

# Battery Emulation Circuit Speeds

A simulated load circuit verifies the dc response and dynamic stability of a Li-ion battery charger in a faster, more convenient manner than if an actual battery were used.

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Testing a Li-ion battery charger using its natural load (i.e., a battery) is time consuming because the charging process can take an hour or more. The test time varies widely, depending on whether you combine a fast-charge battery with a slow charger, a slow-charge battery with a fast charger, or something in between.

In any case, the charging process cannot be accelerated beyond a limit imposed by the battery's maximum charge rate. This is the so-called fast-charge current, and exceeding this limit may damage the battery. For normal batteries of the sort used in consumer products, this current is rarely specified above 1C — that's the current needed to fully discharge the battery in one hour. So the time required to carry the charger through the full cycle will be longer than two hours, in most cases.

If there is a need to repeat the test, you must discharge the battery in full — a process that is shorter than charging but not by much. Another option is to keep a supply of consistently discharged batteries on hand. A more convenient alternative to load testing with a real battery is to test the charger using a simulated but realistic load.

However, battery simulation, which should verify the charger circuit's dc response and dynamic stability, is difficult to implement with the standard bench loads used in power testing. That's because batteries — unlike most of the bench loads — do not behave as resistances or constant-current sinks. In addition, testing should step the charger through its entire operating range: through the transition from constant current to constant voltage (CC-CV) and on to charge termination. A dedicated charger test circuit satisfies all these requirements for battery simulation.

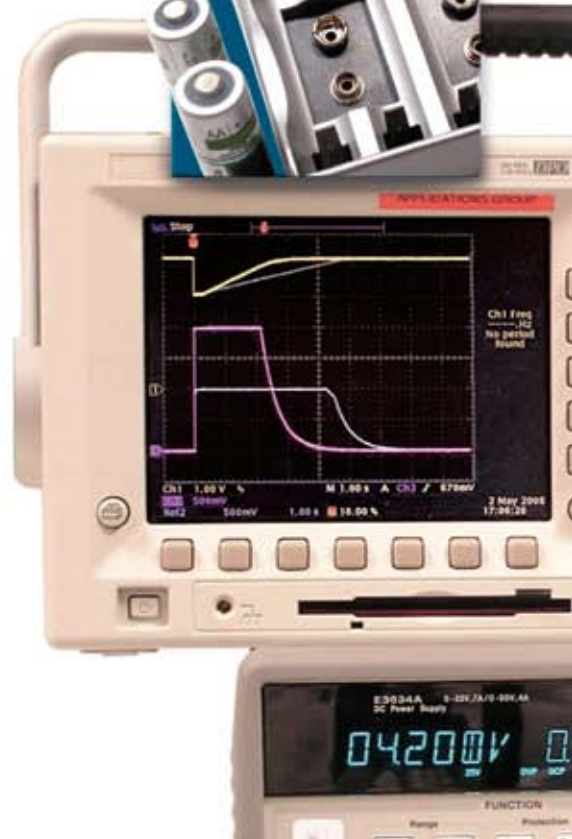
## Complex Charge Requirements

By virtue of the battery they are designed to charge, Li-ion battery chargers are more complex and accurate electronic power systems than chargers used for other battery types. A Li-ion battery needs a different type of charging process than other battery technologies, the CC in a first phase transitioning to the CV in the second phase.

A Li-ion battery also has unique requirements for charge process termination, which involves sensing that the battery has reached its full charge and that the charger must be disconnected or shut down. This is done by detecting, while in the CV phase, the point where the charge current is reduced to a small fraction (usually <10%) of the so-called fast-charge or maximum charge current.

Li-ion is also more delicate than other battery chemistries, with little tolerance for abuse. In addition, this chemistry demands high accuracy for the battery-charger current and voltage settings. Failure to provide the required accuracy can result in a severe reduction in battery life, failure to reach a complete charge and other degradations in battery performance.

Fig. 1 illustrates the V-I characteristic of a modern CC-CV integrated circuit (a MAX1737) used for a Li-ion battery charger. This type of IC is



# Charger Testing

the component at the heart of all Li-ion battery chargers for consumer products. In Fig. 1, the CC and CV regions are clearly shown. In the first region, battery voltage ranges between 2.6 V and 4 V. In the CV region, the battery voltage remains at 4.2 V.

The region below 2.6 V is different. If charging is attempted on a battery discharged below 2.6 V, the charger reduces the charging current to a low value (conditioning current) until the battery reaches the 2.6-V level. This is a safety mechanism made necessary by the behavior of Li-ion batteries when overdischarged. In other words, forcing a fast-charge current when  $V_{BATT}$  is less than 2.6 V can cause the battery to go into an irreversible short-circuit condition.

IC-based Li-ion battery-charger designs usually have two basic building blocks: a digital block (control state machine) and an analog block composed of a well-regulated current/voltage power supply and an accurate reference (better than 1%). A complete test of a Li-ion charger product (not just the IC) may be required at either the design/prototype phase or when verifying or troubleshooting production units. This testing is more involved and time consuming than just verifying some current or voltage values.

## A Battery-Modeled Load

To a first order, a battery can be modeled as a voltage source with capabilities for both current sourcing (discharge) and current sinking (charge), in series with a resistor representing the battery's internal resistance. Because Li-ion batteries demand precision limits for voltage termination and charge current, all Li-ion chargers today are, in effect, regulated power converters.

Another consideration is that the stability of a regulated power converter (the charger) depends on dynamic properties in the attached load (the battery). Consequently, you must choose a load that closely resembles the characteristics of the model. Otherwise, testing may only verify V-I limits in the charger itself.

A shunt power voltage regulator with a resistor in series to simulate the battery's internal resistance may be adequate if the test is a one-time task, and the simplest of battery models satisfies the test requirements. This approach also offers the advantage of being powered by the charger itself.

However, more rigorous testing requires a more elaborate model, whose internal voltage source is a function of the total electrical charge supplied to the battery during the charging process.

The voltage between terminals of a battery being charged at CC varies continuously and with a positive slope. The behavior is caused by the progressive reduction of depolarizing ions accumulated around the battery's cathode

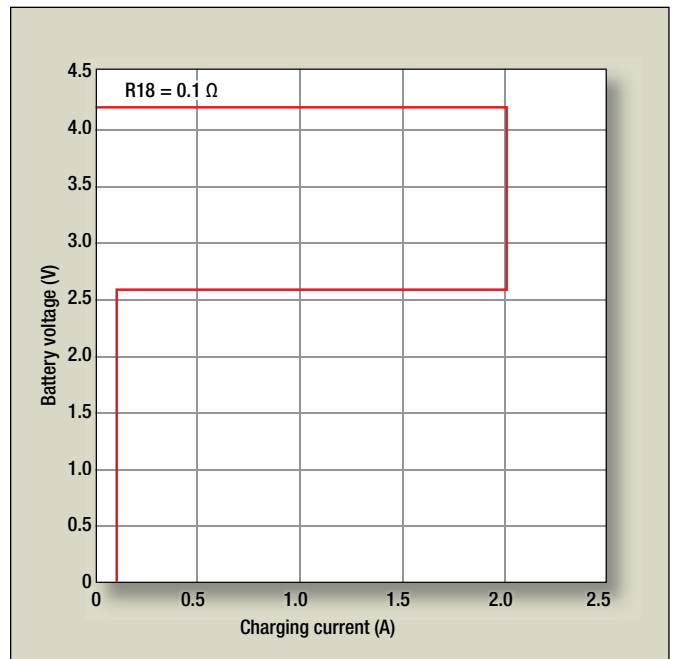


Fig. 1. This V-I curve is typical for lithium-cell chargers.

during discharge and other chemical processes internal to the battery.

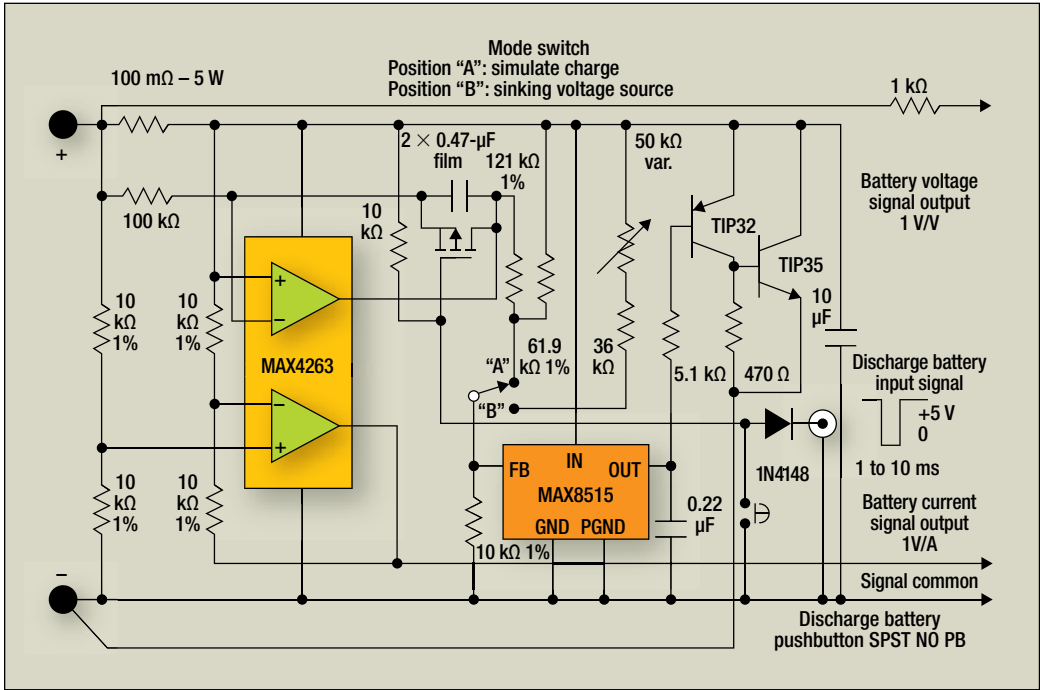
As a result, the charger's operating point depends on the length of time it has been connected to the battery and also on the battery's past history. A load that simulates this more complex model is harder to set up using the general-purpose instruments found in most electronics labs.

When charging circuits must be tested often or when circuit performance must be characterized in detail, a circuit that simulates more closely the battery under charge is a useful bench accessory. The simulation should sweep continuously through all dc operating points possible for the charger. Additionally, results should be displayed so operators can search for problems, glitches and oscillations. If the simulator provides outputs for the battery voltage and signal, these results can be presented directly as a scope shot.

The test can be accelerated (from hours to tens of seconds) and repeated as many times as necessary, making it much more convenient than tests with a real battery. But in such a case, you may need to conduct additional tests over a longer period of time to determine the thermal effects of power stress on the charger circuits. The longer test time may be needed to accommodate thermal time constants in the charger's power and regulation circuits, which may be longer than the accelerated test period.

## Building the Load

The circuit in Fig. 2 simulates a single-cell Li-ion battery. Both the termination voltage and the fast-charge current sourced during the charger's CC phase are commanded by settings on the charger. The internal battery voltage is set at 3 V when the simulator is initialized to the fully discharged



**Fig. 2.** By simulating the behavior of a single lithium cell under charge, this circuit lets you test Li-ion battery chargers without using real batteries.

accommodate nonstandard levels of termination voltage and fully discharged voltage.

The charger under test drives the simulator with charging currents as high as 3 A, subject to a limit set by dissipation in the power transistor. The battery-voltage increase simulated by the Fig. 2 circuit is a function of all charging current integrated by that circuit from the moment the simulator is set to the fully discharged state.

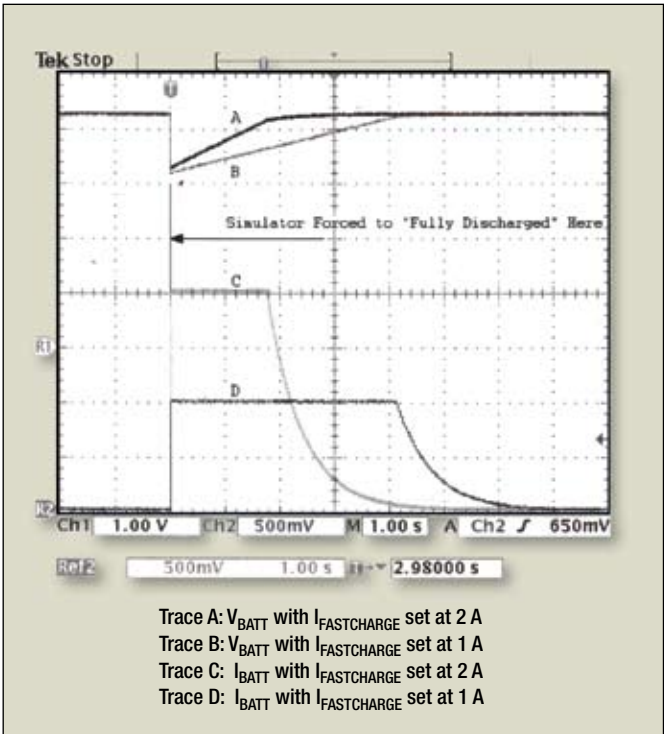
condition, but that level can be raised to 4.3 V for testing an overcharge condition.

The 3-V initialization is typical for the low-battery shutdown circuits used to terminate the discharge of Li-ion batteries. This design is intended for use with standard CC-CV-type Li-ion battery chargers that terminate the charge at 4.2 V. But the circuit can be easily tweaked to

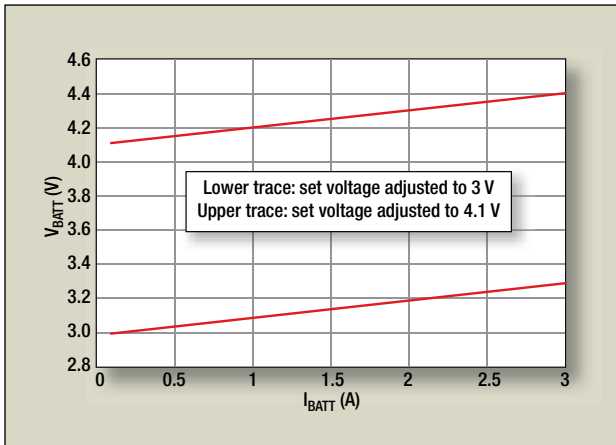
integrated by that circuit from the moment the simulator is set to the fully discharged state.

With the values shown and a 1-A charging current, the integrating time constant is such that the simulator reaches the charger's 4.2-V limit in 6 seconds to 7 seconds. This simulation of current range, internal resistance, charge-termination voltage and fully discharged voltage is based on the specifications of a typical Li-ion cell. In this case, a Sony US18650G3 consumer product battery type is used. The simulated battery voltage does not include a simulation of ambient-temperature effects.

The shunt-power voltage regulator is designed around a MAX8515 shunt regulator and a pair of bipolar power transistors. This regulator was selected for the accuracy of its internal voltage reference. The high-current TIP35 transistor is attached to a heatsink capable of dissipating about 25 W.



**Fig. 3.** Taken from the Fig. 2 cell-simulator circuit, these fast-charge waveforms show the demands on a battery charger delivering 1 A (traces B, D) and 2 A (traces A, C).



**Fig. 4.** The slope of these waveforms, which represent the Fig. 2 circuit sinking current at 4.1 V (top trace) and 3 V (bottom trace), indicates that internal resistance is 0.1  $\Omega$  in both cases.

One-half of the MAX4163 dual op amp integrates the charge current, while the other half amplifies and level-shifts the current-measurement signal. These op amps' high power-supply rejection ratio and rail-to-rail input and output ranges simplify the circuit design for both functions. Note that the 0.100- $\Omega$  current-sense resistor, in series with the positive side of the battery simulator, also serves as the battery's internal resistance.

The simulator can be reset to the fully discharged state either by an external signal, when operating in a system with automated test-data acquisition, or by the push button shown when the test setup is manually operated. A single-pole, double-throw switch lets you choose one of two modes of operation for the simulator. In position "A," it operates as an integrating-charge simulator, as described.

In position "B," it assumes a set output voltage and sinks current as necessary for spot testing a charger at a fixed dc operating point. For that purpose, the set voltage can be manually adjusted between 2.75 V and 5.75 V by the 50-k $\Omega$  variable resistor. These set-voltage values refer to the internal sinking source.

The voltage actually measured between the simulator terminals ( $V_{BATT}$ ) equals the set voltage plus a drop caused by sink current flowing in the simulator's internal resistance (the 0.100- $\Omega$  resistor). All the power necessary for operating the simulator comes from the output of the battery charger.

Fig. 3 shows the typical V-I waveforms obtained while simulating the charging of a Li-ion battery up to 4.2 V. Two test runs are shown, one with an initial fast-charge current of 1 A (traces B, D), and one with a fast-charge current of 2 A (traces A, C). In both cases, the CC phase continues until the termination voltage reaches 4.2 V. After that point, current decays exponentially while the simulated battery voltage remains constant.

The shorter time to termina-

tion for the 2-A run is just what you'd expect after doubling the charging current for a real battery. Notice, however, that doubling the current does not halve the total charge time, it only halves the time required to reach the CV mode, as is the case with a real battery.

Fig. 4 shows the V-I curves obtained when sinking current at two different set voltages: 3 V and 4.1 V. For both curves, the dynamic resistance (indicated by slope) is simply the internal resistance simulated by the 0.100- $\Omega$  resistor.

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