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Power Management Technology

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Fujitsu has developed three power control LSI chips for power management in power circuits to increase the operating time of battery-driven notebook personal computers. The first LSI chip is the MB3841 power management switch that stops supplying power to non-operating sections of the device.
The second LSI chip is the MB3828 DC-DC control circuit that efficiently converts the battery voltage to voltage required by the device. This circuit has been developed for the Pentium CPU to improve performance by about 5 percent over conventional circuits.
The third LSI chip is the MB3814 DC-DC control circuit for the charger of the lithium ion rechargeable battery. This circuit enables simultaneous charging and can charge multiple lithium ion rechargeable batteries concurrently, thus reducing recharging time by half. The MB3814 also implements differential charging in which power consumption of a personal computer is measured and the battery recharging current is controlled dynamically, which reduces the charging time for rechargeable batteries during operation of the personal computer.

1. Introduction

The three key points for prolonging the operation time of battery-driven notebook personal computers (PCs) are: reducing device power consumption, efficiently supplying battery power to the device, and achieving 100% efficient use of the battery.

Device power consumption can be reduced by changing the equipment architecture for power management and reducing the power consumption of semiconductor elements of the equipment. However, in terms of power supply, power management through power control is the main technique. Fujitsu has developed the MB3841 power management control IC that operates at 2.1 V and serves as a switch that controls power supply to reduce device power consumption.

This paper discusses how the DC-DC converter used in the power circuit of notebook PCs is configured to supply battery power efficiently. This paper introduces the MB3828 DC-DC control IC developed for supplying power to the Pentium CPU. Fujitsu has also developed the MB3814 charge control IC to maximize the efficiency of using lithium ion rechargeable batteries to supply power to notebook PCs and to ensure the rapid storage of as much power as possible in each battery.

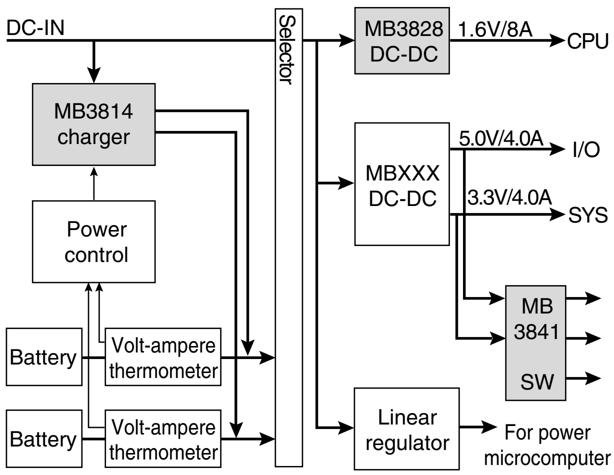

Figure 1.
Block diagram of power circuit.

Figure 1 shows the block diagram of the notebook PC power supply and how the three types of newly developed LSI chips for power supply are used.

2. Power management control (stopping power supply)

The power consumption of semiconductors that make up the notebook PC circuit is expressed by the following formula:

$$Pw = k \times f \times C \times V^2$$

where k is a constant, f is the operating frequency of the circuit, C is the integrated gate size of the circuit, and v is the voltage.

As indicated by the formula, the most common method of reducing the power consumption of semiconductors, which are the principle components of notebook PCs, is to decrease the operating frequency or voltage. In practice, the operating frequency is decreased by controlling the clock frequency.

When an operation is executed while an application is running, the CPU operates at maximum speed. When CPU processing is not required while the system waits for key input from the operator, however, the CPU speed can be cut to reduce power consumption. This is power management control by controlling the clock frequency.

Lowering the clock frequency is generally considered to mean lowering the clock frequency itself. However, the clock frequency in a notebook PC is actually lowered by stopping the clock oscillations at intervals. If the clock oscillation time has a one-to-one correspondence with the clock stop time, stopping the clock oscillations is equivalent to lowering the clock frequency by half. Adjusting the clock frequency can be simulated by arbitrarily changing the ratio of clock oscillation time to clock stop time. Because this method can change the ratio over a wider range than by changing the clock oscillation frequency directly, it is very useful. **Figure 2** shows how the clock frequency is controlled.

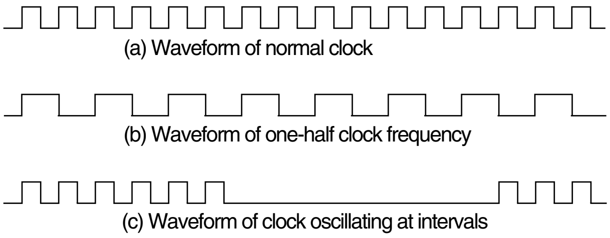

Figure 2.
Clock frequency control.

Note that the clock is stopped under no load and oscillated under a full load in terms of power supply. Because operations switch momentarily between those with no load and those with a full load, a very rapid response to load variations is required. For example, a Pentium II chip operating at 300 MHz consumes 0 mA under clock stop state, but requires 8,000 mA during operation at 300 MHz. Since the chip switches frequently between operation at 300 MHz and the stopped clock state, the power circuit that supplies power to the CPU must respond within 3.3 nanoseconds from 0 mA to 8,000 mA.

Another power management method is reducing the operating voltage.

The speed, integrated gate size and power consumption of CPUs continue to increase each year, while CPU voltage has been reduced to prevent any increase in power consumption. The voltage of the 486DX CPU used for notebook PCs around 1993 was 3.3 V; that of the first Pentium CPU at the end of 1995 was 2.9 V; that of the MMX Pentium CPU at the beginning of 1997 was 2.45 V, and that of the Pentium II CPU in April 1998 had been lowered to 1.6 V.

As previously discussed, lowering the device operating frequency and operating voltage of semiconductors are effective means of reducing power consumption. Another effective method is power management that does not supply power to unused circuits.

The notebook PC consists of various circuit components, not all of which operate all the time. During communication using the Internet or between PCs, the modem circuit used to connect to the telephone line is used, but is not used when other application programs are running that do not use a telephone line.

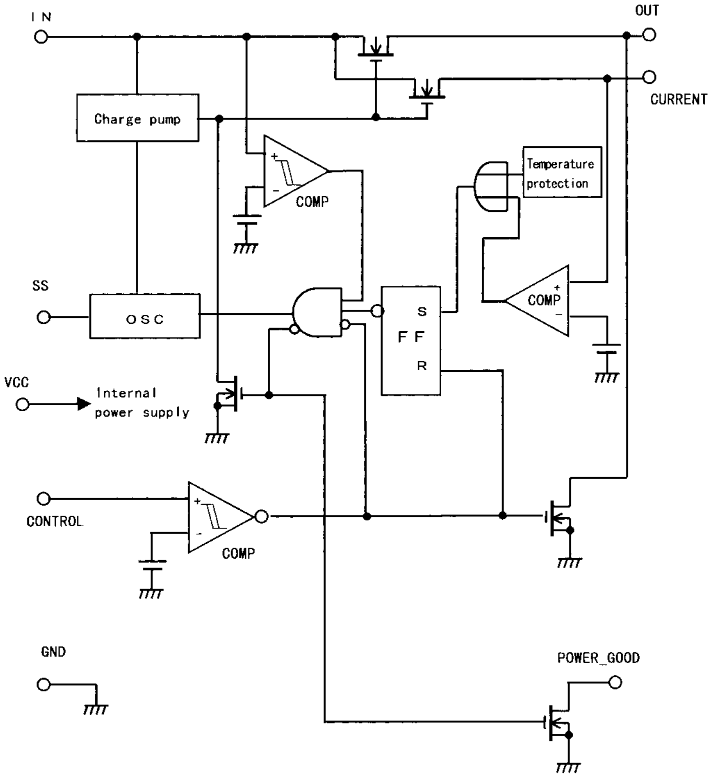

Figure 3.
MB3841 block diagram.

Similarly, the hard disk drive (HDD) must operate to read a program and data from the hard disk, but need not operate while the CPU uses the read program and data to execute processing.

Power consumption can be reduced by stopping the supply of power to circuits that do not operate.

As previously noted, since the operating voltage of semiconductors has been reduced annually, the switch circuit for power management that consists of field-effect transistors (FETs), must operate at a low voltage.

For the same power consumption, the load current becomes larger as the operating voltage is lowered. Therefore, a switch circuit with low impedance during switch operation is required. As the load current increases, voltage variations at the load caused by the power line impedance become larger.

The MB3841 switch circuit for power management operates at low voltage and has low impedance during operation. Fujitsu developed the MB3802 (i.e., similar power management switch) in early 1993 for use in notebook PCs. More than five years have passed since the MB3802 was first introduced. Now an even higher performance switch IC for power management is required. The MB3841 was therefore developed to deliver the required performance and functions to cover the increase in power consumption.

Figure 3 shows the block diagram of the MB3841.

The MB3841 contains a DC-DC converter (charge pump). Since the DC-DC converter is activated and voltage is applied to the FET gate to turn on the switch, the MB3841 operates at a power line voltage of at least 2.1 V. The internal DC-DC converter enables an N-type MOSTr with low impedance to be used for the switch. while minimizing voltage drops in the power line. The NMOSTr back gate is connected to GND to prevent the flow of reverse current caused by the body diode that becomes a problem in DMOSTr when the switch is off. The reverse block structure is achieved without increasing switch impedance. The reverse block structure also enables the MB3841 to have bidirectional switch characteristics and to be used as the switch circuit for switching the voltage supplied to the load.

Since the soft start function can delay the time at which the switch circuit is set on or off, surge current to the load can be prevented when the switch is on. The NMOSTr for the MB3841 switch is used in the existing mirror circuit to ensure overcurrent protection at any current value by simply connecting a resistor to the CURRENT terminal as shown in the diagram.

The performance of the M3841 developed this time has been enhanced, with switch resistance reduced from one-fourth to one-third that of the MB3802.

The switch resistance of the entire MB3802 is about 120 mΩ. Detailed analysis showed that the impedance of an FET containing the switch was 60 mΩ , (i.e., about half the total resistance), the resistance of the lead frame on each side of the IC package was 27 mΩ , and the resistance of Au bonding wire on each side was 3 mΩ (thus resulting in 60 mΩ).

The MB3841 uses a copper lead frame package instead of a conventional iron lead frame to provide lead frame resistance of about 0 mΩ. The diameter of Au bonding wire is thickened whenever possible and many Au wires are bonded to reduce resistance. The shape of the copper frame is also redesigned to suit the IC chip pattern and restrict Au wire length up to 1 mm. As a result, the Au wire resistance is about 0 mΩ.

FET miniaturization and improved processing accuracy help achieve impedance of 30 mΩ or roughly half the conventional impedance.

3. Improved power loss through enhanced efficiency of voltage converter

The characteristics of the battery in a notebook PC are such that the battery voltage is lowered as the battery becomes depleted. The devices that make up the PC require various voltages. Rotating input-output devices using a motor like a hard disk drive and CD ROM drive require a voltage of 5.0 V. Semiconductor circuits that enable main storage and control functions require a voltage of 3.3 V. The voltage required by the CPU has been lowered annually to 1.6 V, and will drop to 1.3 V in the near future.

The DC-DC converter in the notebook PC enables the battery to supply the various voltages required by various devices as its voltage drops during discharge. The conversion efficiency of the DC-DC converter affects the operation time of the device in question. If the efficiency of the DC-DC converter is 50%, for example, the operation time is reduced by half since 50% of the energy contained by the battery is lost in conversion.

The down converter using a synchronized rectifier is currently the most commonly used and most efficient voltage conversion system, achieving an efficiency of 90 to 95% or more. There is still room for improvement, however.

The MB3828 has been developed as a DC-DC control circuit for the Pentium CPU to achieve efficiency higher than conventional DC-DC control circuits while responding rapidly to load variations. **Figure 4** shows the block diagram of the MB3828.

The main features of the MB3828 are its leakage current (through a reduced resistor divider for voltage detection), high-speed response to load variations, and digital output voltage setting.

A typical DC-DC output voltage control circuit uses a resistor divider to measure output voltage and an error amplifier to compare the measured voltage with the reference voltage, thus controlling the DC-DC output voltage. Resistor for voltage detection should be achieved at a high resistance of hundreds of kiloohms to minimize power loss. Unless the divided resistance is set ranging from hundreds of ohms to several kiloohm, however, sufficient response and phase char-

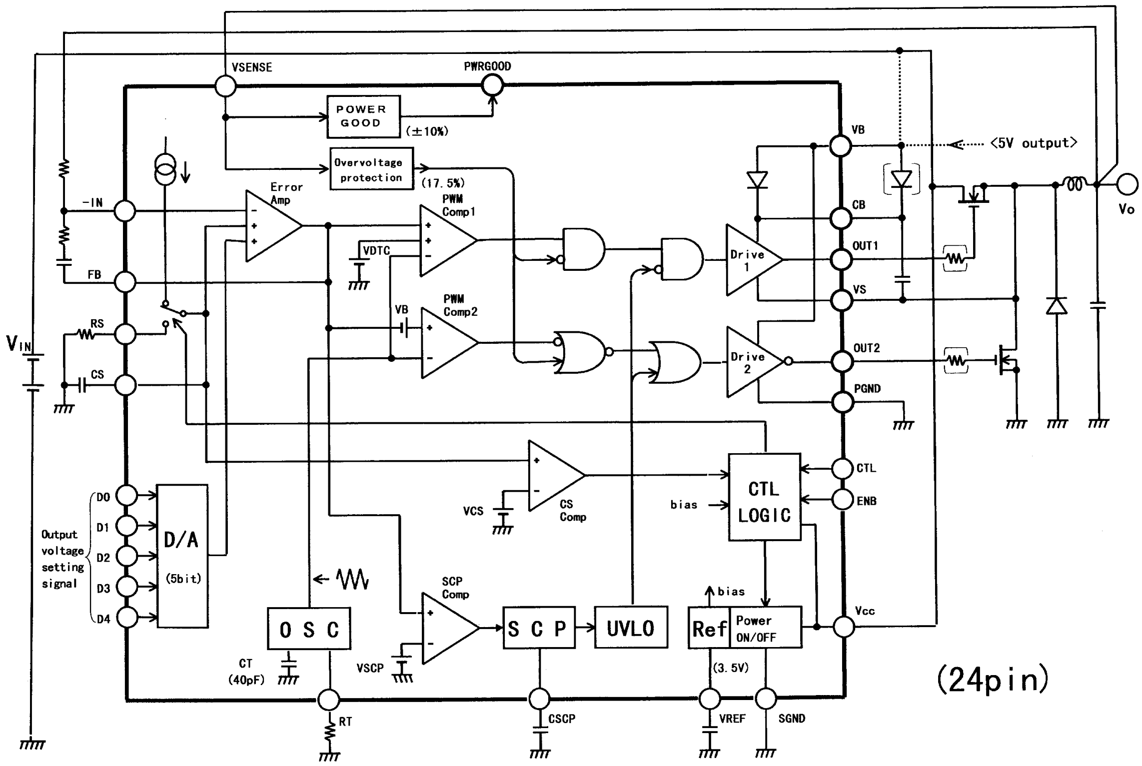

Figure 4.
MB3828 block diagram.

acteristics for load variations cannot be obtained.

The current flowing through the resistor divider for voltage detection is at most several mA to tens of mA, but the power loss caused by these resistors cannot be overlooked.

The MB3828 has a configuration in which the output voltage is input directly to the error amplifier without using the resistor divider for output voltage detection. This ensures sufficient response and phase characteristics for load variations. Eliminating the resistor divider for output voltage detection reduces the current by several mA that conventionally flows through the resistor divider.

If the resistor divider for output voltage detection is eliminated, the output voltage of the circuit is difficult to change, but the voltage required by the CPU is continually being reduced each year, and the required voltage also depends on the type of CPU. The MB3828 is designed to change the reference voltage input to the error amplifier based on fluctuations in the output voltage. The MB3828 can control the output voltage between 1.3 and 3.5 V to within an accuracy of 50 or 100 mV by selecting 32 types of preset reference voltage with a 5-bit digital value that can be externally set.

The second feature of the MB3828 is the elimination of the existing sense resistor used in conventional synchronized rectifiers.

In a conventional DC-DC circuit, a 10 to 30 mΩ sense resistor is inserted in series to sense current flowing through the choke coil. The conventional synchronized rectifier DC-DC circuit improves DC-DC efficiency under a low load by stopping the synchronized rectifier or lowering the DC-DC operating frequency when the current flowing through the sense resistor is measured and is equal to or less than the specified value. Recently, however, as load current has increased in inverse proportion to the lowering of output voltage, the power loss caused by the sense resistor under a full load has reached as much as 3 to 5%. Lowering the DC-DC operating frequency or stopping the synchronized rectifier under a light load poses the problem of sluggish response to load variations if the load rapidly becomes heavy.

The MB3828 eliminates the existing sense resistor and uses a synchronized rectifier based on a voltage mode to provide better response to rapid changes of load through resonance between the choke coil and load capacitor without stopping the synchronized rectifiers even under a light load.

As a result, although the efficiency under a light load is slightly worse than that of a conventional system, the power loss caused by the existing sense resistor at the rated output is improved and overall efficiency is improved by 4 to 5%.

The third feature of the MB3828 is the ability to freely control the rise and fall times of the DC-DC output voltage regardless of alight or heavy load.

The notebook PC uses multiple voltage sources internally. The rise and fall sequences of individual voltage sources are important; unless power-on and power-off sequences are considered, the semiconductor device may cause a latchup and be damaged by fire. Since controlling the power-on and power-off sequences requires a logic circuit, a large and complex circuit is necessary.

However, the MB3828 controls power-on and power-off sequences without a sequence control circuit by freely controlling the rise and fall times of DC-DC output voltage regardless of a light or heavy load.

In the structure of a conventional DC-DC control circuit, the DC-DC rise time depends on a light or heavy load since a PWM controller is used to ensure soft start control that prevents surge current at DC-DC activation.

The MB3828 uses an error amplifier for voltage control to ensure soft start control that prevents surge current at DC-DC circuit activation, and thus achieves rise and fall of the output voltage independently of the load.

4. Method of Charging Lithium Ion Rechargeable Batteries

The operation time of battery-driven notebook PCs cannot be prolonged without reducing the power consumption of devices, maximizing the energy stored in each battery, and extracting the stored energy efficiently. The lithium ion rechargeable battery used to supply power to notebook PCs is generally charged at a constant voltage and constant current. The quantity of energy to be charged is determined by the charging voltage.

The charging voltage of the lithium ion rechargeable battery is 4.2 V (50 mV per cell. Charging the lithium ion rechargeable battery at 4.25 V enables about 6% more energy to be stored than charging at 4.2 V, while charging the battery at 4.15 V stores about 9% less energy than charging it at 4.2 V. Thus, more energy is stored at a higher charging voltage. Charging a lithium ion rechargeable battery at a voltage higher than 4.25 V could cause smoke or fire, however, and also reduces the cycle life (discharge count).

The lithium ion rechargeable battery requires a charging voltage accuracy of 4.2 V ± 50 mV (±1.1%) at all temperatures, but the voltage accuracy that can be guaranteed by general DC-DC converters is about ±5%. The charging voltage can be adjusted to within the ±1.1% range by using a laser to trim the resistor for voltage detection or by using volume control resistor. However, this technique involves more manufacturing effort and is therefore more expensive.

A charge control LSI that can control voltage within ±0.5% accuracy has been developed to achieve a charging voltage of ±1.1% accuracy and control the charging voltage with high accuracy so that about 10% more energy can be charged.

The MB3813A enables high-accuracy voltage control by creating resistor dividers R1 and R2 for output voltage detection inside the LSI. When a resistor is created inside the LSI, defusion caused by impurities causes a ±20 to 30% error in the absolute value of the resistor. However, since the relative value of the resistor created inside the LSI

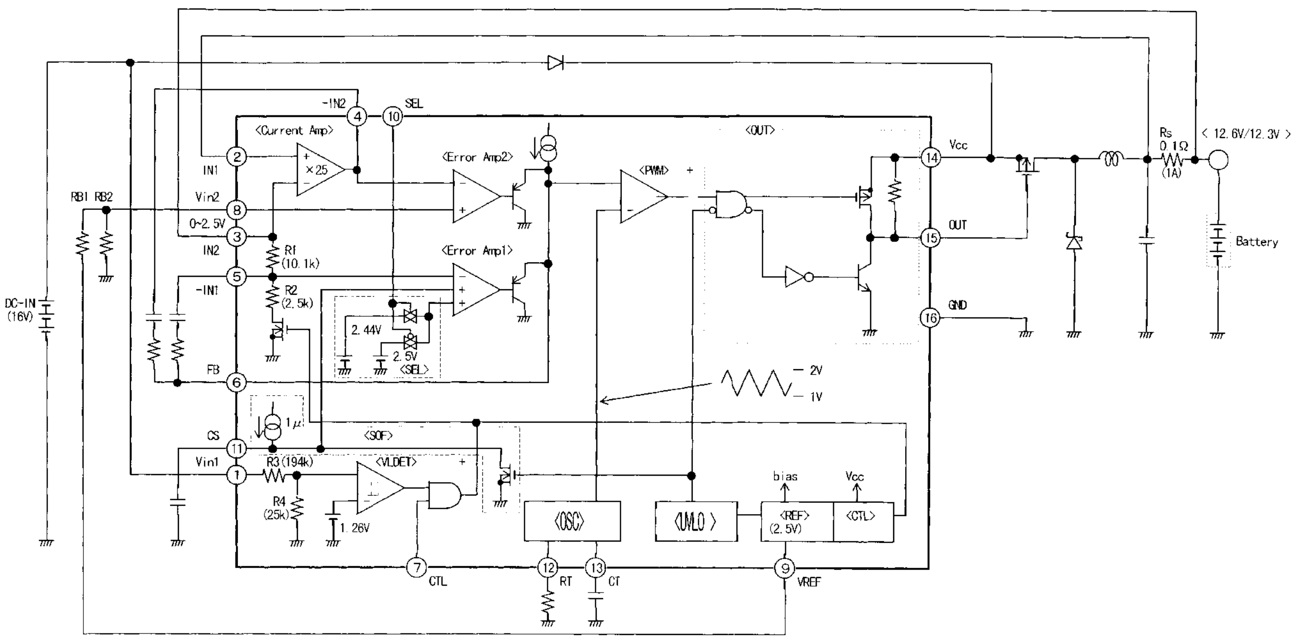

Figure 5.
MB3813A block diagram.

is determined by its external dimensions, an LSI that can control external dimensions to within 0.1 µm can accurately control the ratio of two resistance values.

The MB3813A has R1 set to 10 kiloohms and R2 set to 2.5 kiloohms. Five resistors of 2.5 kiloohms are created, and four are connected in series to configure R1. The remaining resistor is R2.

Figure 5 shows the block diagram of the MB3813A.

4.1 Simultaneous Charging through Constant Voltage, Constant Current Control

We propose a simultaneous charge control method for lithium ion rechargeable batteries. This method uses one charger to charge multiple batteries simultaneously and thus shortens the charging time. Charging one lithium ion rechargeable battery takes about two hours; charging two lithium ion rechargeable batteries sequentially takes about four hours.

Simultaneous charging uses one charger to charge two batteries simultaneously, and fully charges two batteries in about 2.7 hours, which is significantly faster.

Figure 6 shows the block diagram of the MB3814 LSI that achieves simultaneous charging through constant voltage, constant current control.

The MB3814 is a constant voltage, constant current DC-DC control LSI with several functions added to implement simultaneous charging. The first function is an independent voltage control circuit that accurately controls the charging voltage of the two batteries. It is also an independent current control circuit that accurately controls the charge current of batteries.

The second function is a current adder and current control circuit using the current adder that obtains the total value of charge current flowing through both batteries. When two independent charge current control circuits are used to control the charge current, the maximum output of the charger becomes the total current of both circuits. The current control circuit using the current adder enables the maximum DC-DC output current value to be controlled during simultaneous charging, as well as the charge current of individual batteries.

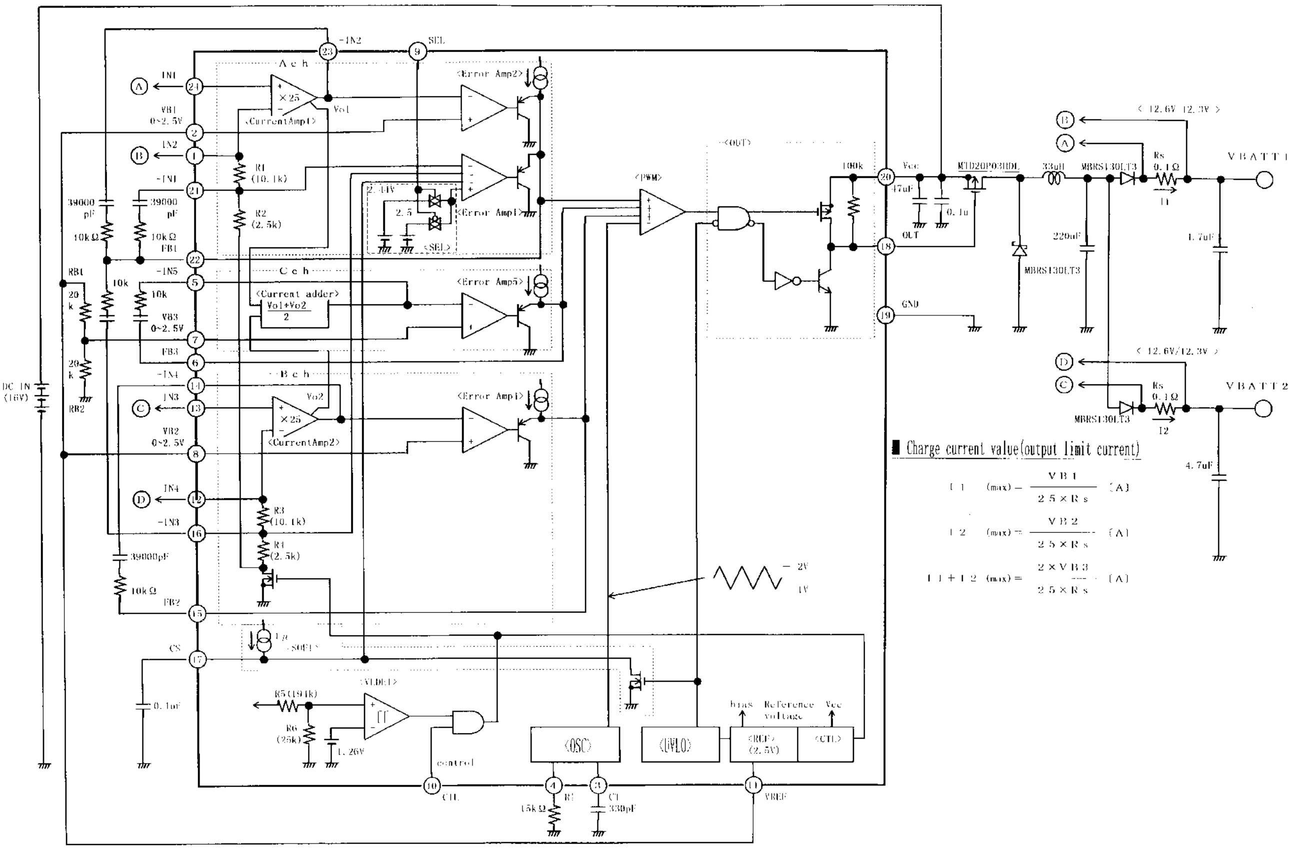

Figure 6.
MB3814 block diagram.

The third function is the output voltage control architecture. The voltage error amplifier adopts two-input system for detecting output voltage for batteries. The error amplifier operates to determine output voltage at the lower voltage of the two batteries to ensure that the correct voltage is supplied, even if only one battery is connected to the charger.

4.2 Differential charging

Notebook PCs have a dual power supply system and can operate on an external power supply from an AC adapter or rechargeable battery mounted in the PC. Since notebook PCs contain a charger, the rechargeable battery mounted in the device can only be easily charged by connecting the AC adapter. The charger inside the notebook PC charges the internal rechargeable battery by two methods: quick charging and normal charging.

Quick charging is done rapidly at the maximum charge current allowed by the battery, while normal charging is done slowly at a low charge current.

If power supplied by the AC adapter connected to the device is sufficiently higher than the maximum power used by the device, and must be used to charge the rechargeable battery, the rechargeable battery can be charged while the PC is being used. Note that power supplied by the AC adapter is limited in practice by cost, size, and weight.

Quick charging of the internal rechargeable battery is done when the device stops. When the device is operating, the internal rechargeable battery is charged at low speed. During normal charging, the charge current is uniquely determined based on the maximum current used by the PC and AC adapter capacity.

However, CPU processing and input-output operations performed by software in the notebook

PC consume power and change continually, however. This is why notebook PCs do not always operate at maximum power. The time taken to charge the internal rechargeable battery can be shortened by controlling the charge current so that the sum of the charge power of the internal rechargeable battery and PC power consumption is always within the maximum output of the AC adapter. This is done as follows. PC power consumption is always measured, and when it increases, the charge current of the internal rechargeable battery is lowered, and vice versa. The charge method that dynamically changes the charge current of the rechargeable battery according to power consumed by the PC is called differential charging.

The MB3814 can perform differential charging. The MB3814 uses one of two current control circuits provided for simultaneous charging to control the charge current of the battery. It uses the other current control circuit to measure PC power consumption. The current adder is used to control the charge current so that the total current of both battery and PC becomes the rated current of the AC adapter. If PC power consumption increases, the current adder controls the DC-DC converter so that the charge current is decreased, and vice versa.

The MB3814 enables dynamic control of the charge current so that the total power consumption of the PC and charge current of the rechargeable battery are always within the maximum output of the AC adapter. As a result, the time taken to recharge the battery is shortened.

4.3 Dynamically-controlled charging

The above section discussed how the MB3814 simultaneous charge control LSI is used for differential charging to shorten the charge time while the PC is running. Fujitsu is developing a dynamically-controlled charger as the next-generation charger.

Differential charging requires that the total power consumed by the PC and power used for charging be preset up to the maximum rated power of the AC adapter used for the PC. The maximum charge power during operation of the PC is set for static conditions, and the AC adapter cannot be selected to suit the operating conditions.

When considering the mobile operation of a notebook PC, a large-capacity AC adapter is needed for quick charging using the PC at home or at the office, but a small-capacity, compact, light AC adapter is needed when on the go.

To satisfy these conflicting requirements, dynamically-controlled charging automatically determines the capacity of the AC adapter connected to the PC and dynamically controls the charge current of the rechargeable battery according to its capability.

The key problem in dynamically-controlled charging is the compatibility to allow old adapters to be automatically determined without requiring a new special interface for determining AC adapter capability.

With the dynamically-controlled charging method, the charger controls the maximum charge current allowed in the battery and monitors the output voltage of the AC adapter to dynamically limit the charge current. The charge current can be controlled so that the optimum charge current is always selected according to AC adapter capacity regardless of output capacity.

5. Conclusions

Fujitsu is currently developing a new charge control LSI MB3874 for the next generation of dynamically-controlled chargers, and will use it in notebook PCs to be released in early 1999.

Fujitsu will also use the MB3828 DC-DC converter for the Pentium CPU to develop 3.3V and 5.0 V DC-DC control LSI chips.

CPU power consumption is increasing exponentially year by year. This is making the development of low-voltage, high-current power circuits increasingly difficult.

Hidekiyo Ozawa Graduated from the Science and Engineering department of Nihon University in 1974 with an M.E. degree in Electrical Engineering. He joined Fujitsu in 1974 and has been engaged in the architectural development and design of mainframe computers. He took charge of designing the architecture of PCs in 1988 and has been working on the development of notebook PCs, especially power supply-related parts since 1991.

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