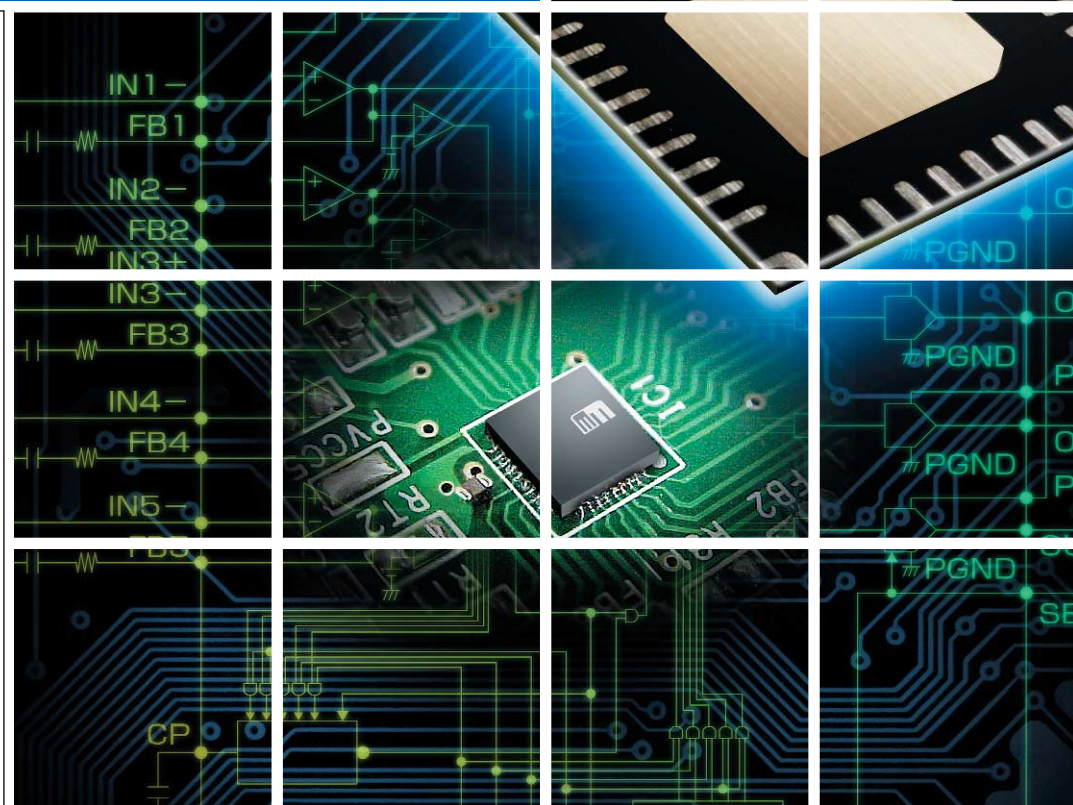


FUJI ELECTRIC REVIEW

IC Technology

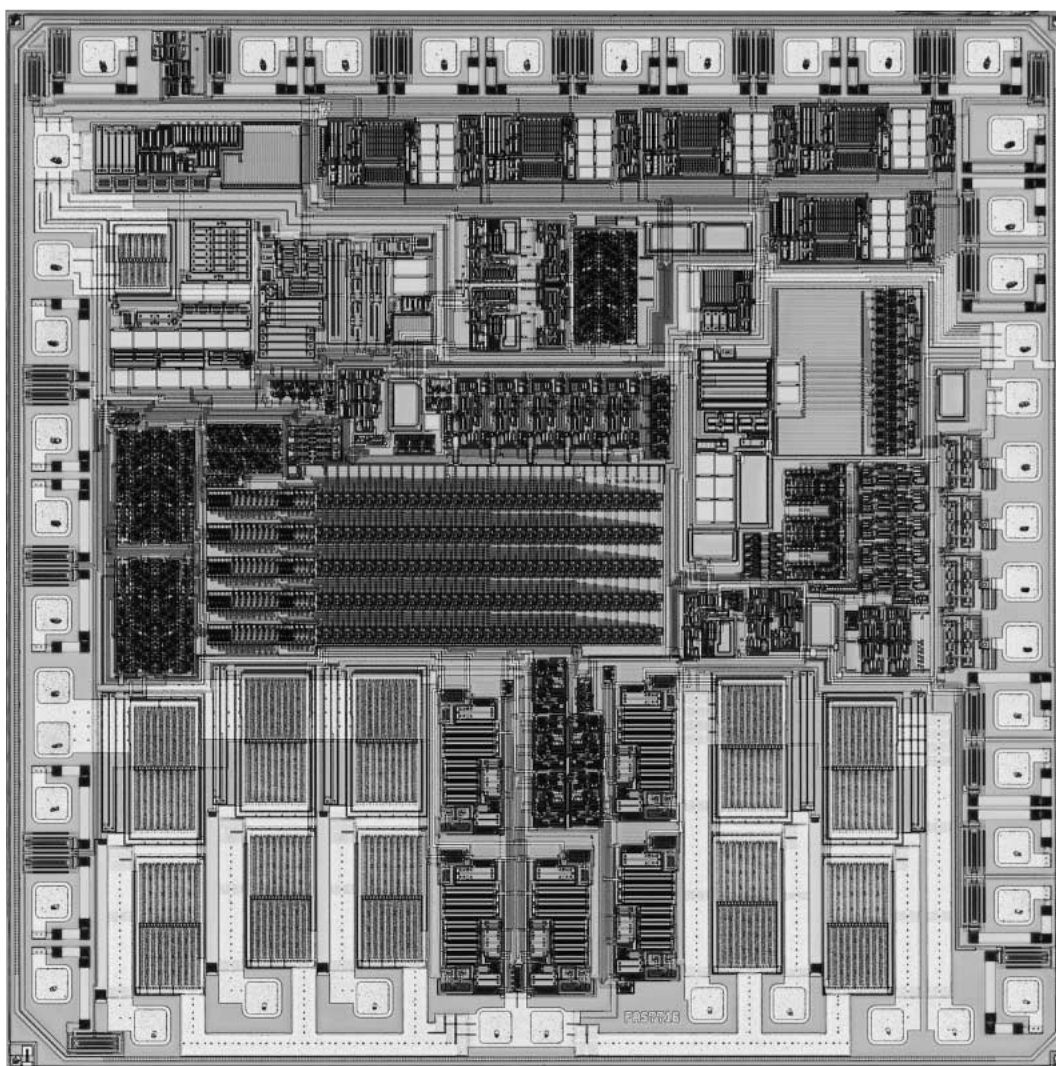
3

2003 VOL.49



Fuji Electric Power Supply ICs

Providing Multiple Solutions for Multiple Requirements

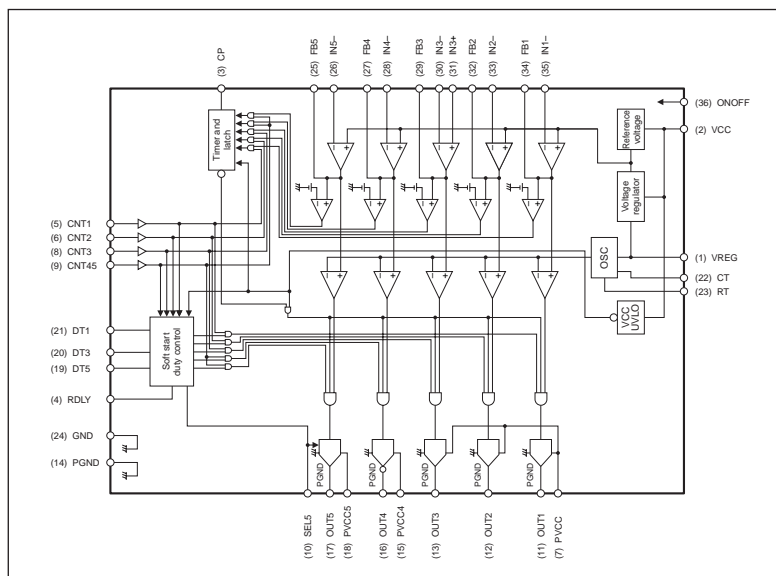


Energy-saving Power Management Realized with a Single Chip

Examples: 1-channel FA7700V, FA7701V, FA7702P
 2-channel FA3686V, FA3687V, FA7703V, FA7704V, FA7715J
 3-channel FA7711V
 5-channel FA7708R, FA7716R
 6-channel FA3675F, FA3676F, FA7709R

Uses: Power supplies for TFT panels, video cameras, digital still cameras, etc.

- Features:
- The single chip solution integrating power transistors and control circuits by C/DMOS process capable of built-in low on-resistance DMOS output transistors.
 - Low power consumption by CMOS analog circuits.
 - Wide range of applications for various power supply configurations such as synchronous rectification, switching polarity of drive transistors, etc.
 - Various protection functions against overcurrent, overheat, short circuits, etc.
 - Wide variety of packages meeting demands for smaller and thinner size.
 TSSOP-8, TSSOP-16, TSSOP-24, SON-16, QFN-36, VQFN-48, LQFP-48, etc.



Example block diagram of FA7716R

Fuji Electric Power ICs for Power Supply Applications

Quality is our message

FUJI ELECTRIC REVIEW

IC Technology

3

2003 VOL.49

CONTENTS

Present Status and Prospects for Fuji Electric's IC Products and Technologies	74
3-channel DC-DC Converter Control IC for Liquid Crystal Displays	79
Small-package 5-channel Output DC-DC Converter Control IC	82
Micro DC-DC Converter Chip Size Module	86
PDP Address Driver IC Technology	89
High-resolution Compact Auto Focus Module with 7 μm Pixels	92
Low On-resistance Trench Lateral Power MOSFET Using 0.6 μm Smart Power Technology	95

Cover photo:

Smaller size, lower power consumption and higher performance are never-ending demands for constantly evolving electronic devices. These same circumstances also apply to ICs, which are said to be the heart of these electronic devices. New products that incorporate the latest technology are developed in response to such demands.

Fuji Electric provides a wide variety of distinctive ICs based on its proprietary CMOS analog technology, ranging from low-voltage to high-voltage devices. And these ICs contribute to the lower power consumption, higher performance and smaller size of the electronic devices in which they are used.

The cover photo shows a photograph of a power supply IC installed in a portable electronic device, and this is superimposed over a drawing of the printed circuit diagram. The close-up photograph at the top right corner shows the newly developed 5mm \times 5mm QFN (quad flat non-lead) package that houses the power supply IC.

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

Yoshio Tsuruta
Eiji Kuroda

1. Introduction

Utilizing core technologies of high voltage technology (power IC technology), high precision CMOS (complementary metal oxide semiconductor) analog technology and the associated digital control technology, Fuji Electric is expanding its offering of IC (integrated circuit) products which is concentrated on such devices as ICs for power supply units and driver ICs for FPDs (flat panel displays) (See Fig. 1).

In the fields of application for these products, small size, light weight, low power consumption and multi-functionality are required. The most important requirement is for low power consumption, which will contribute to efforts to protect the global environment. In response to these requirements, Fuji Electric has developed a low-power high-voltage CMOS analog technology, and has applied this technology to the ICs for power supply units to commercialize power supply ICs for AC adapter-use, cellular phone-use, DSCs (digital still cameras)-use, etc.

In the field of high-voltage devices, Fuji Electric is expanding its product line-up and has developed highly reliable device and process technologies for integrating a 700 V breakdown voltage power MOSFET (metal oxide semiconductor field effect transistor) into an IC device and IC production technology for fabricating an IGBT (insulated gate bipolar transistor) on an SOI (silicon on insulator) substrate.

An additional distinctive characteristic of Fuji Electric's IC devices is complex sensor technology.

This technology is being used in such applications as AFICs (auto focus ICs) for use in cameras equipped with an internal photodiode-based optical sensor and in pressure sensors for automobiles equipped with a built-in piezo-type strain gauge.

This special issue of articles will introduce new products and new technologies that leverage these special features.

2. Present Status of Fuji Electric's IC Products

2.1 Expanding line-up of products

2.1.1 Power supply ICs

Building on its base of high-voltage CMOS analog technology, Fuji Electric is concentrating on developing applications in the power IC field. Fuji has positioned the power supply IC as a top priority device and is expanding its product line. The concept behind these products is to realize low power consumption, high precision, small size and sophisticated functionality by employing proprietary technology from a perspective in which the "customer-is-number-one."

Power supply ICs can be broadly classified as either AC-DC converters that accept a commercial power source input or as DC-DC converters, which are used mainly in portable electronic devices. Fuji Electric is expanding its line of products in both of these categories. As an example, Table 1 lists Fuji Electric's line of CMOS power supply IC devices. In the AC-DC converter category, the issue of power consumption during standby has drawn attention in recent years, and there is an urgent need to lower this consumption. Fuji Electric has been advancing a series of control IC devices that support lower power consumption, and has recently developed a current-mode PWM (pulse width modulation) control IC device having a built-in high-voltage (500 V) starting circuit. By lowering the frequency during light loads, these devices aim to achieve both lower power consumption and lower output ripple voltage. In this category, higher harmonic current depression is also an important issue. Accordingly, an IC device for performing power factor correction is already in commercial production, but product development continues with the

Fig.1 Characteristics of Fuji Electric's ICs

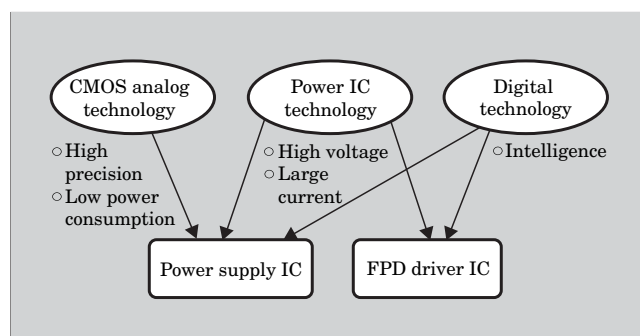


Table 1 CMOS ICs for power supply units

(a) AC-DC category

Model name	D_{\max} (%)	Circuit application			Operating mode		Protection circuit			MOS driving	Package
		Flyback	Feed-forward	PFC	Voltage	Current	OCP	OCV	OTP		
FA13842	96	○				○				○	8-pin
FA13844	48		○			○				○	8-pin
FA3641/3747	70	○			○		○	○		○	8-pin
FA5510/5511 FA5514/5515	46/70	○	○		○		○	○		○	8-pin
FA5501				○			○	○		○	8-pin
FA5502				○			○	○		○	16-pin
FA5701	70	○				○	○	○	○	Internal 700 V MOSFET	6-pin
FA5504	46		○		○		○	○		○	8-pin
FA5506/07/08	80	○				○	○	○		○	8-pin
FA5520	95	○				○		○		○	5-pin

(b) DC-DC category

Model name	No. of channels	D_{\max} (%)	Voltage range			Circuit application				MOS driving	Package
			2.5 to 18 V system	2.5 to 5.5 V system	10 to 25 V system	Step down	Step up	Inverter	Flyback		
FA3675F	6	Arbitrary setting	○			○	○	○	○	○	48-pin
FA3676F	6	Arbitrary setting	○			○	○	○	○	○	48-pin
FA3698F	7	Arbitrary setting	○			○	○	○	○	○	64-pin
FA3630V	2	Arbitrary setting		○		○	○	○	○	○	16-pin
FA13843	1	96					○	○	○	○	8-pin
FA13845	1	48			○		○	○	○	○	8-pin
FA3686V	2	85	○		○		○	○	○	○	16-pin
FA3687V	2	Arbitrary setting	○			○	○	○	○	○	16-pin
FA7700	1	90	○				○		○	○	8-pin
FA7701	1	100	○			○				○	8-pin
FA7703/7704	2	Arbitrary setting	○			○	○	○	○	○	16-pin
FA3629AV	3	Ch1, 87		2.5 to 5.8 V system			○		○	Internal NMOS	16-pin
		Ch2, 87					○		○		
		Ch3, 86				○					
FA3635P	1	Arbitrary setting			10 to 45 V system	○				Internal PMOS	8-pin
FA3685P	1	Arbitrary setting			10 to 45 V system	○				Internal PMOS	8-pin
FA7702	1	100			10 to 45 V system	○				Internal PMOS	8-pin
FA7706	5	Arbitrary setting	2.5 to 12 V system			○				○	48-pin
FA7707	2	Arbitrary setting	○			○		○		○	20-pin
FA7708	5	85	1.4 to 10 V system			○	○		○	○	48-pin
FA7709	6	85	1.4 to 10 V system			○	○		○	○	48-pin
FA7710	2	92			6.5 to 28 V system	○				○	24-pin
FA7711	3	Arbitrary setting	4.5 to 15 V system			○	○	○	○	○	24-pin
FA7715	2	88	1.8 to 12 V system			○	○		○	○	16-pin

(c) Miscellaneous

Model name	No. of channels	Main use	Voltage range	Circuit application				MOS driving	Package
			2.5 to 5.5 V system	Step up	Charge pump	Series regulator	Switch		
FA3721	4	RGB LED PWM control	3.15 to 5.0 V *1 2.7 to 3.2 V *2		○		○	Internal PMOS Internal NMOS	16-pin
FA3717	1	White LED Dimmer control	3.1 to 4.3 V *1 2.75 to 2.95 V *2	○				Internal NMOS	16-pin
FA3705	1	Low noise charge pump	2.7 to 4.4 V		○	○		Internal PMOS	8-pin
FA3901	1	Low power LDO	2.0 to 6.0 V			○		Internal PMOS	5-pin

*1: Power supply for power system, *2: Power supply for control system

goal of developing even easier-to-use products. Applications for an IC device with built-in 700 V power MOSFET center on AC adapter-use, and the market is growing. Although some products are already being mass-produced, Fuji Electric intends to continue to concentrate on product development and to expand its product line-up.

In the DC-DC category, the market for portable electronic devices is expanding and the trend toward use of application specific ICs is continuing. Fuji Electric has recently developed a power supply IC for use in DSCs. Because DSC applications require a different voltage for each circuit block, multi-channel technology is being promoted. Moreover, in order to extend the battery operation time, detailed power management functionality and higher efficiency of the power supply unit are required. Also, in order to support a wide variety of batteries, it is necessary to lower the low limit for operating input voltage. These requirements have been realized through application of CMOS analog technology.

To date, many of Fuji Electric's power supply ICs have been used in the power supplies that drive LCD panels. Fuji Electric has developed a specialized power supply IC for LCD monitors, which are expected to supplant CRT monitors. Capable of directly driving 3 external power MOSFETs and having a wide input voltage range (5 to 20 V), this IC is convenient to use.

To improve the functionality and performance of cellular phones, which are typical portable electronic devices, design rules have been scaled down for the LSI (large scale integrated) ICs incorporated into these devices, and the power supply voltage has been lowered year-by-year. Cellular phones have conventionally been supplied with power from a battery power source that is fed through a series regulator. However, the series regulator method has the drawback of poor efficiency when there is a large voltage difference between the battery and power supply output. Consequently, there is a need to changeover from the series regulator method to the switching method. The switching method, however, uses a large-size external inductor for which an alternative means is desired. As one alternative, Fuji Electric has been working to develop a power supply IC device that

integrates an IC and inductor onto a single chip, and has realized a 1 W-class IC that is the world's thinnest and smallest levels of the power IC device. Fuji Electric intends to consider customer needs as it accelerates development for the commercialization of these devices. Furthermore, Fuji Electric has also commercialized a new LDO (low drop out) regulator device which, when used in combination with the switching method, enables an optimal power supply path to be configured for each application.

For details of the above described products and technologies, please refer to the other articles in this special issue.

2.1.2 PDP driver ICs

The PDP (plasma display panel) is attractive for application to large-screen televisions, and the PDP market is about to enter a period of expansion. As part of the evolution of high-voltage power ICs, Fuji Electric is advancing the commercialization of driver ICs for PDPs. Among PDP driver ICs, there are medium-voltage low-current (85 V, 30 mA) address ICs and high-voltage, high-current (up to 200 V and up to 1,000 mA) scan ICs. Address ICs are being commercialized using C/DMOS (complementary/double diffused MOS) technology, and scan ICs are being commercialized using IGBT device technology on an SOI substrate. Fuji Electric's newly developed PDP driver IC is described in a separate article of this special issue.

2.1.3 AFICs

As an application of optical sensor technology, Fuji Electric is also developing AFIC devices for camera use. The camera market is transitioning rapidly from conventional film cameras to DSCs. In order to decrease the shutter release time, DSCs equipped with a Fuji Electric-made AFIC are beginning to appear in the market, and new products are being developed to accelerate this trend. The key to success, however, is the degree to which we are able to satisfy demands for smaller size and lower price. Accordingly, Fuji Electric has recently integrated a photo module with an IC chip to realize a small-size, low-cost commercial AF module. Details of this AF module are presented in "High-resolution Compact Auto Focus Module with 7 μ m Pixels," a separate article in this issue.

2.1.4 Pressure sensors

Pressure sensor technology is being deployed in automobiles. In contrast to the conventional pressure sensors formed by trimming a thin film on top of a bipolar IC, Fuji Electric has newly developed a digitally trimmed pressure sensor formed by a CMOS process. These chips, provided internally with a gauge for converting pressure into strain, an amplifier, an EMI filter and a surge protection device, can be trimmed stably and with high precision. Standard product packages include a stand-alone type used to monitor the engine manifold air pressure and a self-contained cell type used for such purposes as to correct for atmospheric pressure. A vacuum reference chamber is provided inside both types of sensors to enable high precision measurement of the absolute pressure.

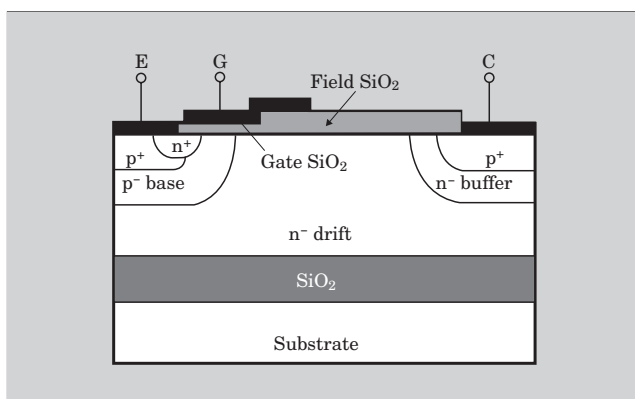
2.2 Technical development

2.2.1 Device process technology

One distinguishing feature of Fuji Electric's device process technology is a trend toward using higher voltage technology. Fuji is currently developing proprietary technology, examples of which include a highly reliable 700 V single-chip power IC device process that utilizes a dual-layer metal shield construction and a device process for PDP driver ICs that realizes a high voltage (200 V) and large current (1,000 mA) output stage by forming an IGBT device on an SOI substrate (See Fig. 2).

Another distinguishing Fuji Electric device and process technology is its 0.6 μm analog C/DMOS device and process technology that was developed for CMOS analog applications. This technology enables the fabrication of analog CMOS devices having a low threshold voltage for use in analog circuits, digital CMOS devices having fine design rules (0.6 μm rule) for use in digital circuits, and as high-voltage MOS devices, HV-MOS devices guaranteed to withstand 30 V and having a DMOS output stage. The application of this technology makes possible the configuration of a high performance analog circuit that can be driven at low-voltage, mixed use with a highly integrated digital control circuit such as a CPU, and the

Fig.2 IGBT structure fabricated on an SOI substrate



commercialization of a high performance, advanced function power supply IC.

2.2.2 Design technology

In response to demands for IC design technology with higher levels of integration, more advanced functionality, quicker turn around time, etc., the industry is promoting the construction of automated design systems, development of highly accurate simulation technology, and the reuse of design properties. Especially for analog ICs such as power supply ICs, which are core products for Fuji Electric, analog macro cell libraries, analog circuit design verification technology, analog automated mask layout design technology, and the like are being developed and are enabling devices to be designed with higher precision, more advanced functionality and with quicker turn around time.

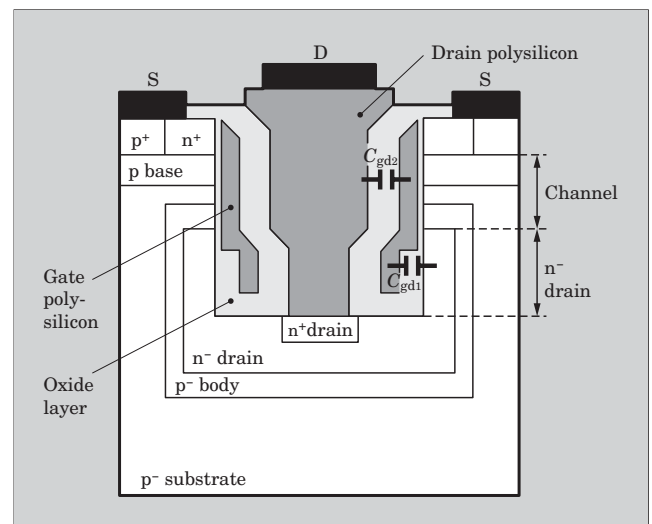
Fuji Electric also constructing a top-down design environment for digital systems. This digital design environment is being used in combination with the previously described analog design environment to achieve a higher level of sophistication in digital-analog hybrid design technology. In addition, Fuji is also developing test and automated design technology, and is forging ahead with the construction of a design environment capable of supporting the development of system power supply ICs for portable electronic devices, which are expected to becoming increasingly sophisticated in the future.

3. Future Prospects

Fuji Electric intends to continue to focus on its core technologies of high-voltage and CMOS analog technology, and to add intelligence to these technologies. Concentrating on power supply ICs, Fuji Electric aims to develop distinguished products in response to market needs.

In the power supply IC field, lower power con-

Fig.3 Structure of the trench lateral power MOSFET (TLPM)



sumption and higher efficiency are important factors in the response to environmental problems, which are only expected to become more severe. Accordingly, Fuji Electric is adopting the switching method, which has highly efficient power conversion, as its main method for supplying power. Fuji will also enhance its high-voltage, low power PWM switching technology, which has been a core technology until now and create power management technology that utilizes this switching technology effectively to develop and commercialize high-precision intelligent power supply ICs.

As for device and process technology, Fuji Electric will further develop low on-resistance device technology. Specifically, Fuji will continue to develop the unique technology described in “Low On-resistance

Trench Lateral Power MOSFET Using 0.6 μm Smart Power Technology,” a separate article of this special issue, and will apply that technology to products (See Fig. 3).

4. Conclusion

The present status and future prospects for Fuji Electric’s IC products, which are concentrated on ICs for power supply units, have been described. Fuji Electric will continue to enhance its proprietary technologies, especially high-voltage and CMOS analog technologies, and to provide products that increase customer satisfaction.



3-channel DC-DC Converter Control IC for Liquid Crystal Displays

Masanari Fujii

1. Introduction

As multimedia becomes more pervasive in our society, there has been a trend for electronic devices to be made lighter in weight, smaller in size and to consume less power. Such features are fully leveraged by liquid crystal displays (LCDs), and in the display device field, the LCD is rapidly supplanting the conventional CRT.

At present, the replacement of CRTs with LCDs has become commonplace. As the size of display devices increases in the future, user demand is expected to increase for large-screen LCDs having light weight, small size and low power consumption. Lower prices, however, will be a critical factor in the promotion and popularization of these LCDs.

Three types of voltages from a boost converter, buck converter and an inverter are typically required to drive an LCD. The specific voltage configuration and power supply sequence required for driving will differ depending on the display manufacturer and model type. Accordingly, there is demand from LCD manufacturers for an improved, highly versatile, power supply IC.

In order to satisfy the abovementioned demand, Fuji Electric, which has previously commercialized a series of power supply ICs for LCD use, has developed and commercialized a new series for use in configuring the power supplies for large-screen LCDs. This new product series is known as the FA7711V, a 3-channel PWM (pulse width modulation) type, switched-mode power supply IC that does not require a buffer for driving an externally attached power MOSFET (metal oxide semiconductor field effect transistor). An overview of the FA7711V is presented below.

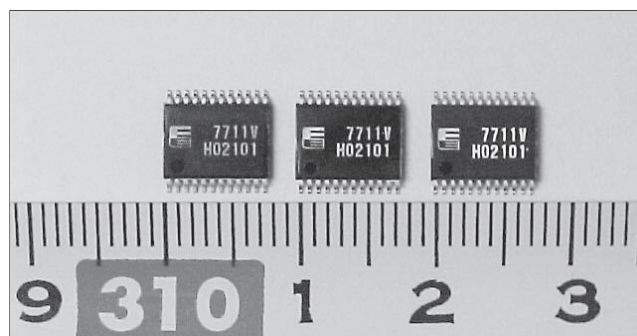
2. Product Overview

Figure 1 shows the appearance of FA7711V chips.

2.1 General IC characteristics

The recently developed FA7711V is a power supply control IC for use in large-screen LCDs, and because the FA7711V is capable of directly driving a large-

Fig.1 Appearance of FA7711V



capacity power MOSFET, there is no need for a buffer as was previously required to drive an externally attached power MOSFET. Moreover, 3-channel PWM control output pins are built-in in order to facilitate the configuration of the required power supply for an LCD.

Special features of the FA7711V are as follows:

- (1) Higher efficiency due to high-speed switching is possible since a large-capacity power MOSFET (C_{iss} = approx. 2,000 pF) can be driven directly
- (2) Built-in 3-channel PWM control output pins can be used to configure boost converter, buck converter, inverter and flyback circuits
 - Channel 1
Dedicated for p-channel MOS driving (buck converter)
 - Channel 2, Channel 3
Switchable for n-channel MOS/p-channel MOS driving (boost, buck, inversion). OUT2 and OUT3 have opposite phases. Polarity is set individually with polarity select pins.
- (3) Wide operating range of power supply voltage: 4.5 to 15 V
- (4) High frequency operation of 200 to 800 kHz is possible. Operating frequency can easily be set with a timing resistor.
- (5) Reference voltage: 3.70 V (± 1 % precision)
- (6) Low current consumption due to CMOS process (7 mA during operation)
- (7) Each channel has an independent soft start circuit and an individually settable maximum duty
- (8) Independent built-in timer and latch-type short

circuit protection for each channel

- (9) Built-in undervoltage lockout circuit
- (10) Small, low-profile TSSOP-24 pin package (installed height 1.20 mm max.)

2.2 Description of operation

Figure 2 shows a block diagram of the internal circuitry of the FA7711V. The operation of the various sections is described below.

Fig.2 FA7711V internal circuitry block diagram

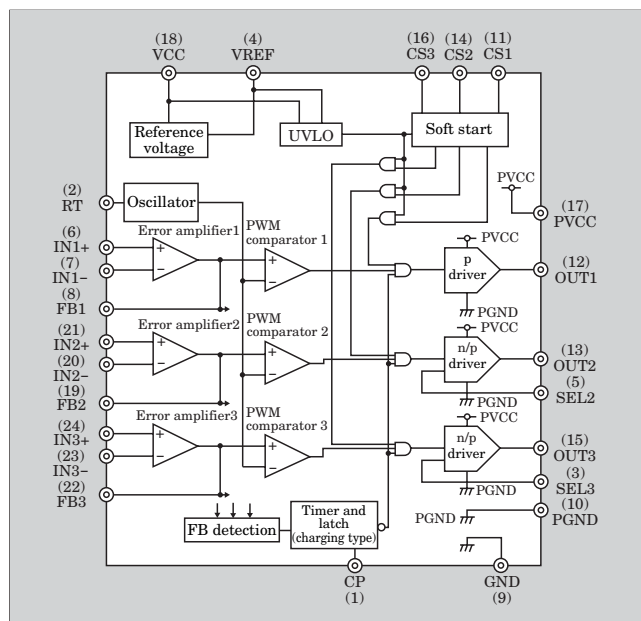
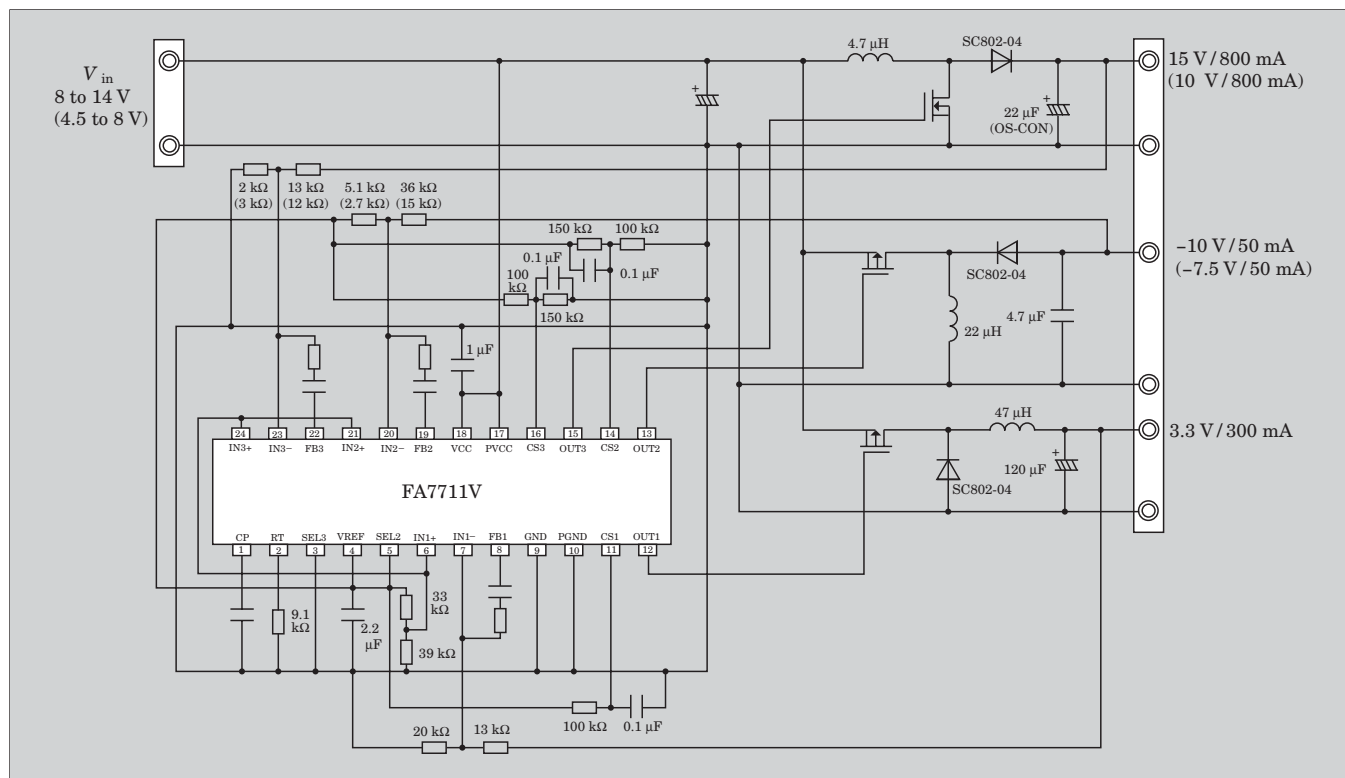


Fig.3 FA7711V application circuit example



(1) PWM control unit

Reference voltages may be individually set for each channel by inputting an external voltage in the range of 1.3 to 2.3 V to the non-inverting input pin (IN+) on error amplifiers.

Output polarity is set with the polarity select pin (SEL). Moreover, the phases of channels 2 and 3 are inverted, and when driving a power supply, input ripple can be reduced by distributing the load of the input power supply.

(2) Maximum duty setting

In the case of boost converter and inverter driving, it is necessary to limit the maximum duty in order to prevent a short circuit between ground and the power supply input from an externally attached power MOSFET that is fully on. For this reason, a maximum duty can be set by inputting a voltage in the range of 1.3 to 2.3 V to the soft start pin (CS) of each channel.

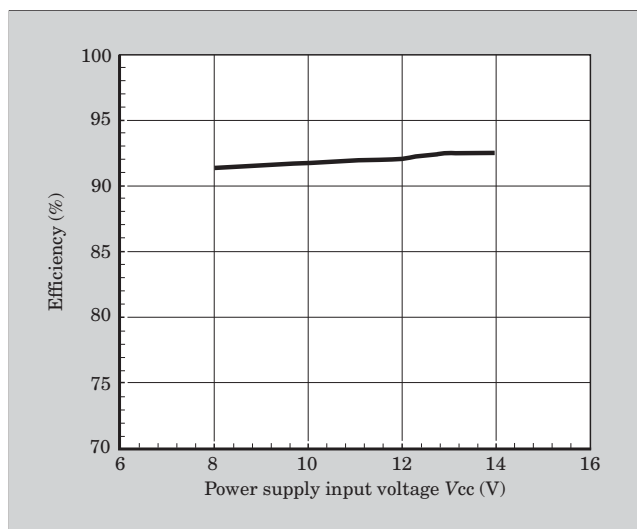
(3) Soft start circuit

At startup, an independent soft start circuit for each channel gradually extends the duty cycle in order to prevent current in-rush of the input power supply and overshoot of the power supply output voltage. The soft start pins (CS) have a built-in current source and therefore are used with an external capacitor connected.

(4) Timer and latch-type short circuit protection

A timer and latch-type short-circuit protection circuit monitors the voltage output from each error amplifier for abnormalities, and after a certain delay time has elapsed, halts the IC output. The delay time

Fig.4 Voltage conversion efficiency for input voltages of 8 to 14 V (560 kHz switching)



can be set with the capacitor connection (CP) pin that interfaces to the built-in timer and latch provided with an internal current source.

(5) Undervoltage lockout circuit

If the voltage of the power supply input pin (VCC) and reference voltage output pin (VREF) drop to 3.3 V or less, the output from all channels is halted.

(6) Oscillator

The frequency of the oscillator can be set to an arbitrary value in the range of 200 to 800 kHz by connecting a resistor (28 to 6 kΩ) to the timing resistor pin (RT). The oscillation waveform has an amplitude of 1.3 to 2.3 V, and is supplied as the reference voltage for the PWM comparator of each channel.

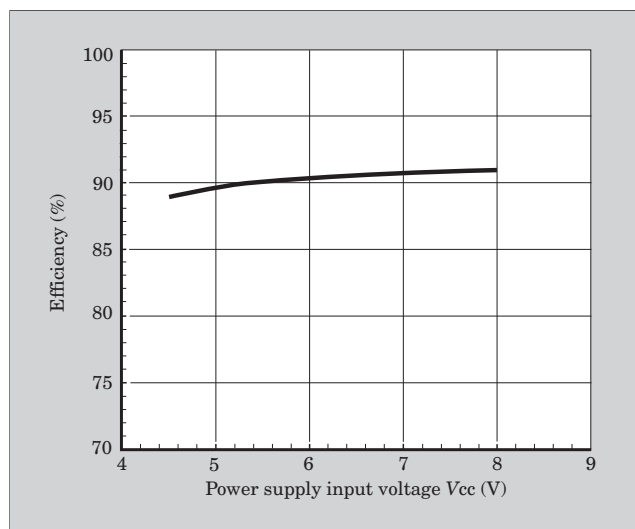
3. Circuit Application Example

Figure 3 shows an example circuit application of the FA7711V. A change in the input voltage range results in a change in the output voltage, and the circuit constant for the output voltage detection resistor will be modified. If the input voltage is more than 8 V, the input and output conditions of the power supply are as follows:

- (1) Input voltage (V_{in}) 8 to 14 V
- (2) Output voltage (V_{out})
 - Channel 1: Buck (3.3 V / 300 mA)
 - Channel 2: Inversion (-10 V / 50 mA)
 - Channel 3: Boost (15 V / 800 mA)

The power conversion efficiency (= output power / input power) in this case is shown in Fig. 4. IC loss is suppressed due to high-speed switching at the output stage and a high efficiency of 91 to 93 % is realized.

Fig.5 Voltage conversion efficiency for input voltages of 4.5 to 8 V (560 kHz switching)



If the input voltage does not exceed 8 V, the input and output conditions of the power supply are as follows.

- (1) Input voltage 4.5 to 8 V
- (2) Output voltage
 - Channel 1: Buck (3.3 V / 300 mA)
 - Channel 2: Inversion (-7.5 V / 50 mA)
 - Channel 3: Boost (10 V / 800 mA)

Figure 5 shows the power conversion efficiency in this case. Since the input voltage is low, power conversion loss increases by the amount of loss generated in elemental resistors due to increased line current. Consequently, efficiency is less than in the case where input voltage is greater than 8 V. Nevertheless, a relatively high efficiency of 89 to 91 % is obtained.

4. Conclusion

An overview of the FA7711V power supply control IC for LCD-use has been presented.

At present, in the display device field, the conventional CRT monitor is rapidly being supplanted by LCDs of all sizes, and demand is growing for power supplies that are smaller, thinner and consume less power. Moreover, demand for lower priced LCDs is driving the need to lower the cost of the power supply, for which the elimination of components externally attached to the IC is an important factor. In response to these market demands, Fuji Electric intends to further advance its series of power supply control ICs for LCD-use by developing ICs that have built-in power MOS circuitry, for example.

Small-package 5-channel Output DC-DC Converter Control IC

Masayuki Yamadaya

1. Introduction

The market for portable electronic devices, which is centered on digital still cameras, has grown rapidly in recent years. Such types of electronic devices have trended toward higher performance and multi-functionality, while at the same time achieving remarkably smaller and thinner dimensions, lighter weight, and lower cost. A diverse range of components is used to configure the electronic devices internally, and those components require many different voltages. Accordingly, the power supply unit of an electronic device accounts for a rather large percentage of space on the circuit board, and demands to reduce this percentage are steadily growing.

Fuji Electric, having previously developed many PWM (pulse width modulation) type multi-channel output DC-DC converter control ICs for portable electronic devices, has recently developed the FA7716R, a 36-pin small-package 5-channel output DC-DC converter control IC that enables a drastic reduction in externally attached components. An overview of the FA7716R is presented herein.

2. Features

In addition to maintaining the equivalent functionality as power supply circuits built with Fuji Electric's previous 5-channel output DC-DC converter control ICs, the internal integration of components that had formerly been attached as discrete external components and the adoption of a small package enable the FA7716R to achieve a drastic reduction in size compared to conventional PWM-type 5-channel output ICs. Moreover, use of Fuji Electric's characteristic CMOS (complementary metal oxide semiconductor) technology enables the realization of low current consumption.

Each of the five output channels is capable of directly driving a MOSFET (metal oxide semiconductor field effect transistor), and is suitable for driving circuits such as boost converters or buck converters that use inductors, or flyback converters that use transformers. In addition, each channel can independently be turned on or off (although some channels are

Table 1 FA7716R main characteristics

Item	Condition	Minimum	Standard	Maximum	Unit
Power supply voltage		2.5		10	V
Oscillation frequency		200	500	1,200	kHz
Reference voltage (error amplifier)		0.09	1.00	1.01	V
Soft start time	0 to 100 %		25		ms
Internal maximum duty limit	When DT = GND	80	85	90	%
	When DT = VREG	65	70	75	%
Undervoltage lockout operating voltage		1.9	2.1	2.3	V
OUT H-level ON-resistance	$I_{out} = 10 \text{ mA}$		15	23	Ω
OUT L-level ON-resistance	$I_{out} = -10 \text{ mA}$		7	11	Ω
Standby current			2	10	μA
Supply current	$f_{osc} = 500 \text{ kHz}$		4	6	mA

Note : Unless otherwise specified, rated values are for the conditions of 3.3 V power supply voltage and room temperature (25°C)

controlled commonly) and such control provides the capability for supporting all types of power supply sequences.

Main characteristics of the FA7716R are shown in Table 1, and other features are listed below:

- (1) 36-pin QFN (quad flat non-lead) package
- (2) Operating voltage: 2.5 to 10 V

Compatible with lithium ion batteries (1 cell, 2 cells), nickel hydrogen batteries (4 cells), alkali dry cells (4 cells)

- (3) Oscillation frequency: 200 kHz to 1.2 MHz

High frequency operation enables reduction of inductor size

- (4) Internal reference voltage: 1.00 V $\pm 1 \%$
- (5) Built-in 5-channel PWM controlled outputs

Channels 1, 2 and 3 are for n-channel driving, channel 4 is for p-channel driving, channel 5 is selectable for either n or p-channel driving

- (6) Built-in timer and latch-type short circuit protection, undervoltage lockout circuit
- (7) Independent on/off control for each channel,

- (channels 4 and 5 are controlled commonly)
- (8) Built-in soft start circuit (fixed internally within IC)
 - (9) Channel 5 startup delay time in relation to channel 4 can be set
 - (10) Built-in maximum duty limits

Channels 1, 3, 5 (during n channel driving) can be set as either 85 % or 70 %. Arbitrary maximum duty limit may also be set. Channel 2 is internally fixed at 85 %.

3. Product Overview

Figure 1 shows an internal block diagram of the FA7716R and an example circuit application. An overview of the various functional sections is presented below.

3.1 PWM control blocks

Except for channel 3, the non-inverted inputs to the error amplifier are internally connected to a reference voltage. The channel 3 error amplifier input can be set externally as either non-inverted or inverted

input.

The outputs of channels 1, 2 and 3 are for n-channel driving, the output of channel 4 is for p-channel driving, and the output of channel 5 can be switched for either n or p-channel driving.

Because its error amplifier is provided with a non-inverted input, channel 3 can be used to drive a LED backlight such as used in a digital still camera.

3.2 Maximum duty limit circuit

The maximum duty limit can be set for n-channel driving by channels 1, 3 and 5. This IC is provided internally with two maximum duty limit settings, 85 % and 70 %, which can be switched by affixing the DT pin voltage to either GND or VREG (See Fig. 2.). An arbitrary maximum duty limit may also be set by applying an external voltage to the DT pin. During p-channel driving by channel 5, the maximum duty limit is completely disabled.

3.3 Soft start circuit

Because each channel generally starts up at its own arbitrary timing, the soft start circuit must be

Fig.1 FA7716R internal block diagram and example circuit application

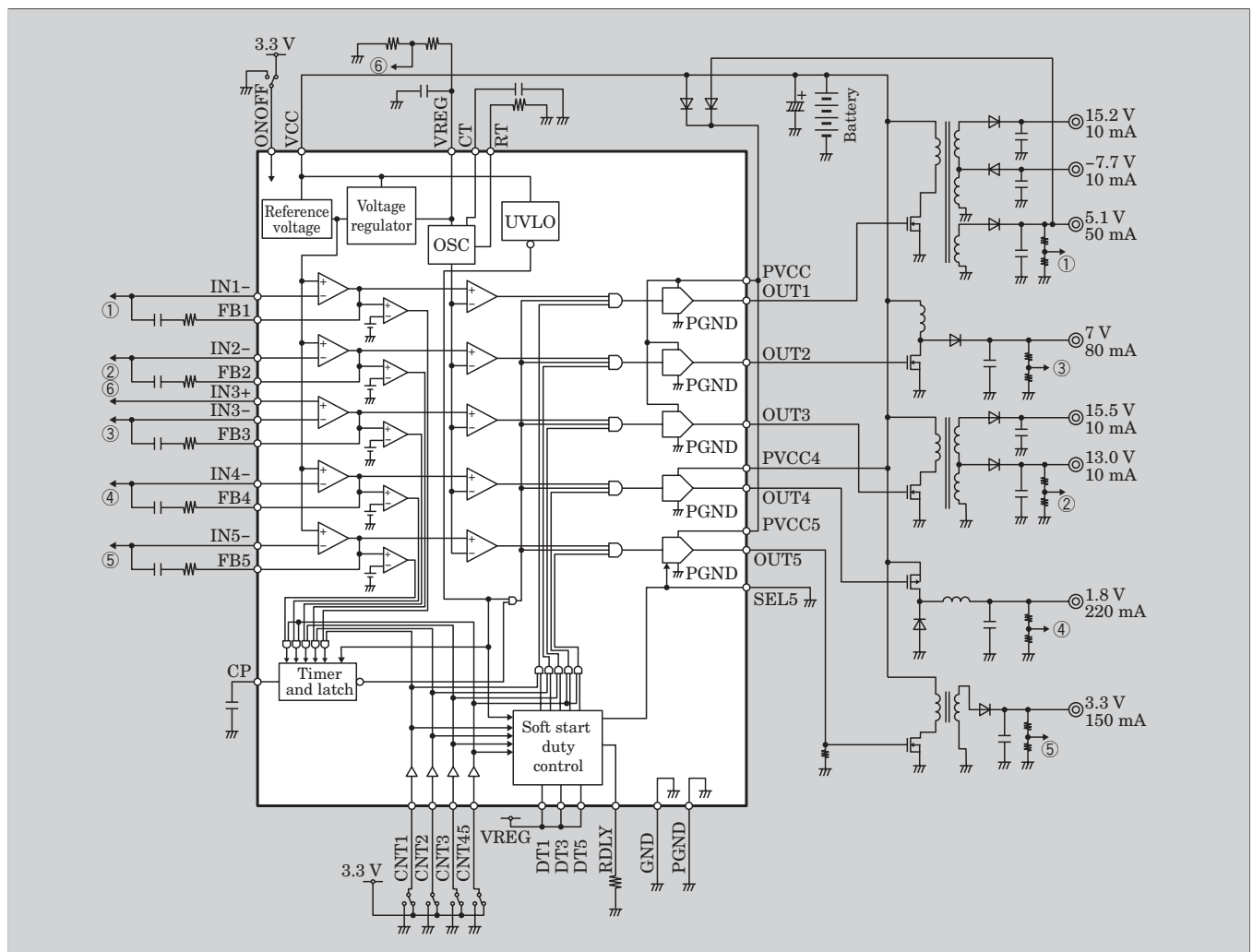
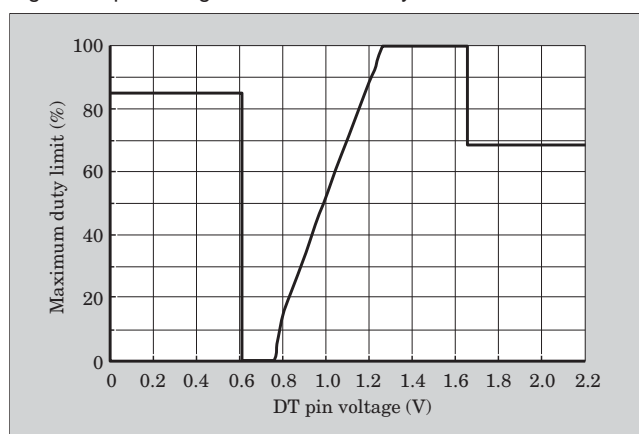


Fig.2 DT pin voltage vs. maximum duty limit



independently settable for each channel, and this has typically required external components to be attached to each channel. The FA7716R, however, has a fully self-contained soft start function that does not require any externally attached components, thereby enabling the FA7716R to realize a reduction in its pin count.

The internal soft start signals are obtained by inputting an oscillating waveform and comparison voltage into a comparator. The comparison voltage has a gradual time slope of several millisecond and is generated by an oscillator, counter and D-A converter. Each channel has its own counter and D-A converter, and a soft start signal is generated when a signal is applied to the CNT pin of each channel. The CNT pin turns each channel on or off (See Fig. 3.).

Channels 4 and 5 are both controlled by the same CNT45 pin. Individual soft start signals can be generated for each using the delay circuit described below.

3.4 Channel 5 delay circuit

Channels 4 and 5 are intended for use in supplying voltage to a digital system, and a common CNT45 pin controls both of these channels. Two types of voltage signals typically determine the sequencing of a digital system, and at startup, one voltage signal must never overtake the other voltage signal.

Accordingly, the FA7716R enables the startup of channel 5 to be delayed with respect to the startup of channel 4, and this delay time is settable. Because the time required for startup of each channel differs depending on the input voltage range used and the load conditions, when using these channels 4 and 5 in combination, an external resistor can be attached to vary the delay time and adjust to optimal conditions.

The relationship between the start up times of channels 4 and 5 is shown in Fig. 3.

3.5 Partitioned power supply pins of output drivers

To power a transformer or other such device, driving by means of a high-voltage MOSFET is sometimes necessary. In such a case, the MOSFET

Fig.3 Soft start signals

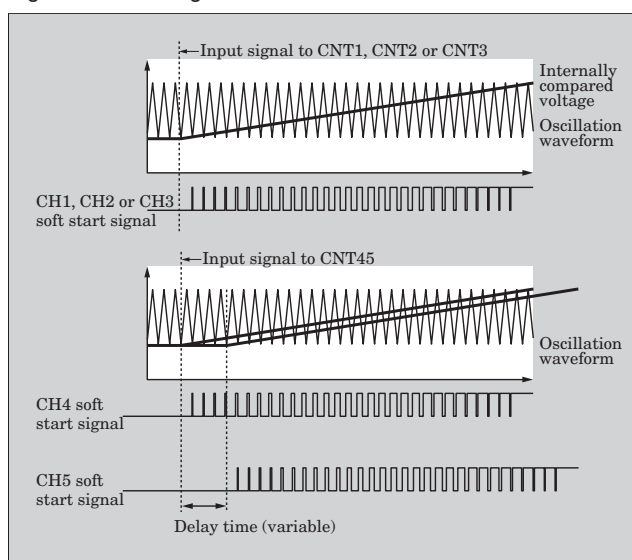
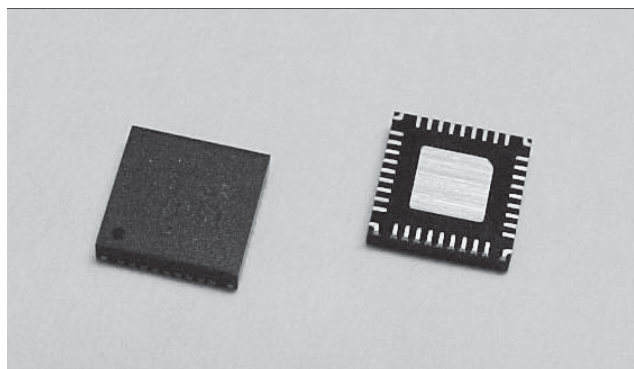


Fig.4 External view of package



threshold voltage has a tendency to increase, and the battery voltage may be insufficient.

As a countermeasure, the voltage generated by a boost converter is fed back to the power supply pin of the driver, enabling the MOSFET to be driven at higher voltage. This countermeasure should also result in improved efficiency.

However, because it may be inconvenient to feed-back this boosted voltage for some channels, the FA7716R is provided with a tri-partitioned driver power supply pin, enabling the design of power supply circuits with high flexibility.

3.6 Package

Miniaturization of the FA7716R contributed to both a reduction in the pin count and shrinking of the package itself.

The adoption of a 36-pin QFN package having 0.4 mm pin pitch enables the realization of a 5 mm × 5 mm body size. The package is a low-profile design having a maximum thickness of 0.95 mm.

Front and rear views of the package are shown in Fig. 4.

3.7 Circuit application example

An example circuit application is shown in Fig. 1. In addition to this example, various other combinations of power supply circuits can be configured.

4. Conclusion

An overview of Fuji Electric's newly developed small-package 5-channel DC-DC converter control IC has been presented.

The development of portable electronic devices, which center on digital still cameras, will undoubtedly continue. Two distinct trends have been observed for power supply circuits, either toward multi-channel functionality or toward fewer channels. At present, it is impossible to predict the future ratio of these trends.

Fuji Electric intends to monitor future trends and to work toward the rapid development of new and attractive products by striving for further internal integration of external components and higher efficiency of power supply circuits.



- (3) Adjustable output voltage by external resistor
- (4) Accurate output voltage ($\pm 4\%$)
- (5) Protection circuits; short-circuit protection, UVLO (under voltage lock-out)
- (6) Built-in oscillator (1 to 2.5 MHz)
- (7) Sleep mode / shutdown mode

3.2 Micro inductor

The inductor is usually the largest component in a DC-DC converter. To reduce the inductor size, Fuji Electric developed a technology for fabricating micro inductors on a ferrite wafer using thin film technology.

Table 1 Major electrical characteristics

Item		Characteristic values
Power supply voltage		2.7 to 5.0 V
Output voltage <accuracy>		Variable with an external resistance < $\pm 4\%$ >
Output current		Up to 500 mA
Oscillating frequency		1.0 to 2.5 MHz
Current consumption	Shutdown mode	1 μ A max.
	Sleep mode	20 μ A max.
	LDO mode	100 μ A max.
	Switching mode (1.8 MHz)	500 μ A max.

Fig.2 Load characteristics of micro inductor

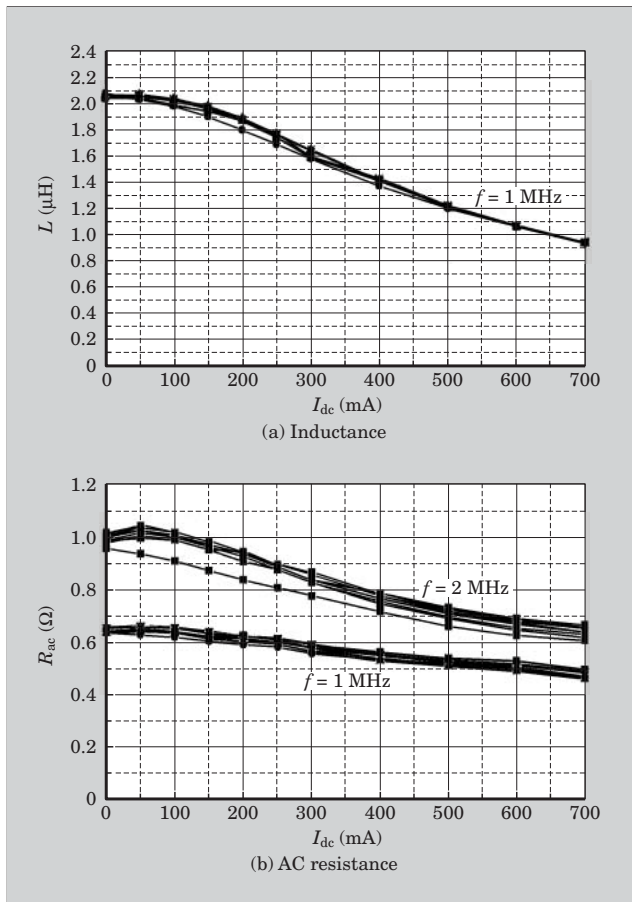


Figure 2 shows the load characteristics and Fig. 3 shows an external view of the new micro inductor. A solenoidal-winding micro inductor is formed by performing electroplating on a 525 μ m-thick ferrite wafer which provides a matrix of through-holes. The number of coil turns is 11. Several peripheral terminal electrodes are formed around the inductor simultaneously. The electrodes on the top side are used to connect the control IC, and those on the bottom side are used as terminals that are to be mounted onto printed circuit boards. This structure enables size reduction when forming the modules.

3.3 Assembly process of the CSM

Fuji Electric has developed CSM (chip size module) technology for integrating an IC chip and an inductor into a structure that is almost same size as the IC chip. This simple structure, in which the magnetic core of the inductor is a ferrite substrate that also functions as a support substrate onto which an IC can be directly mounted, enables substantial reductions in size and thickness. Figure 4 shows a schematic diagram of the CSM structure.

First, IC chips are bonded onto an inductor substrate using an ultrasonic flip chip bonding method with an Au stud bump connection. Next, all gaps between the inductors and IC chips are filled with an under-fill material to enhance peeling resistance.

Fig.3 External view of the micro inductor

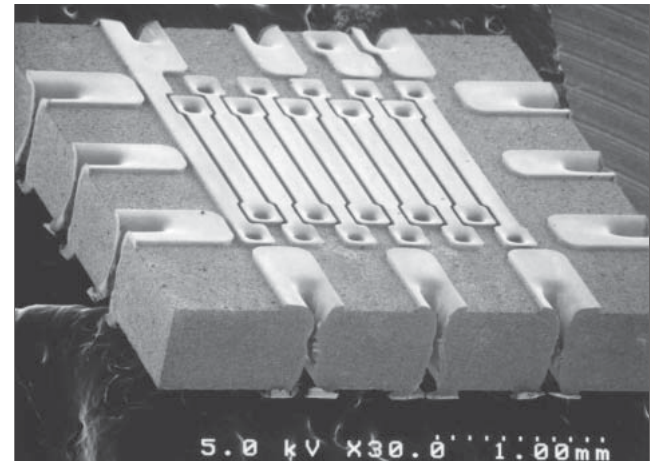


Fig.4 Schematic diagram of CSM structure

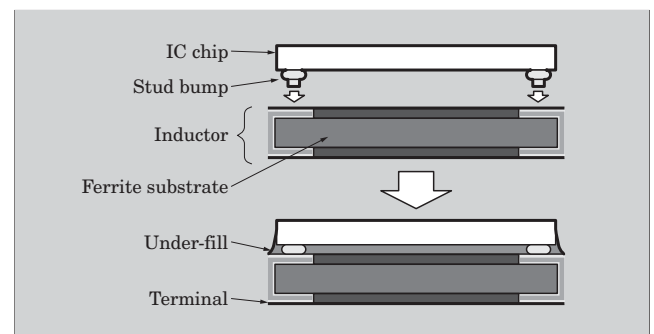
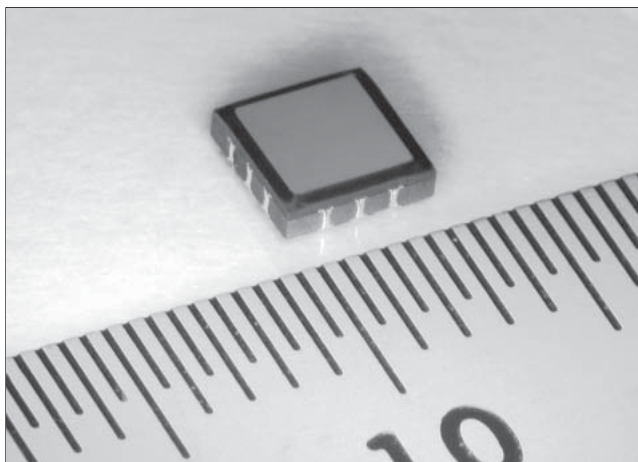


Fig.5 Micro DC-DC converter chip size module (CSM)



Finally, the module is diced into separate modules with the through-holes divided into equal halves.

Figure 5 shows an external view of the DC-DC converter CSM. The module dimensions of 3.5 mm by 3.5 mm by 1.0 mm were realized with a mounted IC chip of size 2.9 mm by 2.9 mm by 0.27 mm. Compared to conventional module assembly methods, the CSM method is very effective in reducing the DC-DC converter module size and mounting area on a printed circuit board.

4. DC-DC Converter Characteristics

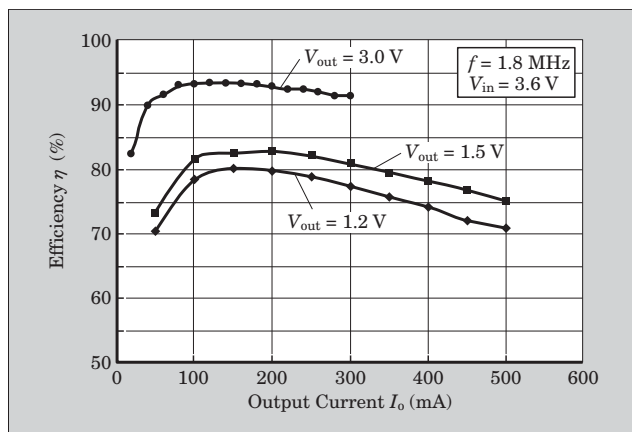
Figure 6 shows the relationship between output current and efficiency at the input voltage of 3.6 V and output voltages of 1.2 V, 1.5 V and 3.0 V. The maximum efficiency of 93.4 % is realized.

5. Conclusion

This paper presented an overview of the ultra-small, light and thin micro DC-DC converter CSM.

Fuji Electric is endeavoring to contribute to the advancement of society by responding to the needs of

Fig.6 Efficiency characteristics of micro DC-DC converter



the growing market for mobile devices and by furthering technical innovation based on ultra-small power supply system technology using high-frequency switching.

References

- (1) Sato, T. et al. A magnetic thin film inductor and its application to a MHz switching DC-DC converter. IEEE Tran. Magn. vol.30, no.2, 1994, p.217-223.
- (2) Mino, M. et al. A compact buck-converter using a thin film inductor, Proc. Appl. Power Electronics Conf. 1996, p.422-426.
- (3) Nakazawa, H. et al. Micro-DC/DC Converter that Integrates Planer Inductor on Power IC, IEEE Tran. Magn. vol.36, no.5, 2000, p.3518-3520.
- (4) Sugahara, S. et al. Characteristics of a Monolithic DC-DC Converter utilizing a Thin-film Inductor. IPEC-Tokyo2000, 2000, p.326-330.
- (5) Katayama, Y. et al. High-Power-Density MHz-Switching Monolithic DC-DC Converter with Thin-Film Inductor. PESC'00, 2000 p.1485-1490.
- (6) Hayashi, Z. et al. The Completely Monolithic DC-DC Converter with a Thin Film Inductor. Journal of Magnetic Society of Japan, vol. 25, no.8, 2001, p.1457-1461.

PDP Address Driver IC Technology

Gen Tada
Kazuhiro Kawamura
Masaru Saitou

1. Introduction

PDPs (plasma display panels) have the merit of large screen size and thin design. They have improved their prior problems of insufficient brightness and contrast to achieve CRT-comparable levels, and consequently, the market for PDPs for use in household televisions is growing rapidly. Lower price is the key for PDPs to become even more popular, and lower priced driver ICs are also in demand.

Fuji Electric developed a 2nd generation address driver IC in 2001, and is presently mass-producing and supplying this chip. However, in response to demands for lower cost, Fuji Electric has recently developed process and device technologies that reduce the chip cost to 2/3 that of a conventional chip, and has applied these technologies to 3rd generation address driver IC products.

This paper presents an overview of the process and device technologies, and an overview of the 3rd generation address driver IC products that utilize these technologies.

2. Process Technology

For manufacturing address driver IC's, Fuji Electric has been applied a pn junction isolated process technology using an epitaxial wafer with a buried layer⁽¹⁾, that is high-performance and lower cost. However, in response to market demand for even lower costs, it is necessary to not only reduce the steps of wafer processing, but also to create a wafer process infrastructure capable of maintaining a stable supply even if production quantity should increase in the future.

In response to these demands, Fuji Electric has developed a new process, features of which are listed below:

- (1) Wafer processing is simplified through sharing of the diffusion layer and reduction of the oxidation process, thereby enabling the number of mask steps to be reduced to 75 % that of conventional process.
- (2) Adoption of 8-inch wafer process, including an

epitaxial wafer process with a buried layer, to provide an infrastructure capable of maintaining a stable supply even if production quantity should increase in the future.

3. Device Technology

In order to decrease chip cost, not only must wafer process be reduced, but also the chip size must be decreased. For these 3rd generation address driver ICs, device design was optimized and the chip size was reduced to less than 70 % of the conventional size. An overview of this device technology is presented below.

3.1 High-voltage device shrinking technology

High-voltage devices occupy approximately 50 % of the total area of an address driver IC. Accordingly, the most efficient way to reduce the chip size is to shrink the size of the high-voltage devices. Figure 1 shows a cross-section of a high-voltage n-channel MOSFET (metal oxide semiconductor field effect transistor), otherwise known as HVNMOS.

HVNMOS uses a Resurf structure, but this time the trade-off characteristics between breakdown voltage and on-resistance were improved by optimizing the length (L_d) of the extended n-well that act as the drain drift region. Moreover, the channel length (L_g), and threshold voltage was optimized and device pitch was shortened. Figure 2 shows the relationship between drain current and drain voltage of the HVNMOS.

We shrunk high-voltage p-channel MOSFET

Fig.1 HVNMOS cross-section

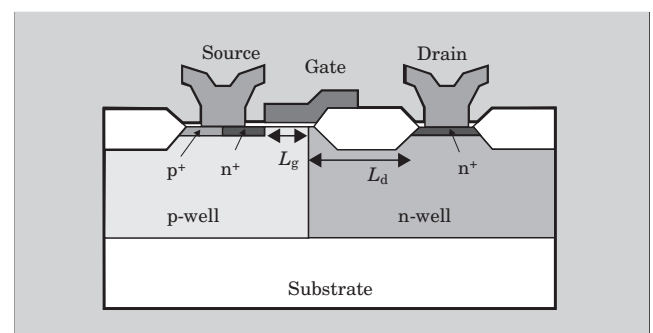


Fig.2 HVNMOS I - V characteristics

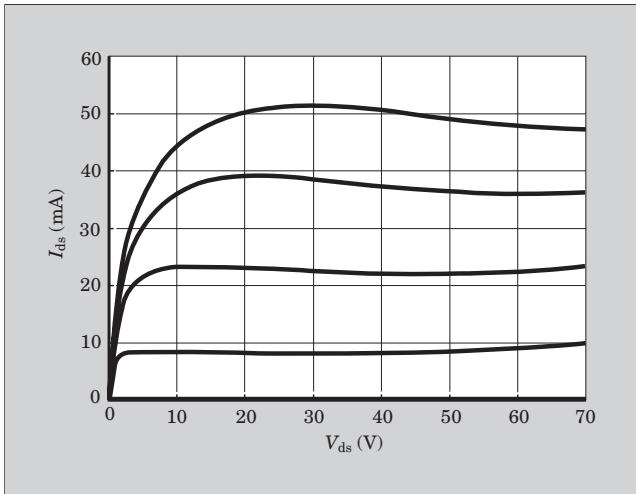


Fig.3 HVP MOS I - V characteristics

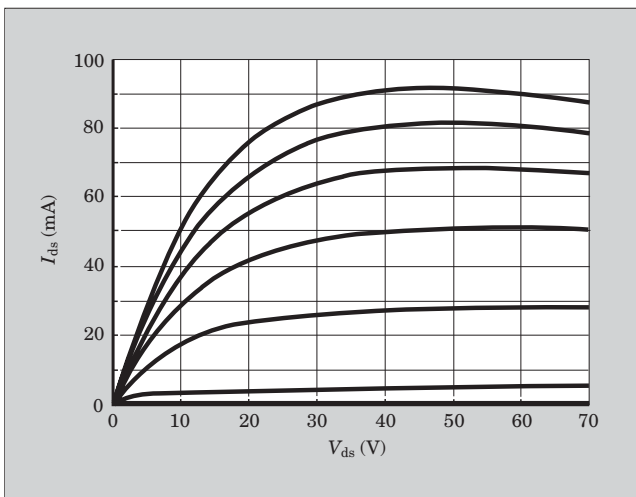
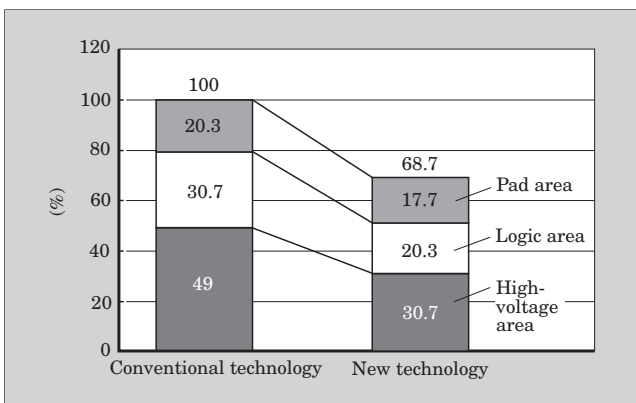


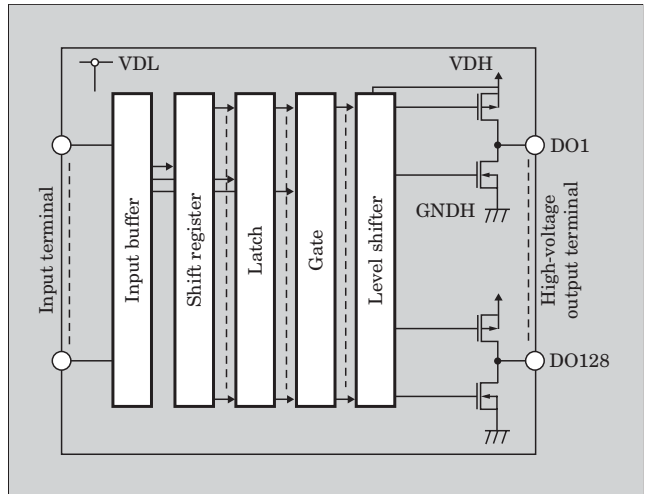
Fig.4 Device size comparison



(HVP MOS) in similar way. Figure 3 shows the I - V characteristics of HVP MOS device.

As a result of implementing this device shrinking technology, high-voltage devices capable of 70 V switching operation were realized with 60 % of the size of Fuji Electric's prior comparable devices.

Fig.5 Block diagram



3.2 Total device size comparison with conventional technology

In addition to high-voltage devices, low-voltage devices (logic area) and the pad size were also reduced.

- (1) Scaled down design rules enabled shrinking of the design area to 2/3 that of Fuji Electric's conventional technology.
- (2) Pad size was reduced to 90 % of the conventional one.

The above results enabled the total device size to be reduced to less than 70 % that of conventional technology (Fig. 4).

4. Application to 3rd Generation Address Driver ICs

These newly developed processes and devices were applied to the development of a color PDP address driver IC, which is introduced below.

4.1 Overview

Features of Fuji Electric's newly developed color PDP address driver IC are listed below:

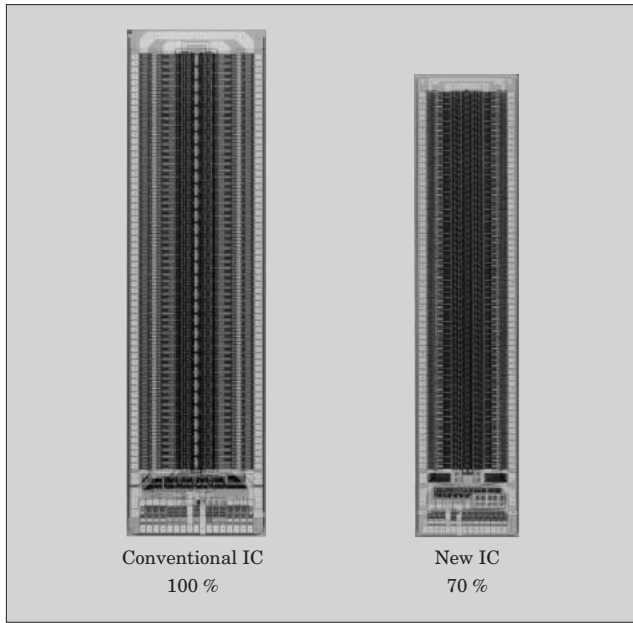
- (1) 128-bit high-voltage push-pull outputs
- (2) High-voltage output: 85 V (max), ± 30 mA (std)
- (3) High-voltage output, high switching speed
- (4) High speed data transfer: 40 MHz
- (5) 3.3 V CMOS input interface
- (6) 4-bit data I/O port
- (7) Four 32-bit bi-directional shift registers

4.2 Block diagram

Figure 5 shows a block diagram of the new IC.

The new IC consists of an input buffer circuit that enables use of a 3.3 V CMOS input interface, four 32-bit bi-directional shift registers, a 128-bit latch, a gate for controlling all H/L/Z high-voltage outputs, a low-power level shifter, and a 128-bit high-voltage push-pull output circuit.

Fig.6 Chip photograph (comparison of chip size)



4.3 Features and comparison to conventional ICs

4.3.1 Chip size

Figure 6 shows photographs of both a conventional IC chip and new IC chip, to provide a visual comparison of the relative chip sizes. By adopting newly developed low on-resistance devices and using a scaled down wafer process, this IC realizes the performance equivalent to a conventional IC, while achieving a smaller chip size which is approximately 70 % that of a conventional IC chip.

4.3.2 Typical characteristics

Table 1 shows the comparison of typical characteristics of new IC with those of conventional IC.

(1) High-voltage H/L output voltage

Characteristics comparable to those of the conventional IC were realized for both H output voltage ($V_{OH\ DO}$) and L output voltage ($V_{OL\ DO}$). Although these characteristics have a large effect on the size of a high-

Table 1 Comparison of typical characteristics

Symbol	Condition	Conventional IC	New IC	Units
$V_{OH\ DO}$	$I_{OH} = -30\text{ mA}$	64.8	65.4	V
$V_{OL\ DO}$	$I_{OH} = 30\text{ mA}$	2.2	2.8	V
I_{DD}	When operating at 40 MHz	34.0	18.8	mA
f_{CLK}	Without load	50.0 or above	50.0 or above	MHz
$t_{p\ HL}$	$C = 50\text{ pF}$	55.8	46.2	ns
$t_{p\ LH}$	$C = 50\text{ pF}$	130.0	135.6	ns
t_r	$C = 50\text{ pF}$	52.3	45.3	ns
t_f	$C = 50\text{ pF}$	75.6	83.5	ns

Note: At the condition of,
 $T_j = 25^\circ\text{C}$, $V_{DL} = 5\text{ V}$, and $V_{DH} = 70\text{ V}$

voltage device, the device size was reduced to approximately 60 % that of a convention device, and characteristics comparable to those of a conventional IC were realized.

(2) Current consumption during operation (logic area)

Optimization of logic circuit device parameters enabled current consumption (I_{DD}) to be decreased to approximately 55 % that of a conventional IC.

5. Conclusion

This paper has presented new PDP address driver IC technology. Fuji Electric has responded to market demands for lower cost by reducing the steps of wafer processing and by shrinking the device size.

Fuji Electric intends to continue to develop high-performance, low-cost driver ICs in order to further promote and popularize PDPs.

References

- (1) Meguro, K. et al. Advances of Driver IC Techniques for PDPs. IDW'02. 2002, p.733-736.
- (2) Appels, A. et al. High Voltage Thin Layer Devices (Resurf Devices). IEEE IEDM. 1979, p.238-241.

High-resolution Compact Auto Focus Module with 7 μm Pixels

Kazuhiro Matsunami

1. Introduction

A high-speed externally attachable auto focus (AF) system is in demand for both conventional film cameras and digital still cameras (DSCs). The trends toward smaller size and lighter weight are advancing rapidly in the compact camera industry, and the extent to which Fuji Electric's AF modules (AFMs) follow these trends will be a decisive factor in their acceptance in the market.

Fuji Electric is already recognized as a successful producer of AFMs. Specifically, in 1992 Fuji Electric began mass-producing an AFM that integrated an optical system with an AFIC, which combined an A/D converter to convert sensor data and AF logic to perform range calculations into a single chip. Then in 1998, Fuji began mass-producing an analog output-type AFM, which enabled the sensor pitch to be made smaller, and this analog output-type AFM has been well received in the marketplace. In response to demands for even further miniaturization driven by the emergence of the advanced photo system (APS) film camera, Fuji Electric has been mass-producing the FM6255AT42, an AFM for 2 \times zoom cameras featuring a 12 μm pitch sensor and a compact optical system.

In response to demands for miniaturization for AF-equipped powerful zoom cameras, Fuji Electric has recently developed the FM6270W45, which features a newly designed IC package and an analog output-type 7 μm pitch sensor for 3 \times and higher zoom class film

cameras and DSCs.

Figure 1 shows the external appearance of the FM6270W45, the structure and features of which are described below. Table 1 lists Fuji Electric's product line-up of analog output-type AFMs.

2. Main Features of the FM6270W45

2.1 IC features

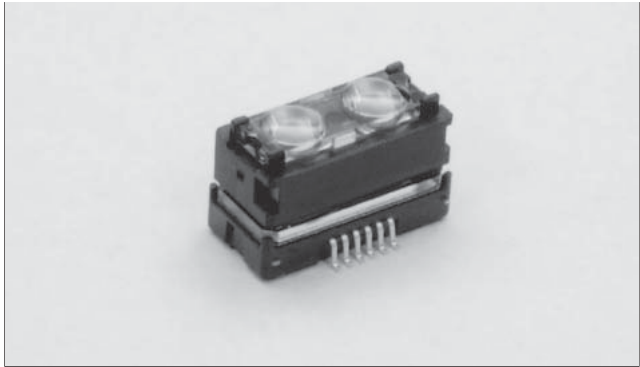
(1) Improved range resolution

Due to the reduction in sensor pitch from the 12 μm pitch of prior models to the 7 μm pitch of the FM6270W45, range resolution has been improved

Table 1 Fuji Electric's product line-up of analog output-type AFMs

Model Item	FM6255 AT42	FM6266 W37	FM6270 W45
AFIC utilized	FB6255AT (clear mold package)	FB6266W (new structure)	FB6270W (new structure)
Number of pins	16	12	12
Target camera	2 \times and lower zoom compact cameras	3 \times and higher zoom compact cameras	3 \times and higher zoom compact cameras
Baseline length B (mm)	5.566	5.566	5.566
Focal length f (mm)	5.7	10.7	5.7
$B \cdot f$ product (mm ²)	32.6	61	32.1
Number of photodiodes	2 \times 130	2 \times 224	2 \times 224
Pitch of photodiodes p (μm)	12	12	7
Sensor response (V/s) (Standard source A: 5EV)	200	147	230
Full view angle of sensor area (degrees)	10.8	10.1	10.8
DC power supply voltage (V)	4.0 to 6.0	3.0 to 6.0	3.0 to 5.5
Range resolution (Bf/p)	2.717	5.083	4.586

Fig.1 Appearance of FM6270W45 AFM



without changing the Bf product.

(2) Improved flexibility and ease-of-use

Prior models had two selectable sensitivity levels, high sensitivity or low sensitivity. The FM6270W45 allows greater flexibility in the setting of sensitivity, and sensitivity can be selected from among four levels. Also, by designating the pixel address, a partial readout can be obtained.

2.2 A new IC package

Features of the high-resolution compact AFM housed in a newly designed IC package structure (hereafter referred to as the new package) are listed below:

(1) Improved package

A new package structure is utilized in which the IC chip is sealed with soft material so that almost no stress is generated during sealing. This new package structure prevents the generation of stress that could lead to fluctuation in product characteristics.

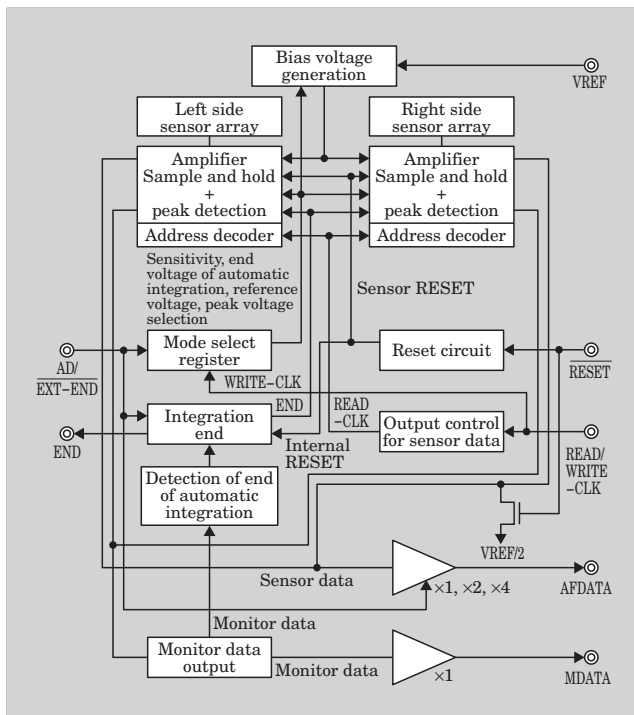
(2) Improved light shielding ability

Use of this new package structure simplifies the light shielding that had been required for the conventional clear mold package. Consequently, the new package can be implemented in a smaller size than a conventional package.

3. AFIC Circuit Configuration

Figure 2 shows a block circuit diagram of the FM6270W45. In this IC, the photocurrent from each photodiode in the left-side and right-side sensor arrays is converted into a voltage by a MOS (metal oxide

Fig.2 FM6270W45 block diagram



semiconductor) based sensing circuit (integrator) and amplifier, and then amplified, sampled and held as sensor data.

Sensing (integration) starts at the reference voltage V_{ref} , and the circuit provides for the output voltage to decrease in proportion to the duration of the sensing interval. Upon receiving an integration end signal, the voltage at that time is sampled and held. The sensor data of each pixel is selected and output in synchronization with an external clock. As can be seen in Fig. 3, in areas where the subject image is bright, the corresponding pixel output voltage is low, and in dark areas, the corresponding pixel output voltage is a value near V_{ref} .

4. Use of a 7 μm Pitch Sensor

Among Fuji Electric's AFMs currently in mass production, the minimum sensor pitch of the

Fig.3 Example of sensor data output

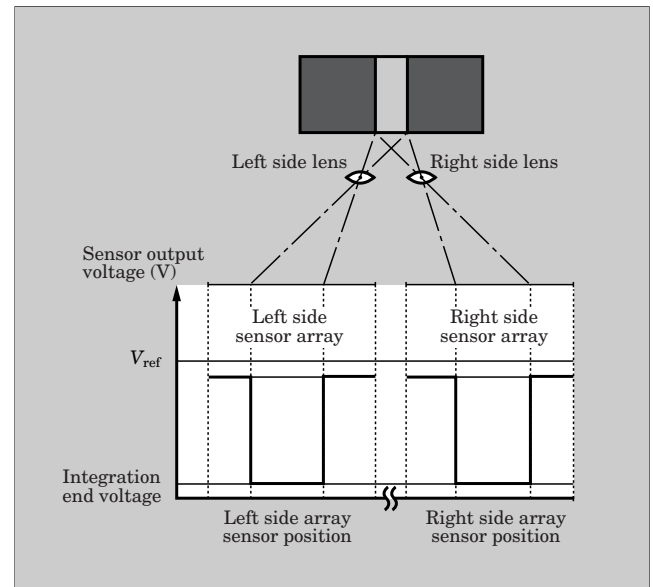


Fig.4 Module downsizing due to sensor pitch reduction

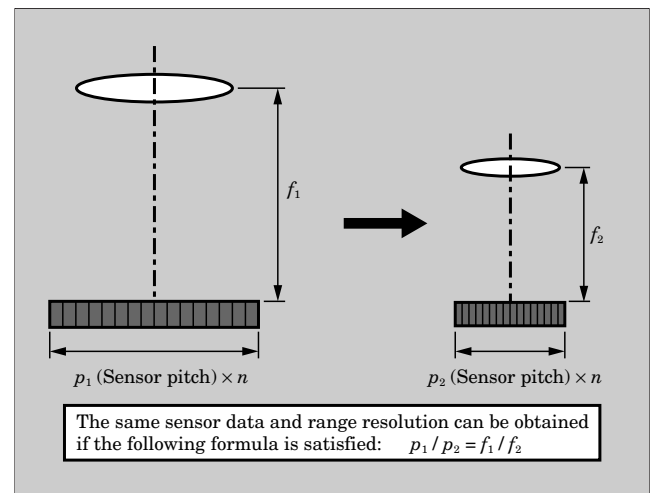
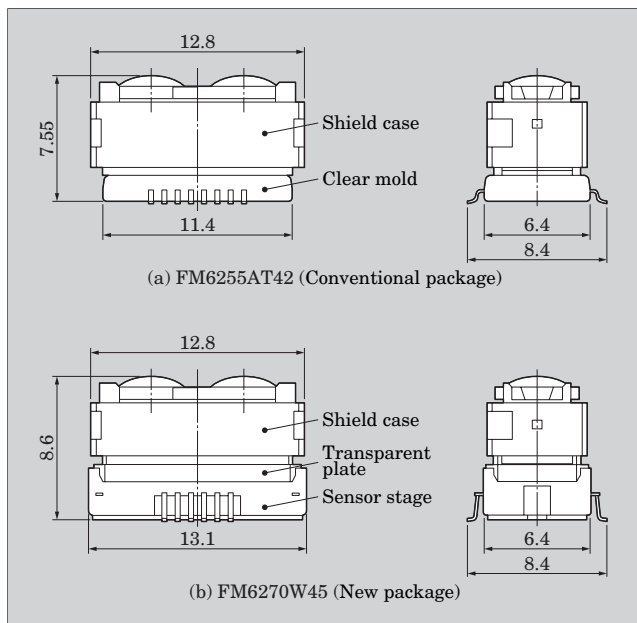


Fig.5 Comparison of conventional and new AFM package dimensions



FM6255AT42, FM6266W37 and other models is 12 μm . The recently developed FM6270W45 has a sensor pitch of 7 μm , however. As can be seen in Fig. 4, if the sensor pitch is reduced and the focal length f of the lens is reduced in the same proportion, the identical range resolution can be achieved without having to change the ratio of the subject image size with respect to the sensor pitch. Accordingly, in approximately the same size package as the FM6255AT42, the FM6270W45 can achieve range resolution sufficient for an AFM for 3 \times and higher zoom cameras.

5. Features of the New Module Structure

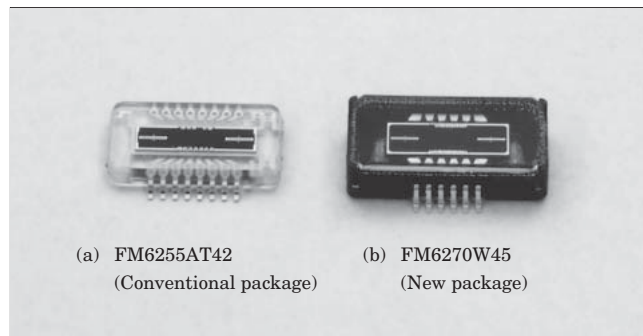
5.1 A new package

Figure 5 shows a comparison between the external dimensions of the FM6255AT42 AFM, which has a conventional package structure, and the FM6270W45, which has a new package structure.

In the construction of the conventional package of the FM6255AT42, an AFIC unit (clear mold package) is initially formed by sealing an AFIC chip, which has been die bonded and wire bonded onto a lead frame, with a transparent epoxy resin. Lens-mounted shield cases are positioned and affixed one at a time onto the AFIC units to complete the AFMs.

With the new package structure of the FM6270W45, however, instead of the conventional clear mold, an AFIC chip is die bonded and wire bonded to a sensor stage made of resin and formed by insert injection molding with a lead terminal. After a transparent plate is bonded to the sensor stage, a transparent encapsulant is injected between the trans-

Fig.6 Comparison of conventional and new AFM packages



parent plate and the AFIC. This encapsulant is then cured to produce the AFIC unit. Then in the same manner as conventional processing, lens-mounted shield cases are individually positioned and affixed one at a time onto the AFIC units to complete the AFMs.

5.2 Improved sensor characteristics

The new package structure also has led to improved sensor characteristics. In the conventional molded IC package, the stress applied to a transparent epoxy resin covered AFIC chip varied according to the temperature and humidity, and this had a subtle effect on sensor characteristics. The effect was negligible when the sensor pitch was large, but became increasingly problematic as the sensor pitch was made narrower.

Because the encapsulant used for the FM6270W45 is not required to provide structural support, a soft material can be utilized and since almost no stress is applied to the AFIC chip, the device characteristics will not fluctuate.

5.3 Improved light shielding

When installing an AFM into a camera, it had previously been necessary to use black tape or to form a structural partition inside the camera in order to shield the transparent clear mold completely. As shown in Fig. 6, in the FM6270W45, the area corresponding to that of the conventional clear mold is formed almost entirely with black resin. In an AFM, this chip only requires minimal shielding at the periphery of the transparent plate where the shield case connects to the new package, and therefore the module requires fewer production processes and less space for installation.

6. Conclusion

An overview of the 7 μm sensor pitch, high-resolution compact AFM has been presented.

Fuji Electric will continue to develop higher performance, lower cost AFMs, and will strive to develop highly original products to meet customer needs.

Low On-resistance Trench Lateral Power MOSFET Using 0.6 μm Smart Power Technology

Mutsumi Sawada
Masanobu Iwaya
Naoto Fujishima

1. Introduction

In response to the requests of recent years for electronic devices that are smaller, lighter, thinner and consume less power, Fuji Electric has concentrated on the field of power supply ICs and has been developing smart power technology. To increase the packing density and reduce on-resistance of the switching devices integrated into a power IC, Fuji Electric has been producing and has verified the effectiveness of a lateral power MOSFET in which a trench is formed. This device is known as a TLPM (trench lateral power metal oxide semiconductor field effect transistor).⁽¹⁾⁻⁽⁴⁾

Fuji Electric has developed a technology for integrating TLPM structures, which have a breakdown voltage of 30 V as required for power ICs used applications such as power management systems and DC-DC converters, into Fuji Electric's existing 0.6 μm rule Bi-C/DMOS (bipolar-complementary/double diffused MOSFET) process technology. This article presents an overview of the newly developed integration technology.

2. Device Structure and Features

2.1 Conventional technology

As can be seen in Fig. 1, a planar LDMOS (lateral double diffused MOSFET) power device has an extended n drain region formed on the surface of the Si substrate. This extended n drain region is necessary in order to achieve a high breakdown voltage, but there is a limit to the level of integration and lowering of on-resistance that may be realized.

2.2 TLPM

Figure 2 shows a cross section of CMOS (complementary MOSFET) and TLPM structures integrated into a single chip.

As shown in Fig. 2, the TLPM structure is formed with a source region at the surface of the substrate, a drain region at the bottom of the trench and a channel region along the sidewall of the trench. To provide a 30 V breakdown voltage, an n drain region is formed, extending from the bottom of the trench to the trench

Fig.1 Cross-sectional view of planer LDMOS

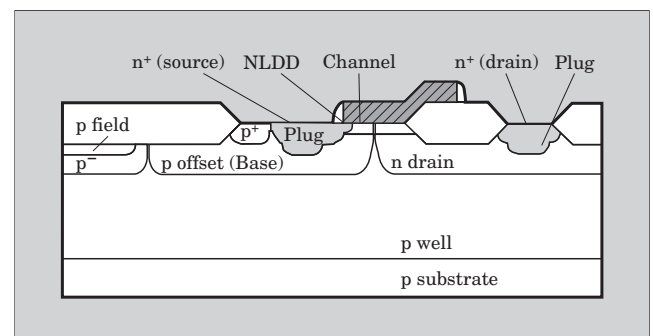
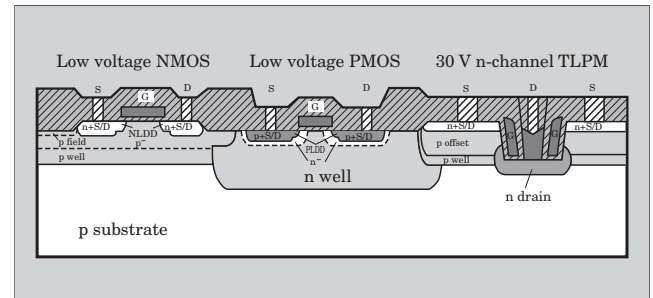


Fig.2 Cross-sectional view of TLPM embedded with 0.6 μm low voltage CMOS

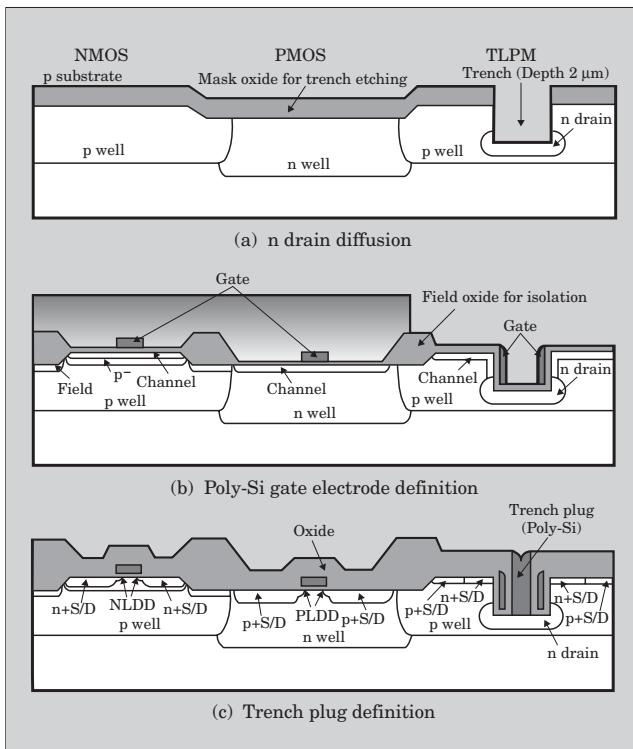


sidewalls. By partially forming the channel and drain vertically as described above, the device pitch has been reduced by 50 % compared to conventional technology and the specific on-resistance has been drastically improved.

3. Process Integration

The process flow is described below. First, a 2 μm trench is formed in a p well that had been fabricated at the same time as the CMOS portion. Using the same mask oxide as is used for trench etching, an n drain region is formed at the bottom of the trench [See Fig. 3(a)]. Next, a p- region is formed, and then a field oxide layer to isolate the devices is fabricated by thermal oxidation. Subsequently, the channel is implanted with ions to adjust the threshold voltage, a relatively thick gate oxide layer is formed on the TLPM

Fig.3 Process flow



portion, a thinner gate oxide layer is formed on the low voltage CMOS portion, and poly-Si, which will become the gate electrode, is deposited. The trench sidewall gate electrode of the TLPM is formed with a self-aligned fabrication method in which the poly-Si is anisotropically etched so that the gate electrode projects outward from the trench oxide layer at a distance which is the same as the thickness of the poly-Si film [See Fig. 3(b)]. After the CMOS and TLPM source/drain regions are fabricated in the same process, an inter-layer dielectric is deposited and a contact hole is formed at the bottom of the trench. Poly-Si is deposited to completely fill the trench and then an overall etch-back process is performed to fabricate the trench plug [See Fig. 3(c)]. Lastly, inter-metal dielectrics are deposited, a contact hole is formed in the silicon substrate surface, and metallization and passivation processes are performed.

Three photolithographic processes for fabricating the trench, gate electrode, and trench bottom contact have been added to the conventional Bi-C/DMOS process.

4. Simulation Results

Two-dimensional process and device simulation techniques have been utilized to optimize the process integration conditions and device structure. Fig. 4(a) shows the off-state potential distribution. The depletion layer extends from the n drain junction to the edge of the n+ drain region at the bottom of the trench, and a blocking capability of 30 V is maintained by the

Fig.4 Simulation results

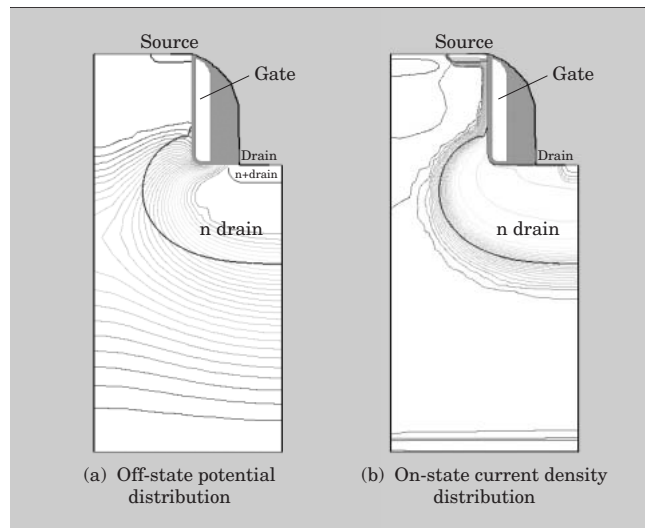
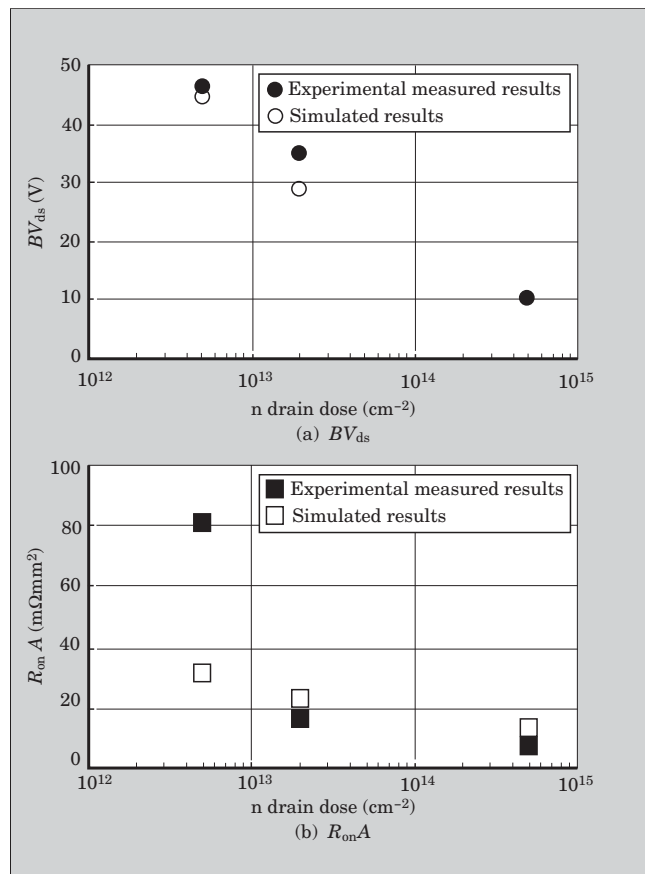


Fig.5 Breakdown voltage and specific on-resistance of TLPM as function of n drain dose



reduced electric field. Here the breakdown point is located at the edge of the gate on the drain-side at the bottom of the trench. Fig. 4(b) shows the current distribution at on-state. The drain current flows vertically along the trench sidewall.

Figure 5 shows both breakdown voltage (BV_{ds}) and specific on-resistance ($R_{on}A$) as a function of the n drain dose. There is a tradeoff relation between BV_{ds} and

Fig.6 SEM micrograph of fabricated TLPM

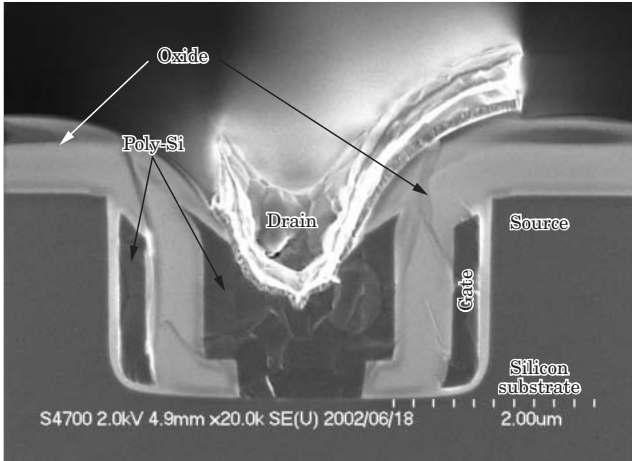
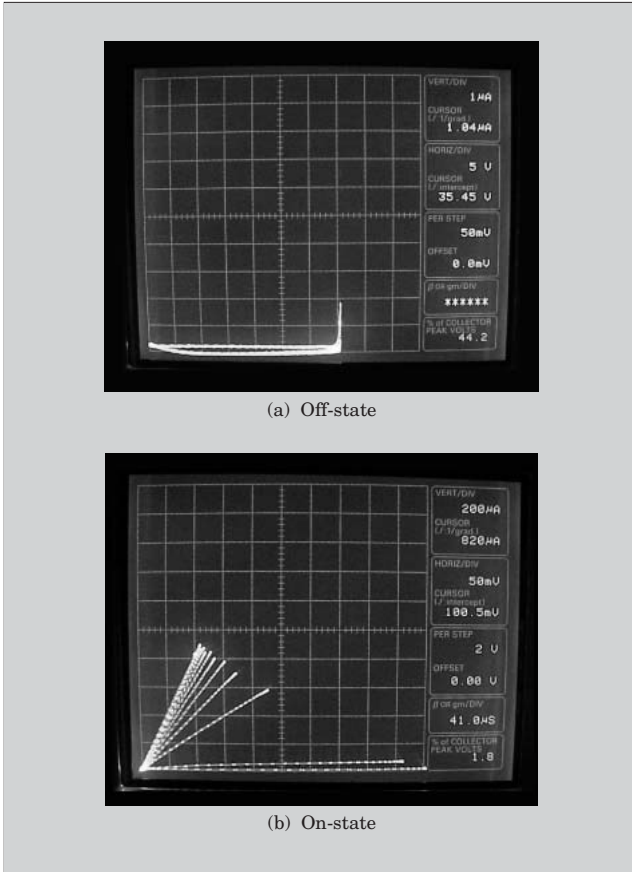


Fig.7 Electrical characteristics of TLPM



$R_{on}A$, and optimum values of $BV_{ds} = 30$ V and $R_{on}A = 23$ m Ω mm² were obtained when the n drain dose was 2×10^{13} cm⁻².

5. Experimental Results

Figure 6 shows a cross-sectional SEM (scanning electron microscope) micrograph of the TLPM portion of a device fabricated with integrated CMOS technology.

Figure 7 shows the electrical characteristics of the

Fig.8 Electrical characteristics of low voltage CMOS

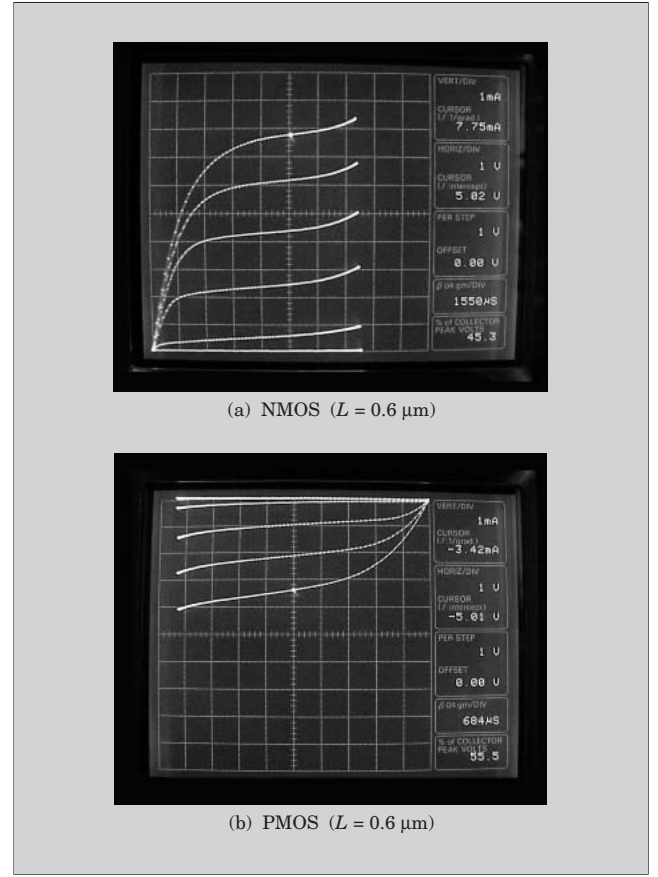
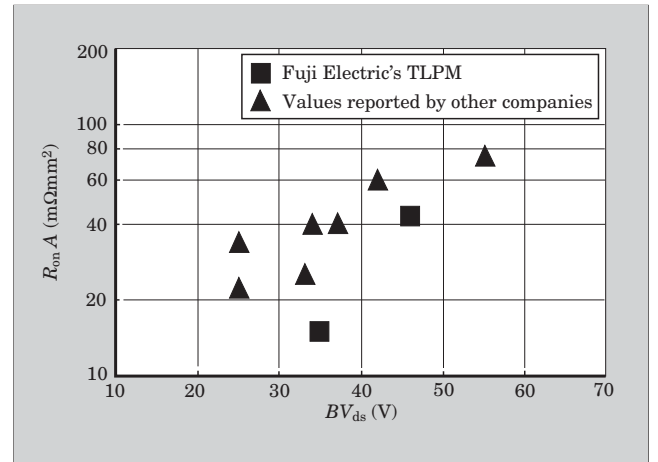


Fig.9 Trend of breakdown voltage and specific on-resistance



TLPM structure. When BV_{ds} is 35 V and $V_{gs} = 18$ V ($E_{ox} = 2.9$ MV/cm, $T_{ox} = 62$ nm), an $R_{on}A$ value of 16 m Ω mm² was obtained. This is the lowest value of $R_{on}A$ for a 30 V class TLPM ever reported thus far in any published paper.

Figure 5 compares the experimentally measured and simulated values of BV_{ds} and $R_{on}A$ as a function of the n drain dose. The simulated results are in good agreement with the measured results. The reason for the lower simulated $R_{on}A$ value when the n drain dose is 5×10^{12} cm⁻² is believed to be due to a discrepancy in

the model for oxidation and diffusion at the corner of the trench bottom in the n drain region.

Figure 8 shows electrical characteristics of the low voltage CMOS. This type of CMOS device will enable the integration of mixed digital-analog control circuits.

6. Conclusion

An overview of the technology for integrating Fuji Electric's existing 0.6 μm rule Bi-C/DMOS process integration technology with low on-resistance trench lateral power MOSFETs has been presented. As can be seen in the trend of breakdown voltage and specific on-resistance depicted in Fig. 9, the Fuji Electric TLPM has the lowest $R_{\text{on}}A$ value for a 30 V class TLPM ever reported thus far in any published paper.

In the future, Fuji Electric plans to incorporate this technology into products, and additionally, intends to develop a p channel TLPM, pursue even higher voltage technology, and to apply this technology to power ICs for power supply units and PDP (plasma display panel) driver ICs.

References

- (1) Fujishima, N.; Salama, C.A.T. A Trench Lateral Power MOSFET Using Self-aligned Trench Bottom Contact Holes. IEDM Technical Digest. 1997, p.359-362.
- (2) Sugi, A. et al. A 30 V Class Extremely Low On-resistance Meshed Trench Lateral Power MOSFET. ISPSD Proceedings. 2002, p.297-300.
- (3) Fujishima, N. et al. A Low On-resistance Trench Lateral Power MOSFET in a 0.6 μm Smart Power Technology for 20-30 V Applications. IEDM Technical Digest. 2002, p.455-458.
- (4) Fujishima, N. et al. US patent application. 2001.
- (5) Parthasarathy, V. et al. A 33 V, 0.25 $\text{m}\Omega\text{-cm}^2$ n-channel LDMOS in a 0.65 μm Smart Power Technology for 20 V-30 V Applications. ISPSD Proceedings. 1998, p.61-64.
- (6) Tsai, C. Y. et al. Optimized 25 V, 0.34 $\text{m}\Omega\text{-cm}^2$ Very-Thin-RESURF (VTR), Drain Extended IGFETs in a Compressed BiCMOS Process. IEDM Technical Digest. 1996, p.469-472.
- (7) Contiero, C. et al. LDMOS Implementation by Large Tilt Implant in 0.6 μm BCD5 Process, Flash Memory Compatible. ISPSD Proceedings. 1996, p.75-78.
- (8) Parthasarathy, V. et al. A 0.35 μm CMOS Based Smart Power Technology for 7 V-50 V Applications. ISPSD Proceedings. 2000, p.317-320.



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
- **FUJI SEMICONDUCTOR, INC.**
USA
Tel : +1-972-733-1700 Fax : +1-972-381-9991
- **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 : +86-411-762-2017 Fax : +86-411-762-2030
- ◆ **SHANDONG LUNENG FUJI ELECTRIC CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-531-726-6228 Fax : +86-531-726-6611

- ◆ **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 : +86-21-5718-5740 Fax : +86-21-5718-1448
- ◆ **SHANGHAI GENERAL FUJI REFRIGERATION EQUIPMENT CO., LTD.**
THE PEOPLE'S REPUBLIC OF CHINA
Tel : +86-21-6921-1060 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 : +852-2313-7900 Fax : +852-2312-0566
- **FUJI ELECTRIC CO., LTD.**
Taipei Representative Office
TAIWAN
Tel : +886-2-2561-1256 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 : +66-2-308-2240, 2241 Fax : +66-2-308-2242
- ◆ **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 : +65-6535-8998 Fax : +65-6532-6866
- ◆ **FUJI/GE PRIVATE LTD.**
SINGAPORE
Tel : +65-6533-0010 Fax : +65-6533-0021

