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(54) **CIRCUIT AND METHOD OF OPERATION FOR AN ADAPTIVE CHARGE RATE POWER SUPPLY**

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(58) **Field of Search** 320/128, 132, 320/133, 160, 164

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(57) **ABSTRACT**

A convenient source of charging power for portable communication devices is an integral power node of a computer data bus, such as a USB (universal serial bus) port. Unfortunately, USB ports have limited power capacity, making them generally incompatible with battery charge controllers (BCCs) which are designed to receive a steady, high capacity input. The invention provides a battery charging circuit which adjusts to the parameters of an external power supply such as a USB port by adding a regulating circuit to a standard BCC design. This regulating circuit maximizes the current drawn by the BCC, while keeping the voltage to the BCC above a preset minimum (the low voltage shut off level for the BCC). If the voltage to the BCC begins to drop, the regulating circuit reduces the current drawn, so the voltage rises and stays within the operating range of the BCC.
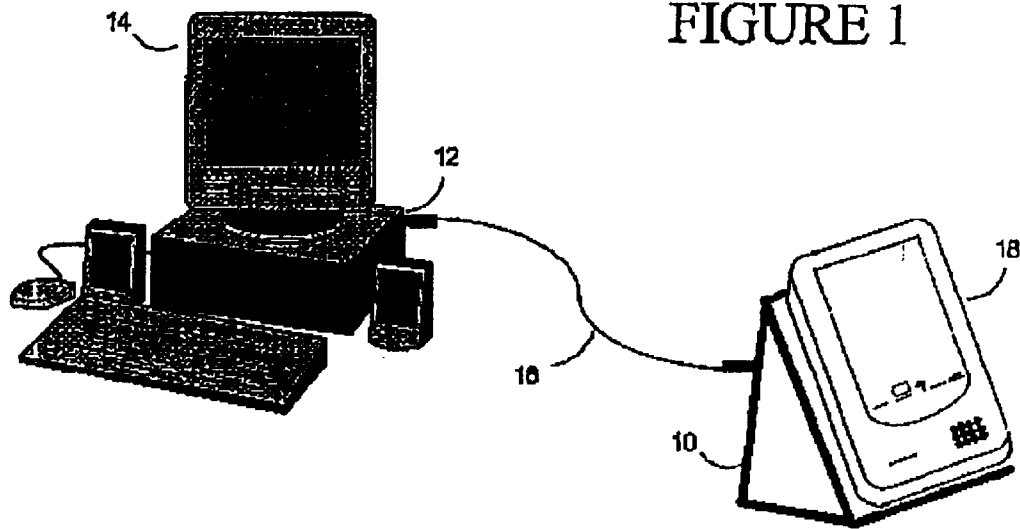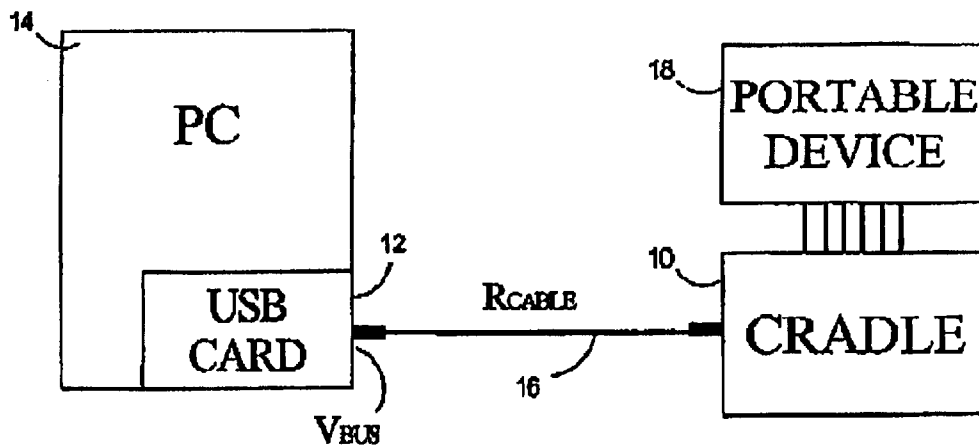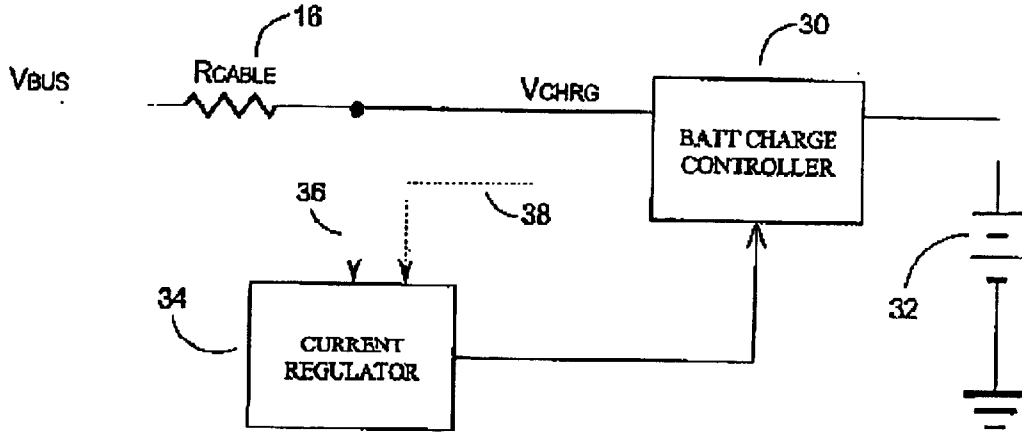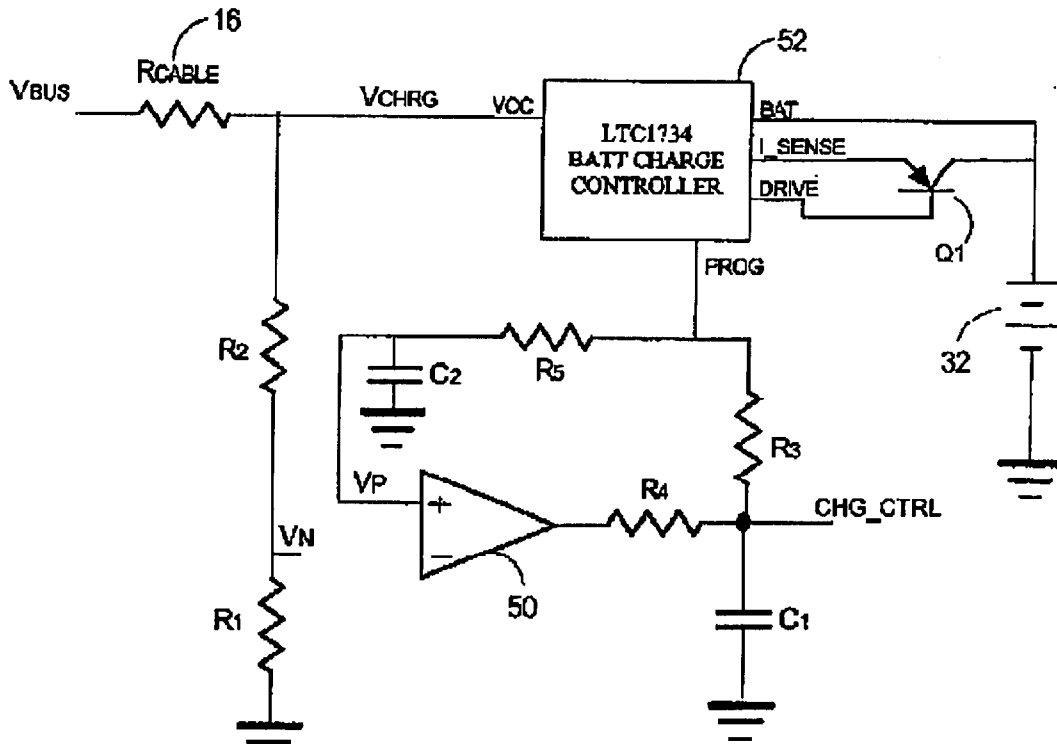
16 Claims, 4 Drawing Sheets

FIGURE 1

FIGURE 2

VBUS   RCABLE 16   VCHRG   BATT CHARGE CONTROLLER 30   32

36   38

34   CURRENT REGULATOR

FIGURE 3

VBUS   RCABLE 16   VCHRG   VCC   LTC1734 BATT CHARGE CONTROLLER 52   BAT   I_SENSE   DRIVE   Q1   32

R2   C2   R5   PROG   R3

VP   R4   CHG_CTRL

VN   R1   50   C1
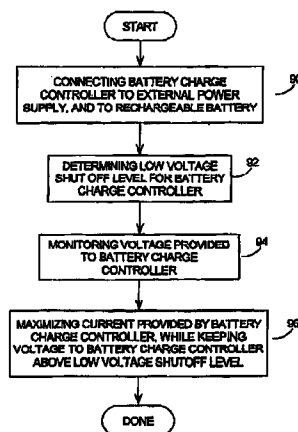
FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

START

↓

CONNECTING BATTERY CHARGE
CONTROLLER TO EXTERNAL POWER
SUPPLY, AND TO RECHARGEABLE BATTERY — 90

↓

DETERMINING LOW VOLTAGE
SHUT OFF LEVEL FOR BATTERY
CHARGE CONTROLLER — 92

↓

MONITORING VOLTAGE PROVIDED
TO BATTERY CHARGE
CONTROLLER — 94

↓

MAXIMIZING CURRENT PROVIDED BY BATTERY
CHARGE CONTROLLER, WHILE KEEPING
VOLTAGE TO BATTERY CHARGE CONTROLLER
ABOVE LOW VOLTAGE SHUTOFF LEVEL — 96

↓

DONE
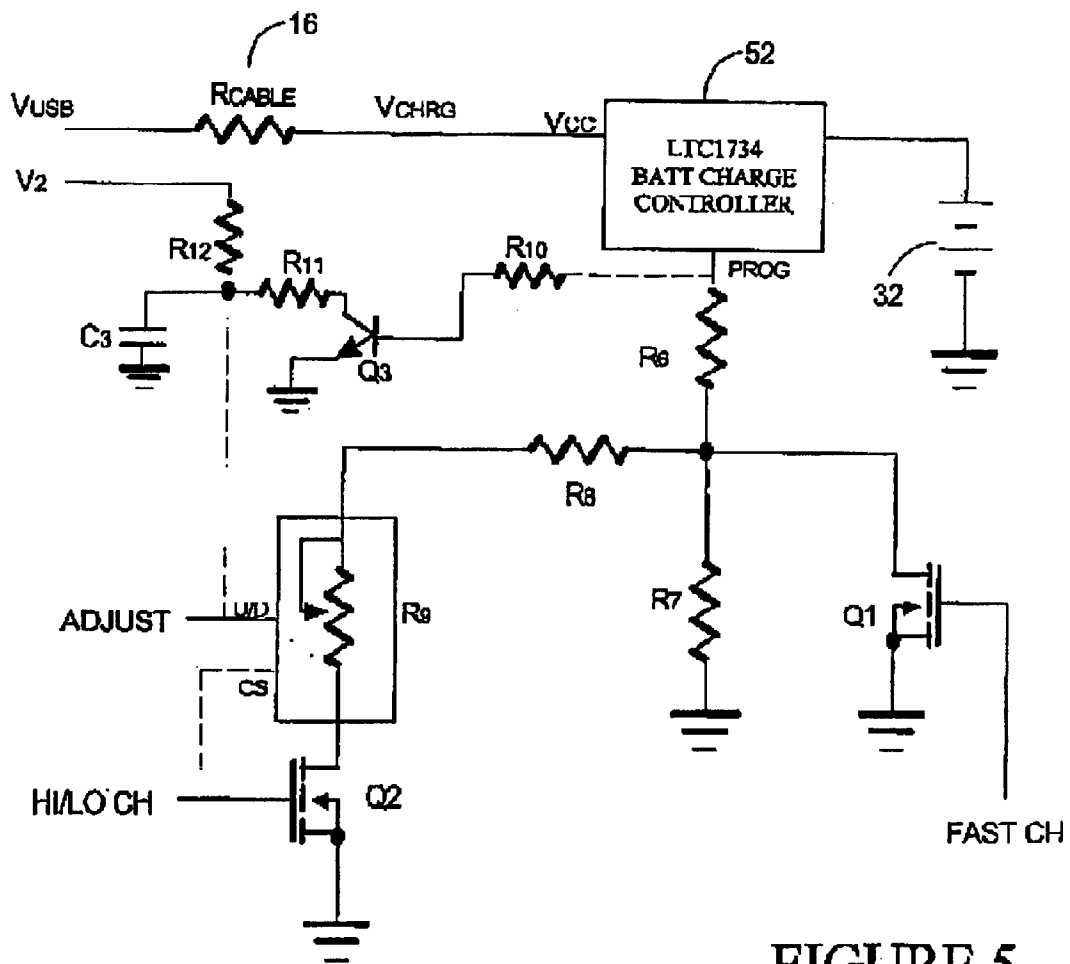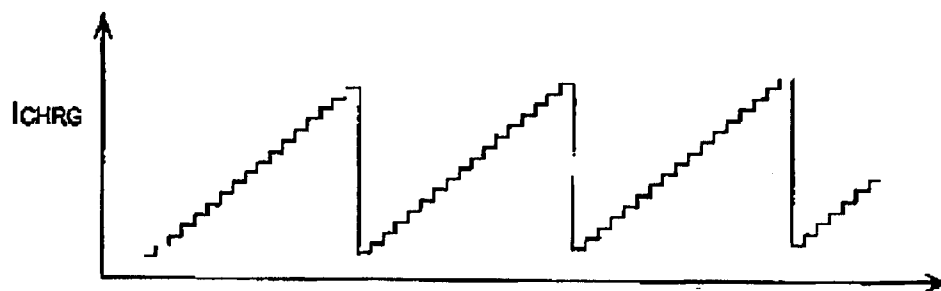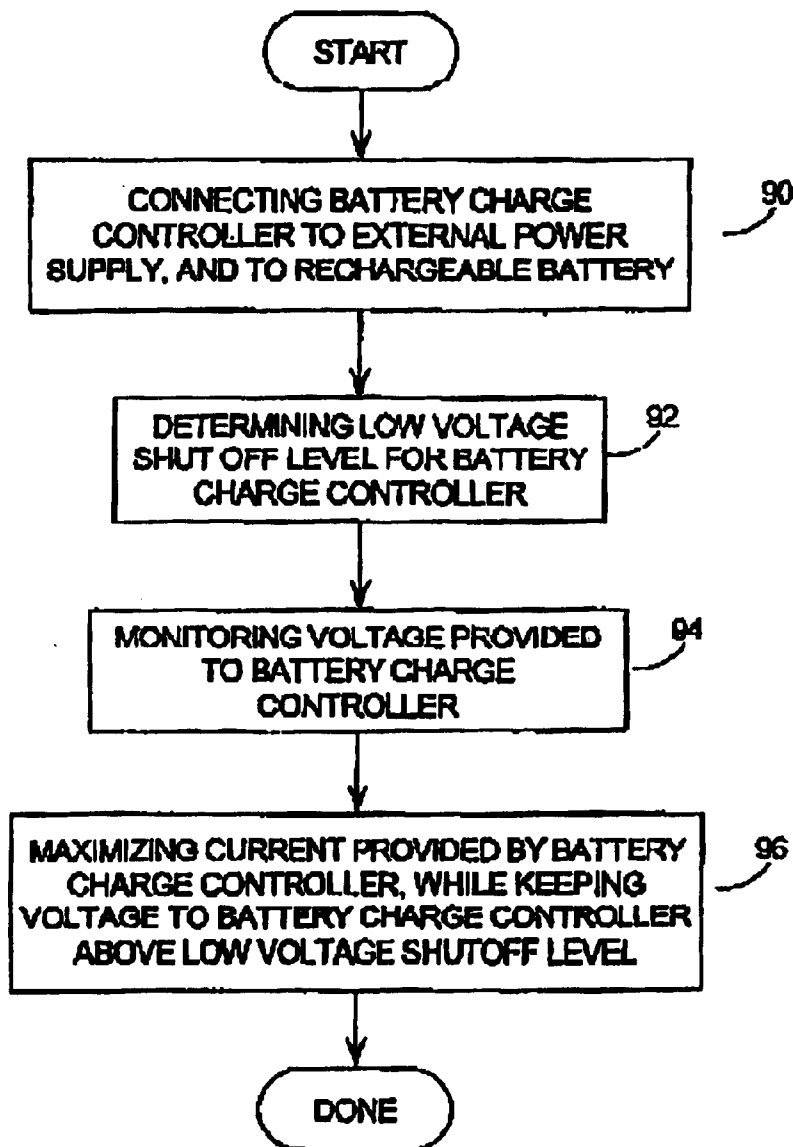
CIRCUIT AND METHOD OF OPERATION FOR AN ADAPTIVE CHARGE RATE POWER SUPPLY

This invention relates in general to battery chargers, and more specifically to a method and apparatus for charging a battery in a portable communication device from a variety of power sources, including limited capacity sources such as an integral power node of a computer data bus. One such computer data bus would be a USB (universal serial bus) port.

BACKGROUND OF THE INVENTION

With the current computing and information revolution, portable electronic devices such as cellular telephones, personal digital assistants (PDAs), digital pagers and wireless email devices, are becoming very common.

These portable devices are typically powered by internal batteries which must be recharged periodically by an external power source, using a battery charger. Battery chargers generally receive power from a standard AC electrical outlet and convert the AC power into a low DC voltage for recharging a battery.

The battery chargers of these portable devices also generally employ a "battery charge controller" to manage the charging of the battery. Such battery charge controllers offer functionality such as:

   regulating the voltage and current levels to the rechargeable battery;

   providing status signals to the main processor of the portable device, or operating one or more status LEDs (light emitting diodes);

   providing protection circuits such as overcurrent, undervoltage, and overtemperature protection; and

   shutting themselves off when the charging source has been removed, to minimize battery drain.

Unfortunately, most of these battery charge controllers are designed to draw from a high capacity power supply with a steady voltage that will not sag appreciably under its current demands. This is a problem when one attempts to use a power supply with limited capacity or when the power is delivered via unknown length and gauge of power wires (the resistance of such power wires cause a voltage drop which aggravates the problem). Some computer data buses such as USB (universal serial bus) buses can be used to provide power to external devices, but while such power supplies are very convenient, they have limited capacity and are delivered via standard USB cables whose power wires could vary in length and gauge (anywhere from 20 AWG–28 AWG, for example).

The majority of personal computers (PCs) and laptop computers available today, are provided with one or more USB ports as standard components. USB ports are designed to support data communication at speeds of 12 megabits and 1.5 megabits per second (USB 2.0 provides for up to 480 megabits per second), support PnP (Plug and Play) installation software, and support hot plugging (i.e. devices can be connected and disconnected while the PC is running). Thus, USB ports are often used as interfaces to connect keyboards, mouses, game controllers, printers and scanners to PCs.

As well, USB ports are able to supply limited power to a connected device. The standard USB specification requires that "high-power" USB ports be operable to provide a supply voltage of 4.75–5.25 VDC and supply a maximum current of at least 500 mA (five units). The specification for "low-power" USB ports requires a supply voltage of 4.40–5.25 VDC and current of 100 mA (one unit).

USB ports would seem to be a very logical choice as a power supply for portable devices for a number of reasons. To begin with, USB ports supply a low DC voltage supply which is often very close to, or just above, the voltage of the battery being charged (many portable devices having battery voltages in the range of 2.5–4.5 VDC). As well, many portable devices may be operable to upload and download data or software, to and from a personal computer or a laptop computer (often referred to as "syncing"). Thus, many portable devices are supplied with docking cradles as shown in the system diagram of FIG. 1. This is quite a straightforward system, as the docking cradle 10 is connected to a USB port 12 of a personal computer (PC) 14, via a simple USB cable and connectors 16. The mobile device 18 need only be placed into the docking cradle 10 and an electronic connection to the (PC) 14, is made.

If the USB port 12 has sufficient power, it makes much more sense to use the USB port 12 to supply charging power to the mobile device 18, rather than using a separate AC charger. For example:

   a USB power supply will have less electrical noise than an AC charger, unless the AC charger incorporates large DC capacitors or inductors;

   an AC charger requires either a heavy transformer or an expensive switching power supply current, neither of which would be required if USB power is used;

   in the USB power supply implementation, the cable and connectors 16 used to connect the docking cradle 10 to the PC 14 could be used to carry both power and data, so no extra physical components would be required at all. In contrast, an AC power supply would have to be provided as a separate physical component, and

   a given AC power supply may require 120 VAC or 240 VAC as an input, and may provide 3, 4.5, 6, 7.5 or 9 VDC out, with one of large number of different possible connectors and polarities. A traveller who forgets an AC power supply at home, may not be able to find a replacement.

In contrast, the USB standard is widely accepted, so that a traveller whose mobile device is equipped with a USB connector will have a much greater chance of finding a charging source.

Unfortunately, USB ports can only provide limited power, while typical battery charge controllers are designed to receive a steady, high capacity power supply (that is, the input voltage at the battery charge controller is at or near its designed value, and does not drop as charging current increases.) The problem becomes clear when considering the block diagram of FIG. 2. The components of FIG. 2 are the same as those of FIG. 1, specifically, a docking cradle 10 powered from a USB port 12 of a PC 14, via cable and connectors 16, and feeding a portable device 18 resting in the cradle 10. From this presentation, it is clear that the voltage output from the USB port 12, V_{USB}, will drop as it crosses the cable and connectors 16, due to its resistance, R_{CABLE}. If either the cable resistance (R_{CABLE}) or the current drawn (I_{CABLE}) is too great, the voltage arriving at the battery charge controller in the mobile device 18, may be too low. This low voltage will cause many standard battery charge controllers to either shut down or to oscillate and fail to charge the battery in the portable device 18 efficiently.

True, new dedicated battery charge controllers could be developed which are operable with the limited USB power supply and resistance of the cable and connector system, but that would be an expensive and complicated solution. Such a design would become even more complicated to be compatible with both computer data bus power supplies and other power sources, such as AC power supplies.

There is therefore a need for a method and apparatus which allows standard battery charge controllers to be supplied with power from standard computer data busses such as USB ports. This design must be provided with consideration for the cost of electrical components, the limited physical board area in portable devices, the reliability and the complexity of the design. It is also desirable that this method and apparatus be operable with both computer data bus power supplies, and other power sources such as AC power supplies.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a novel method and apparatus which allows standard battery charge controllers to be supplied from standard computer data ports and other power sources, which obviates or mitigates at least one of the disadvantages of the prior art.

One aspect of the invention is broadly defined as a battery charging circuit which adjusts to the parameters of an external power supply, to minimize charge time, comprising: a battery charge controller connected to the external power supply and electrifying a battery; and a regulating circuit for maximizing the current drawn by the battery charge controller, while keeping the voltage to the battery charge controller above a preset minimum limit, the preset minimum limit corresponding to a low voltage shut off level for the battery charge controller.

Another aspect of the invention is broadly defined as a method for charging a battery of a portable device via an external power supply, which adjusts to the parameters of the external power supply to minimize charge time, the method comprising the steps of: connecting a battery charge controller to the external power supply and to a rechargeable battery in the portable device; determining a low voltage shut off level for the battery charge controller; monitoring the voltage that the external power supply provides to the battery charge controller; and maximizing the current drawn by the battery charge controller, while keeping the voltage to the battery charge controller above the low voltage shut off level for the battery charge controller.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the invention will become more apparent from the following description in which reference is made to the appended drawings in which:

FIG. 1 presents a physical layout of a personal computer connected to a portable electronic device in a manner known in the art;

FIG. 2 presents a block diagram of the system presented in FIG. 1, highlighting the problem of voltage drop between the personal computer and the portable electronic device;

FIG. 3 presents a electrical schematic diagram of a battery charging circuit in a broad embodiment of the invention;

FIG. 4 presents an electrical schematic diagram of a battery charging circuit using a comparator, in an embodiment of the invention;

FIG. 5 presents an electrical schematic diagram of a battery charging circuit using an electronic potentiometer, in an embodiment of the invention;

FIG. 6 presents a timing diagram of charging current provided by the embodiment of FIG. 5; and

FIG. 7 presents a flow diagram of an example method for charging a battery in a mobile device.

DESCRIPTION OF THE INVENTION

The general problem addressed by the invention is that typical battery charge controllers are designed to received a

steady, high capacity power supply while such a power supply is often unavailable, or is simply inconvenient. One of the most common battery charge controllers, for example, the LTC1734 from Linear Technology Corporation is designed to receive 5 VDC in, and has a low voltage lockout at 4.53V (that is, if the LTC1734 receives a supply voltage of less than 4.53 VDC, it simply shuts down.) When the voltage drop across the supply cable and connectors 16 are considered, the voltage supplied by the power node of a data bus such as a USB port, may be lower than this low voltage lockout. Therefore, though the LTC1734 is widely available, inexpensive and reliable, it cannot be used effectively in this environment.

A circuit which overcomes this problem, is presented as a block diagram in FIG. 3. This figure presents a battery charging circuit which uses a standard battery charge controller 30 known in the art, coupled to a rechargeable battery or batteries 32. The battery charge controller 30 is provided with power from some manner of external power, such as a computer data bus. This power connection is presented in FIG. 3 in the form of input voltage V_{BUS}. This V_{BUS} voltage will be reduced due to the resistance of the electrical cable and connectors 16, R_{CABLE}. Thus, the battery charge controller 30 only receives a voltage of $V_{CHRG}=V_{BUS}-(R_{CABLE} \times I_{CABLE})$.

As will be explained in greater detail hereinafter, the voltage drop across R_{CABLE} may result in the V_{CHRG} voltage being lower than the low voltage threshold for the battery charge controller 30. The invention therefore adds a current regulator 34 to the circuit. The resistance R_{CABLE} is of course fixed, but by reducing the current drawn by the battery charge controller 30, I_{CABLE}, the voltage drop across R_{CABLE} will decrease, thus avoiding the low voltage shut off of the battery charge controller 30, and allowing the battery 32 to be charged.

A number of current regulators 34 are described herein, but in general it desirable that the current regulator:

maximize the current being fed to the battery 32, and therefore maximizing the current drawn from the power supply (I_{CABLE}), while

keeping the V_{CHRG} voltage greater than the low voltage shut off level of the battery charge controller 30.

In some embodiments of the invention the current regulator 34 uses V_{CHRG} as an input (via connection 36), while in other embodiments the current regulator 34 uses an output of the battery charge controller 30 (via connector 38). Still other embodiments use no feedback to the current regulator 34.

Say, for example, that the voltage provided from the computer data bus is 4.75–5.25 VDC; that is, V_{BUS}= 4.75–5.25 VDC; the circuit must therefore be designed to operate at V_{BUS}=4.75 VDC. Suppose also that the resistance of the cable and connectors 16 is 0.5 ohms (R_{CABLE}=0.5 ohms) and that the low voltage shut off of the battery charge controller 30 is 4.53 VDC. The battery charge controller will endeavour to draw as much current as needed to charge the battery 32, which, in the case of a USB bus, will be limited to about 0.5 A. Thus, the voltage arriving at the battery charge controller, V_{CHRG}, will be:

$$V_{CHRG} = V_{BUS} - R_{CABLE} \times I_{CABLE} \tag{1}$$

$$= 4.75 \text{ VDC} - (0.5 \text{ ohms} \times 0.5 \text{ A})$$

$$= 4.5 \text{ VDC}$$

If the low voltage shutdown of the battery charge controller is higher than V_{CHRG}=4.5 VDC, it will therefore

shutdown. This is the case for the LTC1734 controller, for example, which shuts down at 4.53 VDC.

The above calculations did not even take into account component tolerances, which cannot be ignored. The LTC1734 application notes state that this device has a tolerance of 1%. If the current regulator 34 incorporates a number of simple components then the circuit of FIG. 3 may easily have a tolerance of 3% or so.

Thus, V_{CHRG} may effectively be in the range of 4.37 VDC; well below the 4.53 VDC cut off for the LTC1734 battery charge controller.

Equation (1) can also be used to determine a current level, I_{CABLE}, which does not cause the battery charge controller 30 to shutdown:

$$V_{CHRG} = V_{BUS} - R_{CABLE} \times I_{CABLE} \qquad (1)$$

$$\begin{aligned} I_{CABLE} &= (V_{BUS} - V_{CHRG})/R_{CABLE} \qquad (2) \\ &= (4.75 - 4.53)/0.5 \\ &= 0.44 \text{ A} \end{aligned}$$

Thus, reducing the current I_{CABLE} to 0.44 A is sufficient to avoid the low voltage shut off of the battery charge controller 30. Allowing for 3% tolerance:

$$\begin{aligned} I_{CABLE} &= (V_{BUS} - V_{CHRG} \times 3\%)/R_{CABLE} \qquad (2) \\ &= (4.75 - 4.53 \times 1.03)/0.5 \\ &= (0.09)/0.5 \\ &= 0.18 \text{ A} \end{aligned}$$

That is, the current I_{CABLE} may have to be reduced to 0.18 A to avoid the low voltage shutdown.

Thus, the use of the circuit in FIG. 3 allows computer data buses and similar power supplies with limited capacity, to be used to charge mobile devices, without causing the battery charge controller 30 to shut down.

The solution of this embodiment adapts to the capabilities of any external power source to minimize charge time. If, for example, 5 VDC arrives at the input of the battery charge controller 30 with unlimited current and no voltage drop as the current draw increases, then the regulating circuit 34 will not restrict the current drawn.

A number of different embodiments will now be described. Each embodiment uses a very small number of simple, reliable components. Thus, as a whole, the invention provides an effective solution which is inexpensive, reliable and consumes minimal board space in a portable device.

Comparator Embodiment

FIG. 4 presents an electrical schematic diagram charging circuit which employs two main components: a comparator 50 and a LTC1734 battery charge controller 52 having a current control pin PROG. Varying the current drawn through the control pin PROG will vary the current supplied by the LTC1734 battery charge controller 52 to the battery 32. Drawing more current out of the PROG pin will increase the charge current, while reducing the PROG current will reduce the charge current.

Many battery charge controllers have a similar current control system, but this embodiment will be described with respect to the LTC1734 controller. The LTC1734 controller can be operated in either constant current mode, or constant voltage mode.

In the constant voltage mode (entered when the charge voltage of the battery 32 reaches 4.2 VDC externally), the LTC1734 controller 52 servos its DRIVE pin to maintain its BAT pin at 4.2 VDC. In this mode, the current provided by the LTC1734 controller 52 will necessarily drop, and the current flowing out of the PROG pin will drop accordingly. As this latter mode of operation is not affected by the system described herein, it will not be discussed in any further detail.

As noted above, the minimum required voltage at VCC for proper operation of the LTC1734 controller 52 is 4.53 VDC, and the USB specification states that for standard USB equipment under a high load (i.e. 500 mA), V_{CHRG} may be pulled as low as 4.35V—too low for the LTC1734 controller 52 to operate. To prevent this, the comparator 50 monitors V_{CHRG} (scaled down to a more useful voltage— V_N—by the voltage divider R1 and R2) fed to the inverting input of the comparator 50 and compares it to a reference voltage (V_P) which is fed to the comparator 50's non-inverting input.

V_P is derived by low-pass filtering the LTC1734 controller 52's PROG pin output through resistor R5 and capacitor C2, as V_{PROG}=1.5 VDC when the LTC1734 controller 52 is operating in the constant-current mode. R5 also serves to isolate other components from the LTC1734 controller 52, ensuring proper operation of the LTC1734 controller 52. Resistors R1 and R2 are chosen such that V_{CHRG} is a suitable tolerance above 4.53 VDC when V_N=1.5 VDC.

In the intended and published usage of the LTC1734 controller 52, the voltage across resistor R3 is simply V_{PROG} since R3 is intended to be tied between PROG and ground. In such a configuration, determining and setting a fixed charge current I_{CHRG}, is straightforward. In the system of the invention, rather than adjusting R3 to control charge current as most alternative ideas suggest, this circuit adjusts the voltage across a fixed R3 by changing the voltage across C1 (that is, V_{C1}) such that:

$$I_{CHG} = \frac{1.5V - V_{C1}}{R3} \times 1000$$

V_{C1} is controlled by the comparator 50. As the comparator 50 is an open-drain comparator (a MAX9120 comparator was used for testing purposes, though similar parts such as the LMV7235 should work as well), when $V_N > V_P$, the comparator 50 will sink current into its output pin; otherwise the output pin will float.

The control loop operates as follows:

1. as I_{CHRG} drops, the voltage drop across the cable and connectors 16 also drops, so V_{CHRG} rises, per equation (1) above. As V_{CHRG} rises, the positive input to the comparator 50, V_N, will also rise. For V_N rising, when $V_N > V_P + 0.5$ V_{HYS} (V_{HYS} being the input hysteresis for the comparator 50), the comparator 50 will turn on its output and pull charge out of C1, decreasing V_{C1} and causing I_{CHRG} to increase;

2. as I_{CHRG} increases, the voltage drop across the cable and connectors 16 rises, causing V_{CHRG}, and consequently V_N, to drop. For V_N falling, when $V_N < V_P - 0.5$ V_{HYS}, the comparator 50 turns off its output, allowing the LTC1734 controller 52's PROG pin to pour charge into C1, causing VC_1 to increase and decreasing I_{CHRG}.

Resistor R4 smooths out the ripples on C1 and limits current transients through the comparator 50's output.

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When the power supply is capable of supplying all the power the LTC1734 controller **52** can handle, V_{C1} will be at a minimum and I_{CHG} will be approximately determined by:

$$I_{CHG} = \frac{1.5V}{R3 + R4 + R_{OUT}} \qquad (4)$$

R_{OUT} is the resistance from the comparator **50**'s output to GND when the output is active. Because the LTC1734 controller **52** is susceptible to malfunction due to capacitive effects in the PROG circuit, it is best to keep R4≦0.1R3, but this will depend on the application, and can easily be determined by one skilled in the art.

When power is first applied to this circuit through V_{BUS}, V_{C1}=0 and the charger will start and stay on. A high-on-reset signal of 3.0V applied to CHG_CTRL will keep the charger off; once the "off" state has been established, the CHG_CTRL signal can be removed. Conversely, pulling CHG_CTRL to GND for a period of time and then floating it will turn on the charger.

Testing of Comparator Embodiment

The circuit of FIG. **4** was tested with the following component values:

R1=10.0 kΩ

R2=21.0 kΩ

R3=3.09 kΩ

R4=200Ω

R5=10.0 kΩ

C1=1 μF

C2=0.1 μF

The R4, C1 time constant was chosen to be at least 10 times larger than the propagation delay of the MAX9120 for stability.

For testing purposes, a 1Ω resistor was used to simulate the resistance of the supply cable and connectors **16**.

With V_{BUS}=6 VDC, I_{CHRG}=440 mA.

As V_{BUS} was gradually reduced, I_{CHRG} remained at 440 mA until V_{BUS}=5.075 VDC, at which point I_{CHRG} started to drop. By the time V_{BUS}=4.71 VDC, the charge current I_{CHRG}, had dropped to 92 mA.

Using an HP54645D oscilloscope to probe the LTC1734 controller **52**'s VCC pin showed the following;

for I_{CHRG}=440 mA and V_{BUS}=5.075 VDC, VCC=4.63 VDC; and

for I_{CHRG}=92 mA and V_{BUS}=4.71 VDC, VCC=4.63 VDC.

This is consistent with the chosen values of R1 and R2, using the PROG reference scheme.

With V_{BUS}=4.63 VDC the LTC1734 controller **52** turned off and V_{PROG}=4.625 VDC.

By returning V_{BUS} to 6 VDC, the LTC$_{1734}$ controller **52** could be turned on again by momentarily pulling CHG_CTRL to GND. Similarly, pulling CHG_CTRL above about 2.25 VDC turned the LTC1734 controller **52** back off.

Digital Potentiometer Embodiment

The invention is not strictly limited to the case where the low voltage threshold is never exceeded. In the embodiment of FIGS. **5** and **6**, for example, the low voltage threshold could be exceeded with each periodic cycle of current ramping, but the duty cycle still be sufficient to charge the battery. The only difficulty with such a circuit is that it would be necessary to reset the battery charge controller with each cycle. The circuit of FIGS. **5** and **6** ramps through a range

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of current supply, but uses a reset circuit to stop the ramping before the low voltage threshold is exceeded.

Like the embodiment of FIG. **4**, this circuit uses the LTC1734 battery charge controller **52**, though other battery charge controllers having a current control pin PROG could also be used. However, rather than having a comparator circuit as in FIG. **4** which modulates the current draw to avoid the low voltage shut off, this circuit ramps from a low current level, through to a high current level. Before the low voltage threshold is reached, the LTC1734 controller **52** shuts down and the cycle is repeated. The circuit also includes provisions for setting the current draw to a number of predetermined and fixed levels.

Looking first at the simplest case, with the inputs FAST CH, HI/LO CH and ADJUST all at 0 VDC, then there will be no current flow through either of the semiconductors Q2 or Q3. The resistance between PROG and ground will therefore be equal to the sum of resistors R6 and R7, and this will determine the current flow through the LTC1734 controller **52**. If these resistors are set to 2.2 kohms and 12.8 kohms respectively, then the circuit will provide 100 mA.

If the FAST CH is held high, then current will flow through R6, and the resistance from PROG to ground will only be 2.2 kohms. Thus, the current flow through the LTC1734 controller **52** will be approximately 750 mA. This setting would not be useful with a low capacity supply such as a USB port, but could be used with a high capacity supply such as an AC transformer.

Finally, with the HI/LO CH input high, current will flow through resistor R8, electronic potentiometer R9, and Q2. Resistor R8 preferably has a value of 1 kohm, and R9 is preferably a MAX5467 potentiometer, which has a range of 0–10 kohms, in 32 discrete steps. Thus, this circuit will step through a resistance of 11 kohms down to 1 kohm in 32 discrete steps (note that this circuit is in parallel to R7, so R7 must be considered in determined the current drawn from PROG). This would result in the current output similar to that shown in FIG. **6** (the number of steps that would actually be made prior to reaching the low voltage shut off varies with the particular application due to component values and tolerances, and other factors).

The ADJUST and HI/LO CH inputs could be controlled using a microcontroller or similar device. As well, hardware components such as an oscillator could also be used to control the rate through which the steps of potentiometer are stepped.

In the preferred embodiment of the invention, the HI/LO CH input also feeds the CS pin on the MAX5467. This is a "chip select" input—in combination with U/D input fed by the ADJUST input, it is used to increment or decrement the electronic potentiometer R9. Also, a separate reset circuit is provided using resistors R10, R11, R12, capacitor C3, and transistor Q3. This circuit could be powered using any reliable voltage V2 (in the preferred embodiment. V2=+3.3 VDC, which is provided from V_{USB} and a voltage regulator).

The preferred values for the components in this circuit are:

R6=2.2 kohms

R7=12.8 kohms

R8=1.0 kohms

R9=10 kohms

R10=200.0 kohms

R11=10.0 kohms

R12=200 kohms

C3=22 pF

Software Embodiments

Rather than using only electronic hardware as shown above, the invention may also be implemented using a combination a hardware and software components, including programmable devices such as digital signal processors (DSPs), microcontrollers, field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs) and the like. Such an embodiment could be implemented as shown in the flow chart of FIG. 7.

Like the embodiments described above, this method could be used to charge any rechargeable battery in a portable or similar electronic device. Any external power supply could be used, though the invention is most useful with power supplies of limited capacity. The method of the invention adjusts to the parameters of external power supplies to minimize charge time.

As shown in FIG. 7, the method of the invention begins at step **90** by connecting a battery charge controller **30** to the external power supply and to the rechargeable battery in the portable device **18**. As described herein above, the connection to the external power supply is preferably made via a USB cable and connectors **16**, and a cradle **10** to hold the portable device **18**.

A low voltage shut off level for the battery charge controller in the portable device **18** is then determined at step **92**. This low voltage shut off level is generally predetermined as the software algorithm is executed by the portable device **18**, and the parameters of the battery charge controller **30** being used in the portable device **18** can be programmed into it.

The voltage provided by the external power supply to the battery charge controller **30** is then monitored at step **94**. This step could be provided periodically, continuously, or in response to an event, such as a change in the charge current. Various devices, such as microcontrollers, are often provided with integral ADCs (analogue to digital converters) which could be used to perform this monitoring function.

The current drawn by the battery charge controller **30** is then maximized at step **96**, with the limitation that the voltage being supplied to the battery charge controller **30** must be kept above the low voltage shut off level. The current drawn by the battery charge controller **30** could be controlled in a number of manners. For example, most microcontrollers have DAC (digital to analogue converter) outputs which could be used to control the current provided by a device such as the LTC1734 controller **52**, described herein above.

The balance of the software code needed to perform this algorithm would be straightforward to one skilled in the art.

The method steps of the invention may be embodiment in sets of executable machine code stored in a variety of formats such as object code or source code, integrated with the code of other programs, implemented as subroutines, by external program calls or by other techniques as known in the art.

Even the hardware embodiments of the invention could be encoded in a software form such as the hardware development languages (HDL code) used to fabricate integrated circuits. This HDL or similar code could be stored on any electronic memory means such computer diskettes, CD-Roms, Random Access Memory (RAM) and Read Only Memory (ROM). As well, electronic signals representing this software code may also be transmitted via a communication network.

Options and Alternatives

While particular embodiments of the present invention have been shown and described, it is clear that changes and

modifications may be made to such embodiments without departing from the true scope and spirit of the invention. For example:

1. the circuit of the invention could be used with any manner of power source including: conventional AC power supplies (often referred to as "bricks"), computer data busses such as USB ports, external battery packs, laptop power supplies, DC outlets on aircraft;

2. any manner of electrical appliance could be charged with such a circuit including portable laptop computers, personal digital assistants (PDAs), cellular telephones, wireless email and paging devices; and

3. any manner of rechargeable battery could be used including single or multiple lithium-ion, nickel-cadmium, or other types of cells.

Again, such implementations would be clear to one skilled in the art from the teachings herein, and do not take away from the invention.

What is claimed is:

1. A battery charging circuit which adjusts to the parameters of an external power supply, to minimize charge time, comprising:

a battery charge controller connected to said external power supply and electrifying a battery; and

a regulating circuit for maximizing the current drawn by said battery charge controller, while keeping the voltage to said battery charge controller above a preset minimum limit, said preset minimum limit corresponding to a low voltage shut off level for said battery charge controller.

2. The battery charging circuit of claim **1** where said battery charge controller to includes a current control input.

3. The battery charging circuit of claim **2** where said regulating circuit comprises:

a regulating circuit responsive to the voltage at the input to said battery charge controller by adjusting the current drawn by said battery charge controller to keep the voltage at the input to said battery charge controller above said preset minimum limit.

4. The battery charging circuit of claim **3** where said regulating circuit comprises:

a comparator for receiving a voltage signal from the input to said battery charge controller and a reference voltage signal, and responds to said voltage signal being less than said reference voltage by reducing the current supplied by said battery charge controller.

5. The battery charging circuit of claim **3** where said regulating circuit comprises:

an electronic potentiometer operable to incrementally decrease its resistance in response to control pulses from a microprocessor, thereby incrementally increasing the current supplied by said battery charge controller.

6. The battery charging circuit of claim **3** wherein said regulating circuit comprises:

an electronic potentiometer operable to cyclically ramp though its range of resistance, thereby cycling the current supplied by said battery charge controller through a range of 0 A to a current level that causes said battery charge controller low voltage shut off to trip.

7. The battery charging circuit of claim **4** wherein:

said reference voltage is provided by said battery charge controller.

8. The battery charging circuit of claim **4** wherein:

said comparator circuit further comprises a voltage divider for scaling down said voltage signal from said

power mode, and said reference voltage signal is scaled down proportionally.

9. The battery charging circuit of claim **4** wherein:

said regulating circuit further comprises a capacitor coupling the output of said comparator to ground, thereby smoothing out variances in the output of said comparator.

10. The battery charging circuit of claim **4** where said external power supply comprises a computer data bus having a power node.

11. The battery charging circuit of claim **10** wherein:

said computer data bus is a Universal Serial Bus (USB).

12. The battery charger of claim **4**, wherein said comparator circuit has a hysteresis, whereby said battery charge controller will not begin to deliver current again until said voltage level of said computer data bus is well above said reference voltage.

13. The battery charger of claim **4**, wherein said comparator is operable to lower the charge current when the voltage of the external power supply drops below a preset reference level.

14. The battery charger of claim **4**, wherein said battery charge controller includes a low voltage shut off circuit, said battery charge controller shuts off if the incoming voltage falls below a preset limit, and wherein said regulating circuit lowers the current output of said battery charge controller

when the voltage of the supply drops below a preset reference, to avoid said preset limit.

15. A battery charger comprising:

a battery charge controller whose current output varies with the voltage applied to a control signal input; and

a comparator for lowering the charge current when the voltage of the supply drops below a preset reference level.

16. A method for charging a battery of a portable device via an external power supply, which adjusts to the parameters of said external power supply to minimize charge time, said method comprising the steps of:

connecting a battery charge controller to said external power supply and to a rechargeable battery in said portable device;

determining a low voltage shut off level for said battery charge controller;

monitoring the voltage that said external power supply provides to said battery charge controller; and

maximizing the current drawn by said battery charge controller, while keeping the voltage to said battery charge controller above said low voltage shut off level for said battery charge controller.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.   : 6,833,686 B2   Page 1 of 1
APPLICATION NO. : 10/372446
DATED   : December 21, 2004
INVENTOR(S)   : Dusan Veselic et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is
hereby corrected as shown below:

Cover Page, Col. 2, Under (74) *Attorney, Agent or Firm*, remove "Charles B. Meyer"

Signed and Sealed this

Thirty-first Day of October, 2006

JON W. DUDAS
Director of the United States Patent and Trademark Office