Filtering and fast transient response

An active filter—and a typical dc/dc converter—can outperform traditional passive approaches in high transient applications

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Power architects engaged in designing systems requiring low output noise and fast transient response — such as RF transmitters, power amplifiers, test systems, displays, designs supporting low-voltage ASICs, and laser-diode transmitters — understand that when attempting to tailor power systems to meet both requirements using passive components, the two objectives become diametrically opposed. Minimizing periodic and random deviations (PARD) requires filtering, whereas fast transient response is impeded by filtering.

This article demonstrates how an active filter—when paired with a typical off the shelf dc/dc converter—will not only provide superior filtering compared to the passive approach, but will also provide improved transient response. This can either eliminate the need for load capacitance altogether for noise reduction, or reduce the amount required by as much as a factor of 10 for equivalent transient capability.

Sources of ripple and noise

The two major sources of ripple and noise on the output of a dc/dc converter are the switching noise generated by the converter and the line ripple from the converter. For the line ripple, a dc/dc converter source will provide some level of ripple rejection; any remaining ripple will appear at the load.

In general terms, the output ripple specification for a regulated dc/dc converter can range anywhere

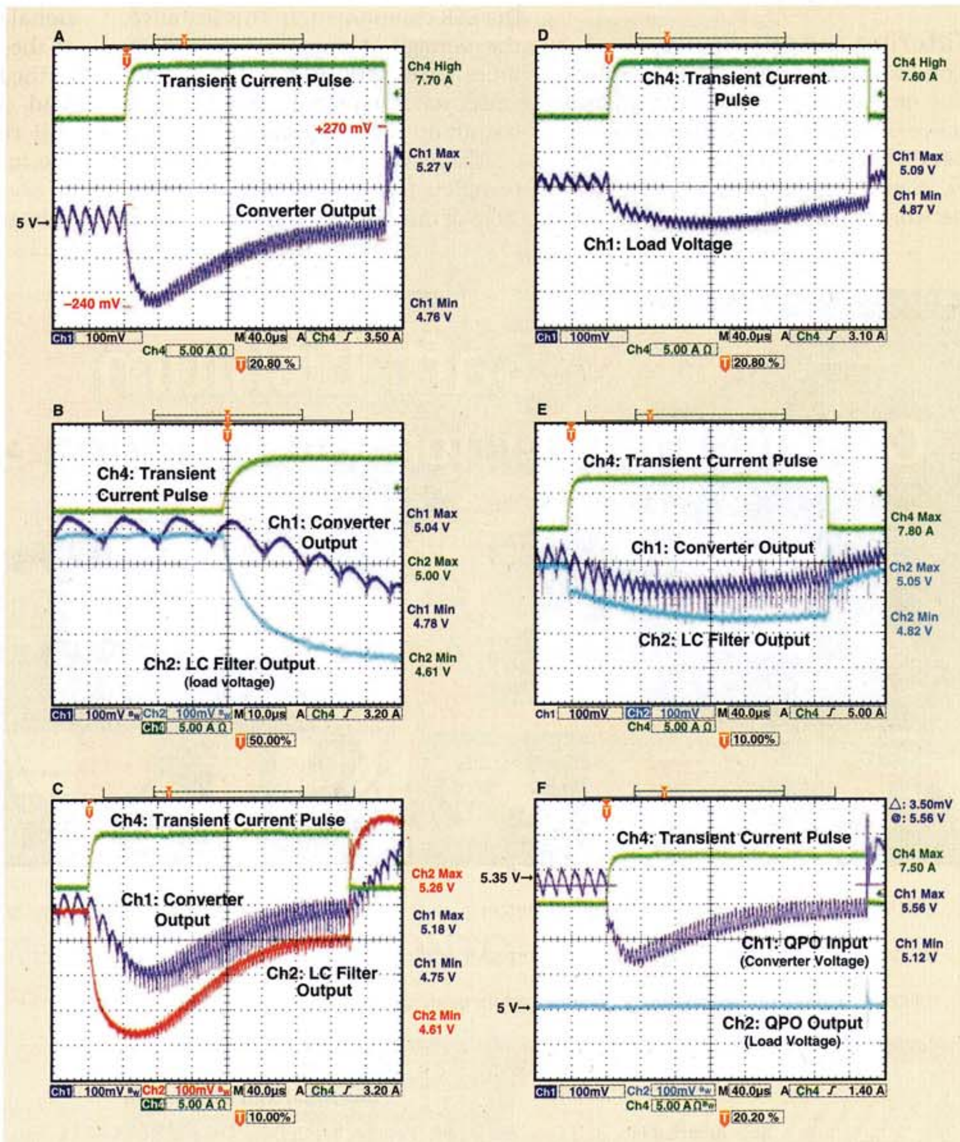

Fig. 1. The different filtering methods available to EEs provide various results.

from 100 mVp-p (5-V output) to 240 mVp-p (24-V output) or more, depending on the converter. The waveforms in *Fig. 1a* depict a typical converter's response to a 7.7-A transient load current with no external filtering or capacitance.

For the converter in Fig. 1a, the steady-state output ripple is approximately 100 mV p-p, far too high for most noise-sensitive applications. However, the larger concern for system designers may be the droop in output voltage. In the example, the output droops when the load transient event begins, and then overshoots at the end of the transient event when the load current falls. This creates an overall output voltage deviation of approximately ±250 mV.

Filtering output ripple

The most common method of filtering output ripple is to add inductance in series and capacitance in parallel at the output of the converter, commonly referred to as an "LC network." The waveforms in *Fig. 1b* and *1c* show the results of the LC network filtering on the converter output ripple (Ch2).

Although the ripple is significantly reduced, the transient drop in load voltage has increased. At the start of the transient there is a sharp drop in the output voltage from the filter.

Since the current through the inductor cannot change instantaneously, the current for the transient load must come from the output capacitors. This initial voltage drop is the result of the transient current multiplied by the capacitor ESR.

To reduce the voltage drop, the overall ESR of the output capacitance would have to be reduced; by either careful selection of lower-ESR caps or by using more capacitors to parallel the ESR component. In this instance, the voltage at the load droops by more than 300 mV before the converter starts to recover, and bring the output up to the regulation voltage.

The waveforms in *Fig. 1c* show the complete transient event, and the resulting undershoot and overshoot of the LC filter, due to the LC filter ringing at its resonate frequency. By the end of the transient, the current through the inductor is providing the transient load current.

When the load transient ends, the current through the inductor remains the same since it cannot change instantaneously and gets dumped into the load capacitors. Forcing this stored energy into the capacitors raises the output voltage by about 300 mV, resulting in a peak-to-peak variation of 600 mV due to the transient load change.

Adding capacitance or inductance

To compensate for such a dramatic variation in output voltage, additional capacitance needs to be added at the load to "hold-up" the voltage to the load. To consider the effects of load capacitance, the same circuit will first be demonstrated without the inductor. The waveforms in *Fig. 1d* show the same converter output voltage during the transient load with an additional 8 mF of capacitance on the converter output.

In this instance, the added capacitance reduced the voltage droop to roughly 100 mV, rather than 300 mV with the LC filter. As expected, the amplitude of the ripple has reduced (to approximately 40 mV pp) as compared to the stand-alone dc/dc converter, although the ripple is higher than with the LC filter.

The results of the addition of the inductor with the additional "hold-up" capacitance are shown in *Fig. 1e.* The waveforms show that the output ripple has improved but the transient response has degraded slightly. Since the resonant frequency of the LC filter is much lower with the 8 mF of capacitance, it is clear that the first step in voltage is due to the capacitor's ESR and the reactance of the inductor.

As illustrated in the previous examples, the primary drawbacks in the passive approach are the effect of the inductance on transient response and the voltage drop across the hold-up capacitance. Active filters provide improved transient response by replacing the passive inductance—which has inherently slow di/dt—with much faster, and smaller, active components.

In the active approach, the inductor reactance is replaced by a power FET and a high-speed controller device that modulates the FET to create linear resistance. During a transient condition, the loop gain of the filter increases the effect of capacitance at the input to the filter by a ratio of the change in the input voltage of the filter divided by the change in the output voltage of the filter ($\Delta Vin/\Delta Vout$), drastically reducing the amount of capacitance required while decreasing transient di/dt response time.

The waveforms in *Fig. 1f* demonstrate the ability of Picor's QPO (Quiet Power Output) to filter both the ripple voltage from the converter as well as the voltage droop of the converter during a transient load event. In this example, the QPO test board was designed to have 350 mV of headroom voltage under low load conditions, which for this test was a 1-A constant load.

Ch1 is the voltage seen on the QPO input; Ch2 is the QPO output voltage. Both channels are DC measurements with a 5 V offset and referenced two divisions down from center.

In Fig. 1f, the load step (Ch4) monitors the transient current only and does not include the static 1-A load. Examining the plot, starting with the left edge of the waveforms, the average dc voltage difference between Ch1 and Ch2 is 350 mV. After about 80 µs, the transient current event occurs (~1 A/µs) and the voltage from the converter (Ch1) droops.

The QPO output voltage (Ch2) remains constant at 5 V for the entire duration of the transient. As a result, the QPO filter virtually eliminates the ripple and the load voltage drop associated with the 7.7 A transient, with no additional capacitance, significantly outperforming all of the passive scenarios. ■