Capacity Expansion Safety Improvement Intelligent System

Technology Reports

Special Articles on Technology Supporting Large-capacity and High-efficiency Communication in the Flat-rate Era

Battery Packs and Chargers for Comfortable Use of Mobile Terminals

Achieving comfortable use of mobile terminals free from the worry of dead batteries will require small, light, and safe battery packs capable of providing long calling times and technology for charging batteries anytime and anywhere. Energy- and resource-saving technology as in batteries that can deal with the increase in mobile terminals users and frequent model changes will also be important. NTT DOCOMO is developing battery packs and chargers to meet these needs.

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1. Introduction

Mobile terminals in Japan are increasingly being equipped with the One Seg TV function and advanced applications like i-motion and i-appli, but at the same time, usage time and power consumption are increasing as transmission speeds increase by High Speed Downlink Packet Access (HSDPA)[*1] and as flat-rate billing schemes come to be adopted. With the development of next-generation mobile-communication systems such as Super 3G[*2] (LTE) and 4G[*3] (IMT-Advanced) now in progress, the reduction of power consumption in mobile terminals is becoming a major issue.

Although measures have been taken to deal with this issue such as saving power through intermittent reception and reducing the power consumed by internal circuits, there is a need for further expansion of battery-pack capacity and for batteries that can support smaller and lighter mobile terminals and longer operating times. The Lithium-ion (Li-ion) battery[*4], which has found widespread use in consumer electronics, has contributed greatly to the spread of mobile terminals due to its high-energy-density feature.

The development of AC adapters is also important for simplifying the use of mobile terminals. An AC adapter should have a compact configuration, power-saving features, and common specifications.

This article describes the development of batteries and power supplies for mobile terminals to date and presents next-generation power-supply technologies.

2. Role of Power Supply and Battery

Figure 1 shows the configuration of a mobile terminal's power-supply system [1]. To charge a battery pack, the system inputs commercial power to the mobile terminal via the AC adapter. This power is input into the battery pack via the charging circuit.

Table 1 shows requirements of

*1 **HSDPA**: A high speed downlink packet transmission technology based on W-CDMA and standardized by 3GPP. It optimizes the modulation method and coding rate according to reception conditions at the mobile terminal.

*2 **Super 3G**: A high speed radio access system extending the Third-Generation mobile communication system under study at 3GPP. Proposed by NTT DOCOMO in 2004, the development of Super 3G is progressing toward practical deployment.

*3 **4G**: Fourth-Generation mobile communication system achieving high speed radio access beyond Super 3G.

*4 **Li-ion battery**: A type of rechargeable battery (secondary battery) in which charging and discharging are performed by the movement of lithium ions through the electrolyte.

power supplies and batteries in mobile terminals. Before 2004, charger specifications and battery-pack specifications differed from one mobile-terminal manufacturer to the next and a different AC adapter was provided for each mobile-terminal model. Since 2004, however, charger specifications have been unified and common AC adapters have been provided for (FOMA) mobile terminals from the viewpoint of user convenience and the elimination of redundant development.

The Li-ion battery that features high energy density has greatly contributed to the development of small, light and high-capacity battery packs in mobile terminals. For this battery, importance is placed on technology for evaluating lifetime characteristics based on charging/calling/standby usage patterns and safety characteristics in the event of abnormal battery-pack usage as described below.

3. Improving Battery-Pack Performance

The Li-ion battery charges and discharges by moving Li-ions between the battery's internal electrodes. **Figure 2** shows the history of battery packs used in mobile terminals. Li-ion batteries came into use around 1995, and their energy density has practically doubled over the 13 years since then. As a result of this progress, standby time-a basic specification of mobile terminals-has more than doubled.

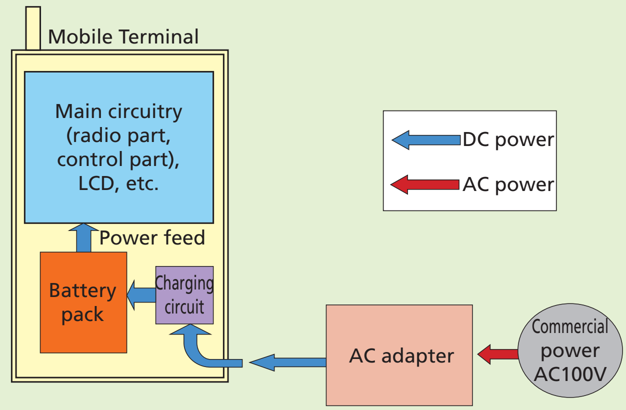

Figure 1 Configuration of a mobile terminal's power-supply system

Table 1 Requirements of power supplies and batteries in mobile terminals

Object	Mobile terminal functions	Anytime Calling	Reliability	Society/ Environment
Charger	Power (energy) saving Universal	Semi-fast charging Anywhere charging	Ultra-long life Safety	Common specs Recyclable
Battery pack	Small, light High capacity	Long-time driving	High reliability High safety	Low environmental impact Recyclable
Built-in power-supply circuit	Small High efficiency	—	Low heat generation Reliability	—

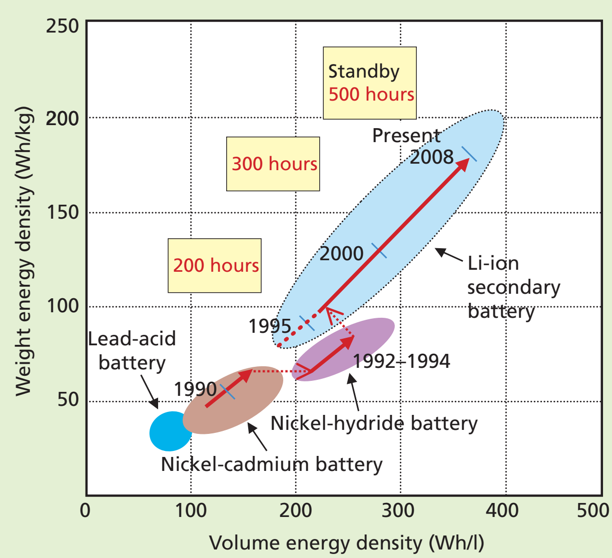

Figure 2 History of battery packs

Figure 3 shows the internal configuration of a battery pack. The following lists three basic evaluation items that must be considered when developing a battery pack for mobile terminals:

1) Battery-pack Charging Characteristics and Protection Circuit Operation
2) Battery-pack Lifetime Evaluation and Deterioration Diagnosis
3) Battery-pack Safety Evaluation

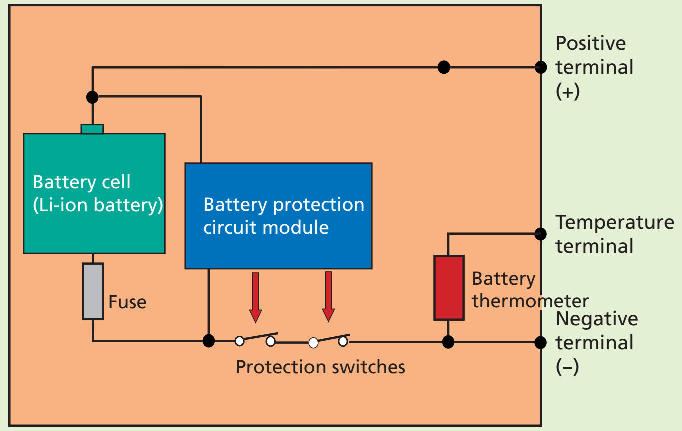

Figure 3 Internal configuration of battery pack

1) Battery-pack Charging Characteristics and Protection Circuit Operation

Figure 4 shows charging characteristics of a battery pack. The charging operation consists of two periods: "preparatory charging" during which a very small amount of current flows while the battery is being checked and "main charging" during which charging current actually flows. In the main charging period, a constant current flows until battery voltage reaches 4.2 V at which time the current begins to drop. A fully charged state is deemed to have been reached when the current decreases to a prescribed value. In the event that excessive voltage or current is applied to the battery cell during the charging process, faults or unsafe behavior may occur. To prevent such problems, the battery protection circuit module[*5] shown in Fig.3 monitors the state of the battery cell and performs various types of protective measures. **Figure 5** shows protection operation conditions for this module. The module may suspend charging to protect the battery cell if overcharging or overdischarging occurs.

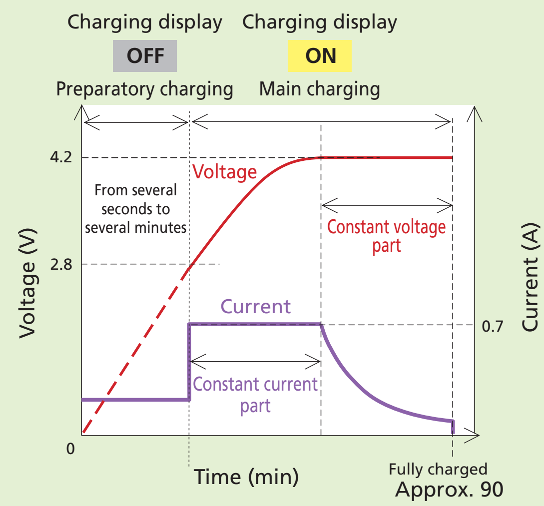

Figure 4 Charging characteristics of battery pack

2) Battery-pack Lifetime Evaluation and Deterioration Diagnosis

Evaluating the lifetime of a battery pack requires technology for evaluating deterioration and lifetime characteristics of the internal battery cell. In general, batteries used for mobile equipment other than mobile terminals are used in a cyclic manner consisting of complete charging and complete discharging. This kind of charging and discharging loop is accompanied by cyclic deterioration[*6], which is one type of battery

*5 **Battery protection circuit module**: A circuit situated inside the battery pack of a mobile terminal to protect the Li-ion battery from excessive voltage and current from the outside.

*6 **Cyclic deterioration**: One cause of a drop in battery capacity (see*8). It is a battery deterioration phenomenon that occurs by repeating the charging and discharging of a battery.

deterioration mode. Mobile terminals, in contrast, feature the three states of charging, calling, and standby, and in addition to cyclic deterioration, a battery cell used in a mobile terminal may experience another type of deterioration mode called "preservation deterioration"[*7] due to the long-term preservation of the charging state. We measured deterioration characteristics of a battery cell while varying battery state (elapsed time) for the above three states of a mobile terminal. **Figure 6** shows an example of measuring lifetime characteristics of a battery cell after one year of use. The horizontal axis represents calling time per day, the vertical axis battery capacity[*8], and Ts in the figure indicates charging interval (every half a day, every day, etc.). From the figure, we see that battery capacity slopes down to the left and decreases as the charging interval shortens. These results indicate that frequent recharging as opposed to calling hastens battery deterioration. Furthermore, by examining the result for 30 minutes of calling per day and a recharging frequency of one day as battery measurement conditions, we see that battery capacity drops by approximately 20% after one year. Considering, therefore, that a 40% drop in battery capacity generally corresponds to the life of a battery, we can see that battery lifetime (time for replacement) is approximately two years [2].

At the same time, it is important that the time for battery replacement, which has traditionally been determined by intuitive means such as by a decrease in calling time, be automatically determined by battery-pack deterioration diagnosis. **Figure 7** shows an example of measuring the relationship between the AC impedance of a battery cell (in the case of 1 kHz) and percentage deterioration in battery capacity. If such data can be prepared beforehand, measuring the internal impedance of the

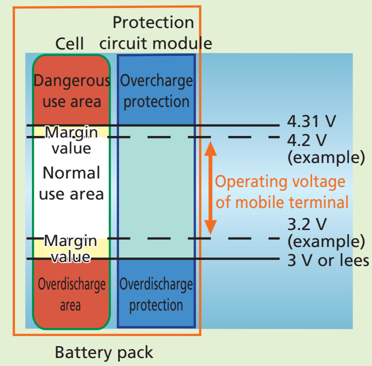

Figure 5 Battery-pack protection operation areas

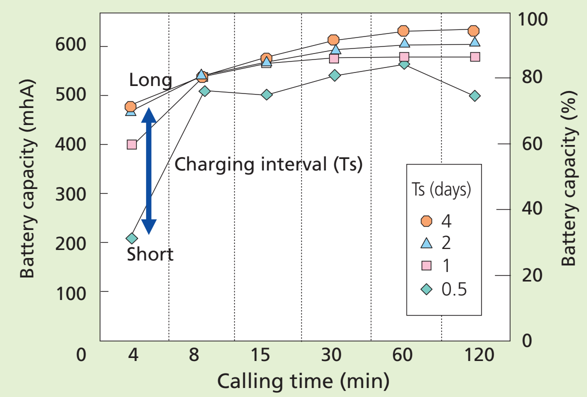

Figure 6 Example of measuring lifetime characteristics of a battery cell

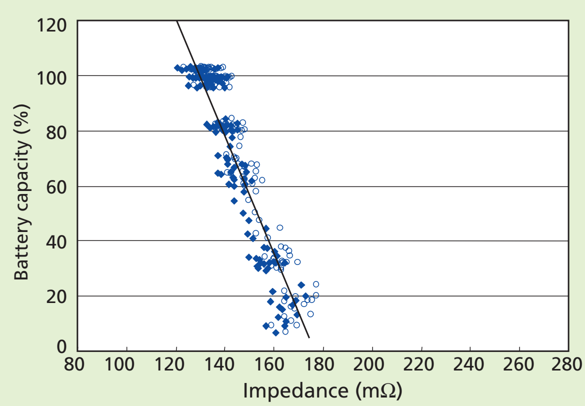

Figure 7 Example of measuring deterioration characteristics of battery capacity

*7 **Preservation deterioration**: One cause of a drop in battery capacity (see *8). It is a battery deterioration phenomenon that occurs by maintaining (preserving) the charging state of a battery for a long time.

*8 **Battery capacity**: Total electrical capacity that can actually be discharged in a battery pack. It is calculated as the product of discharge current and discharge time when discharging a battery pack.

battery in question will enable battery capacity to be estimated at any time and the user to be reliably informed of the battery-replacement period [3].

3) Battery-pack Safety Evaluation

We have conducted verification tests to ensure a certain level of safety in battery packs even if dropped or used under abnormal conditions such as high temperatures. **Table 2** shows examples of abnormal use of battery packs. Mobile terminals are made ready for commercial use by setting test conditions in accordance with each envisioned case of abnormal use and conducting an excessive voltage test, crushing test, high-temperature test and other kinds of tests to check battery safety [4].

4. Improving Charger Performance

Given that standby power*9 of AC adapters used for mobile terminals has traditionally been equal to about three-fourths of the total power of a mobile terminal, we explored means of reducing the standby power of AC adapters. **Figure 8** shows a prototype of an AC adapter with reduced standby power and **Figure 9** shows control waveforms. The operating principle behind this prototype is as follows. Using the load detection terminal of Fig.8, the system detects that the terminals on the mobile terminal side are connected and alters the intermittent signaling on the power-supply charging control IC to

Table 2 Examples of abnormal use of battery packs

Usage environment	Cause	Effects	Verification tests
Overcharge (high voltage, large current)	Non-standard charging Use of unauthorized charging equipment	Swelling, leaking, smoking, igniting, etc.	Overcharging test
Battery terminal short	Chain short in the battery pack itself	Temperature rise, leaking, igniting	Shorting test
Battery damage	Dropping, crushing, etc.	Temperature rise, leaking, etc.	Composite test (crushing + deterioration test)
Water penetration	Careless dropping into water	Swelling, inability to charge (corroded terminals)	Saltwater insertion test
Left under high temperatures	Leaving in car on a hot day, etc.	Capacity deterioration, swelling, leaking	High temperature test

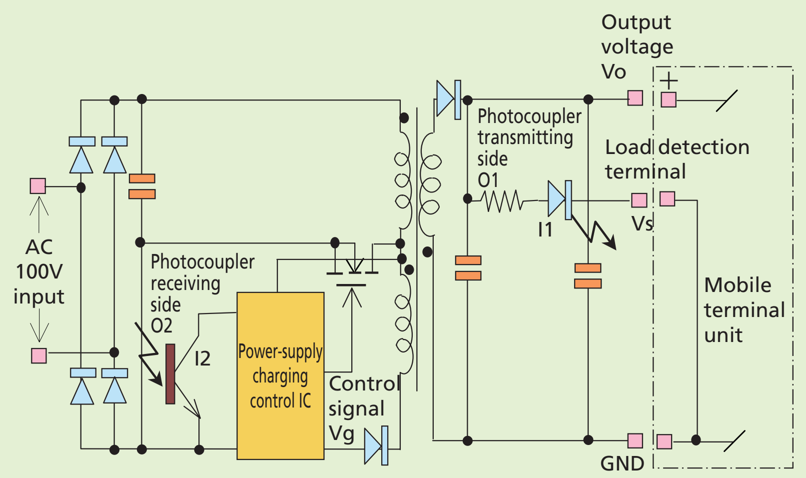

Figure 8 Prototype AC adapter with reduced standby power

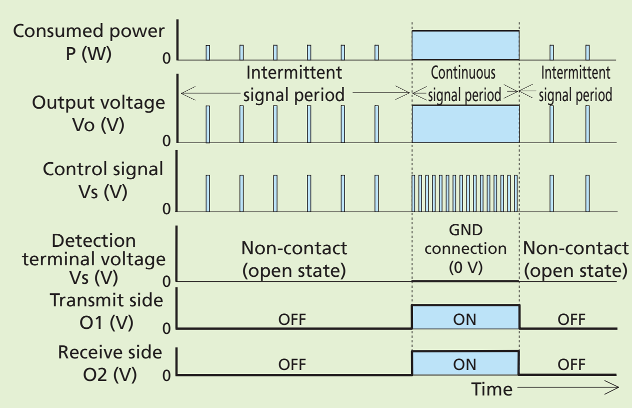

Figure 9 Control waveforms for AC adapter with reduced standby power

*9 **Standby power**: The power that flows in an electronic appliance connected to commercial power even when that electronic appliance is not operating. Its reduction is desired since it is not actually consumed power.

continuous signaling. This has the effect of reducing the power consumed during the intermittent signaling period in which the AC adapter is not being used. The introduction of intermittent signaling control results in a power savings of approximately one-fourth compared to conventional AC adapters (**Figure 10**). **Figure 11** compares daily power consumption by a commercial mobile-terminal AC adapter between 1999 and 2008 levels. As shown, the introduction of power-supply technology such as that described above has reduced power consumption to approximately one-tenth that used ten years earlier.

Furthermore, in an effort to provide common AC adapters for mobile terminals, we have unified electrical specifications as shown in **Figure 12**. We have prescribed electrical characteristics for output voltage and output current on the AC adapter side and electrical characteristics for the charging circuit on the mobile terminal side in match with those AC adapter characteristics.

5. Charging Options and New Technology

As a new technology for making the charging environment of mobile terminals even more comfortable, we have developed devices capable of charging a mobile terminal while the user is moving. **Photo 1** shows example of two such chargers for mobile-terminal use. The Li-ion charger shown in Photo 1(a) comes with a built-in Li-ion battery enabling a mobile terminal to be charged whenever needed. The USB charger shown in Photo 1(b) connects to a notebook computer, for example, to allow charging while performing data communications.

The above types of devices, however, still require external charging tools that may not always be convenient, and the need is felt for a charging infrastruc-

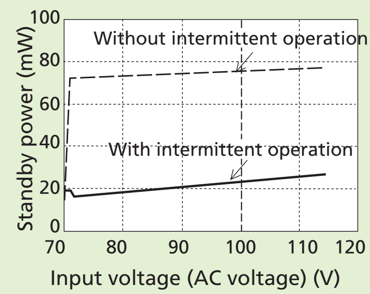

Figure 10 AC adapter standby power

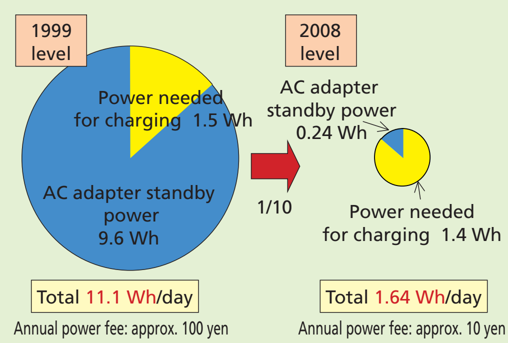

Figure 11 Comparison of daily power consumed by an AC adapter

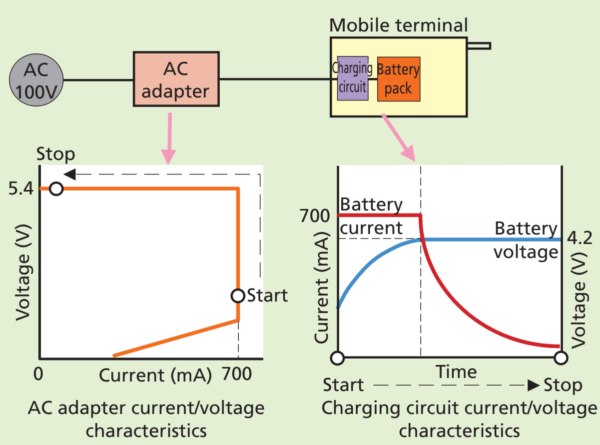

Figure 12 Charging control and common specifications of Li-ion battery

ture that would enable users to charge their mobile terminals with ease regardless of where they might be.

To this end, we are studying wireless power transmission (wireless charging*10) and next-generation Li-ion batteries and micro fuel cells*11 as technologies for a future charging infrastructure.

In wireless charging technology, the mobile terminal and the holder on the side of the transformer conventionally included in the AC adapter are spatially separated, a thin coil is incorporated in both the holder and the mobile terminal, and power is transmitted by bringing the two coils in proximity to each other (**Figure 13**). Although this technology has previously been achieved at a several-hundred-milliwatt level, we are now establishing technology of a several-watt class required by mobile terminals plus associated thin-coil technology [5].

(a) Li-ion charger

(b) USB charger

Photo 1 NTT DOCOMO external chargers (commercial products)

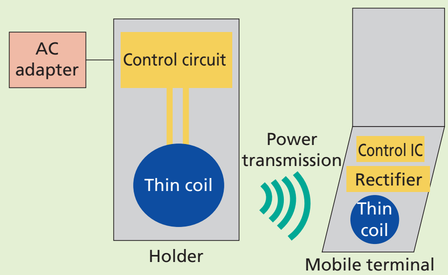

Figure 13 Outline of wireless charger

6. Conclusion

This article has described the state of development of batteries and chargers for mobile-terminal use. For the future, we plan to work on raising battery capacity and developing next-generation chargers and fuel cells with the aim of implementing new types of batteries in mobile terminals and contributing to a comfortable and enjoyable mobile society.

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*10 **Wireless charging**: Transmission of power without an electrical connection. Power transmission can be accomplished by an electromagnetic scheme, by optical means, by sound waves, etc.

*11 **Micro fuel cell**: A cell for generating electrical power by having hydrogen (fuel containing hydrogen) and oxygen react via an organic membrane. Refers in particular to compact fuel cells for mobile devices.