Texas Instruments Incorporated

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TO: Valued Customer
From: Texas Instruments: Analog Power Products (APP): Switching Regulators (SR): Medium Voltage Buck Regulators (MVB)
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Subject: Bode Plot Analysis of DCAP, DCAP2, DCAP3, and DCAP+ Control

Frequently Asked Question: Is it possible to run a Bode Plot analysis of a DCAPx type converter.

DCAP, DCAP2, DCAP3, and DCAP+ control architectures are fundamentally non-linear, semi-hysteretic, large signal control architectures that do not lead well to small signal linear control loop analysis tools such as a Bode Plot.

While it is possible to add a controlled AC noise source into the feedback loop and measure the amplitude ratio (Gain) and time-lag (Phase) response of the feedback input point and Output voltage point to produce a Gain-Phase plot commonly known as a Bode Plot for these architectures, applying small signal analysis tools such as Loop Bandwidth, Gain and Phase Margin to the resulting plots does not, generally produce useful results.

The measured results can vary significantly depending on the injection technique, level, and DCAP implementation. In stead of these linear small-signal analysis tools, MVB recommends the following large signal analysis techniques:

1) Histogram analysis of the Switching Period distribution
    a. DCAPx is fundamentally a Pulse Frequency Modulation scheme where the switching period is modulated on a cycle by cycle basis to adjust the inductor current in order to regulate the output voltage.
    b. Stability of this loop is best derived from the distribution of the Switching Period, which should be gaussian in nature with a single "mode" or peak.
    c. Depending on the implementation, the distribution could be narrow or wide, even distributions exceeding 20% of the mean switching period should be considered normal, as long as two peaks or modes are not observed.
    d. When two modes are observed, either the ESR / Injected Ramp amplitude should be increase, or the output capacitance should be increased.
    e. If two or more pulses separated by minimum on-times dispersed between a long off-time averaging to the target switching frequency is

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observed, there is likely too much delay between the inductor current and the sensed output voltage. Adding a capacitive feedback path from the local output voltage into the resistive feedback path from the remote output voltage sense can typically address his stability concern.

2) Analysis of a Transient Recovery
    a. The recovery of the output voltage following a sudden change in load current (Load Transient) should be smooth and exponential.
    b. If a higher frequency oscillation about the exponential recovery is observed, the LC filter resonant frequency should be increased, or the DC blocking frequency of the ramp injection should be decreased.
    c. If the output voltage passes the final regulation point more than once before settling to the final recovery, the ramp injection should be increased or the output capacitance should be increased.
3) Analysis of a Dynamic Output Voltage Change
    a. The response to an output voltage change, either through reference programming change, feedback divider alternation / injection, or soft-start, should be smooth and free from high-frequency oscillations.
    b. If a high-frequency oscillation is observed, the LC filter resonant frequency should be increased, or the DC blocking frequency of the ramp injection should be decreased.
4) Analysis of Output Voltage Ripple Valley Voltage
    a. DCAPx control is a valley voltage regulation scheme. While there is naturally some cycle to cycle variation in the valley voltage, it should be small. Typically, on the order of 1-2mV
    b. A steady-state constant load output voltage ripple valley voltage that varies more than 2mV is evidence of unstable switching frequency. For remedies, see the Switch Period.