

Programmable Battery Charging in Wireless Devices

Just beyond the fingertips of the handheld device user are a myriad of unseen programmable devices that make these gadgets so convenient and fun to use. Equipped with a battery of capacity exceeding the attention span of the child or the workday of the adult, these handheld marvels are ready for another round of indulgence once the battery is given opportunity to freshen up. A look at the chargers in some of the more sophisticated units reveal yet another area of programmability intended to shorten the recharge cycle while lengthening the useful life of the battery.

The degree of charger programmability extends well beyond these two rudimentary requirements of handheld devices extending into areas of voltage and current monitoring with a sharp eye focused on the battery temperature to gauge the precise rate of charge the battery for optimal recovery and safety. Constant battery voltage monitoring during usage not only provides notification of a low battery but can as well provide a sense of the time remaining before a recharge cycle must be reapplied.

Much of this programmability may reside in the battery charger integrated circuit or the charger may communicate its findings with a semi-dedicated microprocessor whose purpose is to manage the device processes, shutting unused or idle portions of the system off to extend battery usefulness.

While this *Smart Charger* brings some obvious advantages to the handheld device, the standalone charger, in its most primitive form, mustn't be overlooked as the mainstay of battery maintenance during the deliberate or accidental absence of the microprocessor's guidance. Attention must be paid to those circumstances under which the processor is, for some reason, unavailable to favor the charger with its intelligence requiring instead the charger contain some amount of self-reliance. One such scenario requiring the charger to "rise to the occasion" involves the near depletion of the battery whereby the microprocessor has not the voltage it requires to function. Another occurs when the battery pack is internally switched off due to some non-destructive fault. The charger, now powered directly by the external charging appliance, must be designed to correctly apply charge to the depleted or open battery continuing the charging cycle under the strict charge profile guidelines dictated by the battery chemistry without assistance of the microprocessor safely recharging the battery in the shortest possible time.

Having loosely defined a more or less ideal battery charger in the context of the environment of the handheld device, we turn our attention to the external charging appliance. Try as we may, our electrical engineering background is of little use as we find the most difficult task, after specifying the voltage and current requirements, is that of choosing the package, cable length, etc.; tasks better handled by mechanical and marketing types. This, of course, is assuming the charging appliance is AC line powered or secondarily powered by a charging adapter in an automotive backdrop. We may wish to bolster our charger design to be able to withstand the occasional inadvertent application of an overrated charging appliance. The design is altered slightly to self-protect itself and the battery against excessive voltages.

Another charging appliance readily available for a handheld device is our computer's USB port. Outputting up to 500mA of steady state current, a cable is all that is necessary to establish the replenishing link between the port and the handheld device's battery. The abundance of ports on many computers makes the USB port our first choice for a

charging appliance, the line powered wall-wart the secondary choice. Even a computer with a just a single port is likely to be in use only a fraction of the time for downloading photos, uploading MP3's, etc.

Not to downplay the usefulness of the wall-wart, but when compared to a USB port, the wall-wart has many disadvantages not the least of which is additional, unnecessary cost. The most inexpensive wall-wart consists of a 60Hz x-former, bridge rectifier and filter capacitor yielding a very poorly regulated output varying in voltage as does the AC line voltage. Adding a linear regulator eliminates the poor regulation but increases power dissipation. All in all the bottom of the line AC powered charging appliance is inexpensive yet bulky and inefficient. Top of the line adapters use a switched-mode supply resulting in an efficient and compact design at a commensurate cost adder and a propensity for conducted and radiated emissions that when held under FCC and other regulatory agency limits increases in size and cost.

With as many people owning a personal computer as use one at the workplace the ultimate low cost charging solution must be the USB port. Add to this a charging cable for the commuter's vehicle and a continuous charging source exists across time and space for today's commuting worker. We now take a closer look at the battery charger and how to obtain the highest capacity charger without violating the maximum loading specification for the USB port.

A powered USB port is capable of outputting 5V at up to 500mA. Using a linear charger the charge rate is a constant 500mA and therefore a battery with a capacity of 1000mAHrs requires the charger be applied for 2 hours to fully charge the battery. Using a switched mode charger enhances our design by improving the efficiency and reducing the size of the pass element. A closer look reveals yet another advantage of the switcher over the linear charger.

As the USB specification is 500mA maximum one could potentially realize the use of current multiplication when the battery voltage is less than the supply voltage to obtain charging currents in excess of 500mA. Assuming Li-Ion batteries this current multiplication is possible at all voltages as the float voltage of Li-Ion is presently around the 4.2V-4.4V mark. Current multiplication is a natural phenomenon of the buck or step-down switching regulator and is defined as the ratio of the input voltage to output voltage times the available input current or $^1C_M = (V_{IN}/V_{OUT}) \times I_{IN}$. As an example, when a step-down switched mode regulator is operating at a 50% duty cycle or $^2V_{OUT}/V_{IN} = 0.5$, the input is only supplying current for one-half of the cycle. Assuming the input supply has some capacity to supply in excess of its rated output for a short interval of time and providing the average current taken is no more than 500mA for the USB port, the switched mode buck can potentially supply $(5/2.5) \times 500mA = 1A$. An illustration of the effect of current multiplication versus the charging voltage for a USB port is shown in Figure 1. As a reminder to the reader care must be taken when charging Li-Ion batteries at a different float voltage, Figure 2 displays the Li-Ion charging profile. Note the pre-charge current is a fraction of the charge current and current multiplication must not be invoked until the battery has passed the float voltage where the full charge current can replace the pre-charge current.

The switching charger must operate at as high a frequency as possible while maintaining high efficiency and low profile SMD inductors and capacitors. An integrated power switch further reduces size and cost and allows for certain advantages and features otherwise more costly if undertaken external to the integrated charger. One such feature is cycle-by-cycle current limiting and current mode control. Average charge current sensing, while tempting to integrate is best-implemented external to the charger controller directly in series with the battery. A temperature sensing input for

interfacing to a low cost thermistor provides additional protection and long life for the battery. Add the means of communicating with the charger in the form of a 2-wire interface and provide the user with programmable configurability of charging/sensing parameters and we have defined a *Smart Charger* capable of operating from a USB port, charging at predetermined and programmable pre and full charge rates.

The programmable features are maintained after device shutdown by using an on-board EEPROM that the user programs via an I²C interface and a Windows GUI interface. Programmable features include the charging profile key parameters such as: Pre-charge Current, Pre to Fast Charge Transition Voltage, Fast Charge Current, Fast Charge to Taper Charge Transition Voltage, Charge Termination Current and Float Voltage settings. Additional settings aimed at preventing damage to the battery by terminating the charging sequence include: Pre-charge Timeouts, Fast Charge Timeouts and Low/High Temperature Alarm Setpoints. Temperature may be monitored by 3 different standard value thermistors with each having a unique constant current associated with it.

Charging may be initiated by an I²C command or the by assertion of a programmable polarity Enable pin. A Status output pin is programmable as a blinking or steady state open drain active low signal indicating the battery is being charged.

Battery and charger status may be read via the I²C interface. The status includes state of the charger such as Idle, Pre-Charge, Fast Charge and Charge Termination, state of the battery such as Missing, Overvoltage or Undervoltage Over and Under-Temperature. Charger timer status, available in three durations enabled, is also available to the user via the 2-wire interface. Further, the charge controller may be programmed to automatically begin another recharge cycle and can report on whether the current charging cycle is the first since the controller was enabled and whether a charge cycle has been completed since enabling the controller.

A practical design begins once the battery is chosen. We choose a Li-Ion battery with a full charged potential of 4.2V and an ampere-hour capacity of 1000ma-hours. We will use a USB port as our charging supply voltage and intend to recharge the battery as quickly as possible so the TurboCharge™ or current multiplication technique, as mentioned earlier will be exploited. To aid our design we open the Windows GUI tool displayed in Figure 3 and click on the 'Standard Settings' radio button to get a better idea of what parameters need to be set by the user.

Based on the current multiplication guidelines that prevent the USB port's output current from being, we choose a charging current from Equation 1: $C_M \leq (5/4.2) \times 0.5 \leq 595\text{mA}$. Referring to the GUI we find must reduce the sense resistor value from 100 milliohm to 75 milliohm obtain a charge current greater than 500mA. We choose 567mA from the GUI drop-down menu. Although the charger current could have been set higher, allowances are made for charger operating current and other support peripherals such as pullup resistors and a visible LED indicator to ensure the USB port current maximum is not exceeded. As a first pass to completing the charging profile, leave the Pre-charge and Termination currents at 100mA and 33mA respectively. Thermal protection is added by selecting the 100uA/10k thermistor option and the Float and Pre-Charge To Fast Charge Threshold are left at 4.2V and 3.0V.

Next choose the switching inductor and bulk output capacitor. The inductor is chosen for 20-25% ripple current at the chosen switching frequency of 1.25MHz. Roughly, $^3L \geq (5.0-3.0) \times (3/5)/(0.2 \times I_{\text{CHARGE}} \times f_{\text{SW}}) \geq 8.46\mu\text{H}$. Use a 10uH

inductor. A ceramic capacitor with its low ESR is the logical choice for the bulk capacitor and a 10uF with an ESR of 8 milliohms is readily available, cost effective and has adequate bulk capacitance to predict the ripple voltage almost exclusively from the product of the inductor ripple current and the ESR. The addition of a bulk and a bypass capacitor to the input side and a pair for the charger's bias pin completes a standalone design. The USB standard dictates the size of the input bulk capacitor as that value which when hot-swapped into a live USB port does not allow the port voltage to droop by more than some specified value. The charger bias capacitors are used for maintaining the integrity of the internal voltage reference and analog circuitry. Add a Schottky free-wheeling diode of 500mA, 10V and frequency compensate the switcher for stable operation using a simple R-C combo with the charger's transconductance amplifier.

With the 2-wire serial data interface, the charger can, with the help of a low-grade microprocessor, greatly increase its usefulness in a number of ways. Should a battery vendor change occur, the serial interface provides the means of redefining the charging profile and all other aspects of the battery maintenance thus far covered without removing the charger or changing an external component. Switching over to the 'Status/Control' tab of the GUI in Figure 4, we find a number of volatile status and fault registers the microprocessor can read and act upon during the charging event. The charging process can be started or stopped as shown and among other actions, the charger may also be switched over to operate from a USB hub where the maximum current is 100mA.

But the real advantage of the serial interface and the programmability of the charger lies in the Turbo Charging that can be easily altered 'on the fly' with the intervention of the microprocessor and a low cost A-D converter. From Equation 1 we recall that the charging current increases inversely proportional to the duty cycle meaning that at lower battery voltages we may increase the charging current without compromising the USB port's current capability. For example, when the battery voltage reaches Fast Charge Threshold of 3.0V, the battery can be charged at $5.0/3.0 \times 500\text{mA}$ or 833mA minus some 20-50mA for the peripheral components and charger operating current. As the battery voltage increase so must the charging current decrease to keep the average input current below 500mA. Figure 5 displays the complete schematic for the battery charger with 2-wire serial interface.

Innovation prevails once again as a device intended to enhance the power of the PC may now be utilized as a battery-charging source for handheld devices of many kinds. The USB port's communication capabilities boost the charger's features well beyond the benign standalone into an intelligent, Turbo Charging 'docking station' with no more than an inexpensive USB cable. The sometimes bulky AC adapter, while still a common household item, can now become an optional accessory for the battery operated device, yielding ground to the ever more popular USB cable. It would not be surprising to find a Laptop's battery breathing life back into a discharged MP3 player or handheld video game's battery when the need for pleasure outweighs the benefit of completing a business task that can be completed when the final destination is reached.

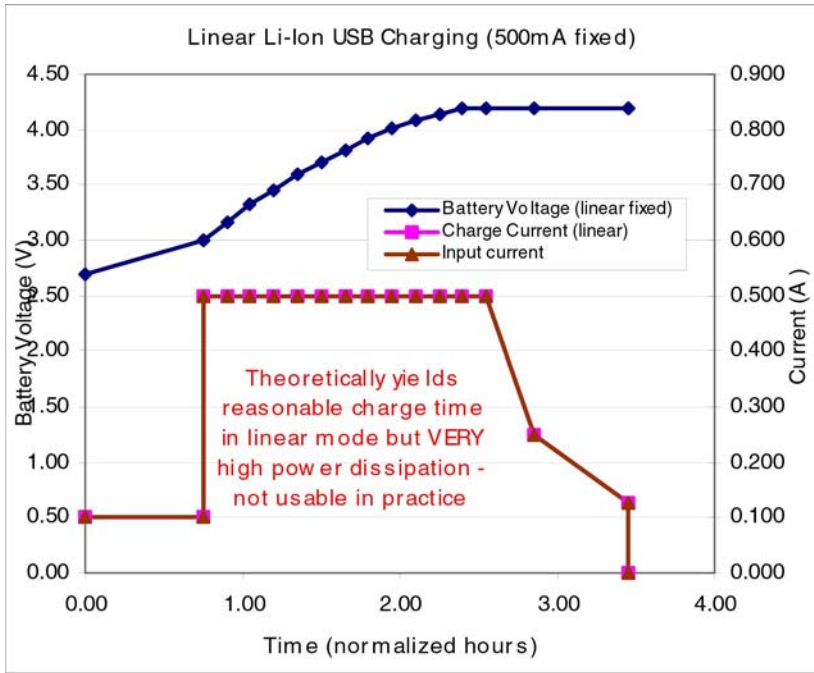


Figure 1: TurboCharge™ (current multiplication) Method Versus Traditional Linear Charger

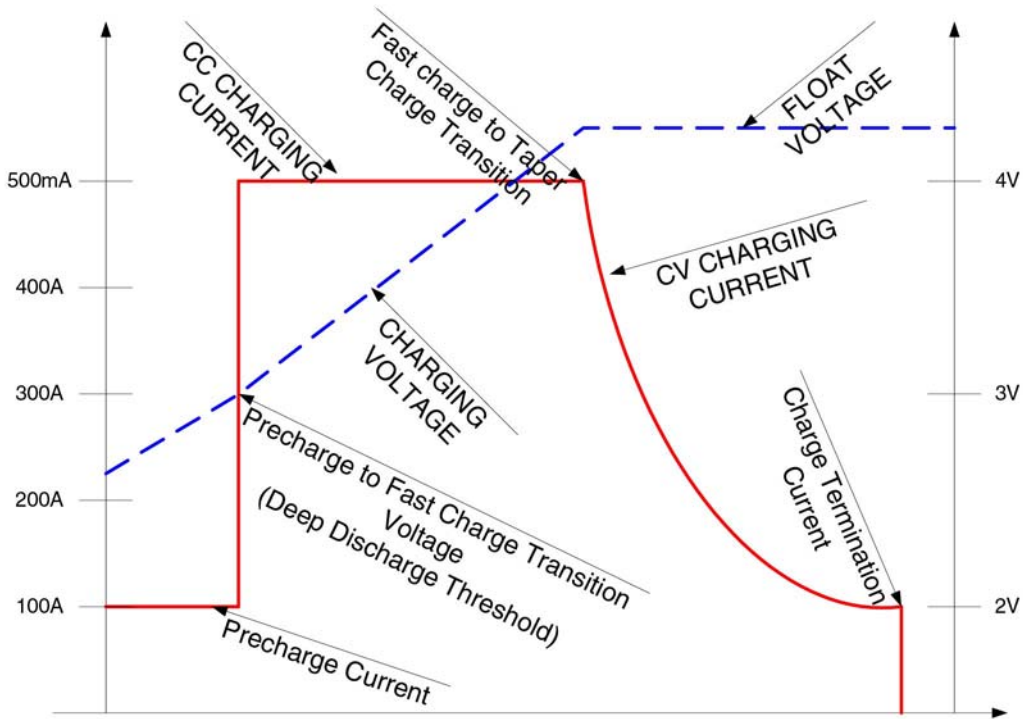


Figure 2: Programmable Charging Profile for Li-Ion Battery

Summit SMB135 Programmer - USB Version 0.3.0

File Configuration Help

HEX HEX [Icons] EXIT

SUMMIT MICROELECTRONICS, INC.
www.summitmicro.com

Programmable, USB, Switch-Mode Battery Charger with 1% Voltage Accuracy

Standard Settings Read Config Write Config

Charge Profile

Sense resistor (milli-ohms)
Affects parameters C, A, G:

C Fast Charge Current (mA):

A Pre-charge Current (mA):

G Termination Current (mA):

A = Pre-charge Current
B = Pre-charge to Fast Charge Transition
C = Fast Charge Current
D = Fast charge to taper charge transition
E = Charging Current
F = Float Voltage
G = Charge Termination
H = t (Pre-charge)
K = t (charge)

I2C Interfacing

THERM Current/NTC Value
 100uA/10k 10uA/100k
 40uA/25k Disabled

EN Pin Polarity
 Active Low Active High

Pre-charge Timeout
 2097 4194
 8387 Off

Charging initiated by
 I2C EN Pin

State of BSTAT output while charging
 Low Blinking

F Final Float Voltage:
B Pre-charge To Fast-charge Threshold:
 Low Temp Alarm Trip Point:
 High Temp Alarm Trip Point:

Automatic Recharge Enabled
 Current Termination Enabled
 Allow volatile writes to R00-R07

Status/Control

Fast-charge Timeout
 16778 33554
 67109 Off

Frequency Select
 750kHz
 1MHz
 1.25MHz

Configuration Registers

Reg	Data
R00	D6
R01	00
R02	0A
R03	F0
R04	E4
R05	20
R06	00
R07	00
R08	80
R09	00
R0A	00
R0B	C8
R0C	01
R0D	E9
R0E	01
R0F	08

Hex
 Bin
 Decimal

Checksum = E1

Figure 3: Windows GUI Provides Easy Programming of Charging Profile Parameters

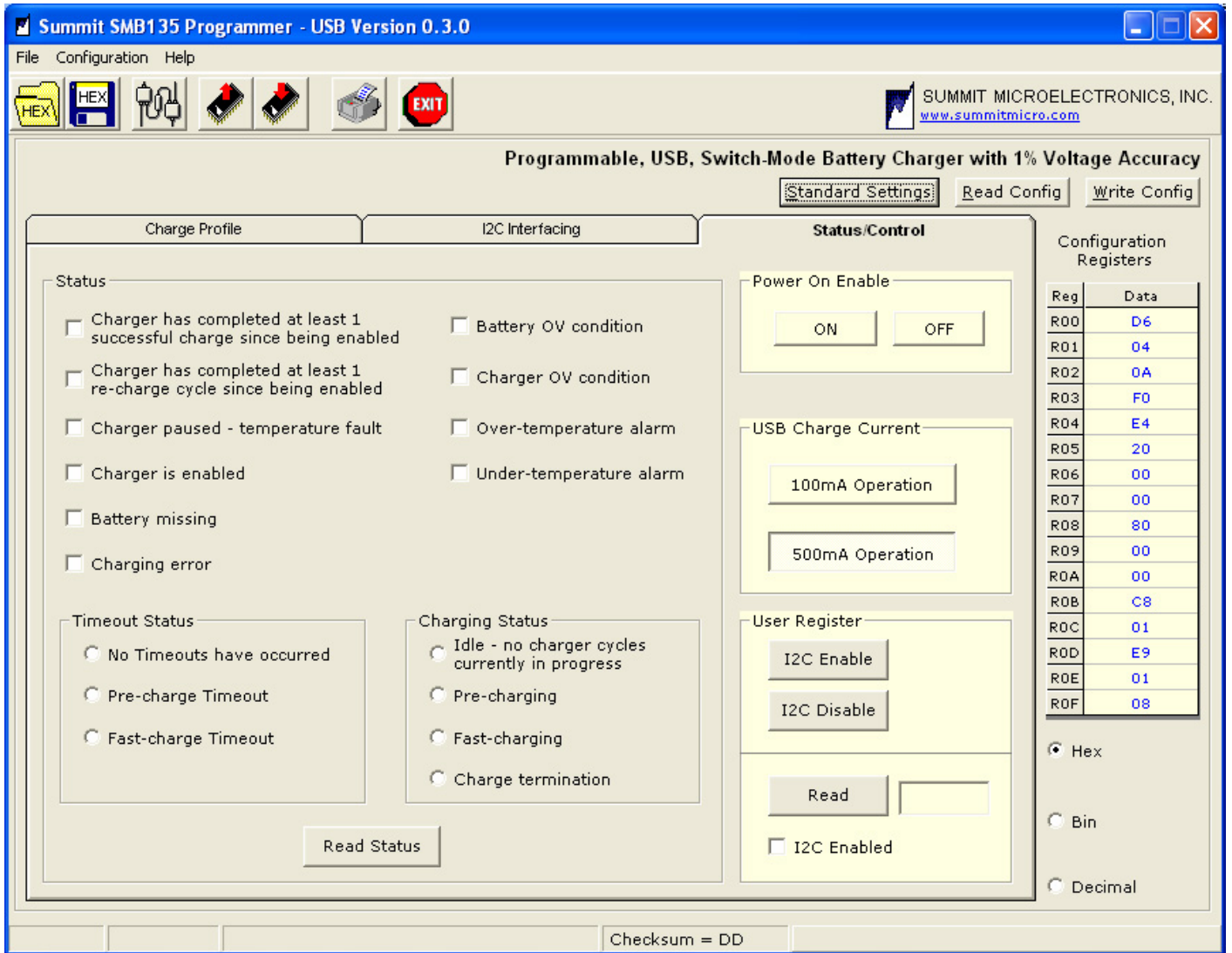


Figure 4: Status and Fault Registers Display Charging State. Command Registers Begin/Terminate Charging

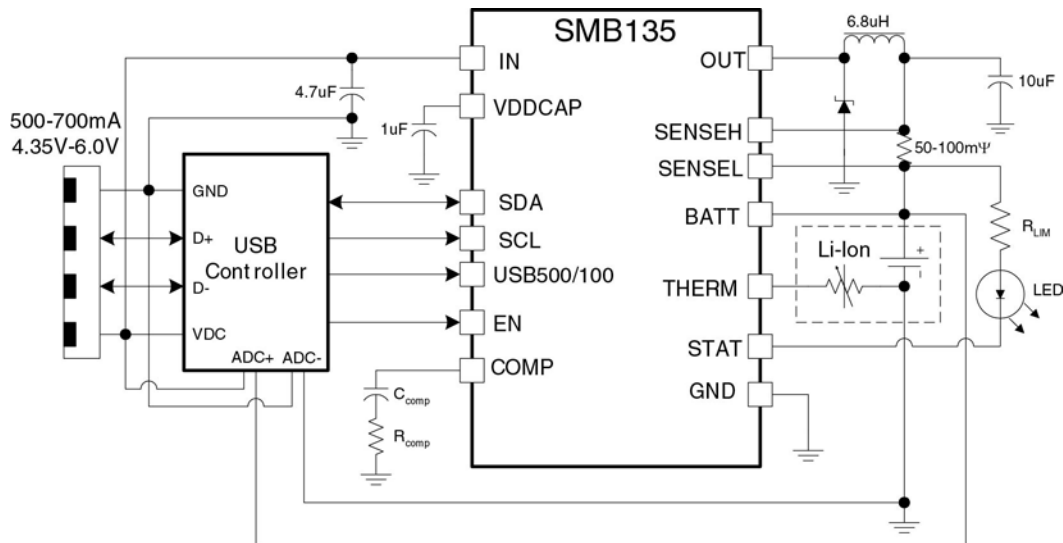


Figure 5: Complete Schematic of User Programmable USB Powered Switched-Mode Li-Ion Charger

- I. Introduce Examples of Programmability Features in Handheld Devices
 - a. Some common programmable features apparent to and controlled by the user.
 - b. Internal and transparent to but beneficial for the user.
- II. Battery Time to Recharge Increased by Monitor/Management
 - a. List a few functions shutdown or placed in Sleep mode.
 - b. Average Ampere-Hour Discharge rate used to compute time remaining before battery depleted.
 - c. Methods of Handling Complete Battery Depletion
- III. Programmable Battery Charging Increases Battery Life, Device Up-Time
 - a. Wall adapter disadvantages as recharger power source
 - b. Common battery parameter handled by recharger programmability
- IV. Marrying the programmable charger with USB ports
- V. Lowering BOM and costs in the Ac and USB charging adaptor.