Avoiding Current Spikes with LEDs

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Hot Switching creates current spikes that can destroy any LED. A properly designed driver is the simple solution.

Unlike many illumination sources, such as incandescent bulbs that are voltage driven, LEDs are current driven devices. This distinction requires different considerations when designing and using driver electronics. We will compare incandescent bulbs to LEDs to highlight this subtle difference.

The relationship between voltage and current is similar to the relationship between water pressure and water flow. Higher water pressure represents higher voltage and higher water flow represents higher current. One can observe flow or pressure, both or neither, depending on the system under consideration. For example, when compared to a standard garden hose, a fire hose has high pressure and high flow. Contrast this to the Amazon River which has a much higher flow and lower pressure. An example of high pressure and no flow is the water behind a dam. The dam acts like an open switch in an electronic circuit storing water (voltage) for immediate release.

To fully understand the difference between incandescent bulbs and semiconductors such as LEDs, let us consider voltage driven devices for a minute. The filament of an incandescent bulb is simply a resistor. When electrically powered, the filament heats to near white hot temperature - more than 5,800°F or 3,250°C. The high temperature of the filament generates the light. When first powered, the filament is cold and has a much lower resistance than when it is hot. According to Ohm's law, V = I R, the current in the filament is higher when the bulb is first turned and the filament is cold. This current is known as the "in-rush" current. Very quickly after turn-on, the filament heats to its operating temperature. As the filament heats, the resistance goes up dramatically and the current drops proportionately. In much less than a second, the filament resistance stabilizes and the current is constant.

Due to the characteristics of filaments, driver designs for bulbs expect an in-rush current as part of their performance. As long as the voltage is constant, bulbs tolerate these current fluctuations. However, bulbs are very sensitive to voltage variations. Different sources cite different levels of sensitivity, a recent check of Wikipedia (http://www.wikipedia.com) stated the lifetime of a bulb was dependant on the inverse of the sixteenth power of the voltage. In other words, an increase in voltage of only 5% could have a dramatic effect on the lifetime of the bulb. Using the equation:

$Lifetime_{bulb} = (105\%\ V_{rated} / 100\%\ V_{rated})^{16}$ - representing a 5% increase in Voltage

$Lifetime_{bulb} = (1.05)^{-16}$

$Lifetime_{bulb} = 45.8\%$ of initial lifetime

Simply stated, a 5% **increase** in voltage **decreases** the bulb *Lifetime* by more than half. Therefore, for a robust product performance, incandescent bulbs depend on well-regulated voltages while being tolerant to some current fluctuations.

LEDs are current-sensitive devices. However, although slight changes in current, such as the 5% mentioned above, do not affect LEDs nearly as much as similar changes in voltage affect filaments in bulbs, it is still important that designers consider transient peak currents when implementing LED driver circuits. Specifically, there are a few areas where switching on the LED causes current spikes that exceed the circuit design current by many times. Fortunately, “forewarned is fore-armed” as they say, and some simple considerations eliminate occurrences of these current spikes.

The terms “Hot Switching” and “Hot Plugging” refer to the act of inserting a device (mechanically or electrically) into a powered electronic circuit. An example of “Hot Plugging” is turning on the socket before screwing in a bulb. When inserting the bulb into the socket, it lights immediately upon contact with the bottom of the socket. This is because there was energy in the metal contacts in the socket. A similar effect occurs when connecting a semiconductor, from high-end computer chips to LEDs, to a hot circuit. However, in the semiconductor case, this “hot-switch” can result in an in-rush current that can damage the device.

Going back to water example, imagine the water in a hose connected to your house. With the faucet on but the nozzle closed, the pressure in the hose is at a maximum. When first opening the nozzle, this water pressure surges though the small opening until the flow drops to the amount regulated by the nozzle. Everyone has probably seen the “spurt” of water when first opening a nozzle. The time it takes for the flow to drop to the regulated level is sufficiently fast that most of us do not care about the “spurt” (although it’s great if you need that little extra distance in a water fight!). Similarly, with electrical circuits, the time it takes for a current to regulate is too fast for us to notice. In fact, we usually want things to turn on immediately. However, semiconductors react millions of times faster than humans do. A very short current pulse – sometimes just a few milliseconds long – can destroy a semiconductor chip.

One might ask the question “How much power is stored in a simple switched circuit?” The easy answer is “A Lot”, enough to cause damage to the semiconductor. The full answer takes a little more explanation. To clearly demonstrate the effect, let us consider a simple circuit consisting of a current source driver, a switch, and a string of n LEDs wired in series (figure 1). In this example, assume the maximum V_f of the LED string is 36V. The driver specifications include forward current (If) = 350mA at a 50V maximum, similar to a typical 25W supply.

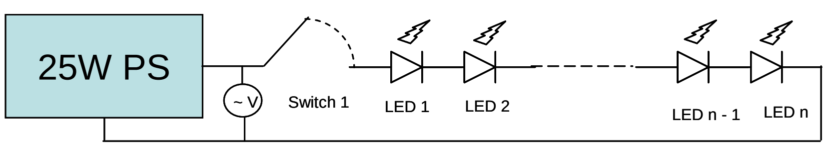
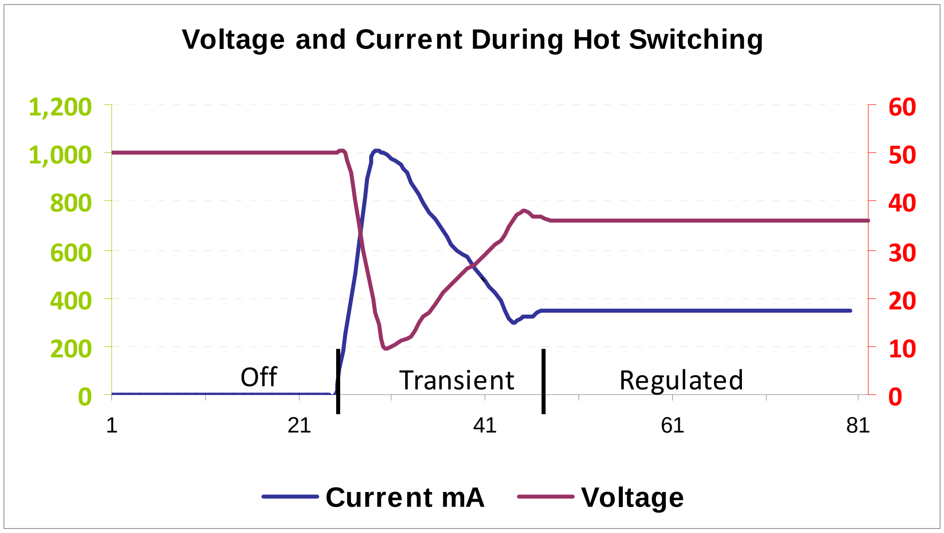


Figure 1 - Typical Switched Circuit

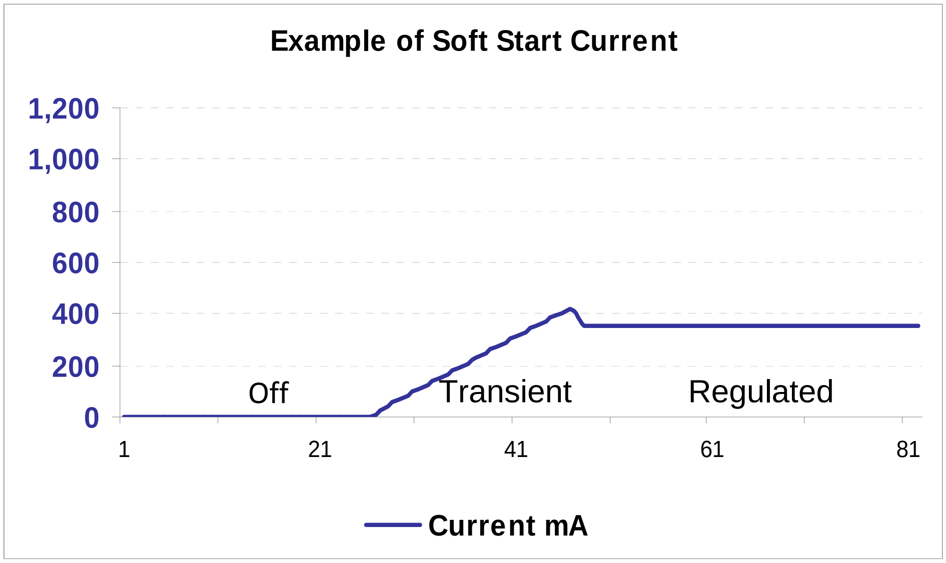
The circuit controls the current to 350mA when the switch is closed. However, when the switch is open, the current flow stops and the circuit is unable to regulate itself. In a short time, the voltage between the output of the power supply (PS) rises to the compliance voltage shown on the specification sheet or +50V. This is easily proven by measuring the voltage between the power supply terminals with a voltmeter. Remembering our water example, there is stored charge in the system similar to stored water in pipes. The output of the power supply, and the wires, act like a very large capacitor by storing charge analogous to the manner pipes and the hose store water. When the switch is closed, this charge flows rapidly through the circuit until the power supply begins to self-regulate. However, the total stored charge in the wires may be sufficient to destroy a semiconductor such as an LED.

Preventing the destructive current surge is a matter of design. The simple statement of “No Hot Switching”, “Soft Start”, or “Cold Switched” is sufficient to assure no current surge. To a lay person the difference between the surging current of a hot-switched unit and a unit with a soft start is best seen in a chart. The chart plots current (on the left y-axis) and voltage (on the right axis) versus time. There are three points of interest: before the device is switched on; during the time it takes the power supply to regulate (usually a few milliseconds); and, after the current regulates.



By using Ohm’s Law, where the Voltage is equal to the current multiplied by the resistance or V = IR, we can calculate Current through the LED. From the graph, it is easy to see how the voltage transient behavior injects a large current spike (in this case, three times the design value) into the LED. These current spikes can cause permanent damage to any semiconductor (ICs, microprocessors, and yes, LEDs).

By specifying a soft start, these ugly current spikes can be easily avoided. A soft start circuit assures the drive wires are at zero volts when the switch is open. With the closing of the switch, the current rises from zero to the design parameters without the current spike shown before. This is analogous to the leaving the nozzle on the hose open while turning on the water at the faucet. It takes a little time for water to reach the nozzle, and when it does, the flow rises to the desired amount.



We have shown how improperly specified driver circuits can and will introduce semiconductor damaging current spikes. Properly specifying the driver assures effective current regulation. Designing for a “Soft Start” is not an unusual request, hard to do, or more expensive. A quick search of National Semiconductor’s WEBBENCH® tools site:

http://www.national.com/appinfo/power/led.html

revealed they have over 200 products in their catalog that, by design, are “Soft Starting” ICs to drive LEDs and other semiconductors. Further, with WEBBENCH® one can immediately download a reference design with complete BOM based on your chosen Luxeon LED and operating parameters.

Other driver manufacturers also sell driver electronics that are specifically designed to work with high-power LEDs such as the LUXEON I, LUXEON III, LUXEON V, LUXEON K2, LUXEON Rebel and LUXEON K2 with TFFC, and “Soft Start” is only one driver characteristic of interest. But it is a critical one.