Application Note 40

Lithium Ion Battery Charging Using Bipolar Transistors

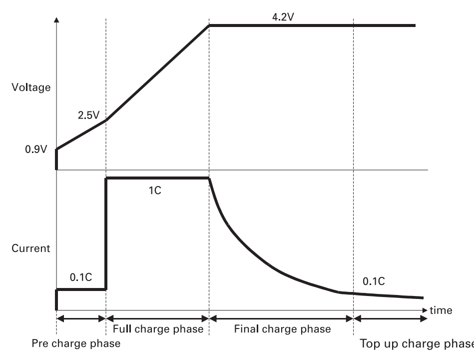
Introduction

Portable applications such as cell phones are becoming increasingly complex with more and more features designed into every generation. This increasing number of features combined with a requirement for smaller size and extended battery life has made Lithium batteries the preferred choice for many of these applications. Lithium batteries have improved in technology with advances in electrodes to provide a flatter discharge characteristic to improved chemistries such as Lithium polymer. More stringent requirements are being placed on manufacturers to improve charge time, maximize battery lifetime and reduce size. This application note will discuss the different types of charge techniques and associated discrete pass elements, highlighting the dominant discrete parameters and selection criteria for each charging technique.

Lithium Ion battery charge cycle

In order to model the losses within the charging circuit we have to understand the charging cycle of the Lithium Ion battery. Figure 1. shows a typical charging cycle for a carbon electrode Lithium Ion battery.

Figure 1



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As shown the charge cycle is split into four cycles:

i) Pre charge phase

This phase is for recharging deeply discharged cells by topping up the charge in the battery so that normal charging can take place without damage. Charging current is typically set to 0.1C while the battery's deep cell discharge voltage reaches its cut-off voltage threshold.

ii) Full charge phase

Once the cut-off voltage threshold is reached constant current charging at 1C begins until the battery reaches its upper voltage threshold. This charging phase only takes a short time when compared to the batteries charging cycle.

iii) Final charge phase

The start of constant voltage charging phase is determined when the battery voltage reaches its upper voltage threshold. The battery voltage is maintained at its upper voltage threshold while the charging current decays exponentially from 1C to 0.1C, as a consequence of an increase in the internal resistance of the battery. The final charge phase takes the majority of time during the batteries charging cycle and thus most of the power dissipated in the pass element is during the phase.

iv) Top up charge phase

In the top up charge phase, trickle charging is employed to maximize battery capacity. The battery voltage is maintained at its upper voltage threshold and charging current set to 0.1C for a fixed time period.

The typical charge cycle for a lithium ion battery is 3 hours.

Charge Conditions

There are various types of lithium ion batteries with different termination voltages and capacity. The specification below represents the battery we used in this applications note.

Battery: single Li-Ion with carbon electrode

Deep cell discharge voltage = 0.9V

Battery cut-off threshold = 2.5V

Battery upper voltage threshold = 4.2V

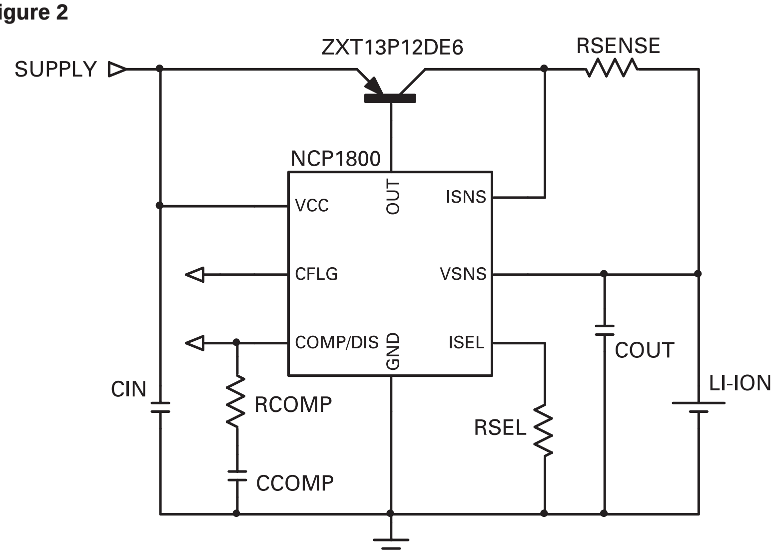
1C = 600mA.

There and three main topologies for charging the batteries, switch-mode, linear and pulse charging each with advantages and disadvantages for differing applications. Switch-mode chargers offer the best efficiency and faster charging currents but have the disadvantage of a more complex design - due to the complex output filter arrangement. Consequently they are typically used where higher charge currents are required, such as notebook computers. For this reason we will concentrate on Linear and Pulse charging in this application note.

Battery charging using linear chargers

Linear chargers are simple in design, small and have no noise making them suitable for low noise environments. They use an external pass element to drop the battery voltage from the input supply to the battery voltage thus power dissipation is high. Bipolar PNP transistors are advantageous in this application because the MOSFET requires a Schottky diode in series to prevent current flowing from the battery to the supply, through its body diode. For this application note a NCP1800 linear charger form OnSemi combined with a Zetex ZXT13P12DE6 bipolar transistor were used for reference. A supply voltage of 5V, a base current of 20mA and base-emitter voltage of 0.8V were assumed. Figure 2. Shows a typical linear charger circuit diagram.

Figure 2



The losses were broken down into their component parts and are given in the formulae opposite.

$Pd_{(IC)} = V_{CC} \times I_{SUPPLY}$ (W)

$Pd_{(SENSE)} = I_{CHG}^{2} \times R_{SENSE}$ (W)

$Pd_{(BASE)} = V_{BE(ON)} \times I_{B}$ (W)

$Pd_{(CE)} = I_{CHG} \times (V_{IN} - V_{DCD} - V_{SENSE}$ (W)

where $V_{SENSE} = I_{CHG} \times R_{SENSE}$ (V)

$Pd_{(TOTAL)} = Pd_{(SENSE)} + Pd_{(BASE)} + Pd_{(CE)}$ (W)

From these formulae we can model, show in graphical format and identify which are key parameters for the discrete element.

The charts below show the losses for each charging phase of the lithium ion battery.

Figure 3 Pre charge phase

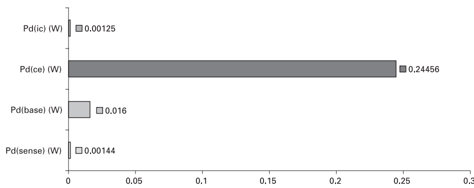


Figure 4 Full charge phase

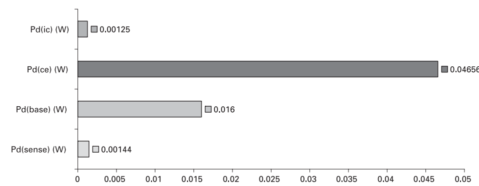


Figure 5 Final change phase

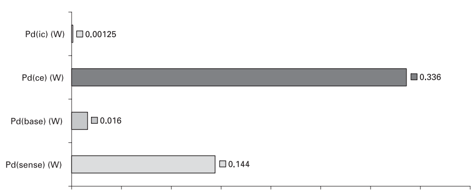
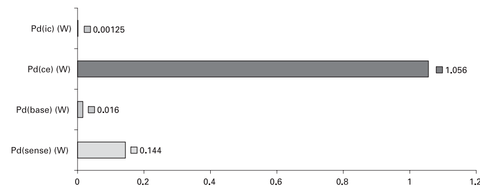


Figure 6 Top up charge phase



Conclusion

From the power dissipation breakdown charts you can see that dominant loss during all phases of the battery charging cycle is the on state loss of the pass element. The power dissipated in the final charge phase is most significant because it represents the bulk of the charging time during the whole cycle. Therefore the key parameter to consider in the pass element is the packaging. Bipolar transistors also offer a cost-effective alternative to MOSFETs because there is no requirement for a series Schottky diode.

The table in Figure 7. shows a selection of Zetex transistors, which are suitable for linear charging lithium ion batteries.

Figure 7

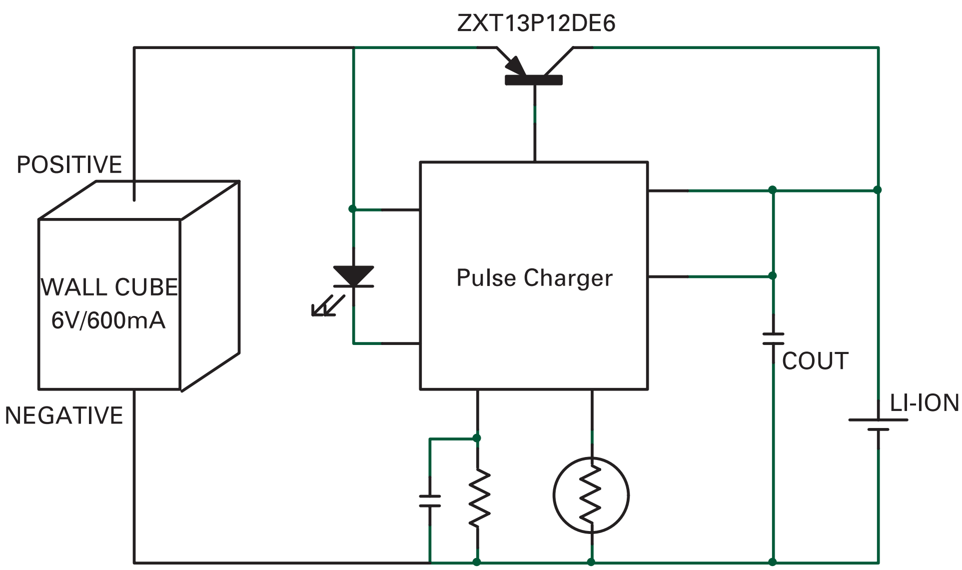
Part number	V_{CEO} (V)	I_C (A)	hFE @ I_C/V_{CE}	Package	Pd (W)
FMMT717	12	2.5	180min @ 2.5A/2V	SOT23	0.625
FMMT718	20	1.5	150min @ 2A/2V	SOT23	0.625
ZXT10P12DE6	12	3	160min @ 2.5A/2V	SOT23-6	1.1
ZXT10P20DE6	20	3	150min @ 2A/2V	SOT23-6	1.1
ZXT13P12DE6	12	4	200min @ 4A/2V	SOT23-6	1.1
ZXT13P20DE6	20	3.5	200min @ 3.5A/2V	SOT23-6	1.1
ZXT1M322	12	4	180min @ 2.5A/2V	MLP322	1.5
ZXT2M322	20	3.5	150min @ 2A/2V	MLP322	1.5
FZT788B	15	3	300min @ 2A/2V	SOT223	2
FZT1147A	12	5	750min @ 4A/2V	SOT223	2.5
FZT968	12	6	200min @ 5A/2V	SOT223	3

Battery charging using pulse chargers

Pulse chargers use a current limited wall adapter to supply a regulated constant current to the battery, whilst the charge controller IC monitor the batteries voltage, temperature and charging time. The charging current is switched on and off during the final charge phase to provide an average current to the battery. The transistor is in saturation during the on period. This method limits' the power dissipated in the transistor during the charging phase when compared to linear charges, allowing effective use in space restricted applications such as cell phones.

Figure 8. shows a typical circuit using a popular pulse charger and a Zetex bipolar transistor as a pass element.

Figure 8



From the pulse charging algorithms (please note the charging algorithms vary between pulse charger manufacturers) we can model, show in graphical format and identify which are key parameters for the discrete element.

The charts below show the losses for each charging phase of the lithium ion battery.

Figure 9 Pre charge phase

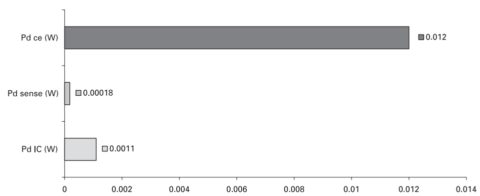


Figure 10 Full charge phase

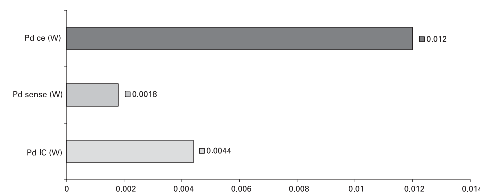


Figure 11 Final change phase

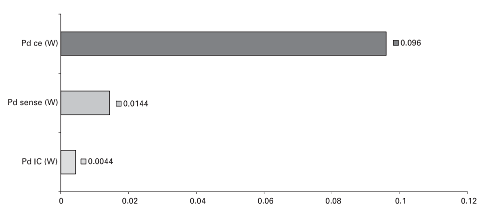
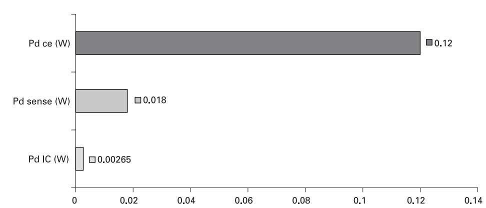


Figure 12 Top up charge phase



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Conclusion

From the charts you can see that power dissipation losses are minimized due to the transistor being in saturation and switching on and off. So the key parameter to consider when selecting a bipolar transistor for this application is its saturation voltage, $V_{CE\ (SAT)}$.

The table in Figure 13. shows a selection of Zetex transistors, which are suitable for pulse charging lithium ion batteries.

Figure 13

Part number	V_{CEO} (V)	I_C (A)	$V_{CE\ (SAT)}$ @ I_C/I_B	Package	Pd (W)
ZUMT717	12	1.25	240mV max @ 1.25A/100mA	SOT323	0.385
FMMT717	12	2.5	220mV max @ 2.5A/50mA	SOT23	0.625
FMMT718	20	1.5	220mV max @ 1.5A/100mA	SOT23	0.625
ZXT10P12DE6	12	3	220mV max @ 2.5A/10mA	SOT23-6	1.1
ZXT10P20DE6	20	3	300mV max @ 2.5A/100mA	SOT23-6	1.1
ZXT13P12DE6	12	4	250mV max @ 4A/50mA	SOT23-6	1.1
ZXT13P20DE6	20	3.5	250mV max @ 3.5A/350mA	SOT23-6	1.1
ZXT1M322	12	4	300mV max @ 4A/150mA	MLP322	1.5
ZXT2M322	20	3.5	300mV max @ 3.5A/350mA	MLP322	1.5

Notes:

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