cap-XX

APPLICATION NOTE No. 1001

Current-Limit and Low-Voltage Lockout Circuit for Portable Devices

December 2001

Outline

High ripple currents in notebooks and other portable devices can be drastically reduced by the use of a cap-XX supercapacitor in parallel with the supply. This can give benefits such as a reduced risk of premature shutdown, improved efficiency (especially with reduced battery voltages), small increases in battery run-time, and potentially increased battery life, thanks to reduced current peaks. However, a supercapacitor needs to be charged on power-up. This application note describes a current-limiting charging circuit with low-voltage lockout and reverse-current protection that can be used in portable devices. The circuit also performs the power-selection function, routing power from the battery or the charger/adapter, if connected. It has low current drain, which makes it suitable for use in battery-powered devices. It can be tailored to suit different batteries and loads. It uses some of the components already present in most notebook computers for the power-selection function.

The Problem

The CPUs and other devices in notebook computers draw high currents that vary enormously. These generate high levels of voltage ripple in the supply. Placing a very low-ESR cap-XX supercapacitor in parallel with the DC power input can reduce the voltage ripple by a factor of 7 to 10 times, and reduce the battery current peaks by a comparable amount.

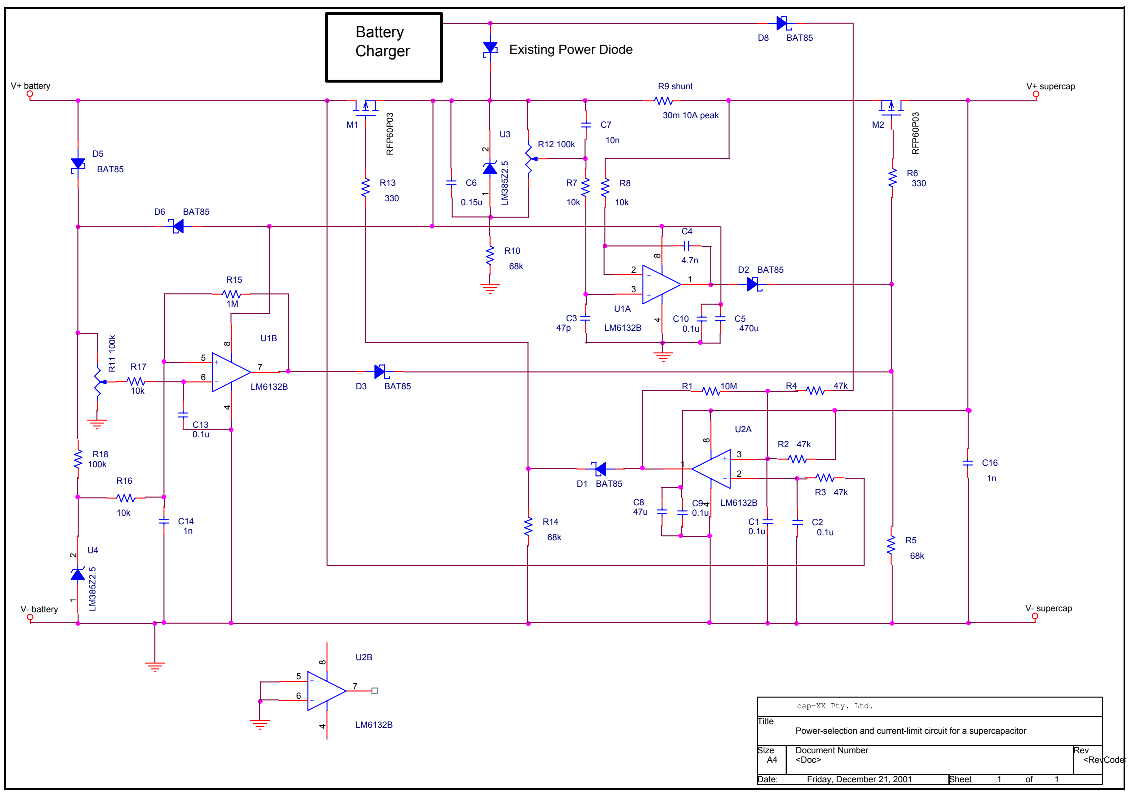
Reducing the voltage ripple can enable designers to reduce the voltage margin before the system shuts down, without the risk that a voltage droop caused by a current peak will crash the system. This can yield additional run-time, by using energy remaining in the battery. It also provides opportunities to improve the efficiencies in the downstream DC-DC converters, particularly if a reduced battery voltage is used. (Reduced voltage results in reduced current peaks in the circuit board traces, inductors and decoupling capacitors, which gives reduced I^2R losses.) The reduced current peaks demanded from the battery may also extend battery life.

It is necessary to charge the supercapacitor to supply voltage when the system is turned on. If it were connected directly to the battery or the charger, the current drawn would be very high. Therefore, it is necessary to limit the charging current until the supercapacitor is charged.

The supercapacitor has a voltage rating that must not be exceeded. Therefore, it is necessary that any charger that is used does not charge the supercapacitor to a higher voltage than this rating.

If a battery is inserted that has a lower voltage than that on the supercapacitor, it is necessary to prevent a large current flowing from the supercapacitor into the battery. The supercapacitor voltage might be higher than the battery voltage if the system was previously being powered by the charger, or if a fresh battery had been in use, and it was quickly removed and replaced with a near-depleted battery. (If the system is drawing very little power, the supercapacitor might not discharge sufficiently in the time it takes to insert the other battery.)

When the battery's voltage drops to a low level, it is necessary to shut down the supply to the device, to prevent possible damage to the battery. This low-voltage lockout should also operate if the system is being powered by the charger, because a low voltage suggests there is a fault in the charger or load; also, the system will not function correctly when the voltage is low, because part or all of it will shut down.


Battery
Charger
Existing Power Diode
D8 BAT85
V+ battery
R9 shunt
30m 10A peak
V+ supercap
M1
RFP60P03
U3
R12 100k
C7
10n
M2
RFP60P03
D5
BAT85
R13
330
C6
0.15u
LM385Z2.5
R7
10k
R8
10k
R6
330
D6 BAT85
C4
4.7n
R10
68k
R15
1M
U1A
LM6132B
D2 BAT85
C3
47p
C10
0.1u
C5
470u
U1B
R11 100k
R17
10k
LM6132B
D3 BAT85
R1 10M
R4 47k
C13
0.1u
U2A
R2 47k
R18
100k
R16
10k
D1 BAT85
C8
47u
C9
0.1u
LM6132B
R3 47k
C16
1n
C14
1n
R14
68k
C1
0.1u
C2
0.1u
R5
68k
U4
LM385Z2.5
V- battery
V- supercap
U2B
LM6132B
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Sheet 1 of 1

The cap-XX Solution

This Application Note describes a circuit (Fig. 1) intended for a notebook computer, but which may also be used in power supply circuits for other portable devices. It limits the current to the supercapacitor and the system while the supercapacitor is charging.

The circuit has reverse-current protection that prevents large currents flowing from the supercapacitor to the battery. It does this by detecting when the voltage on the supercapacitor is higher than that of the battery. Since the conduction path between the supercapacitor and the battery has low impedance, there is necessarily a small current flowing in that direction before the voltage difference is large enough to cause the circuit to activate.

The circuit also has a low-voltage lockout function that cuts off the load when the supply voltage drops below a pre-determined level.

The charger's circuit is not covered by this application note. However, it should not be permitted to supply more than the rated voltage to the supercapacitor used on the internal DC supply. One means of achieving this is to add a simple linear voltage regulator to the output from a standard regulator. A better solution is to modify the circuit of the charger so that its output is the correct voltage; this would minimise the heat generated by the charger's circuit.

Circuit Operation

Introduction

Refer to Fig. 1. The circuit takes advantage of MOSFET switches in a configuration similar to those used in many notebook computer power inputs. These are shown as M1 and M2. In many other designs, these devices are used as switches only (either on or off). In normal operation, both M1 and M2 are fully on. However, M2 is used to limit the current to the supercapacitor and load, which means that it is used as a linear control device while charging the supercapacitor. It is necessary to provide adequate heat-sinking for M2, to dissipate the heat generated while charging the supercapacitor.

The MOSFETs used are RFP60P03 (or surface-mount types RF1S60P03). These are P-channel 60A 27mΩ devices, capable of dissipating up to 176W. They also have relatively low gate threshold voltage (-4V maximum).

The operational amplifiers chosen are able to accept rail-to-rail input voltages. They are type LM6132. These are high-bandwidth devices that have high input impedance and require low power, making them suitable for use with batteries. They can operate from supply voltages well outside the intended range of this circuit, which is approximately 8.4V to 20V. Note that their differential input voltages should not exceed 15V. It is preferable that the inputs of an unused amplifier be connected to the same supply rail.

Low-power 2.5V reference voltages for the current limit and low-voltage detection are provided by U3 and U4, which are LM385Z2.5.

Dual operational amplifiers U1A and U1B take their supply from the left of the shunt resistor, to enable them to control M2. U2A takes its supply from the right of M2, so it can turn off M1 completely when the battery voltage is lower than that on the supercapacitor, or when the charger is supplying power.

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The shunt resistor is selected such as to drop a suitable voltage when the expected current is passed through it, and its power rating must be sufficient to dissipate the expected RMS power losses resulting from the current. The 30mΩ shunt used in the prototype will drop 300mV when a 10A current is flowing. This will cause 3W of heat dissipation. The operational amplifiers have an input offset voltage rating of up to 8mV (maximum). Therefore, there may be an error of up to 267mA in the current measurement resulting from the input offset current. This is considered reasonable for a load current that reaches 7-10A.

Current-Limiting

The current-limit function is performed by U1A. It compares the voltage drop across the shunt with the divided value of the reference voltage. It operates when the current is flowing from left to right, so the shunt voltage is positive on the left, which is what happens when the supercapacitor is being charged. If the current exceeds the reference value for a time determined by its RC time constant (if any), its output swings high to turn off M2. Capacitor C4 and resistor R8 determine the time constant. If the time constant is short enough, the control will be smooth and linear. If a long time constant is used, the control output may become oscillatory. For fast control, C should be a low value, or it may be left out entirely. The time constant should be altered to suit the application. Having a non-zero time constant means that the circuit will not react instantly to current pulses that exceed the limit set by the reference input. This will give some immunity to high current pulses that are short enough not to be of concern. The maximum current must be set high enough to support the maximum short-term average current the load draws in normal operation, otherwise the current limit will operate, causing the voltage to drop and the system to malfunction.

The magnitude of the limit current is set by the potentiometer R12. The greater the voltage across C7, the greater will be the current before U1A begins to turn off M2. In a production version of the circuit, R12 would normally be replaced with two equivalent discrete resistors, with approximately the same total resistance.

Low-Voltage Lockout

Amplifier U1B, which is used as a comparator, performs the low-voltage lockout (shut-down) function. The battery and charger voltages are applied via Schottky diodes to a potentiometer (normally replaced with resistors in a production version). Therefore, the higher voltage of the two is used to determine whether to turn off M2. If the supply voltage is lower than the reference by an amount determined by the hysteresis feedback resistor, R15, the output of U1B goes high, turning off M2.

The supply voltage has to increase beyond its original value before M2 will be turned on again, to prevent rapid spurious switching during transients. To increase the hysteresis effect, R15 should be reduced in value; to reduce the hysteresis effect, R15 should be increased. C13 filters the supply voltage. The greater its value, the larger the effective time-constant of C13 and the combination of R17 and R11 will be, and the longer the circuit will take to respond to a voltage drop below the pre-set level. The filtering therefore helps to prevent unnecessary shutdowns caused by short transients in voltage.

Reverse-Current Protection

U2A is also used as a comparator. It turns off M1 when the voltage on the supercapacitor (and load) is greater than that on the battery. It also turns off M1 when the voltage on the charger input is high enough to power the circuit. The charger's power input is monitored via Schottky diode D8. Because it carries very little current, the cathode of D8 will be at a higher voltage than the cathode of the device's existing input power diode when power is being supplied by the charger. Either a high supercapacitor voltage or a high charger voltage causes U2A to switch its output high.

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Circuit Set-Up

Current Limit Setup

The theoretical value of the current limit is determined from the shunt resistor's value and the voltage drop across C7 (across the upper part of the potentiometer/resistor divider). The current at which limiting begins is $I_{lim}=V_{C7}/R9$. The likely error in this value is determined mainly by the offset voltage of the operational amplifier, as discussed above.

The actual value of the current limit is best confirmed by measurement, by connecting a battery or power supply to the battery input, then noting the value at which the current limits when a load (or short-circuit) is applied to the supercapacitor (load) terminals. The current should be just below the continuous value that will cause the battery to shut down.

The value of the time const in the current limit circuit is determined by R8xC4. C4 may be omitted for fast response, and if this proves to cause limiting in normal operation because of fast transient currents, then a value of C4 may be added that is sufficient to prevent limiting during very short transients. C4 should be as small as possible, without limiting occurring. When a discharged supercapacitor is connected to the supercapacitor terminals and the battery is connected to its terminals, the current should limit to the desired value without being sufficient to cause the battery's protection circuit to shut down. C4 should be small enough that the limiting acts quickly, preventing battery shutdown.

Setting the Low-Voltage Cutoff Circuit

The reference voltage used by this circuit is determined by the component, LM385Z2.5. Once the desired cutoff voltage is known, the resistor values substituted for R11 may be determined, as follows: If there is no hysteresis (R15 is absent), then the divided value of the supply presented to pin 6 of U1B should be equal to 2.5V, the reference voltage. With hysteresis, this value is reduced slightly by approximately 2.5xR16/(R16+R15), the hysteresis voltage. With the values in the circuit, there is approximately 1% hysteresis, or 25mV. Allowance should also be made for the offset voltage of the amplifier, 8mV (maximum).

The time constant of the low-voltage cutoff is determined by R11, R17 and C13. In a production circuit, R11 is effectively the parallel combination of the two resistors that replace it. The total value of this equivalent resistor plus R17 should be multiplied by C13. This time constant should be selected to be approximately the desired response time to short-term voltage drops. If it is less than this time, then the circuit will tend to shut down the supply to the load during such voltage drops.

Determining Hysteresis in the Reverse-Current Protection Circuit

This value is determined from the ratio R2/(R1+R2) for the supercapacitor's voltage, or R4/(R1+R4) for the battery charger input. It should be large enough to prevent the circuit from turning off M1 unnecessarily during voltage transients, but not so large that the supercapacitor/load voltage has to drop very much before the battery is re-connected.

Further Information:

cap-XX will be pleased to supply you with detailed data and design information. To obtain further details, please use the contact information at the foot of this page.

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