Battery chargers in USB OTG devices

Abstract

Today an increasing number of portable electronic devices like PDA's, cameras, mobile phones and other portable storage devices use the USB interface to communicate and exchange data with PC's. Increased user convenience and functionality can be achieved if these devices communicated with each other directly. Presently, the USB 2.0 specifications makes this very difficult to achieve. In response to this limitation, a supplement to the USB 2.0 specifications, called USB On-The-Go (OTG) was released which addresses this limitation by defining how two devices connect via USB without the need for a computer host. USB-OTG is an addendum to USB 2.0 devices that define a new class of devices. These devices are intended to increase the functionality of a peripheral to include limited host capabilities. This paper addresses the power management concerns of these devices by explaining how the boost mode operation of bq24150/1/2 devices can be used to easily meet the power requirements specified in the USB-OTG standard. Various other features like light load efficiency (PFM mode), overload protection are also discussed.

USB as a power source

USB is a bi-directional data port through which peripherals of all types can be connected to the PC. The PC is the host and the device connected is the peripheral. Apart from this USB can also power low power electronics. Since many of the peripherals connected through USB are battery operated, USB can be used to charge the batteries of these devices. The USB 2.0 specifications provide a single 5V supply from which USB devices may draw power. A single USB device can draw a maximum of 5 unit loads of current. A unit load is defined as 100mA in USB 2.0 and 150mA in USB 3.0. There are two types of USB ports:

1. Low power ports
2. High power ports

Low power ports can supply a maximum of 1 unit load of current, with minimum operating voltage of 4.4V. High power ports supply 5 unit loads of current. When any device is connected via USB, an enumeration process first negotiates the maximum power level available. During this time, the device is allowed to draw only 1 unit load of current from the host. After the enumeration process, high power devices are allowed to draw higher currents if the power management software in the host allows it. Some host systems have in built current limiting either through fuses or active current sensing without the enumeration process. If a USB device connected to the host provides a higher load to the port without enumerating, it may shut down one or more USB ports. Hence care must be taken not to overload the USB port.

Li-Ion Battery charging requirements

Li-Ion is a very clean system and does not need any priming like Ni based batteries. The 50^{th} charge is no different from the 1^{st} charge. Most Li-Ion batteries are charged to 4.2V with a tolerance of +/-0.05V. Li-Ion batteries

are initially charged at a constant current (CC) until the voltage regulation threshold is reached. After the voltage threshold is reached the battery is charged at a constant voltage (CV). If the battery voltage before charging is very low, then it may need pre-charging or trickle charge. The charging profile of a Li-Ion charger is as shown in figure 1.

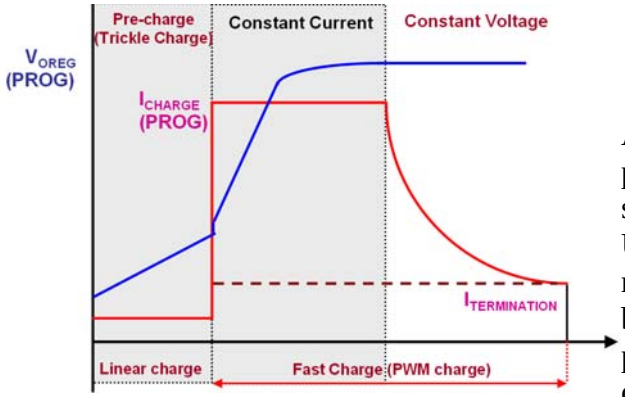

Figure 1: Li-Ion Charging profile

Charging Li-Ion batteries to 4.1 V reduces the capacity by 10% but increases service time.

USB- On The Go (OTG)

The USB 2.0 specification defines a host/peripheral relationship. The PC is always the host and the device that plugs into it is the peripheral. With technological advances in PDA's, digital cameras and various other portable devices, the need to interconnect these devices directly without the necessity of a computer increased. This functionality is not supported by USB 2.0. Hence to overcome this limitation USB-OTG was released. USB-OTG is an addendum to USB 2.0 devices that define a new class of devices. These devices are intended to increase the functionality of a peripheral to include limited host capabilities. USB-OTG is a host centric point to point bus and is not a peer-to-peer network connection. This means that only two devices can be interconnected using USB-OTG. Under USB-OTG, the user plugs in two devices to establish a link. The host/peripheral negotiation is done by the devices without any input from the user to make the experience comfortable. USB-OTG defines two types of devices.

1. A- device which are hosts by default
2. B- device which are peripherals by default.

A-devices have a standard-A or mini-A plug inserted and B-devices have a standard-B or mini-B plug inserted. The USB-OTG devices were formerly referred to as Dual Role Devices (DRD) because they function as hosts or peripherals depending on how they are configured. When the DRD is programmed as a host, it powers all the devices on the USB bus using its power source. When configured as a peripheral, it is powered from the USB host. This has interesting implications in the battery charging market. Since battery chargers are always connected to a power source (the battery), having a USB OTG charger that can be configured to power the USB bus is a logical progression.

Implementation of USB-OTG power requirements using a linear charger

According to USB-OTG specifications, the host must be able to supply at least 8mA of current between 4.4V and 5.25V. Devices can negotiate for more current depending on whether the host can supply more power. Creating the VBUS supply from a battery is a primary concern. A majority of portable devices use a single-cell lithium ion or lithium polymer battery. This means a

voltage converter is required to step up from 3.0-4.2V to 4.4-5.25V in addition to a battery charger. High-efficiency conversion is required to provide the longest possible battery run time. The OTG specification calls for at least 8mA and allows negotiation for higher currents if the peripheral needs more power. OTG devices can provide up to 500mA. In practice, handheld portable electronics don't have 500mA to spare for external loads. 100mA is a commonly accepted realistic maximum. A boost converter can be used from VBAT to VBUS to supply this voltage, but due to the small output capacitance at VBUS, it may cause stability issues. Hence a 1.5X inductorless DC-DC converter (Charge pump) are used. A voltage doubler can also be used in place of the charge pump, but this would decrease the efficiency. For example, if VBUS=5V has to be derived from a 4V battery voltage, we would get an efficiency of 62.5% as opposed to 83.33% while using a 1.5X charge pump.

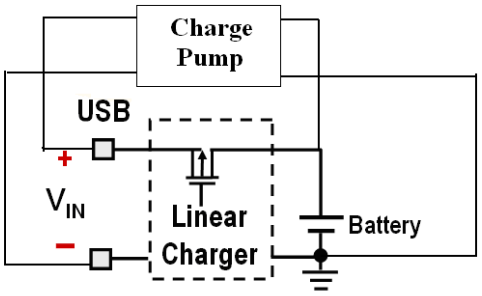

Figure 2: Linear charger and voltage converter implementation of USB-OTG power requirements

Switching charger and Boost mode implementation

When using a switching charger, the switches can be configured as a buck converter from VBUS to VBAT, and as boost converter from VBAT to VBUS, as shown in figure 3, without adding additional external components or ICs. This advantage of a switching regulator is exploited in boost mode operation resulting in easier USB-OTG support

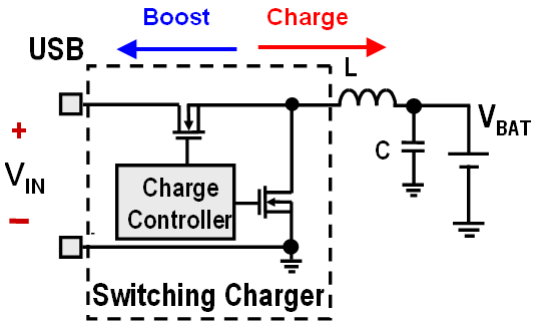

Fig 3: Boost mode

The bq24150/1/2 Switching charger with boost mode operation

The bq24150/1 is a fully integrated switch mode single cell Li-Ion charger that supports USB charging as well as USB OTG. These devices operate in two different modes

1. Charge mode
2. Boost mode

In charge mode, the bq2415x operates as a normal switching charger. In boost mode operation, the charger acts as a boost converter from VBAT to VBUS. The battery voltage is stepped up to 5V and VBUS powers any devices connected to VBUS.

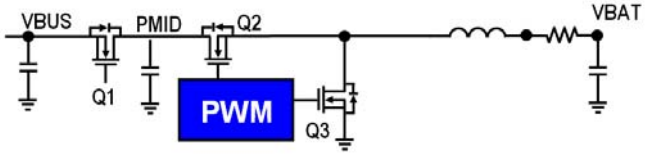

Fig 4: Basic Topology of a battery charger

Figure 4 shows the basic topology of the bq24150/1. In boost mode operation, Q2

is configured as the synchronous rectifier and Q3 is the switching FET. Q1 limits the load current to prevent overloading on VBUS. The voltage control loop is internally compensated using a type 3 compensation scheme for stable operation over wide load and battery voltage conditions.
Some of the unique features of boost mode are:

1. PFM mode operation for increased efficiency under light load conditions
2. Over load protection

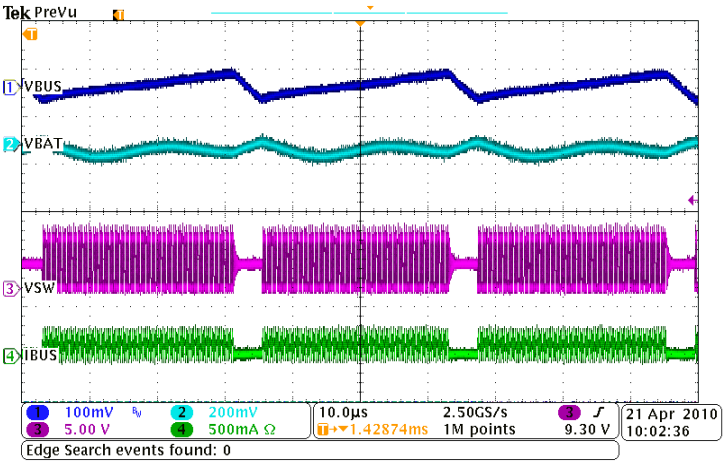

Fig 5: PFM mode operation

PFM mode operation

Pulse frequency modulation (PFM) is a switching method commonly used to improve efficiency at light loads. PFM mode is also referred to as power save mode in TI datasheets. A converter operating in power save mode uses PFM at light loads and pulse width modulation (PWM) at heavier loads. This type of operation allows the converter to maintain high efficiency over a wide range of output current.
In PFM mode, the converter only switches when the output voltage is below the nominal output voltage. In this mode all unnecessary internal circuitry is turned off when the output voltage is above the nominal output voltage resulting in lesser IC quiescent current and also much lower switching losses.
Figure 5 shows the operation of bq24151 in boost mode (PFM). The efficiency curve of the bq24151 is as shown in figure 6.

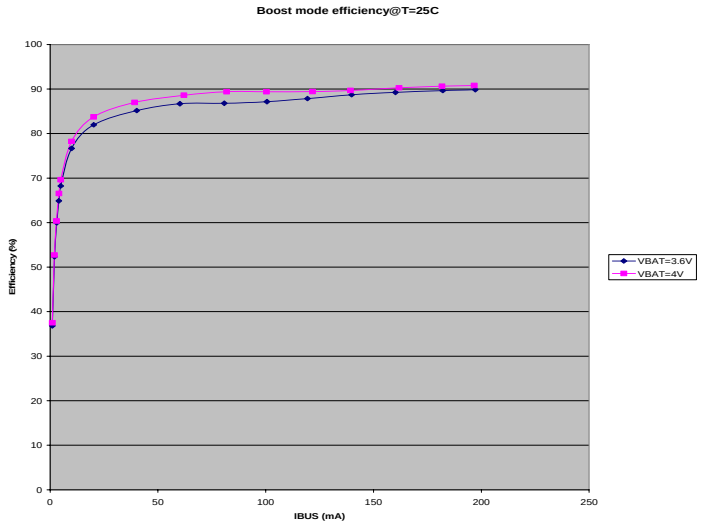

Fig 6: Efficiency in boost mode

Boost overload protection

The bq24150/1 provides a built in overload pbotection to prevent damage to the part/battery from overload conditions on VBUS. When excessive current is detected, Q1 operates in linear mode to limit I_{VBUS} while V_{PMID} maintains regulation at the nominal output voltage. If the overload condition lasts for more than 30 ms, the PWM controller is turned off, the OPA_MOD bit is reset to 0 (boost mode disabled), the fault status bits are set and a fault pulse is sent on the STAT pin. The boost function must be restarted by the host. Figure 8 shows the boost overload protection operation.

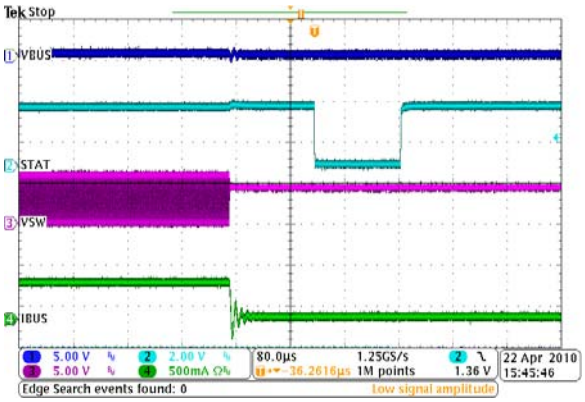

Fig 8: Boost overload protection

Conclusion

The boost mode operation of the bq24150/1 devices simplifies USB OTG support by eliminating the need for a separate boost converter to supply the 5V. The PFM mode operation increase the efficiency in boost mode operation and the boost overload protection feature prevents damage of the part and the battery. These features make the bq24150/1 an excellent choice when selecting a charger for USB OTG support.

References

[1] On-The-Go Supplement to the USB 2.0 Specification-Revision 1.0

[2]BQ2415x data sheet-Fully Integrated Switch-Mode One-Cell Li-Ion Charger with Full USB Compliance and USB-OTG Support-SLUS824A

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