

## A DUAL LI-ION BATTERY CHARGER USING AN ST SILICON TRIPLET

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This application note explains how to use the VIPER20, the ST62  $\mu$ Controller and the TSM102A in an SMPS-type battery charger which features :

- Dual Li-Ion Battery charging with Constant Current/Constant Voltage
- Battery type recognition (4.1V or 4.2V and different capacities)
- Precision Voltage Control
- Temperature and Failing Battery protection
- End of Charge detection

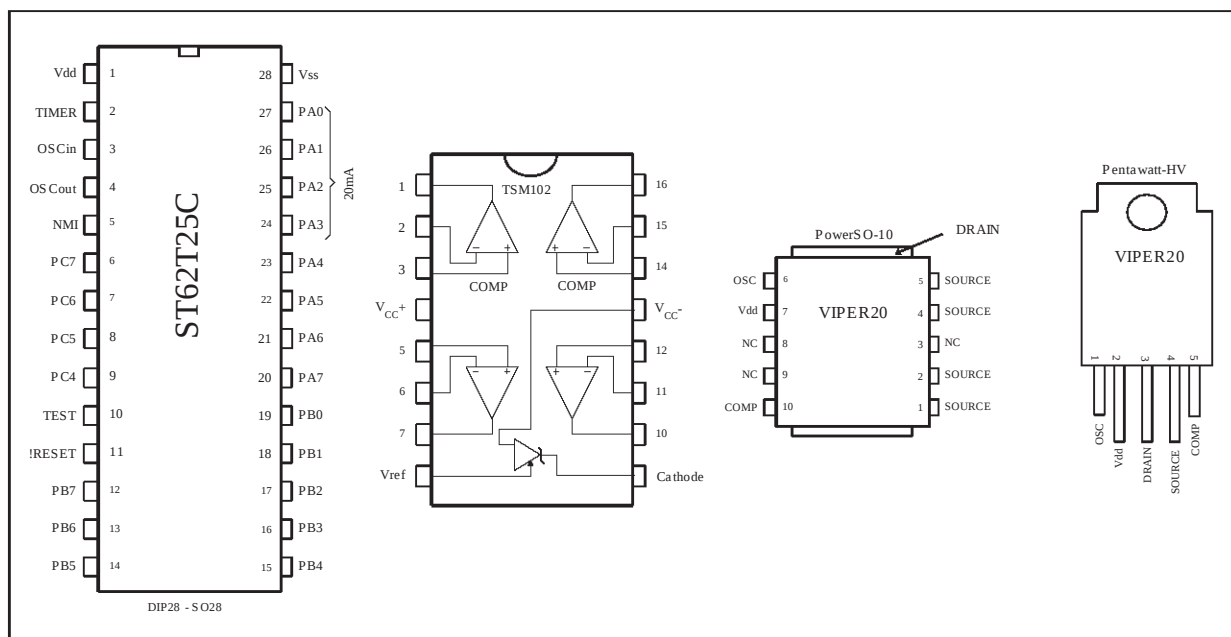
### 1 - DEVICES PRESENTATION

The **VIPER20** integrates on the same chip a PWM circuit together with a high voltage avalanche rugged vertical MOSFET (600V, 0.5A) which make it ideal for primary side control of battery chargers or power supplies featuring up to 20W output. Moreover, this device allows stand-by mode operation without additional components.

The **ST62T25C** is a low cost 28 pins 8-bit Microcontroller available in Mask ROM, FastROM and OTP versions. It features an A/D converter with up to 16 channels, 20 I/O pins of which 4 have High Current capability. An integrated Static Reset circuitry, Oscillator Safe Guard, 3 to 6 V power supply range and high ESD tolerance make the device well suited for noisy environment.

The **TSM102A** integrated circuit includes two Operational Amplifiers (type LM358), two Comparators (type LM393) and one adjustable precision Voltage Reference (type TL1431 : 2.5V to 36V, 0.4% or 1%). TSM102A can sustain up to 36V power supply voltage.

**Figure 1** : ST62T25C, TSM102A and VIPER20 Pin



## 2 - APPLICATION CONTEXT AND PRINCIPLE OF OPERATION

### The Li-Ion Battery

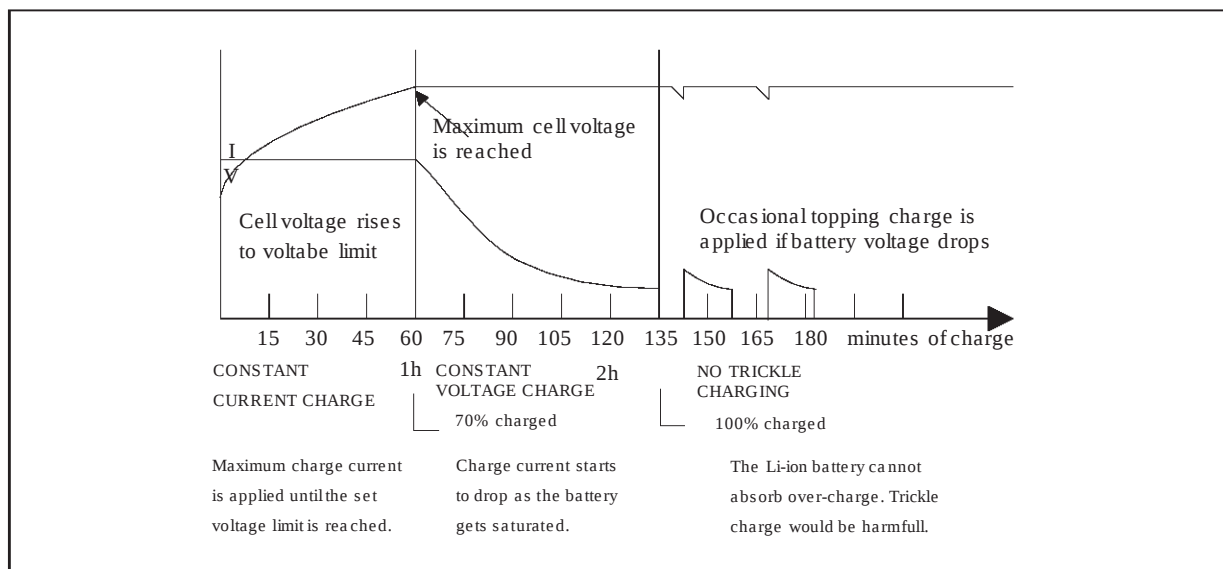
Rechargeable battery using Lithium have high voltage, big capacity and light weight, yielding an extraordinary energy density, more than twice the one of the NiCd. The maximum load current is not as high as for the NiCd, but is still sufficient for many applications such as cellular phone and camcorder.

To improve lifetime and keep the battery in safe operating conditions, some protection circuitry is always added inside the battery pack that can disconnect the electrochemical cell from the external connectors. This protection circuitry is designed to trigger in case of overcurrent (both when charging and discharging), overvoltage (when charging) and undervoltage (when discharging). The cell temperature is also monitored.

### Charging Principle

The charging principle of the Lithium-Ion batteries is very different from the Nickel type. Figure 2 shows the different stages in the charging process. Time values are only indicative and depend on battery type and speed of charge.

**Figure 2 : Li-Ion Charging Scheme**



During Stage 1, the battery is charged at constant current. The battery voltage is slowly increasing from original voltage up to the maximum cell voltage, which depends on the battery electrode technology (4.2V/cell for coke electrode, 4.1V/cell for graphite electrode).

Should this maximum voltage be exceeded and the battery could suffer significant damage and the protection circuitry may trigger.

Thus during Stage 2 a constant voltage charge is applied. Battery chargers manufacturers recommend a highly precise voltage supervision of  $\pm 0.05$  V/cell.

The current is slowly decreasing as the battery gets closer to full capacity.

End of charge can be detected by the charge current getting lower than a fixed threshold value (usually one fifth to one tenth of the constant current charge value).

### The dual Li-Ion Batteries charger :

In this application which requires ever increasing performances in more and more reduced space, the silicon triplet **VIPER20**, **ST62T25C** and **TSM102A** provides an attractive solution in terms of performance, cost efficiency and versatility.

Figure 3a and 3b show the primary and the secondary sides of the battery charger (SMPS type, primary and secondary sides) where the **VIPER20**, the **ST62T25C** and **TSM102A** are combined to ensure safe charging of two Li-Ion battery cells in parallel (main and spare batteries).

The **VIPER20** ensures with a very low component count the energy transfer from the off-line primary side to the secondary side thanks to its PWM ability ( with externally adjustable frequency of operation) and integrated high voltage avalanche-rugged vertical MOSFET.

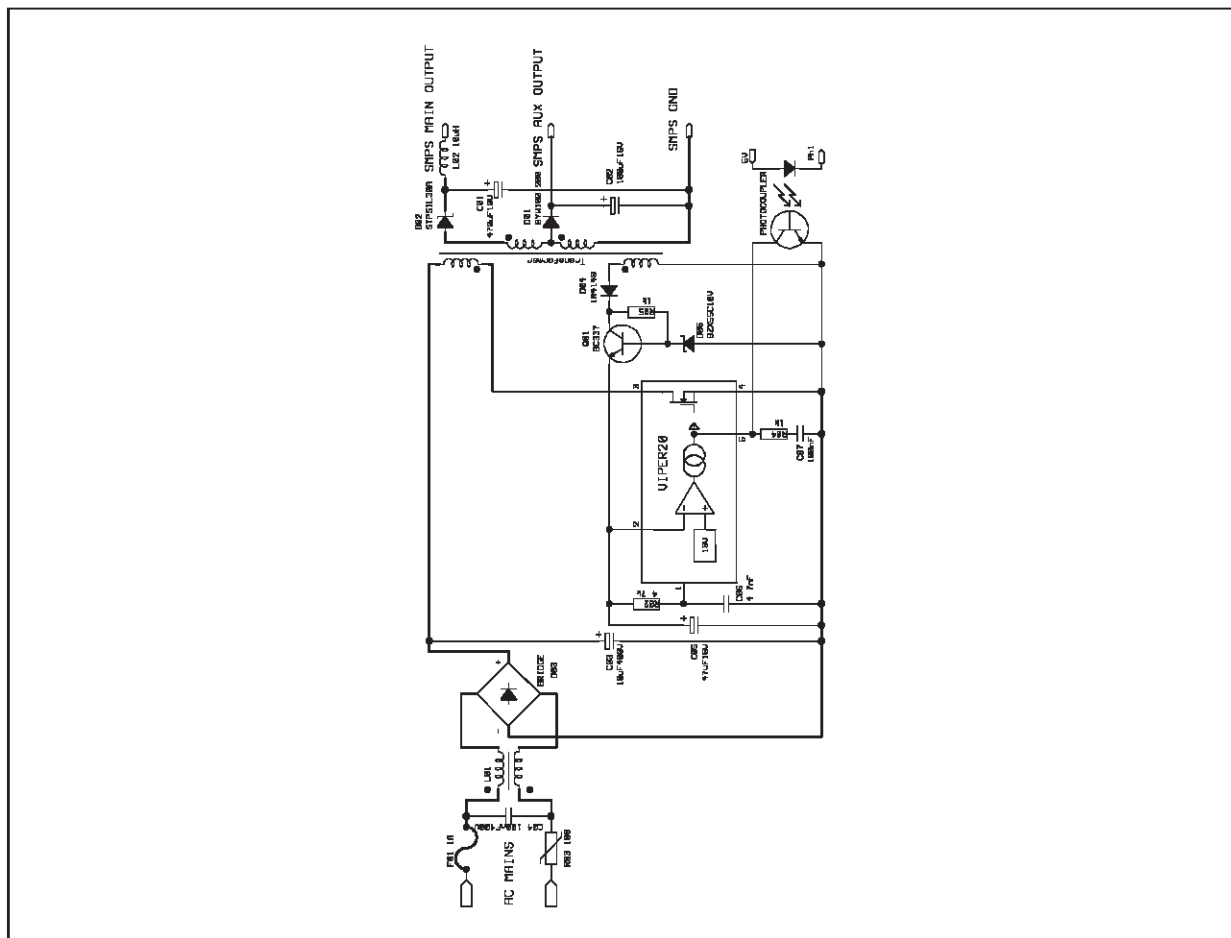
The ST62T25C  $\mu$ Controller is used to :

- recognize the Li-Ion battery type (4.1V or 4.2V and capacity)
- manage the charging of the two different cells in parallel thanks to the proper command of two power switches
- prevent the battery charging in case of overtemperature or undertemperature
- drive adequate LEDs for convenient visual information

The TSM102A can ensure all analog interfacing between the batteries and the  $\mu$ P by

- controlling current and voltage with adequate feedback via the optocoupler to the primary side
- offering highly precise voltage reference for all measurements
- amplifying the current signal through the sense resistor to be monitored by the  $\mu$ Controller
- providing a low cost solution for 5V power supply of the MCU

**Figure 3a : Primary Side of Battery Charger**



In detail :

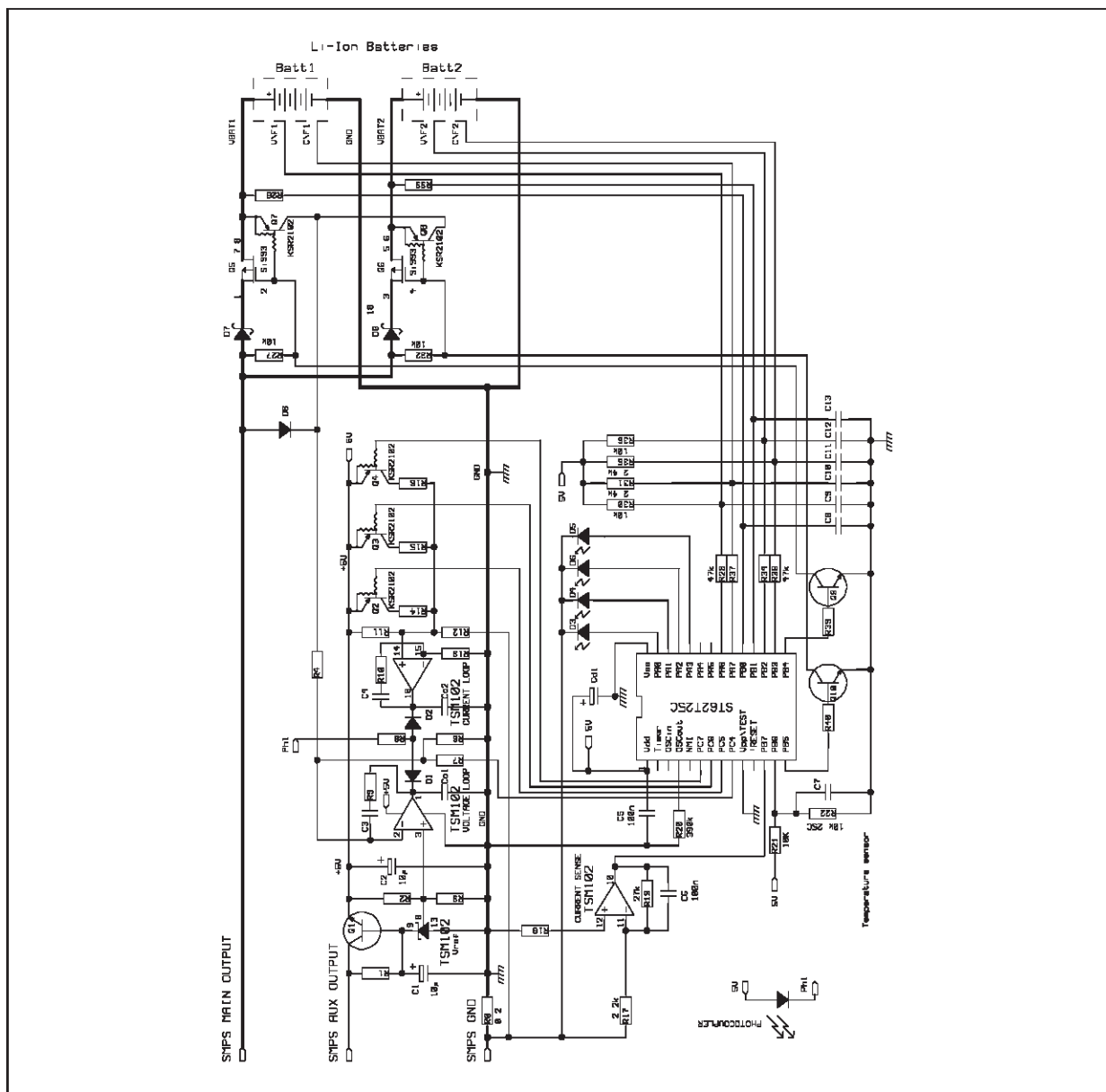
## a - The Primary Side :

The **VIPER20** stands as a PWM circuit with integrated Power MOSFET after the Rectifying-Filtering stage (F01 fuse, R03 NTC, L02 and C04 filtering coil and capacitor, D03 diode bridge and C03 front bulk capacitor).

R01 and D01 ensure the correct supplying of the VIPer20 device during normal operation thanks to the auxiliary winding of the transformer. C05 is in charge of filtering this output, and provides also the needed energy at start up thanks to the integrated start up current source of the VIPer20 device. The PWM function is determined by R02, D06 (frequency of operation) and the collector and emitter of the photocoupler (linear width modulation). The couple R04, C07 is a compensation network.

## b - The Secondary side :

**Figure 3b** : Secondary Side of Battery Charger



**POWER SUPPLY :**

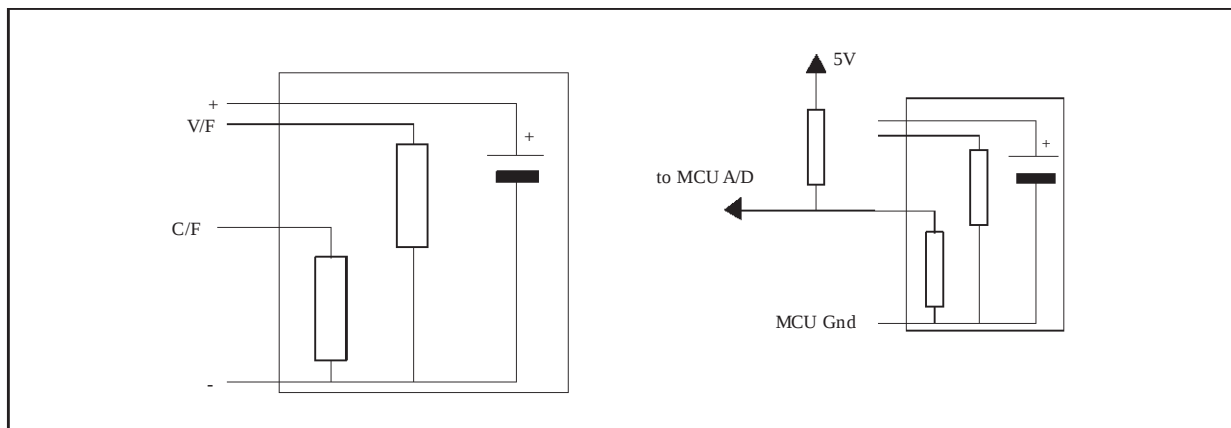
Both **ST62T25C** and **TSM102A** are supplied by a regulated 5V line. This line is regulated from the SMPS Auxiliary output thanks to an NPN bipolar transistor (Q1) polarized via its base by the integrated adjustable precision Voltage reference of the **TSM102A** (R2, R3). The base of Q1 is pulled up by R1 to ensure proper start up conditions and also to limit the current through the Voltage Reference during regulation mode. This 5V regulation circuitry is smoothened by the input and output capacitors C1 and C2.

**VOLTAGE AND CURRENT REGULATION :**

The two comparators of **TSM102A** are used to regulate the voltage and the charging current of the batteries. The first comparator compares the precise 2.5V Reference voltage with a part of the SMPS Main Output (resistor bridge R4, R6) and the second comparator compares the voltage drop through the sense resistor R0 with a part of the regulated 5V line (resistor bridge R11, R12). The feedback to the primary side is achieved thanks to the pair of ORing diodes (D1, D2) which pulls linearly the photocoupler (PH1) down via the resistor R8. Compensation loops (R9, C3 and R10, C4) and output capacitors (Co1 and Co2) are added to stabilize the voltage and current regulations.

**BATTERY TYPE DETECTION AND CHARGE PARAMETERS ADJUSTMENT :**

Pins C/F and V/F of the battery packs are used to provide charging voltage (V/F) and charging current (C/F) information to the charger. Resistors R30, R31, R35 and R36 are used to make resistor bridges with internal battery pack resistors, which connect V/F and C/F pins to the battery pack ground pin as shown on figure 4.

**Figure 4 : Battery Pack Internal Schematics and Principle of Detection****Table 1 : BATTERY VOLTAGE DETECTION FROM V/F**

| V/F Resistor  | V/F Voltage | 8 bit A/D Result | Detected Battery Voltage |
|---------------|-------------|------------------|--------------------------|
| 10k $\pm$ 5%  | 2.375~2.625 | 117~138          | 4.1V                     |
| 4.7k $\pm$ 5% | 3.29~3.51   | 163~183          | 4.2V                     |
| other         | other       | other            | no battery               |

**Table 2 : BATTERY CURRENT DETECTION FROM C/F**

| C/F Resistor        | C/F Voltage | 8 bit A/D Result | Detected Battery Voltage |
|---------------------|-------------|------------------|--------------------------|
| 3.3 ~ 4.7k $\pm$ 5% | 2.375~2.625 | 119~136          | 400mA                    |
| 2.4k $\pm$ 5%       | 3.29~3.51   | 165~181          | 800mA                    |
| 1.1k $\pm$ 5%       | 4.02~4.17   | 203~205          | 1300mA                   |
| other               | other       | other            | no battery               |

The  $\mu$ Controller is using A/D converters inputs PA6, PA7, PB2 and PB3 to measure respectively the voltages on battery pack pins V/F1, C/F1, V/F2 and C/F2. Depending on these voltages the  $\mu$ Controller will switch various Open Drain pins to adjust the Voltage and Current regulation loops to the requirements of the battery currently in charge.

Thus depending on the V/F pin voltage, the resistor R7 can be connected in parallel with R6 through PC4 which is configured in Open Drain mode. This will modify the resistor bridge R4, R6, and will set the voltage regulation to 4.1V or 4.2V in respect with the battery type. The detection of the battery voltage is summarized in Table 1. The 5% tolerance of the resistors, as well as the  $\pm 2$  LSB accuracy of the Analog to Digital Converter are taken into account for the calculation.

In a similar way, and depending on the C/F pin voltage, the charge current is set to match the requirements of the battery. PC5, PC6 and PC7, configured in Open Drain mode, command the PNP transistors Q2 (PC5), Q3 (PC6) and Q4 (PC7). When Q2, Q3 or Q4 (or the three at the same time) are on, the current control value is modified according to the resistor bridge (R11, R12) modification (R14, R15, R16 in parallel with R11). The detection of the battery charge current is summarized in Table 2.

#### CURRENT FEEDBACK TO THE $\mu$ CONTROLLER :

One Operational Amplifier of the **TSM102A** is used to zoom the current that flows through the sense resistor R0 (amplification loop R17, R19) so that this current information can be readable by the  $\mu$ Controller. The  $\mu$ Controller acquires the data through PB7 configured as an A/D input.

#### 2 SLOTS CHARGING FLOW :

In this specific application the first slot (A) is made to receive a complete handy phone while the second one (B) is made to accommodate a spare battery. Thus the user can charge both his phone + battery and a replacement battery.

To ensure efficient charging of both batteries cells (which are connected in parallel), the  $\mu$ Controller commands two low  $R_{ds(on)}$  P-channel MOSFETs alternatively (Q5 and Q6 with PB4 and PB5).

If only one of the slot receives a battery (either A or B) the charger will perform a standard charge of that battery by switching on the corresponding MOSFET.

When the charger receives both the phone + battery (A) and the spare battery (B), the A slot has the priority. Q5 will be turned on first and until A battery is full, B will be in Wait for Charge state, and Q6 will be off. Only when A is full will B be charged (Q5 off, Q6 on). As the phone in slot A may be on, and thus its battery may discharge as B is on charge, the voltage of A slot is continuously monitored. If a significant drop is detected, then the charger will enter an alternate charging mode where both batteries are charged on a time sharing basis, so as to always keep the phone battery in full condition.

#### USER INTERFACING :

The  $\mu$ Controller drives directly 2 bicolor LEDs (one for each battery) through PA0, PA1, PA2, PA3. The meaning of the different signals is given in Table 3.

**Table 3 : USER INTERFACE LEDs**

| State                  | Green | Red   | Bicolor Result | Remark             |
|------------------------|-------|-------|----------------|--------------------|
| No battery             | Off   | Off   | Off            | each slot          |
| Charging               | Off   | On    | Red            | each slot          |
| Full                   | On    | Off   | Green          | each slot          |
| Wait for charge        | On    | On    | Orange         | B slot only        |
| Battery fail           | Blink | Blink | Orange Blink   | each slot          |
| Over/Under temperature | On    | On    | Orange         | only when charging |

## PROTECTION/SAFETY FEATURES :

The  $\mu$ Controller is checking the charging process in several ways so as to make sure that the battery is kept into safe operating conditions.

- Temperature is measured via resistor bridge R21 and R22 (where R22 is an NTC) and PB6 configured in A/D input. According to Li-Ion manufacturers information the cells should be charged only when the temperature is between 0 and 45 °C. Thus when the temperature reaches outside this safe operating range, the charging process is kept in standby (charge timings held, Power MOSFETs off thus stopping the charge current, and user is warned of this condition by corresponding LED turning orange). When the temperature is back to normal, charging process is resumed.
- The 0 and 45 degrees threshold level have a programmable software hysteresis to prevent the charger from oscillating from Temperature protection to Normal mode.
- Open battery condition is detected using current measurement through PB7. If no current is flowing for more than a programmable current establishment delay after the charge has started the battery will be rejected, the charge terminated and the user warned of this condition by the corresponding LED blinking orange.
- Bad voltage battery condition : the  $\mu$ Controller is continuously monitoring the voltage of the batteries. According to the battery manufacturers specifications, and depending on the voltage, the actions of the charger are summarized in Table 4.

Table 4 : CHARGER STATE AS A FUNCTION OF BATTERY VOLTAGE

| Voltage        | State                            | Action          | Condition                       |
|----------------|----------------------------------|-----------------|---------------------------------|
| 0 - 1.5V       | Pack protection circuitry active | Trickle charge  | $V > 1.5V$ within 1 second      |
| 1.5 - 2.7V     | Very low                         | Trickle charge  | $V > 2.7V$ within 30 minutes    |
| 2.7 - 4.1/4.2V | Normal                           | Standard charge | $V > 3.9V$ when battery is full |
| 4.4V and over  | Overvoltage                      | Stop charge     | -                               |

The Condition Column shows what the result of the action must be for the charger to proceed with the charging. In case this condition is not fulfilled, the battery will be rejected, the charge terminated and the user warned of this condition by the corresponding LED blinking orange.

## FULL BATTERY DETECTION :

This is made either by detecting a low current flowing through the battery or by an overtime condition (maximum time after standard charge has been started). A minimum voltage of 3.9 volt must be reached at that time or the battery will be rejected, and the user warned of this condition by the corresponding LED blinking orange.

## 3 - CALCULATION OF THE ELEMENTS

All the components values have been chosen for a two-Lithium-Ion batteries charge application:

## PWM Frequency and Maximum switching ratio of the VIPER20 :

$$R02 > 1.2k\Omega$$

$$Fsw = 2.3 Dmax / (R02 \times C06)$$

$$Dmax = 1 - 550 / (R02 - 150)$$

recommended Dmax values are :

$$100kHz : Dmax > 80\%$$

$$200kHz : Dmax > 70\%$$

$$R02 = 4.7k\Omega$$

$$C06 = 4.7nF$$

$$Dmax = 87.9\%$$

$$Fsw = 91.5kHz$$

## 5V line power supply for TSM102A &amp; ST62T25C :

$$Vout = Vref ( 1 + R2 / R3 )$$

$$R2 = R3 = 10k\Omega$$

$$C1 = C2 = 10\mu F$$

$$R1 = 1.5k\Omega$$

## Voltage Control :

- $Vbatt = 4.100V$

$$Vref = Vbatt \times R6 / ( R6 + R4 )$$

$$\text{With } R6 = 100k\Omega, R4 = 64k\Omega$$

If the battery is a 4.2V type, then, the resistor R7 will be connected in parallel to the resistor R6 by means of the  $\mu$ Controller (PC4) :

- **Vbatt = 4.200V**

$$V_{ref} = V_{batt} \times (R6 // R7) / [(R6 // R7) + R4]$$

$$V_{ref} = V_{batt} \times [R7 \times R6 / (R6 + R7)] / [R7 \times R6 / (R6 + R7) + R4]$$

$$R7 = 1.6M\Omega$$

### Current Control :

- Lowest current limitation : **Ilim1 = 200mA**, with sense resistor **R0 = 0.2 $\Omega$**

$$V_{lim1} = R0 \times I_{lim1} = 40mV$$

$$= V_{cc} \times R12 / (R12 + R11)$$

with **R11 = 10k $\Omega$** , **R12 = 80.6 $\Omega$**

- Second current limitation : **Ilim2 = 400mA**

$$V_{lim2} = R0 \times I_{lim2} = 80mV$$

$$= V_{cc} \times R12 / (R12 + Rlim2)$$

where **Rlim2 = R11 // R14**

$$Rlim2 = 4.957k\Omega$$

Therefore, **R14 = 9.83k $\Omega$**

- Third current limitation : **Ilim3 = 800mA**

$$V_{lim3} = R0 \times I_{lim3} = 160mV$$

$$= V_{cc} \times R12 / (R12 + Rlim3)$$

where **Rlim3 = R11 // R15**

$$Rlim3 = 2.438k\Omega$$

Therefore, **R15 = 3.22k $\Omega$**

- Fourth current limitation : **Ilim4 = 1.3A**

$$V_{lim4} = R0 \times I_{lim4} = 260mV$$

$$= V_{cc} \times R12 / (R12 + Rlim4)$$

where **Rlim4 = R11 // R16**

$$Rlim4 = 1.469k\Omega$$

Therefore, **R16 = 1.72k $\Omega$**

### OTHER COMPONENTS :

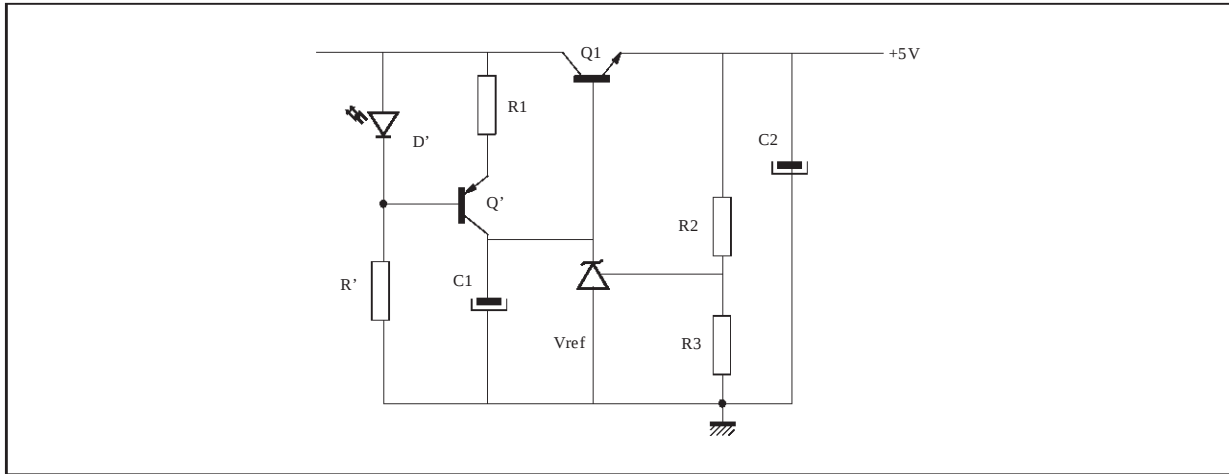
All other components values are indicated on the schematics

### Notes :

- When plugged in the sockets, the two batteries can have very different charge states (ie one is fully charged and the other, almost empty). If no precaution is taken, and as long as the two batteries voltages differ from more than 0.6V, a dramatic current flow can appear between the charged battery towards the empty battery through the intrinsic diodes of the power MOSFETS. This current is not regulated and may either damage the MOSFETS, or trigger the over current protection system of the battery pack itself and block the charging of the battery.

The schottky diodes D7, D8, the diode D6 and the PNP transistors Q7, Q8 solve this problem :

- no current can flow through the intrinsic diodes of the MOSFETS thanks to the schottky diodes
- the voltage regulation is picked directly on the battery packs for increased precision thanks to the PNP bipolar transistors used as low power analog switches
- the diode D6 prevents the voltage regulation from loosing its reference when the two Power MOSFETS are OFF.
- The current control values must be chosen in accordance with the elements of the primary side. The global performances of the battery charger are highly dependent on the adequation of the primary and the secondary elements.
- R13 and R18 are the equivalent resistors seen from the opamp and from the comparator (**R13 = R11//R12, R18 = R17//R19**)
- **C7 to C13** capacitors are optional filtering capacitors which ensure proper stabilization of the analog values imposed to each of the corresponding A/D converters of the  $\mu$ Controller.
- Transistors Q9 and Q10 are inserted to ensure good start up conditions (open collector until the  $\mu$ C is correctly supplied).
- An improvement to the integrated Voltage Reference's line stability is shown on figure 5. The LED D' (used as a visual "charger is ON" signal) polarized by the resistor R' feeds the PNP bipolar transistor Q' with a quasi constant voltage which allows constant current to flow through the Vref. This regulated 5V line provides a very stable voltage even when the SMPS Aux Output varies from 7 to 30V.

**Figure 5 :** Improved Voltage Reference Line Regulation**Caution :**

Li-ion batteries have a very high energy density. Exercise precaution when handling and testing. Do not short circuit, overcharge, crush, mutilate, nail penetrate, apply reverse polarity, expose to high temperature or disassemble. High case temperature resulting from abuse of the cell could cause physical injury.

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