Application Note 26

Fast charging batteries with Zetex high current PNP transistors and benchmarq controller ICs

Neil Chadderton

Introduction

The advances of digital technology and a waiting market have created a huge demand for portable products including cellular telephones, PDAs, laptop computers, CD players, and gaming systems. By their nature, all of these products must derive their energy from an integral rechargeable cell/battery pack that must periodically be re-charged from a mains outlet. The type of battery employed, or its chemistry, depends on the overall pricing available to the product - this will depend on the perceived product lifetime, the required energy/weight ratio, and which marketable advantages there may be apparent from reducing the number of re-charge cycles.

For the latest generations of products, users are expecting higher performance, less re-charge cycles, longer battery pack life and faster charge times. All of these parameters are very dependent on the manner in which the cell or battery pack is treated during the charging process. This includes consideration of the preferred cell charging method, thermal concerns, and pre-charge conditions.

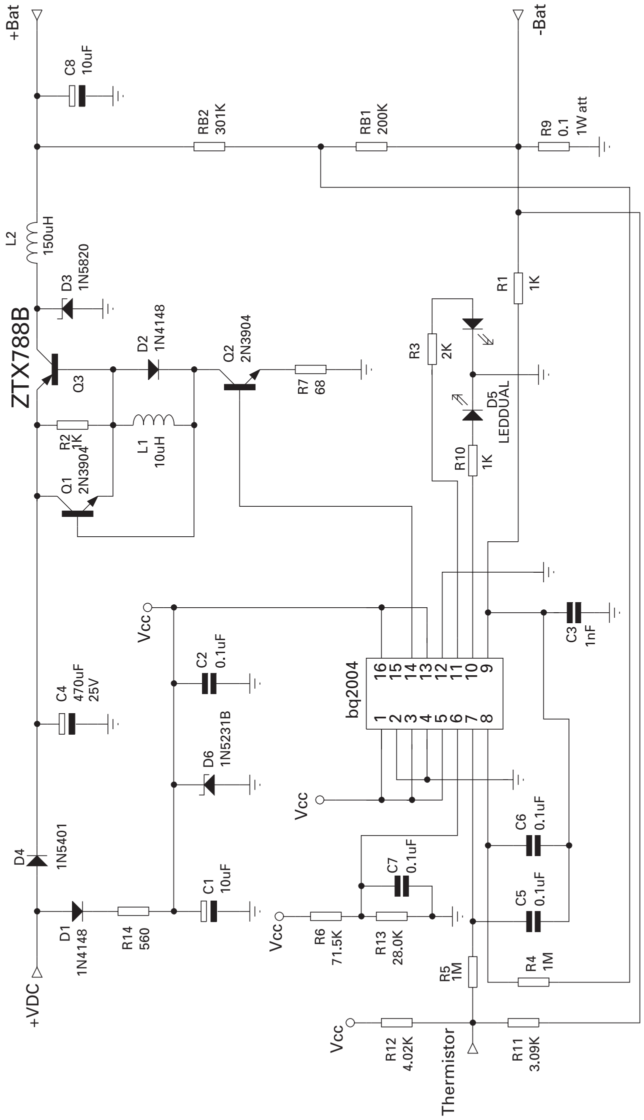
Fast charge controller ICs

There are a number of fast charge controller ICs available that perform all the necessary monitoring and regulation control functions on one monolithic IC. The Benchmarq Microelectronics series of fast charge controller ICs monitor the terminal voltage to determine state of charge, and also the temperature of the battery pack (via a thermistor) to prevent deterioration of the separator material. Fast charge termination is effected by any of the following:

Delta temperature/delta time ($\Delta T/\Delta t$)
Negative delta voltage ($-\Delta V$)
Maximum temperature
Maximum time
Maximum voltage

To allow cost effective IC designs, typical fast charge controller ICs are manufactured on existing CMOS processes, that do not readily lend themselves to incorporating on-chip pass elements within system cost constraints. Therefore the IC controls an external discrete transistor that is used within a linear regulator, or a step-down frequency modulated DC-DC converter topology to provide a suitable current source for charging.

Figure 1. Fast charge circuit (Benchmarq Microelectronics) using the ZTX788B



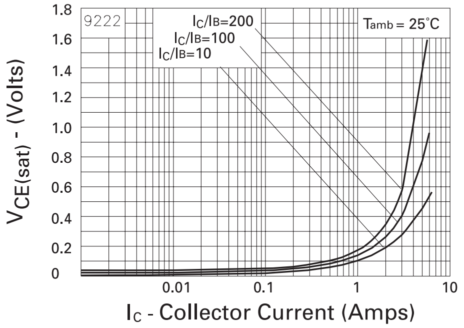
In general, switched mode circuits are preferred due to the higher efficiencies possible, and the smaller packaged pass devices required to perform the sourcing function. For example, a comparison of the power losses for a four `C' cell battery pack charged from a 12V DC source at 2A, leads to values of greater than 12W for the linear control system, but less than 2W for the switched mode option.

The external pass transistor used within either circuit mode can be either a PNP Bipolar or a P-Channel MOSFET. For the linear regulator mode, the device must be capable of being heatsunk to remove the power dissipated, which will probably dictate that the product will be a large packaged, large silicon area device which **will** define a costly component. For the switched mode option, there is more choice available. Due to the higher silicon efficiency of the Bipolar technology compared with MOSFETs, high current fast switching PNP transistors are available that use a fraction of the silicon area required for comparably specified MOSFETs. This allows the bipolar chip option to be encapsulated within a smaller package, and therefore presents a lower cost to the designer.

The circuit shown in Figure 1 is one example of a circuit topology developed by Benchmarq using Zetex E-Line PNP transistors. The circuit allows the fast charging of Ni-Cd or Ni-MH battery packs for laptop computers and similar powered portable systems at a charge current of 2.3A, (defined by the current sense resistor R9). The potential divider formed by RB1 and RB2 is used to feedback a cell corrected level to the IC voltage sense input, that is then used to define the battery pack voltage. Other ICs/circuits are available from Benchmarq for higher current charging and for other cell chemistries.

The PNP transistor chosen for this particular application was the ZTX788B - one member of the ZTX788B to ZTX796A series. These devices are manufactured using a high gain emitter process to produce a Super-β h_{FE} range. The ZTX788B is a 15V, 3A continuous TO92 compatible part that exhibits very low $V_{CE(sat)}$, and can therefore replace much larger packaged components (such as TO220, TO126 and D-Pak) in switching applications. Figure 2 demonstrates the on-state voltage of the `788B as a function of load current with base drive current as parameter. Tables 1, 2 and 3 (Appendix A) summarize the pertinent parameters for the ZTX788B and other devices of interest for this application.

Figure 2. $V_{CE(sat)}$ v collector current chart for the ZTX788B



The circuit employs a circuit modification to provide an active turn-off for the transistor. [This doesn't however impact on the cost advantage over the MOSFET alternative]. Figure 3 shows the area around the pass transistor with the relevant level shift and turn-off components. The small signal switching transistor Q2, provides level translation from the "MOD" output of the controller IC, and its emitter resistor defines the base current for Q3, the ZTX788B. The inductor L2, Schottky diode (1N5820), and the 10µF capacitor are the Buck converter (step-down) components. The 1k base emitter resistor for Q3 would, in the absence of Q1, L1 and the signal diode (1N4148), provide passive turn-off for the pass transistor.

Figures 4 and 5 help to demonstrate the difference in turn-off performance for the two methods. These waveforms were recorded from a charger circuit using the bq2004 and ZTX789A for a 5 cell battery (output voltage to charge to 6V), and an input voltage of 12V. Both figures show the output from the IC controller (from the "MOD" pin), and the voltage from the collector of the ZTX789A with respect to ground.

Figure 3. Active turn-off circuit for Bipolar transistors, allowing high efficiency DC-DC conversion at high frequency

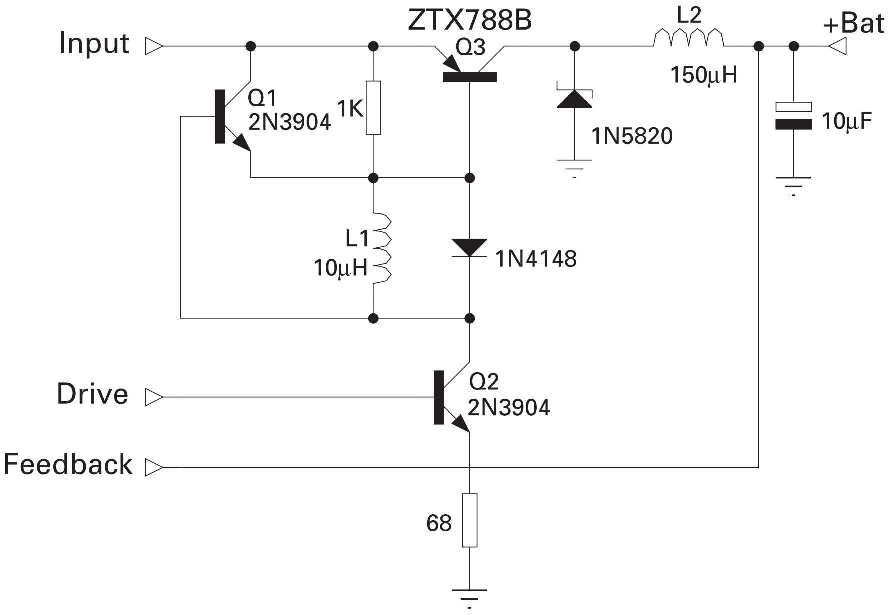


Figure 4. Oscillograph of charger circuit employing passive turn-off for ZTX789A, showing:
1. Collector-to-0V waveform, and
2. IC “MOD” drive waveform. Note bipolar transistor storage and fall times. Channel 1: 5V/div, Channel 2, 2V/div, timebase at 2µs/div

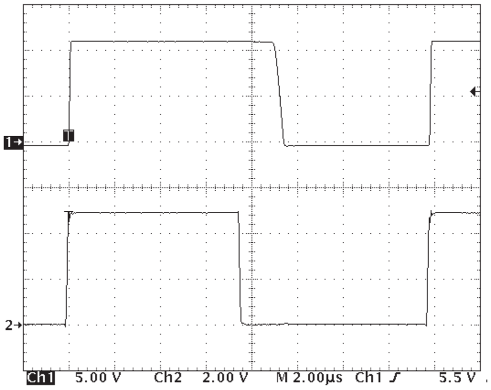


Figure 4 shows the turn-off produced with a passive turn-off circuit - a resistor. The storage time of the bipolar transistor, or the time from the falling edge of trace 2 to the start of the falling edge of trace 1 is shown to be 1.6µs, and the fall time is 340ns. This fall time could represent a major power loss contributer and therefore would (under some circumstances) serve to limit the maximum load current.

Figure 5. Oscillograph of charger circuit employing active turn-off for ZTX789A, showing:
1. Collector-to-0v waveform, and
2. IC “MOD” drive waveform. Note bipolar transistor storage and fall times. Channel 1: 5V/div, channel 2, 2V/div, timebase at 2µs/div

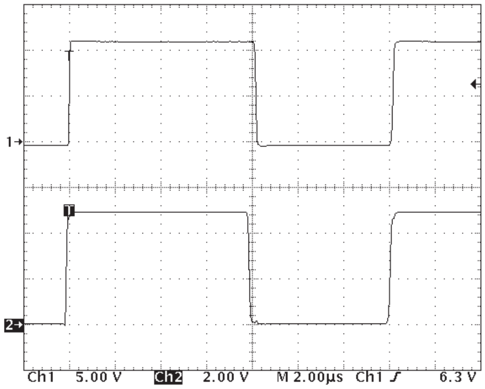


Figure 5 shows the turn-off produced with an active turn-off circuit as shown in figure 3. The storage time has reduced to less than 200ns, and the fall time to 90ns. These switching values are comparable to, or better than the large P-Channel MOSFETs that would otherwise be specified, and allow the bipolar device to be operated to much higher currents than possible with passive turn-off circuitry.

Appendix A

Device	B_{VCEO}	$I_{C(DC)}$	I_{CM}	h_{FE} @I_C/V_{CE}		$V_{CE(sat)(max.)}$	@I_C/IB	Package
FMMT717	12V	2.5A	10A	275(typ)	2.5A/2V	140mV	1A/10mA	SOT23
ZXT13P12DE6	12V	4A	15A	450(typ)	1A/2V	90mV	1A/10mA	SOT23-6
ZXT13P20	20V	4A	10A	450(typ)	1A/2V	130mV	1A/10mA	SOT23-6

Table 1. PNP transistors for fast chargers <1A.

Device	B_{VCEO}	$I_{C(DC)}$	I_{CM}	h_{FE} @I_C/V_{CE}		$V_{CE(sat)(max.)}$	@I_C/IB	Package
ZTX788B	15	3	8	300 min	2A/2V	450mV	2A/10mA	E-Line
FZT788B	15	3	8	300 min	2A/2V	450mV	2A/10mA	SOT23-6
ZTX789A	25	3	8	200 min	2A/2V	450mV	2A/20mA	E-Line
FZT789B	25	3	8	200 min	2A/2V	450mV	2A/20mA	SOT23-6
ZTX90A	40	2	6	200 min	1A/2V	450mV	1A/10mA	E-Line
FZT90A	40	2	6	200 min	1A/2V	450mV	1A/10mA	SOT23-6
ZTX949	30	4.5	20	140(typ)	5A/1V	320mV	5A/300mA	E-Line
FZT949	30	4.5	20	140(typ)	5A/1V	320mV	5A/300mA	SOT23-6
ZTX951	60	4	15	140(typ)	4A/1V	300mV	4A/400mA	E-Line
FZT951	60	4	15	140(typ)	4A/1V	300mV	4A/400mA	SOT23-6

Table 2. PNP transistors for fast chargers 1 to 4A.

Device	B_{VCEO}	$I_{C(DC)}$	I_{CM}	h_{FE} @I_C/V_{CE}		$V_{CE(sat)(max.)}$	@I_C/IB	Package
FZT1147A	12V	5A	20A	340(typ)	2A/12V	130mV	1A/6mA	SOT223
FZT1148A	25V	4A	10A	320(typ)	2A/2V	240mV	1A/7mA	SOT223

Table 3. PNP transistors for linear and switch mode high current (5A) fast chargers.

Application Note 26
ISSUE 2 - SEPTEMBER 2003

Europe

Zetex plc
Fields New Road
Chadderton
Oldham, OL9 8NP
United Kingdom
Telephone (44) 161 622 4444
Fax: (44) 161 622 4446
hq@zetex.com

Zetex GmbH
Streitfeldstraße 19
D-81673 München

Germany
Telefon: (49) 89 45 49 49 0
Fax: (49) 89 45 49 49 49
europe.sales@zetex.com

Americas

Zetex Inc
700 Veterans Memorial Hwy
Hauppauge, NY 11788

USA
Telephone: (1) 631 360 2222
Fax: (1) 631 360 8222
usa.sales@zetex.com

Asia Pacific

Zetex (Asia) Ltd
3701-04 Metroplaza Tower 1
Hing Fong Road
Kwai Fong
Hong Kong
Telephone: (852) 26100 611
Fax: (852) 24250 494
asia.sales@zetex.com

These offices are supported by agents and distributors in major countries world-wide.

ZETEX
SEMICONDUCTORS