Mixed Analog-Digital IC Technology for Power Supply

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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 circuitry

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

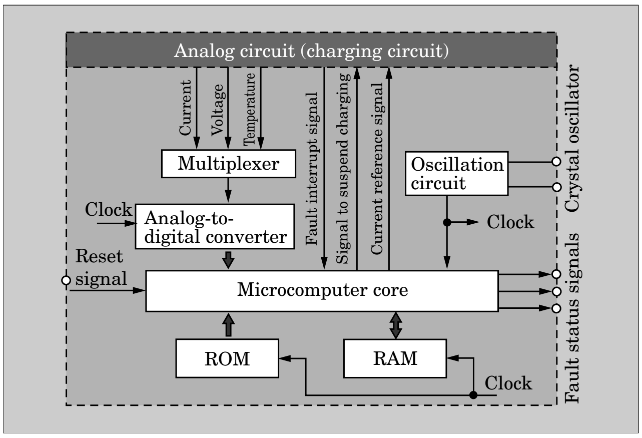
Figure 1 shows a block diagram of the digital circuitry. The digital circuitry reads in battery voltage, charge current and battery temperature through the analog-to-digital converter, and executes each process according to a program programmed in integrated ROM.

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



converter (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 approximation register (SAR).

(1) 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 accuracy 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.

Fig.2 10-bit ADC enlarged picture

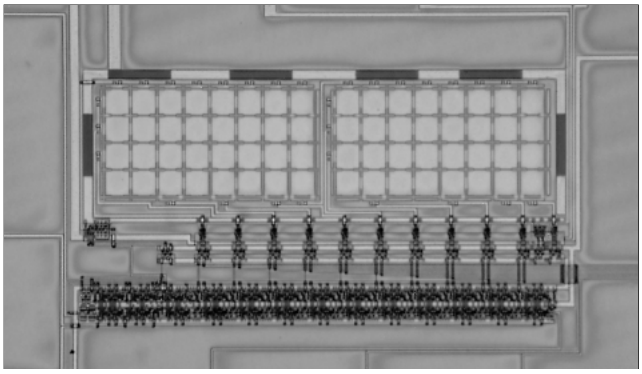
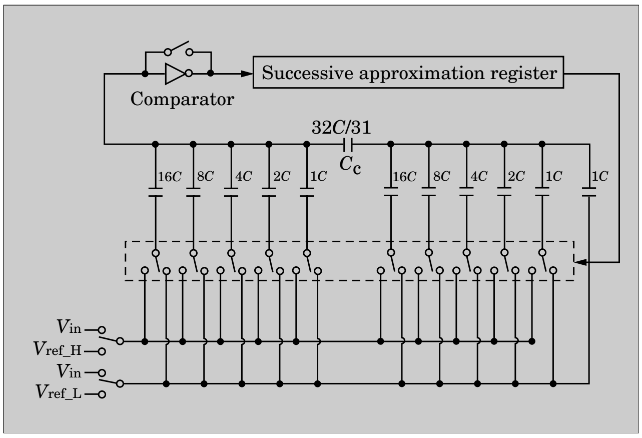


Fig.3 10-bit ADC block diagram



(2) 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.

(3) 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 approximation type of a 10-bit ADC has a function whereby the capacitor array itself holds the charge in proportion 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 successively switched. Through this arrangement, the common node voltage potential of the capacitor array becomes equal to half the input voltage of the comparator.

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

Fig.4 10-bit ADC output signal vs. analog input voltage

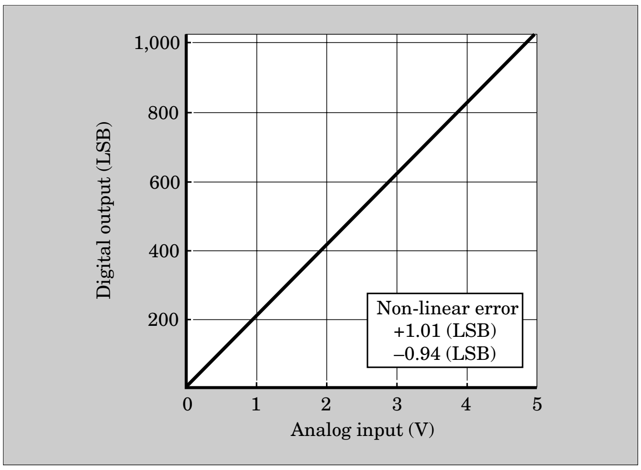


Fig.5 Charger IC block diagram

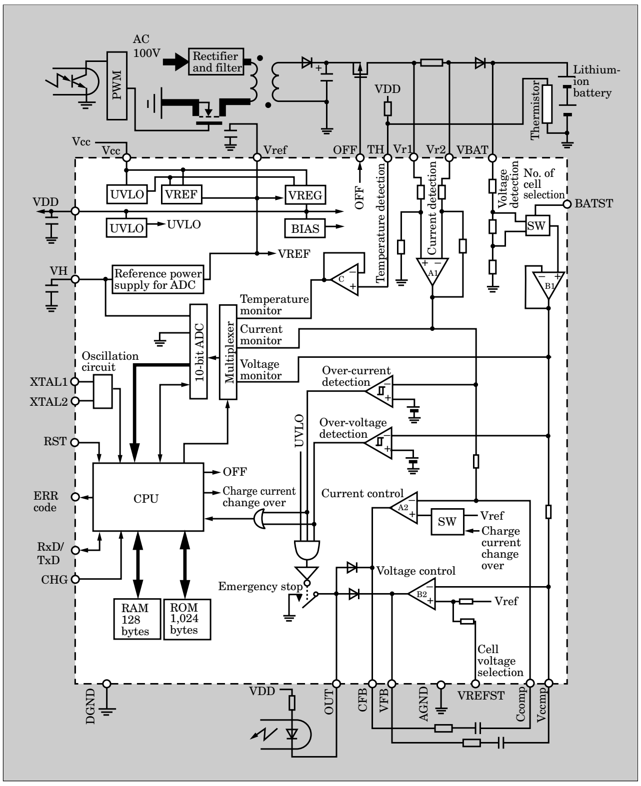
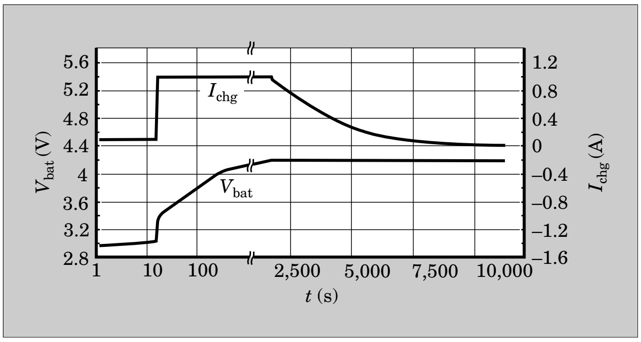


Fig.6 Lithium-ion charging characteristic



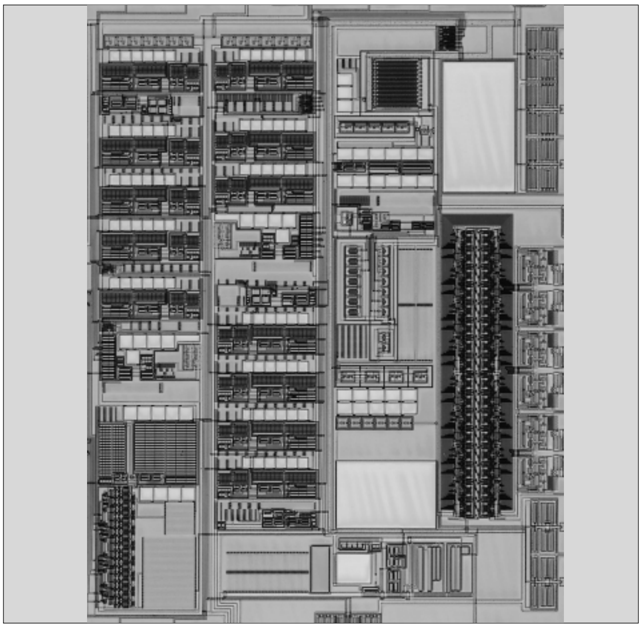
= 0V, V_{ref_H} = 5V) and the input voltage range is also 0 to 5V. Good results with non-linear error of +1.01 LSB and –0.94 LSB are obtained.

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.

Fig.7 Analog circuitry of charger IC



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±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:

(1) Yee, Y. S: A Two-Stage Weighted Capacitor Network for D/A-A/D Conversion. IEEE J. Solid State Circuits. Vol.SC-14, No.4, p.778–781 (1979)