AN-1824 FlexCap Technology Simplifies LDO Design

ABSTRACT

The low dropout (LDO) voltage regulator brings the advantage of power savings to system design by reducing the voltage required to maintain output regulation. However, the traditional LDO has always brought with it the disadvantage of placing tight restrictions on the equivalent series resistance (ESR) of the output capacitor in order to keep the regulator stable. This requirement has been eliminated by Texas Instruments new line of FlexCap LDOs, which are stable with any type of output capacitor.

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1 Introduction

The advantages offered by FlexCap are:

Cost savings: inexpensive capacitors reduce system cost.

Ease of design: no special consideration for the output capacitor is necessary; stability is ensured regardless of ESR.

More robust design: there is no danger of oscillations if the output capacitor's ESR increases with temperature change or aging of components.

The capacitor types most frequently used in system designs are: aluminum electrolytic, tantalum electrolytic, and ceramic. Using LDOs with these types of output capacitors has been typically fraught with a number of drawbacks.

In the case of ceramic, ESR is only a few mΩ, which is too low to allow stable operation with most LDOs.

For aluminum capacitors, ESR can vary from a few tenths of an Ω to many Ωs, depending on size, quality, and temperature. A particularly troublesome property of aluminum capacitors is that their ESR increases exponentially at temperatures below about 10°C. These capacitors are notorious for causing LDO stability problems at cold temperatures where the ESR skyrockets.

And finally, tantalum capacitors are the best fit for the output capacitor used with traditional LDOs, but the tantalum manufacturers constantly reduce ESR to compete with ceramic capacitors (and they offer no guaranteed specs on ESR minimum values). In fact, many low-ESR tantalum capacitors are below the stable range for the output capacitors that can be used on most LDOs.

TI’s FlexCap line of LDO regulators incorporates a proprietary compensation technique which allows for completely stable operation regardless of the ESR of the output capacitor, so any type of capacitor may be used for C_{OUT}.

This is graphically illustrated in Figure 1:

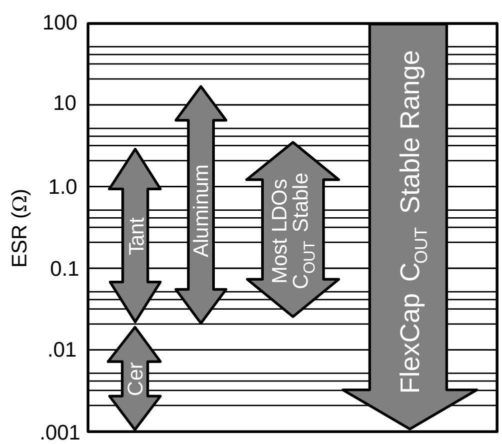

Figure 1. ESR Ranges for Various Output Capacitor Types

As can be seen, both aluminum and ceramic capacitors can be problematic if used as the output capacitor for the typical LDO, but the Flexcap LDO has no restrictions on the ESR of the output capacitor.

2 Measuring Stability Performance

The standard that defines stability is the control loop's phase margin, which measures how far the loop’s operating point is from becoming unstable at the unity-gain point of the loop gain. A phase margin value exceeding 30° is generally considered acceptable, but more phase margin is preferable.

To illustrate how the new FlexCap enhances stability, an LP38501-ADJ LDO regulator, which employs the proprietary FlexCap technology, was tested. For testing, the output voltage was set to 2.5 V. In each case, a 10 µF output capacitor was used, but the type of capacitor was varied. Ceramic, tantalum, and aluminum capacitors were each tested and gain/phase plots were recorded. The gain and phase plots taken at a 2A load current (see Figure 2) show how any type of capacitor can be used for C_{OUT}.

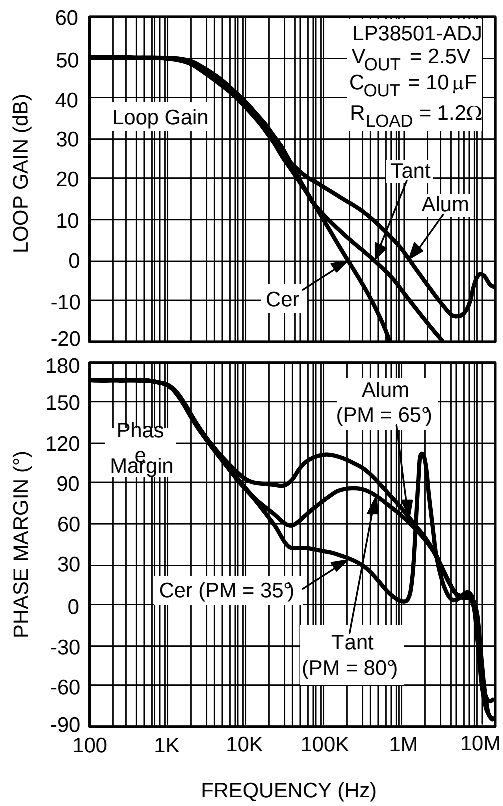

Figure 2. Gain/Phase Plots for 2A Load With Various C_{OUT} Types

It can be seen from the loop-gain plots that the unity-gain crossover frequency actually increases as the output capacitor's ESR increases. The bandwidth with the lowest-ESR capacitor (ceramic) is 200 kHz; the tantalum's bandwidth is 450 kHz; and the aluminum electrolytic is just over 1 MHz. However, phase margin is not sacrificed to get this increase in bandwidth, as both the tantalum and aluminum electrolytic capacitors have very high phase margins.

A characteristic of all LDO regulators is that the load resistance determines the frequency of one of the dominant poles in the loopgain curve. Because of this, bandwidth is reduced at lighter loads where load resistance increases. Gain and phase plots were taken showing the LP38501-ADJ regulator's performance at no load (Figure 3):

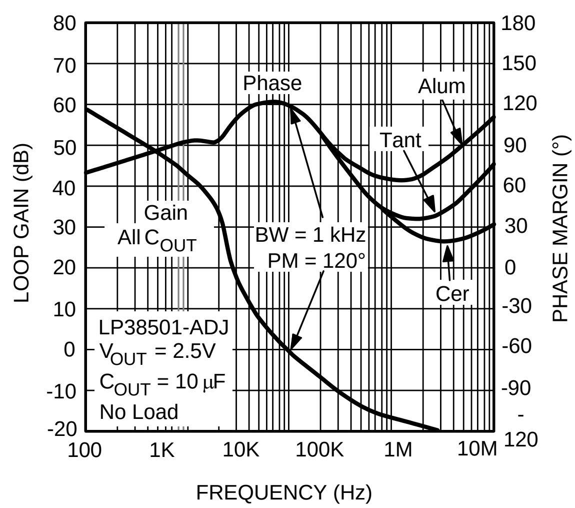

Figure 3. Gain/Phase Plot for No Load Operation With Various C_{OUT} Types

When there is no load, the bandwidth of the loop drops to about 1 kHz and there is no measurable difference among the different capacitor types for bandwidth and phase margin. The phase margin is very high (120°) for all capacitor types.

To determine how high the ESR of the output capacitor can go and still provide stable operation, a worst-case test was performed. The output voltage was adjusted down to the minimum value (0.6 V) and the test was repeated using a 10 µF aluminum output capacitor with a 1k resistor added in series with C_{OUT} to simulate an ESR of 1 kΩ. This value of ESR is far higher than any real 10 µF capacitor would ever have. The results of the test (Figure 4) show that the loop remains stable.

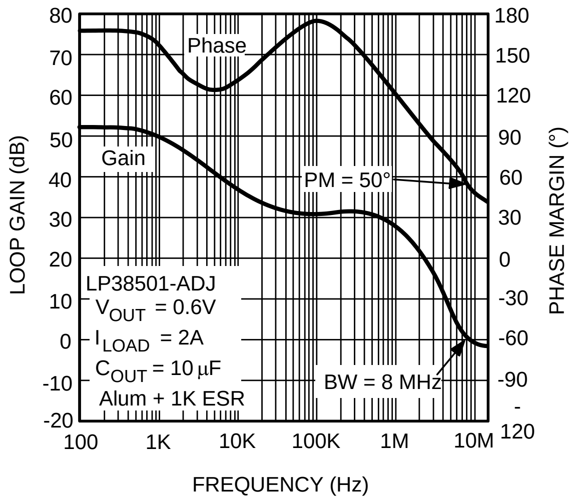

Figure 4. Gain/Phase Plot for Aluminum Output Capacitor With 1K ESR

The 1 kΩ resistor effectively decouples most of the effect of the output capacitor, but the IC's internal compensation still maintains good phase margin even as the bandwidth increases to 8 MHz.

3 Conclusion

The test data demonstrates that the internal compensation used in FlexCap products can maintain stability regardless of the ESR of the output capacitor.