IC Technology

Creating a Better Tomorrow with Trustworthy Technology
These Power Supply Control ICs for Multiple Solutions to Multiple Requirements

Examples: 2-channel FA3630V, 3-channel FA3629V, 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 (2.5V), and sufficient protective functions against overcurrent, overheat, etc.
- Small outline packages TSSOP-16, SSOP-28, LQFP-48

Realize Energy-Saving Power Management with a Chip.

Example block diagram with FA3676F
The IT (information technology) revolution such as the remarkable spread of the internet is going on. Particularly with an explosive increase of mobile apparatus typically represented by portable telephones, long operation with batteries is more required and a tendency toward low power consumption is rising more severely.

To meet the situation, based on analog CMOS (complementary metal oxide semiconductor) technology, Fuji Electric is widely developing low-power-consumption, high-precision CMOS power supply control ICs (integrated circuits) as power-saving key parts.

The cover photo, comparing power supply control ICs working in electrical home appliances and OA (office automation) devices to leaves supporting the growth of trees, gives the image of an environment-friendly power supply control IC integrating itself into ecological society.

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Present Status and Prospects for Fuji Electric’s IC Technology and Products

1. Introduction

Fuji Electric is developing products based on its characteristic technologies and focusing on the power supply control IC (integrated circuit). The integration of power, intelligence and analog technology is a goal of this IC. Special features include high-voltage complementary/double diffused metal oxide semiconductor (C/DMOS) technology and an insulated gate bipolar transistor (IGBT) integration process which relate to power; high performance digital control and sensor-integrated ICs which relate to intelligence; and high-precision reference voltage (±0.5%), high-frequency pulse-width modulation (PWM) control and low-power consumption technology which relate to analog functionality (See Fig. 1).

Applications for power supply control ICs range from AC-DC power supplies such as AC adapters to the DC-DC power supplies for recent popular portable equipment, personal computers and peripheral devices. In addition, Fuji Electric extends flat panel display driver ICs (for plasma and small-sized liquid crystal displays) utilizing high-voltage technology and autofocus ICs for cameras and pressure sensors for automobiles in products.

Semiconductor technology is rapidly advancing. The high integration and high performance of system ICs using sub-micron process and digital ultra large-scale integrated circuits (ULSI) are remarkable. On the other hand, analog technology is becoming increasingly important for power management, chiefly for power supplies that are critical to the system.

Under these circumstances, Fuji Electric plans to initiate improvements in size, power consumption and performance utilizing analog technology based on CMOS process and device technologies, to concentrate on strengthening and expanding power supply control ICs, and to supply unique ICs that satisfy customer needs.

2. Present Status of Fuji Electric’s ICs

2.1 IC process and device technologies

Fuji Electric’s process and device technologies have the advantage of high voltage, low power consumption, and high-precision analog/digital mixed technology. CMOS and C/DMOS processes which withstand voltages of 30 to 60 V are the mainstream, and design rules as low as 0.6μm are prepared.

The typical processes are listed in Fig. 2. Power supply ICs mainly use 30V-class C/DMOS with a 1μm rule, and higher precision, higher performance products can be designed using trimming technology and high-precision processing. The bipolar IC process, formerly in widespread use, is rapidly being replaced with the CMOS IC process that is more effective in conserving power. Regarding high voltage technology,
a 700V C/DMOS process based on a 1µm rule is under development, and high quality, single-chip power ICs which can be recommended with confidence, will soon be manufactured. Fuji Electric has also realized a C/DMOS device process for display drivers that can incorporate an IGBT output section using a 250V silicon-on-insulator (SOI) substrate, thereby reducing size and increasing output.

2.2 Analog IC design technology

Power supply control ICs differ from digital ICs in that their design mainly consists of analog technology and design automation is difficult. This is because when creating the IC layout pattern design from a circuit diagram, subtle differences in layout pattern routing often influence IC characteristics, and under the present conditions, manual design based on an engineer’s experience is still commonly used. However, design support using computer-aided design (CAD) technology is indispensable to shorten the design period and obtain consistent design quality. Fuji Electric utilizes cell-base design with CMOS analog macro cells, and vigorously promotes analog automatic placement and routing design technology using back-annotation techniques.

2.3 IC packages

Figure 3 shows examples of the products. Common plastic packages for power supply control ICs are provided in a dual in-line package (DIP), and additionally in thin shrink SOP (TSSOP), chip size package (CSP), and quad flat non-lead (QFN) packages that satisfy recent needs for surface-mounting, fine pitch, and low profile arrangements. This variety of packaging satisfies customer requirements. The clear molding package applied to auto-focus ICs has characteristics suitable for photosensors and is highly rated by customers as a unique and original Fuji Electric technology. Further, a series of module assembly products with bare chips installed on a flexible substrate (chip on film: COF) to reduce size and price has been developed.

3. Current Status of Power Supply Control ICs

Table 1 lists the model names, main features and functions of Fuji Electric general-purpose power supply control ICs. Because the conservation of resources and energy is required for ecological reasons, power supply control CMOS ICs capable of low standby power consumption are attracting attention, instead of the conventional bipolar ICs. Fuji Electric played a leading role in the promotion of CMOS applications and has prepared a series of products.

Fuji Electric developed a PWM control IC for AC-DC converter use that lowers the operating frequency during a light load to reduce switching loss and conserve power. This IC has an 8-pin construction and incorporates various protective functions for overload, low-voltage, etc. This technology greatly contributes to the realization of high-efficiency, energy conserving power supplies that only consume low input power during standby or no load conditions.

For DC-DC converter use, Fuji Electric developed the optimal control IC for portable apparatus power supplies. For on-board use, a multi-channel (6-channel) synchronous-rectification DC-DC converter control IC was developed. This has 2 channels of synchronous rectification with the advantages of independent on/off and soft-start functions for each channel, and built-in output short-circuit protection of the timer latch type. The operating frequency of up to 1 MHz is effective in reducing size of the power supply. Further, to satisfy sophisticated power management requirements, Fuji Electric integrates digital control circuits and peripheral functions into the power supply control IC. A typical example is the power supply control IC for cellular phones. Other developments in power supply control technology include DC-DC converter technology that realizes high frequency switching at 3 MHz and above. For details, please refer to other articles in this special issue.

The above mentioned power supply control ICs are applied to diverse fields as shown in Table 2, and contribute to reducing the size and power consumption in each field.

4. Current Status of High-Voltage ICs and Sensor ICs

In addition to power supply control ICs, Fuji Electric is also developing characteristic products that relate to high-voltage technology and sensor-integrated ICs. An example is the plasma display driver IC. The scanning driver uses a 250V SOI process and the addressing driver uses a 150 to 85V C/DMOS process. The mounting method is modularized by installing bare chips on a flexible film.

An example of sensor-integrated IC is the auto-focus IC for camera use, which is characterized by the integration of photosensors. There are two series of these ICs, a digital type that calculates distance data and an analog type that outputs photosensor signals. The digital or analog type is selected according to
camera construction and performance. Fuji Electric also supplies autofocus modules that integrate an optical system and an IC; these have a long history of good results as a typical passive sensor with the advantages of small size and easy adjustment.

An example of a piezo-sensor application is the

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Model name</th>
<th>(D_{\text{max}}) (%)</th>
<th>Application circuit</th>
<th>MOS drive</th>
<th>Operating mode</th>
<th>Protective circuit</th>
<th>External form</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOS IC</td>
<td>FA13842</td>
<td>96</td>
<td>Flyback</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>8-pin</td>
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<tr>
<td></td>
<td>FA13844</td>
<td>48</td>
<td>Flyback</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>8-pin</td>
</tr>
<tr>
<td></td>
<td>FA3641/47</td>
<td>70</td>
<td>Flyback</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>8-pin</td>
</tr>
<tr>
<td></td>
<td>(FA5510/11 14/15)</td>
<td>46/70</td>
<td>Flyback</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>8-pin</td>
</tr>
<tr>
<td></td>
<td>(FA5501)</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>8-pin</td>
</tr>
<tr>
<td>Bipolar IC</td>
<td>FA5301B</td>
<td>100</td>
<td>Flyback</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>16-pin</td>
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<td>FA5304A</td>
<td>46</td>
<td>Flyback</td>
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<td>8-pin</td>
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<td>FA5305A</td>
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<td>FA5311B</td>
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<td></td>
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<td>FA5332</td>
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(b) DC-DC converters

<table>
<thead>
<tr>
<th>Item</th>
<th>Model name</th>
<th>No. of channels</th>
<th>(D_{\text{max}}) (%)</th>
<th>Voltage range 2.5 to 18V 2.5 to 5.5V 10 to 25V</th>
<th>Application circuit</th>
<th>Step-down</th>
<th>Step-up</th>
<th>Inverter</th>
<th>MOS drive</th>
<th>External form</th>
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<td></td>
<td>FA3676F</td>
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<td>Optional setting</td>
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<td>○</td>
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<td>○</td>
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<td></td>
<td>FA3630V</td>
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<td>○</td>
<td>8-pin</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(FA3686V)</td>
<td>2</td>
<td>85</td>
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<td>○</td>
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<td>(FA3687V)</td>
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<td>Optional setting</td>
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<td>16-pin</td>
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<td>(FA7700)</td>
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<td>90</td>
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<td>(FA7701)</td>
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<td>100</td>
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<td>○</td>
<td>○</td>
<td>8-pin</td>
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<td>Bipolar IC</td>
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<td>64</td>
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<td>○</td>
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<td>8-pin</td>
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<td>Optional setting</td>
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<td>67</td>
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<td></td>
<td>FA7630C</td>
<td>2</td>
<td>Optional setting</td>
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<td>20-pin</td>
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<td>3</td>
<td>Channel1=87 2.5 to 5.8V</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>16-pin</td>
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<td>Channel2=87</td>
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<td>Channel3=86</td>
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<td>FA3635P</td>
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<td>FA3685P</td>
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<td>Optional setting</td>
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<td>8-pin</td>
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Note: Model names enclosed in parenthesis are under development.
Table 2 Applications of power supply control ICs

<table>
<thead>
<tr>
<th>Group</th>
<th>Item</th>
<th>Model name</th>
<th>Application products</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-DC</td>
<td>FA5301</td>
<td>CRT monitors, etc.</td>
<td></td>
</tr>
<tr>
<td>converters</td>
<td>FA5304A/05A/06A</td>
<td>FA531X series</td>
<td>AC adapters, printers, CRT monitors, faxmiles, word processors, servers, general-purpose inverters, stationary VCRs, general-purpose power supplies, chargers, etc.</td>
</tr>
<tr>
<td></td>
<td>FA1384X series</td>
<td>FA1384X</td>
<td>AC adapters, printers, air-conditioners, CRT monitors, etc.</td>
</tr>
<tr>
<td>DC-DC</td>
<td>FA5332</td>
<td>FA5332</td>
<td>CRT monitors, general-purpose power supplies, air-conditioners, refrigerators, workstations, plasma display panels, projectors, monitor cameras, AC adapters, etc.</td>
</tr>
<tr>
<td>converters</td>
<td>FA5347/41</td>
<td>FA3647/41</td>
<td>Printers, faxmiles, AC adapters, plain paper copiers, game machines, etc.</td>
</tr>
<tr>
<td></td>
<td>FA76XX series</td>
<td>FA6755/76</td>
<td>VCR cameras, digital cameras, etc.</td>
</tr>
<tr>
<td></td>
<td>FA6692/93</td>
<td>FA3629/30</td>
<td>LCD panels, digital cameras, etc.</td>
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<tr>
<td></td>
<td>FA3635/85</td>
<td>FA3629/30</td>
<td>Printers</td>
</tr>
</tbody>
</table>

5. Future Prospects

Fuji Electric will focus its efforts on power management for portable apparatus in connection with information technology (IT), which is expected to develop more and more in the future, and to develop unique products to satisfy market needs by adding power and intelligence to the core technologies of high-voltage and analog CMOS.

6. Conclusion

Emphasizing the power supply control IC, the present status and future prospects for Fuji Electric’s ICs have been outlined. To survive as a future supplier of characteristic products that satisfy customer needs in advance, Fuji Electric will build-up its core technologies and supply high-quality products.

References
1. Introduction

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

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

<table>
<thead>
<tr>
<th>Model Process (pins)</th>
<th>Operating voltage Standard supply current</th>
<th>Maximum switching frequency</th>
<th>Maximum duty cycle</th>
<th>Peak output current</th>
<th>Error amplifier</th>
<th>Reference voltage</th>
<th>Function</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA5304AP/AS Bipolar (8-pin)</td>
<td>10 to 30 V 9 mA</td>
<td>600 kHz 46%</td>
<td>±1.5 A</td>
<td>—</td>
<td>2.0 V ±5%</td>
<td>Overload/overvoltage/overcurrent (positive voltage sensing)</td>
<td>General-purpose power supply</td>
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</tr>
<tr>
<td>FA5305AP/AS Bipolar (8-pin)</td>
<td>10 to 30 V 9 mA</td>
<td>600 kHz 46%</td>
<td>±1.5 A</td>
<td>—</td>
<td>2.0 V ±5%</td>
<td>Overload/overvoltage/overcurrent (negative voltage sensing)</td>
<td>General-purpose power supply</td>
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<td>FA5310BP/BS Bipolar (8-pin)</td>
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<td>600 kHz 46%</td>
<td>±1.5 A</td>
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<td>—</td>
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<td>General-purpose power supply Forward converter</td>
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<td>FA5311BP/BS Bipolar (8-pin)</td>
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<td>600 kHz 46%</td>
<td>±1.5 A</td>
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<td>Overload/overvoltage/overcurrent (positive voltage sensing)</td>
<td>General-purpose power supply Flyback converter</td>
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<td>FA5314P/S Bipolar (8-pin)</td>
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<td>±1.5 A</td>
<td>—</td>
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<td>Overload/overvoltage/overcurrent (negative voltage sensing)</td>
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<td>±1.5 A</td>
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<td>—</td>
<td>Overload/overvoltage/overcurrent (negative voltage sensing)</td>
<td>General-purpose power supply Flyback converter</td>
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</tr>
<tr>
<td>FA5316P/S Bipolar (8-pin)</td>
<td>10 to 30 V 9 mA</td>
<td>600 kHz 46%</td>
<td>±1.0 A</td>
<td>—</td>
<td>—</td>
<td>Overload/overvoltage/overcurrent (positive voltage sensing)</td>
<td>General-purpose power supply Forward converter</td>
<td></td>
</tr>
<tr>
<td>FA5317P/S Bipolar (8-pin)</td>
<td>10 to 30 V 9 mA</td>
<td>600 kHz 46%</td>
<td>±1.0 A</td>
<td>—</td>
<td>—</td>
<td>Overload/overvoltage/overcurrent (positive voltage sensing)</td>
<td>General-purpose power supply Flyback converter</td>
<td></td>
</tr>
<tr>
<td>FA5323BP/M Bipolar (16-pin)</td>
<td>10 to 28 V 10 mA</td>
<td>150 kHz 92%</td>
<td>±1.5 A</td>
<td>1.55 V ±2%</td>
<td>5V ±4%</td>
<td>External synchronization/overvoltage/overcurrent</td>
<td>Power factor controller</td>
<td></td>
</tr>
<tr>
<td>FA13842P/N CMOS (8-pin)</td>
<td>10 to 28 V 3 mA</td>
<td>500 kHz 96%</td>
<td>−0.4 A +1.0 A</td>
<td>2.5 V ±4%</td>
<td>5V ±5%</td>
<td>Current mode</td>
<td>General-purpose power supply Flyback converter</td>
<td></td>
</tr>
<tr>
<td>FA13844P/N CMOS (8-pin)</td>
<td>10 to 28 V 3 mA</td>
<td>500 kHz 48%</td>
<td>−0.4 A +1.0 A</td>
<td>2.5 V ±4%</td>
<td>5V ±5%</td>
<td>Current mode</td>
<td>General-purpose power supply Forward converter</td>
<td></td>
</tr>
</tbody>
</table>
CMOS (complementary MOS) is being promoted.

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

2. Product Summary

2.1 Features

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

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

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

Figure 1 shows the external view.

The main features of the ICs are as follows.

1. Low supply current is realized by adopting a high-voltage CMOS process.
2. Latch-cutoff state: $50\mu A$, during operation: $1.9mA$ (no load)
3. Light loads are automatically evaluated with the FB terminal voltage (switching duty cycle). During light load operation, the frequency is decreased, thereby improving the switching loss.
4. The oscillator frequency is decreased when the FB terminal voltage is $1.18V$ or less (10% or less of the output duty). To prevent the generation of noise at changeover, the frequency is continuously changed corresponding to the FB terminal voltage. Further, the rate of reduction of the oscillation frequency corresponding to the FB terminal voltage can be changed with an external resistor.
5. A built-in circuit prevents low-voltage malfunction of the VCC terminal that has hysteresis characteristics (UVLO: under voltage lock-out).
6. The IS terminal has an overcurrent limiting function, and positive voltage sensing and negative voltage sensing products are arranged in a product series.
   - $235mV$
   - $16.5V$ ON/9V OFF
7. Various protection functions such as overcurrent, overload, overvoltage of the VCC terminal, latch-cutoff and soft-start are built-in.

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

2.2 Circuit configuration and devices

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

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

2.2.1 Devices

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

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

2.2.2 Oscillator

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

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

Table 2  FA3641/3647 main characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>10 to 30V</td>
</tr>
<tr>
<td>Peak output current Source current</td>
<td>–0.5A</td>
</tr>
<tr>
<td>Oscillation frequency</td>
<td>30 to 500kHz</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>–30 to 85°C</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>125°C</td>
</tr>
<tr>
<td>IS terminal current limiting voltage</td>
<td>235mV (FA3641)</td>
</tr>
<tr>
<td>FB terminal overload voltage</td>
<td>3.0V (standard)</td>
</tr>
<tr>
<td>VCC terminal UVLO circuit voltage</td>
<td>16.5V/9.0V</td>
</tr>
<tr>
<td>VCC terminal overvoltage protection threshold voltage</td>
<td>32V±2V</td>
</tr>
<tr>
<td>CS terminal latch-cutoff voltage</td>
<td>8.5/7.9V</td>
</tr>
<tr>
<td>CS terminal ON/OFF voltage</td>
<td>0.82V/0.68V</td>
</tr>
<tr>
<td>FB variable frequency start voltage</td>
<td>1.18V (standard)</td>
</tr>
<tr>
<td>Maximum duty cycle</td>
<td>70%±4%</td>
</tr>
<tr>
<td>Output rising time (C_L = 1,000pF)</td>
<td>50ns (standard)</td>
</tr>
<tr>
<td>Output falling time (C_L = 1,000pF)</td>
<td>40ns (standard)</td>
</tr>
</tbody>
</table>

(b) Electrical characteristics (main characteristics)

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Startup current</td>
<td>12μA (standard)</td>
</tr>
<tr>
<td>Standby current (VCC terminal =14V)</td>
<td>2μA (maximum)</td>
</tr>
<tr>
<td>Operating state supply current</td>
<td>1.9mA (standard)</td>
</tr>
<tr>
<td>Latch-cutoff state</td>
<td>100μA (maximum)</td>
</tr>
<tr>
<td>Reference voltage</td>
<td>5V±5%</td>
</tr>
<tr>
<td>FB terminal overload voltage</td>
<td>3.0V (standard)</td>
</tr>
<tr>
<td>VCC terminal UVLO circuit voltage</td>
<td>16.5V/9.0V</td>
</tr>
<tr>
<td>VCC terminal overvoltage protection threshold voltage</td>
<td>32V±2V</td>
</tr>
<tr>
<td>CS terminal latch-cutoff voltage</td>
<td>8.5/7.9V</td>
</tr>
<tr>
<td>CS terminal ON/OFF voltage</td>
<td>0.82V/0.68V</td>
</tr>
<tr>
<td>FB variable frequency start voltage</td>
<td>1.18V (standard)</td>
</tr>
<tr>
<td>Maximum duty cycle</td>
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</tr>
<tr>
<td>Output rising time (C_L = 1,000pF)</td>
<td>50ns (standard)</td>
</tr>
<tr>
<td>Output falling time (C_L = 1,000pF)</td>
<td>40ns (standard)</td>
</tr>
</tbody>
</table>

Fig.3  FA3641 circuit block diagram

Fig.2  Magnified view of chip (FA3647)

Fig.4  Oscillation circuit (OSC)
The variable oscillation frequency unit has two systems of positive input terminals to the RT amplifier, one system inputs 2.5V for normal operation and the other system has a function to effectively select the lower system voltage for light loads (RM). When RM voltage decreases to less than 2.5V, the RT terminal voltage is lowered from 2.5V to RM voltage, consequently the charge and discharge current decreases and the oscillation frequency is reduced.

### 2.2.3 Variable oscillation frequency circuit for light loads

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

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

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

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

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**Fig.5** Variable oscillation frequency circuit for light loads

**Fig.6** Circuit diagram of power supply for evaluation (FA3641)
3. Application as a Power Supply

3.1 Specification of evaluation circuit

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

The main specifications of this power supply were as follows.

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

The circuit diagram is shown in Fig. 6.

3.2 Reducing oscillation frequency function for light loads

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

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

3.3 Improved efficiency during light loads

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

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

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

The input power is reduced by 0.2W at 100V AC and by 0.9W at 230V AC. Over the entire input
voltage range, input power of 0.5W or less is achieved under the condition of no load.

The main factors responsible for reduced loss and improved efficiency under the conditions of light load and no load can be cited as follows.
(1) Reduced IC operating loss by means of a low operating current
(2) Reduced start-up resistor loss by means of a low start-up current
(3) Reduced switching current by means of a function that lowers the oscillation frequency during light loads

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

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

4. Conclusion

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Loss (mW)</th>
<th>Improvement (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC operating loss</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Startup resistor</td>
<td>100</td>
<td>280</td>
</tr>
<tr>
<td>Switching loss</td>
<td>120</td>
<td>600</td>
</tr>
</tbody>
</table>
1. Introduction

In recent years, portable electronic devices have been made smaller, lighter and with higher level functions. With these trends, DC-DC converters, devices which convert battery power supply DC voltages to other types of DC voltages, are increasingly required to operate at higher efficiency and lower power consumption for longer operation from the battery source.

Multi-channel output of different voltages is particularly required for digital cameras and camcorders with their enhanced functions.

Fuji Electric has developed the FA3676F, a control IC for PWM (pulse-width modulation) switching power supplies that is highly efficient and suitable for multi-channel power supplies. This paper presents an overview of that IC, which integrates six channel control circuits into a single chip. Two of the six channels are compatible with a synchronous rectifier system to achieve high-efficiency power supply, and the IC uses a CMOS (complementary MOS) process to realize low supply current.

2. Product Overview

Table 1 (a) and (b) show the absolute maximum ratings and electrical characteristics of the FA3676F respectively.

Main features of the IC are as follows.
(1) 48-pin LQFP (low profile quad flat package)
(2) Six-channel output and compatibility with a synchronous rectifier
  p-channel MOS driving: five channels (two of the channels are compatible with a synchronous rectifier system)
  p-channel/n-channel selectable MOS driving: one channel
(3) Operable over a wide range of power supply voltages: 2.5 to 18V
(4) Low supply current due to CMOS analog technology
  ○ during operation: 4mA (typical value)
  ○ during standby: 12µA (typical value)

3. Internal Circuity

Figure 1 shows a block diagram of FA3676F’s internal circuitry. The circuitry is comprised of components common among the channels such as a control circuit, 1.0V reference voltage circuit, triangular voltage oscillator and UVLO (under voltage lock-out) circuit, and of components specific to each channel such as an error amplifier, PWM comparator, soft-start circuit and output driver circuit.

Table 2 shows channel control specifications. Based on the specifications, an overview of the control is described below.

3.1 Control specifications

All of the six channels are push-pull drive circuits, which permit direct driving of the switching of external MOSFETs (metal-oxide-semiconductor field-effect transistor). On-state resistance is 6Ω for the No. 3
channel and 10Ω for the other channels, permitting a current flow of up to ±0.2A. A bipolar transistor can be used as an external switching device by connecting a current limiting resistor to the output pin of its channel.

The No.6 channel can be selected for driving on external p-/n-channel MOSFET by Hi/Low connection of the PNSEL pin, allowing buck converter or boost converter circuits to be selected depending on the product system.

Each channel is controlled as shown in Table 2 with two ON/OFF control pins and three soft-start control pins. When both two ON/OFF control pins are set at OFF, the IC goes into standby mode, extremely reducing supply current by turning off the internal control power supply.

CS1 and CS3 of the soft-start control pins are for constant current output. CS2 is not for current output, but the charge completion voltage can be set by an external resistor at CS2 to limit the maximum on-duty of an externally driven MOSFET.

3.2 Synchronous rectifier system

A buck converter circuit compatible with a syn-

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Control IC for 6-Channel Switching DC-DC Converters Compatible with Synchronous Rectifiers
Synchronous rectifier system can be constructed in the No. 1 and No. 2 channels.

Figure 2 (a) shows a synchronous rectifier circuit. In the circuit, a reactor current passes through a diode (D) while the p-channel MOSFET (Q11) is in the off state. Power is dissipated as a result of the on-voltage of the diode and the current passing through the diode produce. When the converter output voltage is low and output current large, power dissipation may reduce the power supply efficiency. Therefore, a synchronous rectifier system is adopted as an effective means to improve power supply efficiency. In the system, an n-channel MOSFET (Q12) having lower on-state resistance than the diode is connected in parallel with the diode; while current is flowing to the diode, the MOSFET is made to turn on and current flows through the MOSFET, reducing power dissipation.

In the synchronous rectifier system, p- and n-channel MOSFETs are connected in series between a

Fig. 2 Synchronous rectifier circuit and driver output waveform

(a) Synchronous rectifier circuit

(b) Driver output waveform

Fig. 3 Relationship of dead time to external resistance

Fig. 4 FA3676F Application circuit example
Turning on both MOSFETs at the same time causes a short circuit in the power supply. To avoid this, dead time (where both MOSFETs are off) is provided as shown in Fig. 2 (b). The dead time depends on the switching characteristic of the external MOSFET and the optimal setting value varies according to the application. In the FA3676F, resistors are connected between DT1/DT2 and GND, allowing dead time to be independently set in each channel according to the resistance values.

Figure 3 shows the relationship between set values of dead time and external resistance.

4. Application Circuit Example

Figure 4 shows an example circuit of an FA3676F application. The circuit consists of buck converters in the No. 1 to No. 4 channels, an inverting converter in the No. 5 channel and a boost converter in the No. 6 channel. A synchronous rectifier system is utilized in the No. 1 and No. 2 channels to improve power supply efficiency.

Switching power supplies in six channels are thus integrated into a single IC chip. In addition, the use of a multi-winding transformer instead of reactors in the channels allows the construction of power supplies having more than six channels.

5. Conclusion

This paper has presented an overview of the FA3676F, a control IC compatible with a synchronous rectifier system for a six-channel DC-DC converter.

Based on the FA3676F, Fuji Electric is determined to respond to future market needs and to develop lower-voltage ICs that can be driven from a single cell lithium battery, power ICs with a built-in battery-charge control function and multiple output control ICs compatible with a synchronous rectifier system for more than six channels.
Power Management System IC for Cellular Phones

1. Introduction

Today, cellular phones are achieving increasingly widespread use among consumers because they are easily portable, have smaller sizes and lower prices, and consume less power enabling extended operation time. Various types of LSIs play important roles in reducing the size, cost and power consumption.

The power supply IC used for cellular phones has transitioned from a bipolar IC to a CMOS IC of lower power consumption, and integrates two or more regulator circuits on a single IC chip to achieve smaller size.

The power supply IC is designed to provide necessary and stable power for various electronic devices and to reduce power consumption during standby.

Fuji Electric has developed the FA3678F, a 48-pin package power management system IC for cellular phones, which incorporates eight LDO (low dropout) regulators, a negative voltage regulator for gate bias of a transmission power amplifier, and an operational amplifier. This paper presents an overview of the FA3678F.

2. Features

The FA3678F, a power management system IC developed for cellular phones, incorporates eight 2.8V-output voltage circuits, LDO regulators of up to 90mA, a negative regulator whose output voltage can be set with an external resistor, an operational amplifier for an ALC (automatic level control) circuit, and a reference voltage output circuit.

Each LDO regulator and operational amplifier can be individually turned on and off, as required, to meet the demand for lower power consumption of the cellular phones, thereby conserving the battery power.

Features are summarized below.

- Built-in eight LDO regulators
- Built-in negative regulator circuit
- Built-in reference voltage circuit
- Low power consumption: 1μA (standard value during standby)
- CMOS silicon gate 1μm process

3. Specifications

3.1 LDO regulator

- Ripple rejection rate: -40dB
- Current consumption: 40μA (standard value per circuit)
- Output voltage: 2.80V±60mV

3.2 Negative voltage regulator

- Output current: 4mA
- Ripple rejection rate: -25dB
- Rise time: 5ms (maximum value)
- Charge pump oscillation frequency: 12kHz (standard value)
3.3 Current consumption
- When all signals are made off:
  1µA (standard value)

4. Main Circuit Characteristics

Figure 2 shows a block diagram of the FA3678F.

4.1 LDO regulator

In the FA3678F, the LDO regulator consists of CMOS transistors, which consume a smaller current than bipolar transistors and have a lower dropout voltage, allowing operation with low battery voltage.

The LDO regulator features a high ripple rejection rate of less than -60dB (Fig. 3), low dropout voltage of 100mV (at $I_O = 20mA$) (Figs. 4 and 5), low supply current of 40µA per circuit and stable operation with an output capacitor as low as 1µF.

The LDO regulator rated at 90mA is provided with a built-in overcurrent limiter to prevent overheating or damage when output lines are grounded.

4.2 Negative voltage regulator

The negative voltage regulator can supply an output current of up to 4mA, suitable for use in the gate bias power supply of a GaAs power amplifier.

Oscillation frequencies for a charge pump can be selected by the value of external capacitance (Fig. 6). By simply mounting an external resistor, the regulation function added to a voltage doubler can change and adjust the output voltage of the regulator corresponding to the characteristics of a power amplifier (Fig. 7).
5. Conclusion

This paper has presented an overview of the newly developed FA3678F, a power management system IC for cellular phones.

In keeping with the trend toward increasingly integrated LSIs, Fuji Electric is determined to develop lower-power consuming, smaller-sized and enhanced-function power management system ICs.
IC Technology for High-Frequency Switching DC-DC Converters

Zenchi Hayashi
Yasushi Katayama
Satoshi Sugahara

1. Introduction

For internal power supply devices installed in portable electric equipment such as cellular phones and PDAs, there have been continuous requests for smaller size, lighter weight and higher efficiency.

The output voltage of the lithium-ion secondary battery, the major battery for portable electric equipment, is 3.6V. However, LSI power supply voltages have been trending lower with advances in fine pattern processing and at present, voltages of 2V or lower are widespread. Due to increasing voltage conversion ratios, attention has focused on the conversion efficiency of power supply circuits. The view that switching regulators will play an advantageous role is spreading. However, since the external dimensions of switching regulators are large compared with conventional linear regulators, further miniaturizing and thinner shape are required.

Fuji Electric has been promoting the development of thin type micro-size DC-DC converters with switching systems that are compatible with lithium-ion secondary batteries. Since the IC for driving the converter has been developed, summary of that IC is introduced here.

2. Summary of Developed Products

This IC for DC-DC converters was developed to drive the switching regulators of portable electric equipment, and has a single output. A PWM (pulse width modulation) system is utilized for voltage control and this IC has the following features.

(1) Switching frequency: 1 MHz to 6 MHz
(2) Each of an n-channel and a p-channel DMOS (double diffused MOS) are integrated as switches
(3) Compatible with synchronous rectifying system operation (No external diode required)
(4) Operation input voltage range: 2.5 V to 6.5 V
(5) Compatible with various conversion modes (buck type, boost type)
(6) Various internal protection circuits

Since this IC executes high-frequency switching on the order of MHz, passive components required for configuration of the DC-DC converter circuits can be miniaturized. In addition, since the switching elements are built-in and operation with a synchronous rectifying system is possible, the external mounting of discrete semiconductor components is unnecessary, enabling the whole DC-DC converter circuit to be made smaller and thinner. Rated specifications of this IC are shown in Table 1.

3. Internal Circuits

The circuit configuration is shown in Fig. 1. CMOS (complementary MOS) devices are used in the basic circuits of the control unit, and DMOS devices are used in the switches of the output unit.

The principal circuit blocks are described here.

3.1 Internal MOSFET

One n-channel DMOSFET (hereafter abbreviated as NDMOS) and one p-channel DMOSFET (hereafter abbreviated as PDMOS) are integrated as switches in the output unit. The maximum voltage is 30V and the maximum driving current is 1A. On-resistance of the NDMOS and PDMOS is 0.4Ω and 0.45Ω, respectively.

In general, MOSFETs have a tendency for switching loss to increase with increasing switching frequenc-

<table>
<thead>
<tr>
<th>Item</th>
<th>Rating (standard value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage range</td>
<td>2.5V to 6.5V</td>
</tr>
<tr>
<td>Output current</td>
<td>1.0A</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>–20 to +85°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>–40 to +125°C</td>
</tr>
<tr>
<td>Oscillation frequency</td>
<td>1.0 to 6.0MHz</td>
</tr>
<tr>
<td>Over-current detection current</td>
<td>1.25A</td>
</tr>
<tr>
<td>Overheat protection temperature</td>
<td>125°C</td>
</tr>
<tr>
<td>Low voltage detection voltage</td>
<td>2.5V</td>
</tr>
<tr>
<td>Reference voltage</td>
<td>1.0V, 1.2V</td>
</tr>
<tr>
<td>Supply current (at 3MHz operation)</td>
<td>3.0mA</td>
</tr>
<tr>
<td>Supply current (at shutdown)</td>
<td>20µA</td>
</tr>
</tbody>
</table>

* including driving current of MOSFET driver
Accordingly, in order to reduce the switching loss, Fuji Electric has improved the structure of the NDMOS and PDMOS gate electrode wiring to lower gate resistance. Through this measure, the rise and fall speeds of the drain-to-source voltage and drain current during switching becomes very fast. Consequently, switches could be realized that have low loss and are compatible with switching on the order of MHz. (Fig. 2 shows waveforms at PDMOS turn-off before and after the improvement.)

3.2 MOSFET drive circuits

The MOSFET drive circuit is mainly composed of a MOSFET driver, dead timer and logic circuit. The MOSFET driver has improved the circuit system and optimized the driving capability to enable high-frequency driving of the internal DMOSFET and to suppress the supply current. It is capable of charging and discharging a capacitance of 200pF within 5ns.

The dead timer is a circuit to prevent penetrating current generated by turn-off delay at the alternating on-off change over of PDMOS and NDMOS, when a buck type converter is operated with a synchronous rectifying system. In this IC, the dead time (forced delay time setting of synchronous rectifying switch-on signal relative to main switch-off signal) is optimized to 10ns in order to optimize conversion efficiency.

3.3 Basic control circuits (error amplifier, PWM comparator)

PWM control suited to higher switching frequency is applied in which output voltage is fed back to an error amplifier, that output is converted into a pulse signal by a PWM comparator, and this signal is used as the driving signal for the switches. Bandwidth of the error amplifier is 10MHz or more and output delay time of the PWM comparator is small at 30ns. As a result, both are compatible with control up to 10MHz.

3.4 Triangular wave oscillator

The triangular oscillator is operated by charging and discharging a timing capacitor from an internal current source with the oscillation frequency of the triangular oscillator as the basic frequency. The oscillation frequency can be set from 1MHz to 6MHz by means of a resistor connected to the RT terminals.

3.5 Protection circuits

In addition to the soft-start circuit that prevents inrush current at startup, the maximum duty cycle limitation that prevents the continuous ON operation of switches during boost mode circuit operation and the low voltage detecting circuit that prevents malfunctions by detecting lowering of the supply voltage, there is a short current protection circuit, an over-current protection circuit and an overheat protection circuit that are integrated as protection functions.

4. Examples of Application Circuits

As shown in Fig. 3, configuration of buck type, synchronous buck type and boost type DC-DC converters are possible depending upon the connecting method. Figure 4 shows a picture of an example mounting of a buck type DC-DC converter circuit module. The constituent components are IC, input and output smoothing capacitors (C_i, C_o), SBD (Schottkey barrier...
Fig. 3 Examples of DC-DC converter configuration

(a) Buck type

(b) Synchronous buck type

(c) Boost type

diode), resistor (R₁) and capacitors (C₁, C₂) for IC adjusting, and inductor (L). A reduction in the number of adjustment components required to configure the circuits is planned. In addition, Fuji Electric has developed technology by which the inductor, the largest among the constituent components of the conventional DC-DC converter, can be integrated onto an IC chip with a thin film deposition process. Through these technologies, a 1W output class micro-size DC-DC converter module with external dimensions of 9 by 10 by 1.8mm and output power density of 6.2W/cm³ (external parts are not required) is realized.

5. Conclusion

A summary has been presented of the IC developments for high-frequency switching DC-DC converters aiming at super miniaturization, lighter weight and thinner shapes.

Fuji Electric is endeavoring to contribute to the growth of electric equipment and the information transmission field by responding to the expanding market needs for portable equipment and by assisting in technical innovation based on PWM control technology of high-frequency switching.

References
1. Introduction

Due to the rapid progress of submicron processing technology for integrated circuits (ICs), the level of IC integration has advanced and systems that were formerly constructed on a board using multiple chips can now be mounted onto a single chip. This technology is advancing toward the mixed mounting of analog and digital circuits.

Fuji Electric has offered a wide range of mixed analog-digital IC products such as power supply ICs, ICs for portable telephones, auto-focus ICs, driver ICs for liquid crystal displays, etc. Recently, intelligent power supply ICs have been realized by a technology that mounts a microcomputer in the analog circuitry of a power supply. In this paper, as an example of such an application, a summary is presented of the lithium-ion battery charger IC which contains an analog charging circuit and a microcomputer, enabling highly accurate control of the final battery voltage.

2. Mixed Analog-Digital IC Technology

In a mixed analog-digital IC, there is the problem of noise generated by rapid action in the digital circuitry leaking into the analog circuitry and inducing a malfunction. Necessary measures to avoid this phenomenon are the application of a noise suppressing circuit in the digital circuitry as well as a layout that isolates the analog circuitry from the digital circuitry.

Different processes, bipolar to the analog circuits and MOS to the digital circuits are applied, respectively because of their ease of use in each circuit. For example, to configure a single chip with different processes for the analog and digital circuitry, Bi-CMOS (bipolar complementary MOS) technology in which a bipolar process is applied to the analog circuitry and a MOS process is applied to the digital circuitry can optimize the performance. However, Bi-CMOS technology is expensive due to complicated processing. Fuji Electric has been working with analog CMOS technology for a long time and has commercialized CMOSIC, using a CMOS process for both the analog and digital circuitry, has excellent cost performance characteristics.

3. Example Applications

The developed lithium-ion battery charger IC is composed of digital circuitry (microcomputer, analog-to-digital converter (ADC)) that executes the charging sequence and processing fault, and analog circuitry that controls charge voltage and charge current of the battery. In the following, the digital circuitry, the analog-to-digital converter and the whole charger IC are described successively.

3.1 Digital circuit

The digital circuit specifications are as follows.
1. 8-bit CPU
2. 1k-bytes ROM, 128-bytes RAM
3. 10-bit analog-to-digital converter, three channels

Figure 1 shows a block diagram of the digital circuitry. The digital circuitry reads in battery voltage, charge current and battery temperature through the analog-to-digital converter, and executes each process according to a program programmed in integrated ROM.

3.2 10-bit analog-to-digital converter

3.2.1 Composition

An enlarged picture of the 10-bit analog-to-digital

![Fig.1 Digital circuitry block diagram](image-url)
converted (ADC) is shown in Fig. 2. The analog-to-
digital converter is composed of a 10-bit capacitor
array, a dynamic comparator and a successive approxi-
mation register (SAR).

10-bit capacitor array

The capacitor array, composed of two binary
weighted capacitor arrays and a coupling capacitor
($C_c$), is a charge successive approximation type. In
proportion to the input voltage, the capacitor array
holds separately an accumulated charge according to
the ratio of each capacitor.

In the case of a 10-bit capacitor array constructed
with binary weighted capacitors, the MSB (most
significant bit) is required theoretically to have a value
$2^{10}$ times that of the LSB (least significant bit).
However, since the maximum practical IC capacitance
is several tens of pFs, the LSB side capacitance
becomes so small that it is easily affected by parasitic
capacitance. Consequently, conversion with high accu-
racy is impossible. Therefore, by connecting two sets
of 5-bit binary weighted capacitor arrays to $C_c$, the
total capacitance of the capacitor array is reduced, the
minimum capacitance of the LSB is maintained at a
certain constant value and shrinkage of chip area is
realized.

The switches connected to each capacitor use p-
channel MOSFET and n-channel MOSFET analog
switches.

Dynamic comparator

The dynamic comparator compares the charge held
separately in the capacitor array and the charge
(corresponding to the digital code. The compared
results are stored in the successive approximation
register.

The chopper type comparator that is utilized has a
low input offset voltage so that high accuracy can be
achieved.

Successive approximation register

The successive approximation register is a 10-bit
register that performs successive comparisons. It
converts the compared results to digital code and
controls analog switches that are the charge path to
the capacitor array.

After the conversion is completed, the converted
results are held in the successive approximation
register until the system is reset or conversion is
executed again.

3.2.2 Operation of analog-to-digital converter

As shown in Fig. 3, the charge successive approxi-
mation type of a 10-bit ADC has a function whereby
the capacitor array itself holds the charge in propor-
tion to analog input voltage. This type of converter is
not provided with a dedicated sample-hold circuit.

During the sampling period of analog input voltage
($V_{in}$), all capacitors are connected to $V_{in}$ and due to
switch-on of the comparator unit, input voltage of the
comparator is fixed to half the voltage of the power
supply.

Next, at the start of conversion, the switches
connecting $V_{in}$ to all capacitors and the comparator
unit switches are opened. Then, relative to the
capacitance of each bit, the higher reference voltage
$V_{ref_H}$ and the lower reference voltage $V_{ref_L}$ are succes-
vively switched. Through this arrangement, the com-
mon node voltage potential of the capacitor array
becomes equal to half the input voltage of the compar-
ator.

Figure 4 shows input and output characteristics of
the 10-bit ADC. The conversion range is 0 to 5V ($V_{ref}$, $1,000$

```
Digital output (LSB)
```

```
0 1,000
```

```
0 800
```

```
0 600
```

```
0 400
```

```
0 200
```

```
0 100
```

```
0 0
```

Non-linear error $+1.01$ (LSB) $-0.94$ (LSB)
= 0V, $V_{ref_H} = 5V$) and the input voltage range is also 0 to 5V. Good results with non-linear error of +1.01 LSB and –0.94 LSB are obtained.

3.3 Lithium-Ion battery charger IC

The circuit block diagram of the newly developed charger IC is shown in Fig. 5. The charger IC contains analog circuitry and digital circuitry. The analog circuitry contains a unit to detect the battery’s charging current and the battery voltage, and feedback control so that the charge current and the battery voltage will be consistent with the reference value. The digital circuitry controls the charge sequence.

After the preliminary charging with constant current at the start of charging, the charging with constant current and constant voltage when the battery voltage exceeds a certain constant value is implemented by the analog circuitry. Change over from the preliminary charging with constant current to the charging with constant current and constant voltage, determination of the end of charging, time monitoring at each mode, fault monitoring and handling of the charge voltage and current are processed by the digital circuitry.

Lithium-ion batteries have the special feature of high energy density, but for safety reasons, must be handled carefully when charging and discharging. The charging voltage requires voltage control with high accuracy within $4.2V \pm 30mV$. By mounting a reference voltage with 0.5% accuracy, the charging voltage can be controlled with an accuracy of within 0.7%.

The charging characteristic and an enlarged picture of the analog circuitry in the charger IC are shown in Fig. 6 and Fig. 7, respectively. In the circuit design, CMOS analog macro cell developed by Fuji Electric are used to shorten the development time.

4. Conclusion

Example applications of mixed analog-digital technology to power supply ICs have been introduced.

In response to the demands for intelligent power supply ICs, Fuji Electric is striving to further develop digital circuits with advanced functions and analog circuit technology with higher accuracy.

Reference:

IC Packages for Power Supply Systems

1. Introduction

In recent years, accompanying the high density board assembly technology that enables the realization of smaller, lighter and higher performance electric products, development has continued for packaging technology, including IC assembly technology.

As such, an overview of Fuji Electric’s IC package technology and IC packages for power supply systems will be presented below.

2. Overview of Fuji Electric’s IC Package Technology

In 1981, Fuji Electric brought to market a DIP (dual in-line package), and thereafter has been providing fine pitch and low profile compatible SOP (small out-line package), QFP (quad flat package), SSOP (shrink small out-line package) and TSSOP (thin shrink small out-line package) packages. Additionally, Fuji Electric is planning a product line of their SON (small out-line non-lead) and QFN (quad flat non-lead) products, and in response to customer requests, can also provide BGA (ball grid alley) and LGA (land grid alley) packages. Figure 1 shows the QFN48 pin package.

Furthermore, Fuji Electric independently developed a clear resin mold package for autofocus ICs and has been providing this package as a finished product since 1988. At present, there is widespread utilization of autofocus modules. In these modules, an optical lens system is precisely positioned and attached onto the clear resin mold package. Figure 2 shows the clear resin package and the AFM (autofocus module) product.

In addition to COB (chip on board) assembly technology with which the driver module is made into a finished product, Fuji Electric also possesses gold bump and solder bump processes, and can comply with CCB (controlled collapse bonding), COF (chip on film) and COG (chip on glass) assembly.

3. IC Packages for Power Supply Systems

Fuji Electric’s power supply IC products can be roughly classified as either small-scale package products of 1 to 3 channels or middle-scale package products of 4 or more channels. At present, all packages being mass-produced for power supply ICs are plastic mold packages.

Small-scale packages are provided as DIP, SOP, SSOP and TSSOP, depending upon the application. Packages are available for proper types of small pin packages, from 6 pins to 20 pins. Middle-scale packages correspond to the package size, lead pitch and lead shape requested by the customer, and at present, mass production mainly centers on the vari-
ous types of QFPs. Product lines are being planned for QFN and LGA packages. Table 1 summarizes Fuji Electric’s main IC packages for power supply systems.

Recently, various packaging technologies have emerged which enable the formation of packages near the chip size, known as CSP (chip size package). Also, customer demands are increasing for CSPs for use in mobile products. However, conflicting issues must be resolved such as the generation of heat that occurs as chips for power supply ICs are made more highly integrated, with higher efficiency and higher speed. Fuji Electric is carefully examining the following topics by considering which form of CSP can be utilized for power supply IC packages and whether there exists other assembly technology.

(1) Realization of low impedance packages for low impedance products

(2) Resolution of thermal problems caused by packaging and the assembly method

(3) Cost merits for small scale power supply IC products

There are many problems in addition to the development of the package itself. In the newly developed packages where the assembly area is small and pitch is fine, development tools are often not commercially available as general components, and the IC socket that connects the electric terminal in the package and electric cell characteristic test system is especially problematic. Based on these conditions, at the development stage of a new package, a socket for measuring the electrical characteristics of the product and a measuring method are concurrently developed, and package engineers, test engineers and design engineers unite to realize stable product specifications.

4. Compliance With Pb-Free IC Packages for Power Supply Systems

There are basically the following two themes involved in making IC packages Pb-free.

(1) Realizing high temperature performance of the package with raising the melting point of the Pb-free solder paste

(2) Making the package Pb-free by utilizing Pb-free electronics finishing

At present, it has been verified that high temperature performance is realized for Fuji Electric’s mass-produced power supply ICs under the assembly conditions of reflow 260°C peak/255°C for 10 seconds. Since their development stage, packages being prepared for mass production have been designed to realize high temperature performance characteristics.

Ti/Pd/Au, Sn-Ag, Sn-Bi and Sn-Cu plating materials are being considered for electronics finishing, and are being diligently promoted so that the mass production and supply of finished products will be Pb-free as of April 2001.

5. Conclusion

As discussed above, until now Fuji Electric’s power supply ICs were supplied mainly as standard packages. However, with the future growth of mobile products and emergence of new electronic devices, various packages and assembly formats will also have to be supplied to the power supply IC field.

So as to be able to respond quickly to these types of market conditions and customer demands, Fuji Electric is committed to promote the development of technology for power supply ICs in consideration of the packaging format through assembly method.
Small, Wide-Angle Autofocus Modules

1. Introduction

In the compact camera market, there is strong competition for higher performance and smaller size cameras with a built-in zoom function. In particular, the relative merits of autofocus (AF) systems largely influence performance of compact cameras.

In the past, Fuji Electric developed small, light and high-performance range sensors which we call AF modules by adding an optical system to a single-chip autofocus IC (AFIC) that integrated an analog-to-digital (A-D) converter for sensor data with a range data calculation circuit. Fuji Electric has been producing these modules since 1992.

Moreover, AF modules with analog image data output were developed for further miniaturization of the cameras based on the advanced photo system. Fuji Electric has continued production of this type of module since 1998 with favorable market acceptance.

Fuji Electric also has developed a small, low-priced FM6260W80 AF module capable of wide-angle range measurement. This module with an analog data output type of sensor and a new optical system can be used in digital cameras and point and shoot cameras with the X2-class zoom lens.

Figure 1 shows a picture of the FM6260W80 module. This paper describes the configuration, structure and features of the FM6260W80 module. Table 1 lists the product line of AF modules with MOS analog sensors.

2. Main Features of FM6260W80

With an analog data output type of sensor and a new optical system, this module has the following features.
(1) Miniaturization
Because the sensor pitch can be made smaller by using an analog data output type sensor, miniaturization of the module can be realized.

(2) Low price
The IC unit and optical system were separated in the conventional AF module. By adopting an integrated structure, the number of processes could be reduced and lower cost realized.

(3) Shading
A new structure eliminates the need for shading, which had been implemented as a clear molded part in the past, and reduces the size of the mounting space of the module.

(4) High sensitivity
Due to the adoption of a bright aspherical lens, range measurement can be performed with a response time of 200ms even when the brightest point of the object to be measured is -1.3EV.

(5) Wide angle
The angle of view covers a visual field of approximately 26 degrees.

3. Circuit Configuration of the Analog AFIC

Figure 2 shows a block diagram of an AFIC with MOS analog sensors. A detailed explanation is omitted, but this IC is configured such that the photocurrent of each photodiode on the left and right side sensor arrays is converted into a voltage and then amplified by integrator and amplifier circuits that are both composed of MOS transistors. Sample-and-hold of the voltage is then performed as sensor data.

Operation of the integrator circuit starts from the initial reference voltage $V_{ref}$ and the output voltage descends according to its integration time. Upon receiving the integration end signal, sample-and-hold of the voltage is performed at that time. After synchronization with an external clock signal, each pixel’s sensor data is selected and passed to the output. As shown Fig. 3, the output sensor voltages which corresponds to pixels projected from bright parts of the object image are low, and the output voltage of pixels...
which corresponds to dark parts of the image approximate to $V_{ref}$.

4. Structure and Characteristics of the Photo-diode

In MOS analog sensors, alteration of the aforementioned sensor circuitry also modified the photodiode structure, which had been used in conventional digital types. Figure 4 is a cross section of the IC structure showing the transistor part. In contrast to the conventional digital types, the photodiode is configured to be electrically isolated from the substrate. This decreases the influence of carriers generated in the substrate. Consequently, any noise in the image data is reduced.

As shown in Fig. 5, this structural modification of the photodiode also changes its spectral sensitivity characteristic. Namely, since the carriers generated from deep regions of the substrate are absorbed at the junction between the substrate and p well-2, sensitivity to light with long wavelengths is decreased in comparison with the digital type. As the dynamic range of the spectral sensitivity characteristic narrows, the influence due to chromatic aberration of lenses is reduced and sharper image signals have been achieved.

5. Features of New Module Structure

5.1 Low price

Figure 6 compares structures of the FM6260W80 module and the conventional FM6255AT42 module.

In manufacturing the conventional FM6255AT42 module, the AFIC unit (clear molded package) was manufactured first by sealing the AFIC chip in transparent epoxy resin after attaching the die to the lead frame and wiring. Next, the optical system (shading case with lens) was positioned and bonded to this AFIC unit to form the AF module.
In contrast, the FM6260W80 module has a new structure. The die-bonding of the AFIC chip and wiring are performed on the sensor stage, which is made from resin by injection molding with the lead frame. After the aperture and lens are bonded to the sensor stage, transparent sealing material is injected and hardened between the lens and AFIC chip.

Because a new AF module can be manufactured with the same number of man-hours as an AFIC unit, a substantial cost reduction is possible compared with a conventional structure.

5.2 Improved sensor characteristic

The AF module features not only lowered cost but also improved sensor characteristics by means of a new structure. With the conventional clear-mold, the stress to the AFIC chip from transparent epoxy resin was not ignorant. That stress, which varies due to the temperature or humidity, could change the sensor characteristics. When the sensor pitch is wide, this stress variation does not make much influence on the sensor characteristic. However, the influence grows in accordance with the sensor pitch narrows.

The sealing material used for the FM6260W80 module need not support the structure of the module. Therefore, a flexible material can be utilized as the sealing material. Consequently, the stress hardly affects the AFIC chip, and there is no resulting change in characteristics.

5.3 Improved shading

When the AF module was installed in the camera, it was necessary to shade the clear-mold part completely with black tape or a partition. Because the part of the FM6260W80 module that corresponds to the conventional clear mold package is constructed with a black resin (shown in Fig. 7), it is already shaded. Therefore, the number of man-hours required for assembly and the mounting space in the camera can be reduced.

6. Bright Wide-Angle Lens

The FM6260W80 is available under low illumination in which the supplementary light is needed with the conventional system.

Therefore, by adjusting the f-number of the lens to 1.4 (approximately four times the brightness of the previous value of 3.0) and optimizing the sensitivity of the sensor chip to the sensor pitch, the sensitivity of the AF module was raised to 880V/s as shown in Table 1. Range measurement at -1.3EV (the brightest part of the object) is available with a response time 200ms. So that the contrast of the object could easily be acquired, the angle of view was designed to be approximately 26 degrees, twice the angle of the conventional type.

The lens shape on not only the front side but also the sealing material side is designed as an aspheric surface to correct individual aberrations such as distortion. Sufficient performance is obtained so that brightness and the wide angle can coexist.

7. Conclusion

The AF module of low-cost, wide-angle, small size and high sensitivity has been introduced. To meet user’s needs, Fuji Electric will continue to develop advanced AF modules and to provide highly original products.
EMI-Prevention Pressure Sensor

Kazuyuki Katoh
Shigeru Shinoda

1. Introduction

Semiconductor pressure sensors that utilize micromachining technology and IC processing are recently being applied to a wide range of applications in the automotive, medical and measurement fields. Especially in the automotive field where demand is quickly increasing for cleaner exhaust to comply with environmental regulations and high level electronic systems that achieve low emissions such as a direct fuel injection engine. In such applications, the high performance and low cost of pressure sensors holds much promise. On the other hand, as the engine room becomes more crowded, along with the adoption of a plastic chassis and the widespread use of car phones and mobile phones, the electromagnetic noise environment of automobiles has become severe. Electronic components to be installed in an automobile must have a high degree of protection against electromagnetic interference (EMI).

In 1992, Fuji Electric introduced a pressure sensor product that integrated onto a single chip a sensing unit and an amplifier and adjustment circuit. The newly developed EMI-prevention pressure sensor further integrates onto the chip a low pass filter for noise prevention. This chip realizes a low-cost pressure sensor that has the necessary noise immunity for automotive use. An overview of the EMI-prevention pressure sensor technology and products are introduced below.

2. Features

(1) Small size and high reliability

The sensing unit, amplifier and adjustment circuit, noise filter and their protection elements are integrated onto a single chip. The chip is constructed with a simple package containing a glass block for alleviating stress to the chip, and input and output pins. With this construction, there is no external mounting of noise prevention components and the chip can be used within the automobile engine room. Compared to the conventional pressure sensor, this sensor enables smaller sizes and lighter weights. (Fig. 1)

Furthermore, due to the wire bonding of the power supply and signal output, there are only three locations of electrical coupling, and high reliability can be achieved.

(2) Low cost

Conventional noise prevention measures required circuit components such as chip capacitors, feed-through capacitors, inductors and the mounting thereof, a circuit board for electrical connections, and a shield case. The costs of these components and assembly processes impeded cost reduction of the finished products. With the EMI-prevention pressure sensor, these externally mounted circuit components and assembly processes for noise prevention are unnecessary, and a low-cost pressure sensor can be realized.

(3) High noise immunity

Proper operation is possible even in noise environments of 100 V/m, from 1 MHz to 1 GHz.

(4) Built-in amplifier and adjustment function

Adjustment and temperature compensation functions, which are formed by thin film resistor laser
trimming, and an amplifier circuit are built into the chip, and by means of which, the user requested pressure signal can be obtained. These functions can be incorporated into the system without changing the electrical characteristics.

3. Chip and Circuit Design

A photograph of the EMI-prevention pressure sensor chip is shown in Fig. 2. The chip size is 3.5 by 3.5 (mm). Diffused strain gauges, transistors, and diodes are constructed by a bipolar process, and additional processes of thin film resistor sputtering and diaphragm etching are added. The low pass filter for noise rejection is constructed with capacitors and thin film resistors. However, a MOS process is utilized for formation of the capacitors because high quality oxidized film is required.

Figure 3 shows the circuit diagram. A C-R secondary filter is connected between the power supply voltage input pin (VCC) and the GND pin, and between the signal voltage output pin (VOUT) and the GND pin. This filters remove line noise that enters through these harnesses.

The output voltage of a strain gauge bridge composed of RG1 to RG4 is amplified, adjusted and then temperature compensated by a circuit formed from operational amplifiers OP1 and OP2, thin film resistors and diffused resistors, and then output.

4. Design for Noise Prevention

4.1 Noise filter design

A MOS capacitor, which was utilized as the capacitor for the low pass filter, is close to an ideal capacitor and its frequency characteristics are exceedingly good. Figure 4 shows those frequency characteristics. For the resistor of the low pass filter, a thin film resistor having low parasitic capacitance and good high frequency characteristics was utilized.

Characteristics of the low pass filter near the cut-off frequency are shown in Fig. 5. In the harness connected to the input and output of the sensor, noise is caused by electromagnetic waves above the vicinity of 10 MHz where they would equal the harness length. Therefore, C and R values are selected so as to set the cut-off frequency to 10 MHz. A secondary filter was selected so that the attenuation characteristic of the low pass filter would have a steep slope.

To suppress voltage drop due to the filter at the power supply voltage input pin, the supply current is suppressed with a strain gauge unit, operational amplifier, compensation and adjustment resistors. As a result, an output operating range of 0.2 to 4.75 V can
be maintained with a power supply voltage of 5 V.

To protect the capacitor of the low pass filter, a zener diode is connected to input and output pins to absorb static electricity and surge voltage. This guarantees the necessary durability for automotive applications.

4.2 Structure design

A structural diagram of the EMI-prevention pressure sensor is shown in Fig. 6. To suppress the infiltration of external noise, the chip and case are wire bonded only at the locations of three input and output pins. Further, to prevent radiated emission noise, a metal shield plate is built-in inside the resin case. This shield plate is connected to the GND pin and has the effect of shielding the chip.

5. Specifications

The test system based on TEM cell for the EMI-prevention pressure sensor is shown in Fig. 7. Using a G-TEM that can test up to 1 GHz, the field intensity is monitored with an electrical field strength meter and the generator power is controlled to obtain a field intensity of 100 V/m over the entire frequency range.

The test results with this system are shown in Fig. 8. It was verified that the output error due to noise was 1% FS or below and that this level is not problematic for practical applications.

Other main specifications are listed in Table 1.

6. Conclusion

Owing to the intensified price competition and the increasing urgency for noise prevention that accompanies the globalization of markets, expansion of the market and applications is expected for small, low-cost pressure sensors with built-in noise prevention measures. Fuji Electric is determined to develop new products, advance its series of products and respond to market requests.
**Business Outline of the Each Internal Company**

<table>
<thead>
<tr>
<th>Company</th>
<th>Business Areas</th>
<th>Major Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy &amp; Electric Systems Company</td>
<td>Providing optimal solutions from information control systems to substations to meet the individual needs and demands of each customer</td>
<td>Water treatments systems; information, telecommunications and control systems; measuring and instrumentation systems; power systems; environmental equipment and systems; industrial power supplies; electrical equipment for rolling stock; substation systems; thermal, hydraulic and nuclear power plant equipment; and others</td>
</tr>
<tr>
<td>ED &amp; C · Drive Systems Company</td>
<td>Delivering broad FA system components, individually or as integrated small-scale systems</td>
<td>Small-scale systems combined with PLCs, inverters and actuators; FA control equipment; low-voltage circuit breakers; molded transformers; drive control and power electronics; and others</td>
</tr>
<tr>
<td>Electronics Company</td>
<td>Providing distinctive electronic devices, based on our world-leading technologies</td>
<td>Power semiconductors; ICs; magnetic disks; photoconductive drums and peripherals; and others</td>
</tr>
<tr>
<td>Retail Support Equipment &amp; Systems Company</td>
<td>Promoting consumer convenience and comfort, through machinery and systems focused on vending machines</td>
<td>Vending machines; beverage dispensers; food machines; freezing and refrigerated showcases; coin mechanisms and bill validators; leisure-related systems; and others</td>
</tr>
</tbody>
</table>
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