# LEAD-ACID BATTERY CHARGER SIGNALS END OF CHARGE

## APPLICATION

Lead-acid batteries have always been the best choice for starting cars, but recent improvements have allowed them to be used in consumer applications previously dominated by Ni-Cd batteries. The lead-acid gel-cell battery (with energy densities exceeding 120 W-hr/litre) now enjoys almost total market share as the power source for full-size VHS camcorders, and also sees service as back-up power in alarms and memory systems.

This design presents a charger which can be used with either gel-cell or wet-cell lead-acid 12V batteries. The proper temperature compensation for the charger output voltage is built in, as well as a detector which signals when the battery is fully charged.

## BATTERY REQUIREMENTS

A lead-acid charger is best charged from a current-limited voltage source, which will source current into the battery until it reaches the voltage set point. The charger should then supply just enough current to keep the battery voltage held at this value.

For “12 V” lead-acid batteries, a set point voltage of about 13.5V @ 25 °C is typically used. However, this “optimum” voltage set point is temperature dependent: a temperature coefficient of approximately -22 mV/°C is recommended by battery makers so that the charger set voltage will track the T.C. of the battery.

<u>FULL CHARGE DETECTION</u>: The state-of-charge of a lead-acid battery can be determined by its voltage and charging current. When charged from a voltage source set to 13.5V, the charging current will gradually taper off to a very low value (typically about 1% of the Amp-hour rating of the battery) when the battery is fully charged.

In this design, a “full-charge detector” circuit is included which lights an LED when the current drops below this threshold.

## **CIRCUIT DESCRIPTION** (Refer to schematic)

A charger using a current-limited voltage source is built using a 12V @ 0.5A wall transformer and an LM2941CT voltage regulator.

The wall transformer provides the unregulated DC voltage to U3 which is used to charge the battery and hold its voltage at 13.5V. R13, R14, and diodes D3 - D12 set the regulator output voltage. R14 should be adjusted for an output voltage of 13.5V with the battery disconnected.

The diodes are used to establish the negative TC output needed to match the battery terminal voltage. Measurements made on some 1N4148 diodes @ 1 mA showed a TC of -2.2 mV/ °C, so ten in series will provide the -22 mV/ °C required TC.

R15 and D13 indicate when power is applied or when a battery is connected to the output, and also provide minimum required loading for U3. C6 is necessary for stability of regulator U3.

An important characteristic of any wall transformer is **poor load regulation**: For example, the one specifiedß here puts out 12V when loaded to 0.5A, but it will put out about 17 - 18V with no load applied. This “feature” is exploited in this design, because it means the regulator U3 will require no heatsink.

A discharged battery will have a terminal voltage of about 10 - 12V. If the battery is connected to the charger output, U3 will fully turn on (saturate) its pass transistor so that it is conducting all of the current it can to try to force the battery voltage up to the set point (which is 13.5V). This means that while the battery is below 13.5V, U3 acts as a current source, with the amount of charging current being limited by the maximum that the wall transformer can provide at that voltage.

As the battery charges (and it’s voltage rises) the amount of current that the wall transformer can provide reduces. In this case, with a battery voltage of 11.5V (where the transformer output voltage is 12V), about 0.5A (maximum) charge current is available. By the time the battery reaches 13.5V, a maximum of only about 250 mA is available.

Note that while U3 is in the “current source” mode, the voltage drop across U3 is about 250 mV, which means the power dissipation will be less than 0.2W. Because of this, U3 requires no heatsink.

The regulator U3 will remain fully turned on until the battery voltage reaches 13.5V, and then U3 will reduce the charging current as required to maintain this voltage across the battery. At this point, the U3 is operating in “constant voltage” mode.

## DETECTING FULL CHARGE:

As a lead-acid battery is charged at constant voltage (13.5V in this design) the charging current continually decreases until it reaches its final value (typically about 1% of the Amp-hour rating of the battery). This charger can be calibrated to correctly detect full charge of any battery up to about 10 A-hr capacity by adjusting R7.

The charging current is measured as the voltage drop across R4. Diode D1 turns on and shunts current around R4 when ever this voltage exceeds about 0.2V, which minimizes power dissipation in R4.

Because of D1, the measured voltage across R4 only reads the charging current accurately when I < 0.2A. However, since the end-of-charge detection will occur at currents where I < 0.1A, this range of measurement is more than adequate.

U2A is a differential amplifier with unity gain, used to take the voltage drop across R4 and level shift it down to where the signal is with respect to ground. U2B takes this signal (which is proportional to the charging current) and compares it to a reference voltage coming from the pot R7 through R9.

When the load current drops low enough that the voltage at pin 6 of U2B drops below pin 5, the output pin 7 will swing high and turn on D2 which indicates the battery is fully charged.

The best way to calibrate the end-of-charge detection circuit is to let the battery fully charge, and then turn R7 until D2 just comes on.