
Built-in power MOS	Poor	Excellent	Excellent
Process cost	Excellent	Poor	Fair

CMOS process technology has previously been widely used in digital ICs. MOS (metal oxide semiconductor) devices are voltage controlled devices and are extremely effective in reducing current consumption, however, their compatibility with analog circuitry is poor and in the past, power supply ICs almost never used CMOS technology. For this reason, products were commercialized using Bi-CMOS (bipolar-CMOS) process technology that combined the advantages of bipolar and CMOS processes into a single chip. However, the Bi-CMOS process was disadvantageous because its bipolar portion was inherently difficult to miniaturize and it had a high processing cost due to the use of epitaxial wafers and the use of at least twice as many mask steps as in a bipolar process. To resolve these problems, Fuji Electric developed several CMOS process technologies specifically for power supply ICs and has promoted the commercialization of products using those technologies. Figure 1 shows the product map of Fuji Electric's CMOS power supply ICs. Fuji Electric provides a wide range of products whose operating voltages span from 1 or 2 dry-cell batteries to worldwide AC power supply input levels.

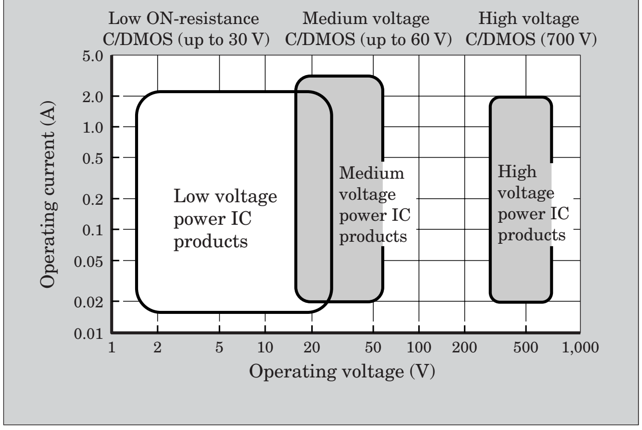
2.2 Analog circuit accuracy with CMOS technology

In the case where CMOS technology is used in a power supply IC, the circuit accuracy generally presents a problem and is less than that of a bipolar process. Circuit accuracy depends on the absolute fluctuations of device characteristics and on the relative accuracy. In response, Fuji Electric has optimized wafer process conditions and strengthened process control to reduce fluctuation in device characteristics, developed device design techniques, and developed circuit technology specifically for CMOS circuits, that when used together with on-chip trimming technology, realize circuit accuracy which exceeds that of bipolar process technology.

2.3 Built-in power elements

In order to reduce the size of power supply circuits and the space they occupy, there is a growing trend to embed the power MOSFET (metal oxide semiconductor field effect transistor), which had been attached as a separate external component in the past, into the power supply IC. Fuji Electric uses a lateral DMOS (double diffused MOS) structure to realize low ON-resistance, which as shown in Fig. 2, is in the top class of the industry. By using a lateral DMOS device with its low gate-drain capacitance and by optimizing the device size for each IC product, operation at higher frequencies with lower current consumption is possible. As an example, Fig. 3 shows a photograph of a 3-channel control IC chip having a built-in n-channel power MOSFET rated at 1 MHz operation and 50 V breakdown voltage.

Fig.1 Product map of CMOS power supply ICs



3. Product Line Up of CMOS Power Supply ICs

3.1 AC-DC power supply ICs

Fuji Electric was quick to adopt CMOS technology in its power supply control ICs designed for a commercial AC line input. An overview is presented below.

3.1.1 PWM control ICs for low standby power

Efforts to reduce the load on the global environment have intensified in recent years. For AC-DC power supplies, the trend toward lower standby power is accelerating because devices for the remote control of an always-on connection, devices built-into a timer, various types of AC adapters and the like are in a standby state for a much longer time than at rated operation. In response to this trend, Fuji Electric has commercialized power supply ICs that feature reduced standby power consumption. As shown in Fig. 4, low standby power consumption has been realized by combining the drastic reduction in low current consumption enabled by the use of CMOS technology and a variable frequency function that reduces switching loss by lowering the switching frequency during light loads. Figure 5 shows the input power characteristic of

Fig.2 Breakdown voltage vs. $R_{on} \cdot A$ (NMOS)

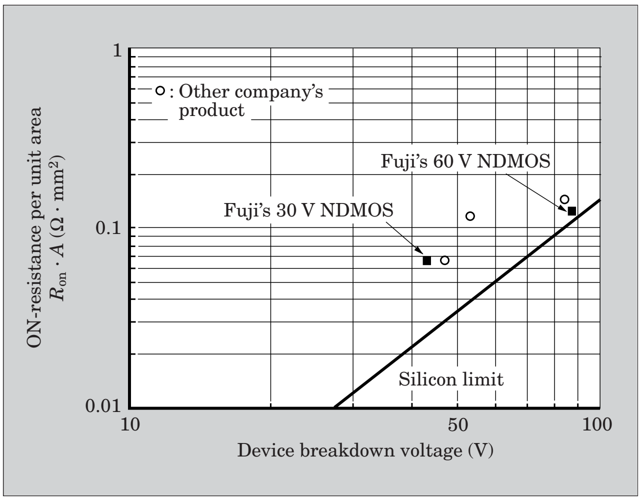


Fig.3 Die photo of power supply IC with a built-in power MOSFET

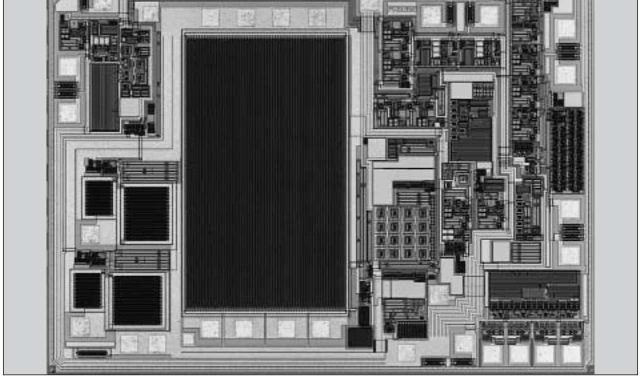


Fig.4 Method of standby power reduction

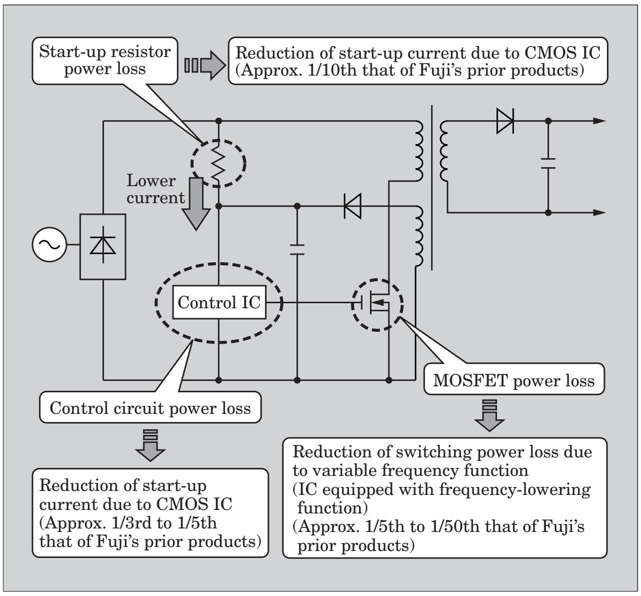
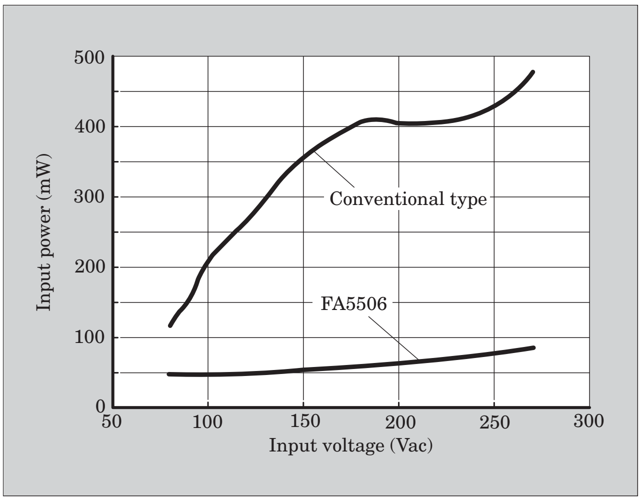


Fig.5 FA5506 input power characteristics at no load



Fuji Electric's newest IC, the FA5506, under unloaded conditions in an evaluation power supply circuit. Even at 240 V AC, the standby power was 0.1 W or less.

3.1.2 700 V monolithic power IC

In order to miniaturize low-output power supplies in the several-tens-of-watts class, it is desirable for the power element to be integrated with the control circuit. Fuji Electric has also commercialized a power supply IC that integrates a 700 V power MOSFET and PWM (pulse width modulation) control circuit into a monolithic chip, which is directly connectable to worldwide commercial power supply inputs. High voltage devices are generally susceptible to fluctuations in their characteristics due to ions in the mold resin, moisture that infiltrates from the exterior and the like, but Fuji Electric's proprietary double metal ion shield structure achieves high reliability. Figure 6 shows an example die photo of this product.

Fig.6 Die photo of 700 V monolithic power IC (FA5701P)

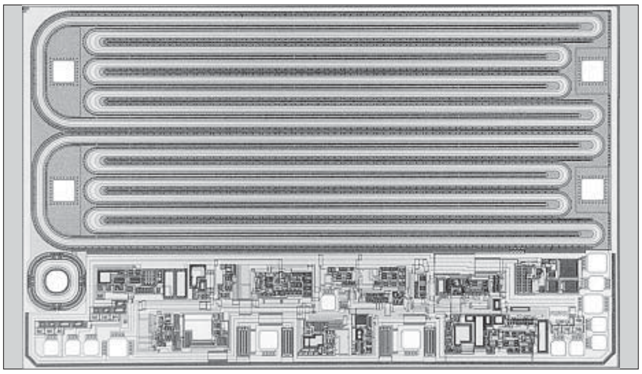
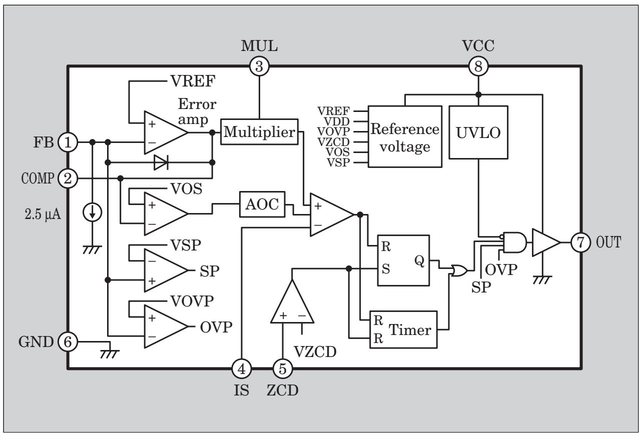


Fig.7 Block diagram of CMOS control IC for power factor correction (FA5500)



3.1.3 CMOS control ICs for power factor correction

In the past, because most power supply circuits used a capacitor input-type rectifier circuit, the AC input current was distorted and a large harmonic input current was generated. Because the presence of harmonic components brought about a decrease in the power factor and they also had a negative impact on the power distribution equipment, regulations concerning the power supply harmonic content were enacted worldwide. Various solutions have been proposed and implemented, but the active filter circuit is widely used because it can easily achieve a power factor of 99 % or higher. Fuji Electric was early to commercialize bipolar technology-based control ICs and has promoted the adoption of CMOS technology in this field as well, commercializing CMOS control ICs that utilize either the peak current control method or the average current control method. Figure 7 shows a block diagram of the peak current control IC.

3.2 Power supply ICs for DC-DC converters

Fuji Electric is applying CMOS technology to commercialize power supply ICs for DC-DC converters used in battery driven devices and the secondary side of AC-DC power supplies. AC-DC power supply ICs are general-purpose products, but power supply ICs for DC-DC converters are a product family that is specially designed per chip set.

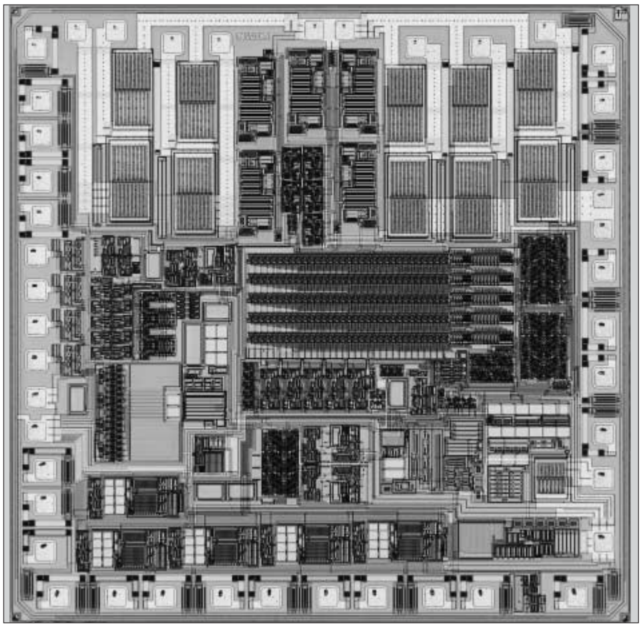
3.2.1 Power supply ICs for portable devices

In order to extend the duration of battery operation for portable devices such as video cameras, digital still cameras and PDAs (personal digital assistants), it is necessary to supply an optimal voltage and to perform precise ON/OFF control for each internal circuit block. Multi-output power supplies are being promoted for this reason. Figure 8 shows a die photo of a 5-channel PWM control IC commercialized for use in a digital still camera. CMOS technology has been applied to integrate the multi-channel PWM control circuit and the driver circuits into a compact size. Moreover, Fuji's proprietary level shift circuit enables the driver unit to achieve both higher speed and lower current consumption. At present, 3 to 10-channel ICs are commercially available, and synchronous rectifier circuits are used in many cases to increase efficiency. Also, as a recent trend, in order to provide flexibility to support the individual power supply specifications for each chip set, settings for the output voltage, maximum duty cycle, ON/OFF control and the like are increasingly being made via serial control data from the CPU (central processing unit).

3.2.2 Power supply ICs for LCD panels

LCD panels require several different driving voltages. Figure 9 is a block diagram of a power supply IC containing a built-in 3-channel PWM control circuit for use with a large-screen LCD monitor. This IC contains a built-in driver circuit capable of providing a peak current of 800 mA in order to drive the externally attached power MOSFET having a large gate capacitance at high speed, and the power supply circuitry necessary for the LCD panel can be configured easily. In addition to this IC, Fuji Electric also provides a line of products with input voltages ranging from 3 to 5 V

Fig.8 Die photo of 5-channel PWM controller (FA7716R)



and that are capable of supporting boost, buck and inverting circuits for LCD panels in notebook computers.

3.2.3 Step-down converter ICs for inkjet printers

Figure 10 shows an IC application circuit for a DC-DC converter that produces an output of 3 to 5 V from a high input voltage (10 to 45 V). A high voltage p-channel power MOSFET is built-in and a step-down converter circuit can easily be configured. The CMOS process reduces IC current consumption down to 1/10th that of a bipolar IC in the same class, and the power consumption of the IC during a high voltage input has been reduced greatly (from 1.1 W to 0.06 W). The result is dramatic since power consumption of the device is decreased and heat sinks are unnecessary.

4. Future Outlook

Continuing to regard high voltage CMOS analog technology as a core technology, Fuji Electric intends

Fig.9 Block diagram of power supply IC (FA7711V) for LCD panel

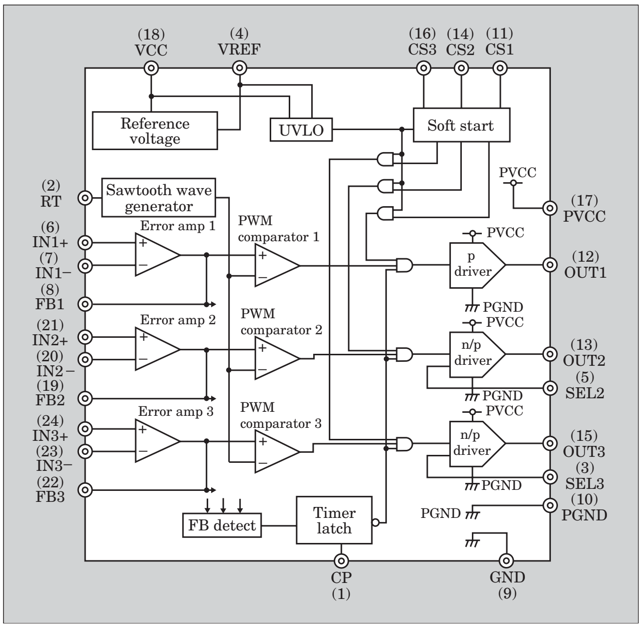
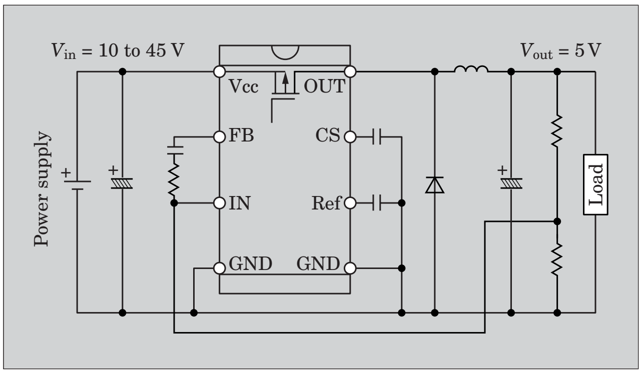


Fig.10 Application circuit of high input voltage step-down converter IC (FA3635P)



to advance technical development in the field of power supply ICs in order to contribute to making electronic devices smaller, lighter and consume less power.

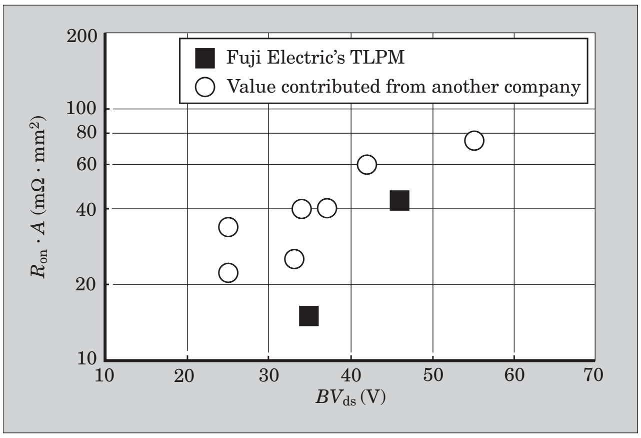
4.1 Low ON-resistance device and process technology

To make the power supply unit smaller and occupy less space, there is a growing trend for integrating the switching power device with the power supply IC. Moreover, due to progress in the miniaturization of the LSI (large scale IC) that is the load and in the lowering of voltage and increasing of current, the development of a lower Ron·A power device that can be integrated onto the IC presents a big challenge for realizing a highly cost effective power supply IC. Rather than the conventional plane structure lateral device, a device having a novel structure based on trench process technology that can easily be integrated with the control IC is presently under development at Fuji Electric. As shown in Fig. 11, this device has already achieved the industry's top class of low ON-resistance. In the future, Fuji Electric plans to promote miniaturization of the power supply by establishing technology for integration of the control unit and by embedding the power device in the IC.

4.2 Circuit technology

The higher the switching frequency, the smaller the magnetic components and capacitors used in the switching power supply can be made. Fuji Electric plans to further advance the development of devices and processes that use CMOS technology, which is advantageous for higher speeds, and to increase the switching frequency up to the 10 MHz level. Switching noise is expected to increase at higher frequencies, but we intend to handle this by incorporating spread spectrum technology and the like. Fuji Electric also plans to promote the development of high performance mixed signal IC technology in preparation for the integration of battery management circuit with the power supply IC.

Fig.11 Breakdown voltage vs. $R_{on} \cdot A$ of TLPM (trench lateral power MOSFET)



4.3 Micro DC-DC converter technology

Cellular phones, PDAs and the like have, until now, generally used a series regulator. To increase the performance of these electronic devices, the LSIs that are installed therein are miniaturized and the power supply voltages supplied to the LSIs have been decreasing year-by-year. At present, a power supply voltage of 1.5 V or less is the mainstream, but 1 V or less is predicted to become the mainstream in the future. Meanwhile, because the lithium-ion batteries typically in use at present have a rated voltage of 3.6 V and the use of a series regulator causes a large power loss to be generated, there is increased awareness of the need to improve conversion efficiency of the power supply circuit. Consequently, a changeover to the switching-type DC-DC converter having excellent conversion efficiency is being considered. However, because the conventional DC-DC converter requires a power inductor and has larger external dimensions than the series regulator, smaller size and lighter weight are strongly demanded. Each company is studying ways to achieve smaller size and lighter weight, and from the perspective of an IC manufactur-

Fig.12 External view of micro DC-DC converter module

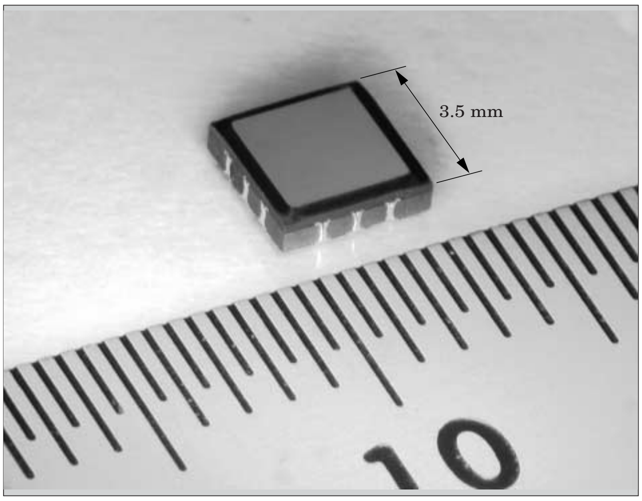
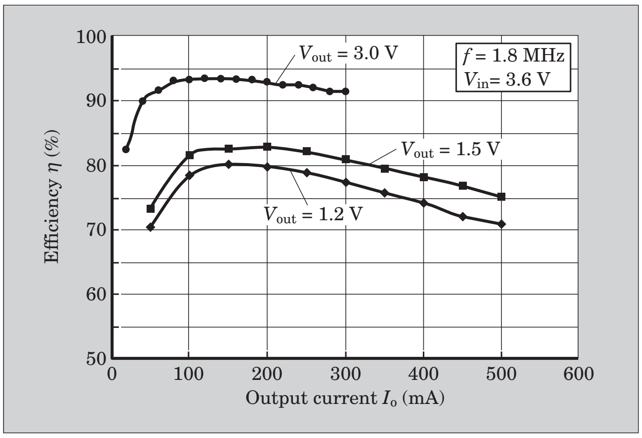


Fig.13 Efficiency of micro DC-DC converter module



er, Fuji Electric had the idea to fabricate an inductor in a ferrate substrate and then use that as the support substrate of the IC chip in a novel structure. Fuji Electric is the first in the industry to realize this structure as a module having external dimensions of 3.5 by 3.5 by 1 (mm). In order to realize a module of this size, Fuji newly developed a proprietary inductor structure, a 2.5 MHz high frequency switching power supply IC with built-in power device, as well as assembly technology to combine the ferrate substrate and IC chip. Figure 12 shows an external view of the module and Fig. 13 shows its efficiency characteristics. Fuji Electric intends to use this technology to promote commercialization of portable electronic devices in the future and to contribute to the realization of chip sets that are smaller in size and consume less power.

5. Conclusion

Fuji Electric's efforts to date concerning the adoption of CMOS technology for power supply ICs and the future outlook for that technology have been discussed above. Power supply circuits and their key component, the power supply IC, are becoming increasingly important for the future progress of electronic devices. Fuji Electric is committed to continue to develop power supply IC technology and products through decreasing their size and power consumption and increasing their level of integration so that in the near future Fuji Electric's name will become synonymous with power supply ICs.

References

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