USB 2.0 Power Budgeting

Overview: Computing Power Use on USB Bus

This white paper describes the power considerations related to powering devices on the USB 2.0 bus, looking at power supplies, power draws, and cable losses. The USB 2.0 bus was chosen as it is the bus applicable to the LAVA SimulCharge capable devices, *Figure 1*, but the general principles of this white paper apply to USB 3.0 as well, making allowance for its higher power output.

Figure 1: LAVA SimulCharge USB TL-002 and eSTS 1U Products

As USB-powered devices become more common, the demands on the USB bus to supply power increase. In many cases, USB peripherals (devices) are powered through USB ports supplying limited power. Understanding the technical characteristics of powering electrical devices, the specific characteristics and constraints of USB power makes powering devices through the USB bus more predictable.

Theoretical underpinnings

Electrical power–wherever it occurs–conforms to a couple of basic formulas. The first of these, Ohm's Law, describes the relationship between voltage (V), current (I), and resistance (R).

Equation 1: Ohm's Law

$$V = I \times R$$

This is essentially a "flow" equation, and can be compared to the equation representing a flow of water, where electrical voltage is equivalent to water pressure; electrical amperage is equivalent to the rate of water flow; and electrical resistance is equivalent to the effect of flow restrictors in a pipe. The analogous formula in hydraulics would therefore be:

Equation 2: Hydraulic Flow Equation

$$Pressure = FlowRate \times FlowRestriction$$

In addition to Ohm's Law, a second equation defines the concept of "Power" (P) as a function of voltage and current as follows:

Equation 3: Power Equation (Version 1)

$$P = V \times I$$

Power, in the electrical sense, is the amount of energy available to do something. Power, measured in Watts, is therefore voltage multiplied by amperage. USB power is defined as a nominal 5 volts. In that context, if a device consumes 300 milliamps (mA), it is said that it consumes 300 mA at a nominal 5 volts. Placing these values into Equation 3, we get a power value of 1.5 Watts. Similarly, if the voltage was 4 volts instead of 5 volts, then the current needed for 1.5 Watts would be approximately 400 mA (that is, $1.5W \div 4V = 400mA$).

It is also possible to combine Equation 1 and Equation 3 to restate power as:

Equation 4: Power Equation (Version 2)

$$P = I^2 \times R$$

These electrical variables-voltage, resistance, amperage, and power–are the relevant characteristics of electrical devices and power supplies, and are used to determine the power budget, where multiple devices share a power source.

A Sample USB Setup

The Power Supply

For this example, a standard power supply, that comes with Samsung tablets (model EP-TA10JWE), see *Figure 2*, will be used. This power supply is typical of power supplies shipped with tablets and phones, and in this case the power supply is labelled with the following characteristics:

- **Input:** 100-240 ~ 50-60 Hz) at 0.35A
- **Output:** 5.3V at 2.0A

Figure 2: Samsung EP-TA10JWE Power Supply

For the purposes of power budgeting, the input values are not particularly important as differences in input voltages are compensated for by the power supply. However, the output values are critical. In keeping with the power specification for USB 2.0, USB power is a nominal 5 volts.

But what does that mean?

It means that, in a no-load situation, the USB bus should be supplying between 4.75 and 5.25 volts to downstream ports while supplying 0 to 500 mA per port. That is, when all USB ports are fully loaded (at 500mA per port) and also when all USB ports are not loaded (quiescent). In reality, these Samsung power supplies test at between 5.08 and 5.32 volts. Why the discrepancy between the USB specification and the power supply's actual output? The answer to this question is explored further down in the "Cable Loss" section.

Power Draw

The power budget is really about the combination of voltage and current: that is, Watts. At the same time, for a system and its components to comply with the USB specification, all three parameters must fall within specified bounds.

Additionally, the USB specification says that USB devices are allowed to consume, at most, 2.5 Watts. At the USB-specified 5 volts, 2.5 Watts has amperage of 0.5 A. What if we are right at the bottom of the USB voltage allowance (4.75 volts)? To supply the maximum 2.5 Watts, higher amperage than 0.5A is now needed, approximately 0.52A. Complications arise as more devices are added, as that happens, the summed demands of the devices can exceed the total USB power budget for a power supply or port.

To begin with, a fully discharged tablet needs more than 0.5A to charge.
To look at specifics, a Samsung Galaxy Tab 4 10.1" will draw up to 1.5A (typically in the range of 1.25A to 1.3A).
A Samsung Galaxy Tab S 10.5" or Galaxy Tab PRO 12" will draw 1.5A, but at that point will not be charging, or charging ineffectually.

Imagine a full picture: a tablet and a couple of hosted USB peripherals on a hub. Specifically, a fully discharged tablet that will draw up to 1.5A at 5V: that's 7.5 Watts; plus, two fully demanding USB devices at 2.5W total, gives a total demand of 10 Watts. Therefore, a discharged tablet and a couple of fully consuming USB devices will take the power supply's full supply, and that's **if** those two USB devices are at a distance of zero from the voltage regulator, in the power supply, and that's **if** the hub itself uses no power, see *Figure 3*.

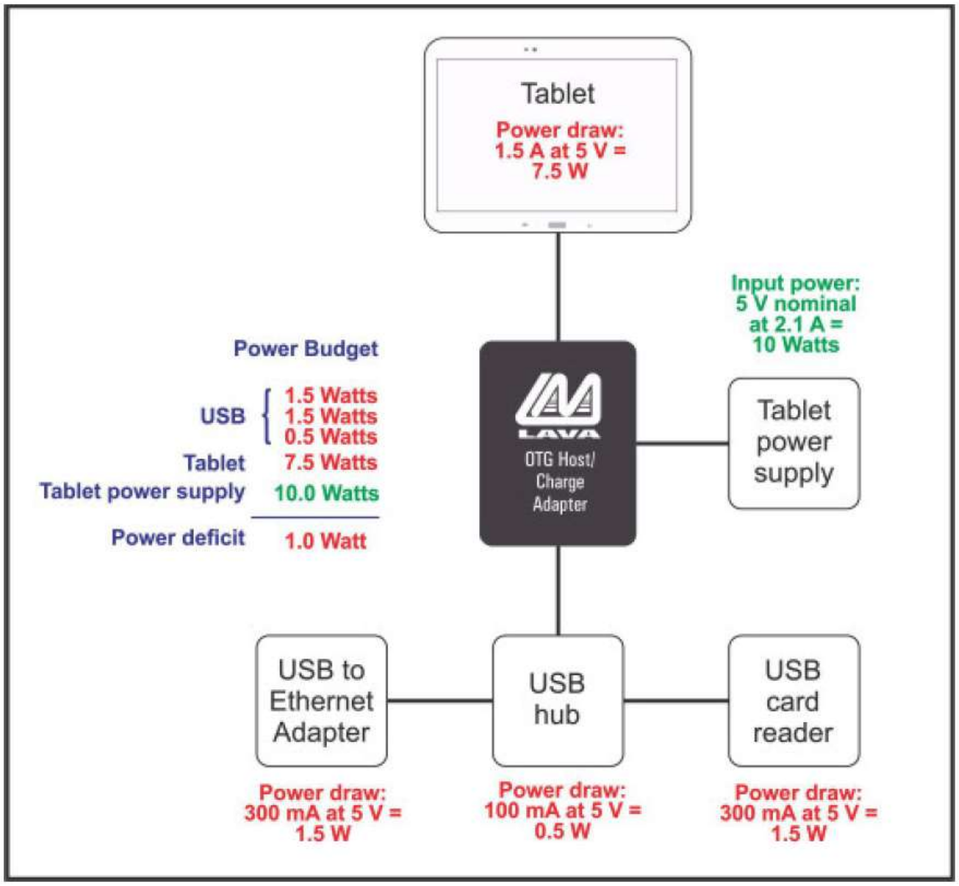

Figure 3: System Power Budget Exceeded from Excessive Tablet and Peripheral Power Consumption

The "zero distance" qualifier is another way of saying that the cables involved are "lossless"; that is, there is no voltage drop over the length of the cable. For our first look at power budgeting, we will make that a working assumption. However, we will look later at the real-world impact of cabling on USB power budgeting.

Remember, a given power supply is rated for three parameters, *none of which can be exceeded:*

- A certain current
- A certain voltage
- A certain power output

Cable Loss

Cable loss is a frequently disregarded aspect of power budgeting - it could almost be called the "elephant in the room". For USB layouts that are operating near their limits, cable losses (and the associated implications for voltage and amperage values) can become critical. Cable losses, in a wire, are a function of cable diameter, cable length, cable material, temperature, and the number of strands in the wire. Put together, these factors influence the cable's overall "resistivity."

The cable running from the power supply to the central distribution point (the SimulCharge USB in this case) is the focus of this cable loss analysis. The power supply in question, the aforementioned model EP-TA10JWE, is provided with a 1 meter (3.3 foot) long cable, with 24 gauge wiring inside, see *Figure 4*. The published resistivity of 24 gauge wiring is 0.084 Ohms per meter, but since the cable being used has both ground and power wires the functional distance is the cable length (1 meter) multiplied by 2. This is to say that the equivalent resistivity produced by this cable is that of a single stranded 24 gauge wire that is 2 meters in length ($1meter \times 2wires = 2meters$).

Figure 4: Samsung USB A to Micro USB "B" Power Supply Cable

So, for example, what is the voltage drop on a 1 meter long 24 gauge cable, with a current of 1.9A?

Given:

$$Resistance(R) = 0.084\,\Omega/m \times 2m = 0.168\Omega$$

$$Current(I) = 1.9A$$

$$VoltageDrop = I \times R = 0.168\Omega \times 1.9A = 0.319V \approx 0.32V$$

Consequently, the voltage at the SimulCharge USB is 5.0-0.32 volts, see *Figure 5*: is this now below spec? Well, recall that earlier it was said: "In actuality, these power supplies test at between 5.08 and 5.32 volts." and asked: "why the discrepancy?" now we are seeing why.

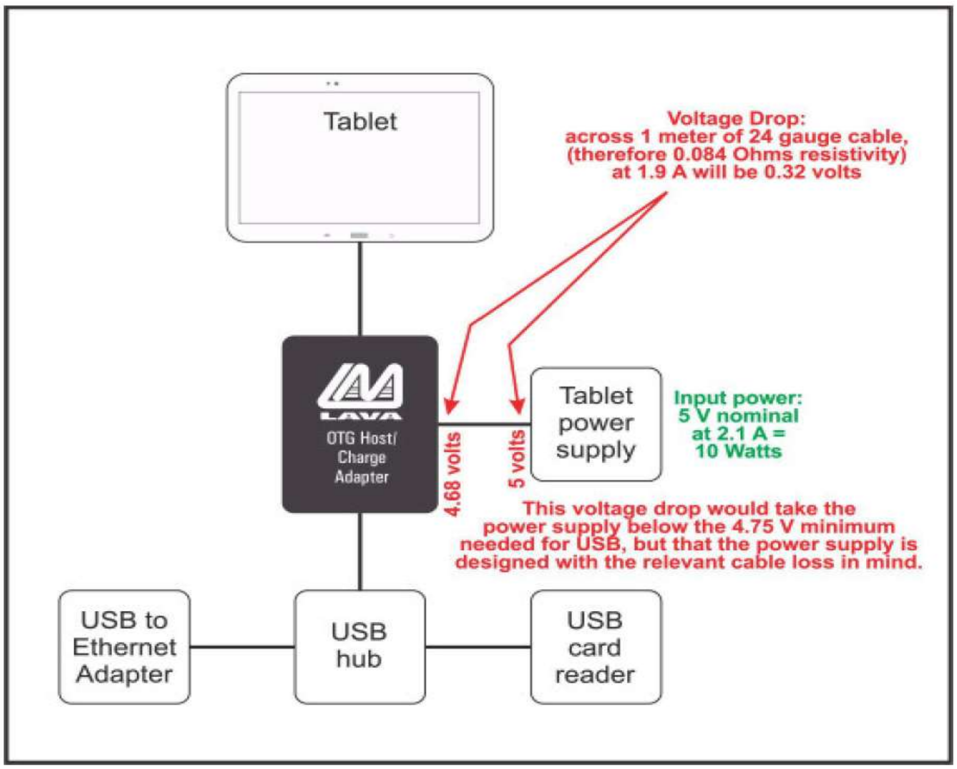

Figure 5: Visualization of Voltage Drop across Cable from Power Supply to LAVA Device

The fact is that if the low end of a nominal 5V, that is, 4.75V, is taken and the voltage drop from the supplied cable is added a voltage of 5.07, let's say 5.08 volts, is achieved. This demonstrates that power supply manufacturers have in fact designed their power supplies with allowances for cable loss, over the cables typical in the application: 24 gauge and 1 meter.

For the connection to be within specifications with a voltage of 4.75 V (allowing for a voltage drop of 0.32 V), the amperage will be correspondingly higher. How much higher precisely is the result of an iterative calculation that feeds the first changed amperage value back into the system and re-computes the system's values repeatedly. This process converges to an overall set of system values (for the mathematically curious, this is a "Runge-Kutta" calculation). Remembering that none of voltage, amperage, or power output can go outside specifications, the implication of loss is that there is little room, to move a system that is outside of specifications, back into conformity without changes to cables, either through heavier cables, shorter cables, or a combination of both.

Powered Hubs

The Samsung tablet's power supply has a small surplus of power that can be used to drive USB peripherals. However, in fully loaded situations with demanding peripherals, tablets with depleted batteries, tablets operating with bright screens and active communication systems (Wi-Fi, Bluetooth etc.), and so forth, the power budget for the tablet's power supply alone is soon exceeded. When the available power will be insufficient to power the complete setup, through the single power source of the tablet's power supply, consider adding a separately powered USB hub to power the USB peripherals, leaving the task of powering the tablet purely to the tablet's power adapter. However, when implementing a second power source into the mix, additional considerations arise.

In particular, the power input from the tablet's power supply and the power input from the powered USB hub need to be kept in separate power domains, see *Figure 6*. This separation is not possible with many inexpensive powered USB hubs, which can lack an isolating diode needed to prevent power feeding through, from the power domain of the powered USB hub to the power domain of the tablet's power supply.

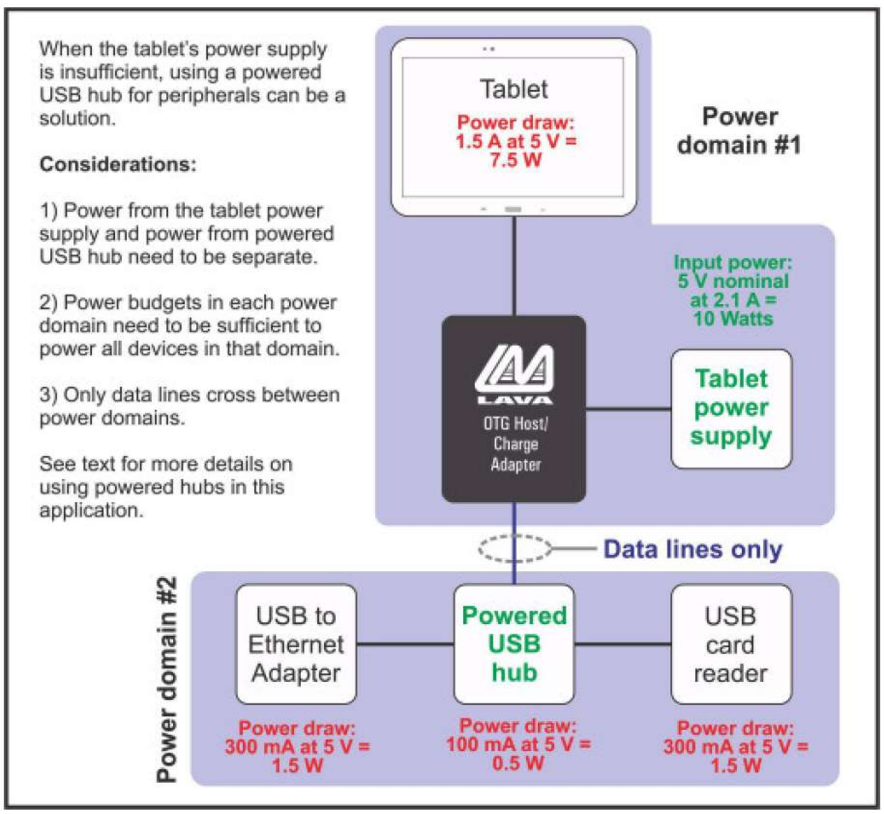

Figure 6: Isolated Power Domains with Attached Powered Hub

This need for isolating power sources occurs in other contexts beyond that of LAVA SimulCharge capable devices. In the case of the Raspberry Pi–a single board computer powered using USB power-adding peripherals to a system that is often powered by a cell phone charger, causes frequent problems. In response, those in the Raspberry Pi community have documented numerous powered hubs that meet the requirement to isolate their power from adjacent power domains (see http://elinux.org/RPi_Powered_USB_Hubs).

Conclusion

USB-powered configurations of peripherals and tablets (or other, similar USB-powered setups) require careful consideration of the system power requirements. Since USB power, especially USB 2.0 power, is closely constrained, it is not hard to exceed its power budget, leading to failures or unpredictable results.

Solutions include careful system design and ensuring that devices are operating efficiently. Such considerations might, in the case of a tablet, include selecting undemanding screen brightness, or seeing that the tablet's radios (Wi-Fi, Bluetooth etc.) are only operating as needed. When a system's power demands cannot be contained within the USB power budget, additional power, such as that from a properly integrated powered USB hub, can help. Also, carefully selecting cables for low resistivity gauges and lengths can often make the difference between success and failure when powering a system through USB.