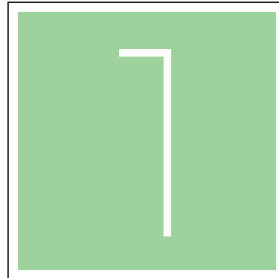


FUJI ELECTRIC REVIEW

IC Technology

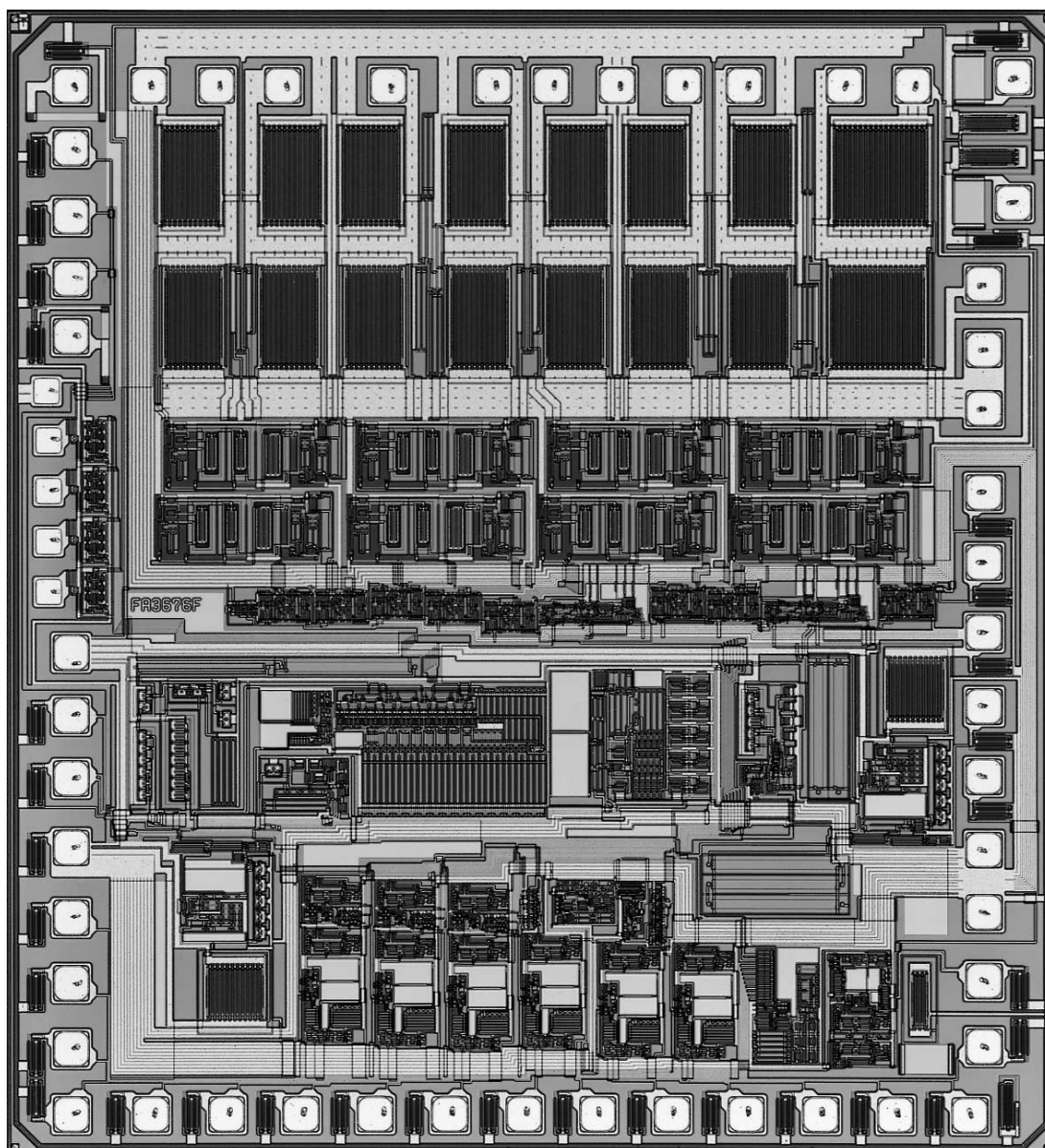


2002 VOL.48



These Power Supply Control ICs for Multiple Solutions to Multiple Requirements

FUJII
ELECTRIC

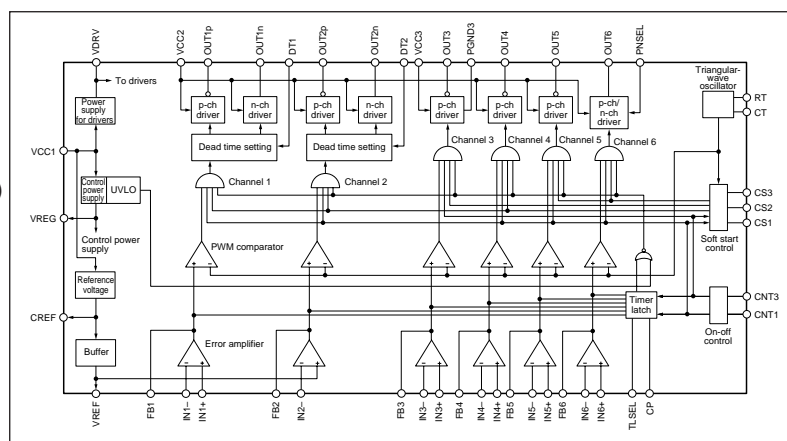


Realize Energy-Saving Power Management with a Chip.

Examples: 2-channel FA3630V, 3-channel FA3629AV,
6-channel FA3621F, 6-channel FA3675F,
6-channel FA3676F

Uses: Multiple output power supplies for TFT panels, video cameras, digital cameras, etc.

- Features:
- Synchronous rectification (for 2 channels of FA3676F)
 - Power and controller circuits integrated on a chip using the C/DMOS process capable of incorporating a low on-state resistance DMOS output transistor.
 - Low power consumption, small size, high efficiency, compatibility with low input voltage (2.5 V), and sufficient protective functions against overcurrent, overheat, etc.
 - Small outline packages
TSSOP-16, SSOP-28, LQFP-48, LQFP-64



Example block diagram with FA3676F

Fuji Electric Power IC for Power Supply

Quality is our message

FUJI ELECTRIC REVIEW

IC Technology

7
2002 VOL.48

CONTENTS

Present Status and Prospects of Fuji Electric's IC Products and Technologies	2
CMOS Power Factor Control IC	6
Power Supply IC for Low Power AC Adapters	9
Power Supply IC for LCD Panels	12
Charge Pump Booster IC	15
Power Management IC for a Cellular Phone with a Li-Ion Battery Charger	18
Second-Generation PDP Address Driver IC	22
Low On-Resistance Trench Lateral Power MOS Technology	26

Cover Photo:

Smaller-size and higher-density electronic devices are increasingly demanded. As the number of those devices increases, the total energy consumption increases to an enormous extent. As a result, energy saving in those devices is an urgent necessity to preserve the global environment.

Fuji Electric's ICs are designed as energy-saving devices, based on the company's proprietary high-voltage CMOS technology. Moreover, these ICs further contribute to power savings by performing power management of the electronic device system.

The cover photograph shows a Fuji Electric's IC, designed as an energy-saving device and having terminals provided with lead-free plating, against the background of fresh green leaves, implying that Fuji Electric's products are environmentally friendly.

Present Status and Prospects of Fuji Electric's IC Products and Technologies

Toshio Komori

1. Introduction

Fuji Electric has been expanding its line of IC (integrated circuit) products by focusing on power supply ICs and developing high-voltage CMOS IC (complementary metal oxide semiconductor IC) technology as core technology, based on the incorporation of the key concepts of added power, intelligence, and analog circuitry.

To cope with recent increased demand for environmental conservation, and energy savings in particular, Fuji Electric has developed low power consumption, high-voltage CMOS analog technology. This technology contributes to extending the available standby time in power supply ICs for cellular phones, and allows longer operation time in digital still cameras (DSCs) through meticulous power management.

In the field of high voltage technology, Fuji Electric has developed highly reliable device and process technologies, which enable the incorporation of 700 V power MOSFETs (metal oxide semiconductor field effect transistors) into ICs.

In addition, Fuji Electric's proprietary sensor integration technology is applied to AF (autofocus) ICs with built-in photodiode-based photosensors for use in cameras, and to pressure sensor ICs with built-in piezoelectric strain gauges for use in automobiles.

This paper introduces new products that utilize these technologies, with a particular emphasis on power supply ICs.

2. Present Status of Fuji Electric's ICs

2.1 IC products

2.1.1 Power supply ICs

As described above, Fuji Electric has developed IC products with emphasis on power supply ICs. The development concepts are low power consumption, high current, high accuracy, multi-functionality, and low costs. Based on these concepts, Fuji Electric has been developing easy-to-use, high value-added products based on a "Customer First" policy.

Table 1 lists Fuji Electric's CMOS products. In the field of power supply ICs, to comply with such AC-DC

converter requirements as low-power standby operation, lower noise due to power factor correction, and higher efficiency, Fuji Electric has developed the FA 3641/3647, a PWM (pulse width modulation) control IC that is provided with a function to suppress switching loss by reducing switching frequencies during light loads. With regard to power factor control, Fuji Electric has newly developed the FA5501, a peak-current mode control IC, utilizing CMOS technology. This IC performs power factor correction suitable for lighting apparatus and small-sized power supplies through incorporating various protection functions in a small 8-pin package. For details, refer to the separate paper "CMOS Power Factor Control IC" in this special issue.

For application to worldwide power supplies, Fuji Electric has also developed the FA5701/5702, a single-chip power IC with a built-in 700 V high voltage MOSFET. This IC is provided in a DIP (dual in-line package)-6 package with reduced external parts and various built-in protection functions, suitable for small-sized AC adapters used for cellular phones and other electronic devices. In particular, this IC was engineered for enhanced reliability through adopting a double metal shield structure which provides the plastic mold package with the ability to withstand a more than 1,000-hour pressure cooker bias test (PCBT). For details of the 700 V single-chip power IC and related device technology, refer to the separate paper "Power Supply IC for Low Power AC Adapters" in this special issue.

In the field of DC-DC converters, Fuji Electric has developed and commercialized 1- and 2-channel general-purpose DC-DC converter ICs which utilize high voltage CMOS technology that allows direct MOSFET driving. In addition, Fuji Electric has developed highly integrated multi-channel custom ICs for use in video cameras and DSCs. Application of cell-based design technology and provision of comprehensive after-sales service enable those ICs to meet customers' requirements such as customization and short lead-time development.

Small size, light weight, thin profile, and low power consumption are increasingly required of elec-

Table 1 List of general-purpose power supply ICs
(a) AC-DC converters

Model name		D_{\max} (%)	Circuit application			MOS drive	Operating mode		Protection circuit			No. of pins
			Flyback	Forward	Power factor correction		Voltage	Current	OCP	OVP	OTP	
MOS	FA13842	96	○			○		○				8 pins
	FA13844	48		○		○		○				8 pins
	FA3641/3647	70	○			○	○		○	○		8 pins
	FA5510/5511 FA5514/5515	46/70	○	○		○	○		○	○		8 pins
	FA5501				○	○			○	○		8 pins
	FA5502				○	○			○	○		16 pins
	FA5701	70	○			Built-in 700 V MOS		○	○	○	○	6 pins
	FA5702	50	○			Built-in 700 V MOS		○	○		○	6 pins

(b) DC-DC converters

Model name		No. of channels	D_{\max} (%)	Voltage range			Circuit application				MOS drive	No. of pins
				2.5 to 18 V	2.5 to 5.5 V	10 to 25 V	Step down	Step up	Inverter	Flyback		
MOS	FA3675F	6	Optional setting	○			○	○	○	○	○	48 pins
	FA3676F	6	Optional setting	○			○	○	○	○	○	48 pins
	FA3698F	6	Optional setting	○			○	○	○	○	○	48 pins
	FA3630V	2	Optional setting		○		○	○	○	○	○	16 pins
	FA13843	1	96					○	○	○	○	8 pins
	FA13845	1	48			○		○	○	○	○	8 pins
	FA3686V	2	85	○		○		○	○	○	○	16 pins
	FA3687V	2	Optional setting	○			○	○	○	○	○	16 pins
	FA7700	1	90	○				○		○	○	8 pins
	FA7701	1	100	○			○				○	8 pins
	FA7703/7704	2	Optional setting	○			○	○	○	○	○	16 pins
	FA3629AV	3	Channel 1 = 87		2.5 to 5.8 V			○	○	○	Built-in n-channel MOSFET (1 channel only)	16 pins
			Channel 2 = 87					○	○	○		
			Channel 3 = 86				○		○			
	FA3635P	1	Optional setting			10 to 45 V	○		○			8 pins
	FA3685P	1	Optional setting			○	○		○			8 pins

tronic devices, particularly of power supplies for liquid crystal display panels of notebook-sized personal computers. To meet these requirements, Fuji Electric has commercialized the FA3686/3687, a high-frequency switching power supply IC (300 kHz to 1.5 MHz), which allows a reduction in size of external parts such as transformers and coils through the utilization of high-frequency PWM technology.

In addition, Fuji Electric has developed a single-chip multi-output, system power supply IC with a built-in low-power, high-PSRR (power supply ripple reduction ratio) series regulator, which performs charging control of a lithium-ion battery, and serves as a power supply for amplifiers, radio communication, and analog circuits in portable electronic equipment such as cellular phones. Fuji Electric has also developed the FA3705, a single-chip power supply IC

with a built-in charge pump circuit and series regulator for applications in which voltage step-up is required. For details, refer to the separate paper “Charge Pump Booster IC” in this special issue.

As described above, Fuji Electric has been developing and commercializing a wide range of power supply ICs for AC-DC and DC-DC converters in a system power source, to meet customers’ various customization requirements.

2.1.2 PDP driver ICs

In addition to power supply ICs, Fuji Electric has developed PDP (plasma display panel) driver ICs utilizing high-voltage technology. Those driver ICs include address driver ICs using 85 to 150 V C/DMOS (complementary double diffused MOS) devices, and scan driver ICs with built-in 200 V IGBT (insulated gate bipolar transistor) output stages using SOI (sili-

con on insulator) substrates.

2.1.3 AFICs

Fuji Electric has developed small-sized AF module ICs in newly designed packages, which integrate optical modules and IC packages, thereby substantially reducing costs. These AF module ICs utilize Fuji Electric's proprietary sensor application technology to meet the requirements for cameras, such as smaller size, lower power consumption, and higher power zoom.

2.1.4 Pressure sensors

In the past, Fuji Electric has developed and commercialized single-chip pressure sensors for automobiles, which integrated sensing gauges and amplifying and adjusting circuits. In 2000, Fuji Electric commercialized pressure sensors with integrated low-pass filters as an anti-EMI (electromagnetic interference) measure, to cope with the increasingly severe EMI environment of automobiles.

Fuji Electric has recently developed new-type resin-mold package pressure sensors, with built-in EPROMs (erasable programmable read only memories), which allow more accurate and stable trimming.

2.2 Technological development

2.2.1 Process device technology

A characteristic of Fuji Electric's process device

Table 2 Process flow

Process flow	STD flow	Option
n-well diffusion	○	
p-well diffusion	○	
p-offset diffusion		○
n-offset diffusion		○
n-Zener diffusion		○
Field oxidation	○	
Channel diffusion	○	
Depletion diffusion		○
Gate electrode formation	○	
Source drain diffusion	○	
High-resistance, low temp. coefficient polysilicon		○
Contact formation	○	
No.1 metal formation	○	
No.2 metal formation		○
Passivation film	○	

Table 3 Device characteristics

Device Item	CMOS		High voltage MOS (60 V)		High voltage DMOS (60 V)		High voltage DMOS (30 V)	
	NMOS	PMOS	Low V_{th} NMOS	Low V_{th} PMOS	Low on-state resistance NDMOS	Low on-state resistance PDMOS	Low on-state resistance NDMOS	Low on-state resistance PDMOS
V_{th}	0.5 V	0.5 V	0.5 V	0.5 V	1.0 V	1.0 V	1.0 V	1.0 V
BV_{dss}	11 V	11 V	90 V	75 V	87 V	75 V	43 V	47 V
$R_{on} \times A$	—	—	—	—	$0.124 \Omega \cdot \text{mm}^2$	$0.315 \Omega \cdot \text{mm}^2$	$0.066 \Omega \cdot \text{mm}^2$	$0.205 \Omega \cdot \text{mm}^2$

technology is the addition of various analog options to high voltage CMOS technology. As listed in Table 2, p- and n-offset diffusion, n-Zener diffusion, depletion diffusion, and high-resistance, low-temperature-coefficient, polysilicon resistance formation are added to the basic $1 \mu\text{m}$ design rule CMOS processes, thereby allowing various built-in devices listed in Table 3.

2.2.2 Design technology

As IC design technology, Fuji Electric possesses analog-digital hybrid design technology based on PWM circuitry technology for power supply ICs. Automated design and cell-based design have been applied to analog IC design to reduce design lead times. Basic circuit blocks (13 circuits, 21 blocks) are available as CMOS analog macro-cells, including reference voltage circuits and constant current circuits. Additional basic circuit blocks are being one by one after their performance has been verified.

The functions required for application specific power supply ICs used in portable electronic equipment and other devices are determined largely by the application. In many cases, the requirements for custom ICs are ultimately based on specifications specific to each customer. The cell-based design of custom ICs allows for short development lead-times, and an engineering sample can be completed within only three months.

Corner simulation technology, an improved circuit simulation technology, has been introduced to enhance design quality, with consideration given to all various combinations of corner models, variation in the performance of passive elements, and ambient temperatures. In addition, full-chip simulation using a behavior model has been adopted to verify the performance of the whole IC circuit and to carry out quality-oriented design.

3. Future Prospects

Fuji Electric is determined to improve its high-voltage analog CMOS IC technology and to supply highly functional power management ICs, including power supply ICs, to meet customers' needs.

Table 4 shows a technological development roadmap of power supply ICs. In the field of AC-DC converters, Fuji Electric will develop power supply IC technology that minimizes power consumption to satisfy the growing demand for lower power consumption.

In the future, power factor correction ICs will

Table 4 Technology roadmap of power supply ICs

Item		2000	2001	2002	2003
Circuit design technology	AC-DC	Power factor correction control Peak current mode control / average current mode control		With standby mode Current mode / voltage mode control	
	DC-DC	Cell base for DC-DC converters 1.0/0.6 μm		Low-voltage start-up cell	
	Battery management	LiB's remaining battery charge measurement accuracy: 1 % Consumption current: 125 μA		Integration of protective switches for LiB	
	Digital control power supply			Next-generation power supply control technology	
Device process technology	Low on-state resistance device	700 V high-reliability power ICs		700 V lower on-state resistance devices	
		Lateral trench power MOS (TLPM)		n-channel TLPM/30 V	
		Trench MOS process / high-reliability oxide film		p-channel TLPM	
High-reliability analog CMOS process				100 V TLPM	
				Lower-resistance metal electrode (power Al, Cu)	
		1.0 μm analog CMOS / 700 V, 60 V, 30 V			
				0.6 μm analog CMOS / 30 V	

increase in importance for reducing harmonic noise and power loss. Fuji Electric has developed peak-current mode CMOS ICs, and hereafter, will develop average-current mode ICs.

In the field of DC-DC converters, Fuji Electric will expand analog cells and improve cell-based design technology to reduce design lead-time. In the future, the operating voltage of high-performance CPUs (central processing units) and ASICs (application specific ICs) is expected to decrease. To comply with this trend, Fuji Electric will develop low-noise switching power supply technology, essential for PWM switching power supplies, which efficiently produces low voltages from battery voltage. Fuji Electric is promoting the development of higher switching frequencies to reduce the size of reactors and transformers, and hence the size of power supplies. Fuji Electric has already developed 3 to 6 MHz high-frequency switching technology and will improve upon this technology for practical applications.

The development of low on-state resistance devices is essential for power IC technology. As described in the separate paper "Low On-Resistance Trench Lateral

Power MOS Technology," Fuji Electric has developed low on-state resistance trench lateral power MOS devices. Fuji Electric plans to enhance the quality of these devices and commercialize them. For the core technology of high-voltage analog CMOS process technology, Fuji Electric will promote fine process, transitioning from 1 μm to 0.6 μm design rules, and will promote total cost reduction.

4. Conclusion

This paper summarized the present status and future prospects of Fuji Electric's ICs, with an emphasis on power supply ICs. In the future, Fuji Electric is determined to develop and manufacture high value-added products, utilizing low power consumption, high-accuracy CMOS technology integrated with high-voltage, high-current power IC technology and intelligent functions using sensors and digital circuits.

Reference

- (1) Komori, T. Present Status and Prospects of Fuji Electric's IC technology and Products. Fuji Electric Review. vol.46, no.4, 2000, p.110-113.

CMOS Power Factor Control IC

Masato Kashima
Hironobu Shiroyama

1. Introduction

Most of the electronic systems in widespread use at present require rectifier circuits to convert alternating current into direct current as they utilize a DC power supply to drive their internal electronic circuits. Capacitor input filters are mainly used as the rectifier circuits. However, these have the undesired effect of producing a large amount of harmonic current due to the distorted input current waveform caused by the fact that the electric current flows into the input smoothing capacitor only when the alternating voltage is at a peak value. And at that time, the power factor drops to about 0.6. This type of increase in harmonic current may lead to malfunction of the electronic equipment, which may result in social problems. There is a movement to establish legal regulations for harmonic current problems. Increased loss in electric power transmission and distribution due to lowering of the power factor has also become problematic.

To resolve the problems of harmonic current and of lowered power factor, various measures have been proposed and active filters have come into widespread use as they are small and lightweight and can realize a high power factor.

As active filter control ICs, Fuji Electric had already commercialized power factor control ICs, FA5331P/M and FA5332P/M, which are based on average current mode control. This paper presents Fuji Electric's newly developed power factor control ICs, FA5500P/N and FA5501P/N, which are based on peak current mode control.

2. Overview of Power Factor Improving Circuit

Figure 1 shows a capacitor-input-rectifier circuit and its input voltage and current waveforms. The input current flows only during short intervals when the input voltage is in the vicinity of the peak voltage, and a large amount of harmonic current is generated. Existence of the harmonic current lowers the power factor, and the relation between them can be expressed by the following equations:

$$PF = 1/\sqrt{1 + THD^2}$$

$$THD = \sqrt{(i_2^2 + i_3^2 + \dots i_n^2)/i_1^2}$$

Where,

PF: power factor,

THD: total harmonic distortion,

i_1 : input current fundamental harmonic,

i_n : n -th order harmonic.

From these equations it is seen that the input harmonic current can be suppressed if the power factor can be improved by a power factor improving circuit.

Power factor is defined as the difference in phases between the waveforms of voltage and current. Accordingly, the power factor can be improved if the current waveform is controlled to be in-phase with that of the voltage. If phases of the voltage and current waveforms coincide completely, the power factor becomes 1.

Figure 2 shows a boost converter circuit used as an active filter circuit to control the current waveform. This is a boost converter circuit connected to a full wave rectifier circuit configured from a diode bridge. Switching element M1 of the circuit in Fig. 2 is switched on and off at a frequency substantially higher than that of the alternating voltage. And by control-

Fig.1 Capacitor-input-rectifier circuit and its input voltage and current waveforms

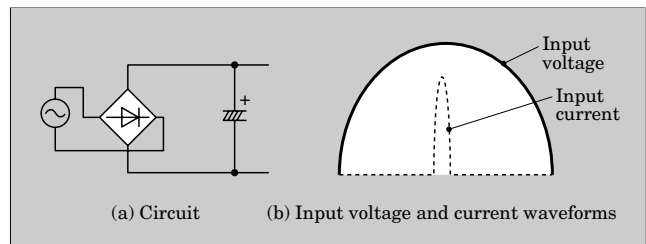


Fig.2 Boost converter circuit

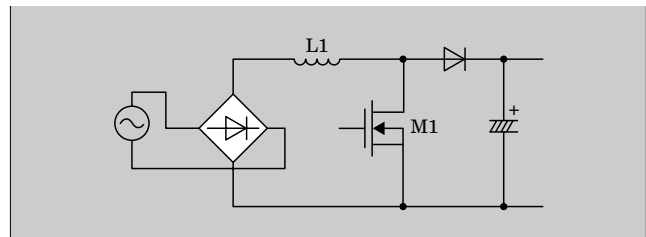


Fig.3 Comparison of waveforms of input voltage and input current between peak current mode control and average current mode control

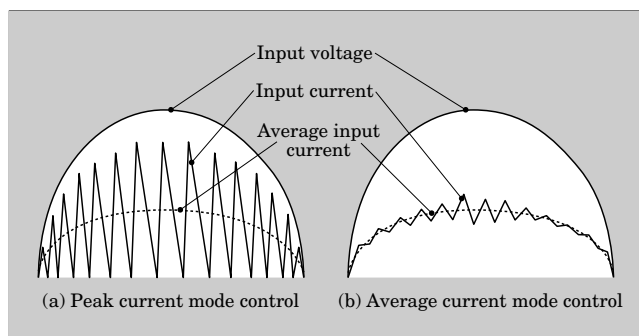


Table 1 Comparison between peak current mode control and average current mode control

Control method	Peak current mode control	Average current mode control
Model	FA5500/FA5501	FA5331/FA5332
Oscillation	Self-oscillation	Externally excited oscillation
Frequency	Variable	Fixed
Output electric power	Small (less than approx. 200 W)	Large (more than approx. 200 W)
Application	Lighting equipment, personal computer etc.	Inverter etc.

ling the on-off ratio, the average of the input current waveform is made into a sinusoidal current in-phase with the waveform of the full-wave rectified input voltage and thus the power factor is improved.

There are two methods to control the on-off ratio. One is the peak current mode control method to control the peak value of the current flowing through the switching element M1 and the other is the average current mode control method to control the continuous current flowing through the reactor L1.

Figure 3 shows a comparison of the waveforms of input voltage and input current for the cases of peak current mode control and average current mode control. When either of these methods is applied to actual products, a high frequency filter is inserted between the active filter circuit and the alternating input voltage. The action of this filter causes the waveform of the input current to become similar to that of the average input current as shown by the broken lines in Fig. 3.

Table 1 shows a comparison between peak current mode control and average current mode control. As shown in this table, the types of products to which these control methods are applied are generally determined according to their required output power capacity. The FA5331P/M and FA5332P/M, with average current mode control, are suited for relatively large output (more than approx. 200 W) and are used for inverters etc. In contrast, the newly developed FA5500P/N and FA5501P/N, with peak current mode

Fig.4 Appearance of FA5500 and FA5501

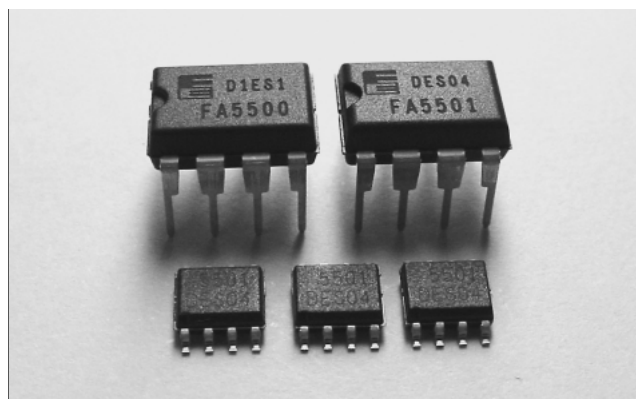
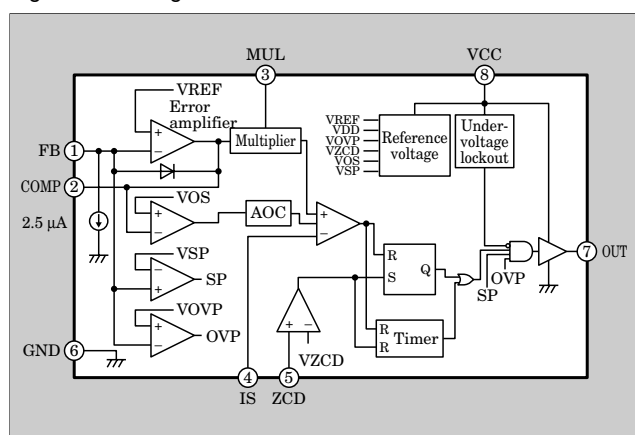


Fig.5 Block diagram



control, are suited for relatively small output (less than 200 W) and are intended for use in lighting equipment, personal computers, etc.

3. Overview of Products

The recently developed FA5500 and FA5501 ICs contain various built-in functions and are housed in 8-pin DIPs (dual in-line packages) or SOPs (small out-line packages). Their appearance and block diagram are shown in Figs. 4 and 5, respectively.

3.1 Characteristics

The features of this IC element are as follows:

- (1) Low power dissipation is realized due to adoption of a 30 V high voltage CMOS (complementary metal oxide semiconductor) process.
Start-up power dissipation: 20 μ A
Operating power dissipation: 2 mA
- (2) A correction circuit for light loads enables constant voltage control throughout the range from the rated load to no-load.
- (3) If the output voltage detector malfunctions, circuit action is stopped by means of an FB short detecting circuit.
- (4) Overvoltage protection is built-in.
- (5) Serialization of undervoltage lockout circuit ac-

Power Supply IC for Low Power AC Adapters

Yasushi Katayama

1. Introduction

The AC adapter is a kind of AC-to-DC converter and is mostly used for supplying power to portable electronics equipment or for charging batteries. Required features of the AC adapter have been small size, light weight and low price. Recently, however, low standby power has also come to be required due to the trend toward energy saving in response to global environmental problems.

To satisfy such requirements for the AC adapter, Fuji Electric developed and produced a power IC (integrated circuit) for switch-mode power supply control. The IC integrates a PWM (pulse width modulation) control circuit containing high accuracy analog CMOS (complementary metal oxide semiconductor) devices with a 700 V power MOSFET (metal oxide semiconductor field effect transistor). This construction achieves small-sized and low priced AC adapters with low power dissipation and high reliability.

This paper presents an overview of the “FA5702P” power IC for switch-mode power supply control, developed for application to 5 W-class low-power AC adapters.

2. Characteristics

Figure 1 shows a block diagram of the FA5702P and Table 1 shows its primary electrical characteristics.

For decreasing standby power consumption of the AC adapter, reduction of the power dissipation of its control circuit is a crucial issue. The FA5702P has achieved a low supply current of 200 μA at MOSFET switching due to significantly reduced current consumption and optimized configuration of the circuit.

Primary advantages of the FA5702P are as follows:

- (1) A power MOSFET and its control circuit are integrated into a single chip.
- (2) A low supply current of 200 μA at MOSFET switching is achieved with a newly designed control circuit.
- (3) The supply current for the internal circuit is fed from the rectified AC input directly. A bootstrap

Fig.1 Block diagram

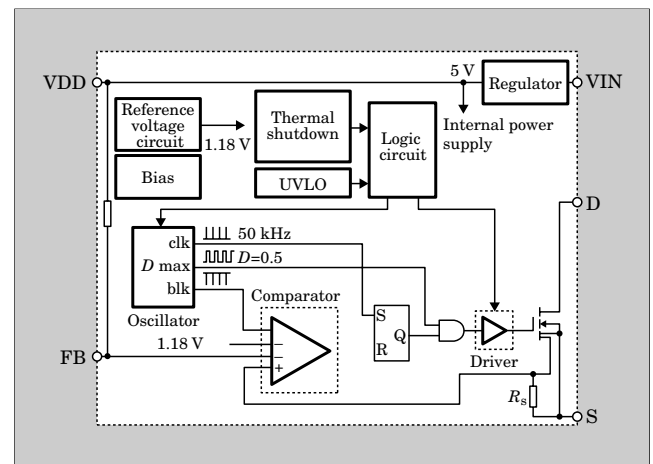


Table 1 Primary electrical characteristics

Item		Characteristic
Power MOSFET	Breakdown voltage	700 V (Minimum)
	On-resistance	20 Ω (Typical)
Control circuit	Supply voltage	500 V (Maximum)
	VDD terminal voltage	5 V (Typical)
	Oscillator frequency	50 kHz (Typical)
	Maximum duty cycle	50 % (Typical)
	Current limit	350 mA (Typical)
	Supply current at MOSFET switching	200 μA (Typical)
	Supply current at latched off	60 μA (Typical)

circuit, consisting of a transformer auxiliary winding, diodes, and capacitors, becomes unnecessary for supplying power to the IC, and thus the circuit configuration of the AC adapter can be simplified.

- (4) The IC accommodates input from any universal AC power supply ranging from 100 V to 240 V, since the supply voltage is 500 V maximum and the breakdown voltage of the power MOSFET is 700 V maximum.
- (5) Peak current mode PWM control is utilized, which is superior in stability and frequency response and suppresses the generation of audible transformer

noise under light load conditions.

- (6) It contains internal protection functions such as overcurrent limiting, thermal shutdown, and undervoltage lockout (UVLO).

Figure 2 shows a top view of the FA5702P chip and Fig. 3 shows external views of the IC packages.

In Fig. 2, the 700 V power MOSFET is shown in the upper half of the figure and the control circuit is

Fig.2 Top view of FA5702P chip

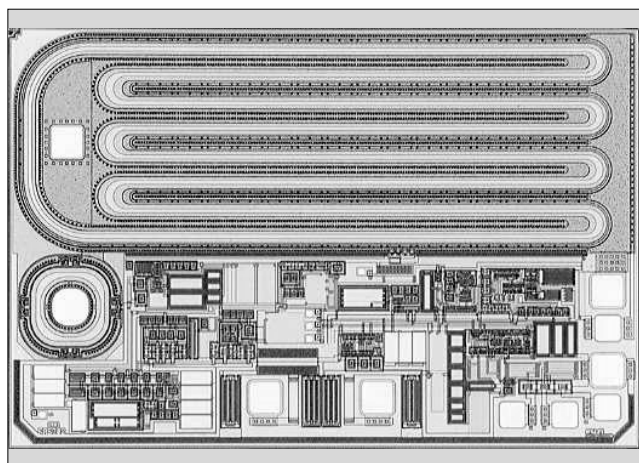


Fig.3 External view of FA5702P packages

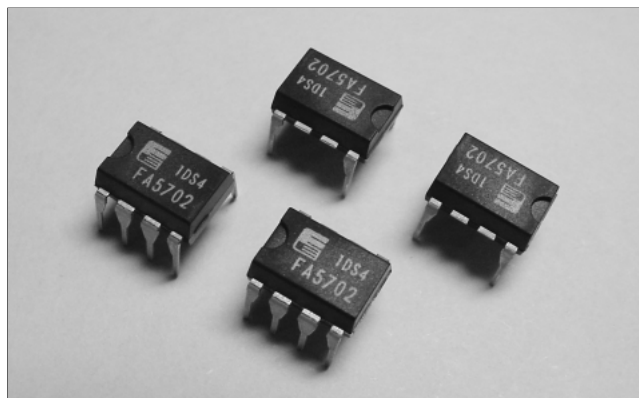
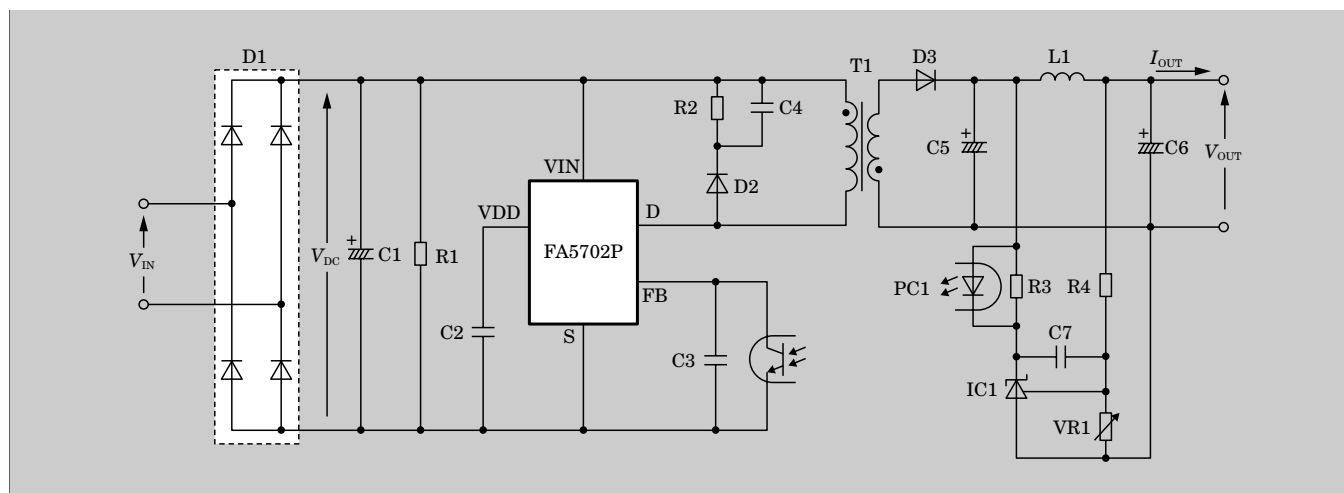


Fig.4 Example of application circuit



shown in the lower half. The IC is constructed with a standard DIP (dual in-line package).

3. Example of Application Circuit

Figure 4 illustrates an example of an AC adapter circuit that utilizes the FA5702P chip. The circuit is configured as a flyback converter, which is used in most low-power AC adapters, and the input range is from 90 V to 264 V AC and the output is 5.8 V/800 mA DC.

The FA5702P contains an internal power MOSFET for the main switch, and the FA5702P can be directly powered from the rectified AC input as shown in Fig. 4. Therefore, in contrast to the usual ICs for switch-mode power supply control which require the use of additional power MOSFETs and bootstrap and startup circuits consisting of a transformer auxiliary winding, diodes, and capacitors, the FA5702P eliminates the need for those additional components. This allows an AC adapter that uses the FA5702P to be configured with

Fig.5 Waveforms at rated output

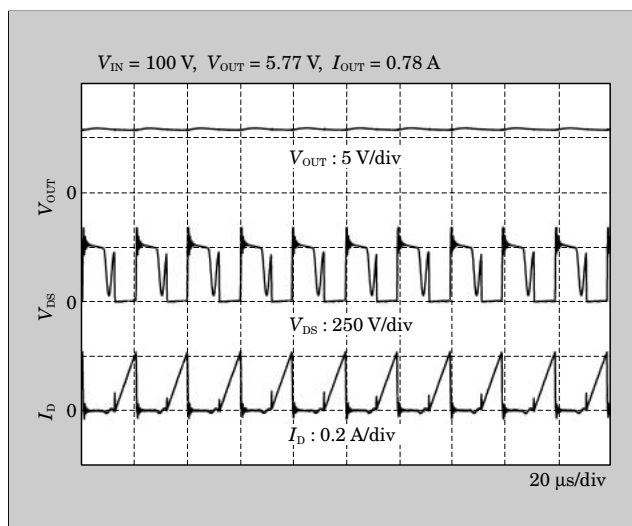


Fig.6 Waveforms at no load

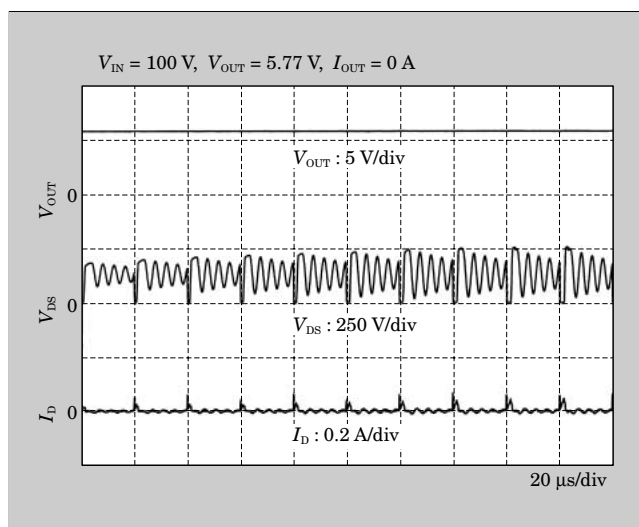
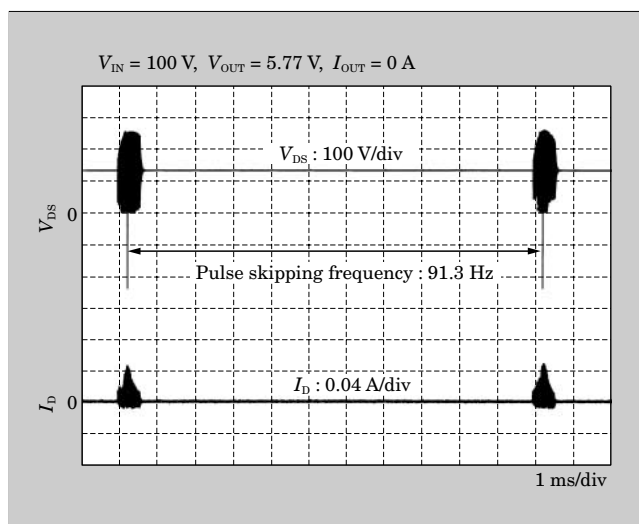


Fig.7 Pulse skipping operation at no load



fewer components than in the case when conventional type ICs are used.

Figure 5 shows electrical waveforms of the operation of this circuit at the rated output. As can be seen, the circuit operates stably while regulating the output voltage with PWM control.

Figures 6 and 7 show electrical waveforms of the operation of this circuit under the condition of no load. In this condition, the circuit status shifts to pulse skipping operation, as shown in the figures. At that time, the pulse skipping frequency has decreased to an audible frequency level. The FA5702, however, generates no audible noise from the transformer core. This is because the IC controls the peak current at a low level with the current mode PWM control and thus the variation in the magnetic flux density excited in the core is also suppressed.

Figures 8 and 9 respectively show the efficiency and the total loss measured in the application circuit

Fig.8 Efficiency in application circuit

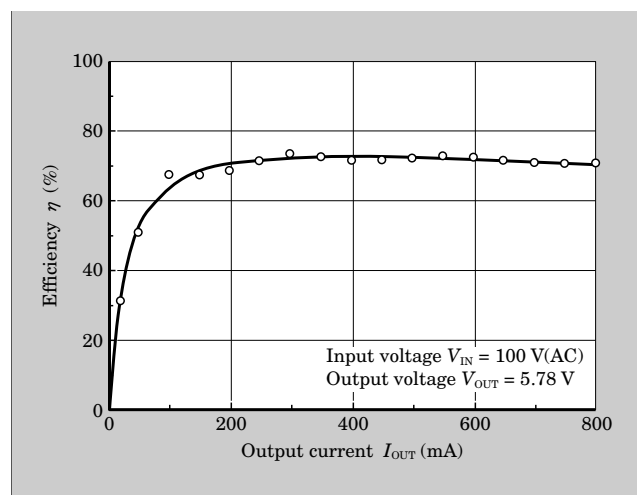
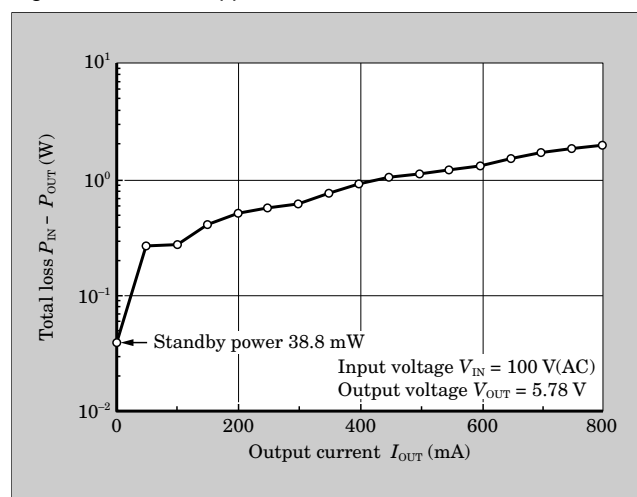


Fig.9 Total loss in application circuit



in Fig. 4. The selection of components in the transformer and feedback circuit greatly effects the efficiency and total loss of the circuit, but this circuit has achieved low standby power of 38.8 mW.

4. Conclusion

This paper has introduced an overview of the FA5702P power IC for switch-mode power supply control, developed for the application to 5 W-class low-power AC adapters.

This IC contains an internal power MOSFET and has the advantage of low current consumption. Therefore, it helps to reduce the standby power consumption of AC adapters and the number of their circuit components.

Fuji Electric will respond further to market needs by expanding the product line of power ICs for switch-mode power supply control to provide devices suitable for application to a variety of applications and output requirements.

Power Supply IC for LCD Panels

Masayuki Yamadaya

1. Introduction

With the widespread popularization of multimedia, electronic devices are increasing being required to be smaller, lighter, thinner and to have lower power consumption. Liquid crystal displays (LCDs), having these merits, account for the majority of display devices.

Three voltages are required in general for driving LCD panels. Among these voltages, the input voltage to the LCD panels, the voltage configuration required for driving them and the power supply sequence are various and depend upon the particular supplier and kind of panel.

Furthermore, to reduce the size of the power supply circuits, it is especially necessary to reduce the size of transformers and coils, which requires operating the power supply circuit at higher frequency.

Fuji Electric has successfully developed power supply ICs (integrated circuits) for LCD panels in the past, and has newly developed the FA3686V and FA3687V PWM (pulse width modulation) switching power supply controller ICs with 2 channels. An overview of this new series is introduced below.

2. Product Outline

Use of the newly developed FA3686V or FA3687V, both power supply ICs for LCD panels, can be selected according to the different power supply configurations and applications required for the LCD panels.

Features common to both of these devices are as follows:

- (1) TSSOP (thin shrink small out-line package) : 16-pin packages are used.
- (2) Operating voltage: 2.5 to 18 V
- (3) Oscillation frequency : 300 kHz to 1.5 MHz, can be set with externally mounted resistor only
- (4) Accuracy of reference voltage and regulated voltage for internal control blocks : $\pm 1\%$
- (5) Built-in PWM control output with 2 channels
- (6) Built-in timer and latch type short circuit protection, undervoltage lockout circuit and soft start circuit

Table 1 Common ratings of the FA3686V and FA3687V

Item	Condition	Minimum	Typical	Maximum	Unit
Power supply voltage		2.5		18	V
Reference voltage		0.99	1.00	1.01	V
Regulated voltage for internal control blocks		2.178	2.200	2.222	V
Oscillation frequency	$RT = 12\text{ k}\Omega$	435	500	565	kHz
Undervoltage lockout operating voltage		2.00	2.20	2.35	V
OUT1, 2 H-level on-state resistance	$I_{\text{out}} = 50\text{ mA}$		10	20	Ω
OUT1, 2 L-level on-state resistance	$I_{\text{out}} = -50\text{ mA}$		5	10	Ω

Note: The ratings are for the power supply voltage of 3.3 V and room temperature (25°C) unless otherwise specified

- (7) The externally mounted switching element can directly drive either a MOSFET (metal oxide semiconductor field effect transistor) or a bipolar transistor.

The main characteristics common to both the FA3686V and FA3687V are shown in Table 1.

3. Characteristics of FA3686V

The FA3686V is distinguished among power supply ICs for LCD panels as a device especially suited for use in power supplies with 3 outputs. It is designed so as to enable the easy configuration of a series regulator by adding an error amplifier in addition to a 2-channel PWM control block.

Figure 1 shows the internal circuit of the FA3686V. The features of the FA3686V are described below.

3.1 PWM control blocks

The non-inverted input to the error amplifier for each of channel 1 and channel 2 is connected to the reference voltage (1.00 V $\pm 1\%$) internally. The output of channel 1 can configure a boost converter at the n-

channel driver and the output of channel 2 can configure an inverting converter at the p-channel driver.

3.2 Maximum duty limit circuit

When driving the boost converter and inverting converter, it is necessary to limit the maximum duty so as to prevent 100 % loading.

The FA3686V has a built-in maximum duty limiting circuit, which limits the duty within about 85 % without requiring any external setting.

3.3 Soft start circuit

The FA3686V is equipped with an independent soft start circuit for each channel. The CS1 and CS2 terminals for setting soft start are provided with

internal current sources and the function is realized by simply connecting capacitors externally.

3.4 Timer and latch circuit

The timer and latch type short circuit protection function monitors the output voltage of the error amplifier. If the error amplifier output exceeds the limit of the switching extension side for a certain delay time, the protection function judges that to be an abnormal condition and stops the switching. The FA3686V counts the oscillation period to determine the delay time. The time can be set as the oscillation period multiplied by either 2^{16} or 2^{17} , without requiring any externally mounted part.

3.5 PGS

FA3686V has a new function, PGS (power good signal). This function is for outputting fault signals of the power supply driven by FA3686V and is configured as an n-channel MOSFET open drain output.

If the input voltage is below a specified value (2.35 V when the voltage is rising and 2.25 V when the voltage is falling), if the undervoltage lockout circuit (UVLO) has been activated, or if the timer and latch circuit has been activated, the n-channel MOSFET has been turned on.

3.6 Example circuit application

Figure 2 shows an example circuit application using the FA3686V.

Channel 1 drives the boost converter and channel 2 drives the inverting converter. Furthermore, the charge pump converter is configured using the switching of channel 1, which is subsequently combined with a series regulator to form another voltage.

Charge pump converters, which can be configured from capacitors and with a little load current, are seen

Fig.1 FA3686V circuit diagram

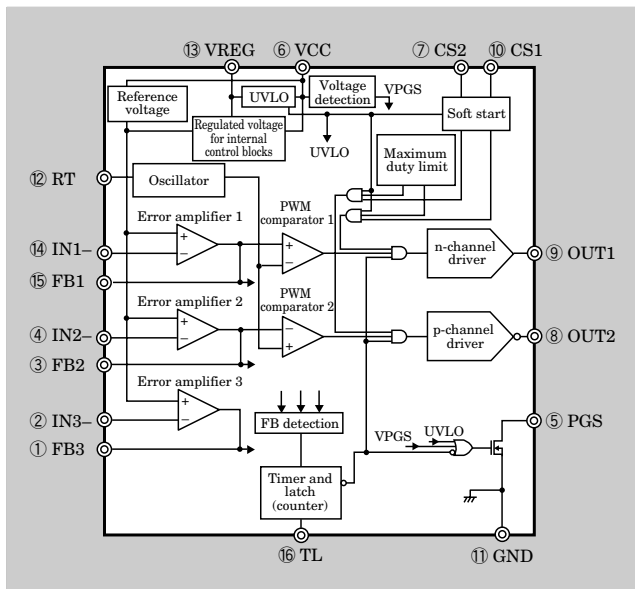
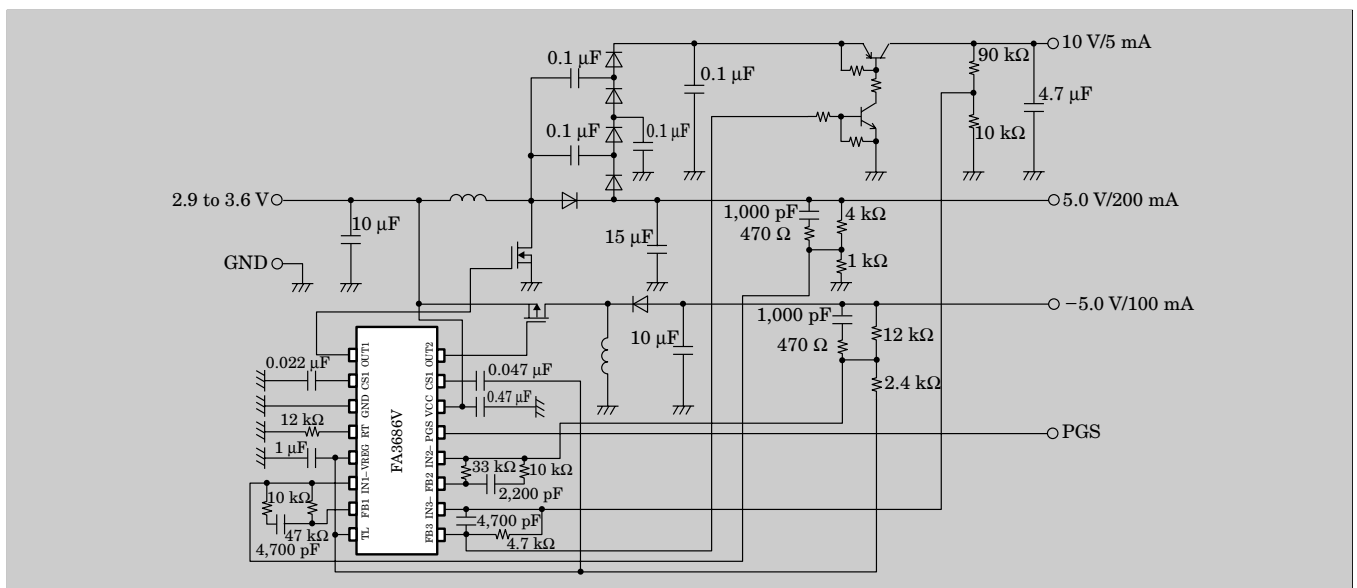


Fig.2 Example circuit application using the FA3686V



Charge Pump Booster IC

Yutaka Yoshida
Hirohisa Arai

1. Introduction

Portable electronic equipment such as PDAs (personal digital assistants) and cellular phones that have rapidly spread into the market requires reduction in size, weight and power consumption because portability and extended battery operation are essential features.

For electronic components used in portable electronic equipment, the power supply voltage of digital ICs has been lowered as device dimensions have been miniaturized. On the other hand, the operating voltage of analog ICs and RF communication components remains around 3 to 5 V as their electrical characteristics are susceptible to change depending on the power supply voltage. Lithium-ion rechargeable batteries used in portable electronic equipment typically provide an output of 3.6 V, therefore use of booster converters is necessary.

Moreover, analog ICs and RF communication parts are susceptible to possible malfunction if the noise of the power source is large; thus a stable power supply is necessary.

This paper introduces the FA3705NM charge pump booster IC, developed in response to market needs for a small-size boost power supply with the features of low ripple voltage and low power consumption.

2. Features

The FA3705NM was developed for components in portable electronic equipment requiring a stable 5 V power supply, and its merits are low ripple voltage, low power consumption and a compact circuit size.

As a boost converter, DC/DC switching converters with inductors or charge pump converters with capacitors are often used, but ripple voltage on the output due to the switching operation is so large that they cannot be utilized in analog ICs or RF communication components.

On the other hand, the FA3705NM integrates a charge pump boost converter operating with capacitors and a series regulator suppressing ripple voltage into a

Fig.1 Magnified view of chip (FA3705NM)

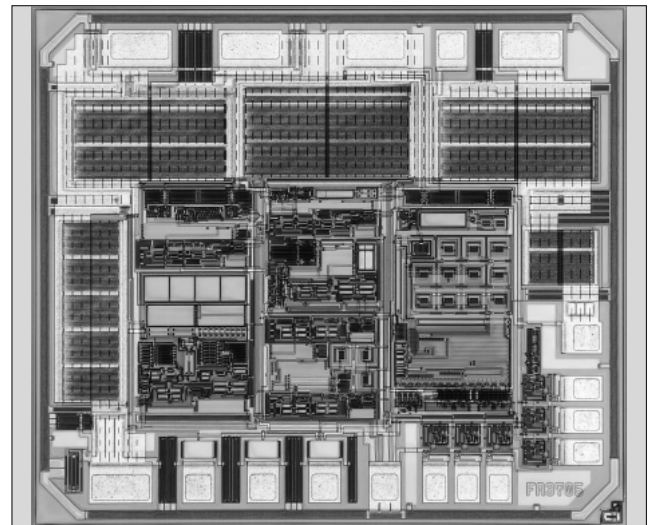
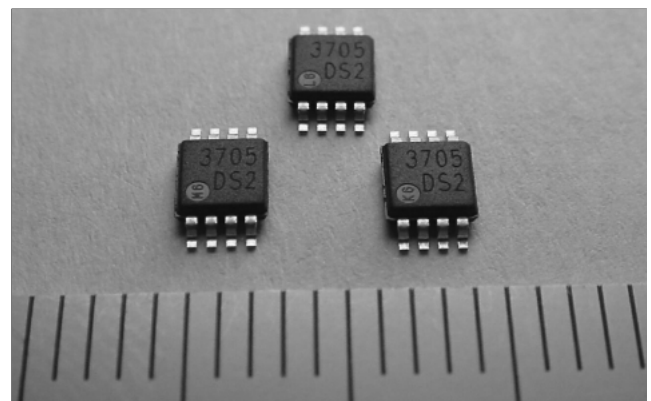


Fig.2 External view (FA3705NM)



single chip, thereby realizing a boost converter with low ripple voltage.

Low power operation is accomplished by using CMOS (complementary MOS) process technology and setting up the shutdown mode. A small size is accomplished by adopting an ultra-small MSOP (micro small out-line package)-8 package and attaching only a small number of external parts (as few as five capacitors).

The features are summarized briefly below.

- (1) Low ripple voltage: typ.1 mV_{p-p}
- (2) Input voltage range compatible with a Lithium-ion battery: 2.7 to 4.4 V
- (3) Shutdown mode available
- (4) Built-in protection circuits for overheating, overloading and low input voltage
- (5) Built-in reference voltage circuit
- (6) Ultra-small MSOP-8 package: 3.0 mm by 4.9 mm (including the tip of the leads)

Figures 1 and 2 show views of the magnified chip and the exterior of the FA3705NM respectively.

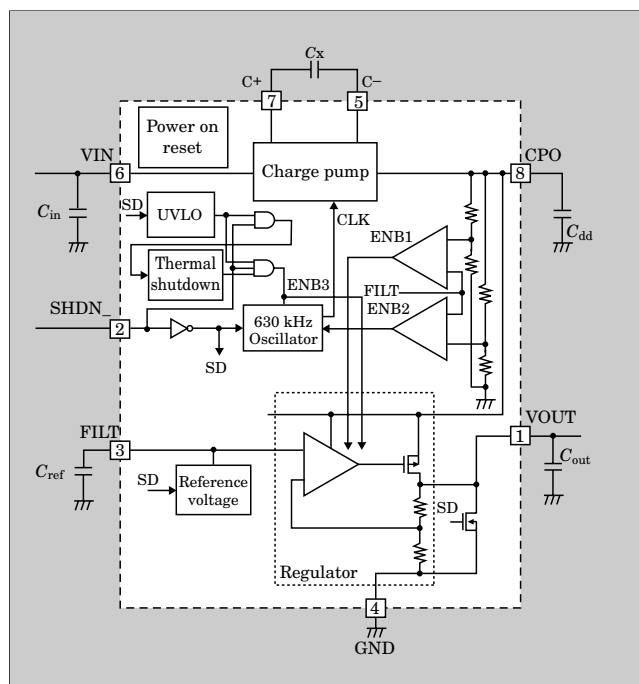
3. Product Summary

Operation of the FA3705NM is described below, and the electrical characteristics are listed in Table 1 and the internal block diagram is shown in Fig. 3.

Table 1 Electrical characteristics

Item	Characteristic
Input voltage range	2.7 to 4.4 V
Startup input voltage	2.5 V (Typical)
Output voltage	5.00 V \pm 0.10 V (Input voltage = 3.2 V, Output current = 1 mA)
Output current	50 mA (Maximum)
Oscillation frequency	630 kHz (Typical)
Supply current	250 μ A (Typical) (Input voltage = 4.4 V, Output current = 0 mA) 4.1 mA (Typical) (Input voltage = 3.2 V, Output current = 1 mA)
Supply current in shutdown	0.1 μ A (Typical)

Fig.3 Block diagram



3.1 Basic operation

The built-in charge pump generates about 5.8 V from the voltage input at the VIN terminal, and outputs that generated voltage to the CPO terminal. In contrast to a conventional charge pump that outputs twice the value of the input voltage, the FA3705NM outputs a constant value by disabling temporarily while the output voltage exceeds 5.8 V. It accomplishes this by monitoring the output voltage with a built-in voltage reference circuit and comparator.

The output of the charge pump contains ripples due to the switching operation, but the built-in series regulator attenuates the ripples and outputs a stable voltage of 5.0 V at the VOUT terminal. In order to prevent malfunction of the series regulator, it stays inactive until the voltage at the CPO terminal reaches 5.1 V.

The oscillating rate of the charge pump is 630 kHz. This frequency has to be selected so as not to cause interference with the intermediate frequency of 450 kHz or 455 kHz used for converting from a high radio frequency to the data transmitting frequency adopted in portable electronic equipment.

The startup operation of the power supply is described below.

- (1) First, the built-in voltage reference circuit starts, and then the voltage at the FILT terminal rises from the initial value of 0 V to about 1.22 V.
- (2) After a while, the built-in charge pump starts, and charges the external capacitor C_{dd} connected at the CPO terminal from an initial value of 0 V to about 5.8 V through the flying capacitor C_x .
- (3) While the voltage at the CPO terminal is less than 5.1 V, the built-in series regulator does not operate and the voltage at the VOUT terminal remains at 0 V. After the voltage at the CPO terminal exceeds 5.1 V, the built-in series regulator starts operation and the voltage at the VOUT terminal increases gradually up to 5.0 V.

Figure 4 shows the startup waveform of the power

Fig.4 Startup waveform

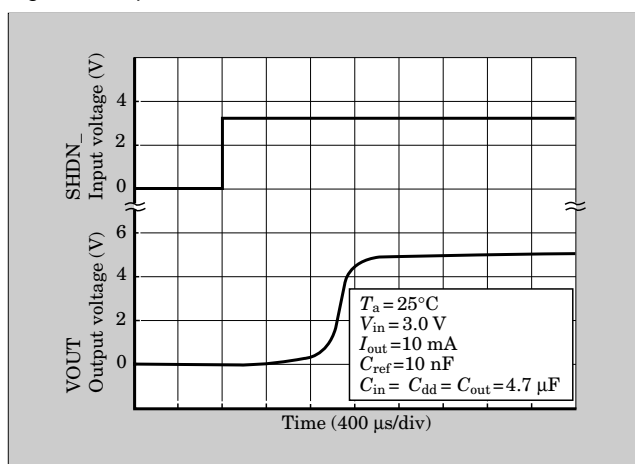


Fig.5 Relationship between C_{ref} and rise time

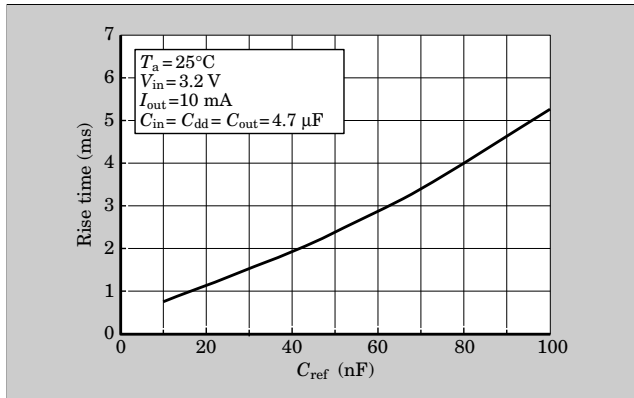


Fig.6 Shutdown waveform

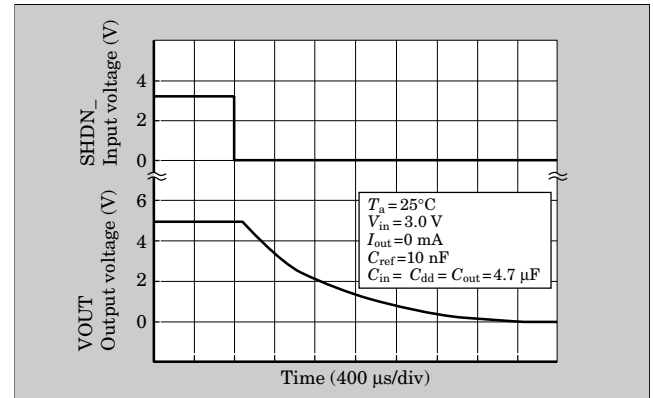
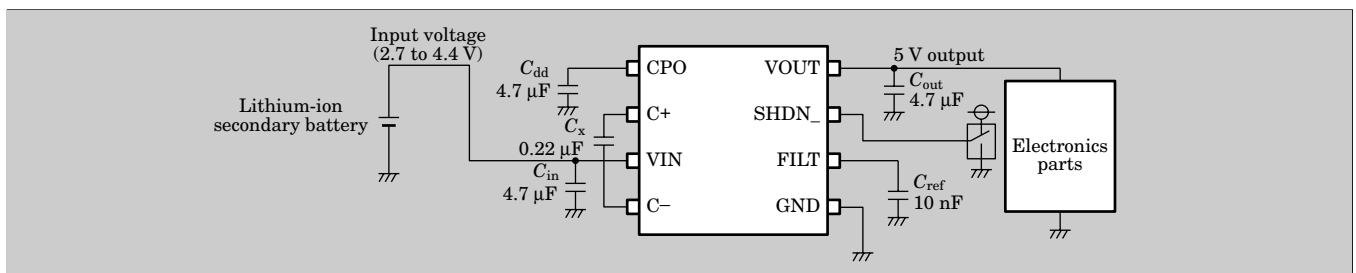


Fig.7 FA3705NM application circuit example



supply. The output voltage settles at the desired value 1.2 ms after startup.

The rise time depends on the value of C_{ref} , which is a 10 nF capacitor in the case of the measurement shown in Fig. 4. Figure 5 shows the relationship between C_{ref} and rise time. There is a tendency for the rise time to become longer but ripples on the output to become smaller with larger values of C_{ref} .

3.2 Shutdown

Setting the SHDN_ terminal to a low level causes all internal circuits to suspend operation, and consequently the consumption current drops below 1 μ A. While the FA3705NM is in shutdown mode, the VOUT terminal is shorted to GND internally and the power supply is cut off. This prevents malfunction of the electronics components that are supplied power by the FA3705NM.

Figure 6 shows the shutdown waveform of the power supply. The voltage settles down to 0 V approximately 2.5 ms after shutdown.

3.3 Protection circuit

To avoid damage caused by accidental external conditions, the following protection circuits are built-in.

- (1) Overheat protection: When the temperature of the IC rises to about 150°C, the charge pump stops its operation and cuts off power to the load. After cooling down to about 140°C, the charge pump resumes operation.

- (2) Overload protection: If the output of the series regulator falls below about 1.22 V, that event is regarded as an overload condition, and the series regulator stops its operation.
- (3) UVLO (undervoltage lockout): While the input voltage is below approximately 2.5 V, all internal circuits except the reference voltage circuit stop their operation to avoid malfunction.

4. Application Circuit

Figure 7 shows an example application circuit that utilizes the FA3705NM. This example is a power supply circuit providing stable 5 V to radio frequency components such as a VCO (voltage controlled oscillator) with a Lithium-ion battery power source.

The only external components necessary are five low-priced ceramic capacitors.

Connecting the SHDN_ port to one of the external ports of the microcontroller makes shutdown mode available.

5. Conclusion

This paper has presented an overview of the FA3705NM, developed as a power supply for portable electronic equipment.

In keeping with the trend toward increasingly higher integration of LSI devices, Fuji Electric is determined to provide technological innovation for more versatile systemized circuits.

Power Management IC for a Cellular Phone with a Li-Ion Battery Charger

Hirohisa Arai
Yutaka Yoshida
Jun Yabuzaki

1. Introduction

Portable electronic equipment has recently been improved with respect to reduced size and weight and to advanced functionality. Cellular phones, as typical products of such equipment, have been favored by many consumers and have attained high market penetration due to their enhanced portability and convenience which allows phone calls to be made whenever and wherever desired, enabled by the reduction of size and extension of standby/talk time with low power consumption.

Fuji Electric developed the FA3694R power supply IC for cellular phones, which provides low power consumption (reduction of IC power consumption) and downsizing (integration of each function) and is housed in a 48-pin small package.

This paper presents an overview of the FA3694R power management IC for cellular phones.

2. Features

The FA3694R is a system power supply IC developed for cellular phones, containing a high-precision battery charger (stand alone), six 2.85 V voltage output terminals, an LDO (low drop out) regulator for maximum output current of 150 mA, a speaker amplifier, various drivers [LED (light emitting diode), buzzer, backlight], various detectors, reference voltage circuits, etc.

Moreover, each LDO regulator, speaker amplifier and various drivers can be individually turned on or off via a serial interface. The ability to switch each power supply on or off as needed makes it possible to save battery power and to achieve low power consumption in a cellular phone.

The features of the FA3694R are summarized as follows:

(1) Built-in integrated battery charger.

- Pre-charge.
- Fast charge.
 - Constant current mode.
 - Constant voltage mode.

This IC, targeting the full charging of the battery

Fig.1 Photograph of the FA3694R package

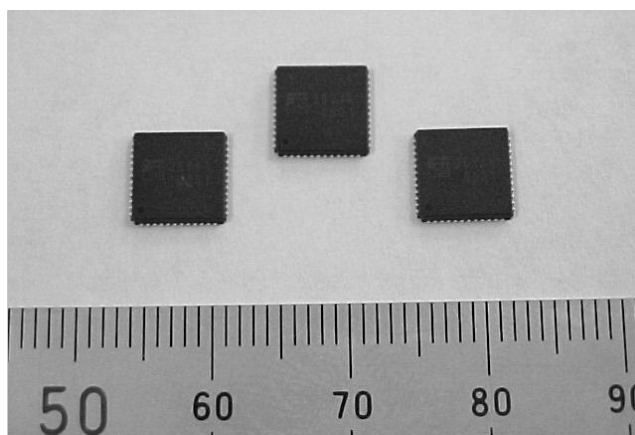
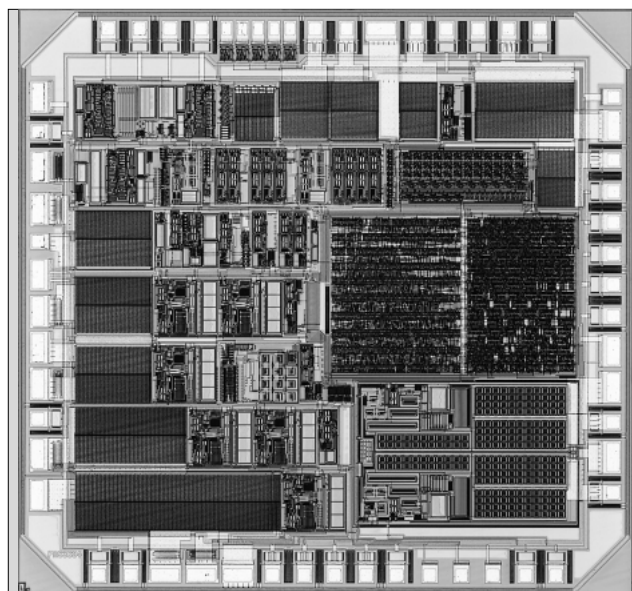


Fig.2 Photograph of the FA3694R chip



(to extend the available period of use) and safety during the charging process (to prevent battery damage caused by overvoltage), regulates the voltage of the constant voltage charge during the fast-charge mode, i.e. in the last stage of the charge, and has realized the voltage with high precision of $4.2 \text{ V} \pm 30 \text{ mV}$.

(2) Built-in six LDO regulators.

- (3) Built-in speaker amplifier (to drive speaker of 32 Ω load)
- (4) Built-in various driver circuits
LED, buzzer, backlight.
- (5) Built-in various detector circuits
Regulator, main power and battery detection.
- (6) Built-in reference voltage circuit
- (7) CMOS (complementary metal oxide semiconductor) silicon gate 1 μm process
- (8) Low consumption current : 100 μA (in standby)

Table 1 Absolute maximum ratings

Item		Ratings	Unit
Supply voltage range	VCHG	6.5	V
	MPWR	6.5	
Input voltage of control terminal		-0.3 to 3.15	V
Input voltage of speaker amplifier		-0.3 to 3.0	V
Power dissipation ($T_a = 25^\circ\text{C}$)		600	mW
Operating temperature		-30 to 85	$^\circ\text{C}$
Storage temperature		-40 to 125	$^\circ\text{C}$

Table 2 Main electrical characteristics

Item	Condition	Typical	Unit
Battery charger			
Pre-charge	$R_s = 0.4 \Omega$	100	mA
Fast-charge (CC Mode)	$R_s = 0.4 \Omega$	1,000	mA
Fast-charge (CV Mode)	$R_s = 0.4 \Omega$	4.20	V
Over voltage threshold for VCHG		6.0	V
Under voltage threshold for VCHG		3.65	V
Over voltage threshold for VBAT		4.55	V
Under voltage threshold for VBAT		2.90	V
Low temperature threshold		0	$^\circ\text{C}$
High temperature threshold to cut off pre-charge		43	$^\circ\text{C}$
High temperature threshold to cut off fast-charge		50	$^\circ\text{C}$
Maximum pre-charge time		140	min
Maximum fast-charge time		140	min
Regulator			
Output voltage	$I_{\text{load}} = 150 \text{ mA}$	2.85	V
Ripple rejection rate	$f = 21 \text{ kHz}$	-60	dB
Load regulation	$I_{\text{load}} = 1 \text{ to } 150 \text{ mA}$	0.2	mV/mA
Buzzer			
Turn on voltage for NMOS	$I_{\text{load}} = 120 \text{ mA}$	0.20	V
LED			
Output current	$V_{\text{in}} = 1.0 \text{ V}$	40	mA
Output current	$V_{\text{in}} = 2.85 \text{ V}$	114	mA
Current dissipation			
Standby current	During standby	100	μA

- (9) 48-pin QFN (quad flat non-lead) package.

The external appearance of the FA3694R is shown in Fig. 1 and a photograph of the chip interior is shown in Fig. 2.

3. Specifications

The absolute maximum ratings are indicated in Table 1 and the main electrical characteristics are indicated in Table 2.

4. Brief Description of the IC

4.1 Charge control

The charge control circuit has been developed for a Li-ion battery. The block diagram of the charge block is shown in Fig. 3.

The charge block consists of a charge current monitor block, a monitor for supply voltage, a charge voltage/current control block (for CC/CV mode), a charge voltage monitor block, a battery temperature monitor block (including monitoring for the presence of a battery), a monitor for clock operation and a sequential logic circuit.

The sequential logic circuit (Fig. 4) monitors and controls the adaptor voltage, the battery voltage, the battery temperature, the charge current and the charge time.

The timing diagram of charging is shown in Fig. 5.

The normal charge process is described as follows.

- (1) When the battery voltage is greater than 3 V and the adaptor voltage is normal ($3.75 \text{ V} < V_{\text{CHG}} < 6.0 \text{ V}$), a fast-charge is performed.
- (2) During a fast-charge, either a constant current

Fig.3 Block diagram of the charge block

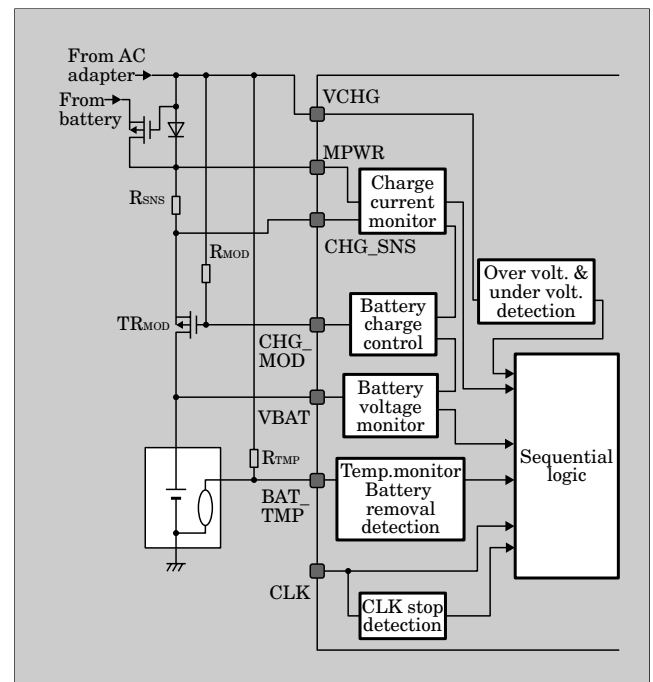
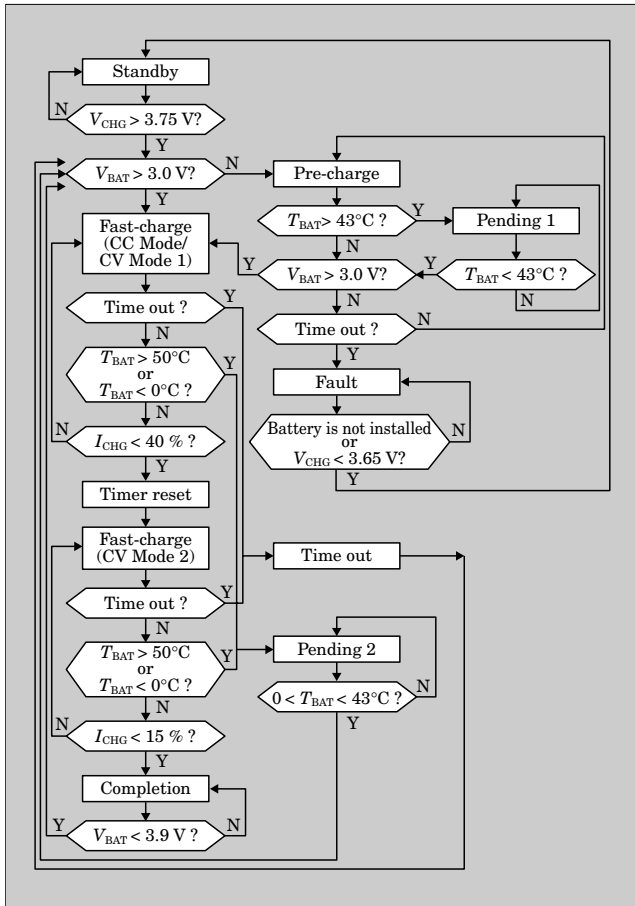


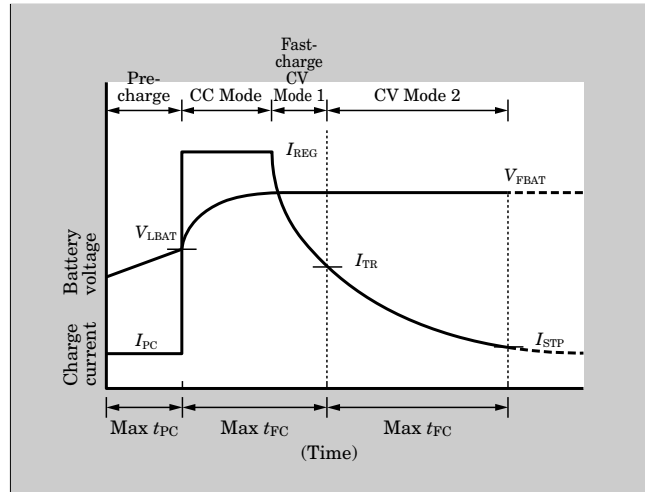
Fig.4 Flowchart of charging sequence



charge or constant voltage charge is performed, according to the charge current and the battery voltage. Normally, a constant current charge with 1 A is performed, and then a constant voltage charge at 4.2 V is done.

- (3) The charge is completed at the point in time when the charge current decreases to less than 150 mA during a constant voltage charge.
- (4) When the battery voltage drops less than 3.9 V, a recharge is initiated.
- (5) When charging is initiated, if the battery voltage is less than 3.0 V, pre-charging is performed. Pre-charging in the constant current mode at 100 mA is continued until the battery voltage exceeds 3.0 V. If pre-charging has continued for more than 140 minutes, it will be stopped and the battery judged to be defective.
- (6) During charging, if the battery temperature rises over 50°C or drops under 0°C, the charging will be stopped. Charging will resume when the battery temperature again falls into the range between 43°C and 0°C.
- (7) Charging will be stopped in the following cases.
 - If the adaptor voltage becomes less than 3.65 V or greater than 6.0 V
 - If the battery voltage exceeds 4.55 V
 - If the battery is not physically present

Fig.5 Timing diagram of charging



- If the clock is stopped

4.2 LDO regulator

The FA3694R incorporates an LDO regulator based on CMOS technology. Compared to bipolar products, CMOS products operate with smaller current consumption and smaller voltage drops, and therefore the FA3694R IC enables the use of smaller battery capacity and also lower battery voltage. The LDO regulator built into this IC has a high ripple rejection rate of -60 dB, up to 21 kHz range, and achieves a low current consumption of 40 μ A per circuit.

4.3 Speaker amplifier

In order to drive the speaker with a BTL (balanced transformer less) configuration, two push-pull amplifiers are built into this IC. By setting the EN terminal to a low-level, the shutdown mode is enabled, therefore the current consumption can be suppressed to less than 1 μ A.

4.4 Various drivers

In order to drive the buzzer and backlight, n-channel MOSFETs (metal oxide semiconductor field effect transmitter) in the open drain configuration are built into this IC.

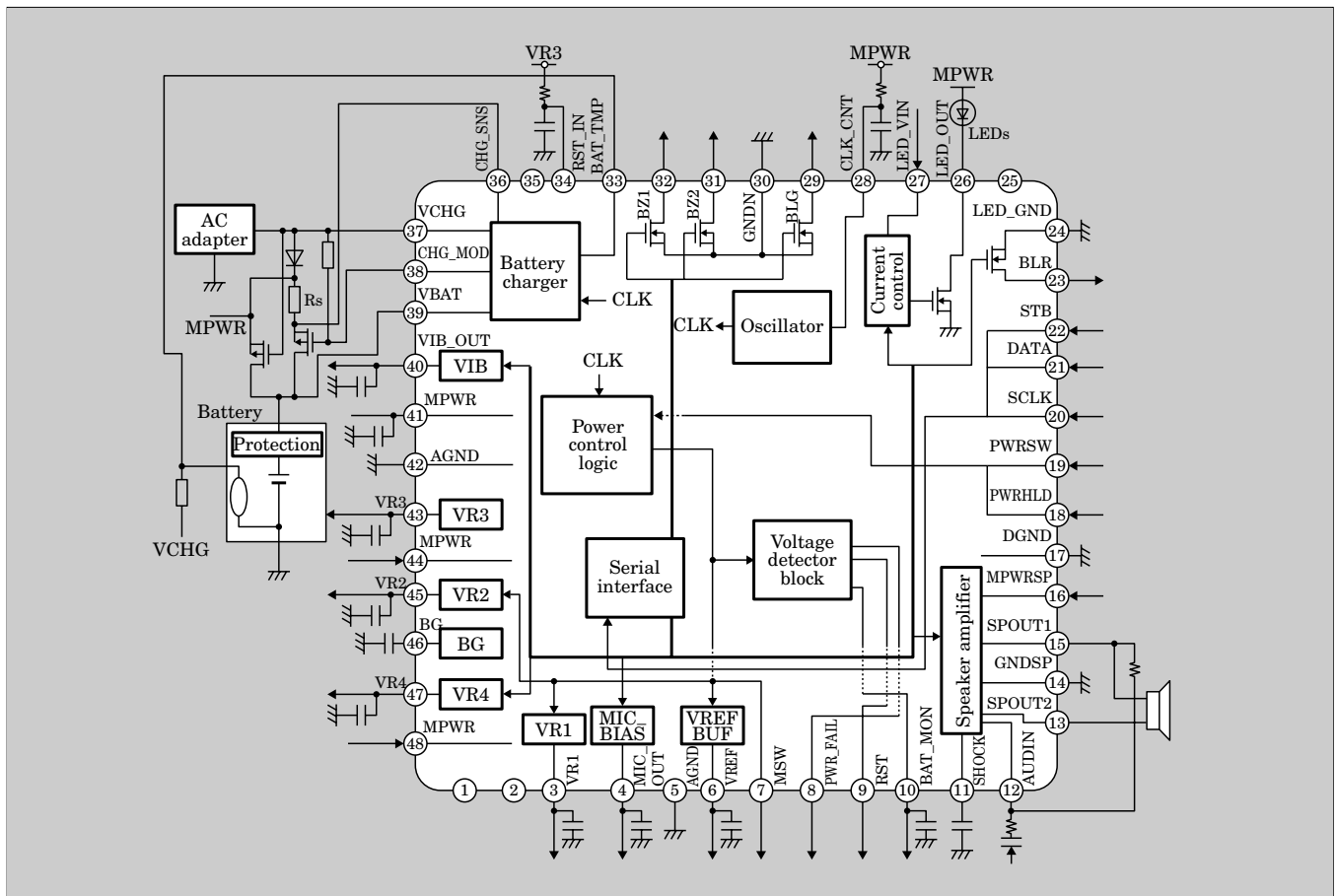
In the LED driver, the driving current is controlled with the input voltage level at the IN terminal, and in order to drive two or more LEDs, the driver is configured so as to be capable of supplying current up to 120 mA.

4.5 Various detectors

The internal regulator (VR1) and the main power (MPWR) are constantly monitored for low voltage, and their signals are output from the IC terminals in order to shutdown the system itself.

Also, in order to confirm the remaining power of the battery, the battery monitor converts the detected signal to an analog voltage and outputs it.

Fig.6 Block diagram of the FA3694R circuit



4.6 Serial interface

On/off switching of each block is controlled via the three-line serial interface.

4.7 Overall circuit

The block diagram of the FA3694R circuit is shown in Fig. 6.

5. Conclusion

This paper has presented an overview of the FA3694R developed as a power management IC for cellular phones having a built-in Li-ion battery charg-

er.

It is forecast that the trend of integration in the field of LSI devices for cellular phones will increase further. Fuji Electric will continue efforts to develop ICs for high-performance systems through pursuing low power consumption and downsizing technology, and also will respond to market needs in the promising field of portable electronic equipment and will contribute to the development of electronic equipment.

Reference:

- (1) Sano, I. et al. Power Management System IC for Cellular Phones. Fuji Electric Review. vol.46, no.4, 2000, p.124-126.

Second-Generation PDP Address Driver IC

Seiji Noguchi
Hitoshi Sumida
Kazuhiro Kawamura

1. Introduction

Color PDPs (plasma display panels) are used in household TV sets because of their distinctive features of thin profile, light weight and wide viewing angle. However, cost reduction of color PDP is an essential pre-condition for it to achieve higher market penetration. Recently, BS (broadcasting satellite) digital broadcasts were launched, and the market is expected to demand higher definition PDPs suitable for digital high vision.

To realize high performance and low cost PDPs, it is essential to improve the driver IC (integrated circuit) technology, in addition to improving the panel technology. Demands have increased for driver ICs having lower cost together with higher performance, such as higher speed switching, lower power consumption, and higher noise resistance.

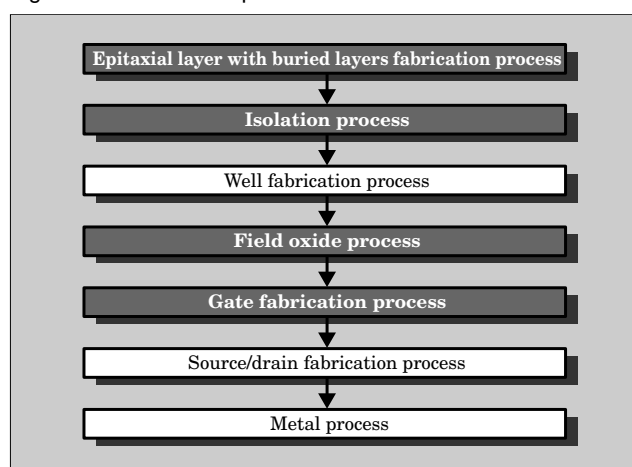
Fuji Electric has been manufacturing scan driver ICs⁽¹⁾ that utilize a dielectric isolation process and address driver ICs⁽²⁾ that utilize a pn junction isolation process as the first-generation PDP driver ICs. Now, we are undertaking the development of second-generation PDP drivers, having even higher performance and lower cost, to realize high performance and low cost PDPs. We recently developed a second-generation PDP address driver IC having a 70 V operating voltage.

This paper introduces a brief overview of the device / process technology and the characteristics of the second-generation address driver IC.

2. Process Technology

During development of the second-generation PDP address driver ICs, we made an effort to decrease on-resistance and reduce the isolation area to realize lower cost. Figure 1 shows an outline of the process flow. The flow is based on a 1 μ m-rule logic CMOS process and the shaded parts of the process were improved from the existing method. We optimized the pn junction isolation process that utilizes an epitaxial wafer with buried layers, which has been adopted from the prior product. We also improved the field oxidiza-

Fig.1 Overview of the process flow



tion and gate fabrication processes based on the existing process. Die size was miniaturized by the introduction of a double metal process. (Prior products utilized a single metal process.) As a result, the targeted performance and miniaturization of the die were both realized.

3. Device Technology

As high-voltage devices, we developed lateral type n-channel MOSFETs (metal oxide semiconductor field effect transistors) (NMOS) and p-channel MOSFETs (PMOS) that guaranteed a switching voltage of 70 V. As a result for both IC devices, we achieved higher current capacity per unit element area and reduced the die area. Also, as the control circuit device, we developed a CMOS (complementary MOS) device having a switching capability of 40 MHz. This device has a breakdown voltage of more than 12 V between drain and source terminals. The following is a brief description of the high voltage devices.

3.1 High voltage devices

3.1.1 Current-voltage characteristics

In a PDP driver IC, the output circuit consisting of high voltage device occupies more than 50 % of the die area. Therefore, the die area occupied by the high

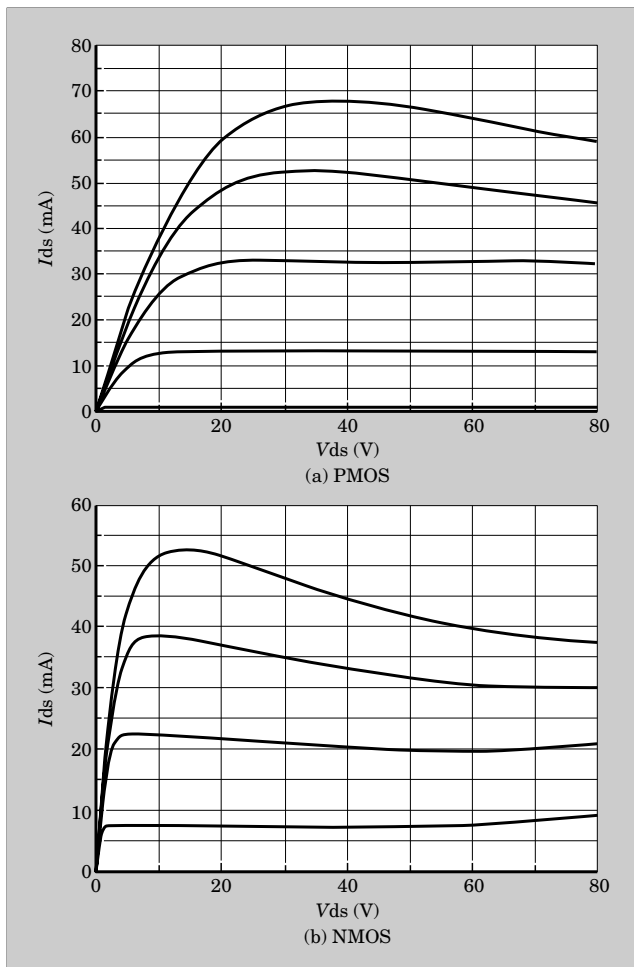
voltage device must be reduced to achieve miniaturization of the PDP driver IC.

Figure 2 shows the current-voltage characteristics of NMOS and PMOS devices developed by Fuji Electric. Current driving capacity per unit element area was increased as the result of reducing the active area by lowering the on-resistance of the element and by miniaturizing the isolation area through improved fabrication techniques. For the purpose of lower on-resistance, we incorporated the following improvements without introducing a complex element structure.

- (1) Improvement of trade-off characteristics between breakdown voltage and current driving capacity by modifying the drain layer fabrication method
- (2) Reduction of channel resistance by modifying the method of channel region fabrication
- (3) Miniaturization of cell size by modifying the element cell pattern and optimizing the device parameters

For the NMOS device, we increased the impurity density of the drain layer by means of the resurf effect⁽³⁾.

Fig.2 Current-voltage characteristics of high-voltage devices



3.1.2 Reliability characteristics

To verify the quality of the devices, we performed a high temperature reverse-bias reliability test (HTRB test) on each device element. The applied voltage was 70 V and the tested temperature was 150°C. Figure 3 shows the current characteristics of the NMOS and PMOS devices during the HTRB test. For both devices, the initial current remained unchanged after testing for 2,000 hours. The breakdown voltage of both devices also remained unchanged though it is not shown in Fig. 3. Since device characteristics were unchanged after the HTRB test, we were able to verify the quality of the devices.

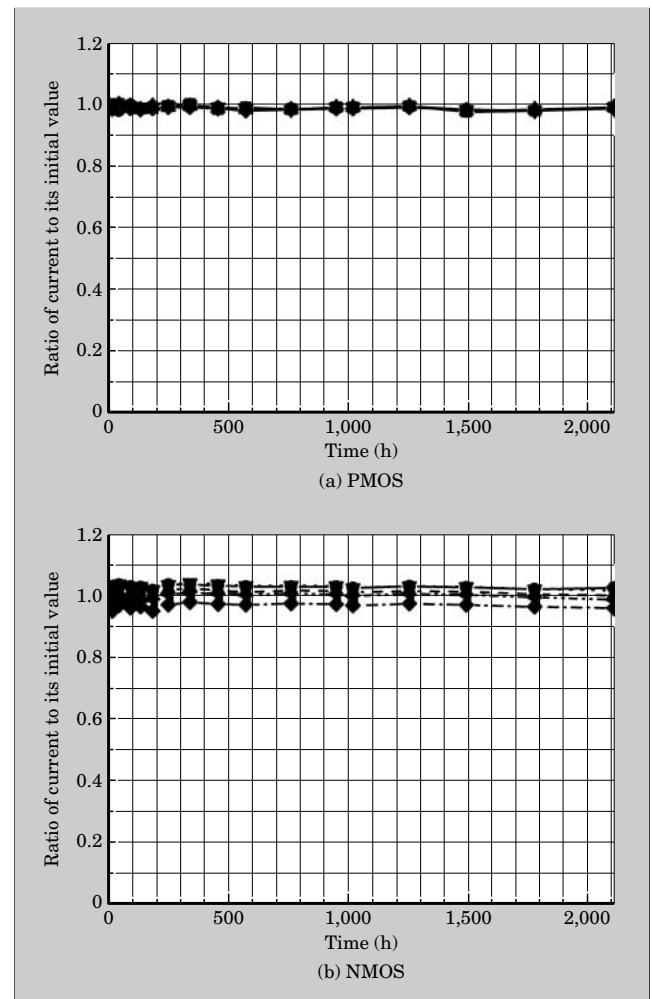
4. Application of Color PDP Driver IC

We also developed a color PDP address driver IC, using the distinctive processes and devices we developed.

4.1 Overview

Principal characteristics of this IC device are as follows:

Fig.3 Current characteristics of high voltage devices under the HTRB test



- Vol. 48 No. 1
- FUJI ELECTRIC REVIEW**

teristics were realized.

(2) Static current dissipation

By improving the level shift circuit, the static current dissipation of 6.6 mA for the prior product was reduced to less than 5 μ A.

(3) Switching speed

High-speed switching is essential for realizing high-definition PDP. We succeeded in speeding up the logic circuit by employing minute precision processing and achieving a high voltage output by improving the level shift circuit.

Other distinctive features of the new IC are that, even in the high speed switching circuits, the rising period does not overlap with falling period during the transition from a high-level period to a low-level period and vice versa ($t_{pLH} \triangleq t_{pHL} + t_f$), and the undesired emission of PDP light is prevented as shown in Fig. 6. This feature was realized through control of the transmission delay time. In the PDP, light is emitted only for those bits which are output from the data driver at a high-level. Therefore, it is desired that bits to be turned off drop down very quickly to low-level output.

5. Conclusion

In this paper, we introduced the major features and process/device technology of the second-generation PDP address driver IC developed by Fuji Electric, and which are based on the pn junction isolation process.

For the application of PDPs to household TV sets to become widespread, higher performance and lower cost are essential. New driver IC technology for the PDP has to be developed for this purpose. Fuji Electric will continue to develop high performance and low cost driver ICs with distinctive features in accordance with market needs.

References

- (1) Sumida, E. et al. Circuit Design and a High Voltage Device for an Advanced PDP Scan Driver IC. The 6th International Display Workshop. 1999, p.739-742.
- (2) Shigeta, Y.; Tada, G. ICs for Color Plasma Display Panel Drivers. Fuji Electric Review. vol.42, no.4, 1996, p.113-116.
- (3) Appels, A. et al. High Voltage thin Layer Devices (Resurf Devices). IEEE IEDM. 1979, p.238-241.



Low On-Resistance Trench Lateral Power MOS Technology

Akio Sugi
Mutsumi Sawada
Naoto Fujishima

1. Introduction

Market demands for smaller sized, lighter weight, lower power consuming and higher efficiency portable electronic devices and communicative devices have propelled power ICs (integrated circuits) to become key components.

Fuji Electric has developed high breakdown voltage and low on-resistance power ICs, which drive DC-DC converters for portable electronic devices and plasma display panel drivers (PDPs).

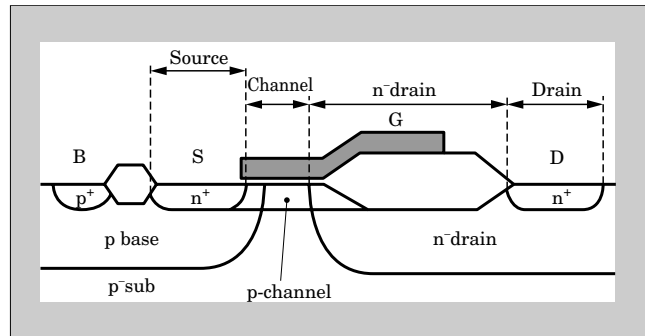
Lateral power MOSFETs are generally used as switching devices and are integrated into power ICs. Required breakdown voltages of MOSFET devices range from 10 to 60 V for portable electronic devices and approximately 100 V for PDPs.

Fuji Electric has used a trench technology and has successfully improved the packing density of the MOSFET devices, achieving a very low on-resistance while keeping the breakdown voltage high.

2. Conventional Lateral Power MOSFET Technology with Low On-Resistance

Fuji Electric has developed technology for power ICs which integrates the 60 V-class planar-type LDMOS (lateral double diffused MOS) devices illustrated in Fig. 1, and has applied these devices to ICs for power supplies in portable appliances⁽¹⁾. In the conventional planar-type LDMOS, the n^- drain with a high resistance is formed horizontally to release an electric field during the blocking mode. The n^- drain limits device packing density and restricts the reduction of on-resistance. In order to solve the problem, lateral MOSFET devices using trench technologies have been proposed. Nakagawa et al. fabricated trenches in the channel region to increase channel density⁽²⁾. Zitouni reduced device pitch by forming trenches in the n^- drain region⁽³⁾. However, the n^- drain is fabricated on the surface of the device in the above studies, and the packing density is limited. On the other hand, Fuji Electric proposed a trench lateral power MOSFET with a trench bottom drain contact (TLPM/D), where the channel and the n^- drain are

Fig.1 Planar-type LDMOS⁽¹⁾



formed along the sidewall of the trench, reducing the device pitch to improve on-resistance⁽⁴⁾. However, the TLPM/D has a relatively high gate-to-drain capacitance between the plugged polysilicon drain and the gate (C_{gd2}), which in addition to the capacitance between the gate and the n^- drain region (C_{gd1}) as shown in Fig. 2, negatively effects switching performance of the device⁽⁴⁾.

3. Device Structure and Process Flow of TLPM/S

3.1 Device structure of TLPM/S

In order to improve the on-resistance and the switching performance, we proposed a Trench Lateral Power MOS device with a trench bottom source contact (TLPM/S)⁽⁵⁾. The cross-sectional view of the TLPM/S device is shown in Fig. 3. The TLPM/S device has an extended trench region at the lower part of the device. Since the source electrode is located at the bottom of the trench, the Miller capacitance of the device equals the gate-to-drain capacitance between the gate and the n^- drain region (C_{gd3}), and is smaller than that of the TLPM/D device ($C_{gd1} + C_{gd2}$), resulting in faster switching speeds.

3.2 Process flow of TLPM/S

Process flow of the TLPM/S device fabrication is shown in Figs. 4(a) to 4(f). An n^- well region is formed on the p^- type silicon substrate and thick oxide is deposited on the n^- well region. Then a trench is etched using the mask oxide. Thereafter, the p^- body

and n^- drain regions are formed on the sidewalls of the trench using tilted ion implantations as shown in Fig. 4(a). Next, the thick oxide is deposited on the surface of the substrate as shown in Fig. 4(b). Then, the oxide is etched back by using anisotropic etching and the trench is expanded at its bottom. In this step, the oxide is left on the sidewall of the trench as well as on the surface of the silicon substrate as shown in Fig. 4(c). Thereafter, the gate oxide is deposited on the

sidewall and at the bottom of the second trench, and the gate electrode is then formed by the deposition and anisotropic etching of polysilicon. The gate electrode and the thick oxide are used as masks to form the p base and n^+ source regions as shown in Fig. 4(d). Following this step, an insulating layer is deposited as shown in Fig. 4(e). Finally, a source contact at the bottom of the second trench is formed, followed by deposition of polysilicon on the inside surface of the

Fig.2 TLPM/D⁽⁴⁾

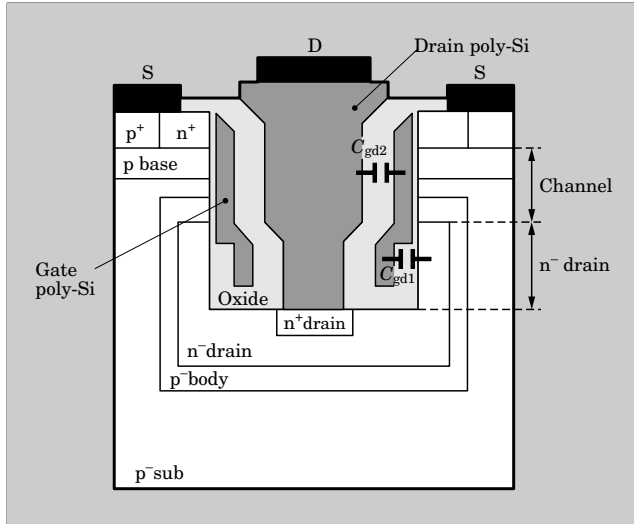


Fig.3 TLPM/S⁽⁵⁾

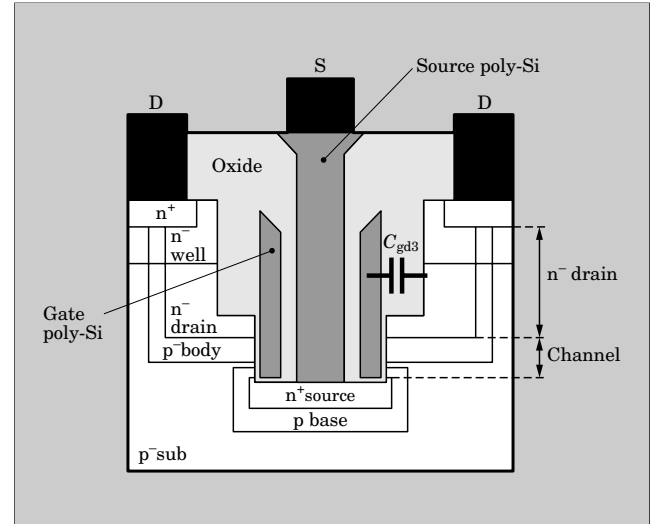
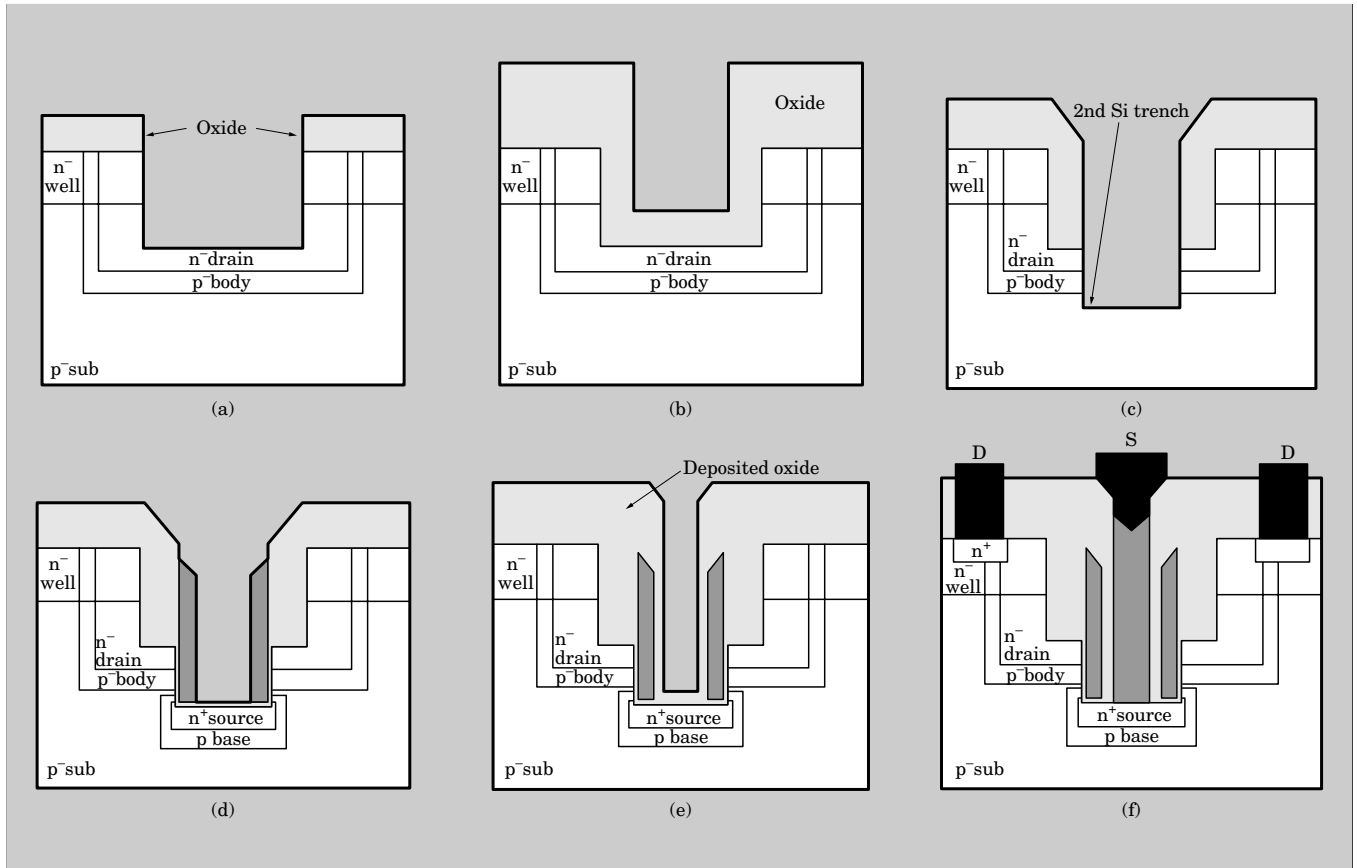


Fig.4 Fabrication process for TLPM/S



trench. Then surface leveling, contact formation and electrode definition are carried out as shown in Fig. 4(f).

In this process, the gate and source polysilicon electrodes are formed along the sidewall of the trench using a method of self-alignment and hence cell pitch is reduced.

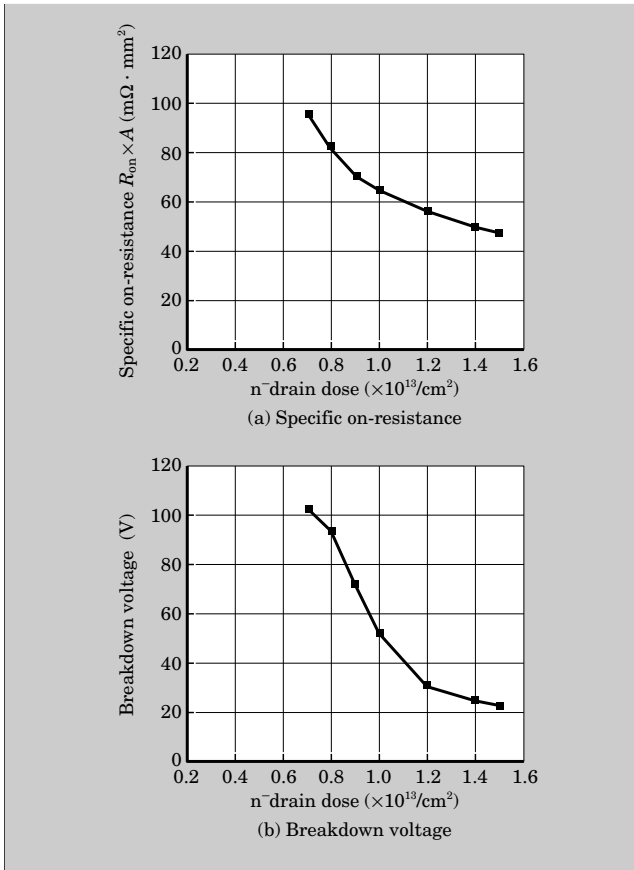
4. Simulation Results

4.1 DC characteristics

The simulated specific on-resistance and breakdown voltage of the TLPM/S device as a function of the n^- drain dose are shown in Figs. 5(a) and (b), respectively. The on-resistance decreases monotonously with increasing n^- drain dose. This is because the resistance of the n^- drain region which dominates the total on-resistance is decreased due to the higher donor concentration in the n^- drain region. The breakdown voltage also decreases monotonously with increasing n^- drain dose because the expansion of the depletion layer is limited due to the higher donor concentration.

Distribution of the current density in the on-state for the TLPM/S device is shown in Fig. 6(a). In the on-state, the current flows from the drain to source along the sidewall of the trench as shown in Fig. 6(a). The distribution of the potential in the off-state for a

Fig.5 Simulated specific on-resistance and breakdown voltage for TLPM/S



TLPM/S device with a breakdown voltage of 73 V is shown in Fig. 6(b). In the off-state, the depletion layer spreads from the n^- drain region to the p^- silicon substrate. Due to the p base around the n^+ source region, punch-through breakdown is prevented.

4.2 Switching characteristics

Gate charge transfer characteristics of the TLPM/S, the TLPM/D, and the planar-type LDMOS⁽¹⁾ devices are shown in Fig. 7, where the concentration of the channel and the thickness of the gate oxide are chosen so that the threshold voltages of the devices are equal to 1.0 V. Since the gate-to-drain capacitance of the TLPM/S device is lower than that of the TLPM/D, the amount of gate charge needed for a gate voltage of 5 V is smaller for the TLPM/S device than for the TLPM/D as is shown in Fig. 7. The amount of the gate charge for a gate voltage of 5 V in the case of the TLPM/S device is also smaller than that of the planar-type LDMOS because the input capacitance of the TLPM/S device is lower than that of the planar-type LDMOS.

Fig.6 Analysis of on- and off-states for TLPM/S

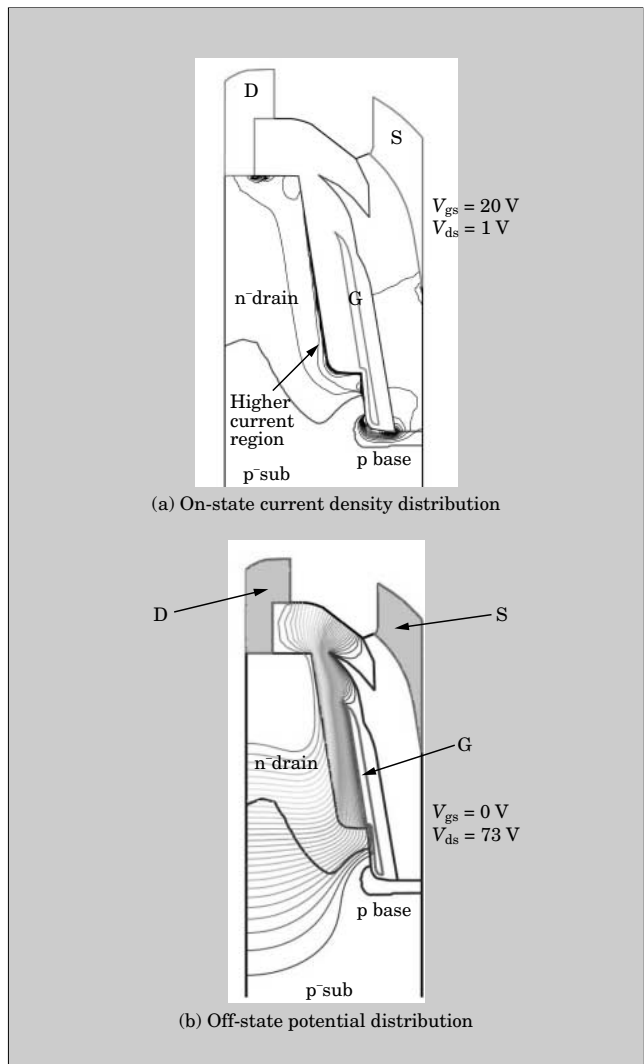


Fig.7 Simulated gate charge transfer characteristics

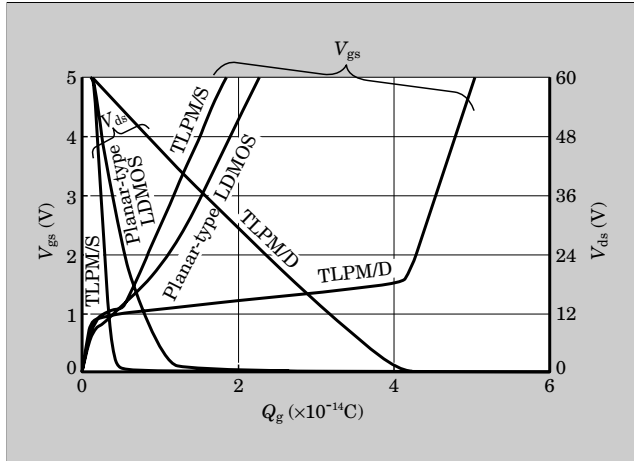
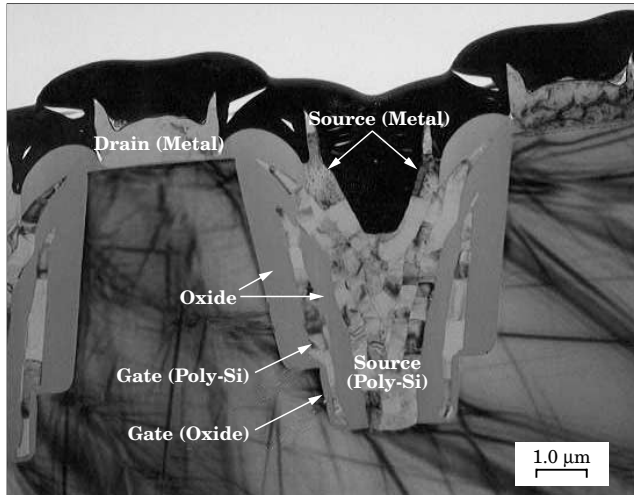


Fig.8 TEM micrograph of cross section of TLPM/S



5. Experimental Results

A TEM micrograph of the cross section of the fabricated TLPM/S device is shown in Fig. 8. The width of the first trench is $5.0 \mu\text{m}$. The depths of the first and second trenches are $4.0 \mu\text{m}$ and $1.2 \mu\text{m}$, respectively. The thick oxide along the first trench, the gate oxide along the second trench, and the source polysilicon which is used as a plug are observed.

The measured specific on-resistance and the breakdown voltage for the TLPM/S device as a function of the n^- drain dose are shown in Fig. 9(a) and (b), respectively. The behaviors of measured on-resistance and breakdown voltage are similar to those predicted by the simulated results shown in Fig. 5(a) and (b).

The on- and off-state I - V characteristics of the TLPM/S device are shown in Fig. 10(a) and (b), respectively. The TLPM/S device has a device pitch of $3.0 \mu\text{m}$, a channel width of $40 \mu\text{m}$, and an n^- drain dose of $7 \times 10^{12}/\text{cm}^2$. This device yields a drain-to-source current of 1.9 mA with $V_{gs} = 20 \text{ V}$ and $V_{ds} = 1 \text{ V}$, which results in a specific on-resistance of $62.0 \text{ m}\Omega \cdot \text{mm}^2$.

Fig.9 Measured specific on-resistance and breakdown voltage for TLPM/S

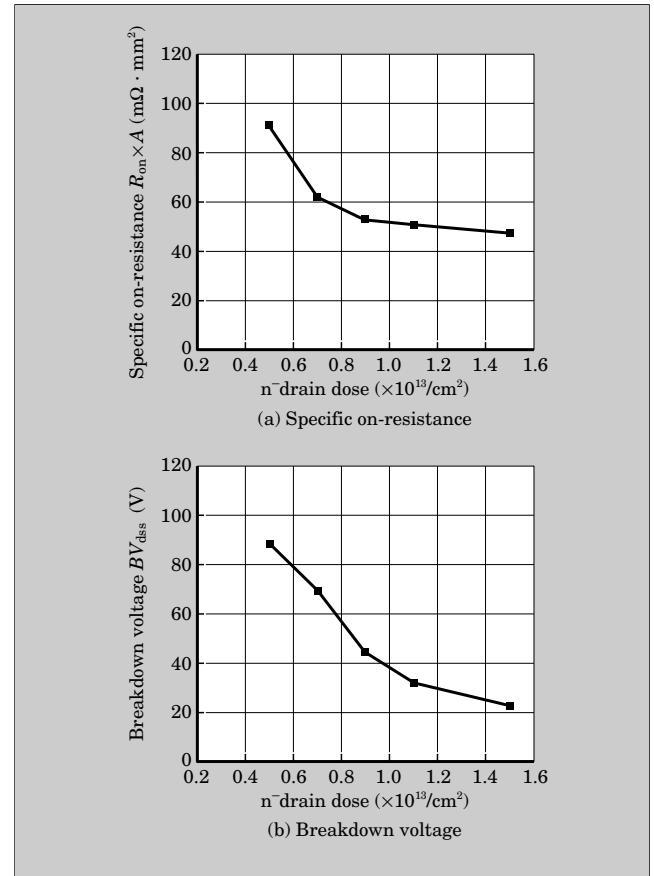
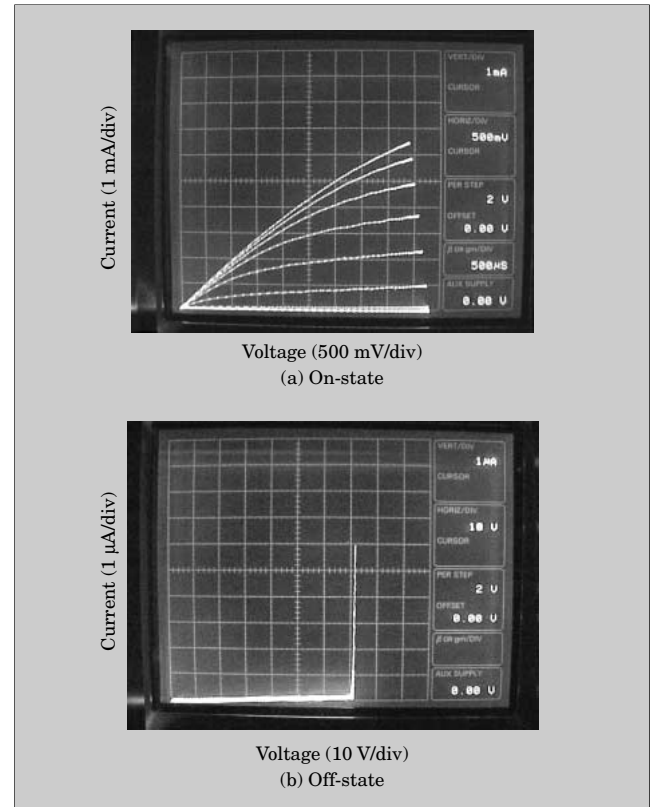


Fig.10 Measured I - V characteristics of TLPM/S



The device has a breakdown voltage of 72 V. The specific on-resistance is also reduced to $53.0 \text{ m}\Omega \cdot \text{mm}^2$ without sacrificing the breakdown voltage by optimizing the conditions of the p^- body and n^- drain ion implantations.

6. Conclusion

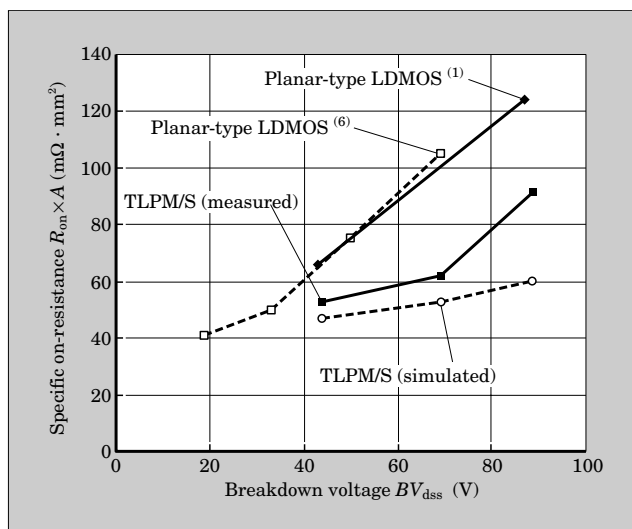
A new Trench Lateral Power MOSFET device with a trench bottom source contact (TLPM/S) was proposed, fabricated, and characterized. As is shown in Fig. 11, the TLPM/S device has improved the trade-off between breakdown voltage and specific on-resistance as compared with planar-type LDMOS devices. The TLPM/S device has also achieved higher switching performance than either that of the TLPM/D or planar-type LDMOS.

Future work includes development of a new process for integrating the TLPM/S with CMOS devices to realize higher performance power ICs. This will provide portable electronic appliances with a smaller number of components, higher reliability, and lower power consumption.

References

- (1) Kitamura, A. et al. Self-Isolated and High Performance Complementary DMOSFETs with Surrounding-Body Regions. Proceedings of ISPSD. 1995, p.42-47.
- (2) Nakagawa, A.; Kawaguchi, Y. Improved 20V Lateral Trench Gate Power MOSFETs with Very Low On-resistance of $7.8 \text{ m}\Omega \cdot \text{mm}^2$. Proceedings of ISPSD. 2000, p.47-50.
- (3) Zitouni, M. et al. A New Concept for the Lateral DMOS

Fig.11 Trade-off between specific on-resistance and breakdown voltage



Transistor for Smart Power IC's. Proceedings of ISPSD. 1999, p.143-146.

- (4) Fujishima, N.; Salama, C. A. T. A trench lateral power MOSFET using self-aligned trench bottom contact holes. IEDM Tech. Dig. 1997, p.359-362.
- (5) Fujishima, N. et al. A High Density, Low On-resistance, Trench Lateral Power MOSFET with a Trench Bottom Source Contact. Proceedings of ISPSD. 2001, p.143-146.
- (6) Tsai, Chin-Yu et al. 16-60V Rated LDMOS Show Advanced Performance in a $0.72 \mu\text{m}$ Evolution BiCMOS Power Technology. IEDM Tech. Dig. 1997, p.367-370.

Global Network

■ : Representative Office ● : Sales Bases ◆ : Manufacturing Bases

AMERICA

- **FUJI ELECTRIC CORP. OF AMERICA**
USA
Tel : +1-201-712-0555 Fax : +1-201-368-8258
- ◆ **U.S. FUJI ELECTRIC INC.**
USA
Tel : +1-732-560-9410 Fax : +1-732-457-0042
- ◆ **FUJI HI-TECH, INC.**
USA
Tel : +1-510-651-0811 Fax : +1-510-651-9070
- **GE FUJI DRIVES, USA INC.**
USA
Tel : +1-540-387-5925 Fax : +1-540-387-8580

EU

- **FUJI ELECTRIC CO., LTD.**
Erlangen Representative Office
F.R. GERMANY
Tel : +49-9131-729613 Fax : +49-9131-28831
- **FUJI ELECTRIC GmbH**
F.R. GERMANY
Tel : +49-69-6690290 Fax : +49-69-6661020
- **FUJI ELECTRIC UK**
U.K.
Tel : +44-208-233-1130 Fax : +44-208-233-1140
- ◆ **FUJI ELECTRIC (SCOTLAND) LTD.**
U.K.
Tel : +44-1355-234111 Fax : +44-1355-238810
- ◆ **FUJI ELECTRIC FRANCE S.A.**
FRANCE
Tel : +33-4-73-98-26-98 Fax : +33-4-73-98-26-99

ASIA

East Asia

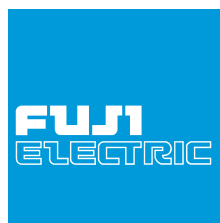
- **FUJI ELECTRIC CO., LTD.**
China Representative Office
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-6471-0897 Fax : +86-21-6471-4903
- **FUJI ELECTRIC CO., LTD.**
Beijing Representative Office
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-10-6505-1263 Fax : +86-10-6505-1851
- **FUJI ELECTRIC (SHANGHAI) CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-6466-2810 Fax : +86-21-6473-3292
- ◆ **FUJI ELECTRIC DALIAN CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-411-762-2000 Fax : +86-411-762-2030
- ◆ **SHANDONG LUNENG FUJI ELECTRIC CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-531-723-1138 Fax : +86-531-726-1737

- ◆ **SHANGHAI FUJI ELECTRIC SWITCHGEAR CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-5718-5740 Fax : +86-21-5718-1448
- ◆ **SHANGHAI FUJI ELECTRIC TRANSFORMER CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-5718-5747 Fax : +86-21-5718-5745
- ◆ **SHANGHAI GENERAL FUJI REFRIGERATION EQUIPMENT CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-6921-1088 Fax : +86-21-6921-1066
- ◆ **HONG KONG FUJIDENKI CO., LTD.**
HONG KONG
Tel : +852-2664-8699 Fax : +852-2664-8040
- **FUJI ELECTRIC (ASIA) CO., LTD.**
HONG KONG
Tel : +852-2311-8282 Fax : +852-2312-0566
- **FUJI ELECTRIC CO., LTD.**
Taipei Representative Office
TAIWAN
Tel : +886-2-2561-1255 Fax : +886-2-2561-0528
- **FUJI ELECTRIC TAIWAN CO., LTD.**
TAIWAN
Tel : +886-2-2515-1850 Fax : +886-2-2515-1860
- **FUJI/GE TAIWAN CO., LTD.**
TAIWAN
Tel : +886-2-2556-0716 Fax : +886-2-2556-0717
- ◆ **ATAI FUJI ELECTRIC CO., LTD.**
TAIWAN
Tel : +886-3-321-3030 Fax : +886-3-321-7890
- **FUJI ELECTRIC KOREA CO., LTD.**
KOREA
Tel : +82-2-780-5011 Fax : +82-2-783-1707

Southeast Asia

- **FUJI ELECTRIC CO., LTD.**
Bangkok Representative Office
THAILAND
Tel : +66-2-653-2020, 2021 Fax : +66-2-653-2022
- ◆ **FUJI ELECTRIC (MALAYSIA) SDN. BHD.**
MALAYSIA
Tel : +60-4-403-1111 Fax : +60-4-403-1496
- ◆ **FUJI ELECTRIC PHILIPPINES, INC.**
PHILIPPINES
Tel : +63-2-844-6183 Fax : +63-2-844-6196
- **P. T. BUKAKA FUJI ELECTRIC**
INDONESIA
Tel : +62-21-572-4282 Fax : +62-21-572-4283
- **FUJI ELECTRIC SINGAPORE PRIVATE LTD.**
SINGAPORE
Tel : +65-479-5531 Fax : +65-479-5210
- ◆ **FUJI/GE PRIVATE LTD.**
SINGAPORE
Tel : +65-533-0010 Fax : +65-533-0021

Fuji Electric, the Pioneer in Energy and Electronics



富士電機