Stability Analysis of Multiphase Current-mode COT Control with Phase overlapping

Processor core voltage regulators (VRs) widely use pulse distributor-based multiphase current-mode constant on-time (COT) control to improve light-load performance, achieve fast transient response, and simplify phase interleaving. The total current loop of an N-phase COT-controlled VR becomes unstable for duty cycle D > 1/N without a sufficient external ramp. Also, the minimum ramp (or critical ramp) required to preserve stability varies with the number of overlapping phases. Hence, this work derives the critical ramp in each phase overlapping region of multiphase current-mode COT control using its general describing function model. As seen in Fig. 1, the control-to-output response has large peaks in phase-overlapping regions with small ramp and hence unstable closed-loop poles of the total current loop cause this issue. This work identifies the characteristic equation that introduces these poles, rearranges it to formulate a theoretical loop gain, and derives a stability condition using the discrete-time Nyquist criterion. The stability condition was also evaluated to determine the exact critical ramp expressions up to four overlapping phases and an analytical approximation for the same beyond four overlapping phases.

With two overlapping phases, the critical ramp slope equals half of the sensed total current rising slope. However, the critical ramp slope with three-overlapping phases equals the sensed total current rising slope and increases further with an increase in the number of overlapping phases. The critical stability limits are verified using SIMPLIS simulations and experimental results from a six-phase COT-controlled buck platform. These limits will provide a lower bound for the ramp design of multiphase current-mode COT controllers.
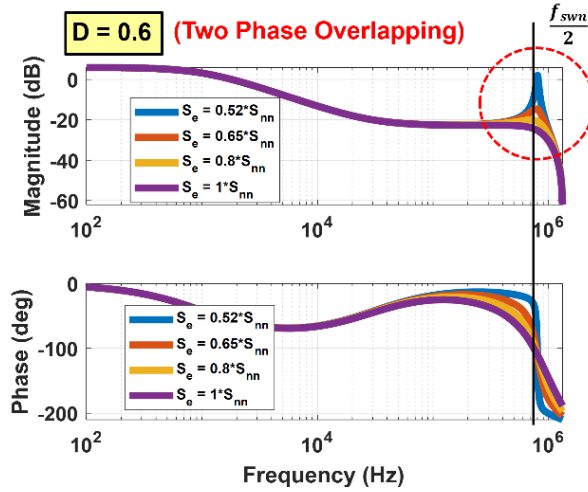

Fig. 1. Control-to-output response of multiphase current-mode COT Control in Two-Phase Overlapping region.
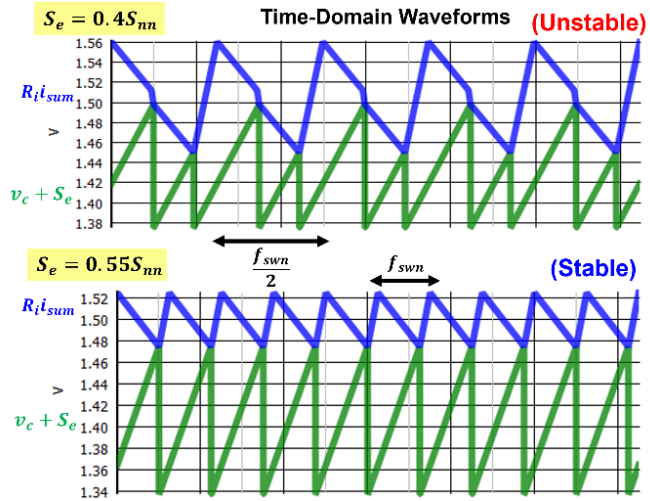

Fig. 2. Critical external ramp in two-phase overlapping region ($S_e = 0.5S_{nn}$) of multiphase current-mode COT Control – Simulation verification.