

## Meeting the Challenges of Switcher Charger IC Design

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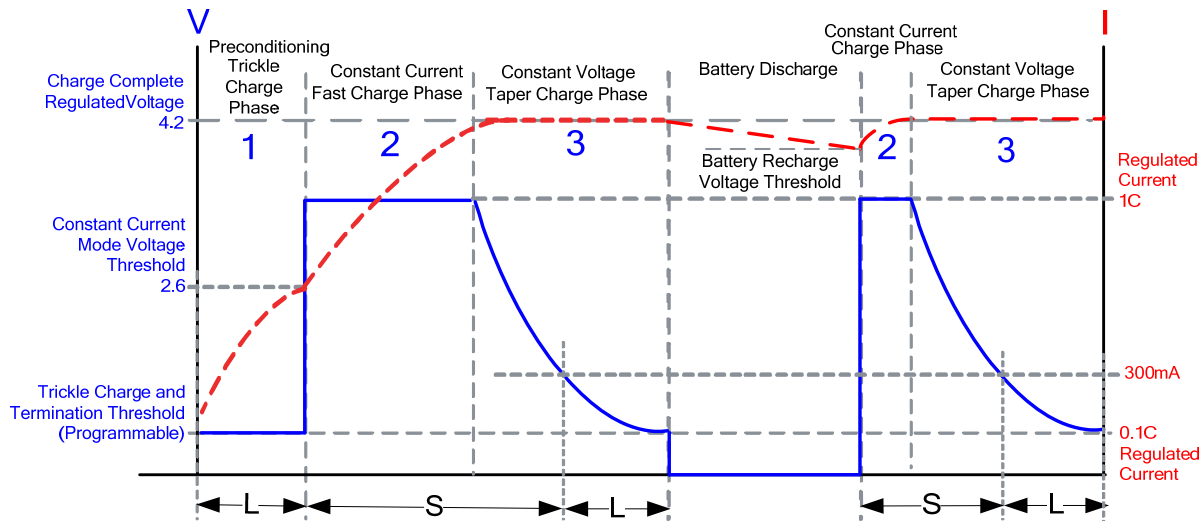
As portable system designers move to higher capacity batteries to support expanding feature sets, charger IC manufacturers are considering switching topologies to meet this growing need. While the linear charger ICs commonly used today to charge single-cell Lithium-ion batteries offer an attractive, low-cost, low noise solution, they can't deliver the higher efficiency levels needed to support higher charge rates and shorter charging cycles. Switchers, on the other hand, promise dramatically improved efficiency and higher charge rates, but present significant challenges in terms of noise, cost and footprint.

This article will take a look at the growing demand for switching charger ICs. It will examine the pros and cons of both switching and linear topologies and the unique and rapidly changing requirements for battery charger ICs in today's competitive portable systems markets. Finally, it will describe the innovative techniques some charger IC manufacturers are exploring that will allow them to take advantage of a switching charger's higher efficiency while minimizing noise, cost and footprint.

### Li-ion Batteries

Li-ion technology is currently the battery technology of choice for small portable devices. It is attractive because it offers tremendous flexibility in terms of size and shape. In its Li-polymer form, batteries can be adapted to fit a wide range of special circumstances in terms of cell size and shape.

Moreover, with proper state machine and safety features, Li-ion batteries can be easily charged using a proven charging algorithm which spans three charge modes: preconditioning, constant current or fast charge and constant voltage or taper charge. (See Figure 1). The preconditioning phase occurs when the battery is first used or has been discharged for a long time. The longest charge time of the three modes can be either during the constant current or fast charge mode or during the taper or constant voltage mode. The length of each mode depends on battery capacity and the charge capability of the charger. The figure below also illustrates a discharge phase during battery use and then a recovery into one of the three charge modes depending on the battery voltage level.



**Figure 1: Li-ion battery charging algorithm.**

### Linear Charging

Today's portable systems typically use linear battery chargers which are relatively easy to implement. As illustrated in figure 2, a typical linear battery charger requires a minimum number of external components. This type of charger also generates minimal noise because it uses no switching components. Its primary liability is relatively high power dissipation through the linear regulator pass FET. Therefore, as long as battery charging current requirements stay low, the linear charging topology offers an attractive option.

However, as portable system designers continue to reduce system footprint, and increase system complexity and power consumption, the higher power dissipation associated with linear chargers presents a significant problem. Consider the following: the voltage of a typical lithium-ion battery ranges from 2.7V to 4.2V. Maximum dissipation in the linear pass transistor occurs at maximum adaptor input voltage and minimum battery output voltage. For a typical 1A charging current, the charger's power dissipation can exceed 3 watts. Therefore, if the portable device user wants to both use the device and charge the battery at the same time, the charger will generate significant heat, potentially damage the system or the battery, and take longer to complete the charge cycle. Moreover, since users want to maximize run time, portable system designers have begun migrating to higher capacity batteries. These batteries require a higher charge current to achieve full charge in the same amount of time. Given their high level of power dissipation, linear chargers are not able to deliver these higher charge currents without wasting large amounts of energy and risking damage to the device.

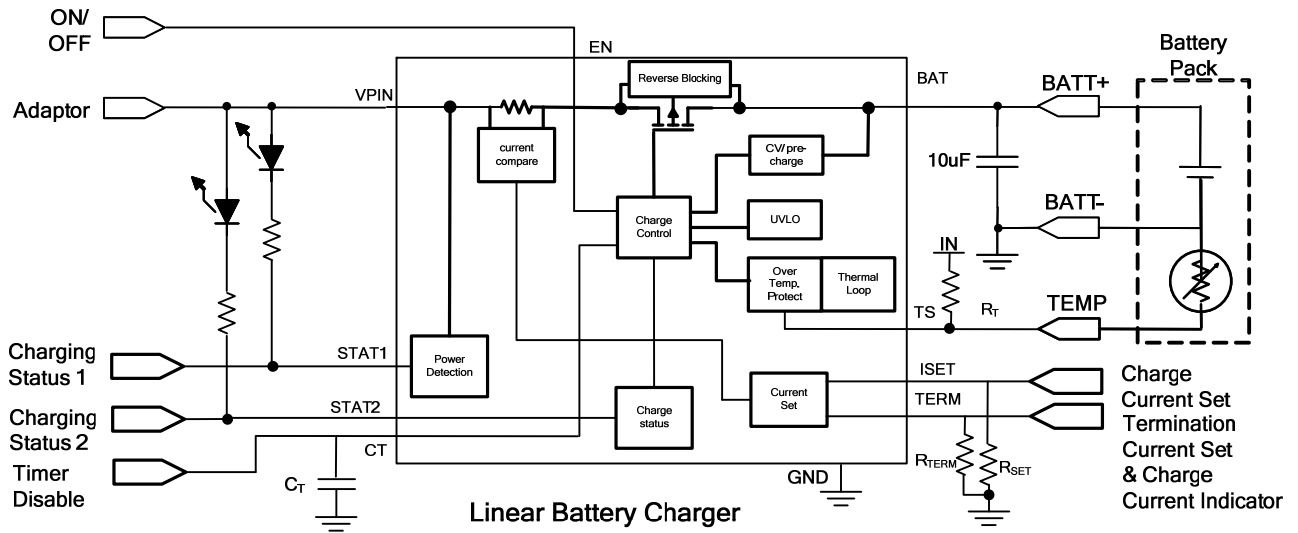
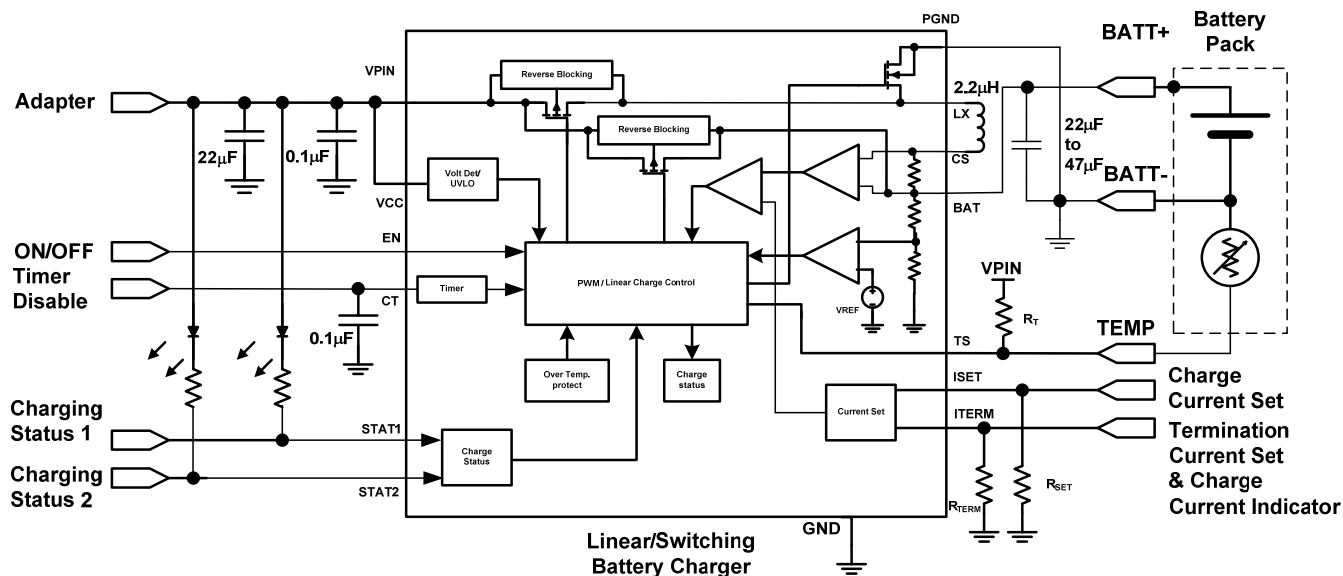


Figure 2 – Linear battery charger device with typical external components.

## Switching Battery Charging

As portable system designers move to higher capacity batteries and battery power density rises, they need a more efficient battery charging topology. By taking advantage of the higher efficiency of the switching devices and inductor, switch-mode battery charger ICs offer designers an opportunity to supply much higher current to the battery than comparable linear chargers while using less power.



**Figure 3 – Switching battery charger device with normal external components.**

However, most switching chargers suffer from noise generated by the switching function. This is due to the operation of the switcher during light load operation, particularly during preconditioning and taper charge modes. As the charge current decreases, some switching chargers will enter pulse skipping operation where the PWM frequency changes in an asynchronous manner. This characteristic causes system level EMI noise issues that are difficult to filter.

To address this problem and take advantage of the unique characteristics of both charging topologies, some power semiconductor manufacturers have begun to develop new battery charger designs that can supply high charge current with minimal thermal impact to the system using a switching charger and then switch into a linear charger during low current charging modes to minimize noise. This new type of PWM switch mode charger with a linear mode provides high efficiency at the full constant current (fast charge) rate. The switching charger controls the constant current charge mode up to 2.0A with a PWM switching regulator and automatically switches to linear mode during the battery preconditioning mode and near the end of constant voltage taper charge mode. This capability is especially useful when charging a portable device during the longer taper charge mode since the switch mode can be used to accelerate the charge cycle and, when the charge current level dips below 300mA, the linear mode takes over and noise generated by the switching converter is eliminated.

1. Preconditioning-Current Mode (Trickle) Charge – Linear Mode
2. Constant-Current (Fast) Mode Charge – Switching Mode
3. Constant-Voltage Mode (Taper) Charge – Switching/Linear Mode

## Linear vs. Switching Battery Charging

The switching charger performs battery charging using the benefits of the step-down or "buck" architecture to multiply the input current when stepping down the output voltage. This property is expressed mathematically in the comparison below, and provides the ability to maximize battery charging from current limited devices, as well as greatly decreasing power and heat related dissipation.

Example: Power Savings

Conventional Linear Charger IC:

$$P_D = (V_{PIN} - V_{BAT}) \cdot I_{BAT} = (5V - 2.8V) \cdot 1A = 2.2W$$

Switch-Mode Charger IC:

$$P_D := \frac{(V_{BAT} \cdot I_{BAT})}{\eta} - (V_{BAT} \cdot I_{BAT})$$

Where efficiency  $\eta = 90\%$

$$P_D = (2.8V \cdot 1A / 0.9) - (2.8V \cdot 1A) = 0.311W$$

Clearly at higher charge currents the higher efficiency of the switching charger offers significant power savings compared to the low efficiency linear charger which dissipates too much power and heat. During the lower current charging portions of the algorithm, however, the linear charger can meet charge requirements while significantly reducing noise. Furthermore, if the battery can accept a greater than 1A charge rate, the switching charger would complete the fast charge time very quickly. Another benefit of the buck switch-mode topology is in the use of lower current sources such as a current limited adaptor. The buck topology maximizes the effectiveness of any current limiting power source using the concept of current multiplication. So, for a maximum input current of 1.25A, a charger with an input voltage of 5V and operating at 90 percent efficiency, and a battery voltage of 2.8V, the battery charge current would be as high as 2A.

## Conclusion

Both linear and switching charging topologies offer distinct advantages. The low noise benefits of linear charging offer a better solution when charge currents are low, such as during the preconditioning and the lower end of the taper charge phase of the charge cycle. On the other hand, higher efficiency switch-mode charging, and its ability to quickly charge a battery at higher current without generating substantial heat, offers a better alternative during the higher current fast charge mode and the higher end of the taper charge mode. By using the best of both charging methodologies, the approach described in this paper offers portable system designers a new way to quickly charge a new generation of higher capacity batteries while minimizing the inherent noise of switch-mode power supplies.