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Application Hint 76

The Need for Speed in LDOs

By Dave Ritter

Introduction

An LDO (Low Drop Out regulator) is a DC regulator designed to operate from a supply voltage only slightly above the output voltage. They find use in many places; among the most popular are core voltage regulators for FPGA's, CPLD's, uP's or complex digital ASICs. There is at least one in every cell phone. As we shall see, the logic in a cell phone can provide a challenging load to an LDO.

Logic as a Load

Let's look inside your cell phone. If you are keeping up with the times you undoubtedly have a camera phone. But you aren't taking snapshots all of the time so there's a lot of stuff inside your phone that spends most of its life doing nothing. Occasionally you do pull out your phone and snap a picture. What happens then?

Right before you push the button, a big chunk of the logic in your phone is idle. Since it is CMOS logic it consumes no power in this state. But as soon as you push the button there is a sudden frenzy of digital magic that grabs the picture and applies a zillion mathematical operations that compress, slice, dice, and neatly fold those pixels into something compact enough to send over your wireless network. During that frenetic fragment of a second the picture processing CMOS logic draws a lot of power. It's like a drag race: sudden application of massive horsepower for a trip that lasts a few seconds (or milliseconds in this case). The LDO is the engine. It supplies the power to spin those huge digital racing slicks and then, at the end, it down-shifts, applies the brakes and releases the chutes to slow things back to normal. So how much of an engine do you need? Is 50 horsepower enough? Is 500 horsepower too much? Actually, either might do the job, but not in the same way. With a small engine it could take a long time to get up to speed. LDO's are like that: some can rev-up to a few amps in a couple microseconds, some take a lot longer. It's a lot like the difference between a Prius and a Corvette and the way they pass a truck on a hill.

A Hybrid Analogy

Hybrids have a small internal combustion engine, a bunch of batteries, and electric motors on every wheel. The don't have a lot of power, but they do have amazing acceleration. Hit the pedal and they really step out smartly. How do they do it with such a tiny engine? It's all in the batteries and the energy stored there. For a short time the batteries can make up for the lack of output from the engine by supplying a burst of current to the motors. It even works great when you hit the brakes. When a hybrid needs to stop it can absorb energy from the wheels (the motors act like generators when you're stopping) and stuff it back in the batteries. The difference between a FAST LDO and a SLOW LDO is a lot like the difference between an 'Explorer' and an 'Escape'. Here's why.

The Difference Between SLOW and FAST

When you snap a picture in your cell phone something has to supply the power to the processing chip or bad things will happen. Usually the voltage dips as the load increases. If it dips too far the circuitry will make a mistake: one's will turn into zero's and vice versa. Logic will lock up and processors will grind to a halt. Your phone goes dead. That's what happens if your LDO is too slow. How do we fix it? There are two approaches to the problem.

The Hybrid Solution: Fixing a SLOW LDO

A hybrid car makes up for a small engine by using batteries to store energy. The energy is used during the peak demand times to keep the voltage from dipping (or from rising at other times as we shall see). That's what makes hybrids so quick off the line. To help a SLOW LDO, we can use something like a battery: a capacitor … a BIG capacitor. A capacitor stores electrical energy like a battery. If you had a big enough capacitor you could start your car with it. If you put a big capacitor on the output of an LDO, it can supply the necessary energy when you snap a picture and your LDO can recharge it when you aren't taking pictures. Your phone wouldn't go dead, and a certain amount of stress would be removed from your personal life.

The Fast Solution

Or you could just have a big engine. A V8 is pretty quick without all the batteries and motors and control circuitry and such. It can handle sudden increases in load (passing a truck, climbing a hill) without calling in reinforcements. A FAST LDO is like having a big engine under the hood. And at the moment a big engine is cheaper than a hybrid. The same holds for some LDO's. The cost of keeping a SLOW LDO happy may be more than the cost of a FAST LDO.

Behavior of Load Transients in Simulation

To make things a little more precise we simulated two identical LDOs. They are both behavioral models built from ideal Spice elements. The only difference between the two is speed. Figure 1 shows the frequency response of both the FAST and SLOW versions. The point where they cross zero is a measure of their speed. SLOW has a zero crossing of about 20kHz (with 10uF load cap) and FAST has a zero crossing of 370kHz. FAST is about 18.5 x faster than SLOW. [For reasons beyond the scope of this discussion it is only fair to compare the curves with the same load capacitor. In this case it's 10uF]

But that's small signal AC. What we really want to look at is the load transient voltage behavior of these models. Imagine that we are operating at a constant load of 2 Amps when the load suddenly vanishes. Although up to now we have only considered what happens when we suddenly increase the load (push the picture button or pass the truck on the freeway), it is actually more important to look at what happens when the load suddenly stops. This is when you have passed the truck and driven over the crest of the hill. Suddenly you are faced with a 6% down grade with no brakes. (LDO's don't usually have brakes.) In a hybrid the speed would be controlled by absorbing energy from the wheels and putting it back into the batteries. In a V8, we could accomplish the same thing by downshifting and letting the big engine absorb the energy. But something has to absorb the energy or the vehicle will run away and probably ruin your day. In the LDO world a run away condition results in voltage overshoot. The load disappears and the LDO keeps pumping out current. The voltage rises, sometimes to catastrophic levels. A SLOW LDO is helped again by a large capacitor, a FAST LDO doesn't need much help. Just as the capacitor can supply energy during a sudden increase in load, it can absorb energy when load is suddenly removed. Figure 2 shows what happens to both SLOW and FAST LDO's when the load disappears.

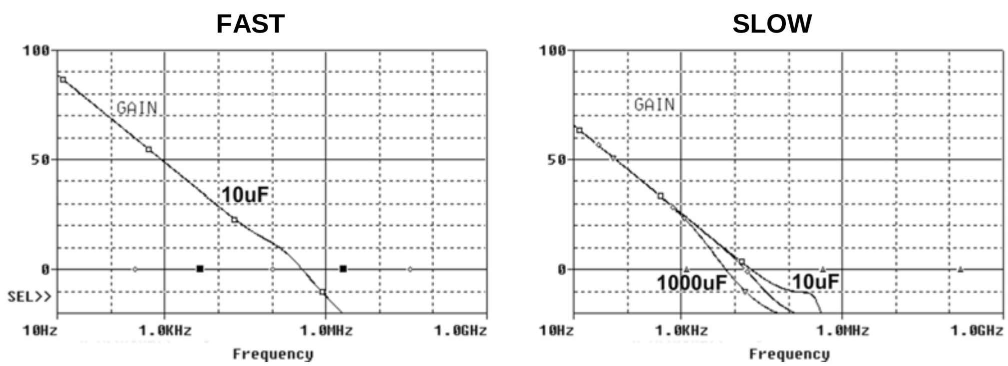

Fig. 1: AC Small Signal response of LDO Model

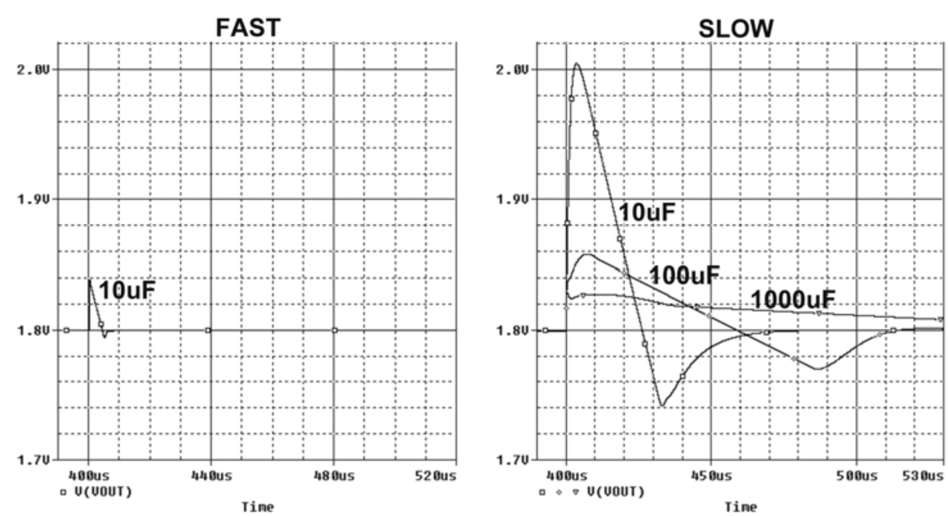

Fig. 2: Transient 'OFF' Response of LDO Model – 2A Step

Notice the huge difference in amplitude between the SLOW and FAST curves. A FAST LDO never loses control. The load drops 2 Amps and the output voltage only glitches about 40 millivolts. Under the same conditions the SLOW LDO glitches 200 millivolts. We can tame the SLOW LDO with a larger capacitor. The SLOW curves are labeled according to the cap used in each case. Check out the 1000uF curve. It has about the same peak amplitude as the FAST LDO (which uses only 10uF). So we need to go from a 10uF to a 1000uF cap if we use a SLOW LDO. That's 100 times bigger. But these are just models. What about the real world?

Behavior of Real LDOs

As you may have guessed, the models were adjusted to reflect reality as closely as possible. Figure 3 shows two real LDOs. One is a normal LDO, designed for precision regulation with loads up to 3Amps, and the other is the Micrel MIC5190, specifically designed for large loads and high speeds. It is at least 10x faster than most LDOs on the market. The curves show responses similar to the behavioral models above. The response of the MIC5190 with 10uF load is similar (in amplitude, not time) to the slower LDO with a 1000uF load. So in the real world, this particular slow LDO would need a high quality (low ESR chip type tantalum) 1000uF capacitor to match the fast LDO (MIC5190) with a much smaller 10uF ceramic load. The difference in cost can be significant. Currently available capacitors in this range show volume pricing of $0.05 for the 10uF ceramic, and up to $1.00 for the 1000uF low ESR tantalum.

The Economics of Speed

In conclusion there are are two choices for powering complex logic chips: a FAST LDO such as the MIC5190, MIC49150, MIC49300 or MIC49500 (with a small output capacitor) or a SLOW LDO with a large, expensive output capacitor. The actual loads and transients in each particular system will dictate the best choice, but many times cost will dictate a 'Need for Speed'.

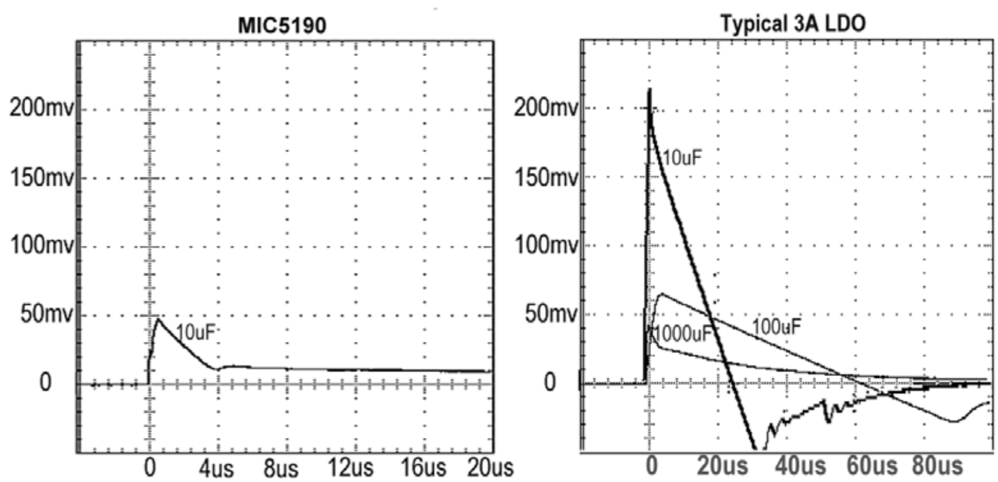

Fig. 3: Transient 'OFF' Response of 2 Real LDOs – 2A Step

MICREL, INC. 2180 FORTUNE DRIVE SAN JOSE, CA 95131 USA
TEL +1 (408) 944-0800 FAX +1 (408) 474-1000 WEB http:/www.micrel.com